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GLOBAL CHANGE TECHNOLOGY ARCHITECTURE TRADE STUDY

L. Bernard Garrett, Warren D. Hypes, and Robert L. Wright (Editors)

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TABLE OF CONTENTS

TABLE OF CONTENTS iii

EXECUTIVE SUMMARY 1
L. Bernard Garrett and Warren D. Hypes

SCIENCE REQUIREMENTS FOR A GLOBAL CHANGE TECHNOLOGY ARCHITECTURE TRADE STUDY 73
John T. Suttles, Edwin F. Harrison, Gary G. Gibson, and Thomas G. Campbell

SATELLITE ORBIT CONSIDERATIONS FOR A GLOBAL CHANGE TECHNOLOGY ARCHITECTURAL TRADE STUDY 91
Edwin F. Harrison, Gary G. Gibson, John T. Suttles, James J. Buglia, and Israel Taback

SELECTION OF REPRESENTATIVE INSTRUMENTS FOR A GLOBAL CHANGE TECHNOLOGY ARCHITECTURAL TRADE STUDY . . 109
Warren D. Hypes, Lloyd S. Keafer, Rogard Ross, Heather R. Knight, Anthony Jalink, and Cheryl L. Allen

MICROWAVE SENSING TECHNOLOGY ISSUES RELATED TO A GLOBAL CHANGE TECHNOLOGY ARCHITECTURE TRADE STUDY. . . 181
Thomas G. Campbell, Jim Shiue, Denis Connolly, and Ken Woo

SUNSYNCHRONOUS LOW EARTH ORBIT SPACECRAFT CONCEPTS AND TECHNOLOGY REQUIREMENTS FOR GLOBAL CHANGE MONITORING 187
L. Bernard Garrett, Ansel J. Butterfield, Israel Taback, Paul Garn, and Donald R. Burrowbridge, Jr.

HOOP COLUMN SOIL MOISTURE SPACECRAFT IN LOW EARTH ORBIT FOR GLOBAL CHANGE MONITORING. 271
Melvin J. Ferebee, Jr.

GEOSTATIONARY ORBIT EARTH SCIENCE PLATFORM CONCEPTS FOR GLOBAL CHANGE MONITORING 281
Jeffery T. Farmer, Thomas G. Campbell, William T. Davis, Paul A. Garn, Charles B. King, and Cheryl C. Jackson

OPTIONS IN THE GLOBAL CHANGE FLEET ARCHITECTURE PROVIDED BY THE PRESENCE OF AN EOS-A AND -B 293
Warren D. Hypes and Rogard T. Ross

INFORMATION DATA SYSTEMS FOR A GLOBAL CHANGE TECHNOLOGY INITIATIVE ARCHITECTURE TRADE STUDY. 309
Nicholas D. Murray

APPENDIXES

APPENDIX A - GLOBAL CHANGE TECHNOLOGY INITIATIVE ARCHITECTURE TRADE STUDY PLAN 341

APPENDIX B - PHYSICAL AND PERFORMANCE CHARACTERISTICS OF INSTRUMENT SELECTED FOR GLOBAL CHANGE MONITORING . 351
Cheryl L. Allen

APPENDIX C - PLOTS OF GROUND COVERAGE ACHIEVABLE BY GLOBAL CHANGE MONITORING INSTRUMENTS AND SPACECRAFT. 381
Heather R. Knight and Lynda Foernsler

EXECUTIVE SUMMARY

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ABSTRACT

Systems concepts were developed and technology assessments conducted for science instrument combinations and spacecraft architecture options to measure long-term global climate changes on Earth. An extensive series of atmospheric; land, ocean, and ice; and Earth and solar radiation measurements, to be accumulated over decades, were defined requirements for the study. The need for full global coverage with repeated daily samplings, augmented by near continuous regional intensive coverage measurements, led to orbit selections at both Sun synchronous low-Earth orbit (LEO) and geostationary Earth orbit (GEO) locations. For global studies, temporal requirements were to sample every 1 to 12 hours for atmospheric and radiation parameters and one day or more for most Earth surface measurements. Spatial resolution needs varied from 1 km for land and ocean surface parameters to 50 km for some atmospheric parameters.

Twenty-seven instrument concepts were selected, with multiple units on duplicate spacecraft, to meet the measurement requirements. The instruments were selected from surveys of existing instruments or developed as new concepts during the study. New concepts include a large soil moisture radiometer and an atmospheric pressure LIDAR in LEO. New GEO instruments included a high-resolution microwave radiometer for precipitation measurements and several new high-resolution, increased-sensitivity instruments normally associated with LEO missions to meet temporal sampling requirements of less than 3 hours. The latter approach was necessary to keep the total number of spacecraft within practical limits.

Several combinations of spacecraft and the large space platform architecture options were assessed including Delta-launched small LEO spacecraft of the upgraded multimission modular variety and Titan IV-launched large LEO platforms that are new designs with high-performance, high-capacity spacecraft buses. All architectures also included a Titan IV-launched LEO soil moisture radiometer spacecraft and several GEO platforms with optional launch and deployment or on-orbit assembly possibilities. Individual technology development needs in science instrumentation, spacecraft subsystems, and information and data systems were identified.

INTRODUCTION

Extensive study efforts have been completed to define and propose Earth science missions that are best conducted through utilization of spacecraft platforms. The science relates to a broad range of deep space and Earth-related missions. The focus for this study is the Earth-related systems in the Mission to Planet Earth (MPE) Program and the enabling Global Change Technology (GCT) program.

The need for the Earth science missions and their applicability to global change studies are well described in the NASA Advisory Council, Earth Sciences Committee Reports of 1986 (ref. 1) and 1988 (ref. 2). The reports provide a list of variables and parameters that must be measured periodically or continuously in order to monitor and quantify global conditions and changes. A second series of documents, the NASA Office of Space Sciences and Applications Strategic Plans of 1988 and 1989 (refs. 3, 4) also discuss Earth-related sciences and, in addition, describe a conceptual set of spacecraft and space platforms that will support the missions. The key platforms are the two Polar Orbiting Platforms, the Earth-Observing Systems A and B (Eos-A and Eos-B). As stated in the 1988 Strategic Plan, "---the Earth-Observing System will place a suite of instruments in low-Earth orbit to make comprehensive observations of Earth's atmosphere, oceans, land surfaces, and biota--- for at least 15 years, the mission will study the global-scale processes that shape and influence the Earth as a system." The U.S. provided Eos will be complemented by other scientific platforms provided by international partners to achieve global coverage of the planet. The first series of the U.S. Eos spacecraft are scheduled for launch by Titan IV vehicles in the mid-to-late 1990s, with subsequent launches of similar instruments planned on 5-year cycles. A second major spacecraft system featuring a geostationary orbit has been defined and is being proposed for approximately the same time period as the Eos platforms. Thus NASA has major LEO and GEO systems proposed for application to MPE and GCT programs in the immediate future.

The need for global change science studies will extend well beyond these early major systems, but the mix of advanced science instruments, spacecraft, and mission orbits for the later science studies has not been defined. The definition of these future systems are critically needed to provide a road map for long lead technology development programs of NASA and other agencies. For example, measurements requiring the highest resolution and sensitivities are currently planned for low-Earth orbits. If near continuous coverage is also required, then a large number of instruments and spacecraft are needed. An alternative is to develop advanced sensors capable of providing equivalent resolutions and measurement accuracies from geostationary orbits, thereby reducing the spacecraft fleet to more affordable numbers.

In 1989 the NASA Office of Aeronautics, Exploration, and Technology conducted a series of workshops in preparation for a new Global Change Technology Initiative (GCT) on the major technologies for a comprehensive set of MPE spacecraft, including upgrade/replacement platforms for Eos (ref. 5). These workshops developed an extensive set of sensor, spacecraft/platform, and information system technology needs and development plans. The study concluded that systems studies and analyses were needed to continually refine the scope of the technology effort and to ensure continued relevance to evolving requirements for the Mission to Planet Earth instruments. Similar issues were reported by the Space System and Technology Committee's Ad Hoc Review Team on Planet Earth Technologies (ref. 6) in which they stated "One fundamental issue pervaded the review team's discussion of the Mission to Planet Earth and GCT's support of it: lack of a coherent architecture. The committee felt hampered in their ability to assess OAST's GCT plans because of insufficient mission and system planning and analysis....Considerations such as orbital configuration and constellation (including altitude and number of spacecraft), refurbishment capabilities, and platforms and instrument lifetimes will significantly impact not only technology selection but also development and deployment costs."

This report describes an architecture trade study conducted at Langley Research Center to develop a representative mix of advanced science instrumentation, spacecraft, and mission orbits to assist in the technology selection processes. The analyses concentrated on the highest priority classes of global change measurements which are the global climate changes (ref. 7). With sufficient lead time and resources to develop advanced sensors and science instruments, opportunities will exist to significantly improve our predictive capabilities to project the impacts of natural- or human-induced activities on global climate changes.

The study is divided into five major areas:

(1) Definition and synthesis of science requirements.

(2) Selection of representative science instruments and instrument complements with limited conceptual design.

(3) Selection of mission orbits.

(4) Development of spacecraft and platform architectural mix.

(5) Technology assessments.

The overall study process is shown in figure 1. Issues addressed in the tradeoffs included assessments of the economics of scale of large platforms with multiple instruments relative to smaller spacecraft; the influences of current and possible future launch vehicles on payload sizes and on-orbit assembly decisions; and the respective roles of low-Earth versus geostationary Earth orbiting systems. The time frame for implementation is the first decade of the twenty-first century.

STUDY ELEMENTS

Science Requirements

Science objectives, requirements, and priorities for a comprehensive global climate change program were developed from science committee reports (refs. 1, 2, 7) and in close collaboration with the LaRC science study team members and other NASA centers (fig. 2). The important science necessary to monitor and predict global climate changes over decades and centuries require a combination and synthesis of data on the Earth's physical systems (atmosphere, oceans, and land surfaces), the hydrological and biogeochemical cycles, and solar/Earth radiation influences. In this study these disciplines were combined into three major classifications: atmospheric, surface, (land and ocean), and solar/Earth radiation. Specific primary measurement parameters were defined within each major category. The spatial and temporal requirements for the parameters were developed from several NASA working group studies. The resulting list of science requirements that formed the basis for this study is in Table 1.

Requirements are given separately for global change studies and regional process studies. The global change studies require long-term and highly accurate measurements to detect trends, sufficient temporal resolution to obtain accurate daily to monthly averages, and observations covering the entire globe. Spatial sampling requirements vary from 1 km for land and surface characteristics to 50 km for some atmospheric parameters. Temporal sampling requirements include sampling every 1 to 12 hours for atmospheric and radiation parameters and 1 day or more for most Earth surface measurements. Such observations are essential for the development, verification, and improvement of global models. The regional process studies are critical to understanding the Earth as a system and the individual regional processes that define the complete system. These studies require intensive sampling at the highest possible temporal and spatial resolutions but are of limited time and areal extent. Spatial sampling requirements vary from 30 meters to several hundred kilometers depending on the particular parameter. The temporal sampling requirements are also intense and vary from 15 minutes to 1 hour for the atmospheric

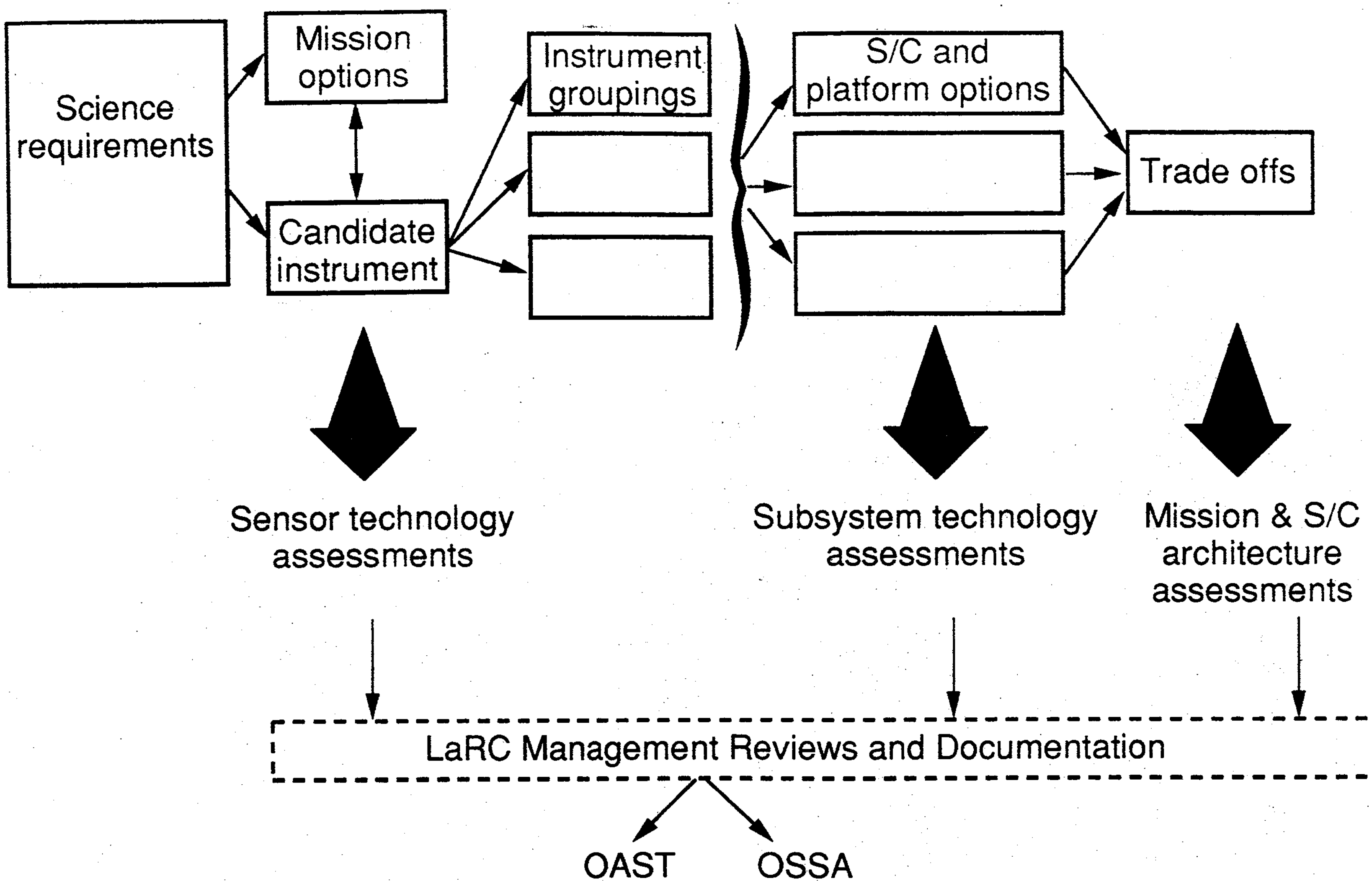


Figure 1. GCT ARCHITECTURE TRADE STUDY PROCESS.

Developed by: Tim Suttles, Edwin Harrison, Gary Gibson, Tom Campbell, Bruce Kendall, and colleagues

Sources: Science Committee Reports, NASA, and other Government Agency Scientists including Earth System Sciences Committee Report, January 1989; Committee on Earth Sciences-Federal Coordinating Council on Science, Engineering, and Technology; LaRC and GSFC scientists.

Science Objectives: Monitoring and predicting global climate changes over decades and centuries in the following categories:

- Physical systems (atmosphere, oceans, land surfaces)
- Biogeochemical cycles
- Water cycle
- Solar/Earth Radiation influences

Science Data:

- Global climate change long-term surveys
- Intensive regional climate processes studies

Science Categories:

- Atmosphere
- Surface (land, ocean)
- Solar and Earth radiation

Figure 2 - GCT Architecture Study Science Requirements

TABLE 1: GCTI SCIENCE REQUIREMENTS.

Regime/ Category	Measurable	Diurnal Cycle	Global Change Study Temporal	Global Change Study Spatial	Regional Process Studies Temporal	Regional Process Studies Spatial
Solar	Spectral radiation	No	1D	Sun disk	1D	Sun disk
Atmosphere	Pressure (surface)	No	3-12H	10 km		
	Temperature profile	Yes	1-3H	10-50 km	15M-1H	5 km
	Stratospheric gases	No	3-12H	50 km	30M	5-10 km
	Aerosols & part.	No	3-12H	10 km	15M-1H	0.1-1 km
	Tropospheric H_2O	No	3-12H	10 km	30M-1H	10 km
	Cloud cover & height	Yes	1-3H	1 km	15M-1H	1 km
	Tropospheric gases	Yes	1-3H	10 km	30M-1H	10-50 km
	Wind fields	Yes	1-3H	10 km	30M-1H	
Radiation bubdget	Reflected SW & emitted LW flux	Yes	1-3H	10-30 km	30M-1H	1-30 km
Earth (land/ ocean)	Surface temperature	Yes	1-3H	1-4 km	6M-24H	30 m-200 km
	Precipitation	Yes	1-3H	1-30 km	3M-3H	1-200 km
	Vegetation cover/type	No	7D	1 km	1-30D	30 m-10 km
	Soil moisture	No	2D	1-10 km	12H-7D	30 m-10 km
	Biomass inventory	No	7D	1 km	1-30D	1-10 km
	Ocean color (chloro.)	No	2D	1-4 km	2D	30 m-4 km
	Ocean circulation	No	2D	1-4 km	1D	30 m-4 km
	Sea level rise	No	2D	10 km	2D	10 km
	Sea ice cover/depth	No	7D	1-20 km	1-3D	1-25 km
	Ocean CO_2	No	2D	500 km		
	Snow cover/depth	No	7D	1- km	12H-3D	1-10 km

parameters to several days for many of the Earth (land/ocean) parameters. These observations are essential for developing the understanding of the processes and to provide experimental data for developing accurate regional models. A detailed discussion of the science requirements and the rationale for the requirements are presented in reference 8.

Mission Options

A range of orbits were evaluated by the mission design team as shown in figure 3 and Table 2. The need for full global coverage with repeated daily samplings, augmented by near continuous regional intensive coverage measurements, led to orbit selection at both Sun synchronous low Earth orbit and geostationary Earth orbit locations. A detailed discussion of the orbital possibilities and recommendations are in reference 9.

Instrument Selection

The instrument selection team surveyed instruments used on past and current spacecraft and those proposed for spacecraft of the near future in order to select a representative set of instruments for making the measurements defined by the science requirements. Details of the survey and the rationale for the subsequent selection of instruments are presented in reference 10. Performance and physically descriptive data were collected on nearly 100 instruments. Many of the instruments are in such an early stage of design and development that numerous changes in their measurement capabilities and physical characteristics can be expected. A summary of findings of the science instrument definition team is presented in figure 4. Four of the measurements could not be made with existing or proposed instruments. For three of these four measurements, new instruments were conceptualized as part of the GCT architecture study. The three concepts include a Geostationary High Resolution Microwave Radiometer (GHRMR) for measuring tropospheric water vapor from a geostationary orbit; a Soil Moisture Microwave Radiometer (SMMR) for measuring soil moisture from a low-Earth orbit; and an Atmospheric Pressure Lidar (APL) for measuring atmospheric surface pressure from low-Earth orbit. Separate adjunct studies were accomplished to develop design concepts for the GHRMR and SMMR instruments and the spacecraft buses. They are

Developed by: Ed Harrison, Gary Gibson, Tim Suttles, Israel Taback, Jim Buglia, and Heather Knight

Principal mission design drivers were the temporal coverage and resolution requirements for:

- Global Climate Change Studies - 3- to 12-hour temporal coverage
- Regional Climate Process Studies - minutes to 1 hour temporal resolution

Orbits analyzed included:

- Mid-Inclined (i = 28.5 - 57°, h = 400 - 600 km)
- Polar/Sun Synchronous (i = 97.8 - 99.5°, h = 600 -1000 km)
- Equatorial Low Altitude (i = 0, h = 1300 - 5200 km)
- Equatorial Intermediate Altitude (i = 0, h = 5300 - 20,000 km)
- Geosynchronous (i = 0°, h = 36,000 km)

Orbits selected:

- Sun synchronous (4 platforms to provide 3-hour global coverage with equally spaced equatorial crossing times, h ≈800 km)
- Geosynchronous (1 or 2 moveable in latitude to provide minutes to 1 hour coverage)
- Mid-Inclined (Space Station Freedom instruments)

Figure 3 - GCT Architecture Study Mission Design Options

Table 2. COMPARISON OF SATELLITE ORBITS

Orbit	Advantages	Disadvantages	Comments
MID-INCLINED i = 28.5-57° h = 400 - 600 km	- Pressure thru all local hours - High resolution - Maximize payload with shuttle launch (i=28.5°) - Compatible with space station	- No high latitude coverage	
Polar/Sun-synch i = 97.8-99.5° h = 600 - 1000 km	- Global coverage - Same local time coverage - High resolution - Compatible with NOAA operational satellites	- Limited temporal coverage from 1 satellite	- 4 satellites will provide 3-hour, global coverage
Equatorial (i = 0°) low altitude h = 1300 - 5200 km	- Moderate temporal coverage (2 - 4 hours)	- Very limited geographical coverage	
Equatorial (i = 0°) intermediate altitude h = 5300 - 20000 km	- Limited temporal and moderate geographical coverage - Higher resolution or smaller optics/propulsion requirements than GEO, but greater than for low orbits	- No high latitude coverage - Not compatible with NOAA operational satellites for correlative or auxiliary data	- 5 satellites required to cover all hours in the tropics and mid-latitudes
Geosynchronous i = 0° h = 36000 km	- Very high temporal coverage - Excellent for climate process case studies over a selected region - Compatible with operational satellites for auxiliary data	- Limited geographical coverage	- 5 satellites required to cover tropics and mid-latitudes

Developed by: Warren Hypes, Glenn Taylor, Jack Dodgen, Tony Jalink, Cheryl Allen, Rogard Ross, Lloyd Keafer, Tom Campbell, Bruce Kendall, Tom Swissler, Charles Husson, Tim Suttles, and colleagues

Surveyed ~ 100 candidate instruments and sensors:

- Instruments on current or past spacecraft (NOAA, DMSP, UARS, LANDSAT, ERBS, TOPEX, ERS, RADARSAT, SPOT, SST
- Near-term spacecraft (Eos-A, Eos-B, Eos-E, Eos-J, TRMM, SSF)

Selected 27 instruments:

- Existing instruments (7)
- Heritage (or derivatives of current) instruments (17)
- New instrument concepts (3)

Accumulated/developed instrument data base descriptions

Developed complementary, compatible instrument groupings

Assessed temporal and spatial resolution requirements achieved against the mission design and spacecraft options selected

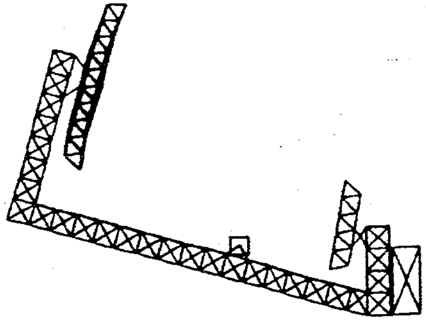
Developed requirements for several new classes of GEO instruments to meet < 3-hour temporal resolution requirements

Figure 4 - GCT Architecture Study Instrument Selections

detailed in references 11 and 12 and outlines of the concepts are shown on figures 5 and 6. A general concept for the APL was also developed, but a detailed design concept was not produced. An outline of the concept is shown on figure 7. Currently there is no instrument concept for the fourth measurement, ocean/atmosphere CO_2 exchange, from either a GEO or LEO spacecraft.

The initial selection of instruments was made based on an instrument's ability to make the required measurement at the specified spatial resolution. The temporal requirements for the measurements were also a factor driving instrument selection towards instruments that can operate from geostationary orbit for measurements with temporal requirements of 1 hour or less. The only practical way of meeting this temporal requirement is to place an instrument in a stare, sweep, or scan mode in geostationary orbit. Some of the measurements with short temporal requirements, however, cannot be accomplished from GEO with existing or near-term instruments. The technology needs for new classes of GEO instruments were developed within this study; however, they were not carried forward into the mission options and spacecraft/platform architecture studies because the current technology base will not support their inclusion. Thus, some of the short temporal requirements were accommodated in LEO using multiple spacecraft to shorten the time between measurements. Various options for the number of GCT spacecraft, orbit inclination, orbit altitudes, etc. are discussed in reference 5.

The instruments selected are listed in Table 3. Design and performance information on the selected instruments are in reference 10. The three instruments for which new concepts were developed are indicated in the table. During instrument selection, three changes were made in the written format of the science requirements to correlate science requirements with instrument availability. The measurable "stratosphere gases" was separated into "ozone" and "other gases" since ozone can be measured from a geostationary spacecraft with current conceptual instruments while the other gases cannot. "Wind fields" was separated into "Stratospheric" and "Tropospheric" because the measuring instruments for the two types of winds are entirely different and, again, one may be inferred from a geostationary orbit measurement while the other cannot.



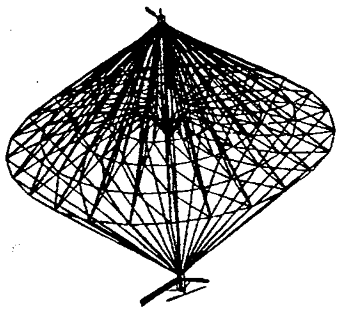
Title: Geostationary High Resolution Microwave Radiometer (GHRMR)

Measurement: Tropospheric Water Vapor, Precipitation

Contact: Tom Campbell, LARC   Jeff Farmer, LARC

Instrument Type: Microwave Radiometer
Dimensions: 15m X 15m X 30m
Mass: 2525 kg
Average Operational Power: 370 watts
Data Rate: 90 kbps
Spectral / Frequency Range: 18 - 220 GHz
No. of Channels / Frequencies:
Viewing Field: Earth Disc
Scanning Characteristics: Mechanical mirror with electronic phased array scanning
Resolution (Horizontal / Vertical): 10 - 120 km /
Swath Width:
Satellite Application: None (new concept)
Technology Status: Conceptual design, GCTI spacecraft, no formal study

Figure 5. Conceptual geostationary microwave radiometer for water vapor and percepitation.



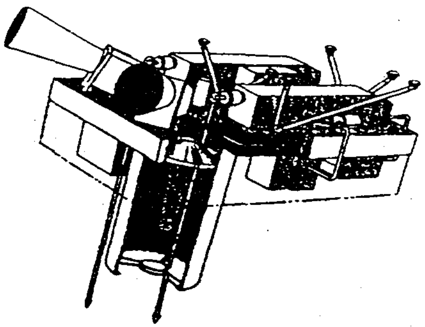
Title: Soil Moisture Microwave Radiometer (SMMR)

Measurement: Soil Moisture

Contact: Tom Campbell, LARC   Melvin Ferebee LARC

Instrument Type: Microwave Radiometer
Dimensions: 118m X 118m X 100m
Mass: 4000 kg
Average Operational Power: 500 watts
Data Rate: 1 kbps
Spectral / Frequency Range: 1.4 GHz
No. of Channels / Frequencies: 1 Frequency
Viewing Field: Nadir (+/-18.5° cross track)
Scanning Characteristics: Pushbroom
Resolution (Horizontal / Vertical): 12 km /
Swath Width: 535 km
Satellite Application: None (new concept)
Technology Status: Heritage - Airborne Low Freq. Microwave Instr. for Soil Moisture, Sea Surface Temp., and Salinity / Aircraft
Current - Conceptual Design, GCTI Spacecraft, No formal study

Figure 6. Conceptual microwave radiometer for measuring soil moisture.



Title: Atmospheric Pressure Lidar (APL)

Measurement: Surface Pressure, Aerosols and Particulates, Cloud Cover and Height

Contact: Larry Korb, GSFC; Edward Browell, LARC

Instrument Type: Differential Absorption Lidar

Dimensions: .8m X 1m X .8m (per unit -- two units)

Mass: 500 kg (total mass)

Average Operational Power: 1200 watts (total)

Data Rate: 1400 kbps (peak), 1200 kbps (avg)

Spectral / Frequency Range: 720 - 770 nm

No. of Channels / Frequencies:

Viewing Field: Nadir

Scanning Characteristics: Receiving telescope on scanning platform +/-45 deg

Resolution (Horizontal / Vertical): 10 km /

Swath Width: 1600 km

Satellite Application: None (new concept)

Technology Status: Heritage - LITE & LASE Instrument for Atmospheric Parameters / Aircraft, Derivative of LASA - EAGLE design

Current - Conceptual design, GCTI Spacecraft, No formal study

Figure 7. Conceptual lidar for measuring atmospheric pressure at the surface.

Table 3 - Science Requirement Measurables and Selected Instruments

Measurable	Selected Instruments: Global Change Studies	Selected Instruments: Regional Process Studies
Solar Spectral Radiation	• Active Cavity Radiometer (ACRIM) • Solar Stellar Irradiance Comparison Experiment (SOLSTICE) • X-Ray Imager (XRI)	• Active Cavity Radiometer
Atmospheric Surface Pressure	• Atmospheric Pressure Lidar (APL)	• No Requirement
Atmospheric Temperature Profile	• Advanced Microwave Sounding Unit B (AMSU-B) • Atmospheric Infrared Radiation Sounder (AIRS)	• Infrared Vertical Sounder (IRVS)
Stratospheric Gases (Ozone)	• Stratospheric Aerosols & Gas Experiment III (SAGE)	• Ozone Mapper (OZMAP)
Stratospheric Gases (Other)	• Spectroscopy of the Atmosphere Using Far-Infrared Emission (SAFIRE)	• Same as Global Change
Aerosols and Particulates	• Stratospheric Aerosols and Gas Experiment III • Earth Observing Scanning Polarimeter (EOSP)	• Infrared Vertical Sounder
Tropospheric Water Vapor	• Atmospheric Infrared Radiation Sounder • Advanced Microwave Sounding Unit-B * High Resolution Microwave Spectrometer Sounder (HIMSS)	• GEO High Resolution Microwave Radiometer (GHRMR)
Cloud Cover, Type, Height	• Moderate Resolution Imaging Spectrometer-Nadir Scan (MODIS-N) • Atmospheric Infrared Radiation Sounder	• GEO Moderate Resolution Imaging Spectrometer (GMODIS) • Goes Imager

Table 3 - Continued

Measurable	Selected Instruments: Global Change Studies	Selected Instruments: Regional Process Studies
Tropospheric Gases	• Tropospheric Emissions Spectrometer (TES) • Tropospheric Radiometer for Atmospheric Chemistry and Environmental Research (TRACER)	• Same as Global Change
Wind Fields-Stratospheric	• Stratospheric Wind Infrared Limb Sounder (SWIRLS)	• Same as Global Change
Wind Fields-Tropospheric	• GOES Imager	• Same as Global Change
Reflected Short Wave and Emitted Long Wave Flux	• Cloud and Earth Radiant Energy System (CERES)	• Geostationary Earth Radiation Sensor (GERS)
Surface Temperature	• Moderate Resolution Imaging Spectrometer - Nadir Scan	• GOES Imager
Precipitation	• High Resolution Microwave Spectrometer Sounder	• GEO High Resolution Microwave Radiometer (GHRMR)
Vegetation Cover Type	• Moderate Resolution Imaging Spectrometer-Nadir Scan	• High Resolution Imaging Spectrometer (HIRIS)
Soil Moisture	• Soil Moisture Microwave Radiometer (SMMR)	• Same as Global Change
Biomass Inventory	• Moderate Resolution Imaging Spectrometer-Nadir Scan	• High Resolution Imaging Spectrometer
Ocean Color	• Moderate Resolution Imaging Spectrometer-Tilt Scan (MODIS-T)	• Moderate Resolution Imaging Spectrometer-Tilt Scan • High Resolution Imaging Spectrometer

LBG-MP 32

Table 3 - Concluded

Measurable	Selected Instruments: Global Change Studies	Selected Instruments: Regional Process Studies
Ocean Circulation	• Moderate Resolution Imaging Spectrometer-Tilt Scan • Altimeter (ALT) w/3 Channel Microwave Radiometer (3 Ch MR)	• Same as Global Change
Sea Level Rise	• Altimeter w/3 Channel Microwave Radiometer	• Same as Global Change
Sea Ice Cover	• Moderate Resolution Imaging Spectrometer-Nadir Scan	• Same as Global Change
Snow Cover	• Moderate Resolution Imaging Spectrometer-Nadir Scan	• Same as Global Change
Ocean CO_2	• No Concept Available	• No Requirement
Snow Depth Ice Depth	• High Resolution Microwave Spectrometer Sounder	• Same as Global Change

The "cover" and "depth" measurements for the "sea ice" and "snow" measurables were broken out as separate measurements since instruments applicable to measuring cover are entirely different than those for measuring depth.

Instrument Complements

The definition of GCT spacecraft represents an ordered approach to the accommodation of scientific measurement and instrument requirements. Accommodation of the temporal science requirements effectively establishes the onboard instrument inventory for a particular spacecraft. Instrument operating requirements such as power, mass, spatial resolution, and data rates establish the performance specifications for the spacecraft subsystems. Instrument viewing requirements, together with heat rejection radiator considerations, establish the onboard positioning and layout within each of the spacecraft.

The first selection of instruments for manifesting aboard specific spacecraft is to separate those for LEO application from those for GEO application. The low-Earth orbits for all the spacecraft are assumed to be Sun synchronous, thus allowing observations at any point on the Earth at 12-hour intervals. Accordingly, one spacecraft satisfies the 12 hour and longer temporal measurement requirement and also meets the upper limit of a 3- to 12-hour requirement. Four spacecraft in complementary orbits (45 degrees apart) satisfy the upper limit for a 1- to 3-hour requirement.

The only practical way to accommodate the 1 hour or less temporal coverage objective is to place instruments in geostationary orbit; however, some of the instruments do not have the spatial resolution and sensitivities for the geostationary altitude. Instruments for temporal measurements of 1 hour and less, that currently have or in the near future can be expected to have geostationary capability, were manifested onboard a geostationary spacecraft. Those that are not near-term candidates for geostationary application were manifested on LEO spacecraft with a 3-hour temporal cycle. Early in the study it was concluded that measurements more frequent than the 3 hours provided by four sunsynchronous LEO spacecraft cannot realistically be provided because of the excessive number of spacecraft required.

Thus, the spacecraft instrument complements and the composition of the spacecraft fleet were determined based on the ground rule that the temporal measurement requirements of less than three hours would be met by geostationary systems if currently projected instrument technologies developments occurred. If not, the LEO spacecraft would accommodate instruments for 3 hours and longer repeat coverage periods. Table 4 presents two options for the LEO spacecraft fleet, with designations of A through E assigned for the individual spacecraft. Note on the table that spacecraft E of the small spacecraft constellation includes instruments for the less than 1-hour temporal measurements. Although grouped according to this temporal requirement, as previously stated, measurements from LEO could not be accommodated at less than the 3-hour frequency without a prohibitive number of spacecraft and instruments.

Seven of the instruments listed in Table 3 are proposed for use on geostationary spacecraft. Of the seven instruments proposed, six can be placed on a single spacecraft but the seventh, the new concept GHRMR microwave instrument, requires a dedicated spacecraft due to the large size antennae and unique configuration of microwave instruments. The instrument complements of the two geostationary spacecraft are listed in Table 5 as Option G2, spacecraft A&B. This assumes packaging and launch by existing Titan IV vehicles and a Centaur upper stage.

Separate options for packaging and deployment for an on-orbit assembly of the entire seven geostationary instruments on a single platform was also examined. This option, designated G1 in Tables 4 and 5, is possible with Shuttle or Titan IV launches and with on orbit assembly at Space Station Freedom. Alternatively, if a Shuttle C, Block 1 with its large 7.6 m-diameter shroud is developed, the entire complement of seven instruments might be packaged and launched as a single, complete platform with automated deployment occurring on orbit.

Table 4 - GCT Architecture Trade Study
Spacecraft and Instrument Complement Summary

GCTI Spacecraft	Spacecraft Instrument Complement	Option 1 Constellation for 3-Hour Coverage	Option 2 Platforms for 3-Hour Coverage
• **Low Earth Orbit**			
A, Soil Moisture	SMMR	1	1
B, 12-Hr.+Temporal	ACRIM, SOLSTICE, XRI, MODIS-T, HIRIS, EOSP, ALT, 3ChMR	1	} 4 (B through E)
C, 3 to 12-Hr. Temporal	APL, SAGE III, EOSP	1 (12-hour)	
D, 1 to 3-Hr. Temporal	CERES, ACRIM, MODIS-N, EOSP, AMSU-B, AIRS, HIMSS	4 (3-hour)	
E, Less than 1-Hr. Temp.	SAFIRE, MLS (EOS), TES, TRACER, SWIRLS, EOSP	4 (3-hour)	
• **Geostationary Orbit**			
G1, Less than 1-Hr. Temp.	GERS, ACRIM, IRVS, OZMAP, GOES Imager, GHRMR, GMODIS	1	1
--OR--			
G2, Less than 1-Hr. Temp.	G1 Complement Less GHRMR	1	1
	GHRMR Alone	1	1
	TOTAL	1 Special Purpose LEO 10 Delta Class LEO 1 or 2 GEO	1 Special Purpose LEO 4 Titan IV Class LEO 1 or 2 GEO

LBG-MP 16

Table 5 - Spacecraft and Instrument Complements for Geostationary Earth Orbit Measurements

Geostationary Spacecraft

	Option G1	Option G2 A	Option G2 B
GERS	*		*
ACRIM	*		*
IRVS	*		*
O2MAP	*		*
GOES IMAGER	*		*
GMODIS	*		*
GHRMR	*	*	

The combination of the one or two GEO spacecraft and the two options of the LEO spacecraft produce the final fleet architecture listed in Table 6. Note that two major options are suggested. Option 1 features ten Delta Class LEO spacecraft while Option 2 features four large Titan IV Class LEO spacecraft. Under both options, the special purpose soil moisture microwave spacecraft (LEO Spacecraft A) and the one or two GEO spacecraft are required. The GEO spacecraft are assumed to be moveable in latitude to monitor regional areas of high scientific importance.

Spacecraft Configurations

The spacecraft and platform concept development team surveyed existing and proposed spacecraft and contacted several NASA centers and aerospace industry sources in developing the spacecraft architecture options outlined on figure 8. Several combinations of space architecture options were assessed which included small Delta launched LEO spacecraft and large Titan IV launched LEO platforms. All architectures included a Titan IV launched soil moisture radiometer for LEO operations and one or two geostationary platforms with several launch, deployment and/or on-orbit assembly options. Instrument allocations and spacecraft/platform designs are discussed below.

The configurations of the GCT spacecraft vary from modification of existing modularized spacecraft to entirely new conceptual designs. The new designs are related to the three special purpose spacecraft: the LEO Spacecraft A and the two GEO Spacecraft options.

The modified modular spacecraft used extensively to provide the spacecraft operating subsystems for the remainder of the GCT fleet is the Multimission Modular Spacecraft (MMS) developed by the NASA Goddard Space Flight Center. The modified MMS and its application to the GCT fleet are detailed in reference 13. For the GCT application, the communication and data handling module would be replaced with the new NASA Data Link Module, the Attitude Control System would incorporate advances developed for the TOPEX spacecraft, and the power and propulsion modules would incorporate recent advances that evolved from Space Station Freedom

Table 6 - Number of Spacecraft in the GCT Fleet

Spacecraft Type and Designation (Temporal Requirement)	Number of GCTI Spacecraft: Option 1 (Temporal Achieved)	Option 2 (Temporal Achieved)
Low Earth Orbit		
A, Special Purpose (12-hour+)	1 (12-hour)	1 (12-hour)
B, (12-hour)	1 (12-hour)	
C, (3 to 12-hours)	1 (12-hour)	4 Combines the functions of Option 1 Spacecraft B,C,D, and E platforms are designated L1,L2,L3,L4
D, (1 to 3-hours)	4 (3-hour)	
E, (Less than 1-hour)	4 (3-hour)	
Geostationary Orbit		
G1, (Less than 1hour)	1 (continuous)	1(continuous)
G2-A, (Less than 1-hour)	1(continuous)	1(continuous)
B, (Less than 1-hour)	1(continuous)	1(continuous)
TOTAL	1 Special Purpose LEO 10 Delta Class LEO 1 or 2 GEO	1 Special Purpose LEO 4 Titan IV Class LEO 1 or 2 GEO

Developed by: Bernard Garrett, Ansel Butterfield, Jeff Farmer, Melvin Ferebee, Paul Garn, Bill Davis, Charles King, Don Burrowbridge, Tom Campbell, Bruce Kendall, Israel Taback, and Dick Wrobel

Surveyed existing and proposed spacecraft (e.g. MMS, Advanced Tiros N/NOAA-11, EOS, GOES I-M, TDRSS, UARS, SSF, Lightsats/Earth Probes)

Selected contacts with MSFC, GSFC, TRW, Spartan Space Services, Fairchild, Ford Aerospace

Developed concepts for two LEO options and two GEO options

LEO:

1. Constellation of multiple (10) spacecraft using similar Advanced Modular Multimission spacecraft buses and one unique spacecraft--Delta Launch Vehicle Compatible/Titan IV for unique spacecraft.
2. Constellation of 4 platforms (one EOS class, three UARS class) plus one unique spacecraft--Titan IV compatible.

GEO:

1. One GEO spacecraft with full GEO instrument complement--Shuttle C--Block 1/ Centaur G compatible or assemble at SSF with two Shuttle or Titan IV launches.
2. Two GEO spacecraft--Titan IV/Centaur G compatible.
   a) High Resolution Microwave Radiometer Instrument
   b) Six Regional Processes Instruments

Modified scanning instrument design (APL) to minimize viewing obstructions.
Completed launch vehicle packaging assessments and assembly/deployment sequences.

Figure 8 - GCT Architecture Study Spacecraft/Platform Concept Development

and Earth Observing System studies and designs. For the smaller spacecraft B, C, D, and E of Option 1, the baseline design triangle-shaped module support structure of the MMS has been replaced with a graphite fiber composite beam frame covered with facing sheets to serve as the mounting surface for the operating subsystems and payload instruments. The spacecraft and payload can be accommodated inside a Delta payload shroud and can be launched with a Delta Series 6920 or Series 7920 booster capable of placing 2500 kg and 3300 kg, respectively, into a 650 km polar (Sun synchronous) orbit. These LEO spacecraft configurations are shown in figure 9. Mass, power, and data rate estimates for the instrument payloads of these LEO spacecraft are shown in figures 10, 11, and 12, respectively.

For the large spacecraft of Option 2, the upgraded MMS with the conventional triangle shaped module support structure is attached to a support structure of graphite fiber composite tubes similar to that used on the UARS spacecraft. Two sizes of the support structure are utilized. Large spacecraft L1, supporting twenty instruments, is 14.8 m in length while large spacecraft 2, 3, and 4, with identical configurations and supporting thirteen instruments are 9.7 m in length. Large spacecraft L1, the largest of the multiple instrument GCT spacecraft, has a mass of approximately 14,400 kg and a power requirement of approximately 10.9 kW. All of the large spacecraft fit within a Titan IV shroud and are placed in a near polar, Sun synchronous orbit with a Titan IV booster. These LEO platform configurations are shown in figure 13. Total mass estimates for the LEO and GEO spacecraft including instrument complements and spacecraft/platform options are presented on figure 14.

Data Rates

Peak and average data rates for the spacecraft vary widely as dictated by the spacecraft's instrument complement. The range in peak rates varies from .001 MBPS for the special purpose spacecraft A of both options to a high of 314 MBPS for the LI spacecraft of Option 2. A single instrument, the High Resolution Imaging Spectrometer (HIRIS-see table 3) establishes the upper values of both Option 1 and Option 2. Excluding this single instrument that occurs on Spacecraft

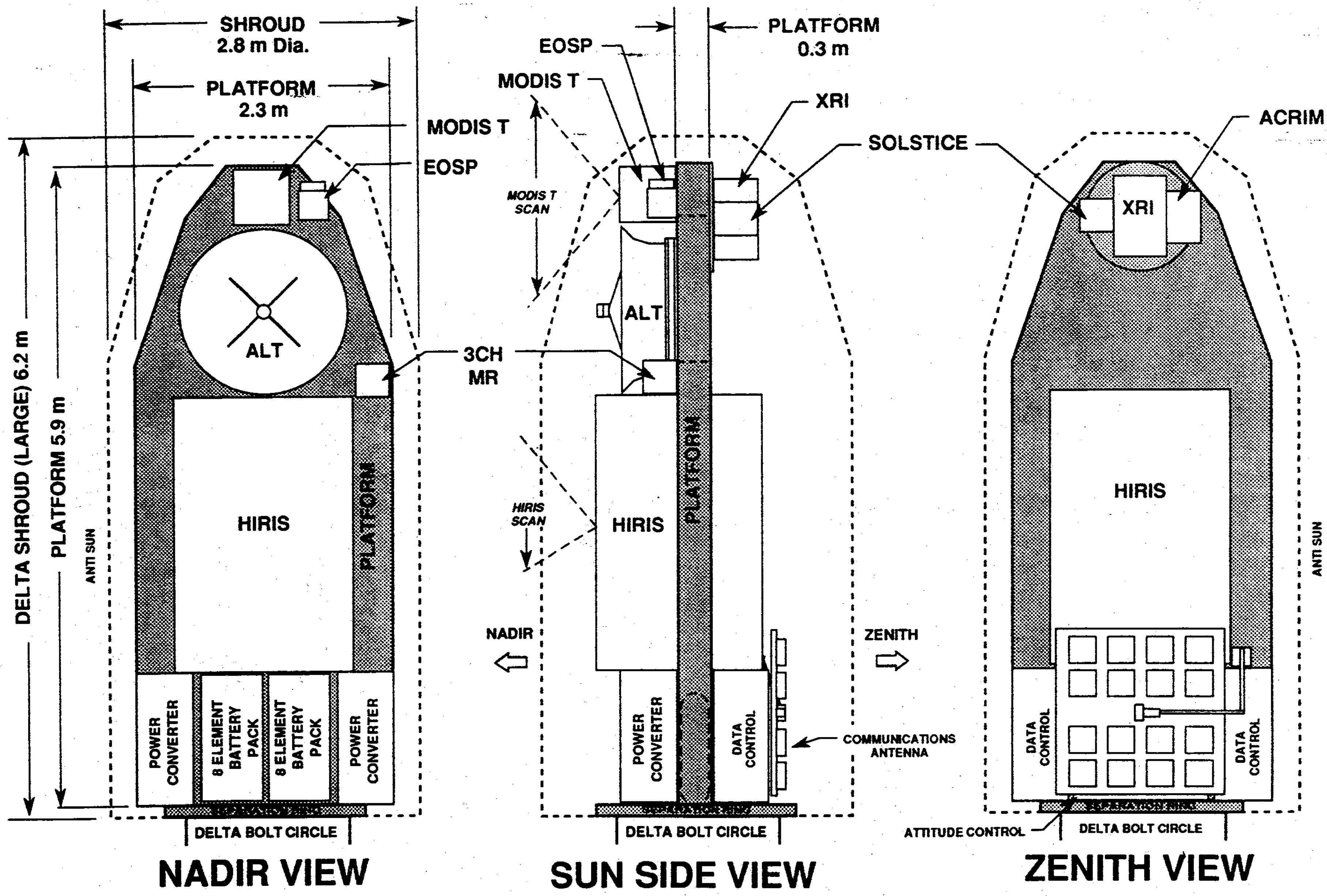
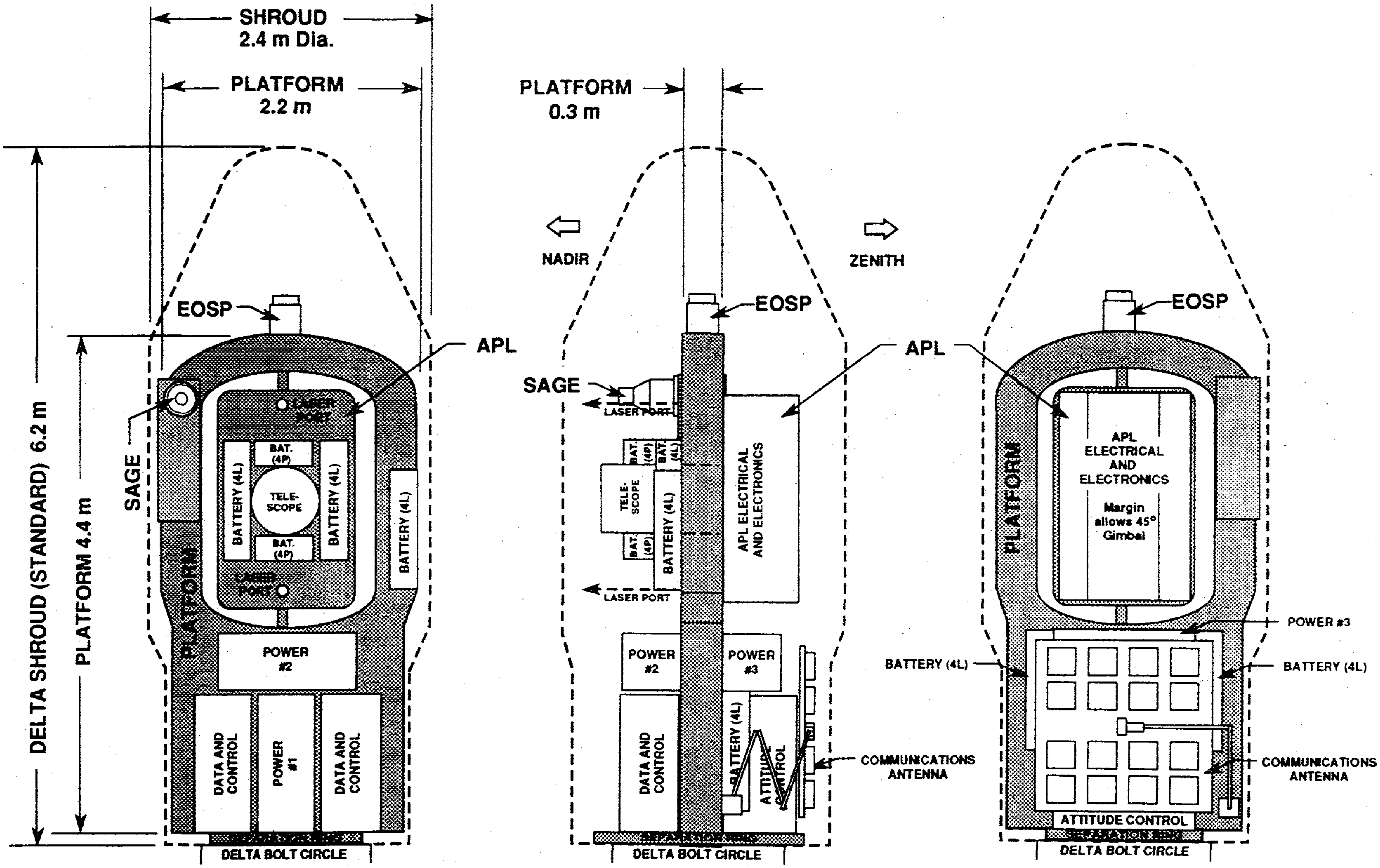


Figure 9(a). Side View Features for Spacecraft Configuration B (12 Hour and Longer Measurement).



NADIR VIEW
Launch Configuration

SUN SIDE VIEW
Launch Configuration

ZENITH VIEW
Launch Configuration

Figure 9(b). Side View Features for Spacecraft Configuration C (3 to 12 Hour Measurements).

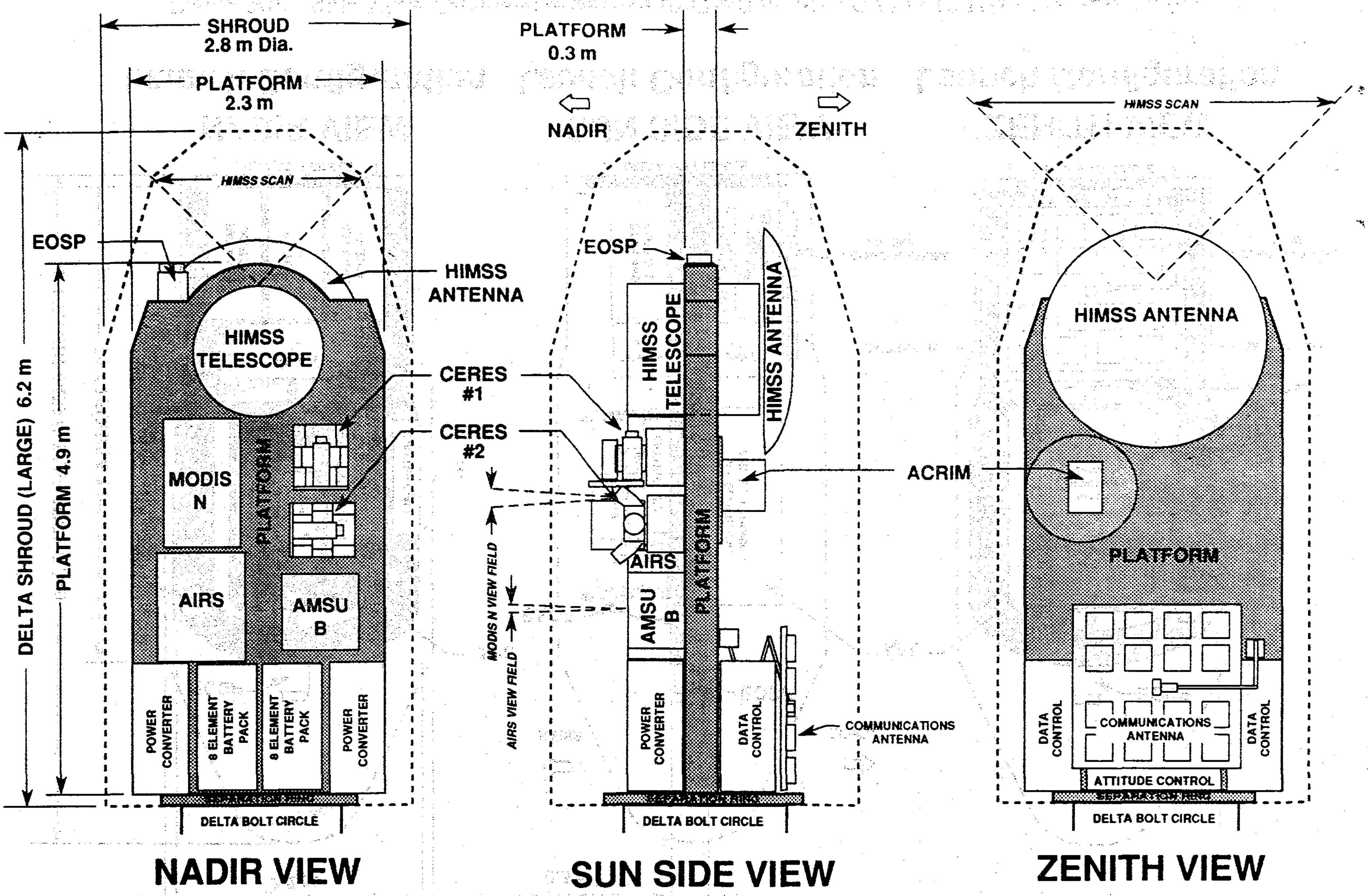


Figure 9(c). Side View Features for Spacecraft Configuration D (1 to 3 Hour Measurements).

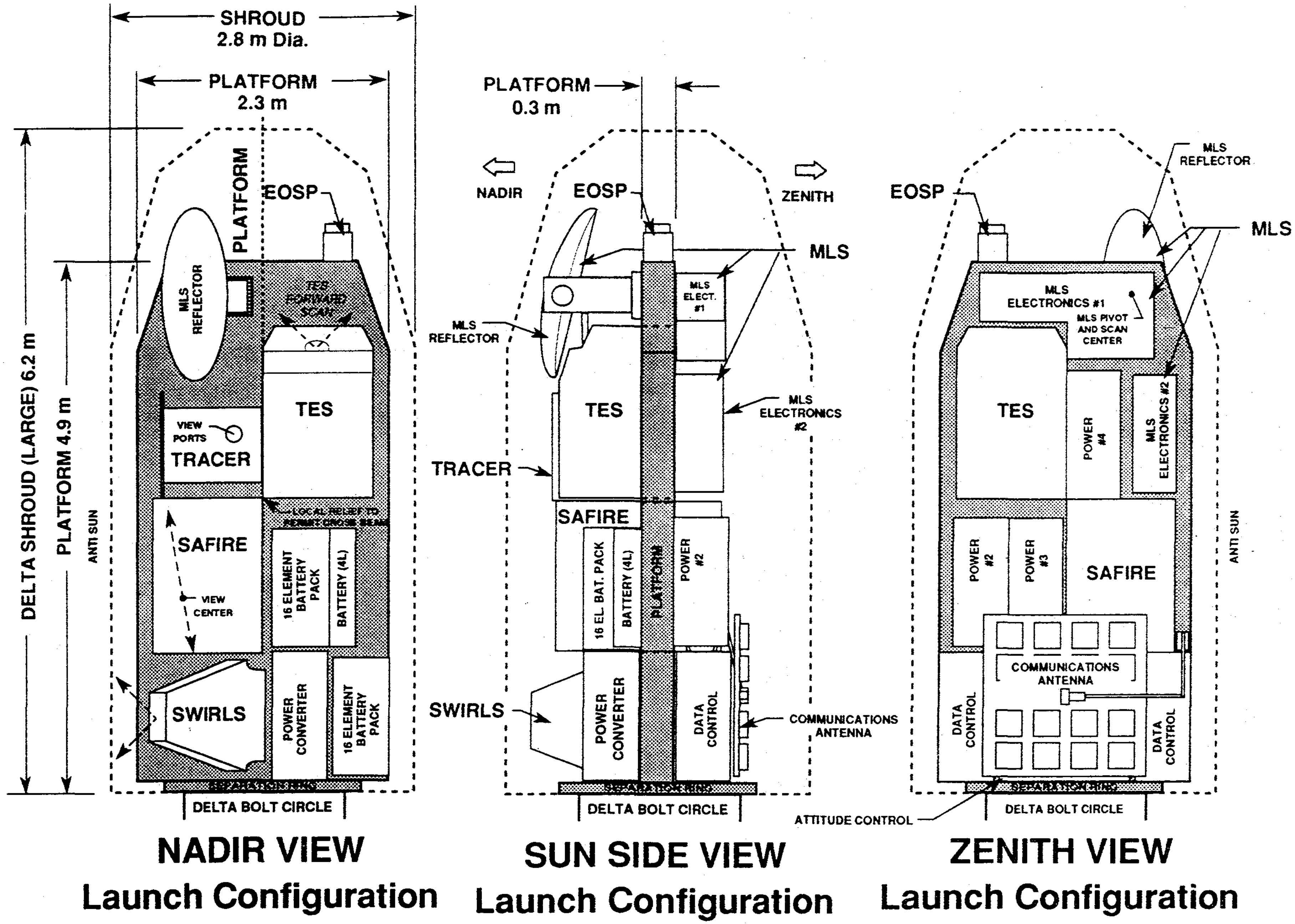


Figure 9(d). Side View Features for Spacecraft Configuration E (Less than 1 Hour Measurements).

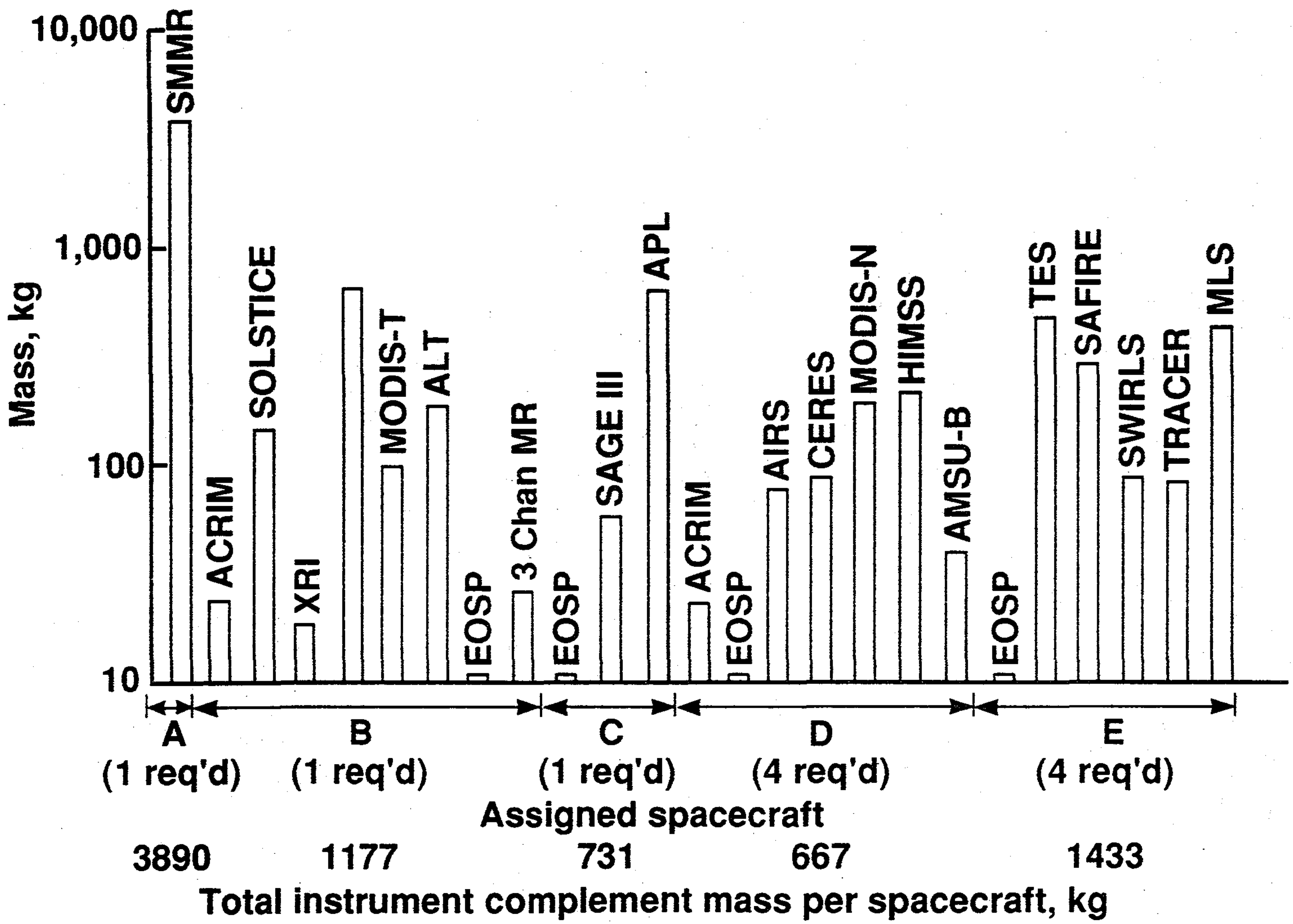


Figure 10. Low Earth Orbit Science Instruments, Mass Estimates

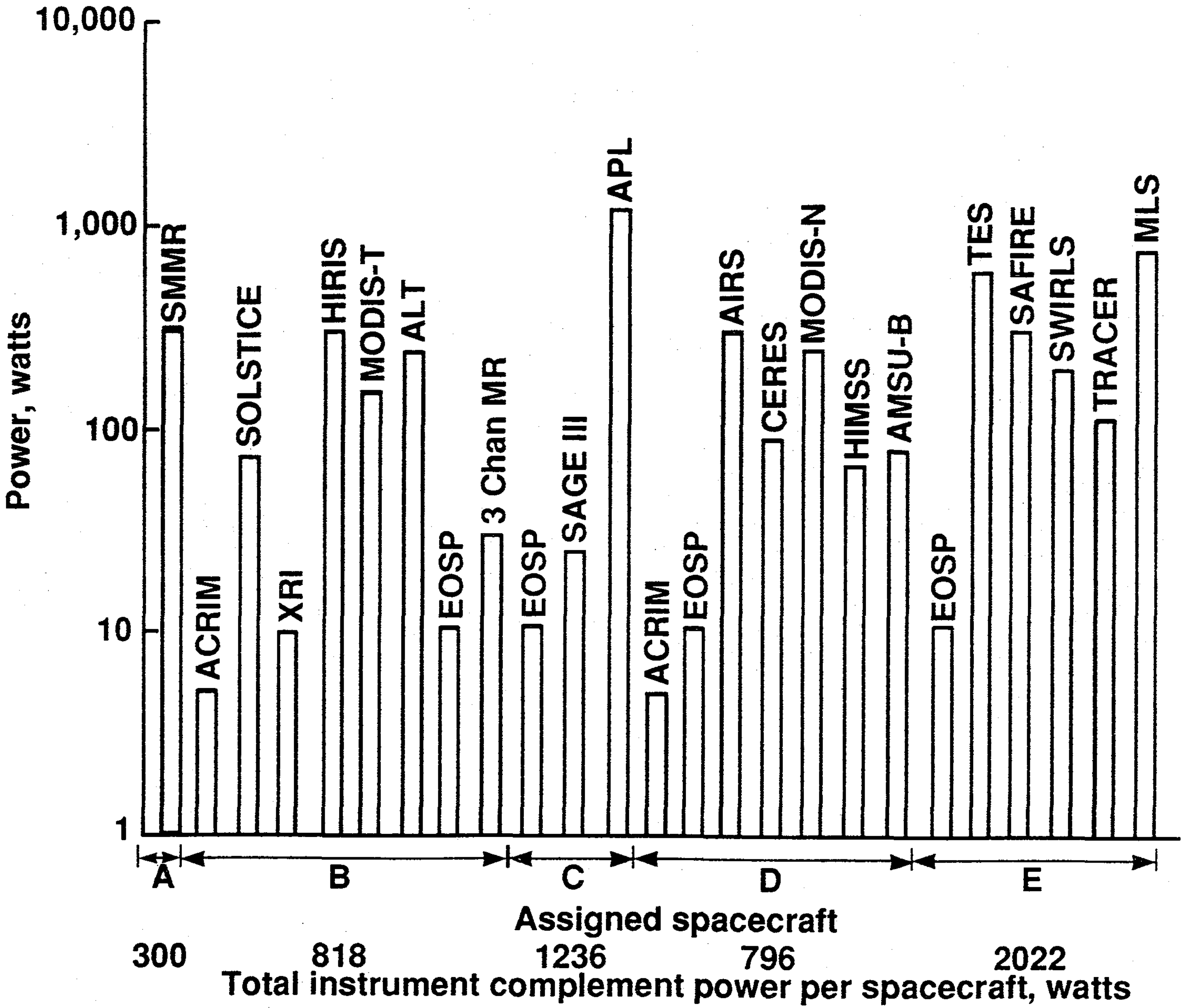


Figure 11. Low Earth Orbit Science Instruments, Power Estimates

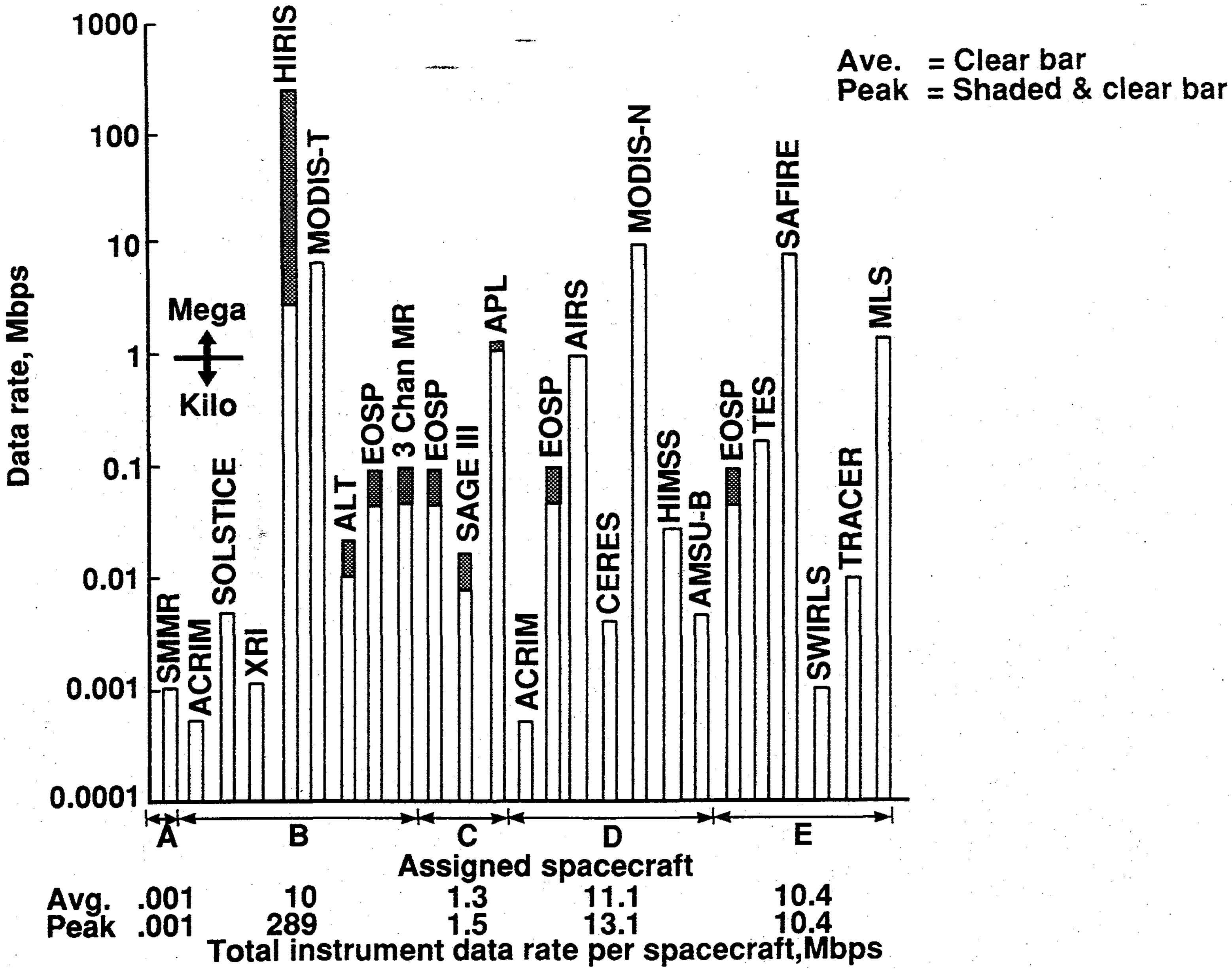


Figure 12. Low Earth Orbit Science Instruments, Data Rate Estimates

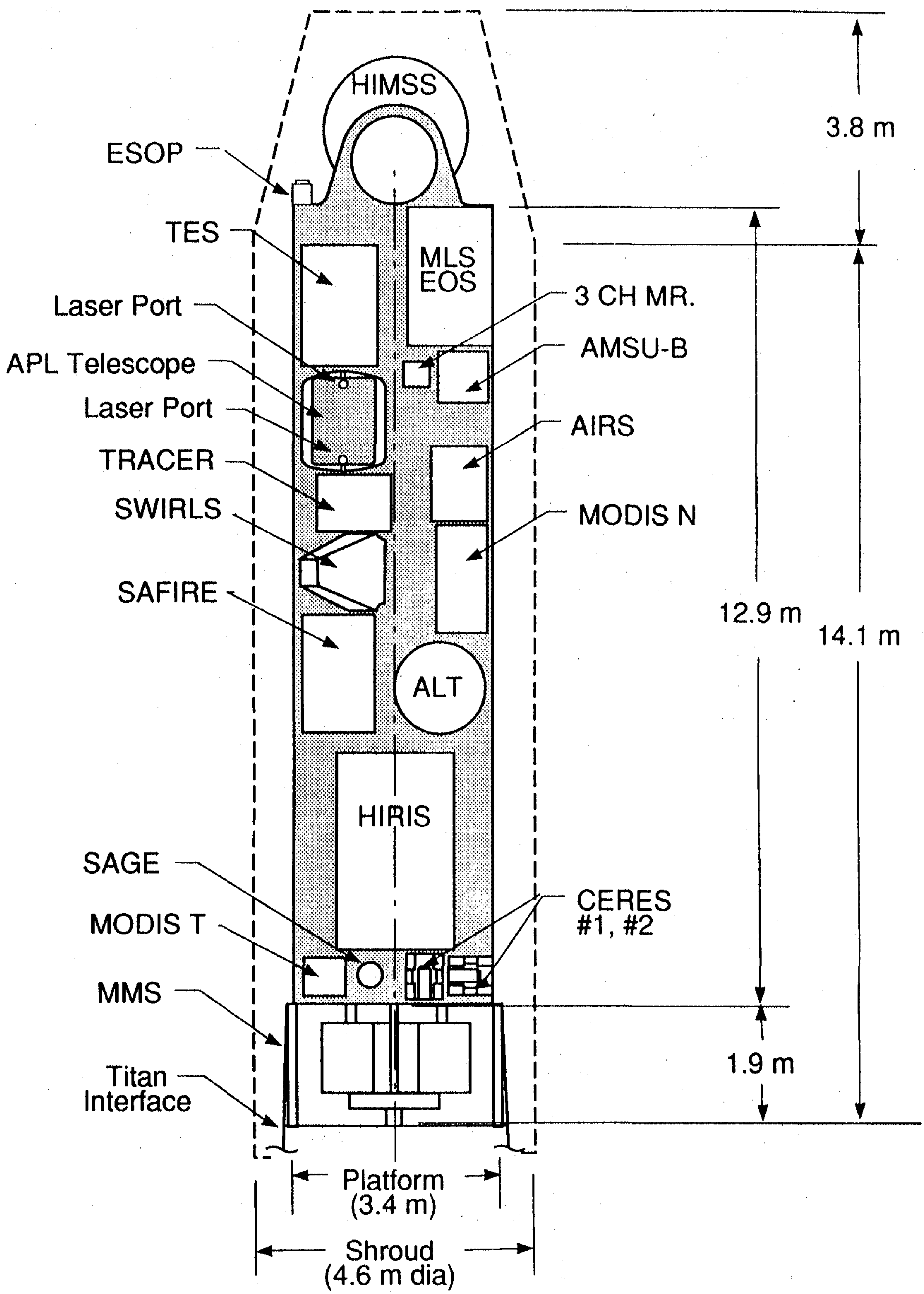


Figure 13(a). Layout of Instruments and Accommodation Within a Titan Shroud for the Large Spacecraft Configurations L-1.

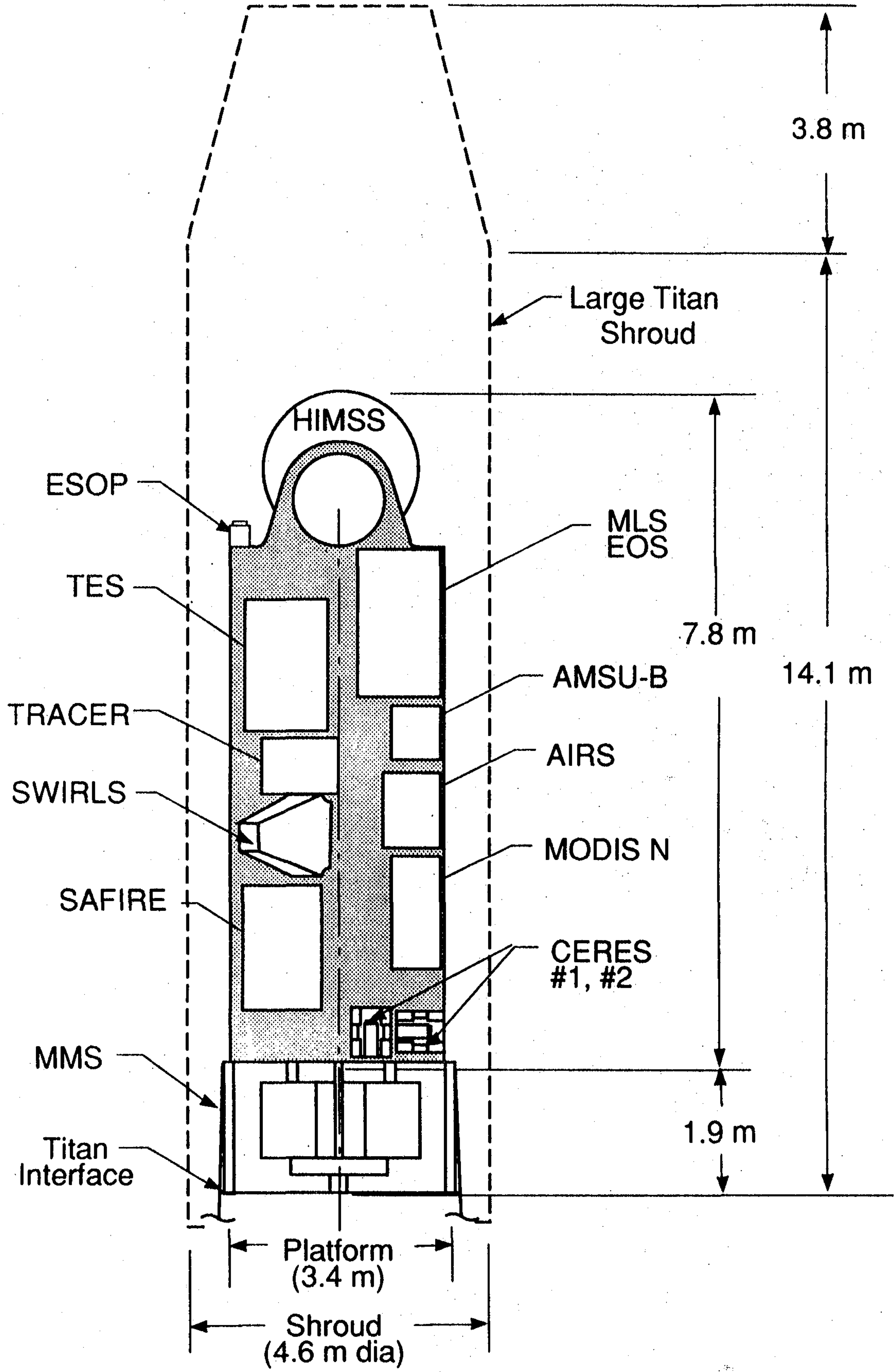


Figure 13(b). Layout of Instruments and Accommodation Within a Titan Shroud for the Large Spacecraft Configurations L-2, L-3 and L-4.

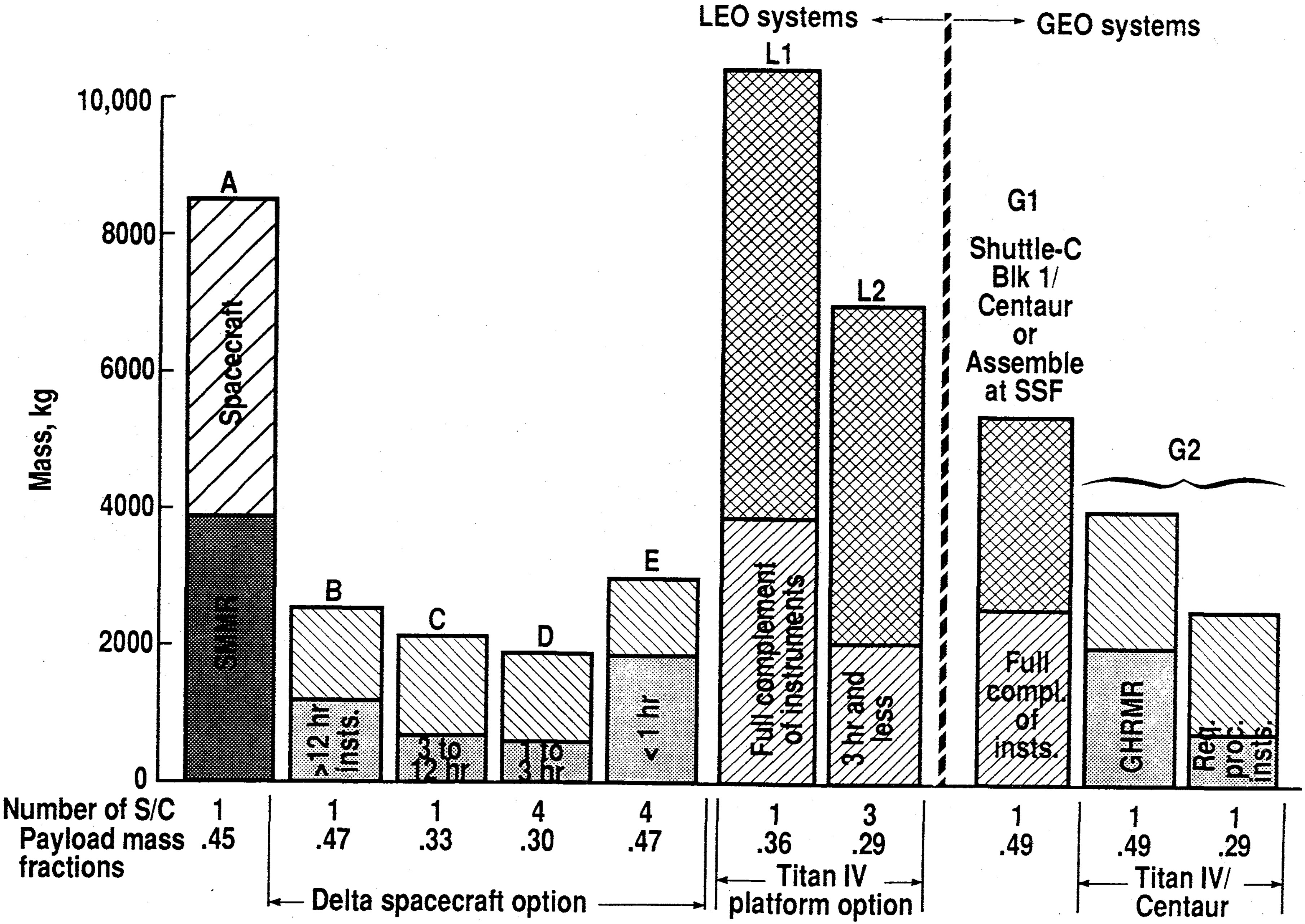


Figure 14. GCT Architecture Study Spacecraft/Platform Mass Estimates.

B of the small spacecraft option and spacecraft L1 of the large spacecraft option, the maximum data rate for both Option 1 and Option 2 is the 45.8 MBPS that occurs with the geostationary spacecraft G1. Thus, the nominal range for the majority of the spacecraft is .001 to 45.8 MBPS with the peak value of 289 to 314 MBPS occurring on only one spacecraft in each option due to a single instrument. A detailed discussion of instrument data rates and a concept for data management is presented in reference 14.

Summary of Science Requirements Met

Figure 15 and Table 7 present summations of the degree to which the science requirements of Table 1 have been met by the two options for the GCT fleet. As a general statement, temporal sampling requirements of less than 3 hours have not been proposed because of the excessive number of spacecraft needed. An exception to this general statement is the group of measurables in the regional process studies group that can be accommodated from a geostationary platform, thus providing a nearly continuous measurement capability.

There is a wide range in the ability of the instrument complements to meet the spatial resolution requirements of both the global change and regional process measurables. The inability to meet the spatial resolution requirements are sensor and instrument technology limits rather than the practical limit of numbers of spacecraft as in the temporal sampling analysis. A separate analysis of sensor and instrument technology needs is being conducted to complement the basic GCT study.

Eos A and B Presence

As an adjunct to the basic GCT Study, an analysis was conducted to determine how the presence of an operational EOS A and B spacecraft may alter the architecture of the two GCT fleet options. While maintaining equivalent temporal and spatial measurements, four Delta-class LEO spacecraft of Option 1 could be deleted or one of the Titan IV class LEO spacecraft of Option 2 could be deleted. The requirement for the one special purpose LEO spacecraft (with the soil moisture instrument) and the two GEO spacecraft of both Options 1 and 2 remains unchanged.

I Global Change Study

- No known instrument for ocean CO_2 measurements
- **Temporal Sampling Requirements:**
  - 15 fully met
  - 1 (tropospheric wind fields) conditionally met with GOES Imager on GEO platform
  - Remaining 8 are within the range of the requirements (3 hr. or greater) with two exceptions:
    - (1) Atmospheric pressure lidar (APL) is power intensive. Deemed not advisable to allocate instrument to multiple LEO spacecraft to meet 3-hour objective - meet 12 hour repeat coverage requirement
    - (2) Stratospheric aerosols and gas experiment (SAGE III) result of instrument complement distribution among spacecraft - meets 12-hour requirement
- **Spatial Resolution Requirements:**
  - 13 fully met
  - 1 (tropospheric wind fields) conditionally met with GOES Imager
  - 4 (temperature profile, tropospheric water, radiation budget, and sea level rise) judged acceptable range
  - 3 (precipitation, soil moisture sea, ice depth) are within range of requirement
  - 3 not met:
    - Tropospheric gases (10 km requirement, achieved 6 - 65 km resolution)
    - Stratospheric wind fields (10 km requirement, achieved 250 x 350 km with SWIRLS)
    - Snow depth (1 km requirement, achieved 5 - 15 km)

Figure 15. Summary of GCT Science Requirements Met/Not Met

II Regonal Process Studies

- The following measurements not achievable from geostationary orbit distances with any known instruments
  - Stratospheric gases (except ozone)
  - Stratospheric wind fields
  - Tropospheric gases

Instruments to accomplish above measurements assigned to low Earth orbit spacecraft. Impact: Temporal/coverage requirements less than 3 hours not met.

- **Temporal Sampling Requirements:**
  - Virtually all 14 solar/radiation budget and land/ocean requirements met
  - None of the 9 atmospheric science requirements met (15 minute to 1 hour requirement, 3 hour achieved) although 5 were deemed to be conditionally met
- **Spatial Resolution Requirements:**
  - 8 fully met
  - 3 (temperature profile, tropospheric water and sea level rise) judged acceptable
  - 9 within range of requirements but instrument limitations prevent meeting most stringent requirements
  - 1 (stratospheric ozone) not met (5 - 10 km required, 43 km achieved)

Figure 15. Concluded.

TABLE 7: SUMMARY OF SCIENCE REQUIREMENTS MET/NOT MET.

Regime/ Category	Measurable	Diurnal Cycle	Global Change Study: Temporal Sampling	Global Change Study: Spatial Resolution	Regional Process Studies: Temporal Sampling	Regional Process Studies: Spatial Resolution
Solar	Spectral radiation	No	1D	Sun disk	1D	Sun disk
Atmosphere	Pressure (surface)	No	3-12H (12H)	10 km	NR	NR
	Temperature profile	Yes	1-3H (3H)	10-50 km	15M-1H	5 km
	Stratospheric gases					
	Ozone	No	3-12H	50 km	30M	5-10 km (43 km)
	Other gases	No	3-12H	50 km	30M (3H)	5-10 km
	Aerosols & part.	No	3-12H (12H)	10 km	15M-1H	0.1-1 km (5km)
	Tropospheric H_2O	No	3-12H	10 km	30M-1H	10 km
	Cloud cover/type/height	Yes	1-3H (3H)	1 km	15M-1H	1 km
	Tropospheric gases	Yes	1-3H (3H)	10 km (6 to 65 km)	30M-1H (3H)	10-50 km (20 km)
	Wind fields					
	Stratospheric	Yes	1-3H (3H)	10 km (250 x 350 km)	30M-1H (3H)	NR
	Tropospheric	Yes	1-3H	10 Km	30M-1H	NR
Radiation budget	Reflected SW & emitted LW flux	Yes	1-3H (3H)	10-30 km	30M-1H	1-30 km (5-15 km)
Earth (land/ ocean)	Surface temperature	Yes	1-3H (3H)	4 km	6M-24H	30 m-200 km (8 km)
	Precipitation	Yes	1-3H (3H)	1-30 km (5-15 km)	3M-3H	1-200 km (10 or 25 km)
	Vegetation cover/type	No	7D	1 km	1-30D	10 km
	Soil moisture	No	2D	1-10 km (10 km)	12H-7D	30 m-10 km (10 km)
	Biomass inventory	No	7D	1 km	1-30D	1-10 km
	Ocean color (chloro.)	No	2D	1-4 km	2D	30 m-4 km
	Ocean circulation	No	2D	1-4 km	1D	30 m-4 km (1 km)
	Sea level rise	No	2D	10 km	2D	10 km
	Sea ice					
	Cover	No	7D	1-20 km	1-3D	1-25 km
	Depth	No	7D	1-20 km (5-15 km)	1-3D	1-25 km (5-15 km)
	Ocean CO_2	No	2D (—)	500 km (—)	NR	NR
	Snow					
	Cover	No	7D	1- km	12H-3D	1-10 km
	Depth	No	7D	1- km (5-15 km)	12H-3D	1-10 km (5-15 km)

No block = Requirements met

[shaded] = Absolute requirement not met but judged to be acceptable

[hatched] = Requirements met conditional upon accepting assumptions

[black] = Requirements not met

NR = No Requirement

(#) = Value achieved

A summary of the GCT fleet architecture with and without an operational Eos A and B is presented in Table 8. A more detailed presentation of the adjunct study is presented in reference 15.

TABLE 8 - GCT Architecture Trade Study
Preliminary Selection Of Spacecraft And Instrument Complements

	Spacecraft Instrument Complement	Option 1 Constellation for 3-Hour Coverage	Option 2 Platforms for 3-Hour Coverage	With Eos-A and B: Option 1 Constellation	With Eos-A and B: Option 2 Platforms
	SMMR	1	1	1	1
B, 12-Hr.+Temporal	ACRIM, SOLSTICE, XRI, MODIS-T, HIRIS, EOSP, ALT, 3ChMR	1		-	
C, 3 to 12-Hr. Temporal	APL, SAGE III, EOSP	1 (12-hour)	4*	-	3**
D, 1 to 3-Hr. Temporal	CERES, ACRIM, MODIS-N, EOSP, AMSU-B, AIRS, HIMSS	4 (3-hour)		3	
E, Less than 1-Hr. Temp.	SAFIRE, MLS (Eos), TES, TRACER, SWIRLS, EOSP	4 (3-hour)		3	
G1, Less than 1-Hr. Temp.	GERS, ACRIM, IRVS, OZMAP, GOES Imager, GHRMR, GMODIS	1	1	1	1
G2-A ,Less than 1-Hr. Temp.	G1 Complement Less GHRMR	1	1	1	1
G2-B, Less than 1-Hr. Temp.	GHRMR Alone	1	1	1	1
	TOTAL	1 Special Purpose LEO 10 Delta Class LEO 1 or 2 GEO	1 Special Purpose LEO 4 Titan IV Class LEO 1 or 2 GEO	1 Special Purpose LEO 6 Delta Class LEO 1 or 2 GEO	1 Special Purpose LEO 3 Titan IV Class LEO 1 or 2 GEO

* All four do not have identical instrument complements. See Table 1(a) for the instrument complements.
**One of these three must be an Option 2, L-1 Platform. See Table 1(a).

TECHNOLOGY NEEDS

Science Instruments

During the instrument selection process, a summary was prepared to portray the heritage of the representative instruments selected for GCT measurements. The heritage is presented in Tables 9 and 10. Of the 27 selected instruments, 7 are current operational instruments, 17 are Eos type instruments, and 3 are newly defined instrument concepts. The chart effectively conveys the message that there is a long-term buildup of instrument technology that results in the proposed capabilities for the GCT representative instruments. What the chart does not show, however, is the additional technology advances that must be made and applied to these representative instrument types to yield all of the desired instrument capabilities.

The first effort undertaken in the task of identifying technology needs was to review stated instrument performance capabilities and to note deficiencies and needed improvements. Deficiencies in three areas stand out: spatial resolution, capability to operate in geostationary orbit, and swath/scan capabilities. Improvements in spatial resolution are needed to provide the required observational detail. Improved and new instruments for operation in GEO are needed since GEO systems offer the only practical way of achieving temporal resolutions of 1 hour or less (GEO operation also requires much better spatial resolution capability). Improvements in swath/scan capabilities are needed for contiguous geographic coverage. Improvements in four additional areas are strongly implied from the performance assessments: measurement sensitivity, measurement specificity, measurement precision and accuracy, and alternative complementary measurements. To this list of needed sensor and instrument technology improvements, other instrument needs that are inherent for long-term accurate sensing of Earth parameters from satellites are added: less demand on spacecraft resources, simplicity, reliability/lifetime, and operational maturity.

All of these categories of needed instrument improvements are listed in Table 11. Listed across the top of the table are the technology areas in which advances can be applied to yield the needed instrument improvements. The first nine items deal with hardware technologies, the next

TABLE 9: HERITAGE OF EARTH OBSERVING SENSORS, LOW EARTH ORBIT APPLICATIONS.

Descriptor	Current [1]	Proposed [2]	GCTI list
Meteorological	HIRS - - - →	AIRS ——→	AIRS
	AVHRR,* OLS* - - - →	AMRIR	MODIS-N
Imaging	ETM, HRV - - - →	MODIS-N/T, HIRIS* ——→	MODIS-T, HIRIS
		HRIS,* ITIR, MISR	
Stratospheric gas	CLAES	HIRRLS	
	HALOE	SAFIRE ——→	SAFIRE
	HRDI	SWIRLS ——→	SWIRLS
	ISAMS - - - →	DLS	
	MLS (UARS) - - - →	MLS (EOS) ——→	MLS
	WINDII		
Ozone/aerosols	SAGE III ——→	SAGE III ——→	SAGE III
	SBUV	GOMR	
		EOSP ——→	EOSP
Tropospheric gas	MAPS - - - →	TRACER,* MOPITT* ——→	TRACER
	ATMOS - - - →	TES ——→	TES

Footnotes:

1 Current S/C: NOAA, DMSP, UARS, LANDSAT, ERBS, TOPEX, ERS, RADARSAT, SPOT, SST

2 Proposed S/C: Eos-A, Eos-B, Eos-E, Eos-J, TRMM, SSF

——→ Same or upgraded instrument. - - - - - → Heritage instrument.

