TOPSAT
GLOBAL SPACE TOPOGRAPHIC MISSION

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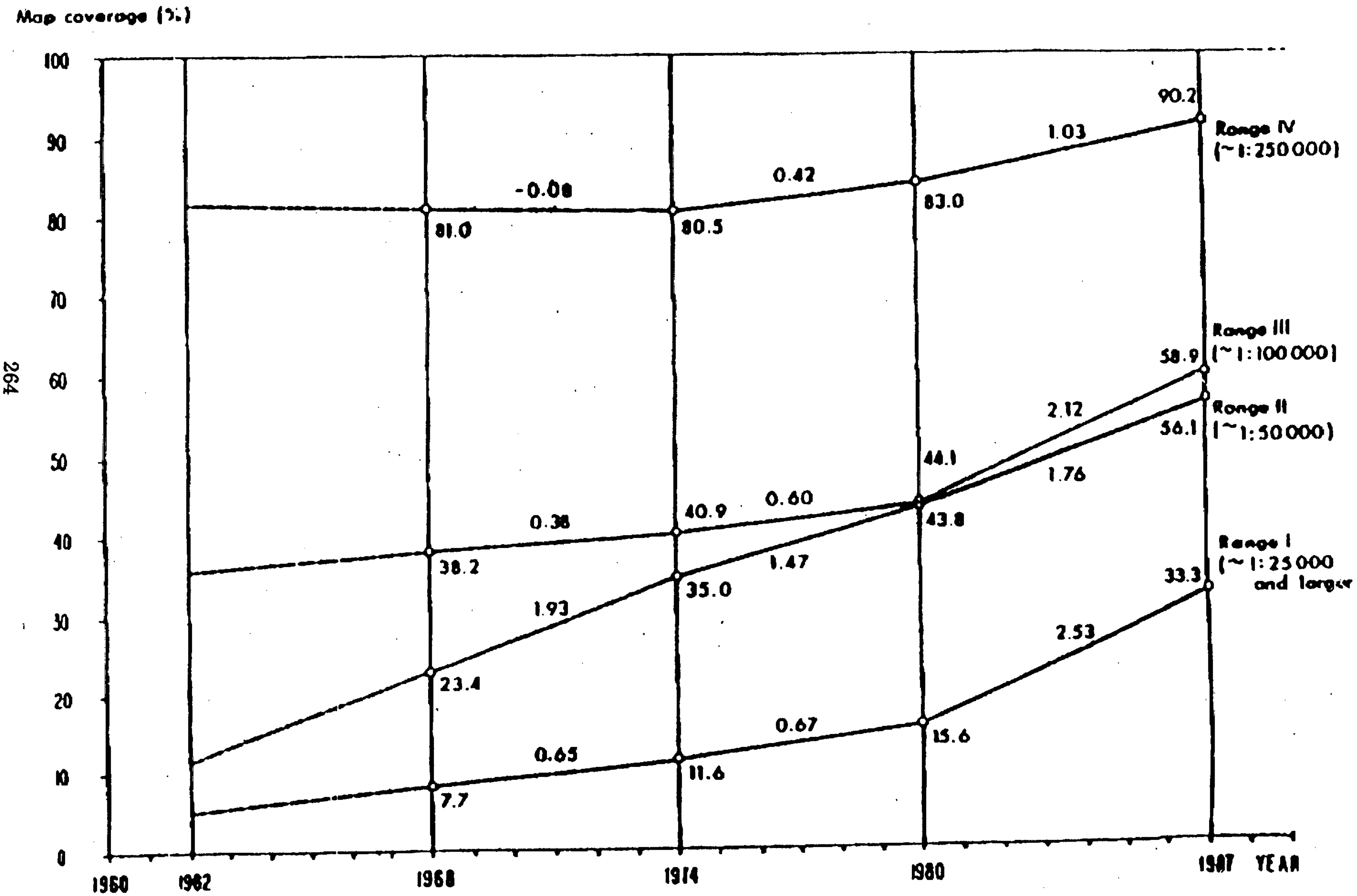
Third Spaceborne Imaging
Radar Symposium

Figure 2. Percentages of total world area covered in each scale category, 1968-1974-1980-1987



I	**HYDROLOGY**
I.1	Global water balance
I.2	Lumped catchment rtg.
I.3	Funct. rel. model
I.4	Snow accumulation
I.5	Fin. elem. / diff. mod.
I.6	Westland Circulation
II	**ECOLOGY**
II.1	Life Zones
II.2	Hillslope position
II.3	Wetland dynamics
III	**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
IV	**GLACIOLOGY**
IV.1	Glacial Moraines
IV.2	Alpine glaciers
IV.3	Ice sheets
V	**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
VI	**DISASTER MANAGEMENT**
VI.1	Earthquakes
VI.2	Volcanic Eruptions
VI.3	Avalanches
VI.4	Landslides
VI.5	Floods
VI.6	Wildfire
VII	**CARTOGRAPHY**
VII.1	1:1.000.000
VII.2	1: 500.000
VII.3	1: 250.000
VII.4	1: [illegible]00.000

JPL

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 CO_2 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, $\cong$ 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

Application	Planimetric Resolution min-max	Planimetric Error A/P min max	Altimetric error A/P min-max	Extent G/R/L	Site E/A/SS	Repetitevity	Vegetation V/G	Sensor I(m)/N	Mission Lifetime
HYDROLOGY									
Global water balance	1000-100	500-100	10-5	G	E	0.5	G	I(2)	>10
Lumped catchment rtg.	500-50		5-1^{A}	R	A	∞	V		
Funct. rel. model	100-50		1-0.5^{P}	R	A	∞	V		
Snow accumulation	80-10	50-20	1^{A}-02	R/L	E	0.3	G	I(2)	>10
Fin. elem./ diff. mod.	20-8		0.6-0.1^{P}	L	SS	∞	G		
Westland circulation	700-100		0.2-0.1^{A}	R	A/SS	∞	G		
ECOLOGY									
Life zones	5000-1000		10-5^{A}	R	A	∞	V	I(>6)	
Hillslope position	60-10		1-0.5	L	E	∞	G		
Wetland dynamics	700-100		0.1-0.05^{A}	R	A	5	G	I(2)	
GEOMORPHOLOGY									
Tectonic provences	10.000-2000		100-40^{A}	G	A	∞	G	I	
Mountain ranges	5000-200		50-8^{A}	G	A	∞	G		
Large valley systems	500-100		10^{A}-1	R	A	∞	G	I	

