Microwave Remote Sensing of Soil Moisture

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Soil Moisture (SM)

- **Agriculture**
- **Hydrology**
- **Meteorology**

Measurement Techniques

Survey of methods for soil moisture determination, Water Resources Research, Vol. 16, No.6, Page961-879, 1980, Schmugge et al. (1980)

In Situ Methods

- **Gravimetric**
- **Nuclear Techniques**
- **Electromagnetic Techniques**
- **Tensiometric Techniques**
- **Hygrometric Techniques**

Remote Sensing Methods

- **Visible & near IR – Reflected Solar**
- **Thermal IR – Surface Temperature**
- **Passive Microwave – Microwave Emission/Brightness Temperature**
- **Active Microwave – Backscattering coefficient/dielectric properties**

Gravimetric Techniques

- **Oven drying a soil sample at 105^{0}C for about 12 hours.**

$$\%M_{wt} = \frac{W_{wet} - W_{dry}}{W_{dry}} * 100$$

Volumetric Soil Moisture (gm/cm^3)

$$\%M_{wt} * Y_d$$

Y_d Oven Dry Bulk Density

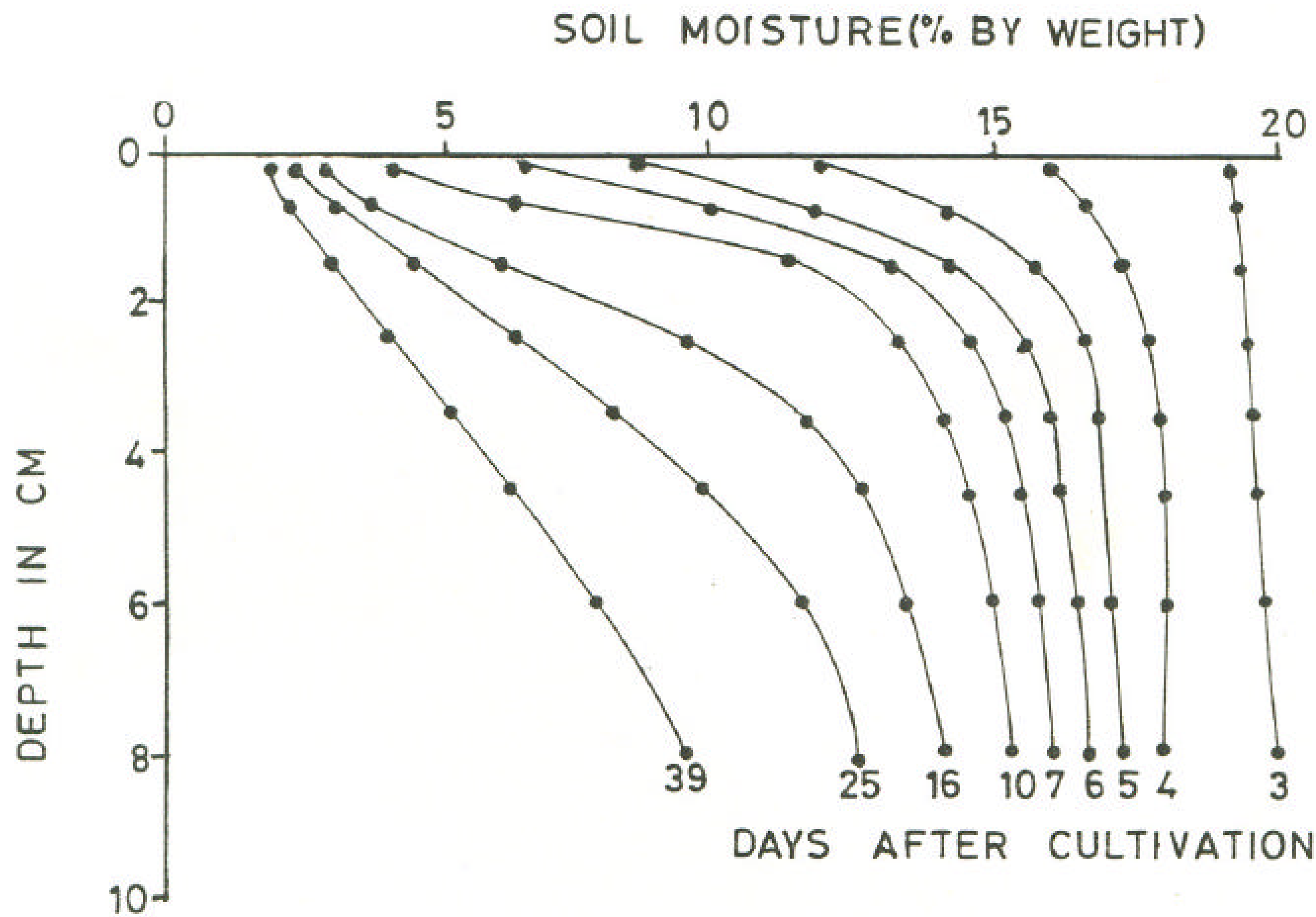


Fig. 5.2 Soil moisture profiles for loamy soil during drying period The field was irrigated on March 2, 1971. (Jackson, [81]).

Nuclear Techniques

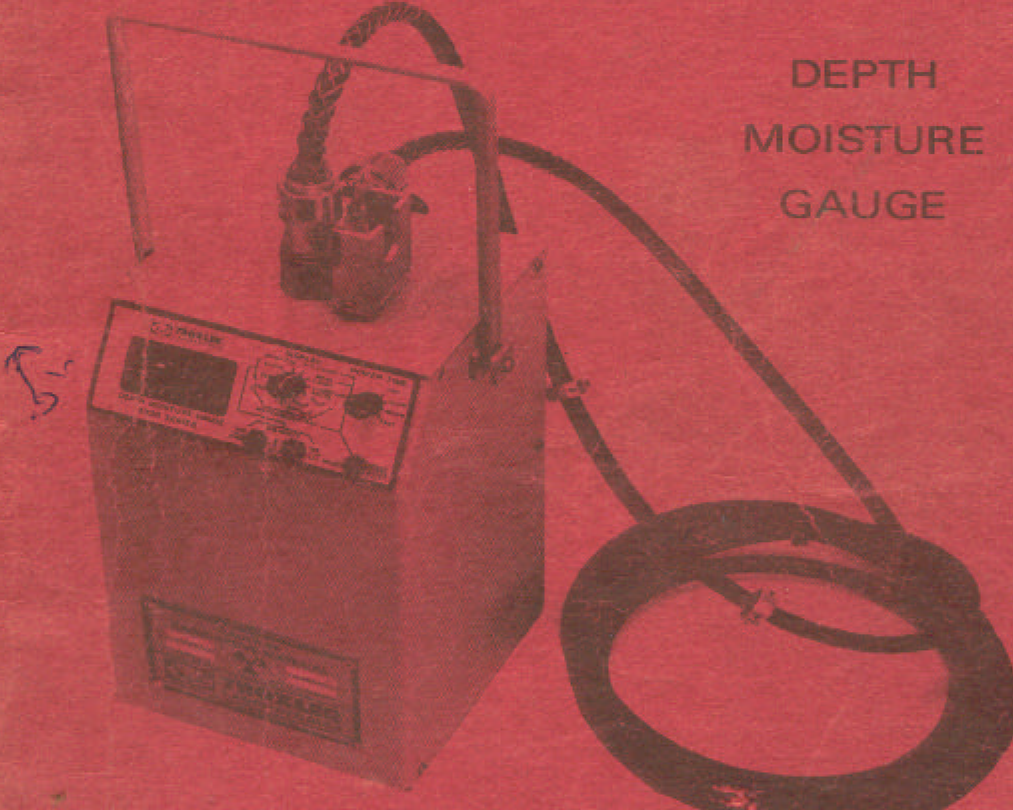
- **Fast neutrons emitted by an Americium 241: Beryllium radioactive source are themalised (slowed) by hydrozen in the test sample**

Advantages : SM can be measured at the any time, average SM can be measured with depth, system can be interfaced for automatic recording, temporal SM changes can be measured, readings are directly related SM

Disadvantages : Surface soil moisture is not accurate, care must be taken to minimize health risks.

3300 SERIES

Instruction Manual



DEPTH MOISTURE GAUGE

TROXLER ELECTRONIC LABORATORIES, Inc.
AND SUBSIDIARY
TROXLER INTERNATIONAL, Ltd.
3008 Cornwallis Rd. • Research Triangle Park, North Carolina 27709 USA

TROXLER

P.O. Box 12057
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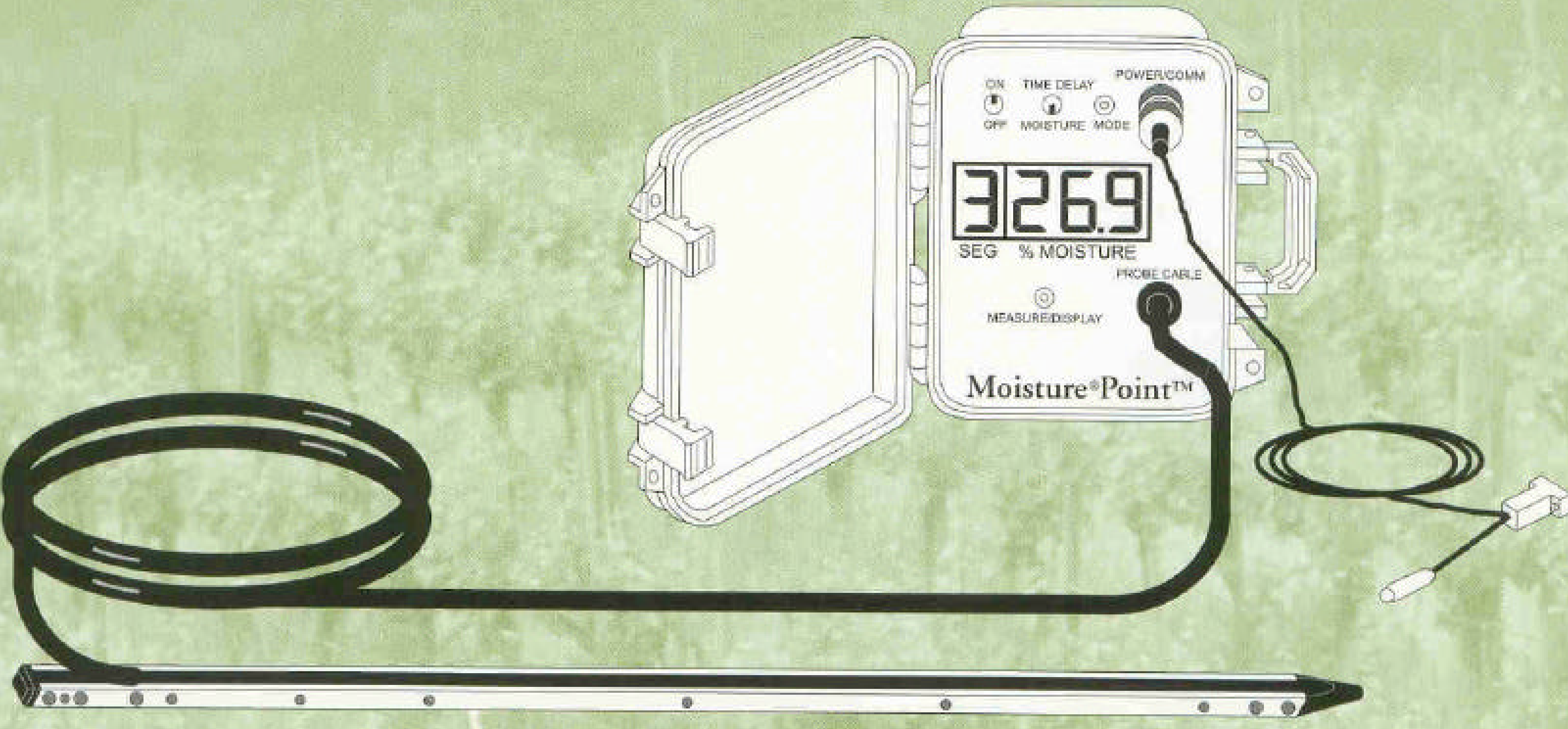
Electromagnetic Techniques

- **The technique is based on the electrical properties of the soil that varies with soil moisture. Resistivity or Capacitance between electrodes in a soil is measured for Soil moisture.**

Complex Dielectric Constant

$$e = e_r + j e_i$$

Dig deeper.



ON
OFF
TIME DELAY
MOISTURE
MODE
POWER/COMM
3 26.9
SEG
% MOISTURE
PROBE CABLE
MEASURE/DISPLAY
Moisture®Point™

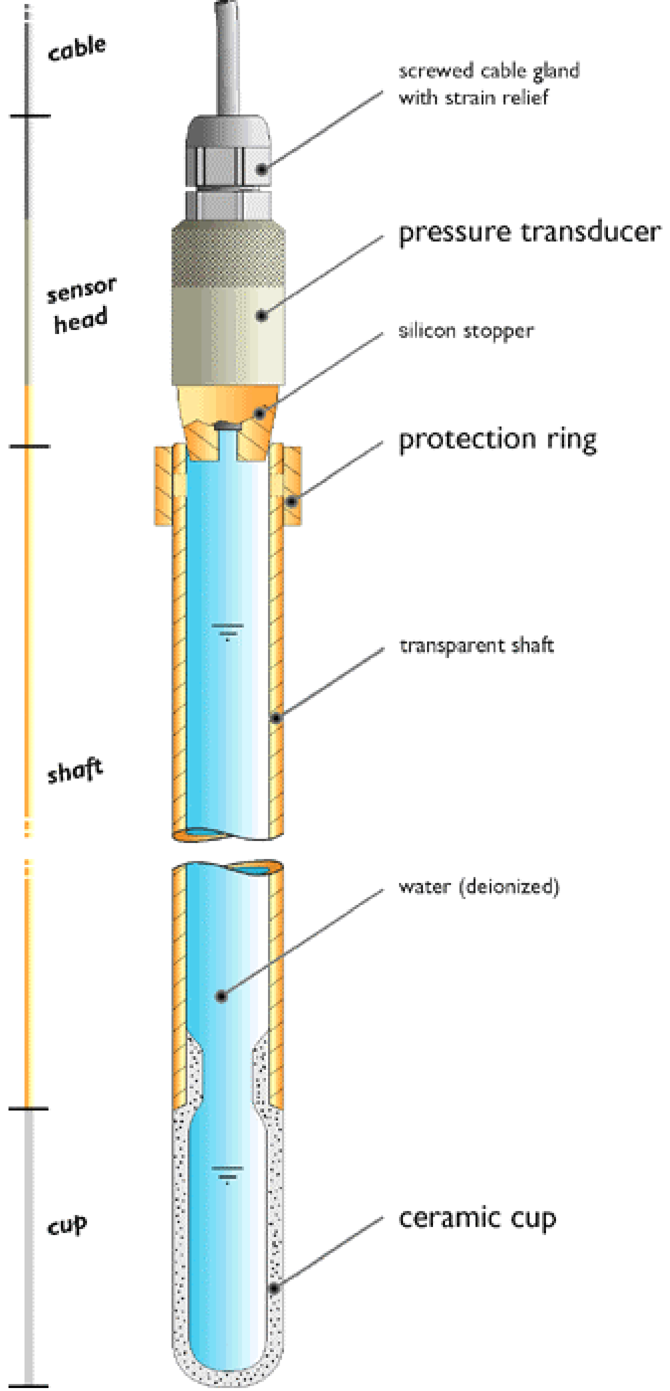
Tensiometric Techniques

Measures the capillary tension or the energy with which water is held (suction) by the soil.

Tensiometers consist of porous ceramic cup connected by a continuous liquid column to a vacuum gauge or transducer.

