Spatial Tools in Water Resource Management

Susan Steele-Dunne

6. Microwave Remote-Sensing

Outline

- **Introduction** to microwave remote sensing
- **Passive** microwave remote sensing
- **Active** microwave remote sensing
- **Exercise: Soil moisture retrieval from ERS WS data**

Acknowledgements

- Canadian Center for Remote Sensing
- NASA, ESA
- Comet/MetEd at UCAR

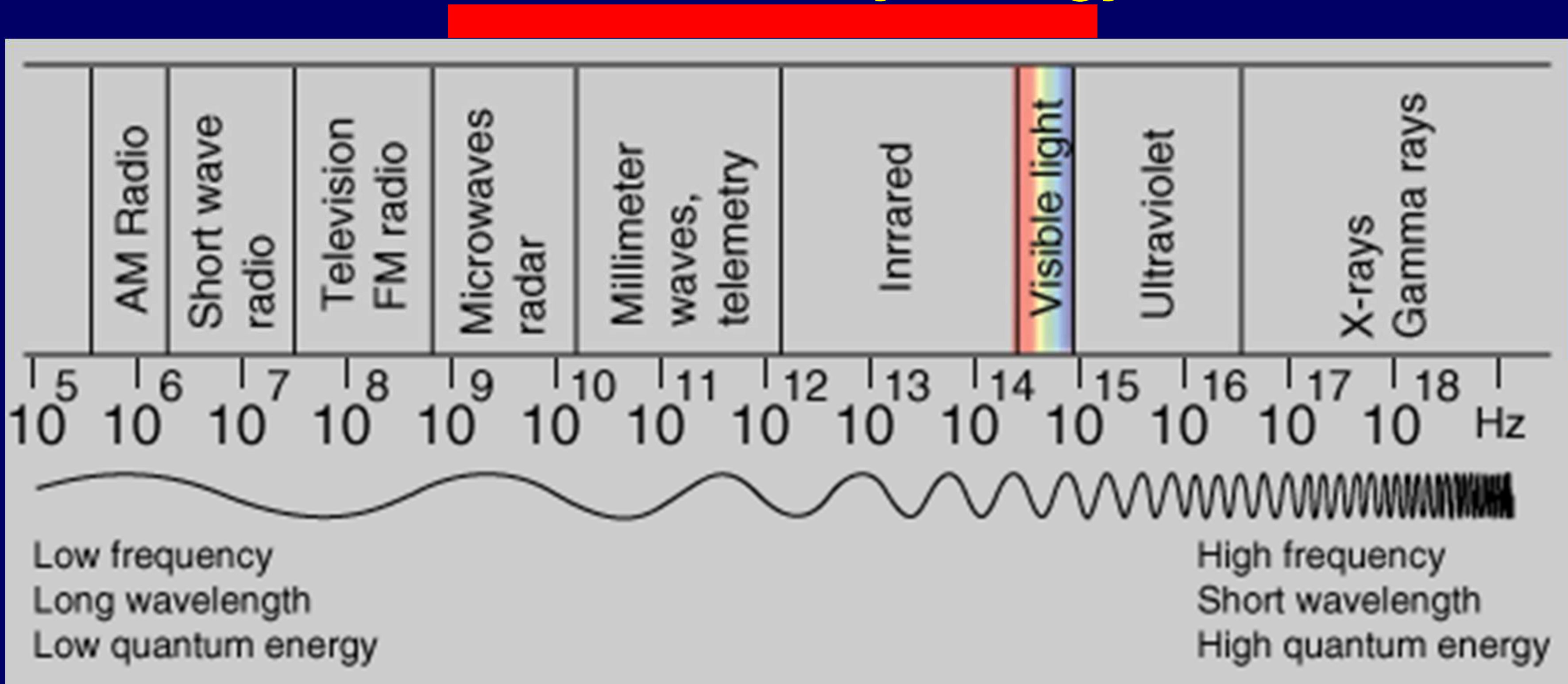
Introduction to Microwave Remote Sensing

By the end of this section, you will be able to:

- List the advantages of MW remote sensing
- Discuss how MW remote sensing compliments VIS and IR remote sensing
- Define the dielectric constant and explain its significance in MW RS
- Discuss the differences between active and passive MW RS

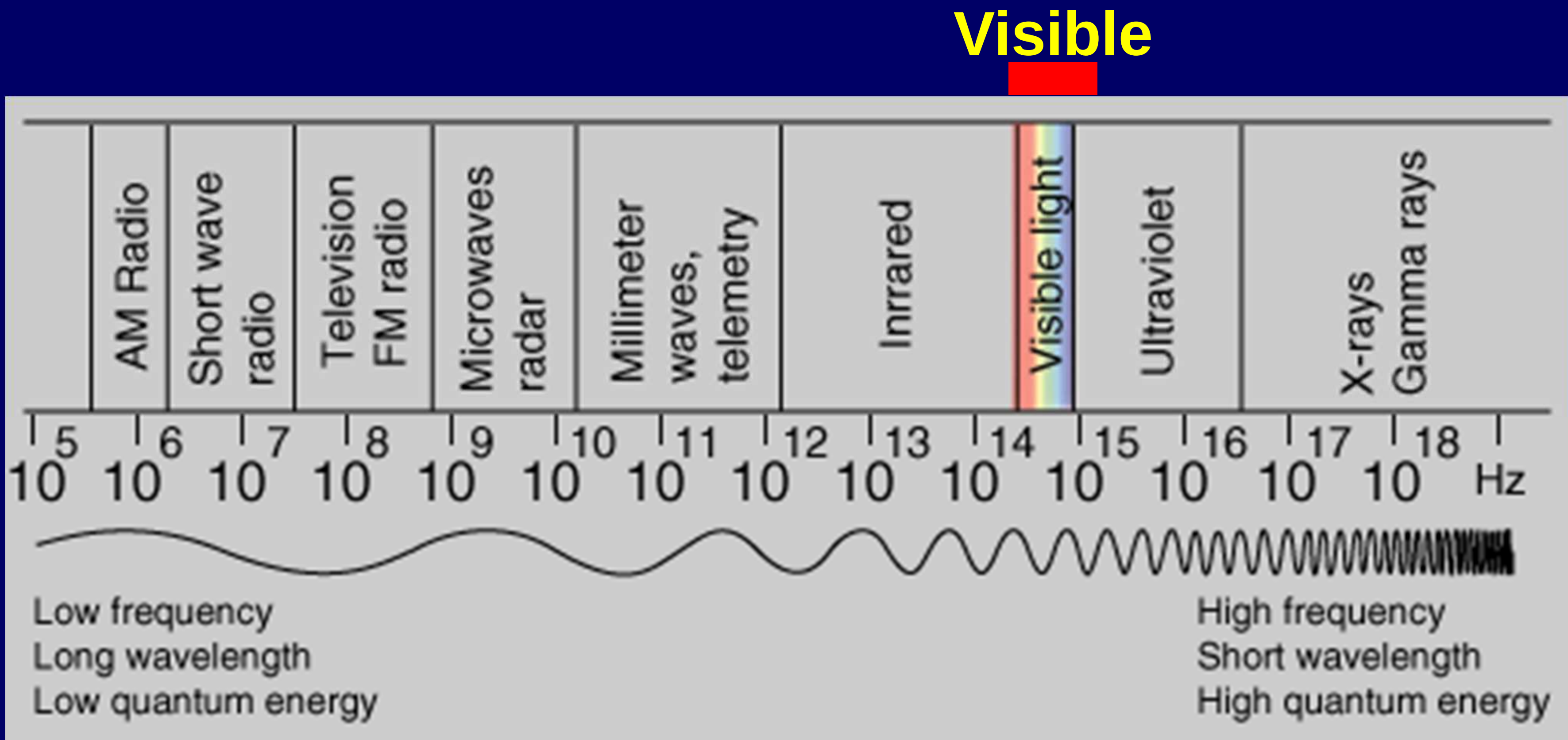
Satellite principles: The Spectrum

Most useful for hydrology



[1]

Satellite principles: The Spectrum



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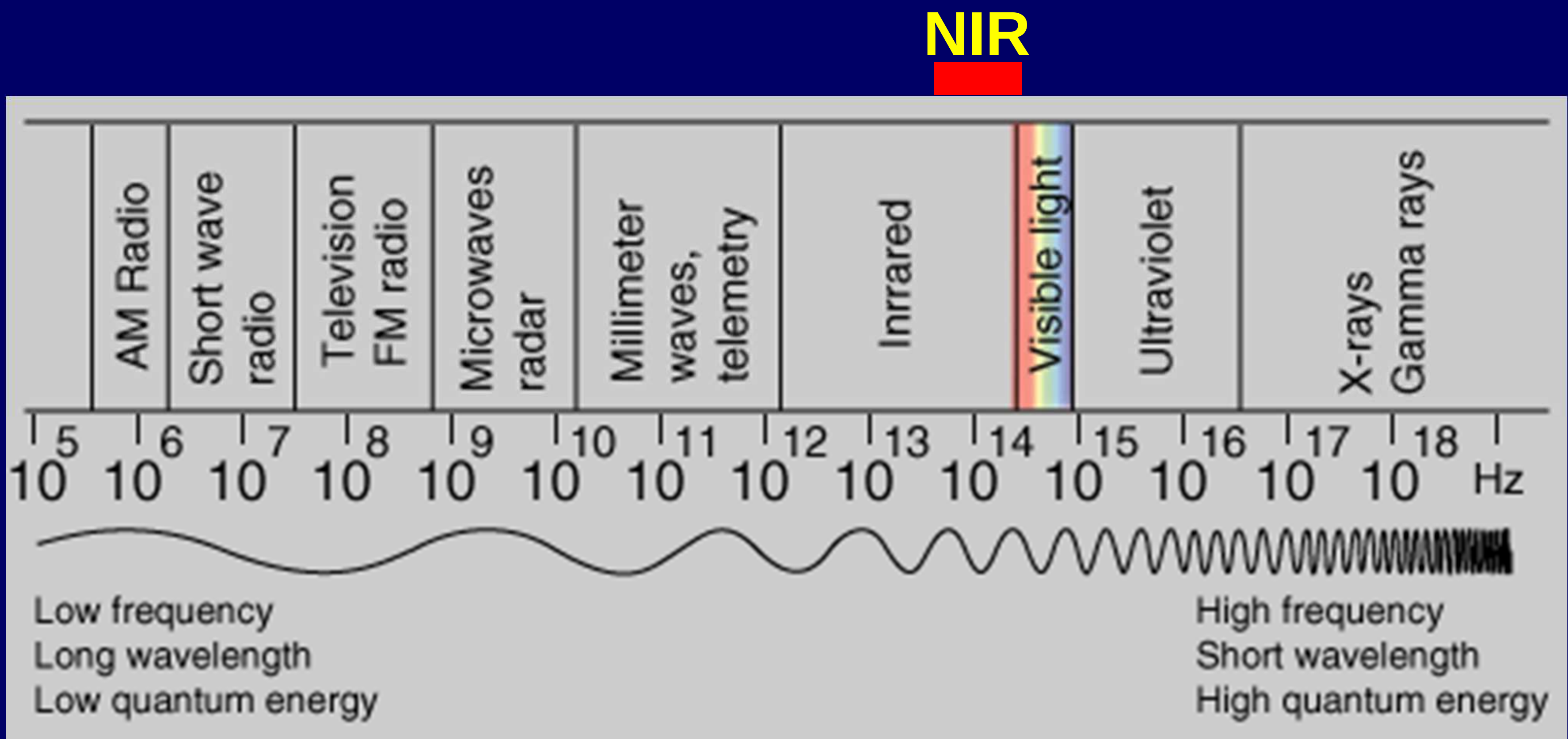
Satellite principles: The Spectrum



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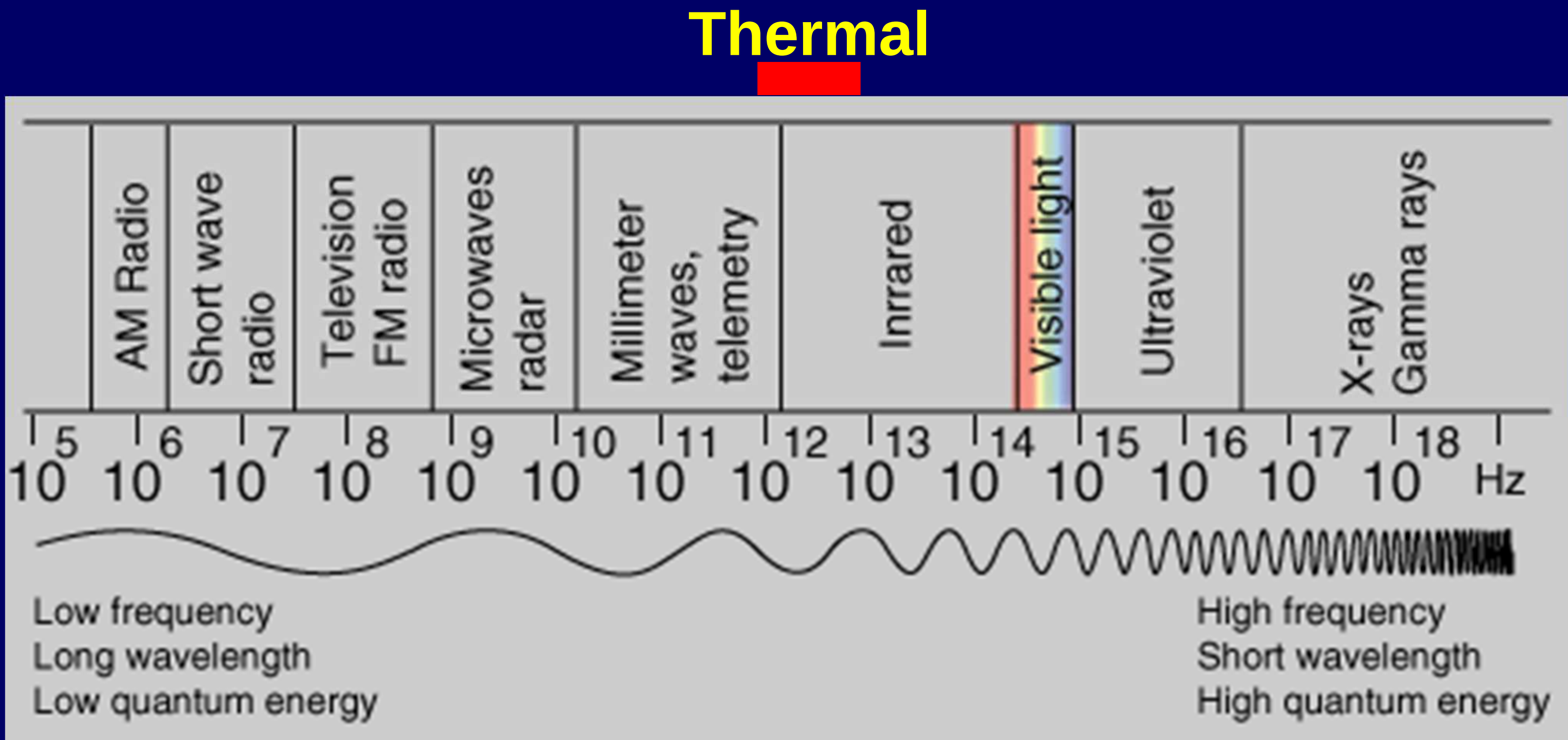
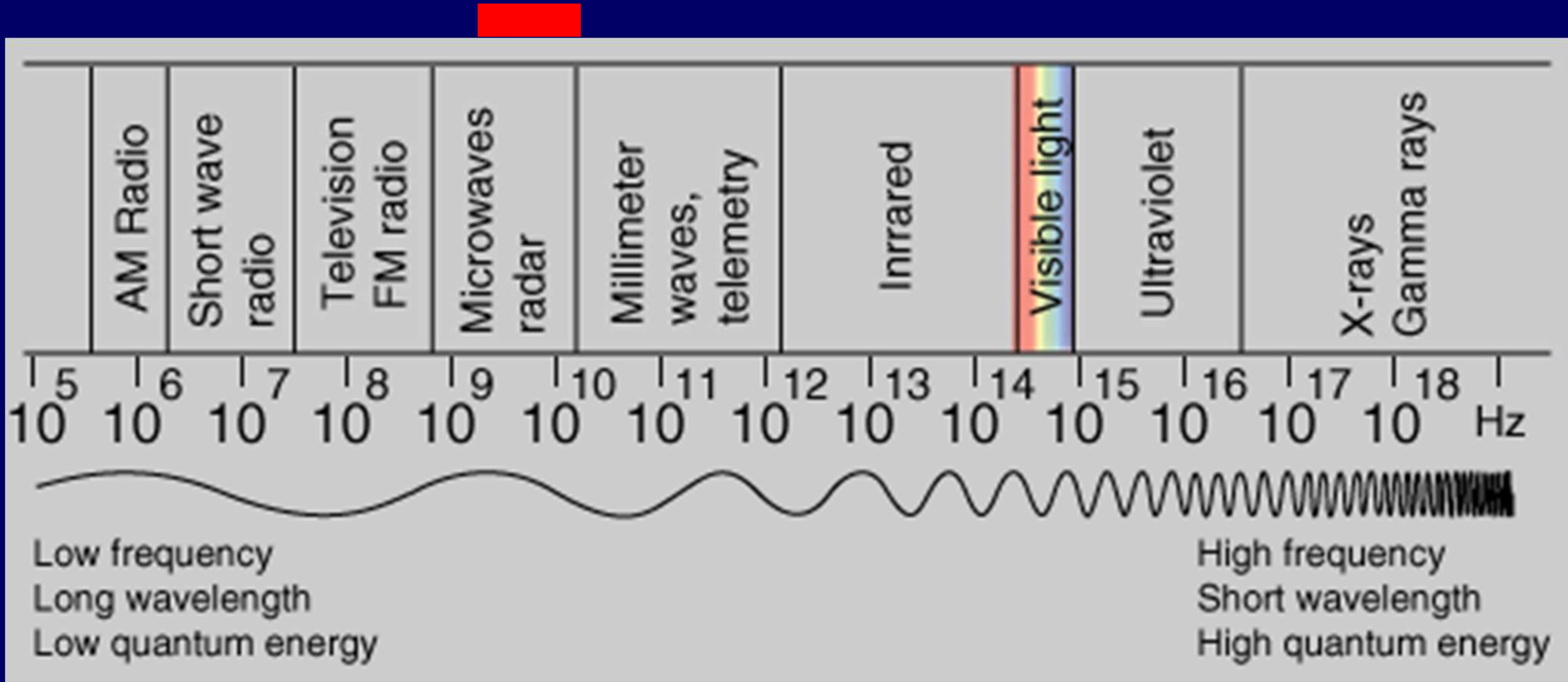