Application	Planimetreic resolution min	max	Planimetric crorr min A/P	max	Altimetric error min A/P	max	Extent G/R/L	Site Select E/A/SS	Frequency repetitivity period	Vegetation V/G	Class numeric value I/N	Mission lifetime	Note
Cartografy (scale)													
1:1.000.000	57	95	100 300	(A)	30 (A)	60	G	E	10	G/V	8	> 10	
1:500.000	29	48	50 150	(A)	15 (A)	30	G/R	E	10	G/V	8	> 10	
1:250.000	14	25	25 (A)	75	8 (A(	16	R	E/SS	7	G/V	8	≥ 7	
1:100.000	6	10	10 (A)	30	6 (A)	12	R/L	SS	5	G/V	20	> 3	
1:50.000	3	5	5 (A)	15	3 (A)	6	L	SS	5	G/V	20	> 3	
1:25.000	1,5	2,5	2,5 (A)	7,5	1,5 (A)	3	L	SS	5	G/V	20	> 3	

GLOBAL TOPOGRAPHY MISSION

SCIENCE REQUIREMENTS

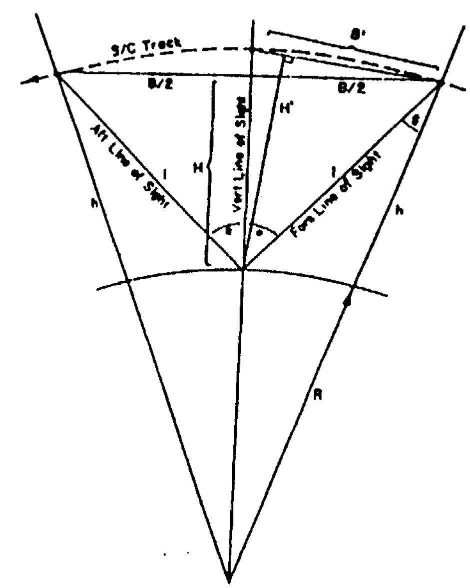
Obtain global, contiguous Earth center-of-mass referenced surface elevation measurements with horizontal resolution of 30 m, horizontal accuracy of 10 m, and vertical accuracy of 1 - 3 m over $\geq$ 95% of the Earth's land surfaces and ice sheets.

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.

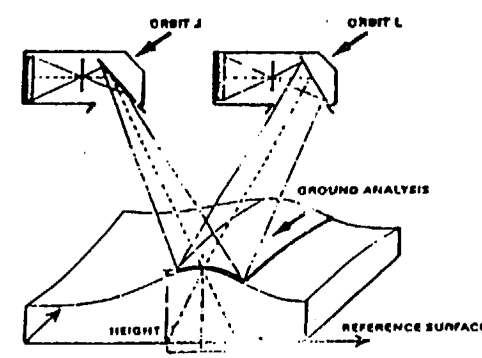
Stereo electro-optical sensors

- 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

LATERAL STEREOSCOPY PRINCIPLE



SPACE-BASED STEREOSCOPIC * MISSIONS

INSTRUMENT/ MISSION	AGENCY/ YEAR	RESOLUTION OR GROUND PIXEL SIZE (m)	BASE/ HEIGHT	RMS-ACCURACY (m) HEIGHT†	RMS-ACCURACY (m) PLANIM.	TOTAL GROUND COVER‡ 10^6 km^2	SWATH WIDTH km
METRIC CAMERA SPACELAB-1/STS-9	ESA/DFVLR 1983	~13	1:3-1.6	15	15	12	190
LARGE FORMAT CAM. STS-41C	NASA 1984	~8	1:1.6-1:0.8	10	10	8	190
HRV SPOT-1	CNES 1986	10	1:2-1:1	10	10	?	60
MEOSS SROSS-II	DFVLR/ISRO 1988	80	1:1	~50	~30	INDIA, SOUTHERN EUROPE	255
HRV SPOT-2	CNES 1988/89	10	1:2-1:1	10	10	NOT DEFINED	60
METRIC CAMERA ATLAS-1	DFVLR/NASA 1991	5	1:3-1:1.6	~10	~10	10	190
STEREO-MOMS SPACELAB-D2	DFVLR/NASA 1991/92	5-10	1:1	~10	~10	0.25	32
SPOT 3	CNES 1991/92	10	1:2-1:1	10	10	NOT DEFINED	60
ADVANCED LANDSAT (LANDSAT-7)	EOSAT 1992	10	TBD	TBD	TBD	NOT DEFINED	41

* 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 ($\simeq 2 \times 10^8$ km^2 LAND PLUS ICE SURFACE AREA) WITH OPTICAL STEREO

GLOBAL TOPOGRAPHY MISSION

OPTICAL STEREO APPROACH

ADVANTAGES

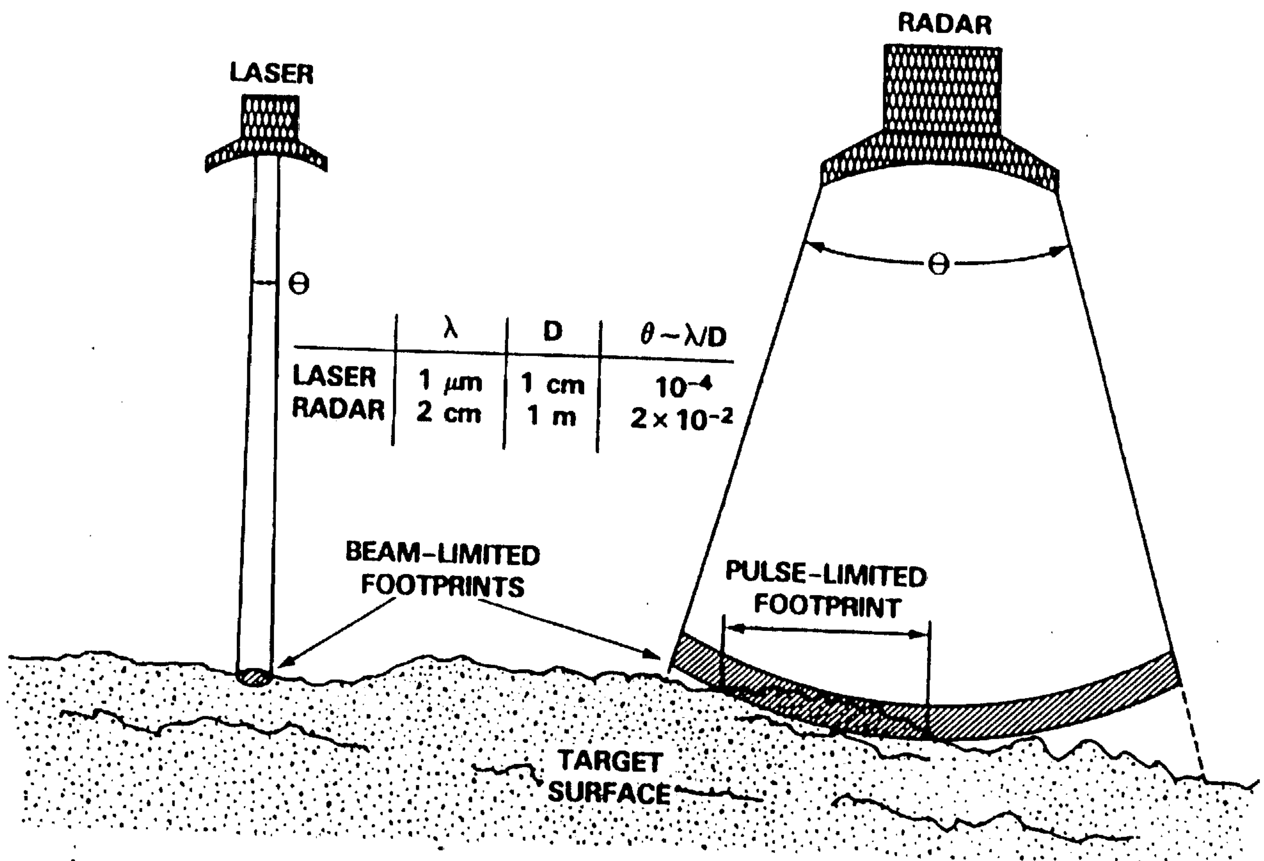
- EXISTING TOPOGRAPHIC DATA BASED ON OPTICAL STEREO (MAINLY AIRCRAFT); STRONG TECHNICAL HERITAGE
- SPACE-BASED STEREO (e.g., SPOT) IS FEASIBLE NOW FOR SELECTED AREAS; NO ADDITIONAL SPACE SEGMENT COSTS
- SPATIAL RESOLUTION 10-30 m