* Similiar instruments ○ New instrument concept

TABLE 9: (CONCLUDED).

Descriptor	Current[1]	Proposed[2]	GCTI list
Microwave Radiometer	AMSU, SSM-T, ATSR →	AMSU →	AMSU(B)
	SSMI - - →	HIMSS, AMSR* MIMR,* AMIR,* ESMR →	HIMSS
			(SMMR)
Active systems	ALT(+3CMR) →	ALT →	ALT(+3CMR)
	AMI,* SAR* →	AMI,* SAR*	
	RSCAT - - →	SCANSCAT	
		ATLID	
		LAWS	
		GLRS	
		LASA Eagle - - →	(APL)
Solar	ACRIM →	ACRIM →	ACRIM
	SOLSTICE →	SOLSTICE →	SOLSTICE
	PEM	ENAC, POEMS	
	SUSIM		
		XRI →	XRI
Radiation budget	ERBE - - →	CERES →	CERES

TABLE 10: HERITAGE OF EARTH OBSERVING SENSORS, GEOSTATIONARY ORBIT APPLICATIONS.

Descriptor	Current[1]	Proposed[2]	GCTI list
Meteorological	Imager →	Imager →	Imager
	Sounder →	Sounder →	IRVS
Imaging		GMODIS →	GMODIS
		HRIS	
Microwave Radiometer		HFMR	GHRMR
Radiation budget		GERS →	GERS
Ozone monitors		OZMAP →	OZMAP
Atmospheric gas		HRII	
		TGI	
Solar		ACRIM →	ACRIM
		SOLTICE	
		XRI	
Active systems (Lidar)		GLRS	

Footnotes:
1 Current S/C: GOES-next
2 Proposed S/C: MSFC Geo-platform

Table 11: Improvements Provided By Advanced Technology.

Improvements provided (instruments and operations) / Technology areas (candidates for advancement)	Instrument components									Instrument systems			Non - hardware		
	Bigger/better collectors (optics, antennas)	Better detectors - arrays, responsivity	Cryogenics - detector coolers, cooled optics	Light weight optics	Stabilization & control systems	Pointing systems	Scanning systems	Smart data systems	Structures (includes controlled/smart structures)	New instruments - techniques, spectral bands/lines	Lidar systems (especially lasers)	Large microwave systems - passive, active	Systems engineering	Corroboration science	Software
Spatial resolution - horizontal, vertical	X		⊗	⊗								⊗			
Operation in GEO - better temporal resolution		⊗			X	X	X					⊗			
Operation in GEO - better spatial resolution	⊗	⊗	⊗	⊗	⊗	⊗			X			⊗			
Swath/scan capabilities - contiguous coverage	X				X	X	X		X			⊗			
Measurement sensitivity	X	X	X	X						X	⊗				
Measurement sensitivity - spectral selectivity, calibration, truthing	X	X	⊗			X		X		X				X	
Measurement precision/ accuracy	⊗	X		X	⊗	⊗				X	X		X	X	
Alternative, complementary measurements										X	X	X		X	X
Less demand on S/C resources - • Mass • Volume				⊗					X			⊗			
• Power • Data • Pointing/tracking/scanning • Heat reduction				X	X	X	X	X			⊗				X
Simplicity • Data sequence • Calibration								X					X		X
• Less engineering data • Less interference • Simpler data reduction • More direct interpretation			X					X		X				X	X
Reliability, lifetime			X								⊗		X		X
Operational maturity		X	X					X			X	X	X		X

three deal with the complete instrument system, and the last three deal with non-hardware technology A need for a particular technology to provide a particular instrument improvement is designated by x. Strong needs are designated by an ⊗. This matrix represents an initial attempt at scoping the technology needs for GCT instruments.

By necessity the technology needs for the three new instrument concepts selected for GCT had to be addressed. The selection of the Geostationary High Resolution Microwave Radiometer (GHRMR) and the Soil Moisture Microwave Radiometer (SMMR) forced a look at the technologies involved in large aperture multi-frequency microwave passive systems (see column 12 of the needs chart). Jeffery Farmer et al. (ref. 11) in defining the GHRMR anticipated technology advances in the areas of large antennas, structures, controls, and microwave signal detection in order to develop a space flight instrument system with adequate sensitivity and spatial resolution when operating in geostationary orbit. Melvin Ferebee et al., (ref. 12) in defining a concept for the SMMR, primarily addressed the large collector (including structures and controls) technologies in order to obtain adequate spatial resolution at the low microwave frequency required for sensing moisture in various soils to usable depths in the order of 12 cm or more.

The third new GCT instrument is a concept for the measurement of surface pressure. The instrument has been titled Atmosphere Pressure Lidar (APL). The selection of APL forced a look at lidar system technology needs (see column 1 of the need chart). The measurement principle is based on the experimental work of Korb et al. (ref. 16) at the NASA Goddard Space Flight Center. The Earth Observing System Volume 11d, LASA document describes the principle as it could be employed in a Lidar Atmospheric Sounder and Altimeter instrument as follows: "The surface pressure experiment is a two-wavelength DIAL measurement utilizing the backscattered energy from the Earth's surface or from low-lying clouds. A pressure-sensitive measurement is obtained by locating one wavelength in a temperature insensitive absorption trough region. A trough region is the region of minimum absorption between two strongly absorbing lines in the oxygen A-band near 0.76 μm, or 13,150 cm^{-1}. The absorption in the trough is proportional to the square of the pressure. A second wavelength located in an absorbing region with a shift of 0.0001 to 0.001 μm is used as a reference to normalize out the effects of surface reflectance. The use of an absorption trough technique reduces the sensitivity of the measurement to the effects of laser frequency jitter by up to two orders of magnitude. The integrated path absorption method used for the measurement allows high sensitivity to be achieved." The Eos document envisions the above technique to be capable of surface pressure measurement with an accuracy of ±2 mb with a vertical resolution of 1 to 2 km.

The Eos LASA document and the follow-on Eos Atmospheric Global Lidar Experiment (EAGLE) proposal for Eos published in July 1988 by the NASA Langley Research Center provide a detailed engineering study which serves as a baseline for the GCT Atmospheric Pressure Lidar (APL) concept. The LASA/EAGLE instrument was proposed with a 1.25-m-diameter telescope to be used in investigations of water vapor, temperature, tropospheric and stratospheric aerosols, and clouds. During discussions with LaRC personnel responsible for the LASA/EAGLE concept, it was concluded that by eliminating the water vapor capability of the LASA/EAGLE instrument and tailoring it as a surface pressure measuring instrument, the telescope diameter could be reduced to 0.5 m. This results in the mass and power being reduced by one-third to one-half. The more conservative one-third reduction was selected; thus, the GCT/APL instrument concept became a LASA/EAGLE type instrument with a telescope diameter of 0.5 m and a mass and power of one-third less than a fully capable LASA/EAGLE instrument. A ±45° crosstrack scan capability was also assumed for the APL instrument. Needless to say, an instrument concept this preliminary in design would require extensive design and development before it becomes a viable candidate for flight. Technology needs have been identified in the areas of lightweight, precision, durable telescopes, precise frequency controlled lasers with power and pulse characteristics to provide measurement sensitivity, infrared detectors and coolers, and most importantly, complete lidar instrument system simplicity, reliability, and long lifetime.

The need for the three new GCT instrument concepts and the general technology needs matrix presented in Table 11 illustrate the need for an extensive instrument development program. The detailing of the elements of this program is a major follow-on task. This task is to be undertaken separately by appropriate instrument specialists at the Langley Research Center. To conclude this section of this report, therefore, we have only their introductory narrative which addresses the general technical areas of detectors, cryogenic coolers, lightweight optics, and lasers.

Detectors

The majority of Eos proposals reflects significant instrument performance benefits obtained through the use of arrayed detectors, as compared with single element detectors or a few point detectors, as were used in the 1980s. Dectector arrays for the mid-infrared wavelengths from 2 to 20 μm have recently become available that exhibit greatly increased capability while being virtually identical in size and mass to previously available designs. This improvement is reflected in better experiment radiometric sensitivity and spectral or spatial resolution. Currently, arrayed mid-infrared (up to 10 μm) detectors in line arrays on the order of a hundred detectors and area arrays of up to 64 by 64 elements are available. In the next decade these detectors should become more available with their capability size, and cost further improved. Active, remote sensors such as lidars would benefit from the development of improved Avalanche Photo Dectectors or other solid state detectors capable of photon noise limited performance in the 0.7 to 2.0 μm range. This is just longward of the wavelength range where multiplier-photo tubes can operate. This improved performance would benefit the very important water vapor, pressure, and temperature profile measurement made with lidar instruments. Earth budget remote sensing experiments from GEO with temporal sampling capability of fraction of hours would be enabled through the development of cryogenically cooled active cavity receiver detectors. These detectors have been shown in the laboratory to be capable of nano-watt sensitivity.

Table 12. Concluded

Current MMS Characteristics	GCT Advanced MMS Characteristics
Propulsion:	Propulsion:
• Thrusters, (Redundant)	• Thrusters, (Redundant)
-- Velocity Correction: 22.25 N(4)	-- Same Units: Delta S/C, at Corners of Platforms Large Platform, as part of the Module
-- Attitude Control: 0.9 N(12)	
-- Valves	
• Control from On-board Computer	• Dedicated 80386 Microprocessor
• Tanks 3 Spherical 0.4 m Dia. 75 kg N_2H_4 On-board	• Delta S/C Cylindrical Tanks Contain 125 kg • Large Platform Auxiliary Tanks to 700 kg
• Total Mass 150 kg	• Delta S/C System 200 kg Large S/C Platform 800 kg

Cryogenic Coolers

Remote sensor measurements can be widened in scope and substantially improved with high capability, efficient cryo-coolers with operational life times of 5 years. Coolers are needed for several types of applications:

(1) Cold Optics: Remote sensors looking Earth-ward from space view a scene that is at approximately 250 K. Optimum instrument performance for this level of scene photon flux requires the instrument optics to operate at intermediately cold temperatures of approximately 150 K.

(2) Detector Coolers: A great number of applications require detectors operating at liquid nitrogen temperature. An energy efficient, reliable 5-year life cryo-cooler delivering 1 W at 80 K is needed. The cooler should impart a negligible mechanical vibration level to the alignment sensitive instrument focal plane assembly.

(3) High Capability Coolers: The sensitivity of detectors ranging in spectral frequency over the entire mid-infrared spectrum would be much improved if a cryo-cooler capable of a 1 W load at 20 K were available. For far-infrared (20 to 500 microns) experiments efficient long-life cryostats are needed. Present technology provides hybrid coolers that use a liquid helium dewar with cold shields held at intermediate, progressively colder (30, 80, and 150 K) temperatures.

Lightweight Optics

Space based lidar instruments must use receiver telescopes on the order of 1 m in diameter to attain the desired sensitivity. Far-infrared and other remote sensing instruments also use large diameter optics to maintain small diffraction effects as compared with spatial resolution; however, the need for large optics contrasts with the need for low instrument mass for efficient launch in space. The development of lightweight optical systems can thus contribute greatly to reducing launch costs while maintaining performance. Present technology is on the verge of producing diffraction limited optical elements with a mass of 20 kg/m^2 for optical element diameters of up to 1 m. Several technologies capable of this low density are presently being pursued:

(1) Silicon-Carbide mirrors where the material is vapor deposited on a carbon mandrel, (2) chemically milled Aluminum mirrors where lightning holes are chemically machined into the mirror blank, and (3) Fritted Glass where two thin glass face-plate blanks are spaced by a set of thin-wall glass tubes fused in between. These techniques need to become more available to be cost effective. To reach the full potential of mass savings, it is imperative that the optics support structure, i.e., the telescope structure, also be light weight while element de-space and tilts are controlled to the needed tolerances by a metering system.

Lasers

To perform adequately, atmospheric particle and gas lidars and differential absorption lidars (DIAL) require non-tunable (albeit multi-spectral) and tunable laser outputs respectively of at least one and preferably two Joules per pulse at pulse repetition rates of 10 Hz or more. Qualified lasers of this output level have not been flown in space. LaRC's LITE project will use a 1.5-Joule-per-pulse class, three color (1.064, 0.532, 0.352 μm) laser for atmospheric constituent and wind sensing. For the post year-2000 time period, lasers will need to use diode pumping to increase their efficiency and reduce laser power requirements. The laser power consumption, and the waste heat they generate that needs to be rejected to space with bulky radiators, can be reduced from the several thousand watts required for flashlamp pumped systems to the order of a few hundred watts with diode pumps.

Spacecraft and Subsystems

The study identified spacecraft and subsystem areas where technology advances will enable or enhance the systems. Some of the technology improvements are already in work and were incorporated into the spacecraft and platform designs. There are other elements where good, reliable engineering designs and system integration are sufficient using current technology.

Technology developments and demonstrations are mandatory for the large antenna structures. If we are to provide the required sizes and surface accuracies to meet the resolution requirements, then these antenna must be packaged for launch and either deployed or assembled

Table 12 - Characteristics of the Current and GCT Advanced Multimission Modular Spacecraft

Current MMS Characteristics	GCT Advanced MMS Characteristics
Communication and Data Handling:	NASA Data Link Module:
• S Band Transponder	• S Band Transponder (TDRSS) Ku Band Transponder (TDRSS) Capability to Communicate with ATDRSS
• On-board Computer 18 Bit Words Supports all other Modules	• Dedicated 80386 Microprocessor 32 Bit Words
• Real Time Data Handling 2.048 Mbps Max. Record Data Rate 2.7 Mbps Max. Playback Data Rate 2.7 Mbps Max. Command Rate 2.0 kbps Max.	• Real Time Data to 450 Mbps Record Data Rate to 300 Mbps Playback Data Rate to 300 Mbps Same Command Rate Science Uplink Data Rate, 100 kbps
• Recorders, Tape, 10^9 Bit Max.	• Recorders: Options to 10^{10} Bits Available, 10^{12} Bits Under Development
• Redundant System in Single Module	• Single System Modules, 2 or More per S/C Optical Fiber Data Links Within the S/C
• Parabolic Antenna, with Waveguides	• Planar Array Antenna. Carries RF Elements, 4 S Band, 16 Ku Band
	Benefits:
	• Increase in Capacity, Data Rates, and Processing Speeds
	• Potential for Some Level of On-board Processing

on-orbit to exacting tolerances. Although there is limited technology development work ongoing on the assembly of precision reflectors, there are currently no technology programs with significant funding within NASA to develop the on-orbit deployable hardware and verify reliability. The balance between mechanical or electronically steering of the beams has not been established. To the extent that mechanical steering is required to point the antenna there, this could be a source of significant onboard disturbances which must be isolated and/or predictably controlled by the spacecraft. Advanced, thermally stable materials or predictably controlled structures are also needed to maintain surface accuracies and antenna dish and feed alignments.

Design of the spacecraft recognized NASA-published technology and were guided by active efforts within Goddard Space Flight Center to uprate the Multi-Mission Modular Spacecraft (MMS) subsystems. Table 12 sumarizes the capabilities for each of the MM3 modules to show current performance, planned upgrades, and any particular adaptations proposed for GCT spacecraft applications. The modular design of spacecraft is the preferred approach in this study which affords maximum flexibility in tailoring the individual spacecraft to meet the particular instrument complement and mission requirements. On-orbit serviceability was not incorporated into the designs because of inaccessibility of the orbits by the STS and no firm NASA plans for robotic servicing in polar or geostationary orbits. Specific subsystem development needs are addressed below.

Communications and onboard data handling requirements established a critical need for significant advances. Data and information technologies are addressed separately; however, the implications to spacecraft onboard elements imply operations that utilize imbedded high-speed microprocessors with internal communications and data transferred through fiber optic links. Data transmission rates exceed the Tracking and Data Relay Satellite System (TDRSS) down-link capabilities and would require the Advanced TDRSS. Onboard data rates estimate established the need for high speed optical disc recorders with storage capacities ranging up to 10^{12} bits.

Table 12. Continued

Current MMS Characteristics	GCT Advanced MMS Characteristics
Attitude Control:	Attitude Control:
• 4 Reaction Wheels, 20.3 N-m-sec each	• 4 Reaction Wheels with Integral Electronics
• Gyro, Conventional	• Laser Gyro
• Magnetometer 1 Star Trackers 4° (2) Magnetic Torque 0.01 N-m	• Same Same Torque to 0.015 N-m
• Microprocessor Algorithm Located in Control-Data Handling Module 16 K Word Memory Limit	• Dedicated 80386 Microprocessor Algorithm Responds to Spacecraft Requirements
• Module Designed for On-orbit Servicing Total System Mass 220 kg	• Simplified Module, Total System Mass 215 kg
• Present Capability 0.01° Pointing	• Pointing Accuracy Tailored to Science Requirements
	Benefits:
	• Higher Performance Components
	• Pointing Algorithm for Each Spacecraft

Table 12 - Continued

Current MMS Characteristics	GCT Advanced MMS Characteristics
Power and Signal Conditioning and Control:	Power and Signal Conditioning and Control:
• Power Regulated at 28 VDC	• Power Regulated at 120 VDC
• Power Level 1200 W Avg., up to 2000 W	• Power Modules Sized for 1300 W Input from Solar Array
• Switching Control from Control Data Handling Computer	• Dedicated 80386 Microprocessor for all Switching Functions
• Pyro Control, Thermal Control in Separate Sub Unit Module	• Pyro and Thermal Control Uses Dedicated Microprocessor
• Batteries Ni-Cd at 30 Wh/kg Carried Within the Module. Range 1120 Wh, Standard to 4200 Wh Max.	• Batteries Ni-H_2, 45 Wh/kg, 33% DOD, Modularized at 60 Wh, Separate Mount. Range 1050 Wh to 2166 Wh Delta S/C, 4811 Wh Large Platform
• Solar Array: Silicon, 100 W/m^2 Areas Defined by S/C Applications	Solar Array Silicon (100 W/m^2) or GaAS/Ge (158 W/m^2) as Defined by S/C Applications
	Benefits: • 120 VDC Reduces Wire Gages • 1300 W, Larger Capacity • Microprocessor Switching Control • More Efficient Batteries and Solar Arrays

The attitude control and pointing stability requirements for spacecraft in LEO appear within the capabilities planned in an uprating of the present MMS module for use on the TOPEX and UARS spacecraft. The larger Titan platform would use planned Eos spacecraft control systems. Instrument resolution requirements for operation in GEO result in pointing accuracy limits that generate need for active isolation techniques. Pointing accuracy requirements for GCT instruments in GEO are shown in figure 16, proposed technologies for accomplishment are identified in figure 17 in comparison with present listed capabilities. A design goal of the study was to control the GEO spacecraft to a pointing accuracy of 5×10^{-3} degrees and utilize dynamically isolated scan platforms with advanced star trackers for the fine pointing systems. The spacecraft operating in GEO underscore the need for a dynamic active control system that can maintain the instrument pointing within the accuracy limits while accommodating the structural responses associated with onboard effects such as antenna scanning, stationkeeping, and thermal cycling.

GCT instrumentation tends to exhibit heavy power demands and thereby emphasize the need for low mass elements with improved power handling capabilities. A minimum performance equal to that identified for GaAs/Ge cell end-of-life at 158 W/m^2 and 45 W/kg is needed. Candidate cell systems meeting their requirement are under development and their availability would be incorporated into any GCT configuration as a means to reduce the area of the solar array. The instruments which require the most power also operate continuously and, therefore, require an energy storage capability for complete orbit operation. A fully developed Ni-H_2 battery unit operating at 45 W hr/kg with a 33 percent depth of discharge is needed for a GCT type mission. An additional need is the development of a dedicated microprocessor for overall load management with a power output regulated at the higher 120 volts d.c. Further, the control and regulator elements need modularization at power levels that allow the use of multiple units in responding to the design requirements for individual spacecraft. For example, modularization at 1300 watts would accommodate power demands from 1 to 6 kW within the range of 5 units.

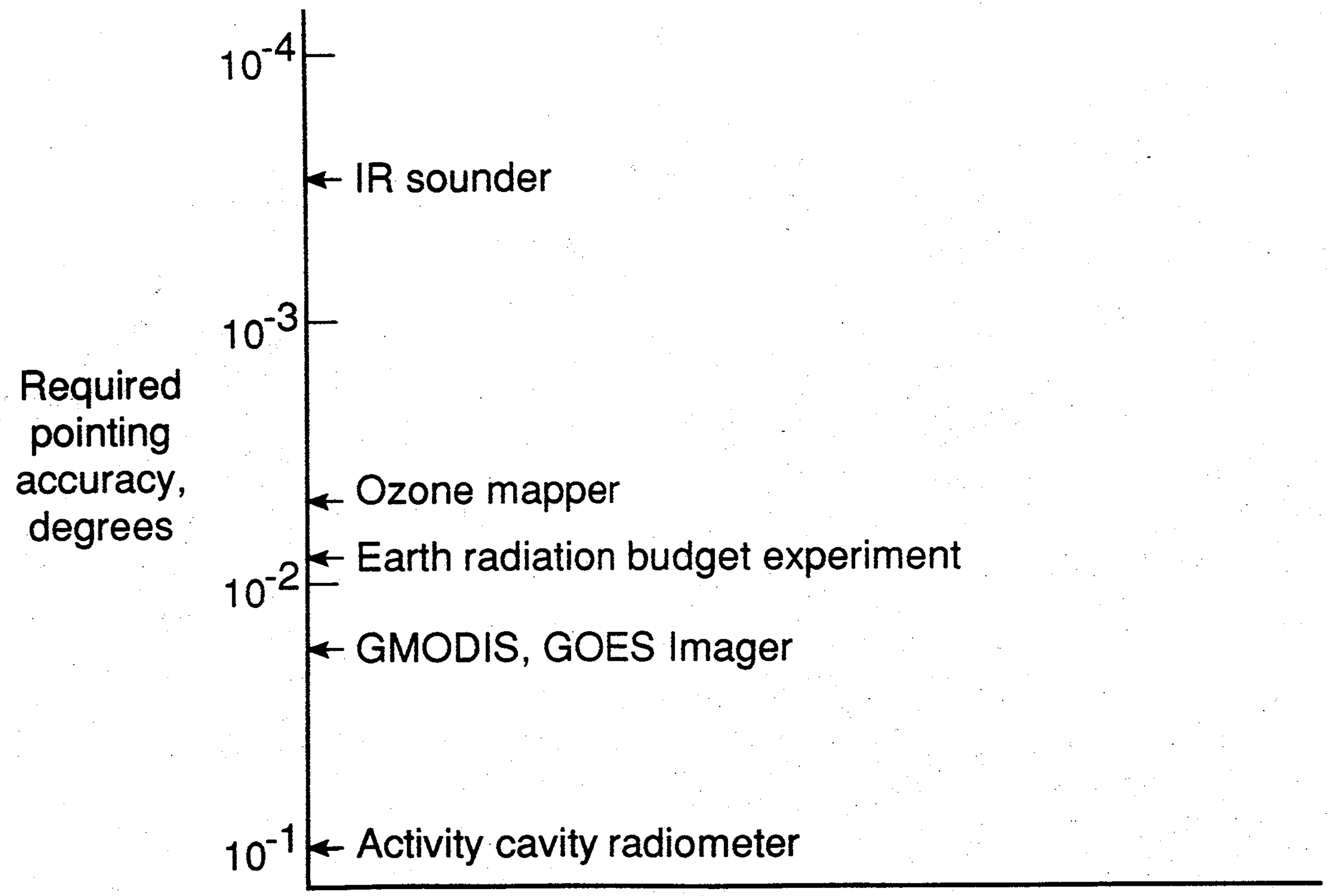


Figure 16. Pointing requirements for gerstationary platform instruments.

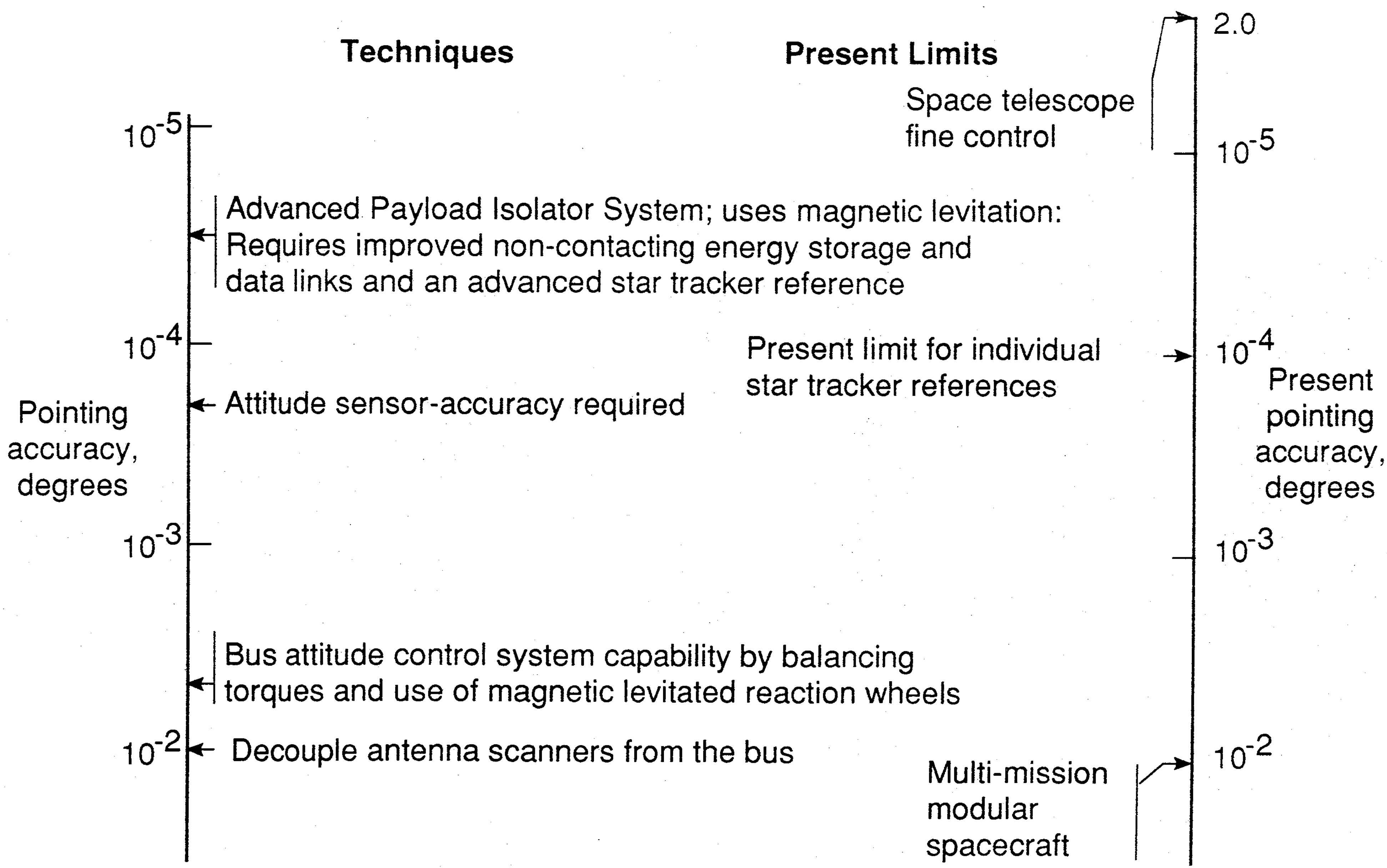


Figure 17. Proposed pointing techniques and capabilities.

Propulsion requirements for the spacecraft in LEO also fall within the capabilities identified for an uprated modular system. On the other hand, GCT spacecraft operating in GEO, with the large antenna, identify a need for an advanced electrical propulsion system capability of minimizing what could amount to prohibitive propellant masses for stationkeeping. Figure 18 compares a stationkeeping propellant requirements for GEO spacecraft and shows the relative advantages of electric propulsion for GCT configurations which carry large antenna rediometers. GEO spacecraft show an order of magnitude range for their area densities and a change from hypergolics and hydrazine to an advanced electrical system significantly reduces the propellant requirement. For GCT spacecraft configurations having equal mass, an advanced electric propulsion system allows more than 1,000 kg for other utilization within the spacecraft.

Structural components for spacecraft demand and will utilize technology advances that show low mass coupled with high yield stress and rigidity plus long term material stability in orbital environments. All structural elements must accommodate launch induced forces either as ELV boosters for LEO or some combination of boosters to GEO. Orbital operation requires structure which is both stable and dynamically predictable. The GEO spacecraft add the additional complexity of compatibility with erection or deployment sequences. In addition, the GCT spacecraft identify the need for advanced, reliable, dynamically predictable elements which can accommodate the motions or manipulations which move instruments into viewing positions, deploy antennas or solar panels, or operate any mechanisms needed during flight. GCT spacecraft do not identify any preferred structural materials or concepts, on the other hand, the small LEO spacecraft configurations were based upon an assumption that graphite fiber composites formed into plates and various shapes could provide an 0.3-m-thick platform at an area mass ratio of 22 kg/m^2. The large LEO spacecraft was configured as tubular trusses at an assumed mass ratio of 210 kg/m^2 for the length above the booster interface. It was also assumed from previous studies

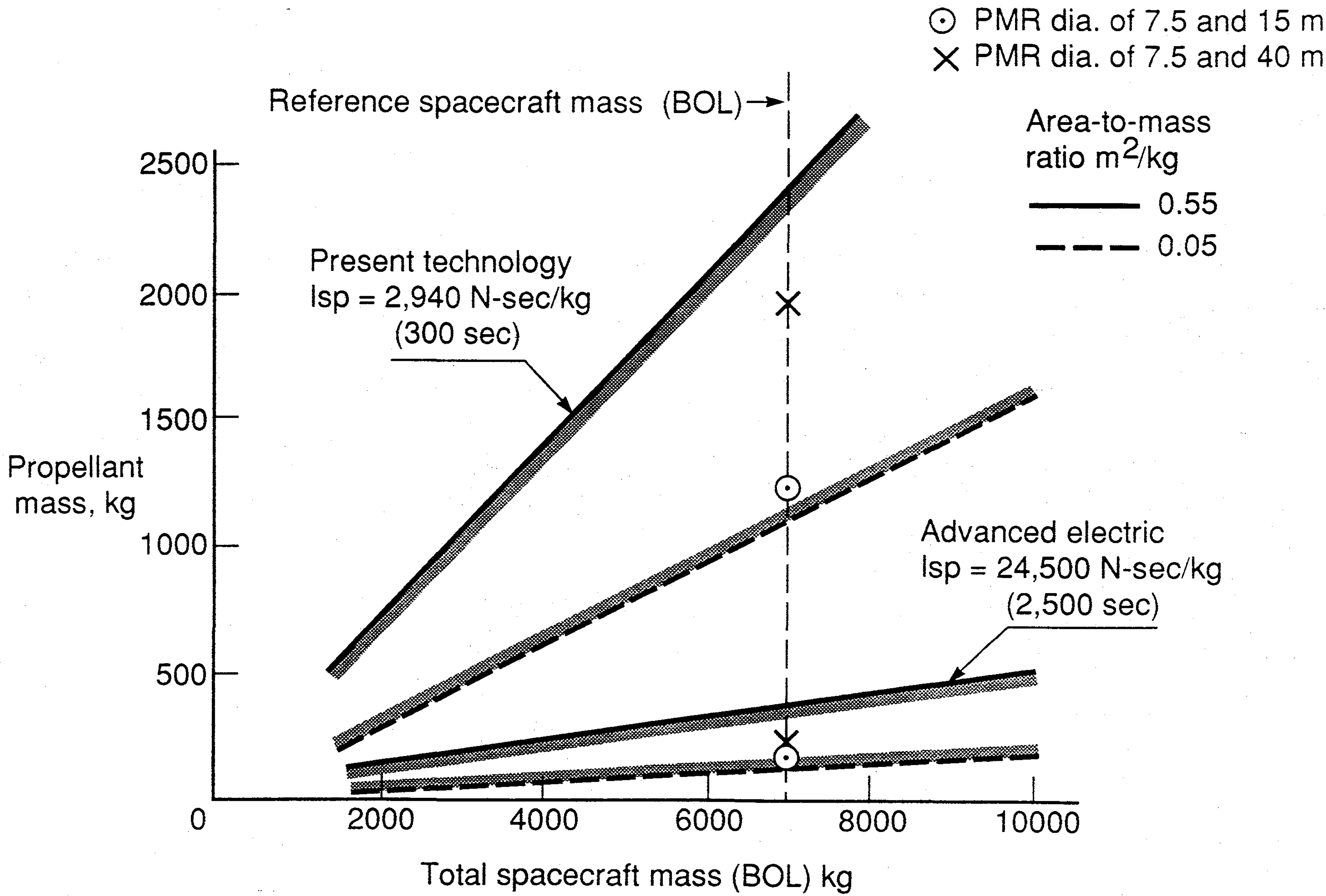


Figure 18. Comparison of stationkeeping propellant requirements for 10 year life in GEO.

that a combination of materials with a low thermal coefficient of expansion approaching 10^{-7} m/m-°K and thermal shielding or blanketing was necessary to maintain dimensional stability of the spacecraft and large antenna.

The process of assembly integration and testing of a spacecraft is a recognized time consuming sequence and the global change requirements for multiple spacecraft identify a development need in this area. Specifically the subsystem modules are designed for ease of integration in that information flows through fiber optical links and imbedded microprocessors control internal operations. Spacecraft integration then focuses upon software and, thereby, can take advantage of a test bed concept developed at the LaRC for application to aircraft control systems. The GCT identifies the need for an integration test facility that will support development of operating interface software by working with spacecraft elements at any stage of definition from an algorithm simulation to flight-ready hardware. The degree of simulation needs to include accommodations of dynamic effects as they are anticipated during flight. In such a context, the GCT identifies the need for predefined structural elements which can be combined to form the spacecraft and show the predicted structural dynamic responses accommodated in the integrated test bed.

The study has underscored the needs for innovative techniques which will permit the rapid implementation of a spacecraft to loft a group of instruments. The need emphasizes modularization for both operating and structural elements while allowing synergy between elements. As an example, power conversion and regulation modules generally will need to dissipate heat by radiation. A module that utilized metal matrix composites as the heat sink radiator could make these elements as the side plates of spacecraft platform. The metal would accept launch loads during boost and operate as a coldplate during the remainder of the flight. In summary, modularization of components is both a requirement and a well accepted means to deliver flexibility. The recent development of fiber optics for information transfer eliminates electrically introduced disturbances. Imbedding of microprocessors transfers integration into software development and the innovative extension of modularization into predictable structural elements provides an approach to spacecraft integration that bypasses the tedious steps associated with present spacecraft systems.

Information Data Systems

Three options were defined for the GCT data system. These options are outlined in reference 14. In the option described as the baseline system, all data gathered are transmitted to the ground without any conversion or processing and all processing to generate science information products for users are performed on the ground. The baseline system uses data management and information product methods that are currently in operation or under development by ongoing NASA programs so they will not be discussed as Technology Needs. The other two options, discussed as Option 1 and Option 2, do require advanced technology. A summary of the needed technologies is presented in the following paragraphs.

The Option 1 approach represents an intermediate step to providing science users direct and near real term access to science products. For this option, all instrument data gathered are still transmitted to the ground without conversion or processing; onboard satellite processing is performed to generate intermediate and limited final science products for direct transmission to users; and most of the final science information products for users are still processed on the ground. The improvements imposed on the baseline information system in order to serve the Option 1 requirements are modest. The primary needs are for: an onboard data system processing complex of medium computing power (10-50 MIPS); a medium data rate distribution network (50-150 MBPS); and a medium speed access (0.1 - 10 ms) moderate capacity (10*11 BITS) mass storage unit.

The Option 2 approach would provide the science user full and direct science information products in real-time. Although this approach was not defined in detail in the GCT Study, it is recognized that the approach would require: high data rate communications for instrument data transmission and for collaborative processing and accessing data between the space system and the ground system; high performance processing/computing both on the spacecraft and on the ground; and high capacity and fast access mass data storage on the spacecraft and on the ground. To meet these requirements, technology advances are needed in the disciplines of global data communication and processing architectures, optical communications, optical networking (> 500 MIPS capability), optical disk recorders (10^{12} - 10^{13} bits capacity, 0.01 - 1MS access), high performance computing (> 100 Giga flops), and wide area optical networking.

Additional details on the Information Data Systems options and the technology needs that accompany the options are contained in reference 14.

CONCLUDING REMARKS

The GCT Architecture Trade Study has attempted to define a viable approach to a mixed fleet of spacecraft and remote sensors that can, with reasonable advances in technology, satisfactorily meet a set of science requirements focused on detecting and quantifying global changes that may occur with the Earth's physical systems that affect climate, i.e., atmosphere, oceans, and land surfaces. The global changes of interest in this study are those that occur over time scales of decades to centuries. It is recognized that there are global changes that occur on much longer time scales, but they are more appropriately evaluated by in-situ sensor systems.

Measurements required for detecting and quantifying global changes are of two classes: related to regional scale processes and those related to global scale processes. The process class by itself is not a driver in the selection of instruments or their distribution on spacecraft; however, the spatial and temporal measurement requirements related to the process class are drivers of the overall system architecture both at the individual instrument/spacecraft level and at the combined fleet level. In general, the spatial resolution requirements drive the selection of sensors and instruments and the assignment to LEO or GEO application while the temporal resolution requirements drive the distribution of instruments on the spacecraft, the orbit inclinations of the spacecraft, and the number of similar or identical spacecraft.

It is important to note that no reasonable architecture can meet all of the science requirements to the full extent. Two different fleet architectures were defined in this study, one based on a larger number of smaller spacecraft compatible with a Delta class launch system and one based on a fewer number of larger spacecraft compatible with a Titan class launch system. These two architectures provide the same capability relative to the spatial and temporal requirements for the science measurables. The choice of a large number of small spacecraft vs. a smaller number of large spacecraft is not, however, the total issue when defining the total fleet architecture. With either approach, specific science measurables require additional dedicated spacecraft such as the LEO spacecraft dedicated to the large microwave atnennae for measuring soil moisture. Other dedicated spacecraft required include the one or two GEO spacecraft needed to meet some of the measurements required on the frequent temporal sampling rate of 1 hour or less. Spacecraft operating at the GEO altitude are of particular interest. If advances in sensor and instrument technology can be accomplished to permit some of the instruments now limited to LEO applications to be used at GEO altitude, temporal sampling frequence can be improved and perhaps the number of LEO spacecraft can be reduced because multiple spacecraft with similar instrument complements would not be needed just to gain temporal sampling frequency. Two example instruments which are included on multipe LEO spacecraft in the GCT Study to gain sampling frequency but which are candidates for GEO applications are the SAFIRE and TRACER. There are additional instruments that are also candidates for GEO application.

The technology of sensors and instruments needs to be advanced for a wide range of applications. Requirements for horizontal resolutions down to 30 m and vertical resolutions of a kilometer or less are not possible at this date except in a few specific instruments. The need for advanced technology can be defined on an instrument-to-instrument basis but suffice it to say that overall advances in the technology of detectors, coolers, lightweight optics, and laser systems would significantly enhance the degree to which science objectives are met. The same type of statement can be made relative to information data systems. Current technology will support a GCT-type fleet, but overall technology advances in the information data system disciplines would support a much-enhanced data management network. The spacecraft technology advances that would return the greatest dividends are those related to up-rating many of the subsystems on current or proposed versions of the modular spacecraft buses, such as the NASA Multimission Modular Spacecraft (MMS). A spacecraft technology which, if advanced, would provide the science community new capabilities for Earth sciences studies is the one related to the design, packaging, and deployment of the large frame-type structures associated with the microwave instruments. The basic microwave technology is at hand, but the ability to apply it to the development of the large antennas and support spacecraft required for a GCT-type fleet has not been demonstrated.

Perhaps the most significant contribution of the GCT Architecture Trade Study is to identify some of the technology needs that will pace the extent to which global change science can be supported during the next two or three decades. The basic study can now serve as a baseline from which an appropriate technology development program can be framed.

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SCIENCE REQUIREMENTS FOR A GLOBAL CHANGE TECHNOLOGY INITIATIVE ARCHITECTURE TRADE STUDY

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SCIENCE REQUIREMENTS FOR A GLOBAL CHANGE TECHNOLOGY INITIATIVE ARCHITECTURE TRADE STUDY

by

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SUMMARY

Science requirements for a Global Change Technology Initiative (GCTI) Architecture Trade Study have been established by reviewing and synthesizing results from recent studies. A scientific rationale was adopted and used to identify a comprehensive set of measurables and their priorities. Spatial and temporal requirements for a number of measurement parameters were evaluated based on results from several working group studies. Science requirements have been defined using these study results in conjunction with the guidelines for investigating global changes over a time scale of decades to centuries. Requirements are given separately for global studies and regional process studies. For global studies, temporal requirements are for sampling every 1 to 12 hours for atmospheric and radiation parameters and 1 day or more for most Earth surface measurements. Therefore, the atmospheric measurables provide the most critical drivers for temporal sampling. Spatial sampling requirements vary from 1 km for land and ocean surface characteristics to 50 km for some atmospheric parameters. Thus, the land and ocean surface parameters have the more significant spatial variations and provide the most challenging spatial sampling requirements.

INTRODUCTION

Global observations of the physical parameters required to detect and quantify changes in global climate, composition of the atmosphere, surface properties, and the biosphere can only be accomplished using sophisticated instruments on orbiting spacecraft. Defining such a mission is a formidable task involving several essential elements. First, the overall goals of the effort must be defined and the associated science requirements established. Next, goals and

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requirements must be prioritized according to scientific importance, feasibility, cost, and risk factors. Then, mission analysis, sensor selection, and spacecraft design can proceed as appropriate. Results of these studies are used in a re-examination of mission priorities by the Science Requirements Definition Team.

The purpose of this paper is to adopt a science rationale and identify the associated measurables, priorities, and measurement requirements for the Global Change Technology Initiative (GCTI) Architecture Trade Study.

SCIENTIFIC RATIONALE, MEASURABLES, AND PRIORITIES

The Earth System Sciences Committee (ESSC) report (ref. l) made a number of recommendations concerning the most critical needs in a program to investigate global change. The committee confirmed the need for sustained, long-term measurements over the globe. These measurements would be used to establish a fundamental description of the Earth and its history, to conduct focused research and process studies, and to develop and apply Earth system models. Because of the interdisciplinary nature of the problems and the very large data requirements, the committee strongly recommended that an information system be a major segment of the program.

In their report, the ESSC gave some important guidelines for establishing a science rationale, the associated measurements, and the measurement priorities. These guidelines are given in table 1. An essential part of any scientific program is the use of observational data with conceptual and numerical models. Models are currently being developed to describe global change on two distinct time scales: thousands to millions of years, and decades to centuries. Processes on both time scales are important; however, those operating on the scale of decades to centuries are particularly relevant to the concerns and planning of human societies. For example, processes on the time scale of decades to centuries include those related to ozone depletion, greenhouse warming (due to carbon dioxide and other trace gases), deforestation, and desertification. Therefore, the current study focuses on measuring parameters of the physical systems (e.g., atmosphere, oceans, and land surfaces), the biogeochemical cycles, and the hydrological cycle for global change studies covering decades to centuries. For the most part, science problems on the longer time scale of thousands to millions of years are not as urgent for global change studies, can be addressed with measurements that only need repeating every few years, or are appropriate for in situ observations. In this work, observational requirements are primarily for remote sensing from satellites. In evaluating the observational requirements, it must be recognized that some studies give needs in terms of instantaneous measurements while others give needs in terms of the final data products. Finally, the ESSC indicated the need for two basic types of studies: global studies or surveys, and case studies involving regional processes.

Table 2 shows the measurables and ESSC priorities for Earth science studies on the time scale of decades to centuries. The measurables are broken down into categories relating to the atmosphere, the Earth land and ocean surfaces, and the energy components of the solar and Earth radiation. While this list of measurables is widely accepted, the priorities are subject to debate. For example, the priority framework of the U. S. Global Change Research Program shown in table 3 (from ref. 5, a report by the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET)), gives all the measurables in table 2 as high priority, but places much higher relative importance on clouds and water vapor than does the ESSC. At a recent meeting, the Investigator Working Group of the Earth Observing System (EOS) found substantial agreement with the priorities in table 3, but voiced the need for a relative measure of importance to give proper perspective to the separation between the highest and lowest priorities.

It seems prudent at this point to examine some parameters that are excluded by adopting the rationale stated above. To this end, the measurables for the time scale of thousands to millions of years are shown in table 4. Several items on this list warrant comment. Although given low priority by the FCCSET, two measurables were given the highest priority by the ESSC: seismic properties (including plate motions and deformations), and gravity and geoid. The seismic properties are presently being measured to high accuracy by in situ techniques supplemented by precise position information from the Global Positioning System (GPS). Some monitoring improvements can be achieved by the Geodynamic Laser Ranging System (GLRS). The gravity measurable is pertinent to this study, particularly as it relates to satellite position determination for analysis of altimetry measurements. This is an indirect requirement, and the GPS can provide the needed information. Therefore, based on the low priority for the adopted science rationale and the existing capabilities for these two measurables, we feel justified in not including these parameters. Also included on the list in table 4 is the lightning measurable, even though it was not included in the ESSC science discussions. Lightning has been included in several measurement system studies, however, so it was included for completeness. With regard to lightning, we have not found any specific scientific requirement for this measurement, and, therefore, it is not included in our study.

INITIAL MEASUREMENT REQUIREMENTS

Numerous scientific groups have undertaken to establish spatial and temporal requirements for Earth science measurements. Results of the most relevant studies are given in table 5 for temporal requirements and in table 6 for spatial requirements. The Science and Mission Requirements Working Group for the Earth Observing System (EOS) defined scientific requirements for a wide variety of measurements of atmospheric, radiative, and Earth surface parameters (ref. 2). A study by a group from JPL (ref. 3) encompassed a larger number of measurables and tended to confirm the EOS requirements for many parameters, but generally called for higher temporal resolutions for most atmospheric measurements. The Langley Research Center has also conducted a comprehensive study which focused on identifying the technology needs for a global change science program (ref. 4). Scientific requirements established by a group affiliated with the geosynchronous Earth observing system (unpublished report, Earth Science Geostationary Platform Science Steering Group) established temporal requirements from a few minutes to about 3 hours, and less severe spatial sampling requirements than identified by other studies.

These studies generally tended to establish measurement criteria which mirrored the capabilities of the satellite system that the study group was affiliated with. For example, the EOS group set temporal requirements from 12 hours to several days. The single Sun-synchronous EOS satellite meets these requirements. The JPL group generally set measurement criteria consistent with the capabilities of a two-satellite system. The geosynchronous Earth observing system group focused on process studies which resulted in requirements which could only be met by a system which sampled almost continuously.

SCIENCE GUIDELINES AND MEASUREMENT REQUIREMENTS

In order to make sense of the widely divergent sets of initial measurement requirements, it is necessary to view them within the guidelines of the ESSC science rationale. First, it must be recognized that for some studies and measurables, instantaneous measurement requirements are given, while in other cases, requirements are given for final data products. Second, requirements are frequently intermixed for two distinct types of studies: (1) Global Change Studies; and (2) Regional Process Studies. Finally, it should be noted that it may not be possible to meet all measurement requirements with satellite observations alone, and systems involving combinations of in situ, aircraft, balloon, and satellite techniques may be necessary.

The Global Change Studies require long-term and highly accurate measurements to detect trends, sufficient temporal resolution to obtain accurate daily to monthly averages, and observations covering the entire globe (see table 7). Such observations are essential for the development, verification, and improvement of global models. The spatial and temporal resolutions for measurements and for data products are based on estimates of the variability of parameters involved and on the data product resolutions needed by modelers. The best guidelines for observational requirements are global climate model characteristics.

Based on current climate model characteristics, the spatial resolution for data products must be 100-250 km (horizontal) and have a vertical resolution equivalent to 9-17 pressure levels. Resolution requirements for instantaneous measurements should, therefore, be in the range of 10-25 km.

The best estimates of temporal resolution for data products range from less than 1 day to 1 month. For adequate temporal sampling, some variables such as cloud cover and associated radiation parameters require measurements across the entire diurnal cycle to avoid aliasing daily and longer-term variations. Other physical properties change at a much slower rate. Some examples are sea ice distribution and land surface properties.

Regional Process Studies are crucial to understanding the Earth as a system and to evolving improved models. These studies require the highest possible temporal and spatial resolutions, but are of limited time and space extent. They involve satellite, aircraft, and ground-based measurements used together in an intensive field study. Some of the important existing regional climate process studies are listed in table 8 for the Physical Climate System and for the Biogeochemical Cycles. These are the programs that must be continued and expanded upon in order to adequately understand regional processes and develop accurate models.

FINAL SCIENCE REQUIREMENTS

The requirements recommended for the GCTI Architecture Trade Study are shown in table 9. The requirements are given separately for Global Change Studies and Regional Process Studies. The requirements are to be interpreted as instantaneous measurement requirements, and the appropriate data products are given as a footnote. Parameters for which measurements over the diurnal cycle are critical are so noted. Where a range of values is given, the lower value is an ideal to provide an objective while the upper value is an adequate level or minimum requirement.

For Global Change Studies, temporal requirements are for sampling every 1 to 12 hours for atmospheric and radiation parameters and 1 day or more for most Earth surface measurements. For temporal variations, the most rapidly changing parameters are those related to the Earth's atmosphere. For this reason, these measurables provide the most critical drivers for temporal sampling. Spatial sampling requirements vary from 1 km for land and ocean surface characteristics to 90 km for atmospheric parameters. Thus, the land and ocean surface parameters have the more significant spatial variations and provide the most challenging spatial sampling requirements.

Regional Process Studies require temporal sampling of minutes to days and spatial sampling from 30 meters to several hundred kilometers, depending on the particular parameter. The only feasible satellite methods for meeting the very high temporal resolutions shown (i.e., minutes) would involve instruments on a geostationary platform and operating in a staring mode. On the other hand, the very high spatial resolutions required would probably dictate measurements from low Earth orbit. Thus, a mixed fleet of satellites appears necessary for providing information for the regional process studies. Data products for the regional studies are highly variable and depend on the particular process being investigated. Therefore, no data product resolutions have been given.

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TABLE 1. GUIDELINES FOR SCIENCE REQUIREMENTS

- CONCEPTUAL AND NUMERICAL MODELS

  THOUSANDS TO MILLIONS OF YEARS - EARLY EARTH, CORE AND MANTLE, PLATE-TECTONICS, AND SOLAR-DRIVEN

  DECADES TO CENTURIES - PHYSICAL SYSTEMS (ATMOSPHERE, OCEANS, LAND SURFACES), BIOGEOCHEMICAL CYCLES, WATER CYCLE

- OBSERVATIONAL REQUIREMENTS

  REMOTE SENSING VS. IN SITU OBSERVATIONS

  INSTANTANEOUS MEASUREMENTS VS. ANALYZED DATA PRODUCTS

- SCIENTIFIC STUDIES

  GLOBAL VARIABLES (SURVEYS)

  PROCESSES (CASE STUDIES)

TABLE 2. EARTH SCIENCE MEASUREMENT REQUIREMENTS
TIME SCALE: DECADES TO CENTURIES

REGIME/ CATEGORY	MEASURABLE	ESSC* PRIORITY (1=HIGHEST)
SOLAR	SPECTRAL RADIATION	1
ATMOSPHERE	PRESSURE (SURFACE)	1
	TEMPERATURE PROFILE	1,2
	STRATOSPHERIC GASES	1,2
	AEROSOLS & PARTICULATES	2,3
	TROPOSPHERIC WATER VAPOR	2
	CLOUD COVER & HEIGHT	2
	TROPOSPHERIC GASES	2,3
	WIND FIELDS	2,3
RADIATION BUDGET	REFLECTED SW & EMITTED LW FLUX	2
EARTH (LAND/ OCEAN)	SURFACE TEMPERATURE	1
	PRECIPITATION	1
	VEGETATION COVER/TYPE	1
	SOIL MOISTURE	1
	BIOMASS INVENTORY	1
	OCEAN COLOR (CHLOROPHYLL)	1
	OCEAN CIRCULATION	1
	SEA LEVEL RISE	2
	SEA ICE COVER/DEPTH	2
	OCEAN CO_2	2
	SNOW COVER/DEPTH/WETNESS	3

* EARTH SYSTEM SCIENCES COMMITTEE, NASA ADVISORY COUNCIL

TABLE 3. U.S. GLOBAL CHANGE RESEARCH PROGRAM PRIORITY FRAMEWORK

SCIENCE PRIORITIES

INCREASING PRIORITY (↑)

Climate and Hydrologic Systems	Biogeochemical Dynamics	Ecological Systems and Dynamics	Earth System History	Human Interactions	Solid Earth Processes	Solar Influences
Role of Clouds Ocean Circulation and Heat Flux Land/Atm/Ocean Water & Energy Fluxes Coupled Climate System & Quantitative Links Ocean/Atm/ Cryosphere Interactions	Bio/Atm/Ocean Fluxes of Trace Species Atm Processing of Trace Species Surface/Deep Water Biogeochemistry Terrestrial Biosphere Nutrient and Carbon Cycling Terrestrial Inputs to Marine Ecosystems	Long-Term Measurements of Structure/ Function Response to Climate and Other Stresses Interactions between Physical and Biological Processes Models of Interactions, Feedbacks, and Responses Productivity/ Resource Models	Paleoclimate Paleoecology Atmospheric Composition Ocean Circulation and Composition Ocean Productivity Sea Level Change Paleohydrology	Data Base Development Models Linking: Population Growth and Distribution Energy Demands Changes in Land Use Industrial Production	Coastal Erosion Volcanic Processes Permafrost and Marine Gas Hydrates Ocean/Seafloor Heat and Energy Fluxes Surficial Processes Crustal Motions and Sea Level	EUV/UV Monitoring Atm/Solar Energy Coupling Irradiance (Measure/ Model) Climate/Solar Record Proxy Measurements and Long-Term Data Base

(←) INCREASING PRIORITY

SOURCE: COMMITTEE ON EARTH SCIENCES
FEDERAL COORDINATING COUNCIL ON SCIENCE, ENGINEERING, AND TECHNOLOGY

TABLE 4. EARTH SCIENCE MEASUREMENT REQUIREMENTS
TIME SCALE: THOUSANDS TO MILLIONS OF YEARS

REGIME/ CATEGORY	MEASURABLE	PRIORITY (1 = HIGHEST) ESSC	FCCSET	COMMENTS
GEOPHYSICAL FIELDS & VARIABLES	PLATE MOTIONS	2	3	IN SITU WITH GPS
	PLATE DEFORMATIONS	1	3	GLRS FOR IMPROVED MONITORING
	POLAR MOTION & EARTH ROTATION	3	3	
	MAGNETIC FIELD	3	3	
	GRAVITY & GEOID	1	3	GPS PROVIDES ORBIT DETERMINATION
	LIGHTNING	NONE	NONE	
LAND-SURFACE DATA	TOPOGRAPHY (ABS. HT.)	2	3	
	SLOPE & ASPECT	3	3	
	LITHOLOGY & MINERAL COMPO.	2	3	
	DEPOSITS & SOIL MAPS	3	3	

ESSC = EARTH SYSTEM SCIENCES COMMITTEE
FCCSET = FEDERAL COORDINATING COUNCIL ON SCIENCE, ENGINEERING, & TECHNOLOGY

TABLE 5. TEMPORAL REQUIREMENTS FOR EARTH SCIENCE MEASUREMENTS

REGIME/ CATEGORY	MEASURABLE	TEMPORAL REQUIREMENTS (D=DAY, H=HOUR, M=MINUTE)			
		EOS	JPL	LaRC	GEO-EOS
SOLAR	SPECTRAL RADIATION	NA	1D	1D	1 SEC
ATMOSPHERE	PRESSURE (SURFACE)	NA	30M	1-3H	NA
	TEMPERATURE PROFILE	1D	1D	1-3H	15M
	STRATOSPHERIC GASES	1D	12H	3-12H	30M
	AEROSOLS & PARTICULATES	1D	1D	3-12H	15-60M
	TROPOSPHERIC WATER VAPOR	12H	12H	3-12H	30-60M
	CLOUD COVER & HEIGHT	6H	3H	1-3H	1-3H
	TROPOSPHERIC GASES	1D	3H	1-3H	1H
	WIND FIELDS	12-24H	30M-12H	1-3H	NA
RADIATION BUDGET	REFLECTED SW & EMITTED LW FLUX	6-24H	12H	1-3H	1-3H
EARTH (LAND/ OCEAN)	SURFACE TEMPERATURE	12H	6-24H	1-3H	15-60M
	PRECIPITATION	1D	3H	1-3H	15-60M
	VEGETATION COVER/TYPE	3-30D	3-30D	3-30D	1-3H
	SOIL MOISTURE	2-7D	12H-3D	12H-3D	30-60M
	BIOMASS INVENTORY	2-7D	7D	2-7D	1H
	OCEAN COLOR (CHLOROPHYLL)	2D	2D	2D	NA
	OCEAN CIRCULATION	2D	Hs-Ds	1D	15-60M
	SEA LEVEL RISE	NA	2D	2D	NA
	SEA ICE COVER/DEPTH	7D	7D	7D	NA
	OCEAN CO_2	NA	2D	2D	NA
	SNOW COVER/DEPTH/WETNESS	7D	1-7D	1D	NA

NA = NOT AVAILABLE

TABLE 6. SPATIAL REQUIREMENTS FOR EARTH SCIENCE MEASUREMENTS

REGIME/ CATEGORY	MEASURABLE	SPATIAL REQUIREMENTS (IN KM EXCEPT AS NOTED) EOS	JPL	LaRC	GEO-EOS
SOLAR	SPECTRAL RADIATION	NA	SUN DISK	SUN DISK	SUN DISK
ATMOSPHERE	PRESSURE (SURFACE)	NA	100	100	NA
	TEMPERATURE PROFILE	100 - 500	100 - 500	100 - 500	5
	STRATOSPHERIC GASES	500	500	500	5 - 10
	AEROSOLS & PARTICULATES	10 - 500	10 - 500	10	0.1 - 1
	TROPOSPHERIC WATER VAPOR	100	100	100	20
	CLOUD COVER & HEIGHT	1	1	1	1
	TROPOSPHERIC GASES	10	10	10 - 100	10 - 50
	WIND FIELDS	100 - 500	10 - 100	10 - 100	NA
RADIATION BUDGET	REFLECTED SW & EMITTED LW FLUX	1 - 100	1	10 - 30	1 - 30
EARTH (LAND/ OCEAN)	SURFACE TEMPERATURE	30m - 4km	1 - 4	1	1 - 5
	PRECIPITATION	1	1	1	15 - 30
	VEGETATION COVER/TYPE	30m - 1km	30m - 1km	30m - 1km	30m - 50m
	SOIL MOISTURE	30m - 10km	30m - 10km	30m - 10km	1
	BIOMASS INVENTORY	1	30m - 1km	30m - 1km	0.5
	OCEAN COLOR (CHLOROPHYLL)	30m - 4km	30m - 4km	30m - 4km	NA
	OCEAN CIRCULATION	30m - 4km	30m - 100km	30m - 100km	0.2 - 1
	SEA LEVEL RISE	NA	10	10	NA
	SEA ICE COVER/DEPTH	1 - 20	1 - 20	1 - 20	NA
	OCEAN CO_2	NA	0.5	0.5	NA
	SNOW COVER/DEPTH/WETNESS	1	30m - 10km	30m - 10km	NA

NA = NOT AVAILABLE

TABLE 7. GLOBAL CLIMATE CHANGE STUDIES

- MODELS ARE REQUIRED TO UNDERSTAND VERY COMPLEX EARTH SYSTEM
- GLOBAL OBSERVATIONS ESSENTIAL TO MODEL DEVELOPMENT, VERIFICATION, AND IMPROVEMENT
- HIGH ABSOLUTE ACCURACY FOR OBSERVATIONS IS ESSENTIAL TO DETECTION OF LONG-TERM TRENDS
- BEST GUIDES FOR OBSERVATIONAL REQUIREMENTS ARE GLOBAL CLIMATE MODEL CHARACTERISTICS:

- SPATIAL RESOLUTION*	100-250 KM (HORIZONTAL) 9-17 PRESSURE LEVELS
- SPATIAL COVERAGE	GLOBAL EXTENT
- TEMPORAL RESOLUTION*	1 DAY - 1 MONTH
- TEMPORAL COVERAGE	DECADES

* VALUES ARE RESOLUTIONS FOR DATA PRODUCTS, MEASUREMENT RESOLUTION REQUIREMENTS MAY BE HIGHER

TABLE 8. REGIONAL CLIMATE PROCESS STUDIES

PHYSICAL CLIMATE SYSTEM

- ATMOSPHERIC PHYSICS AND DYNAMICS:
  - CLOUD DYNAMICS AND RADIATION (FIRE/ISCCP)
  - PRECIPITATION (PRECIP)
  - AIR-SEA EXCHANGE (TOGA)
- OCEAN DYNAMICS:
  - GLOBAL OCEAN CIRCULATION (WOCE)
  - SEA-ICE DYNAMICS (GSP)
- TERRESTRIAL SURFACE MOISTURE/ENERGY BALANCE:
  - VEGETATION AND LAND CLIMATOLOGY (FIFE/ISLSCP)
  - SOIL MOISTURE (ISMRM)

BIOGEOCHEMICAL CYCLES

- TROPOSPHERIC CHEMISTRY:
  - GLOBAL TROPOSPHERIC CHEMISTRY (GTE)
- STRATOSPHERE-MESOSPHERE:
  - OZONE CHEMISTRY
- MARINE BIOGEOCHEMISTRY:
  - OCEAN NUTRIENT FLUX (GOFS)
- TERRESTRIAL ECOSYSTEMS:
  - CANOPIES (BIOME)
  - LARGE SCALE ECOSYSTEM DYNAMICS (GED)

TABLE 9. REQUIREMENTS* FOR EARTH SCIENCE MEASUREMENTS

REGIME/ CATEGORY	MEASURABLE	DIURNAL CYCLE CRITICAL	GLOBAL CHANGE STUDIES		REGIONAL PROCESS STUDIES	
			TEMPORAL	SPATIAL	TEMPORAL	SPATIAL
SOLAR	SPECTRAL RADIATION	NO	1D	SUN DISK	1D	SUN DISK
ATMOSPHERE	PRESSURE (SURFACE)	NO	3-12H	10km		
	TEMPERATURE PROFILE	YES	1-3H	10-50km	15M-1H	5km
	STRATOSPHERIC GASES	NO	3-12H	50km	30M	5-10km
	AEROSOLS & PARTICULATES	NO	3-12H	10km	15M-1H	0.1-1km
	TROPOSPHERIC WATER VAPOR	NO	3-12H	10km	30M-1H	10km
	CLOUD COVER & HEIGHT	YES	1-3H	1km	15M-1H	1km
	TROPOSPHERIC GASES	YES	1-3H	10km	30M-1H	10-50km
	WIND FIELDS	YES	1-3H	10km	30M-1H	
RADIATION BUDGET	REFLECTED SW & EMITTED LW FLUX	YES	1-3H	10-30km	30M-1H	1-30km
EARTH (LAND/ OCEAN)	SURFACE TEMPERATURE	YES	1-3H	1-4km	6M-24H	30m-200km
	PRECIPITATION	YES	1-3H	1-30km	3M-3H	1-200km
	VEGETATION COVER/TYPE	NO	7D	1km	1-30D	30m-10km
	SOIL MOISTURE	NO	2D	1-10km	12H-7D	30m-10km
	BIOMASS INVENTORY	NO	7D	1km	1-30D	1-10km
	OCEAN COLOR (CHLOROPHYLL)	NO	2D	1-4km	2D	30m-4km
	OCEAN CIRCULATION	NO	2D	1-4km	1D	30m-4km
	SEA LEVEL RISE	NO	2D	10km	2D	10km
	SEA ICE COVER/DEPTH	NO	7D	1-20km	1-3D	1-25km
	OCEAN CO_2	NO	2D	0.5km		
	SNOW COVER/DEPTH/WETNESS	NO	7D	1km	12H-3D	1-10km

* SAMPLING REQUIREMENTS ARE GIVEN; DATA PRODUCTS FOR GLOBAL CHANGE STUDIES ARE DAILY MEANS AND 100-250km MEANS, DATA PRODUCTS FOR REGIONAL PROCESS STUDIES ARE HIGHLY VARIABLE.

SATELLITE ORBIT CONSIDERATIONS FOR MISSION TO PLANET EARTH

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SATELLITE ORBIT CONSIDERATIONS FOR A GLOBAL CHANGE TECHNOLOGY ARCHITECTURE TRADE STUDY

by

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SUMMARY

A study has been conducted to determine satellite orbits for Earth observation missions aimed at obtaining data for assessing global climate change. A multisatellite system is required to meet the scientific requirements for temporal coverage over the globe. The best system consists of four Sun-synchronous satellites equally spaced in local time of equatorial crossing. This system can obtain data every 3 hours for all regions. Several other satellite systems consisting of combinations of Sun-synchronous orbits and either the Space Station Freedom or a mid-altitude equatorial satellite can provide 3- to 6-hour temporal coverage, which is sufficient for measuring many of the parameters required for the global change monitoring mission. Geosynchronous satellites are required to study atmospheric and surface processes involving variations on the order of a few minutes to an hour. One or two geosynchronous satellites can be relocated in longitude to study processes over selected regions of Earth.

INTRODUCTION

Since the beginning of the space age, scientific instruments have been placed in orbit to observe the Earth from space. These experiments have contributed a wealth of information about the Earth-atmosphere system. Scientists are now just beginning to understand some of the complex processes and interactions that drive the chemistry and dynamics of our planet. For example, the Earth Radiation Budget Experiment has provided valuable information on the role of clouds in climate change. Other experiments have measured ozone, carbon dioxide, aerosols, and trace species concentrations in the stratosphere and troposphere. As our understanding improves, researchers can better determine which variables are most crucial, how and why atmospheric constituents and climate parameters change, and what measurement criteria must be adhered to in order to accurately assess changes in the Earth-atmosphere system and distinguish between naturally occurring variations and those resulting from anthropogenic influences.

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It is not practical to expect that satellite and ground stations can continuously measure all the environmental parameters over the globe. Such a measurement system would not only require an unacceptably large number of orbiting platforms, but would also yield a prohibitively large volume of data for processing. A more reasonable approach to observations for assessing global change is to establish realistic priorities for measurement parameters, estimate the required sampling frequency, and then define the best satellite system for obtaining these measurements. The goal of the present study is to define the characteristics of the satellite orbits which will meet the science requirements.

SCIENCE REQUIREMENTS

Suttles et al. (1991) conducted a study to establish spatial and temporal requirements for Earth science measurements. They examined the findings of numerous scientific working groups and compiled criteria for a wide variety of measurements of atmospheric, radiative, and Earth surface parameters.

The science requirements for global change and regional process studies are summarized in table 1 which was taken from Suttles et al. (1991). For global change studies, the temporal requirements are generally for coverage every 1 to 3 hours for atmospheric, radiation budget, and climate-related parameters. Most land and ocean surface measurements are needed on time scales of a day or more. For each measurable, an assessment of the criticality of obtaining data over the diurnal cycle is given. For example, tropospheric parameters generally tend to change rapidly during a day while most stratospheric gas concentrations vary over longer time scales. The spatial resolution requirement for global change studies normally ranges from 1 to 10 km. These spatial and temporal resolutions are for the sensor measurements. Data products for global change studies are daily means and 100- to 250-km means. Measurement priorities for each variable are discussed in Suttles et al. (1991).

For regional process studies, the required temporal resolution is 15 to 60 minutes. The spatial resolution ranges from a few meters to 10 km. Frequent, high spatial resolution observations are necessary in order to understand and model physical processes in atmospheric physics and dynamics, ocean dynamics, and biogeochemical cycles in the Earth-atmosphere system. Data product requirements for regional process studies are highly variable.

ORBITAL CONSIDERATIONS

The requirement for global monitoring dictates the need for a system which can view regions over the entire planet. Also, the instruments must have sufficient spatial resolution capability to meet scientific requirements for measurements. In some cases, this consideration might tend to limit orbital altitude. However, in this analysis, temporal sampling requirements are the primary drivers in selecting a system of satellites for monitoring global change.

The science requirements for temporal resolution in table 1 can be summarized as (1) global climate change studies require 3- to 12-hour resolution, and (2) regional climate process studies require 15 minutes to 1-hour resolution. High temporal resolution coverage can be obtained in several ways:

- Multiple Sun-synchronous satellites
- Sun-synchronous plus mid-inclined satellites
- Low- and mid-altitude equatorial satellites
- Single or multiple geosynchronous satellites.

Computer simulations of satellite orbital dynamics and sensor techniques were developed to determine time and space coverage capabilities from the various orbits. First-order orbital perturbations were included to take into account Earth's nonsymmetrical gravitational field and the motion of the Earth with respect to the Sun (Brooks, 1977). This model is sufficient for preflight mission planning and analysis.

Sun-synchronous orbits

Currently, there are two Sun-synchronous (SS) satellites proposed for the Earth Observing System (EOS). The two satellites are planned for identical orbits at 705-km altitude and an equatorial crossing local time of 13:30 on the ascending node. The relatively low orbit altitude ensures high spatial resolution for measurements. The first of these spacecraft (EOS A) will be launched in 1997 and the second (EOS B) in 1999.

Ground tracks for 2 days for the EOS A or B satellite are shown in figure 1. For this orbit, a crosstrack scanner can provide global coverage each day with viewing zenith angles less than 70°. As shown in figure 1, ground tracks for day 2 fall approximately midway between the ground tracks on day 1. This ensures that regions will be covered at both high and low viewing zenith angles.

Latitude-local time coverage for the EOS A or B satellite is shown in figure 2. The temporal coverage repeats for each orbit for the life of the mission. A single SS satellite views a region twice each day, once on the ascending node and again on the descending node. Thus, at the Equator, the measurements are spaced 12 hours apart in local time. Additional temporal coverage can be provided with SS satellites proposed by the European Space Agency (1997 launch) and the Japanese (1998 launch). These two spacecraft, designated as the European Polar Orbiting Platform (EPOP) and the Japanese Polar Orbiting Platform (JPOP), are at about 824-km altitude and have a descending node equatorial crossing local time near 10:30. The addition of the EPOP or JPOP will provide a temporal coverage resolution of 3 to 9 hours for each region. With ideal spacing in equatorial crossing time, three SS satellites can provide 4-hour coverage capability, and four SS spacecraft (see figure 3) can cover each region of the globe every 3 hours.

The advantages of Sun-synchronous orbits are (1) global coverage, (2) high spatial resolution, (3) repeatable local time coverage, and (4) compatibility with NOAA operational satellites for auxiliary data.

Mid-inclined orbits

A mid-inclined orbit such as Space Station Freedom (SSF) at 28.5° inclination and 400-km altitude can be used to supplement the temporal coverage of SS satellites. Figure 4 shows the latitude-local time coverage for two SS satellites and the Space Station Freedom for 1 month. For this inclination, the SSF orbit precesses through all local hours at the Equator in about 23 days when both ascending and descending nodes are considered. For any particular day, the SSF complements the SS coverage by supplying measurements at 2 local hours. Of course, the local times of these measurements change as the orbit precesses. Latitudinal coverage of the SSF is limited by the inclination of the orbit; however, polar coverage is obtained with the SS spacecraft.

The advantages of low-altitude, mid-inclined orbits are (1) temporal coverage precesses through all local hours, (2) high spatial resolution can be obtained, (3) payloads are maximized with a shuttle launch, and (4) orbit requirements are compatible with the Space Station Freedom. The primary disadvantage of mid-inclined orbits is that high latitudes are not covered.

Equatorial orbits

Equatorial orbits can offer a real advantage for viewing the Tropics. Every region visible from the satellite is viewed on every orbit. Local time of measurements and the revisit time are a function of orbital altitude. Coverage capabilities of equatorial orbits are summarized in figure 5 for a viewing zenith angle limit of 70°. Latitudinal coverage is very limited for low-altitude orbits. A 200-km altitude orbit can view the Earth up to only 4° latitude, but views each region every 1.5 hours. A 3400-km altitude orbit views about half of the planet with a temporal coverage frequency of 3 hours. At an altitude of 20,000 km, latitude coverage extends to ±57° (84 percent of the Earth), but temporal coverage of a given region is only once per day. Orbit altitudes from 3000 to 8000 km offer the best compromise between geographical coverage capability and temporal resolution.

An equatorial orbit at 20,000-km altitude has other features of possible interest. A fully pointable sensor can continuously view a particular target for long periods of time to study some physical processes. Figure 6 shows the maximum time on target for a satellite in this orbit. For a target at the Equator, a sensor can obtain continuous measurements for over 7 hours. However, each region around the globe viewed in this manner would be covered at a different range of local times. The times of coverage for different longitudes for this orbit are shown in figure 7. While this type of temporal coverage may be useful for some applications, it does not appear to be particularly desirable for sampling missions involving large areas of the globe, for long-term monitoring, or for diurnal studies.

In summary, low altitude equatorial orbits (below 10,000 km) have good temporal coverage, but offer very limited geographical coverage. Intermediate altitude equatorial orbits (10,000 to20,000 km) have moderate geographical coverage, but temporal coverage is limited. Spatial resolution constraints are not as great as for geosynchronous altitude orbits, but are greater than for low orbits. Equatorial orbits do not cover the high latitudes, and they are not compatible with NOAA satellites for correlative or auxiliary data.

Geosynchronous orbits

A special case of the equatorial orbit is the 24-hour period (geosynchronous) orbit. A satellite in this orbit always appears to remain in the same longitudinal position over the Equator. From this vantage point at about 36,000-km altitude, latitudes up to 62° can be viewed. Since the position of the satellite is constant with respect to the Earth, longitudinal coverage is similarly restricted. A single geosynchronous satellite can view only about 26 percent of the Earth. The advantage of this orbit is its temporal coverage capability. Data can be obtained every 15 to 60 minutes for measuring rapidly changing phenomena and conducting the intensive process studies necessary for understanding how our environment changes. Such studies will allow scientists to develop models which better simulate the Earth-atmosphere system.

The geographical coverage of five geosynchronous satellites is shown in figure 8. This system of satellites is currently covering the Earth up to about 62° in latitude, with some overlap in the Tropics, for weather and special environmental studies. Additional experiments would have to be added to these satellites or new geosynchronous satellites to meet the measurement requirements for global change studies.

Geosynchronous satellites have very high temporal coverage capability which is excellent for climate process case studies over a selected region. These spacecraft are compatible with operational satellites for auxiliary data. The primary deficiency of geosynchronous satellites is their limited geographical coverage. Also, high spatial resolution measurements are more difficult to achieve because of the high altitude of geosynchronous orbits.

RESULTS AND CONCLUSIONS

The proposed EOS provides a good starting point for defining a satellite system for global change studies. The first NASA EOS, planned for a 1997 launch, will be in a 705-km altitude SS orbit with an ascending node equatorial crossing time of 13:30. NASA plans to launch a second, nearly identical, satellite in this orbit 2 years later. The European Space Agency (ESA) satellite is planned for a 1997 launch into an 824-km altitude SS orbit with a daytime equatorial crossing (descending node) at about 10:30. The Japanese are also considering launching a polar orbiting platform in about the same orbit as the ESA spacecraft in 1998. Thus, in the late 1990's, there should be at least two polar orbiting platforms in place which can form the nucleus of the system for long-term monitoring of global change.

Mission options are summarized in table 2 for several temporal resolutions. The best combination of satellites for meeting the science requirements for global coverage and a 3-hour temporal resolution for diurnal coverage is to add two additional SS satellites with appropriate equatorial crossing times to the EOS and ESA (or Japanese) polar orbiting platforms. Another attractive option is adding one additional SS spacecraft and the SSF to the EOS and ESA (or Japanese) satellites. This combination provides temporal coverage of 3 to 4 hours and concentrates the coverage of one satellite (SSF) in the Tropics. The three SS satellites will provide good polar coverage. Diurnal sampling is not required for many of the parameters to be measured. Consequently, some instruments would only need to be flown on one SS spacecraft. Table 2 also identifies several three-satellite orbit combinations with temporal sampling capability from 4 to 6 hours.

Regional studies of physical processes require much higher temporal resolutions than can be obtained from the satellite systems designed for global change monitoring applications. One or two geosynchronous satellites are needed to provide this capability. These satellites should be movable in longitude so that they can be repositioned around the globe as required to study particular regions.

REFERENCES

1. Brooks, David R.: An introduction to orbit dynamics and its application to satellite-based Earth monitoring missions. NASA RP-1009, November 1977.

2. Suttles, John T., Edwin F. Harrison, Gary G. Gibson, and Thomas G. Campbell: Science requirements for a global change technology architecture trade study. NASA TM-104082, May 1991.

TABLE 1. REQUIREMENTS* FOR EARTH SCIENCE MEASUREMENTS

REGIME/ CATEGORY	MEASURABLE	DIURNAL CYCLE CRITICAL	GLOBAL CHANGE STUDIES		REGIONAL PROCESS STUDIES	
			TEMPORAL	SPATIAL	TEMPORAL	SPATIAL
SOLAR	SPECTRAL RADIATION	NO	1D	SUN DISK	1D	SUN DISK
ATMOSPHERE	PRESSURE (SURFACE)	NO	3-12H	10km		
	TEMPERATURE PROFILE	YES	1-3H	10-50km	15M-1H	5km
	STRATOSPHERIC GASES	NO	3-12H	50km	30M	5-10km
	AEROSOLS & PARTICULATES	NO	3-12H	10km	15M-1H	0.1-1km
	TROPOSPHERIC WATER VAPOR	NO	3-12H	10km	30M-1H	10km
	CLOUD COVER & HEIGHT	YES	1-3H	1km	15M-1H	1km
	TROPOSPHERIC GASES	YES	1-3H	10km	30M-1H	10-50km
	WIND FIELDS	YES	1-3H	10km	30M-1H	
RADIATION BUDGET	REFLECTED SW & EMITTED LW FLUX	YES	1-3H	10-30km	30M-1H	1-30km
EARTH (LAND/ OCEAN)	SURFACE TEMPERATURE	YES	1-3H	1-4km	6M-24H	30m-200km
	PRECIPITATION	YES	1-3H	1-30km	3M-3H	1-200km
	VEGETATION COVER/TYPE	NO	7D	1km	1-30D	30m-10km
	SOIL MOISTURE	NO	2D	1-10km	12H-7D	30m-10km
	BIOMASS INVENTORY	NO	7D	1km	1-30D	1-10km
	OCEAN COLOR (CHLOROPHYLL)	NO	2D	1-4km	2D	30m-4km
	OCEAN CIRCULATION	NO	2D	1-4km	1D	30m-4km
	SEA LEVEL RISE	NO	2D	10km	2D	10km
	SEA ICE COVER/DEPTH	NO	7D	1-20km	1-3D	1-25km
	OCEAN CO_2	NO	2D	0.5km		
	SNOW COVER/DEPTH/WETNESS	NO	7D	1km	12H-3D	1-10km

* SAMPLING REQUIREMENTS ARE GIVEN; DATA PRODUCTS FOR GLOBAL CHANGE STUDIES ARE DAILY MEANS AND 100-250km MEANS, DATA PRODUCTS FOR REGIONAL PROCESS STUDIES ARE HIGHLY VARIABLE.

TABLE 2. SUMMARY OF MISSION OPTIONS

SCIENTIFIC REQUIREMENT	TEMPORAL RESOLUTION (HR)	RECOMMENDED SATELLITE ORBITS
GLOBAL (DIURNAL)	3 3 - 4	4 SUN-SYNCH 3 SUN-SYNCH + SSF (i = 28.5°)
	4 <4 - 6 4 - 6	3 SUN-SYNCH 2 SUN-SYNCH + EQUATORIAL (i = 0°, h = 5200 km) 2 SUN-SYNCH + SSF (i = 28.5°)
	6	2 SUN-SYNCH
GLOBAL (NO DIURNAL)	12	1 SUN-SYNCH
REGIONAL	MINUTES TO 1 HR	1 OR 2 GEO-SYNCH (MOVABLE IN LONGITUDE)

NOTE: MULTI-SUN-SYNCH SATELLITES ARE ASSUMED TO HAVE EQUALLY SPACED EQUATORIAL CROSSING TIMES

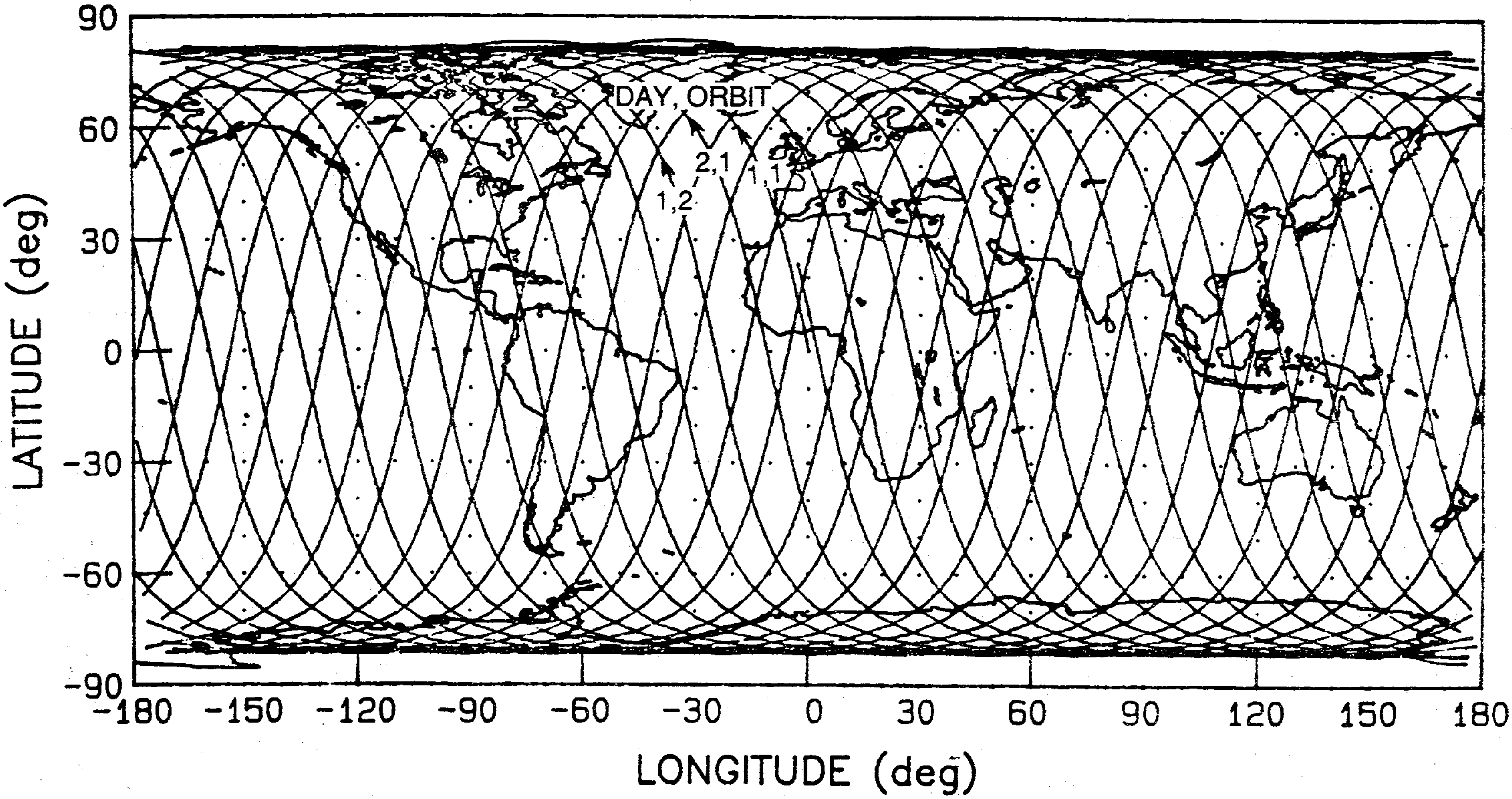

Figure 1. Geographical coverage of a 705-km altitude Sun-synchronous satellite for 2 days.

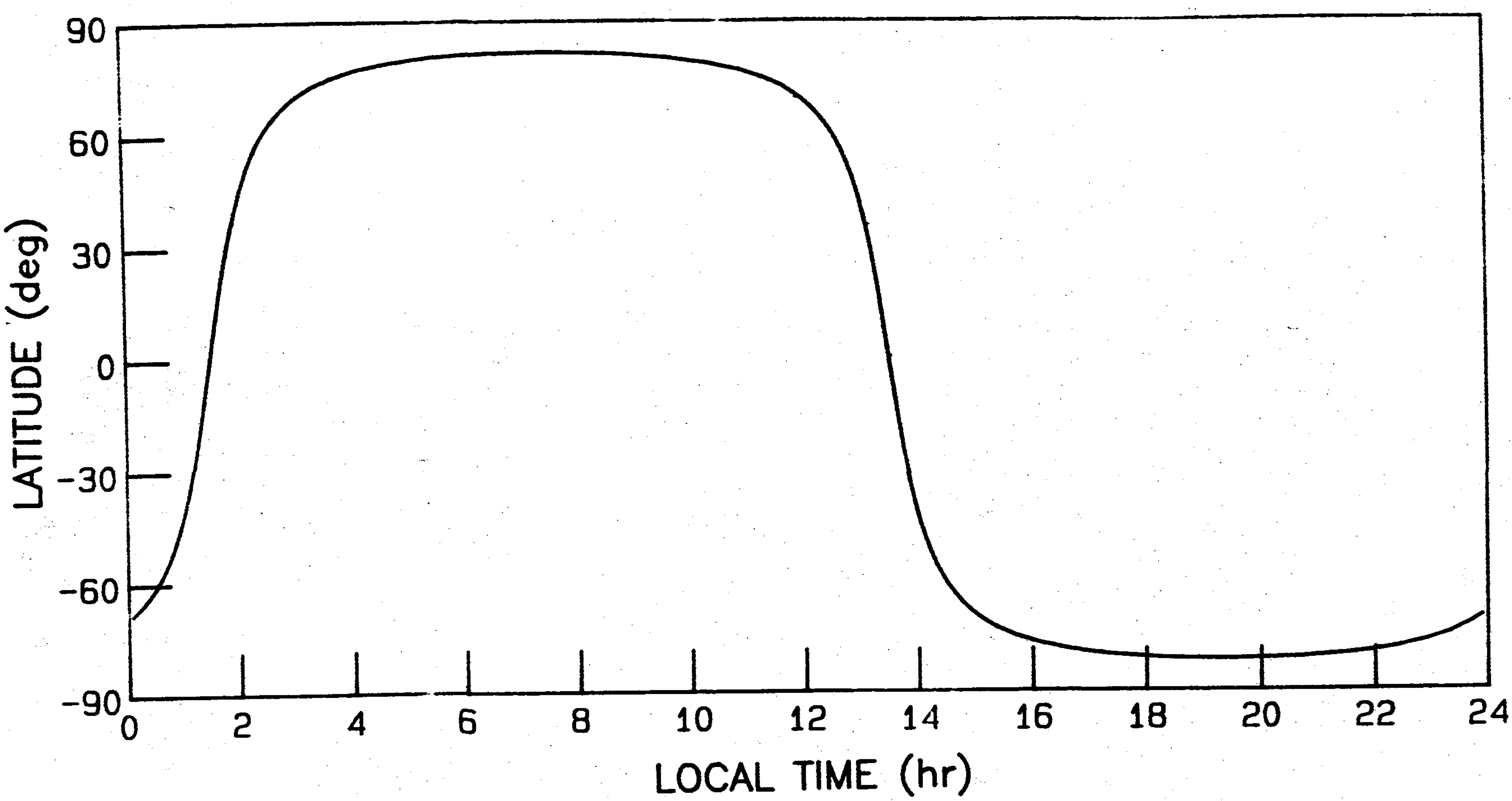

Figure 2. Latitude-local time coverage of a Sun-synchronous NASA EOS satellite.

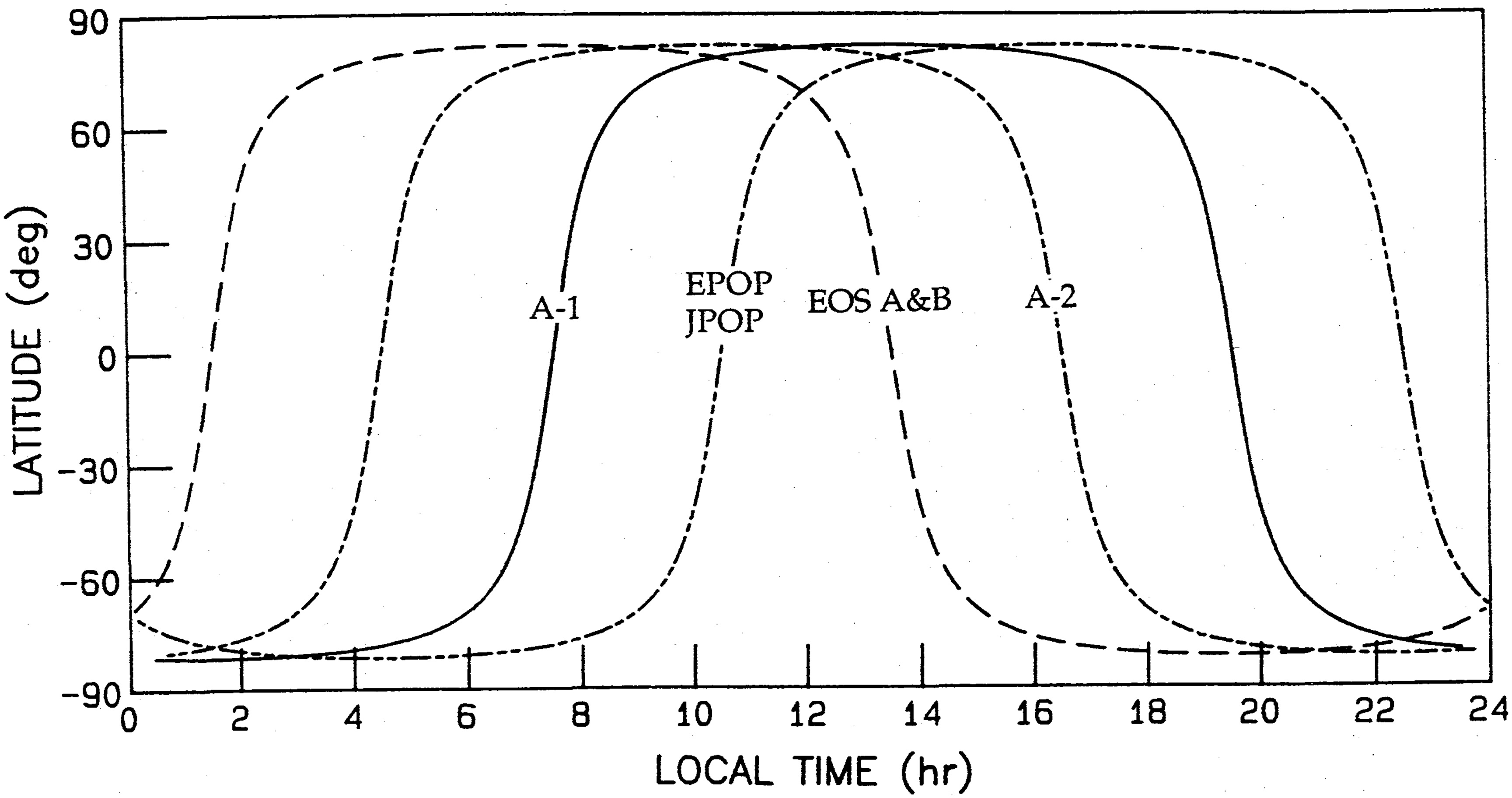

Figure 3. Latitude-local time coverage of four Sun-synchronous satellites (NASA EOS, ESA or Japanese, and two additional polar orbiting platforms).

