POST LANDSAT D
ADVANCED CONCEPT EVALUATION

MIDTERM BRIEFING
DECEMBER 1, 1977
AGENDA

INTRODUCTION

MISSION OBJECTIVES AND REQUIREMENTS

SYSTEM ELEMENTS

SYSTEM CONCEPTS

TECHNOLOGY REQUIREMENTS AND FORECASTING

PRIORITY ANALYSIS
PLACE OBJECTIVES


- TO PROVIDE A COMPREHENSIVE ‘SPACE SYSTEMS TECHNOLOGY MODEL’ FOR EARTH RESOURCES PROGRAMS FOR THIS PERIOD

- TO DEVELOP A TOOL TO ALLOW FOR PRIORITY STRUCTURING OF THESE KEY TECHNOLOGIES AS A DECISION AID
NASA MANDATE FOR VISION

- STUDY SHOULD ATTEMPT TO EMPLOY IMAGINATION, VISION AND INSPIRATION. SEEK TO GO BEYOND THE CREDIBLE TO THE 'SEMI-CREDIBLE'

- IN BOTH MISSION ANALYSIS AND TECHNOLOGY FORECASTING – ASK WHAT 'CAN BE' RATHER THAN WHAT 'WILL BE.'
**MISSION CATEGORY** — THE MAJOR AREAS TO BE STUDIED, E.G., AGRICULTURE, FORESTRY, ETC.

**MISSION OBJECTIVES** — GOALS TO BE OBTAINED UNDER THE MAJOR CATEGORY HEADINGS, E.G., GLOBAL CROP PRODUCTION FORECASTING, WATER AVAILABILITY FORECASTING

**MISSION SUBOBJECTIVES** — SUBGOALS REQUIRED TO FULFILL THE NEEDS OF MISSION OBJECTIVES E.G., SOIL MOISTURE MONITORING, CROP STRESS, ETC. SOME OF THESE MISSION SUBOBJECTIVES MAY BE USEFUL FOR MORE THAN ONE OBJECTIVE

**SYSTEM** — A COMBINATION OF HARDWARE, SOFTWARE, AND PEOPLE REQUIRED TO PROVIDE DATA FOR THE VARIOUS MISSION OBJECTIVES, E.G., LANDSAT-D, GEOSYNCHRONOUS RADAR SATELLITE, ETC.

**PROGRAM** — THE EFFORT AND RESOURCES THAT GO INTO THE DEVELOPMENT OF A SYSTEM

**SYSTEM SCENARIO** — A SCHEDULE OF FUTURE SYSTEMS THAT ACCOMPLISH THE SET OF MISSION OBJECTIVES
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MISSION OBJECTIVES AND REQUIREMENTS

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MISSION OBJECTIVES AND REQUIREMENTS

SELECT MISSION OBJECTIVES

NASA REVIEW

KEY SET

EVALUATE INCLUSIVENESS OF KEY SET

DETERMINE USER REQUIREMENTS

IDENTIFY SYSTEM REQUIREMENT TRENDS

ESTIMATION OF FUTURE

LITERATURE REVIEW

GE DISCIPLINE SCIENTISTS
• SPACECRAFT AND ASSOCIATED DATA PROCESSING FOR REMOTE SENSING OF THE EARTH

• EXCLUDED FROM CONSIDERATION:
  — WEATHER AND CLIMATE
  — EARTH AND OCEAN DYNAMICS
  — ENERGY/COMM/NAV
  — MILITARY APPLICATIONS
  — AIRCRAFT/DCP’S
  — EXTRATERRESTRIAL
  — CRIMINAL ACTIVITIES (EXCEPT POLLUTION)

• EIGHT KEY OBJECTIVES FOCUS PLACE STUDY
KEY OBJECTIVES

- AGRICULTURE — CROP PRODUCTION FORECASTING
  - IDENTIFY CROPS
  - MEASURE ACREAGE
  - ESTIMATE YIELD
  - MEASURE PRODUCTION

- RANGE MANAGEMENT — GRAZING POTENTIAL DETERMINATION
  - EVALUATE STATUS AND MEASURE CARRYING CAPACITY
  - ESTIMATE LIVESTOCK COUNT
  - ESTIMATE FORAGE PALATABILITY

- FORESTRY — TIMBER STAND VOLUME ESTIMATION
  - IDENTIFY TREES
  - EVALUATE QUANTITY AND QUALITY OF TIMBER

- GEOLOGY — GEOLOGICAL RESOURCES LOCATION
  - LOCATE ORES
  - LOCATE FOSSIL FUELS
  - LOCATE CONSTRUCTION MATERIALS
  - LOCATE GEOTHERMAL RESOURCES
KEY OBJECTIVES

- **LAND USE — LAND USE AND CENSUS ENUMERATION**
  - CREATE THEMATIC AND LAND USE MAPS
  - DETECT CHANGE IN LAND USE
  - ESTIMATE POPULATION

- **WATER RESOURCES — WATERSHED MONITORING**
  - MONITOR SURFACE SUPPLY OF FRESH WATER
  - MEASURE GROUNDWATER FLOW AND STORAGE
  - INTEGRATE RAINFALL AND EVAPORATION DATA

- **ENVIRONMENTAL QUALITY — WATER POLLUTION DETECTION**
  - DETECT, MONITOR, AND TRACE FRESH WATER POLLUTANTS
  - MONITOR EUTROPHICATION
  - MEASURE SALTWATER INCURSION