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, CONTIGNUOUS DATA SET



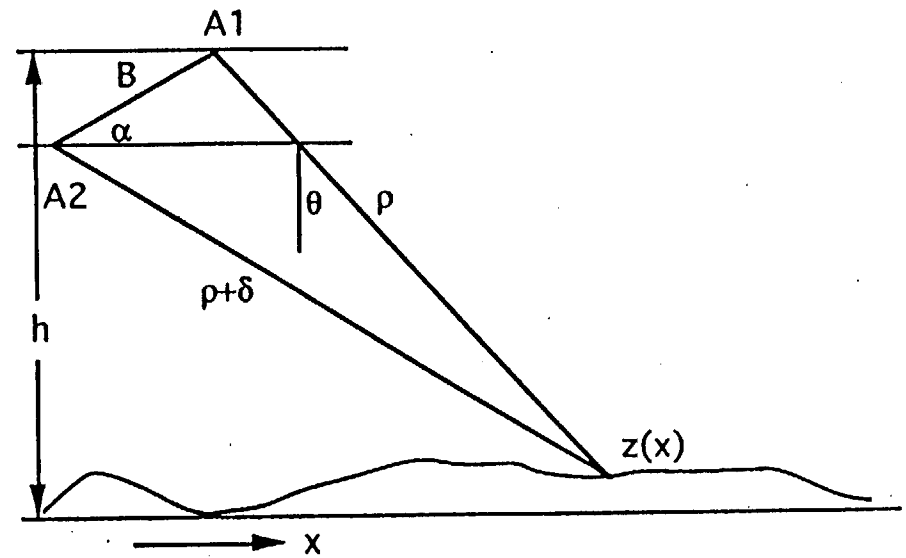
Comparison of laser and radar altimetry.

RADAR INTERFEROMETRY

THEORY

DEFINING GEOMETRY AND PARAMETERS:

SURFACE TOPOGRAPHY	$z(x)$
AIRCRAFT ALTITUDE	h
BASELINE DISTANCE	B
SLANT RANGE	ρ
LOOK ANGLE	θ
BASELINE ANGLE	α
PATH LENGTH DIFFERENCE	δ



RESULTING EQUATIONS FOR MEASURED PHASE ϕ, WAVELENGTH λ

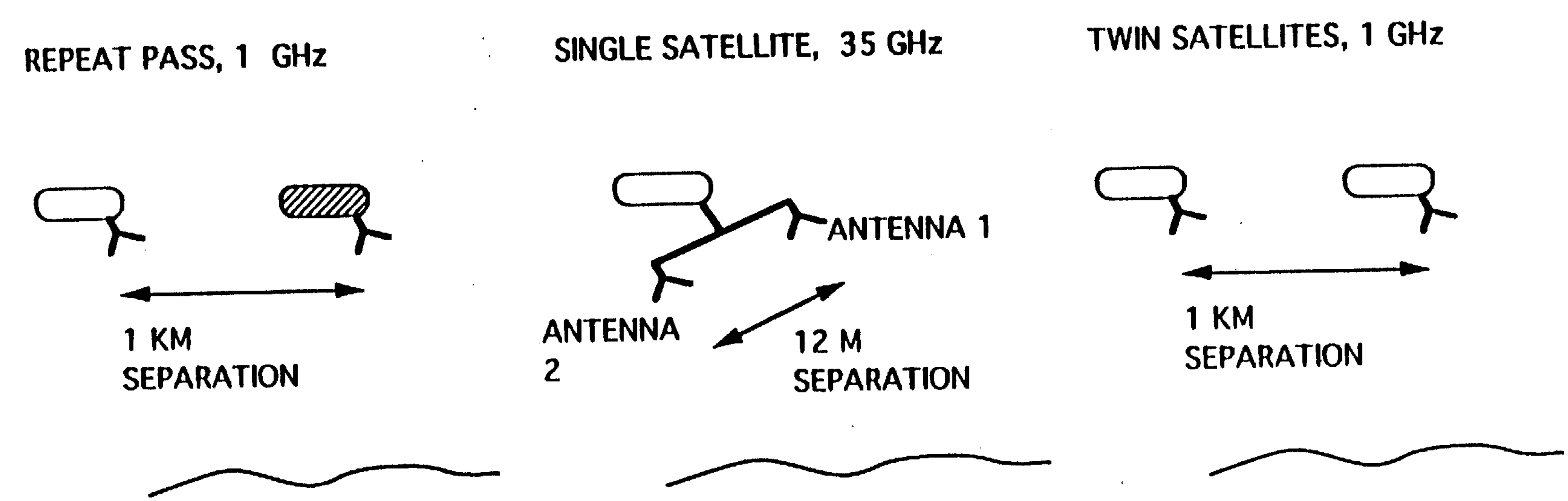
$$\delta = \phi\lambda/2\pi \quad (1)$$

$$\sin(\theta-\alpha) = ((\rho+\delta)**2 - \rho**2 - B**2)/(2*\rho*B) \quad (2)$$