Advantages : easy to design, cost little, at any conditions in real time, placed in soil easily,

Disadvantages : Only measures soil water suction, but only indirect measurement of soil moisture content; during installation, it may break.


cable
sensor head
shaft
cup
screwed cable gland
with strain relief
pressure transducer
silicon stopper
protection ring
transparent shaft
water (deionized)
ceramic cup

Soil Water Models

$$SM_t = SM_{t-1} + P - R - L - E - T + C - Q$$

SM_t – Soil moisture at time t

SM_{t-1} – Soil moisture at previous time

P – Precipitation

R – Surface Runoff

L - net lateral subsurface outflow

E –Evaporation or condensation

T – Transpiration

C – Capillary rise from lower levels

Q - percolation

- USDAHL Model
- NWSRFS model

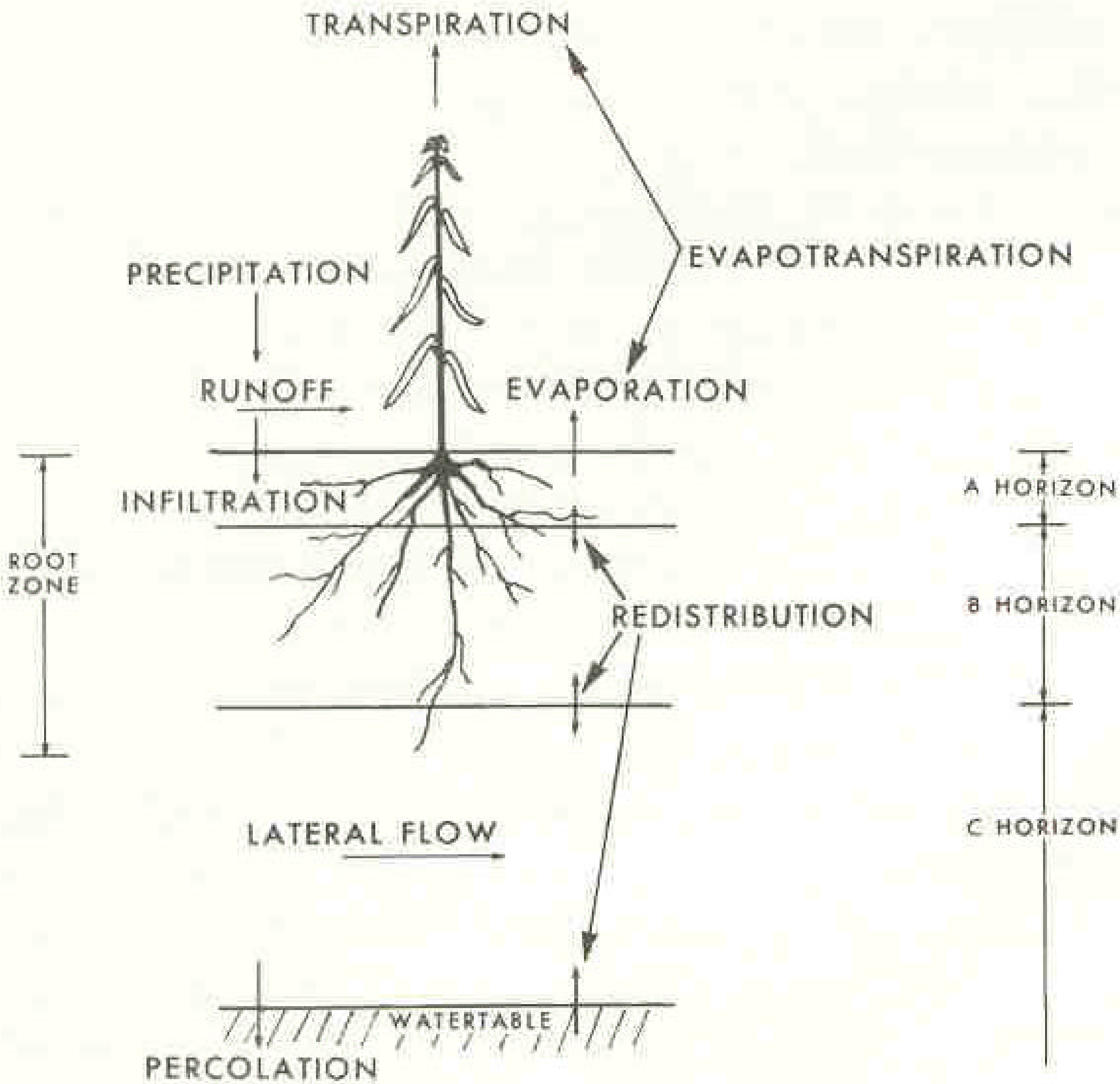


Fig. 2. Schematic diagram of soil-plant-atmosphere-water (SPAW) system.

Remote Sensing Methods

Visible Technique: **Reflected solar energy is measured.**
(0.4 – 1.7 mm)

- **Relationship between Reflectance and SM Depends on reflectance of dry soil, roughness, colour, illumination, organic matter, soil texture.**

Thermal Infrared Techniques

- **Diurnal range of Surface Temperature(T_{max}-T_{min}) or Measurement of crop canopy – air temperature differential.**

- **(T_{max}-T_{min}) depends on internal and external factors**

- **Internal factors : Thermal conductivity(K) and heat capacity (C) where $P = (KC)^{1/2}$ is known as Thermal Inertia. K and C increases with Soil Moisture.**

- **External Factors : solar radiation, air temperature, RH, cloudiness, and wind.**

Diurnal Temperature Variation versus Soil Moisture

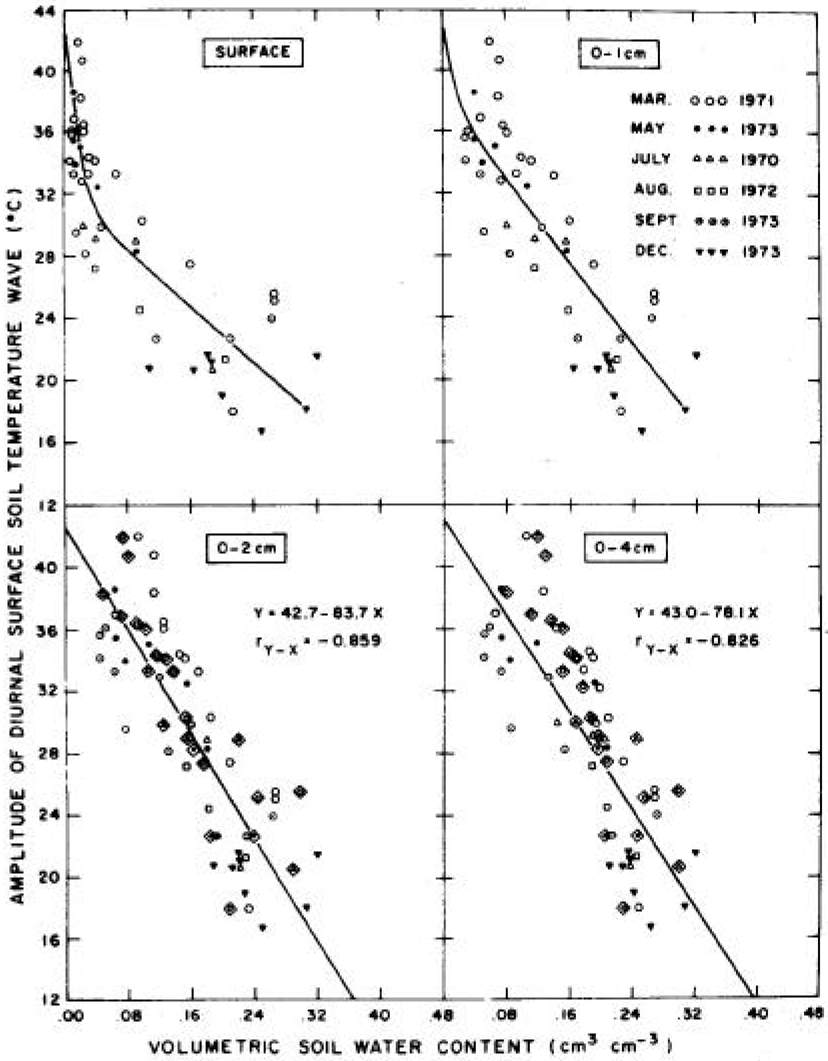


Fig. 7. Summary of results for the diurnal temperature variation versus soil moisture [*Idso et al.*, 1975*a*].

MODIS Data from Terra and Aqua Satellites

Swath : 2330 Km and covers the same area 1 or 2 days

Spectral Bands : 36 ; Wavelength : 0.405 – 14.385

Resolution : 250m (bands 1-2, 500m (bands 3-7), 1000m(8-36).

Surface/Cloud
Temperature 31 10.780 - 11.280

32 11.770 - 12.270

LANDSAT – 7 band-6 (10.4 – 12.5 microns, Resolution 60 m)

Microwave Remote Sensing

0.3 - 300 GHz (wavelength 1 m - 1 mm)

Passive

(Radiation or T_B)

Radiometers

$$T_B = e\,T$$

Where e is emissivity and T is physical Temperature

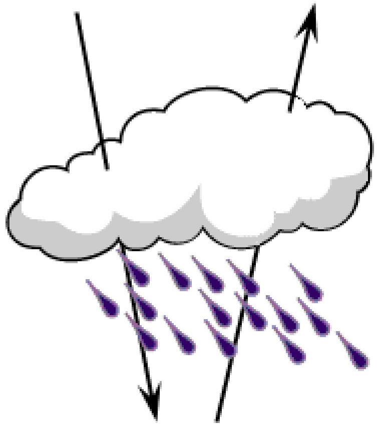
Active

(Backscattering s_0 dB)

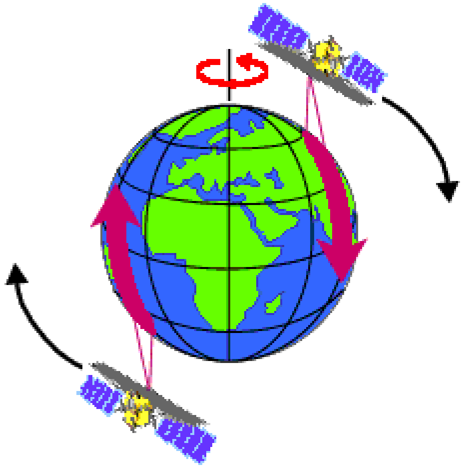
Radar

σ_0 depends on dielectric properties of soil, geometric properties and system parameters.

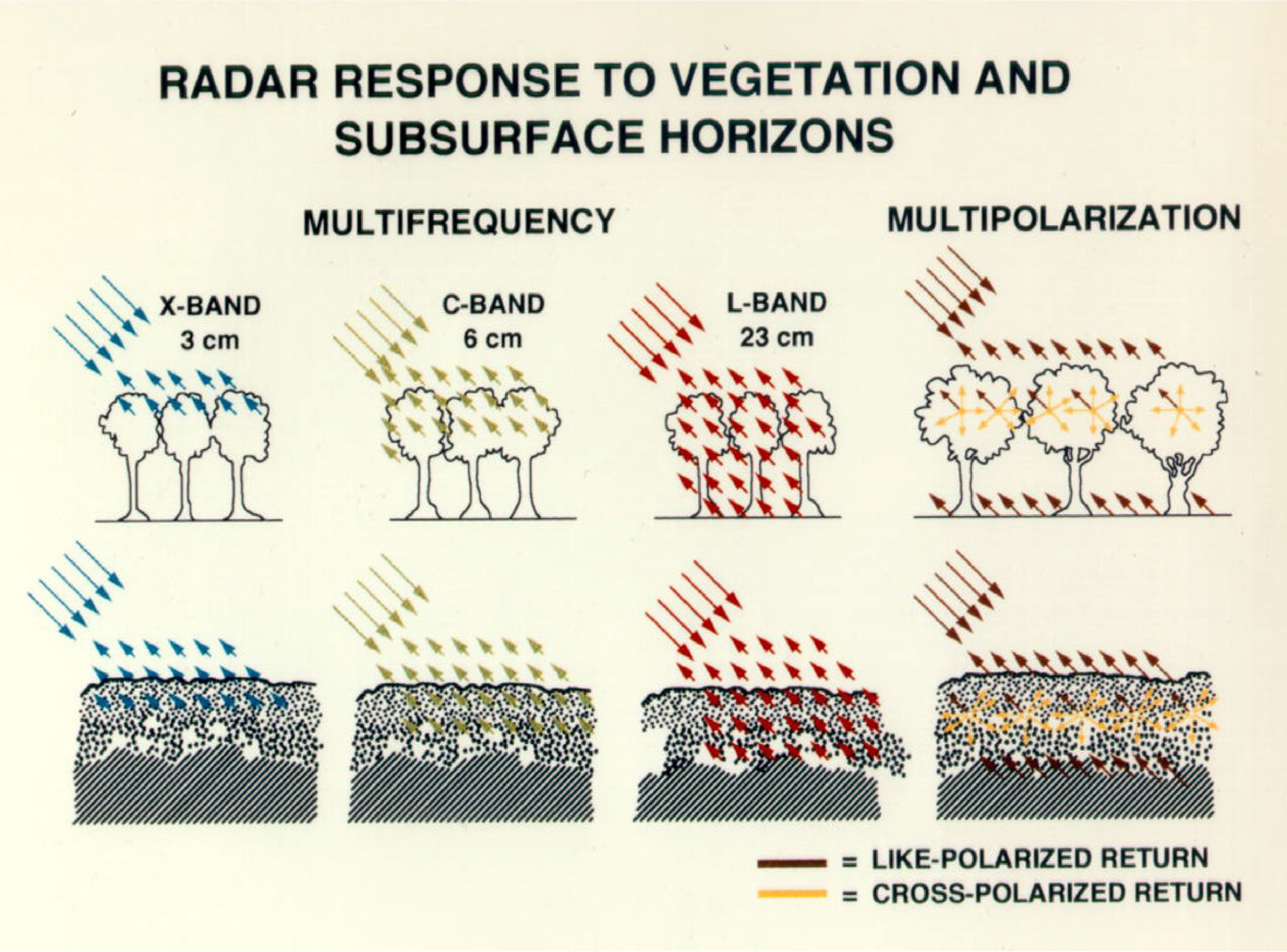
Advantages



- All weather Capability
- Day-night ability
- Penetration through a medium



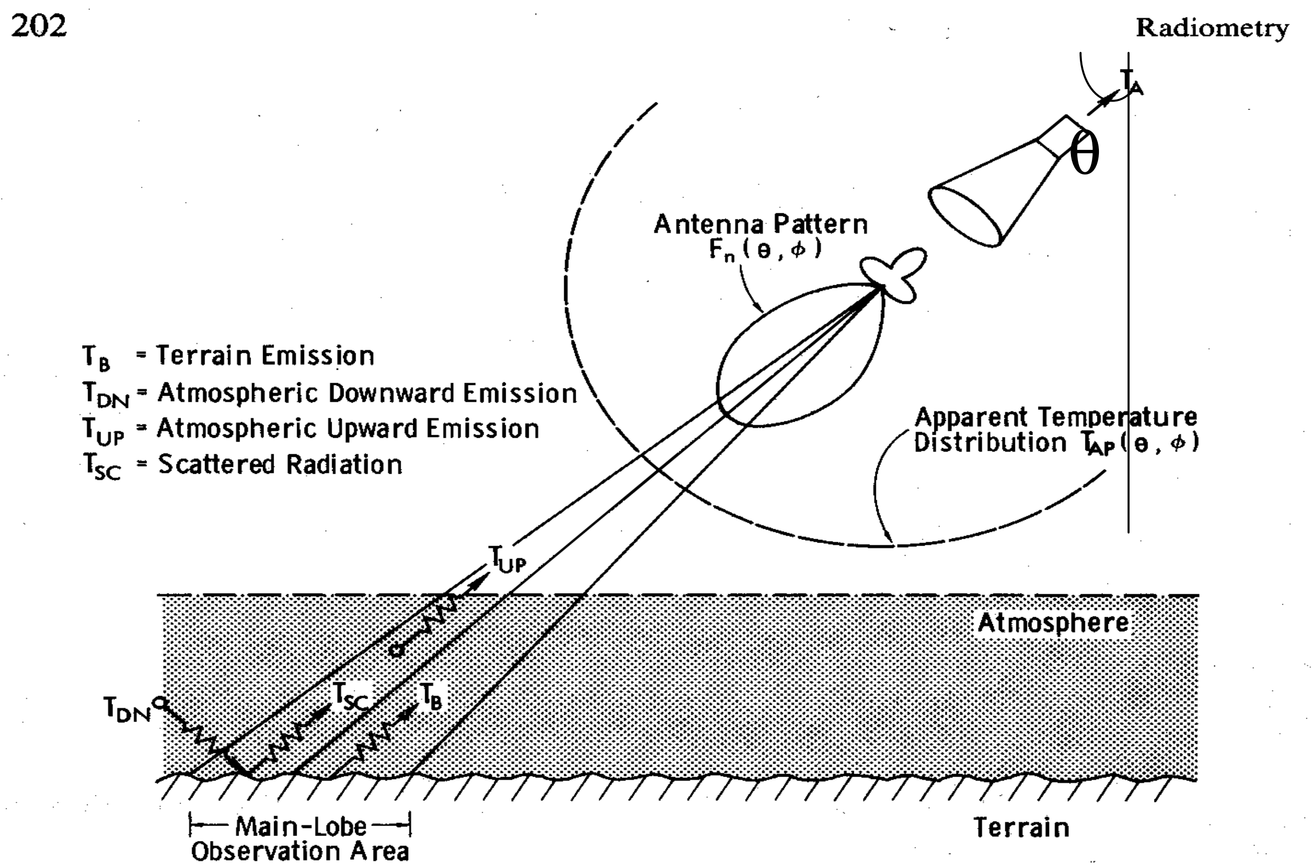
Penetration



Passive Microwave Remote Sensing

Emitted Radiation in Passive MRS

$$T_{Bp} = T_u + e^{-t_a} T_{bp} + e^{-t_a} R_p \left[T_d + T_{sky} e^{-t_a} \right] \quad .....$$



