TOPSAT
GLOBAL SPACE TOPOGRAPHIC MISSION

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Third Spaceborne Imaging Radar Symposium
Figure 1. Percentages of total world area covered in each scale category, 1960-1974-1980-1987

Map coverage (%)
HYDROLOGY
1 Global water balance
1.2 Lumped catchment rta.
1.3 Funct. rel. model
1.4 Snow accumulation
1.5 Fin. Elem. / diff. mod.
1.6 Westland Circulation

ECOLOGY
II.1 Life Zones
II.2 Hillslope position
II.3 Wetland dynamics

GEOMORPHOLOGY
III.1 Tectonic provences
III.2 Mountain ranges
III.3 Large valley Systems
III.4 Hillslopes streams
III.5 Dunes
III.6 Coastal Changes
III.7 Large landslides and landslides fields in seismically active areas
III.8 Worldwide landslide mapping
III.9 Study of specific landslides

GLACIOLOGY
IV.1 Glacial Moraines
IV.2 Alpine glaciers
IV.3 Ice sheets

GEOLOGY/GEOPHYSICS
V.1 Gravity/Magnetics
V.2 Plate boundaries
V.3 Marine geology
V.4 Structural geology
V.5 Fault Zone Tectonics
V.6 Flow and ash volumes
V.7 Volcanic swelling
V.8 Volcano morphology
V.9 Global long term monitoring in regional tectonic movements
V.10 Subsiding area

DISASTER MANAGEMENT
VI.1 Earthquakes
VI.2 Volcanic Eruptions
VI.3 Avalanches
VI.4 Landslides
VI.5 Floods
VI.6 Wildfire

CARTOGRAPHY
VII.1 1:1,000,000
VII.2 1:250,000
VII.3 1:500,000
VII.4 1:1,000,000
CONTINENTAL TOPOGRAPHY
POLAR REGION APPLICATIONS

WHY STUDY THE POLAR REGIONS?

• POLAR ICE SHEETS HOLD 80-90% OF WORLD's FRESH WATER
• CHANGES IN ICE SHEET VOLUME COULD HAVE MAJOR EFFECTS ON GLOBAL SEA LEVEL AND CLIMATE
• ICE SHEET STABILITY IS NOT KNOWN
• ATMOSPHERIC CO₂ IS INCREASING; GREENHOUSE EFFECT?

WHY IS ELEVATION DATA IMPORTANT IN THE POLAR REGIONS?

1) BASIC LANDFORM INVENTORY

• UNDULATIONS
• RIFTS
• FLOW LINES

} GIVE INFORMATION ON DETAILED FLOW DYNAMICS

2) MASS BALANCE AND DYNAMICS

• ICE FLOW IS RELATED TO SURFACE HEIGHT AND THICKNESS
• REPEAT, HIGH RESOLUTION ELEVATION DATA WOULD ALLOW MONITORING OF ICE TRANSPORT AND ABLATION
CONTINENTAL TOPOGRAPHY
TERRESTRIAL ECOSYSTEM
APPLICATIONS

• ABSOLUTE ELEVATION, LOCAL SLOPE AND SLOPE ASPECT (e.g., N OR S-FACING) EXERT FUNDAMENTAL INFLUENCE ON THE TERRESTRIAL ECOSYSTEM

EXAMPLES INCLUDE:

1) TEMPERATURE, INFLUENCED BY
   a) ABSOLUTE ELEVATION
   b) SLOPE ASPECT

2) MOISTURE AVAILABILITY, INFLUENCED BY
   a) OROGRAPHIC EFFECTS
   b) REGIONAL DRAINAGE NETWORKS
   c) LOCAL RUNOFF CONDITIONS
      i) LOCAL SLOPE
      ii) SLOPE ASPECT (AFFECTS EVAPO-TRANSPIRATION)
   d) SOIL TYPE, AFFECTED BY
      i) ABSOLUTE ELEVATION
      ii) LOCAL SLOPE
      iii) SLOPE ASPECT

• MOST OF THESE APPLICATIONS REQUIRE

1) HIGH SPATIAL RESOLUTION TOPOGRAPHIC DATA, $\approx 30$ m (TO MATCH RESOLUTION OF IMAGING SENSORS SUCH AS LANDSAT TM)

2) GOOD VERTICAL ACCURACY (5 m OR BETTER) FOR ACCURATE SLOPE CALIBRATION

• EXISTING DATA ARE INADEQUATE; BEST QUALITY DEM DATA MAY HAVE 30 m HORIZONTAL RESOLUTION, BUT VERTICAL ACCURACY 10-50 m DEPENDING ON RELIEF
Table 1 - List of requirements for each of the applications

