Earth Science and Applications Division

Shelby Tilford, Director

A COMPREHENSIVE MISSION TO PLANET EARTH

Woods Hole Space Science and Applications Advisory Committee Planning Workshop

July 29, 1991
A comprehensive mission to Planet Earth

A major national and international initiative is needed to seek new solutions for ozone depletion and global warming and acid rain. And this initiative -- Mission to Planet Earth -- is a critical part of our space program.

President George Bush, July 20, 1989

... it is the Mission to Planet Earth which connotes some degree of urgency... This effort will provide us with a much better understanding of our environment, how we may be affecting it, and what might be done to restore it.

Augustine Committee Report, December 1990
A Balanced Space Program for America

Mission to Planet Earth

Technology & Transportation
(Enabling Infrastructure)

Mission from Planet Earth

Space Science

Management
Problem: Earth System is Changing

- Increasing greenhouse gases
- Decreasing levels of stratospheric ozone
- Acid rain
- Deforestation
- Decreasing biodiversity

There are strong indications that human activity accelerates the rate of change
# The Earth System is Changing

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   How fast?
The magnitude of global change
   How much?
The timing of global change
   How soon?
The local and regional impact
   What about me?

At present, scientists are unable to accurately predict the consequences of human actions on the future habitability of the Earth
Global Change Research Program Goal

Establish the scientific basis for national and international policymaking relating to natural and human-induced changes in the global Earth system
Global Change

What Do We Know? Where Are We Going?

APPROACH:
- Gain Sufficient Scientific Understanding
- Understand the Potential Impacts
- Actions Based on Sound Science

RESPONSE:
- Increased Commitment to Sustained Observations and Research
- Conduct International Assessments, Build Consensus
- Establish Appropriate Laws, Regulations, and Investments
Global Change Research Program Objectives

Establish an integrated, comprehensive, and sustained program to document the Earth system on a global scale.

Conduct a program of focused and exploratory studies to improve understanding of the physical, chemical, biological, and social processes that influence Earth system changes and trends on global and regional scales.

Develop integrated, conceptual, and predictive Earth system models on global and regional scales.
Key Areas of Scientific Uncertainty in Global Change Prediction

- Role of greenhouse gases
- Role of clouds
- Role of oceans
- Role of polar ice sheets
- Land surface hydrology
- Ecosystem response
International Coordination of Global Change Research

- United Nations Environment Program
- World Meteorological Organization
- International Council of Scientific Unions
  - Intergovernmental Panel on Climate Change
  - World Climate Research Program
  - International Geosphere-Biosphere Program
  - National Academy of Sciences

U.S. Global Change Research Program

- NASA
- NSF
- DOE
- ESA
- NOAA
- DOI
- USDA
- DoD

Committee on Earth and Environmental Sciences
International Coordination of Mission to Planet Earth

Committee on Earth Observing Satellites

Working Group on Data

Working Group on Calibration/Validation

WMO World Meteorological Organization
UNEP United Nations Environment Program
ICSU International Council of Scientific Unions
IOC International Oceanographic Commission
WCRP World Climate Research Program
IPCC Intergovernmental Panel on Climate Change

CSIRO Australia
CSA Canada
NASA USA
NOAA USA
ESA Europe
STA Japan
CNES France

EUMETSAT Europe
DAAA Germany
ASI Italy
BNSC UK
INPE Brazil
ISRO India

CNS Norway
CCRS Canada
DSIR New Zealand
Comprehensive Understanding Requires Comprehensive Space Observations

EOS Polar Platform Orbit (LEO)

Earth Probes: Special Orbits (LEO)

Geostationary Platform Orbit (GEO)
Mission To Planet Earth
Complementary Space Observations

Sun-synchronous polar orbits
- Global coverage: Fixed crossing times
- Repeat sampling at intervals of hours to weeks
- Laser, radar, and passive remote sensing

Low-inclination, low-altitude orbits
- Tropical coverage: All local times
- Repeat sampling at intervals of hours to weeks
- Laser, radar, and passive remote sensing

Geostationary orbits
- Regional views or full Earth disk
- Continuous coverage of selected areas
- Passive remote sensing

Ground Measurements
- Calibration and validation of satellite observations
- Local and regional process studies
Mission to Planet Earth
# Approved Missions in ESAD’s Base and MTPE Programs

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Airborne Science and Applications Program

Present Program includes operation of a single DC-8 aircraft. This aircraft supports major segments of the Space Science and Applications program dealing with the Earth, the oceans, and the atmosphere. Recently completed or planned program support missions:

- Solid Earth Science, Biogeochemistry & Geophysics, Ecosystem Dynamics & Biogeochemical Cycles Programs - Observational campaigns utilizing the Airborne Synthetic Aperture Radar (SAR);
- Multiple Airborne Campaign - Europe
- Atmospheric Chemistry Program - Studies of Polar Stratospheric Chemistry and Ozone Depletion through intensive Airborne observation campaigns
- Radiation, Dynamics & Hydrology Program - Global Aerosol Backscatter Experiment (GLOBE)
- Mission To Planet Earth Support - Ground Truth Observations for EOS Precursor and Earth Probe Missions

Because of its long range and high altitude capabilities and the need for these characteristics by the Earth sciences research community, the NASA DC-8 is over subscribed.

Typically, demand exceeds availability. Downtime due to integration and deintegration of the AIRSAR instrument results in loss of available flying time.

Demand and criticality of this resource to the NASA and US Global Change Research Programs justify the acquisition of a second DC-8 to dedicate to the AIRSAR instrument.
The Earth Probes Program—Mission Definition

Definition of all missions based on science measurement requirements identified by the National Academy of Sciences (NAS)


The Earth Probes Program

Approved

Total Ozone Mapping Spectrometer (TOMS)/Meteor—1991
TOMS/Free Flyer—1993
TOMS/ADEOS—1995
NASA Scatterometer (NSCAT)/ADEOS—1995
Tropical Rainfall Measuring Mission (TRMM)—1997

Proposed

Applications and Research Involving Space Technologies Observing the Earth's Field from Low Orbiting Satellite (ARISTOTELES)
Global Topography Mission (GTM)

Future (Not in Order of Priority)

Geopotential Research Mission
Measurement of Air Pollution from Satellites
Mesoscale Research Explorer
Magnetic Field Experiment
Rain Mapping Mission
Earth Radiation Budget Mission
Solar Input Mission
Volcano Mapping Mission
Other complementary missions
ARISTOTELES Mission

ARISTOTELES = Applications and Research Involving Space Technologies
Observing The Earth's field from Low Earth orbiting Satellite

Scientific objectives contribute to the understanding of:
- The dynamics of the Earth's core and origin of the magnetic field
- The composition and dynamics of the mantle
- The structure and dynamics of the continental crust
- Improved ocean circulation models through high resolution ocean geoid

ARISTOTELES is a joint NASA/ESA mission

NASA provides: scalar and vector magnetometers, onboard Global Positioning Satellite (GPS) receiver, and tracking

ESA provides: gravity gradiometer, spacecraft, mission operations
ARISTOTELES Mission Phases

ARISTOTELES will measure the Earth's gravity and magnetic fields in two phases:

Phase 1: First 6-8 months of the satellite mission
- Altitude of about 200 km
- Measures the Earth's short wavelength gravity field and crustal magnetic field at high spatial resolution

Phase 2: Remainder of the mission lifetime (about 3 years)
- Altitude of about 500 km
- Measures the Earth's long wavelength gravitation field and secular variation of the Earth's main magnetic field with high measurement resolution

Launch date is based on the projected solar cycle: Mid-to-late 1997 atmospheric drag will be at a minimum and conditions optimal for low altitude phase of the mission
ARISTOTELES Mission Concept
Global Topography Mission

Designed to measure surface elevation of the continents and ice caps

Provides fundamental data for hydrology, ecology, geology, geophysics, and other disciplines

Current digital mapping in North America, Australia and Western Europe is not adequate for many global change studies

Major portions of Africa, Asia, South America, and Antarctica have poor or no topographic coverage

The Global Topographic Mission will be performed using one or both of two technological approaches:

Radar Interferometry:

High frequency (35 GHz) radar interferometer provides rapid global coverage with high spatial (30 m) and vertical (1-3 m) resolution

Laser Altimetry:

A multi-beam laser altimeter provides high resolution (30 m) and high vertical accuracy (about 10 cm)

Plus:

A GPS receiver provides high accuracy ephemeris (about 10 cm) to minimize systematic errors due to orbit uncertainty
GTM-Laser Altimeter Mission Concept
EOS Synthetic Aperture Radar (EOS SAR)

EOS SAR will address a large range of scientific needs:
- Sea Ice, including transport, morphology, moisture content
- Soil Moisture and Snow
- Vegetation, including canopy structure, biomass, composition
- Geological surface features, structure