(a)

Brightness Temperature

$$T_B = eT$$

e – Emissivity,   T – Physical Temperature

Fresnel Reflection Equations $T_B = eT$

$$e_h = 1 - R_h = 1 - \left| \frac{Cos\, q - \sqrt{e - Sin^2 q}}{Cos\, q + \sqrt{e - Sin^2 q}} \right|^2$$

$$e_v = 1 - R_v = 1 - \left| \frac{e\, Cos\, q - \sqrt{e - Sin^2 q}}{e\, Cos\, q + \sqrt{e - Sin^2 q}} \right|^2$$

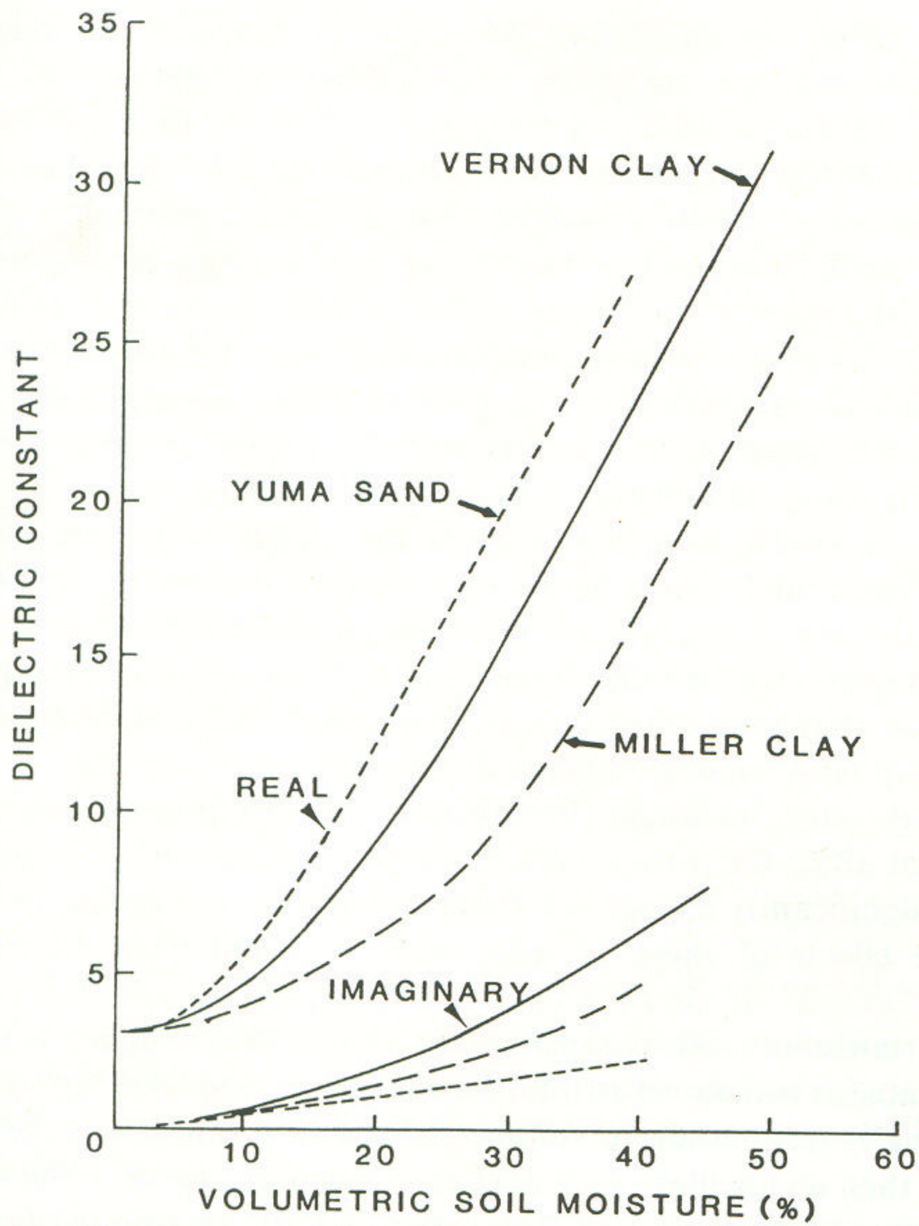
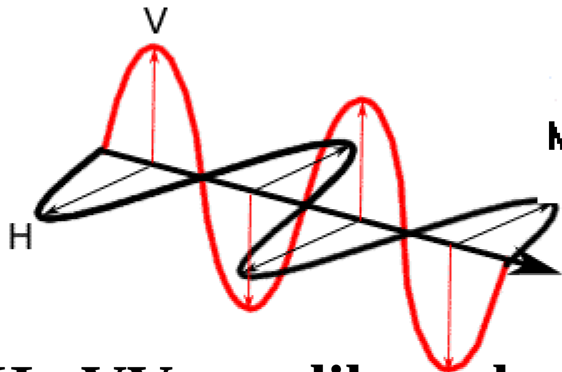


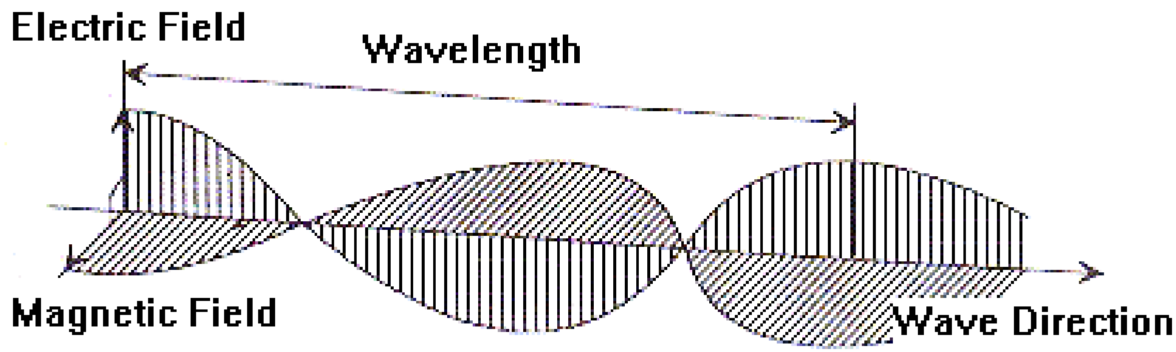
FIG. 6. Real and imaginary parts of the dielectric constant for three soils as a function of gravimetric soil moisture, $\lambda = 21$ cm. [From Wang and Schmugge (1980).]

Radiometer Systems and their Parameters

Parameters	**SSMR in NIMBUS-7**	**SSM/I**	**IRS-P4, MSMR**	**EOS Aqua AMSR-E**	**ADEOS-II AMSR**
Launch date	1978-87	1987/92/95	May 26, 1999	May 4, 2002	Jan. 16, 2004
Frequency (GHz.)	6.6, 10.7, 18.0, 21 and 37 GHz	19.3, 22.2 (V), 38.0 and 85.5 GHz	6.6, 10.65, 18, 21	6.6, 10.65, 18.7, 23.8, 36.5, 89	6.6, 10.7, 18.7, 23.8, 36.5, 89, (50.3 V and 52.8 V polarization only)
Polarization	H & V	H &V (except 22.2 GHz)	H&V	H&V	H&V (except last 2)
IFOV (km x km)	148x95, 91x59, 55x41, 46x30, 27x18	69x43, 60x40, 37x28, 15x13 km	150x144, 75x72, 50x36, 50x36 km	76x44, 49x28, 28x16, 31x18, 14x8, 6x4 km	70x40,46x27,25x14,28x17,14x8,6x3,10x6 km
Swath width (km)	822 km	1400 km	1360	1445	1600
Revisit coverage(days)	--	1 day	2	2	2
Incidence angle (deg.)	50.3 (at the surface)	53.3 (at the surface)	43.13	54 (at the surface)	54 (at the surface)
Sensitivity	0.4, 0.5, 0.7, 0.7, 1.1	0.8, 0.8, 0.6, 1.1	0.6, 0.75, 1.05, 1.1	0.3, 0.6, 0.6, 0.6, 0.6, 1.0	0.3,0.6,0.6,0.6,0.6,1.0, 1.3,0.9