<table>
<thead>
<tr>
<th>Application</th>
<th>Planimetric Resolution min-max</th>
<th>Planimetric Error A/P min max</th>
<th>Altimetric Error A/P min-max</th>
<th>Extent G/R/L</th>
<th>Site E/A/SS</th>
<th>Repetitivy</th>
<th>Vegetation V/G</th>
<th>Sensor I(m)/N</th>
<th>Mission Lifetime</th>
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<tbody>
<tr>
<td><strong>HYDROLOGY</strong></td>
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<td>Global water balance</td>
<td>1000-100</td>
<td>500-100</td>
<td>10-5</td>
<td>G</td>
<td>E</td>
<td>0.5</td>
<td>G</td>
<td>I(2)</td>
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<td>Lumped catchment rtg.</td>
<td>500-50</td>
<td>5-1A</td>
<td>R</td>
<td>A</td>
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<td></td>
<td>V</td>
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<td>1-0.5P</td>
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<td>A</td>
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<td>V</td>
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<td>80-10</td>
<td>50-20</td>
<td>1A-02</td>
<td>R/L</td>
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<td>Fin. elem./diff. mod.</td>
<td>20-8</td>
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<td>Westland circulation</td>
<td>700-100</td>
<td>0.2-0.1A</td>
<td>R</td>
<td>A/SS</td>
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<td><strong>ECOLOGY</strong></td>
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<td>V</td>
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<td>Altimetric error min</td>
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<td>Extent G/R/L</td>
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<td>95</td>
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<td>10</td>
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GLOBAL TOPOGRAPHY MISSION

SCIENCE REQUIREMENTS

Obtain global, contiguous Earth center-of-mass referenced surface elevation measurements with horizontal resolution of 30 m, horizontal accuracy of 10 m, and vertical accuracy of 1 - 3 m over ≥ 95% of the Earth's land surfaces and ice sheets.

Obtain regional, contiguous Earth center-of-mass referenced surface elevation, roughness, and vegetation height measurements with horizontal resolution of 30 m, horizontal accuracy of 10 m, and vertical accuracy of 20 cm - 1 m over selected areas of the Earth's land surfaces and ice sheets.

Obtain complete global coverage in less than 6 months and continue measurement capability for at least 12 months in order to monitor seasonal and shorter period changes of ice, vegetation, wetlands, and time-varying landforms.
Stereo electro-optical sensors

- Along-track stereoscopic observation (e.g. Large Format Camera, Stereo MOMS)
  - allows simultaneous acquisition of a stereoscopic pair
  - requires a complex attitude control system to ensure automatic correlation along epipolar planes

- Cross-track stereoscopic observation (e.g. HRV SPOT)
  - stereoscopic pair obtained from two different orbits under different illumination conditions
# SPACE-BASED STEREOSCOPIC MISSIONS

<table>
<thead>
<tr>
<th>INSTRUMENT/MISSION</th>
<th>AGENCY/YEAR</th>
<th>RESOLUTION OR GROUND PIXEL SIZE (m)</th>
<th>BASE/HEIGHT</th>
<th>RMS-ACCURACY (m) HEIGHT†</th>
<th>PLANIM.</th>
<th>TOTAL GROUND COVER† 10^6 km^2</th>
<th>SWATH WIDTH km</th>
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<td>15</td>
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<td>10</td>
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<td>1986</td>
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<td>~30</td>
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<td>1991/92</td>
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<td>ADVANCED LANDSAT (LANDSAT-7)</td>
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* SOURCE: NASA TOPOGRAPHIC SCIENCE WORKING GROUP REPORT; M. SCHROEDER, DFVLR, 1987
† NOTE THAT VERTICAL ACCURACY DOES NOT MEET MAJORITY OF SCIENCE REQUIREMENTS
‡ PROBLEMS ASSOCIATED WITH CLOUD COVER DATA, REDUCTION COSTS, AND COSTS DUE TO NEED FOR EXTENSIVE GROUND CONTROL PRECLUDE FULL GLOBAL COVERAGE (~2 x 10^6 km^2 LAND PLUS ICE SURFACE AREA) WITH OPTICAL STEREO
GLOBAL TOPOGRAPHY MISSION

OPTICAL STEREO APPROACH

ADVANTAGES

- EXISTING TOPOGRAPHIC DATA BASED ON OPTICAL STEREO (MAINLY AIRCRAFT); STRONG TECHNICAL HERITAGE
- SPACE-BASED STEREO (e.g., SPOT) IS FEASIBLE NOW FOR SELECTED AREAS; NO ADDITIONAL SPACE SEGMENT COSTS
- SPATIAL RESOLUTION 10-30 m