- **DISASTER ASSESSMENT — ABRUPT EVENT EVALUATION**
  - MONITOR AND ASSESS DISASTERS
  - MONITOR NON-CALAMITOUS ABRUPT EVENTS
<p>| USER REQUIREMENTS TO SATISFY OBJECTIVES |
| OF KEY SET IN 2000 |
|-------------------|------------------|------------------|------------------|
| CROP PRODUCTION FORECASTING | PRECISION | PARAMETER RANGE | OBSERVATION FREQUENCY | RESPONSE TIME |
| IDENTIFY CROPS | 98% | ALL | 8 DA | 2 WK |
| MEASURE ACREAGE | 98% | &gt;1 HA | 8 DA | 2 WK |
| ESTIMATE YIELD | 95% | ALL | 3 DA | 1 WK |
| DETERMINE PRODUCTION | 90% | ALL | 8 DA | 3 WK |
| GRAZING POTENTIAL DETERMINATION | | | | |
| IDENTIFY VEGETATION | 90% | ALL | 1 MO | 3 MO |
| ESTIMATE PALATABILITY | | | 1 WK | 3 DA |
| MEASURE FORAGE BIOMASS | 90% | 4 DA | 4 DA | |
| EVALUATE RANGE PHYSICAL CONDITION | | 1 DA | 6 HR | |
| TIMBER STAND VOLUME ESTIMATION | | | | |
| IDENTIFY TREES | 90% | ALL | 1 YR | 1 YR |
| DETERMINE DENSITY DISTRIBUTION | 95% | 1 YR | 1 YR | |
| MEASURE HEIGHT AND DIAMETER | 90% | ALL | 1 YR | 1 YR |
| DETECT INSECT AND DISEASE ATTACK | 80% | 1 MO | 2 WK | |
| GEOLOGICAL RESOURCES LOCATION | | | | |
| LOCATE ORES | 90% | $10^7$ KG | ONCE | 1 YR |
| LOCATE CONSTRUCTION MATERIALS | 70% | $10^3$ M$^3$ | ONCE | 1 YR |
| LOCATE FOSSIL FUELS | 95% | $10^4$ M$^3$ | ONCE | 1 YR |
| LOCATE GEOTHERMAL RESOURCES | 75% | | | |</p>
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<th>Land Use and Census Enumeration</th>
<th>Precision</th>
<th>Parameter Range</th>
<th>Observation Frequency</th>
<th>Response Time</th>
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<tr>
<td>Map Land Use to Level III</td>
<td>98%</td>
<td></td>
<td>1 YR</td>
<td>6 MO</td>
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<tr>
<td>Detect Change in Land Use</td>
<td>95%</td>
<td></td>
<td>2 MO</td>
<td>4 MO</td>
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<tr>
<td>Perform Demographic Census</td>
<td>95%</td>
<td></td>
<td>2 YR</td>
<td>1 YR</td>
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<tr>
<td>Watershed Monitoring</td>
<td></td>
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<tr>
<td>Measure Snow and Ice Volume</td>
<td>80%</td>
<td>&gt;100m³</td>
<td>3 DA</td>
<td>1 DA</td>
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<tr>
<td>Measure Stream and River Flow</td>
<td>90%</td>
<td>All</td>
<td>3 HR</td>
<td>1 HR</td>
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<tr>
<td>Measure Lake and Reservoir Volume</td>
<td>95%</td>
<td>&gt;100m³</td>
<td>1 DA</td>
<td>1 DA</td>
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<tr>
<td>Water Pollution Detection</td>
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<tr>
<td>Detect, Identify, and Monitor Pollutants</td>
<td>85%</td>
<td>2 HR</td>
<td>30 MN</td>
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<tr>
<td>Monitor Eutrophication</td>
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<td>Measure Salt Water Incursion</td>
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<td>Abrupt Event Evaluation</td>
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<tr>
<td>Monitor and Assess Disasters</td>
<td>95%</td>
<td>Demand</td>
<td>1 MN</td>
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<tr>
<td>Monitor Non-Calamitous Abrupt Events</td>
<td>90%</td>
<td>Demand</td>
<td>1 HR</td>
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USER AND SYSTEM REQUIREMENTS:
SOME DISTRIBUTIONS

FREQUENCY OF OBSERVATION

NUMBER OF NEEDS
1 HOUR 1 WEEK 1 YEAR 10 YEARS
FREQUENCY OF OBSERVATION

RESPONSE TIME

NUMBER OF NEEDS
1 HOUR 1 WEEK 1 YEAR
RESPONSE TIME

SPATIAL RESOLUTION

NUMBER OF NEEDS
0 20 40 60 80 100

RESOLUTION, IN METERS

0.001 0.01 0.1 1.0 10

VERTICAL (DEPTH) RESOLUTION IN METERS

0 1 2 3 4 5 6 7 8 9 10

VERTICAL RESOLUTION

NUMBER OF NEEDS

0 1 2 3 4 5
• IFOV DOWN TO 5-10 METER
• AMPLITUDE RESOLUTION TO 0.1-0.5% (8-10 BITS)
• DATA RATE TO GIGABIT/SEC RANGE
• VARIABLE RESOLUTION/ZOOM CAPABILITY
• MAKE OBSERVATIONS IN ANY WEATHER, DAY OR NIGHT, UP TO REAL TIME
• MORE USE OF MODELS AND DATA BANKS
FORMATION OF SYSTEM CONCEPTS

(USER DRIVEN)

MISSION OBJECTIVES → USER REQUIREMENTS → SYSTEM SPECIFICATIONS → SYSTEM CONCEPTS

(PLACE METHODOLOGY)