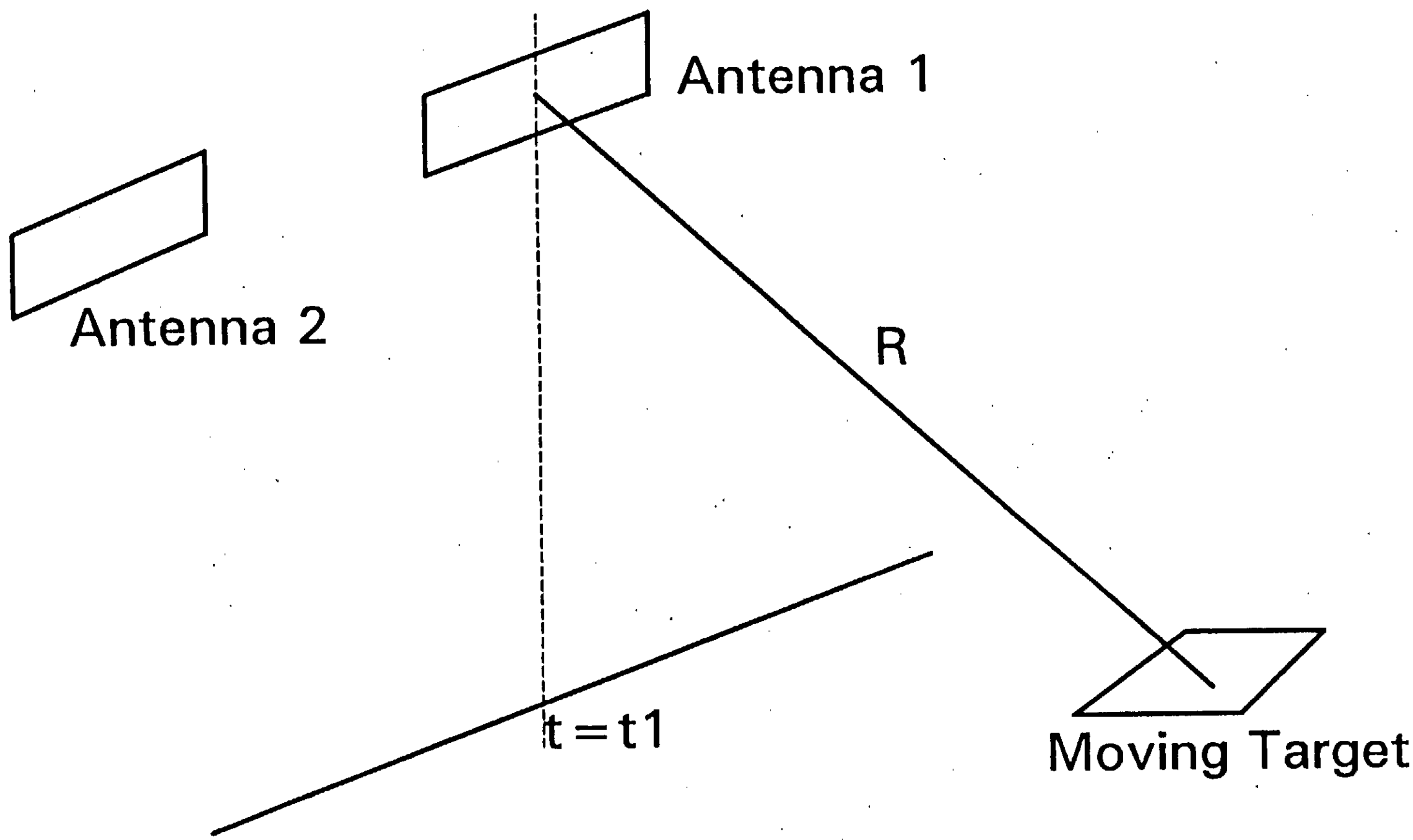
$$z(x) = h - \rho\cos(\theta) \quad (3)$$

TOPSAT SATELLITE IMPLEMENTATIONS

REPEAT PASS / SINGLE / TWIN SATELLITES



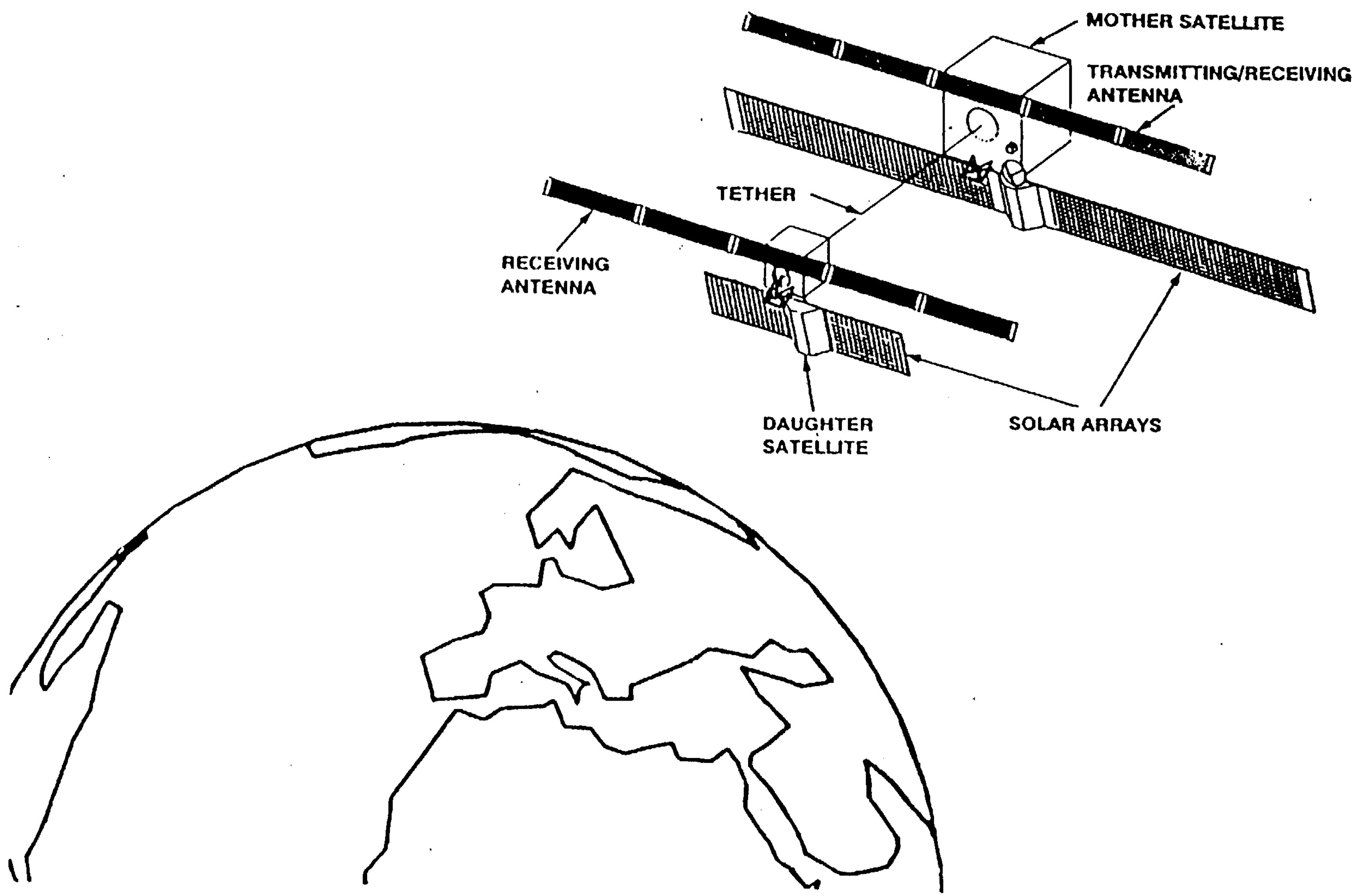
ALONG TRACK INTERFEROMETRY



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.