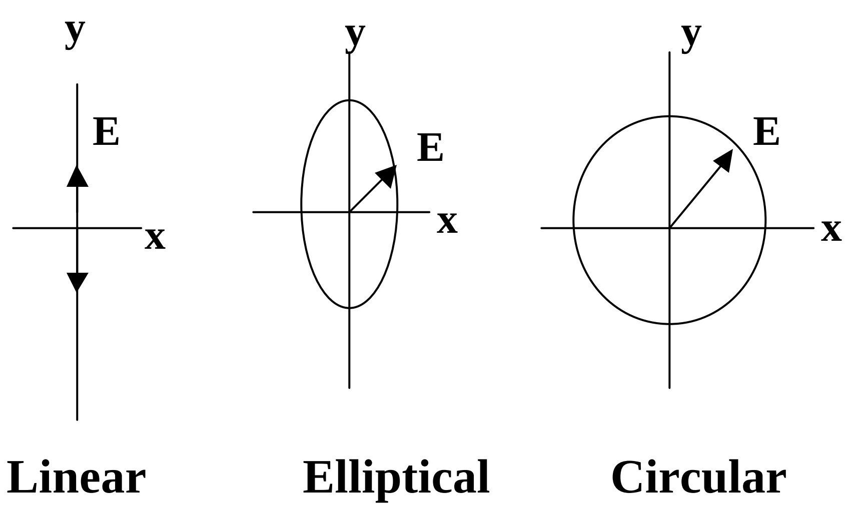
Polarization



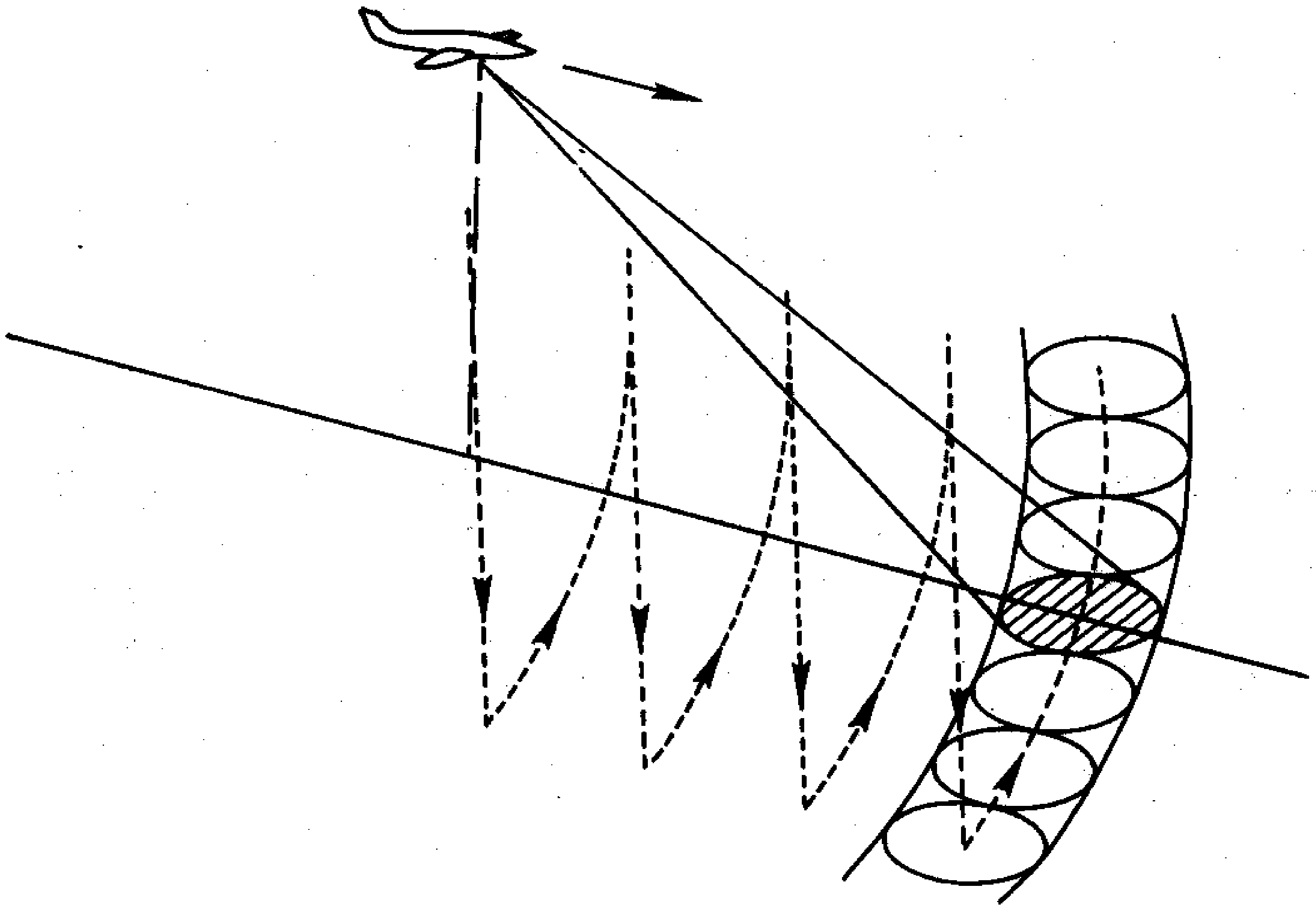


HH, VV are like polarized

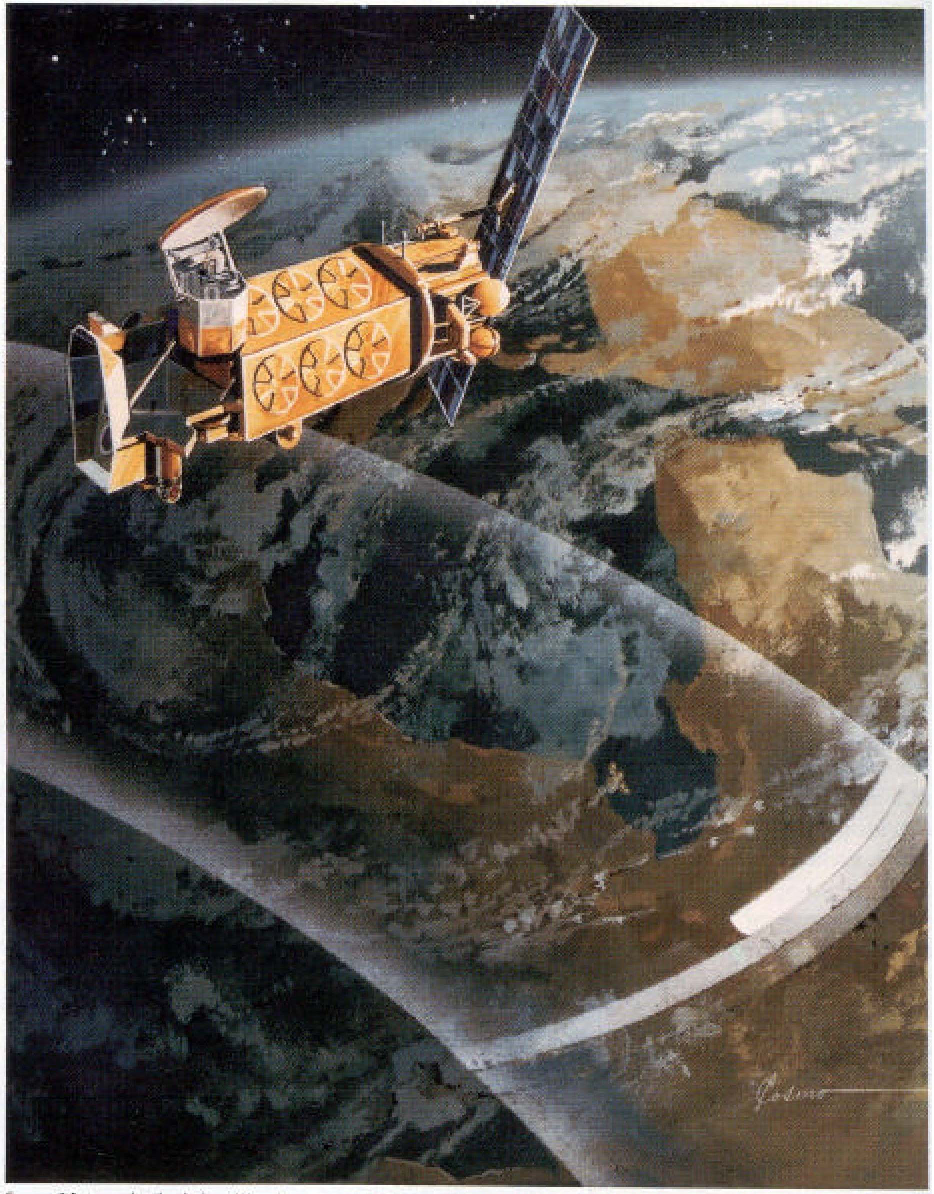
HV, VH are cross polarized



IFOV, Swath, Incidence Angle



SSM/I Satellite



)efense Meteorological Satellite Program (DMSP) Block 5D-2 satellite with the Special Sensor Microwav
(SSM/I) located at the upper left.

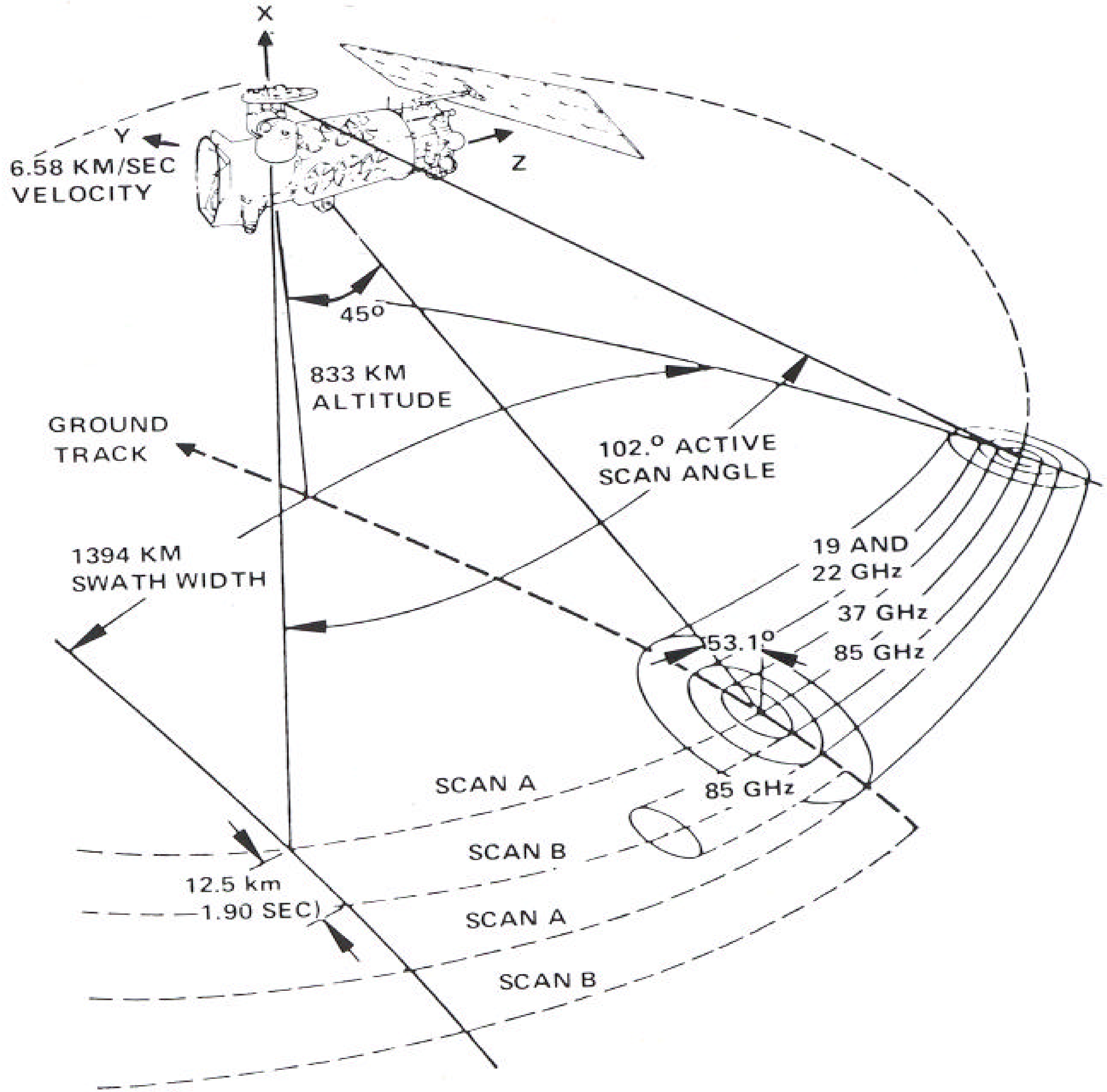


Fig. 4. SSM/I scan geometry.

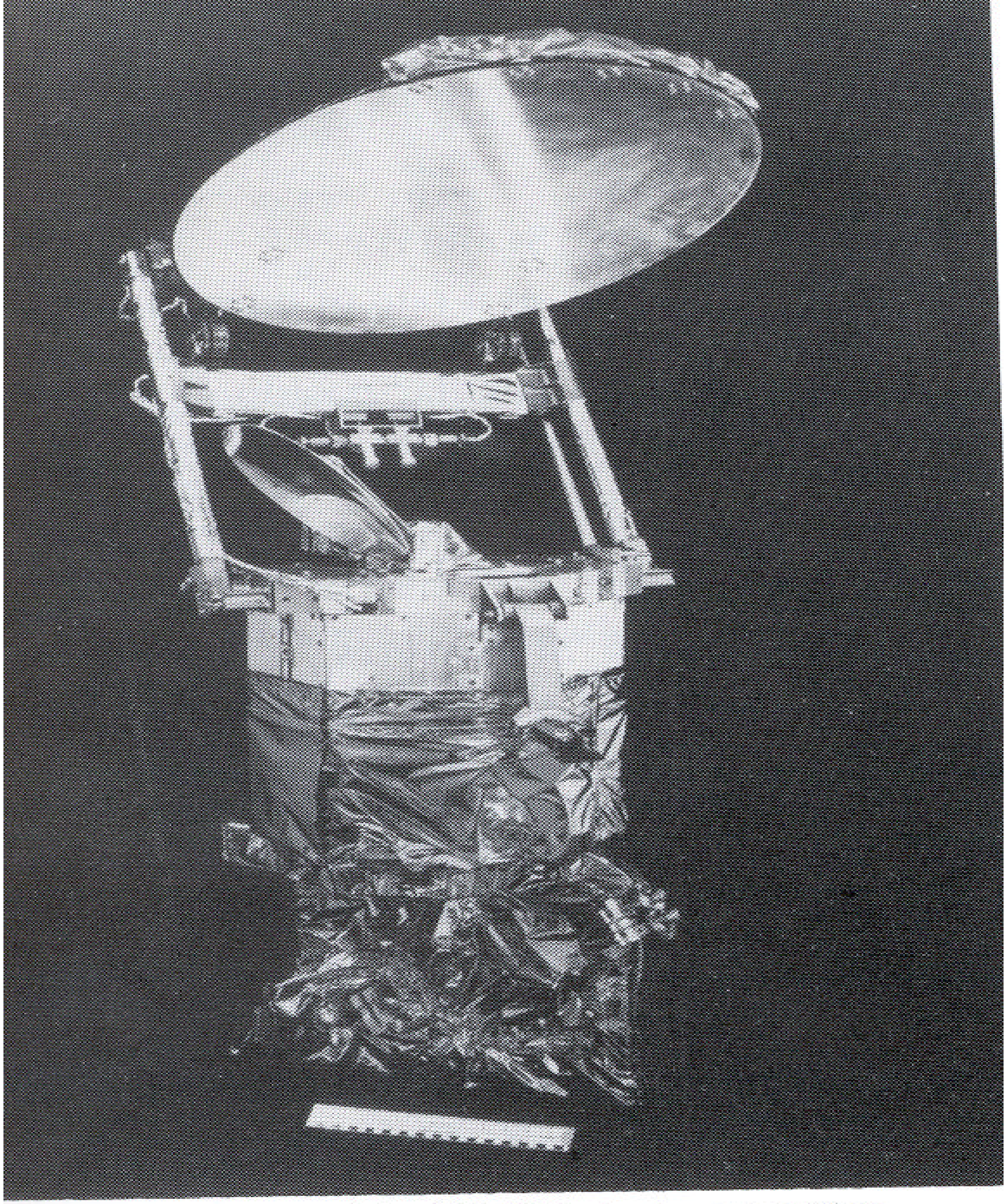
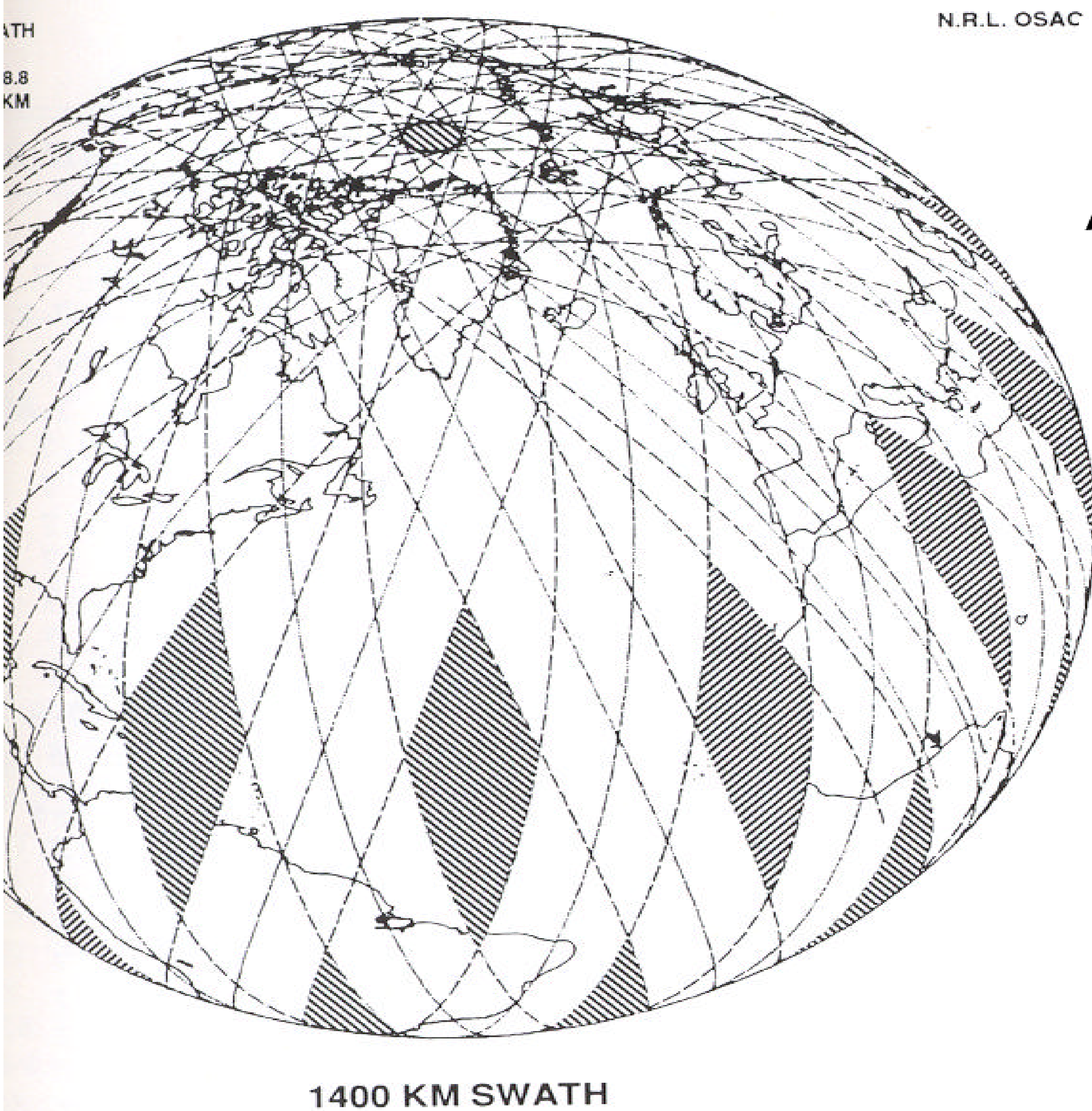
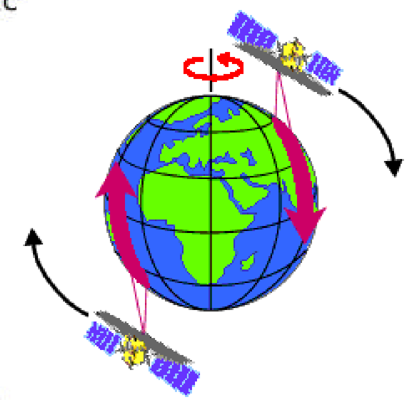