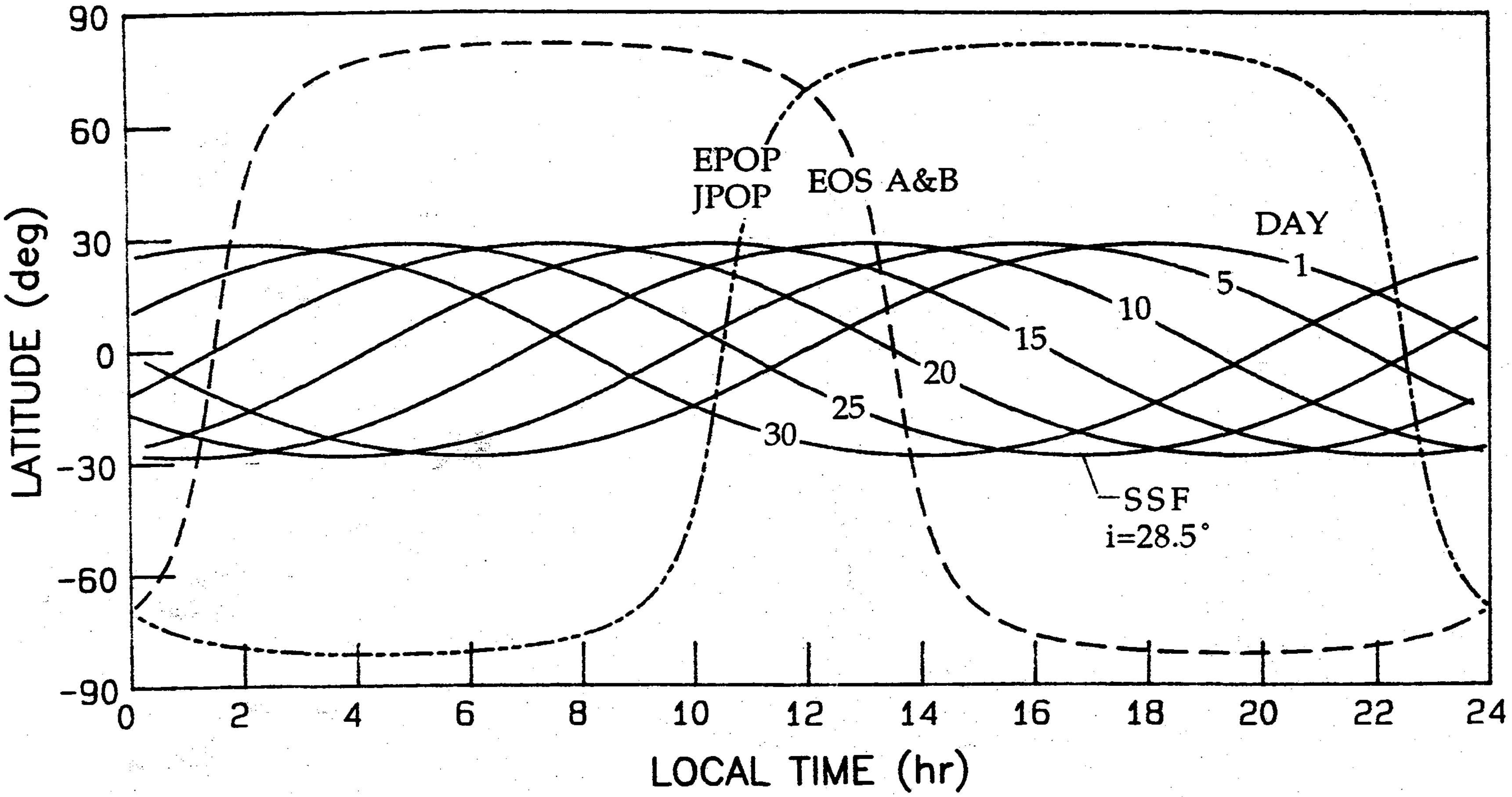

Figure 4. Latitude-local time coverage of two Sun-synchronous satellites and the Space Station Freedom.

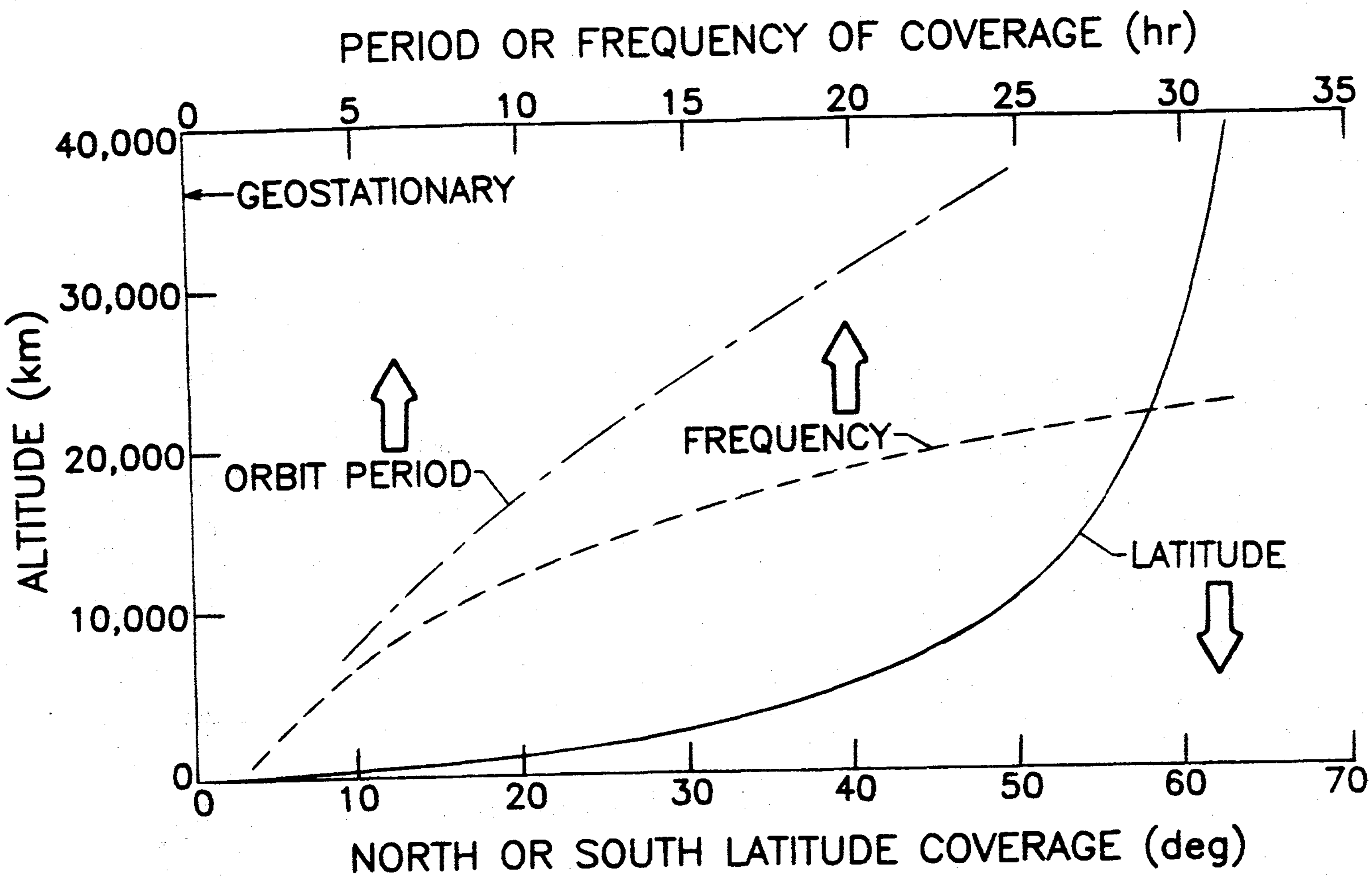

Figure 5. Coverage characteristics of equatorial orbits (viewing zenith angle ≤ 70°).

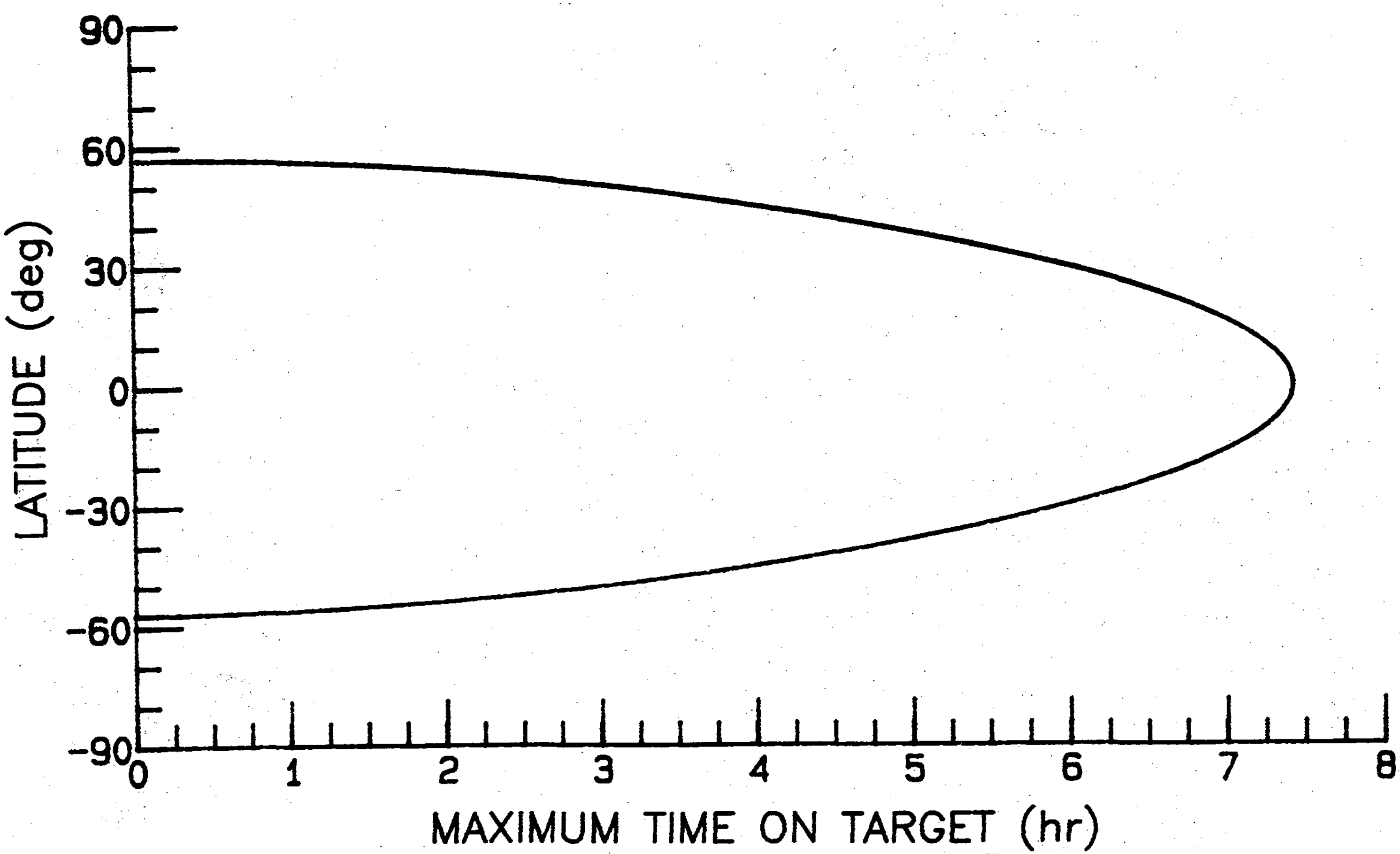

Figure 6. Continuous target coverage capability of an intermediate-altitude equatorial orbit (h = 20,000 km, viewing zenith angle ≤ 70°).

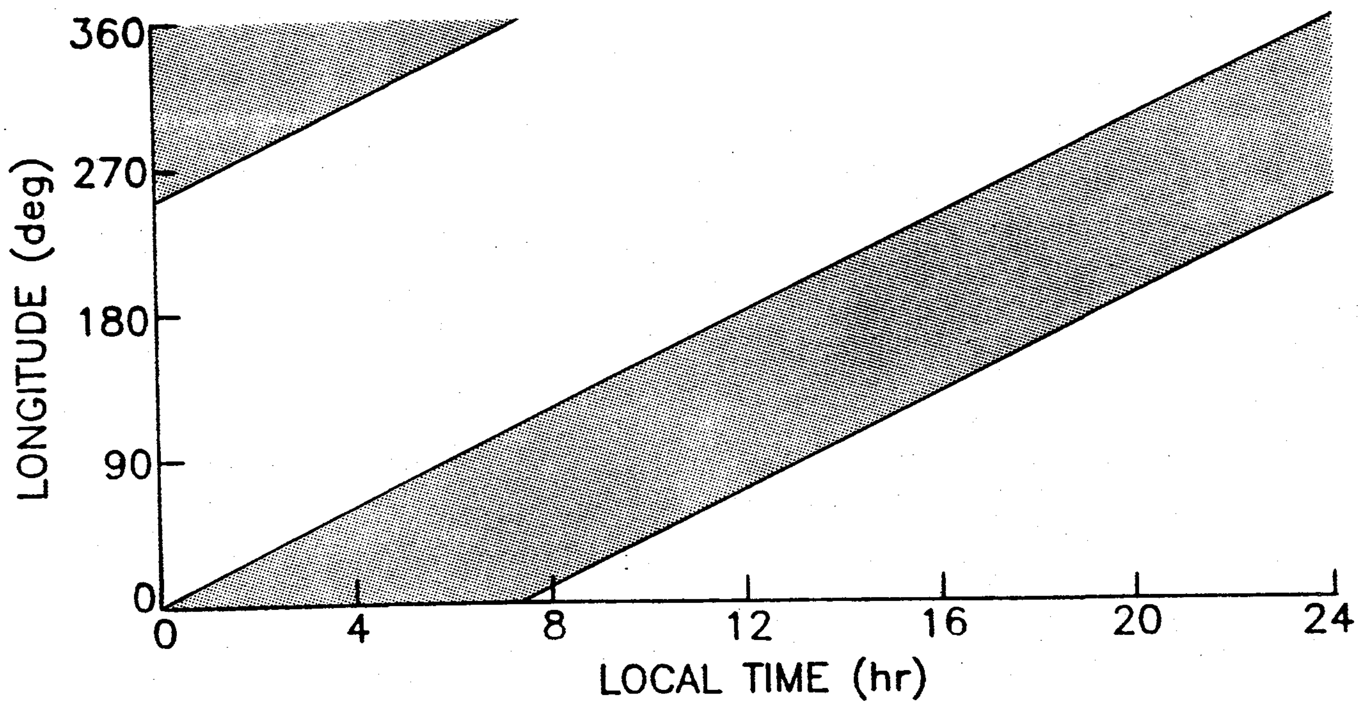

Figure 7. Longitude-local time coverage at the Equator for an orbit at h = 20,000 km and i = 0° with viewing zenith angle ≤ 70°.

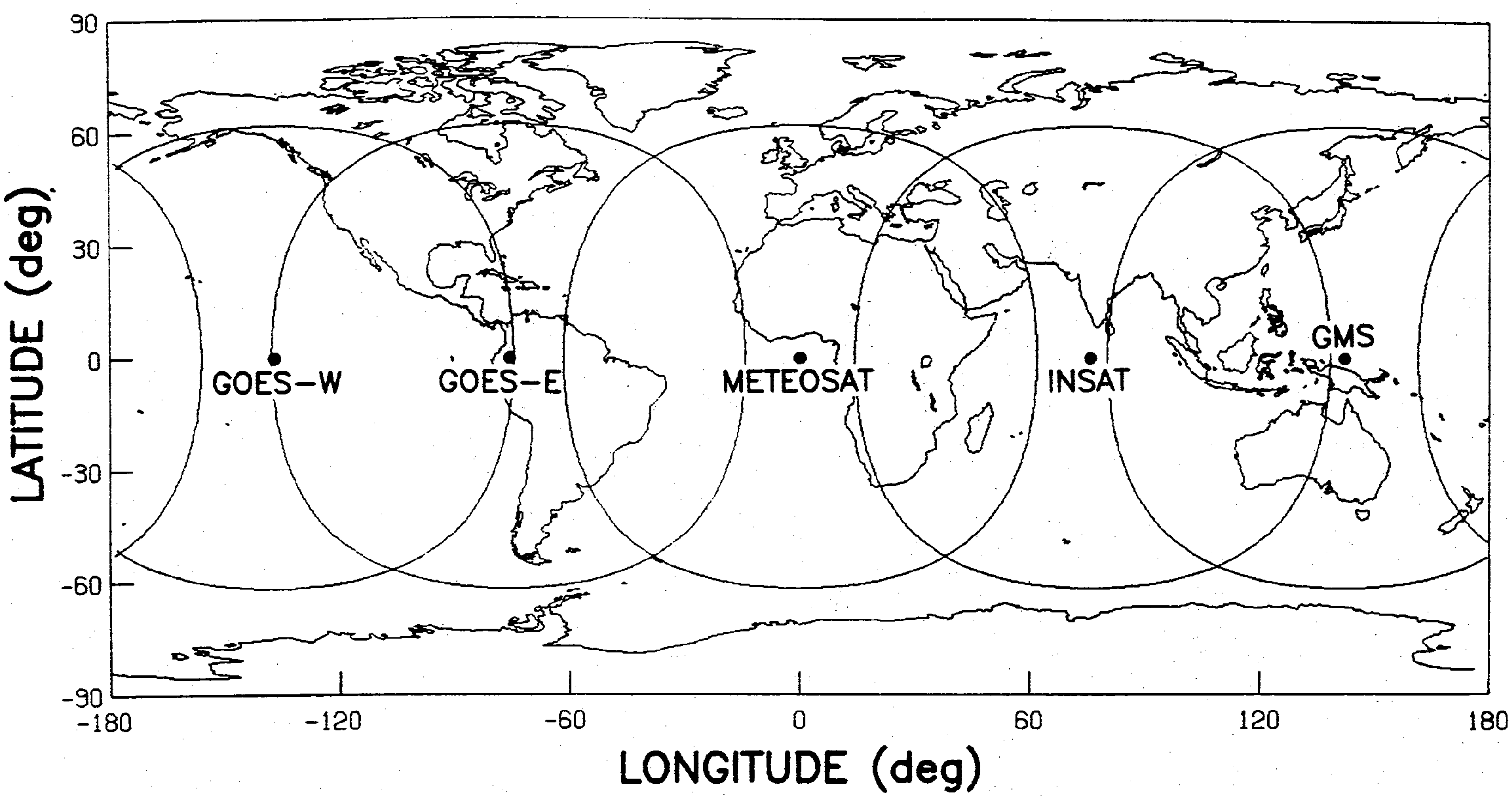

Figure 8. Geographical coverage of five geosynchronous satellites with viewing zenith angle ≤ 70°.

SELECTION OF REPRESENTATIVE INSTRUMENTS FOR A GLOBAL CHANGE TECHNOLOGY ARCHITECTURE TRADE STUDY

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INTRODUCTION

This report documents a portion of effort conducted within the Global Change Technology Initiative (GCTI) Architectural Trade Study. The purpose of the GCTI Trade Study is to develop and evaluate architectural mixes of spacecraft and sensor (instrument) groupings at LEO, GEO, and intermediate orbits to meet the science needs of global change studies. The Trade Study Plan entilted, Global Change Technology Initiative Architecture Trade Study Plan dated April, 1989 specifies a study divided into nine tasks. Task 1 of the Study was to develop a set of science requirements that specified the measurements to be made and the spatial resolution and temporal frequency at which they should be made. This task was completed, and a set of science requirements have been established. The completion of Task 1 permitted the GCTI Study to move into the Task 2 effort. Task 2 is entitled Sensor Requirements and Constraints but more appropriately it would be entitled Instrument Selection and Complementary Packaging. Due to the scope of the total GCTI Study and the unavoidable overlap between Tasks, the completion of Task 2 required interfacing with Task 3, Mission Design Options; Task 4, Spacecraft and Platform Development and Options; Task 6, Spacecraft and Sensor Performance Assessments; and Task 9, Technology Assessment. The approach to and the results of the Task 2 effort and its interfaces with the other Tasks are the subject of this paper.

OBJECTIVES

The objectives of Task 2 of the GCTI Architecture Trade Study are to select representative sets of instruments for making the science measurements specified in Task 1 and to identify instruments that, when flown together, form special complementary package for measurement purposes. The list of representative instruments and their complementary relationships provide a payload manifest defined in terms of mass, power, size, viewing angles, data rates, etc. which can be used to focus spacecraft trade studies and the definition of a candidate GCTI fleet.

SCIENCE REQUIREMENTS

The rationale for and the definition of science requirements established during the Task 1 effort has been presented by Suttles, et al. (1989). Table I taken from the Suttles document summarizes the requirements in tabular form. Values are presented for two types of measurements, global change study and regional process studies. The global change study requirements relate to measurements that are essential to the detection of long-term trends on a global scale. These measurements often provide the basic experimental data for the development and verification of large geographical area environmental models. The regional process studies relate to measurements that are essential to short-term, intensive field experiments on a local or regional scale. In general, they require higher resolutions on a more frequent temporal schedule than those of the global change studies.

Both spatial and temporal requirements are specified. The spatial values represent the required horizontal resolution measuring capability of the instrument and the temporal values represent the required measurement frequency. Although the science requirements do not specify values for vertical resolution, the instruments selection team and the science requirements team agreed that for measurables where vertical distribution is important, the data would be enhanced if measurements were made at nine to seventeen levels in the total depth of the atmosphere and at least two or three levels in the troposphere. These guidelines were used in the instrument selection process.

CANDIDATE INSTRUMENTS

In order to select a representative set of instruments for making the scientific measurements, a survey was made of instruments used on past and current spacecraft and those proposed for spacecraft of the near future. Data describing candidate instruments were collected from a variety of sources including NASA Technology Models and NASA Instrument Handbooks. A number of documents on the Upper Atmosphere Research Satellite and the Earth Observation System proved valuable. Reports on the progress of the geostationary platforms under study at NASA Marshall were closely examined. Used as guidelines

TABLE I: GCTI SCIENCE REQUIREMENTS.

Regime/ Category	Measurable	Diurnal Cycle	Global Change Study		Regional Process Studies	
			Temporal	Spatial	Temporal	Spatial
Solar	Spectral radiation	No	1D	Sun disk	1D	Sun disk
Atmosphere	Pressure (surface)	No	3-12H	10 km		
	Temperature profile	Yes	1-3H	10-50 km	15M-1H	5 km
	Stratospheric gases	No	3-12H	50 km	30M	5-10 km
	Aerosols & part.	No	3-12H	10 km	15M-1H	0.1-1 km
	Tropospheric H_2O	No	3-12H	10 km	30M-1H	10 km
	Cloud cover & height	Yes	1-3H	1 km	15M-1H	1 km
	Tropospheric gases	Yes	1-3H	10 km	30M-1H	10-50 km
	Wind fields	Yes	1-3H	10 km	30M-1H	
Radiation bubdget	Reflected SW & emitted LW flux	Yes	1-3H	10-30 km	30M-1H	1-30 km
Earth (land/ ocean)	Surface temperature	Yes	1-3H	1-4 km	6M-24H	30 m-200 km
	Precipitation	Yes	1-3H	1-30 km	3M-3H	1-200 km
	Vegetation cover/type	No	7D	1 km	1-30D	30 m-10 km
	Soil moisture	No	2D	1-10 km	12H-7D	30 m-10 km
	Biomass inventory	No	7D	1 km	1-30D	1-10 km
	Ocean color (chloro.)	No	2D	1-4 km	2D	30 m-4 km
	Ocean circulation	No	2D	1-4 km	1D	30 m-4 km
	Sea level rise	No	2D	10 km	2D	10 km
	Sea ice cover/depth	No	7D	1-20 km	1-3D	1-25 km
	Ocean CO_2	No	2D	500 km		
	Snow cover/depth	No	7D	1- km	12H-3D	1-10 km

throughout the entire effort were two reports, one by NOAA, the Department of Commerce and NASA to Congress on Space Based Remote Sensing of Earth (1987) and the other by a NASA Advisory Council to NASA and NOAA on the Earth System Science (1988). A full list of sources is included in the reference section.

Data on more than 100 instruments were collected continuously throughout this study. Frequent consultations were made with numerous contacts in the Earth science and remote sensing fields to maintain an information base that remained current. Even with this effort, many of the instruments are in such an early state of design that numerous changes in their specifications must be expected. In the few cases where there were no existing instruments to meet specific measurement requirements, new instruments were conceptualized. These efforts were done in cooperation with the various organizations which are involved in developing the respective instrument technology.

On the following pages is a discussion of some of the qualitative aspects of most of the instruments considered in this study.

Solar Viewing Instruments

Observing the sun is crucial to any observation of the Earth's environment since many of the phenomena that occur in the environment or on the Earth's surface are powered by the Sun's energy. Some instruments, such as the Active Cavity Radiometer Irradiance Monitor (ACRIM) observe the sun over virtually its entire electromagnetic spectrum. Instruments such as the X-ray Imager (XRI) and the X-ray Imaging Experiment (XIE) observe the sun in the X-ray portion of the spectrum. The Solar Stellar Irradiance Comparison Experiment (SOLSTICE), the solar Ultraviolet Spectral Irradiance Monitor (SUSIM), and the Solar Spectrometer (SOS) all monitor the sun in the ultraviolet spectrum. Instruments such as ACRIM also provide valuable calibration data for other instruments which observe the Earth directly, such as the Cloud and Earth Radiant Energy System (CERES) instrument.

Nadir Viewing Instruments

The nadir viewing instruments perform all the surface observations as well as many of the atmospheric measurements. Most of the instruments can be broadly divided into several categories: visible-infrared radiometers, visible-infrared spectrometers, microwave radiometers, gas correlation radiometers, and a variety of active systems.

Visible-Infrared Radiometers

The visible-infrared radiometers are probably the most utilized instrument type. NOAA first incorporated a visible-infrared radiometer in its polar orbiting weather satellites in 1970. The primary mission of these instruments is to provide day and night data on cloud coverage and height, surface temperature, and atmospheric temperature profiles. A variety of data on land and oceanic vegetation parameters can also be derived from the images returned. The NOAA weather satellites currently employ a combination of the Advanced Very High Resolution Radiometer (AVHRR) and the High Resolution Infrared Sounder (HIRS). Work is currently underway in developing advanced versions of these instruments, the Advance Medium Resolution Infrared Radiometer (AMRIR), which actually has a higher resolution than the AVHRR, and the Atmospheric Infrared Sounder (AIRS), which incorporates much colder and more sensitive detectors and nearly three times as many spectral bands as HIRS.

NOAA has also used visible-infrared radiometers on its geostationary satellites. On the current generation spin stabilized platforms, a combination imager-sounder known as the Visible-Infrared Spin Stabilized Radiometer (VISSR) Advanced Sounder (VAS) is used. On the next generation three-axis stabilized platforms, new instruments, simply called the GOES Imager and GOES Sounder, will be used. More advanced instruments, such as the Infrared Vertical Sounder (IRVS) are being developed for future geostationary platforms.

Several radiometers have been developed to specifically study the Earth's radiation balance, including the Earth Radiation Budget Instrument (ERBI), and the newer Cloud and Earth Radiant Energy System (CERES) instrument. Geostationary versions of these instruments are also being studied under names such as the Geostationary Earth Radiation Sensor (GERS) or the Broad Band Earth Radiation Radiometer (BERR).

Visible-Infrared Spectrometers

One set of spectrometers, which straddle the boundary between spectrometers and radiometers, was optimized for land usage and resource observation. The set includes the flight proven Thermal Infrared Mapping Spectrometer (TIMS) and its advanced versions, the Intermediate Thermal Infrared Radiometer (ITIR) and the Thermal Infrared Ground Emission Radiometer (TIGER). Currently the most utilized spectrometer is the Landsat Thematic Mapper (TM). A set of advanced instruments which take their heritage from both the TM and NOAA's AVHRR is also being developed. These instruments include the Moderate Resolution Imaging Spectrometer—Nadir and Tilt modes (MODIS-N and MODIS-T) and the High Resolution Imaging Spectrometer (HIRIS). The Europeans are also developing versions of these instruments: the Medium Resolution Imaging Spectrometer (MERIS) and the High Resolution Imaging Spectrometer (HRIS). Activity is also underway to develop geostationary versions of these spectrometers, such as the Geostationary MODIS (GMODIS) and the High Resolution Multi-spectral Imager (HRMI).

There are also specialized spectrometers, such as the Multi-angle Imaging Spectrometer (MISR) which provides data used to correct the measurements made by the MODIS and HIRIS instruments. The Tropospheric Emissions Spectrometer (TES) is being developed specifically to study the composition of the troposphere.

Microwave Radiometers

Microwave radiometers are well suited for measuring hydrological phenomena including atmospheric water vapor, precipitation, soil moisture, snow and ice parameters. They are also able to determine atmospheric temperature profiles and to make surface temperature measurements. NOAA currently flies the Advanced Microwave Sounding Unit (AMSU) on its polar orbiting platforms. The Department of Defense flies a larger instrument known as the Special Sensor Microwave/Imager (SSMI) on its weather satellites. While AMSU has two modules which cover most of the microwave spectrum from 23–183 GHz, the SSMI targets the lower frequencies from 18–90 GHz. An advanced version of the SSMI, known as the High Resolution Microwave Spectrometer Sounder (HIMSS), is being developed for the Eos program. The HIMSS instrument would cover the spectrum from 6-90 GHz. The SSMI and HIMSS instruments both have mechanically scanned antennas, but there are numerous proposals for more advanced microwave radiometers which use electronic scanning. These include the Advanced Microwave Scanning Radiometer (AMSR) and the Advanced Microwave Imaging Radiometer (AMIR).

Work is underway to develop concepts of microwave radiometers for use from geostationary orbit. The great difficulty is that to maintain adequate measurement resolution the size of microwave antenna must be large; greater than 10 m. Even these large instruments will be dwarfed by the microwave radiometers required for soil moisture measurements. A current instrument with soil moisture capability is the Electronically Steered Thinned Array Radiometer (ESTAR). This instrument features an 18-m diameter antenna and a low frequency of 6.0 GHz. In order to make soil moisture measurements that penetrate the surface, a low frequency of 1.4 GHz and a much larger antennae is required. There is no current instrument with this capability.

Gas Correlation Radiometers

Gas correlation radiometry is currently employed to measure selected gases in the troposphere. A gas correlation radiometer known as Measurement of Air Pollution from Satellite (MAPS) produced inferred measurements of carbon monoxide during flights on the Shuttle Orbiter in 1981 and 1984. An advanced version of the MAPS instrument known as Tropospheric Radiometer for Atmospheric Chemistry and Environmental Research (TRACER) is now being developed for flight on the Eos platform. A similar instrument known as Measurement of Pollution in the Troposphere (MOPITT) is being designed by the Canadians for flight on the Eos. These instruments may also have the capability to measure methane and nitrous oxide.

Active Systems

A variety of active systems have been proposed for Earth observation. Active systems that have been flown on spacecraft utilize the microwave spectrum. These include the radar Altimeter (ALT) which is used to measure sea surface waves and thus ocean circulation, and Scatterometers (SCANSCAT or SCATT) which measure sea surface winds. The Synthetic Aperture Radar (SAR) has also proven itself in many fields varying from sea surface and land topography to vegetation surveys. Active microwave techniques have also been proposed for measuring atmospheric pressure at the Earth's surface. Promising even more capability, although not inexpensively, are space-borne lidars. Currently tectonic movements are being measured by firing ground-based lasers at orbiting reflectors, such as LAEGOS. In the future there are proposals to place the lasers in orbit and to reflect their beams off the Earth. One such design proposed for Eos is the Geoscience Laser Ranging System (GLRS). Space-borne lidars may also yield significant improvements in the ability to remotely measure wind fields in the atmosphere. The Japanese are developing the Laser Atmospheric Wind Sounder (LAWS) which would measure tropospheric winds with an accuracy on the order of 1 m/s. Lidars can also be used to accumulate data on cloud heights, atmospheric discontinuities, aerosols distributions, water vapor and temperatures profiles, and atmospheric surface pressure. One such set of lidars known as differential absorption lidars (DIAL) have been extensively tested on aircraft. Space-borne versions that are being considered include the Atmospheric Lidar (ATLID), the Lidar Atmospheric Sounder and Altimeter (LASA), and the Orbiter/STS Carried Lidar In-Space Technology Experiment (LITE).

Virtually all the lidar systems are very power intensive and require large optics to receive the reflections of the signals they emit. These factors severely strain the capabilities of any host spacecraft.

Other Instruments

A variety of other techniques have been employed to handle specific tasks. One such instrument is the Earth Observing Scanning Polarimeter (EOSP) which measures polarization of upwelling energy from the Earth and thus provides atmospheric connections for a number of spectrometers such as the MODIS, HIRIS, and TES. The EOSP also provides information on cloud properties and aerosol distributions.

Limb Viewing Instruments

Limb viewing instruments are a special class of instruments that view the Earth's upper atmosphere at or near the apparent upper edge of the atmosphere when viewed laterally from the spacecraft. Measurements are based on transmission and absorbance of the sun's energy as it passes through the atmosphere path (sun in occultation behind the atmosphere) or upon the spectra of thermal energy emitted by the constituents of the atmosphere. Limb viewers are, therefore, especially adaptable to spectral analysis of atmospheric gases. Because of the viewing geometry of limb viewers, the strongest signal results at a point along the viewing path where the path is tangent to the Earth's surface so that vertical scanning provides a profile of the vertical distribution of the emiting gases in the stratosphere and upper troposphere. The measurement is obtained many kilometers from the subsatellite location of the viewing instrument, thus lower measurement altitude is a function of cloud height. The measurement techniques can again be divided into a number of categories: visible-infrared radiometers, gas correlation radiometers, visible-infrared spectrometers, visible-infrared interferometers, grating spectrometers, microwave radiometers, and a number of sensors operating in the ultraviolet spectral region.

Visible-Infrared Radiometers

A pair of infrared radiometers proposed for the Eos program are the High Resolution Research Limb Sounder (HIRRLS) and the Dynamic Limb Sounder (DLS). Both instruments measure several gases including ozone, water vapor, methane and nitrogen dioxide in the spectral region from 6 to 8 μm.

Gas Correlation Radiometers

The Upper Atmosphere Research Satellite (UARS) will carry two gas correlation radiometers. The Improved Stratospheric and Mesospheric Sounder (ISAMS) and the Halogen Occultation Experiment (HALOE). Together the two instruments cover the spectrum from 2 to 17 μm although the HALOE instrument is only operational at sunrise and sunset. The Stratospheric Wind Infrared Limb Sounder (SWIRLS) is being developed for the Eos program. This instrument employs new gas correlation techniques to measure upper atmospheric wind fields and temperature profiles as well as several gas species.

Visible-Infrared Spectrometer

The Cryogenic Limb Array Etalon Spectrometer (CLAES) was developed for UARS to be an extremely versatile instrument capable of measuring a wide range of gas species. Unfortunately this instrument also dominates half of the satellite's payload allowance. The Spectroscopy of the Atmosphere Using Far Infrared Emission (SAFIRE) instrument is being developed for the Eos program. This instrument will also be able to measure a wide variety of gases using a combination of far-infrared spectrometry and mid-infrared radiometry.

Visible-Infrared Interferometers

A great deal of information about the atmospheric conditions can be determined using interferometer techniques. The UARS mission carried two interferometers, a Fabry-Perot interferometer named the High Resolution Doppler Imager (HRDI) and a Michelson interferometer called the Wind Imaging Interferometer (WINDII). Both instruments are useful for measuring upper atmosphere wind fields and temperature profiles.

Grating Spectrometers

The Stratospheric Aerosol and Gas Experiment (SAGE) III is an instrument with a long heritage dating back to NIMBUS-7 launched in 1978. This instrument measures ozone, water vapor, nitrogen dioxide and aerosols. Measurements are made by observing the sun as it passes through the atmosphere at sunrise and sunset. The light entering the instrument is diffracted by a grating, thus the name grating spectrometer.

Microwave Radiometers

The Microwave Limb Sounder (MLS) was first developed for the UARS mission. It makes measurements in three channels with a total spectral range of 63 to 205 GHz. The improved instrument planned for the Eos era will expand the coverage to five channels covering the spectral range of 117 to 637 GHz.

Ultraviolet Sensors

Sensors employing the ultraviolet spectral region are used primarily to measure ozone. The SAGE III instrument extends to the ultraviolet region. Current NOAA polar orbiting satellites carry the Solar Backscatter Ultraviolet Spectrometer (SBUV), and a Global Ozone Monitoring Radiometer (GOMR) is planned for the Eos era. There are plans to place similar instruments in geostationary orbit. These instruments are currently being referred to as the Geostationary Total Ozone Monitoring System (GEO-TOMS) or simply, the Ozone Mapper (OZMAP).

INSTRUMENT SELECTION

It is important to reiterate early in this instrument selection discussion that the objective of the Task 2 effort was to select a representative set of instruments that could be used to conceptualize individual GCTI spacecraft and various options for the fleet architecture. The Task 2 effort was not intended as an in-depth, detailed engineering trade-off study of competitive instruments. Where instrument or instrument concepts existed for making required measurements, the written literature describing the instrument was accepted as factual. Where instruments or concepts did not exist, new concepts were generated except for one measurement. There is no instrument or concept available for measuring the ocean-atmosphere CO_2 exchange (Ocean CO_2-Table I). New instrument concepts developed during this study include a Soil Moisture Microwave Radiometer (SMMR) for measuring soil moisture, an Atmospheric Pressure Lidar (APL) for measuring surface atmospheric pressure, and a Geostationary High Resolution Microwave Radiometer (GHRMR) for measuring tropospheric water vapor and precipitation from geostationary orbit. These new instrument concepts are included on the proposed instrument lists that follow and are discussed in more detail in the TECHNOLOGY NEEDS section of this report.

Rationale

When first viewing the science requirements on Table I, it becomes readily apparent that both the spatial resolution and temporal sampling requirements will impact instrument selection. One would expect that spatial resolution would have a major impact but the first impact comes from the temporal requirement. Note on Table I that ten of Regional Process Studies temporal requirements are in the minutes-hours range and eight of the ten are in the minutes—1 hour range. Without an unreasonable number of spacecraft in LEO, there in no way to achieve repeating temporal sampling of 1-hour or less except by the use of a positionable geostationary spacecraft. Thus, instruments for ten of the measurables need to be capable of operation from GEO while attempting to come reasonably close to the spatial resolution requirement. Of the ten measurables, two of them, stratospheric gases and tropospheric gases cannot be measured from the GEO altitude (with the possible exception of stratospheric ozone which can be measured from GEO). Instruments for these measurables are relagated to LEO spacecraft. In addition, wind field measurements are complementary to the atmospheric gases measurements so they are assigned to the same host spacecraft as the atmospheric gases instruments. Six of the Regional Process measurable plus one element of a seventh measurable remain as candidates for GEO instruments. Thus, the first level instrument selection step related to the temporal sampling requirements establishes the need for instruments that operate at both LEO and GEO altitudes.

In addition to the temporal sampling requirement that, in effect, becomes the first level instrument selection criteria, seven other criteria had some effect on instrument selection. They are listed in Table II and are discussed in the paragraphs that follow.

Instrument Signal Source

With remote sensing instruments, data on the desired measurable are not obtained directly, but are inferred from measured electromagnetic radiation usually in the optical and microwave spectral regions. Often the measurable can be sensed in more than one spectral band and by more than one technique. Furthermore, sometimes the measurable is inferred from some other quantity or characteristic, e.g., winds from cloud motions, vegetation type and ocean chlorophyll from surface color, aerosols and particles from light scattering. Therefore, an important piece of information in instrument selection is what is actually being sensed and what is its relation to the desired measurable over the range of conditions experienced during the whole observation period. Often the relationship has been established empirically via in situ "truth" measurements, and the limitations of the "truthing" must be understood.

The source of the signal may be the instrument itself in the case of a radar or lidar. More often for global change measurables, natural signals such as reflected/scattered sunlight or surface and atmospheric infrared and microwave emissions provide the signal. Often source signals are weak and must be selected from a noisy background or interfering radiation. Two impacts on GCTI instrument selection are:

(1) Measurables where the diurnal cycle is critical must be sensed by an active sensor or by sensing emitted radiation, i.e., the signal cannot depend on solar radiation.

(2) Auxiliary instruments may be required to assess and correct for interference such as clouds, polarization and microwave radiation.

TABLE II.- INSTRUMENT SELECTION CRITERIA

Categories	Considerations	Comments
Temporal Requirements	• Temporal Repeat Capability • Altitude at which instruments must sense measurable	• ≥ 1 set of instruments at GEO
Instrument Signal Source	• Quantity being sensed to obtain measurable data • Diurnal measurement capability • Signal strengths (see next category) • Interference with signals (see next category)	• Measurables where diurnal cycle is critical must be sensed with an active sensor or by emitted radiation • Auxiliary/complementary instruments may be required to handle interferences, e.g., polarization, clouds, absorption features
Instrument Spectral Selectivity, Responsivity, Signal-to-Noise Ratio, Precision, Accuracy, etc.	• Spectral band pass, spectral selection techniques • Basic instrument types • Instrument with long records of accurate/precise measurements	• Atmosphere: Species absorption line strengths and background noise are important • Solar and Earth radiation budget: Accuracy extremely important • Land-Ocean: Spectral specs are important
Spatial Resolution	• Horizontal - Collector size, configuration, articulation • Vertical - For atmospheric measurements (viewing geometry)	• Size of antenna is main driver for microwave instruments • Nadir viewers: Multiple bands • Limb viewers of stratosphere (vertical resolution)
Complementary Measurements	• Measurements that should be made of same spot simultaneously • Measurements made in different spectral regions or by different instrument techniques that complement, e.g., IR vs. microwave, radar/lidar vs. radiometer/spectrometer • Additional measurements by other than primary selected instruments	• Complementary instrument groups are identified • Apparent duplication may be deliberate for complementarity • Additional measurements are identified
Geographic Coverage	• Spatial sampling vs. contiguous geographic coverage • Single instrument swath and scanning capability vs. duplicate instruments on multiple spacecraft	• Need definition of science requirements • Need better definition of "regions"
Instrument Maturity	• Developmental status: Conceptually designed, developed, flown, operational • Lifetime, service, repair, refurbish, replace, etc. • Technology advancements	• Many Eos class instruments, but a few new concepts identified • 7–10 year lifetime goal • Advances sensor arrays, coolers, active systems, etc. • Dev. costs not considered
Instrument Impact on Hosting Spacecraft	• Reasonable mass, power and data requirements • Orientation, clear FOV, thermal radiators, etc. • Pointing, tracking, scanning, etc.	• Synthetic aperture radar and laser atmospheric wind sounder strain hosting capabilities

Instrument Spectral Selectivity, Responsivity, and Accuracy

The most important characteristics of remote sensing instruments for GCTI measurables are the spectral region of operation and the applicability of that spectral region to the particular measurement. Sensing of atmospheric and land/ocean measurables is especially dependent on selecting specific spectral lines or bands. Responsivity and signal-to-noise, although separately defined characteristics dependent on a number of other instrument features, are often also strongly dependent on spectral selectivity. The names of basic instrument types usually make some reference to spectral band and/or selection technique, e.g., infrared spectrometer, Fabry-Perot interferometer, gas correlation radiometer, grating spectrometer, etc. Two other important instrument characteristics, especially for solar and Earth radiation budget measurables, are precision and accuracy. Selection of instruments with the right spectral resolution, radiometric sensitivity, and other characteristics for a particular measurable entails assessment of the general capabilities of the types of instruments, the design and tradeoffs of specific embodiments, and the historical record of measurements made in the space environment by identical or similar instruments. Although for an actual mission such assessments require extended comparative analysis, the selection for each GCTI measurable of an appropriate instrument type and a representative or example instrument was based on published documents and the judgment of personnel with remote sensing experience.

Spatial Resolution

The spatial resolution values given for the Science Requirements listed on Table I are for horizontal resolution and are generally interpreted as the maximum allowable dimension of a single measurement "footprint."

Vertical resolution for atmospheric measurables was considered during instrument selection; however, since the science requirements were presented only in terms of horizontal spatial resolution, an instruments horizontal resolution capability dominated the selection procedure. This approach could, and did, become the primary selection criteria. An example is the selection of the GOES Imager for Tropospheric Winds rather than the specific wind measuring LAWS instrument. The science requirement for the measurable tropospheric winds is a horizontal resolution of 10 km. With the GOES Imager instrument, tropospheric winds can be inferred from the motion of clouds at a stated horizontal resolution of 8 km. Its vertical resolution, however, is limited to specific altitudes where clouds exist. Frequently this results in data at two or three levels. The stated horizontal resolution for the LAWS instrument is approximately 100 km. Thus the LAWS instrument misses the science requirement by a factor of ten. Its stated vertical resolution, however, is an impressive 1 km with an accuracy of 1 m/s. If vertical resolution was the dominant selection criteria, LAWS would be the instrument of choice. In this particular instrument selection case, the Regional Process Studies temporal requirement of 30 min–1 H for tropospheric winds also strongly suggested the selection of the Geostationary GOES instrument. The instrument design impacts of the spatial resolution requirements are primarily on the signal collector ("optics") size, configuration including viewing geometry, and articulation. For examples: (1) The size of the antenna is the main design driver for the long wavelength microwave instruments, (2) Limb viewing is the most practical approach for good vertical spatial resolution in the upper troposphere and in the stratosphere. For the vertical resolution of the atmosphere by nadir viewing instruments an additional consideration is the selection of differently weighted spectral channels for emission sensing or the use of an active sensor such as a lidar or a radar. Note that designing instruments for horizontal spatial resolution is not generally limited by the "physics," but by practical engineering constraints and tradeoffs. Therefore, if a particular instrument type is the choice for other reasons, design changes to meet the spatial resolution requirements are often possible.

Complementary Measurements

Often a particular scientific investigation requires simultaneous spatial and temporal data on several measurables. In addition, data on an individual measurable acquired by different measurement techniques or in different spectral bands is helpful in scientific interpretation of the measurement results. Although not specifically stated as science requirements, considerations of complementary measurement needs are instrument selection criteria. In response to these needs, the instruments selected for the individual measurables were grouped into nine complementary packages. All instruments within a single package are to be flown together on a single spacecraft. The complementary packages are as follows:

Spectral radiation	Spectral radiation/radiation budget (LEO)
Meteorology	Spectral radiation/radiation budget (GEO)
Stratospheric gases/wind fields	High resolution spectrometry
Aerosols (GCS)	Ocean
Tropospheric gases	

Many other complementary packages could be defined; e.g., a biomass burning package of instruments to measure tropospheric gases and winds, surface temperature and biomass inventory, but with diminishing returns regarding GCTI instrument selection.

For completeness, measurements from several selected instruments require supplementary data to be obtained simultaneously from auxiliary instruments. These data are used to correct or calibrate the primary data. For example, a polarimeter (EOSP) instrument has been chosen to correct for polarization of signal sources when used in conjunction with some of the selected spectrometers.

Geographic Coverage

Implied in the science requirements is the concept that geographic coverage should be contiguous or spatial sampling should be sufficiently dense to discern the geographic variations. The instrument characteristics of interest to this criteria category are the overall field-of-view or swath and the off-track scanning capability. The usable overall field-of-view may be limited by viewing angle, i.e., the physics of the remote sensing observations. For example, high latitude coverage from a geostationary spacecraft at the equator is limited by the slant angle of observation. Similarly, in low Earth orbit instruments with large "pushbroom" swaths or with large off-track scans may be limited by the allowable slant angle of observation of the desired measurables. On the other hand, swath and scanning capabilities of the instruments are often limited by their optical designs or scanner mechanisms and necessary improvements in particular types are not usually limited by the physics, but by engineering and design tradeoffs.

Instrument Maturity

The timeframe of the missions envisioned in the GCTI architecture study is far enough in the future to allow instrument candidates ranging from those that have flown in space on an operational basis to those that have only recently been conceptually designed. Mature or nearly mature instruments or concepts have been favored to maximize the probability of adequate instrument lifetime. Completely new concepts were selected only for measurables where there were no satisfactory candidates, however, there appears to be sufficient time to develop the new instrument technology and to incorporate it into new instrument concepts.

Instrument Impacts on the Hosting Spacecraft

The final category of instrument selection criteria deals with those instrument characteristics which impact the hosting spacecraft. Table II lists about ten such characteristics which were evaluated in the selection process. Two characteristics, mass and power, are included in the final instrument lists since they have a large impact on spacecraft selection and design.

Lists of Selected Instruments

Once a set of measurables was established and a set of candidate instruments and instrument concepts for making the measurements was identified, the selection process could begin. Candidate instruments and concepts are listed in Table III according to the measurable to which they relate. The selected instrument or concept identified and key reasons for its selection are included. The reasons for selection are extensions of the selection rationale previously discussed. At this point, instrument selection was complete; however, to be of maximum practical value, the selection needed to be grouped into lists of instruments making measurements at the same temporal frequency. In an earlier discussion in this paper it was established that the temporal sampling requirement of ≤ 1 hour requires the GCTI

TABLE III.- CANDIDATE AND SELECTED INSTRUMENTS

Measurable (Type Study)	Candidate Instruments	Selected	Reasons
Solar Spectral Radiation (GCS)	ACRIM SOLSTICE XRI SUSIM SOS	ACRIM	• Measures total spectral irradiance, complements the Earth Radiation Budget instrument • Continuity with UARS and EOS • Doesn't strain host spacecraft
		SOLSTICE XRI	• Complements ACRIM in specific spectral regions SOLSTICE—Ultraviolet irradiance XRI—X-ray and energy input by charged particles • Small impact on spacecraft to add these two instruments
(RPS)	Same as GCS	ACRIM	Same as GCS
Amospheric Surface Pressure (GCS)	None	APL	• New instrument concept based on successful technique (aircraft experiments) and conceptual design of a similar type instrument (LASA-EAGLE)
(RPS)		No Requirement	
Atmospheric Temperature Profile (GCS)	AMSU-B AIRS HIRS HIMSS AMRIR SWIRLS	AMSU-B	•Proven technology •Good spatial resolution •All weather capability
		AIRS	•Very good spatial resolution •Very good spectral resolution in thermal IR (gives good vertical resolution) •Day/night capability
(RPS)	IRVS GMODIS GOES Sounder VAS	IRVS	•Next generation IR Sounder for GEO

TABLE III.- CONTINUED

Measurable (Type Study)	Candidate Instruments	Selected	Reasons
Stratospheric Gases (Ozone) (GCS)	SAGE III SAFIRE MLS CLAES HALOE ATMOS	SAGE III	•A flight proven instrument for ozone •Measurement technique based on solar occultation. Thus supplements SAFIRE (Spectrometer) and MLS (microwave) instruments selected for other stratospheric gases but also measuring ozone
(RPS)	OZMAP	OZMAP	•Only candidate for ozone measurement from GEO •GEO measurement needed to meet temporal requirement
Stratospheric Gases (Other) (GCS)	SAGE III SAFIRE MLS CLAES HALOE ATMOS HIRRLS SWIRLS DLSD HRI TOMS SBUV GOMR ISAMS LIMS	SAFIRE	•Measures key stratospheric gases •Combines multi-channel Fourier spectrometer with multi-channel broad band radiometer •LIMS and HALOE heritage (broad band) radiometer ATMOS heritage (Fourier spectrometer)
		MLS	•Specific for species related to ozone depletion •Measurements by microwave—complements other techniques of SAGE and SAFIRE
(RPS)	Same as GCS	Same as GCS	•Same as GCS

TABLE III.- CONTINUED

Measurable (Type Study)	Candidate Instruments	Selected	Reasons
Aerosols and Particulates (GCS)	SAGE III HIRRLS MISR EOSP	SAGE III	•Proven instrument •Limb viewer measuring ultraviolet scattering •Good supplement to ozone measuring instruments
		EOSP	•A nadir viewer measuring polarization •Provides a supplementary correction measurement (polarization) for other prime instruments •Complements SAGE III
(RPS)	IRVS	IRVS	•Only viable candidate from GEO with reasonable horizontal resolution and good vertical resolution
Tropospheric Water Vapor (GCS)	AIRS AMSU-A AMSU-B HIMSS AMSR SWMR AMIR SSM/I HIRS LASA ATLID AVHRR MODIS-N MODIS-T	AIRS	•Infrared spectral bands provide good vertical resolution •Infrared measurement complements microwave measurements
		AMSU-B	•Has specific frequencies (high frequency) for water vapor •Proven instrument •Wide swath
		HIMSS	•Has specific frequencies (low frequencies) for water vapor •Wide swath •Proven instrument (SSM/I heritage) •Lighter weight than electronically scanning microwave radiometer
(RPS)	None acceptable	GHRMR	•New concept developed for geostationary sensing based on applying advanced but feasible microwave technology

TABLE III.- CONTINUED

Measurable (Type Study)	Candidate Instruments	Selected	Reasons
Cloud Cover, Type and Height (GCS)	MODIS-N MODIS-T AVHRR AMRIR ATLID LASA	MODIS-N	•An imaging instrument with sufficient spectral range and discrete frequencies to measure cloud cover, height, and type •Day/night capability
	AIRS HIRS HIRIS APL	AIRS	•Very good spatial resolution •Very good spectral resolution in thermal IR band •Good vertical resolution •Day/night capability
(RPS)	GMODIS GOES Imager	GMODIS	•Same as GCS, MODIS-N
	VAS IRVS	GOES Imager	•Instrument specifically designed for cloud cover measurements from GEO—does both infrared and visible imaging •Provides good temporal resolution from GEO
Tropospheric Gases (GCS)	TES TRACER MOPPITT MODIS-N HIRRLS LASA SAGE III AIRS	TES	•Multiple gas capability •Good spectral resolution and sensitivity via Fourier transform spectrometer •Both nadir and limb viewing providing good horizontal and vertical resolution, respectively
	AIRS	TRACER	•Specific capability for CO and CH_4 •Proven instrument with flight heritage—Shuttle/MAPS
(RPS)	Same as GCS	Same as GCS	•Same as GCS

TABLE III.- CONTINUED

Measurable (Type Study)	Candidate Instruments	Selected	Reasons
Wind Fields—Stratospheric (GCS)	SWIRLS MLS	SWIRLS	•Specifically designed for this measurement using Doppler shift of N_2O emission spectra •Acquires continuous vertical profiles of horizontal wind fields •Only viable candidate
(RPS)	Same as GCS	Same as GCS	•Same as GCS
Wind Fields—Tropospheric (GCS)	LAWS HRDI GOES Imager	GOES Imager	•Good horizontal resolution (only instrument capable of meeting science requirement) •Acceptable impact on the host spacecraft
(RPS)	Same as GCS	Same as GCS	•Same as GCS
Reflected short wave and Emitted Long Wave Flux (GCS)	ERBI CERES	CERES	•Improved ERBI Flight Instrument •Continuity with Eos
(RPS)	GERS	GERS	•Only candidate for radiation Budget from GEO
Surface Temperature (GCS)	MODIS-N MODIS-T HIRIS AVHRR AMRIR AIRS HIRS HIMSS AMSU-A AMSR	MODIS-N	•Instrument with multiple measurable capability •Includes specific spectral bands for surface temperature •Day/night capability •Meets spatial resolution requirements •Acceptable Impact on host spacecraft •Required for other measurements

TABLE III.- CONTINUED

Measurable (Type Study)	Candidate Instruments	Selected	Reasons
(RPS)	GMODIS GOES Imager VAS	GOES Imager	•Includes specific spectral bands for surface temperature •Continuity with GOES spacecraft measurements •Day/night capability •Required for other measurements
Prescipitation (GCS)	AMSU-A AMSU-B HIMSS AMSR SWMR SSM/I	HIMSS	•Includes specific microwave frequencies for measuring precipitation •Adequate spatial resolution •Proven instrument (SSM/I heritage) •Wide swath •Light weight relative to other microwaves with electronic scanning
(RPS)	None acceptable	GHRMR	•New concept developed for geostationary sensing based on applying advanced but feasible microwave technology
Vegetation Cover/type (GCS)	MODIS-N MODIS-T HIRIS AVHRR AMRIR TM SAR	MODIS-N	•Instrument with multiple measurable capability •Includes specific spectral bands for discriminating vegetative classes •Day/night capability •Meets required spatial resolution •Required for other measurements •Acceptable impact on host spacecraft
(RPS)	Same as GCS	HIRIS	•Needed to meet the stringent spatial resolution requirement (30-m) •Provides continuity with Eos

TABLE III.- CONTINUED

Measurable (Type Study)	Candidate Instruments	Selected	Reasons
Soil Moisture (GCS)	ESTAR HIMSS AMSR SWMR SSM/I	SMMR	•New concept based on previous engineering design studies. New concept instrument is only candidate for meeting spatial resolution •Improved swath width
(RPS)	Same as GCS	Same as GCS	•Same GCS
Biomass Inventory—same candidate instruments, selected instruments and reasons as for vegetation cover/type (GCS and RPS)			
Ocean Color (GCS)	MODIS-N MODIS-T HIRIS AVHRR AMRIR TM OCI	MODIS-T	•Capable of avoiding sun glint at high sun angles •Has specific spectral bands for this measurable •Meets spatial resolution requirements •Acceptable impact on spacecraft •Provides continuity with Eos
(RPS)	Same	HIRIS	•Complements MODIS-T •Provides very high resolution imaging to meet stringent 30-m requirement (however data invalid at high sun angles) •Provides continuity with Eos
Ocean Circulation (GCS)	MODIS-N MODIS-T HIRIS AVHRR AMRIR TM	MODIS-T	•Provides wide swath width •Required for other measurements •Provides continuity with Eos
	ALT + 3 chMR	ALT + 3 chMR	•Flight proven technology •Day/night all weather capability •Provides continuity with TOPEX/Poseidon and Eos
(RPS)	Same as GCS	Same as GCS	•Same as GCS

TABLE III.- CONTINUED

Measurable (Type Study)	Candidate Instruments	Selected	Reasons
Sea Level Rise (GCS)	LASA ATLID ALT with 3 chMR SAR	ALT w/3 chMR	•An altimeter is the preferred technique for height differentation •Provides continuity with TOPEX/Poseidon and Eos •Flight proven technology •Day/night all weather capability •Acceptable impact on host spacecraft
(RPS)	Same as GCS	Same as GCS	•Same as GCS
Sea Ice Cover (GCS)	MODIS-N HIRIS AVHRR AMRIR TM HIMSS AMSR SWMR SSM/I ALT W/chMR SAR	MODIS-N	•Instrument with multiple measurement capability •Includes specific spectral bands for this measurable •Day/night capability •Meets required spatial resolution •Required for other measurements •Provides wide swath width
(RPS)	Same as GCS	Same as GCS	•Same as GCS
Snow Cover (GCS)	MODIS-N HIRIS AVHRR AMRIR TM HIMSS AMSR SWMR SSM/I	MODIS-N	•Instrument with multiple measurement capability •Includes specific spectral bands for this measurable •Day/night capability •Meets required spatial resolution •Required for other measurements •Provides wide swath width
(RPS)	Same as GCS	Same as GCS	•Same as GCS

TABLE III.- CONCLUDED

Measurable (Type Study)	Candidate Instruments	Selected	Reasons
Ocean CO_2 (GCS)	None	None	•Only in-situ measurements feasible
(RPS)	Same as GCS	Same as GCS	•Same as GCS
Snow Depth and Ice Depth (GCS)	AMSU-A AMSU-B HIMSS AMSR SWMR SSM/I	HIMSS	•Includes specific microwave frequencies for measuring snow and ice depth •Adequate spatial resolution •Wide swath •Proven instrument (SSM/I heritage) •Lightweight relative to other microwaves with electronic scanning
(RPS)	Same as GCS	Same as GCS	•Same as GCS

fleet include at least one geostationary spacecraft. This consideration did affect the selection of instruments for select measurables. The remaining temporal requirements do not affect instrument selection but they, along with instrument complementarity considerations, do affect the number of spacecraft and the grouping of instruments on the spacecraft. Two quotations from the Task 3 report (Harrison, et al., 1989) provide a perspective:

> "A multisatellite system is required to meet the scientific requirements for temporal coverage over the globe. The best system consists of four sun-synchronous satellites equally spaced in local time of equatorial crossing. This system can obtain data every 3-hours for all regions."

and

> "Some measurement parameters require observations every 12-hours which can be achieved with a single sun-synchronous satellite."

This perspective prompts the groupings of measurables by temporal requirements for both Global Change and Regional Process Studies. Six groupings were chosen and are presented as blocked-off temporal requirements in Table IV. With instruments selected to make the measurables and the measurables assembled into groups of similar temporal requirements, the instrument lists to be subsequently used in spacecraft design were prepared. The six instrument lists are presented in Tables V–X. Note on the instrument lists that more than one measurable is identified with most of the individual instruments. There was a primary instrument selected for each measurable and the measurable is labelled with a (P) where listed along with the instrument that is prime for its measurement. Some instruments are prime for more than one measurement, therefore, there may be two or more measurables with (P) labels associated with a single instrument. Most instruments can make additional measurements other than those for which it may be prime. They are shown in the Tables as additional (A) measurements. Note that the instrument lists also include the mass and power characteristics of the instruments plus a designation of its complementary status with other instruments. Additional physical and performance characteristics of instruments selected are presented in Appendix A.

Low-Earth Orbit Instrument Lists

Beginning with the Global Change Study, the measurables needing the most frequent sampling are those with a 1–3H temporal requirement. They are presented on Table IV as group 1 and the corresponding instrument list is presented in Table V as Instrument List No. 1.

TABLE IV: GCTI SCIENCE REQUIREMENTS GROUPING.

Regime/ Category	Measurable	Diurnal Cycle	Global Change Study		Regional Process Studies	
			Temporal	Spatial	Temporal	Spatial
Solar	Spectral radiation	No	1D	Sun disk	1D	Sun disk
Atmosphere	Pressure (surface)	No	(2) 3-12H	10 km		
	Temperature profile	Yes	(1) 1-3H	10-50 km	(6) 15M-1H	5 km
	Stratospheric gases	No	3-12H	50 km	(4) 30M	5-10 km
	Aerosols & part.	No	(2) 3-12H	10 km	15M-1H	0.1-1 km
	Tropospheric H_2O	No	3-12H	10 km	(6) 30M-1H	10 km
	Cloud cover & height	Yes	1-3H	1 km	15M-1H	1 km
	Tropospheric gases	Yes	1-3H	10 km	30M-1H	10-50 km
	Wind fields	Yes	(1) 1-3H	10 km	(4) 30M-1H	
Radiation bubdget	Reflected SW & emitted LW flux	Yes	1-3H	10-30 km	(6) 30M-1H	1-30 km
Earth (land/ ocean)	Surface temperature	Yes	1-3H	1-4 km	6M-24H	30 m-200 km
	Precipitation	Yes	1-3H	1-30 km	3M-3H	1-200 km
	Vegetation cover/type	No	7D	1 km	1-30D	30 m-10 km
	Soil moisture	No	2D	1-10 km	12H-7D	30 m-10 km
	Biomass inventory	No	7D	1 km	1-30D	1-10 km
	Ocean color (chloro.)	No	2D	1-4 km	2D	30 m-4 km
	Ocean circulation	No	(3) 2D	1-4 km	(5) 1D	30 m-4 km
	Sea level rise	No	2D	10 km	2D	10 km
	Sea ice cover/depth	No	7D	1-20 km	1-3D	1-25 km
	Ocean CO_2	No	2D	500 km		
	Snow cover/depth	No	7D	1- km	12H-3D	1-10 km

TABLE V. INSTRUMENT LIST 1:

GLOBAL CHANGE STUDIES, 1–3 HOUR TEMPORAL, LOW-EARTH ORBIT SPACECRAFT (GCS, 1-3 H, LEO)

Measurable (P)-Primary; (A)-Additional	Instrument Types	Representative Instrument	Mass (kg)	Power (W)	Complementary Package
(P) Cloud Cover & Type (P) Surface Temperature (A) Sea Ice & Snow Cover (A) Vegetation Cover (A) Biomass Inventory (A) Ocean Color (A) Ocean Circulation	Surface Imaging Vis/ Infrared Spectrometer	MODIS-N Moderate Resolution Imaging Spectrometer-Nadir Scan	200	250	a
(P) Temperature Profile (P) Cloud Height (A) Tropospheric Water Vapor	Atmospheric Infrared Sounder	AIRS Atmospheric Infrared Radiation Sounder	80	300	a
(P) Temperature Profile (A) Tropospheric Water Vapor	Atmospheric Microwave Sounder	AMSU-B Advanced Microwave Sounding Unit-B	40	80	a
(P) Precipitation (P) Temperature Profile (A) Tropospheric Water Vapor (A) Surface Temperature (A) Sea Ice & Snow Depth	Microwave Spectrometer Sounder	HIMSS High Resolution Microwave Spectrometer Sounder	222	66	a
(P) Tropospheric Gases: CO, CH_4	Tropospheric Gas Correlation IR Radiometer	TRACER Tropospheric Radiometer for Atmospheric Chemistry and Environmental Research	80	120	b
(P) Tropospheric Gases: O_3, H_2O, NO_2, N_2O, HNO_3, Cl species	Tropospheric Infrared Spectrometer	TES Tropospheric Emissions Spectrometer	491	600	b

TABLE V. INSTRUMENT LIST 1: CONCLUDED

Measurable (P)-Primary; (A)-Additional	Instrument Types	Representative Instrument	Mass (kg)	Power (W)	Complementary Package
Atmospheric Correction for Polarization (A) Aerosols and Particulates	Optical Polarimeter	EOSP Earth Observing Scanning Polarimeter	11	11	a,b
(P) Wind Fields (Tropospheric)	–	Measurement accomplished by the GOES Imager; see list RPS, $\leq$1 H, GEO			
(P) Spectral Radiation	Solar Irradiance Monitor	ACRIM Active Cavity Radiometer	24	5	c
(P) Radiation Budget	Earth Infrared Radiometer	CERES Cloud and Earth Radiant Energy System	90	90	c

TABLE VI.- INSTRUMENT LIST 2:
GLOBAL CHANGE STUDIES, 3–12 HOUR TEMPORAL, LOW-EARTH ORBIT SPACECRAFT (GCS, 3–12 H, LEO)

Measurable (P)-Primary; (A)-Additional	Instrument Type	Representative Instrument	Mass (kg)	Power (W)	Complementary Package
(P) Surface Pressure (A) Aerosols and Particulates (A) Cloud Cover and Height	Differential Absorption Lidar	APL* Atmospheric Pressure Lidar	660	1200	
(P) Stratospheric Gases O_3, H_2O, H_2O_2, NO_2, HNO_3, N_2O_5, CH_4, HF, HBr, HCl, HOCl	Limb Scanning Infrared Spectrometer/Radiometer	SAFIRE Spectroscopy of the Atmosphere Using Far-Infrared Emission	304	304	d
(P) Stratospheric Gases: O_3, H_2O, H_2O_2, ClO	Microwave Limb Sounder	MLS Microwave Limb Sounder	450	790	d
(P) Wind Fields (Stratospheric) (A) Temperature Profile	Gas Correlation IR Wind Sounder	SWIRLS Stratospheric Wind Infrared Limb Sounder	90	197	d
(P) Stratospheric Gases: O_3, NO_2, H_2O (P) Aerosols and Particulates	Solar Occultation Grating Spectrometer	SAGE III Stratospheric Aerosols and Gas Experiment	60	25	h
(P) Aerosols and Particulates	Polarimeter	EOSP Earth Observing Scanning Polarimeter	11	11	h
		(The following instruments also appear on other lists and offer options for exclusion from/or distribution among spacecraft)			
(P) Tropospheric Water Vapor (A) Temperature Profile (A) Cloud Height	Infrared Sounder	AIRS (See list GCS, 1–3 H, LEO) Atmospheric Infrared Radiation Sounder	80	300	a

TABLE VI.- INSTRUMENT LIST 2: CONCLUDED

Measurable (P)-Primary; (A)-Additional	Instrument Type	Representative Instrument	Mass (kg)	Power (W)	Complementary Package
(P) Tropospheric Water Vapor (A) Temperature Profile	Microwave Radiometer	AMSU-B (See list GCS, 1-3 H, LEO) Advanced Microwave Sounding Unit-B	40	80	a
(P) Tropospheric Water Vapor (A) Temperature Profile (A) Surface Temperature (A) Precipitation (A) Sea Ice and Snow Depth	Microwave Radiometer	HIMSS (See list GCS, 1-3 H, LEO) High Resolution Microwave Spectrometer Sounder	222	66	a

*New Concept Instrument

TABLE VII.- INSTRUMENT LIST 3:

GLOBAL CHANGE STUDIES, ≥12 HOUR TEMPORAL, LOW-EARTH ORBIT SPACECRAFT (GCS, ≥12 H, LEO)

Measurable (P)-Primary; (A)-Additional	Instrument Types	Representative Instrument	Mass (kg)	Power (W)	Complementary Package
(P) Spectral Radiation	Solar Irradiance Monitor	ACRIM Active Cavity Radiometer	24	5	f
(P) Spectral Radiation	Solar UV Spectrometer	SOLSTICE Solar Stellar Irradiance Comparison Experiment	146	72	f
(P) Spectral Radiation	X-ray Imager	XRI X-ray Imager	19	30	f
(P) Soil Moisture	Low Frequency Microwave Radiometer	SMMR* Soil Moisture Microwave Radiometer	4000	500	
(P) Ocean Color (P) Ocean Circulation (A) Vegetation Cover (A) Biomass Inventory (A) Cloud Cover	Surface Imaging Infrared Spectrometer	MODIS-T Moderate Resolution Imaging Spectrometer-Tilt Scan	100	150	
(P) Ocean Circulation (P) Sea Level Rise (A) Sea Ice Cover	Altimeter	ALT Altimeter	190	240	e
Atmospheric Correction for Water Vapor	Multiple Frequency Microwave Radiometer	3 Chan MR Three Channel Microwave Radiometer	27	30	e
Ocean CO_2**	—	—	—	—	

* New concept instrument

** No known remote sensing capability

TABLE VII.- INSTRUMENT LIST 3: CONCLUDED

Measurable (P)-Primary; (A)-Additional	Instrument Type	Representative Instrument	Mass (kg)	Power (W)	Complementary Package
		(The following instruments also appear on other lists and offer options for exclusion from/or distribution among spacecraft)			
(P) Vegetation Cover (P) Biomass Inventory (P) Snow Cover (P) Sea Ice Cover (A) Ocean Color (A) Ocean Circulation (A) Cloud Cover and Type (A) Surface Temperature	Imaging Spectrometer	MODIS-N (See list GCS, 1-3 H, LEO) Moderate Resolution Imaging Spectrometer-Nadir Scan	200	250	a
(P) Snow Depth (P) Sea Ice Depth (A) Tropospheric Water Vapor (A) Temperature Profile (A) Surface Temperature (A) Precipitation	Microwave Radiometer	HIMMS (See list GCS, 1-3 H, LEO) High Resolution Microwave Spectrometer Sounder	222	66	a
Atmospheric Correction for Polarization (A) Aerosols and Particulates	Polarimeter	EOSP (See list GCS, 1-3 H, LEO) Earth Observing Scanning Polarimeter	11	11	a

TABLE VIII.- INSTRUMENT LIST 4:

REGIONAL PROCESS STUDIES, ≤1 HOUR TEMPORAL, LOW-EARTH ORBIT SPACECRAFT (RPS, ≤1 H, LEO)

Measurable (P)-Primary; (A)-Additional	Instrument Type	Representative Instrument	Mass (kg)	Power (W)	Complementary Package
(P) Stratospheric Gases: O_3, H_2O, H_2O_2, NO_2, HNO_3, N_2O_5, CH_4, HF, HBR, HCl, HOCl	Limb Scanning Infrared Spectrometer/Radiometer	SAFIRE Spectroscopy of the Atmosphere Using Far-Infrared Emission	304	304	d
(P) Stratospheric Gases: O_3, H_2O, H_2O_2, ClO	Microwave Radiometer	MLS Microwave Limb Sounder	450	790	d
(P) Wind Fields (Stratospheric) (A) Temperature Profile	Gas Correlation Radiometer	SWIRLS Stratospheric Wind Infrared Limb Sounder	90	197	d
(P) Tropospheric Gases: CO, CH_4	Gas Correlation Radiometer	TRACER Tropospheric Radiometer for Atmospheric Chemistry and Environmental Research	80	120	b
(P) Tropospheric Gases: O_3, H_2O, NO_2, N_2O, HNO_3, Cl species	Infrared Spectrometer	TES Tropospheric Emissions Spectrometer	491	600	b
Atmospheric Correction for Polarization (A) Aerosols and Particulates	Polarimeter	EOSP Earth Observing Scanning Polarimeter	11	11	b
(P) Wind Fields (Tropospheric)	—	Measurement accomplished by the GOES Imager; see list RPS, ≤1 H, GEO			

TABLE IX.- INSTRUMENT LIST 5:

REGIONAL PROCESS STUDIES, ≥12 HOUR TEMPORAL, LOW-EARTH ORBIT SPACECRAFT (RPS, ≥12 H, LEO)

Measurable (P)-Primary; (A)-Additional	Instrument Type	Representative Instrument	Mass (kg)	Power (W)	Complementary Package
(P) Vegetation Cover (P) Biomass Inventory (P) Ocean Color (A) Ocean Circulation (A) Snow Cover (A) Sea Ice Cover (A) Cloud Cover (A) Surface Temperature	Imaging Spectrometer	HIRIS High Resolution Imaging Spectrometer	660	300	g
Atmospheric Correction for Polarization (A) Aerosols and Particulates	Polarimeter	EOSP Earth Observing Scanning Polarimeter	11	11	a,g
		(The following instruments also appear on other lists and offer options for exclusion from/or distribution among spacecraft)			
(P) Spectral Radiation	Solar Irradiance Monitor	ACRIM (See list GCS, ≥12 H, LEO) Active Cavity Radiometer	24	5	f
(P) Spectral Radiation	UV Spectrometer	SOLSTICE (See list GCS, ≥12 H, LEO) Solar Stellar Irradiance Comparison Experiment	146	72	f
(P) Spectral Radiation	X-ray Telescope	XRI (See list GCS, ≥12 H, LEO) X-ray Imager	19	30	f
(P) Soil Moisture	Microwave Radiometer	SMMR* (See list GCS, ≥12 H, LEO) Soil Moisture Microwave Radiometer	4000	500	
(P) Ocean Circulation (P) Sea Level Rise (A) Sea Ice Cover	Altimeter	ALT (See list GCS, ≥12 H, LEO) Altimeter	190	240	e
Atmospheric Correction for Water Vapor	Microwave Radiometer	3 Chan MR (See list GCS, ≥12 H, LEO) Three Channel Microwave Radiometer	27	30	e

TABLE IX.- INSTRUMENT LIST 5: CONCLUDED

Measurable (P)-Primary; (A)-Additional	Instrument Type	Representative Instrument	Mass (kg)	Power (W)	Complementary Package
(P) Ocean Color (P) Ocean Circulation (A) Vegetation Cover (A) Biomass Inventory (A) Cloud Cover	Imaging Spectrometer	MODIS-T (See list GCS, ≥12 H, LEO) Moderate Resolution Imaging Spectrometer-Tilt Scan	100	150	
(P) Vegetation Cover (P) Biomass Inventory (P) Snow Cover (P) Sea Ice Cover (A) Ocean Color (A) Ocean Circulation (A) Cloud Cover (A) Surface Temperature	Imaging Spectrometer	MODIS-N (See list GCS, 1-3 H, LEO) Moderate Resolution Imaging Spectrometer-Nadir Scan	200	250	a
(P) Snow Depth (P) Sea Ice Depth (A) Tropospheric Water Vapor (A) Temperature Profile (A) Surface Temperature (A) Precipitation	Microwave Radiometer	HIMSS (See list GCS, 1-3 H, LEO) High Resolution Microwave Spectrometer Sounder	222	66	a

* New Concept

TABLE X.- INSTRUMENT LIST 6:

REGIONAL PROCESS STUDIES, $\leq$1 HOUR TEMPORAL, GEOSTATIONARY ORBIT SPACECRAFT (RPS, $\leq$1 H, GEO)

Measurable (P)-Primary: (A)-Additional	Instrument Type	Representative Instrument	Mass (kg)	Power (W)	Complementary Package
(P) Spectral Radiation	Solar Irradiance Monitor	ACRIM Active Cavity Radiometer	24	5	i
(P) Radiation Budget	Earth Infrared Radiometer	GERS Geostationary Earth Radiation Sensor	110	90	i
(P) Tropospheric Water Vapor (P) Precipitation (A) Ocean Circulation	Multiple Frequency Microwave Radiometer	GHRMR* GEO High Resolution Microwave Radiometer	3110	370	
(P) Temperature Profile (P) Aerosols and Particulates	Atmospheric Infrared Spectrometer	IRVS Infrared Vertical Sounder	150	150	
(P) Cloud Cover and Height (A) Temperature Profile (A) Biomass Inventory	Surface Imaging Infrared Spectrometer	GMODIS GEO Moderate Resolution Imaging Spectrometer	230	250	
(P) Surface Temperature (P) Cloud Cover (A) Wind Fields	Surface Visible/Infrared Imager	GOES Imager	118	130	
(P) Stratospheric Gases: O_3	UV Spectrometer	OZMAP Ozone Mapper	100	130	

* New Concept

The second grouping of Global Change Study measurables and instruments includes those supporting a 3-12 hour temporal requirement. The temporal sampling group is shown in Table IV and the corresponding instrument list is presented in Table VI as Instrument List No. 2. Since each temporal sampling group and its related instrument list is a separate and complete entity and since there are measurables that repeat from list-to-list, there are instruments that repeat from list-to-list. The instruments that repeat are identified. The first of the repeating instruments are identified on Instrument List No. 2. Note that the other lists upon which they appear are identified in the representative instrument column. The same type of repeating instrument identification is used on subsequent Instrument Lists. Also note on Instrument List No. 2 that the first of the three new instrument concepts appears. The new concept instrument is the Atmospheric Pressure Lidar (APL). It is discussed in more detail in the TECHNOLOGY NEEDS section of this paper.

The third grouping of Global Change Study measurables and instruments includes those supporting a temporal sampling frequency of greater than 12-hours (actually 2–7 days). The temporal sampling group 3 is shown in Table IV and the corresponding instrument list is presented in Table VII as Instrument List No. 3. Note that an instrument entitled three Channel Microwave Radiometer (3 ChMR) has been added, not to meet a specific science requirement measurable, but as an instrument providing correction data for the required altimeter (ALT). List No. 3 also includes a new concept instrument, the Soil Moisture Microwave Radiometer (SMMR). Details of the new concept are discussed in a separate document by Farmer (1989). A unique entry in List No. 3 is the one for the measurable Ocean CO_2. This measurable is the only one from the science requirement table for which there are no known instruments or instrument concepts for remote measurement. The phenomenon to be measured is the exchange of CO_2 between the atmosphere and the ocean waters.

The fourth grouping is the first of the Regional Process Groups still utilizing LEO instruments. Temporal requirement group 4 in Table IV is a unique group with a temporal requirement of $\leq$ 1- hour. The preferred way to meet this requirement is with the use of a geostationary spacecraft; however, the instruments available for measuring Stratospheric Gases and Tropospheric Gases cannot perform from GEO except for an ozone measuring instrument. These instruments along with the complementary wind measuring instruments have been grouped in Table VIII as Instrument List No. 4 for use on a LEO spacecraft. The three measurables have been further subdivided because of instrument specificity. Note also that one of the measurables is not supported with a LEO instrument. The Tropospheric Wind Fields measurement is supported by the GEOS Imager in Instrument List No. 6 specified as a GEO Instrument List.

The fifth group of requirements in Table IV relates to Regional Process Studies measurables with a temporal sampling frequency of $\geq$ 12-hours. The corresponding Instrument List is presented in Table XIX as Instrument List No. 5. Note that the EOSP instrument does not appear as a repeat instrument although it does appear on an earlier list. In this case, the EOSP is flown as a complementary instrument to HIRIS to provide atmospheric correction data.

Geostationary Earth Orbit Instrument List

The last temporal grouping shown as group 6 on Table IV is the Regional Process Studies group which can be measured by GEO instruments. The corresponding Instrument List is List 6 presented in Table X. Note that the list includes a new concept, the GEO High Resolution Microwave Radiometer (GHRMR), for measuring Tropospheric Water Vapor and Precipitation. Details of the new concept are discussed in a separate document by Ferebee (1989).

Complementary Packages

Throughout Tables V–X (Instrument Lists), the complementary package column has been showing a small letter designation for many of the instruments. All instruments with the same letter designation should be flown together as a package because they are making complementary measurements. The complementary packages are listed in Table XI.

TABLE XI.- COMPLEMENTARY PACKAGES

Package a:	Meteorology - MODIS-N, AIRS, AMSU-B, HIMSS, EOSP
Package b:	Tropospheric Gases - TRACER, TES, EOSP
Package c:	Spectral Radiation/Radiation Budget (LEO) - ACRIM, CERES
Package d:	Stratospheric Gases/Wind Fields (GCS) - SAFIRE, MLS, SWIRLS
Package e:	Ocean - ALT, 3 Chan MR
Package f:	Spectral Radiation - ACRIM, SOLSTICE, XRI
Package g:	High Resolution Spectrometry - HIRIS, EOSP
Package h:	Aerosols (GCS) - SAGE III, EOSP
Package i:	Spectral Radiation/Radiation Budget (GEO) - ACRIM, GERS

PERFORMANCE ASSESSMENT

The ability of a single instrument or a group of instruments to meet a set of science requirements cannot be assessed totally independent of spacecraft and mission consideration. As previously discussed the 3-30 minute temporal sampling requirement for several of the measurables under Regional Process Studies dictated the use of at least one geostationary spacecraft. Instruments capable of making good measurements from a geostationary altitude are not numerous, and their current spatial resolution capability is approximately 5–10 km. Some instruments will not make measurements from the geostationary altitude and, regardless of the temporal sampling requirement, must operate in a lower Earth orbit. Other temporal sampling requirements listed in Table I present other spacecraft and mission implications. The requirement to sample the entire globe at a temporal sampling frequency of 3 and 12 hours implies 4 and 1 sun-synchronous spacecraft, respectively. A requirement of 1–30 days implies that the requirement can easily be met with one or more sun-synchronous spacecraft.

Based on these reasons, early mission analysis and spacecraft design efforts under Tasks 3 and 4 arrived at a preliminary set of spacecraft and mission options for matching instruments to spacecraft and to temporal sampling requirements. A 3 hour temporal requirement was selected as a reasonable goal for baselining options. Exceptions to the 3-hour goal include those measurables with temporal requirements greater than 3 hours and those with temporal sampling requirements of several minutes which can be accommodated by a geostationary spacecraft. One constellation option features one special purpose spacecraft, ten Delta-class spacecraft, and one geostationary spacecraft. The other option features one special purpose spacecraft, four Titan IV class spacecraft, and a geostationary spacecraft. These options are outlined in Table XII. The designations A–F refer to the spacecraft instrument complements also shown on the table. In terms of meeting the science requirements, the two options provide the same capability provided the following assumption is applied. Under option two with the four Titan IV class platforms, each of the four spacecraft includes spacecraft D and E instrument complements and the spacecraft B and C instruments are distributed among the four Titan IV class platforms in a manner that provides a 12 hour sampling frequency for that instrument. With this preliminary choice of spacecraft and mission options and the set of science requirements listed in Table I, an initial assessment of the ability to meet the science requirements can be made. Before the assessment can be presented, however, a slight alteration of the format of the requirements has to be made. The measurable "stratosphere gases" was separated into "ozone" and "other gases" since ozone can be measured from a geostationary spacecraft with current conceptual instruments while the other gases cannot. "Wind fields" was separated into "Stratospheric" and "Tropospheric" because the measuring instruments for the two types of winds are entirely different and, again, one may be inferred from a geostationary orbit measurement while the other cannot. The "cover" and "depth" measurements for the "sea ice" and "snow" measurables were broken out as separate measurements since instruments applicable to measuring cover are entirely different than those for measuring depth.

Tables XIII to XVI present an assessment of how well the science requirements can be met with the combination of instruments selected and the preliminary spacecraft and mission options used as a focus. Table XVII is a shade-coded summary of the detailed Tables XIII to XVI. There is, however, one qualification of the individual and summary

TABLE XII GCTI ARCHITECTURE TRADE STUDY
PRELIMINARY SELECTION OF SPACECRAFT AND INSTRUMENT COMPLEMENTS

Spacecraft	Spacecraft Instrument Complement	Option 1 Constellation for 3-Hour Coverage	Option 2 Platforms for 3-Hour Coverage
• <u>Low Earth Orbit</u>			
A, Soil Moisture	SMMR	1	1
B, 12-Hr.+Temporal	ACRIM, SOLSTICE, XRI, MODIS-T, HIRIS, EOSP, ALT, 3ChMR	1	
C, 3 to 12-Hr. Temporal	APL, SAGE III, EOSP	1 (12-hour)	4 (B through E combined)
D, 1 to 3-Hr. Temporal	CERES, ACRIM, MODIS-N, EOSP, AMSU-B, AIRS, HIMSS	4 (3-hour)	
E, Less than 1-Hr. Temp.	SAFIRE, MLS (Eos), TES, TRACER, SWIRLS, EOSP	4 (3-hour)	
• <u>Geostationary Orbit</u>			
G1, Less than 1-Hr. Temp.	GERS, ACRIM, IRVS, OZMAP, GOES Imager, GHRMR, GMODIS	1	1
--OR--			
G2-A, Less than 1-Hr. Temp.	G1 Complement Less GHRMR	1	1
G2-B, Less than 1-Hr. Temp.	GHRMR Alone	1	1
	TOTAL	1 Special Purpose LEO 10 Delta Class LEO 1 or 2 GEO	1 Special Purpose LEO 4 Titan IV Class LEO 1 or 2 GEO

TABLE XIII.- SCIENCE REQUIREMENTS MET/NOT MET
GLOBAL CHANGE STUDY/TEMPORAL REQUIREMENTS

Measurable	Primary Instrument	Temporal Frequency Required	Temporal Frequency Provided	Requirement Met
Spectral Radiation	ACRIM (LEO&GEO) SOLSTICE (LEO) XRI (LEO)	1 D ↓	12 H ↓	Yes ↓
Pressure (Surface)	APL (LEO)	3–12 H	12 H	3 H, No – 12 H, Yes
Temperature Profile	AIRS (LEO) AMSU-B (LEO)	1–3 H ↓	3 H ↓	1 H, No – 3 H, Yes ↓
Stratospheric Gases Ozone Other Gases	SAGE III (LEO) SAFIRE (LEO) MLS III (LEO)	3–12 H ↓	12 H 3H ↓	Yes ↓
Aerosols and Part.	SAGE III (LEO) EOSP (LEO)	3–12 H ↓	12 H ↓	3 H, No – 12 H, Yes ↓
Tropospheric H_2O	AIRS (LEO) AMSU-B (LEO) HIMSS (LEO)	3–12 H ↓	3 H ↓	Yes ↓
Cloud Cover, Depth, Type	MODIS-N (LEO) AIRS (LEO)	1–3 H ↓	3 H ↓	1 H, No – 3 H, Yes ↓
Tropospheric Gases	TRACER (LEO) TES (LEO)	1–3 H ↓	3 H ↓	1 H, No – 3 H, Yes ↓
Wind Fields Stratospheric Tropospheric	SWIRLS (LEO) GOES Imager (GEO)	1–3 H ↓	3 H ?	1 H, No – 3 H, Yes Conditional*
Reflected SW& Emitted LW Flux	CERES (LEO)	1–3 H	3 H	1 H, No – 3 H, Yes
Surface Temperature	MODIS-N (LEO)	1–3 H	3 H	1 H, No – 3 H, Yes
Precipitation	HIMSS (LEO)	1–3 H	3 H	1 H, No – 3 H, Yes
Vegetation Cover Type	MODIS-N (LEO)	7 D	3 H	Yes
Soil Moisture	SMMR (LEO)	2 D	12 H	Yes
Biomass Inventory	MODIS-N (LEO)	7 D	3 H	Yes
Ocean Color (Chloro.)	MODIS-T (LEO)	2 D	12 H	Yes

TABLE XIII.- CONCLUDED

Measurable	Primary Instrument	Temporal Frequency Required	Temporal Frequency Provided	Requirement Met
Ocean Circulation	MODIS-T (LEO)	2 D	12 H	Yes
	ALT (LEO)	↓	↓	↓
Sea Level Rise	ALT (LEO)	2 D	12 H	Yes
Sea Ice				
Cover	MODIS-N (LEO)	7 D	3 H	Yes
Depth	HIMMS (LEO)	7 D	3 H	↓
Ocean CO_2	None available	2 D	–	No
Snow				
Cover	MODIS-N (LEO)	7 D	3 H	Yes
Depth	HIMMS (LEO)	7 D	3 H	↓

* Conditional: Requirement met conditional upon accepting the assumption of one geostationary satellite that can be repositioned

TABLE XIV.- GLOBAL CHANGE STUDY/SPATIAL REQUIREMENTS

Measurable	Primary Instrument	Spatial Resolution Required	Instrument Performance	Requirement Met
Spectral Radiation	ACRIM (LEO&GEO) SOLSTICE (LEO) XRI (LEO)	Sun disk ↓	Sun disk ↓	Yes ↓
Pressure (Surface)	APL (LEO)	10 km	10 km	Yes
Temperature Profile	AIRS (LEO) AMSU-B (LEO)	10–50 km ↓	15–50 km 15 km	10 km, acceptable; 50 km, yes
Stratospheric Gases Ozone Other Gases	SAGE III (LEO) SAFIRE (LEO) MLS (LEO)	50 km ↓	10 km 1–10 km 3-10 km	Yes ↓
Aerosols and Part.	SAGE III (LEO) EOSP (LEO)	10 km ↓	10 km ↓	Yes ↓
Tropospheric H_2O	AIRS (LEO) AMSU-B (LEO) HIMSS (LEO)	10 km ↓	15-50 km 15 km 5–50 km	Acceptable* ↓
Cloud Cover, Depth, Type	MODIS-N (LEO) AIRS (LEO)	1 km ↓	0.5–1.0 km 15–50 km	Yes ↓
Tropospheric Gases	TRACER (LEO) TES (LEO)	10 km ↓	20 km 6 × 25 km Nadir, 25 × 65 km Limb	No ↓
Wind Fields Stratospheric Tropospheric	SWIRLS (LEO) GOES Imager (GEO)	10 km ↓	200 × 350 km 8 km	No Conditional*
Reflected SW& Emitted LW Flux	CERES (LEO)	10–30 km	10 km SW– 35 km LW	Acceptable
Surface Temperature	MODIS-N (LEO)	1–4 km	1 km	Yes
Precipitation	HIMSS (LEO)	1–30 km	5–15 km	1 km, No – 30 km, Yes
Vegetation Cover Type	MODIS-N (LEO)	1 km	1 km	Yes
Soil Moisture	SMMR (LEO)	1–10 km	10 km	1 km, No – 10 km, Yes
Biomass Inventory	MODIS-N (LEO)	1 km	1 km	Yes
Ocean Color (Chloro.)	MODIS-T (LEO)	1–4 km	1 km	Yes

* Conditional: Requirement met conditional upon accepting the assumption of one geostationary satellite that can be repositioned

TABLE XIV.- CONCLUDED

Measurable	Primary Instrument	Spatial Resolution Required	Instrument Performance	Requirement Met
Ocean Circulation	MODIS-T (LEO)	1–4 km	1 km	Yes
	ALT (LEO)	↓	1–15 km	↓
Sea Level Rise	ALT (LEO)	10 km	1–15 km	Acceptable
Sea Ice				
Cover	MODIS-N (LEO)	1–20 km	1 km	Yes
Depth	HIMMS (LEO)	↓	5–15 km	1 km, No – 20 km, Yes
Ocean CO_2	None available	500 km	–	No
Snow				
Cover	MODIS-N (LEO)	1 km	1 km	Yes
Depth	HIMMS (LEO)	↓	5–15 km	No

* Acceptable: Absolute requirement not met but instrument performance close enough to be judged acceptable.