VISTA

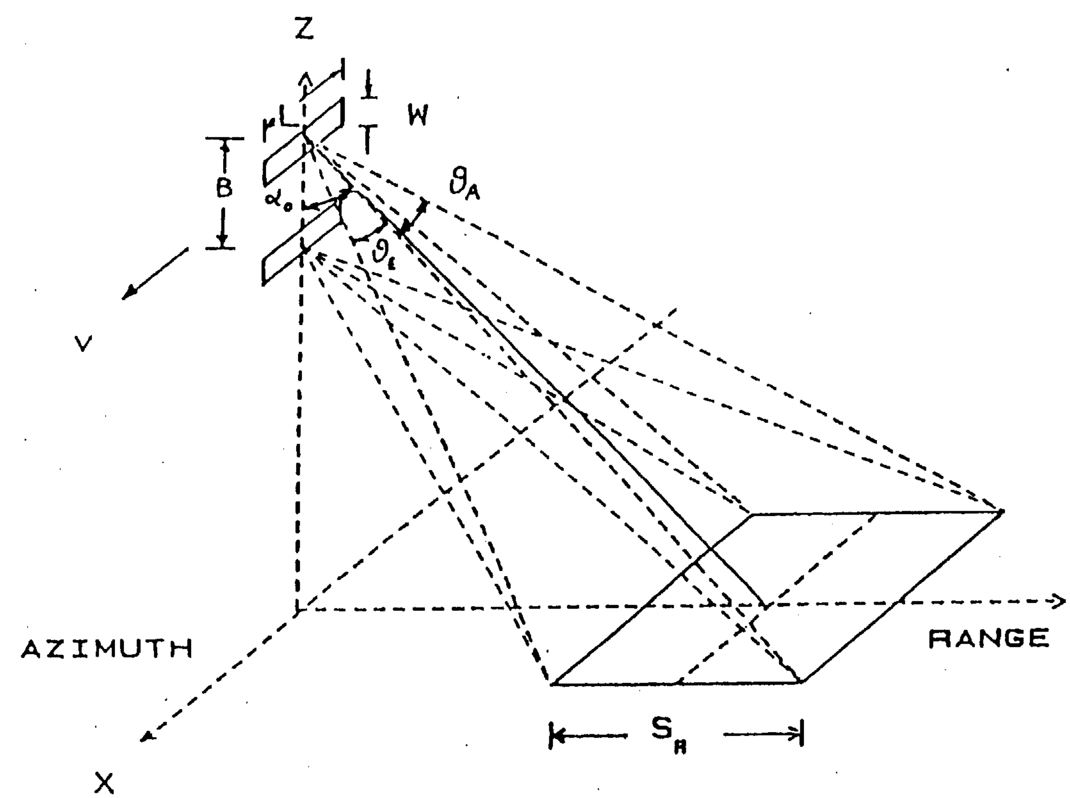
ON-ORBIT CONFIGURATION



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 (S_R) cross-track swath achieved by side-looking at 25 deg (α_0)
- 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%
- SNR19.5 dB (at 25 deg surface incidence and for -20 dB σ_0)
- Antenna elevation beamwidth (θ_E) (-3 dB): 5.29 deg
- Antenna azimuth beamwidth (θ_A) (-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.