[1]

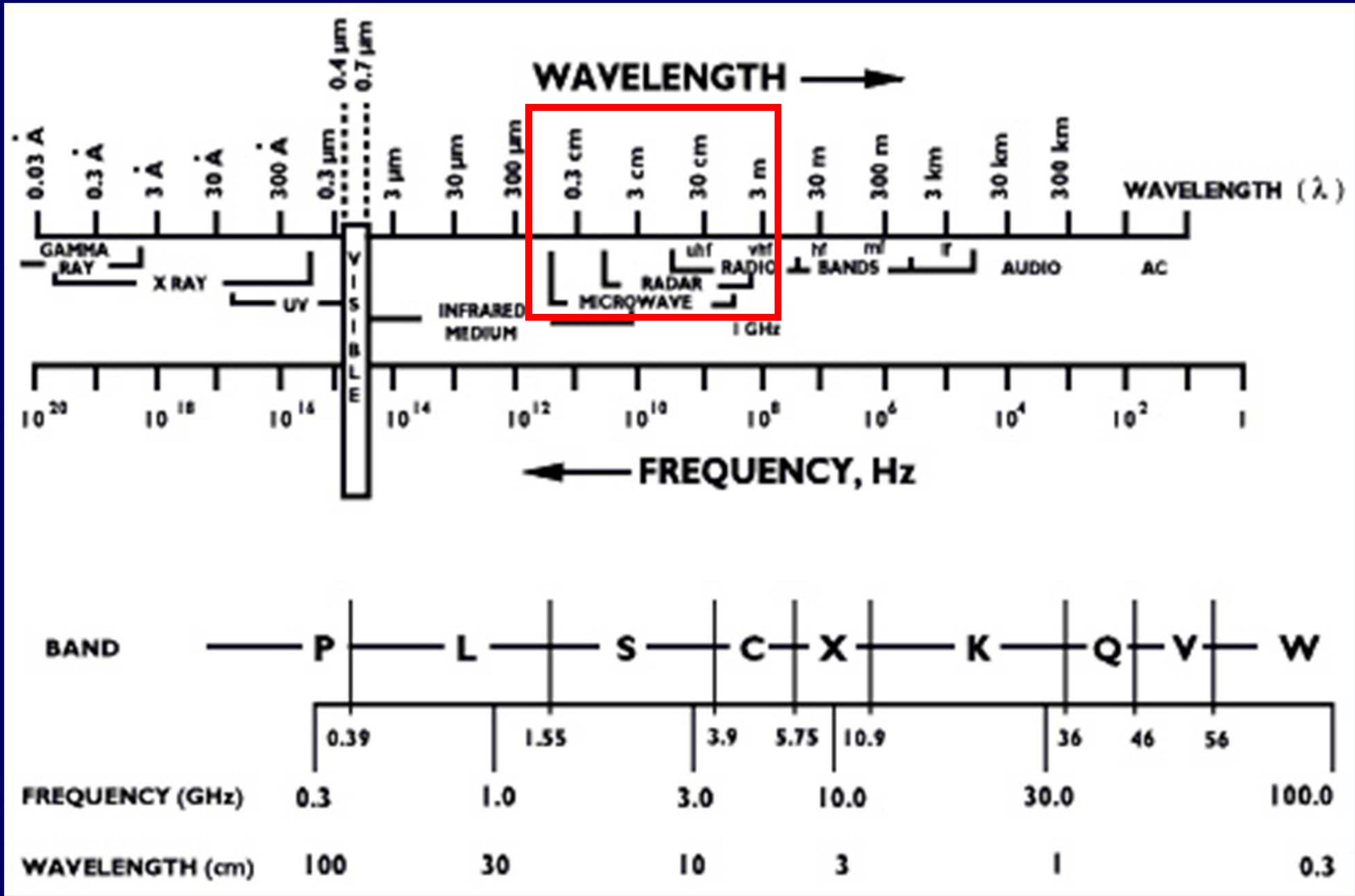
Satellite principles: The Spectrum

Microwave



[1]

Microwaves have wavelengths of 0.1-100cm



Source: ESA

Different microwave bands provide information about different object characteristics.

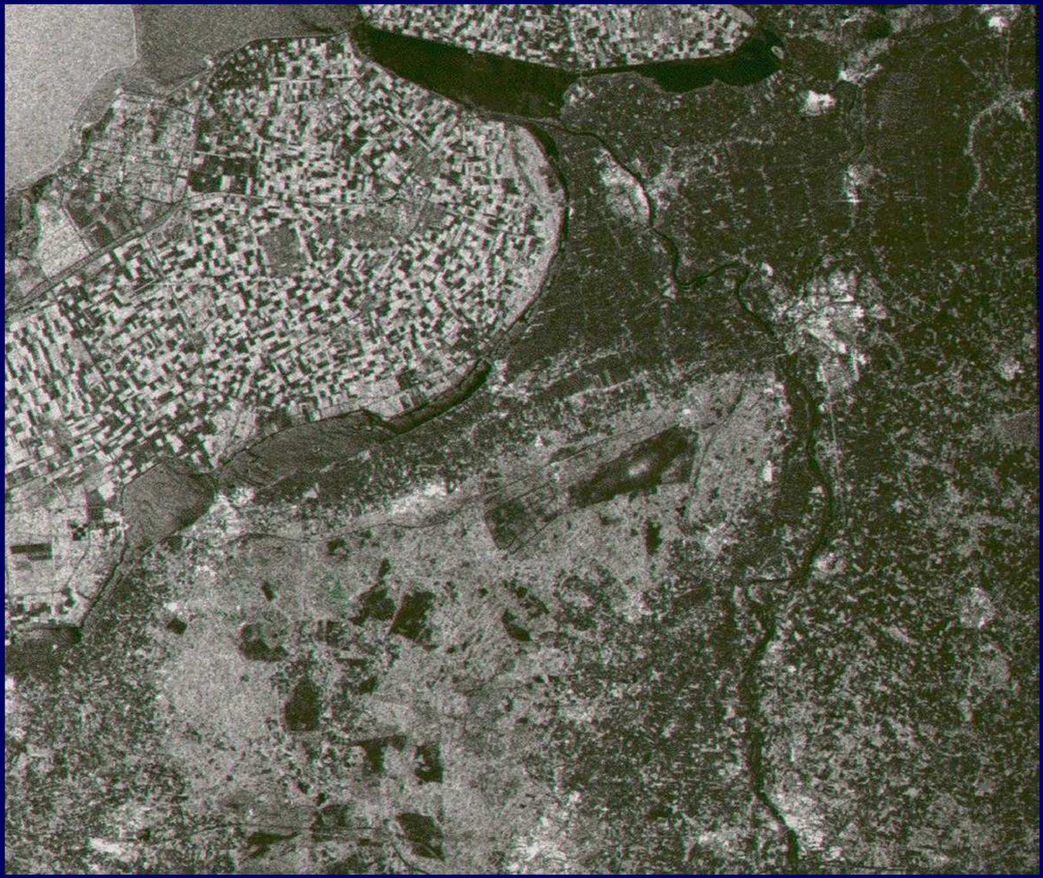
Advantages of using microwave (λ = 1-100cm)

SAR image (ERS-1),
The Netherlands
02/08/1991 local time $\boxed{23:40}$
Source: ESA

Advantages of using microwave (λ = 1-100cm)

Do not need illumination from the sun

=> images can be acquired day and night!



SAR image (ERS-1),
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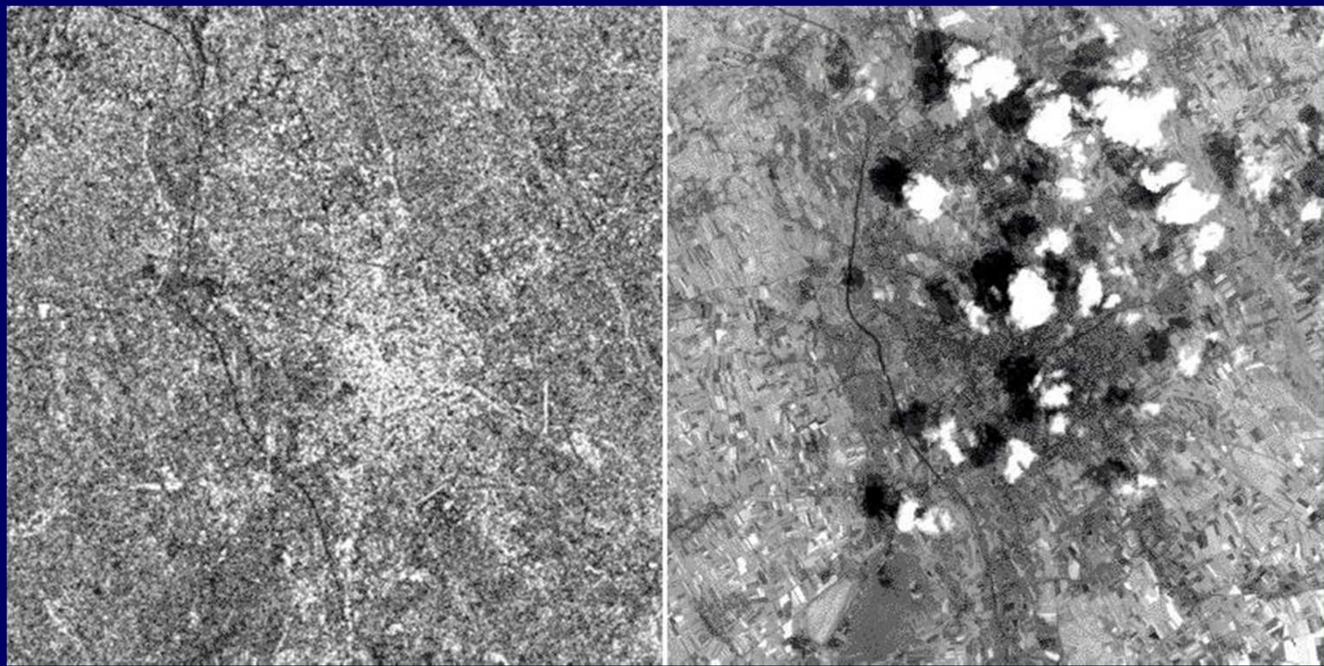


Udine, Italy

ERS-1(microwave)
04/07/1993
9:59am (GMT)

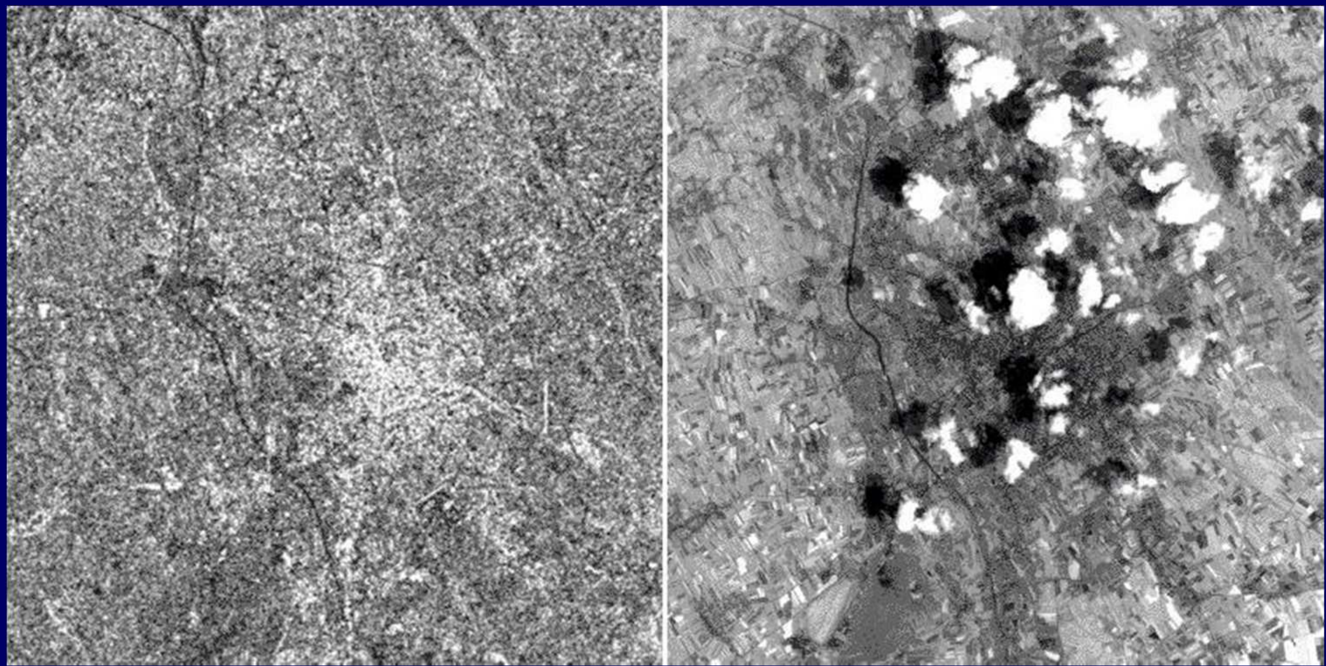
Landsat-5 (optical)
04/07/1993
9:14am(GMT)

Source: ESA

Advantages of using microwave (λ = 1-100cm

Can penetrate clouds

& Independent of atmospheric effects like haze.



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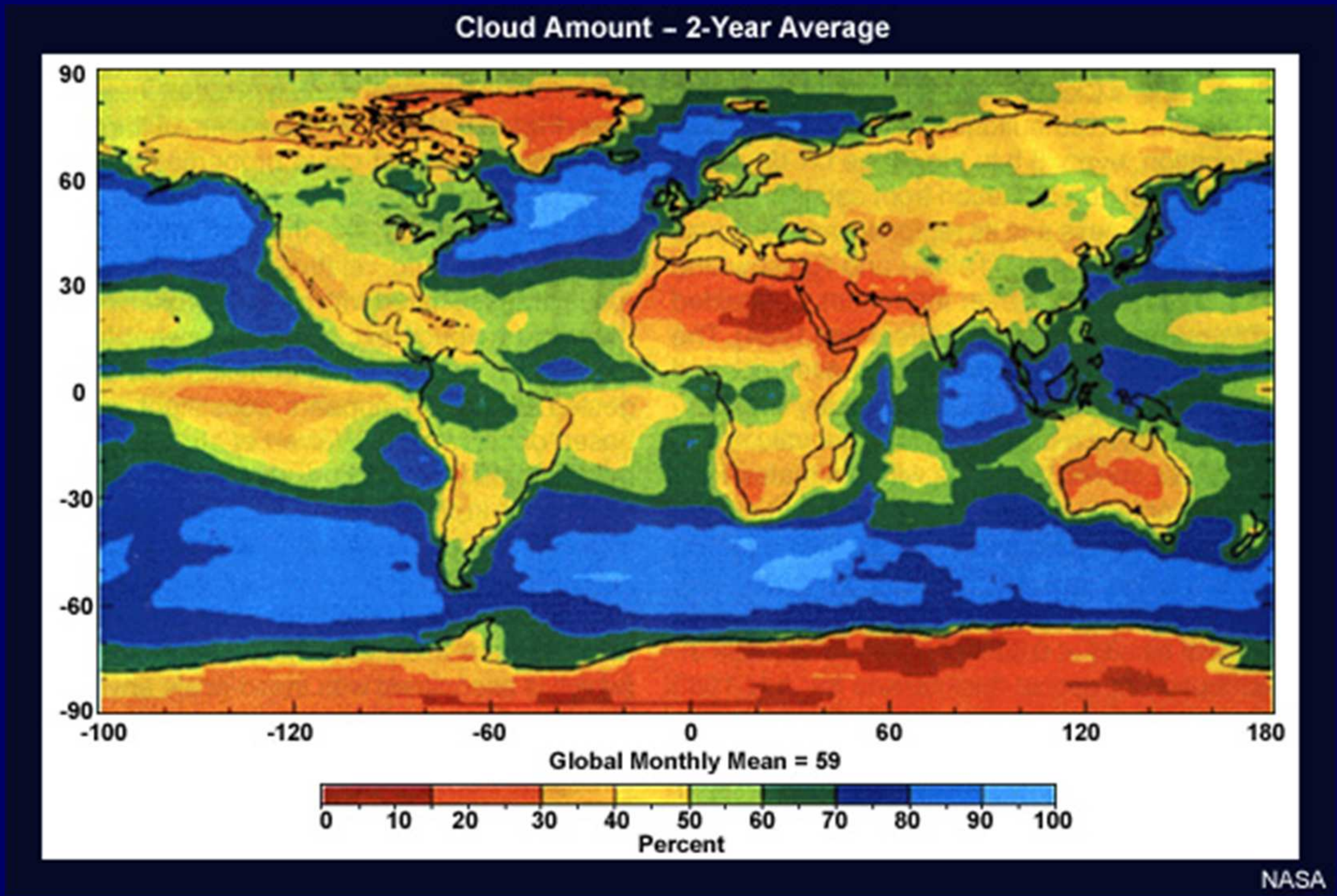