ENGINEERING AND SCIENTIFIC JUDGMENT → SYSTEM CONCEPTS

(TECHNOLOGY DRIVEN)

EXPLORATORY TECHNOLOGY FORECASTING → AVAILABLE TECHNOLOGY → BEST POSSIBLE SYSTEMS
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PRIORITY ANALYSIS
SYSTEM ELEMENTS

SENSOR → PLATFORM
- ORBIT
- SUPPORT
  SUB-SYSTEMS → COMMUNICATIONS

COMMUNICATIONS → USER

COMMUNICATIONS → PREPROCESS
  AND EXTRACT → END-TO-END

USER → COMMUNICATIONS

ORIGINAL PAGE IS OF POOR QUALITY
• VISIBLE/IR IMAGERS
  – PASSIVE – PUSH BROOM, WHISK BROOM, SOLID STATE CAMERAS
  – ACTIVE – ATMOSPHERIC CALIBRATION, FLUORESCENCE, NIGHT IMAGING
  – SMART SENSORS
• MICROWAVE IMAGERS/ALTIMETERS
  – SYNTHETIC APERTURE RADAR – LEO, GEOSYNCHRONOUS
  – REAL APERTURE RADAR – GEOSYNCHRONOUS, HOLOGRAPHY, LEO
  – RADIOMETER
  – ALTIMETER
• TEXTURE MEASURING SENSORS
  – OPTICAL
  – SWEEP FREQUENCY RADAR – SCATTEROMETER
• FIELD MEASURING SENSORS
  – MAGNETIC
  – GRAVITY
PLACE FAMILY ORBITS

- SPACE SHUTTLE SORTIE
- LANDSAT CLASS – SUN SYNCHRONOUS
- EARTH WATCH
- 24 HOUR ORBITS
EACH LINK MAY CONTAIN RAW DATA, PROCESSED DATA, OR RESOURCE MANAGEMENT INFORMATION
GEO-REFERENCED LAND INFORMATION
DATA BASE SYSTEM CONCEPT

TYPICAL DATA SETS

RASTERS
- LANDSAT/AIRCRAFT SCANNER DATA
- AIRCRAFT PHOTOGRAPHY
- RELIEF PROFILES/TOPOGRAPHY
- GEOLOGIC STRUCTURES & SOILS
- DRAINAGE BASINS
- VEGETATION & WILD LIFE

POLYGONS
- LAND USES & ZONING
- HOUSING
- PROPERTY BOUNDARIES & ASSESSMENT
- HIGHWAYS, ROADS, STREETS
- CENSUS TRACTS & POLITICAL BOUNDARIES

POINTS
- AIR QUALITY
- WEATHER STATIONS

ORIGINAL PAGE IS OF POOR QUALITY
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EXPLORATORY TECHNOLOGY FORECASTING

- OBJECTIVE
  - IDENTIFY MISSION ENABLING CONCEPTS

- METHODS
  - "BLUE SKY" MEETINGS
  - LITERATURE SEARCH
  - PERSONAL CONTACTS
  - "IMAGINEERING"

- RESULTS
  - SENSING CONCEPTS
  - PLATFORM/SUPPORT CONCEPTS
  - DATA SYSTEM CONCEPTS
SENSOR AND SYSTEM CONCEPTS

1. LANDSAT H
2. EARTHWATCH
3. SEOS
4. TEXTUROMETER
5. HCMM FOLLOW-ON
6. NITE-LITE
7. MICROSAT
8. PARASOL RADIOMETER
9. RADAR ELLIPSOMETER
10. FERRIS WHEEL RADAR
11. SATCLOUD
12. RADAR ALTIMETER
13. SWEEP FREQUENCY RADAR
14. GEOSYNCHRONOUS SAR
15. RADAR HOLOGRAPHER
16. FARADAY Magsat
17. TETHERSAT
18. SHUTTLE CALIBRATION FACILITY
19. OPERATIONAL SHUTTLE FLIGHTS
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<td>LANDSAT F (OPTICAL IMAGER (DEVELOPMENTAL)</td>
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LANDSAT H — SYSTEM CONCEPT

- Extension of Operational Landsat Program (approx. 1995)
- Incorporates optical and SAR developments of Landsat F and G
- Smart optical sensor allows for intelligent on-board editing/data reduction
- Synthetic aperture radar provides multi-frequency, all-weather imaging capability
- On-board processing and storage allows for change detection and/or information extraction
- High resolution pointable imager provides greater detail in selected target areas
- Active visible sensor provides atmospheric calibration, luminescence, night imaging
PERFORMANCE PARAMETERS

- SMART VISIBLE/IR SENSOR
  - Forward/backward looking
  - 10 M resolution
  - 3 forward bands/7 backward
  - 1.25 GBPS data rate
  - 185 KM swath width
- SYNTHETIC APERTURE RADAR
  - L, C, X-band
  - 25 meter resolution
- HIGH RESOLUTION POINTABLE IMAGER
  - 5 M resolution
  - 5 KM x 5 KM targets
  - 4 spectral bands
- LASER ATMOSPHERIC CALIBRATION
  - Also used for luminescence, night imaging
- ORBIT-SUN SYNCHRONOUS — (700 - 900 KM)
  - 3 SPACECRAFT CONSTELLATION
  - 6 DAY REPEAT CYCLE

SYSTEM CONSIDERATIONS

MISSIONS CONTRIBUTED TO: ALL

RELATED SPACECRAFT: EARTHWATCH
SAT CLOUD
GEOSYNCHRONOUS SAR
RADAR HOLOGRAPHER


MEASURE OF RISK: MEDIUM
- Intermediate (subsynchronous) orbits originally suggested by astronaut Bill Pogue