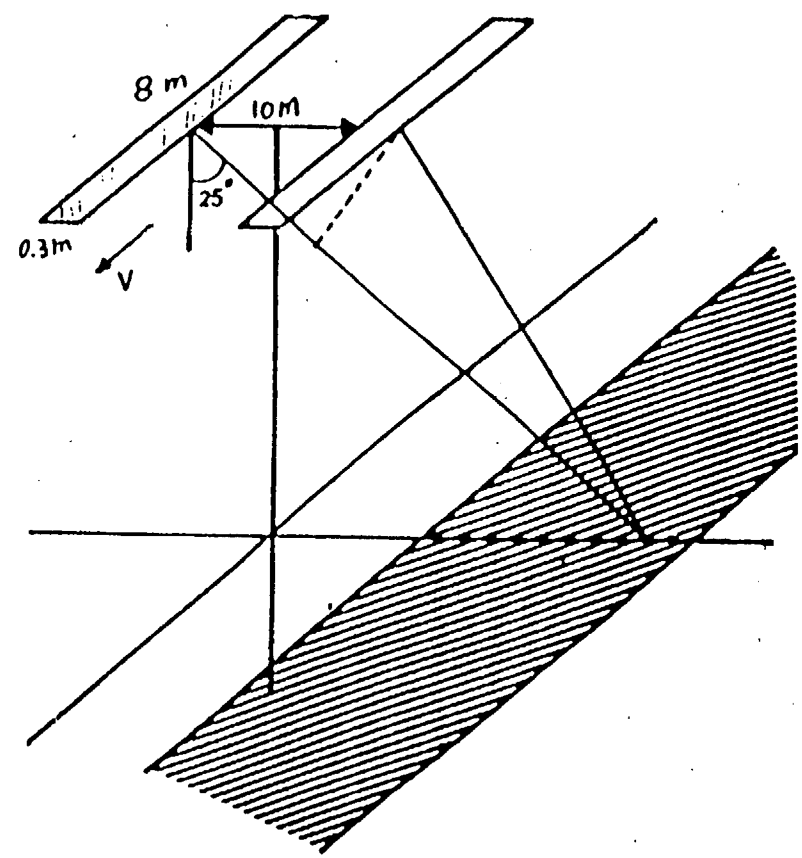
VISTA Disadvantages

- 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

ISARA

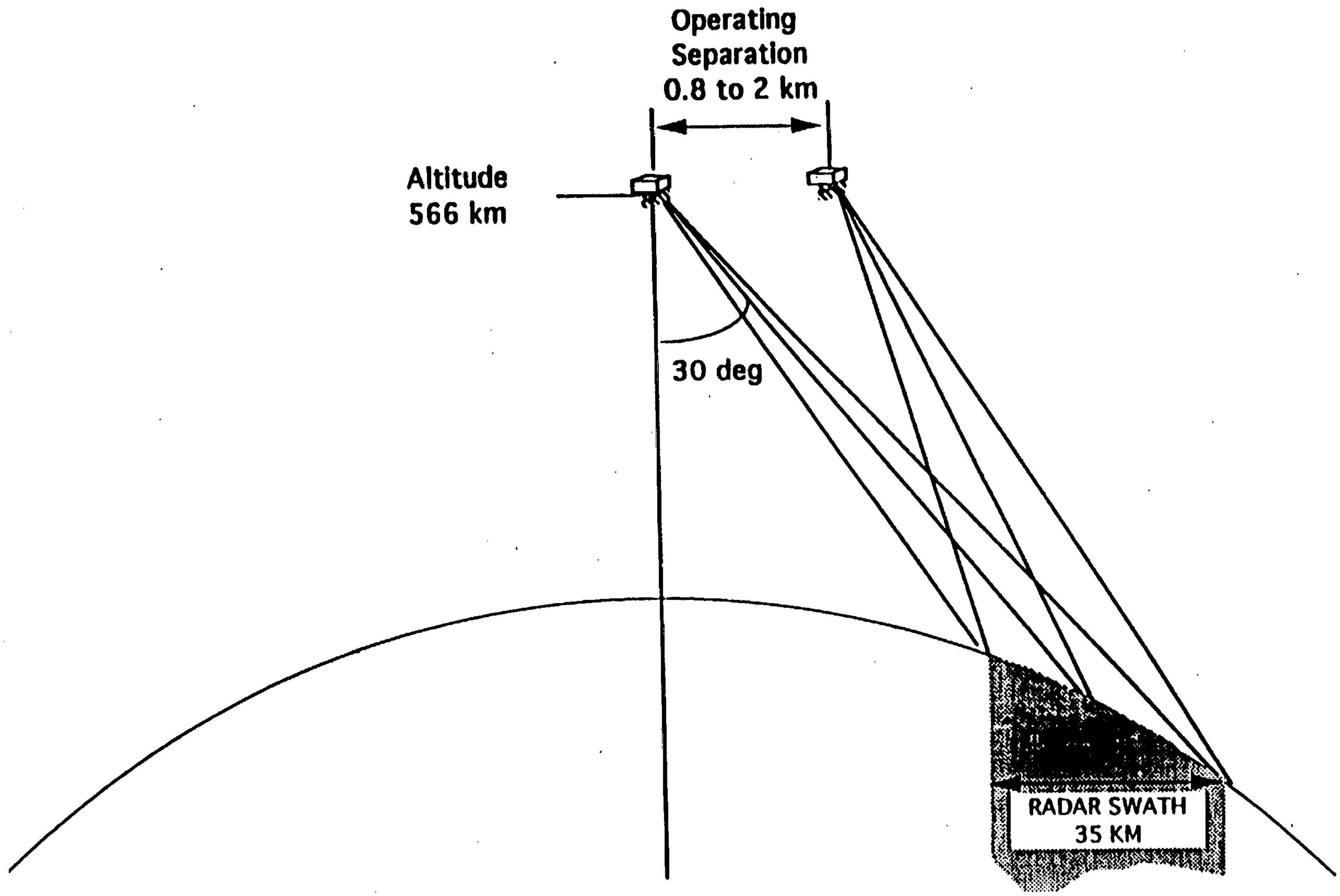
System Approach

- 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