Scientific needs require a multiparameter SAR:
- L-band and C-band quad-polarization (US)
- X-band dual polarization (Germany/Italy)
- Multiple look angles
- Scansar, multiple resolution, and swath combinations

Further international cooperation opportunities are under discussion:
- European Space Agency (ESA) and Japanese interest
- Follow-on to European Remote Sensing Satellite-1 (ERS-1) and Japanese Earth Resources Satellite-1 (JERS-1) SAR missions

EOS SAR was initially part of EOS-A
- Deferred due to mass, power, and cost implications
EOS SAR - Evolution

US Spaceborne Imaging Radar Program

SEASAT SAR (1978)
SIR-A (1981)
SIR-B (1984)
SIR-C/X-SAR (1993, 1994, 1996; partnership with Germany and Italy)

International Missions

ALMAZ-1 (1991, USSR)
JERS-1 (1992, Japan)
RADARSAT (1994, Canada)

Airborne Programs

NASA/JPL AIRSAR
Navy P-3
Canada
Denmark
France
Germany
EOS SAR Mission

Physical Climate Subsystem

Ocean Waves and MesoScale Features
(Surface Wave Fields and Current Velocity)
Sea Ice Type, Motion, and Concentration

Hydrologic Cycle

Soil Moisture
Surface Water Distribution
Snow Moisture
Water Equivalent, and Extent
Glacier and Ice Sheet Extent and Velocity

Biogeochemical Subsystem

Topography
Erosion
Surface Roughness
Landforms
Sand Depth

Vegetation Type and Extent
(Including Deforestation)
Biomass (Woody and Green)
Phenological and Environmental State
Wetland Extent and Frequency
Landscape Pattern
EOS SAR Mission Spacecraft Summary

- DRY MASS - 2963 KG
- LAUNCHED MASS - 3306 KG
- AVE POWER - 2498 W
- PEAK POWER - 7332 WS
- 3-AXIS STABILIZED
- 300 MBPS DOWNLINK MAX
- 15 MBPS AVE
- 100 KBPS UPLINK
- 5-YEAR DESIGN LIFETIME
- MONO PROPELLANT HYDRAZINE
  DRAG MAKE UP (143 KG PROPELLANT)
- PASSIVE THERMAL CONTROL
- 1078 KG SAR
- QUAD POLARIZATION L-BAND
- DUAL POLARIZATION X, C-BAND
- EOS MAPPING/HIGH RESOLUTION MODES
Geostationary Earth Observatory (GEO)

Several spacecraft oriented over fixed equatorial locations positioned around the world

Observations of vital Earth system processes that cannot be made from polar or low-inclination orbit

Rapidly developing phenomena and diurnal processes viewed at any time and on a continuous basis

Instruments complementary to EOS

Direct intercomparison of EOS/GEO observations

Data integrated in the EOS Data and Information System

Science measurements

Crucial to understanding short-term processes essential for the development of predictive Earth system models
Why GEO?

GEO observes regional scale rapid changes (Process Studies)

EOS observes global scale slower changes (Global Monitoring)

RESULT: Comprehensive monitoring of the Earth system required to understand and predict global change

With GEO, the impact of large daily fluctuations on long-term global change will be understood.
Key GEO Mission Characteristics

GEO permits time-continuous observations necessary for comprehensive physical and dynamical modeling of the global Earth System

- Diurnal observations
- Multiple image compositing
- Timely observation of transient events
- Long-duration sensor staring
- Hemispheric coverage
- Fast sequential imaging
- Constant viewing angle
- Varying sun angle
- Continuous solar observations

Potential GEO facility instruments include:
- Microwave Imager/Sounder
- IR Atmospheric Profiler
- Visible/IR Spectrometer (moderate resolution)
- Visible/IR High-Resolution Imager
- Lightning Sensor
MTPE Space Assets for Global Change Studies

|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| TOMS/MEOR | TOMS/ADEOS | TOMS/SCOUT | NSCAT/ADEOS | SHM | ESS\n
Earth Probes

EOS

EOS Data & Information System

Foreign

ADEOS

ARISTOTELES

GTW

GEO

EOS\n
EOS SAR

JEOS

POEM/M1

TES/M1

Future Earth Probe Candidate

Proposed Mission

Approved, Under Development, or Operating Mission

1 USSR Satellite

2 Japanese Satellite

3 Joint with Japan

4 Proposed International Cooperation
Base Program Space Assets for Global Change Studies

NASA Satellites


- LAGEOS-1
- LAGEOS-2
- UARS
- TOPEX/POSEIDON
- SRL
- ATLAS/SSBUV
- GEOSAT
- SALT
- ERS-1
- ERS-2
- JERS-1
- RADARSAT
- ADEOS
- POLAR
- GOES
- DMSP
- LANDSAT
- GMS, INSAT, METEOSAT
- SPOT
- SeaWIFS