- 3000-6000 mile repeating orbits — provide near continuous earth coverage

- Could provide both earth resources management information (mapping) and quick-look capability (disaster assessment)

- 2 pointable optical sensors
  - Hi-res for quick-look capability
  - Med-res for mapping capability

- Synthetic aperture radar/radiometer frequency share the same antenna
PERFORMANCE PARAMETERS

- Orbit period of 6 hours (inertial frame)
- 20 satellites in constellation
- Continuous coverage of the entire globe with elevation angle >20°
- Pointable sensors required
- Visible/IR imager
  - 3-6 M resolution
    - Targets of (5 KM)² - 2.7 M pixels
  - 30 M resolution
    - 90 K x 90 K images - 9 M pixels
- Passive radiometer — 15 M antenna
  - X-band — 12 KM resolution
  - S-band — 60 KM resolution
  - L-band — 120 KM resolution
- Synthetic aperture radar
  - 10-25 M resolution
  - X-band, S-band, L-band

SYSTEM CONSIDERATIONS

- Missions contributed to: All
- Related spacecraft: Landsat SEOS Satcloud Geosynchronous SAR Radar holographer
- Measure of risk: Medium
TEXTUROMETER — SYSTEM CONCEPT

- Measures the texture of the ground surface at scales from 1 mm to 1 m
- Spatial frequency would assist in classification of ground materials - method currently not pursued

METHOD 1
- Visible/IR laser used as a scatterometer — pulses range gated to achieve spatial frequencies
- Statistical measure of ground periodicity is the desired output

METHOD 2
- Variation in reflectance in three directions (60° apart) provides a point sample of texture
- Three lines of mirrors, each containing adaptive optics, provide the measurements
- Complex data processing is required to transform the data to spatial frequency distribution
- Atmospheric scattering may limit resolution

Energy

Spatial Signature

Spatial Frequency

Energy

1 mm 1 cm 10 cm 1 m
PERFORMANCE PARAMETERS

- Use either CO2 (9-11 μm) or Nd/YAG (1.064 μm)
- Requires picosecond pulses
- Data rate — 25 samples - 90 KBPS
- Each line of mirrors contains 100 mirrors, each 3.0 meters square
- Orbit is 600 km circular
- Optical spectrum: visible through IR
- Adaptive optics and image motion compensation required
- Mirror focal length ≈ 600 m, mirror line length 300 m

SYSTEM CONSIDERATIONS

- Missions contributed to:
  - Identification of vegetation,
  - Measurement of particle size,
  - Ground periodicity

- Related spacecraft: Sweep frequency radar
- Time projection: 1995
- Measure of risk: High
MICROSAT – SYSTEM CONCEPT

- L-BAND PASSIVE RADIOMETER

- PARABOLIC TORUS ANTENNA WITH CLUSTER OF FEED HORNS IN A FOCAL ARC

- WOULD REQUIRE PREVIOUS COMMITMENT TOWARD LARGE STRUCTURES IN SPACE
PERFORMANCE PARAMETERS

- FREQUENCY IS 1.4 GHZ (L BAND)
- ANTENNA SIZE APPROXIMATELY 600M X 1300M
- GROUND RESOLUTION — 1KM, ORBIT — 1000KM, REPEAT CYCLE — 3 DAYS (2 SPACECRAFT), RADIOMETRIC TEMP. RES. — 10K
- DATA RATE (PEAK) — 59 KBPS

SYSTEM CONSIDERATIONS

OBJECTIVE CONTRIBUTED TO: SOIL MOISTURE

RELATED SPACECRAFT: ALL MICROWAVE SYSTEMS EXCEPT TEXTURE SYSTEMS

TIME PROJECTION: 1988-1992

MEASURE OF RISK: MEDIUM
- Based on early work by Siegfried Auer
- Bistatic radar approach employs one spacecraft for transmitter and one for receiver (specular reflection only)
- System will map dielectric constant of the soil, dielectric constant of vegetation, and height of vegetation
- Measures effect of reflection on polarization of plane polarized waves (3 measurements of ellipticity)
- One problem area appears to be the Faraday rotation through the ionosphere
PERFORMANCE PARAMETERS

- FREQUENCY — 300 MHZ
- GROUND RESOLUTION — 100 M
- DATA RATE — 2.65 MBPS
- SWATH WIDTH — 160 KM
- ALTITUDE — 600 KM (NOMINAL)

SYSTEM CONSIDERATIONS

OBJECTIVES CONTRIBUTED TO:
- SOIL MOISTURE,
- VEGETATION HEIGHT,
- VEGETATION CLASSIFICATION,
- VEGETATION MOISTURE CONTENT

RELATED SPACECRAFT: ALL

TIME PROJECTION: 1995

MEASURE OF RISK: HIGH
FERRIS WHEEL RADAR – SYSTEM CONCEPT

- LARGE (30 KM DIAMETER) ROTATING CABLE STRUCTURE THAT RELIES ON CABLE TENSION FOR SUPPORT. PRESUMES PREVIOUS COMMITMENT TO ASSEMBLY OF LARGE STRUCTURES IN SPACE
- REAL APERTURE RADAR OPERATES AT LOW FREQUENCY (30-300 MHZ) FOR GROUND PENETRATION
- RESULTANT RETURN SIGNAL CAN MAP MATERIALS (BOUNDARY LAYERS AND GROUNDWATER) TO AN AVERAGE DEPTH OF 75 M
- SPACECRAFT SPIN VECTOR IS FIXED IN INERTIAL SPACE
- PROBLEM AREA TO BE EXAMINED IS THE ATTENUATION EFFECTS OF THE IONOSPHERE.
- IC CHIPS FORM ELEMENTS OF A RANDOM SPARSE PHASED ARRAY
- TRADE BETWEEN CW AND PULSED IMPLEMENTATION YET TO BE PERFORMED
PERFORMANCE PARAMETERS