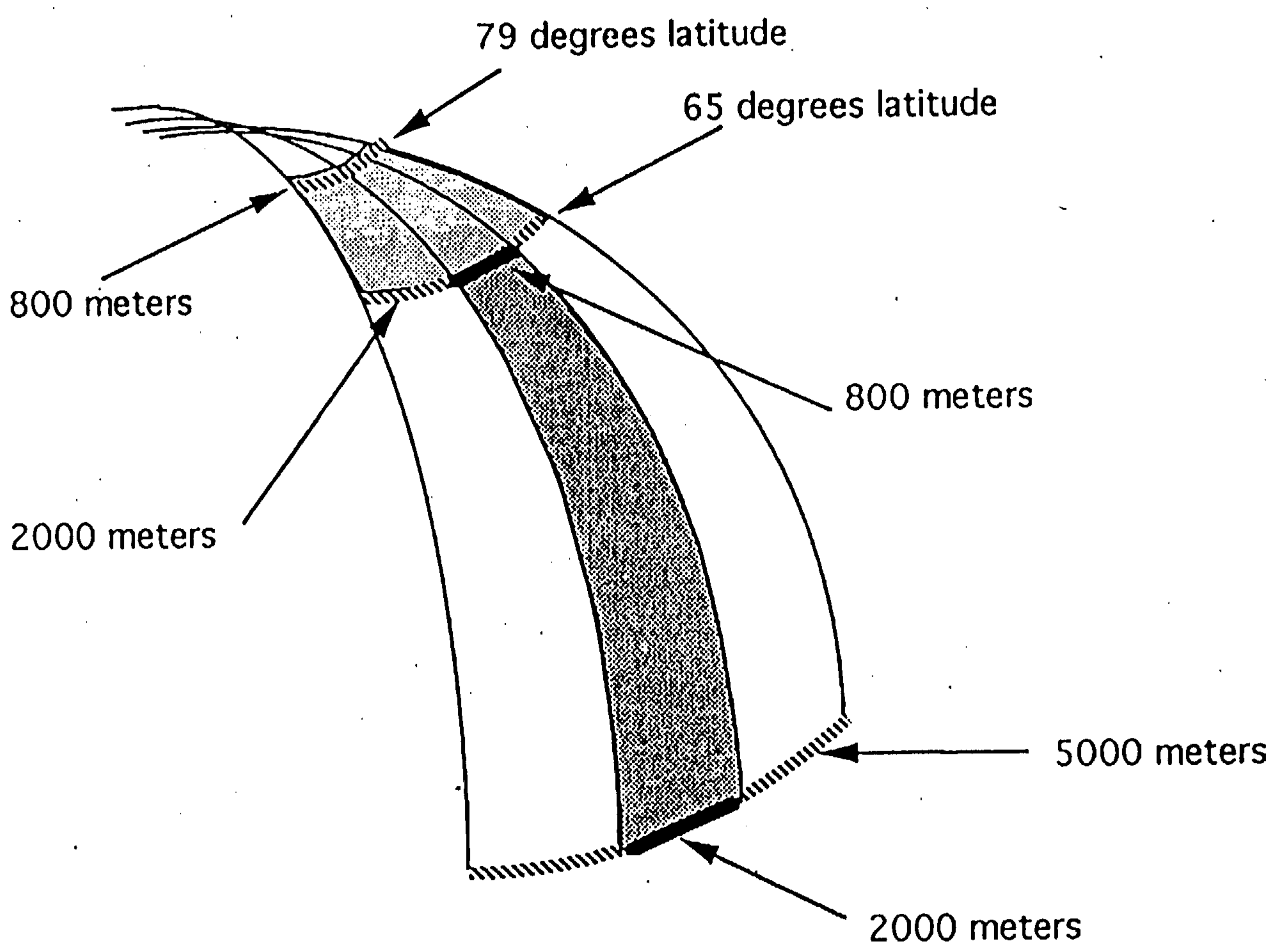


DUAL SPACECRAFT CONCEPT

VIEW FROM BEHIND VELOCITY VECTOR



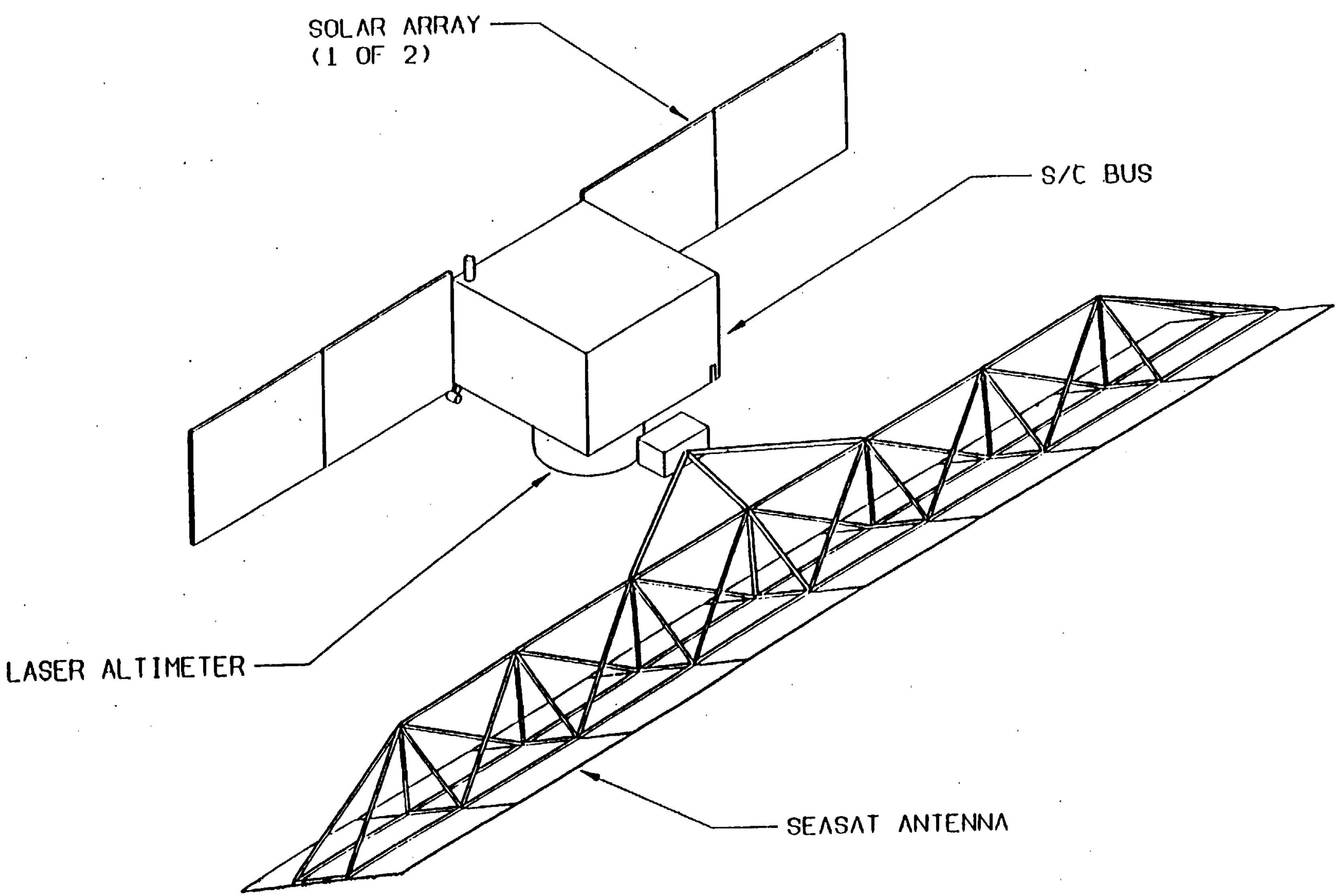
GEOMETRY NEEDED TO OBTAIN NEAR POLAR COVERAGE 65° TO 79° LATITUDE