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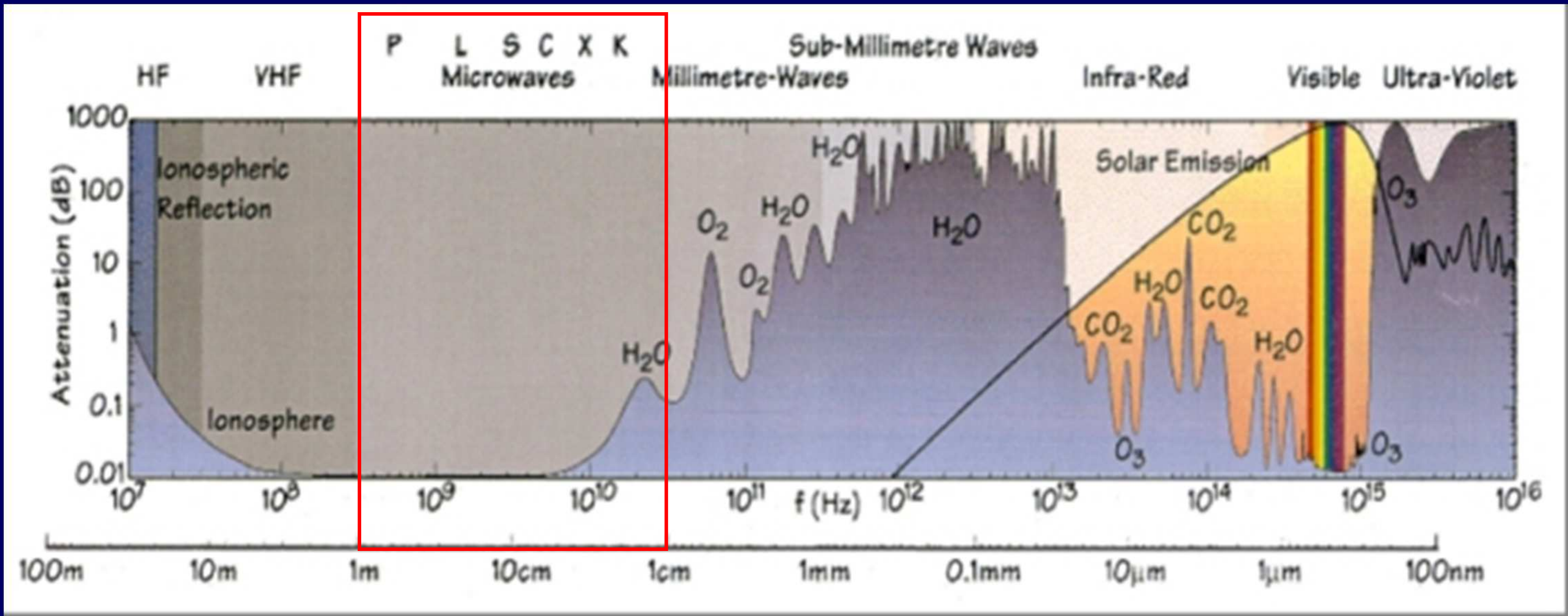
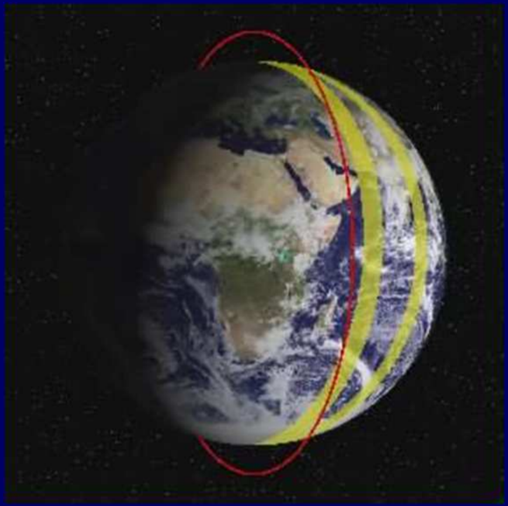


[2]

Microwave sensors in polar orbits

- Polar or near polar orbit
- Sun-synchronous
- Altitude ~800km



- View fixed point at same local time (e.g. 6am/6pm)
- Need more frequent observations? – extra satellites!

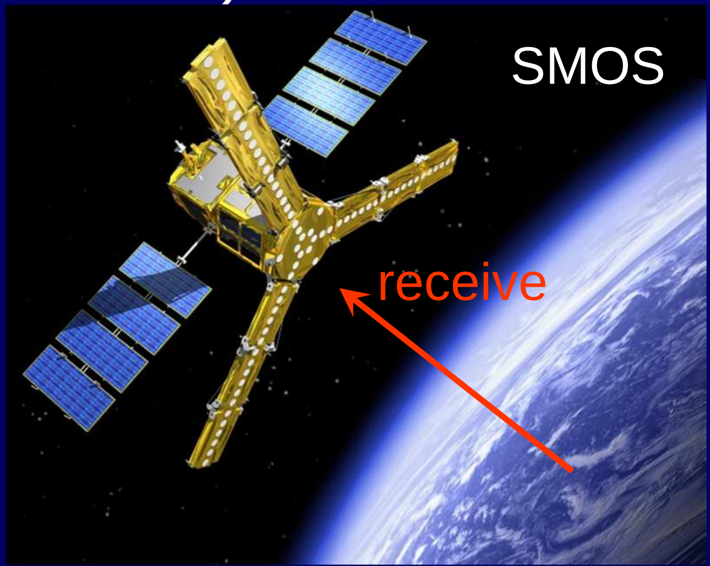
http://en.wikipedia.org/wiki/File:Polar_orbit.ogg

Remote-sensing techniques

Passive

Employ natural sources of energy,

e.g. the sun (optical) or the earth itself (MW) or both (thermal).



[3]

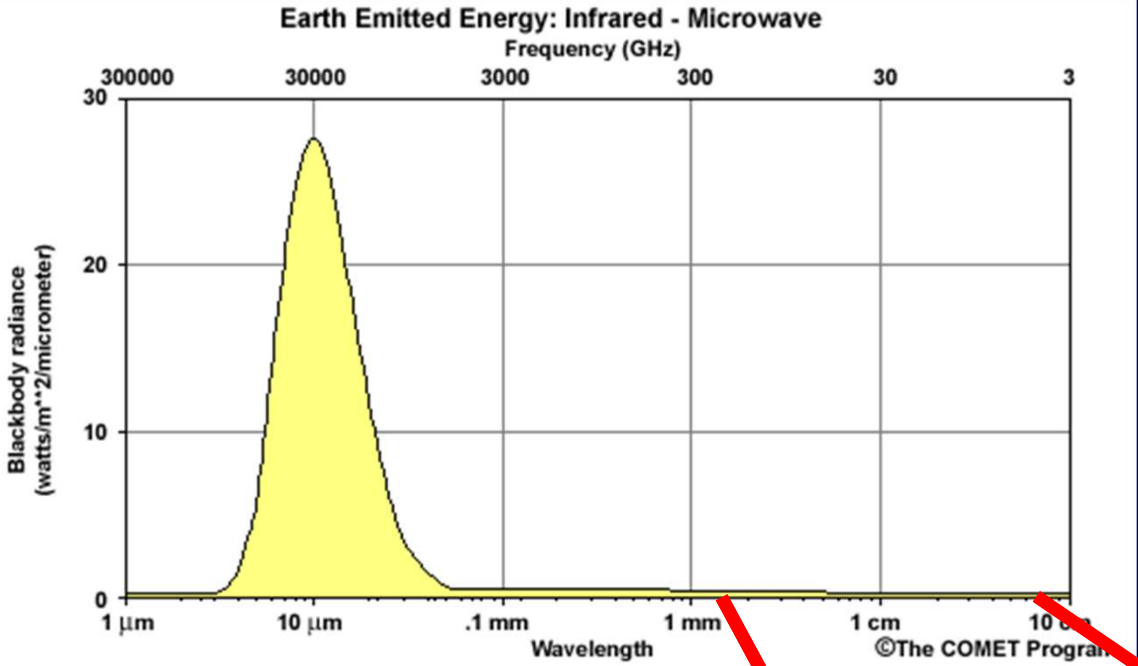
Active

Have their own source of energy.

In lidar, this source is optical.
In radar, this source is MW.

[4]

Energy available to Passive MW sensors



Lower frequency

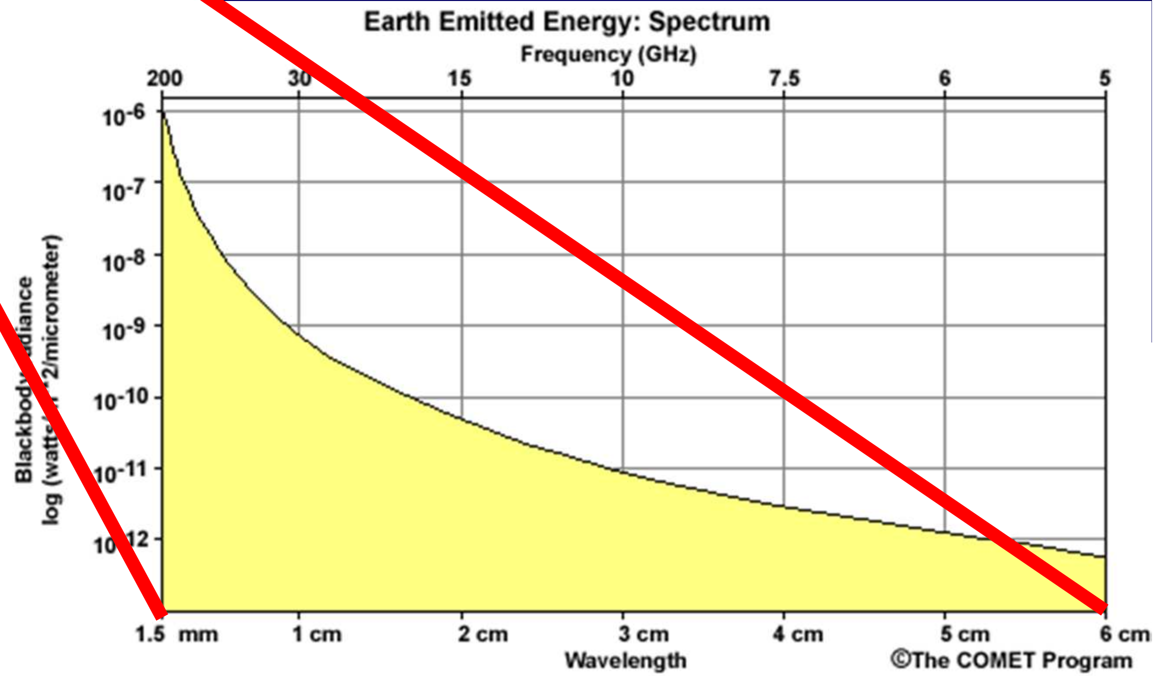
Less energy

Need a larger

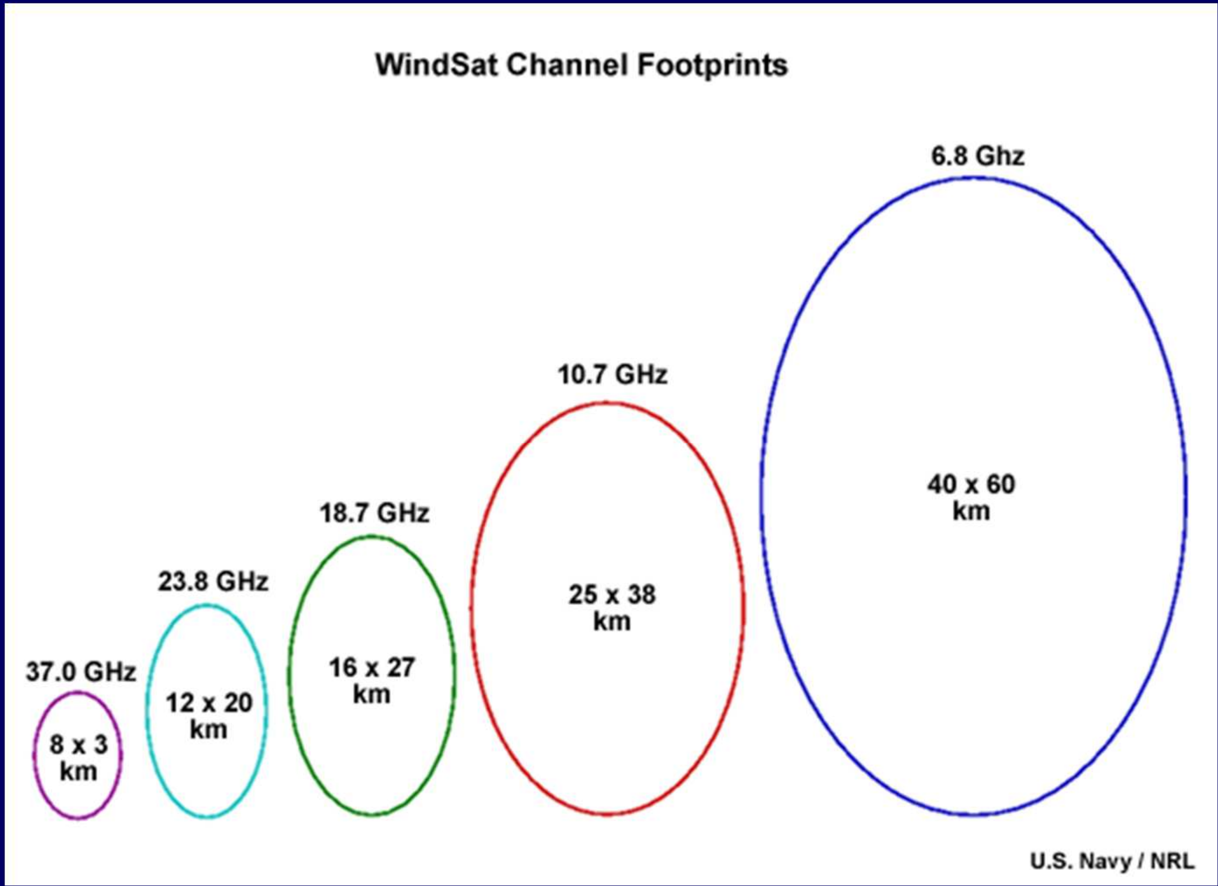
"field of view"