- 30 KM DIAMETER
- 75 M DEPTH
- 300 M GROUND RESOLUTION
- VERTICAL TARGET RESOLUTION BELOW GROUND SURFACE — APPROXIMATELY 2M
- FREQUENCY — 30-300 MHZ
- SPIN RATE APPROXIMATELY 1 REV/HR
- 900 KM ORBIT

SYSTEM CONSIDERATIONS

MISSIONS CONTRIBUTED TO:
- GEOLOGIC RESOURCES LOCATION
- GROUNDWATER MAPPING
- SOIL MOISTURE

COMPETING SPACECRAFT: NONE

TIME PROJECTION: 1995-2000

MEASURE OF RISK: HIGH
- Concept of building a small (20 in.)³, cheap (K$), light (mostly plastic) daughter spacecraft
- Launch many \(10^3 - 10^4\) in a geosynchronous orbit to provide a real aperture radar
- Would require mother satellite for station-keeping, command and control
- Many potential problems in deployment, surveillance, timing
- Based on sparse phased array system
- Two mode operation would allow for variable resolution and swath width
- Alternative application in radar holographer system concept (not presented)
PERFORMANCE PARAMETERS

• FREQUENCY — 3 GHZ

• CONSTELLATION — $10^4$ SPACECRAFT — 100 KM DIAMETER ARRAY

• SWATH WIDTH — 100M/75KM

• GROUND RESOLUTION — 1M/100M

SYSTEM CONSIDERATIONS

MISSIONS CONTRIBUTED TO: ALL

RELATED SPACECRAFT: LANDSAT H, EARTHWATCH

GEOSYNCHRONOUS SAR

TIME PROJECTION: 1995-1997

MEASURE OF RISK: HIGH
GEOSYNCHRONOUS SAR – SYSTEM CONCEPT

- System uses the north-south drift of a geosynchronous spacecraft to provide the range-rate for a synthetic aperture.
- The system maps footprints of the Earth by staring at them (integrating) for about 8 minutes.
- Typical elevation angles of 30° - 60°.
- Approximate time to map the entire U.S. is 4½ hrs.
- Potential problems in data storage ($10^{12}$ bits), processing and oscillator stability.
PERFORMANCE PARAMETERS

- FREQUENCY = 2.5 GHZ - S-BAND
- FOOTPRINT SIZE = 1050 KM x 650 KM
- GROUND RESOLUTION = 100 M
- INTEGRATION TIME/FOOTPRINT = 8-12 MIN.
  MAP ENTIRE U.S. ~ 4.5 HRS. (~1.1B PIXELS)
- AVERAGE RF POWER = 800 W
- ANTENNA SIZE = 7.3 M DIAMETER
- ORBIT INCLINATION ANGLE = 1°

SYSTEM CONSIDERATIONS

MISSIONS CONTRIBUTED TO: ALL
RELATED SPACECRAFT:
  LANDSAT
  EARTHWATCH
  SAT CLOUD
  RADAR HOLOGRAPHER
TIME PROJECTION: 1987 - 1990
MEASURE OF RISK: LOW

ELEMENTS

OPTIONS

- EARTH TO LEO
  - SHUTTLE
  - SUPER-SHUTTLE
  - HLLV

- LEO TO HIGH LEO (1000 KM)
  - SPACE TAXI
  - SELF PROPELLED
    - CHEMICAL
    - ELECTRICAL

- LEO TO GEO
  - SSUS
  - IUS
  - "TUG"
  - AEROTUG
  - SEPS

OPINIONS

SHUTTLE 'TIL 1992
$500 - 1000/KG

SUPER SHUTTLE
$50 - 100/KG
AMORTIZATION DOMINATES

CHEMICAL SELF-PROPELLED

EARLY SOLID
~$3000-8000/KG

FROM LATE 80's ON -- SEPS
$1000 - 2000/KG (EARLY)
PLACE FAMILY ORBITS

- SPACE SHUTTLE SORTIE
- LANDSAT CLASS – SUN SYNCHRONOUS
- EARTH WATCH
- 24 HOUR ORBITS
## Earthwatch Viewing Conditions

### Visibility — Minutes

<table>
<thead>
<tr>
<th>Latitude</th>
<th>Elevation</th>
<th>Orbit No. 1</th>
<th>Orbit No. 2</th>
<th>Orbit No. 4</th>
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<tr>
<td>~0</td>
<td>10</td>
<td>96</td>
<td>130</td>
<td>130</td>
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<tr>
<td></td>
<td>20</td>
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<td>104</td>
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<td>60</td>
</tr>
<tr>
<td>20</td>
<td>10</td>
<td>142</td>
<td>120</td>
<td>120</td>
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<td>20</td>
<td>106</td>
<td>96</td>
<td>96</td>
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<td>0</td>
<td>42</td>
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<td>30</td>
<td>10</td>
<td>143</td>
<td>115</td>
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<td></td>
<td>20</td>
<td>114</td>
<td>90</td>
<td>90</td>
</tr>
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<td></td>
<td>30</td>
<td>87</td>
<td>62</td>
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<tr>
<td></td>
<td>40</td>
<td>59</td>
<td>32</td>
<td>32</td>
</tr>
</tbody>
</table>