TABLE XV.- REGIONAL PROCESS STUDIES/TEMPORAL REQUIREMENTS

Measurable	Primary Instrument	Temporal Frequency Required	Temporal Frequency Provided	Requirement Met
Spectral Radiation	ACRIM (LEO&GEO)	1 D	12 H	Yes
	SOLSTICE (LEO)	↓	↓	↓
	XRI (LEO)			
Pressure (Surface)	–	No Req.	–	–
Temperature Profile	IRVS (GEO)	15 M-1 H	Full Disk–1 H	Conditional
Stratospheric Gases				
Ozone	OZMAP (GEO)	30 M	?	Conditional
Other Gases	SAFIRE (LEO)	|	3 H	No
	MLS (LEO)		↓	↓
Aerosols and Part.	IRVS (GEO)	15 M-1 H	Full Disk–1 H	Conditional
Tropospheric H_2O	GHRMR (GEO)	30 M-1 H	?	Conditional
Cloud Cover, Depth, Type	GMODIS (GEO) GOES Imager	15 M-1 H	?	Conditional
Tropospheric Gases	TRACER (LEO)	30 M-1 H	3 H	No
	TES (LEO)	↓	↓	↓
Wind Fields				
Stratospheric	SWIRLS (LEO)	30 M-1 H	3 H	No
Tropospheric	GOES Imager (GEO)	↓	Full Earth–25M 1000 × 1000 km - 40 S	Conditional
Reflected SW& Emitted LW Flux	GERS (GEO)	30 M-1 H	Full Disk–1 to 3 H	Conditional
Surface Temperature	GOES Imager (GEO)	6 M–24 H	Full Earth–25 M 1000 × 1000 km–40 S	Conditional
Precipitation	GHRMR (GEO)	3 M–3 H	?	Conditional
Vegetation Cover Type	MODIS-N (LEO)	1-30 D	3 H	Yes
	HIRIS (LEO)	↓	12 H	↓
Soil Moisture	SMMR (LEO)	12 H-7 D	12 H	Yes
Biomass Inventory	MODIS-N (LEO)	1-30 D	3 H	Yes
	HIRIS (LEO)	↓	↓	↓
Ocean Color (Chloro.)	(HIRIS)(LEO)	2 D	12 H	Yes

Table XV.- CONCLUDED

Measurable	Primary Instrument	Temporal Frequency Required	Temporal Frequency Provided	Requirement Met
Ocean Circulation	MODIS-T (LEO)	1 D	12 H	Yes
	ALT (LEO)	↓	↓	↓
Sea Level Rise	ALT (LEO)	2 D	12 H	Yes
Sea Ice				
Cover	MODIS-N (LEO)	1-3 D	3 H	Yes
Depth	HIMMS (LEO)	↓	↓	↓
Ocean CO_2	–	No Req.	–	–
Snow				
Cover	MODIS-N (LEO)	12 H-3 D	3 H	Yes
Depth	HIMMS (LEO)	↓	↓	↓

* **Conditional: Requirement met conditional upon accepting the assumption of one geostationary satellite that can be repositioned**

TABLE XVI.- REGIONAL PROCESS STUDIES/SPATIAL REQUIREMENTS

Measurable	Primary Instrument	Spatial Resolution Required	Instrument Performance	Requirement Met
Spectral Radiation	ACRIM (LEO&GEO)	Sun Disk	Sun Disk	Yes
	SOLSTICE (LEO)	↓	↓	↓
	XRI (LEO)			
Pressure (Surface)	–	No Req.	–	–
Temperature Profile	IRVS (GEO)	5 km	5–10 km	Acceptable
Stratospheric Gases				
Ozone	OZMAP (GEO)	5–10 km	43 × 43 km	No
Other Gases	SAFIRE (LEO)	↓	1–10 km	Yes
	MLS (LEO)		3–10 km	↓
Aerosols and Part.	IRVS (GEO)	0.1–1.0 km	5 km	0.1 km, No–1 km, No
Tropospheric H_2O	GHRMR (GEO)	10 km	10 or 25 km	Conditional
Cloud Cover, Depth, Type	GMODIS (GEO)	1 km	0.5–1 km	Yes
	GOES Imager (GEO)	↓	8 km	↓
Tropospheric Gases	TRACER (LEO)	10–50 km	20 km	10 km, No–50 km, Yes
	TES (LEO)	↓	6 × 25 km Nadir, 25 × 65 km Limb	
Wind Fields				
Stratospheric	–	No Req.	–	–
Tropospheric	–	↓	–	–
Reflected SW& Emitted LW Flux	GERS (GEO)	1–30 km	5 km Nadir 15 km Horizon	1 km, No–30 km, Yes
Surface Temperature	GOES Imager (GEO)	30 m–200 km	8 km	30 m, No–200 km, Yes
Precipitation	GHRMR (GEO)	1–200 km	10 or 25 km	1 km, No–200 km, Yes
Vegetation Cover Type	MODIS-N (LEO)	30 m–10 km	1 km	Yes
	HIRIS (LEO)	↓	30 m	↓
Soil Moisture	SMMR (LEO)	30 m–10 km	10 km	30 m, No–10 km, Yes
Biomass Inventory	MODIS-N (LEO)	10 km	1 km	Yes
	HIRIS (LEO)	↓	30 m	↓
Ocean Color (Chloro.)	HIRIS (LEO)	30 m–4 km	30 km	Yes

TABLE XVI.- CONCLUDED

Measurable	Primary Instrument	Spatial Resolution Required	Instrument Performance	Requirement Met
Ocean Circulation	MODIS-T (LEO)	30–4 km	1 km	30 m, No–4 km, Yes
	ALT (LEO)	↓	1–15 km	↓
Sea Level Rise	ALT (LEO)	10 km	1–15 km	Acceptable
Sea Ice				
Cover	MODIS-N (LEO)	1–25 km	1 km	Yes
Depth	HIMMS (LEO)	↓	5–15 km	1 km, No–25 km, Yes
Ocean CO_2	–	No Req.	–	–
Snow				
Cover	MODIS-N (LEO)	1–10 km	1 km	Yes
Depth	HIMMS (LEO)	↓	5–15 km	1 km, No–10 km, Acceptable

* Conditional: Requirement met conditional upon accepting the assumption of one geostationary satellite that can be repositionec
* Acceptable: Absolute requirement not met but instrument performance close enough to be judged acceptable.

TABLE XVII: SUMMARY OF SCIENCE REQUIREMENTS MET/NOT MET.

Regime/ Category	Measurable	Diurnal Cycle	Global Change Study: Temporal Sampling	Global Change Study: Spatial Resolution	Regional Process Studies: Temporal Sampling	Regional Process Studies: Spatial Resolution
Solar	Spectral radiation	No	1D	Sun disk	1D	Sun disk
Atmosphere	Pressure (surface)	No	3-12H (12H)	10 km	NR	NR
	Temperature profile	Yes	1-3H (3H)	10-50 km	15M-1H	5 km
	Stratospheric gases					
	Ozone	No	3-12H	50 km	30M	5-10 km (43 km)
	Other gases	No	3-12H	50 km	30M (3H)	5-10 km
	Aerosols & part.	No	3-12H (12H)	10 km	15M-1H	0.1-1 km (5km)
	Tropospheric H_2O	No	3-12H	10 km	30M-1H	10 km
	Cloud cover/type/height	Yes	1-3H (3H)	1 km	15M-1H	1 km
	Tropospheric gases	Yes	1-3H (3H)	10 km (6 to 65 km)	30M-1H (3H)	10-50 km (20 km)
	Wind fields					
	Stratospheric	Yes	1-3H (3H)	10 km (250 x 350 km)	30M-1H (3H)	NR
	Tropospheric	Yes	1-3H	10 km	30M-1H	NR
Radiation budget	Reflected SW & emitted LW flux	Yes	1-3H (3H)	10-30 km	30M-1H	1-30 km (5-15 km)
Earth (land/ ocean)	Surface temperature	Yes	1-3H (3H)	4 km	5M-24H	30 m-200 km (8 km)
	Precipitation	Yes	1-3H (3H)	1-30 km (5-15 km)	3M-3H	1-200 km (10 or 25 km)
	Vegetation cover/type	No	7D	1 km	1-30D	10 km
	Soil moisture	No	2D	1-10 km (10 km)	12H-7D	30 m-10 km (10 km)
	Biomass inventory	No	7D	1 km	1-30D	1-10 km
	Ocean color (chloro.)	No	2D	1-4 km	2D	30 m-4 km
	Ocean circulation	No	2D	1-4 km	1D	30 m-4 km (1 km)
	Sea level rise	No	2D	10 km	2D	10 km
	Sea ice					
	Cover	No	7D	1-20 km	1-3D	1-25 km
	Depth	No	7D	1-20 km (5-15 km)	1-3D	1-25 km (5-15 km)
	Ocean CO_2	No	2D (–)	500 km (–)	NR	NR
	Snow					
	Cover	No	7D	1- km	12H-3D	1-10 km
	Depth	No	7D	1- km (5-15 km)	12H-3D	1-10 km (5-15 km)

No block = Requirements met

(grey block) = Absolute requirement not met but judged to be acceptable

(hatched block) = Requirements met conditional upon accepting assumptions

(black block) = Requirements not met

NR = No Requirement

(#) = Value achieved

assessments that must be stated. The actual ground coverage provided is rarely 100-percent based on the swath widths of the instruments selected and the proposed temporal sampling. Ground coverages have been plotted and they are presented in Appendix B except for the Earth limb viewing and solar disk viewing instruments for which ground coverage plots are inappropriate.

TECHNOLOGY NEEDS

During the instrument selection process, a summary of instrument heritage was prepared to portray the heritage of the representative instruments selected for GCTI measurements. The heritage is presented in Tables XVIII and XIX. Of the 27 selected instruments, 7 are current operational instruments, 17 are Eos type instruments, and 3 are newly defined instrument concepts. The chart effectively conveys the message that there is a long-term buildup of instrument technology that results in the proposed capabilities for the GCTI representative instruments. What the chart does not show, however, is the additional technology advances that must be made and applied to these representative instrument types to yield all of the desired instrument capabilities.

The first effort undertaken in the task of identifying technology needs was to review stated instrument performance capabilities and to note deficiencies and needed improvements. Deficiencies in three areas stand out: spatial resolution, capability to operate in geostationary orbit (GEO), and swath/scan capabilities. Improvements in spatial resolution are needed to provide the required observational detail. Improved and new instruments for operation in GEO are needed since GEO systems offer the only practical way of achieving temporal resolutions of 1-hour or less (GEO operation also requires much better spatial resolution capability). Improvements in swath/scan capabilities are needed for contiguous geographic coverage. Improvements in four additional areas are strongly implied from the performance assessments: measurement sensitivity, measurement specificity, measurement precision and accuracy, and alternative complementary measurements. To this list of needed instrument improvements several categories that are inherent and continuing needs for long-term

TABLE XVIII: HERITAGE OF EARTH OBSERVING SENSORS
LOW EARTH ORBIT APPLICATIONS.

Descriptor	Current[1]	Proposed[2]	GCTI list
Meteorological	HIRS - - - →	AIRS ———→	AIRS
	AVHRR*, OLS* - - - →	AMRIR	MODIS-N
Imaging	ETM, HRV - - - →	MODIS-N/T, HIRIS* ———→	MODIS-T, HIRIS
		HRIS*, ITIR, MISR	
Stratospheric gas	CLAES	HIRRLS	
	HALOE	SAFIRE ———→	SAFIRE
	HRDI	SWIRLS ———→	SWIRLS
	ISAMS - - - →	DLS	
	MLS (UARS) - - - →	MLS (EOS) ———→	MLS
	WINDII		
Ozone/aerosols	SAGE III ———→	SAGE III ———→	SAGE III
	SBUV	GOMR	
		EOSP ———→	EOSP
Tropospheric gas	MAPS - - - →	TRACER*, MOPITT* ———→	TRACER
	ATMOS - - - →	TES ———→	TES

Footnotes:

1 Current S/C: NOAA, DMSP, UARS, LANDSAT, ERBS, TOPEX, ERS, RADARSAT, SPOT, SST

2 Proposed S/C: Eos-A, Eos-B, Eos-E, Eos-J, TRMM, SSF

———→ Same or upgraded instrument. - - - - → Heritage instrument.

* Simillar instruments ○ New instrument concept

TABLE XVIII: (CONCLUDED).

Descriptor	Current[1]	Proposed[2]	GCTI list
Microwave Radiometer	AMSU, SSM-T, ATSR →	AMSU →	AMSU(B)
	SSMI - - →	HIMSS, AMSR* →	HIMSS
		MIMR,* AMIR,* ESMR	
			(SMMR)
Active systems	ALT(+3CMR) →	ALT →	ALT(+3CMR)
	AMI,* SAR* →	AMI,* SAR*	
	RSCAT - - →	SCANSCAT	
		ATLID	
		LAWS	
		GLRS	
		LASA Eagle - - →	(APL)
Solar	ACRIM →	ACRIM →	ACRIM
	SOLSTICE →	SOLSTICE →	SOLSTICE
	PEM	ENAC, POEMS	
	SUSIM		
		XRI →	XRI
Radiation budget	ERBE - - →	CERES →	CERES

TABLE XIX: HERITAGE OF EARTH OBSERVING SENSORS
GEOSTATIONARY ORBIT APPLICATIONS.

Descriptor	Current[1]	Proposed[2]	GCTI list
Meteorological	Imager →	Imager →	Imager
	Sounder →	Sounder →	IRVS
Imaging		GMODIS →	GMODIS
		HRIS	
Microwave Radiometer		HFMR	GHRMR
Radiation budget		GERS →	GERS
Ozone monitors		OZMAP →	OZMAP
Atmospheric gas		HRII	
		TGI	
Solar		ACRIM →	ACRIM
		SOLTICE	
		XRI	
Active systems (Lidar)		GLRS	

Footnotes:
1 Current S/C: GOES-next
2 Proposed S/C: MSFC Geo-platform

accurate sensing of Earth parameters from satellites are added: less demand on spacecraft resources, simplicity, reliability/lifetime, and operational maturity.

All of these categories of needed instrument improvements are listed in Table XX. Listed across the top of the table are the technology areas in which advances can be applied to yield the needed instrument improvements. The first nine items deal with hardware technologies, the next three deal with the complete instrument system, and the last three deal with non-hardware technologies. A need for a particular technology to provide a particular instrument improvement is designated by x. Strong needs are designated by an ⊗. This matrix represents an initial attempt at scoping the technology needs for GCTI instruments.

TABLE XX: IMPROVEMENTS PROVIDED BY ADVANCED TECHNOLOGY.

Improvements provided (instruments and operations) / Technology areas (candidates for advancement)	Instrument components										Instrument systems		Non - hardware		
	Bigger/better collectors (optics, antennas)	Better detectors - arrays, responsivity	Cryogenics - detector coolers, cooled optics	Light weight optics	Stabilization & control systems	Pointing systems	Scanning systems	Smart data systems	Structures (includes controlled/smart structures)	New instruments - techniques, spectral bands/lines	Lidar systems (especially lasers)	Large microwave systems - passive, active	Systems engineering	Corroboration science	Software
Spatial resolution - horizontal, vertical	X		⊗	⊗								⊗			
Operation in GEO - better temporal resolution		⊗			X	X	X					⊗			
Operation in GEO - better spatial resolution	⊗	⊗	⊗	⊗	⊗	⊗			X			⊗			
Swath/scan capabilities - contiguous coverage	X				X	X	X		X			⊗			
Measurement sensitivity	X	X	X	X						X	⊗				
Measurement sensitivity - spectral selectivity, calibration, truthing	X	X	⊗			X		X		X				X	
Measurement precision/ accuracy	⊗	X		X	⊗	⊗				X	X		X	X	
Alternative, complementary measurements										X	X	X		X	X
Less demand on S/C resources - • Mass • Volume				⊗					X			⊗			
• Power • Data • Pointing/tracking/scanning • Heat reduction				X	X	X	X	X			⊗				X
Simplicity • Data sequence • Calibration								X					X		X
• Less engineering data • Less interference • Simpler data reduction • More direct interpretation			X					X		X				X	X
Reliability, lifetime			X								⊗		X		X
Operational maturity		X	X					X			X	X	X		X

By necessity the technology needs for the three new instrument concepts selected for GCTI had to be addressed. The selection of the Geostationary High Resolution Microwave Radiometer (GHRMR) and the Soil Moisture Microwave Radiometer (SMMR) forced a look at the technologies involved in large aperture multi-frequency microwave passive systems (see column 12 of the needs chart). Jeffrey Farmer et al. (Farmer, 1989) in defining the GHRMR anticipated technology advances in the areas of large antennas, structures, controls, and microwave signal detection in order to develop a space flight instrument system with adequate sensitivity and spatial resolution when operating in geostationary orbit. Melvin Ferebee et al., (Ferebee, 1989) in defining a concept for the SMMR, primarily addressed the large collector (including structures and controls) technologies in order to obtain adequate spatial resolution at the low microwave frequency required for sensing moisture in various soils to usable depths in the order of 12 cm or more.

The third new GCTI instrument is a concept for the measurement of surface pressure. The instrument has been titled Atmosphere Pressure Lidar (APL). The selection of APL forced a look at lidar system technology needs (see column 1 of the need chart). The measurement principle is based on the experimental work of Korb et al. (Korb, et al., 1983) at the NASA Goddard Space Flight Center. The Earth Observing System Volume 11d, LASA document describes the principle as it could be employed in a Lidar Atmospheric Sounder and Altimeter instrument as follows: "The surface pressure experiment is a two-wavelength DIAL measurement (Korb and Werg, 1983) utilizing the backscattered energy from the Earth's surface or from low-lying clouds. A pressure-sensitive measurement is obtained by locating one wavelength in a temperature insensitive absorption trough region. A trough region is the region of minimum absorption between two strongly absorbing lines in the oxygen A-band near 0.76 μm, or 13,150 cm^{-1}. The absorption in the trough is proportional to the square of the pressure. A second wavelength located in an absorbing region with a shift of 0.0001 to 0.001 μm is used as a reference to normalize out the effects of surface reflectance. The use of an absorption trough technique reduces the sensitivity of the measurement to the effects of laser frequency jitter by up to two orders of magnitude. The integrated path absorption method used for the measurement allows high sensitivity to be achieved." The Eos document envisions the above technique to be capable of surface pressure measurement with an accuracy of ±2 mb with a vertical resolution of 1 to 2 km.

The Eos LASA document and the follow-on Eos Atmospheric Global Lidar Experiment (EAGLE) proposal for Eos published in July, 1988 by the NASA Langley Research Center provide a detailed engineering study which serves as a baseline for the GCTI Atmospheric Pressure Lidar (APL) concept. The LASA/EAGLE instrument was proposed with a 1.25 m-diameter telescope to be used in investigations of water vapor, temperature, tropospheric and stratospheric aerosols, and clouds. During discussions with LaRC personnel responsible for the LASA/EAGLE concept, it was concluded that by eliminating the water vapor capability of the LASA/EAGLE instrument and tailoring it as a surface pressure measuring instrument, the telescope diameter could be reduced to 0.5 m. This results in the mass and power being reduced by one-third to one-half. The more conservative one-third reduction was selected; thus, the GCTI/APL instrument concept became a LASA/EAGLE type instrument with a telescope diameter of 0.5 m and a mass and power of one-third less than a fully capable LASA/EAGLE instrument. A ±45° crosstrack scan capability was also assumed for the APL instrument. Needless to say, an instrument concept this preliminary in design would require extensive design and development before it becomes a viable candidate for flight. Technology needs have been identified in the areas of lightweight, precision, durable telescopes, precise frequency controlled lasers with power and pulse characteristics to provide measurement sensitivity, infrared detectors and coolers, and most importantly, complete lidar instrument system simplicity, reliability, and long lifetime.

The need for the three new GCTI instrument concepts and the general technology needs matrix presented in Table XX illustrate the need for an extensive instrument development program. The detailing of the elements of this program is a major follow-on task. This task is to be undertaken separately by appropriate instrument specialists at the Langley Research Center. To conclude this section of this report, therefore, we have only their introductory narrative which addresses the general technical areas of detectors, cryogenic coolers, lightweight optics, and lasers.

Detectors

The majority of Eos proposals reflect significant instrument performance benefits obtained through the use of arrayed detectors, as compared with single element detectors or a few point detectors, as were used in the 1980's. Detector arrays for the mid-infrared wavelengths from 2 to 20μm have recently become available that exhibit greatly increased capability while being virtually identical in size and mass to previously available designs. This improvement is reflected in better experiment radiometric sensitivity and spectral or spatial resolution. Currently, arrayed mid-infrared (up to 10μm) detectors in line arrays on the order of a hundred detectors and area arrays of up to 64 by 64 elements are available. In the next decade these detectors should become more available with their capability size, and cost further improved. Active, remote sensors such as lidars would benefit from the development of improved Avalanche Photo Detectors or other solid state detectors capable of photon noise limited performance in the 0.7 to 2.0μm range. This is just longward of the wavelength range where multiplier-photo tubes can operate. This improved performance would benefit the very important water vapor, pressure, and temperature profile measurement made with lidar instruments. Earth budget remote sensing experiments from GEO- synchronous orbit with temporal sampling capability of fraction of hours would be enabled through the development of cryogenically cooled active cavity receiver detectors. These detectors have been shown in the laboratory to be capable of nano-watt sensitivity.

Cryogenic Coolers

Remote sensor measurements can be widened in scope and substantially improved with high capability, efficient cryo-coolers with operational life times of 5-years. Coolers are needed for several types of applications:

(1) Cold Optics: Remote sensors looking Earth-ward from space view a scene that is at approximately 250 K. Optimum instrument performance for this level of scene photon flux requires the instrument optics to operate at intermediately cold temperatures of approximately 150 K.

(2) Detector Coolers: A great number of applications require detectors operating at liquid nitrogen temperature. An energy efficient, reliable 5-year life cryo-cooler delivering 1 W at 80 K is needed. The cooler should impart a negligible mechanical vibration level to the alignment sensitive instrument focal plane assembly.

(3) High Capability Coolers: The sensitivity of detectors ranging in spectral frequency over the entire mid-infrared spectrum would be much improved if a cryo-cooler capable of a 1 W load at 20 K were available. For far-infrared (20 to 500 micron) experiments efficient long-life cryostats are needed. Present technology provides hybrid coolers that use a liquid helium dewar with cold shields held at intermediate, progressively colder (30, 80, and 150 K) temperatures.

Lightweight Optics

Space based lidar instruments must use receiver telescopes on the order of one meter in diameter to attain the desired sensitivity. Far-infrared and other remote sensing instruments also use large diameter optics to maintain small diffraction effects as compared with spatial resolution; however, the need for large optics contrasts with the need for low instrument mass for efficient launch into space. The development of lightweight optical systems can thus contribute greatly to reducing launch costs while maintaining performance. Present technology is on the verge of producing diffraction limited optical elements with a mass of 20 kg/m^2 for optical element diameters of up to on the order 1 m. Several technologies capable of this low density are presently being pursued:

(1) Silicon-Carbide mirrors where the material is vapor deposited on a carbon mandrel

(2) Chemically milled Aluminum mirrors where large lightning holes are chemically machined into the mirror blank

(3) Fritted Glass where two thin glass face-plate blanks are spaced by a set of thin-wall glass tubes fused in between. These techniques need to become more available to be cost effective. To reach the full potential of mass savings, it is imperative that the optics support structure, i.e., the telescope structure also be light weighted while element despace and tilts are controlled to the needed tolerances by a metering system.

Lasers

To perform adequately atmospheric particle and gas lidars and differential absorption lidars (DIAL) require non-tunable (albeit multi-spectral) and tunable laser outputs respectively of at least one and preferably two Joules per pulse at pulse repetition rates of 10 Hz or more. Qualified lasers of this output level have not been flown in space. LaRC's LITE project will use a 1.5-Joule-per-pulse class, three color (1.064, 0.532, 0.352μm) laser for flight on the space shuttle in the mid-1990's. Research is progressing toward laboratory demonstration of a tunable (0.6–1μm) Ti:Sapphire laser of at least 1 Joule/pulse at 10 Hz by mid-1990. During this time period 2-μm laser research will produce eye-safe lasers for atmospheric constituent and wind sensing. For the post year-2000 time period lasers will need to use diode pumping to increase their efficiency and reduce laser power requirements. The laser power consumption, and the waste heat they generate that needs to be rejected to space with bulky radiators, can be reduced from the several thousand watts required for flashlamp pumped systems to the order of a few hundred watts with diode pumps.

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(This list of references is not suitable for use in a formal publication; however it is presented to document the sources of information used to accomplish the Task 2 effort).

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MICROWAVE SENSING TECHNOLOGY ISSUES RELATED TO A GLOBAL CHANGE TECHNOLOGY ARCHITECTURE TRADE STUDY

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MICROWAVE SENSING TECHNOLOGY

INTRODUCTION

The Global Change Technology Initiative (GCTI) will develop technology which will enable the use of satellite systems for Earth observations on a global scale. As described previously (ref. 1,2), geostationary satellites will be a major component of the total satellite system which will include polar orbiters and experiments in low inclination, low altitude orbits. Even though tremendous advances have been made in microwave remote sensing techniques, the potential of using microwave sensors from geostationary orbit will extend the observational capability far beyond what has been demonstrated thus far. Therefore, the purpose of this paper is to identify the critical technology areas that must be developed if precision, high-resolution microwave sensors are to be used in future Earth observing systems.

The fundamental properties of viewing from geostationary orbit such as high temporal and spatial resolutions offer unique advantages for Earth observation measurements. High temporal resolution can be achieved which will allow near perfect time and space matching with data collected from other sources (e.g., low orbiting satellites, radar, radiosondes). Since the atmospheric slant ranges do not vary as in the case of low Earth orbit systems, excellent interpretations can be made of spatial and temporal gradients. Since a large percentage of a hemisphere can be seen at one time from geostationary orbit, sensors can be designed to provide nearly instantaneous coverage over large areas. One important result of this is that small-scale, rapidly changing events such as severe storms can be surveyed quickly, and their interactions with the surrounding environment can be determined.

Calibration difficulties are minimized since the same instrument can be used for a particular measurement throughout the sequence. On some NOAA spacecraft, for example, two sensors are often used for the same task (profiling instruments). Also, the geostationary satellite can be its own data relay, as it acts as its own communication spacecraft. Thus, the remote sensing observations can be transmitted directly to any ground station within the field of view of the satellite for analysis. This capability would also require much lower data rates than for comparable measurements obtained from low orbits.

Review of previous sensing systems indicates that the surface has been barely scratched in measuring temperature and moisture profiles from geostationary orbit. This is primarily due to fundamental difficulties of viewing from this orbit, and consequently, only a first generation of sensors have been flown and operated (ref. 3). While microwave temperature profiles and total water vapor content have been measured from low-orbiting satellites, this has yet to be done from geostationary (Vonder Haar et. al, 1986). Not only would microwave temperature and moisture profiles increase the coverage since the profiles can then be made in nonprecipitating clouds, but the combination of infrared and microwave gives a complete sounding system with better accuracy than either system could achieve by itself. Also, microwave profiles give the best vertical resolution above about 25 km.

If microwave antennas can be made sufficiently large and accurate to provide 1-5 km resolution, the geostationary orbit should yield useful results when passive techniques are used. The optimum frequencies necessary for measuring sea surface temperature, wind speed, precipitation, sea ice, etc., are in the range 6-37 GHz, but very useful results are available between 90 and 220 GHz. Even microwave resolutions of 10-30 km, along with simultaneous higher spatial resolution visible and infrared data, would be a powerful combination. High temporal resolution (1-30 minutes) will allow the determination of where in the life cycle of a precipitating event the measurements are being taken. This is especially important for convective precipitation since a similar radiance can be associated with a different rain rate or precipitation coverage at various stages of the life cycle of a convective cell.

One of the most powerful uses of high frequency microwave radiances could be the determination of snowfall coverage and intensity. Moderate spatial and temporal resolutions should be sufficient to resolve and follow the progress of a developing snowstorm. It must be emphasized, however, that achieving high spatial resolution from geostationary orbits comes at a high cost, because usually higher weight and power are required.

SCOPE OF RESEARCH AND TECHNOLOGY

The identification of the critical microwave remote sensing technology areas which would enable advanced geostationary systems was achieved by first developing the work breakdown structure (WBS) for the related technology disciplines. This WBS area is a subset of the Observational Thrust Section of the GCTI WBS program plan. Three major WBS elements were identified for the microwave sensor technology area which are: (1) large space antenna technology (which includes filled and unfilled aperture techniques), (2) passive microwave sensor (radiometer) technology, and (3) active microwave sensor (radar) technology. Specific research and technology development tasks were identified and prioritized for each of the WBS technology areas listed above. The prioritization was based on the selection of those technology areas believed to be critically needed if the feasibility of new microwave sensors is to be demonstrated in a time to affect the design and development of the final satellite system. The objectives, science implications, and the technical issues associated with this technology program will now be discussed.

OBJECTIVES

The objectives for this research program are to enable the development of significantly lighter and less power-consuming, high resolution microwave sensors which will operate at frequencies from 1-200 GHz. These systems will use large aperture antenna systems (both reflector and phased arrays) capable of wide scan angle, high polarization purity, and utilize sidelobe suppression techniques as required. Essentially, the success of this technology program will enable high-resolution microwave radiometers from geostationary orbit, lightweight and more efficient radar systems from low Earth orbit, and eliminate mechanical scanning methods to the fullest extent possible--a main source of platform instability in large space systems.

SCIENCE IMPLICATIONS OF THIS TECHNOLOGY PROGRAM

The development of advanced radiometer and radar technology will provide measurements of the Earth's hydrological cycle, including precipitation, clouds, water vapor, snow cover, soil moisture, ice type and thickness, air temperature profile, sea surface temperature, and sea surface wind speed. Also, this work is significant in that large and higher frequency antennas will be developed which will enable measurements with higher resolution and sensitivity. These characteristics will improve spatial imaging, provide more accurate information on cloud column height and evolution, rain and precipitation, surface temperature (ocean and land), ocean and wind patterns, biomass inventory, and snow and ice formations. These measurements, in turn, will provide much needed information on the greenhouse warming effect, air pollution and acid deposition, and land surface climatology.

TECHNICAL ISSUES

The key technical issues in the microwave sensor technology area were identified by representatives from the NASA Centers, JPL, and by reviewing the results of the Earth Science Geostationary Platform Technology Workshop (ref. 1) which was conducted at the Langley Research Center in September 1988. The critical task areas for each of the WBS elements are listed below:

(1) Large Space Antenna Technology

- Precision membrane reflector antenna technology (<40 GHz)
- Distributed, phased array antenna technology (<40 GHz)
- Precision, solid reflector antenna technology (40-220 GHz)
- Rapid scanning techniques for large reflector antennas
- Optically-controlled Beam Forming Network (BFN) technology
- Distributed phased array antenna technology (40-220 GHz)

Specific task descriptions on each of these technology areas were developed and provided as inputs to the GCTI planning activity.

(2) Passive Microwave Sensing Technology

- ° Electronic scanning radiometer technology (filled aperture)
- ° Quasi-optical millimeter wavelength component technology
- ° Synthetic aperture radiometer technology (unfilled aperture)

Specific task descriptions on each of these technology areas were developed and provided as inputs to the GCTI planning activity.

(3) Active Microwave Sensing Technology

- ° MMIC component technology for 1-90 GHz radar applications
- ° High power, non-MMIC, high frequency radar systems components
- ° Pulse modulator technology for sidelobe suppression techniques

Specific task descriptions on each of these technology areas were developed and provided as inputs to the GCTI planning activity.

Summary

Advanced microwave sensing technologies are critically needed if the science objectives of the Global Change Technology Initiative are to be met. The development of microwave sensing technology by NASA has been sporadic during the past 5-10 years, especially in the area of advanced sensor development. For example, the Push Broom Microwave Radiometer (PBMR), developed by Langley for soil moisture measurements in 1985, was the last microwave sensor supported by OAET for an OSSA application. Therefore, the GCTI provides a new opportunity for a renewed effort by NASA to address a much needed technology--the development of advanced microwave remote sensing systems for LEO and GEO applications.

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SUNSYNCHRONOUS LOW EARTH ORBIT SPACECRAFT CONCEPTS AND TECHNOLOGY REQUIREMENTS FOR GLOBAL CHANGE MONITORING

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1.0 INTRODUCTION, SCOPE AND CONTENTS

The GCTI listing of instruments for operation in low Earth, sunsynchronous orbits shown in Table 1-1 contains 21 entries, of which 20 are carried aboard multi-instrument spacecraft. This list identifies the temporal requirements for repetition of measurements and also includes groups of instruments that make complementing measurements. Definitions for individual spacecraft follows the temporal and grouping requirements to establish constellations which will provide the measurement data. The definitions of constellations for multi-instrument spacecraft show two alternatives:

1. A constellation of 10 spacecraft, each compatible with launch by a Delta booster; or,
2. A constellation of 4 spacecraft, each requiring a Titan booster.

Operating subsystems for the individual spacecraft can utilize modular concepts that are adaptations based upon current plans for improving the performance of the NASA-GSFC Multimission Modular units.

The descriptions of the spacecraft and constellations begin with a compilation of instrument-related requirements that define the principal system performance parameters and operating capabilities. Spacecraft operating subsystem capabilities are then compared with the existing Multimission Modular elements to identify the improvements required or adaptations. The descriptions of the individual spacecraft first address the smaller Delta booster units and then the larger Titan booster units. A comparison of features leads to a summary of results and identification of the technology advances required for the GCTI spacecraft.

Abbreviations and Acronyms

C and DH	Communication and Data Handling
DOD	depth of discharge
EOS	Earth Observing Satellite
GCTI	Global Change Technology Initiative for 1989
GSFC	Goddard Space Flight Center
kbps	kilobits per second
LASE	Lidar Atmospheric Sensing Experiment
LEO	Low Earth orbit
Mb	megabits
Mbps	megabits per second
MMS	Multimission Modular Spacecraft
NASA	National Aeronautics and Space Administration
NDLM	NASA Data Link module
RF	Radio Frequency
S/C	spacecraft
TDRSS	Tracking and Data Relay Satellite System
TIROS-N	Television Infrared Observation Satellite
TOPEX	Terrestrial and Ocean Profile Experiment
UARS	Upper Atmosphere Research Satellite
VDC	Volts, Direct Current

TABLE 1-1 ACRONYMS AND INSTRUMENTS DEFINED FOR OPERATION IN LOW EARTH, SUNSYNCHRONOUS ORBIT

ACRIM	Active Cavity Radiometer
AIRS	Atmospheric Infrared Sounder
ALT	Altimeter (microwave)
AMSU-B	Advanced Microwave Sounding Unit
APL	Atmospheric Pressure Lidar
CERES	Cloud and Earth Radiant Energy System
EOSP	Earth Observing Scanning Polarimeter
HIMSS	High Resolution Microwave Spectrometer Sounder
HIRIS	High Resolution Imaging Spectrometer
MLS	Microwave Limb Sounder
MODIS,N,T	Moderate Resolution Imaging Spectrometer, Nadir Scan, Tilt Scan
3ChMR	Three channel Microwave Radiometer
SAGE	Stratospheric Aerosols and Gas Experiment
SAFIRE	Spectroscopy of the Atmosphere using Far Infrared Emission
SOLSTICE	Solar-Stellar Irradiance Comparison Experiment
SMMR	Soil Moisture Microwave Radiometer
SWIRLS	Stratospheric Winds Infrared Limb Scanner
TES	Tropospheric Emissions Spectrometer
TRACER	Tropospheric Radiometer for Atmospheric Chemistry and Environmental Research
XRI	X-ray Imager

2.0 INSTRUMENT REQUIREMENTS AND SPACECRAFT DEFINITION

The definition of GCTI spacecraft represents an ordered approach to the accommodation of scientific measurement and instrument requirements. Accommodation of the desired range for times between measurements effectively establishes the on-board instrument inventory for a particular spacecraft. Instrument operating requirements such as power, mass, spatial resolution, and data rates establish the performance parameters for the spacecraft subsystems. Instrument viewing requirements, together with heat rejection radiator considerations, establish the on-board positioning and layout within each of the spacecraft. These requirements are summarized by tables and described below, all of the instrument related data have been drawn from References 1, 2 and 3.

2.1 Temporal Requirements, Accommodation of Measurement Intervals

The acronyms for the 21 instruments in low Earth orbit appear in Table 2-1. The listing includes the role of the instrument for global or regional processes and indicates an assignment to spacecraft configurations in the order of decreasing measurement intervals. The Soil Moisture Microwave Radiometer (SMMR) presents a unique case and requires a dedicated spacecraft (Configuration A). Details of that instrument and its associated spacecraft are subjects of a separate study. Each of the other 20 instruments have been identified for flight aboard two or more spacecraft configurations.

The orbits for all the GCTI spacecraft are assumed to allow observations at any point on the Earth in 12-hour intervals (observation opportunities include both ascending nodes and descending nodes). Accordingly, one spacecraft satisfies the 12-hour and longer intervals and also meets the upper limit of a 3 to 12 hour requirement. Four spacecraft in complementing orbits (45 degrees apart) satisfy the upper limit for a 1 to 3 hour requirement and become a practical compromise relative to any shorter intervals.

TABLE 2-1 INSTRUMENTS IN LEO SPACECRAFT AND ORBIT CONSTELLATIONS

Instruments	Small Spacecraft Configurations A 12 hr.	B 12 hr.	C 3 to 12 hr.	D 1 to 3 hr.	E Less than 1 hr.	Large Spacecraft L-1	L-2	L-3	L-4
SMMR (G,R)	*								
HIRIS (R)		*				*			
3ChMR (G,R)		*				*			
ALT (G,R)		*				*			
MODIS-T (G,R)		*				*			
EOSP (G,R)		*	*	*	*	*	*	*	*
SAGE III (G)			*			*			
APL (G)			*			*			
AIRS (G)			<u>D</u>	*		*	*	*	*
ACRIM (G,R)		*		*		*	*	*	*
SOLSTICE (G,R)		*				*			
XRI (G,R)		*				*			
CERES (G)				*		*	*	*	*
MODIS-N (G,R)		<u>D</u>		*		*	*	*	*
AMSU-B (G)				*		*	*	*	*
HIMSS (G)		<u>D</u>	<u>D</u>	*		*	*	*	*
TES (G,R)				<u>E</u>	*	*	*	*	*
SAFIRE (G,R)			<u>E</u>		*	*	*	*	*
SWIRLS (G,R)			<u>E</u>		*	*	*	*	*
TRACER (G,R)				<u>E</u>	*	*	*	*	*
MLS (Eos) (G,R)			<u>E</u>		*	*	*	*	*

Small Spacecraft Constellations in Orbit (A+10)

Orbits #1	#2	#3	#4
A			
B			
C			
D-1	D-2	D-3	D-4
E-1	E-2	E-3	E-4
(5)	(2)	(2)	(2)

Large Spacecraft Constellations in Orbit (A+4)

A			
L-1	L-2	L-3	L-4
(2)	(1)	(1)	(1)

LEGEND:
(G) GLOBAL, (R) REGIONAL   * ON BOARD INSTRUMENT   <u>D</u>, <u>E</u>, MEASUREMENTS FROM INSTRUMENTS ON S/C INDICATED

The constellations of small spacecraft (Configurations B, C, D and E) flow directly from the measurement interval listings. Within these spacecraft, instruments which provide measurements for more than one temporal requirement are carried on the shorter interval spacecraft and share measurements data for both time interval requirements. The four small-spacecraft constellations in sunsynchronous orbits show one orbit with all five configurations operating as a group. The other three complementing orbits, 45 degrees apart, will each have two spacecraft (Configurations D and E). Within the instrument listing, the EOSP provides an on-board reference for the optical characteristics of the atmosphere and is included on all spacecraft. In a similar manner, the ACRIM instrument provides a solar reference for some of the instruments in the 1 to 3 hour measurement list, and accordingly, is carried aboard the configuration D spacecraft.

The large spacecraft carry all the instruments required for that particular orbit. One large spacecraft (Configuration L-1) carries all 20 instruments and will operate paired with the Configuration A unit. The other three spacecraft (Configurations L-2, L-3, L-4) are identical units carrying 12 instruments each and will operate singly in the other three complementing orbits 45 degrees apart.

2.2 Instrument Operating Requirements

The operating support accommodation requirements for the instruments define the principal performance parameters of the spacecraft subsystems. The particular requirements of the on-board instruments for each of the multi-instrument spacecraft are summarized in Table 2-2 and they define the spacecraft accommodations required. These summary tabulations translate the science measurement requirements into spacecraft operational parameters. Estimates of total mass for the on-board instruments are within the capability of existing launch vehicles (Reference 4), and, in particular for the small spacecraft, suggest that these instruments can be accommodated by spacecraft compatible with the present Delta Series 7920 booster, which has a listed capacity of 3300 kg into a 650 km polar orbit.

TABLE 2-2 SUMMARY OF INSTRUMENT REQUIRMENTS PERTINENT TO SPACECRAFT DEFINITION

1. Spacecraft B (12 hour or longer measurements)

Instrument	Measurable	Spatial Resolution Required	Mass kg	Power Watts	Data Rate (kbps) Peak	Avg.	Duty Cycle
ACRIM	Spectral radiation	Sun disk	24	5	0.52	0.52	100% Day only
SOLSTICE	Spectral radiation	Sun disk	146	72	5.0	5.0	50% Day only
XRI	Spectral radiation	Sun disk	19	10	1.1	1.1	50% Day only
HIRIS	Vegetation cover Biomass inventory Ocean color Ocean circulation	1 km 1 km 1-4 km 1-4 km	660	300	280000	3000	15% high rate. Low rate at all other times.
MODIS-T	Ocean color Ocean circulation	1-4 km 1-4 km	100	150	9000	7000	Equal time, Day only
ALT	Ocean circulation Sea level rise	1-4 km 10 km	190	240	12.0	10.0	Equal time, continuous
EOSP	Atmospheric correction for polarization	10 km	11	11	86.0	44.0	Average continuous
3ChMR	Atmospheric correction for water vapor		27	30	0.128		Continuous

Spacecraft Design Requirements	700 km Orbit	800 km Orbit
Total instrument mass	1177 kg	
Total instrument power	818 Watts	
Resolution angular requirement (most stringent)	0.082 deg 295 arc sec	0.069 deg 248 arc sec
Instrument with most stringent resolution requirement	HIRIS	
Spatial resolution required	1 km	
Total data storage requirement	300×10^9 bits per orbit	

TABLE 2-2 SUMMARY OF INSTRUMENT REQUIRMENTS PERTINENT TO SPACECRAFT DEFINITION (Continued)

2. Spacecraft C (3 to 12 hour measurements)

Instrument	Measurable	Spatial Resolution Required	Mass kg	Power Watts	Data Rate (kbps) Peak	Data Rate (kbps) Avg.	Duty Cycle
EOSP	Aerosols and particulates	10 km	11	11	86.0	44.0	Average continuous
SAGE III	Stratospheric gases: O_3, NO_2, H_2O Aerosols and particulates	50 km	60	25	11.0		Two 10-minute period (sunrise and and sunset)
APL	Surface Pressure	10 km	660	1200	1400	1200	Average continuous

Spacecraft C Design Requirements	700 km Orbit	800 km Orbit
Total instrument mass	731 kg	
Total instrument power	1236 Watts	
Resolution angular requirement (most stringent)	0.82 deg 2950 arc sec	0.687 deg 2480 arc sec
Instruments with most stringent resolution requirement	EOSP, APL	
Spatial resolution required	10 km	
Total data storage requirement	8×10^9 bits per orbit	

TABLE 2-2 SUMMARY OF INSTRUMENT REQUIRMENTS PERTINENT TO SPACECRAFT DEFINITION (Continued)

3. Spacecraft D (1-3 hour measurements)

Instrument	Measurable	Spatial Resolution Required	Mass kg	Power Watts	Data Rate (kbps) Peak	Avg.	Duty Cycle
ACRIM	Spectral radiation	Sun disk	24	5	0.52	0.52	100% Day only
EOSP	Atmospheric correction for polarization	10 km	11	11	86.0	44.0	Continuous
AIRS	Temperature Profile	10-50 km	80	300	3000	1000	Average Continuous
	Tropospheric Water Vapor	10 km					
	Cloud Height	1 km					
CERES	Radiation Budget	10-30 km	90	90	4.0	4.0	Average Continuous
MODIS-N	Vegetation Cover	1 km	200	250		10000 (day)	100%
	Biomass Inventory	1 km					
	Sea Ice and Snow Cover	1-20 km					
	Cloud Cover and Type	1 km				2500 (night)	100%
	Surface Temperature	4 km					
HIMSS	Tropospheric Water Vapor	10 km	222	66	27.0		Continuous
	Temperature Profile	10-50 km					
	Precipitation	1-15 km					
	Sea Ice and Snow Depth	1-20 km					
AMSU-B	Temperature Profile	10-50 km	40	80	4.4		Continuous
	Tropospheric Water Vapor	10 km					

Spacecraft D Design Requirements	700 km Orbit	800 km Orbit
Total instrument mass	667 kg	
Total instrument power	802 Watts	
Resolution angular requirement (most stringent)	0.082 deg 295 arc sec	0.069 deg 248 arc sec
Instruments with most stringent resolution requirement	AIRS, MODIS-N	
Spatial resolution required	1 km	
Total data storage requirement	64.1×10^9 bits per orbit	

TABLE 2-2 SUMMARY OF INSTRUMENT REQUIRMENTS PERTINENT TO SPACECRAFT DEFINITION (Continued)

4. Spacecraft E (Less than 1 hour measurements)

Instrument	Measurable	Spatial Resolution Required	Mass kg	Power Watts	Data Rate (kbps) Peak	Data Rate (kbps) Avg.	Duty Cycle Average
EOSP	Atmospheric correction for polarization Aerosols and particulates	10 km	11	11	86.0	44.0	Continuous
TES	Tropospheric Gases: O_3, H_2O, NO_2, HNO_3, Cl Species	20 km	491	600	200		Continuous
SAFIRE	Stratospheric Gases: O_3, H_2O, H_2O_2, NO_2, HNO_3, N_2O_5, CH_4, HF, HBr, HCl, HOCl	--	304	304	9000		Continuous
SWIRLS	Stratospheric Wind Fields	No Requirement	90	197	1.0		Continuous
TRACER	Tropospheric Gases: CO, CH_4	20 km	87	120	10.0		Continuous
MLS (EOS)	Stratospheric Gases: O_3, H_2O, H_2O_2, ClO	5-10 km	450	790	1150		Continuous

Spacecraft E Design Requirements	700 km Orbit	800 km Orbit
Total instrument mass	1433 kg	
Total instrument power	2022 Watts	
Resolution angular requirement (most stringent)	0.82 deg 2950 arc sec	0.69 deg 2480 arc sec
Instrument with most stringent resolution requirement	EOSP	
Spatial resolution required	10 km	
Total data storage requirement	63.0×10^9 bits per orbit	

TABLE 2-2 SUMMARY OF INSTRUMENT REQUIRMENTS PERTINENT TO SPACECRAFT DEFINITION (Concluded)

5. Large Spacecraft, L-1
Instruments Carried: All 20 Listed Above

Spacecraft L1 Design Requirements	700 km Orbit	800 km Orbit
Total instrument mass	3951 kg	
Total instrument power	4840 Watts	
Resolution angular requirement (most stringent)	0.082 deg 295 arc sec	0.069 deg 248 arc sec
Instruments with most stringent resolution requirement	HIRIS, AIRS, MODIS-N	
Spatial resolution required	1 km	
Total data storage requirement	414.00×10^9 bits per orbit	

6. Large Spacecraft, L-2, L-3, L-4
Instruments Carried:

ACRIM, AIRS, AMSU-B, CERES, EOSP, HIMSS, MODIS-N

Instrument requirements are listed in Table Section 3 (Spacecraft D) above.

MLS (EOS), SAFIRE, SWIRLS, TES, TRACER

Instrument requirements are listed in Table Section 4 (Spacecraft E) above.

Spacecraft L-2, L-3, L4 Design Requirements	700 km Orbit	800 km Orbit
Total instrument mass	2089 kg	
Total instrument power	2813 Watts	
Resolution angular requirement (most stringent)	0.082 deg 295 arc sec	0.069 deg 248 arc sec
Instruments with most stringent resolution requirement	AIRS, MODIS-N	
Spatial resolution required	1 km	
Total data storage requirement	110.62×10^9 bits per orbit	

The power needed to operate the instruments provides the principal requirement that defines the electrical generation and storage elements. The Instrument resolution becomes the principal requirement for attitude control or pointing stability. Both of these requirements show some interaction with the altitude of the orbit. A final definition of the orbits for the GCTI spacecraft will represent an optimized balance between ground coverage (or swath) traded against number of orbits per day. In anticipation of such a trade, these evaluations considered operations at both 700 km and 800 km in order to accommodate the critical conditions for each orbital case. Operation at 800 km imposes the limiting condition for pointing accuracy and attitude stability. The 1 km spatial resolution requirement shows an 0.069 degree angular intercept from an orbit at 800 km. Pointing accuracies and platform stabilities need controls to achieve about one order of magnitude less to assure adequate resolution. On the other hand, operation at 700 km altitude provides the criteria for electrical power generation. At the lower altitude, eclipse accounts for a larger portion of the orbit period and reduces the time available for battery charging which in turn results in a larger solar array.

Within each of the spacecraft configurations, the on-board instruments establish the principal requirements for data handling rates and data storage. The data handling rates vary throughout the course of an orbit, and Table 2-3 summarizes the data rates and data storage for the 20 instruments on board the multi-instrument spacecraft. The table shows the orbital variations in data rates and estimates the storage requirements for an orbit with 60 minutes of illumination and 40 minutes in eclipse. A summing of data rates and storage estimates for the on-board instruments establishes the requirements for each spacecraft; Table 2-4 summarizes these results. The totals for data storage include a generous arbitrary increment of 600 Mb per orbit for spacecraft-generated data to cover operating parameters, timing, and positioning data associated with each orbit. The data storage requirements may extend beyond one orbit; therefore, the on-board data storage unit has been increased by one order of magnitude.

TABLE 2-3 ESTIMATES OF DATA REQUIREMENTS FOR GCTI INSTRUMENTS ON LEO SPACECRAFT

	Illuminated Orbit Period (3600 sec.)		Eclipse Orbit Period (2400 sec.)		
Instrument	Bit Rates kbps, Duty	Total Mb	Bit Rates kbps, Duty	Total Mb	Orbit Total Mb
ACRIM	0.52 Cont.	1.872	0	0	1.87
SOLSTICE	5.0 (0.5)	9.0	0	0	9.0
XRI	1.1 (0.5)	3.96	0	0	3.96
EOSP	86, 44 Cont.	158.4	86, 44 Cont.	105.6	2.64
HIRIS	280 k, (0.15), 3 k	160380	280 k (0.15) 3 k	106920	267300
3ChMR	0.128 (0.7)	0.322	0.128 (0.7)	0.215	0.537
ALT	12, 10, (0.5 each)	39.0	12, 10 (0.5 each)	26.4	66
MODIS-T	9 k, 7 k (0.5 each)	28800	0	0	28800
SAGE III	11, (600 sec.)*	6.6	11, (600 sec.)*	6.6	13.2
APL	1.4 k, 1.2 k Cont.	4320	1.4 k, 1.2 k Cont.	2880	7200
AIRS	3 k, 1 k Cont.	3600	3 k, 1 k Cont.	2400	6000
CERES	4 Cont.	14.4**	4	9.6	24**
MODIS-N	10 k Cont.	36000	2.5 k	6000	42000
AMSU-B	4.4 Cont.	15.84	4.4 Cont.	10.56	26.4
HIMSS	27 Cont.	97.2	27 Cont.	86.8	162
TES	200 Cont.	720	200 Cont.	480	1200
SAFIRE	9 k Cont.	32400	9 k Cont.	21600	54000
SWIRLS	1 Cont.	3.6	1 Cont.	2.4	6
TRACER	10 Cont.	36	10 Cont	24	60
MLS, EOS	1.15 k Cont.	4140	1.15 k Cont.	2760	6900

*Sunrise and Sunsets are 600 sec. each
**Rate for a single instrument, S/C carries two units.

TABLE 2-4 SUMMARY OF DATA HANDLING AND ON BOARD STORAGE REQUIRMENTS - SMALL SPACECRAFT

SPACECRAFT	B	C	D	E
<u>Illuminated Science</u>				
Max. Data Rate Mbps	289.1	1.497	13.122	10.447
Min. Data Rate Mbps	10.05	1.244	11.080	9.2561
Total Stored Science Mb	189393.15	4485	55577.7	37458
<u>Eclipse Science</u>				
Max. Data Rate Mbps	280.1	1.497	5.621	10.447
Min. Data Rate Mbps	3.05	1.244	3.579	9.256
Total Stored Science Mb	107052.21	2512.2	8599.6	24972
Total Orbit Science Mb	296445.36	6997.2	64177.87	62430
Spacecraft Data Mb	600.0	600.0	600.0	600.0
On Board Storage Mb	297045.30	7597.2	64777.8	63030
Spacecraft On Board Storage	10^{12} Bits	10^{10} Bits	10^{11} Bits	10^{11} Bits

SUMMARY OF DATA HANDLING AND ON BOARD STORAGE REQUIREMENTS - LARGE SPACECRAFT

	L-1	L-2, 3, 4
<u>Illuminated Science</u>		
Max. Data Rate Mbps	313.912	23.482
Min. Data Rate Mbps	25.675	21.441
Total Stored Science Mb	270761.19	77201.71
<u>Eclipse Science</u>		
Max. Data Rate Mbps	297.805	15.982
Min. Data Rate Mbps	18.150	13.940
Total Stored Science Mb	142399.77	33466.6
Total Orbit Science Mb	414060	110668
Spacecraft Data Mb	600	600
On Board Storage Mb	414660	111268
Spacecraft On Board Storage System	10^{12} Bits	10^{12} Bits

2.3 Instrument Mounting and Accommodation

In addition to the mass and power, the accommodations of the instruments on board a spacecraft must address the physical dimensions of the package with critical attention to both the viewing requirements for measurements and the space radiator requirements for those instruments which carry cooled detectors. The combination of viewing for data and radiant heat rejection effectively determines the layout of instruments aboard any spacecraft configuration. Accommodation requirements for each group of instruments are summarized in Table 2-5 in terms of mass, power, dimensions, viewing, and heat rejection requirements. These data summarize the pertinent information gathered and refined during the process of instrument selection.

These combinations of requirements for spacecraft accommodations represents the finalized product of an iterative process and also continued an initial concept of either small, Delta-booster compatible spacecraft or large, Titan-booster compatible spacecraft. In addition, the finalized summary of spacecraft operating subsystems continued to show compatibility for accommodation by a modularized approach, and the existing Multimission Modular units provided the basis for comparison.

TABLE 2-5 SUMMARY OF INSTRUMENT ACCOMMODATION REQUIREMENTS

Instruments for the 12 Hour or Longer Spacecraft, "B" Configuration

Instrument	Mass (kg)	Power (W)	Dimensions m	Mounting Details and Considerations
ACRIM	24	5	0.3 x 0.47 x 0.44	Zenith Surface, Solar Pointing, 180° Traverse Through Zenith.
SOLSTICE	146	72	0.3 x 0.3 x 0.1 (Sensor Tubes)	Zenith Surface, Solar Pointing. Multi Tube Unit on 2 Axis Gimbal 180° Traverse Through Zenith.
XRI	19	10	0.73 x 0.47 x 0.44	Zenith Surface, Solar Pointing, Tubular. 180° Traverse Through Zenith.
HIRIS	660	300	2.5 x 1.6 x 1.5	Cross Track Scanner, ±5° View Field, Swept ±26° From Nadir. Scan Position From 52° Fore, to 30° Aft of Nadir. Unit has Solar Diffuser and Anti Sun Radiators for Cooled Detectors. The Outline of the Instrument is Irregular Within the Dimensional Limits Stated (EOS Shows Flight in 2.5 m direction).
MODIS-T	100	150	0.5 x 0.5 x 0.4	Cross Track Scanner ±3.5° View Field, Swept ±50° From Nadir. Scan Position From 50° Fore to 50° Aft of Nadir. (May Require Anti Sun Radiator.)
ALT	190	240	1.5 Dia (Antenna Dish)	Nadir Sounder, ±1° Conical Beam. Radiator Panels on Electronics Boxes that Carry the Antenna.
EOSP	11	11	0.3 x 0.3 x 0.3	Cross Track Scanner, ±3° View Field, Swept ±55° From Nadir.
3 Chan MR	27	30	0.3 x 0.3 x 0.3	Nadir Viewer ±3° Conical Field of View.

TABLE 2-5 SUMMARY OF INSTRUMENT ACCOMMODATION REQUIREMENTS (Continued)

Instruments for the 3 to 12 Hour Spacecraft, "C" Configuration

Instrument	Mass (kg)	Power (W)	Dimensions m	Mounting Details and Considerations
EOSP	11	11	0.3 x 0.3 x 0.3	Cross Track Scanner, ±3° View Field, Swept ±55° From Nadir.
SAGE III	60	25	0.35 Dia by 0.5	Limb Scanner. 23° to 30° Below Direction of Flight (60° to 67° From Nadir). Scan ±50° From Plane of Orbit. Viewing Both Forward and Aft. Mounting Position Requires 360° Azimuth Rotation.
APL	660	1200	0.5 Dia x 1.5 Telescope	Cross Track Scanner, Swept ±45° From Nadir. Dual Lasers Operating in a Differential Absorption Mode, Both Laser Output Ports Optically Aligned with Telescope for Signal Return. Laser Optical Elements are in a Thermally Controlled Enclosure, Laser Cooling up to 1000 W Max.

TABLE 2-5 SUMMARY OF INSTRUMENT ACCOMMODATION REQUIREMENTS (Continued)

Instruments for the 1 to 3 Hour Spacecraft, "D" Configuration

Instrument	Mass (kg)	Power (W)	Dimensions m	Mounting Details and Considerations
ACRIM	24	5	0.3 x 0.47 x 0.44	Zenith Surface, Solar Pointing, 180° Traverse Through Zenith.
EOSP	11	11	0.3 x 0.3 x 0.3	Cross Track Scanner, ±3° View Field, Swept ±55° From Nadir.
AIRS	80	300	1.0 x 0.8 x 0.5	Cross Track Scanner, ±2° View Field, Swept ±50° From Nadir. Requires a Space Radiator, Anti Sun Side.
CERES	90	90	0.6 x 0.5 x 0.7 (Each of 2 Units)	Wide Angle Scanner. Cross Track Swept From +100° (Above Spacecraft Plane Sun Side) to -73° Anti Sun Side. Scan Positioned Fore and Aft up to ±73° From Nadir.
MODIS-N	200	250	1.2 x 0.7 x 0.5	Cross Track Scanner, ±4° View Field, Swept ±50 From Nadir. Solar Diffuser, Space Radiator Anti Sun Side.
HIMSS	222	66	1.2 Dia x 1.2 Barrel 2 m Dia Antenna	Conical Forward Scan at 53° From Nadir Swept ±45° From Plane of Orbit. Barrel Rotates at 30 rpm.
AMSU-B	40	80	0.7 x 0.7 x 0.5	Cross Track Scanner, ±1° View Field, Swept ±50° From Nadir.

TABLE 2-5 SUMMARY OF INSTRUMENT ACCOMMODATION REQUIREMENTS (Continued)

Instruments for the 0.5 Hour Measurement Interval Spacecraft, "E" Configuration

Instrument	Mass (kg)	Power (W)	Dimensions m	Mounting Details and Considerations
EOSP	11	11	0.3 x 0.3 x 0.3	Cross Track Scanner, ±3° View Field, Swept ±55° From Nadir.
TES	491	600	1.6 x 1 x 1.5	Dual Mode Capability. Nadir Scan Sweeps ±68° From Nadir Cross Track, Scan Position ±45° From Nadir Fore and Aft. Forward Scan at 23° to 30° Below Direction of Flight (60° to 67° From Nadir) Swept ±45° From Plane of Orbit. Unit has Sterling Cycle Coolers and Space Radiators on the Anti Sun Side.
SAFIRE	304	304	1.5 x 1 x 1.5	Limb Scanner From 17° to 30° Below Direction of Flight (57° to 60° From Nadir). Azimuth 2 Views 180° Apart. View Forward is 10° From Orbit Plane Away From the Sun, Aft View is 190° From Orbit Plane Away From the Sun. Space Radiators on Anti Sun Side.
SWIRLS	90	197	1 x 1 x 1	Limb Scanner from 23° to 30° Below Direction of Flight (57° to 60° From Nadir) with ±2° View Field. View Along 2 Directions, Forward +45° From Orbit Plane Away From Sun, Aft +135 Degrees From Orbit Plane Away From Sun.
TRACER	87	120	0.71 x 0.9 x 1.23* *(EOS Radiator)	Nadir Viewer, Conical View Field ±0.6° From Nadir. Space Radiator on Anti Sun Side.
MLS (EOS)	450	790	2.2 x 1.3 x 1.9	Forward Viewing Limb Scanner Swept ±90° From Plane of Orbit at 17° to 30° Below Direction of Flight, (60° to 73° From Nadir).

3.0 SPACECRAFT OPERATING SUBSYSTEMS

The concepts for modularization of spacecraft operating subsystems have been developed and successfully flown in the form of the GSFC Multimission Modular Spacecraft (MMS). GCTI spacecraft operating subsystems utilize the same approach to modularization and incorporate new or additional components that respond to GCTI requirements. The MMS consists of three major electrical subsystem assemblies, a mounting structure and a propulsion module; Reference 5 summarizes the pertinent performance capabilities of the assembly. Modules within the MMS are currently being uprated and adapted to advanced flight projects; and for these units, the module interfaces remain unchanged such that commonality for change-out can be assured. Adaptation to GCTI spacecraft does not require such an interchangability, therefore, improved MMS units in simplified packages become the GCTI modules; Figure 3-1 shows the MMS modules and summarizes the changes or modifications proposed. The numbers of spacecraft defined for operation in sunsynchronous LEO would justify the modifications described below. An estimate for the status of present MMS modification is also included.

3.1 Communication and Data Handling Module (C and DH)

The communication and data handling subsystem has received a major uprating; the replacement assembly is the NASA Data Link Module (NDLM, Reference 6). Modifications expand the initial capabilities for data rates, storage capacities, and transmission links to include K band for TDRSS, which in turn changes the antennas. The differences between the original MMS unit and the NDLM assumed for GCTI appear summarized in Table 3-1. Improvements proposed allow matching the capabilities of the module to the particular requirements of a spacecraft; the principal adaptation element becomes the algorithm within a dedicated microprocessor. NDLM units have capabilities that accommodate any of the instrument combinations identified. The configuration and layout of components within the NDLM are shown in Figure 3-2 and appear as redundant systems packaged for change-out on orbit. Since GCTI spacecraft

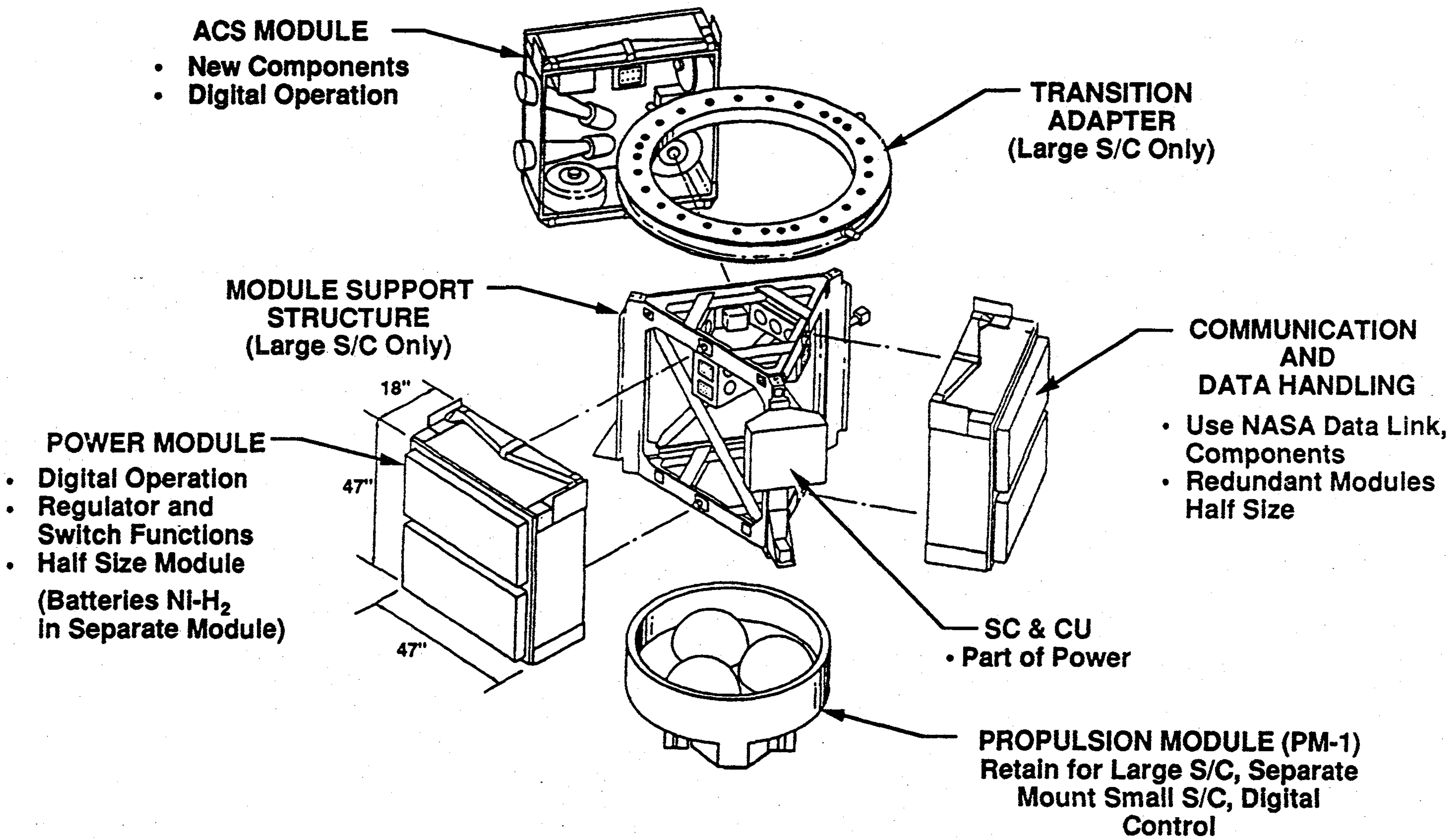
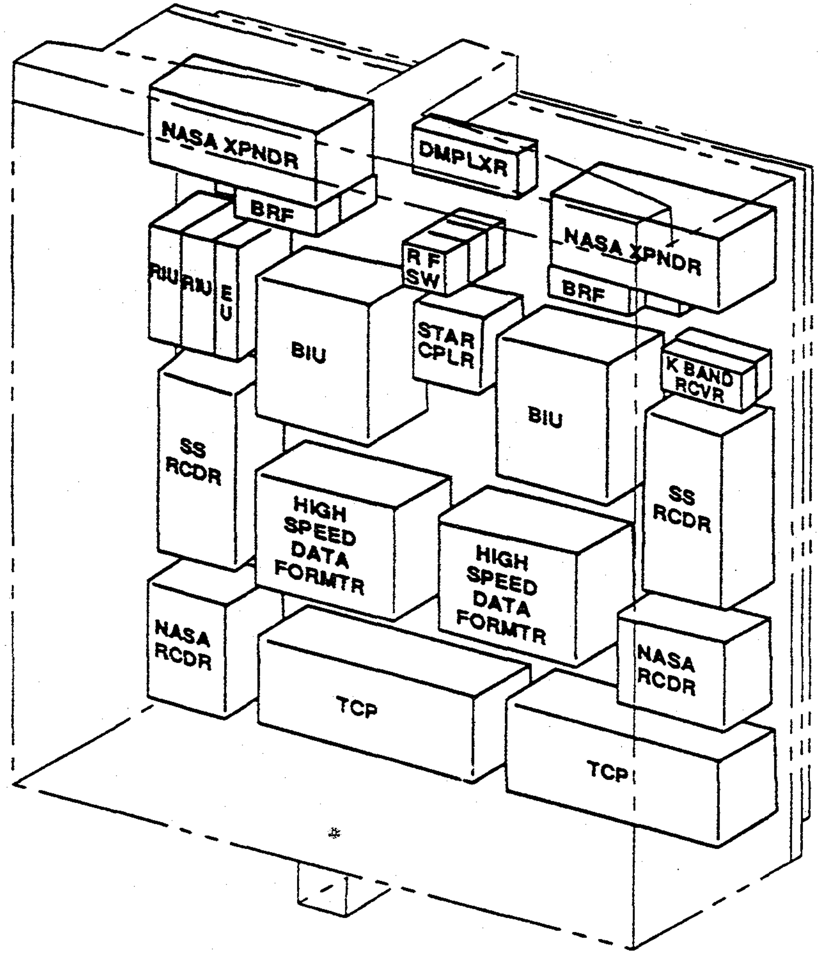


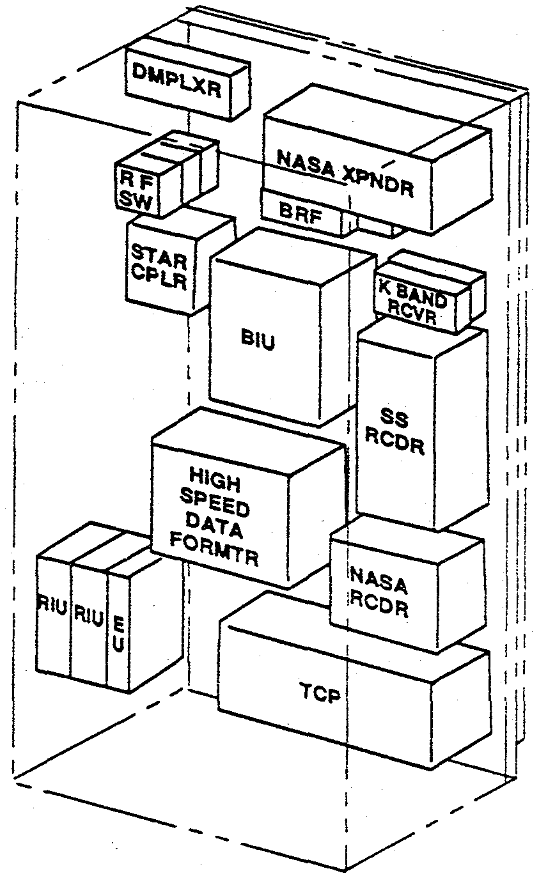
Figure 3-1 Components and Elements of the Multimission Modular Spacecraft and Principal Adaptations to GCTI Application.

TABLE 3-1 COMMUNICATION AND DATA HANDLING SUBSYSTEM BASED UPON MULTIMISSION MODULAR ELEMENTS

CURRENT MMS ELEMENTS	GCTI ADVANCED MMS
Communication and Data Handling	NASA Data Link Module (Proposed Upgrade to Current MMS)
S Band Transponder	S Band Transponder (TDRSS) Ku Band Transponder (TDRSS) Capability to Communicate with ATDRSS
On Board Computer 18 Bit Words Supports All Other Modules	Dedicated 80386 Microprocessor 32 Bit Words
Real Time Data Handling 2.048 Mbps Max Record Data Rate 2.7 Mbps Max Playback Data Rate 2.7 Mbps Max Command Rate 2.0 Kbps Max	Real Time Data to 450 Mbps Record Data Rate to 300 Mbps Playback Data Rate to 300 Mbps Same Science Uplink Data Rate, 100 Kbps
Recorders, Tape, 10^9 Bit Max	Recorders: Options to 10^{10} Bits Available, 10^{12} Bits Under Development
Redundant System in Single Module	Single System Modules, 2 or more per S/C Optical Fiber Data Links within the S/C
Parabolic Antenna, with Waveguides	Planar Array Antenna. Carries RF Elements, 4 S Band, 16 Ku Band.



ADVANCED MMS, NDLM
COMMUNICATIONS AND
DATA HANDLING UNIT
Configured for In-Orbit Servicing
(Dual Systems)



ADVANCED MMS, NDLM
COMMUNICATIONS AND
DATA HANDLING UNIT
Configured for GCTI Spacecraft
(Two Redundant Systems)

Figure 3-2 The NASA Data Link Module Configured for GCTI Application.

in sunsynchronous orbits do not require change-out capability, NDLM units will be carried as two separately packaged subsystems each configured for conventional bolt-on mountings. Estimates of masses for elements within the NDLM show some potential for an overall reduction; however for this study, the C and DH system mass will be assumed identical to that for an existing MMS module plus mass estimates based upon the wide-band TDRSS link communication elements used in Landsat D (Reference 7).

3.2 Attitude Control Module

Uprating for the attitude control module is summarized in Table 3-2 and effectively incorporates improvements to components within the system. The principal change in operation appears in the use of a dedicated microprocessor which eliminates a previous dependence upon a central computer in the C and DH module. Internally, the module co-locates sensors, such as gyros and star trackers, the microprocessor and active control elements such as momentum wheels, in a manner that achieves more rapid and more precise system response to disturbances. Existing units offer stabilization to 0.01 degree (36 arc sec.) which would nominally accommodate a resolution requirement of about 0.1 degree. The most stringent instrument resolution requirement listed in Table 2.2 is 0.069 degree (248 arc sec.) and appears compatible with the capabilities of improved components and a dedicated microprocessor. Elimination of on-orbit change-out capability does not change module dimensions but does permit a simpler and less massive module package.

3.3 Electrical Power System

The uprating features for the electrical power system are summarized in Table 3.3. A change from a 28 VDC to a 120 VDC distribution follows both Space Station Freedom and EOS conventions. Within GCTI spacecraft, a dedicated microprocessor in the power conversion module accommodates the instruments and performs all spacecraft power switching functions including those for heaters and pyros. A separate submodule element of the MMS is not retained

TABLE 3-2 ATTITUDE CONTROL SUBSYSTEM BASED UPON MULTIMISSION MODULAR ELEMENTS

CURRENT MMS ELEMENTS	GCTI ADVANCED MMS
Attitude Control Module:	
4 Reaction Wheels 20.3 N-m-sec	4 Reaction Wheels with Integral Electronics
Gyro, Conventional	Optical Gyro
Star Trackers 4° (2)	Same
Magnetic Torquer	Same
Microprocessor Algorithm Located in Control-Data Handling Module 16 K Word Memory Limit	Dedicated 80386 Microprocessor Algorithm Responds to Spacecraft Requirements
Module Designed for On-Orbit Servicing Total System Mass 220 kg	Simplified Module, Total System Mass 215 kg
Present Capability 0.01° Pointing	Pointing Accuracy tailored to Science Requirements

TABLE 3-3 ELECTRICAL POWER SUBSYSTEM BASED UPON MULTIMISSION MODULAR ELEMENTS

CURRENT MMS ELEMENTS	GCTI ADVANCED MMS
Power and Signal Conditioning and Control Unit	Power Module Contents
Power Regulation at 28 VDC	Power Regulated at 120 VDC
Power Level 1200 W Avg. up to 2000 W Peak	Power Modules Sized for 1300 W Input From Solar Array
Switching Control From Control Data Handling Computer	Dedicated 80386 Micropressor for all Switching Functions
Pyro Control, Thermal Control in Separate Sub Unit Module	Pyro and Thermal Control Uses Dedicated Microprocessor
Batteries Ni-Cd at 30 W-h/kg Carried Within the Module. Range 1120 W-h, Standard to 4200 W-h Max	Batteries Ni-H_2, 45 W-h/kg, 33% DOD, Modularized at 60 W-h, Separate Mount. Range 1050 W-h to 4811 W-h
Solar Array: Silicon, 100 W/m^2 Areas Defined by S/C Applications	Solar Array Silicon (100 W/m^2) or GaAs/Ge (158 W/m^2) as Defined by S/C Applications

for GCTI. Each of the power conversion modules is sized to accommodate and distribute up to 1300 W as input from the solar array. For GCTI spacecraft, modules have masses of 95 kg each in a package half the size of the present MMS units. Storage batteries for the GCTI spacecraft are separately mounted Ni-H_2 units in modules of 60 W-h each. These batteries anticipate a development to the point where they can deliver 45 W-h/kg at complete discharge and operate with a 33 percent depth of discharge during each orbit (Reference 8).

Power requirements for each of the spacecraft configurations define appropriate solar arrays. Present technology utilizes silicon cells which have an end-of-life capability of about 100 W/m^2 and deliver 29 W/kg from a typical array installation. These capabilities are compatible with modest power requirements; however, the power requirements for some of the GCTI spacecraft indicate a need for more efficient solar cells to ease area requirements for the arrays. Therefore, GCTI assumes availability of GaAs/Ge solar cells in arrays that have end-of-life capabilities of 158 W/m^2 and deliver 45 W/kg (References 8 and 9).

3.4 Propulsion

The existing MMS propulsion module utilizes a direct blow-down catalytic-burn hydrazine system which the GCTI spacecraft also use with the same thrusters, valves and valve controllers. A dedicated microprocessor provides the control requirements particular to a spacecraft; Table 3-4 summarizes the pertinent features. The principal differences appear in the integration into the spacecraft and the amount of propellant aboard the spacecraft. Small spacecraft integrate the propulsion system into the structure and carry the propellant in cylindrical tanks; large spacecraft retain the present MMS module with extra propellant carried in auxiliary spherical tanks.

3.5 Assessments of Status for MMS Subsystem Improvements

The improvements or changes as described above have been recognized and addressed in development efforts that range from near complete to that of a

TABLE 3-4 PROPULSION SUBSYSTEM BASED UPON MULTIMISSION MODULAR ELEMENTS

CURRENT MMS ELEMENTS	GCTI ADVANCED MMS
Propulsion Module	
Thrusters, (Redundant)	Thrusters, (Redundant)
Velocity Correction: 22.25 N (4) Attitude Control: 0.9 N (12) Valves	Same Units: Delta S/C; at Corners of Platforms Large Platform; as part of the Module
Control from On Board Computer	Dedicated 80386 Microprocessor
Tanks 3 Spherical 0.4m Dia. 75 kg N_2H_4 On Board	Delta S/C; Cylindrical Tanks Contain 125 kg Large Platform; Auxiliary Tanks to 700 kg
Total Mass 150 kg	Delta S/C; System 200 kg Large Platform; System 800 kg

concept. An initial assessment of subsystems status relative to the instruments identified for Global Change measurements becomes a restatement of need. The instrument requirements establish a need for flexibility in configuring a host spacecraft and modularized subsystems using advanced electronics together with advanced fabrication techniques can provide such a flexibility. A scientific investigation that requires flight data from the instruments listed above will also justify the corresponding subsystem modularization. The present status of the MMS subsystems toward improvements in performance and modularization compatible with the GCTI spacecraft concepts appears summarized in Table 3-5, the pertinent assessments of status are addressed below.

a. Communication and Data Handling. The NDLM provides the capabilities required for the GCTI spacecraft. The components identified in Figure 3-2, provide the necessary flexibility and options for on-board data storage. Some of the GCTI spacecraft show the need for a 10^{12} bit data storage capacity: such an optical disc unit is in development at the LaRC and intended for use aboard EOS (Reference 10). The NDLM components are presently completing their system performance testing (Reference 11). Planning for flight qualification is in preparation. At the present time no mission exists for the on-orbit serviced module, however, the components developed foresee use in special purpose modules. The concept for the NDLM assumed module contents would be tailored to mission requirements and the modules proposed for GCTI fit within that general approach. All the GCTI spacecraft will need the data transmission rates associated with the Ku Band operation. The principal variable appears in the requirements for on-board data storage.

b. Attitude Control. The improvements cited are essentially "next step" developments for the components within the attitude control module. Modules prepared for the UARS and Explorer Platform incorporate larger momentum wheels and digital control. Proposed applications for future missions incorporate optical gyros and improved (solid state)

TABLE 3-5 SUMMARY STATUS OF ADVANCED MMS SUBSYSTEMS RELATIVE TO GCTI APPLICATIONS

Subsystem	Component Technology	Digital Microelectronics	Components	Performance Verification	Flight Qualification	Comment
Communication and Data Handling	NDLM Developed	Included (Not 80386)	NDLM Developed	Test Completed	Pending	Flexible Modularization Included
High Capacity Data Storage	Multiple Optical Discs	Included	Development by LaRC	EOS	EOS	Could be available before EOS
Attitude Control	Next Step Evolution	Included (Not 80386)	Available for UARS and TOPEX Vehicles	UARS and TOPEX Tests	UARS and TOPEX Flight	GCTI Modularizes TOPEX Application
Power Regulation Pyro Control Thermal Control	Space Station and EOS, 120 VDC EOS 1500 W Modules	Included (Not 80386)	Advanced MMS Continues 28 V, with Improved Batteries, GCTI not Presently Configured	EOS, Space Station	EOS, Space Station	Module Estimated for GCTI Need
Energy Storage	NiCd Standard $Ni\text{-}H_2$ Space Station and EOS	--	Modules in Development	EOS, Space Station	EOS, Space Station	GCTI Modules Based Upon Units in Development
Solar Array	Si Standard GaAs/Ge in Development	--	Si Available GaAs/Ge Development	Si General GaAs/Ge Planned	Si General GaAs/Ge Planned	GCTI Requires Both
Propulsion	Existing Components. Revised Tank Shapes and Volumes	Not Included	Existing Items Available. Tanks New	Existing. Revised System Test Required	Existing Items Flown	Minimal Change for GCTI

star trackers to achieve pointing accuracies of 0.0003 degrees (1 arc sec). An application of improved momentum wheels with an optical gyro and digital electronics operation is being configured for the TOPEX spacecraft and packaged by the spacecraft builder. The GCTI module retains the present module dimensions to house improved momentum wheels, optical gyros and existing star trackers plus a dedicated microprocessor for control.

c. Electrical Power. Improvements to the existing MMS power module support the application to UARS which accommodates a 1600 W average power level. Additional improvements proposed would utilize uprated Ni-Cd batteries or incorporate Ni-H_2 units. The module configuration and operating voltage would not change. Spacecraft components have standardized on 28 VDC, and integration testing benefits from co-location of the power converter-regulators and the batteries. GCTI modules make a significant departure principally for thermal and mounting flexibility considerations. They contain converter-regulators and a microprocessor for switching controls in a module half the size of present units. Operation at 120 VDC assumes availability of EOS or Space Station Freedom technology. Modularization of power regulation at 1300 W and Ni-H_2 batteries at 60 W-h represents a best-fit estimate based upon available data.

d. Propulsion. The changes to the propulsion system are considered available. The principal difference appears as the adaptation of the valves, sensors and control elements to the particular digital interface associated with the 80386 microprocessor. Cylindrical tanks of the dimensions required for the small spacecraft are considered available technology. Large spherical tanks are also considered available technology.

In summary, the subsystem definitions for the GCTI spacecraft recognized that the present MMS units would complete their flight assignments with the

UARS and the Explorer Platform, however, the need for advanced modularization concepts would continue. The NDLM presented a comprehensive advanced configuration and was utilized accordingly. The attitude control system needed for the TOPEX spacecraft was considered the model for future modularization and therefore utilized. Space Station Freedom and EOS addressed electrical power system advances in voltages, modularization and energy storage that offered a basis for a GCTI module, and finally, changes in driver electronics, tank shapes and fluid lines uprate the MMS propulsion module to a GCTI application. A decision to fly a group of GCTI defined instruments on other than their present host spacecraft such as UARS, EOS or TIROS-N would turn the GCTI concepts into requirements for subsystem modules.

4.0 SMALL SPACECRAFT CONFIGURATIONS

The small spacecraft concepts utilized the published capabilities of the current Delta series boosters and the availability of larger volume shrouds as the baseline envelopes for spacecraft configurations; launch capabilities listed are:

Delta 6920 - 2500 kg to a 650 km polar orbit
Delta 7920 - 3300 kg to a 650 km polar orbit

The principal dimensions for the Delta shrouds are shown in Figure 4-1; in flight, the shroud separates as a clam-shell and thereby makes all the internal volume available to a spacecraft. In the descriptions which follow, spacecraft Configuration B is the baseline concept with the other three as adaptations to fit particular requirements. The descriptions first summarize the configuration and then address the pertinent features such as structural accommodations, electrical, and subsystem accommodations and operating accommodations.

4.1 Small Spacecraft, 12 Hour or Longer Measurement Interval, Configuration B

The features of the B configuration spacecraft are summarized in Table 4-1; the layout and concepts for accommodation are shown in Figures 4-2, and 4-3. This spacecraft accommodates the instruments, their viewing requirements and heat rejection requirements all within the dimensions of a large Delta shroud and shows total mass well within the launch capability of a Delta 7920. Definition of the Sun side for GCTI spacecraft arbitrarily assumes a flight direction away from the booster separation plane and operation with a morning sun during a descending node.

Structure and On Board Accommodation

The principal structural elements for all of the small spacecraft consist of a graphite fiber composite platform and an aluminum separation ring that adapts the thrust face of the Delta booster to the base of the platform. The structural

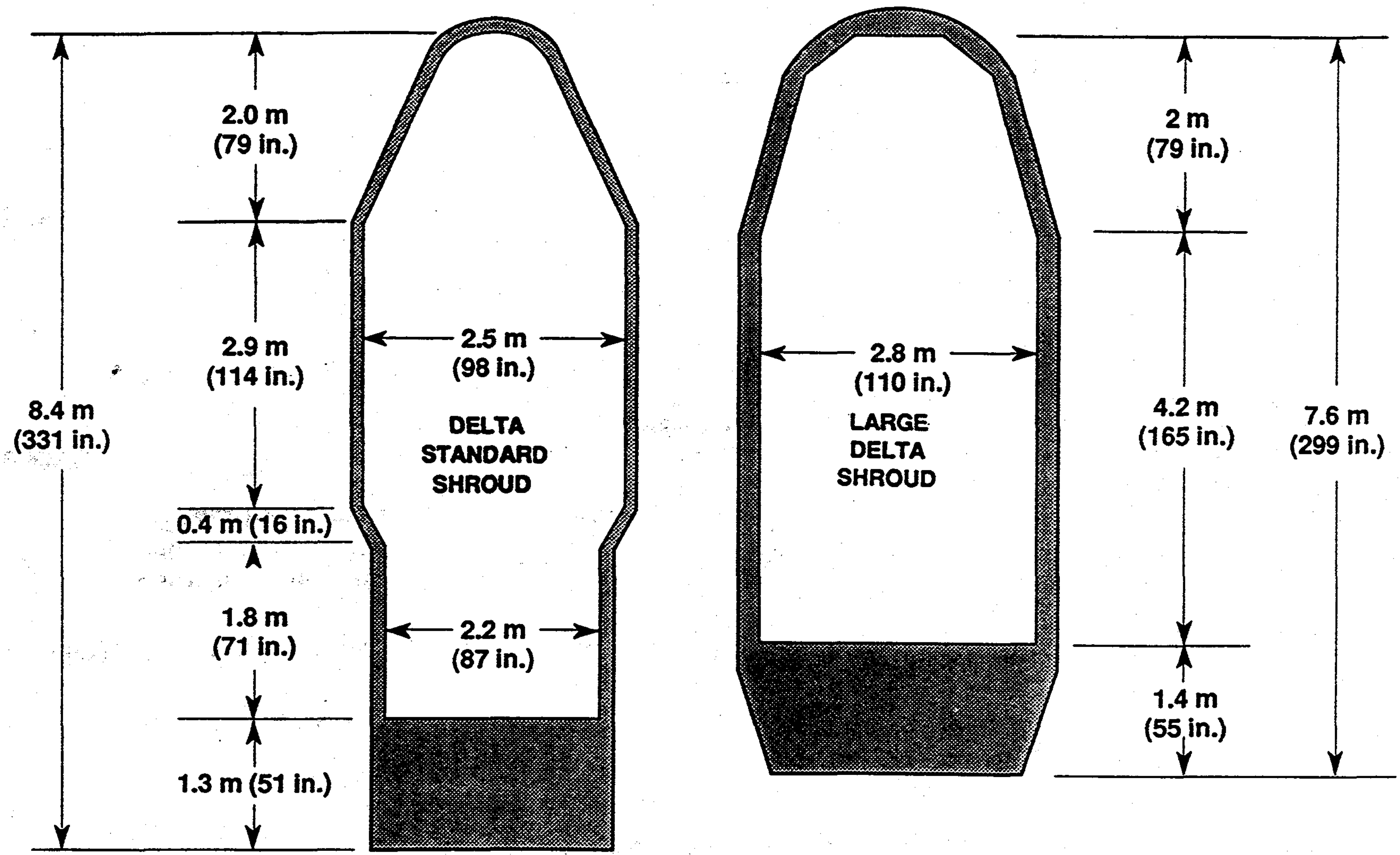


Figure 4-1 Principal Dimensions for the Delta Booster Shroud Configuration.

TABLE 4-1 SPACECRAFT CONFIGURATION "B" FEATURES (Large Shroud, Delta Booster)

INSTRUMENTS: 5 Nadir, 3 Solar

MOUNTING: Graphite Fiber Composite Platform 5.9 m by 2.3 m by 0.3 m

4 Instruments Direct
3 Solar Instruments on Gimballed Tracking Table
HIRIS Mounts Through the Platform

OPERATING SUBSYSTEMS: Advanced MMS (Includes: 1 Attitude Control, 2 Data Control, and 2 Power Converter Modules; Propulsion Internal to Platform; Dual Frequency Planar Array Antenna with 16 Elements Ku, 4 Elements S Band)

POWER AND STORAGE: 1950 W-h in Ni-H_2 Batteries. Silicon Solar Array 25 m^2 (100 W/m^2) (Stow as 25 Panels, 3.3 m by 0.3 m in a Cylindrical Wrap)

UNIQUE FEATURE: HIRIS Instrument Requires 300 Mbps Recording Capacity aboard this Spacecraft

SUMMARY:

Instrument Mass	1177 kg	Instrument Power	816 W
Spacecraft Mass	2485 kg	Spacecraft Power	1320 W
		Solar Array Power	2410 W

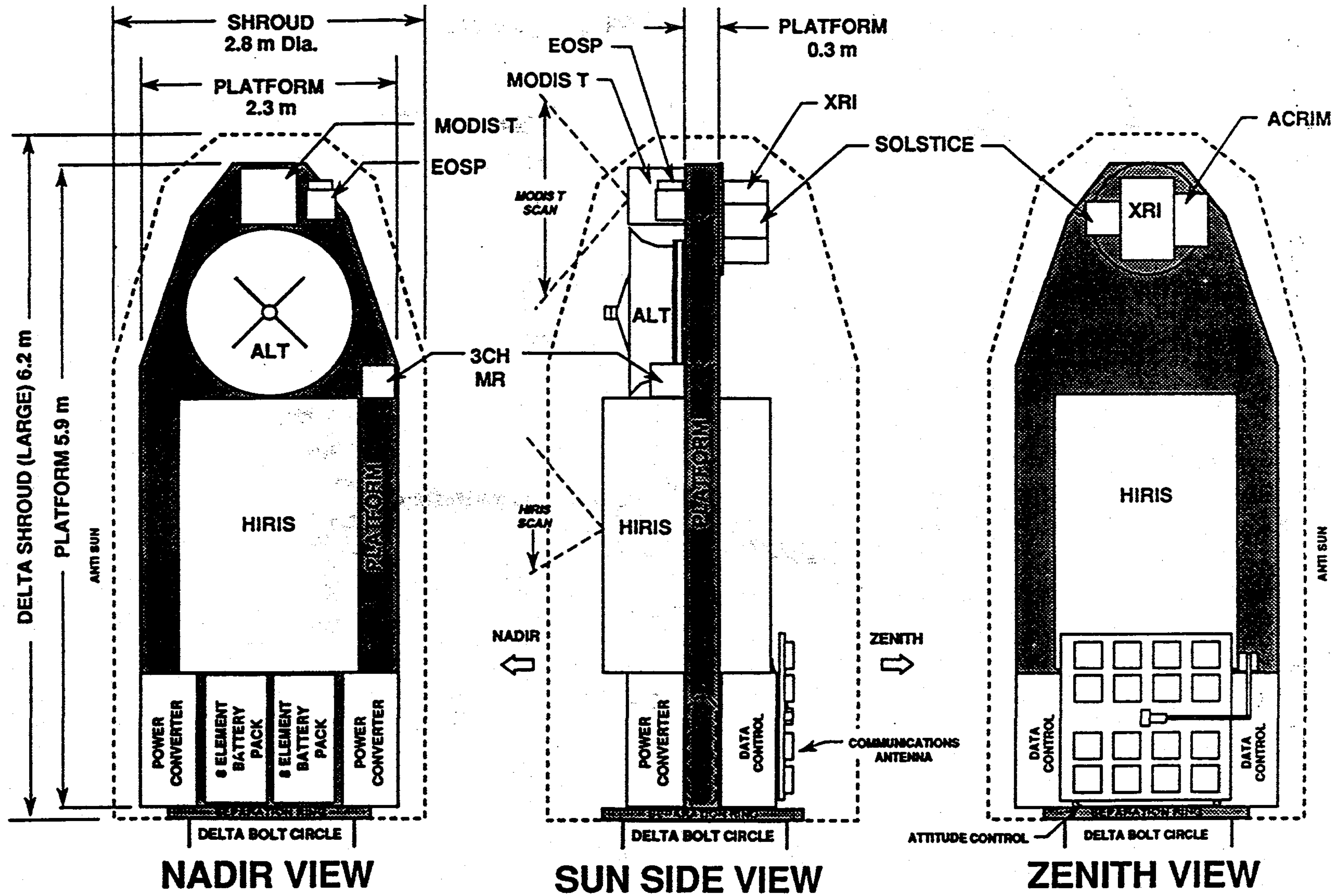


Figure 4-2 Side View Features for Spacecraft Configuration B (12 Hour and Longer Measurement).