compared to VIS and IR

> 10km



Energy available to Passive MW sensors



Lower frequency

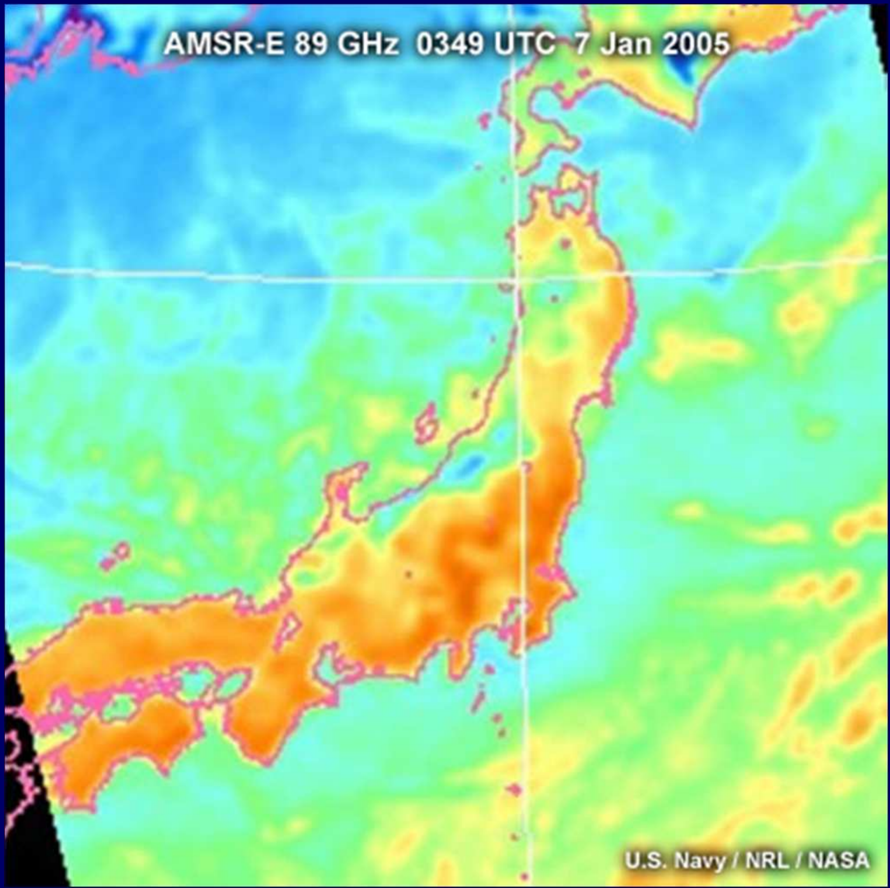
Longer wavelength

Less energy

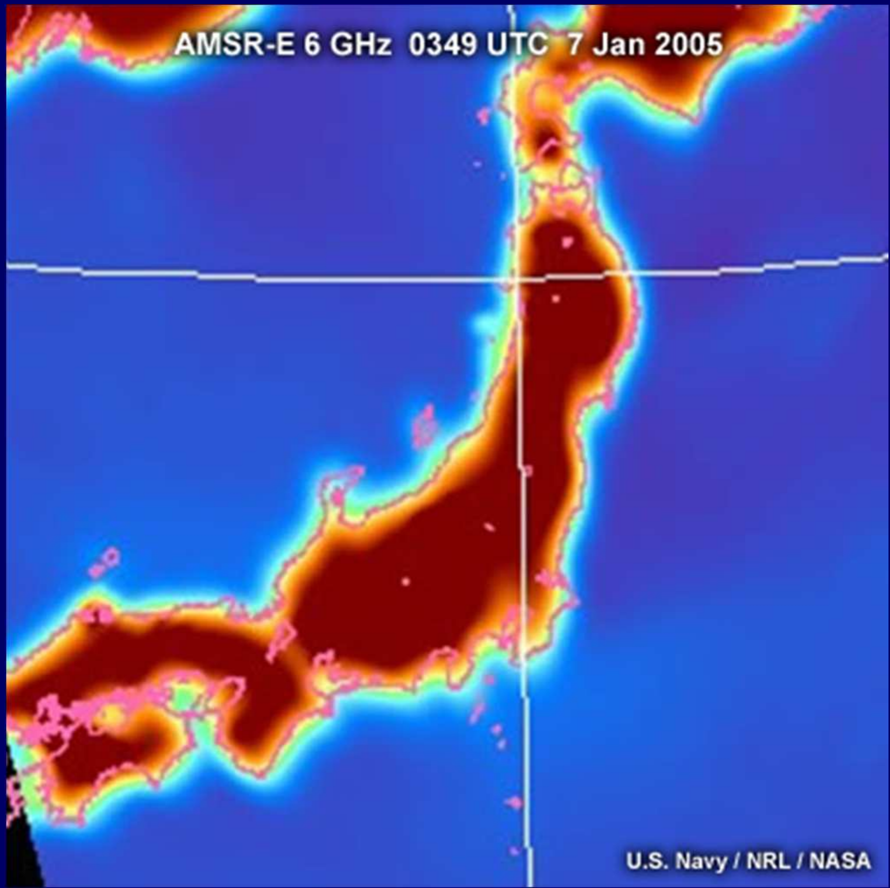
=> Need larger field of view!

Energy available to Passive MW sensors

5km FOV



50km FOV

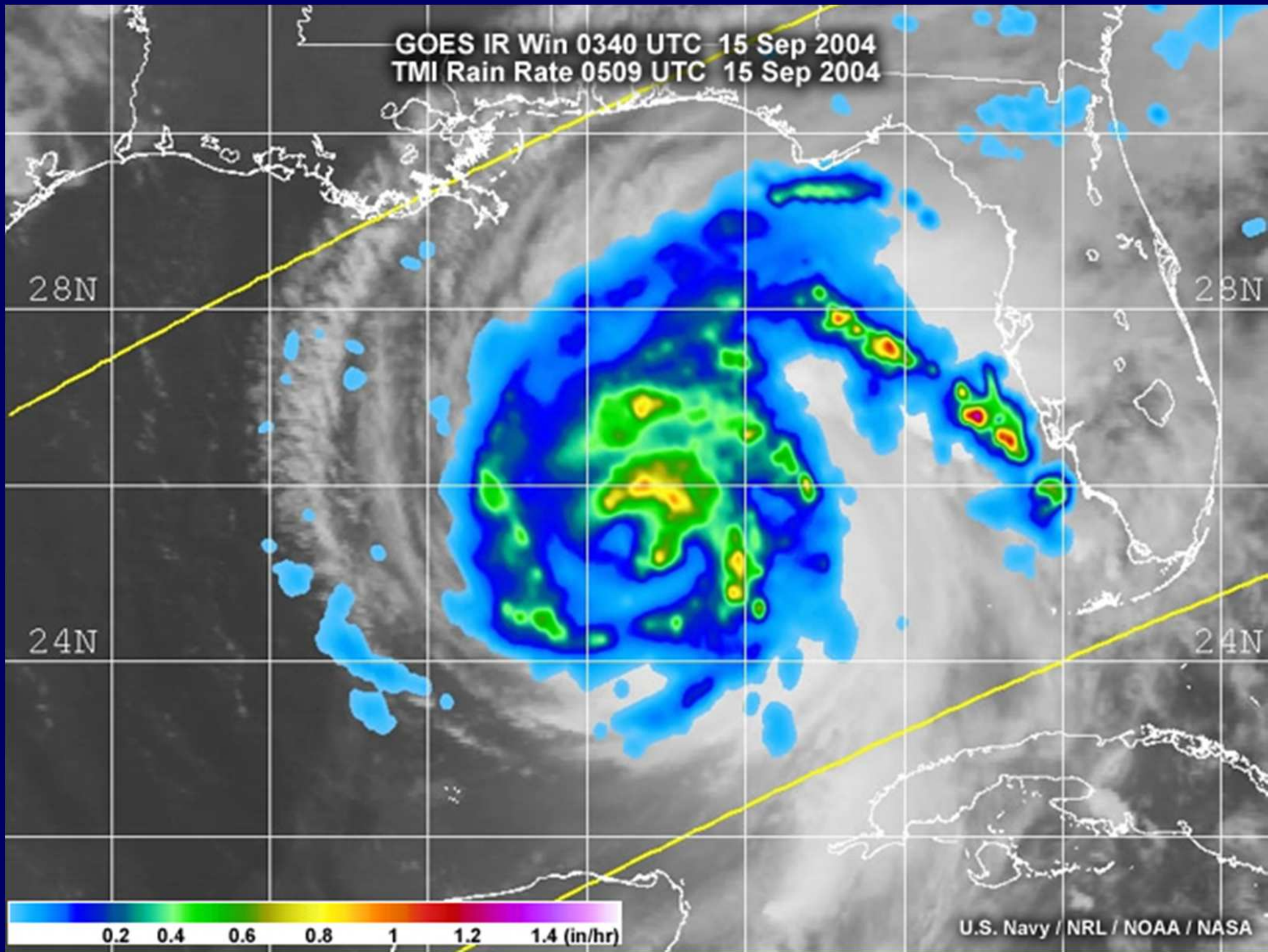


Effect of changing field-of-view on image quality

Influence of water on signal along coastline

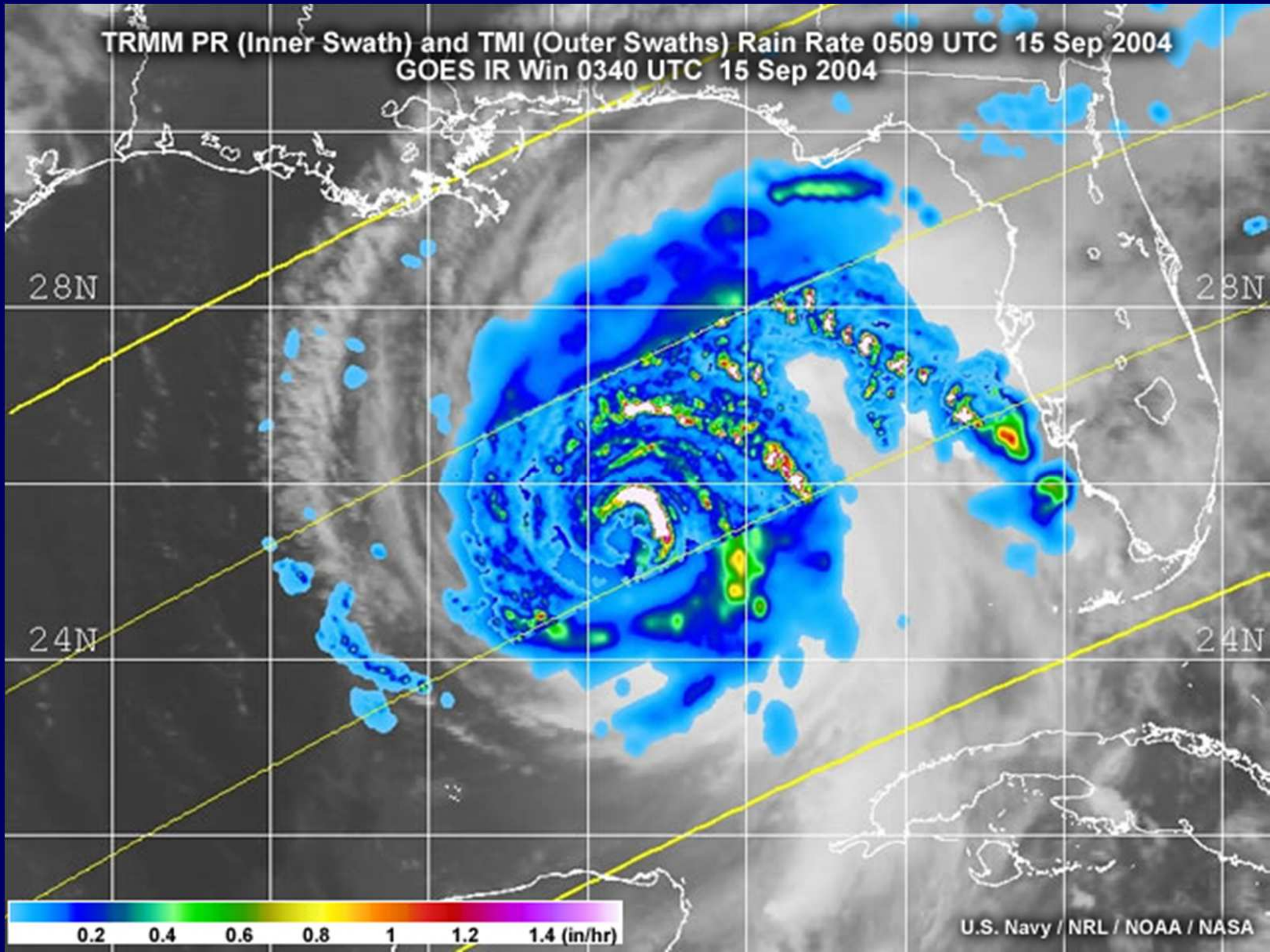
Active v. Passive Precipitation Sensing

TRMM (passive) microwave imager



Active v. Passive Precipitation Sensing

TMI + TRMM Precipitation Radar



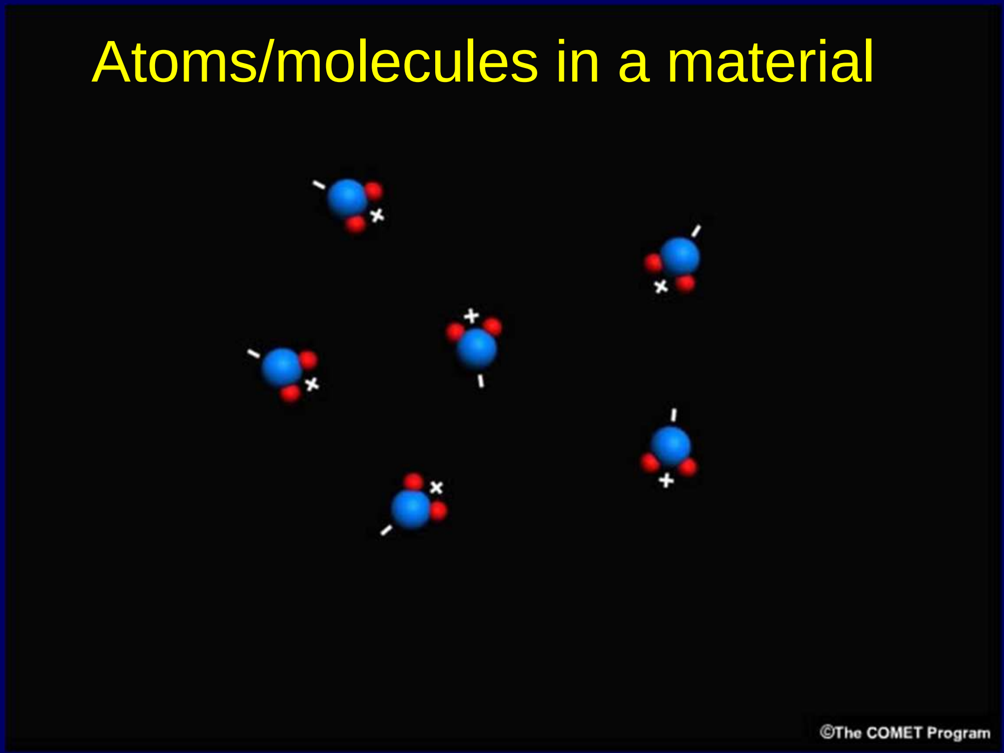
Active v Passive MW Sensors

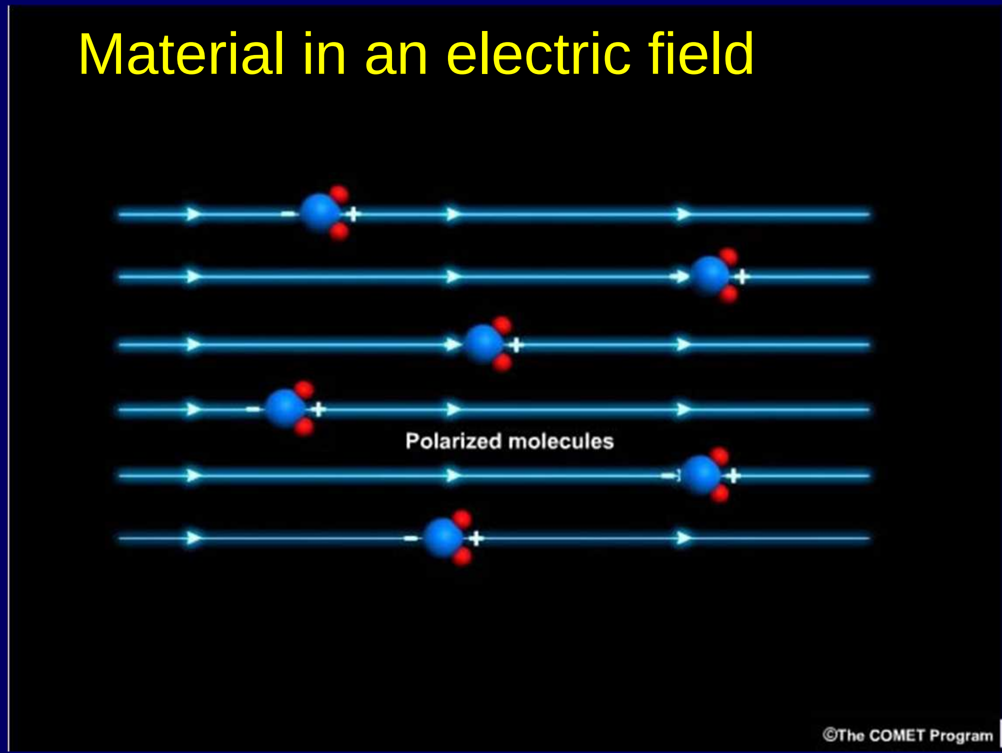
Comparing Active and Passive Microwave Sensors

Passive Microwave Remote Sensing	Active Microwave Remote Sensing
Sensor Examples	
AMSU-A & -B, MHS, AMSR-E, SSM/I/T1/T2, SSMIS, TRMM-TMI, WindSat, NPOESS MIS*, and ATMS	QuikSCAT, TRMM-PR, RADARSAT, MetOp ASCAT, CloudSat, U.S. Navy GFO, Jason-1 and 2, ERS-2 SCAT & SAR, Envisat ASAR, and RA-2
Measurement Capabilities	
Sense emitted microwave energy from terrestrial sources	Send and receive electromagnetic pulses of energy
Cloud and precipitation information from layers	Cloud and precipitation information from discrete levels
Sea surface wind vectors (WindSat, MIS*), salinity	Sea surface wind vectors, salinity
Precipitation (rain rate and snowfall)	Precipitation (rain rate, snowfall, cloud particles and profiling)
Cloud properties (microphysics, cloud top and base)	Cloud properties (microphysics, cloud top, and base)
Atmospheric temperature and moisture profiling	Not applicable for listed sensors
Snow and sea ice coverage and extent, sea ice age	Snow and sea ice coverage and extent, river ice movement
Snow cover characteristics	Snow cover characteristics
Soil moisture / surface wetness	Soil moisture / surface wetness
Vegetation water content, land surface temperature	Vegetation, biomass, land use, surface roughness, topography, and geology (SAR, SCAT, ASCAT, RADARSAT)
Sea surface temperature	Ocean surface topography, sea surface state, heat storage and transfer (from radar altimeters)

*NPOESS microwave imager/sounder capabilites TBD

The Dielectric Constant and Emissivity





A material that becomes polarized in an electric field is a "dielectric" material

The Dielectric Constant and Emissivity

Dielectric Constant

Fundamental parameter of natural materials, relating to its electrical properties:

$$\varepsilon = \varepsilon' + j\varepsilon''$$

Real component
aka “dielectric constant”

Affects scattering

Imaginary component
aka “lossy component”

Affects absorption/losses

It affects the reflective and emissive properties of a medium

High dielectric constant => more reflective => more surface scattering
=> Low emissivity!