### Case
- **Period:** 6 Hours
- **Satellites:** 20
- **Repeat GRD Tracks:** ONE

### Diagram
- Minimum Elevation vs Latitude

---

**Note:** The table and diagram represent the viewing conditions for different latitudes and elevations in relation to various orbits.
VARIATIONS ON THE 24-HOUR ORBIT
EXPLORATORY PLATFORM CONCEPTS

- LARGE STRUCTURES
  - LARGE STRUCTURE DEVELOPMENT (E.G., BEAM BUILDERS)
  - UV POLYMERIZED STRUCTURES

- MULTIPLE SATELLITES
  - SATELLITE SWARM

- LOW COST DEVELOPMENTS
  - MICROCIRCUITS
  - SOLAR CELLS
  - "IMPOSSIBLE ORBITS"

- ELECTRIC PROPULSION
  - LOW COST HIGH ORBITS
  - SEPS "SORTIE" MISSIONS
ELEMENTS

OPTIONS

• POWER SOURCE
  — SOLAR ARRAY
    • ORIENTED OR FIXED
    • CENTRAL OR DISPERSED
  — SOLAR DYNAMIC
  — ISOTOPES

• POWER STORAGE
  — ADVANCED BATTERIES
  — FUEL CELLS
  — FLY WHEELS
  — OTHER

• DISTRIBUTION
  — AC VS DC
  — 28V OR HIGHER

OPINIONS

ORIENTED — CONCENTRATED
PROBABLY GaAs
— RADIATION RESISTANT

CLOSE
PROBABLY BATTERIES
200-300 WHR/KG
50% + DOD

28V DC
<table>
<thead>
<tr>
<th>ELEMENTS</th>
<th>OPTIONS</th>
<th>OPINIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TORQUER</td>
<td>REACTION WHEELS</td>
<td>REACTION WHEELS IN LEO</td>
</tr>
<tr>
<td>SUN</td>
<td>JETS (ION/PLASMA)</td>
<td>HIGH ORBIT?</td>
</tr>
<tr>
<td>ATTITUDE SENSORS</td>
<td>SUN</td>
<td>ADVANCED INERTIAL</td>
</tr>
<tr>
<td></td>
<td>HORIZON</td>
<td>STAR</td>
</tr>
<tr>
<td></td>
<td>STAR</td>
<td>MONOPULSE</td>
</tr>
<tr>
<td></td>
<td>INERTIAL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MONOPULSE</td>
<td></td>
</tr>
<tr>
<td>EPHEMERIS</td>
<td>GPS</td>
<td>TRILATERATION PLUS</td>
</tr>
<tr>
<td></td>
<td>RADIO TRILATERATION</td>
<td>ON-BOARD MODELING</td>
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<tr>
<td></td>
<td>LASER TRACKING</td>
<td></td>
</tr>
<tr>
<td>PROCESSING</td>
<td>SHARED CENTRAL</td>
<td>DEDICATED LSI</td>
</tr>
<tr>
<td></td>
<td>DEDICATED</td>
<td>(EACH SENSOR/TORQUER CLUSTER)</td>
</tr>
<tr>
<td></td>
<td>DISPERSED</td>
<td></td>
</tr>
</tbody>
</table>
EXPLORATORY SENSING CONCEPTS

- TEXTURE DISCRIMINATION
  - WIDE BAND SWEEP RADAR
    - PLANT WIND-RESPONSE SCATTEROMETER
  - OPTICAL TEXTURE

- GEOSYNCHRONOUS SAR

- LASER ATMOSPHERE CALIBRATOR

- MICROWAVE HOLOGRAPHY

- LONG BASELINE INTERFEROMETRY
  - MULTIPLE SATELLITES
  - MULTITUDE OF SATELLITES

- GRAVITY/MAGNETIC FIELD SENSING
  - TETHER SATELLITE
  - FARADAY ROTATION MAGNETOMETER
**THE TDRS SYSTEM**

**TDRS I — 80-81 LAUNCH**

- 2 SPACECRAFT — 1 GROUND STATION
- S-BAND (S/C TO GROUND) — 12 MBPS MAX. (GROUND TO S/C) - 300 KBPS
- K-BAND (S/C TO GROUND) - 300 MBPS MAX., 50 MBPS TYPICAL
  (GROUND TO S/C) - 25 MBPS

**TDRS II — POST '90 LAUNCH**

- ON-BOARD STORAGE AND BANDWIDTH REDUCTION PROCESSING
  - CALL-UP AND RETRIEVAL OF SAMPLED DATA
  - 107 MEGABIT MEMORY, (5-50 BIT COMPRESSION RATIOS)
- GROUND DATA STORAGE AND PROCESSING AVAILABLE
- SPACECRAFT TO GROUND LINK
  - S-BAND - 20 MBPS
  - K-BAND - 300 MBPS
  - MMW - 1 GBPS
- SPACECRAFT TO SPACECRAFT LINK
  - MMW - 500 MBPS
  - LASER - 3 GBPS
- GROUND TO TDRS TO USER SPACECRAFT
  - S-BAND - 12 MBPS
  - K-BAND - 100 MBPS
  - MMW - 500 MBPS
PROJECTED MILLIMETER WAVE (MMW) DATA LINKS