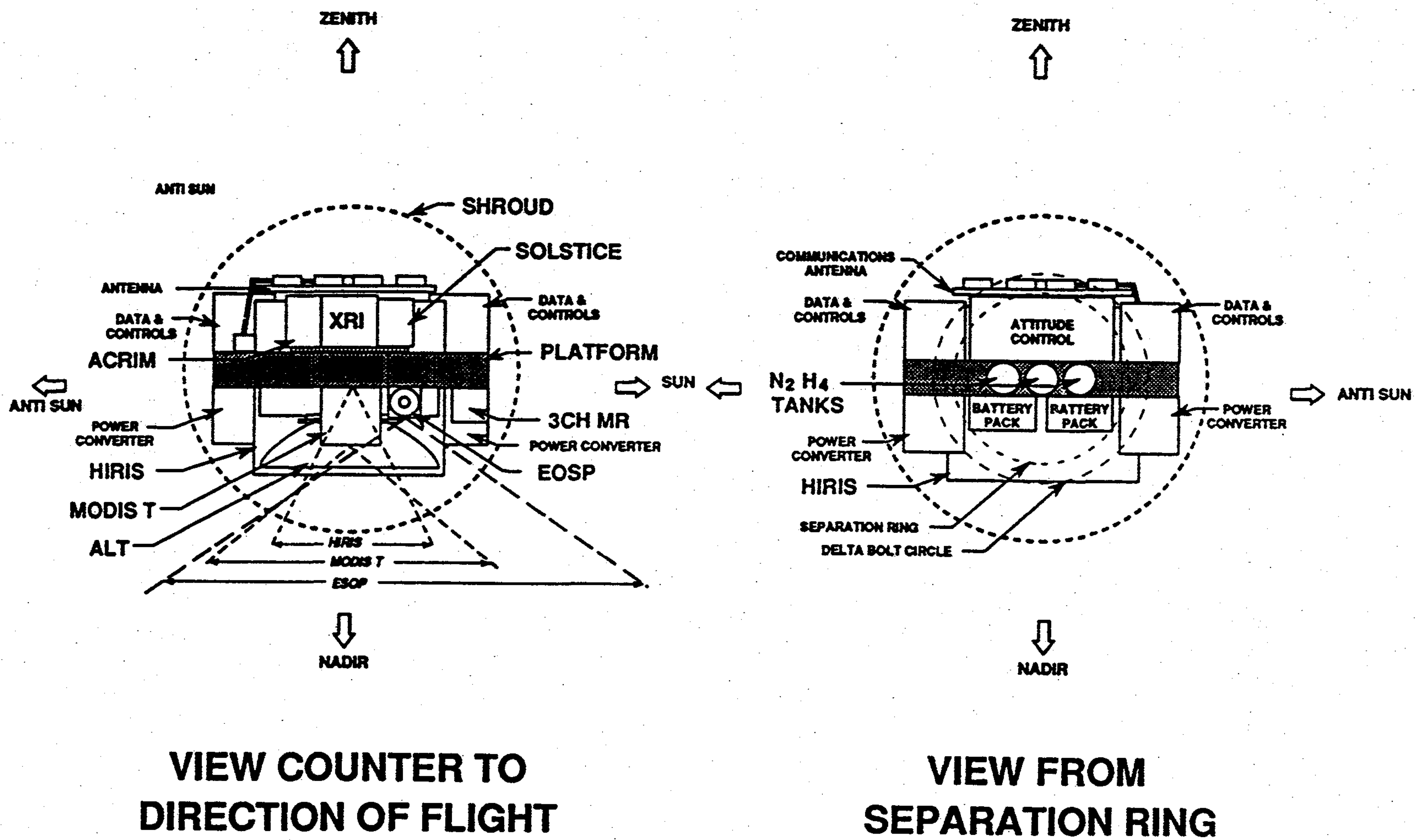


Figure 4-3 End View Features for Spacecraft Configuration B.

concept adopted for the platform utilizes a gridwork of beams covered by sheets to form the mounting surfaces. GCTI platform design is an extension of a concept developed to provide an equipment mounting deck for the Lidar Atmospheric Sensing Experiment (LASE, Reference 12); Figure 4-4 shows the layout for the beams. The LASE deck also acts as an optical bench which carries about 325 kg of instrumentation that includes dual frequency-controllable lasers and an 0.6 m dia by 0.9 m telescope. A platform for a GCTI spacecraft will have the major loading condition occur during launch. Therefore the beams which form the internal bracing must transfer forces from the separation ring into the mounting points for the instruments and subsystem components. A graphite composite structure constructed as contiguous hollow square beams with 0.3 m sides and 3 mm walls shows a mass of 22 kg/m^2, and this value is assumed for all the small spacecraft platforms.

Accommodation of the instruments is considered straightforward. Four of the Nadir directed instruments are considered "bolt-ons". The trio of solar reference instruments mounts on a gimballed platform that allows tracking the sun throughout the illuminated portion of the orbit. The location indicated is somewhat arbitrary with the actual location determined by the orbit selected for flight. The HIRIS instrument requires particular accommodation. Available definitions of the exterior shape and mountings provide only envelope dimensions and an indication of trunions as the pivot elements in the scanning system. In addition, the unit has a space radiator. The accommodations provided accept the envelope dimensions and will accommodate trunions for scanning in either or both of the directions as indicated. A platform can be configured to apply launch acceleration forces to the instrument at any point or combination of points around the periphery of the opening in the platform. Arrangement of the other instrumentation, as shown, minimizes the bending moments applied to the platform during launch accelerations.

Electrical and Subsystem Accommodations

Spacecraft operating subsystem modules mount on the platform just forward

EQUIPMENT MOUNTING DECK - BASIC

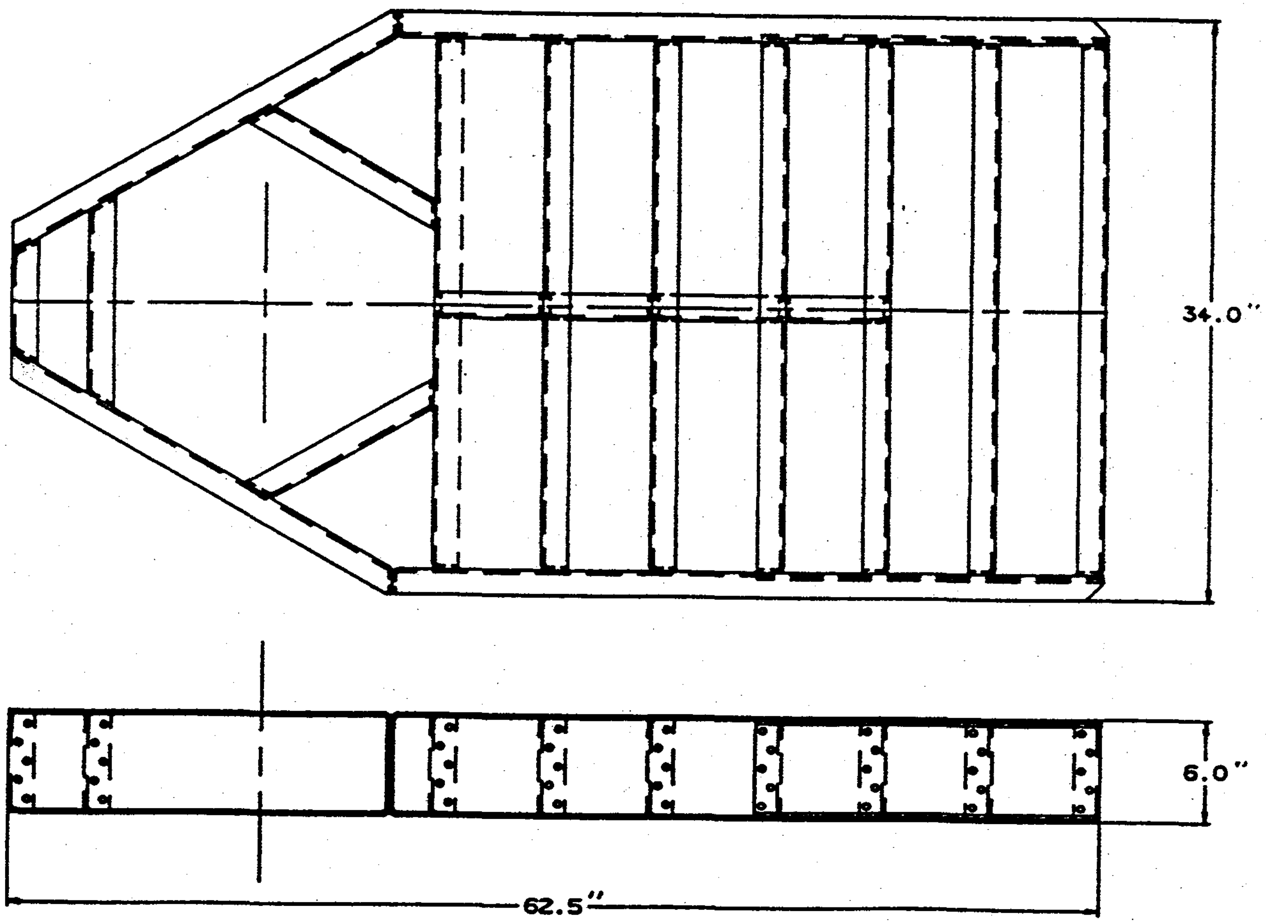


Figure 4-4 Graphite Fiber Composite Beam Structure for the LASE.

of the separation ring. The attitude control module centers on the zenith side, and the location of the attitude control module is the same for all the GCTI spacecraft. Data control modules are the units shown in Figure 3-2; both modules feed the communication antenna. The communication antenna consists of a 4 by 4 matrix of K-band elements with 4 S-Band elements around the periphery to form a planar array 1.2 m square. High frequency components are located on the antenna, such that the antenna support is an erectable mast (or other erectable structure) and not a waveguide. Antenna pointing units are also located at the antenna. Power converter modules carry only the regulation and load control logic elements and mount on the nadir surface of the platform. Storage batteries (in packs of 8 modules each) also mount on the nadir surface of the platform. This spacecraft carries a total of 18 battery modules. The other 2 unit battery module would be located near an instrument-of-need or combined with the pack shown.

The propulsion system is integrated into the platform. The 12 small thrusters, 0.9 N each, are carried as 4 clusters of 3 each arranged to provide corrections in pitch, yaw and roll. These 4 clusters also carry one velocity correction thruster of 22.2 N with the thrust vector aligned with the direction of flight. All units are located within the platform at positions outboard of the separation ring. The cylindrical hydrazine tanks are carried within the platform structure.

Operating Accommodations

Operating accommodations include the deployments associated with separation from the booster and considerations relative to functioning during orbit. Spacecraft configuration B has a straightforward deployment and separation sequence. After jettison of the shroud, the first deployment extends the solar array to activate the power system. A second deployment erects the antenna to achieve communication. Latches or locks that secured instruments during launch release next. The actual separation from the booster proceeds in two steps. Auxiliary supports (not shown) between the platform and the separation ring provide additional stiffness and reaction members for acceleration loads during launch, these can be either struts or webs (the layout of modules allows for such elements). These struts or webs release first and clear from the platform; release from the Delta booster leaves the separation ring and auxiliary supports with the spent booster.

Instrument accommodations for viewing and heat rejection show no unusual complexities. The principal consideration in flight could become momentum compensation or reaction. Two of the instruments (EOSP, MODIS-T) have internal rotating elements. The solar pointing instruments move to track the sun, and the HIRIS may have a large oscillating mass associated with the scanning function. A continuously active attitude control system can be anticipated.

4.2 Small Spacecraft, 3 to 12 Hour Measurement Interval, Configuration C

The features of the spacecraft configuration C are summarized in Table 4-2 the layout and accommodations are shown in Figures 4-5 and 4-6. This configuration carries the least number of instruments and will fit within the dimensions of a standard Delta shroud. In addition the spacecraft mass falls well within the launch capabilities of a 6920 series booster. The crosstrack scanning of the APL instrument generates the principal requirements relative to on-board accommodations and operational accommodations.

Structure and On-Board Accommodations

This spacecraft continues the concept for a graphite fiber composite platform with an opening that accommodates an instrument. The APL instrument mounts on a gimballed subplatform within the opening in a manner that allows a crosstrack, 45 degree deflection in both directions from nadir. APL scans identify rates up to 10 seconds per cycle; therefore, the center of mass for the gimbal-mounted assembly must be on the gimbal axis, and the gimbal axis must coincide with the centerline of the spacecraft. A traversing gimbal platform as shown will impose some envelope limits on the platform-mounted elements. Since the APL

TABLE 4-2 SPACECRAFT CONFIGURATION "C" FEATURES (Standard Shroud, Delta Booster)

INSTRUMENTS: 3 Nadir

MOUNTING: Graphite Fiber Composite Platform 4.4 m by 2.2 m by 0.3 m

EOSP Direct
APL Lidar on Gimballed Sub Platform (90° Sweep)
SAGE on Deployable Outrigger

OPERATING SUBSYSTEMS: Advanced MMS, Augmented to 3 Power Converter Units

POWER AND STORAGE: 1480 W-h in Ni-H_2 Batteries. GaAs/Ge Solar Array 22 m^2 (158 W/m^2)
(Carry as 33 Panels 2.2 m by 0.3 m, Stored in 3 Semicircular Layers)

UNIQUE FEATURES: APL Lidar Gimbal Carries the Instrument and 66 Percent of Batteries
SAGE on Outrigger for Field of View Clearance

SUMMARY:

Instrument Mass	731 kg	Instrument Power	1236 W
Spacecraft Mass	2185 kg	Spacecraft Power	1860 W
		Solar Array Power	3393 W

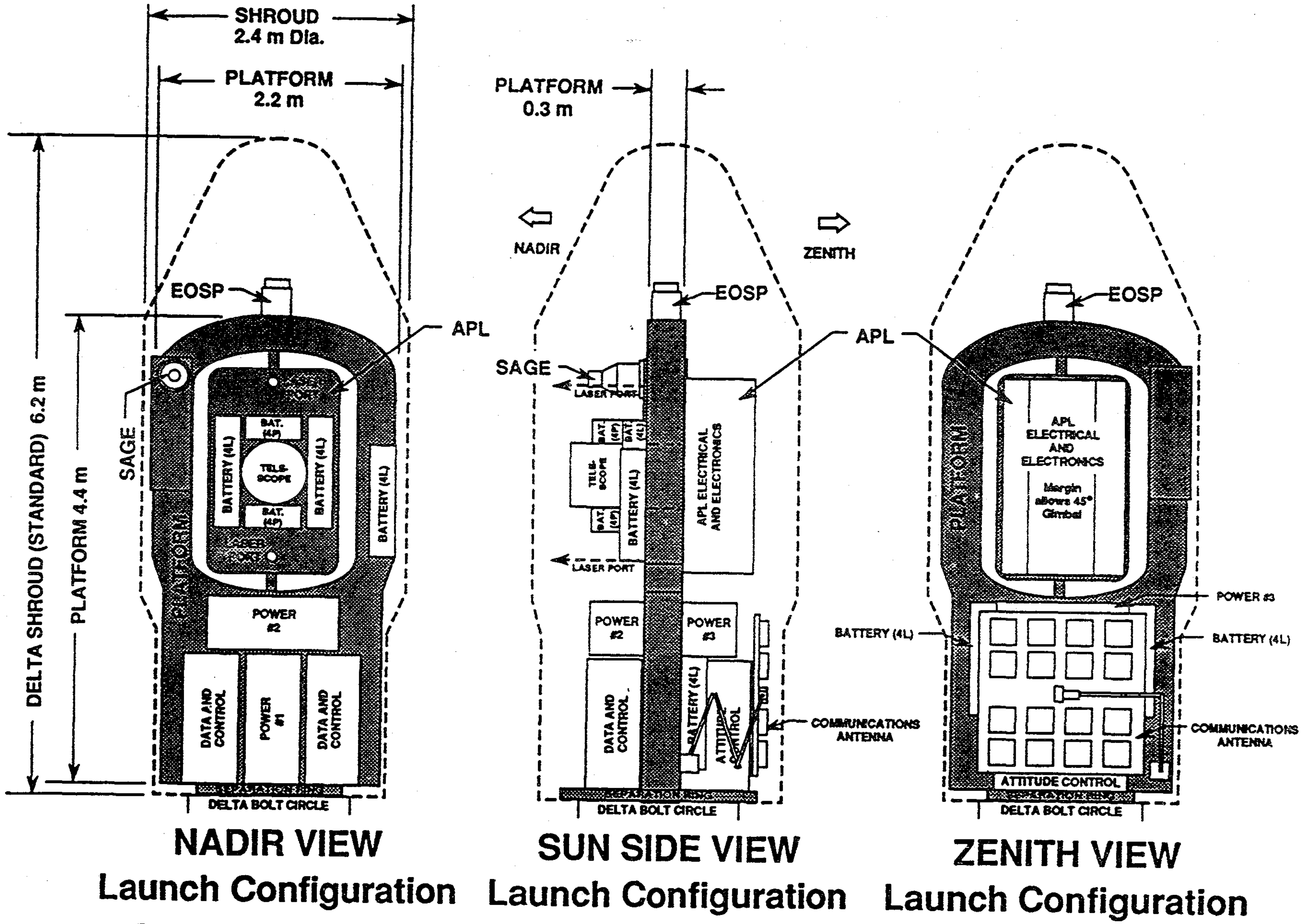
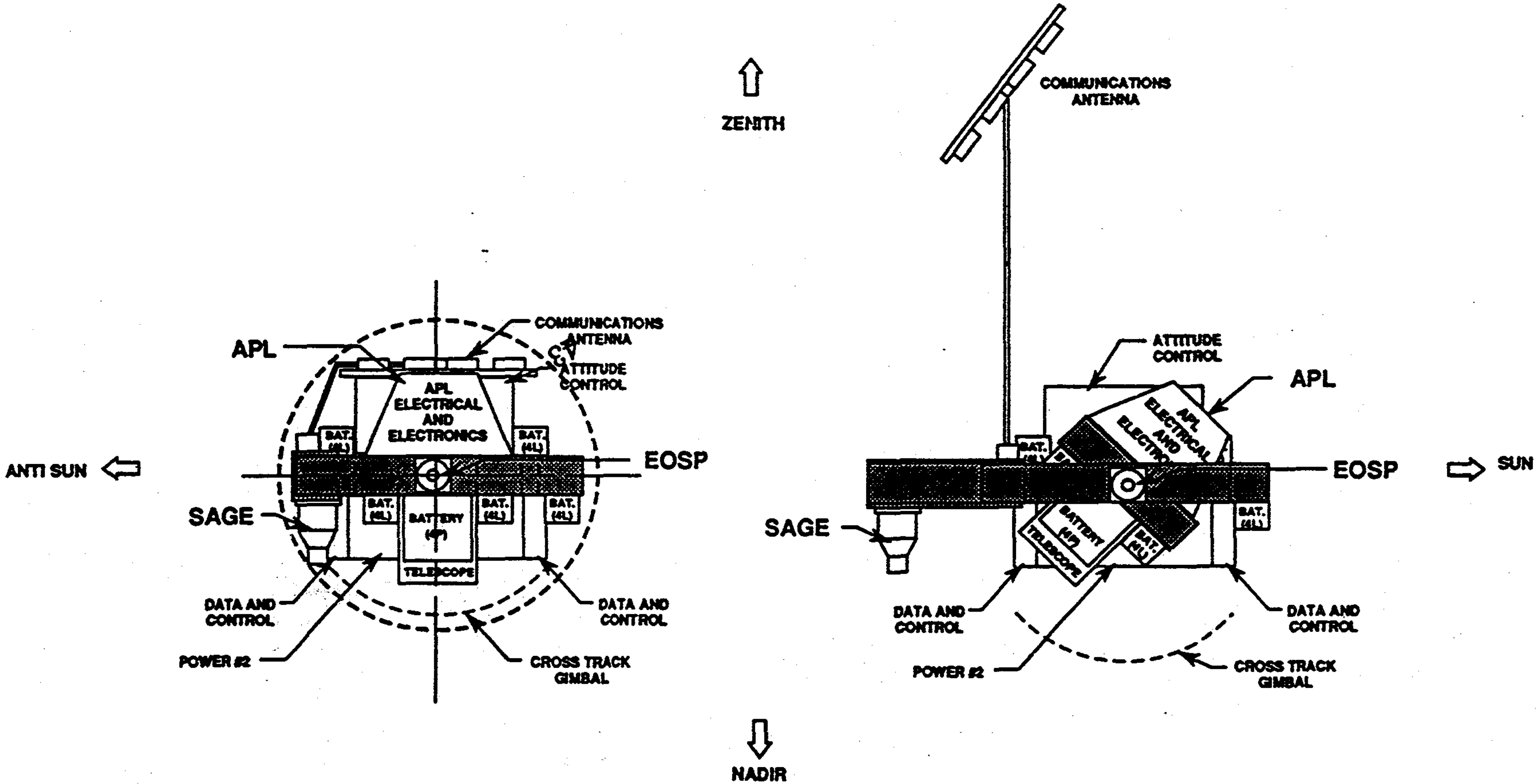


Figure 4-5 Side View Features for Spacecraft Configuration C (3 to 12 Hour Measurements).



VIEW COUNTER TO DIRECTION OF FLIGHT
Launch Configuration

VIEW COUNTER TO DIRECTION OF FLIGHT
Flight Configuration

Figure 4-6 End View and Flight Configuration for Spacecraft C.

instrument presently is in an early stage of configuration definition, envelope considerations for a host spacecraft can be accommodated. The fore and aft fields of view for the SAGE III instrument must be free from intrusion by the scanning motion of the APL. Therefore, the SAGE III mounts on a deployable outrigger beam that places the instrument in line with the APL scan plane but outboard at a distance sufficient for unobstructed viewing of the sunrise and sunset events associated with the measurement sequences.

A potential alternate configuration would use the on-board attitude control subsystem to provide the roll cycling or positioning for the APL. The entire platform and APL would move as a unit and thereby relieve some of the envelope constraints for the APL electrical components. Such an operation would incur the expense of adding additional gimbal mountings for the antenna, solar array and the SAGE instrument.

Electrical and Subsystem Accommodations

The locations of the electrical operating modules adjust to accommodate the smaller diameter of the standard Delta shroud. Power requirements for the APL result in a solar array that necessitates three power conversion modules with the third unit mounted just forward of the attitude control module on the zenith surface of the platform. Continuous operation of the APL justifies placing 16 of the 28 battery units on the platform and accepting the need for additional momentum compensation. Power requirements for this relatively small spacecraft also justify the use of GaAs/Ge solar cells principally as a means to reduce the array area.

Operating Accommodation

Operating accommodations also relate to the APL. The deployment sequence for shroud release, solar array deployment and antenna erection are the same as for the configuration B. The sequence then executes the extension of the SAGE III before release of the platform and energizing the APL. Separation from the spent booster occurs after all instruments are operationally verified. Operation of the APL can employ a range of scanning options ranging from step scanning to continuous cycling at rates up to 10 seconds per cycle. The gimballed platform will carry an integral momentum compensation element which limits the spacecraft disturbance to levels within the range of accommodation by the attitude control module.

4.3 Small Spacecraft, 1 to 12 Hour Measurement Intervals, Configuration D

The features of the Configuration D spacecraft are summarized in Table 4-3; layout and accommodations are shown in Figures 4-7 and 4-8. The inventory of instruments totals 8 units of 7 configurations with the CERES units carried as a pair. Accommodation of the instruments demands the large shroud; however, the total mass of the spacecraft falls well within the capabilities of the Delta 6920 series booster. This spacecraft shares a general commonality with the configuration B; however, the HIMSS instrument introduces an additional step in the deployment sequence.

Structure and On-Board Accommodations

Within the on-board instrumentation, six of the units are "bolt-ons," and the ACRIM instrument utilizes the same gimballed platform as used on the configuration B. The HIMSS instrument mounts through a circular opening in the platform in a manner analogous to the HIRIS unit. Descriptions of the HIMSS instrument identify the barrel as a rotating element; the interface with the platform is configured accordingly.

Electrical and Subsystems Accommodations

Operating subsystem modules, battery complements, and solar array have the same layout and contents as for configuration B. The principal difference relates to the HIMSS instrument, where the configuration accommodations anticipate a set of releases and deployment actuators that could utilize pyro

TABLE 4-3 SPACECRAFT CONFIGURATION "D" FEATURES (Large Shroud, Delta Booster)

INSTRUMENTS: 7 Nadir, 1 Solar

MOUNTING: Graphite Fiber Composite Platform 4.9 m by 2.3 m by 0.3 m

6 Instruments Direct
Solar (ACRIM) on Gimballed Tracking Table
HIMSS Mounts Through the Platform and Extends Antenna for Measurment

OPERATING SUBSYSTEMS: Advanced MMS (See Configuration B)

POWER AND STORAGE: 1050 W-h in Ni-H_2 Batteries. Silicon Solar Array 25 m^2 (100 W/m^2)
(Stow as 25 Panels 3.3 m by 0.3 m, Circumferential Wrap)

UNIQUE FEATURES: HIMSS Extends Reflective Antenna as part of Preseparation Sequence
HIMSS Barrel Rotates 30 rpm, during measurement

SUMMARY:

Instrument Mass	587 kg	Instrument Power	802 W
Spacecraft Mass	1935 kg	Spacecraft Power	1320 W
		Solar Array Power	2410 W

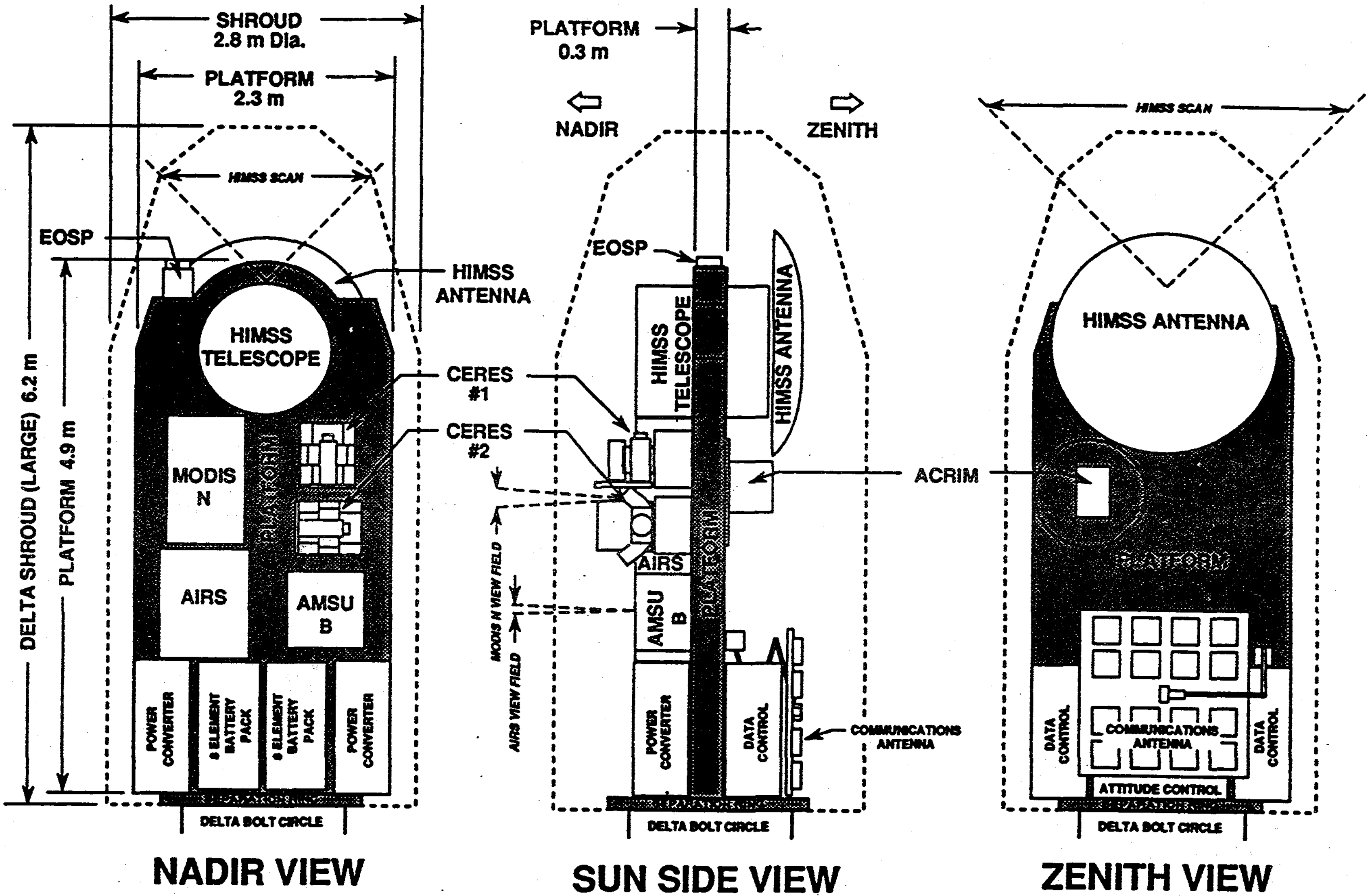


Figure 4-7 Side View Features for Spacecraft Configuration D (1 to 3 Hour Measurements).

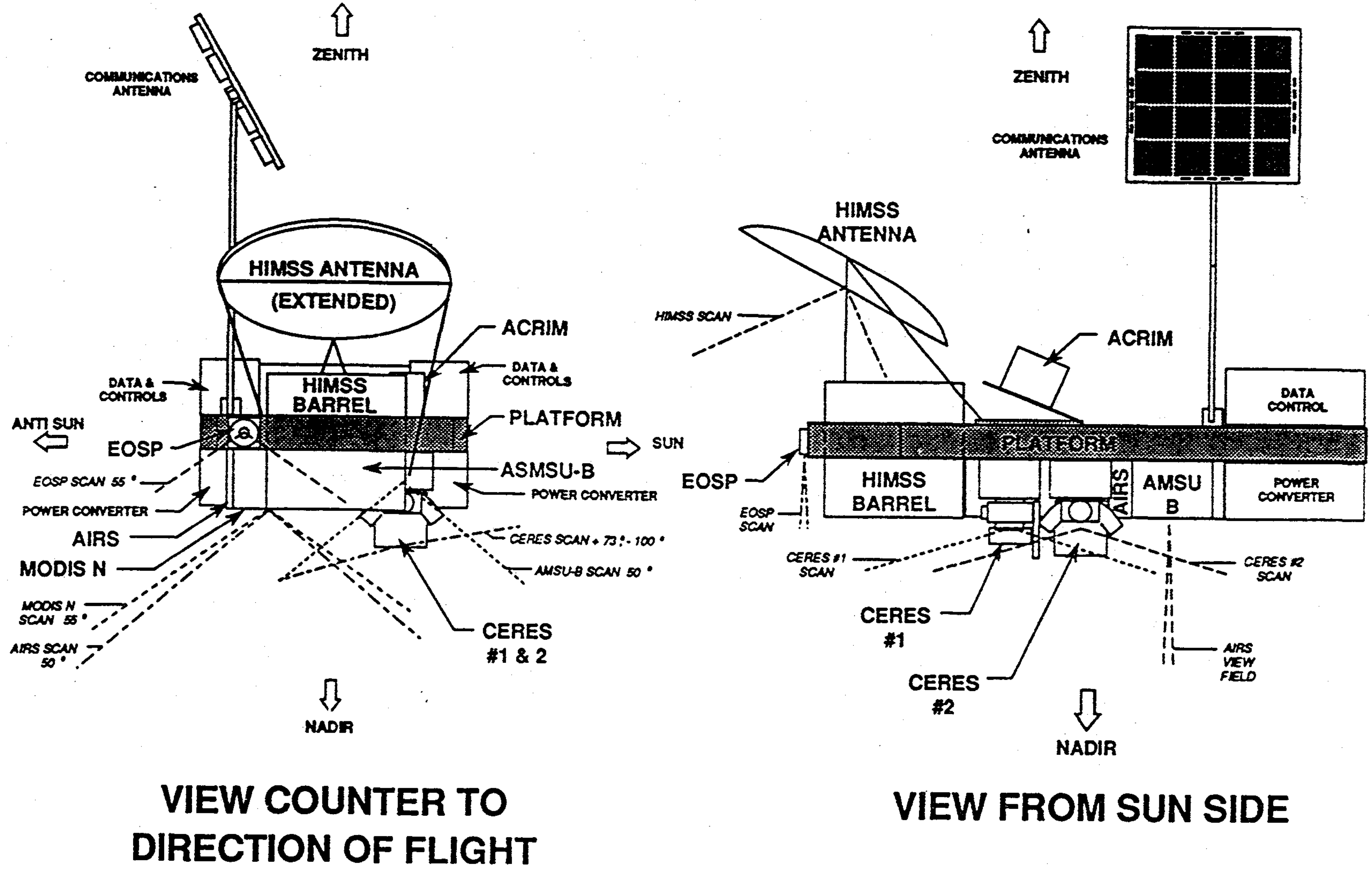


Figure 4-8 End View and Flight Configuration for Spacecraft D.

devices for both functions.

Operating Accommodations

The operational accommodations also relate to the HIMSS instrument. Initial steps in the separation follow the established sequence for shroud, power and communication. Steps to initiate the HIMSS then deploy the antenna and establish the rotation before separation from the spent booster. The rotating portions of the HIMSS instrument are expected to include momentum compensation such that the attitude control module can achieve the pointing stability identified for the AIRS and MODIS-N instruments.

4.4 Small Spacecraft, 1 Hour or Less Measurement Interval, Configuration E

The features of spacecraft configuration E are summarized in Table 4-4; layout and accommodations are shown in Figures 4-9 and 4-10. This unit requires the most electrical power and is the heaviest of the small spacecraft configurations. In addition dimensional limits for a large Delta shroud do impose particular accommodations upon three of the instruments, which, in turn, add steps to the deployment sequence.

Structure and On-Board Accommodations

Of the six instruments aboard configuration E, three are considered "bolt-ons" and three require particular accommodations. The particular accommodations required for the SAFIRE and TES instruments continue the concept of mounting through openings in the platform. For these two instruments, the position of the instrument during boost addresses launch forces; in orbital flight, the instruments move into positions compatible with both viewing and thermal radiation heat transfer requirements. Accommodations for the presently-defined enclosures result in about a 0.75 m deployment motion to bring the identified mounting surface into a plane coincident with the nadir face of the platform. Dimensions defined for the MLS reflector combine with the cross track scanning requirement to define the

TABLE 4-4 SPACECRAFT CONFIGURATION "E" FEATURES (Large Shroud, Delta Booster)

INSTRUMENTS: 6 Nadir

MOUNTING: Graphite Fiber Composite Platform 4.9 m by 2.3 m by 0.3 m

3 Instruments Direct
SAFIRE and TES Mount Through the Platfrom
MLS: Electronics and Scanner Individual Packages, Scanner Deploys

OPERATING SUBSYSTEMS: Advanced MMS Augmented to 4 Power Converter Units

POWER AND STORAGE: 2166 W-h in Ni-H_2 Batteries. GaAs/Ge, Solar Array 32 m^2 (158 W/m^2)
(Stow as 33 Panels 3.3 m by 0.3 m, Circumferential Wraps)

UNIQUE FEATURES: TES and SAFFIRE Move Below Platform as part of Preseparation Sequence
MLS Scanner Reflector Moves and Scanner Rotates into Operating Position as part of Preseparation Sequence

SUMMARY:	Instrument Mass	1433 kg		Instrument Power	2022 W
	Spacecraft Mass	3031 kg		Spacecraft Power	2725 W
				Solar Array Power	4970 W

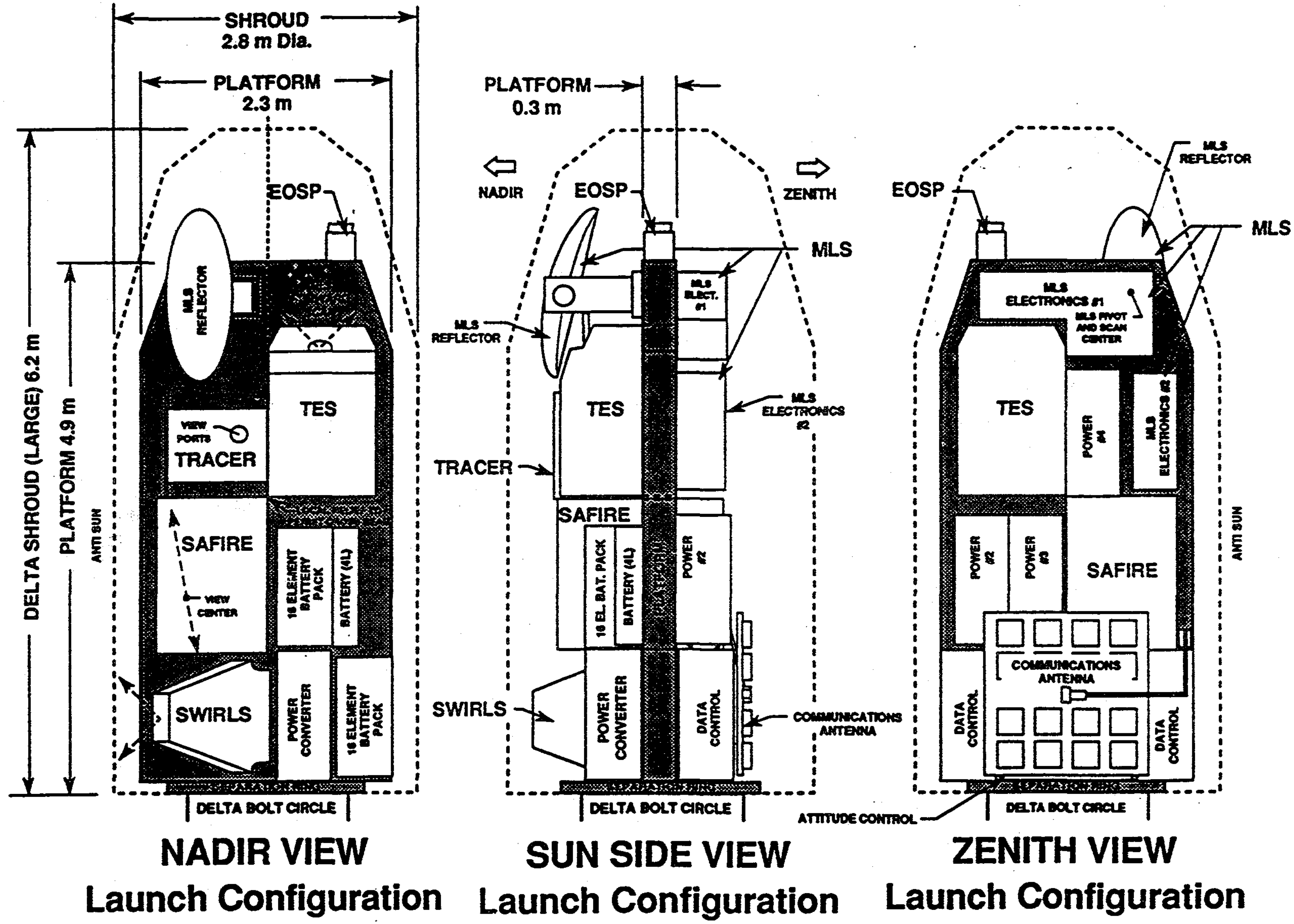


Figure 4-9 Side View Features for Spacecraft Configuration E (Less than 1 Hour Measurements).

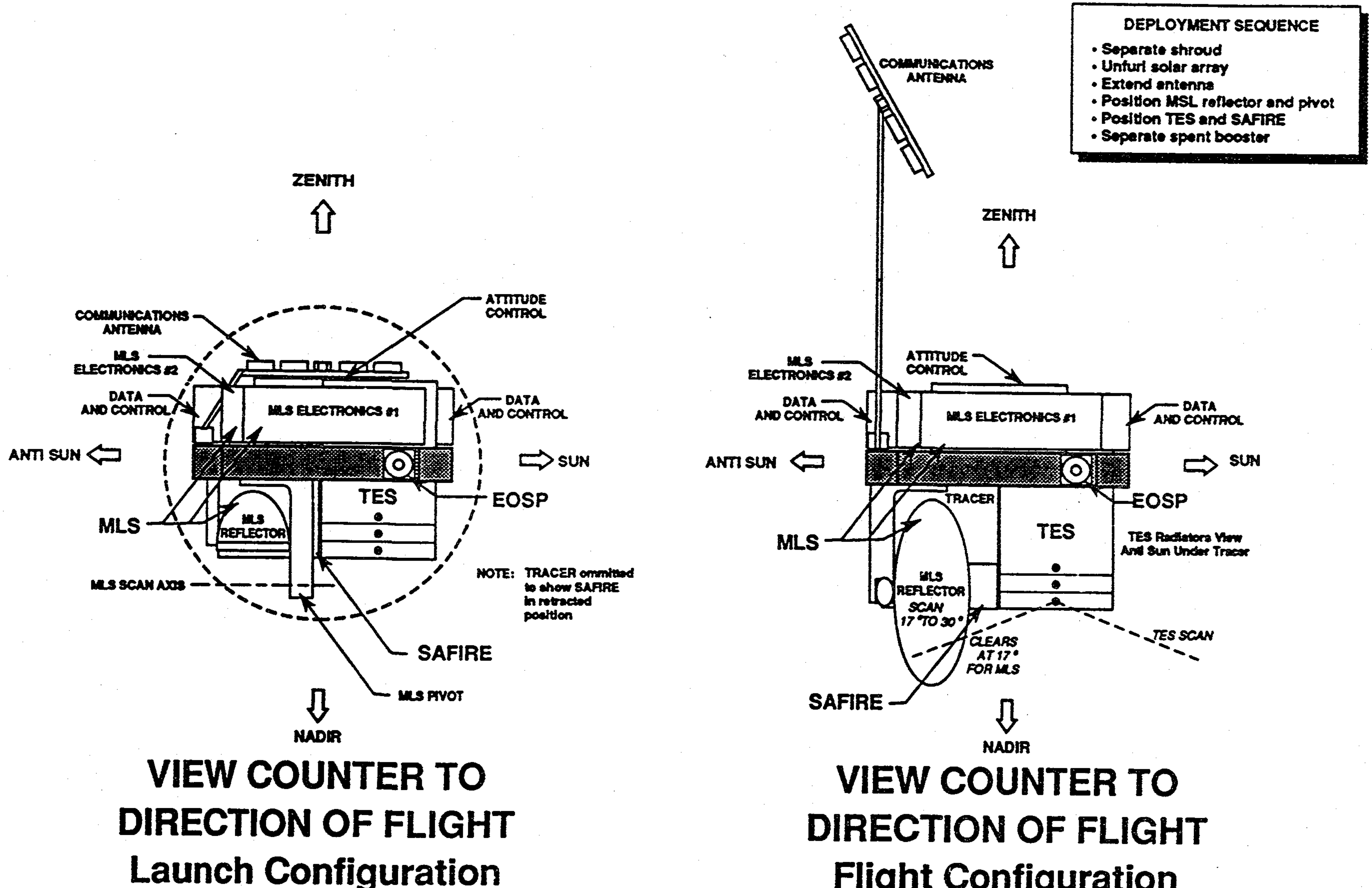


Figure 4-10 End View and Flight Configurations for Spacecraft E.

location of the pivot axes for the moving elements within the MLS instrument. The reflector will move from a launch-compatible position into the flight configuration as part of the deployment sequence. Electronics for the MLS mount on the zenith face of the platform and can accept modularized elements in a multi-unit configuration.

Electrical and Subsystem Accommodations

The six instruments together have the highest power demand of the small spacecraft series which leads to a solar array requirement that results in four power converter modules and a 36-element battery installation. GaAs/Ge solar cells are needed to minimize the area of the array and launch mass. Scanning elements of the MLS instrument are expected to include momentum compensations; however, the attitude control system can anticipate a continuous action in response to residual disturbances. Requirements for platform pointing and stability are associated with the EOSP 10 km resolution and appear as within the momentum capabilities of a single attitude control module.

Operating Accommodations

The principal steps in the deployment sequence for the configuration E appear outlined in Figure 4-10. The MLS is the first to move into a flight operating configuration. Motions of the TES and SAFIRE instruments involve controlled translations accomplished in a straightforward sequence. Scanners within the TES instrument appear to involve small optical elements and do not introduce any significant disturbances into the system. MLS operations include large elements moving about two axes and anticipate momentum compensations to cancel the dynamic interactions such that an active attitude control system can maintain the required stability.

5.0 LARGE SPACECRAFT CONFIGURATION

The large spacecraft configurations address the same temporal requirements as the small spacecraft by placing all the instruments required for a particular orbit aboard a single spacecraft. The large spacecraft constellation alternative, therefore, consists of a dedicated "Configuration A" unit plus four multi-instrument units, of which three are identical. Large spacecraft all require Titan boosters and use the long Titan shroud. Figure 5-1 shows the dimensions of the shroud and the clearance dimensions needed for the proposed spacecraft support structure. Large Titan-launched spacecraft have been proposed that can utilize the present multimission modular elements to provide the spacecraft operating subsystems. Figure 5-2 shows this concept in flight configuration, and Figure 5-3 shows how the load carrying structure will fit into a large Titan shroud.

5.1 Large Spacecraft, 20 On-Board Instruments, Configuration L-1

The features of the spacecraft are summarized in Table 5-1; the layout and accommodations of instrumentation are shown in Figures 5-4 and 5-5. This configuration carries all of the instruments listed for low Earth orbit except the Soil Moisture Measurement Radiometer (SMMR). The 20 on-board instruments amount to 21 units, since the CERES instrument is duplicated in the same manner as for the small spacecraft (Configuration D).

<u>Structural and On-Board Accommodations</u>

The support structure for the large spacecraft utilizes a truss assembly of graphite fiber composite tubes similar to that used on the UARS spacecraft (Reference 13). Estimates of mass as a function of truss length based on UARS data yields a value of 210 kg/m. This value allows for localized tailoring of the support structure to accommodate the specific needs of particular instruments. For truss structures in the length range 10 m to 14 m, the value is considered somewhat conservative.

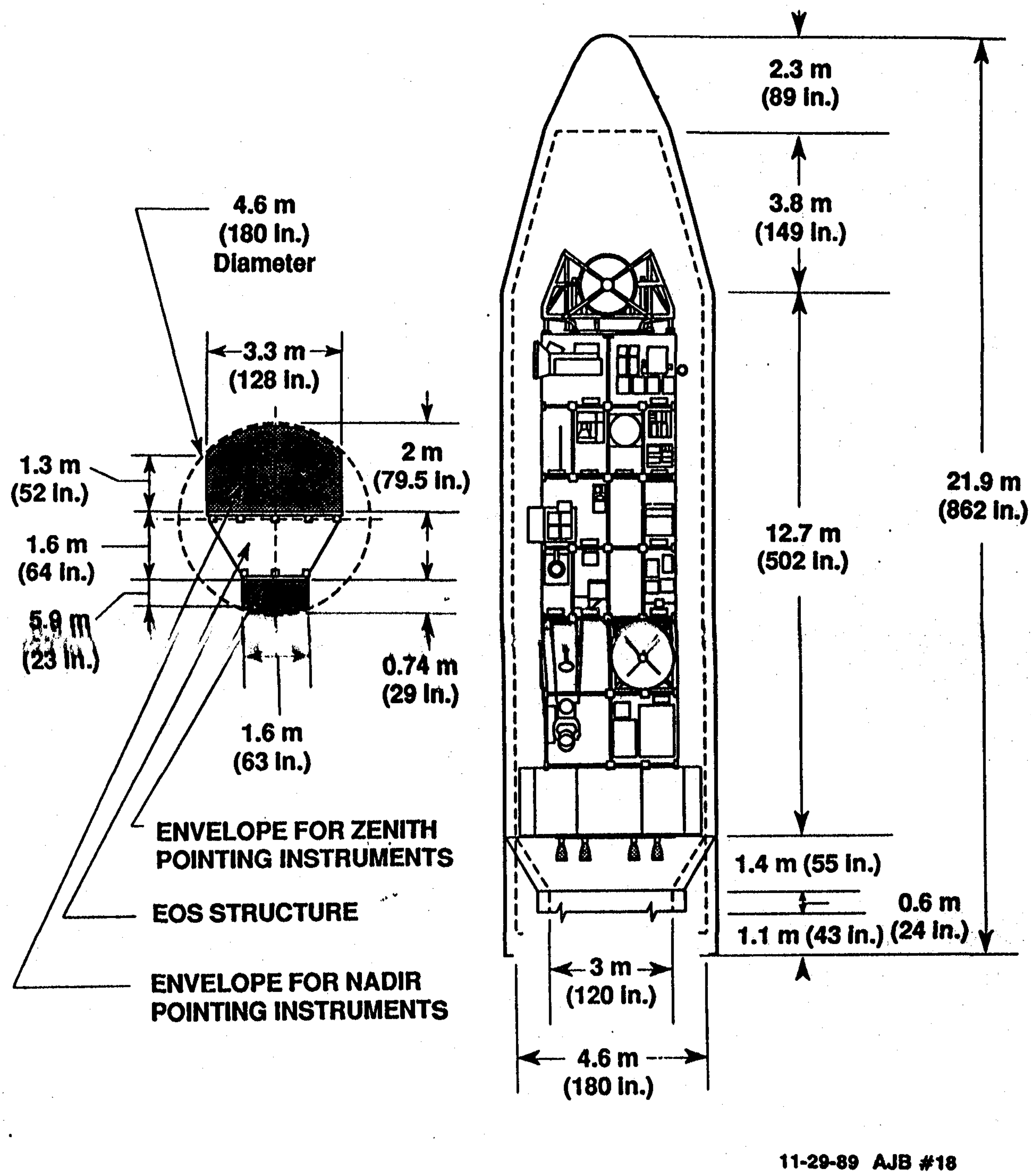


Figure 5-1 Dimensions for the Large Titan Shroud and Spacecraft Clearances Required.

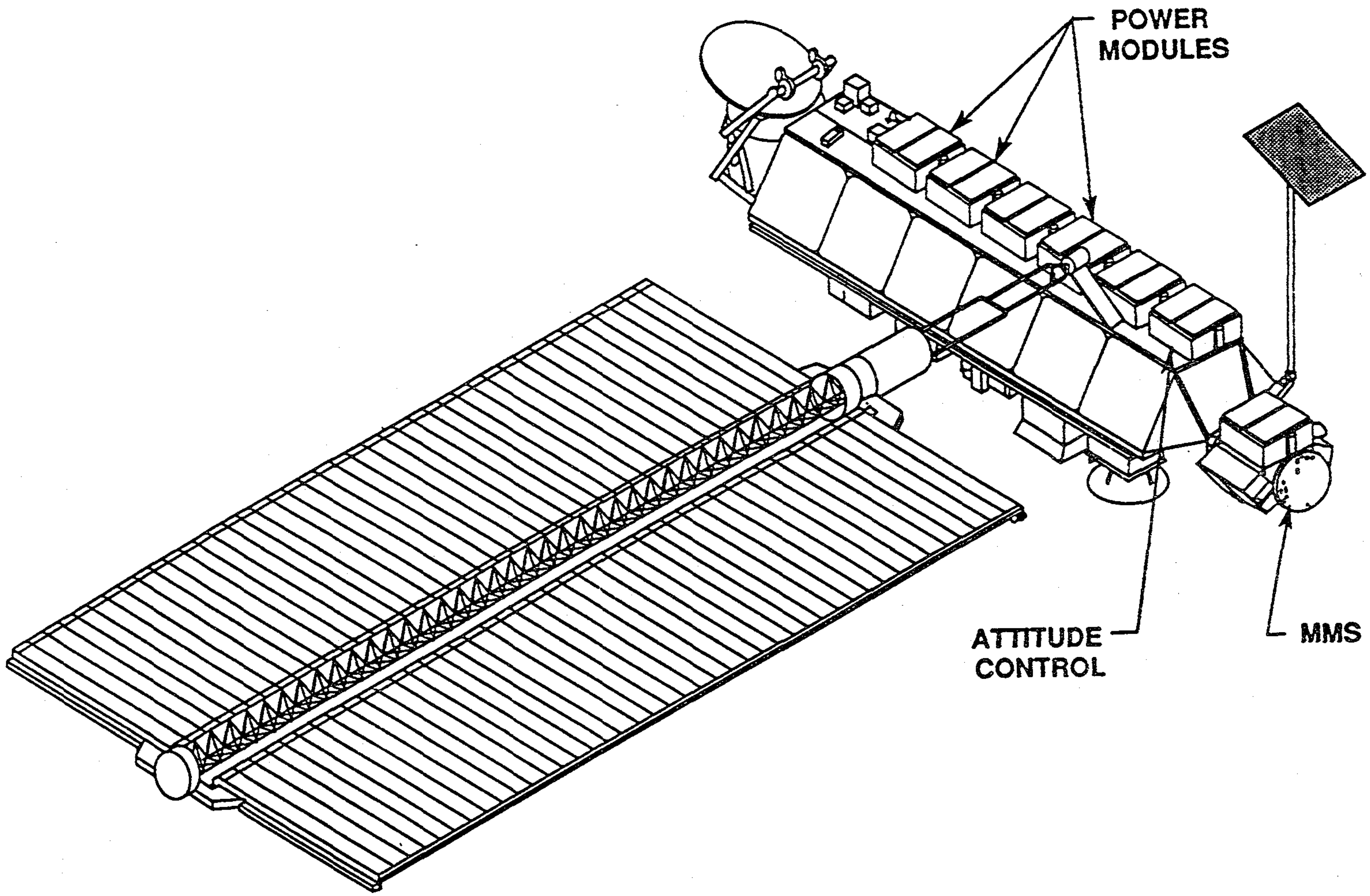


Figure 5-2 Concept for a Large Spacecraft Utilizing the Multimission Modular Spacecraft for Operating Subsystems.

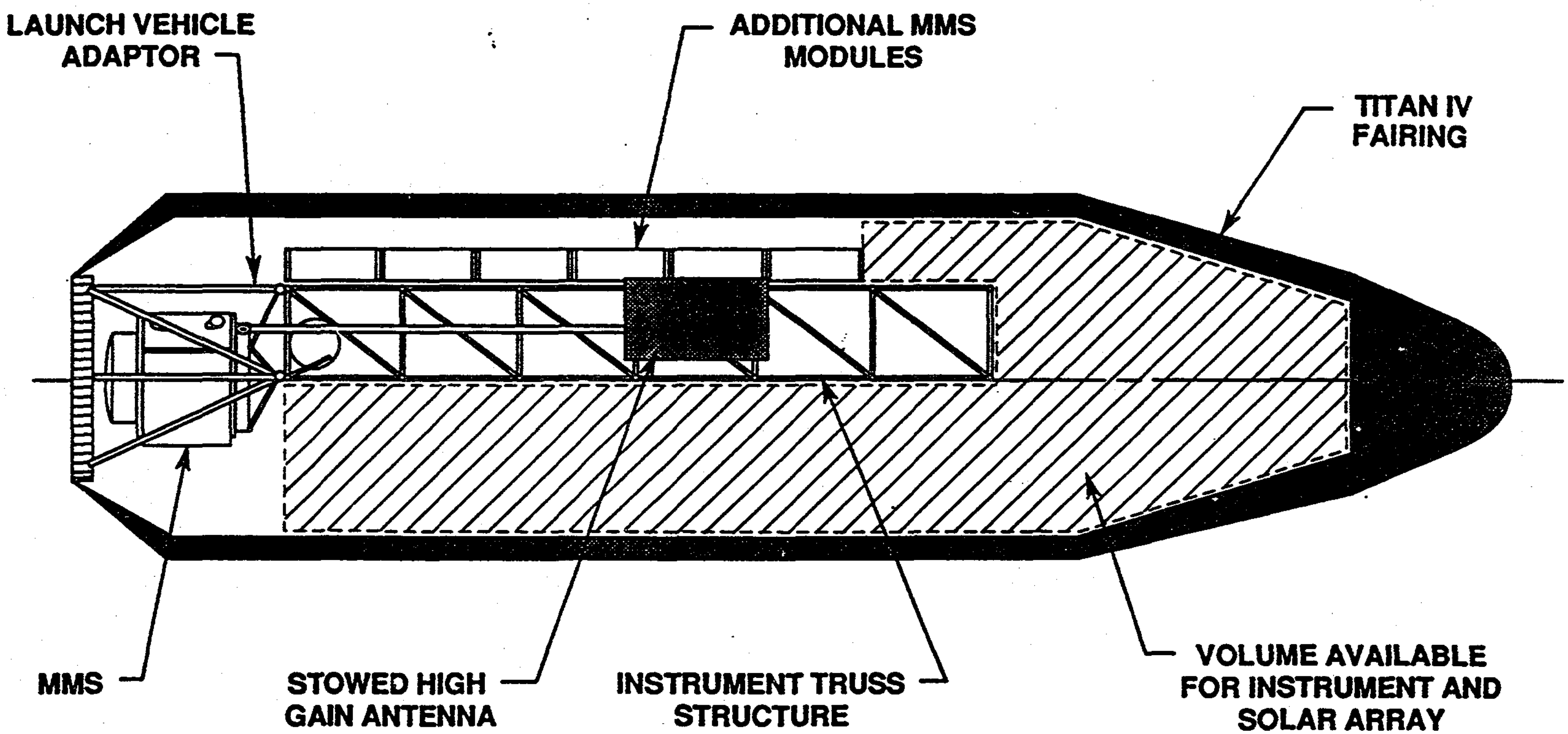


Figure 5-3 Large Spacecraft Structure Within the Long Titan Shroud.

TABLE 5-1 LARGE SPACECRAFT #1 (Large Shroud, Titan Booster)

INSTRUMENTS: 17 Nadir, 3 Solar

MOUNTING: Graphite Fiber Epoxy Truss 14.8 m overall, 3.4 m by 1.6 m

15 Nadir Direct to Truss
APL on Gimbal Platform
HIMMS with Deployable Antenna
3 Solar on Gimballed Tracking Platform

OPERATING SUBSYSTEMS: Advanced MMS in a Triangular Module
Augmentation on Zenith Surface to 4 Attitude Control, 4 Data and 9 Power Converter Units, Auxiliary Internal Tanks Store 700 kg Propellant

POWER AND STORAGE: 4811 W-h in Ni-H_2 Batteries. Solar Array GaAs/Ge, 70 m^2 (158 W/m^2)
(Stow as 7 m by 10 m folded, Space Station Freedom Concept)

UNIQUE FEATURES: Requires 300 Mbps Recording Capability and 10^{11} Bit Storage Capacity
Instruments Arranged to Accommodate Space Radiator Requirements in addition to Field of View Requirements

SUMMARY:	Instrument Mass	3871 kg	Instrument Power	4840 W
	Spacecraft Mass	10491 kg	Spacecraft Power	6050 W
			Solar Array Power	11040 W

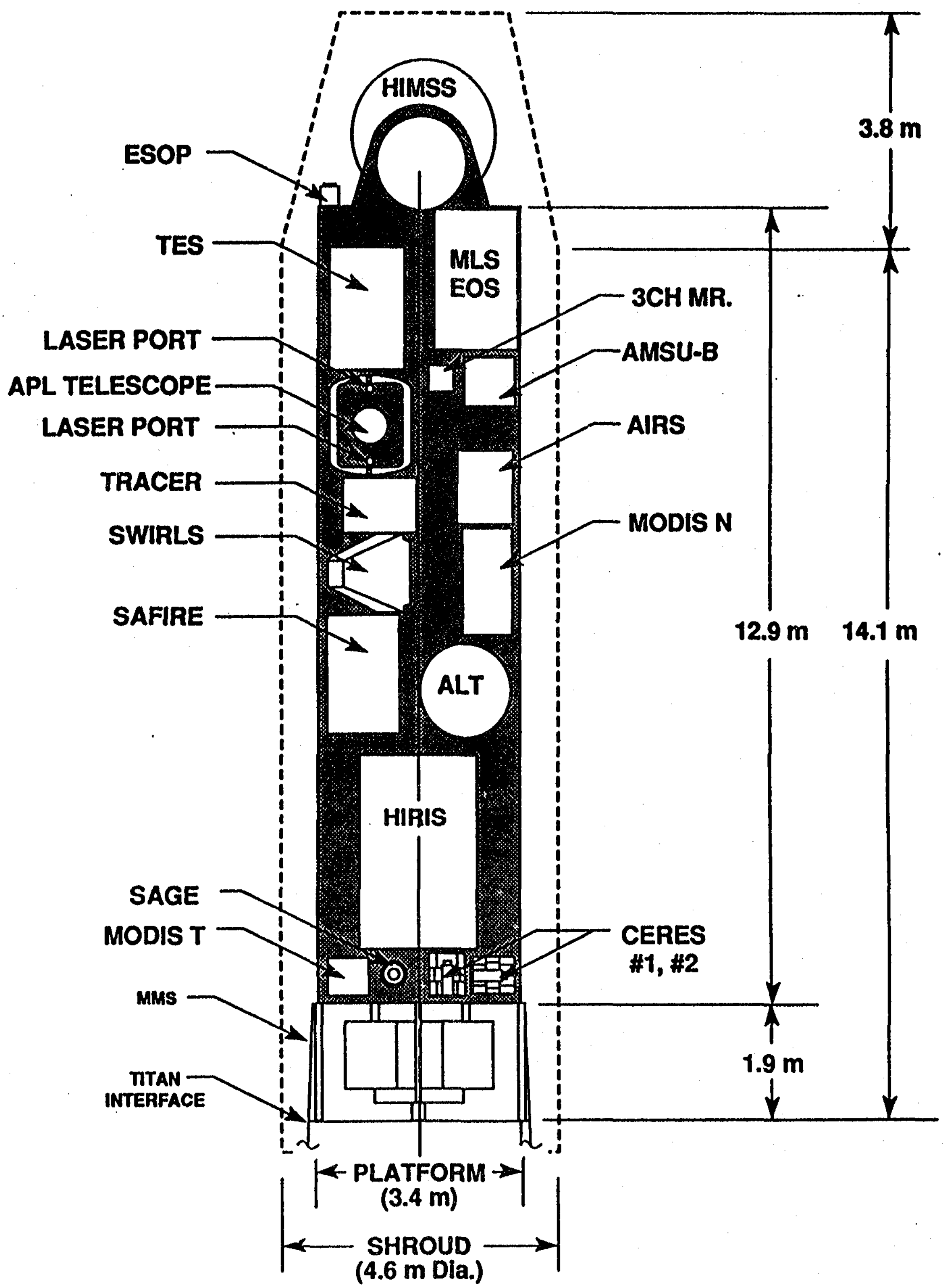


Figure 5-4 Layout of Instruments and Accommodations Within a Titan Shroud for the Large Spacecraft Configuration L-1.

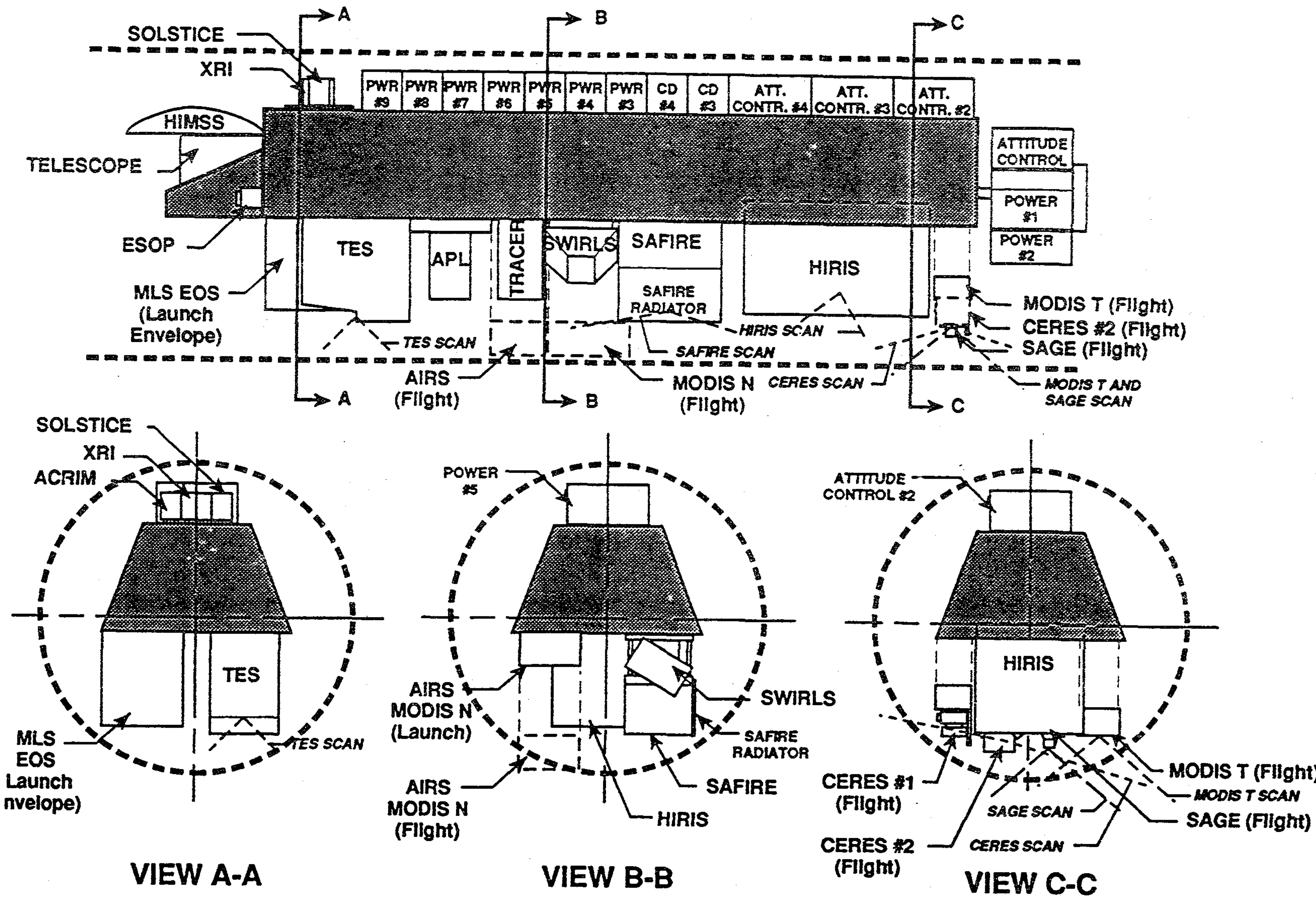


Figure 5-5 Side View and Cross Section for the Large Spacecraft Configuration L-1.

Instrument accommodations follow the requirements defined in terms of both viewing and heat rejection by space radiators and are the same as to the small spacecraft. Solar-sensing instruments mount on the same gimballed table used for the small spacecraft (Configurations B and D) and it is located at the forward end of the zenith surface. The other instruments are arranged to accommodate their particular viewing requirements. Truss structure allows some flexibility, since instruments can extend into the truss envelope and both the APL and HIRIS instruments take advantage of that flexibility. Space radiation requirements for the AIRS and MODIS-N instruments require mounting on a deployable substructure. (Figure 5-5 illustrates the concept.) The deployable mount carries the instruments against the truss during launch; during orbital flight operation, the instruments are positioned to allow space radiators to view in the anti-sun direction below the envelopes of the instruments mounted on the anti-sun side of the truss. A similar deployable substructure carries the MODIS-T, SAGE and CERES units. For these instruments, the deploying mount accommodates the viewing requirements.

Electrical and Subsystem Accommodations

Masses, power demands, data rates, and data recording capacities require multiple subsystem modules for their accommodations. The capacity of the attitude control momentum wheels has been estimated at 3000 kg for a dynamically active spacecraft; additional modules are added proportionately. Data handling requirements are potentially within the capabilities of the NDLM; however, the need for flexibility in data accommodation leads to an on-board duplication of the small spacecraft system. Modularization of power conversion modules on the basis of a 1300 W solar array input establishes the number of units carried. Mounting of subsystem modules for the large spacecraft includes an assembly like an existing MMS with the auxiliary units mounted along the zenith surface of the truss structure; Figure 5-5 shows the accommodations for the subsystem modules. Energy storage requirements (4811 W-h) equate to 80 battery elements which would be assembled into the 8 element modules as used for the small spacecraft (Configurations B and D). These 10 battery modules then mount on the truss side of the zenith surface in a manner that best suits inertial and center-of-mass considerations. The propulsion system, as shown, utilizes the existing MMS module to carry the attitude control and velocity correction thrusters. A large spacecraft will require additional propellant, and the extra inventory is carried in spherical tanks located within the truss envelope in a manner that minimizes the effects of propellant utilization on the inertial properties of the spacecraft.

Operating Accommodations

Operating accommodations for the large spacecraft assume that the last stage of the booster system provides the thrust and controls to achieve the desired sunsynchronous orbit. The sequence to achieve spacecraft operation begins with jettison of the shroud and proceeds through solar panel deployment and erection of the antenna in the same general manner as for the small spacecraft. Particular steps associated with the spacecraft instruments begins with the deployment of the extension sections for the AIRS-MODIS-N and the MODIS-T-SAGE-CERES instruments. Instrument-specific actions include the positioning of the HIMSS antenna together with initiating the barrel rotation; the initiation of scan by the APL; and the verification of traverse by the MLS. The final instrument-related events are the release of the HIRIS gimbals and solar acquisition by the ACRIM, XRI and SOLSTICE. Actual separation from the spent booster occurs at the aft end of the truss, the interface adapter beams and struts release from the truss joints and move to clear the MMS module.

In orbital operation, this spacecraft combines the requirement for a 1 km resolution at the Earth surface in an assembly that includes all the active scanning or rotating instruments (APL, HIMSS, HIRIS, MLS, etc.) plus a large area solar array. Momentum compensation included in the instruments will minimize disturbances; however, the attitude control elements will be active, therefore the additional momentum wheel capacity has been incorporated to provide an appropriate margin.

5.2 Large Spacecraft, 12 On-Board Instruments, Configurations L-2, L-3 and L-4

The features of these spacecraft are summarized in Table 5-2; the layout and accommodations of instruments are shown in Figures 5-6 and 5-7. This configuration carries the same instruments as the combination of Configurations D and E from the small spacecraft series. These large spacecraft will operate in three complementing orbits, thereby satisfying a 3-hour measurement interval for the instruments identified.

Structural and On-Board Accommodations

These three large spacecraft are identical units formed by truncating the support structure defined for Configuration L-1. The layout of the instruments also retains the mounting accommodations defined for the larger unit. Requirements for viewing and space radiators continue for the AIRS, MODIS-N and CERES units and, the deployable mounts are retained on this spacecraft. Truncation reduces both the length of the platform and the mass delivered to orbit; however, the envelope dimensions and masses require a Titan-series booster for delivery to orbit.

Electrical and Subsystem Requirement

The reduced scope of instrumentation decreases the subsystem support requirements. Attitude control modules are reduced by one unit relative to the larger spacecraft to assure adequate margin for momentum control. A doubled communication system has been retained for commonality with the larger spacecraft and power control modules relate to the solar array power. The propulsion capability retains the same configuration.

Operating Accommodations

Operating accommodations follow the same steps as outlined for the larger, Configuration L-1, spacecraft. The steps for shrouds, solar array, antennas and

TABLE 5-2 LARGE SPACECRAFT #2, 3, 4 (Large Shroud, Titan Booster)

INSTRUMENTS: 12 Nadir, 1 Solar

MOUNTING: Graphite Fiber Composite Truss 9.7 m overall, 3.4 m by 1.6 m

11 Nadir Direct to Truss
HIMSS With Deployable Antenna
Solar (ACRIM) on Gimballed Tracking Table

OPERATING SUBSYSTEMS: Advanced MMS as a Triangular Module
Augmentation to 3 Attitude Control, 4 Data and 5 Power Conversion Units
Auxiliary Internal Tanks Store 700 kg Propellant

POWER AND STORAGE: 2584 W-h in Ni-H_2 Batteries. Solar Array GaAs/Ge, 40 m^2 (158 W/m^2)
(Stow as 4 m by 10 m folded, Space Station Freedom Concept)

UNIQUE FEATURES: Instruments Arranged to Accommodate Space Radiator Requirements in Addition to Field of View Requirements

SUMMARY:	Instrument Mass	2009 kg	Instrument Power	2813 W
	Spacecraft Mass	6703 kg	Spacecraft Power	3520 W
			Solar Array Power	6195 W

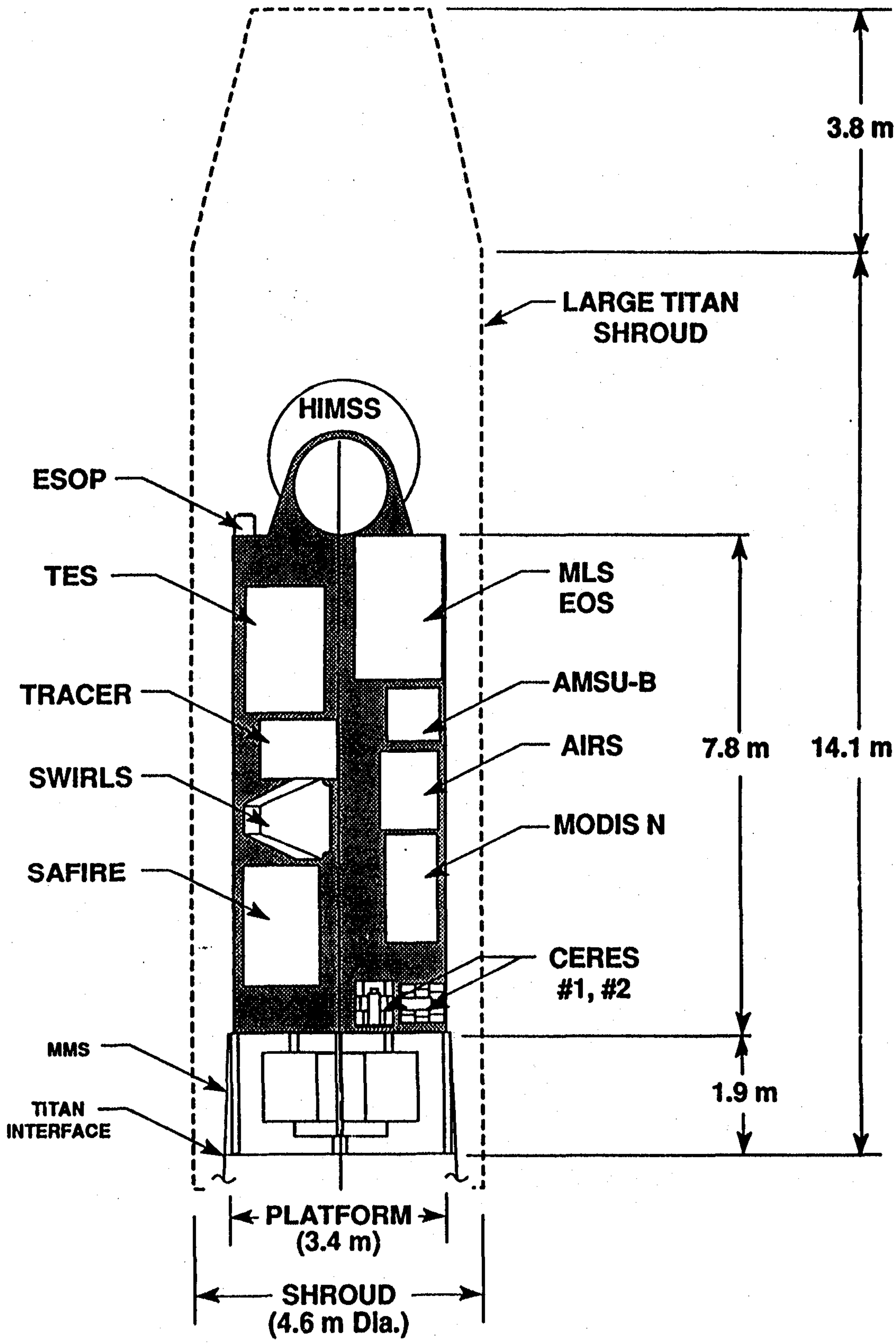


Figure 5-6 Layout of Instruments and Accommodation Within a Titan Shroud for the Large Spacecraft Configurations L-2, L-3 and L-4.

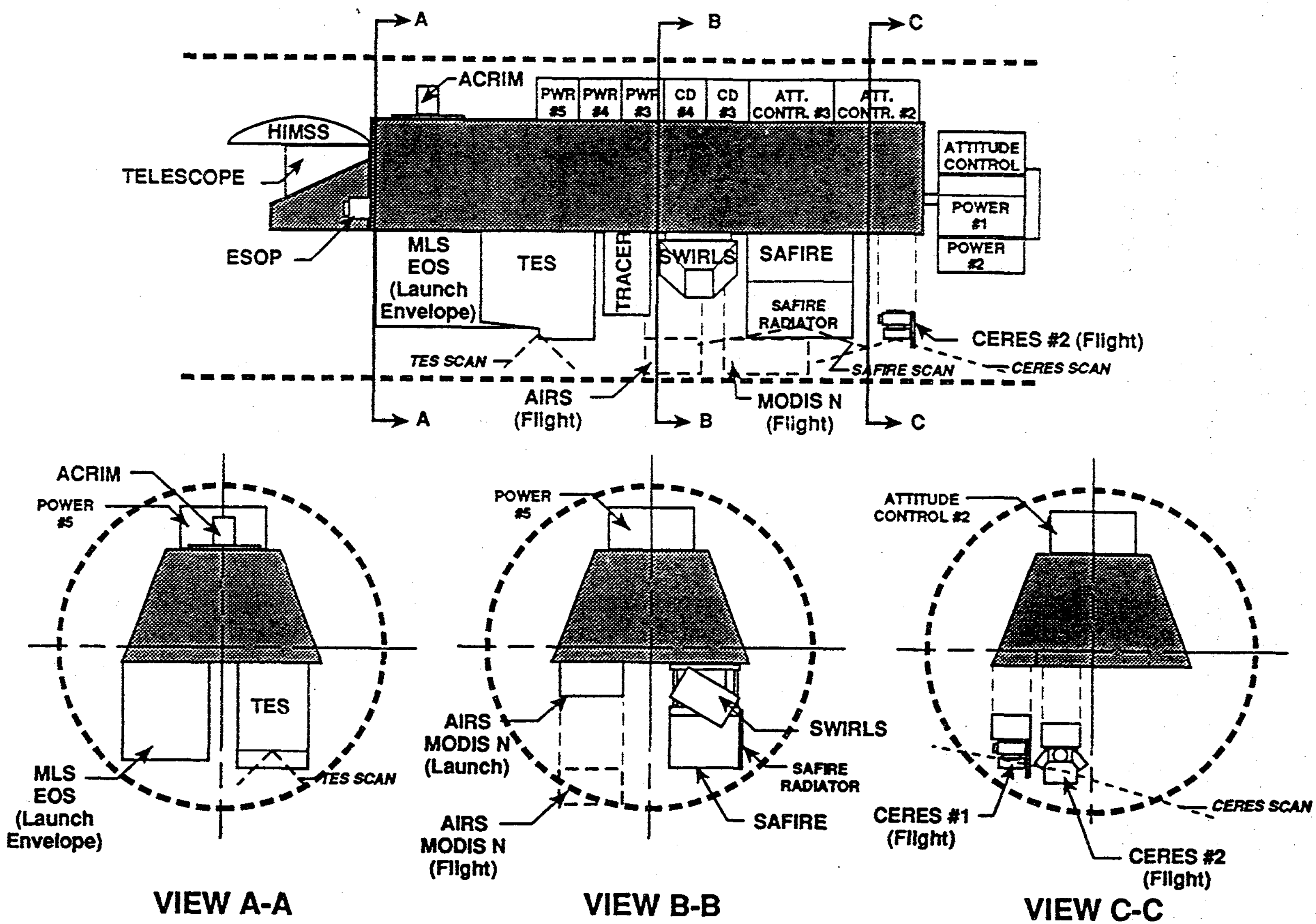


Figure 5-7 Side View and Cross Section for the Large Spacecraft Configurations L-2, L-3 and L-4.

instrument deployments are identical. Actions to initiate the dynamic instruments are the same for HIMSS and MLS which then followed by the ACRIM acquisition of the solar disc as precursor to separation from the spent booster. HIMSS and MLS operation during an orbit will require a continuous momentum correction. The momentum margin provided by three attitude control modules will assure the 1 km resolution of the Earth surface for the AIRS and MODIS-N instruments.

6.0 COMPARISONS AND ASSESSMENTS OF SPACECRAFT ALTERNATIVES

The comparisons of the spacecraft alternatives address the numbers of spacecraft, the boosters required and the masses delivered to orbit. Assessments of the spacecraft address operational considerations such as flexibility and replacement. Both of the alternate spacecraft constellations include the large antenna radiometer unit intended for measurement of soil moisture, therefore, comparisons and assessments need consider only the 10 unit small spacecraft configurations and the 4-unit, large spacecraft configurations. The pertinent considerations first address numbers of units and masses delivered to orbit as comparisons of equipment requirements and then address the operational features. Operational considerations identify the inherent advantages and disadvantages for each of the alternatives while recognizing that an advantage offered by one alternative could be the disadvantage associated with the other alternative.

6.1 Comparison of Masses and Quantities

The summaries of masses and quantities of equipment delivered to orbit appear in Tables 6-1 and 6-2. Overall comparisons of spacecraft assembled and boosters expended stand as 10 small or 4 large which becomes the basis for comparing total masses and quantities of spacecraft equipment delivered into orbit.

The total mass for the 10 small spacecraft shows a slight advantage relative to the total mass for the large spacecraft. A comparison of contributing elements summarized in Table 6-2 indicates the principal differences. Numbers of instruments and total mass of instruments delivered to orbit are essentially equal; the difference is the 6 additional EOSP units and the one extra ACRIM unit required for the small spacecraft. The principal difference appears in structure, and this difference relates to the accommodation of loads during launch acceleration. The small spacecraft utilize short, stiff platforms and carry instruments in a manner that minimizes bending reactions. During launch they act as axial-compression loaded, deep-webbed beams with the loads effectively applied within the dimensions of the web. The structures for the large spacecraft

TABLE 6-1 COMPARISON OF SPACECRAFT ALTERNATES

	Small Spacecraft Option	Large Spacecraft Option
All Spacecraft And Mass Total	10 Spacecraft Total: 1 "B" Large Delta, 2,500 kg 1 "C" Small Delta, 2,200 kg 4 "D" Large Delta, 8,000 kg 4 "E" Large Delta, 12,400 kg	4 Spacecraft Total: 1, L-1 Titan 10,500 3, L-2 Titan 20,100
Total Mass In Orbit	25,100 kg	30,600 kg
Number of Boosters Required	10 Delta	4 Titan

TABLE 6-2 MASS ELEMENT COMPARISON

	Small Spacecraft (10)		Large Spacecraft (4)	
	No. Units	Mass kg	No. Units	Mass kg
Instruments	67	9988	60	9898
Structure	(10)*	3500	(4)	8925
Communication Data Handling	10	2750	8	1680
Attitude Control	10	2150	13	2795
Electrical Cont.	29	2755	26	2470
Batteries	254	1025	209	836
Solar Array	(10)	931	(4)	793
Propulsion	(10)	2000	(4)	3200
Totals		25099		30597

*Numbers identified ( ) are numbers of spacecraft.

are two to three times the length and about two times the width of the smaller spacecraft. In addition, the shroud limitations identified in Figures 5-1 and 5-5 requires mounting all the nadir facing instruments in a manner that introduces unbalanced bending moments during launch. The truss structure defined for the large spacecraft follows present technology and assumes that the launch forces and their effects on the asymmetric support structure can be accommodated within the mass limits identified.

The electrically operating subsystems show some mass advantages that favor the large spacecraft systems, these represent economies of scale associated with modularization. The attitude control appears as the exception, and stems from modularization based upon mass (3000 kg). The propulsion system also has a larger mass requirement for each of the spacecraft. These values are considered estimates based upon relative masses and relative cross section areas.

In assessing the differences between the masses delivered to orbit, the instruments and subsystems are either equal or show some advantage associated with scale. The significant differences appear in propellant requirements and structure, and these estimates carry the largest degree of uncertainty. A more comprehensive analysis for each area could reduce the differences. Since the total difference between the estimates is less than 20 percent, the comparisons of mass do not show major differences between the two alternatives.

6.2 Assessments of Small Spacecraft

The temporal requirements associated with the GCTI measurements establish the need for multiple, identical spacecraft and the small spacecraft alternative turns that requirement into an advantage at the expense of some additional complexity in the operation of ground controls. Specific anticipated advantages and disadvantages are summarized as follows.

Anticipated Advantages

1. Modularization. The multi spacecraft requirements generated by the GCTI mission necessitate modularization of the spacecraft operating subsystems. The small spacecraft configurations can make an effective utilization of the modularization. Concepts generated for the study provide redundancy in the data handling and communication links and a capacity to effectively tailor power control elements to the power demands of the spacecraft. These capabilities are advantageous to the GCTI spacecraft configurations since they require relatively large amounts of power, the smallest solar array defined generates 2410 W, which is about two times that used for the present operational NOAA units (TIROS-N).

2. Integration of Instruments. The small spacecraft configurations carry fewer instruments and thereby reduce the interface and integration requirements associated with a spacecraft. The grouping of instruments also eases some of the constraints within the operation of the spacecraft. Such an effect shows for the cases of configurations C and E where the attitude control requirements relate to a 10 km surface resolution as compared to configurations B and D which must respond to a 1 km surface resolution requirement. GCTI spacecraft will use dedicated microprocessors communicating by optical fibers as the principal means for operating control and exchange of data such that software accomplishes most of the integration. Grouping instruments with similar needs for spacecraft support functions also eases the integration of instruments into a spacecraft system, a feature provided by the small spacecraft option.

3. Fabrication and Assembly. The combination of standardized modules, a standard adaptor ring and a platform fabricated from conventional structural elements (eg. channels, angles, sheets) eases the processes of fabrication and assembly. The platforms and solar arrays are the

only unique elements within a small spacecraft configuration, and these are essentially modularized at the sub element level.

4. Configuration Flexibility. The four configurations defined for the GCTI spacecraft show the inherent flexibility of the design approach. These concepts provide the capability to configure a spacecraft to fit a need. These spacecraft can respond to the availability of an instrument in a manner that provides the earliest opportunity for the return of measurement data. Small spacecraft can supplement larger systems to extend the range of measurements needed to evaluate an effect of interest. Finally, small spacecraft are readily duplicated such that additional units can be placed in complementing orbits or a critical instrument can be replaced in orbit by flying a small unit companion to another spacecraft.

Recognized Disadvantages

1. Multiple Spacecraft Operation. The small spacecraft configurations have two or more units in each of 4 sunsynchronous orbits. The ground control systems will need the capability to handle up to 11 spacecraft with as many as 5 moving in a closely spaced group.

2. Implementing Organization. The implementation of the small spacecraft will require a dedicated organization capable of addressing and controlling four spacecraft configurations in which data from one spacecraft complements measurements from a companion unit. Effective implementation of the small spacecraft alternates will require design, fabricating, assembly and test teams that can respond to the integration and interaction requirements. In such a context, the small spacecraft series differs from previous scientific probes which have tended to be independently configured and independently operated.

6.3 Assessments of the Large Spacecraft

The large spacecraft alternatives appear as the conventional approach to a multi-instrument, dedicated-mission spacecraft. The required instruments are placed in orbit aboard the least number of spacecraft. Corresponding advantages and disadvantages are summarized as follows.

Advantages

1. System Commonality. The large spacecraft series makes a direct approach to the integration of instruments and yields two spacecraft configurations in which the smaller unit is a derivative of the larger. These spacecraft offer the economy of scale in the use of the operating subsystem modules which support both alternates. A selection of one size spacecraft to provide the design approach would allow some adjustment in the increments for modularization of power, mass, data rates, etc. The larger spacecraft have the capability to utilize commonality up to the practical limits.

2. Operational Commonality. The ground control operation for these spacecraft would follow the presently established procedures that address near-identical units in complementing orbits such as the NOAA-TIROS-N series. The quantity of data return presents its own complexity which is independent of spacecraft configuration.

Disadvantages

1. Design and Operating Constraints. The operating subsystems and structure for the large spacecraft must accommodate the combined requirements of narrow earth measurement resolutions and highest data rates. Large spacecraft result in the most inherently flexible structure while demanding pointing accuracies and attitude controls to operate within the closest tolerances.

2. <u>Measurement Opportunity</u>. The instrument (or instruments) which incur the longest development and delivery cycle will effectively establish the earliest time for data availability from any of the instruments. In addition the large spacecraft limit recoveries from on-board instrument anomalies to just the actions associated with an operational work-around.

6.4 Assessment Summary

The assessments of the two configuration alternatives do not define a preferred approach. In contrast they identify a potential means for implementing the science measurements in a manner that allows feedback from ongoing measurements to assist or refine follow-on investigations.

The instruments identified for the GCTI measurements show a range in development status that extends from preliminary design to flight ready. A number of the GCTI instruments are presently identified for flight aboard spacecraft presently moving through their design and fabrication phases. The small spacecraft concepts offer the capacity to augment the data from existing spacecraft by placing selected instruments in companion orbits. In a similar manner small spacecraft can operationally evaluate refined or improved versions of presently operational instruments. At some time later, the flight-proven, effective instruments can be placed aboard a large platform and operated for an extended period of time. Small units can then provide special support or specially focused measurements in response to need. This concept for a combined, integrated approach to spacecraft appears well suited to a scientific program that assesses changes occurring in the time frame of decades-to-a-century.

7.0 ASSESSMENTS OF SPACECRAFT AND SUBSYSTEM TECHNOLOGY REQUIREMENTS

The assessments of spacecraft-related technology requirements immediately show the need for accommodating large quantities of data with a particular emphasis on transmission links. The total data transmission requirements for GCTI include the additional contributions from the Soil Moisture Radiometer Spacecraft and spacecraft in geosynchronous orbit. These combined requirements are recognized and addressed separately. In addition, the technology associated with accommodating high data rates within spacecraft are also addressed as part of the data transmission system and appear in the spacecraft definitions as part of the dedicated microprocessor utilization. In context, therefore, assessments of the spacecraft related technologies or technical considerations are addressed below in terms of the operating subsystems and structure beginning with communication and data handling.

7.1 Communication and Data Handling

The data storage requirements identify the need for recorders with a 10^{12} bit capacity. Summaries of spacecraft operating requirements (Tables 2-2 and 2-4) show data rates which can generate more than 10^{11} bits during the course of an orbit. Estimates of storage requirements do not address intervals between data transmissions or any requirements for assured data that results in redundancy of recording. A number of data storage systems have been identified as candidates for achieving capacities up to 10^{12} bits (Reference 6) and techniques approaching 10^{11} bit storage are considered within the capabilities of present spacecraft subsystems. Requirement for spacecraft on-board compatibility in terms of power demand and physical size combine to establish the level of achievement necessary for GCTI application. The LaRC is developing a modularized unit based upon a 0.36 m diameter optical disc which appears as a candidate of promise (Reference 10).

The balance of the components within the communications and data handling system are addressed in the development efforts associated with the NDLM (Reference 6) and would be available for GCTI subsystem modules.

7.2 Attitude Control

The requirements for attitude control subsystem operations appear within the capabilities of the planned improvements for the present MMS units or the Hubble Space Telescope reaction wheels. Stability requirements for a 1 km surface resolution limit approximate those listed for the present MMS units (knowledge to 0.01 degree). Improvements in response to momentum control plus the improvements in accuracy associated with the an optical gyro are expected to provide the necessary control capability. In addition, any improvements in the sensitivity of the star tracker, a larger magnetic torquer and the use of a dedicated microprocessor should combine to provide the combinations of position knowledge, attitude reference, and overall computational cycle times that will assure the required precision through the orbital measurement sequences.

7.3 Electrical Power Generation and Distribution

The electrical power generation and control subsystem shows three areas which require the achievement of present development goals:

a. Solar Array Conversion Efficiencies. The power demands for the GCTI instruments require a minimum performance equal to that identified for GaAs/Ge end-of-life at 158 W/m^2 and 45 W/kg. These values equate to about a 12 percent energy conversion efficiency. Candidate cell systems exist which have conversion efficiencies extending past the 20 percent level, (Reference 8) and availability of these alternates would be incorporated into any GCTI configuration as a means to reduce the area of the solar array.

b. Energy Storage. The instruments which require the most power also operate continuously and therefore require an energy storage capability that equates to a fully developed Ni-H_2 system at 45 W-hr/kg operating with a 33 percent depth of discharge. A limited number of GCTI compatible alternate storage systems exist (Reference 8), such that the Ni-H_2 system may represent the realistically available option; the GCTI study underscores the need for continued development.

c. Power Regulation Efficiency. The modularization of power control and regulation at 120 VDC and 1300 W input assumes operation at efficiencies that have less than a 60 W total power loss within the module. Performance at these levels is considered achievable, (Reference 8) and becomes necessary to allow the freedom of placement as indicated in the concepts shown. The present MMS unit with the internally mounted Ni-Cd batteries has a mounting constraint such that direct sun light must not fall on the thermal control louvers.

7.4 Propulsion

The GCTI spacecraft will utilize the presently defined MMS system modified to operate with dedicated microprocessor controls and modified tankage for storing the propellant. The performance achievable by a monopropellant hydrazine system offers the best alternate compatible with the GCTI mission and spacecraft configurations (Reference 8). Relocation of thrusters and the addition of auxiliary tanks are considered available technology.

The principal function of the propulsion system will be reboost velocity correction using the large thrusters; vernier thrusters operate to reestablish the nadir facing orientation. Reboost requirements have not been specifically defined; individual spacecraft appear relatively small and dense, with correspondingly small drag effect predictions. On the other hand, the relatively large area solar arrays do increase the potential for drag effects, therefore, an increased propellant capacity has been included for each of the spacecraft configurations.

7.5 Structure

The GCTI spacecraft utilize a refinement of existing structural concepts as follows:

a. Small Spacecraft Platforms. Structure is based upon the development of graphite fiber reenforced composites to achieve a specific mass of 22 kg/m^2 while subjected to the launch accelerations of a Delta booster. The technology identified would extend present approaches based upon structural shapes to permit modularizing a platform to accommodate the instruments and supporting electronics modules during both launch accelerations and orbital operation.

b. Large Spacecraft Trusses. The truss structure assumes development to the point of 210 kg/m over the working length above the booster interface with the capability to accept asymmetric dynamic loadings during a Titan launch. Worst case instrument asymmetry could impose a loading of up to 300 kg/m at 0.5 m offset distributed over the nadir facing portion of the truss.