FEASIBLE EXTRACTED MISSION

APPROVED, UNDER DEVELOPMENT, OR OPERATING MISSION

1 Joint with Italy
2 Joint with Peesco
Earth Science and Applications Division

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Physical Aspects of the Climate System

Atmosphere

Hydrological Cycle

Biogeochemical Cycles

Oceans

Land

The Earth System

Biogeochemical Aspects of
Key Areas of Scientific Uncertainty in Global Change Prediction

- Role of greenhouse gases
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- Role of oceans
- Role of polar ice sheets
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International Science Requirements

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**MTPE approved**

| **NSCAT**<br>NASA Scatterometer/ADEOS (Japan) | February 1995, February 1997 |
| **TRMM**<br>Tropical Rainfall Monitoring Mission (Japan) | December 1997 |
| **EOS-A Series**<br>Earth Observing System-A1/A2/A3 | 2001 (B1) |
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- The dynamics of the Earth's core and origin of the magnetic field
- The composition and dynamics of the mantle
- The structure and dynamics of the continental crust
- Improved ocean circulation models through high resolution ocean geoid

ARISTOTELES is a joint NASA/ESA mission

NASA provides: scalar and vector magnetometers, onboard Global Positioning Satellite (GPS) receiver, and tracking

ESA provides: gravity gradiometer, spacecraft, mission operations
ARISTOTELES Mission Phases

ARISTOTELES will measure the Earth's gravity and magnetic fields in two phases:

Phase 1: First 6-8 months of the satellite mission
   Altitude of about 200 km
   Measures the Earth's short wavelength gravity field and crustal magnetic field at high spatial resolution

Phase 2: Remainder of the mission lifetime (about 3 years)
   Altitude of about 500 km
   Measures the Earth's long wavelength gravitation field and secular variation of the Earth's main magnetic field with high measurement resolution

Launch date is based on the projected solar cycle: Mid-to-late 1997 atmospheric drag will be at a minimum and conditions optimal for low altitude phase of the mission
ARISTOTELES Mission Concept
Global Topography Mission

Designed to measure surface elevation of the continents and ice caps

Provides fundamental data for hydrology, ecology, geology, geophysics, and other disciplines

Current digital mapping in North America, Australia and Western Europe is not adequate for many global change studies

Major portions of Africa, Asia, South America, and Antarctica have poor or no topographic coverage

The Global Topographic Mission will be performed using one or both of two technological approaches:

Radar Interferometry:

High frequency (35 GHz) radar interferometer provides rapid global coverage with high spatial (30 m) and vertical (1-3 m) resolution

Laser Altimetry:

A multi-beam laser altimeter provides high resolution (30 m) and high vertical accuracy (about 10 cm)

Plus:

A GPS receiver provides high accuracy ephemeris (about 10 cm) to minimize systematic errors due to orbit uncertainty
GTM-Laser Altimeter Mission Concept
GTM-Radar Interferometer Mission Concept

GLOBAL TOPOGRAPHIC MAPPING
MISSION CONCEPT

- FREQUENCY: 35 GHz
- SPATIAL RESOLUTION: 30 m
- HEIGHT ACCURACY: 10 m
- SWATH WIDTH: 10 km
- TOTAL INSTRUMENT POWER: 400 W
- TOTAL INSTRUMENT WEIGHT: 450 kg
- BANDWIDTH: 1 GHz
- PRF: 3.68 KHz
- ANTENNA SIZE: 0.6 m x 0.5 m
- ANTENNA SEPARATION: 1 m
- ANTENNA BEAMWIDTHS: 0.05 x 0.15
- DYNAMIC RANGE: 22 dB
- DATA RATE INTO RECORDER (THROTTLED): 120 Mbit/sec
- ORBIT: SUN-SYNCHRONOUS (600 km)
- MISSION DURATION: 2 yrs
EOS Synthetic Aperture Radar (EOS SAR)

EOS SAR will address a large range of scientific needs
- Sea Ice, including transport, morphology, moisture content
- Soil Moisture and Snow
- Vegetation, including canopy structure, biomass, composition
- Geological surface features, structure

Scientific needs require a multiparameter SAR
- L-band and C-band quad-polarization (US)
- X-band dual polarization (Germany/Italy)
- Multiple look angles
- Scansar, multiple resolution, and swath combinations