- FREQUENCY — 20-40 GHz
- PROJECTED PARAMETERS — 10 WATTS (TWT), 30% EFFICIENT, 1 KG WEIGHT
  UNCOOLED PARAMP (SPACE) -80°C — COOLED (17°C)
  PARAMP (GROUND) -15°C
- PROJECTED MMW LINK DATA RATES — 1 GIGABIT/SEC FROM SPACECRAFT
  500 MEGABITS/SEC TO SPACECRAFT

PROJECTED LASER DATA LINKS

- CANDIDATES — NEODYNIUM GLASS (Nd/YAG - 1.064 μm) AND
  CARBON DIOXIDE (CO₂ - 9 TO 11 μm)
- PROJECTED PARAMETERS:
<p>|</p>
<table>
<thead>
<tr>
<th>Nd/YAG</th>
<th>CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8W, 10% EFF.</td>
<td>10 W, 15% EFF.</td>
</tr>
<tr>
<td>40 CM TRANSMIT OPTICS</td>
<td>25 CM TRANSMIT OPTICS</td>
</tr>
<tr>
<td>60 CM RECEIVE OPTICS</td>
<td>25 CM RECEIVE OPTICS</td>
</tr>
<tr>
<td>9 x 10⁷ M RANGE (IN SPACE)</td>
<td>7.4 x 10⁷ M RANGE (IN SPACE)</td>
</tr>
<tr>
<td>0.2 M³ SIZE</td>
<td>0.7 M³ SIZE</td>
</tr>
<tr>
<td>2 KG WEIGHT</td>
<td>75 KG WEIGHT</td>
</tr>
<tr>
<td>SOLID-STATE SYSTEM</td>
<td>SEALED-OFF GAS SYSTEM</td>
</tr>
</tbody>
</table>
- PROJECTED 2-WAY LINK DATA RATES — 3 GIGABITS/SEC
## Examples of Extractive Processing Requirements

<table>
<thead>
<tr>
<th></th>
<th>Crop Production</th>
<th>Watershed Monitoring</th>
<th>Geology</th>
<th>Disaster Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Area in 10^6 m^2</strong></td>
<td>5.9 x 10^6</td>
<td>.188 (U.S.) x 10^6</td>
<td>59 x 10^6</td>
<td>510 x 10^6</td>
</tr>
<tr>
<td><strong>Sampling Strategy</strong></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>10^-6</td>
</tr>
<tr>
<td><strong>Pixels in 10^6 m^2 (30 Meter)</strong></td>
<td>10^3</td>
<td>10^3</td>
<td>10^3</td>
<td>10^3</td>
</tr>
<tr>
<td><strong>No. of Spectral Channels</strong></td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td><strong>No. of Looks</strong></td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Sum + Ancillary Equivalent</strong></td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Bytes</strong></td>
<td>1.2 x 10^{11}</td>
<td>4 x 10^9</td>
<td>1.2 x 10^{12}</td>
<td>10^{13}</td>
</tr>
<tr>
<td><strong>Operations Per Byte</strong></td>
<td>1.8 x 10^3</td>
<td>3.8 x 10^3</td>
<td>3.7 x 10^3</td>
<td>1.1 x 10^3</td>
</tr>
<tr>
<td><strong>Total Operations</strong></td>
<td>2.2 x 10^{14}</td>
<td>3.7 x 10^{12}</td>
<td>8.1 x 10^{15}</td>
<td>1.1 x 10^{10}</td>
</tr>
<tr>
<td><strong>÷ Turnaround Time</strong></td>
<td>1.2 x 10^6 (2 Wk.)</td>
<td>8.6 x 10^4 (1 Day)</td>
<td>3.15 x 10^7 (1 Yr.)</td>
<td>600 (10 Min.)</td>
</tr>
<tr>
<td><strong>MOPS/SEC</strong></td>
<td>180</td>
<td>43</td>
<td>260</td>
<td>18</td>
</tr>
</tbody>
</table>
EXPLORATORY DATA SYSTEM CONCEPTS

• MICROCIRCUITS
  • SILICON
    • SIZE, COST, SPEED — NO END IN SIGHT
  • MULTIFUNCTION CHIPS
    • SENSE, PROCESS (CID IMAGE, HADAMARD TRANSFORM)
    • LOGIC IN MEMORY
  • LITHIUM NIOBATE/SILICON
    • ACOUSTICAL, OPTICAL, ELECTRONIC
  • GaAs
    • IR SENSE/PROCESS
    • FASTER

• LARGE DATA BASE STORAGE

• LARGE DATA BASE MANAGEMENT
  • REAL TIME EXTRACTION; STORE ESSENTIALS ONLY
  • ARTIFICIAL INTELLIGENCE; INTERACTIVE LANGUAGES
  • SOPHISTICATED INDEXING

• OPTICAL PROCESSING
THE DATA PROCESSING EXPLOSION

DATA PROCESSING REQUIREMENTS

DATA PROCESSING CAPABILITIES

PROCESSING SPEED (MIPS)

PROCESSING BITS/DAY

DATA PROCESSING REQUIREMENTS

PROCESSING SPEED (MIPS)

PROCESSING BITS/DAY

10^14

10^13

10^12

10^11

10^10

10^9


10000

1000

100

10

1


LANDSAT-D

LANDSAT-1

NIMBUS-G

SMS

ITOS

ILiac4

MPPC

GE/FFP

GE/VAP

IBM ASP

GE/SPACE (5 X 5 ARRAY)