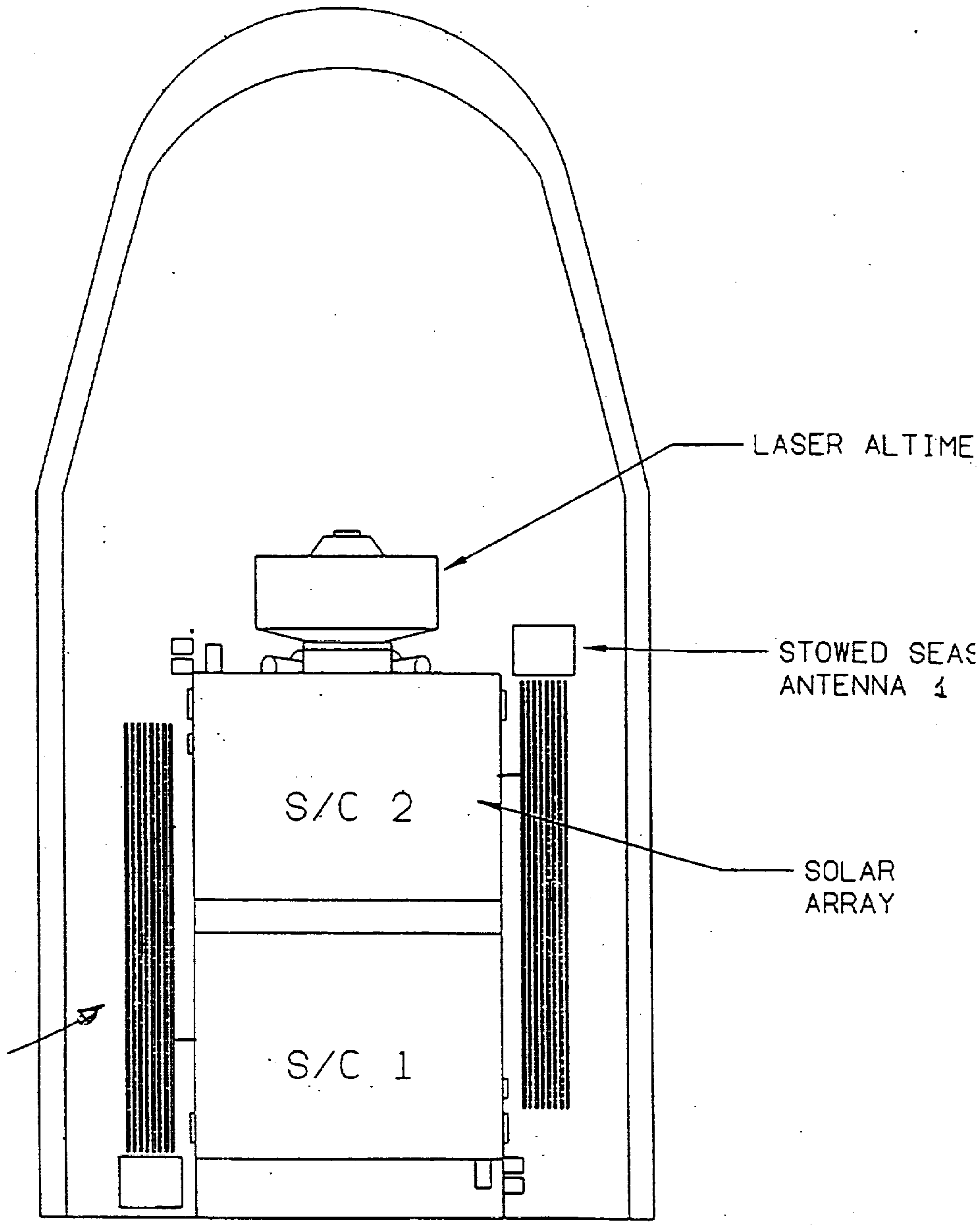


L-band Technology Assessment Summary

Subsystem	Technology	Performance	Availability/Heritage	Risk
Antennas				
	Microstrip array	3.5 x 9.0 m	SEASAT	Low
Transmitter				
	Solid state	8 x 200 w	SEASAT/Magellan	Low
Waveform gen/ ref. frequency generation				
	Digital chirp	20 MHz variable 50 us	SIR-C	Low
Stalo				
	Quartz oscillator	$<10^{-11}$	SEASAT/Voyager	Low
Receiver				
	HEMT/GAs Fet	3-4 dB (<450K)	SEASAT/SIR-C	Low
Range processor				
	SAW		SEASAT	Low
A/D system				
	Offset video	20MHz	SIR-B / SIR-C	Low
Digital data system				
	CMOS FPGA	45MHz clock	SIR-B	Low
Calibration Subsystem				

TOPSAT TWO S/C / DELTA II
FLIGHT CONFIGURATION



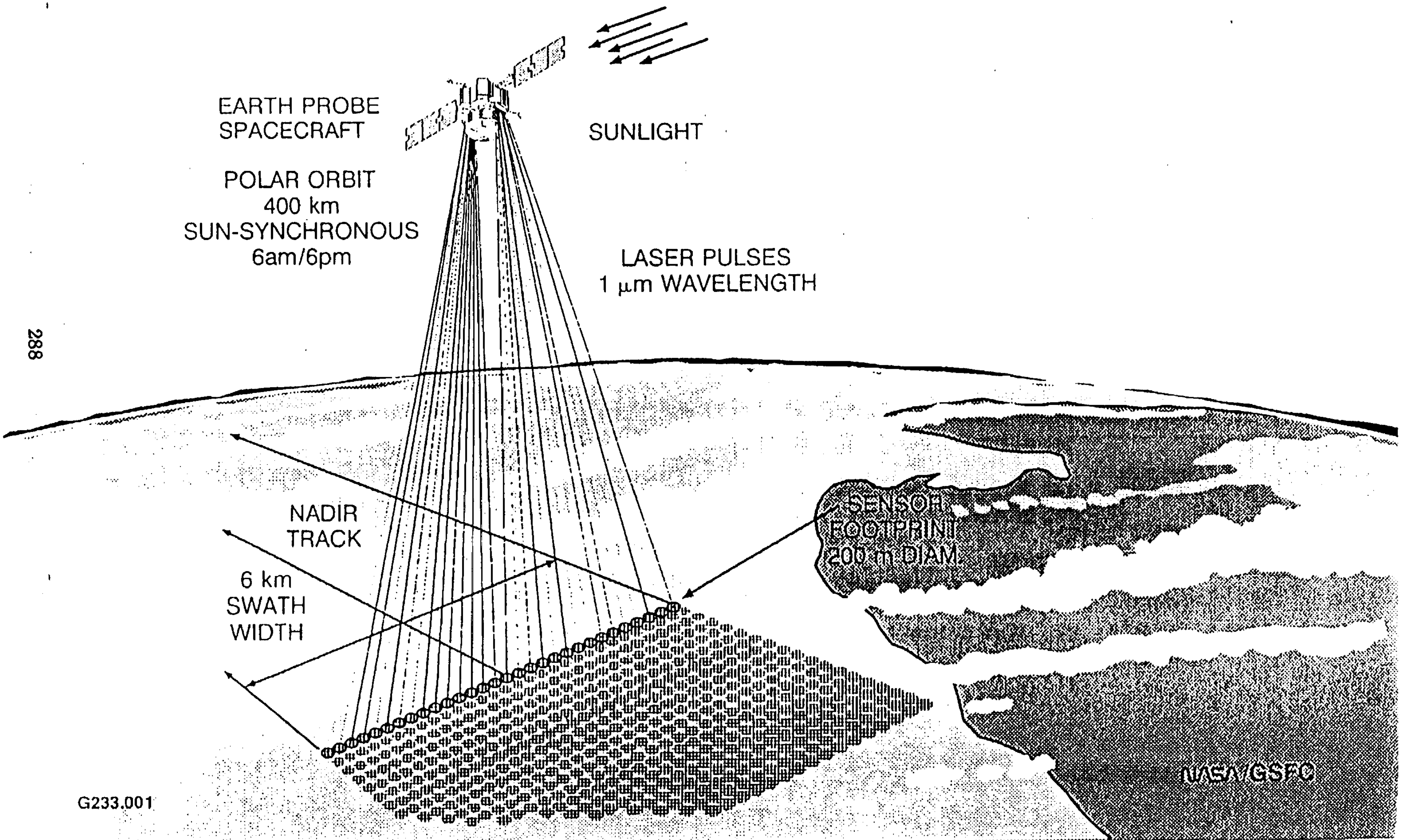


TWO S/C / DELTA II
LAUNCH CONFIGURATION

RISK SUMMARY

Issue	L-band Dual Spacecraft	K-band Single Spacecraft
Sensor development	Low	Moderate/Hi-amplifier &antenna
Spacecraft development	Low	Moderate-12m boom cont'l&know
Orbit/Operations	Moderate-navigation	Moderate-Frequent reboost
Science	Degraded performance near poles	Loss of data in severe weather
Mission duration	6 months	2 years
S/C failure scenario	Repeat-pass viable	None

TOPOGRAPHIC MAPPING LASER ALTIMETER



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