7.6 Assembly Integration and Test

The GCTI spacecraft identify developmental requirements and particular improvements related to these elements of the implementation sequence.

a. Integration Test Bed. The concepts for operational integration utilizing dedicated microprocessors moves much of the system complexity into software. A test bed using linked microprocessors, instrument simulators, and operating subsystem modules would allow the operational integration to proceed in concert with the fabrication of the spacecraft. The test bed would follow the concepts utilized for the present LaRC Air Lab such that the electrical operating portions of flight equipment could be operationally verified before assembly into the actual spacecraft. (GCTI spacecraft assembly assumes all operations will be in a "clean room".)

b. Structural Dynamics Predictions. All of the GCTI spacecraft carry instruments with moving or rotating elements and some of the motions involve components with masses sufficient to interact directly with the attitude control function (eg. HIMSS rotation, HIRIS, MLS, APL scanning). The GCTI spacecraft identify the need for structural dynamic modeling to the level necessary for predicting the type of interaction (eg. transient, cyclic, steady state), establishing the level of the interaction (eg. forces, deflections) and the verifying the responses as programmed into the attitude control algorithm.

c. Scanning Element Reaction Force Profiles. The instruments with large scanning elements such as APL, MLS and HIRIS were assumed to include momentum compensators, however, the method employed and techniques for implementation were not specifically defined. Experience with oscillating equipment has shown the presence of transient disturbances coincident with reversals in direction of motion (Reference 14). The GCTI spacecraft identify the need for both scanning drives and momentum compensation elements which generate predictable transients with levels and profiles that fall within the response capabilities of the attitude control elements.

d. Integration of Structure, Thermal and Electrical Assemblies. The GCTI spacecraft concepts utilized stand-alone modularization for all of the electrically operating assemblies. Freedom of placements implied improvements in efficiency such that thermal dissipations were not a constraint upon location. The MMS concept of controllable louvers is implied by the general retention of package dimensions and estimates of masses. An opportunity exists within the GCTI spacecraft to integrate the mounting plates for electrical functions into the structure of the platforms or trusses in a manner that provides both structural stiffening and thermal radiation. The small spacecraft configurations B and D offer a potential example. The power control modules could be mounted upon an aluminum-based metal matrix composite plate element that formed the anti-sun side of the platform. During launch the structural elements would carry the thrust loads, during operation the same elements would provide a space radiator for heat dissipation.

7.7 Implications of Technology Assessments

The study to define spacecraft configurations to implement the modeling of global changes has generally reenforced the rationales for continuing the present areas of subsystem and component development. On-board data storage requirements for GCTI instruments would arise from any scenario addressing the combination of measurements identified by similar science requirements. The need for flexibility in the configuration of spacecraft exists and underscores the need for uprating the performance of circuitry and improving the modularization. Presently defined, large, research-oriented spacecraft show configurations intended to support a number of investigations within a roster of on-board instruments. Global Change Initiative requirements identify the need for measurements in addition to those provided by existing spacecraft and thereby establishes a need for rapid response in configurating a spacecraft. The structural, assembly, integration and test related developments cited above specifically address features of a technology infrastructure capable of making a rapid spacecraft response to a set of scientific requirements that can be defined in terms of specific flight instruments.

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HOOP COLUMN SOIL MOISTURE SPACECRAFT IN LOW EARTH ORBIT FOR GLOBAL CHANGE MONITORING

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1.0 INTRODUCTION, SCOPE AND CONTENTS

A subset of the total GCTI instruments are required to be in low Earth, sun-synchronous orbits. There is one instrument, however, that requires its own specialized spacecraft; the Soil Moisture Microwave Radiometer (SMMR) as seen in Figure 1. The characteristic structure of the instrument is the 118m hoop column support structure. The hoop is supported by an axially placed column. Tension cables support and shape an electromagnetically reflective mesh surface. The instrument is capable of detecting frequencies in the 1.4 GHz range (Soil Moisture and Sea Salinity). Three apertures are used to reduce the degree of paraboloid offset and improve beam quality.

The spacecraft configuration is determined by the instrument support requirements and the requirement that it can fit into the Titan IV cargo bay. The configuration is derived by cross-referencing the instrument performance requirements with the performance of the spacecraft. The spacecraft design is similar with the Multi-mission Modular Spacecraft in terms of size and packaging. A description of the spacecraft's features will yield a summary of the technologies needed for the SMMR spacecraft.

2.0 INSTRUMENT REQUIREMENTS AND SPACECRAFT DEFINITION

2.1 Spatial and Temporal Requirements

In order to detect soil moisture and sea salinity from orbit, Foldes [1] states that a minimum spatial resolution is 1 - 10 km. Other resolutions are required for specialized applications such as climate, hydrology, and open ocean sensing. The orbit for the SMMR is one that allows a 12 hour repeat coverage in sun-synchronous orbit.

2.2 Instrument Operating Requirements

The instrument requirements impact the spacecraft in every critical area from attitude control to vehicle sizing. The instruments mass, 3895 kg, is the primary driver in the spacecraft's bus design. The instrument's power requirement, 300 W, is within established power subsystem design criteria.

2.3 Instrument Mounting and Accommodation

The SMMR has only two desired attachment points for the spacecraft bus. These points are at the top and the bottom of the column. It is unacceptable to place the spacecraft bus along the hoop segments because of the maximum diameter packaging requirement for the Titan IV cargo bay. Figure I shows the Spacecraft/instrument combination.

2.4 Spacecraft Definition

The SMMR spacecraft is a cylindrical spacecraft two meters long and three meters in diameter. The spacecraft and the instrument are launched into sun-synchronous orbit via a Titan IV booster. The subsystems were sized using a combination of flight-proven hardware and empirical formulas derived for spacecraft similar in mission and design. The control system is a three axis stabilized system with reaction wheels for momentum storage and a mass expulsion system for momentum desaturation. The propulsion system is a Hydrazine propulsion system capable of providing reaction control as well as translational control for the spacecraft. The data management system is a system consisting of tape recorders for data storage and a general purpose computer for command decoding and execution. The communications subsystem is designed to link with the Tracking and Data Relay Satellite System (TDRSS). The spacecraft is designed for a 7-year lifetime in a 250 Nmi orbit. The driving feature of this instrument is the feed array. It consists of three sets of feeds (one for each aperture, as seen in Figure 2) and weighs some 2858 kg alone. Although most of the instrument's mass is concentrated in the feed area, the overall size of the reflective surface is what increases the inertia and what the spacecraft must control and point to the right location on the planet.

3.0 SPACECRAFT OPERATING SUBSYSTEMS

3.1 Attitude Control

The attitude control system for the SMMR is a three-axis controlled system consisting of reaction wheels for momentum storage and a monopropellant hydrazine thruster system for momentum desaturation. Since the spacecraft is an Earth-pointing system horizon sensors are required to maintain this orientation. Table I is an assembly level listing of the component parts of the Attitude Control subsystem.

3.2 Communications and Data Management

The SMMR utilizes a modified TDRSS communications subsystem for telemetry, tracking and command. The system requires a dedicated data link of 1.0 kbps and a on-board storage of 260 megabits. Data transfer would be accomplished via S-band or Ku-band link over a three day cycle. A subsystem mass breakdown is shown in Table II.

3.3 Electrical Power

The Electrical power subsystem is a subsystem with a regulated DC bus designed for a 7-year lifetime and a 70% depth of discharge for Nickel-Hydrogen batteries. The subsystem was designed to provide up to 1 kW power for the spacecraft and the instrument. It is a solar array- based system for energy generation and Nickel-Hydrogen batteries are used for energy storage. The solar arrays are separated from the spacecraft bus and placed at the top of the column in order to prevent shadowing of the arrays by the reflective mesh. Electrical cabling will then need to be provided to the power handling systems on the spacecraft bus. Table III shows a breakdown of the component parts of the electrical power subsystem.

3.4 Propulsion

The Propulsion subsystem, as alluded to in the Attitude control subsystem description, is a monopropellant Hydrazine subsystem consisting of six reaction control jets and two translational thrusters. Of all the subsystems on the spacecraft, this one is the only distributed subsystem. In this particular case, the attitude control thrusters are placed on the top and bottom of the column as well as on the hoop in order to utilize the large moment arms afforded by the reflective mesh structure. Therefore, there is a requirement to allow fuel lines and control lines to run from the spacecraft bus to the remote thrusters. A subsystem mass breakdown is shown in Table IV.

4.0 SPACECRAFT PACKAGING

The tri-aperture SMMR is designed to fit into the Titan IV cargo bay. Foldes presents two means of meeting this requirement. The hoop is segmented and designed to fold accordion-style around a telescoping column. This method of folding the reflective surface is employed in both packaging methods. The more challenging problem is packaging the feed array structure to meet the Titan's cargo bay envelope. Again. Foldes discusses two ways of folding the feed structure, the end package and the wrap package. The end package requires that the feed structure be foldes and housed in a "box" placed at the end of the telescoping column. The wrap package indicates that the feed structure is wrapped around the reflective surface package (the stowed hoop and column). Because of the spacecraft's position on the instrument structure (at the end of the column. The end package method is eliminated. Thus, the packing scheme utilized is the wrap package for the feed structure, the hoop is collapsed onto a telescoping column and the spacecraft is attached to the end of the column. This is shown in Figure 3. As seen in the figure, the spacecraft/instrument system does fit within the Titan's payload bay.

5.0 Spacecraft Mass Summary

The total spacecraft mass summary is shown in Table V. The overall mass of the spacecraft/instrument system is 5827 kg. These estimates are based on actual flight hardware mass values and empirical relationships relating capabilities masses of previous spacecraft in this class and their associated subsystems to the predicted performance and mass of future spacecraft. This mass is well within the Titan's payload carrying capabilities. The propellant is sized for a 7-year lifetime and includes propellant for attitude control and stationkeeping. The structure and the thermal control values were estimated using the empirical relationships described above.

6.0 Spacecraft Technology Requirements

The technologies used to size the spacecraft bus and its supporting subsystems are based on current flight-ready and flight-proven hardware [2]. The improvements in technology in the various subsystem disciplines could only help to increase the performance of the spacecraft. The instrument utilizes state-of-the-art materials in its reflective mesh and support structures. Improvements can be realized in the feed arrays and its electronics in order to drive the weight down to a more reasonable level. There is need to further study deployment methodologies for the reflective mesh structure in order to understand the dynamics associated with the unfurling of such a large structure with distributed utility lines.

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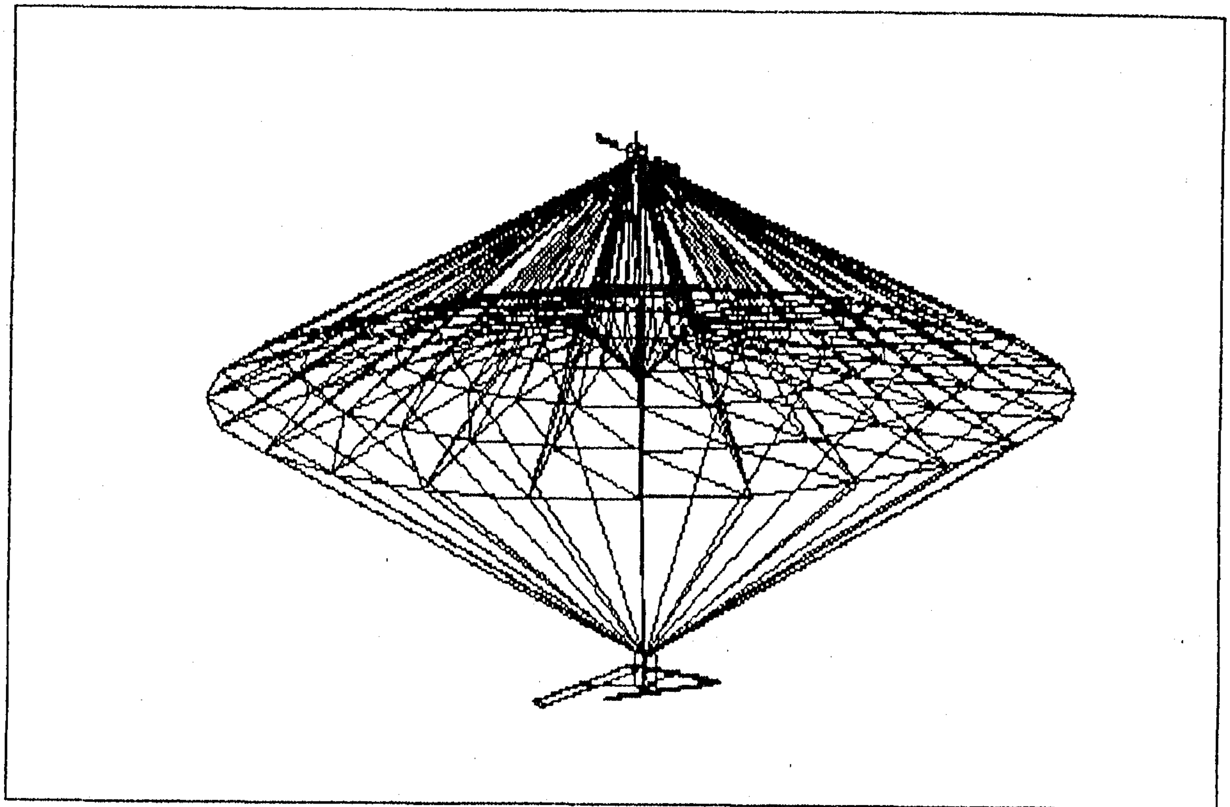

Figure 1. Hoop Column Soil Moisture Experiment

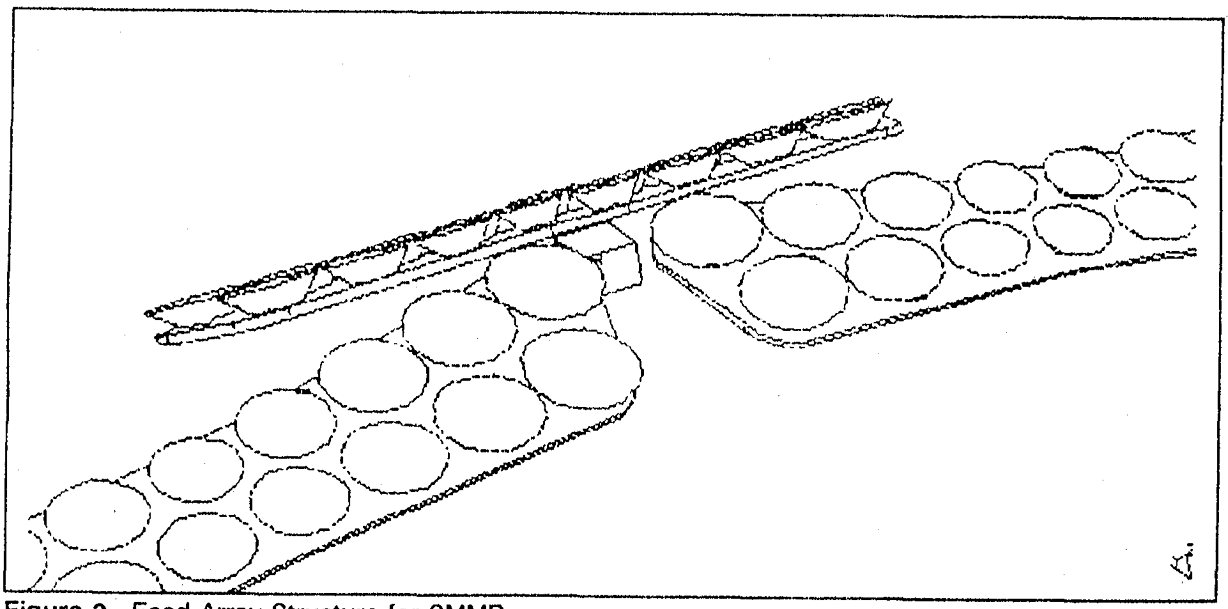

Figure 2. Feed Array Structure for SMMR

Table I. Attitude Control Subsystem Component Breakdown

Item	Quantity	Mass kg	Volume m^3	Total Mass	Total Volu me
Earth Sensor	2	10.10	.022	20.20	0.04
Momentum Wheels	3	8.80	.0088	26.40	0.03
Control Electronics	3	4.00	.025	12.00	0.08
Rate Integrating Gyros	3	1.40	.001	4.20	0.00
Valve Driver Electronics	1	0.72	.0045	0.72	0.00

Table II. Communications and Data Management Subsystem Breakdown

Item	Quantity	Mass kg	Volume m^3	Total Mass kg	Total Volume m^3
S-band Transponder	1	.4	0	0.40	0.00
Autotrack Receiver	1	1	0	1.00	0.00
Gimbal Drive Assembly	1	18	0	18.00	0.00
Gimbal Drive Electronics	1	1.6	0	1.60	0.00
RF Front End	1	82	.233	82.00	0.23
K-Band Controller	1	3	0	3.00	0.00
K-Band Up Converter	1	1.30	0	1.30	0.00
S-Band Omni Antenna	1	0.45	0	0.45	0.00
High Gain Antenna	1	7.40	1.89	7.40	1.89
Digital Telemetry Unit	2	8.50	.0069	17.00	0.01
Command Decoder/ Distribution	1	12.30	.0087	12.30	0.01
Computer	2	11.30	.0021	22.60	0.00
Tape Recorder	1	32.70	.0651	32.70	0.07

Table III. Propulsion Subsystem Component Breakdown

Item	Quantity	Mass	Volume m^3	Total Mass kg	Total Volume
Attitude control Thrusters	6	.45	.0028	2.70	0.02
Translational Thrusters	2	.41	.0026	0.82	0.01
Isolation Valves	2	.68	.0043	1.36	0.01
Filter	1	.23	.0014	0.23	0.00
Fuel Tanks	3	15.59	2.683	46.77	8.05
Fill/Drain Valves	1	.11	.0006	0.11	0.00

Table IV. Electrical Power Subsystem Component Breakdown

Item	Quantity	Mass	Volume m^3	Total Mass kg	Total Volume
Solar Array	2	70	1.5	140.00	3.00
Charge Array	2	17.5	.25	35.00	0.50
Batteries (NiH_2)	1	114.3	2.86	114.30	2.86
Shunt	1	25	.2	25.00	0.20
Charge Control	1	10	.2	10.00	0.20
Discharge Control	1	41.7	.2	41.70	0.20

Table V. Spacecraft Mass Summary

Item	Mass, kg
Instrument	3895
Communications and Data Management	200
Attitude Control	63
Electrical Power	366
Propulsion	52
Propellant	487
Thermal Control	205
Structure	559
Total	5,827

GEOSTATIONARY ORBIT EARTH SCIENCE PLATFORM CONCEPTS FOR GLOBAL CHANGE MONITORING

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1.0 Introduction and Scope

Functionality of a geostationary spacecraft to support Earth science regional process research has been identified in reference 1. Most regional process studies require high spatial and temporal resolution. These high temporal resolutions are on the order of 30 minutes and may be achievable with instruments positioned in a geostationary orbit. Reference 1 has identified a compliment of typical existing or near term instruments to take advantage of this altitude. This paper lists this set of instruments, discusses the requirements these instruments impose on a spacecraft, then presents a brief description of the geostationary spacecraft concepts which support these instruments.

2.0 Instruments and Requirements

The following instruments were identified in reference 1 as representative of the types of Earth science instruments which could be employed on a geosynchronous spacecraft for regional process studies. The name of each instrument is given along with its measurable and proposed spatial resolution (temporal resolutions were all approximately 30 minutes) as well as its mass and power requirements in Table I.

Table I. Instrument List

Name	Measurable	Spatial Resolution km	Mass kg	Power W
ACRIM	solar radiation	sun disk	24	5
GERS	Earth radiation	40	110	90
GOESI	surface temperatures, wind speed	1-8	118	130
IRVS	air temperatures, trace gases	5-10	150	150
OZMAP	ozone levels	43	100	130
GMODIS	clouds,biomass	0.5	230	50
GHRMR-a	H_2O profiles	10	2417	370
GHRMR-b	H_2O profiles	25	1947	296

where the full names of the instruments are:

ACRIM - Active Cavity Radiometer
GERS - Geostationary Earth Radiation Sensor
GOES - GOES Imager
IRVS - Infrared Vertical Sounder
OZMAP - Ozone Mapper
GMODIS - Geostationary Moderate Resolution Imaging Spectrometer
GHRMR - Geostationary High Resolution Microwave Radiometer

The total instrument mass and power (assuming GHRMR-a, described below) are 3149 kg and 1125 W, respectively. Other design requirements imposed by the instruments include a system pointing accuracy of 3.6 arc sec, and a total data rate of 45 Mbps (including instrument and subsystem data).

Most of the instruments exist in some advanced stage of development, except the GHRMR instrument which was conceptualized during the architectural trade study (ref. 1) in conjunction with efforts in the Antenna and Microwave Research Branch to examine passive earth sensing microwave technology. The GHRMR concept, a cassegrain multiple reflector antenna, provides wide angle scanning to cover large portions of a given hemisphere of the Earth from a single geostationary position. Its large aperture provides both high spatial resolution and high accuracy measurements. The concept is composed of a 15 m diameter primary reflector, a 7.5 m secondary reflector, a moving tertiary reflector, and a phased array feed system. The large scanning angle capability necessitates a long focal length on the order of 30 m for the primary reflector. Two options were developed for the structure of the GHRMR: GHRMR-a, an erectable concept which provides a surface sufficiently accurate to operate up to 220 GHz and GHRMR-b, a deployable concept which provides a surface which can operate up to 90 GHz. The first option was based on Precision Segmented Reflector (PSR) technology which includes solid surface reflector panels designed to operate in infrared wavelength applications and stiff, light-weight supporting truss. The second option is based on a Harris hex panel concept which can be autonomously deployed on orbit and was designed to operate up to 40 GHz. Mass and power estimates are listed for both concepts, with the PSR option having more mass and needing more power because of the additional operating frequencies (up to 220 GHz). A comparison summary including more detailed mass breakdown of both concepts is shown in Table II and Table III. The GHRMR is illustrated in figure 1.

Table II. GHRMR Summary

Concept Option	GHRMR-a	GHRMR-b
Origin	PSR	Harris
Max Operating Frequency(GHz)	220	90
Best Spatial Resolution(km)	10	25
Emplacement Method	Erectable	Deployable
Power Requirement(W)	370	296
Data Rate(kbps)	90	72

Table III. GHRMR Mass Breakdown

15m Primary Reflector	1239 kg	884 kg
7.5m Secondary Reflector	308	193
Feed/Radiometer Assembly	140	140
Tertiary Reflector	245	245
Positioner Assembly	140	140
Supporting Mast	245	245
SignalProcessing+Misc.	100	100
Total GHRMR Mass	2,417 kg	1,947 kg

3.0 Spacecraft Operating Subsystems

The subsystems for the spacecraft supporting these instruments were selected based on availability of technology, simplicity of design and commonality with existing spacecraft. For example, the amount of data for this set of instruments and the rate at which it is communicated is similar to that which a TDRS transmits. Consequently, the communication subsystem employs TDRSS Ku and S band technology. However, all communications go to directly to the ground, ie they do not pass through the TDRSS. Additionally, it is assumed that all data generated by the instruments are transmitted to the ground, and that there is no onboard processing of the scientific data other than that inherent in each instrument.

Along the same reasoning, total electrical power requirements are similar to other systems such as communication satellites currently in operation in geosynchronous orbit, consequently standard power system technology is used. The power system selected employs high efficiency flexible substrate fold-out silicon solar arrays (specific power = 30 W/kg) and nickel-hydrogen batteries (specific energy = 55 W-hr/kg) for infrequent eclipse periods. A depth of discharge of 50% is used for battery sizing keeping in mind the eclipse characteristics of geosynchronous orbit and a prescribed mission lifetime of seven years. The power management and distribution system is a fully regulated 28 Vdc bus with an assumed efficiency of 85%.

The attitude control system is designed to provide three axis stabilization and accurate pointing of the entire platform to within the pointing requirement stated above. In earlier designs, attitude control was maintained using reaction wheels positioned on the major spacecraft axes. However, preliminary control system analysis indicates that because of the extremely large non-zero cross products of inertia of the spacecraft (due to the asymmetric design of the GHRMR) single gimble cmg's may be a better way to control the spacecraft and were selected on the basis of increased control torque and reduced mass and power. Additionally, various sensors are required, including coarse and fine earth, sun, star and inertial sensors.

The propulsion system serves to desaturate the reaction wheels or cmg's and to provide station keeping and station repositioning (changing of longitude) which is mandated by the requirement to cover different regions of the Earth. Electrothermal monopropellant hydrazine (isp=230 sec) was used as the fuel. The system is composed of the three tanks of hydrazine and three of nitrogen (pressurant), an assortment of thrusters including eight 2.2 N thrusters for station keeping and orbit repositioning and four 0.44 N thrusters for cmg desaturation plus the necessary fluid lines and control electronics.

The spacecraft structure is dominated by that which supports the GHRMR. The large diameter reflectors are composed of solid precision surface panels supported by graphite composite tetrahedral trusses for the PSR option and other types of framework for the Harris option. The reflectors and feed array are separated by a deployable pac truss concept also made of graphite composites. Preliminary structural analysis attests to the integrity of the structures. These trusses are also assumed to be sufficiently thermally insulated to reduce excessive thermal distortions. Finally, the structure supporting the spacecraft bus and the other instruments is composed of graphite/aluminum honeycomb and integrated louvered radiators on a composite frame. This combination provides sufficient structural support and thermal transport and rejection capability.

4.0 Spacecraft Configurations

The GHRMR strongly influences the configuration of the spacecraft in that its large size and offset parabolic design as well as its viewing requirements greatly limit the placement of the other instruments and the spacecraft bus. Additionally, its large size also drives the attitude control system which then influences the power system as well as other subsystems. Also, complex assembly of the GHRMR may drive the configuration. To address these effects of the GHRMR, two alternative types of configurations were conceptualized. The first configuration (called GEO1) is a single spacecraft supporting all instruments including the GHRMR. The second configuration (called GEO2) is a pair of deployable spacecraft: one supporting only the GHRMR (G1) and the other (G2) supporting all remaining instruments. The two configurations were examined to identify any advantages in mass, power, launch volume, and complexity and to surface any other important issues.

A comparison of total spacecraft mass and power can be made by examining Table IV which shows mass and power estimates for two GEO1 designs (each supports a different GHRMR option) and one GEO2 design supporting the Harris GHRMR and the remaining instruments separately on a pair of spacecraft, G1 and G2. These estimates are broken up into payload mass and power and spacecraft bus mass. Note that the payload to spacecraft mass fraction for the spacecraft carrying the GHRMR are more favorable than that of spacecraft G2, whose mass fraction is closer to historical trends. The high mass fraction is a result of the large mass of GHRMR instrument (concentrated primarily in the structural components) compared to the relatively small requirements it places on the spacecraft subsystems.

Table IV. Spacecraft Mass Summary

Configuration	GEO1	GEO1	GEO2-G1	GEO2-G2
GHRMR Option	GHRMR-a	GHRMR-b	GHRMR-b	none
Payload Mass(kg)	3149	2679	1947	732
Spacecraft Mass(kg)	6159	5433	3934	2514
Spacecraft Power(W)	2159	2087	974	1406
Payload Mass Fraction	.51	.49	.49	.29

These mass estimates indicate that a Titan IV/Centaur class launch vehicle might suffice. However, based on examining several packaging designs and deployment sequences it was determined GEO1/GHRMR-b (with deployable GHRMR) would not fit in the TitanIV/Centaur launch envelop but instead required the Shuttle-C envelop dimensions as shown in figure 2. The erectable concept (which is assembled by astronauts at Space Station or Shuttle), GEO1/GHRMR-a can be packaged into a single shuttle flight. The GEO2-G2 can be packaged and deployed from a variety of launch vehicles. The GEO2-G1, on the other hand, still has a packaging problem because of the length of the stowed configuration. For this spacecraft, even if the bus were significantly reduced in size or repositioned (no alternate concept was fully developed), the length would still exceed the TitanIV/Centaur envelop.

5.0 <u>Spacecraft Subsystem Technology Assessment</u>

As stated earlier, an effort was made to use existing, flight-tested technology where possible in designing the subsystems. However, some necessary advanced technologies were identified and assumed in the design. Two of these, related to structural components of the GHRMR, include large, deployable, highly accurate space trusses and solid reflector surfaces. Although research in both of these areas has been underway for several years, none similar to the types needed for the GHRMR have been flown on civilian space missions. Another critical technology issue for the spacecraft as a whole is how to maintain the tight pointing accuracy required by the GHRMR and other instruments. In order to achieve the pointing goals, higher accuracy Earth and inertial sensors and higher momentum, higher torque, low power, low mass actuators are needed. Also control-structures interaction technology may have to be employed in order to maintain a stable structure. Another aspect that relates to all the subsystems and instruments is extended lifetime. The initial goal for mission lifetime goal was 15 years, however, it has been reduced to seven years based on limited lifetimes of the instruments. Although this seven years may still exceed the lifetime of some of the instruments, development of longer life materials and mechanisms will enhance mission reliability and flexibility in meeting changing scientific goals.

Advanced technology in the other major subsystems was not assumed although improvements could be made. For instance, on-board processing of scientific data will help to reduce communication needs and improve calibration and synchronization of data from the various instruments providing better overall measurements. Improvements in solar cell technology and battery lifetime and energy density and utilization of higher voltages could reduce weight and increase reliability. Finally, higher specific impulse fuels or application of ion propulsion would help reduce the mass of propellant and tankage needed on orbit and development of an orbit transfer vehicle would provide an alternative means to achieve to geostationary altitude which might alleviate packaging problems and launch vehicle constraints.

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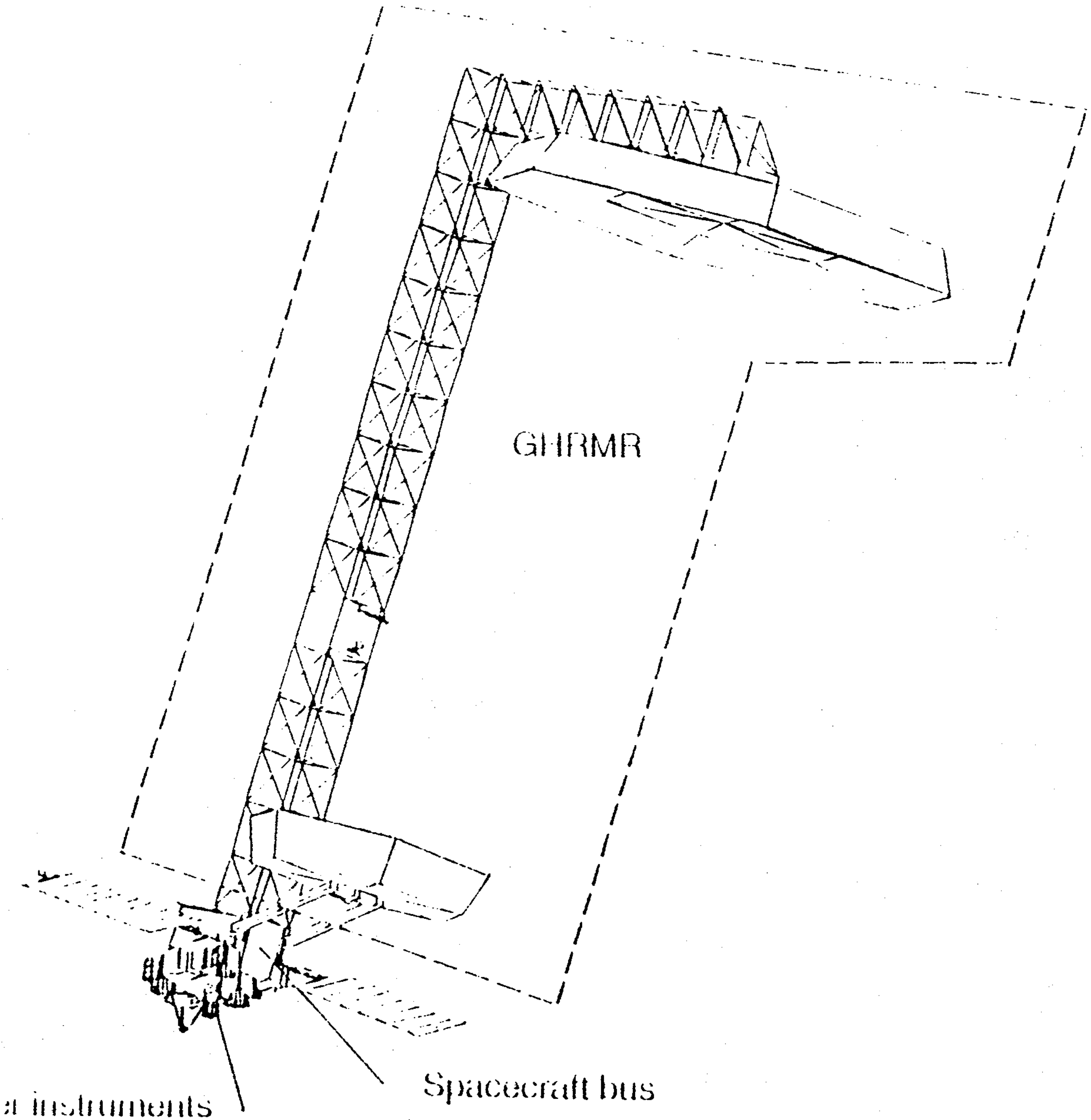

Figure 1: GCTI architecture trade study geostationary platform (configuration GEO1).

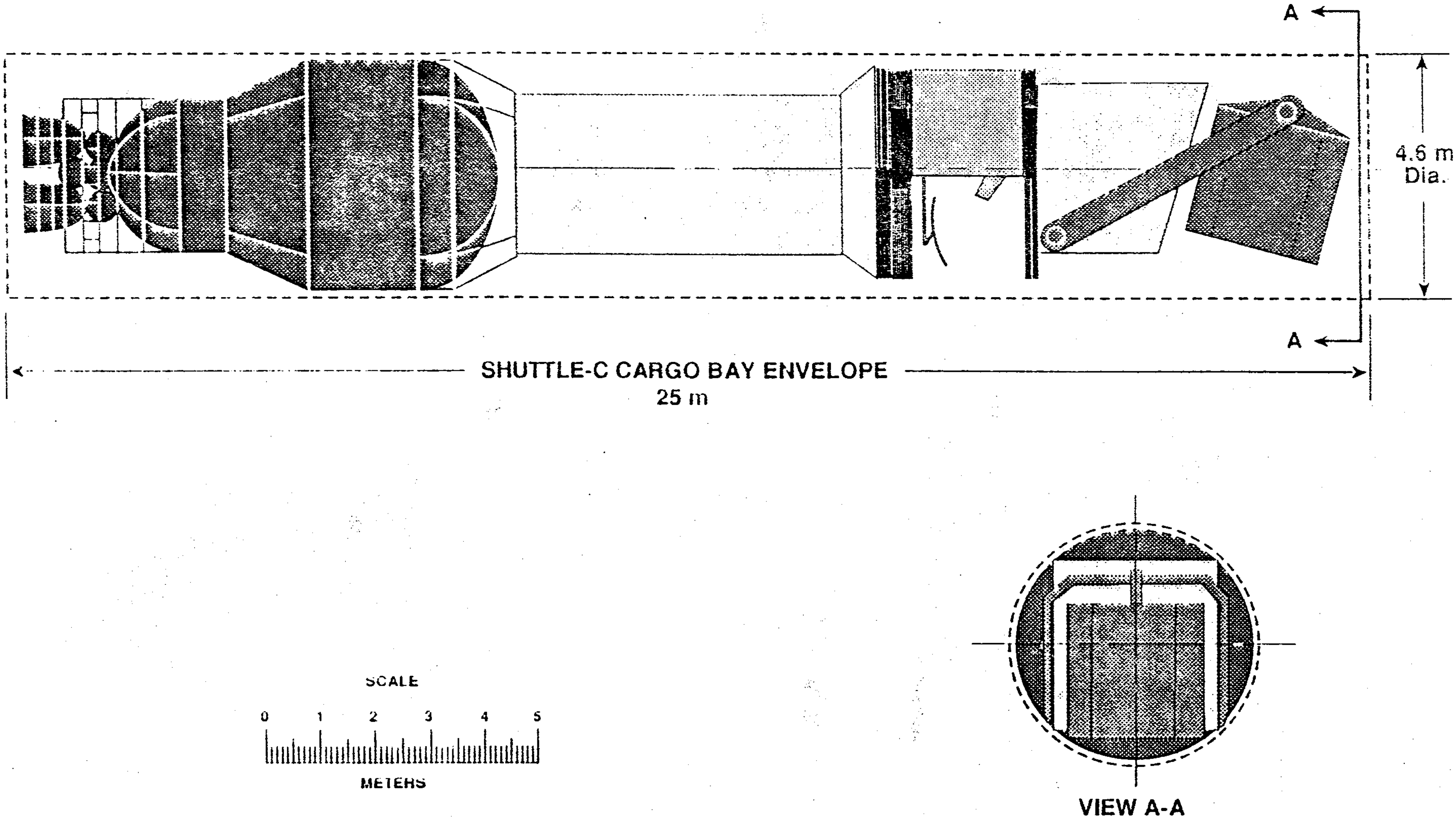

Figure 2a: GCTI platform stowed in Shuttle-C cargo bay.

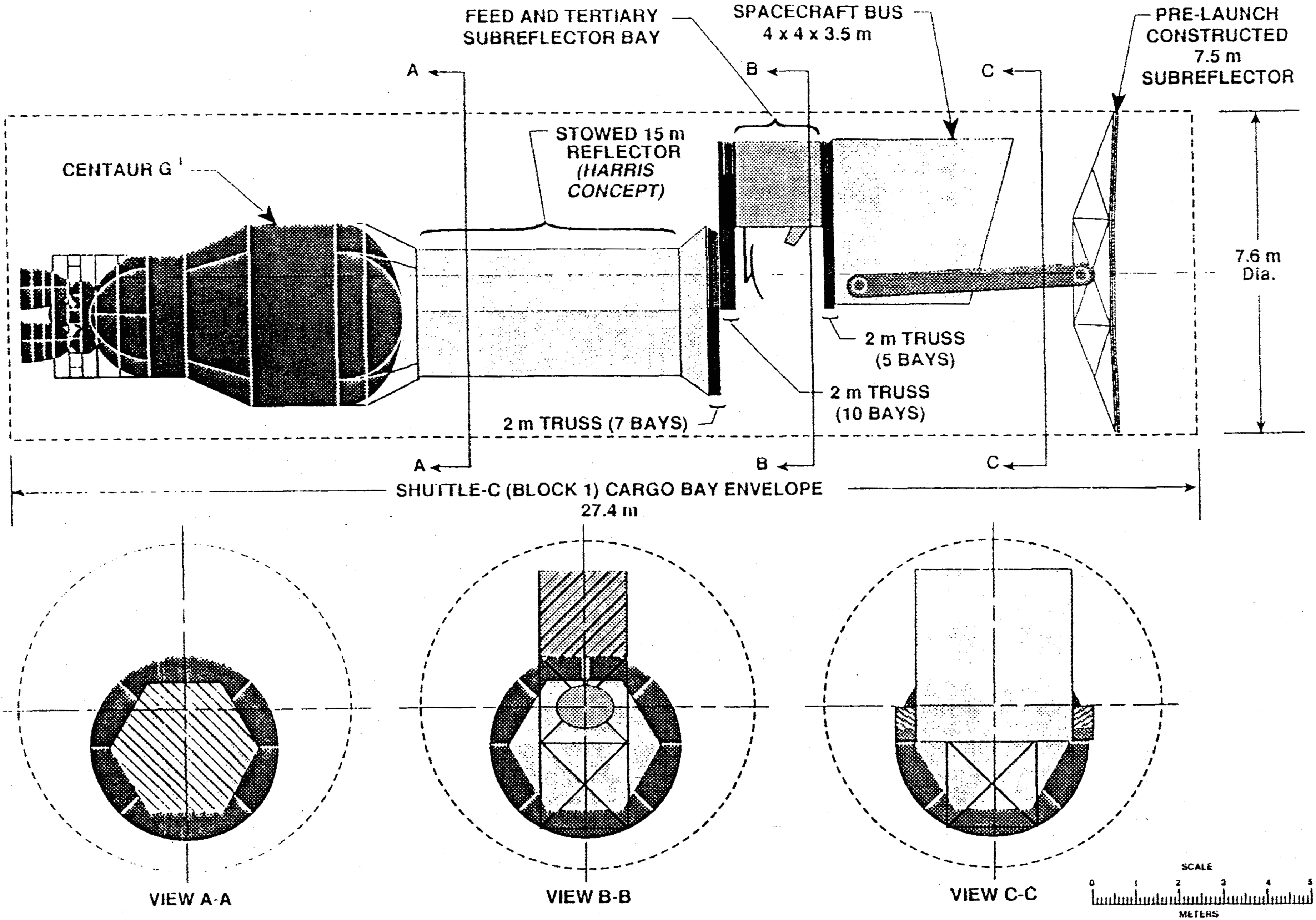

Figure 2b: GCTI platform stowed in Shuttle-C (block 1) cargo bay.

OPTIONS IN THE GLOBAL CHANGE FLEET ARCHITECTURE PROVIDED BY THE PRESENCE OF AN Eos-A AND -B

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INTRODUCTION

The baseline architecture of the GCTI fleet was established by selecting and designing spacecraft and instruments to meet the science requirements developed under the Task 1 effort. While attempting to meet the temporal sampling portion of the science requirements, no consideration was given to the presence of the proposed Earth Observing System (Eos) Spacecraft that would be making many of the same measurements with many of the same instruments. After establishing the GCTI baseline independent of the Eos Spacecraft, however, it is now prudent to examine the impact of the presence of the Eos Spacecraft on the GCTI fleet. A small scope, GCTI Study supplement was accomplished to assess the impact. The content and results of the supplementary study are the subject of this white paper.

OBJECTIVE

The objective of this study is to determine the impact of considering an operational EosA and B upon the two options of the proposed GCTI fleet.

ASSUMPTIONS

The following assumptions apply to the study:

1. Eos-A and Eos-B are operational. Both are in the same sun-synchronous orbit at an attitude of 705 km with a crossing time of 1330 hours. The instrument complements are those presented on the Santa Barbara Research Center chart #90527 dated May 1989 and titled, Earth Observing System (Eos).

2. The GCTI Spacecraft and instrument complements are those selected during the GCTI Architectural Trade Study. They are reproduced in Table 1.

3. The GCTI science requirements, including the spatial resolutions and temporal sampling frequencies, are applicable.

ANALYSIS

The instrument complement for the Eos-A spacecraft is presented in Table 2. The Table also includes instruments on GCTI spacecraft B, C, D, and E that are the same instruments as those on Eos-A. The instrument complement for the Eos-B spacecraft is presented in Table 3. The table also includes instruments on GCTI spacecraft B and E that are the same instruments as those on Eos-B. Table 4 lists the GCTI instruments that are not included on either the Eos-A or Eos-B spacecraft. These comparative instrument lists provide the baseline for the following analysis.

Two of the GCTI spacecraft, or the specific use of the spacecraft, are significantly different from the Eos spacecraft to the extent that the presence or absence of the Eos spacecraft have little impact on the GCTI fleet. GCTI spacecraft A is a special purpose spacecraft dedicated to a single Soil Moisture Microwave Radiometer (SMMR) instrument. Eos does not include a comparable instrument. The GCTI Architecture must, therefore, include spacecraft A with the SMMR instrument. GCTI spacecraft G1 or G2 are Geostationary spacecraft with specific Geo instruments. Eos concepts do not include comparable instruments, therefore, the GCTI Architecture must include spacecraft G1 or the two part G2.

With the above spacecraft and instruments excluded from this GCTI Study supplement (they must be included in the GCTI Architecture regardless of the presence or absence of Eos), the issue now becomes the relationship between the two Eos spacecraft and GCTI spacecraft B, C, D, and E of Option 1 or GCTI spacecraft L_1, L_2, L_3, and L_4 of Option 2 along with their respective instrument complements.

GCTI Option 1 Constellation for 3-Hour Coverage:

Since GCTI and Eos spacecraft are in similar polar, sun-synchronous orbits instruments that are the same on GCTI and Eos spacecraft can make comparable measurements. In these cases there is no reason to duplicate the Eos instruments on GCTI spacecraft except where needed to meet the GCTI temporal science requirements. The GCTI architecture requires one spacecraft B. Eos-A includes all of the GCTI spacecraft B instruments except ACRIM, SOLSTICE, XRI, and 3chMR. The ACRIM instrument on spacecraft B fulfills the GCTI science requirement to measure spectral radiation (total solar irradiance - full disk) with a temporal requirement of 1-Day. Spacecraft D, however, includes an ACRIM instrument as a complement to the CERES Radiation Budget instrument and this ACRIM can make the required measurements. The ACRIM instrument on spacecraft B can be deleted. The SOLSTICE and XRI instruments on spacecraft B are not required by GCTI science requirements. They were included to make a complementary measurement (solar UV irradiance - full disk) to the total irradiance of the ACRIM instrument. The Eos program places the ACRIM and SOLSTICE on a space station attached payload since the solar viewing mode eliminated the Earth orbit track and the temporal sampling frequency as prime considerations. There is no reason why this arrangement would not suffice for meeting the GCTI science requirements. The XRI can also be added to the atached payload. The remaining spacecraft B instrument to be accounted for is the 3 ch MR. Again, this instrument was added as a supplement. It assists in the calibration of the ALT instrument data. There is an ALT on Eos-A and, although not known for certainty, it is likely to include a 3 ch MR or else other instruments in the Eos-A complement provide the needed data. It is assumed with confidence that the arrangement that Eos-A has for the ALT instrument is adequate. In summary, with Eos-A and B present, GCTI spacecraft B can be eliminated although it requires a reasonable redistribution of ACRIM, SOLSTICE, XRI, and 3 Ch MR.

The GCTI spacecraft C is configured to meet the 3 to 12-hour temporal measurables of the GCTI science requirements. It includes only three instruments (APL, SAGE III, EOSP), two of which are included on Eos-A. Only the new concept atmosphere pressure lidar (APL) is not included on an Eos platform. Thus, GCTI spacecraft C could be eliminated if some way of accommodating the APL instrument is found. This potential accommodation has not been worked in detail, but the GCTI spacecraft design personnel state that it is a possibility that one Spacecraft D could be reconfigured to include APL although the reconfiguration would be extensive in scope.

The GCTI Spacecraft D is configured to meet the 1 to 3-hour temporal measurements of the GCTI science requirements. During the basic GCTI architecture study, it was concluded that the 1-hour temporal requirement placed excessive demands on the GCTI fleet and that the 3-hour temporal requirement was reasonable. With polar, sun-synchronous spacecraft such as Eos-A and B and GCTI spacecraft B, C, D, and E, a 3-hour temporal cycle can be met with four spacecraft. The Eos-A spacecraft includes all of the instruments on GCTI spacecraft D with the exception of the ACRIM instrument; thus, except for ACRIM, Eos-A will replace one of the GCTI spacecraft D's. With three remaining GCTI spacecraft D's with an ACRIM instrument and the possibility of ACRIM and SOLSTICE also flying on the space station attached payloads, the loss of one ACRIM is not considered to be a major problem. In summary, the Eos-A spacecraft will replace one of the GCTI spacecraft D's leaving three of the D's. Three of the four spacecraft will include an ACRIM.

The GCTI spacecraft E is configured to meet the stratospheric and tropospheric gases and wind measurements of the GCTI science requirements except, as previously stated, only a 3-hour temporal coverage for both Regional Process and Global Change Studies was used to drive the recommended architecture. The Eos-A and Eos-B spacecraft include all of the instruments on GCTI spacecraft E. Therefore, the Eos spacecraft will replace one of the GCTI spacecraft E's leaving the requirement of three GCTI spacecraft E's to meet the 3-hour temporal target.

The Eos-A and B spacecraft do not include any of the instruments on the GCTI spacecraft G1 or G2. In addition, the orbits are not comparable since the Eos spacecraft are planned for LEO operations while the GCTI spacecraft G's are planned for Geostationary operation. Thus, either the G1 or G2 selection for the GCTI architectural fleet will be needed regardless of the presence or absence of the Eos spacecraft.

GCTI Option 2 - Platforms for 3-Hour Coverage:

As presented on Table 1 there are some elements of the GCTI Option 2 architecture that are the same as in the Option 1 architecture. As in Option 1, Option 2 includes the GCTI spacecraft A dedicated to the SMRR instrument in LEO. Option 2 also includes the same geostationary spacecraft that are in the Option 1 architecture. As in Option 1, the presence or absence of the Eos spacecraft does not impact either the LEO Spacecraft A or the GEO spacecraft G1/G2 elements of Option 2. They continue to be needed to fulfill the science requirements of the GCTI study. The remaining GCTI spacecraft - B, C, D, and E - and their instrument complements vary significantly between Options 1 and 2.

In Option 2 the instrument complements of GCTI spacecraft B, C, D, and E are assembled onto four large platforms, three of which are configured to achieve the target 3-hour temporal coverage, and the fourth (L_1) configured to meet a 12-hour temporal coverage as well as the 3-hr coverage. The combined instrument complements of Eos-A and B include all of the instruments on GCTI spacecraft B, C, D, and E except for ACRIM, SOLSTICE, 3chMR, and APL. With the exception of the four instruments, the impact of Eos-A and B on the GCTI architecture would be that one of the three GCTI Titan IV launched platforms L_2, L_3, or L_4 could be eliminated but L_1 must remain. The remaining GCTI platforms and the combined Eos A and B could then be time sequenced to provide the required temporal coverage.

It is now important to consider the impact of the four GCTI instruments missing from the combined Eos-A and B complements. One scenario is to leave the four platforms, three GCTI platforms and the two spacecraft Eos platform, with their current instrument complements. The loss of one of the L_2, L_3, or L_4 ACRIM instruments results in one of the 3-hour CERES measurements not having the ACRIM support data. The absence of the SOLSTICE from Eos will not have an impact since SOLSTICE is a support instrument to ACRIM for the solar spectral radiation measurement required once a day. The GCTI L_1 large spacecraft with an ACRIM and SOLSTICE meets the requirement. The same analysis is applicable to the absence of the 3 Ch MR. It is a support instrument for the ALT instrument required once/12-hours and can be met by the GCTI L_1 spacecraft. The APL instrument makes the surface pressue measurement on a 12-hour cycle. Again, the GCTI L_1 spacecraft meets this requirement. Thus, the only effect of the four instruments missing from the Eos spacecraft is that the ACRIM support data for one of the four CERES instruments will be missing. In a second scenario, if the ACRIM and SOLSTICE instruments are placed on the space station attached platforms as described in the Option 1 discussion and the ACRIM measurement can suffice for supporting the CERES on Eos, there is no impact on temporal sampling of four GCTI instruments missing from the combined Eos A and B complements.

CONCLUSION

The impact of assuming an operational Eos-A and B spacecraft on the architecture of the baseline GCTI spacecraft fleet and instrument complements is as follows:

GCTI Option 1 Constellation for 3-hour Coverage:

- Spacecraft A — Required/No Change
- Spacecraft B — If ACRIM, SOLSTICE, and XRI can be placed on a space station attached platform and the small 3chMR placed on the Eos platform containing the ALT which it supports, Spacecraft B can be eliminated. These changes appear feasible.
- Spacecraft C — If the APL can be placed on one of the GCTI spacecraft D's, spacecraft C can be eliminated. This changeappears possible but would require an extensive rearrangement of the spacecraft D.
- Spacecraft D — The four spacecraft can be reduced to three; Three of the four spacecraft (3 GCTI D's and 1 Eos combination) will include an ACRIM. The ACRIM currently proposed for the Space Station Freedom attached payload could possibly serve as the fourth ACRIM.
- Spacecraft E — The four spacecraft can be reduced to three. There are no changes required.
- Geostationary Spacecraft G1 or G2 - Required/No Change

Table 5 presents the above in a visual summary format.

- Spacecraft A   Required/No Change
- Combined Spacecraft B, C, D, E Platform - the four Titan IV class platforms can be reduced to three; however the GCTI large platform eliminated must be one of the spacecraft designated L_2, L_3, and L_4. Spacecraft L_1 must be retained. The CERES instrument on Eos will not be supported by an ACRIM. The ACRIM currently proposed for the Space Station Freedom attached payload could possibly serve as the fourth ACRIM.
- Geostationary Spacecraft G1 or G2 - Required/No Change

Table 5 presents the above in a visual summary format.

TABLE 1 (a) - INSTRUMENT COMPLEMENTS FOR THE FOUR OPTION 2 PLATFORMS

Instruments	Option 2 Platforms			
	L-1	L-2	L-3	L-4
HIRIS	*			
3 ChMR	*			
ALT	*			
MODIS-T	*			
EOSP	*	*	*	*
SAGE III	*			
APL	*			
AIRS	*	*	*	*
ACRIM	*	*	*	*
SOLSTICE	*			
XRI	*			
CERES	*	*	*	*
MODIS-N	*	*	*	*
AMSU-B	*	*	*	*
HIMSS	*	*	*	*
TES	*	*	*	*
SAFIRE	*	*	*	*
SWIRLS	*	*	*	*
TRACER	*	*	*	*
MLS	*	*	*	*

TABLE 1 - GCTI ARCHITECTURE TRADE STUDY
PRELIMINARY SELECTION OF SPACECRAFT AND INSTRUMENT COMPLEMENTS

Spacecraft	Spacecraft Instrument Complement	Option 1 Constellation for 3-Hour Coverage	Option 2 Platforms for 3-Hour Coverage
Low Earth Orbit			
A, Soil Moisture	SMMR	1	1
B, 12-Hr.+Temporal	ACRIM, SOLSTICE, XRI, MODIS-T, HIRIS, EOSP, ALT, 3ChMR	1	
C, 3 to 12-Hr. Temporal	APL, SAGE III, EOSP	1 (12-hour)	4*
D, 1 to 3-Hr. Temporal	CERES, ACRIM, MODIS-N, EOSP, AMSU-B, AIRS, HIMSS	4 (3-hour)	
E, Less than 1-Hr. Temp.	SAFIRE, MLS (Eos), TES, TRACER, SWIRLS, EOSP	4 (3-hour)	
Geostationary Orbit			
G1, Less than 1-Hr. Temp.	GERS, ACRIM, IRVS, OZMAP, GOES Imager, GHRMR, GMODIS	1	1
--OR--			
G2-A, Less than 1-Hr. Temp.	G1 Complement Less GHRMR	1	1
G2-B, Less than 1-Hr. Temp.	GHRMR Alone	1	1
	TOTAL	1 Special Purpose LEO 10 Delta Class LEO 1 or 2 GEO	1 Special Purpose LEO 4 Titan IV Class LEO 1 or 2 GEO

*All four do not have identical instrument complements, see Table 1(a) for the instrument complements.

TABLE 2 - Instruments Common to the Eos-A and GCTI Spacecraft B, C, D, E

Eos-A Instrument Complement	GCTI Spacecraft and Instrument Complement	
	Spacecraft	Instrument
AIRS	D	AIRS
ALT	B	ALT
GLRS	-	-
HIRIS	B	HIRIS
MODIS-N	D	MODIS-N
MODIS-T	B	MODIS-T
SEM	-	-
MIMR	-	-
AMSR	-	-
ITIR	-	-
CERES	D	CERES
DLS	-	-
ENAC	-	-
EOSP	B,C,D,E	EOSP
GG1	-	-
HIMSS	D	HIMSS
HIRRLS	-	-
IPEI	-	-
MISR	-	-
MOPITT	-	-
POEMS	-	-
SAGE III	C	SAGE III
SCANSCAT	-	-
TRACER	E	TRACER
AMSU-A and B	D	AMSU-B

TABLE 3 - INSTRUMENTS COMMON TO THE Eos-B AND GCTI SPACECRAFT B AND E

Eos-B Instrument Complement	GCTI Spacecraft and Instrument Complement	
	Spacecraft	Instrument
SAR	-	-
SEM	-	-
GGI	-	-
GOS	-	-
IPEI	-	-
LIS	-	-
MLS	E	MLS
SAFIRE	E	SAFIRE
SWIRLS	E	SWIRLS
TES	E	TES
XIE	B	XRI

TABLE 4 - GCTI INSTRUMENTS NOT ON AN Eos SPACECRAFT

GCTI LEO Spacecraft	Instrument
B, D	ACRIM
B	SOLSTICE
B	3 Ch MR
C	APL
A	SMMR

GCTI GEO SPACECRAFT	
G1	GERS
	ACRIM
	IRVS
	OZMAP
	GOES Imager
	GHRMR
	GMODIS
OR	
G2-A	G1 Complement
G2-B	GHRMR

TABLE 5 - GCTI ARCHITECTURE TRADE STUDY
PRELIMINARY SELECTION OF SPACECRAFT AND INSTRUMENT COMPLEMENTS

Spacecraft	Spacecraft Instrument Complement	Option 1 Constellation for 3-Hour Coverage	Option 2 Platforms for 3-Hour Coverage	With Eos-A and B: Option 1 Constellation	With Eos-A and B: Option 2 Platforms
• Low Earth Orbit					
A, Soil Moisture	SMMR	1	1	1	1
B, 12-Hr.+Temporal	ACRIM, SOLSTICE, XRI, MODIS-T, HIRIS, EOSP, ALT, 3ChMR	1		-	
C, 3 to 12-Hr. Temporal	APL, SAGE III, EOSP	1 (12-hour)	4*	-	3**
D, 1 to 3-Hr. Temporal	CERES, ACRIM, MODIS-N, EOSP, AMSU-B, AIRS, HIMSS	4 (3-hour)		3	
E, Less than 1-Hr. Temp.	SAFIRE, MLS (Eos), TES, TRACER, SWIRLS, EOSP	4 (3-hour)		3	
• Geostationary Orbit					
G1, Less than 1-Hr. Temp.	GERS, ACRIM, IRVS, OZMAP, GOES Imager, GHRMR, GMODIS	1	1	1	1
--OR--					
G2-A ,Less than 1-Hr. Temp.	G1 Complement Less GHRMR	1	1	1	1
G2-B, Less than 1-Hr. Temp.	GHRMR Alone	1	1	1	1
	TOTAL	1 Special Purpose LEO 10 Delta Class LEO 1 or 2 GEO	1 Special Purpose LEO 4 Titan IV Class LEO 1 or 2 GEO	1 Special Purpose LEO 6 Delta Class LEO 1 or 2 GEO	1 Special Purpose LEO 3 Titan IV Class LEO 1 or 2 GEO

* All four do not have identical instrument complements. See Table 1(a) for the instrument complements.
**One of these three must be an Option 2, L-1 Platform. See Table 1(a).

INFORMATION DATA SYSTEMS FOR A GLOBAL CHANGE TECHNOLOGY INITIATIVE ARCHITECTURE TRADE STUDY

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INFORMATION DATA SYSTEMS FOR A GLOBAL CHANGE TECHNOLOGY INITIATIVE ARCHITECTURE TRADE STUDY

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INTRODUCTION

The Global Change Technology Initiative (GCTI) was established to develop technology which will enable use of satellite systems for Earth observations on a global scale, enable use of the observations to predictively model Earth's changes, and provide scientists, government, business, and industry with quick access to the resulting information. At NASA Langley Research Center, a GCTI Architecture Trade Study was undertaken to develop and evaluate the architectural implications to meet the requirements of the global change studies and the eventual implementation of a global change system. The output of the trade study are recommended technologies for the Global Change Technology Initiative. This paper documents that portion of the study concerned with the information data system.

The information data system for an earth global change modeling system can be very extensive and can be beyond affordability in todays' cost terms. Therefore, an incremental approach to gaining a system is most likely and this study developed an options approach to levels of capability versus needed technologies. The primary drivers of the requirements for the information data system evaluation were the needed science products, the science measurements [1], the spacecraft orbits [2], the instrument configurations [3], and the spacecraft configurations and their attendant architectures [4]. The science products requirements were not studied here; however, some consideration of the product needs were included in the evaluation results. The information data system technology items were identified from the viewpoint of the desirable overall information system characteristics.

REQUIREMENTS

The recommended satellite fleets are detailed by Table 1 [4,5]. The spacecraft instrument configurations are given as A,B,C,D,E for the low earth orbit (LEO) constellation, and as A, L1 = B+C+D+E and L2 = D+E for platforms. The options given were with and without the earth observing satellites (EOS) A and B. For the options with the EOS A and B, the constellation and platform fleets have a reduced number of satellites. Working in conjunction with the LEO satellites are geosynchronous earth orbit (GEO) spacecraft with the possibility of two instrument configurations, G1 or G2 and G". The total LEO spacecraft for constellations are eleven without EOS and seven with EOS; the total LEO platform spacecraft are five without the EOS and four with the EOS; and the GEO spacecraft are one or two for all options depending upon the variation chosen.

The recommended instrument configurations for A,B,C,D,E, are shown by Figure 1 [3]. The data rates for each instrument were estimated for peak rates and average rates. Also the data rate for each satellite instrument configuration was estimated for peak and average rates. These rates are useful for estimating the onboard spacecraft data distribution requirements. Figure 2 shows the instrument and spacecraft data rate estimates for the GEO satellites. Figure 3 summarizes the range of onboard data rates required for each instrument configuration. The tall poles which will require special design consideration for the onboard data system are the HIRIS instrument(280 peak/3 average), the B instrument configuration(total 289 pk./10 avg.), and any spacecraft using the B instrument configuration such as the L1 instrument configuration on the platforms. Also the tall pole instrument for GEO is GMODIS(42 pk./42 avg.) and the G1 or G2 spacecraft will require special design consideration for the onboard data system. All other instrument configurations have medium instrument data rates that do not exceed about 11 MBPS in the worst case.

Data rate estimates were also made for individual satellites under all the configurations and options. These estimates are useful in determining the space data communications requirements. Figure 4 summarizes the range of data rates for the satellite fleets. Complete data rate estimates are contained in Appendix A. From Figure 4, the L1 satellite data rate (314 MBPS peak) exceeds the present TDRSS communications satellite channel capacity (300 MBPS) but is well within the ATDRSS channel capacity of 650 MBPS. The communications data rates for the constellations, the platforms, and the GEO satellites are all within the ATDRSS channel capacity. For the cases with the EOS A and B, the EOS was assumed to have a data rate of about 300 MBPS [6].

Data per orbit estimates for each satellite were made as a measure of the mass data storage requirements. These estimates were made using the instrument and therefore the satellite average data rates. Figure 5 summarizes the data per orbit requirements for the satellite fleet. Complete data per orbit estimates are in Appendix B. The maximum storage estimate for a single satellite is 177 GBPS (1.77 x 10*11 bits) per orbit or 3185 GBPS (3.185 x 10*12 bits) per day. The maximum storage requirement for a fleet of satellites (constellation without EOS A and B) is 567 GBPS (75.67 x 10*11 bits) per orbit or 10,206 GBPS (1.0206 x 10*13 bits) per day.

STUDY OPTIONS

The most likely scenario for the development of an information data system to meet the GCTI requirements are with incremental improvements over a long time period. The reasons for this are two fold: a full capability information data system will be very expensive and the cost is better borne incrementally; and a full capability information data system will be very extensive with a degree of collaborative processing between diverse elements that is unprecedented - the incremental approach provides the opportunity to learn and gain confidence for each step of improved capability before deciding on the next (and larger) step. For these reasons, an options approach with increasing information system capabilities was chosen for the study.

The study considered three options for the information data system:

1) A baseline system that represents the data measurements and information product methods that are currently in operation. For this method, all data gathered is transmitted to ground without any conversion or processing and all processing to generate science information products for users are performed on the ground.

2) An option 1 system that represents an intermediate step to providing science users direct and near realtime access to science products. For this system, all instrument data gathered is still transmitted to the ground without conversion or processing; onboard satellite processing is performed to generate intermediate and limited final science products for direct transmission to users; and most of the final science information products for users are still processed on the ground.

3) An option 2 system that would provide the science user full and direct science information products in realtime. This approach will require combined and collaborative onboard satellite and ground processing and quickly accessible data archiving. The study of this option was too extensive for the GCTI Architecture Trade Study and is incomplete. However, initial results will be discussed.

BASELINE RESULTS

The information data system (Figure 6) would consist of the following items: a data distribution network; network interfaces (NI); embedded data processors (EDP); data processors in a processing complex; mass data storage; time and frequency; and communications and tracking. The instrument configurations are variable depending upon the configurations A,B,C,D,E,L,G. The onboard processing complex is variable depending upon the onboard processing required by the options of baseline, option 1, and option 2. The communications and tracking subsystem communicates data to a ground computing complex through a TDRSS or ATDRSS communication satellite via a ground network.

The issue for the onboard system raised by the requirements is how to efficiently handle the few instruments with high data rates, which are the HIRIS for LEO and the GMODIS for GEO. These data rates can be handled by high rate cables separately from the data distribution network. With this approach (Figure 7), a high data rate instrument would have separate cables to the data processing subsystem, to the mass data storage subsystem, and to the communication and tracking subsystem. All other data rate requirements would be handled by the data distribution network at a medium data rate of about 11 MBPS. The processing complex needs are minimal under the baseline option. Two tape recorders are adequate to handle the onboard storage needs on a per orbit basis. The space data communication rates can be handled by today's TDRSS or the planned communications satellites. The ground data system is adequate but very slow in serving science information requests.

With the high data rate cable technique, all the needed data management system (DMS) components are under advanced development by NASA programs--Polar Orbiting Platform, Multimission Modular Elements, Space Station Freedom, and EOS Data Information System. The DMS component capabilities being developed are: 100 MBPS data distribution network; 10 to 12 MBPS connections to instruments and subsystems; 1 to 4 MIPS embedded data processors; 4 to 8 MIPS data processors; and 10*11 bits tape recorders.

OPTION 1 REQUIREMENTS

With some new technology DMS component additions, the baseline onboard system could begin to process data and provide science information products in near realtime. Some of the potential realtime science information products are listed in Table 2 [7]. A significant number of applications have been identified that need onboard processing as well as realtime data transmission. The time response range of these applications are: continuous, such as for chlorophyll and temperature maps; rapid response to emergency events, such as large storms and earthquakes; and selective for surface areas, such as sea/ice interface and support for local remote sensing experiments. Also needed are continuous search of instrument data for warning signs, such as volcanic gases and surface thermal events. For this option, the instrument data would still be transmitted to ground and archived, but some of the realtime earth sciences data needs as science products could be supplied to the science users directly on request either through the TDRSS/ATDRSS ground network or by direct broadcast to local receiving stations.

The improvements imposed on the baseline information system in order to serve the option 1 requirements are modest. The primary needs are for: an onboard data system processing complex of medium computing power (10-50 MIPS); a medium data rate data distribution network (50-150 MBPS); and a medium speed access (0.1-10 MS) moderate capacity (10*11 BITS) mass storage unit.

OPTION 2 REQUIREMENTS

The option 2 requirements are extensive and probably unprecedented. Although the study results are incomplete, it can be recognized that there are needs for: high data rate communications not only for instrument data transmission but also for collaborative processing and accessing data between the space system and the ground system; high performance processing/computing both on the spacecraft and on the ground; and high capacity and fast access mass data storage on the spacecraft and on the ground. An immediate need is to determine a global approach to the collaborative processing/computing and data communications.

CANDIDATE TECHNOLOGIES

Since the baseline option can be formed with existing and/or developmental components, no candidate technologies are required for the baseline. Recommended technologies were derived for options 1 and 2 as listed by Table 3. Each technology need is identified with the information data system element. The option 1 technologies coincide with some of the option 2 technologies but the required capabilities for the option 2 technologies are greater. The recommended technology descriptions follow and are identifiable with the analysis results.

TITLE: Global Data Communication and Processing Architectures

DESCRIPTION: In order to serve science users with information products in near realtime, an extensive collaborative processing system will need to be established. The steps to this type of unprecedented system are to understand the needs of the science community, to formulate requirements through analytical methods, and to establish architectural structures for the information system. This candidate technology would perform all three of these functions and would cover satellite systems, space data communications systems, and ground systems. Key areas that require further research, definition and trade studies include global system architectures that meet the science needs; subsystem architectures that are optimized for local or regional tasks; control system architectures that enable efficient operations; and intelligent system approaches to fault containment and management.

TITLE: Optical Communications

DESCRIPTION: Collaborative processing to serve science users will require high capacity communication links. These high capacity communication links will be required between polar orbiting LEO spacecraft, GEO observation platforms, and ground systems. It is essential that the communication system selected have the capability to grow and to evolve to handle sensors which can be expected in the future. The unprecedented high bandwidth requirements can best be served by optical communications in space rather than by limited RF spectrum. Optical communications permits high performance systems to be implemented using very small antennas which is a major advantage in space.

TITLE: Optical Networking

DESCRIPTION:The requirements of the onboard data distribution networks will become increasingly demanding for high data rates in support of onboard processing and combined collaborative processing between the satellite system and the ground system. At these rates, optical media is the most efficient and the technology of choice. The need is to develop networks that are more and more optical to the point of developing all optical networks. Research and development is needed in higher level protocols, high performance and fault tolerant network topologies, and optical nodes and devices. The performance levels required are approximately:

Option 1 - 50-150 MBPS effective transmission rates

Option 2 - >500 MBPS effective transmission rates

TITLE: Parallel Processing/ High Performance Processing

DESCRIPTION:In order to serve science users effectively, there is a need for eventual onboard processing. The technology most likely to lead to the performance levels for the immediate time period is parallel processing. Many inexpensive commercial parallel processing systems are beginning to become available and this effort would look to build on these efforts to produce parallel processing at 10-50 MIPS capability for option 1 application. Exploitation of the super computer technology is required to attain the performance levels for high performance processing which is the choice for option 2.

Option 1 - 10-50 MIPS capability

Option 2 - > 500 MIPS capability

TITLE: Optical Disk Recorder

DESCRIPTION:Serving science users directly with science products also requires onboard data storage and fast data access. The most promising recording technology with this combination of requirements is the optical disk. For quick turn around of ground processed science products, quick access mass data storage is also required. The collaborative processing of Option 2 will extend these needs even more.

Option 1 - 10*11 bits capacity, 0.1-10 MS access

Option 2 - 10*12-10*13 bits capacity, 0.01-1 MS access

TITLE: High Performance Computing

DESCRIPTION: The concept of providing science users with quick access science products, with realtime global event data, and with interactive science processing requires high performance ground computing at multiple sites. Computational requirements of more than 100 Gigaflops have been cited as the need for the year 2000. To achieve this overall high performance, technology efforts are required to improve parallel processing concepts, operating systems, processing hardware, interconnection systems, and software programming.

TITLE: Wide Area Networking (Optical)

DESCRIPTION: Ground based wide area computer data communications are required to support the advancing scientific investigations, to enable distributed user access to science data and information products, and to access data archives and supercomputing resources. The increasing volume of data and increasing distribution points makes high bandwidth optical networking technology the choice for the future. Combining optical networking with todays network system would provide an order of magnitude improvements required for the future. Research and development is needed in communications controller level interfaces, high speed routers, higher level protocols and architectural alternatives.

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2. Harrison, E. F. ; Gibson, G. G. ; Suttles, J. T. ; Buglia, J. J. ; and Taback, I. : "Satellite Orbit Considerations For Mission to Planet Earth". Report to the Global Change Technology Initiative Architecture Trade Study Working Group, NASA Langley Research Center.

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5. Hypes, W. D. ; and Ross, R. : "The Impacts of an EOS-A and B on the Architectural Mix of the GCTI Spacecraft Fleet". Report to the Global Change Technology Initiative Architecture Trade Study Working Group, NASA Langley Research Center, January, 1990.

6. Report of the EOS Data Panel - Earth Observing System Data and Information System, NASA Technical Memorandum 87777.

7. Report of the ISES Earth Sciences Workshop, Williamsburg, Va., May 1-4, 1989.

Table 1: The GCTI Architecture Study Sattellite Fleets

GCTI FLEET W/O EOS A&B		GCTI FLEET W/ EOS A&B	
OPTION 1 CONSTELLATION	OPTION 2 PLATFORMS	OPTION 1 CONSTELLATION	OPTION 2 PLATFORMS
1 A	1 A	1 A	1 A
1 B			
1 C	1 L1=B+C+D+E		1 L1=B+C+D+E
4 D		3 D	
4 E	3 L2=D+E	3 E	2 L2=D+E
1 G1 OR 1 G2 & G"	1 G1 OR 1 G2 & G"	1 G1 OR 1 G2 & G"	1 G1 OR 1 G2 & G"

Table 2. Some Real-Time Earth Sciences Data Needs

<u>GEOLOGY</u>

- o EARLY WARNING DETECTION
- o RAPID IMPACT/DAMAGE ACCESS

<u>ATMOSPHERIC SCIENCES</u>

- o DETECTION OF EVENT TRIGGERS; E.G., STRATOSPHERIC WARMING AND CO2 OUTFLUX

- o ATMOSPHERIC ALERTS OTHER THAN VOLCANIC GASES; E.G., OZONE, CO, INDUSTRIAL POLLUTION, ETC.

<u>OCEANS</u>

- o CHLOROPHYLL DATA
- o OCEAN BOUNDARIES

<u>COSTAL ZONE</u>

- o ALGAE BLOOMS
- o ESTAURINE TRANSPORT; E.G., OCEAN DUMPING, OIL SPILLS, SEDIMENT RUNOFF, ETC.

<u>VEGETATION</u>

- o CROP MANAGEMENT; E.G., IRRIGATION, SENESENCE, POLLUTION, ETC.
- o TRANSIENT EVENTS; E.G., CROP DRYING HOURS FLOODING, FOREST FIRES

<u>SNOW. ICE AND SEASTATE</u>

- o SEA/ICE BOUNDARY
- o ICE/LEADS RATIO FOR METEROLOGICAL MODELS OF POLAR AREAS
- o SNOW/RAIN RATIO IN STORMS

<u>METEROLOGY</u>

- o LARGE STORM WIND FIELDS; HURRICANE EYE NOT ALWAYS CENTER OF STORM
- o NOCTILUCENT, HIGH CIRRUS AND CIRRUS CLOUDS; IMPORTANT FOR SHUTTLE RE-ENTRY
- o CLOUD INVENTORY FOR METEROLOGICAL MODELING, TRANSPORTATION, ETC.

<u>INSTRUMENT SCIENCE</u>

- o DECISION TO ACQUIRE DATA; E.G., USE OF LIGHTNING STRIKES FOR NITROGEN OXIDE STUDY
- o DECISION NOT TO ACQUIRE DATA; E.G., TURN OFF LASER OVER CLOUDS
- o ACQUIRE DATA FOR IMPROVED QUALITY; E.G., UP POWER FOR BETTER SIG/NOISE
- o COMBINING DATA FOR ENHANCED QUALITY; E.G., USE OZONE AND AEROSOL DATA TO IMPROVE MODIS DATA INTERPRETATION

Table 3. Information Data System Technologies

SYSTEM ELEMENT	OPTION 1 TECHNOLOGIES	OPTION 2 TECHNOLOGIES
DATA SYSTEM TOPOLOGY		GLOBAL DATA COMMUNICATION AND PROCESSING ARCHITECTURES
COMMUNICATIONS & TRACKING		OPTICAL COMMUNICATIONS
DATA DISTRIBUTION NETWORK	OPTICAL NETWORKING	OPTICAL NETWORKING
ONBOARD PROCESSING	PARALLEL PROCESSING	HIGH PERFORMANCE PROCESSING/ PARALLEL PROCESSING
MASS DATA STORAGE	OPTICAL DISK RECORDER	OPTICAL DISK RECORDER
GROUND COMPUTING		HIGH PERFORMANCE COMPUTING
GROUND NETWORK		WIDE AREA NETWORKING(OPTICAL)

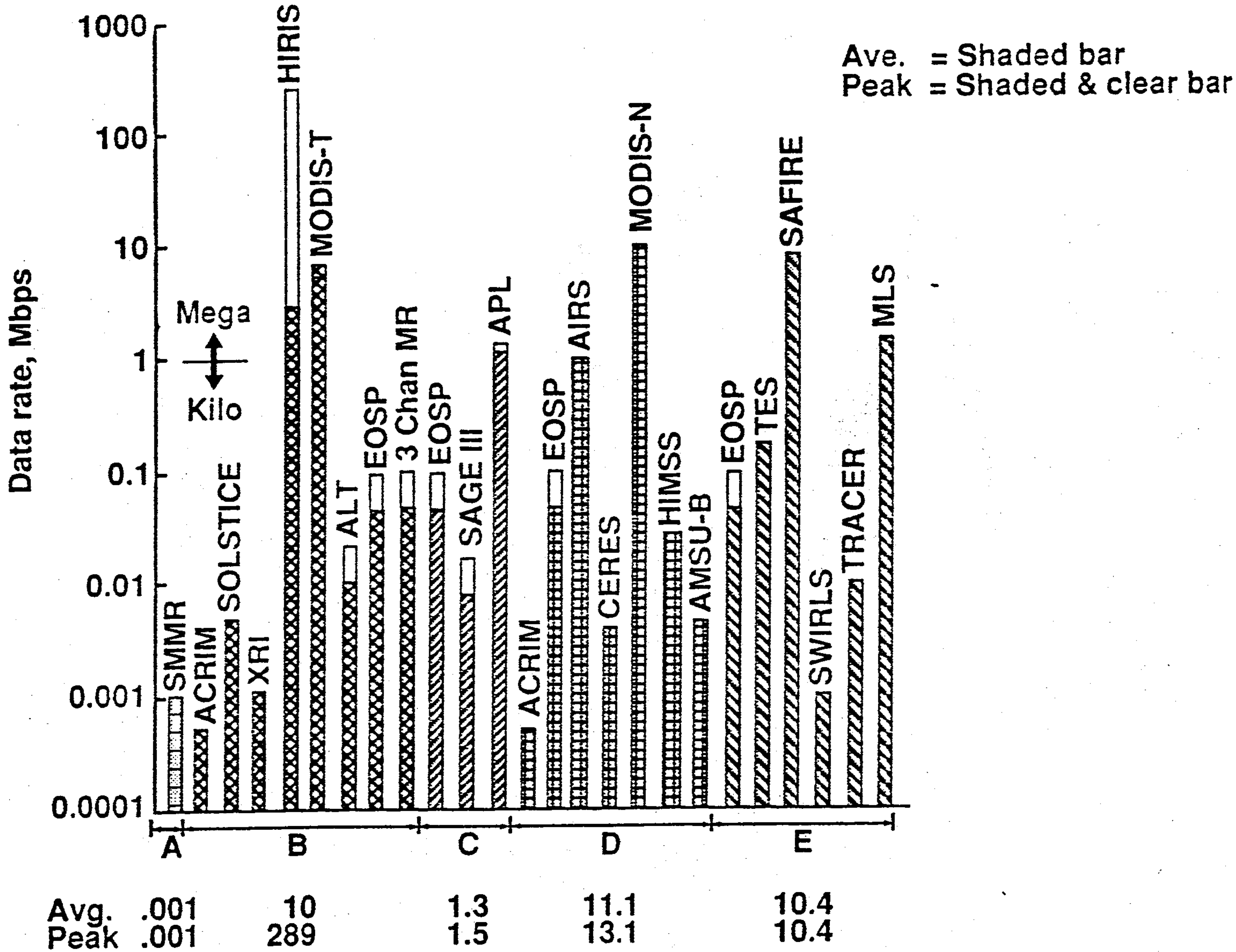
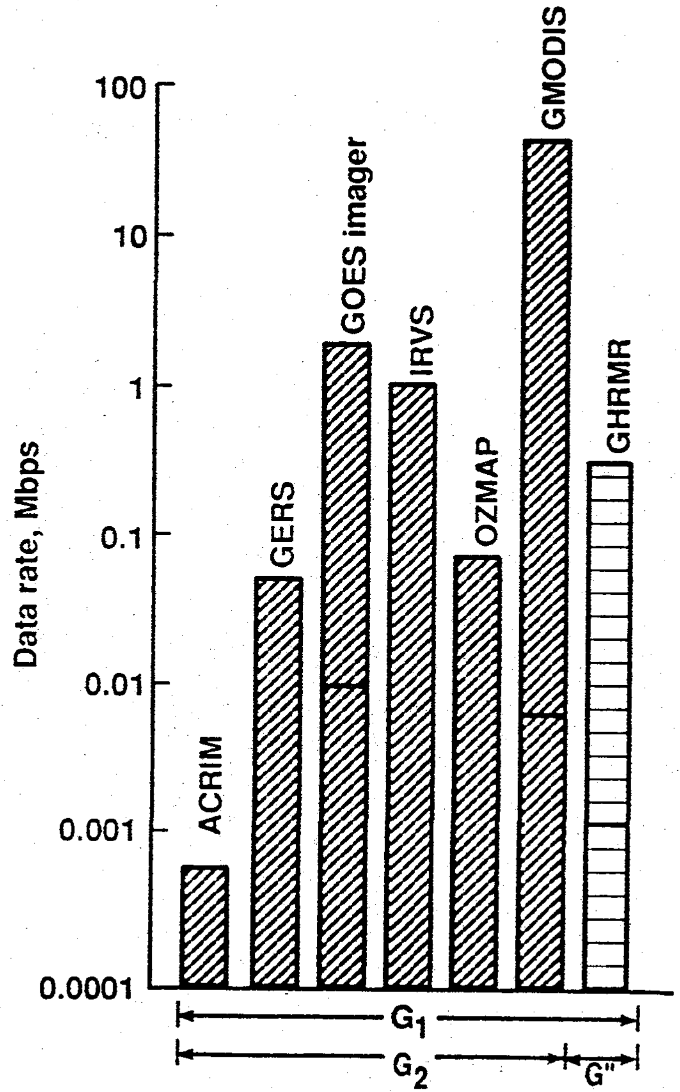


Figure 1. Data Rate Estimates For Low Earth Orbit Science Instruments.



	Peak	Average
G_1	45.8	3.85
G_2	44.9	3.75
G"	0.09	0.09

Figure 2. Data Rate Estimates For Geostationary Earth Orbit Science Instruments.