DISADVANTAGES

- VERTICAL PRECISION 5-10 m; VERTICAL ACCURACY >10 m, EXACT AMOUNT DEPENDING ON NUMBER OF GCP’s
- GLOBAL COVERAGE UNLIKELY (LIMITED BY CLOUDS, ORBITAL CONSTRAINTS, IMAGING GEOMETRY)
- POLAR COVERAGE RESTRICTED DUE TO NEED FOR TERRAIN MATCHING AND TIE POINTS
- COVERAGE ACQUIRED PIECEMEAL (5-10 years) PRECLUDING CONTIGUOUS, UNIFORM QUALITY DATA SET, AND COMPLICATING CHANGE DETECTION
- COST
  - ACQUISITION COSTS AT CURRENT PRICES > $400 M
  - DATA REDUCTION
  - GROUND CONTROL POINTS

CONCLUSIONS

- "MISSION" COSTS > $500 M
- VERTICAL ACCURACY DOES NOT MEET SCIENCE REQUIREMENTS
- COVERAGE NOT GLOBAL
- DIFFICULT TO ENSURE UNIFORM QUALITY, CONTIGUOUS DATA SET
Comparison of laser and radar altimetry.

<table>
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<th></th>
<th>λ (μm)</th>
<th>D (cm)</th>
<th>θ - λ/D</th>
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<tbody>
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<tr>
<td>RADAR</td>
<td>2</td>
<td>1</td>
<td>2 × 10^{-2}</td>
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RADAR INTERFEROMETRY

THEORY

DEFINING GEOMETRY AND PARAMETERS:

- SURFACE TOPOGRAPHY
- AIRCRAFT ALTITUDE
- BASELINE DISTANCE
- SLANT RANGE
- LOOK ANGLE
- BASELINE ANGLE
- PATH LENGTH DIFFERENCE

RESULTING EQUATIONS FOR MEASURED PHASE $\phi$, WAVELENGTH $\lambda$

\[ \delta = \frac{\phi \lambda}{2\pi} \]  
\[ \sin(\theta - \alpha) = \frac{((\rho + \delta)^2 - \rho^2 - B^2)/2 \rho B}{2 \rho B} \]  
\[ z(x) = h - \rho \cos(\theta) \]
ALONG TRACK INTERFEROMETRY

In the case of along-track interferometry, only the line of site velocity can be measured and therefore the along track velocity component is unknown.
TOPSAT - VISTA

System Approach

- Sun-synchronous orbit, 6 pm local time ascending node, 450 Km altitude
- Frequency: 1.25 GHz
- Cross-track resolution by bandwidth projection
- Along-track resolution by focused SAR
- Spatial resolution 30 m x 30 m
- 50 Km (SR) cross-track swath achieved by side-looking at 25 deg (a0)
- Two 8.7 m (L) x 2.6 m (W) antennas
- Antenna separation (B): 500 to 1000 m
- Antennas bound by flexible tether
- Two satellites needed
- Global land coverage in six months: 95%
- SNR 19.5 dB (at 25 deg surface incidence and for -20 dB a0)
- Antenna elevation beamwidth (θE) (-3 dB): 5.29 deg
- Antenna azimuth beamwidth (θA) (-3 dB): 1.58 deg
- Number of looks: 8 azimuth / 1 range
- Height accuracy: ~3 m
VISTA Advantages

- Meets all science requirements, including vertical and horizontal resolution;
- Uses existing SAR technology with proven history of use;
- Exploits existing investments by NASA and ASI in tether technology;
- Configuration is stabilized by the gravity gradient force;
- A long variable baseline is offered for new experiments.

VISTA Disadvantages

- Tether technology is new
- Antenna attitude uncertainty may be a major source of error
- Tether lifetime may be a problem
- Two platforms are required
- Attitude control of each platform
- Larger antennas are more difficult to stow and deploy
System Approach

- Frequency: 35 GHz
- Cross-track resolution by bandwidth projection
- Along-track resolution by unfocused SAR
  - Spatial resolution: 33 m × 33 m
- 10-km cross-track swath achieved by side-looking at 25°
  - Two 8 m × 0.3 m antennas
  - Antenna separation: 10 m
  - Complete global coverage in 1 year
- Single pulse SNR ≥ 17 dB (at 30° surface incidence and for -10 dB σ°)
- Number of looks = 8
- Height accuracy: ~4 m
DUAL SPACECRAFT CONCEPT