The Dielectric Constant and Emissivity

Dielectric Constants for Various Materials

Common naturally occuring materials	Typical Dielectric Constants between ~1 to 100 GHz ε'
Air, vacuum	1.00059, 1.0 (by definition)
Ice (fresh, sea)	3.2, 4-8
Snow (dry, wet)	1.3-1.6, 1.4-1.9
Permafrost	4-8
Water (fresh)	80 (20°C, <3 GHz), ↓15-25 (~3 GHz) and decreasing with frequency
Sea water	78 (20°C, <3 GHz), decreasing with frequency
Sandy soil (dry, wet)	2.5-5, 15-30
Loamy soil (dry, wet)	4-6, 10-20
Clayey soil (dry, wet)	4-6, 10-15
Silts	5-30
Granite	4-6
Limestone	4-8
Salt	4-7

The Dielectric Constant and Emissivity

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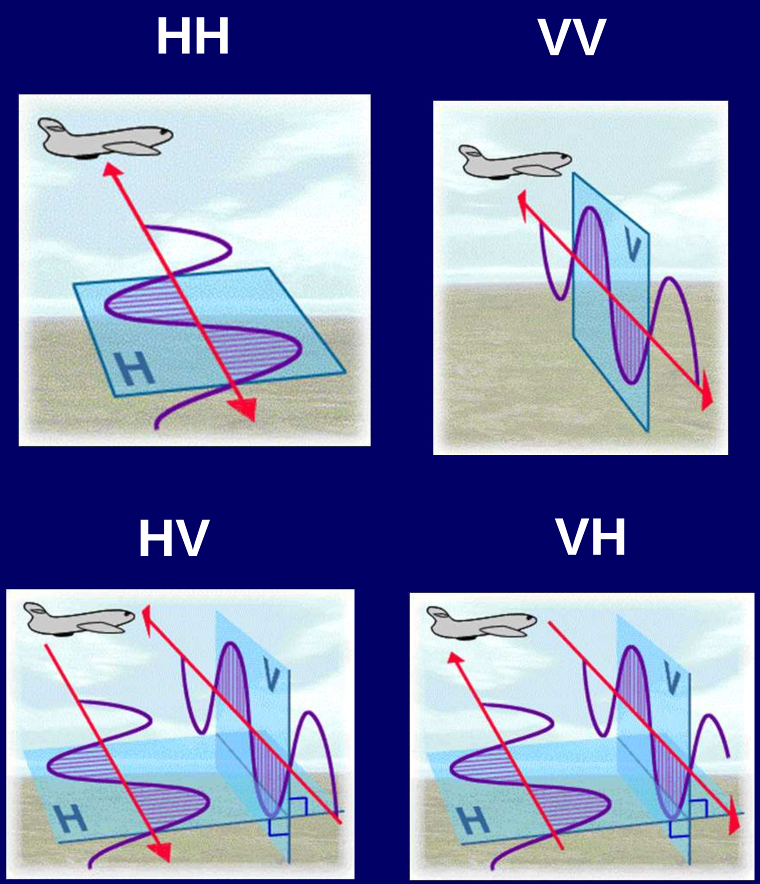
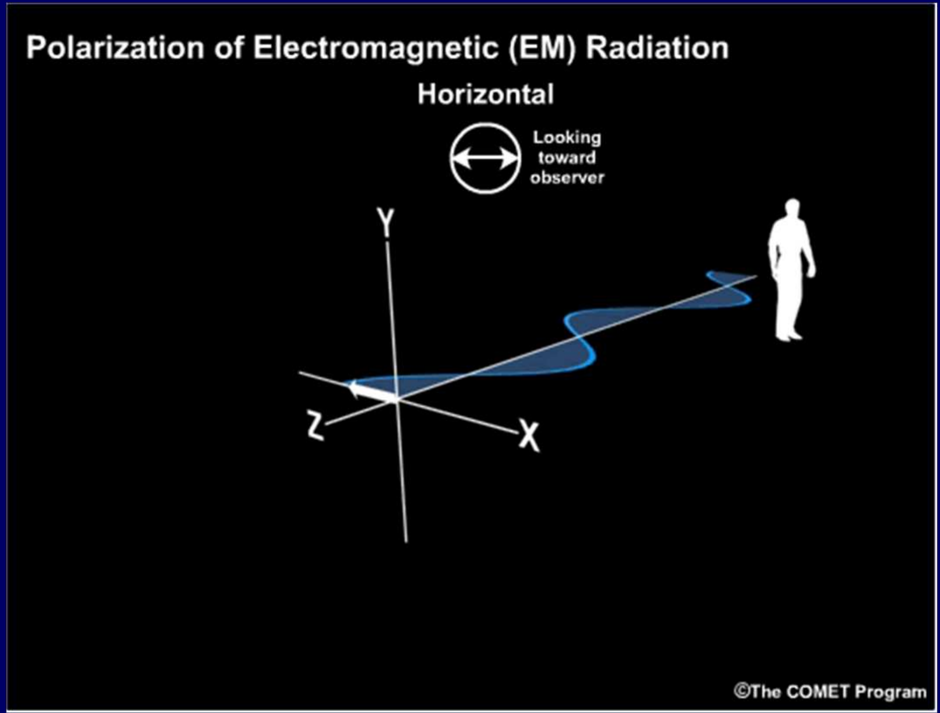
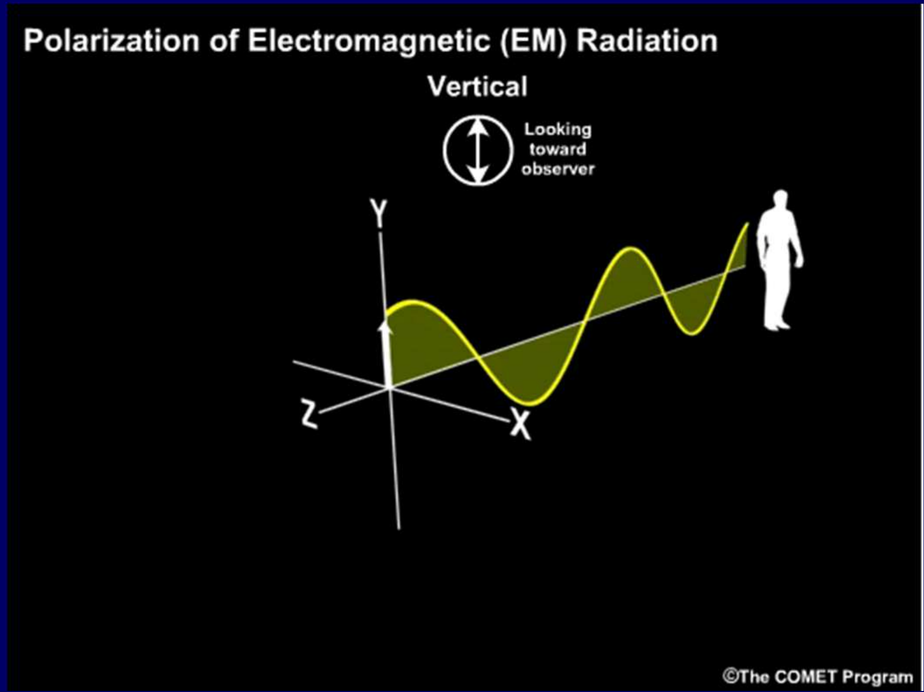
Polarization



Source: CCRS





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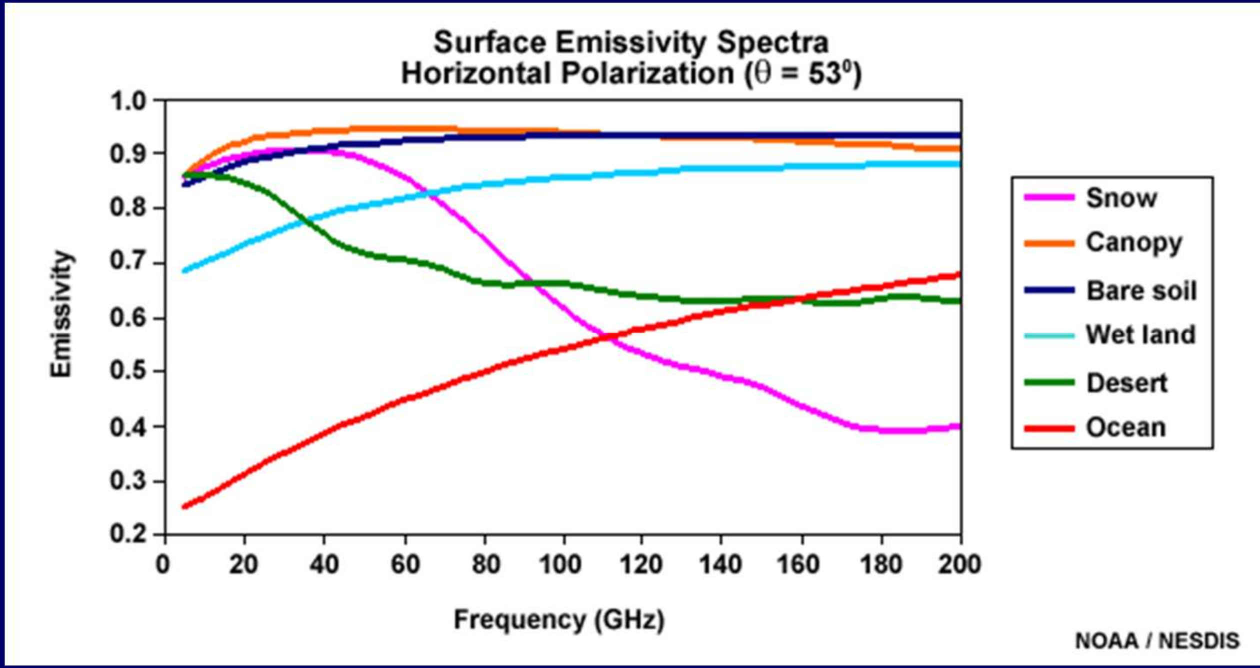

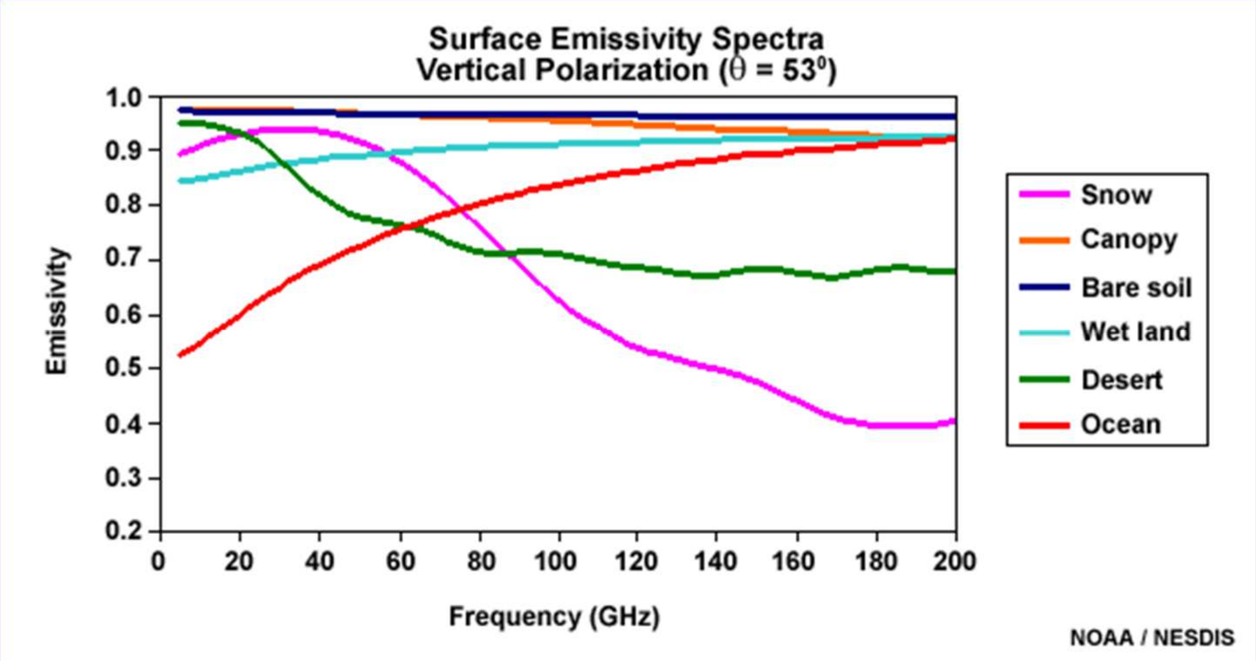

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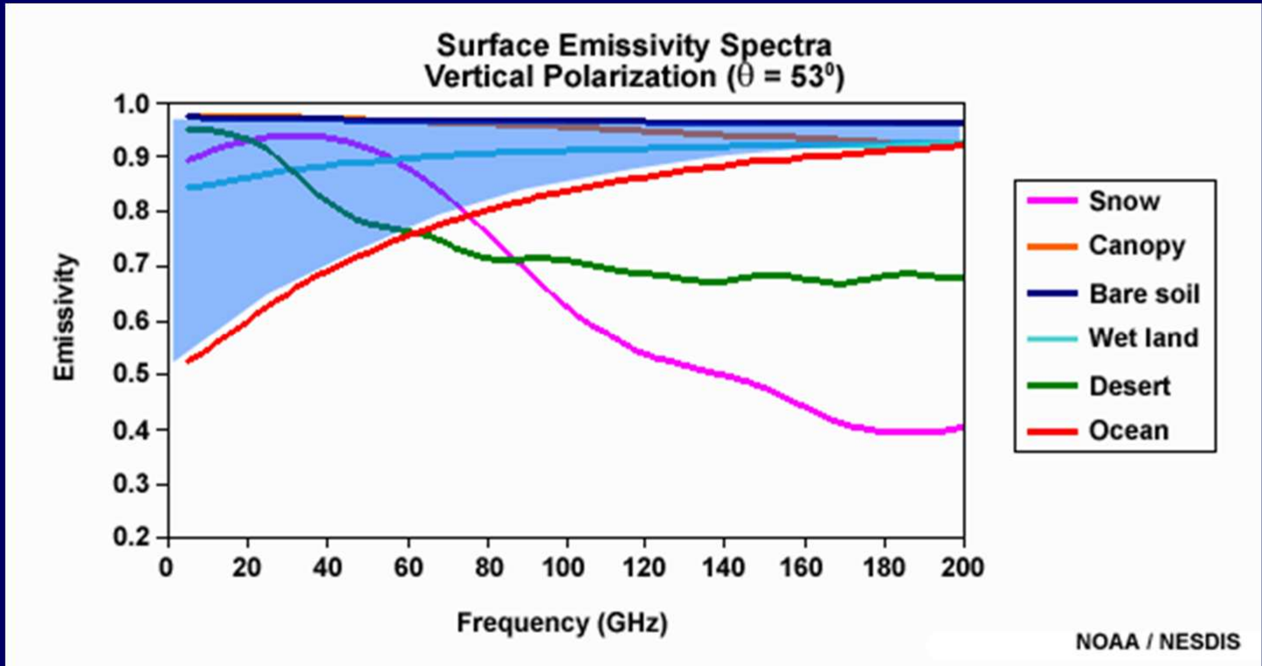
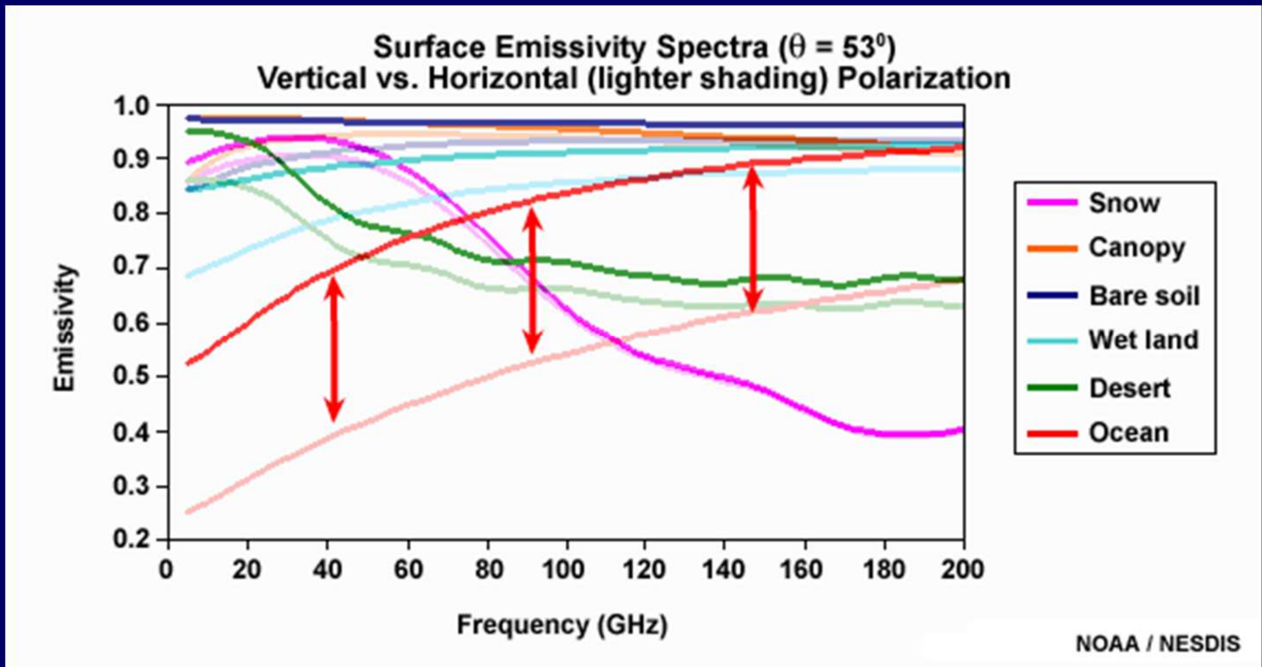