Further international cooperation opportunities are under discussion
- European Space Agency (ESA) and Japanese interest
- Follow-on to European Remote Sensing Satellite-1 (ERS-1) and Japanese Earth Resources Satellite-1 (JERS-1) SAR missions

EOS SAR was initially part of EOS-A
- Deferred due to mass, power, and cost implications
EOS SAR - Evolution

US Spaceborne Imaging Radar Program

SEASAT SAR (1978)
SIR-A (1981)
SIR-B (1984)
SIR-C/X-SAR (1993, 1994, 1996; partnership with Germany and Italy)

International Missions

ALMAZ-1 (1991, USSR)
JERS-1 (1992, Japan)
RADARSAT (1994, Canada)

Airborne Programs

NASA/JPL AIRSAR
Navy P-3
Canada
Denmark
France
Germany
EOS SAR Mission

Physical Climate Subsystem
Ocean waves and mesoscale features (surface wave fields and current velocity)
Sea ice type, motion, and concentration

Hydrologic Cycle
Soil moisture
Surface water distribution
Snow moisture
Water equivalent, and extent
Glacier and ice sheet extent and velocity

Biogeochemical Subsystem
Topography
Erosion
Surface roughness
Landforms
Sand depth

Vegetation type and extent (including deforestation)
Biomass (woody and green)
Phenologic and environmental state
Wetland extent and frequency
Landscape pattern
EOS SAR Mission Spacecraft Summary

- DRY MASS - 2963 KG
- LAUNCHED MASS - 3306 KG
- AVE POWER - 2498 W
- PEAK POWER - 7332 WS
- 3-AXIS STABILIZED
- 300 MBPS DOWNLINK MAX
- 15 MBPS AVE
- 100 KBPS UPLINK
- 5-YEAR DESIGN LIFETIME
- MONO PROPELLANT HYDRAZINE
  DRAG MAKE UP (143 KG PROPELLANT)
- PASSIVE THERMAL CONTROL
- 1078 KG SAR
- QUAD POLARIZATION L-BAND
- DUAL POLARIZATION X, C-BAND
- EOS MAPPING/HIGH RESOLUTION MODES
Geostationary Earth Observatory (GEO)

Several spacecraft oriented over fixed equatorial locations positioned around the world

Observations of vital Earth system processes that cannot be made from polar or low-inclination orbit

Rapidly developing phenomena and diurnal processes viewed at any time and on a continuous basis

Instruments complementary to EOS

Direct intercomparison of EOS/GEO observations

Data integrated in the EOS Data and Information System

Science measurements

Crucial to understanding short-term processes essential for the development of predictive Earth system models
Why GEO?

GEO observes regional scale rapid changes (Process Studies)

EOS observes global scale slower changes (Global Monitoring)

RESULT:
Comprehensive monitoring of the Earth system required to understand and predict global change

With GEO, the impact of large daily fluctuations on long-term global change will be understood.
Key GEO Mission Characteristics

GEO permits time-continuous observations necessary for comprehensive physical and dynamical modeling of the global Earth System

- Diurnal observations
- Multiple image compositing
- Timely observation of transient events
- Long-duration sensor staring
- Hemispheric coverage
- Fast sequential imaging
- Constant viewing angle
- Varying sun angle
- Continuous solar observations

Potential GEO facility instruments include:
- Microwave Imager/Sounder
- IR Atmospheric Profiler
- Visible/IR Spectrometer (moderate resolution)
- Visible/IR High-Resolution Imager
- Lightning Sensor
Geostationary Earth Observatory (GEO) Mission Concept
# MTPE Space Assets for Global Change Studies

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- **Earth Probes**
  - **MTPE APPROVED**
    - TOMS/METEOR<sup>1</sup>
    - TOMS/ADEOS<sup>2</sup>
    - TOMS/SCOUT
    - NSCAT/ADEOS<sup>2</sup>
    - TIMM<sup>3</sup>

- **EOS**
  - EOS DATA & INFORMATION SYSTEM
  - EOS/A
  - EOS/B

- **Foreign**
  - ADEOS
  - ARISTOTELES
  - GTM

- **Earth Probes**
  - GEOS
  - GEO
  - JEOS

- **Foreign**
  - POEM/HAI

- **Future Earth Probe Candidate**
  - Proposed Mission
  - Approved, Under Development, or Operating Mission

- **USSR Satellite**
- **Joint with Japan**
- **Japanese Satellite**
- **Proposed International Cooperation**