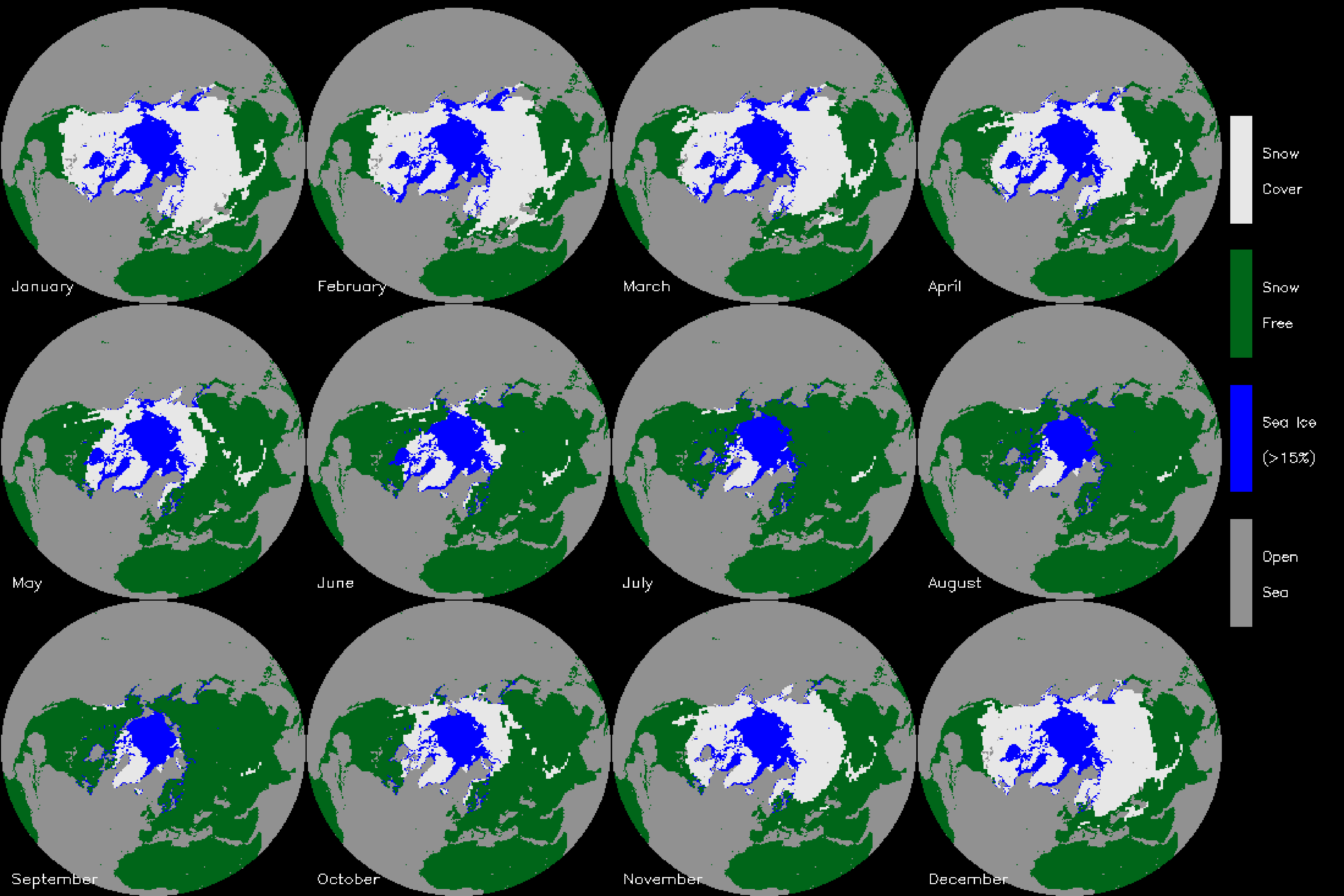
Fig. 3. Prototype of the SSM/I in deployed position.



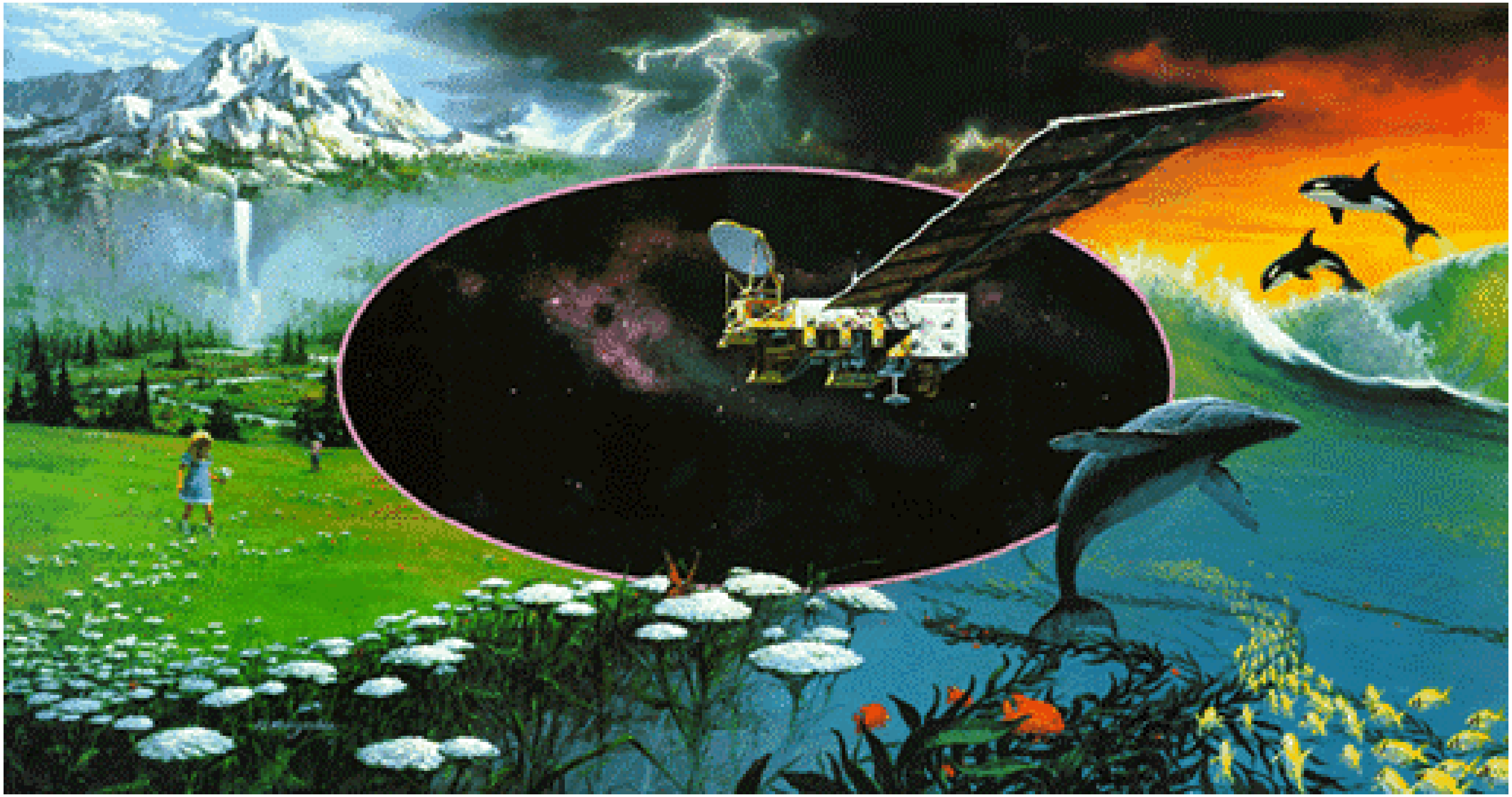


rth coverage of the SSM/I in a 24 h period. Only the shaded areas are not observed in this time period.

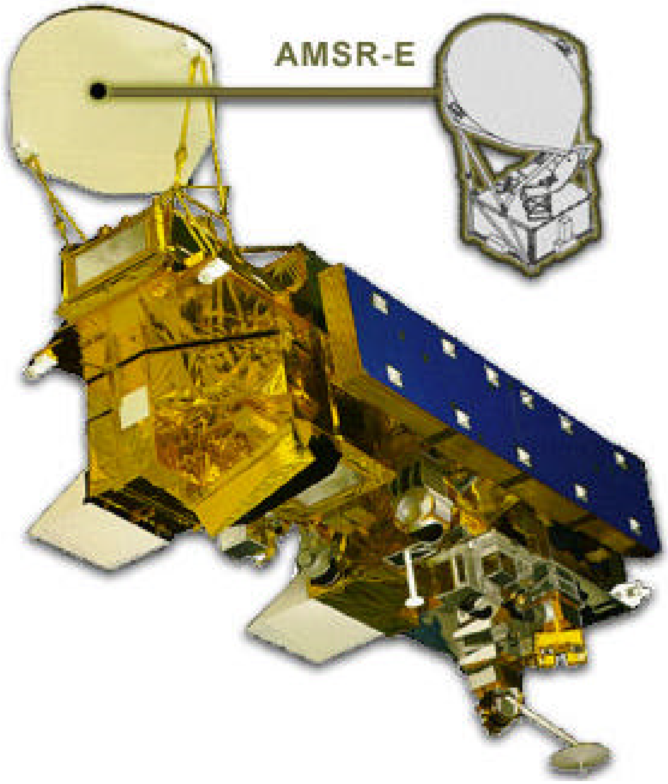
Average Snow Cover (71–95) & Sea Ice Extent (78–95)



EOS-PM (AQUA-1) Satellite http://www.aqua.nasa.gov



AMSR-E, Launched May 4, 2002



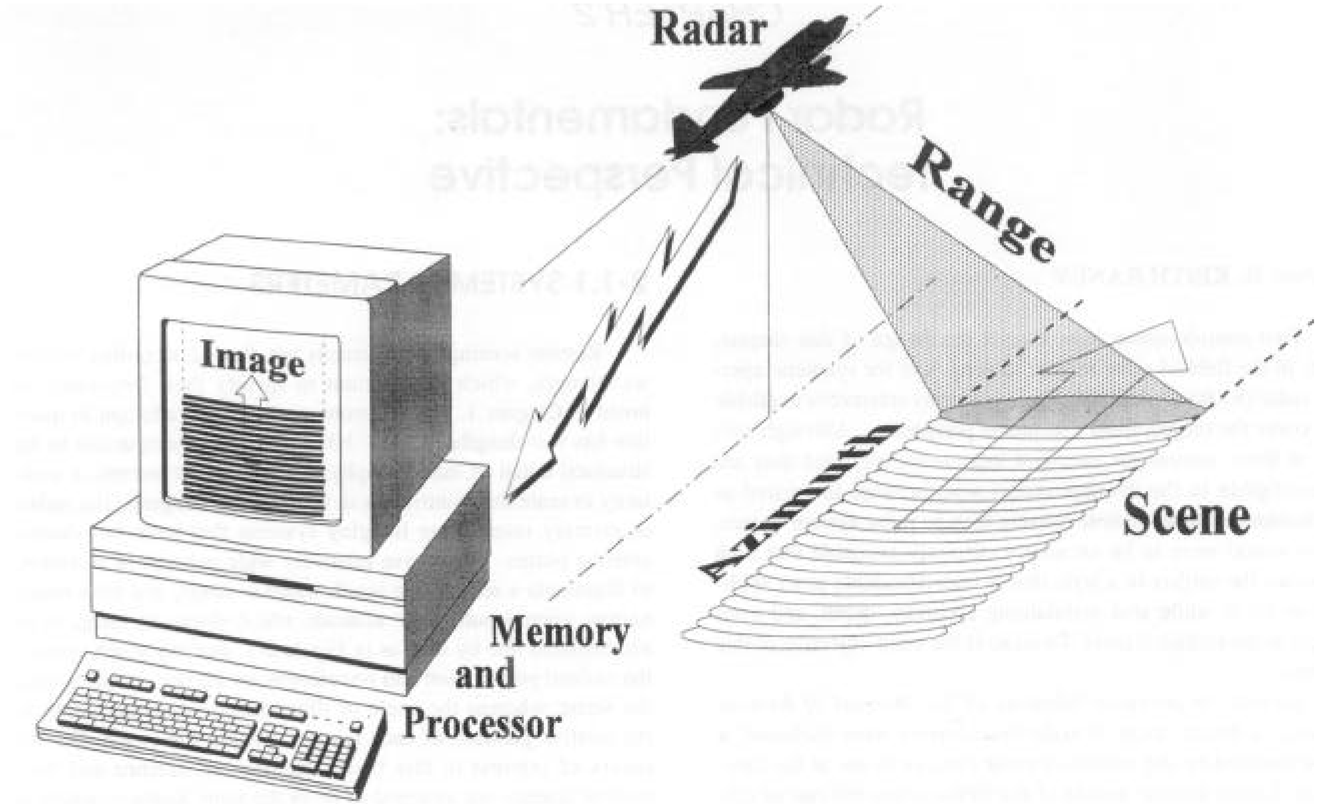
Data Available from Feb. 2003 onwards

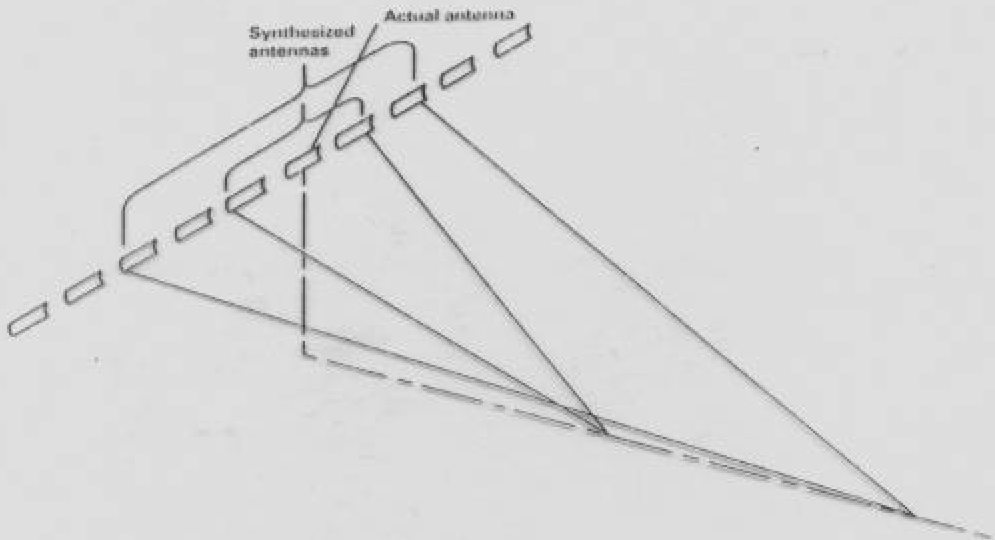
Frequencies (GHz)	**Resolution (km)**
6.6, 10.65, 18.7,	76x44, 49x28, 28x16,
23.8, 36.5, 89	31x18, 14x8, 6x4

Active Sensor Systems and System Parameters

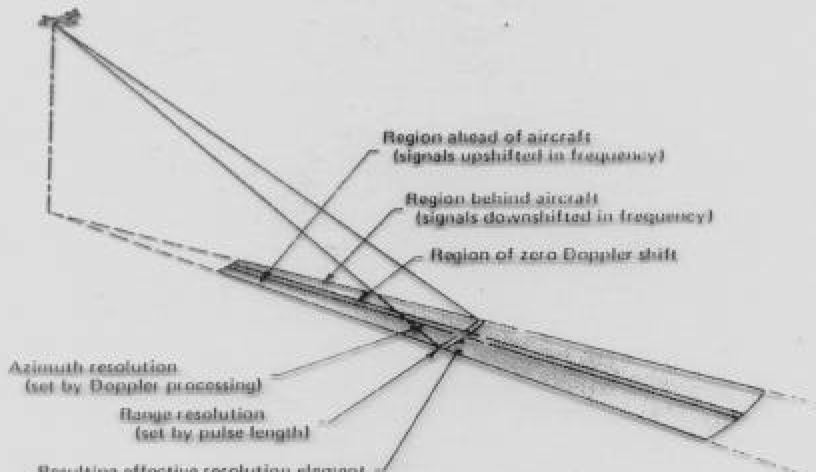
Parameters	Sea-sat	ERS-1,2	JERS -1	Radarsat	SIR-C	ENVISAT	Radarsat -2
Launch	June 1978	July 91 &Apr 95	Feb. 92	Nov. 95	Apr & Oct. 1994	March 1, 2002	2004
Frequency	1.275	5.3	1.275	5.3	1.2,5.3,9.8	5.3	5.3
Waveleng.,cm	23.5	5.6	23.5	5.6	23.5,5.6,3.1	5.6	5.6
Resolution(m)	25	30	18	10 - 100	25	30	10-100
Swath (km)	100	100	75	35 - 500	15 - 90	150–1km	35 – 500
Look anlge	23	23	35	20 - 50	20 - 55	20 - 50	20 –50
Polarization	HH	VV	HH	HH	HH,VV,HV	HH,VV	HH,VV
Looks	4	4	3	1- 4-14	4		