AP120B

IBM 360/195

PDP 11/70

CDC 6600
ON-BOARD PROCESSING —
THE NEED FOR LESS DATA

- RADIOMETRIC CORRECTION
- GEOMETRIC CORRECTION
  - USE REAL TIME EPHEMERIS/ATTITUDE DATA
  - RESAMPLING USING AN OVERSAMPLED DETECTOR ARRAY
- IMAGE SELECTION
  - CLOUD COVER DETECTION — 3 SPECTRAL BANDS, LOW NUMBER OF SCENE SAMPLES
  - HAZE DETECTION — USE HISTOGRAM COMPARISONS/ACTIVE MEASUREMENTS
- CHANGE DETECTION
  - PIXEL TO PIXEL COMPARISON
  - HISTOGRAM COMPARISON
  - CORRELATION (FFT)
  - THEME CHANGES/CLASSIFICATION
- DATA COMPRESSION
GLOBAL DATA BASE ALTERNATIVES

DISTRIBUTED

CENTRALIZED

INDEPENDENT MISSION FACILITIES

INTEGRATED DATA BASE

INDEPENDENT DATA BASES

FULLY INTEGRATED SYSTEM

ANCILLARY INPUT DATA

REMOTE SENSING DATA

ANCILLARY DATA

MISSION J FACILITY

MISSION J DATA BASE

MISSION K FACILITY

MISSION K DATA BASE

GLOBAL DATA BASE

MISSION J FACILITY

MISSION K FACILITY

MULTI-DISCIPLINE INFORMATION EXTRACTION FACILITY

INFORMATION TO EARTH RESOURCES MANAGERS

ANCILLARY DATA

REMOTE SENSING DATA

ANCILLARY DATA

OUTPUT INFORMATION

OTHER DATA BASES
INTRODUCTION
MISSION OBJECTIVES AND REQUIREMENTS
SYSTEM ELEMENTS
SYSTEM CONCEPTS
TECHNOLOGY REQUIREMENTS AND FORECASTING
PRIORITY ANALYSIS
• GROUND RULES
  - TECHNOLOGIES SUPPORT PROGRAMS
  - ENHANCING TECHNOLOGIES JUST REDUCE IMPLEMENTATION COSTS
  - ENABLING TECHNOLOGIES MUST ALL BE FUNDED FOR THE PROGRAM TO BE COMPLETE
  - COMPLETED PROGRAMS CONTRIBUTE TO GOALS
  - GOALS MAY BE FULLY OR PARTIALLY MET
  - MEETING GOALS PRODUCES BENEFITS

• OBJECTIVE
  - ALLOCATE A GIVEN AMOUNT OF MONEY AMONG THE TECHNOLOGIES TO MAXIMIZE THE BENEFITS PRODUCED

• TWO METHODS
  - BOTTOM UP/GOODNESS MEASURE
  - TOP DOWN
**TOP-DOWN METHOD**

- **ADVANTAGES**
  - Short run time
  - Can be used to simplify or obtain a starting point for the bottom-up method

- **DISADVANTAGES**
  - Doesn't guarantee true global optimum
  - Won't show which other combination of technologies are nearly as good

**VALUE OF PROG = [VALUE OF EACH GOAL IT CONTRIBUTES TO]**

**ASSUME ALL TECHS FUNDED**

**DETERMINE WHICH PROGS ARE ENABLED**

**CAN YOU AFFORD THIS SET OF TECHS**

**VALUE OF TECH = [VALUE OF EACH PROG IT ENABLES] + \sum [ENHANCEMENTS TO COMPLETE PROGS]**

**DISCARD TECH WITH LOWEST VALUE/COST**

**CALCULATE TOTAL BENEFIT FROM COMPLETE PROGS & THEIR ENHANCEMENTS**

**PRINT RESULTS**

**STOP**
**BOTTOM-UP METHOD**

- **ADVANTAGES**
  - Thorough
  - Allows human decision maker to examine all combinations that are nearly as good as the best

- **DISADVANTAGES**
  - Long run-time—If there are many (> 20) techs it is impossible to examine every contribution

---

**Diagram**

1. **PICK A NEW SET OF TECHNOLOGIES**
2. **DOES IT MEET BUDGET CONSTRAINTS?**
3. **DETERMINE WHICH PROGRAMS ARE ENABLED**
4. **\( G_0 = \sum \text{ ENHANCEMENTS TO ENABLED PROGRAMS} \)**
5. **PRINT SCORE, G'S, + LIST OF FUNDED TECHS**
6. **\( G_i = \sum \text{ CONTRIBUTIONS OF COMPLETE PROGS TO GOAL } i \)**
7. **SCORE = \( \sum \alpha_i G_i \)**

---

**Flowchart**

- Start with \( G_0 \)
- **Y** if meets budget constraints, proceed to determine which programs are enabled
- **N** if does not meet budget constraints, return to pick a new set of technologies
- **Y** if programs are enabled, calculate score and print
- **N** if programs are not enabled, calculate contributions and return to pick a new set of technologies
• MISSION ANALYSIS ACTIVITY, EXPLORATORY TECHNOLOGY FORECASTING, PRIORITY STRUCTURING METHODOLOGY ALL HAVE BEEN COMPLETED

• FUTURE SYSTEM CONCEPTS WITH RICH TECHNOLOGICAL CONTENT HAVE BEEN ESTABLISHED

• CHALLENGE TO THE PLACE TEAM IS TO REALIZE THE FULL “TECHNOLOGY REQUIREMENT POTENTIAL” OF THESE SYSTEM CONCEPTS
  – ACCURATE TECHNOLOGY REQUIREMENTS
  – WELL-BASED NORMATIVE TECHNOLOGY FORECASTING
  – INSIGHTFUL PRIORITY STRUCTURING AND DECISION SUPPORT