Introduction to Remote Sensing

Summary

- Microwave measurements can be made day/night regardless of cloudiness
- Differences in dielectric constant and hence emissivity allow us to measure surface properties
- Microwave sensors can be classified as active or passive

Passive microwave remote sensing
Learning objectives

By the end of this section, you will be able to:

1) Explain emissivity and brightness temperature
2) List some data products derived from passive microwave remote sensing
3) Explain how soil moisture can be retrieved from brightness temperature measurements

Passive Microwave Remote-Sensing

Planck's Law:
Spectral brightness (B_f)

$$B_f = \frac{2hf^3}{c^2}\frac{1}{e^{hf/kT}-1}$$

Rayleigh-Jeans Approximation of Planck's Law

For low frequencies $\frac{hf}{kT} << 1$

$$B_f = \frac{2f^2kT}{c^2} \Rightarrow \boxed{B_f \propto T}$$

Passive Microwave Remote-Sensing

Blackbody = perfect absorber, perfect emitter
(emissivity = 1)

All other materials are grey bodies (emissivity <1)

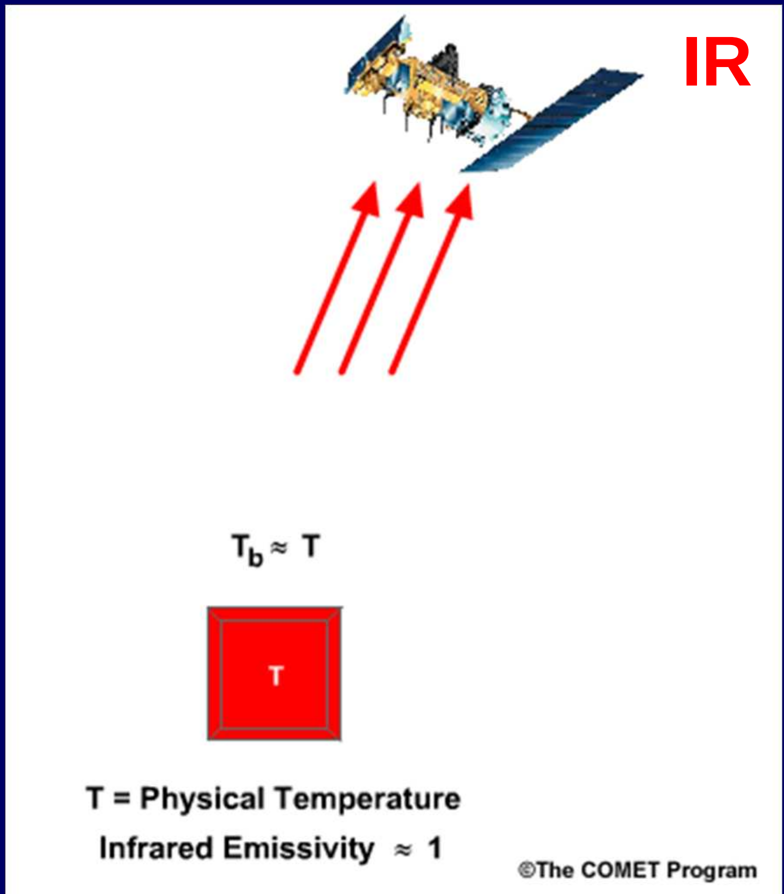
Brightness temperature

$$T_B = e\ T$$

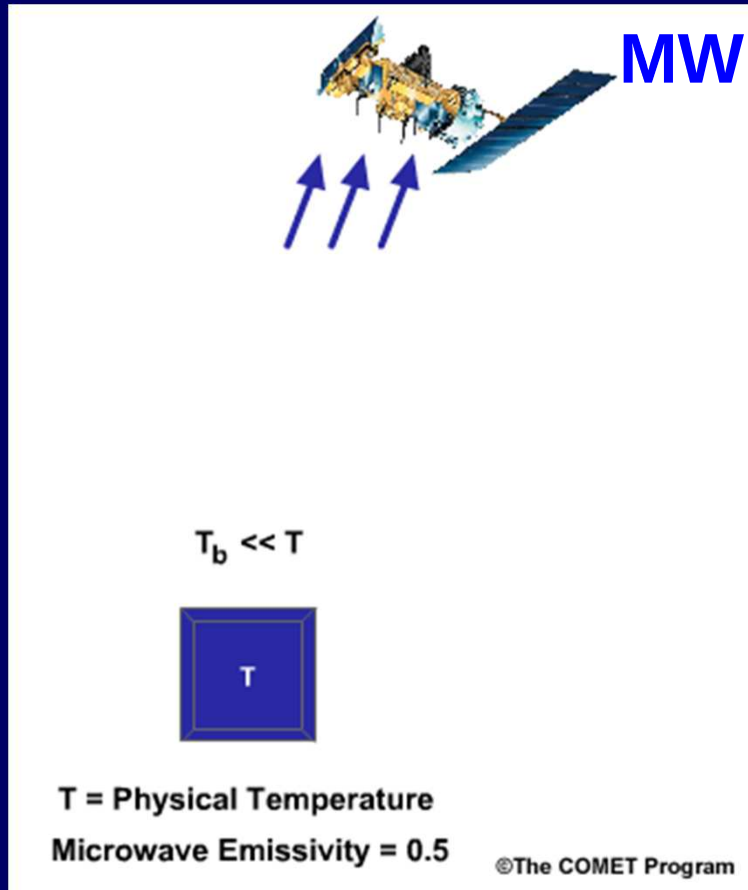
T_B is the temperature a blackbody would have to have the same brightness (at some frequency f) as a grey body with emissivity e and temperature T.

Passive Microwave Remote-Sensing

Infrared v Microwave Temperature



Little reflection or scattering

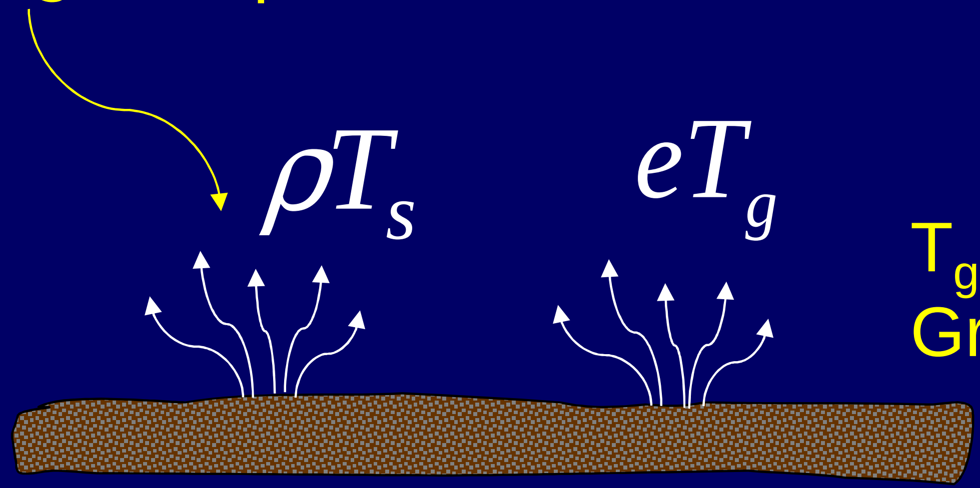


Dielectric effect

=> Reflection, scattering

Passive Microwave Remote-Sensing

T_s Sky temperature

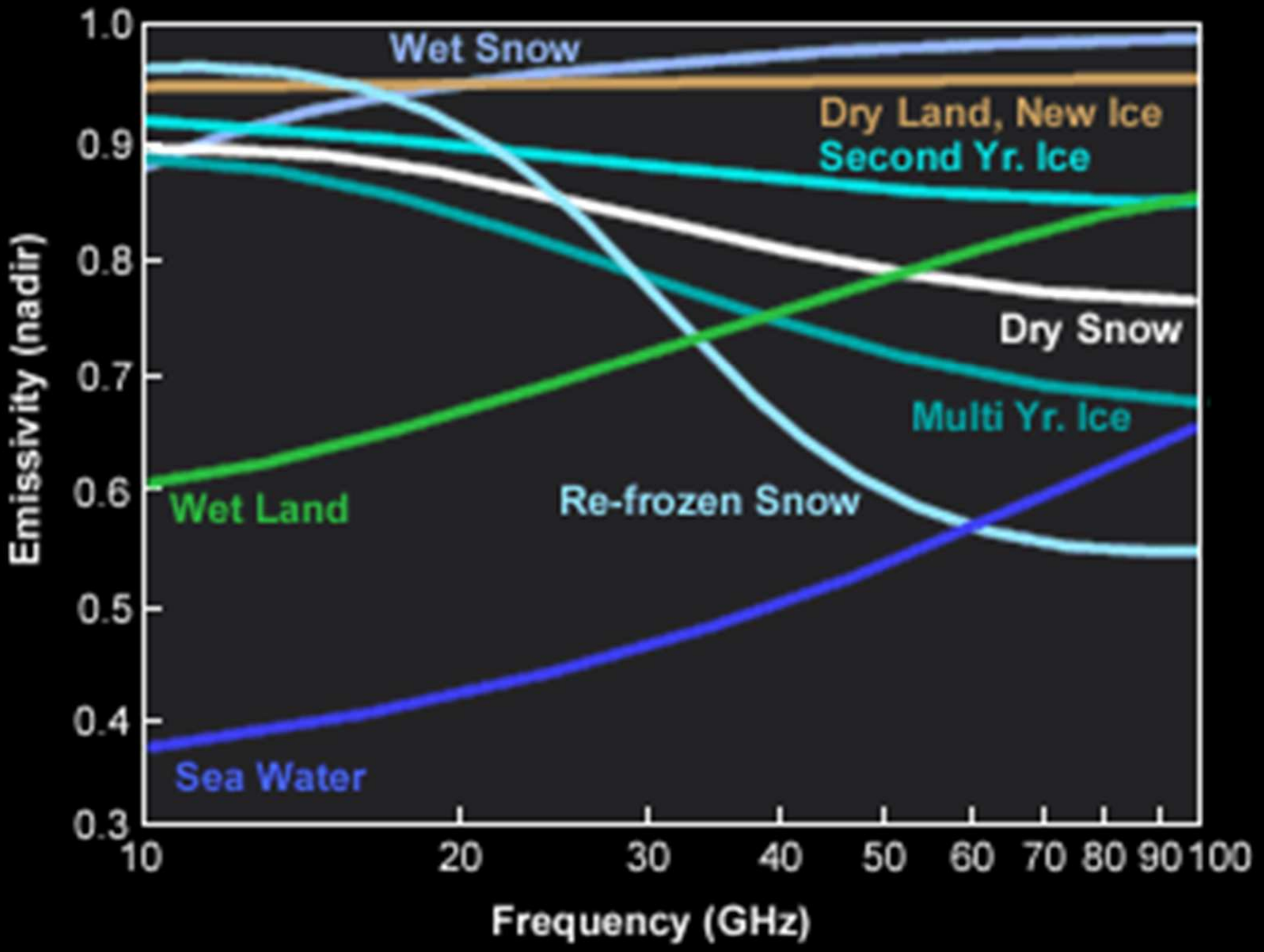


T_g= Ground temperature

$$T_b = \rho T_s + eT_g$$

$$\equiv T_b = T_s + e(T_g - T_s)$$

Passive Microwave Remote-Sensing



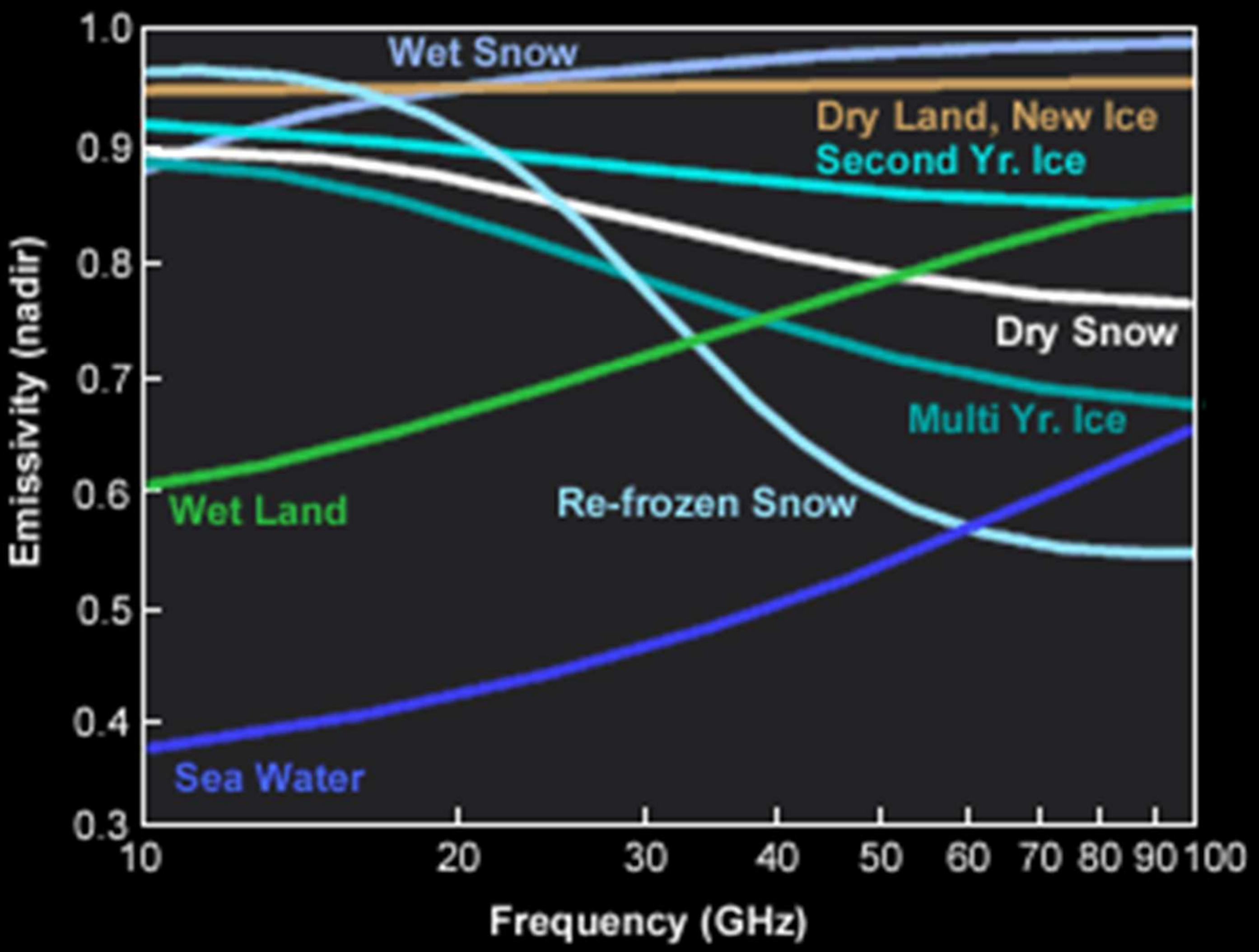
Surface emissivity at nadir as a function of frequency for scattering materials (aged sea ice and snow cover) and absorption materials (water, wet and dry soil and new sea ice).