Elements of a Typical Remote Sensing Radar

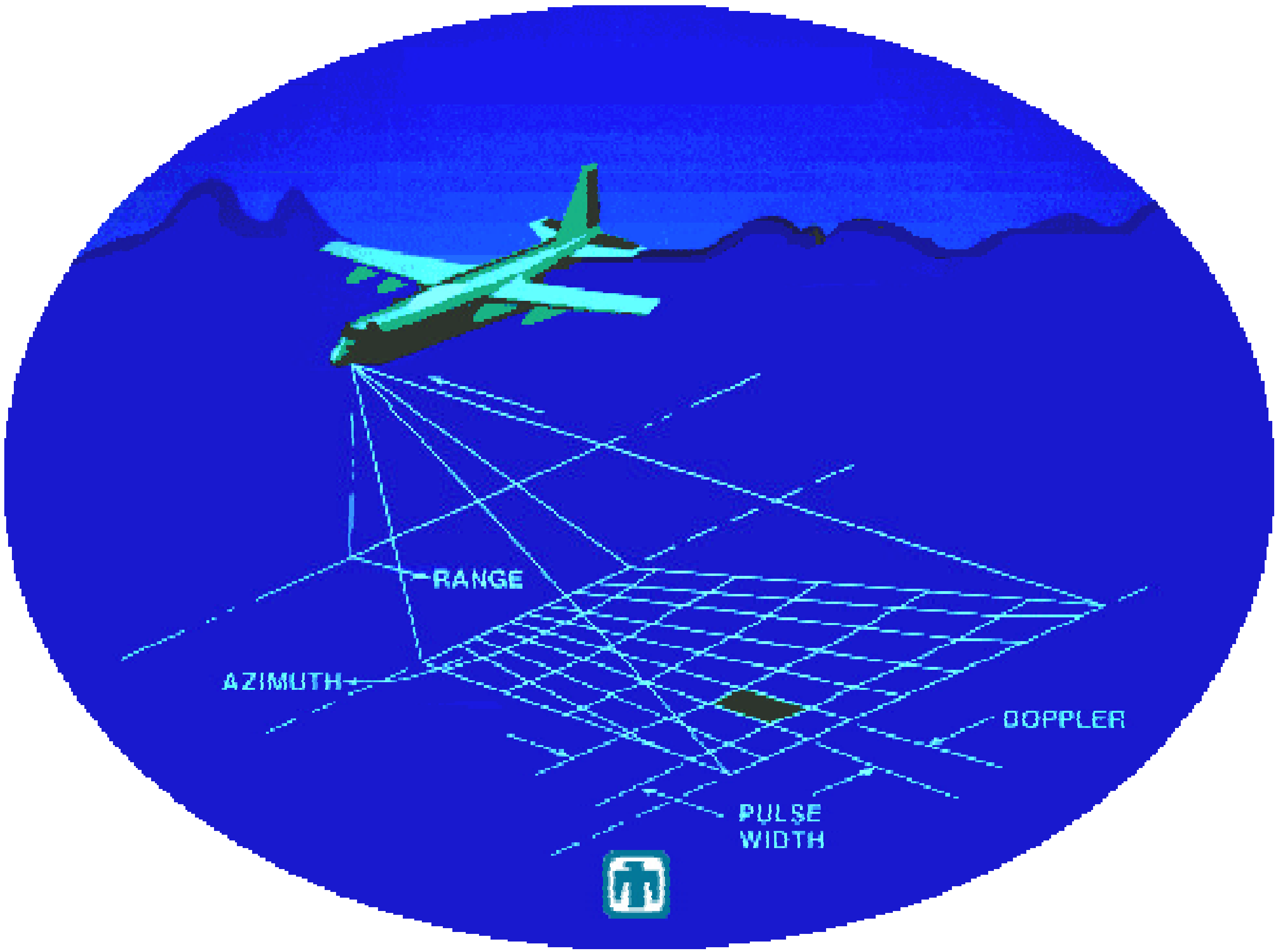




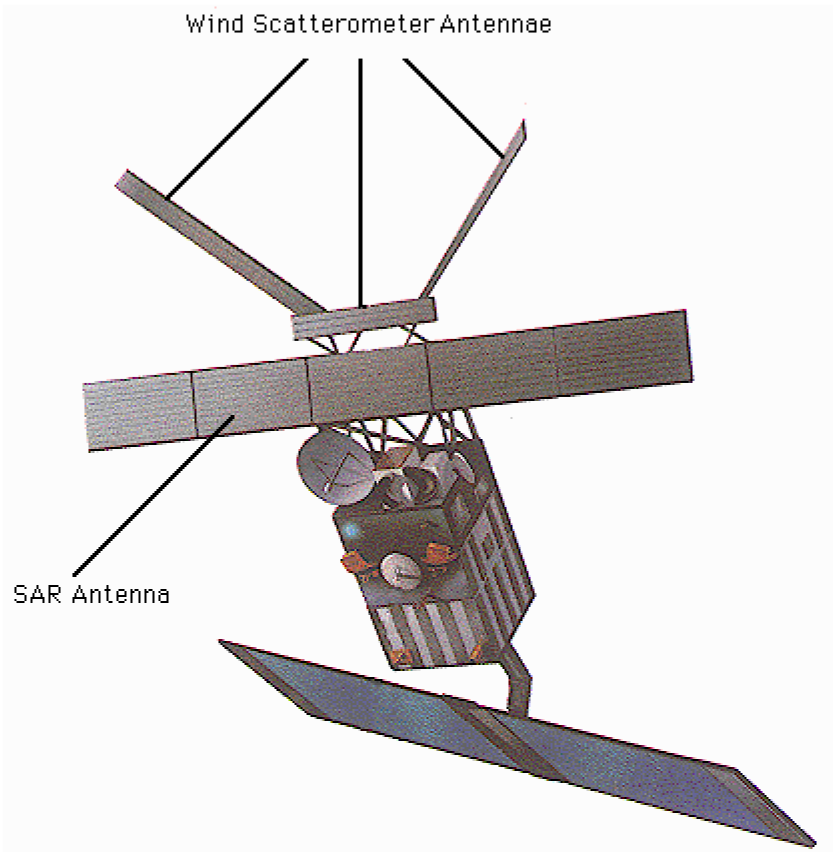
Concept of an array of real antenna positions forming a synthetic aperture.



Determinants of resolution in synthetic aperture SLAR


RANGE
AZIMUTH
DOPPLER
PULSE
WIDTH

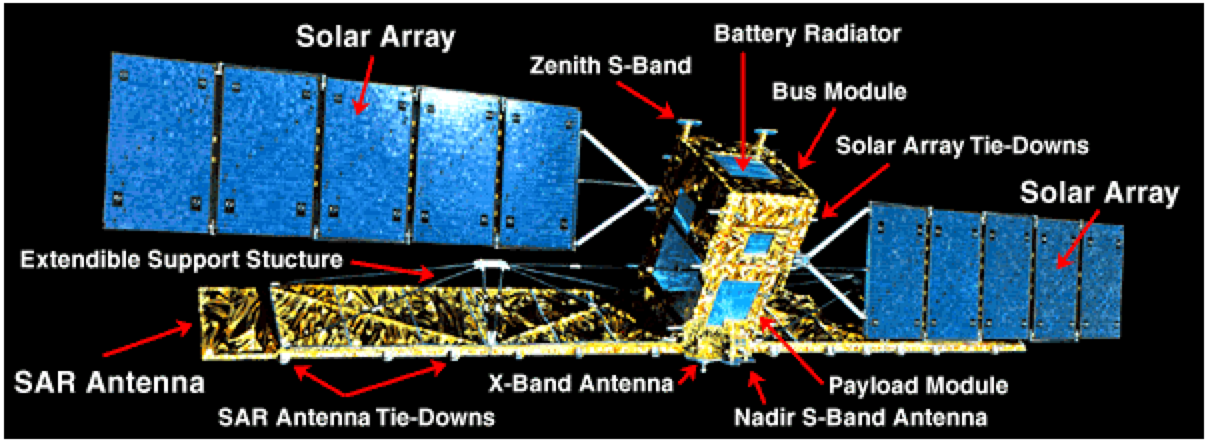
ERS-1 Satellite with C-band VV SAR system



System Parameters

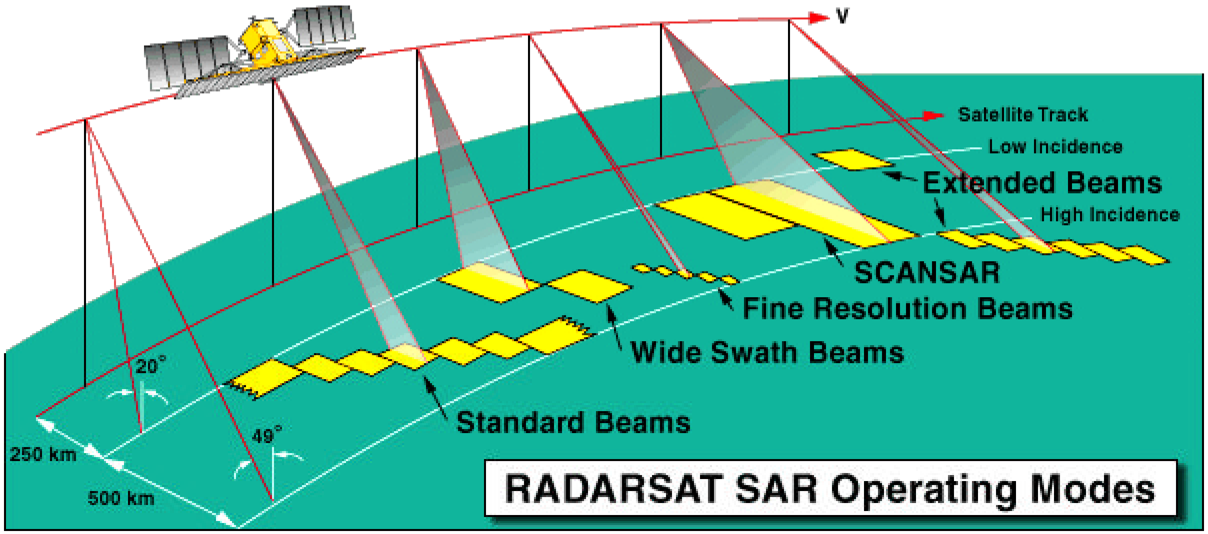
Launch: July 91 & Apr ‘95 (ERS2)
Frequency : 5.3 GHz (l =5.6 cm)
Resolution : 30 m
Swath : 100 km
Look Angle : 23^0
Polarization: VV
Looks : 4

RADARSAT-I



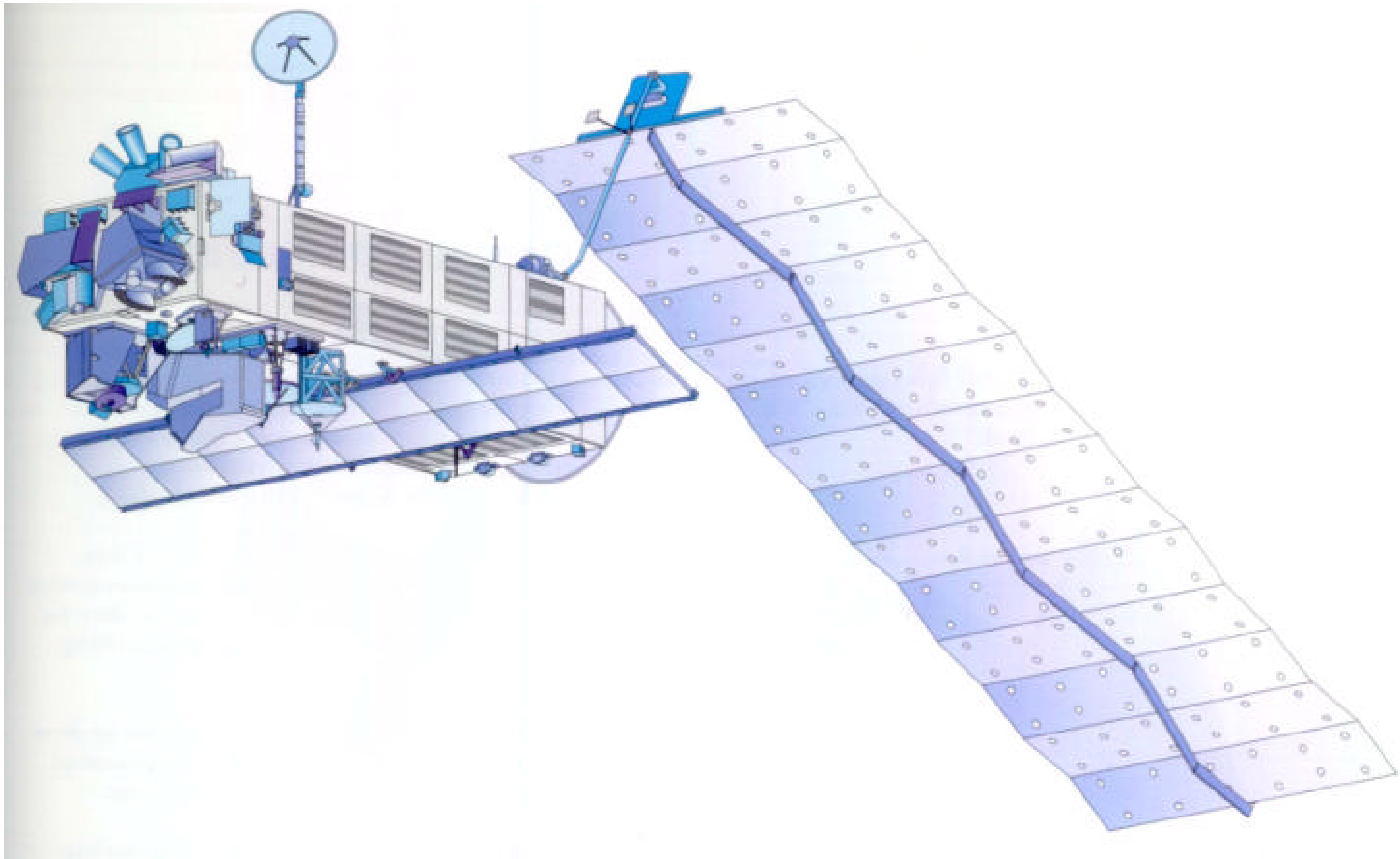
System Parameters

Frequency : 5.3 GHz
(l =5.6 cm)
Resolution:10 -100 m
Swath : 35 -500 km
Look Angle: 20 -50^0
Polarization : HH
Looks : 4 to 14