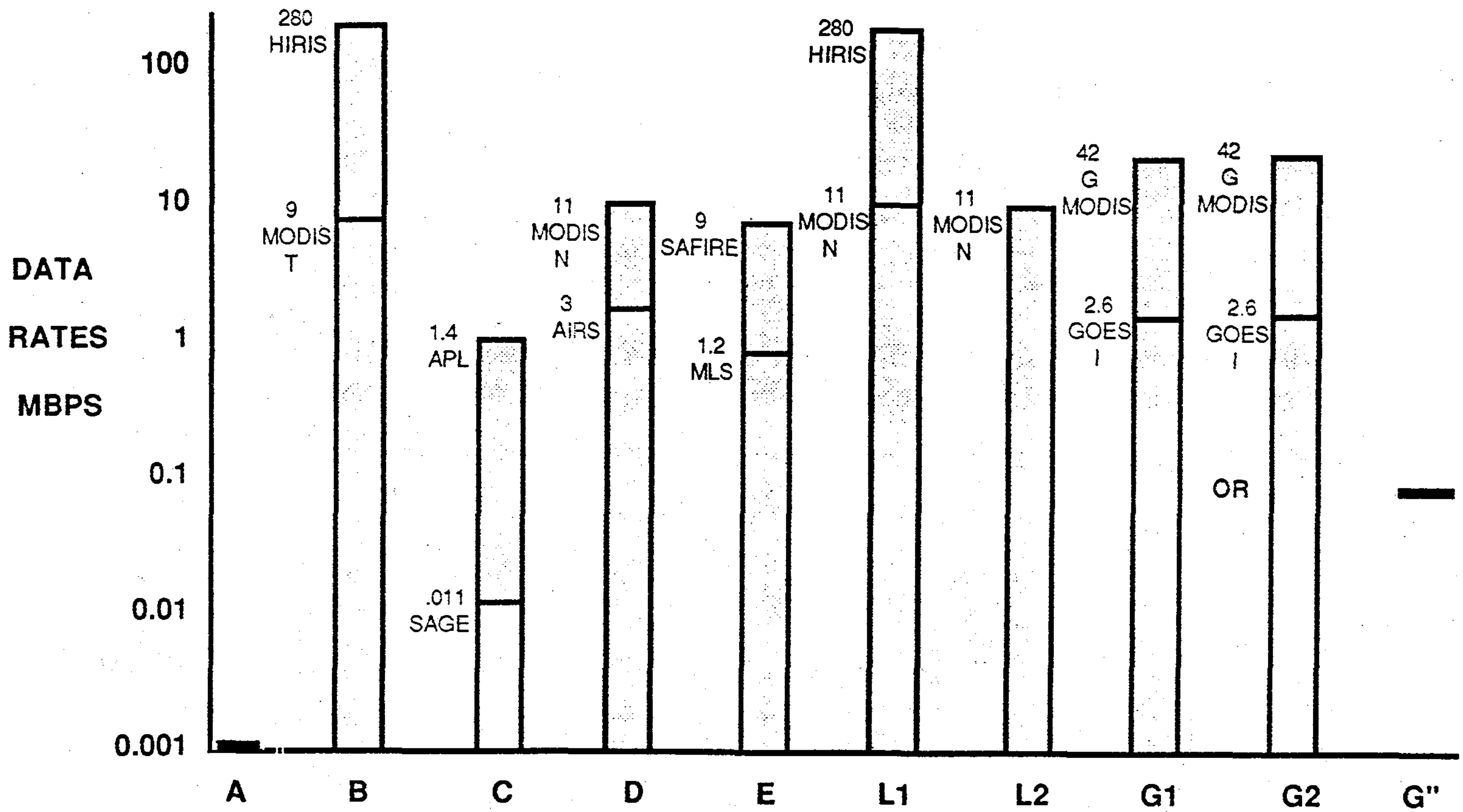


Figure 3: The Range of Peak Data Rates For The GCTI Instrument Configurations

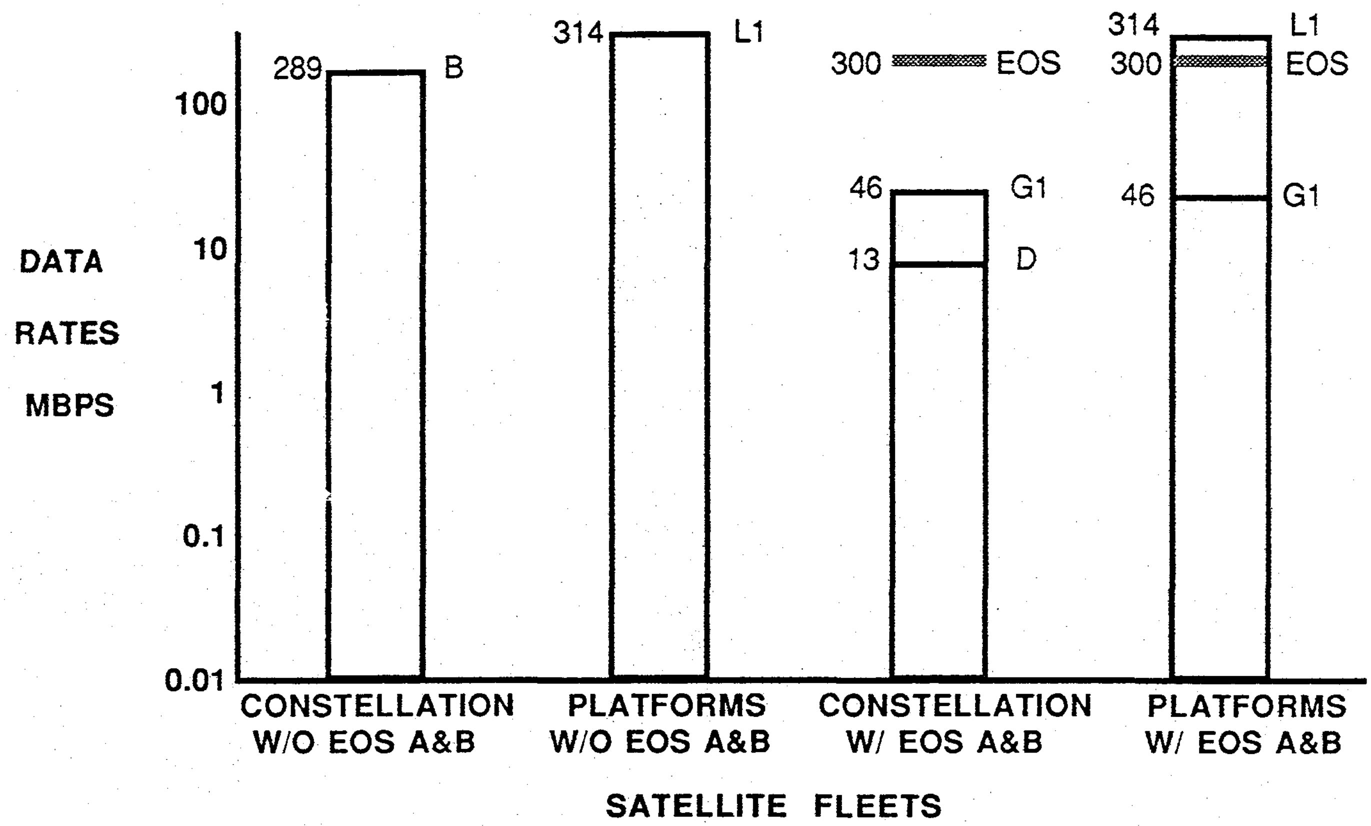


Figure 4. The Range of Data Rates for the GCTI Satellite Fleets

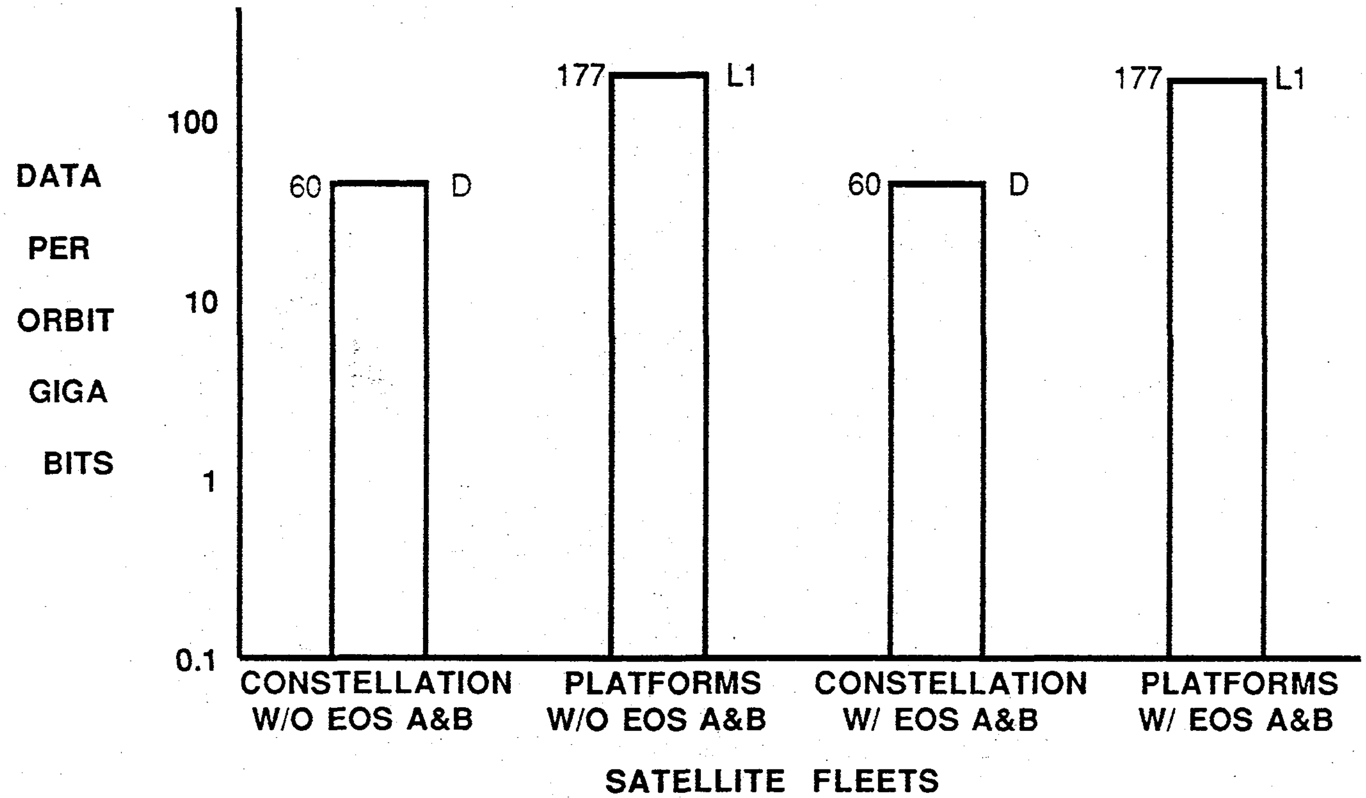


Figure 5. The Range of Data Per Orbit for the GCTI Satellite Fleets

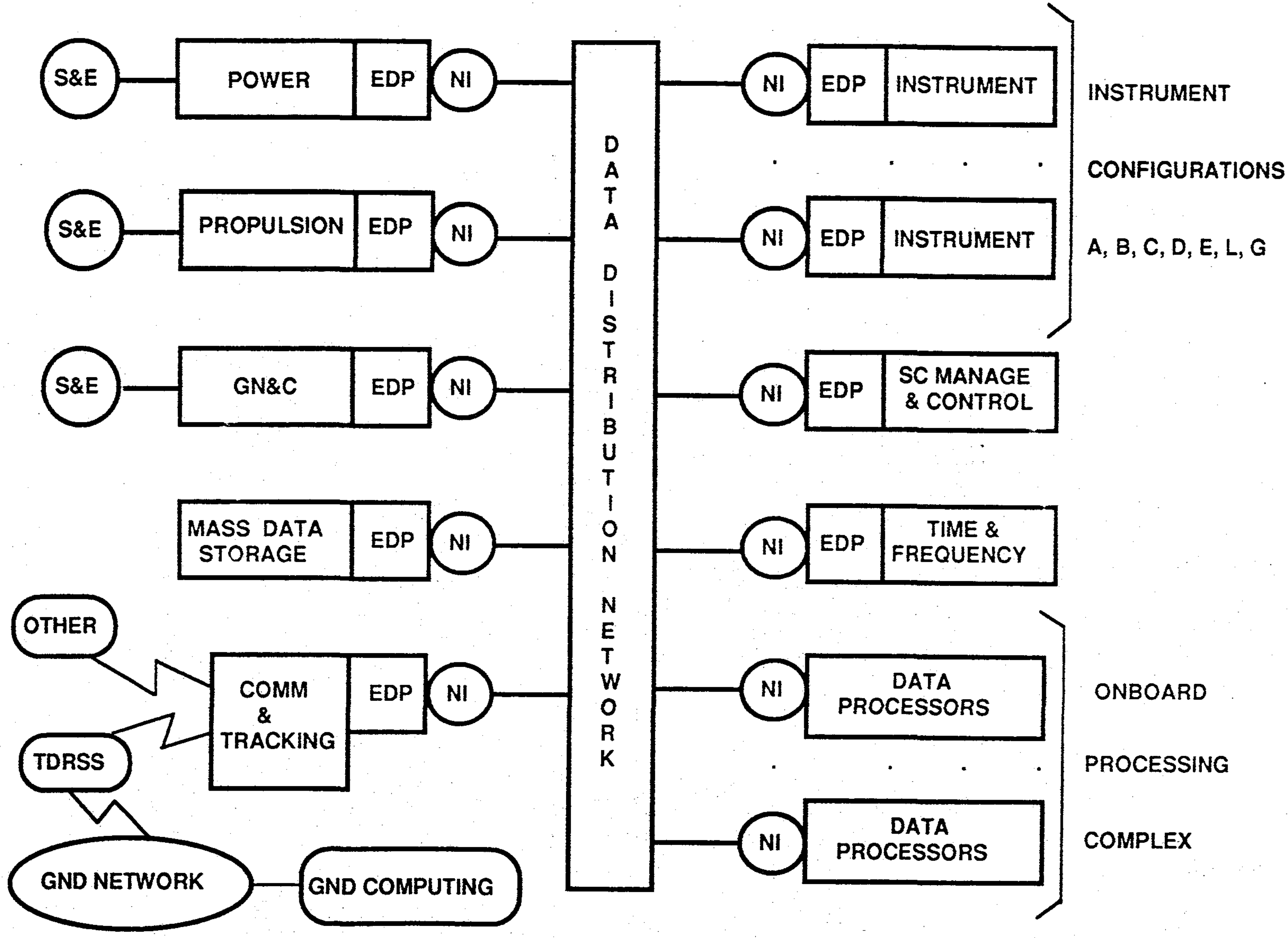


Figure 6. The GCTI Information Data System

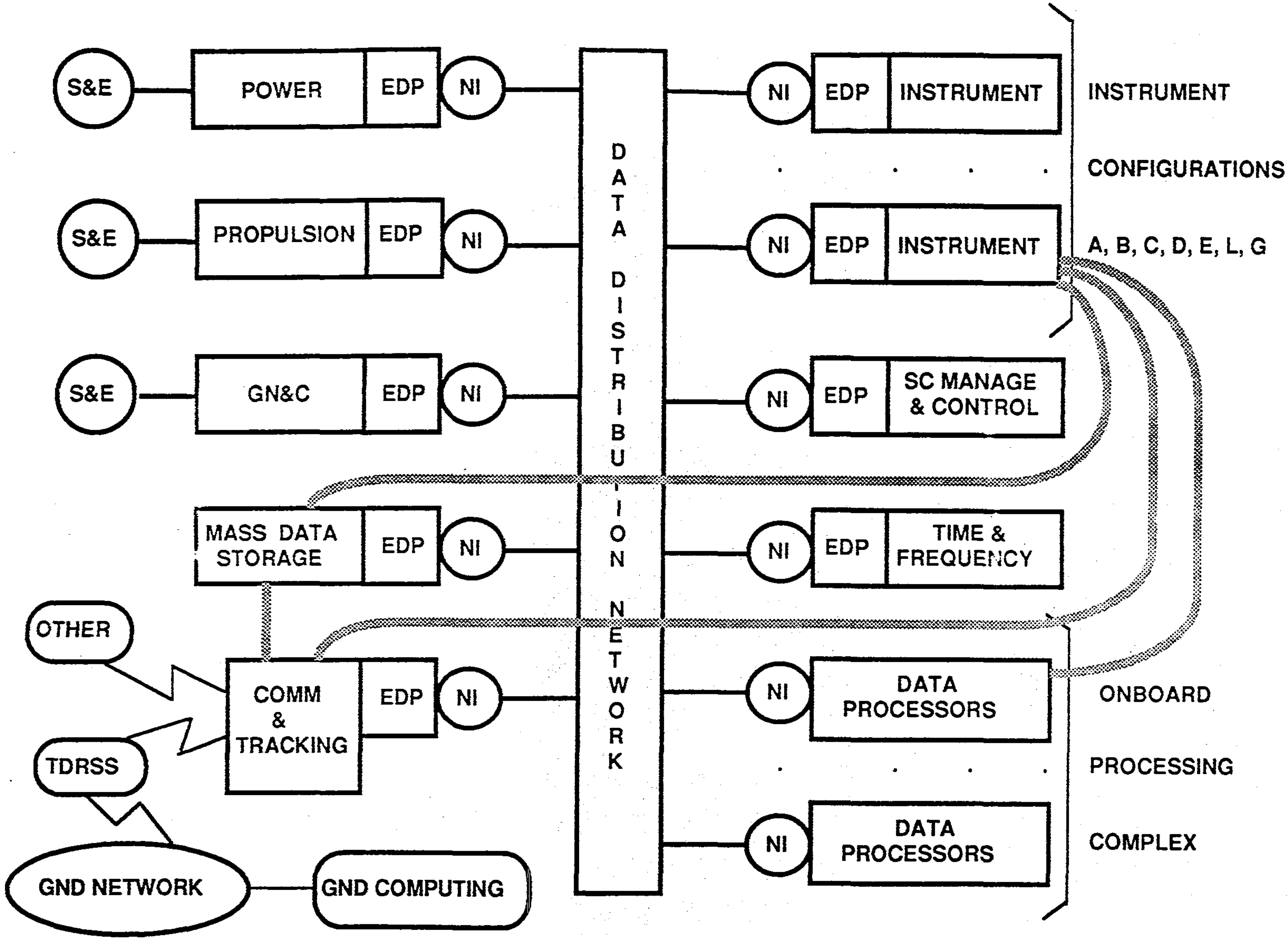


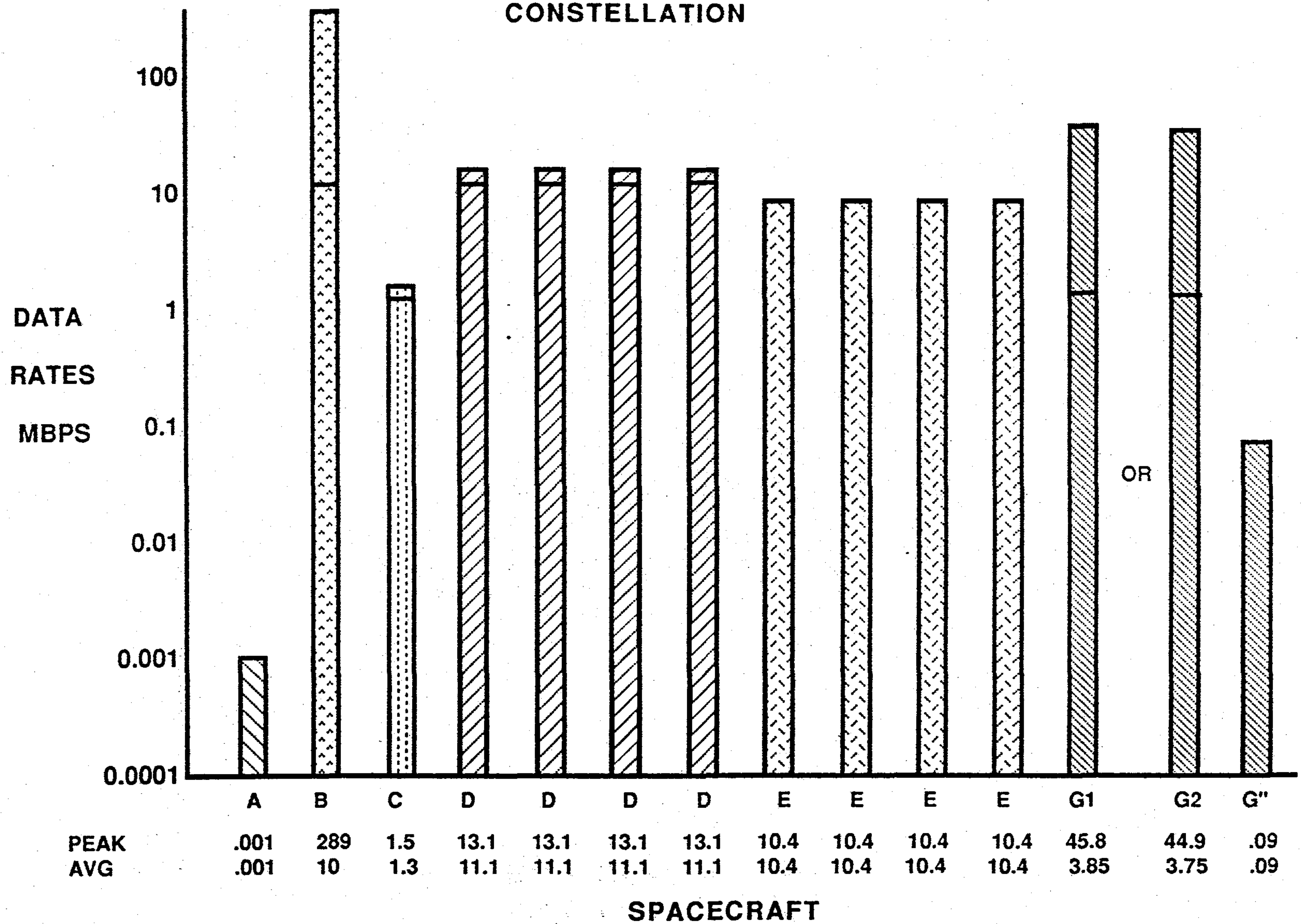
Figure 7. Example Of The High Data Rate Cable Technique

APPENDIX A

DATA RATE ESTIMATES FOR THE GCTI FLEET

DATA RATES

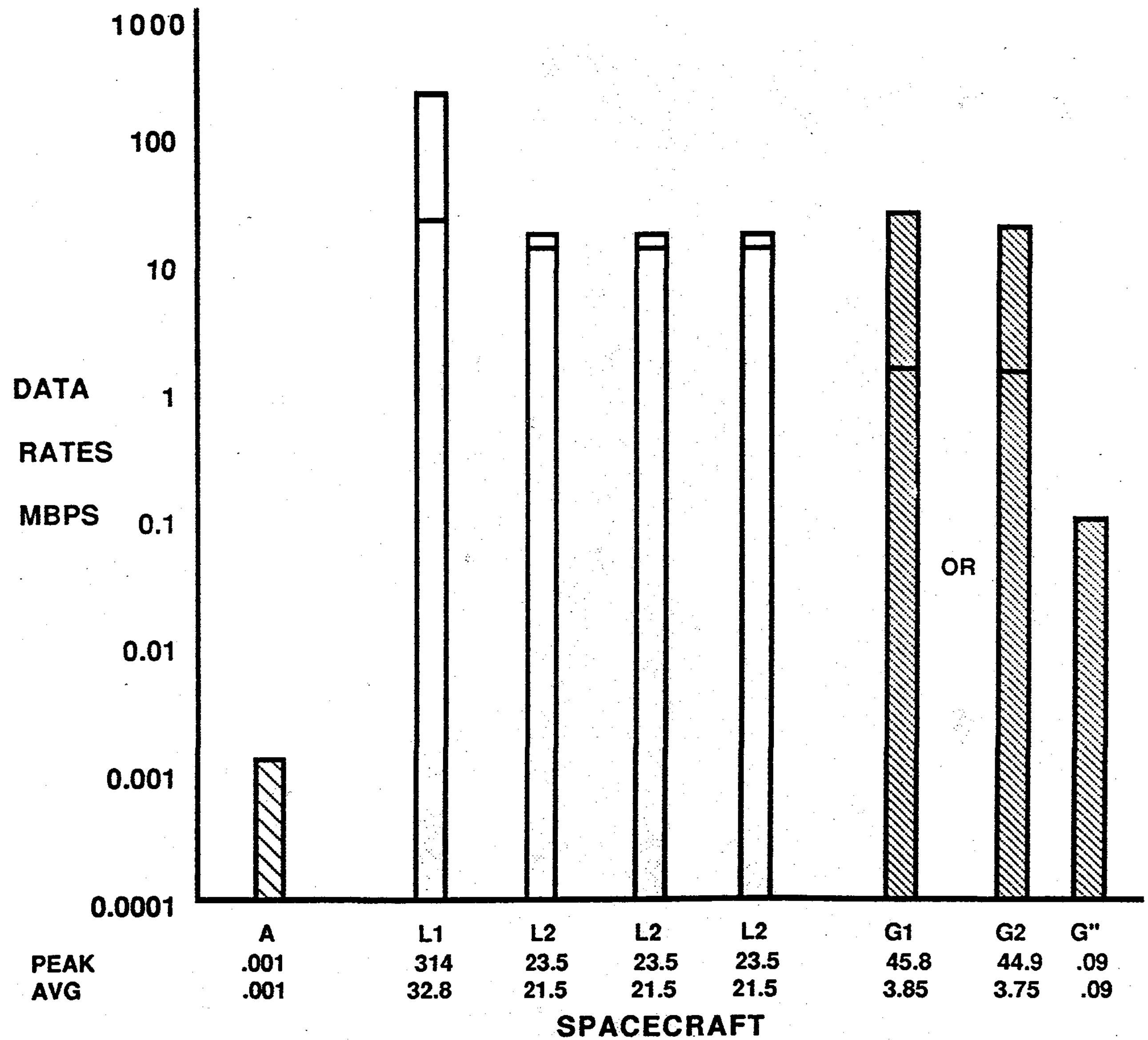
GCTI FLEET WITHOUT EOS A&B CONSTELLATION



DATA RATES

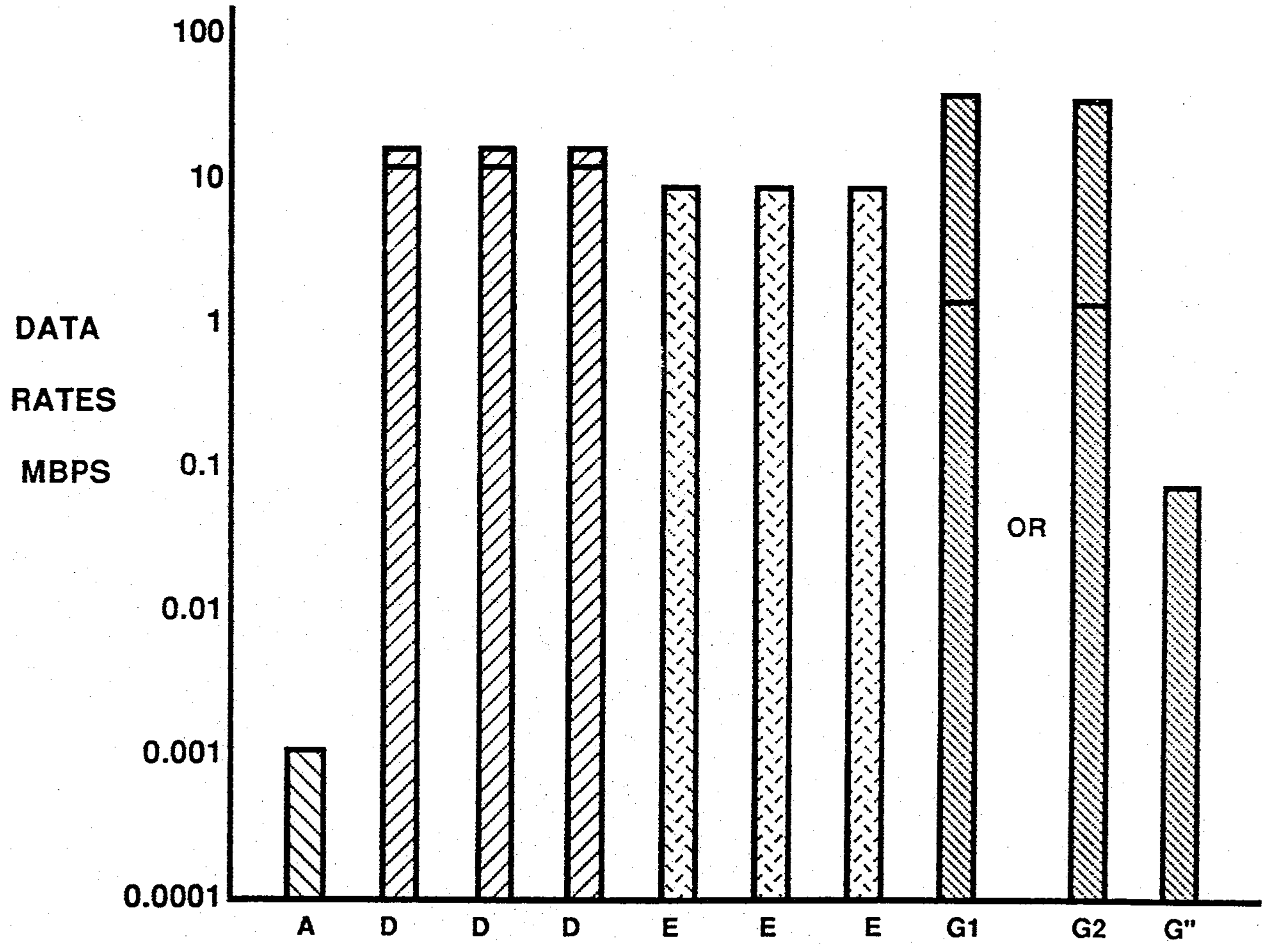
GCTI FLEET WITHOUT EOS A&B

PLATFORMS



DATA RATES

GCTI FLEET WITH EOS A&B CONSTELLATION

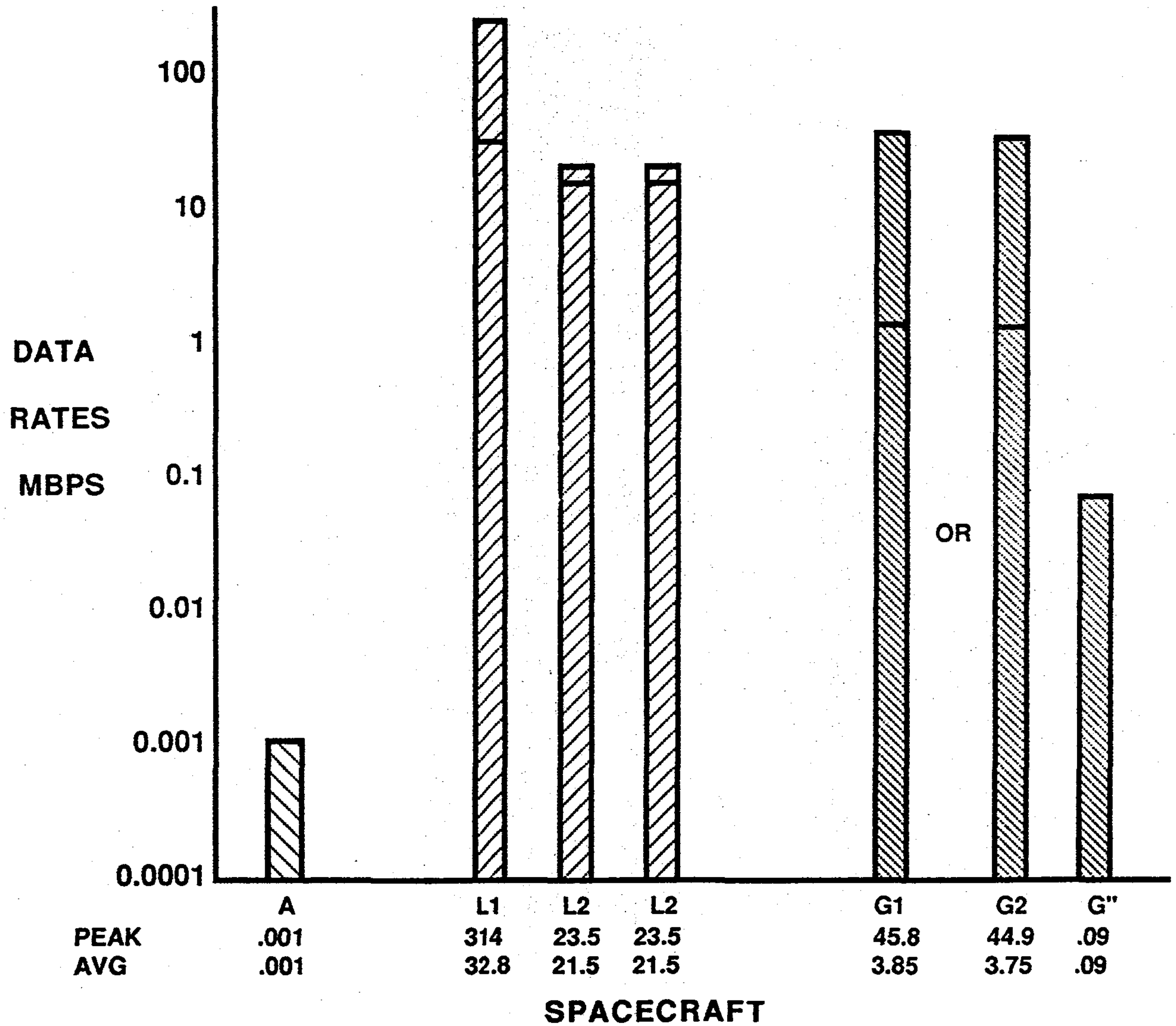


	A	D	D	D	E	E	E	G1	G2	G"
PEAK	.001	13.1	13.1	13.1	10.4	10.4	10.4	45.8	44.9	.09
AVG	.001	11.1	11.1	11.1	10.4	10.4	10.4	3.85	3.75	.09

SPACECRAFT

DATA RATES

GCTI FLEET WITH EOS A&B PLATFORMS



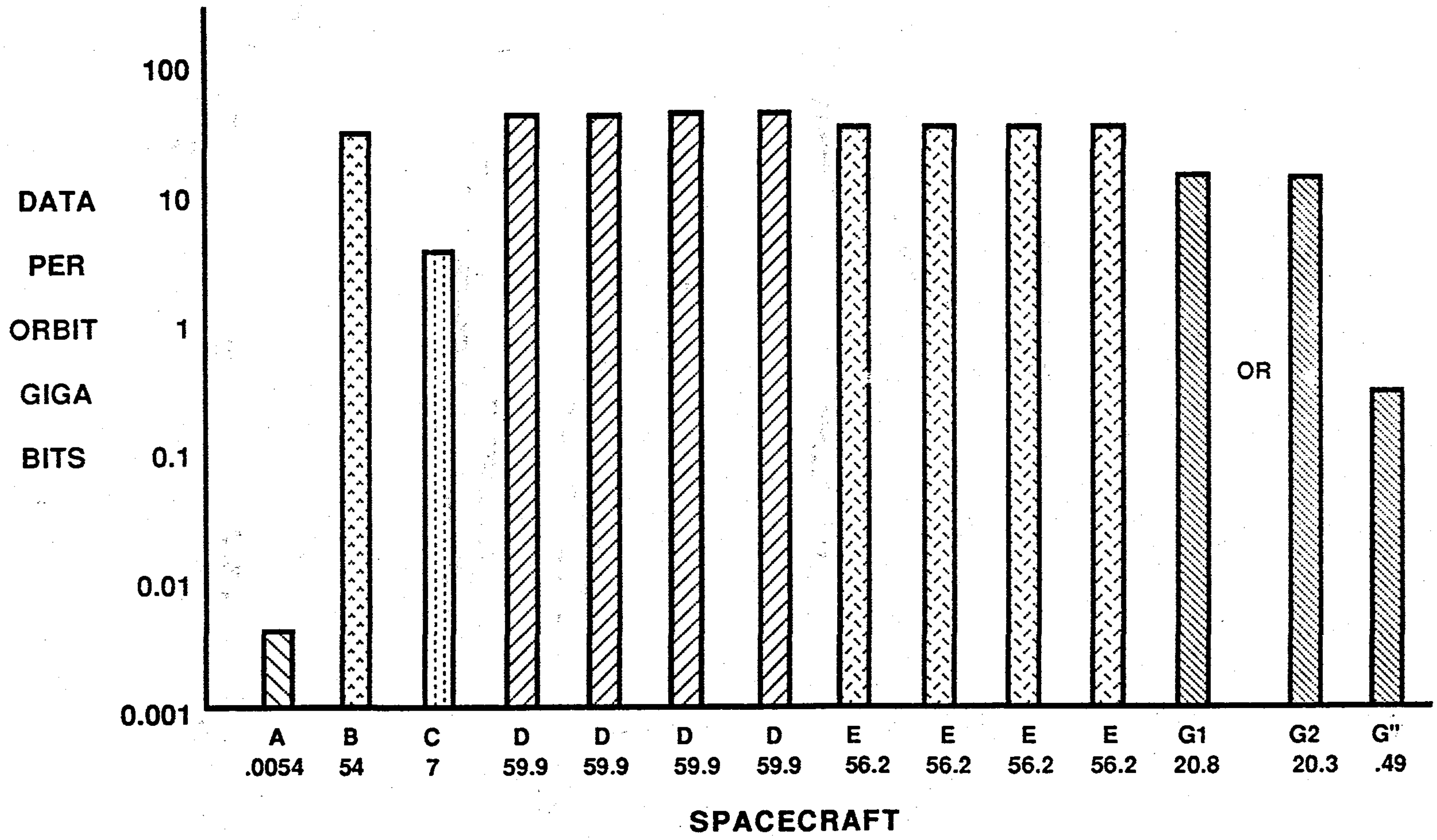
APPENDIX B

DATA PER ORBIT ESTIMATES FOR THE GCTI FLEET

DATA PER ORBIT

GCTI FLEET WITHOUT EOS A&B

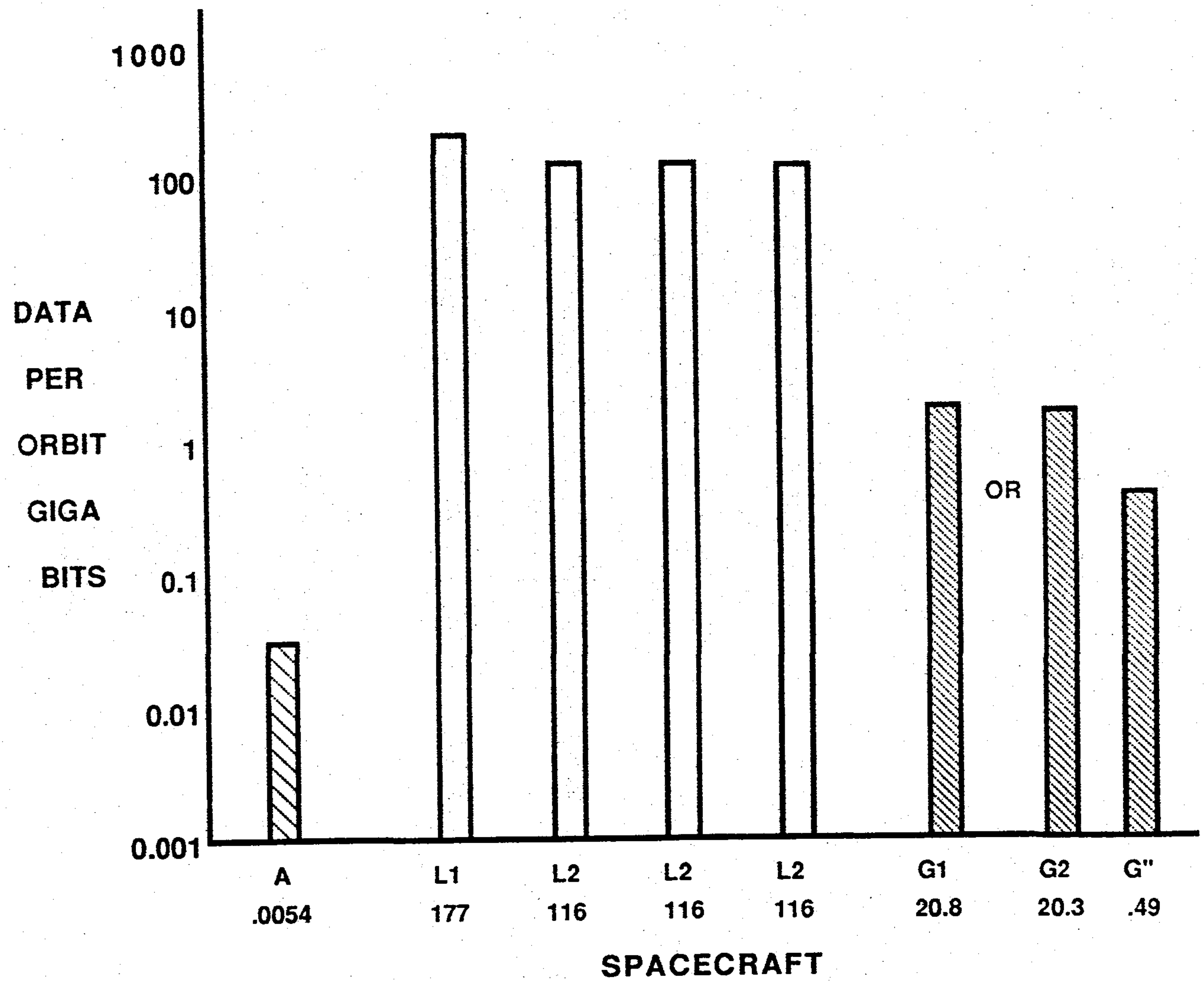
CONSTELLATION



DATA PER ORBIT

GCTI FLEET WITHOUT EOS A&B

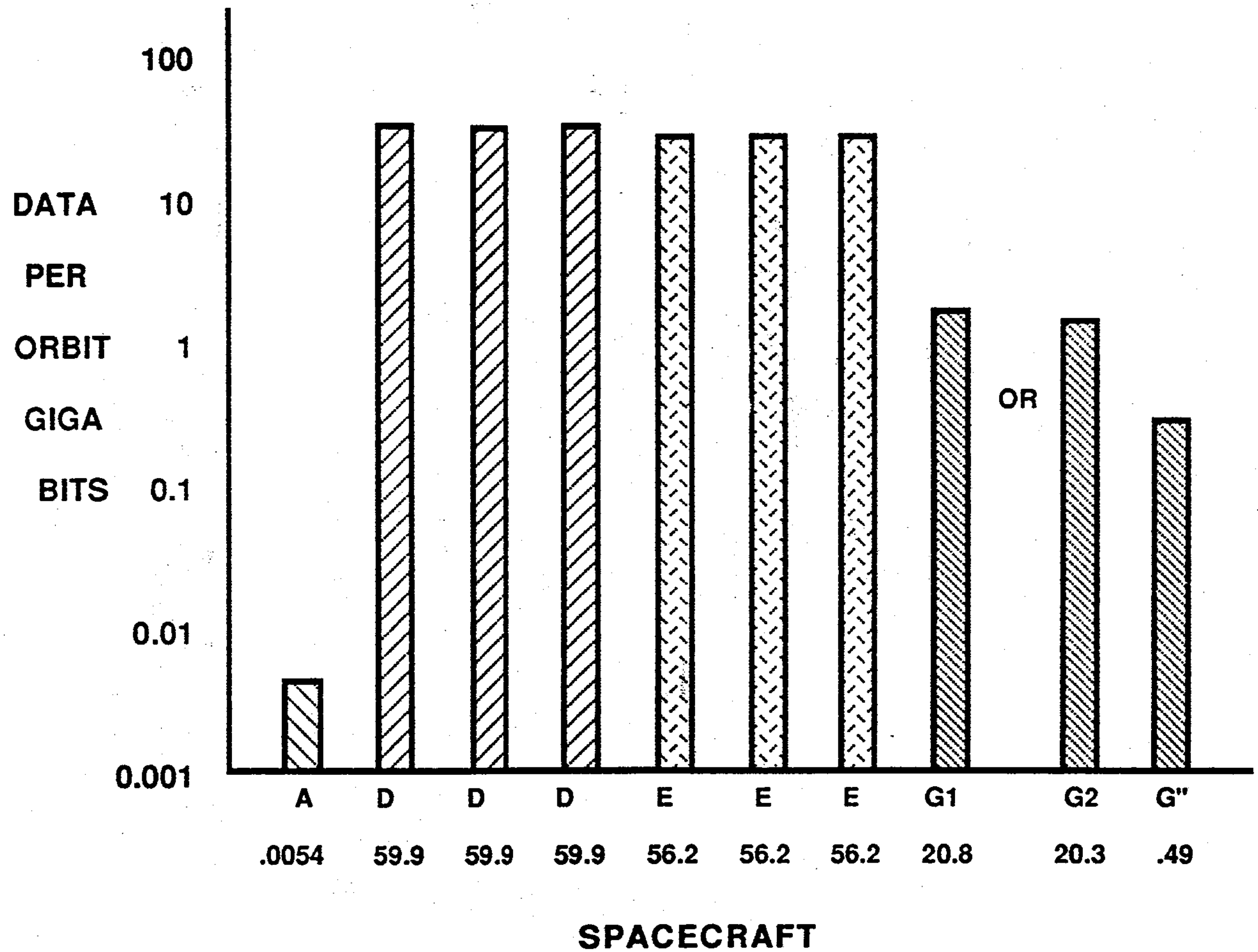
PLATFORMS



DATA PER ORBIT

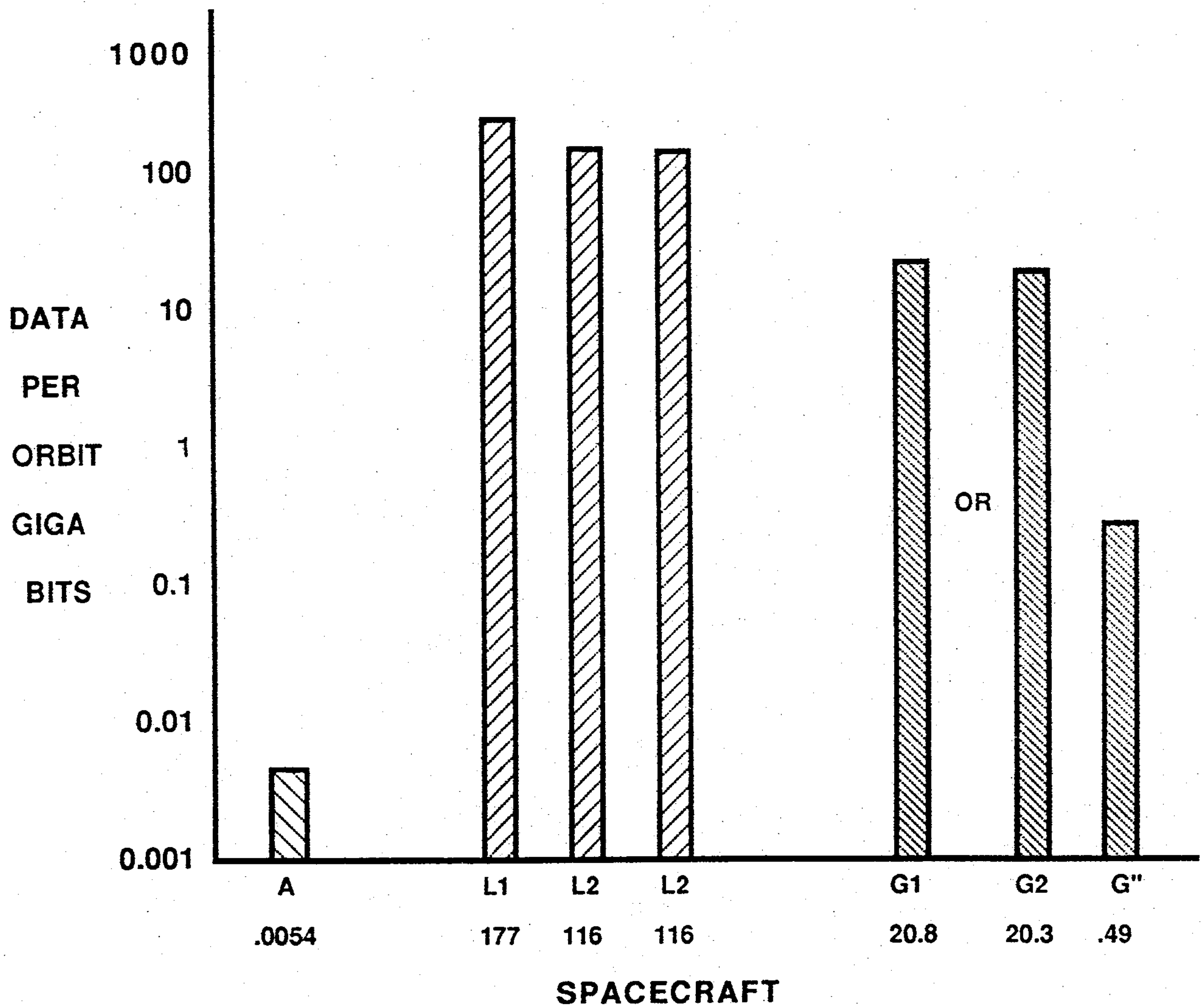
GCTI FLEET WITH EOS A&B

CONSTELLATION



DATA PER ORBIT

GCTI FLEET WITH EOS A&B PLATFORMS



APPENDICES

APPENDIX A

GLOBAL CHANGE TECHNOLOGY INITIATIVE ARCHITECTURE TRADE STUDY PLAN

Prepared by

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GLOBAL CHANGE TECHNOLOGY INITIATIVE
ARCHITECTURE TRADE STUDY PLAN

Background

Extensive study efforts have been completed to define and propose Earth science missions that are best conducted through utilization of spacecraft platforms. The science relates to a broad range of deep space and Earth-related missions. The focus for this study is the Earth-related systems in the Mission to Planet Earth (MPE) Program and the enabling technology program provided by the Global Change Technology Initiative (GCTI).

The need for the Earth science missions and their applicability to global change studies are well described in the NASA Advisory Council, Earth Sciences Committee Report of 1986. The report provides a list of variables and parameters that must be measured periodically or continuously in order to monitor and quantify global conditions and changes. This list will provide a baseline departure point for the science requirements definition task of this study. A second document, the NASA Office of Space Sciences and Applications Strategic Plan of 1988 also discusses Earth-related sciences and, in addition, describes a conceptual set of spacecraft platforms that will support the missions. The key platforms are the two Polar Orbiting Platforms, the Earth-Observing Systems A and B (Eos-A and Eos-B). As stated in the Strategic Plan, "---the Earth-Observing System will place a suite of instruments in low-Earth orbit to make comprehensive observations of Earth's atmosphere, oceans, land surfaces, and biota--- for at least 15 years, the mission will study the global-scale processes that shape and influence the Earth as a system."

A second major spacecraft system featuring a geostationary orbit has been defined and is being proposed for approximately the same time period as the Eos platforms. Thus we have one major LEO and one major GEO system proposed for application to MPE and GCTI programs in the immediate future. The need for global change science studies will extend well beyond these early major systems, but the mix of missions, spacecraft, and sensors for the later science studies has not been defined. The purpose of this trade study is to develop and evaluate architectural mixes of spacecraft and sensor groupings at LEO, GEO, and intermediate orbits to meet the future science needs. The sizes of the spacecraft platforms and single vs. mini-fleet options will be included in the study.

Objectives

The overall objective of the trade study is to define the architectural mix of missions, spacecraft/platforms, and sensors to meet the science requirements of the MPE/GCTI Program beyond the early Eos and GEO spacecraft missions. Within the overall objective, the study includes the following specific objectives.

1. Substantiate the selected mix of LEO, GEO, or intermediate orbit spacecraft/ platforms.
2. Define the required number and size of spacecraft related to objective 1.
3. Define a generic sensor complement for the spacecraft/platforms.
4. Evaluate current spacecraft capabilities to meet the mission requirements and develop conceptual designs of spacecraft/platforms as required.
5. Identify advanced or new technology needed to most efficiently accomplish the MPE/GCTI Program.

Technical Approach

The approach is to use a set of technical tasks with definable completion points to focus and guide the trade study. The tasks are:

Task 1 - Science Requirements Identification

The effort under this task will develop a list of science requirements that will focus the efforts of the subsequent tasks. The task effort is not intended to develop science requirements in great detail but to produce a representative set that can be related to mandatory LEO, GEO, or intermediate altitudes or that provide options in the selection of candidate missions and spacecraft. Establishing priorities for the science requirements for Global Change will also be addressed in the conduct of the study.

Task 2 - Sensor Requirements and Constraints

Once the representative set of science requirements and measurements have been identified, the next task is to identify the appropriate generic sensors. In addition, sensor compatibility will be evaluated so that sensor grouping can be factored into the mission and spacecraft trades. The operational characteristics of the sensors and the constraints they impose need detailed study. Their impact on spacecraft and mission design is great. As a beginning, the following is a list of sensor operational characteristics and constraints that need to be considered for each of the sensors identified.

Sensor type

Mass/dimensions

Power

Sensor duty cycle/power use profile

Antenna sizes and precision requirements

Spatial coverage and resolution required

Temporal coverage required

Viewing mode (nadir, scan, sweep, etc.)

Viewing angles (forward, rear, lateral)

Pointing accuracy (roll, pitch, yaw)

Day/night viewing cycle

Number of information channels

Operational temperature requirement

Operational frequency band

Thermal control (heat to dissipate, temperature tolerance of sensor)

Data transmission rate (kilo bits/sec)

Special calibration requirements

Susceptibility to contamination

In-operation servicing requirement

Potential EMI constraints (on the sensor or imposed by the sensor)

Task 3 - Mission Design Options

The third task is to integrate the science requirements from task 1 and the candidate sensors and sensor characteristics from task 2 into a set of conceptual missions. This task will address the trades between GEO, LEO, and intermediate altitude missions. For missions other than those of GEO, the trades must evaluate altitude and orbit inclination combinations that provide the required spatial coverage. Another mission variable to be defined is the number of spacecraft required to provide the temporal coverage or to provide the spatial and temporal coverage by a multiple set of spacecraft. Science requirements for repeat and/or specific frequency observations will also impact the single vs. multiple spacecraft trades.

Task 4 - Spacecraft and Platform Concepts Development and Options

This task consists of surveys and assessments of existing spacecraft and the development of new spacecraft/platform concepts to support the missions that evolve from tasks 1-3. This task is intended to generate a representative set of spacecraft including, single-purpose spacecraft, intermediate systems for compatible science sensors, and large platforms with a significant number of sensors. Representative systems include Explorer class, and multimission spacecraft; several large spacecraft platforms including concepts like a free-flying large antenna with dedicated spacecraft bus; and several large platforms. The primary design criteria will be the ability of the spacecraft/ platform to provide the necessary resources to the sensors and to meet the performance requirements for the mission set(s). Also, to be emphasized as design drivers are the issues of compatibility with projected available launch vehicles and transportation systems, ease of deployment, potential for in-space assembly, growth potential, and frequency and ease of servicing. Because of schedule and resource limitations, this task is not expected to lead to a comprehensive, fully optimum space architecture but will produce sufficient data on representative classes and numbers of spacecraft/platform concepts to provide the Agency with options for future in-depth studies. Also, broader, more comprehensive studies involving multiple field centers and Headquarters could be undertaken in the ensuing year.

Task 5 - Subsystem Definitions

This task is a parallel effort to task 4 to define the spacecraft/platform subsystems. Major subsystems that have a pronounced effect on the capabilities of the spacecraft to meet the resource and performance requirements will be studied. Other subsystems of secondary importance will be defined as necessary to establish overall spacecraft mass, and performance characteristics will be developed but to lesser detail. Recommended subsystem modifications to existing spacecraft will be identified.

Task 6 - Spacecraft and Sensor Performance Assessments

This task includes simulation and quantification of the on-orbit performance of the spacecraft, its associated subsystems, and the sensors to meet the science and mission requirements. Outputs from this task include, but are not limited to, assessments in the areas of pointing control and stability, vibrational disturbances and need for suppression, power utilization conflicts, and thermal distortion and control. Results can lead to recommended modifications in the designs and/or to the identification of technology needs to be incorporated in task 9.

Task 7 - Trade-Off Criteria

A formal task will be conducted to arrive at a set of trade criteria that will result in a set of candidate systems for enabling the MPE Program. No attempt will be made at this time to preselect the criteria; however, some application of costs and technology development timelines will be included in the criteria.

Task 8 - Trade-Off Evaluations

This task blends all the results of tasks 1-7 and results in a set of conceptual missions and spacecraft that will meet the science objectives of the MPE at minimum cost of resources. The trade studies will define the architectural mix of spacecraft and sensor groupings for flight at LEO, GEO, and intermediate orbits. Practical, achievable sizes of the spacecraft in the mix will be established. An approximate schedule compatible with science needs and realistic availability of technology will be proposed. Spacecraft subsystems will be defined in sufficient detail to support the accomplishment of task 9.

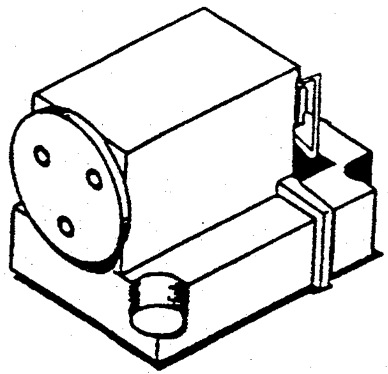
Task 9 - Technology Assessment

During the accomplishment of tasks 1-6, study efforts will not be restricted to the ground rule that conceptual missions, sensors, spacecraft, and subsystems must be based on existing technology. In fact, the specified science needs extend well into the 21st century and, thus, dictate that extended and new technology may be required to support the advanced missions. A concentrated effort will be made throughout the study to identify and specify these needed technology advances. The effort of task 9 will document these findings for incorporation into the GCTI program.

APPENDIX B

PHYSICAL AND PERFORMANCE CHARACTERISTICS OF INSTRUMENTS SELECTED FOR GLOBAL CHANGE MONITORING

Cheryl L. Allen
NASA Langley Research Center

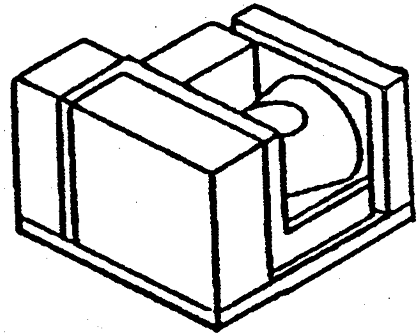


Title: Active Cavity Radiometer Irradiance Monitor (ACRIM)

Measurement: Spectral Radiation

Contact: Richard Wilson
JPL

Instrument Type: Solar Irradiance Monitor
Dimensions: .3m X .47m X .44m
353 **Mass:** 24 kg
Average Operational Power: 5 watts
Data Rate: .52 kbps
Spectral / Frequency Range: 1 - 1,000,000 nm
No. of Channels / Frequencies:
Viewing Field: Sun Tracking (90° - 270° cross track)
Scanning Characteristics: Instrument placed on sun pointing platform
Resolution (Horizontal / Vertical): Sun Disk
Swath Width:
Satellite Application: UARS, Space Station attached payload
Technology Status: Heritage - ACRIM II on UARS
Current -

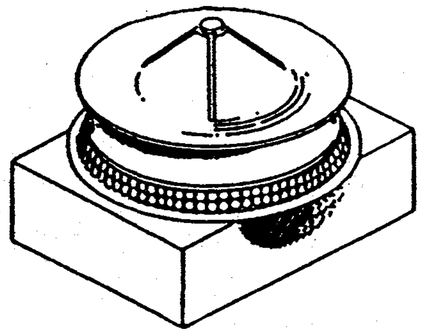


Title: Advanced Microwave Sounding Unit (AMSU-B)

Measurement: Temperature Proifle, Tropospheric Water Vapor, Surface Temperature

Contact:

Instrument Type: Microwave Radiometer
Dimensions: .55m X .55m X .4m
Mass: 40 kg
Average Operational Power: 80 watts
Data Rate: 4.4 kbps
Spectral / Frequency Range: 23.8 - 89 GHz
No. of Channels / Frequencies: 17 Channels
Viewing Field: Nadir (+-50° cross track, +-1° along track)
Scanning Characteristics:
Resolution (Horizontal / Vertical): 15 - 50 km /
Swath Width: 1900 km
Satellite Application: NOAA, TIROS-N
Technology Status: Design studies in progress



Title: Altimeter (ALT)

Measurement: Ocean Circulation, Sea Level Rise, Sea Ice Coverage

Contact: Lee Fu
JPL

Instrument Type: Altimeter

Dimensions: 1.5m X 1.5m X 1m

Mass: 190 kg

Average Operational Power: 240 watts

Data Rate: 12 kbps (peak), 10kbps (avg)

Spectral / Frequency Range: 5.3 - 13.6 GHz

No. of Channels / Frequencies:

Viewing Field: Nadir (+-1° cross track, +-1° along track)

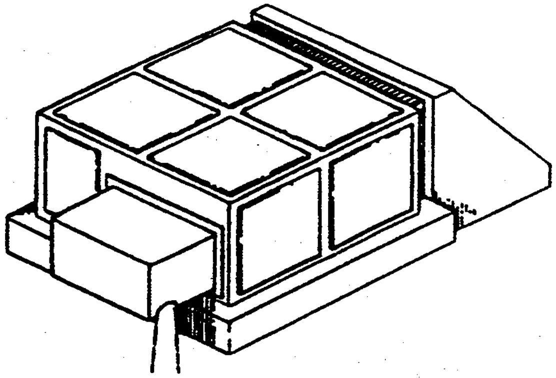
Scanning Characteristics:

Resolution (Horizontal / Vertical): 1 - 15 km / 3.5 cm

Swath Width: 15 km

Satellite Application: TOPEX, Poseidon

Technology Status: Phase - B I/F study in progress

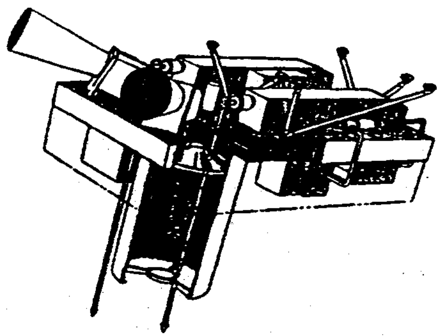


Title: Atmospheric Infrared Sounder (AIRS)

Measurement: Temperature Profile, Tropospheric Water Vapor, Cloud Height

Contact: Moustafa Chahine
JPL

Instrument Type: Infrared Sounder
Dimensions: 1m X .5m X .8m
Mass: 80 kg
Average Operational Power: 300 watts
Data Rate: 3000 kbps (peak), 1000 kbps (avg)
Spectral / Frequency Range: 3000 - 17000 nm
No. of Channels / Frequencies: 115 Bands
Viewing Field: Nadir (+-49° cross track, +-2° along track)
Scanning Characteristics:
Resolution (Horizontal / Vertical): 15 - 50 km / 1 km
Swath Width: 1800 km
Satellite Application: EOS - A
Technology Status: Phase - B/C/D in place; SCR complete

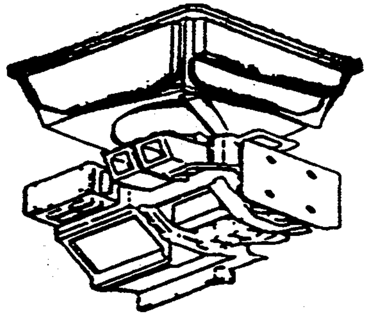


Title: Atmospheric Pressure Lidar (APL)

Measurement: Surface Pressure, Aerosols and Particulates, Cloud Cover and Height

Contact: Larry Korb, Edward Browell
GSFC LARC

Instrument Type: Differential Absorption Lidar
Dimensions: .8m X 1m X .8m (per unit -- two units)
Mass: 500 kg (total mass)
Average Operational Power: 1200 watts (total)
Data Rate: 1400 kbps (peak), 1200 kbps (avg)
Spectral / Frequency Range: 720 - 770 nm
No. of Channels / Frequencies:
Viewing Field: Nadir
Scanning Characteristics: Receiving telescope on scanning platform +-45 deg
Resolution (Horizontal / Vertical): 10 km /
Swath Width: 1600 km
Satellite Application: None (new concept)
Technology Status: Heritage - LITE & LASE Instrument for Atmospheric Parameters / Aircraft, Derivative of LASA - EAGLE design
Current - Conceptual design, GCTI Spacecraft, No formal study

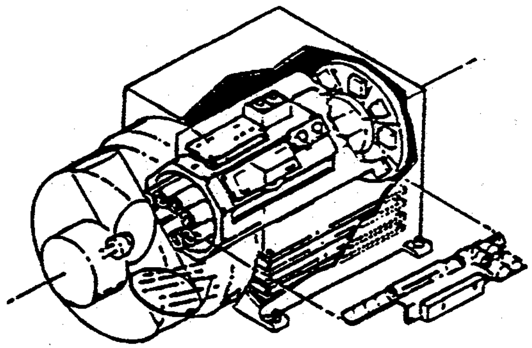


Title: Cloud and Earth Radiant Energy System (CERES)

Measurement: Radiation Budget

Contact: Bruce Barkstrom
LARC

Instrument Type: Infrared Radiometer
Dimensions: .6m X .5m X .7m (two units)
Mass: 90 kg (total)
Average Operational Power: 90 watts (total)
Data Rate: 4 kbps
Spectral / Frequency Range: 200 - 100000 nm
No. of Channels / Frequencies: 3 Channels
Viewing Field: Nadir (-100° - +73°cross track, +-73° along track)
Scanning Characteristics: Cross track and Bi-axial Scan
Resolution (Horizontal / Vertical): 10 - 35 km
Swath Width: 2400 km
Satellite Application: EOS - A
Technology Status: Heritage - ERBE from ERBS
Current - Phase - B in progress

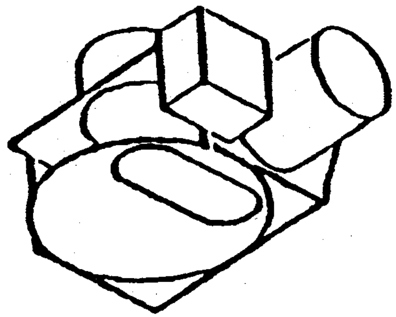


Title: Earth Observing Scanning Polarimeter (EOSP)

Measurement: Aerosols and Particulates, Ozone

Contact: Larry Travis
GSFC

Instrument Type: Polarimeter
Dimensions: .3m X .3m X .3m
Mass: 11 kg
Average Operational Power: 11 watts
Data Rate: 86 kbps (peak), 44 kbps (avg)
Spectral / Frequency Range: 410 - 2250 nm
No. of Channels / Frequencies:
Viewing Field: Nadir (+-55°cross track, +-3° along track)
Scanning Characteristics:
Resolution (Horizontal / Vertical): 10 km /
Swath Width: 2280 km
Satellite Application: EOS - A
Technology Status: Phase - B start early 1990

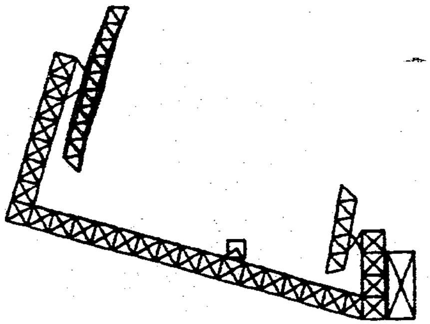


Title: Geostationary Earth Radiation Sensor (GERS)

Measurement: Radiation Budget

Contact: Frank Staylor
LARC

Instrument Type: Infrared Radiometer
Dimensions: 1.5m X 1m X 1m
Mass: 110 kg
Average Operational Power: 90 watts
Data Rate: 20 kbps
Spectral / Frequency Range: 200 - 5000 nm
No. of Channels / Frequencies:
Viewing Field: Earth Disc
Scanning Characteristics:
Resolution (Horizontal / Vertical): 40 km /
Swath Width:
Satellite Application: Proposed geostationary platforms
Technology Status: Phase - A in progress



Title: Geostationary High Resolution Microwave Radiometer (GHRMR)

Measurement: Tropospheric Water Vapor, Precipitation

Contact: Tom Campbell, LARC   Jeff Farmer, LARC

Instrument Type: Microwave Radiometer

Dimensions: 15m X 15m X 30m

Mass: 2525 kg

Average Operational Power: 370 watts

Data Rate: 90 kbps

Spectral / Frequency Range: 18 - 220 GHz

No. of Channels / Frequencies:

Viewing Field: Earth Disc

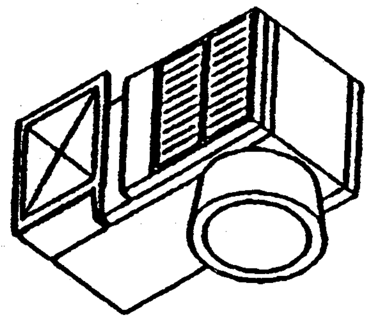
Scanning Characteristics: Mechanical mirror with electronic phased array scanning

Resolution (Horizontal / Vertical): 10 - 120 km /

Swath Width:

Satellite Application: None (new concept)

Technology Status: Conceptual design, GCTI spacecraft, no formal study



Title: Geostationary Moderate Resolution Imaging Spectrometer (GMODIS)

Measurement: Cloud Coverage and Height, Temperature Profile, Biomass Inventory

Contact:

Instrument Type: Imaging Spectrometer

Dimensions: 2.1m X .9m X 1.2m

Mass: 230 kg

Average Operational Power: 250 watts

Data Rate: 42000 kbps

Spectral / Frequency Range: 400 - 12000 nm

No. of Channels / Frequencies:

Viewing Field: Earth Disc

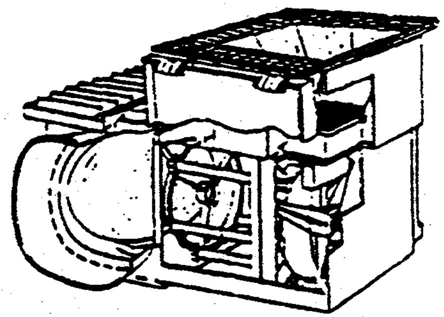
Scanning Characteristics:

Resolution (Horizontal / Vertical): .5 km /

Swath Width:

Satellite Application: Proposed geostationary platforms

Technology Status:



Title: Geostationary Operational Environmental Satellite (GOES) Imager

Measurement: Surface Temperature, Cloud Cover, Wind Fields

Contact:

Instrument Type: VIS / IR Radiometer

Dimensions: 1.5m X 1m X 1m

Mass: 118 kg

Average Operational Power: 130 watts

Data Rate: 2621 kbps

Spectral / Frequency Range: 700 - 12000 nm

No. of Channels / Frequencies: 5 Channels

Viewing Field: Earth Disc

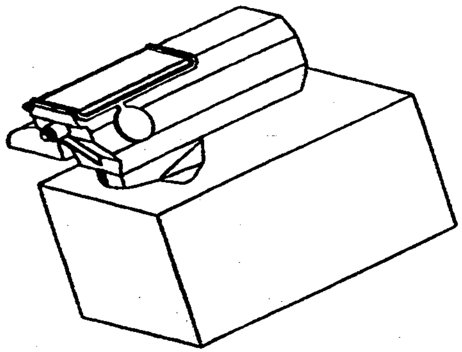
Scanning Characteristics:

Resolution (Horizontal / Vertical): 8 km / 1 km

Swath Width:

Satellite Application: GOES

Technology Status:



Title: High Resolution Imaging Spectrometer (HIRIS)

Measurement: Cloud Cover, Sea Ice and Snow Cover, Vegatation, Biomass Inven., Ocean Color

Contact: Alexander Goetz
University of Colorado

Instrument Type: Imaging Spectrometer
Dimensions: 2.5m X 1.6m X 1.5m
Mass: 660 kg
Average Operational Power: 300 watts
Data Rate: 280000 kbps (peak), 3000 kbps (avg)
Spectral / Frequency Range: 400 - 2500 nm
No. of Channels / Frequencies: 200 Channels
Viewing Field: Nadir (+-26°cross track, -30° - 52° along track)
Scanning Characteristics: Pointable Mirror
Resolution (Horizontal / Vertical): .03 km /
Swath Width: 30 km
Satellite Application: EOS - A
Technology Status: Heritage - ETM Instrument for Earth (land) Resources/LandSat 6
HRV Instrument for Earth (land) Resources/SPOT
Current - Extensive Phase - B in progress

Title: High Resolution Microwave Spectrometer Sounder (HIMSS)

Measurement: Trop Water Vapor, Temp Profile, Surface Temp, Precip, Sea Ice and Snow Depth

Contact: Roy Spencer
MSFC

Instrument Type: Microwave Radiometer

Dimensions: 2m X 2m X 1.2m

Mass: 222 kg

Average Operational Power: 66 watts

Data Rate: 27 kbps

Spectral / Frequency Range: 6.6 - 90 GHz

No. of Channels / Frequencies: 10 Frequencies

Viewing Field: Nadir (+-45° cross track, +-53° along track)

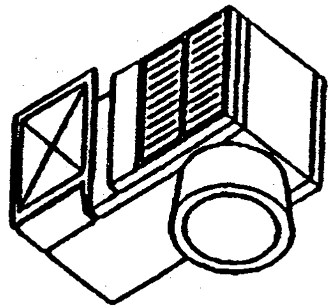
Scanning Characteristics: Rotating Drum at 30 RPM (+-45° momentum comp.)

Resolution (Horizontal / Vertical): 50 km - 5 km (depending on frequency) /

Swath Width: 1470 km

Satellite Application: EOS - A

Technology Status: Heritage - SSM/I from DMSP
Current - Phase - B in progress

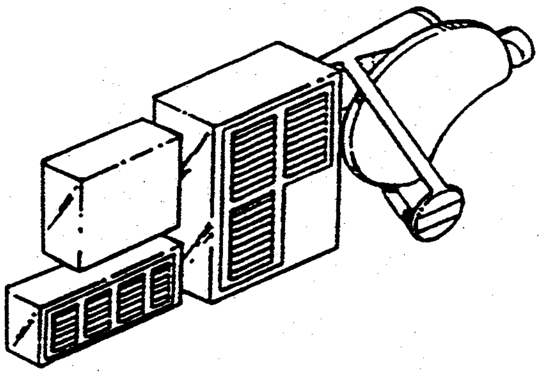


Title: Infrared Vertical Sounder (IRVS)

Measurement: Temperature Profile, Aerosols and Particulates

Contact:

Instrument Type: Infrared Radiometer
Dimensions: 1.5m X 1m X 1m
Mass: 150 kg
Average Operational Power: 150 watts
Data Rate: 1000 kbps
Spectral / Frequency Range: 4200 - 5200 nm
No. of Channels / Frequencies: 20 Channels
Viewing Field: Earth Disc
Scanning Characteristics:
Resolution (Horizontal / Vertical): 10 - 5 km / 1 - .2 km
Swath Width:
Satellite Application: Proposed geostationary platforms
Technology Status:

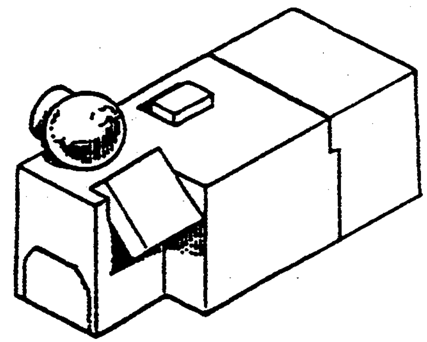


Title: Microwave Limb Sounder (MLS)

Measurement: Stratospheric Gases: O3, H2O, H2O2, ClO

Contact: Joe Waters
GSFC

Instrument Type: Microwave Radiometer
Dimensions: 2.2m X 1.3m X 1.9m
Mass: 450 kg
Average Operational Power: 790 watts
Data Rate: 1150 kbps
Spectral / Frequency Range: 117 - 637 GHz
No. of Channels / Frequencies: 5 Frequencies
Viewing Field: Limb View (+-90° along track, -30° - -17° vertical limb)
Scanning Characteristics: Limb Scanning Microwave Radiometer
Resolution (Horizontal / Vertical): 3-10 km / 3 km
Swath Width: 100 km
Satellite Application: EOS - B
Technology Status: Heritage - MLS Instrument for Stratospheric Gases / UARS
Current - Preliminary Design, EOS Spacecraft



Title: Moderate Resolution Imaging Spectrometer - Nadir Scan (MODIS - N)

Measurement: Vegatation, Biomass Inventory, Oceans, Sea Ice and Snow, Clouds, Surface Temp.

Contact: Vincent Salomonson
GSFC

Instrument Type: Imaging Spectrometer

Dimensions: 1.2m X .7m X .5m

Mass: 200 kg

Average Operational Power: 250 watts

Data Rate: 10000 kbps (peak), 5500 kbps (avg)

Spectral / Frequency Range: 470 - 14200 nm

No. of Channels / Frequencies: 40 Bands

Viewing Field: Nadir (+-50°cross track, +-4° along track)

Scanning Characteristics:

Resolution (Horizontal / Vertical): .5 km

Swath Width: 1800 km

Satellite Application: EOS - A

Technology Status: Heritage - ETM Instrument for Earth (land) Resources/LandSat 6
HRV Instrument for Earth (land) Resources/SPOT
Current - Dual Phase - B complete; RFP release early 1990

Title: Moderate Resolution Imaging Spectrometer - Tilt Scan (MODIS - T)

Measurement: Cloud Cover, Sea Ice and Snow Cover, Vegatation, Biomass Inven., Ocean Color

Contact: Vincent Salomonson
GSFC

Instrument Type: Imaging Spectrometer

Dimensions: .5m X .5m X .4m

Mass: 100 kg

Average Operational Power: 150 watts

Data Rate: 8500 kbps (peak), 3500 (avg)

Spectral / Frequency Range: 400 - 1040 nm

No. of Channels / Frequencies: 64 Channels

Viewing Field: Nadir (+-50°cross track, +-50° along track)

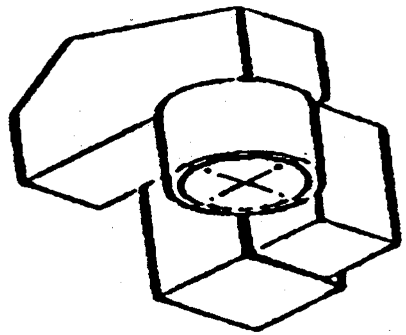
Scanning Characteristics: Scan Mirror

Resolution (Horizontal / Vertical): 1 km /

Swath Width: 1800 km

Satellite Application: EOS - A

Technology Status: Heritage - ETM Instrument for Earth (land) Resources/LandSat 6
HRV Instrument for Earth (land) Resources/SPOT
Current - Extended Phase - B study complete; design in hand

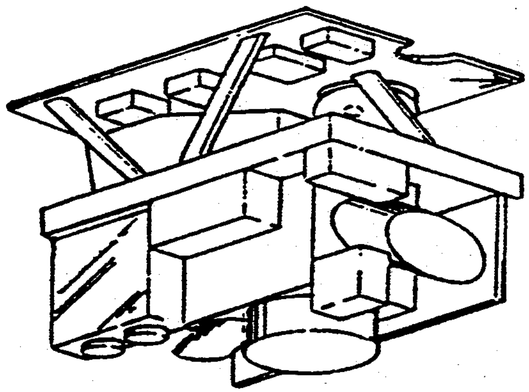


Title: Ozone Mapper (OZMAP)

Measurement: Ozone

Contact:

Instrument Type: UV Spectrometer
Dimensions: 1m X 1m X 1.67m
Mass: 100 kg
Average Operational Power: 130 watts
Data Rate: 70 kbps
Spectral / Frequency Range: 295 - 318 nm , 6000 - 18000 nm
No. of Channels / Frequencies:
Viewing Field: Earth Disc
Scanning Characteristics:
Resolution (Horizontal / Vertical): 43 km / .6 km
Swath Width:
Satellite Application: Proposed geostationary platforms
Technology Status:



Title: Spectroscopy of the Atmosphere Far-Infrared Emission (SAFIRE)

Measurement: Stratospheric Gases : O3,H2O,H2O2,NO2 HNO3,N2O5, CH4,HF,HBR,HCl,HOCl

Contact: James Russell
LARC

Instrument Type: Limb Scanning Infared Spectrometer / Radiometer

Dimensions: 1.4m X 1m X 1.5m

Mass: 304 kg

Average Operational Power: 304 watts

Data Rate: 9000 kbps

Spectral / Frequency Range: 6000 - 32000 nm

No. of Channels / Frequencies:

Viewing Field: Limb View (-10° - 170° along track, -30° - -17° vertical limb)

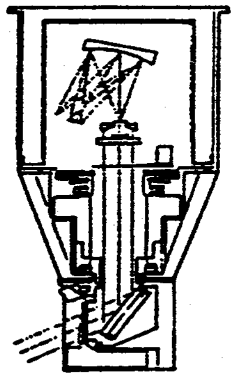
Scanning Characteristics: Limb Scanning

Resolution (Horizontal / Vertical):

Swath Width: 10 km (limb viewed)

Satellite Application: EOS - B

Technology Status:



Title: Stratospheric Aerosol and Gas Experiment (SAGE III)

Measurement: Stratospheric Gases: O3, NO2, H2O, Aerosols and Particulates

Contact: Patrick McCormick
LARC

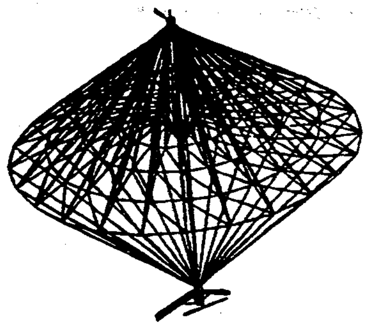
Instrument Type: Limb Scanning Grating Spectrometer
Dimensions: .35m X .35m X .5m
Mass: 60 kg
Average Operational Power: 25 watts
Data Rate: 11 kbps (peak), 8 kbps (avg)
Spectral / Frequency Range: 300 - 1500 nm
No. of Channels / Frequencies:
Viewing Field: Nadir (+-180° along track, -30° - -23° vertical limb)
Scanning Characteristics: Scanning Mirror
Resolution (Horizontal / Vertical): / 1 - 2 km
Swath Width:
Satellite Application: EOS - A
Technology Status: Heritage - SAGE II on ERBS
Current - Phase B/C/D scheduled for 1990

Title: Stratospheric Wind Infrared Limb Sounder (SWIRLS)

Measurement: Wind Fields (Stratospheric), Temperture Profile

Contact: Daniel McCleese
JPL

Instrument Type: Gas Correlation Radiometer
Dimensions: .52 m3
Mass: 90 kg
Average Operational Power: 197 watts
Data Rate: 1 kbps
Spectral / Frequency Range: 7600 - 17200 nm
No. of Channels / Frequencies:
Viewing Field: Limb View (45° - 135° along track, -30° - -23° vertical limb)
Scanning Characteristics: Scan Mirror
Resolution (Horizontal / Vertical): 200 km/ 3 km
Swath Width: 200 km (limb)
Satellite Application: EOS - B
Technology Status: Heritage - PMR instrument for stratospheric gases/ NIMBUS
Current - Preliminary design, EOS spacecraft

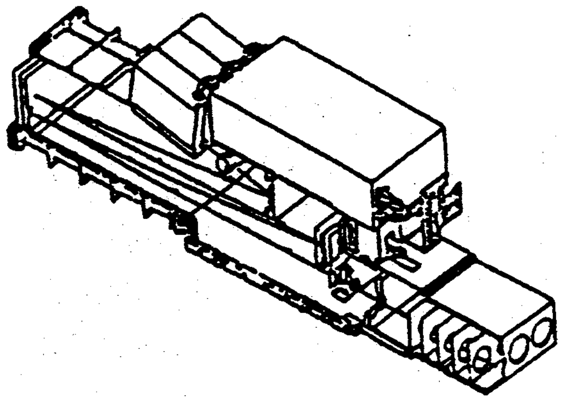


Title: Soil Moisture Microwave Radiometer (SMMR)

Measurement: Soil Moisture

Contact: Tom Campbell, LARC   Melvin Ferebee LARC

Instrument Type: Microwave Radiometer
Dimensions: 118m X 118m X 100m
Mass: 4000 kg
Average Operational Power: 500 watts
Data Rate: 1 kbps
Spectral / Frequency Range: 1.4 GHz
No. of Channels / Frequencies: 1 Frequency
Viewing Field: Nadir (+-18.5° cross track)
Scanning Characteristics: Pushbroom
Resolution (Horizontal / Vertical): 12 km /
Swath Width: 535 km
Satellite Application: None (new concept)
Technology Status: Heritage - Airborne Low Freq. Microwave Instr. for Soil Moisture, Sea Surface Temp., and Salinity / Aircraft
Current - Conceptual Design, GCTI Spacecraft, No formal study



Title: Solar Stellar Irradiance Comparison Experiment (SOLSTICE)

Measurement: Spectral Radiation

Contact: Gary Rottman
University of Colorado

Instrument Type: Ultra-Violet Spectrometer
Dimensions: .3m X .3m X .1m
Mass: 146 kg
Average Operational Power: 72 watts
Data Rate: 5 kbps
Spectral / Frequency Range: 120 - 500 nm
No. of Channels / Frequencies: 3 Channels
Viewing Field: Sun Tracking (90° - 270° cross track)
Scanning Characteristics: Instrument placed on sun pointing platform
Resolution (Horizontal / Vertical): Sun Disk
Swath Width:
Satellite Application: UARS, Space Station attached payload
Technology Status:

Title: Three Channel Microwave Radiometer (3CMR)

Measurement: Ocean Circulation, Atmospheric Water Vapor Correction

Contact:

Instrument Type: Microwave Radiometer

Dimensions: .3m X .3m X .3m

Mass: 27 kg

Average Operational Power: 30 watts

Data Rate: .128 kbps

Spectral / Frequency Range:

No. of Channels / Frequencies:

Viewing Field: Nadir (+-3° cross track, +-3° along track)

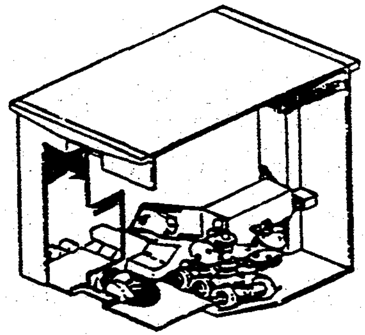
Scanning Characteristics:

Resolution (Horizontal / Vertical):

Swath Width: 50 km

Satellite Application: TOPEX, Poseidon

Technology Status:

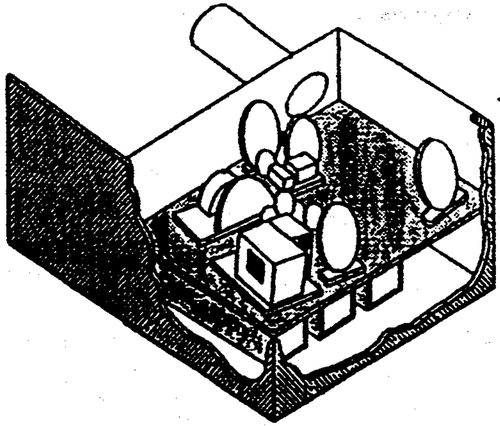


Title: Tropospheric Emmisions Spectrometer (TES)

Measurement: Tropospheric Gases: O3,H2O,NO2, HNO3, Cl Species

Contact: Richard Beer
JPL

Instrument Type: Infrared Spectrometer
Dimensions: 1.6m X 1m X 1.5m
Mass: 491 kg
Average Operational Power: 600 watts
Data Rate: 200 kbps
Spectral / Frequency Range: 2900 - 16700 nm
No. of Channels / Frequencies:
Viewing Field: Nadir (+- 68°cross, +- 45° along),Limb (+- 45° along, -30° - -23° vert.)
Scanning Characteristics: Scan Mirror
Resolution (Horizontal / Vertical): .6 X 6 km / 2.5 km
Swath Width: 1600 km
Satellite Application: EOS - B
Technology Status: Heritage - ATMOS Instrument for Atmospheric Gases / Spacelab
Current - Preliminary Design, EOS Spacecraft



Title: Tropospheric Radiometer for Atmospheric Chemistry and Environmental Research (TRACER)

Measurement: Tropspheric Gases: CO, CH4

Contact: Henry Reichle
LARC

Instrument Type: Gas Correlation Radiometer

Dimensions: 1m X 1m X .5m

Mass: 80 kg

Average Operational Power: 10 watts

Data Rate: 10 kbps

Spectral / Frequency Range: 200 - 4600 nm

No. of Channels / Frequencies:

Viewing Field: Nadir (+- .6° cross track, +- .6° along track)

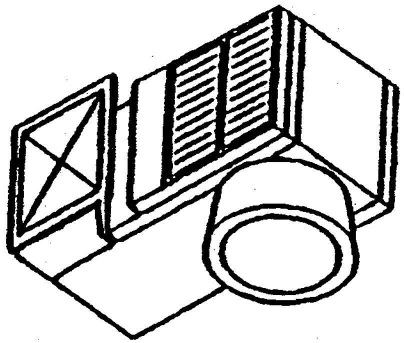
Scanning Characteristics:

Resolution (Horizontal / Vertical): 17 km

Swath Width: 20 km

Satellite Application: EOS - A

Technology Status: Heritage - MAPS Instrument for CO2 / Shuttle
Current - Preliminary design, EOS Spacecraft



Title: X-Ray Imager (XRI)

Measurement: Spectral Radiation

Contact:

Instrument Type: X-Ray Telescope
Dimensions: .73m X .47m X .44m
Mass: 19 kg
Average Operational Power: 10 watts
Data Rate: 1.1 kbps
Spectral / Frequency Range: 1 - 6, 25-30 nm
No. of Channels / Frequencies:
Viewing Field: Sun Tracking (90° - 270° cross track)
Scanning Characteristics: Instrument placed on sun pointing platform
Resolution (Horizontal / Vertical): Sun Disk
Swath Width:
Satellite Application:
Technology Status:

APPENDIX C

PLOTS OF GROUND COVERAGE ACHIEVEABLE BY GLOBAL CHANGE MONITORING INSTRUMENTS AND SPACECRAFT

Heather R. Knight
Joint Institute for Advancement of Flight Sciences

Lynda Foernsler
University of Auburn

The plots assume the following constellation of spacecraft:

LEO

1 Spacecraft A

1 Spacecraft B

1 Spacecraft C

4 Spacecraft D

4 Spacecrarft E

GEO

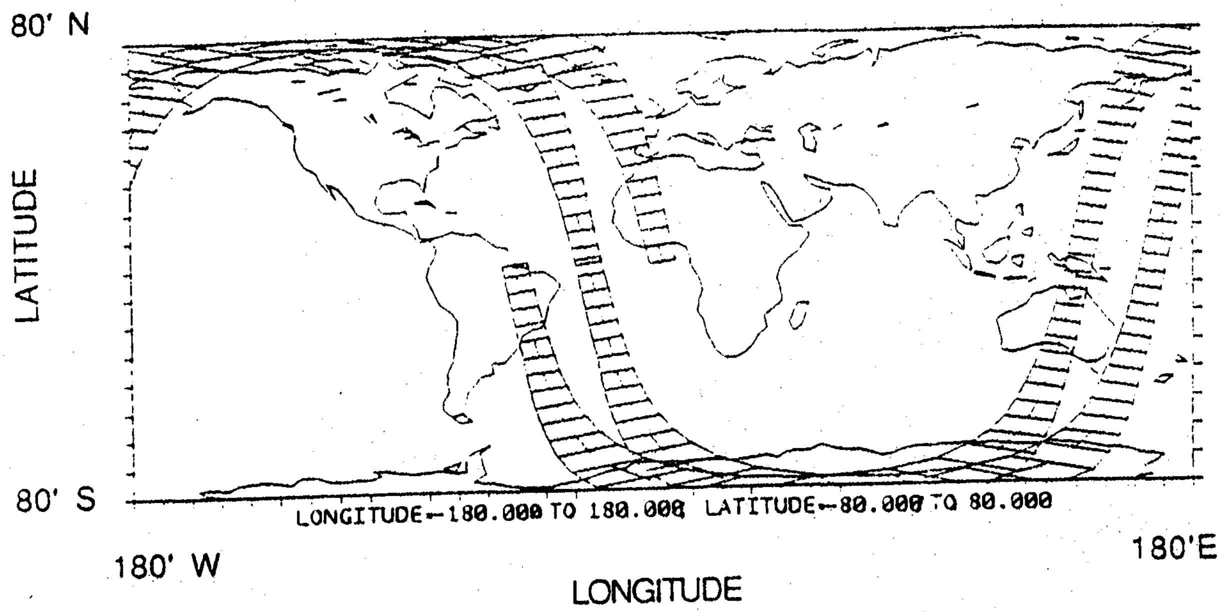
1 Geostationary Spacecraft

The LEO spacecraft plots were made using the Interactive Graphics Orbit Selection (IGOS) software. The IGOS software can plot only one satellite at a time. To overcome this limitation, it was assumed that the coverage provided by one satellite for x-hours is equivalent to coverage provided by four satellites for x/4-hours, i.e.,

1 satellite for 12 hours = 4 satellites for 3 hours

The first plot shown is an example plot with labels of the key information on the plots.

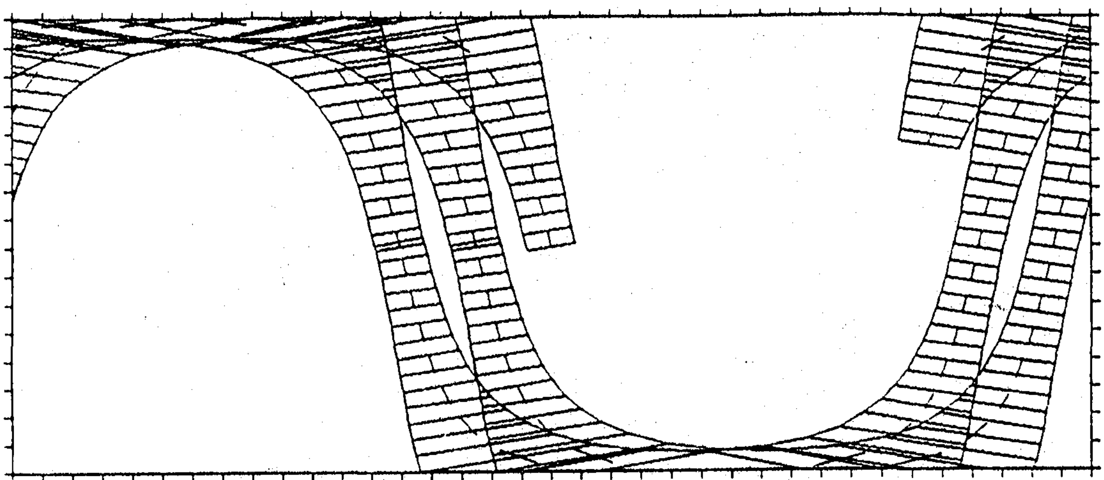
SAMPLE PLOT



All satellites are in an 800km circular orbit at an inclination of 98.6 degrees (sun-synchronous). Specifics of the instrument are listed at the top of the page while the time period of the plot and the percentage of the Earth covered during this time period are listed on the right.