Adapted from Dr. Norman C. Grody

Passive Microwave Remote-Sensing

Ice

Water



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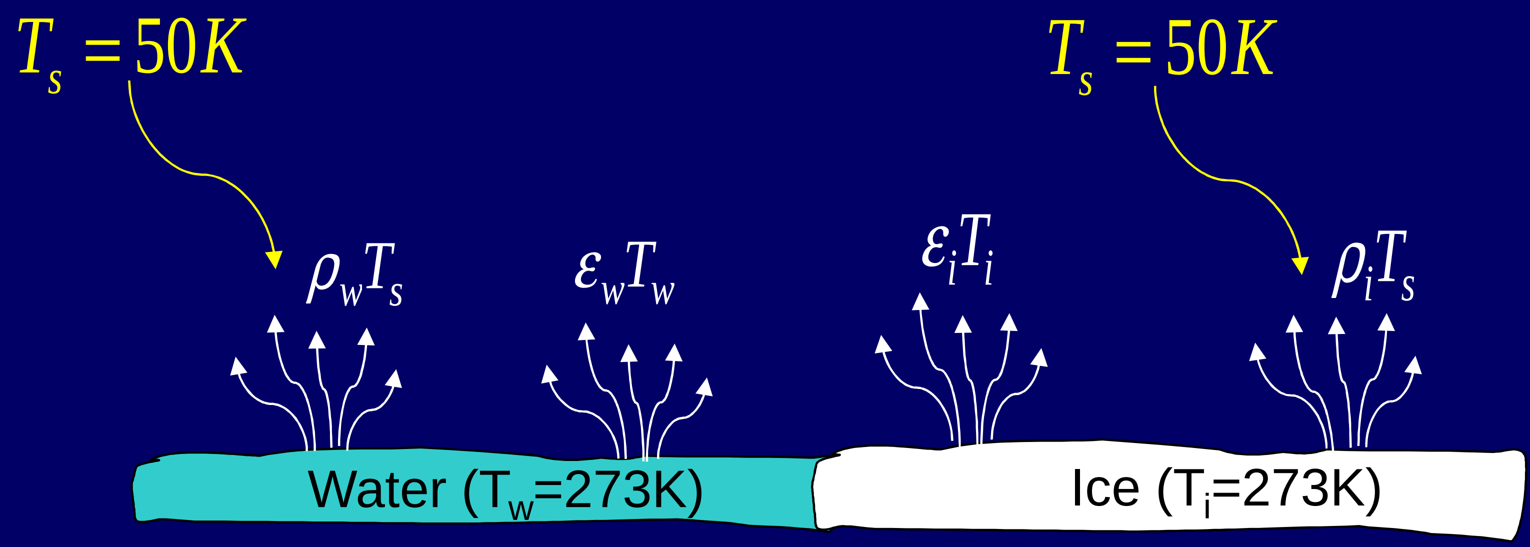
Passive Microwave Remote-Sensing: Polar Mapping



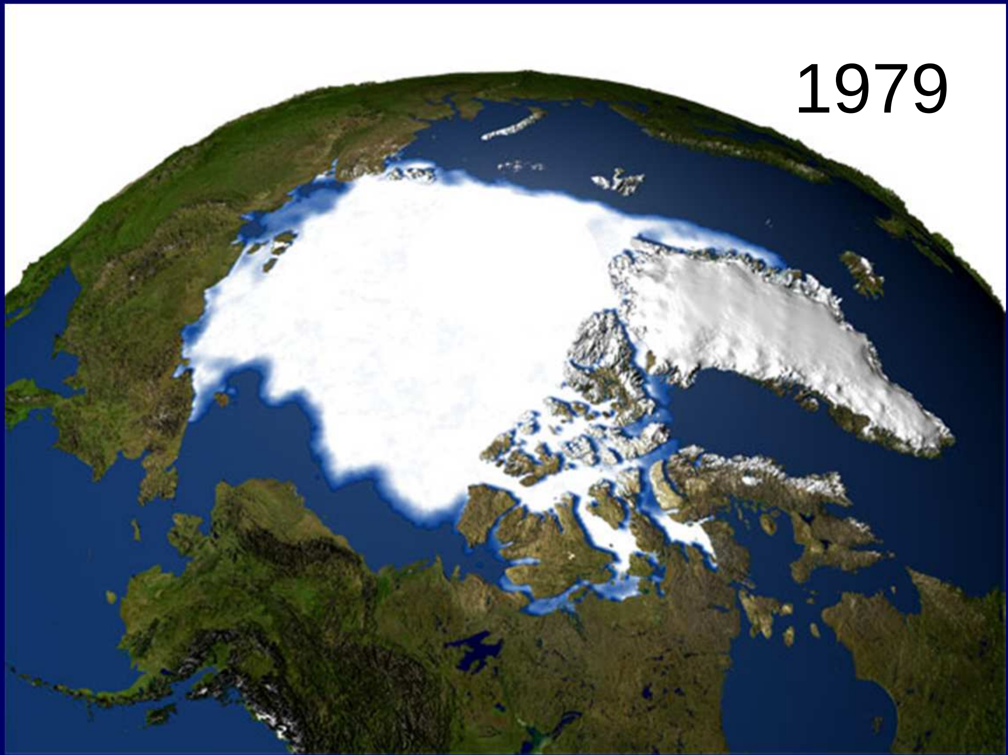
$$T_{b,w} = T_s + e_w(T_w - T_s) \qquad T_{b,i} = T_s + e_i(T_i - T_s)$$

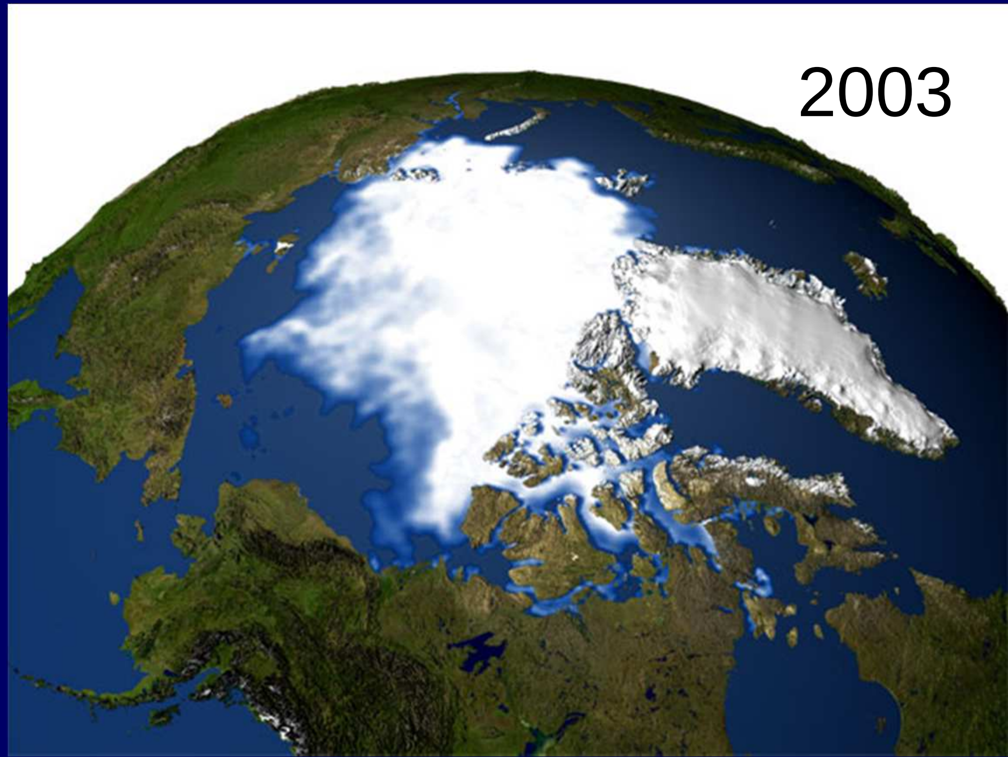
$$\Delta T_b = T_{b,i} - T_{b,w} = (e_i - e_w)(273 - 50)$$

	Dielectric constant	Emissivity
water	80	0.36
Ice	3	0.93

$$\Delta T_b = 127K$$

Passive Microwave Remote-Sensing: Polar Mapping



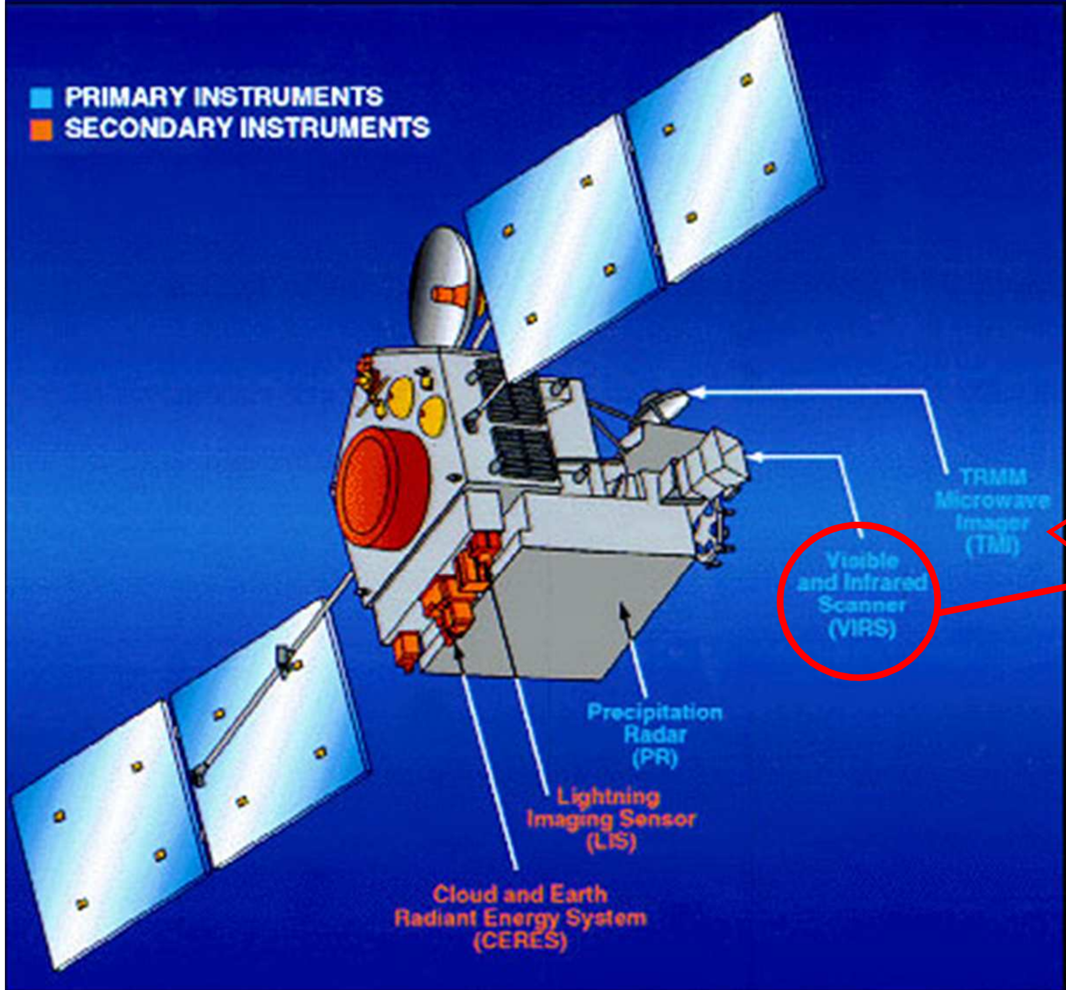


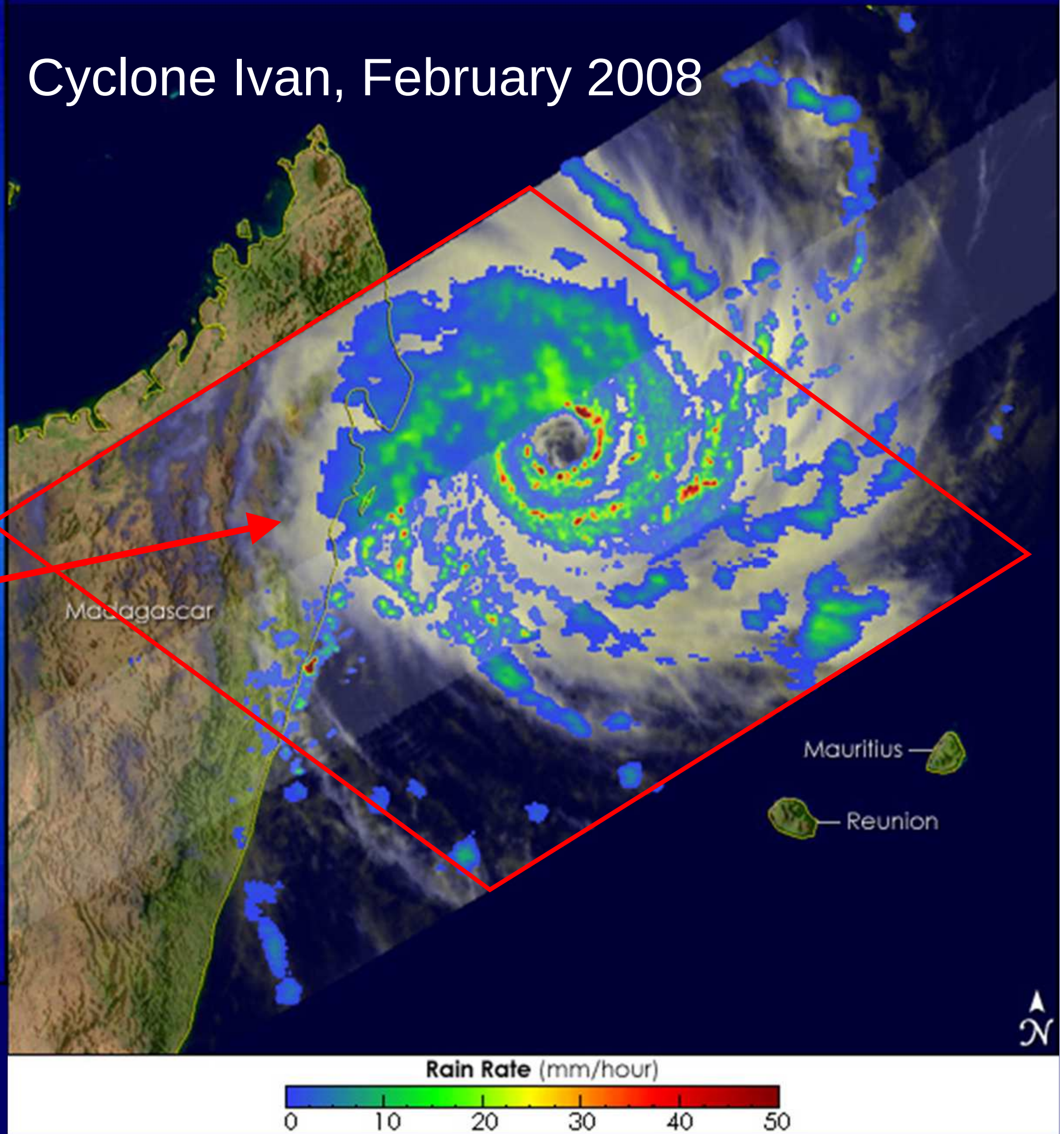
Arctic perennial sea ice has been decreasing at a rate of 9% per decade.

Special Sensor Microwave Imager (SSMI). Credit: NASA

Passive Microwave Remote-Sensing: Precipitation

Tropical Rainfall Measuring Mission (NASA/NASDA)





Launched July 1997

Passive Microwave Remote-Sensing: Precipitation

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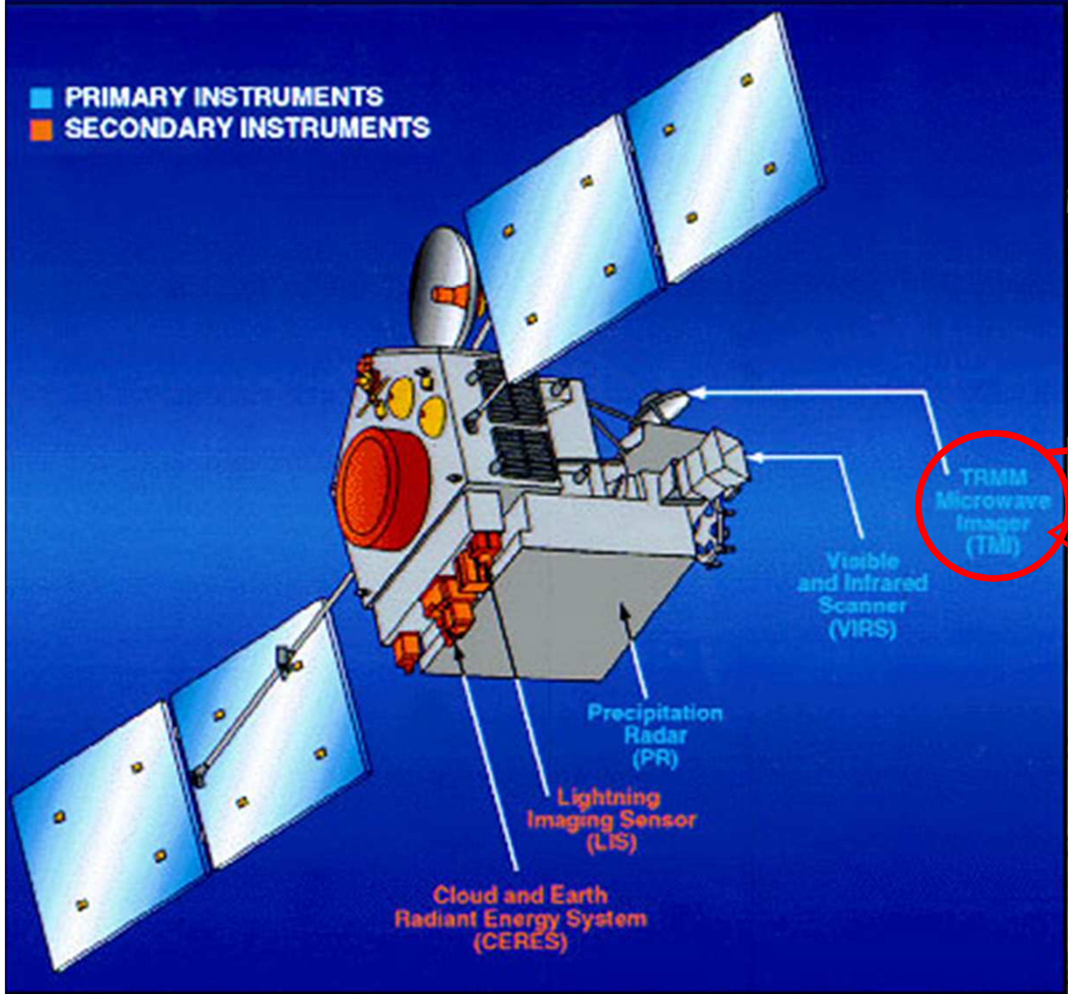