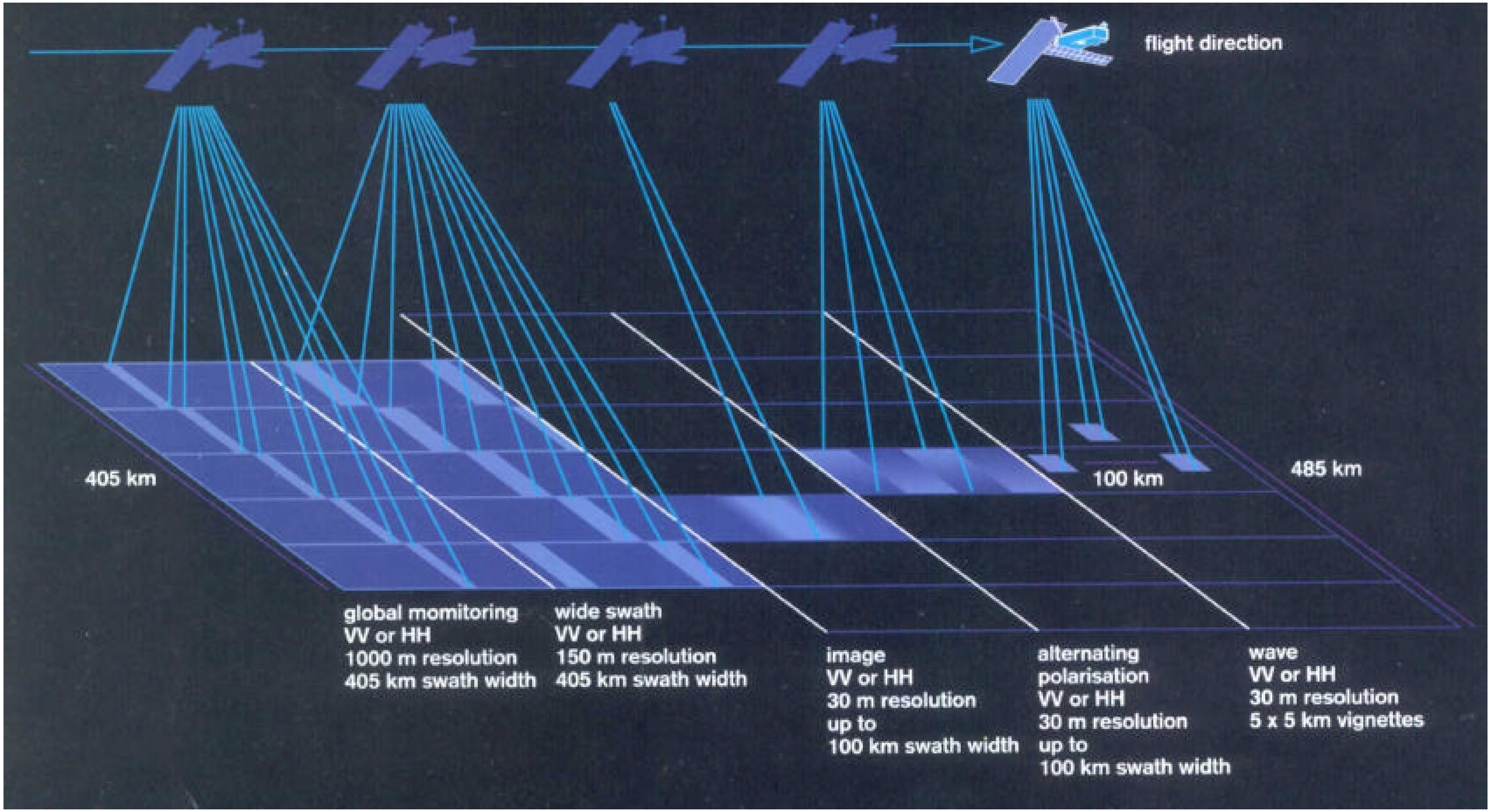


Future SAR Systems

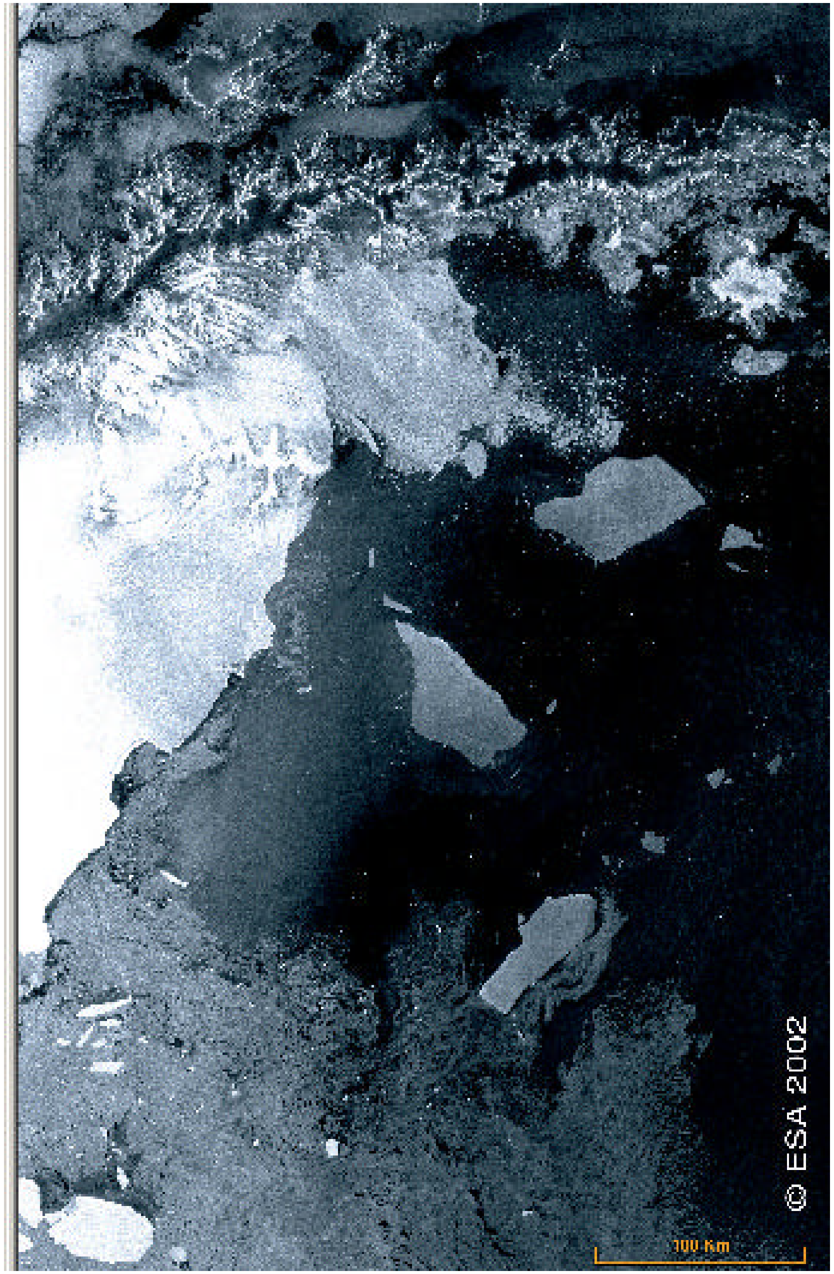
ENVISAT (Launch Date : March 1, 2002)



ENVISAT ASAR Operating Models



First Image from ENVISAT

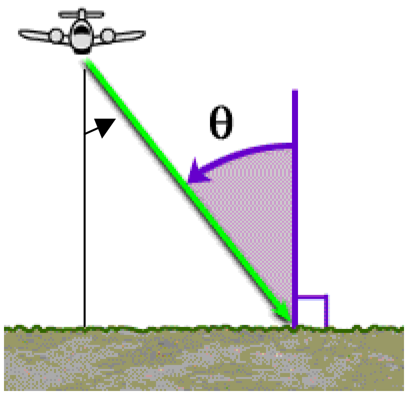


Antarctica Larsen B ice shelf

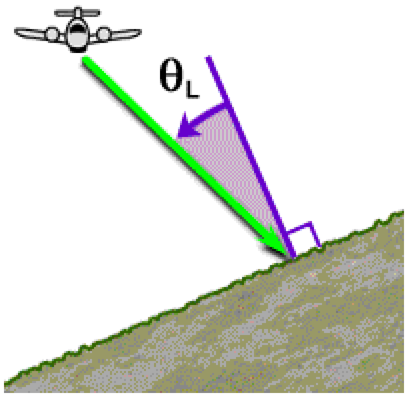
Wide Swath 400 km

150 m resolution

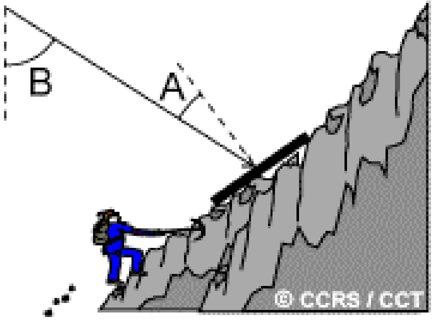
March 18, 2002



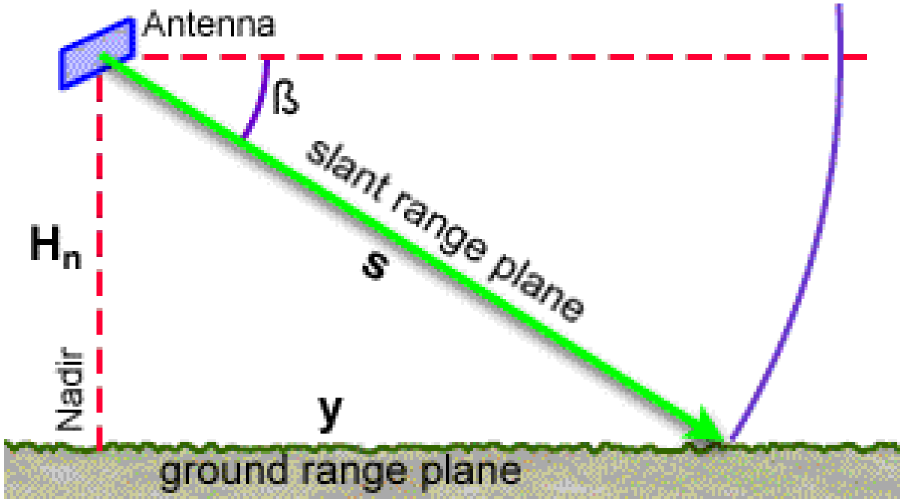
Incidence Angle

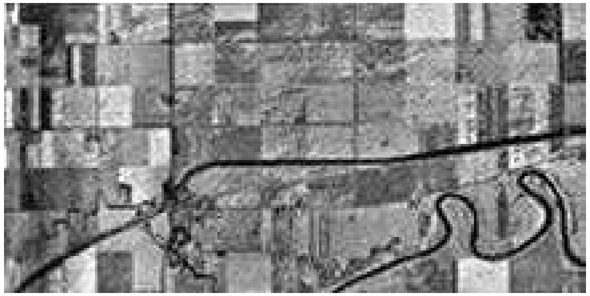


Local incidence angle



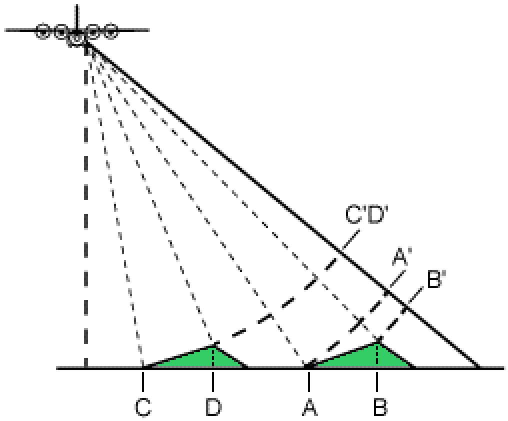
Slant Range to Ground Range

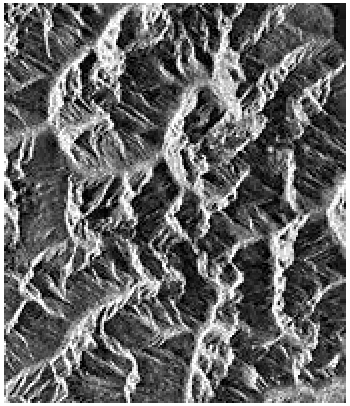




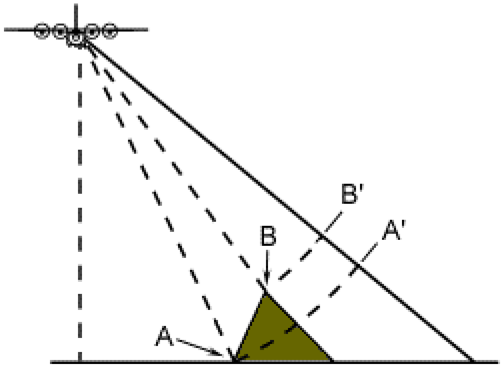
Geometric Effects

Foreshortening

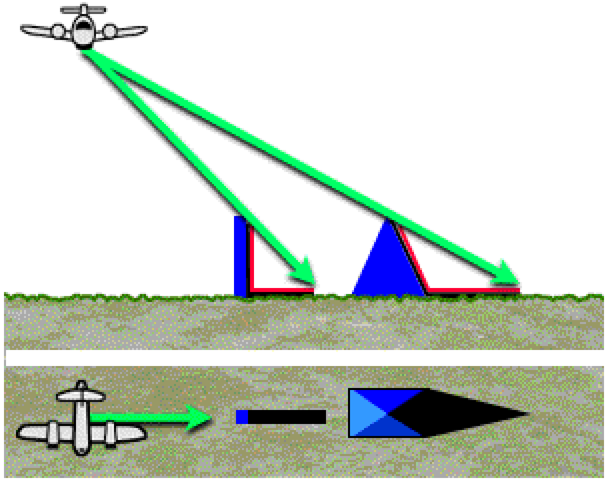




Layover

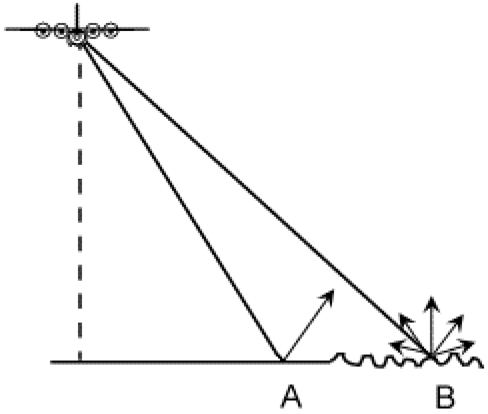


Shadow

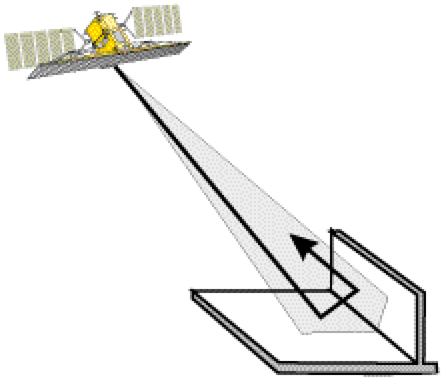


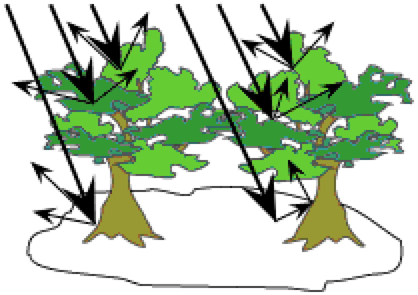
Speckle Reflection,

Diffuse scattering



Corner Reflector



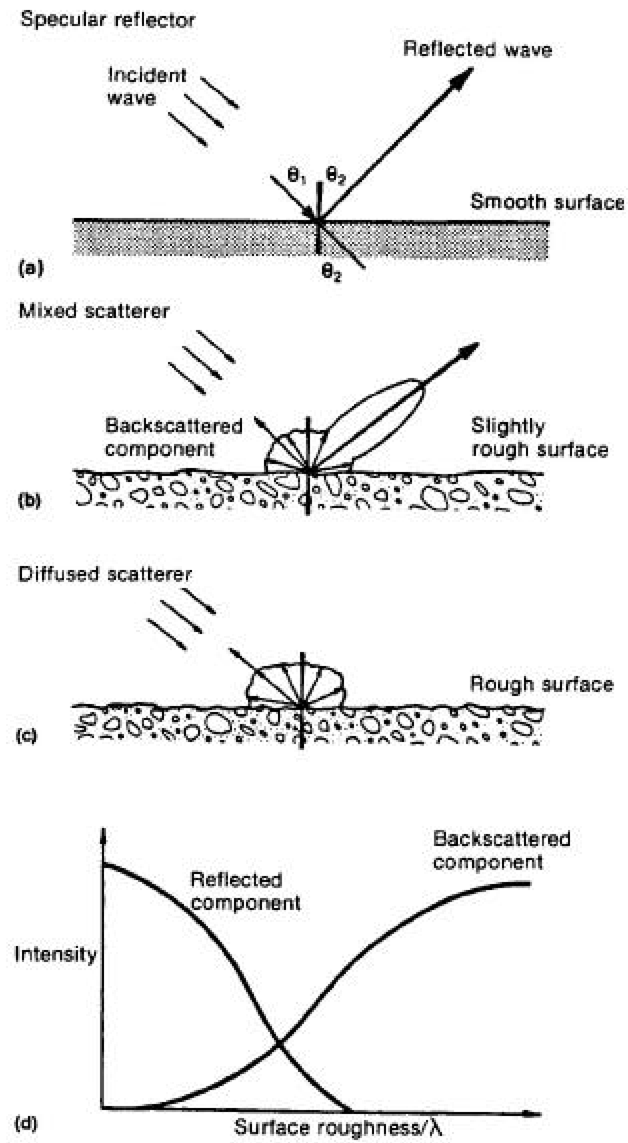


Volume Scattering

Surface Roughness

$$s=\sqrt{\frac{1}{N-1}\left(\sum(z)^2-N(\bar{z})^2\right)}$$

s	X-band	C-band	L-
0.05	smooth	smooth	smooth
0.5	rough	interm.	smooth
1.5	rough	rough	interm.
10.0	rough	rough	rough