VIEW FROM BEHIND VELOCITY VECTOR

Operating Separation 0.8 to 2 km

30 deg

Altitude 566 km

RADAR SWATH 35 KM
GEOMETRY NEEDED TO OBTAIN NEAR POLAR COVERAGE
65° TO 79° LATITUDE

79 degrees latitude

65 degrees latitude

800 meters

800 meters

2000 meters

5000 meters

2000 meters
## L-band Technology Assessment Summary

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Technology</th>
<th>Performance</th>
<th>Availability/Heritage</th>
<th>Risk</th>
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<tbody>
<tr>
<td>Antennas</td>
<td>Microstrip array</td>
<td>3.5 x 9.0 m</td>
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<td>SEASAT</td>
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TOPSAT TWO S/C / DELTA II
FLIGHT CONFIGURATION
SOLAR ARRAY (1 OF 2)
S/C BUS
SEASAT ANTENNA
LASER ALTIMETER
TWO S/C / DELTA II
LAUNCH CONFIGURATION
## Risk Summary

<table>
<thead>
<tr>
<th>Issue</th>
<th>L-band Dual Spacecraft</th>
<th>K-band Single Spacecraft</th>
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<tbody>
<tr>
<td>Sensor development</td>
<td>Low</td>
<td>Moderate/Hi-amplifier &amp; antenna</td>
</tr>
<tr>
<td>Spacecraft development</td>
<td>Low</td>
<td>Moderate-12m boom cont'l &amp; know</td>
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<tr>
<td>Orbit/Operations</td>
<td>Moderate-navigation</td>
<td>Moderate-Frequent reboost</td>
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<tr>
<td>Science</td>
<td>Degraded performance near poles</td>
<td>Loss of data in severe weather</td>
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<tr>
<td>Mission duration</td>
<td>6 months</td>
<td>2 years</td>
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<tr>
<td>S/C failure scenario</td>
<td>Repeat-pass viable</td>
<td>None</td>
</tr>
</tbody>
</table>
TOPOGRAPHIC MAPPING LASER ALTIMETER

EARTH PROBE SPACECRAFT
POLAR ORBIT 400 km SUN-SYNCHRONOUS 6am/6pm
SUNLIGHT
LASER PULSES 1 µm WAVELENGTH
NADIR TRACK
6 km SWATH WIDTH
SENSOR FOOTPRINT 200 m DIAM

NASA/GSFC
GLOBAL TOPOGRAPHY MISSION

ROLE OF MULTI-BEAM LASER ALTIMETER

* ABSOLUTE MEASUREMENT OF SURFACE ELEVATION
  UNAMBIGUOUS, DIRECT MEASUREMENT BY PULSE TIME-OF-FLIGHT
  SUB-METER VERTICAL CONTROL FOR INSAR AND STEREO-PHOTOGRAMMETRY
  SUB-PIXEL (~ 10 m) HORIZONTAL CONTROL
  REFERENCE TO A SINGLE, EARTH CENTER-OF-MASS COORDINATE SYSTEM
  GLOBAL COVERAGE AT 200 m SPATIAL RESOLUTION OR PARTIAL COVERAGE AT
  HIGH RESOLUTION (30 m)

* GROUND TOPOGRAPHY AND VEGETATION HEIGHT
  LASER PENETRATION OF VEGETATION CANOPY
  RETURN-PULSE WAVEFORM MEASUREMENTS OF GROUND AND CANOPY

* SURFACE SLOPE MEASUREMENT
  SLOPE MEASUREMENT ACCURACY at the 1° LEVEL
  ALONG-TRACK AND ACROSS-TRACK SLOPES
ROLE OF MULTI-BEAM LASER ALTIMETER

(CONTINUED)

* HIGH-ACCURACY ICE SHEET TOPOGRAPHY
  SINGLE PULSE MEASUREMENT ACCURACY: ~ 20 cm
  ICE SHEET MAPPING - HIGH DENSITY OF DATA POINTS, TRACK CROSSINGS

* METER-LEVEL DATA QUALITY IN HIGH-RELIEF TERRAIN
  < 3 m VERTICAL ACCURACY AT 20° SURFACE SLOPE
  DATA ACQUISITION FOR ALL SLOPES (NO SHADOWING OR LAYOVER)

* SUB-PIXEL MEASUREMENT OF SURFACE VERTICAL STRUCTURE (i.e. roughness)
  RETURN-PULSE WAVEFORM SPREADING

* HIGH-ACCURACY CONNECTION OF LAND AND OCEAN TOPOGRAPHY
  ≤ 20 cm SURFACE HEIGHT ERRORS IN COASTAL REGIONS
  < 10 cm WITH MULTI-PULSE AVERAGING