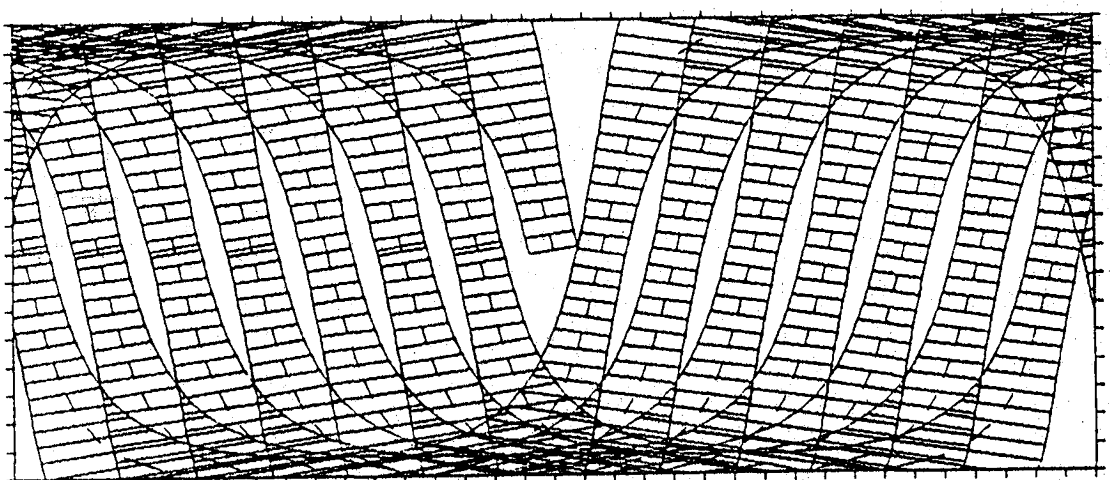
AIRS

CONSTELLATION: 4 SAT SW: ·1840 KM
MEASURABLE: Temperature Profile, Cloud Height



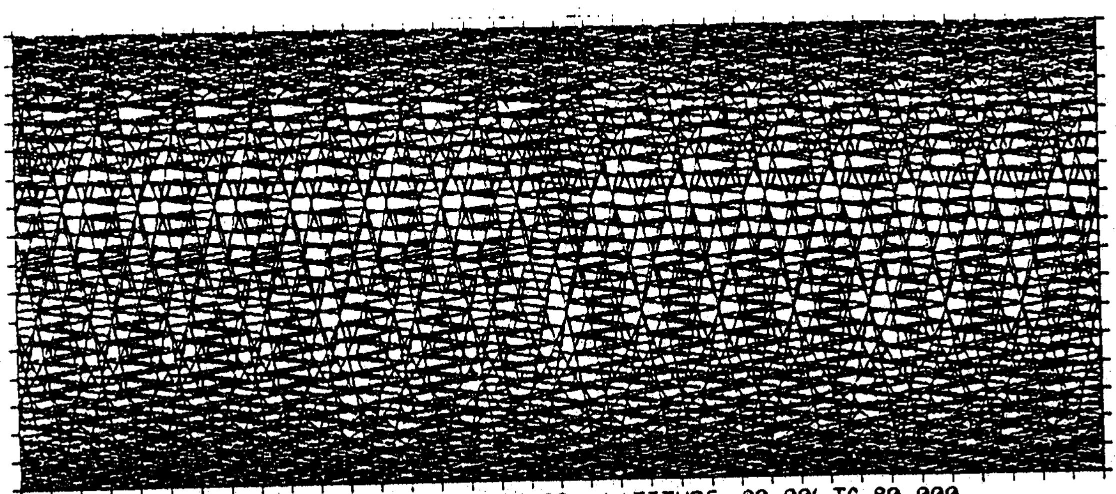
LONGITUDE--180.000 TO 180.000 LATITUDE--80.000 TO 80.000

1 HR
35.8%



LONGITUDE--180.000 TO 180.000 LATITUDE--80.000 TO 80.000

3 HR
84.8%

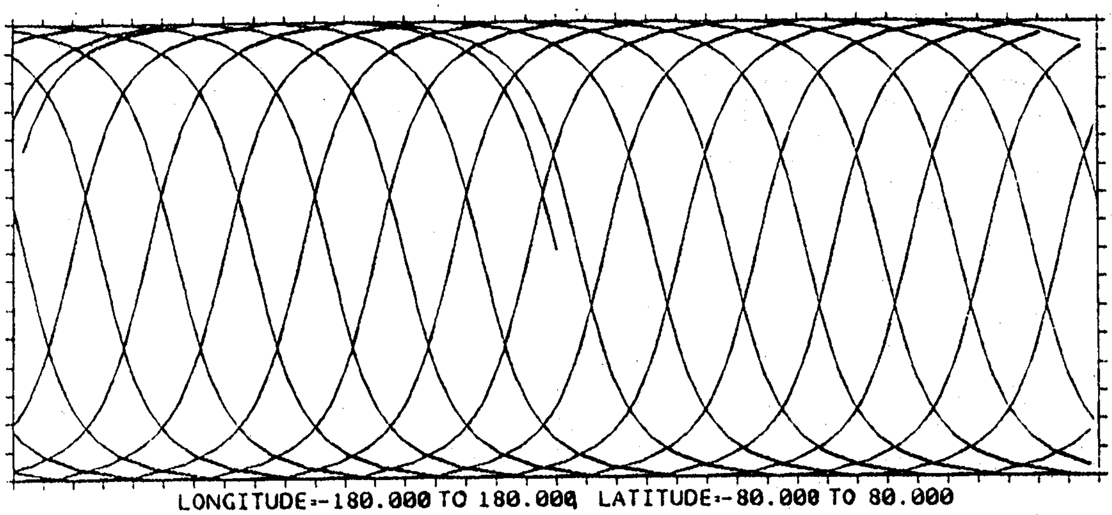


LONGITUDE--180.000 TO 180.000, LATITUDE--80.000 TC 80.000

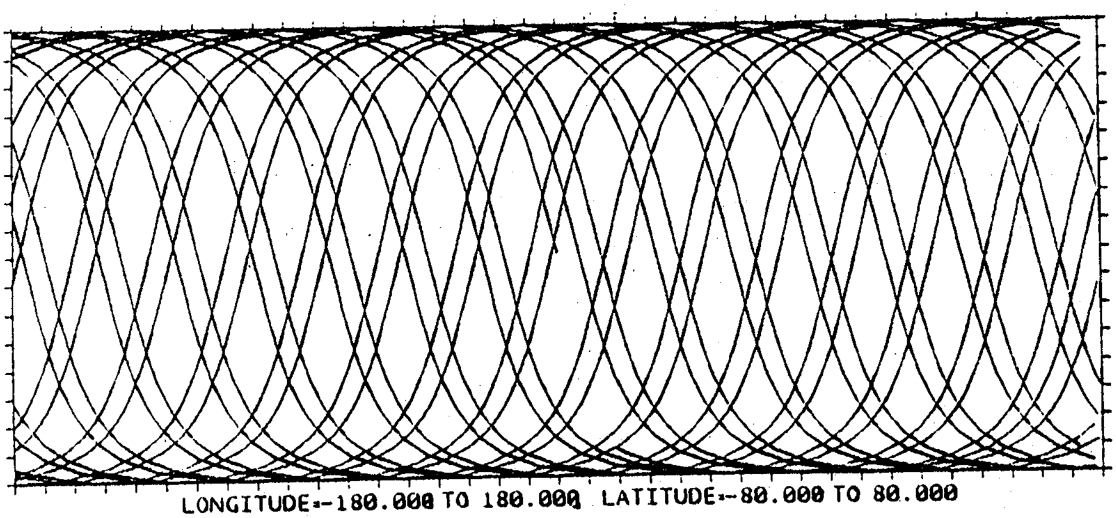
12 HR
99.9%

ALT

CONSTELLATION: 1 SAT SW:~15 KM
MEASURABLE: Ocean Circulation, Sea Level Rise



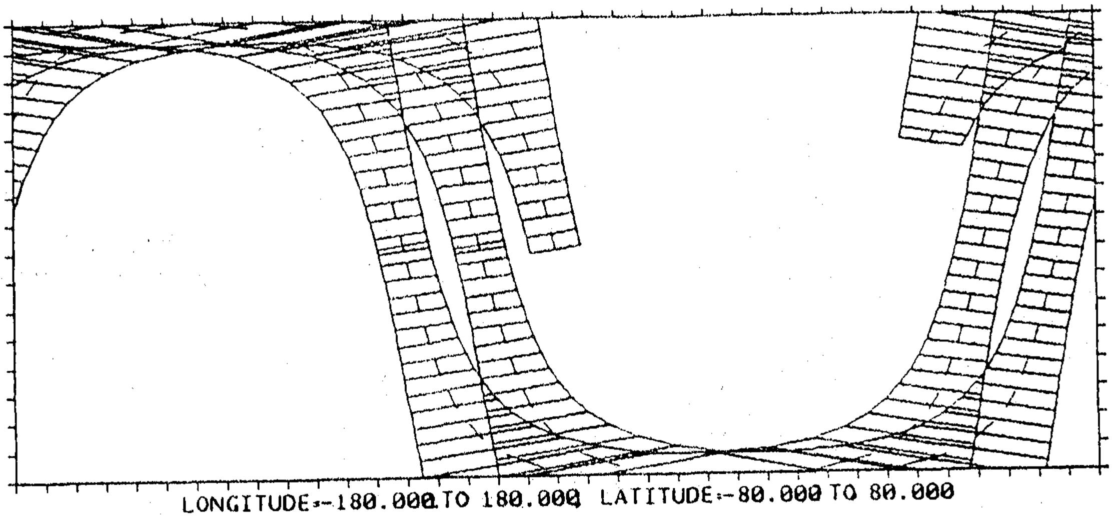
1 D
4.7%



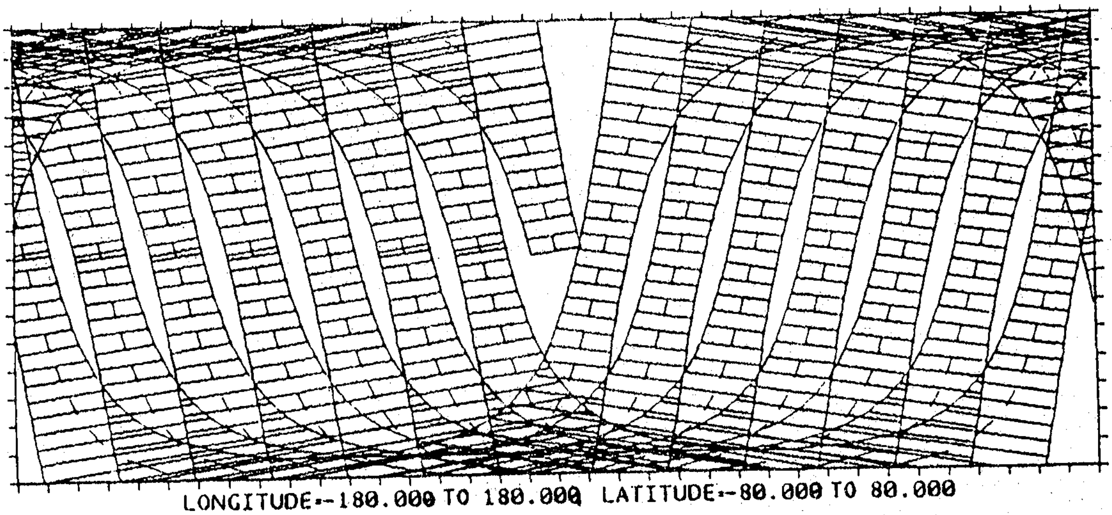
2 D
9.3%

AMSU

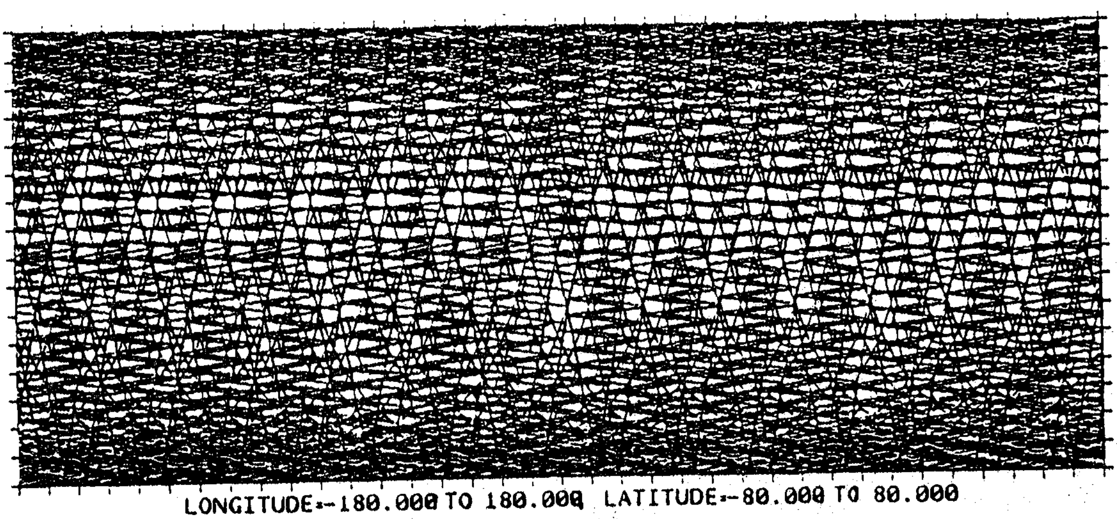
CONSTELLATION: 4 SAT   SW: 1900 KM
MEASURABLE: Temperature Profile



1 HR
37.1%



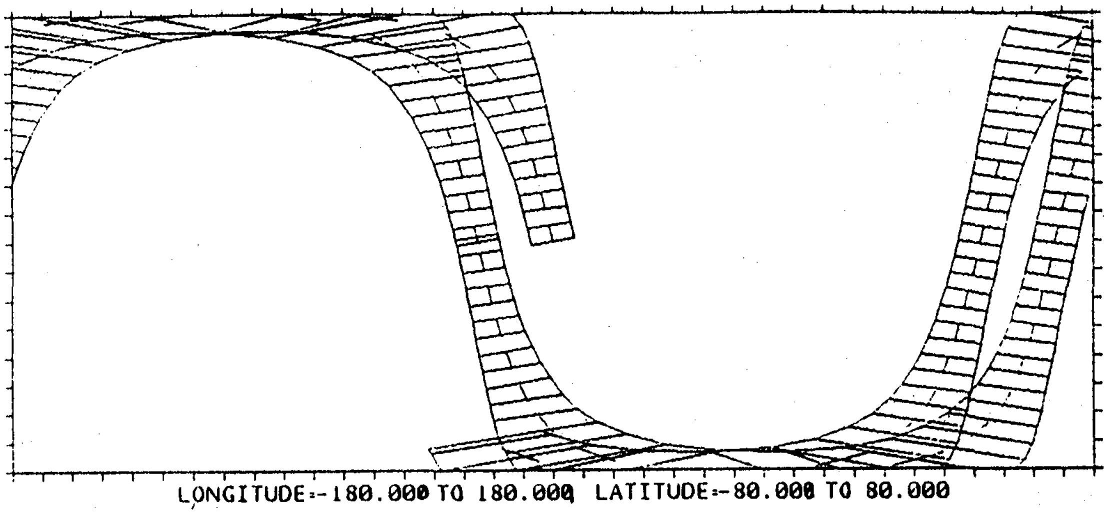
3 HR
86.4%



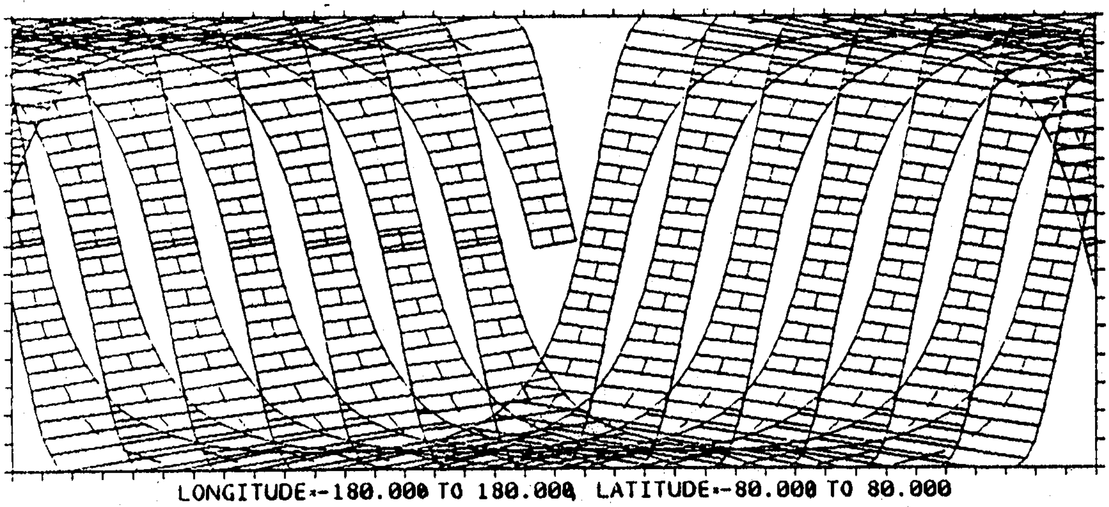
12 HR
99.9%

APL

CONSTELLATION: 1 SAT SW: 1600 KM
MEASURABLE: Surface Pressure



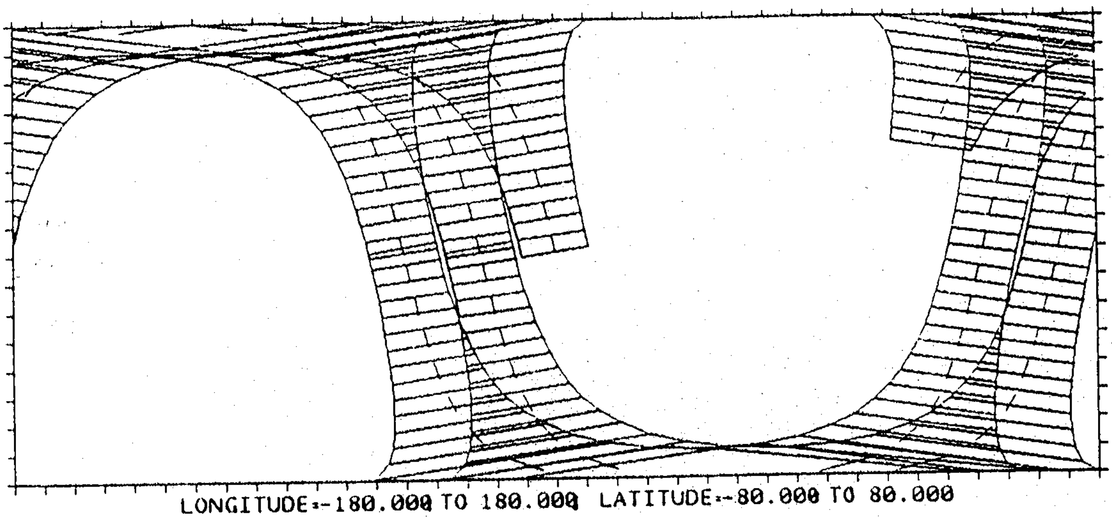
3 HR
22.7%



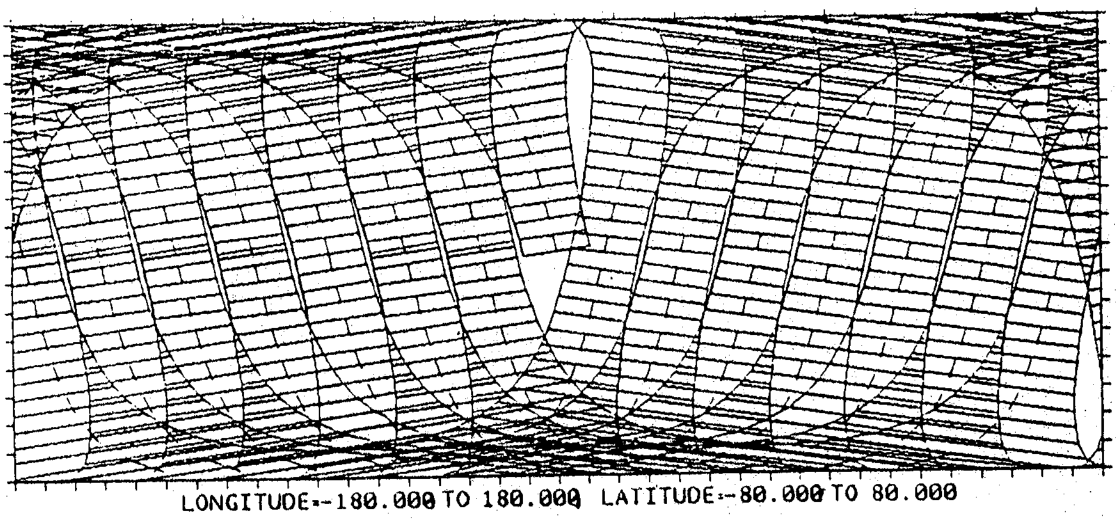
12 HR
78.8%

CERES

CONSTELLATION: 4 SAT   SW: 2500 KM
MEASURABLE: Radiation Budget



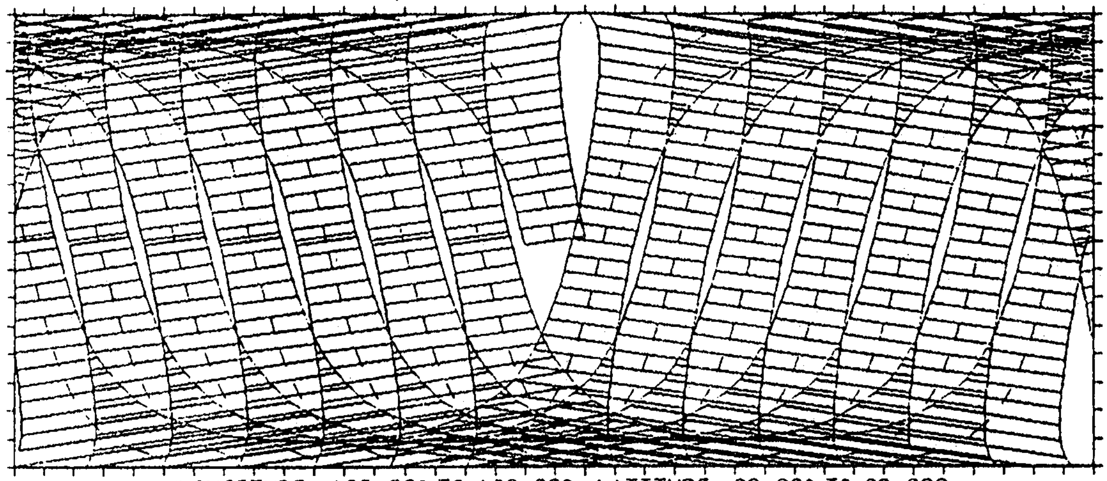
1 HR
51.6%



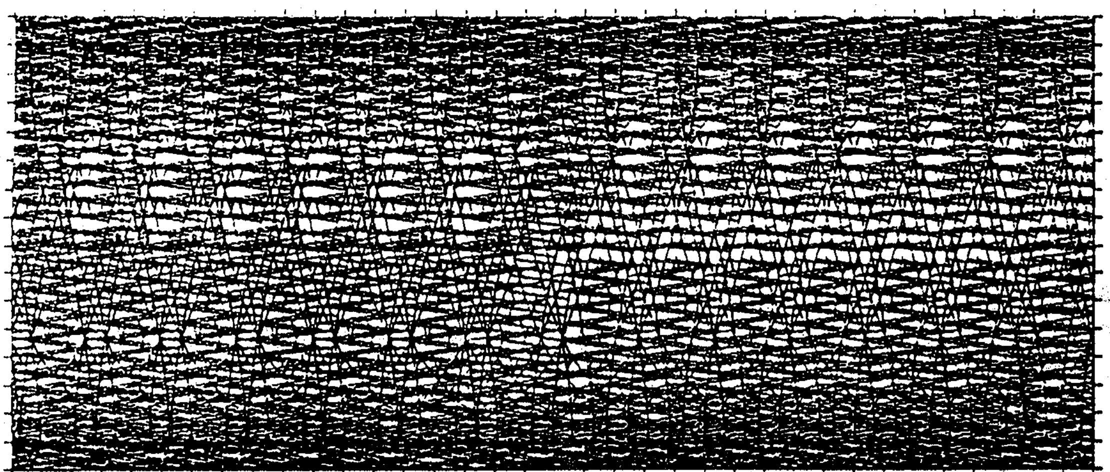
3 HR
96.1%

EOSP

CONSTELLATION: 4 SAT SW: 2280 KM
MEASURABLE: Aerosols and Particulates, Ozone


LONGITUDE=-180.000 TO 180.000, LATITUDE=-80.000 TO 80.000

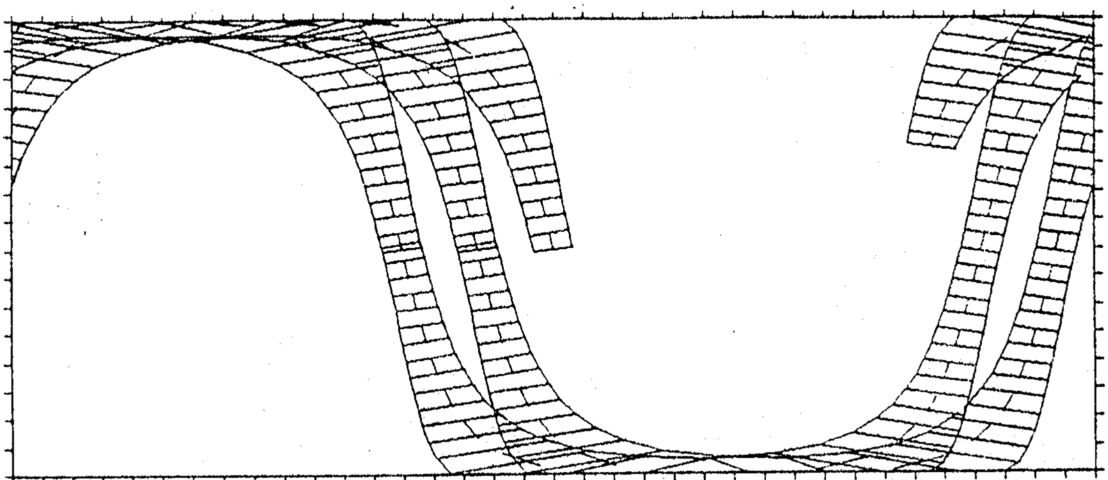
3 HR
93.8%


LONGITUDE=-180.000 TO 180.000 LATITUDE=-80.000 TO 80.000

12 HR
99.9%

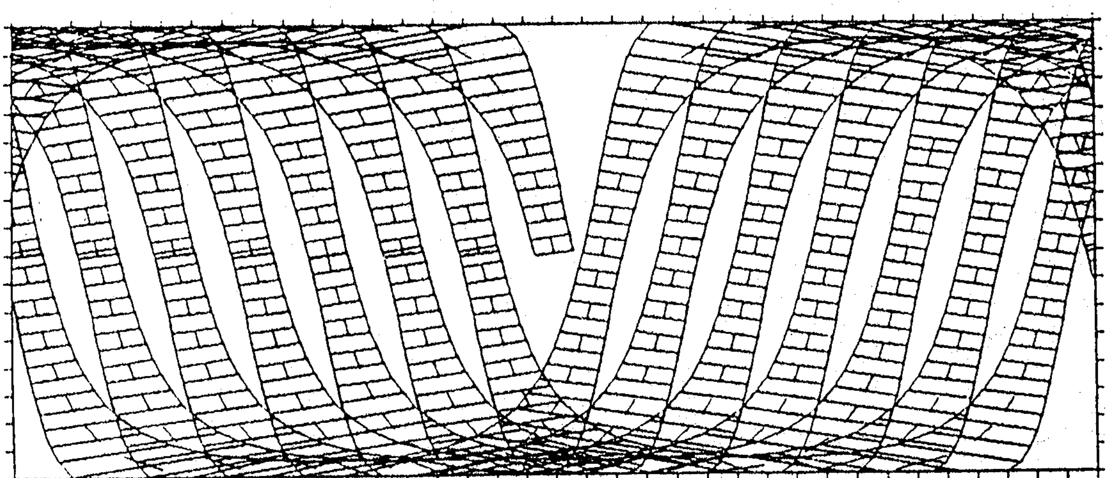
HIMSS

CONSTELLATION: 4 SAT SW: 1470 KM
MEASURABLE: Precipitation, Temperature Profile, Surface Temperature



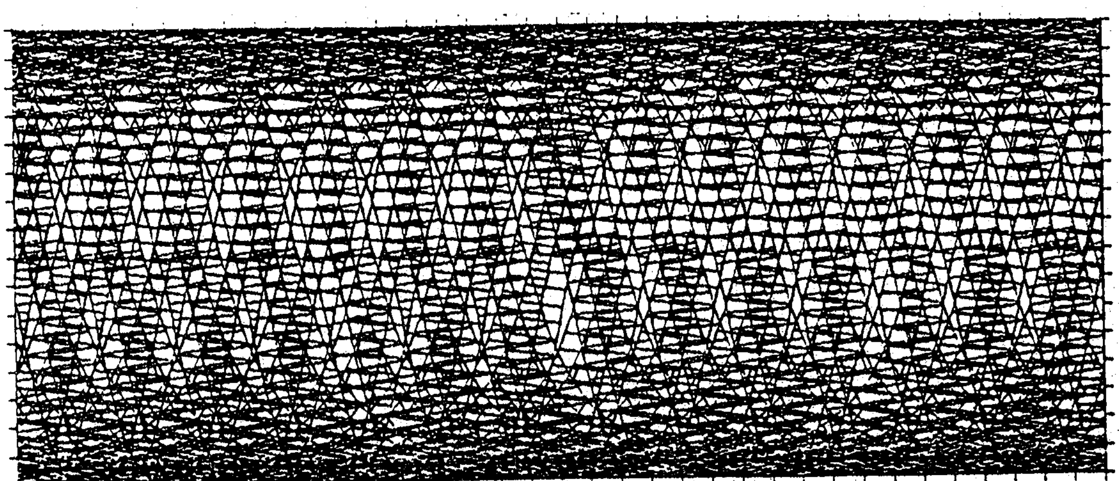
LONGITUDE=-180.000 TO 180.000 LATITUDE=-80.000 TO 80.000

1 HR
28.1%



LONGITUDE=-180.000 TO 180.000 LATITUDE=-80.000 TO 80.000

3 HR
71.5%

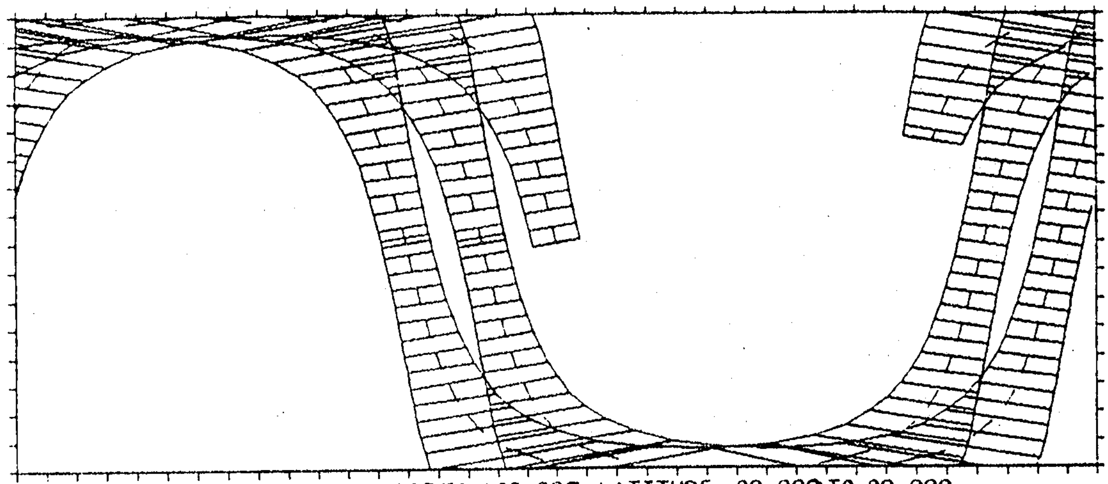


LONGITUDE=-180.000 TO 180.000 LATITUDE=-80.000 TO 80.000

12 HR
99.6%

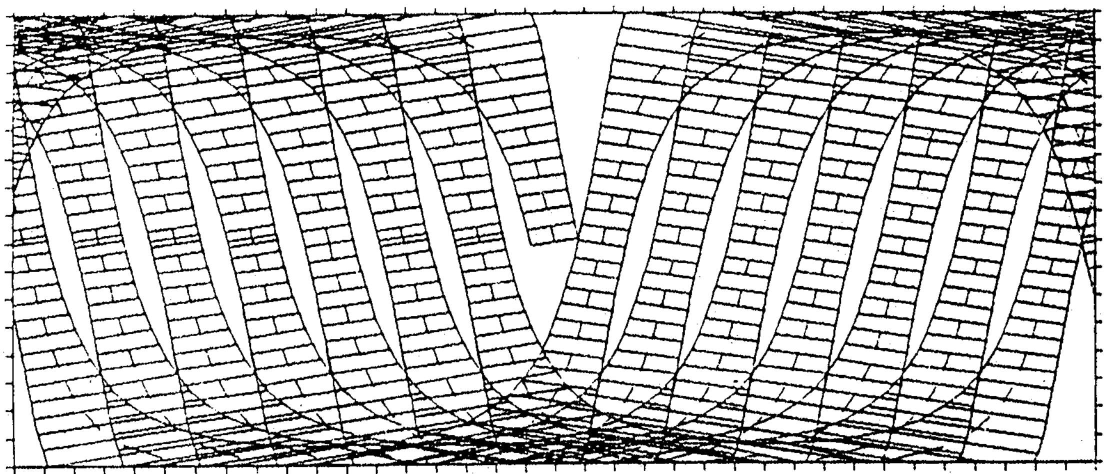
MODIS-N

CONSTELLATION: 4 SAT   SW: 1800 KM
MEASURABLE: Cloud Cover & Type, Surface Temperature



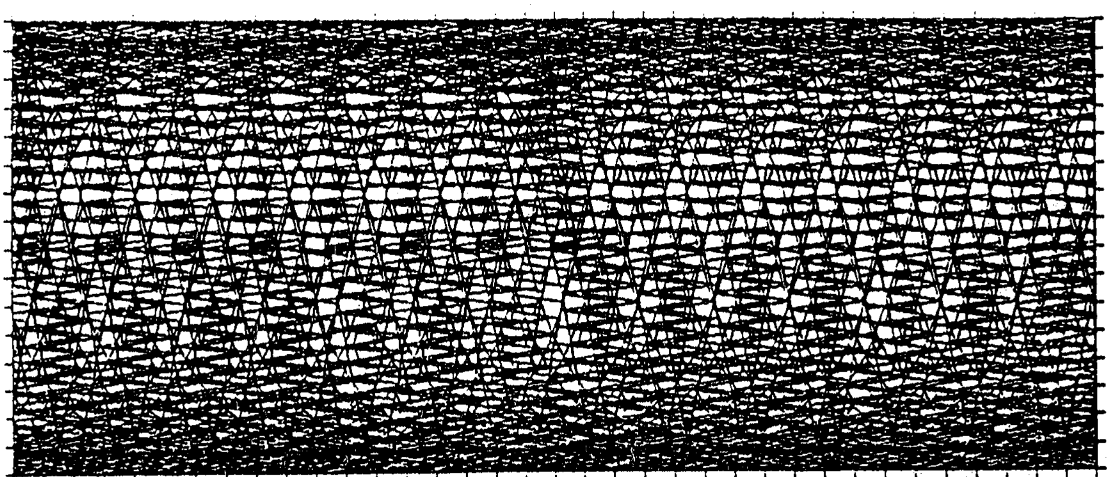
LONGITUDE=-180.000 TO 180.000 LATITUDE=-80.000 TO 80.000

1 HR
35.1%



LONGITUDE=-180.000 TO 180.000 LATITUDE=-80.000 TO 80.000

3 HR
83.7%

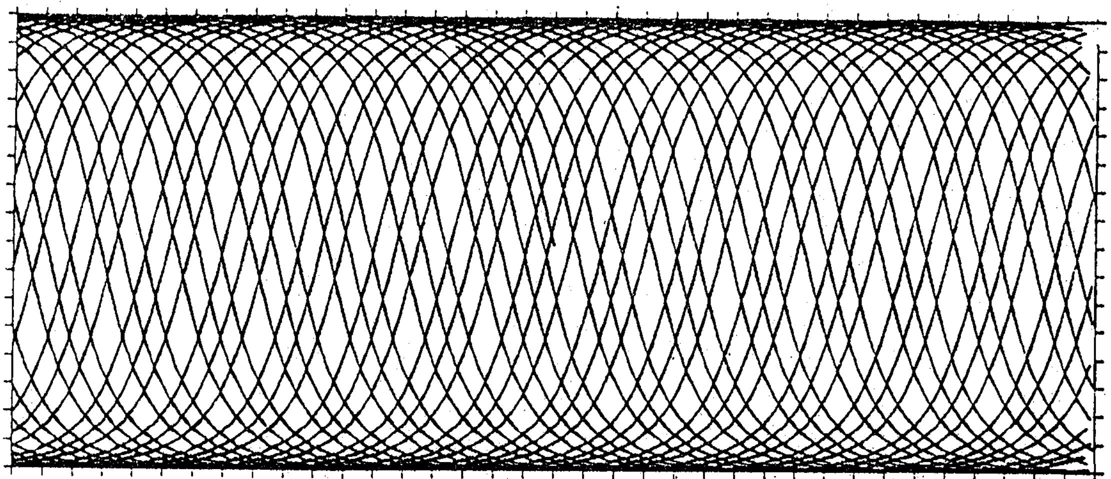


LONGITUDE=-180.000 TO 180.000 LATITUDE=-80.000 TO 80.000

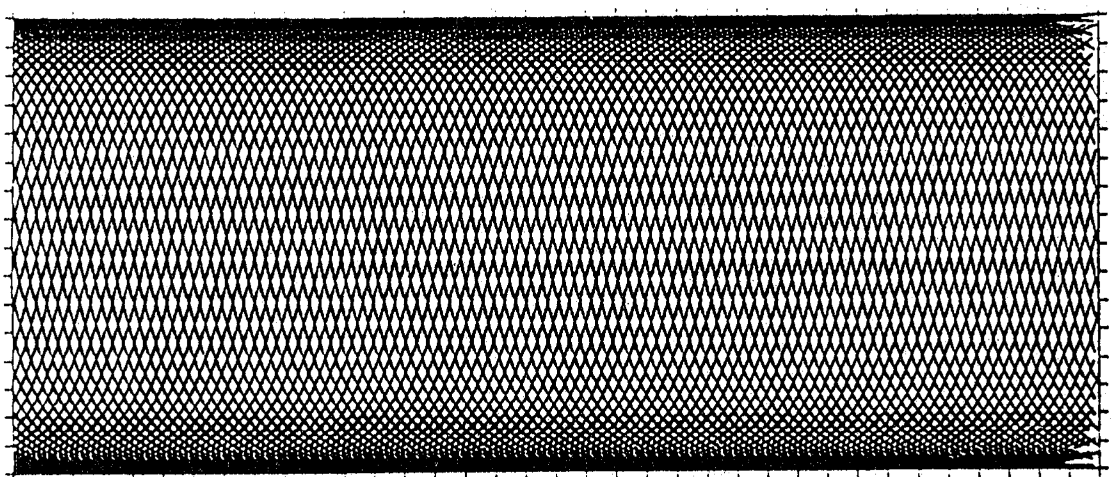
12 HR
99.9%

HIRIS

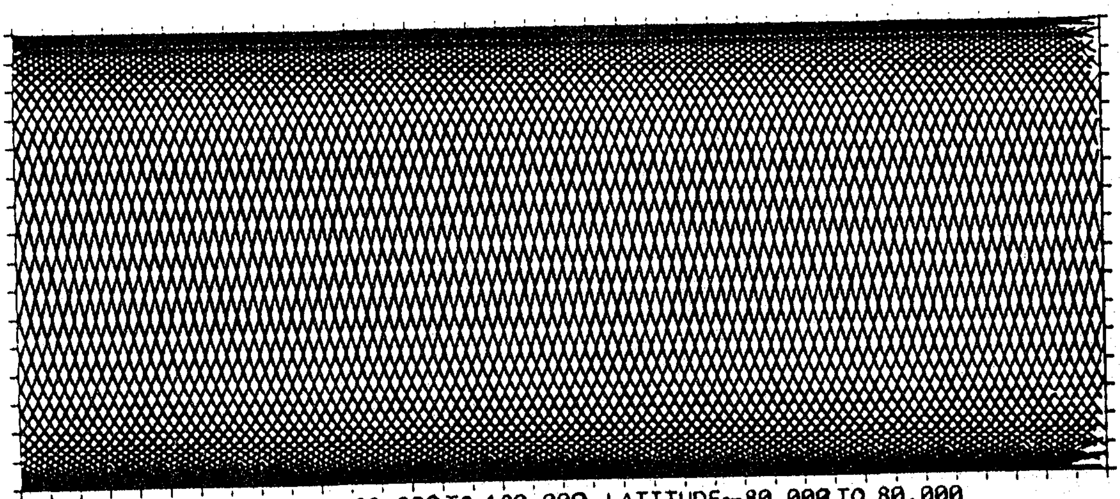
CONSTELLATION: 1 SAT SW: 30 KM
MEASURABLE: Vegetation Cover, Biomass Inventory



3 D
18.9%



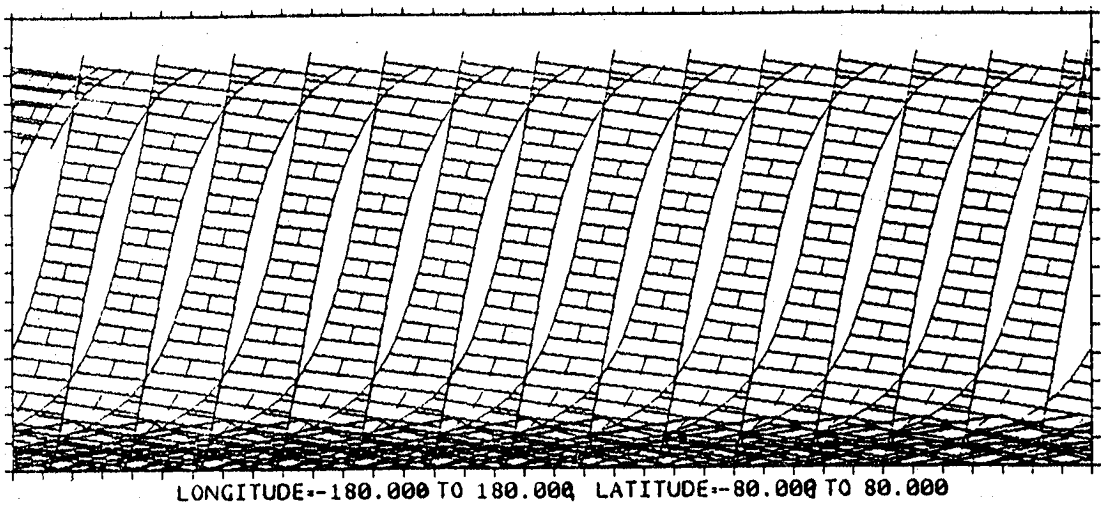
7 D
39.6%



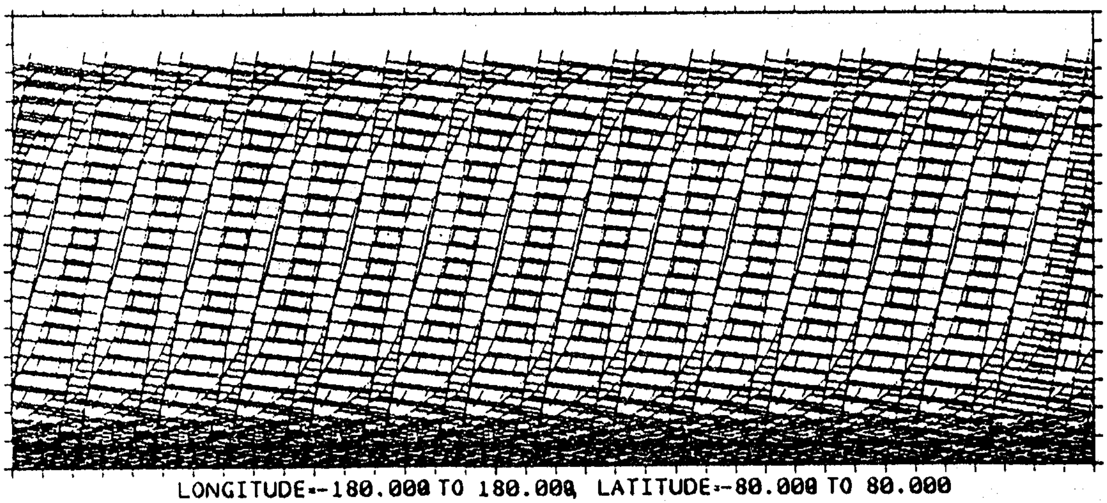
30 D
96.4%

MODIS-T

CONSTELLATION: 1 SAT SW: 1800 KM
MEASURABLE: Ocean Color, Ocean Circulation, Vegetation Cover



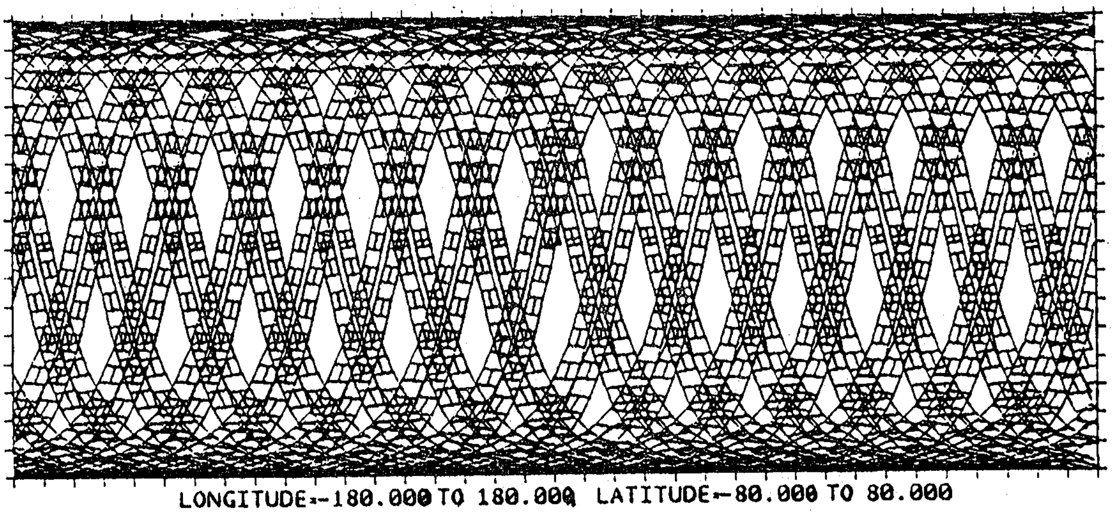
1 D
97.6%



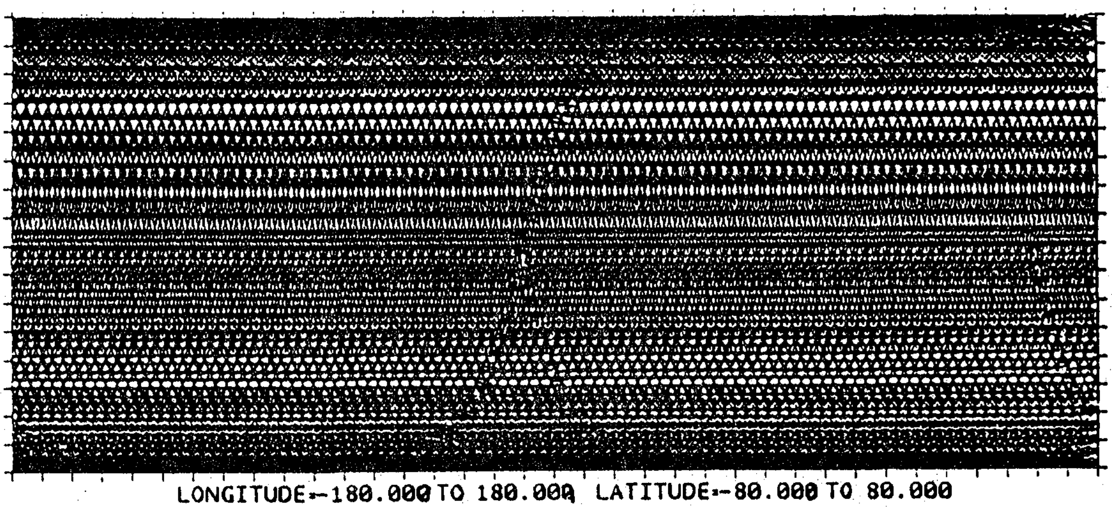
2 D
99.9%

SMMR

CONSTELLATION: 1 SAT SW: 535 KM
MEASURABLE: Soil Moisture



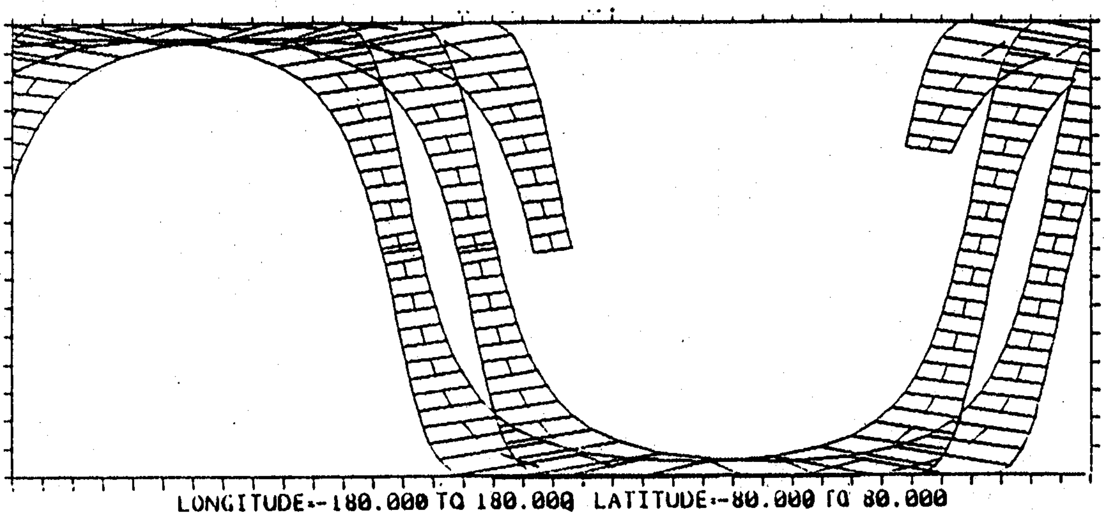
2 D
76.8%



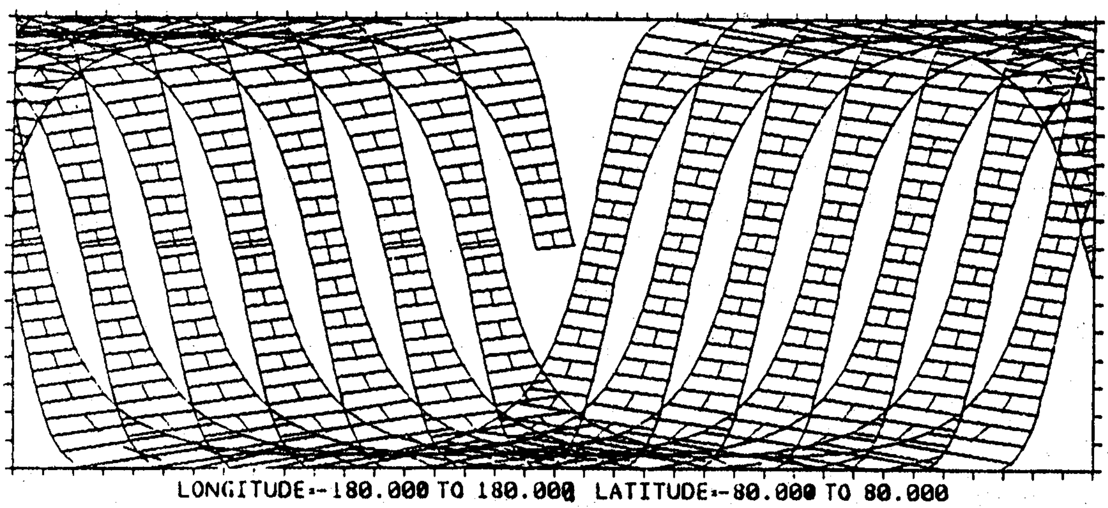
7 D
99.3%

TES

CONSTELLATION: 4 SAT SW: 1400 KM
MEASURABLE: Tropospheric Gases(O3,H2O,NO2,N2O,HNO3,C:L)



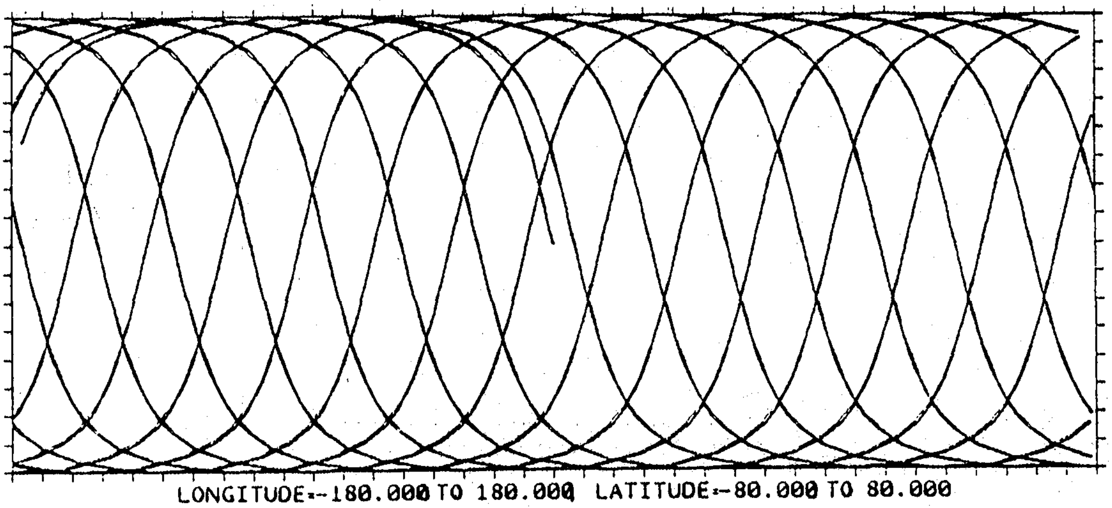
1 HR
26.7%



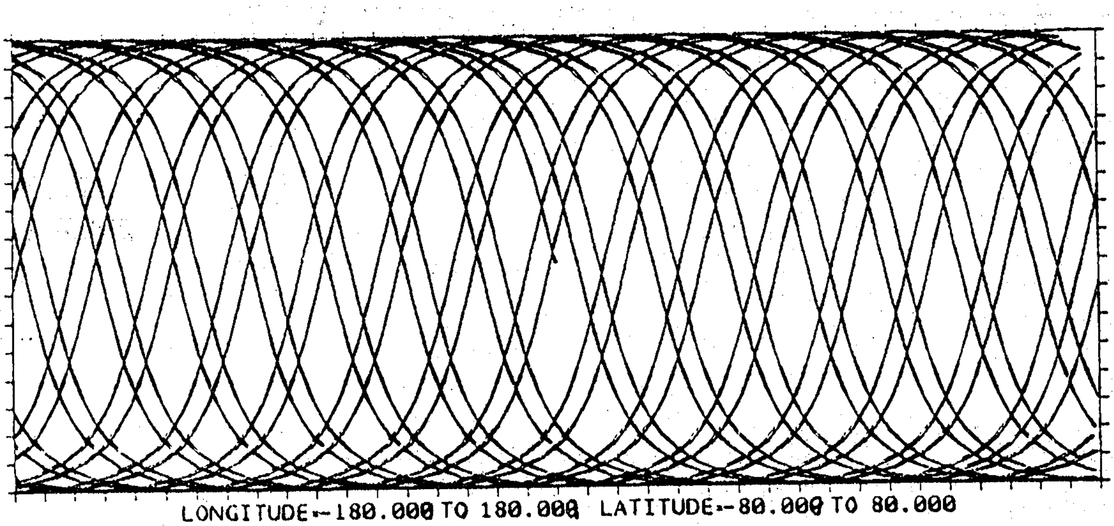
3 HR
68.6%

3CHANMR

CONSTELLATION: 1 SAT SW: 50 KM
MEASURABLE: Atmospheric Correction for H2O



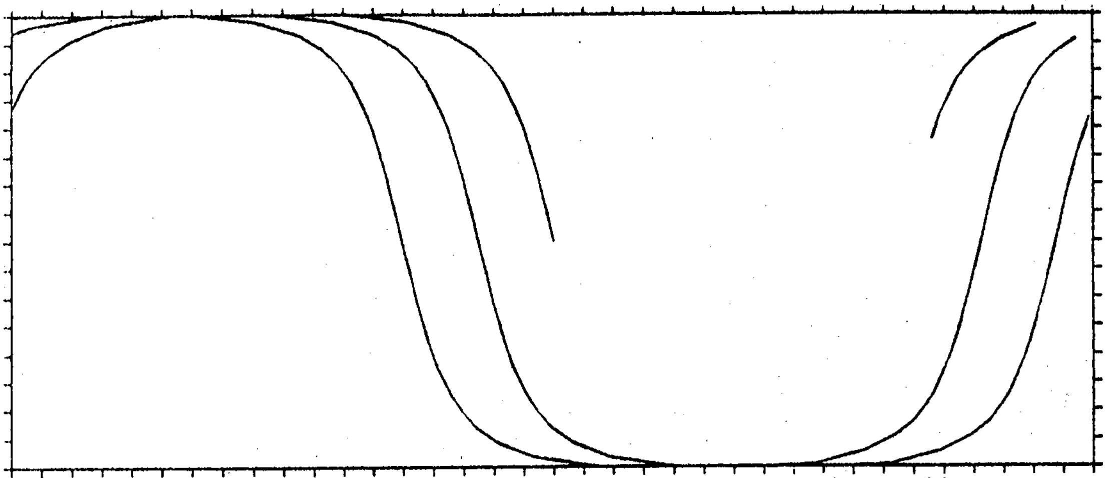
1 D
8.9%



2 D
17.2%

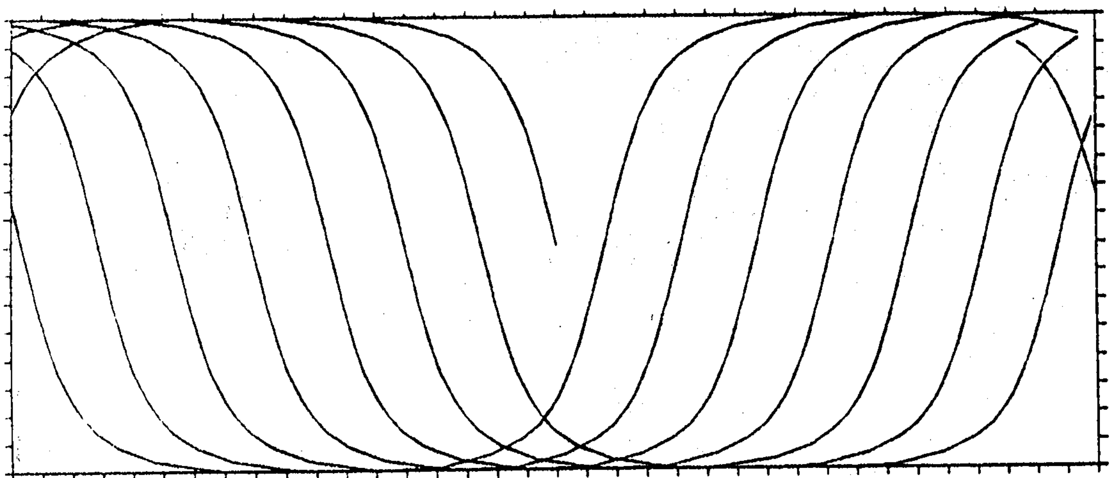
TRACER

CONSTELLATION: 4 SAT SW: 17 KM
MEASURABLE: Tropospheric Gases(CO,CH4)



LONGITUDE:-180.000 TO 180.000 LATITUDE:-80.000 TO 80.000

1 HR
0.9%



LONGITUDE:-180.000 TO 180.000 LATITUDE:-80.000 TO 80.000

3 HR
2.6%

Results From Geostationary Sensor Coverage

The following sensors were studied at geostationary altitude:

GHRMR
GERS
GOES Imager
IRVS
OZMAP
GMODIS

The scan rates for each of these sensors are presented on the following page.

All of the sensors, except OZMAP, were able to achieve full disc span in a specified amount of time. Full disc span is defined as 9160 km x 9160 km.

The GOES Imager is able to achieve full disc span in the shortest amount of time (25 minutes). The GHRMR and GMODIS sensors achieve full disc span in 30 minutes, and the GERS and IRVS sensors achieve full disc span in 60 minutes. The maximum amount the OZMAP sensor can scan is 3000 km x 3000 km in 41 minutes (see Figure 5).

The scan coverage of each sensor is depicted in Figures 1-6. The figures were obtained by utilizing the Spacecraft Orbit Design and Analysis (SODA) computer program. In each figure, the name of the sensor being depicted is indicated in the center of a box located on a world map. The outlined box represents the sensor's scan coverage over a specified amount of time.

Figures 7-10 compare the scan coverage of various sensors over a specified amount of time. Each sensor in represented by an outlined box with the name in the center on a world map. Figure 3 shows the three different selectable frames available for the GOES Imager.

Sensor	Scan Rate
Geostationary High Resolution Microwave Radiometer (GHRMR)	9160x9160 km in 30 min
Geostationary Earth Radiation Sensor (GERS)	Full disc span in 1 to 3 hours
Geostationary Moderate Resolution Imaging Spectrometer (GMODIS)	Full disc span every thirty min
Geostationary Operational Environmental Satellite (GOES) Imager	Selectable Frame Available Full earth in 25 min, 3000x3000 km in 3.1 min, or 1000x1000 km in 40 sec
Active Cavity Radiometer Irradiance Monitor (ACRIM)	Not applicable. Faces sun.
Infrared Vertical Sounder (IRVS)	Full earth coverage in 1 hr
Ozone Mapper (OZMAP)	OZMAP coverage may be similar to GOES Sounder which is 3000x3000 km in 41 minutes

Figure	Title
1	Full Disc Span of GHRMR Sensor
2	Full Disc Span of GERS Sensor
3	Three Selectable Frames of GOES Imager
4	Full Disc Span of IRVS Sensor
5	Disc Span of OZMAP Sensor
6	Full Disc Span of GMODIS Sensor
7	Comparison of Scan Coverage Between GHRMR and OZMAP in 41 Minutes
8	Comparison of Scan Coverage Between GHRMR, GOES Imager, GERS, and OZMAP in 25 Minutes
9	Comparison of Scan Coverage Between GHRMR, OZMAP, and GERS in 30 Minutes
10	Comparison of Scan Coverage Between GHRMR, GOES Imager, GERS, and OZMAP in 3.1 Minutes

Figure 1 Full Disc Span of GHRMR Sensor

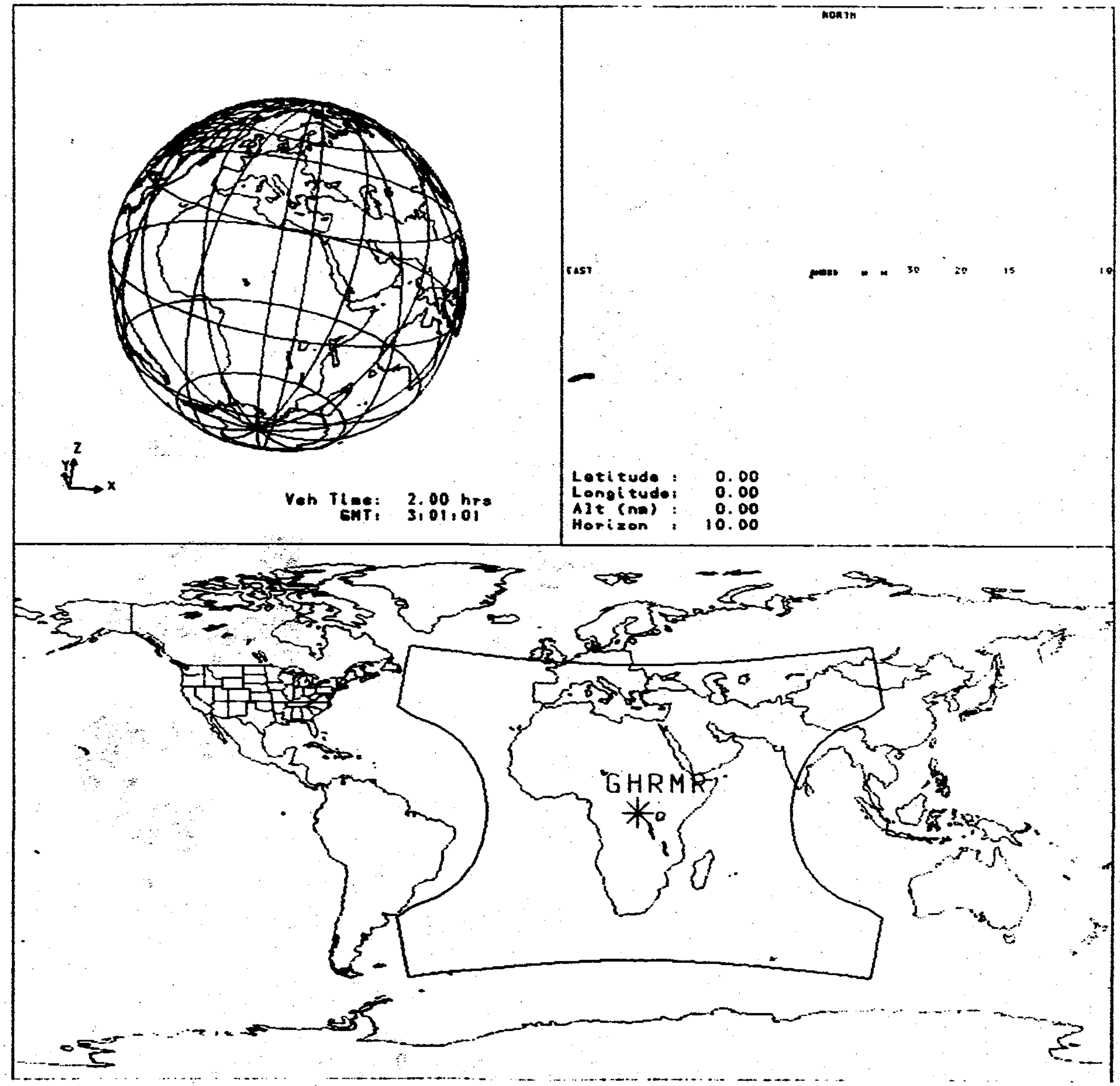


Figure 2. Full Disc Span of GERS Sensor

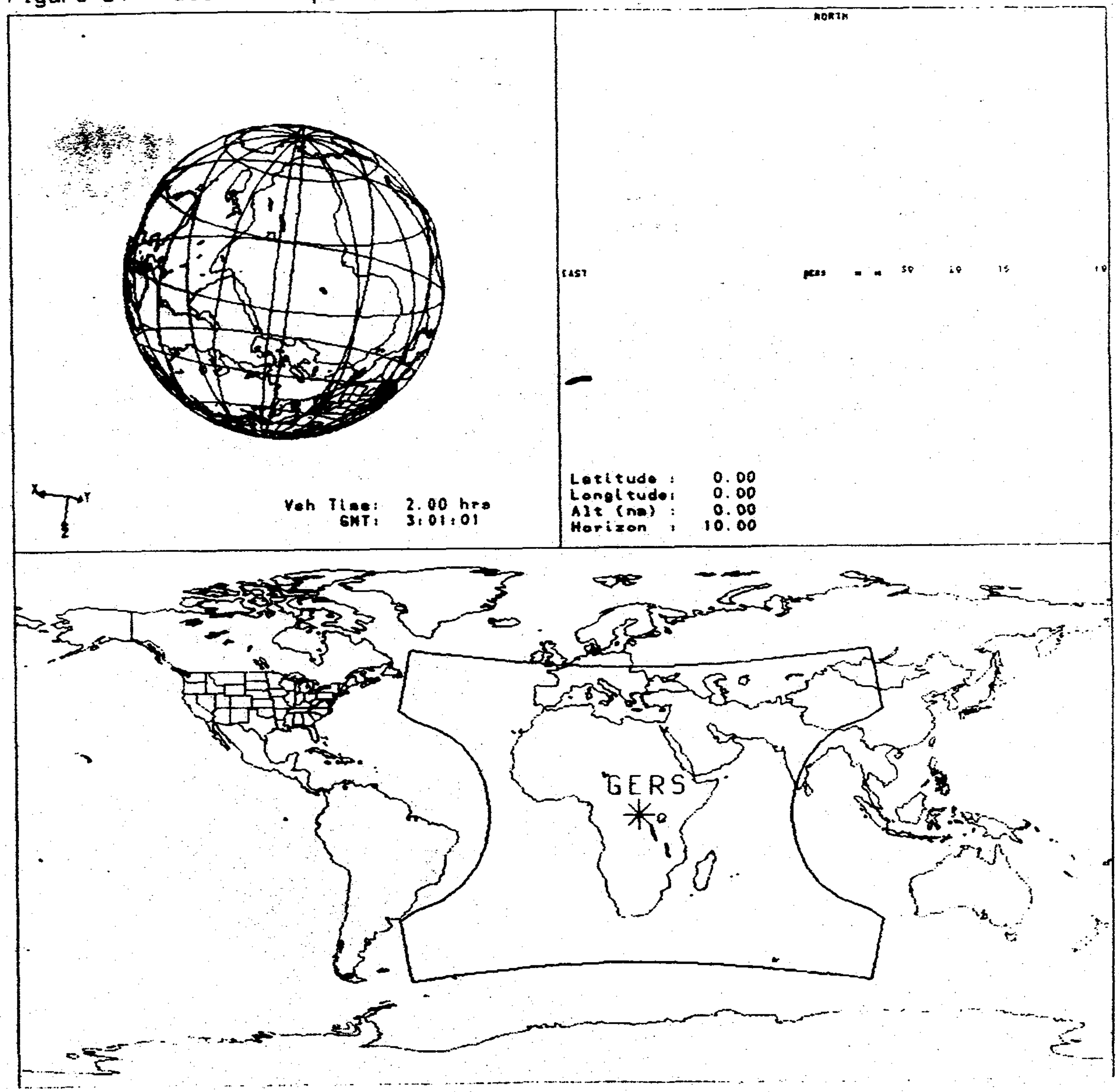


Figure 3 Three Selectable Frames of GOES Imager

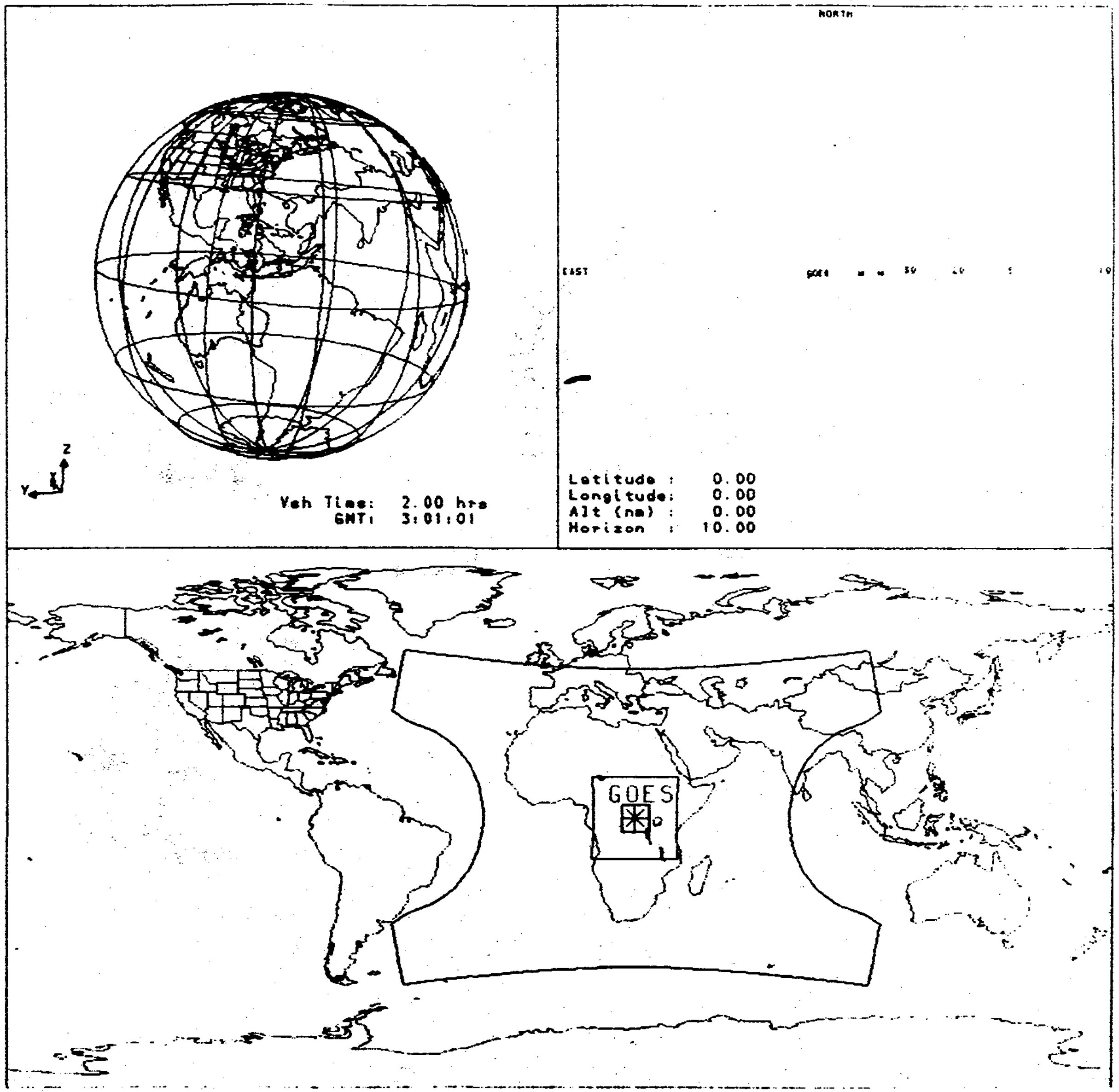


Figure 4. Full Disc Span of IRVS Sensor

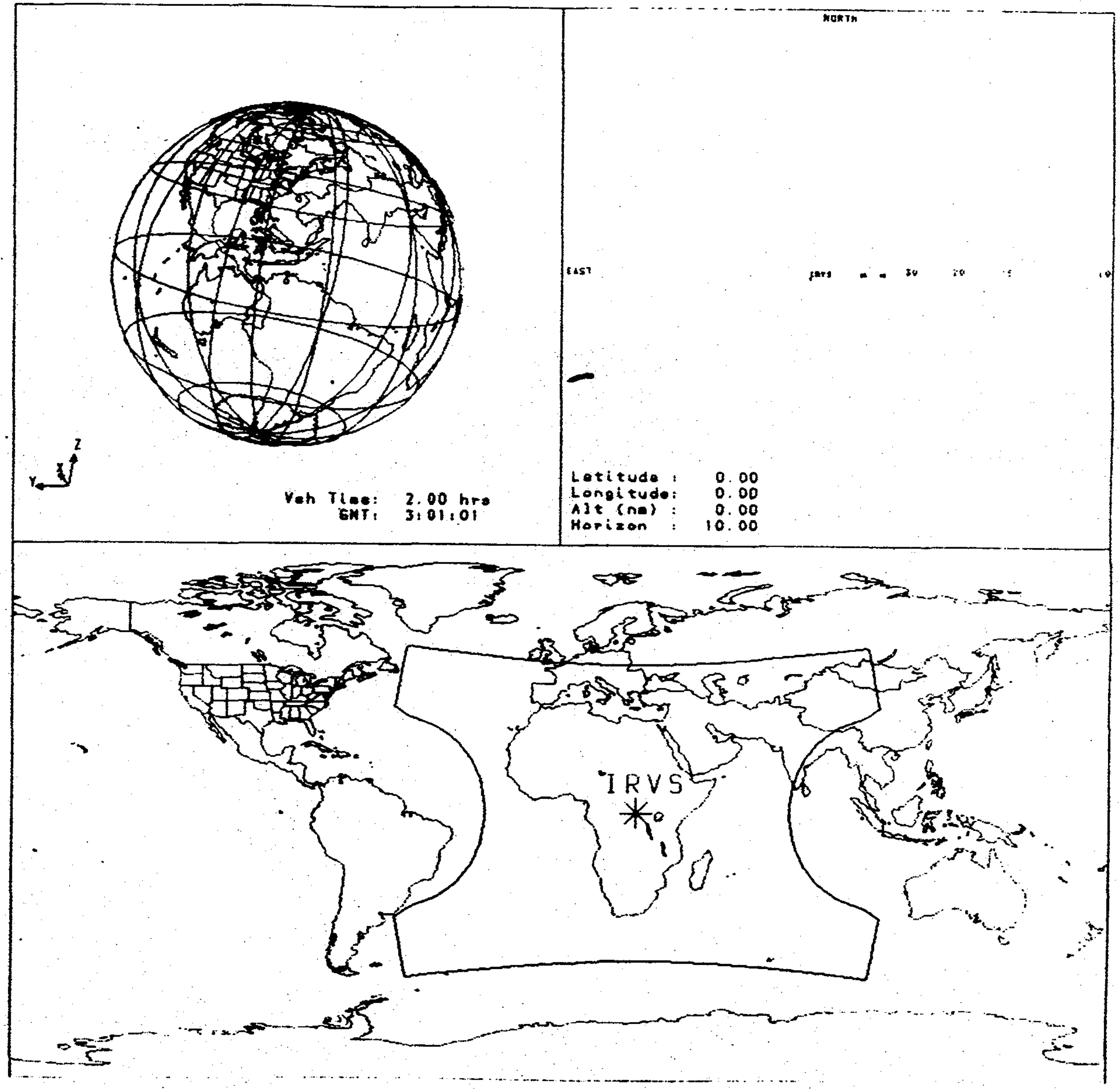


Figure 5. Disc Span of OZMAP Sensor

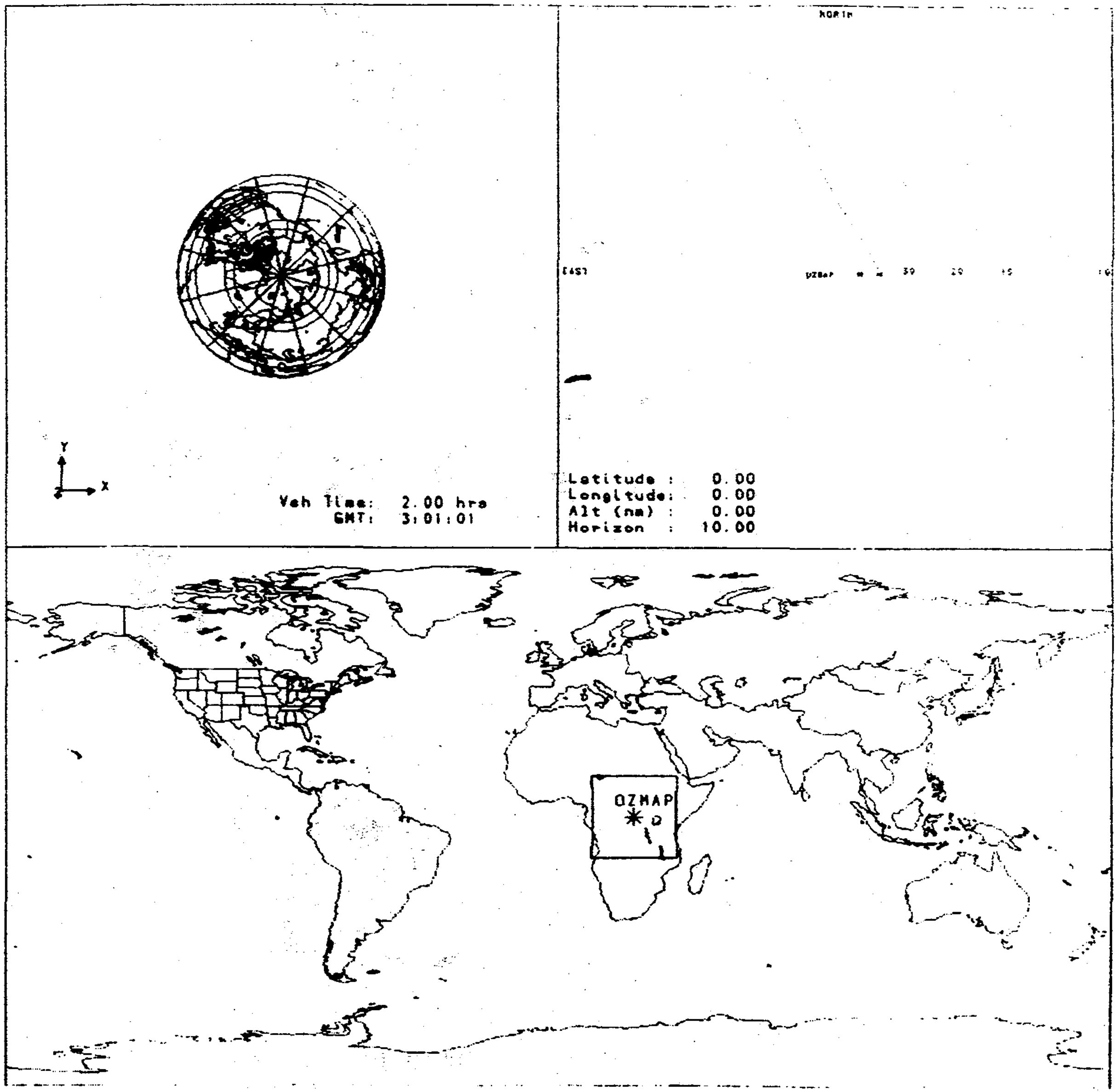


Figure 6. Full Disc Span of GMODIS Sensor

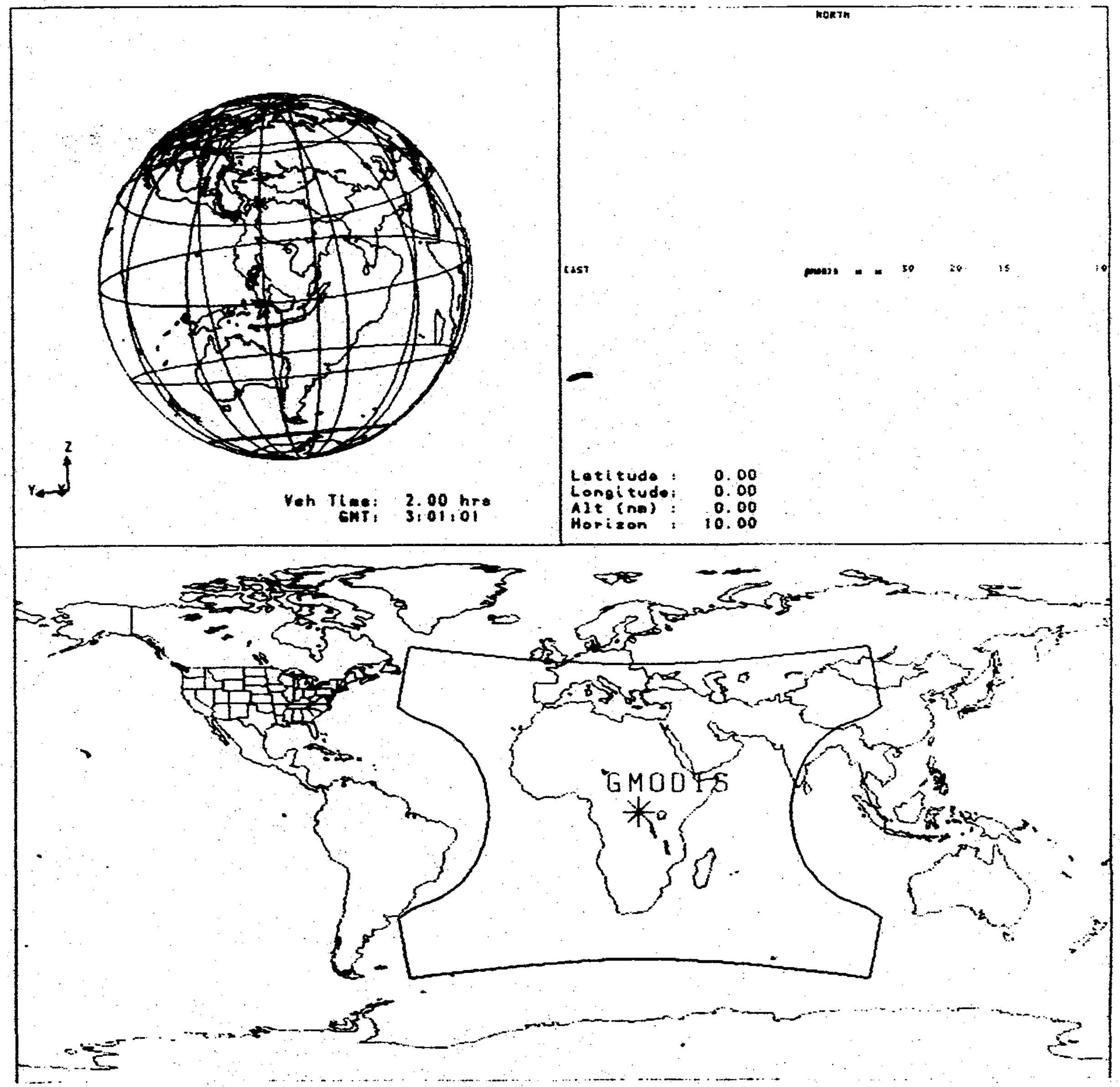


Figure 7. Comparison of Scan Coverage Between GHRMR and OZMAP in 41 Minutes

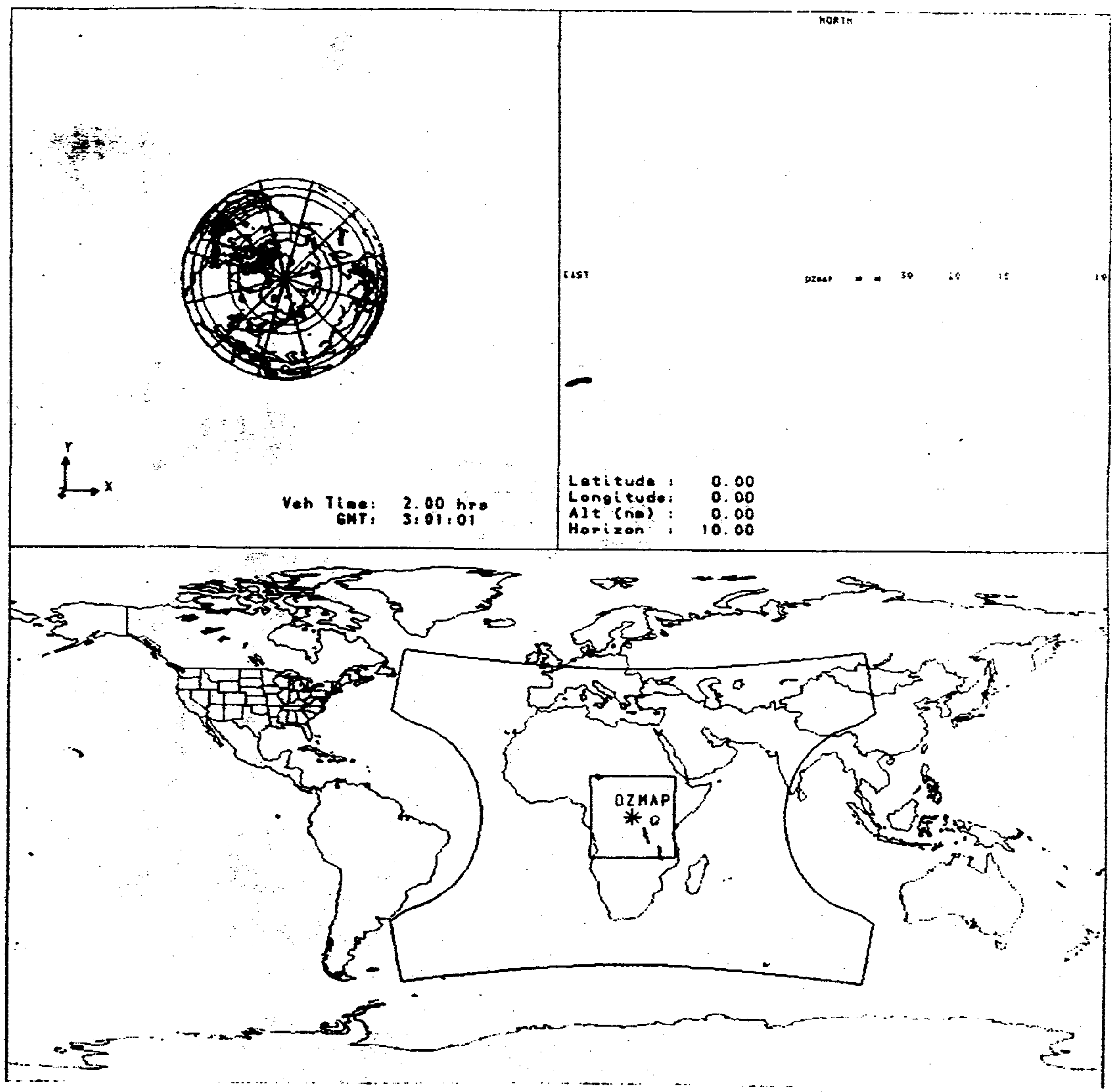


Figure 8 Comparison of Scan Coverage Between GHRMR, GOES Imager, GERS, and OZMAP in 25 Minutes

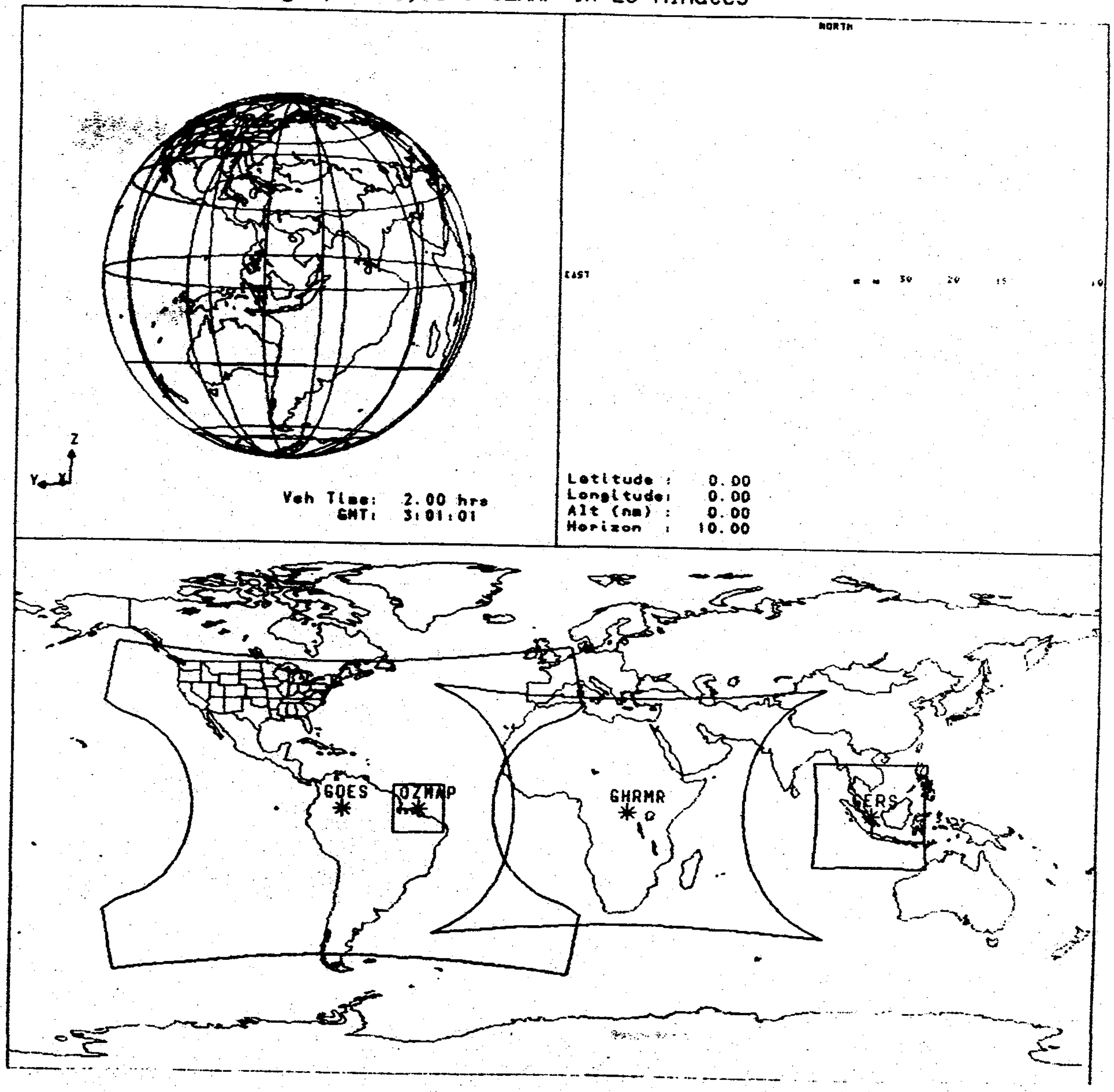


Figure 9 Comparison of Scan Coverage Between GHRMR, OZMAP, and GERS in 30 Minutes

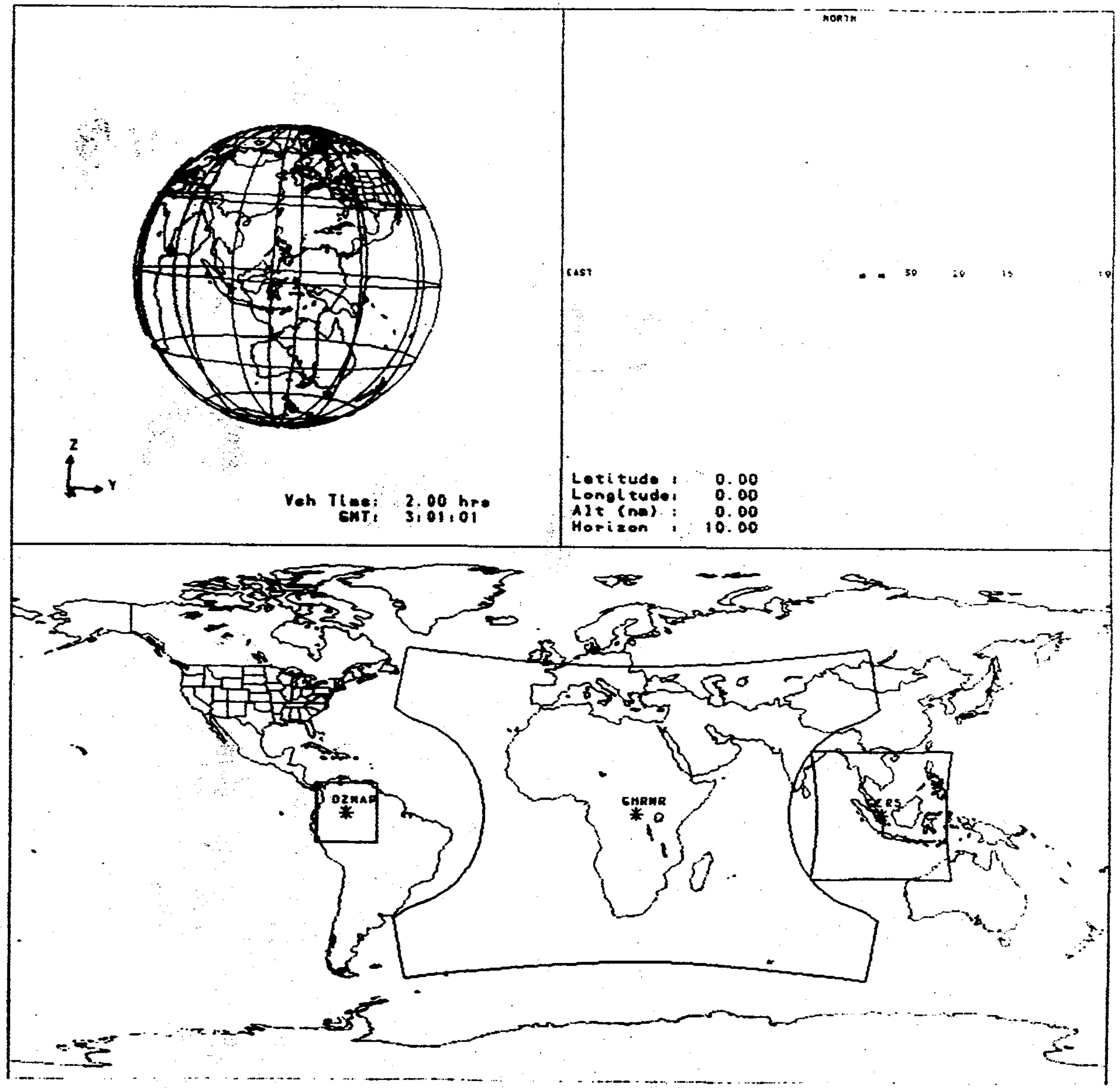
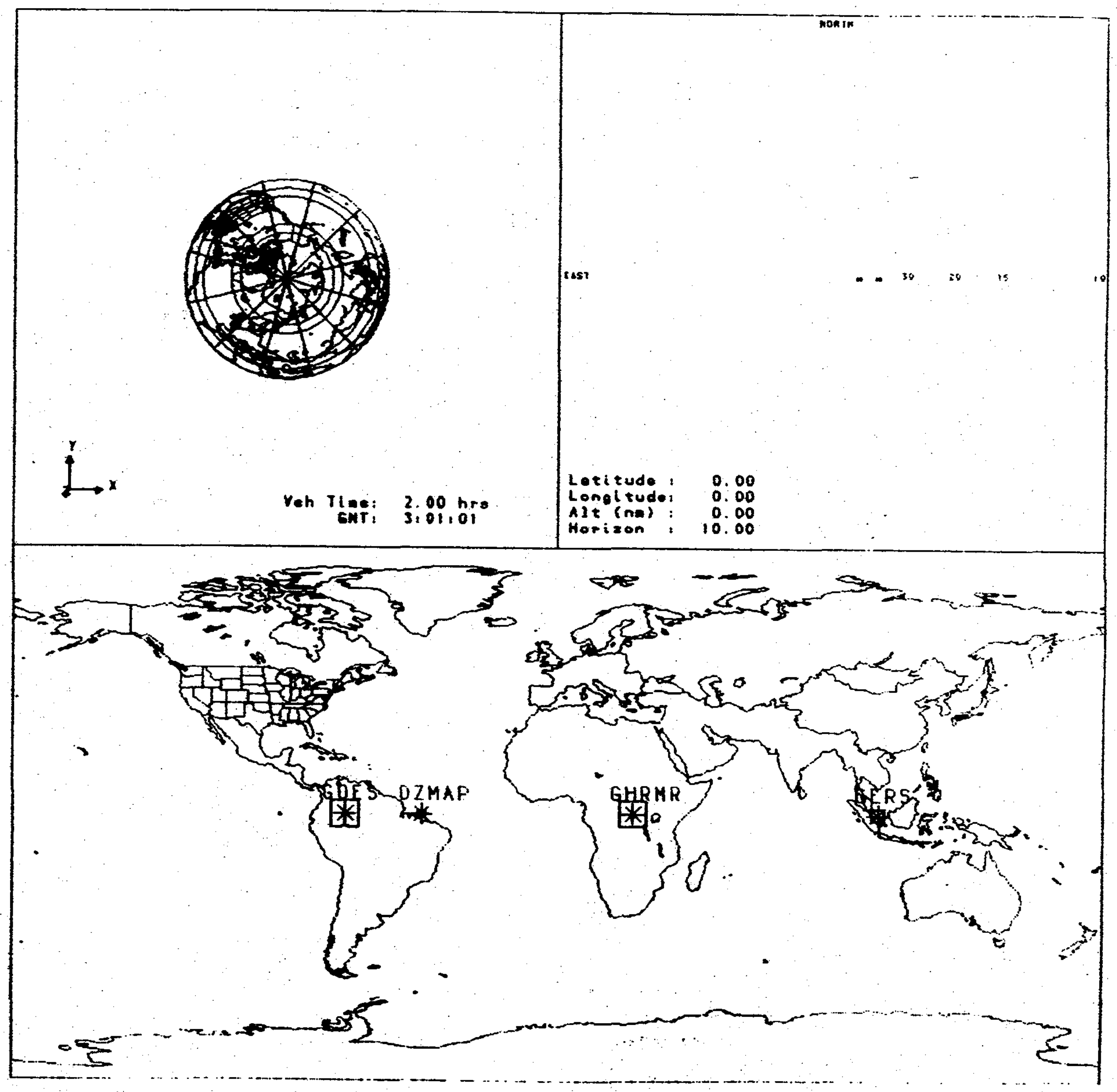


Figure 10   Comparison of Scan Coverage Between GHRMR, GOES Imager, GERS, and OZMAP in 3.1 Minutes



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L. Bernard Garrett and Robert L. Wright: Langley Research Center, Hampton, Virginia.
Warren D. Hypes: The Bionetics Corporation, Hampton, Virginia.

16. Abstract

Systems concepts were developed and technology assessments conducted for science instrument combinations and spacecraft archietecture options to measure long-term global climate changes on Earth. An extensive series of atmospheric; lang, ocean, and ice; and earth and solar radiation measurements, to be accumulated over decades, were defined requirements for the study. The need for full global coverage with repeated daily samilings, augumented by near continuous regional intensive coverage measurements, led to orbit selections at both Sun synchronous low-Earth orbit (LEO) and geostationary Earth orbit (GEO) locations. For global studies, temporal requirements were to sample every 1 to 12 hours for atnospheric and radiation parameters and one day or more for most Earth surface measurements. Spatial resolution needs varied from 1 km for land and ocean surface parameters to 50 km for some atmospheric parameters. Twenty seven instrument concepts were selected with multiple units on duplicate spacecraft, to meet the measurement requirements. Several combinations of spacecraft and the large space platform architecture options were assessed including Delta-launched small LEO spacecraft, Titan IV-launched large LEO platforms, a Titan IV-launched LEO soil moisture radiometer spacecraft and several GEO platforms with optional launch and deployment or on-orbit assembly possibilities.

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