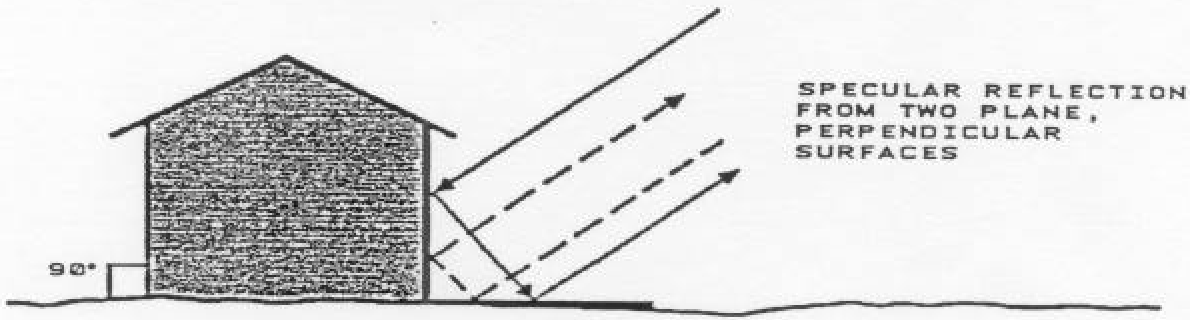
Plot 4 of 1989 field (Pomaz) experiment

POINT TARGETS

DISCRETE TARGET WITH SIMPLE CONFIGURATION
STRONG RADAR RETURN DISPROPORTIONATE TO ITS SIZE

EXAMPLES: BUILDINGS, TRANSMISSION TOWERS, BRIDGES:

A: DIHEDRAL CORNER REFLECTOR



B: TRIHEDRAL CORNER REFLECTOR

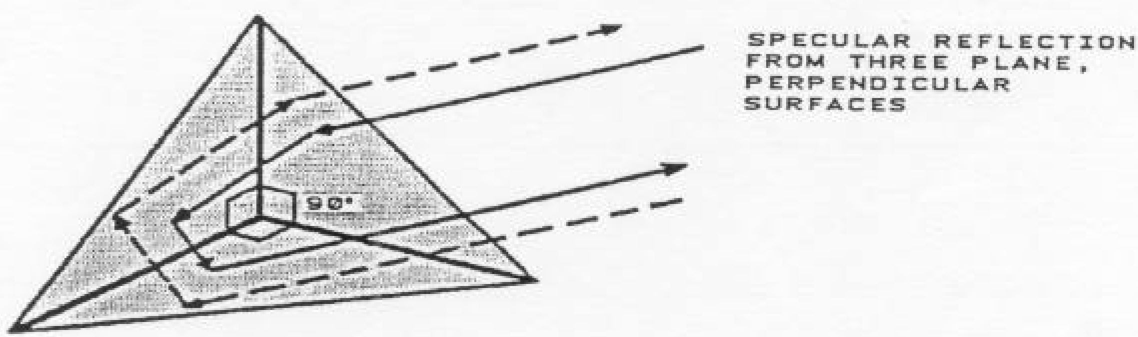
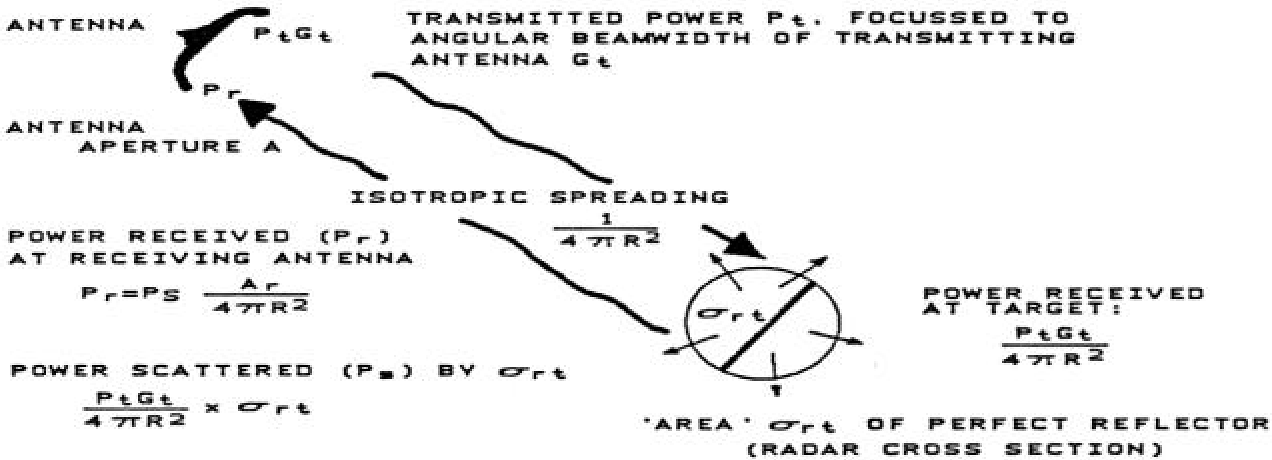


FIGURE 2-6

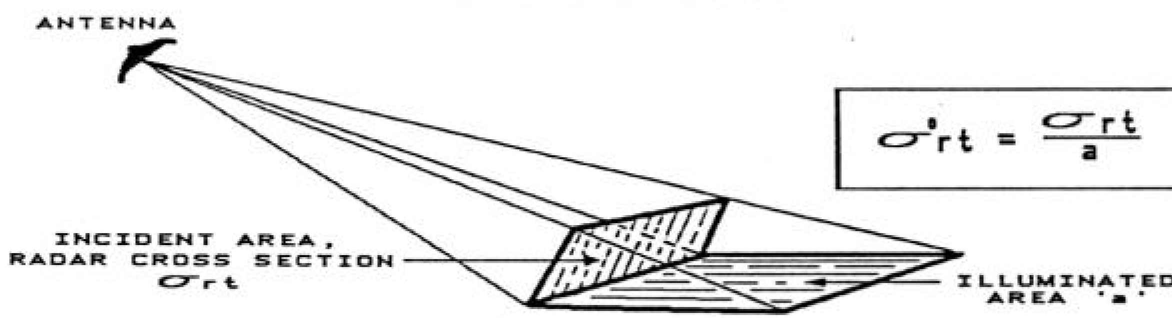
RADAR EQUATION

RELATES RECEIVED POWER (Pr) TO RADAR AND TARGET PARAMETERS

$$P_r = \frac{P_t G_t}{4 \pi R^2} \sigma_{rt} \frac{A_r}{4 \pi R^2}$$



RADAR BACKSCATTER COEFFICIENT



$$\sigma^{\circ}_{rt} = \frac{\sigma_{rt}}{a}$$

Radarsart 2

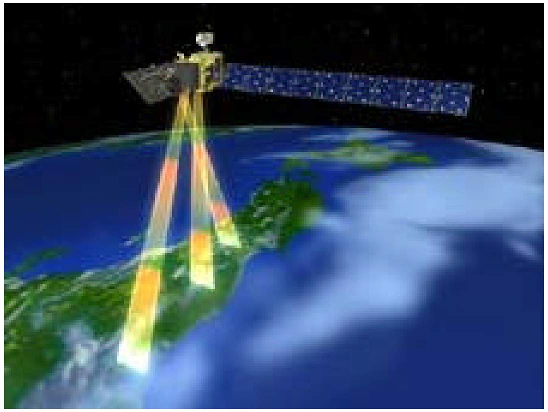
2003

HH,VV,

HV, VH

Advanced Land Observing Satellite (ALOS) 2004

PALSAR (Phased array SAR)



PRISM

LightSAR (USA & Germany

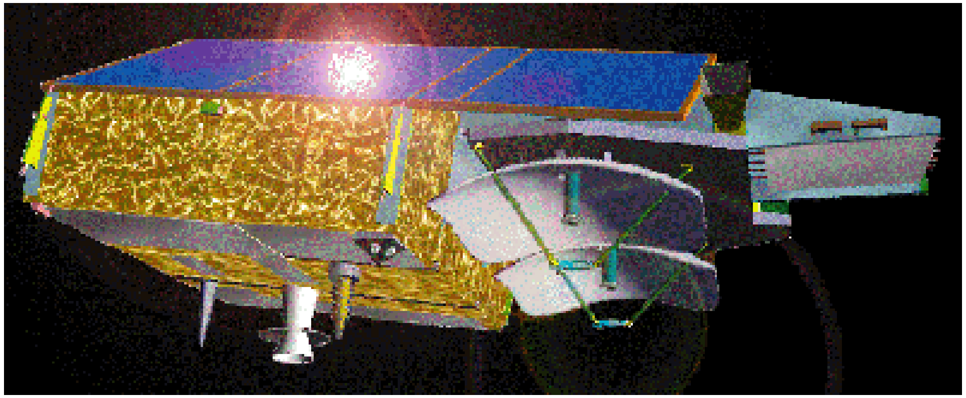
L- and X-band

All Polarizations

RISAT (Radar Imaging Satellite)

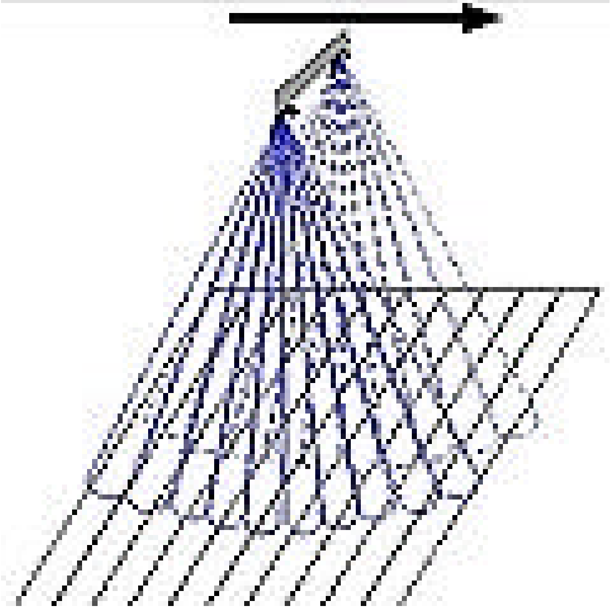
C-band in 3 modes

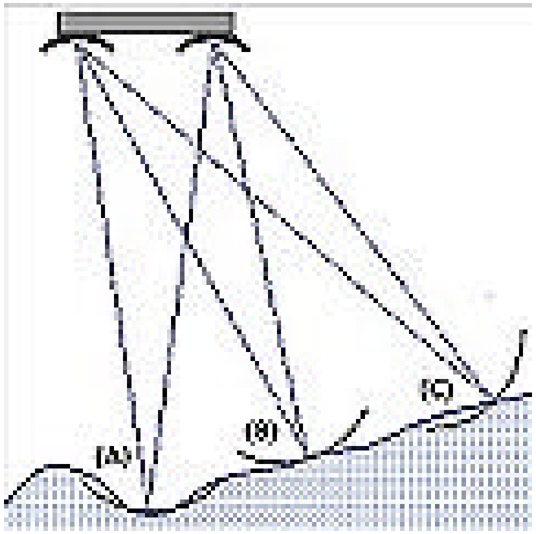
Cryosat



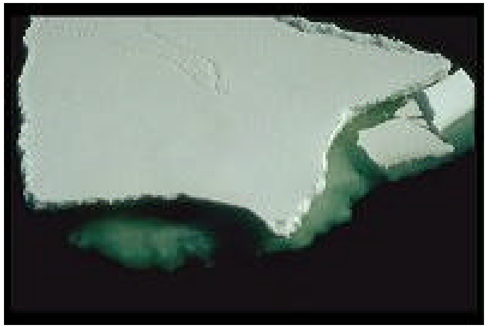
Radar Altimeter Mission

Determine the variation in the thickness of the Ice sheets to be planned to Launch 2004

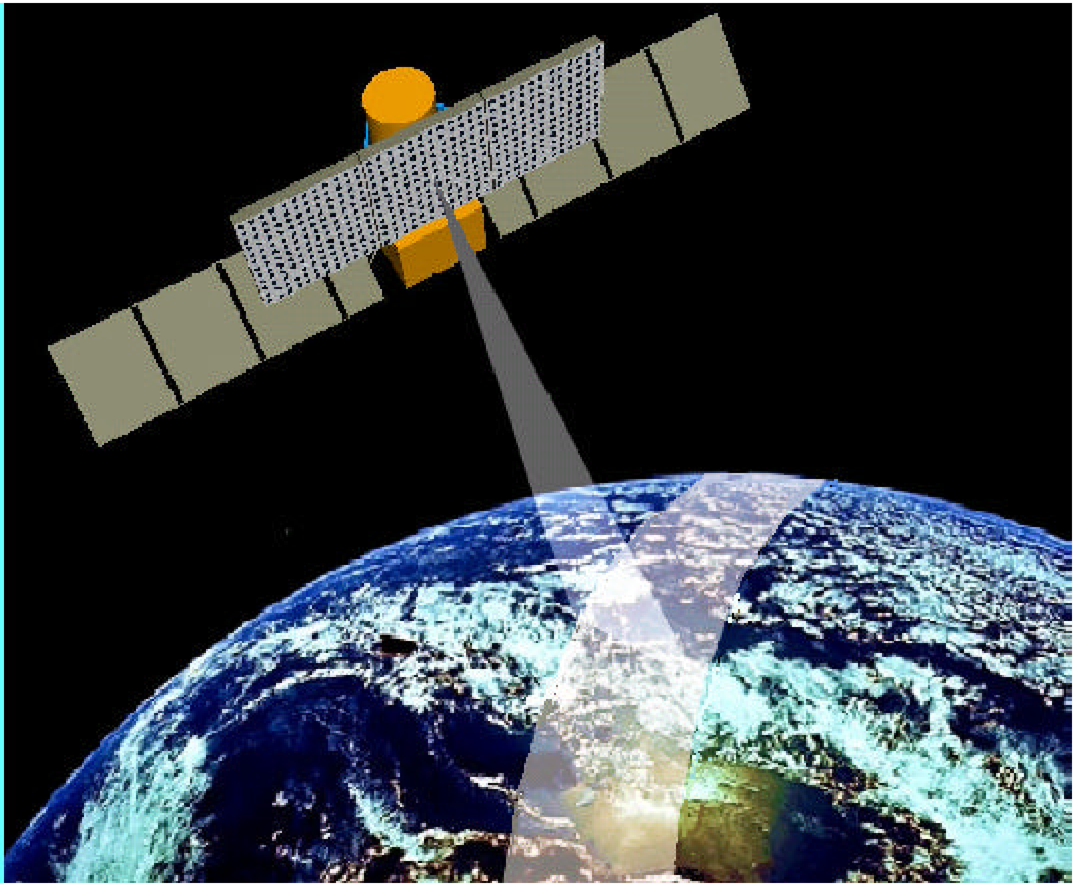




Range Resolution 4.6 cm, accuracy 1 or 2 cm



Indian RISAT SAR



Launch year - 2006

Frequency = 5.35 GHz

Resolution HRS 1-2 m with Swath 10 x 10 km, single/dual polarization

FRS-1 mode 3-6 m with swath 30 km, single/dual polarization

FRS-2 model 9-12, with swath 30 km, Quad polarization

MRS/CRS mode 25- 50 m, with swath 120/240 km, single/quad