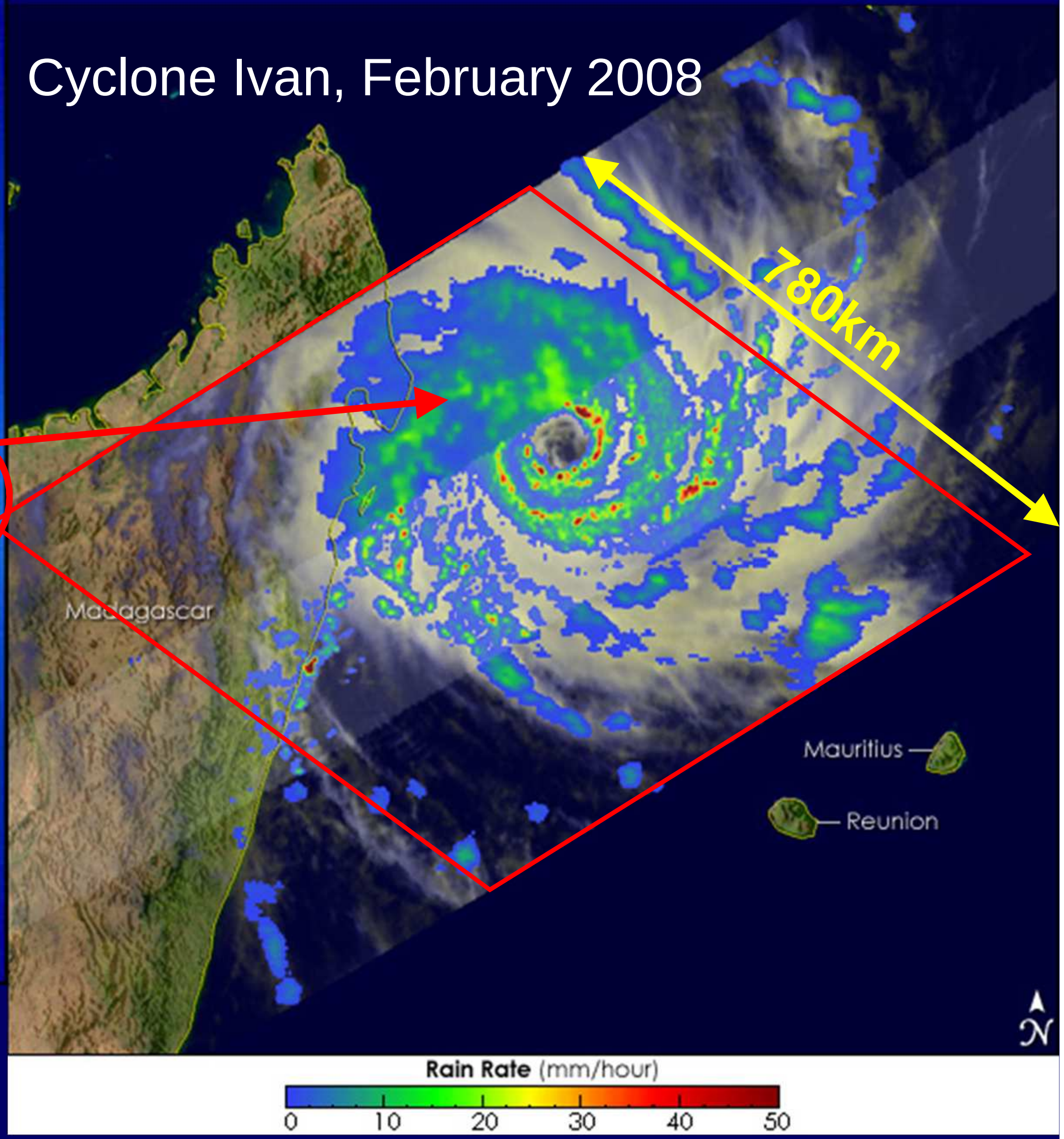

Passive Microwave Remote-Sensing: Precipitation

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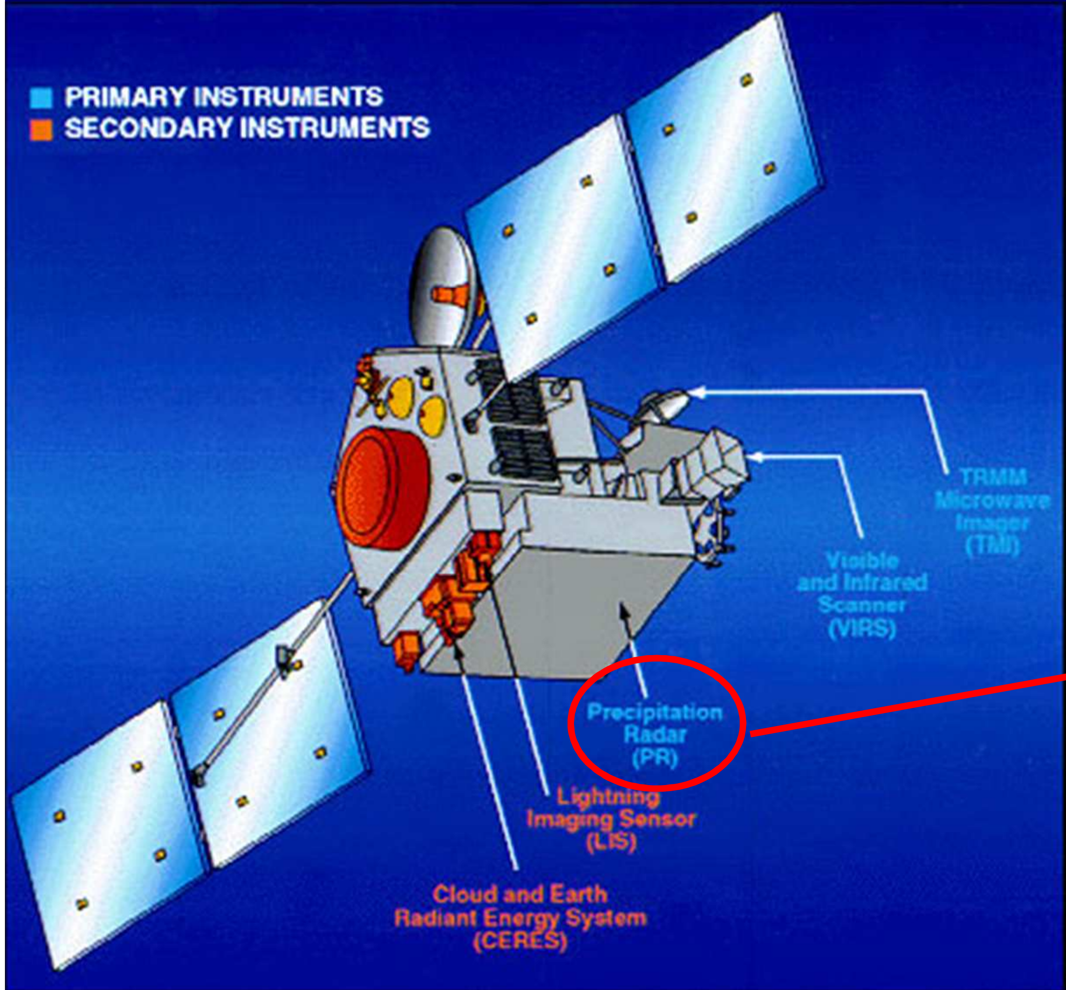
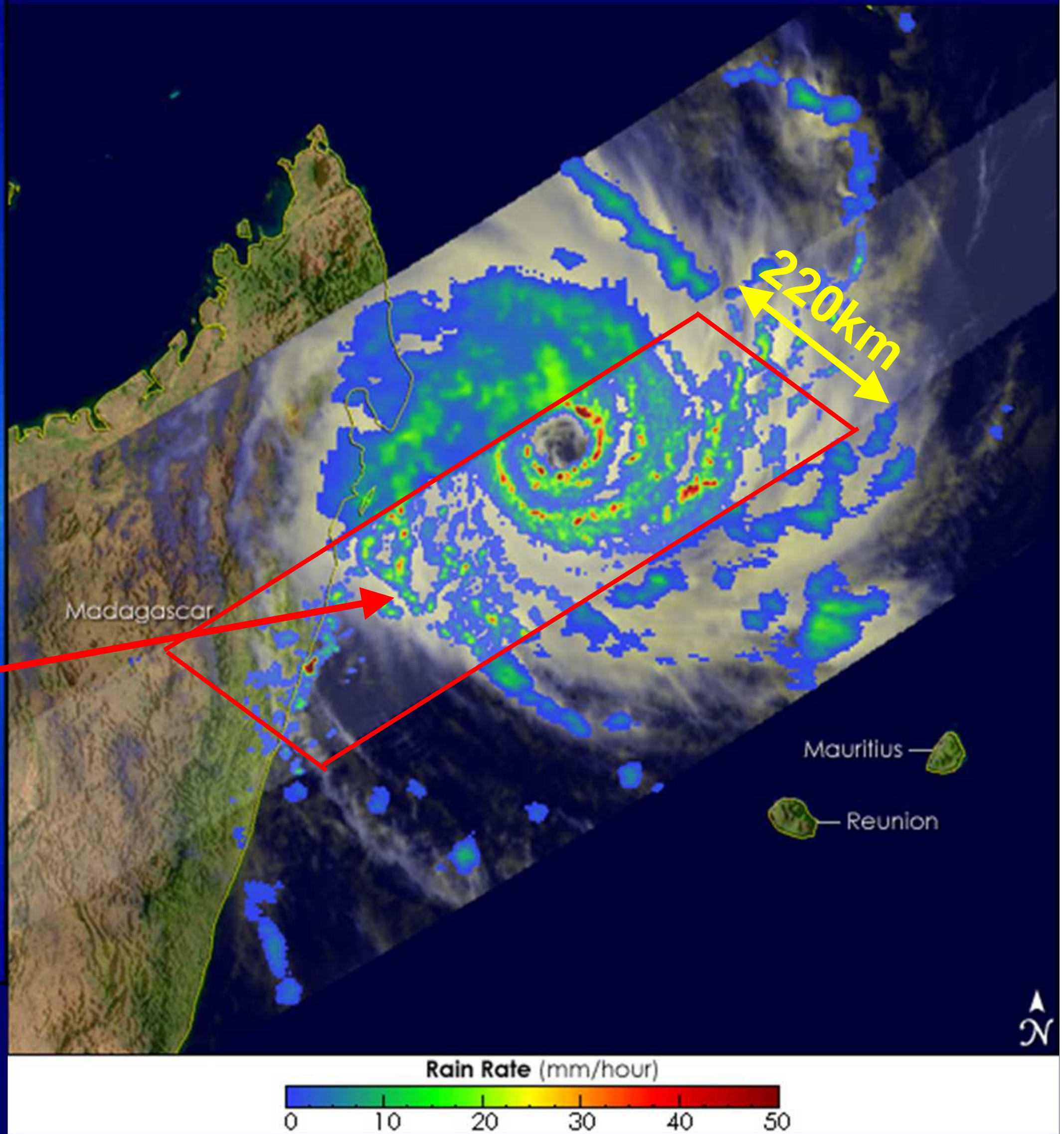




Passive Microwave Remote-Sensing: Precipitation

Tropical Rainfall Measuring Mission (NASA/NASDA)

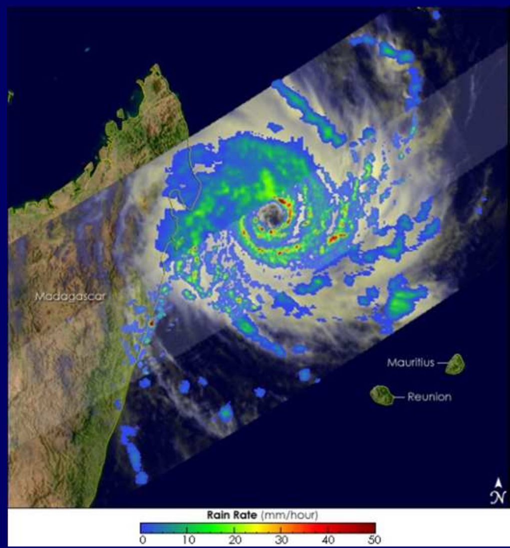
<u>TRMM Microwave Imager (TMI)</u>

•Microwave Radiometer

Range of frequencies
(10.7GHz, 19.4GHz, 21.3GHz, 37.0GHz, 85.5GHz)

=>Range of resolutions & penetration depths

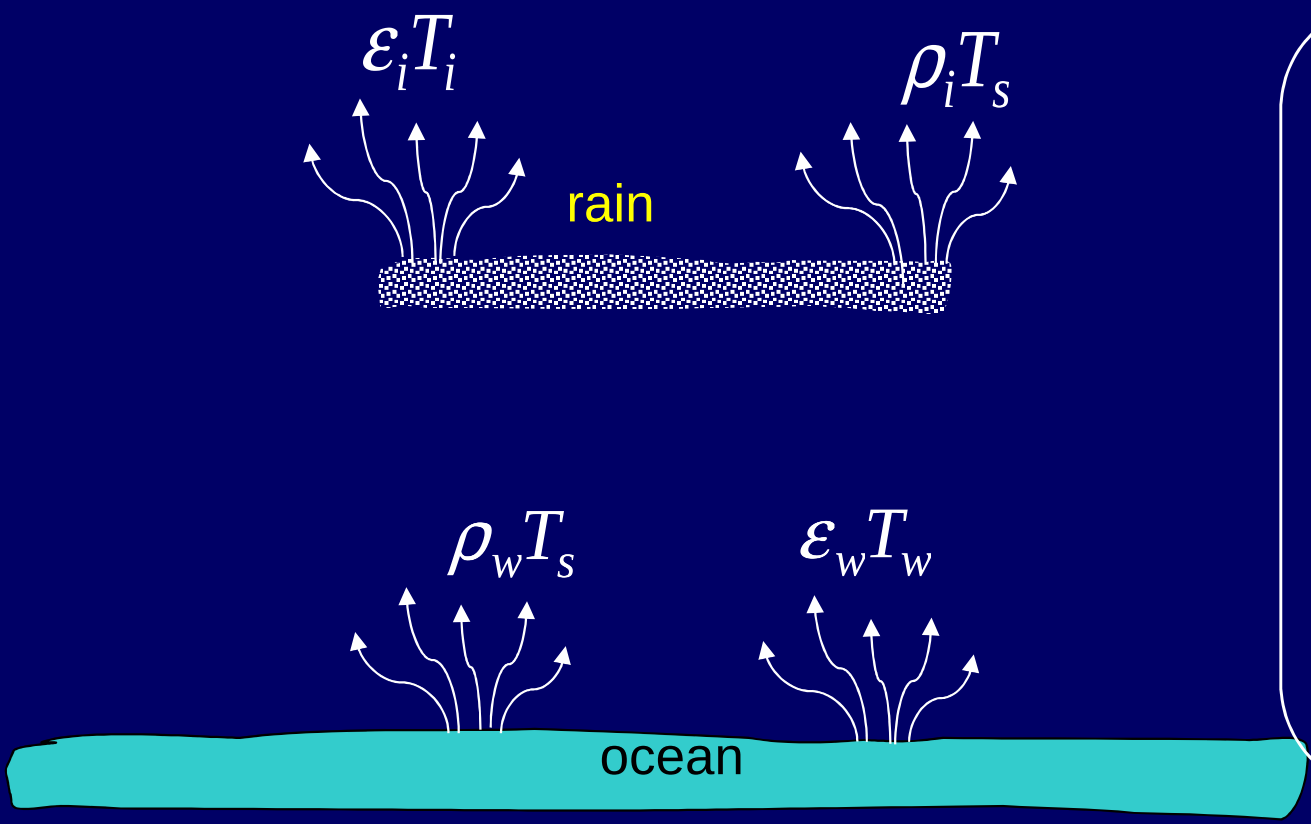
•Measures ***integrated column precipitation***



Passive Microwave Remote-Sensing: Precipitation

Tropical Rainfall Measuring Mission (NASA/NASDA)

TRMM Microwave Imager works best over oceans:



Remember low emissivity of sea water?
- Oceans appear “cold”.

Raindrops appear “warm”

=> more raindrops make scene “warmer”.

Passive Microwave Remote-Sensing: Precipitation

Tropical Rainfall Measuring Mission (NASA/NASDA)

http://trmm.gsfc.nasa.gov

Water surfaces
Dry atmosphere - blue
moist atmosphere - dark blue

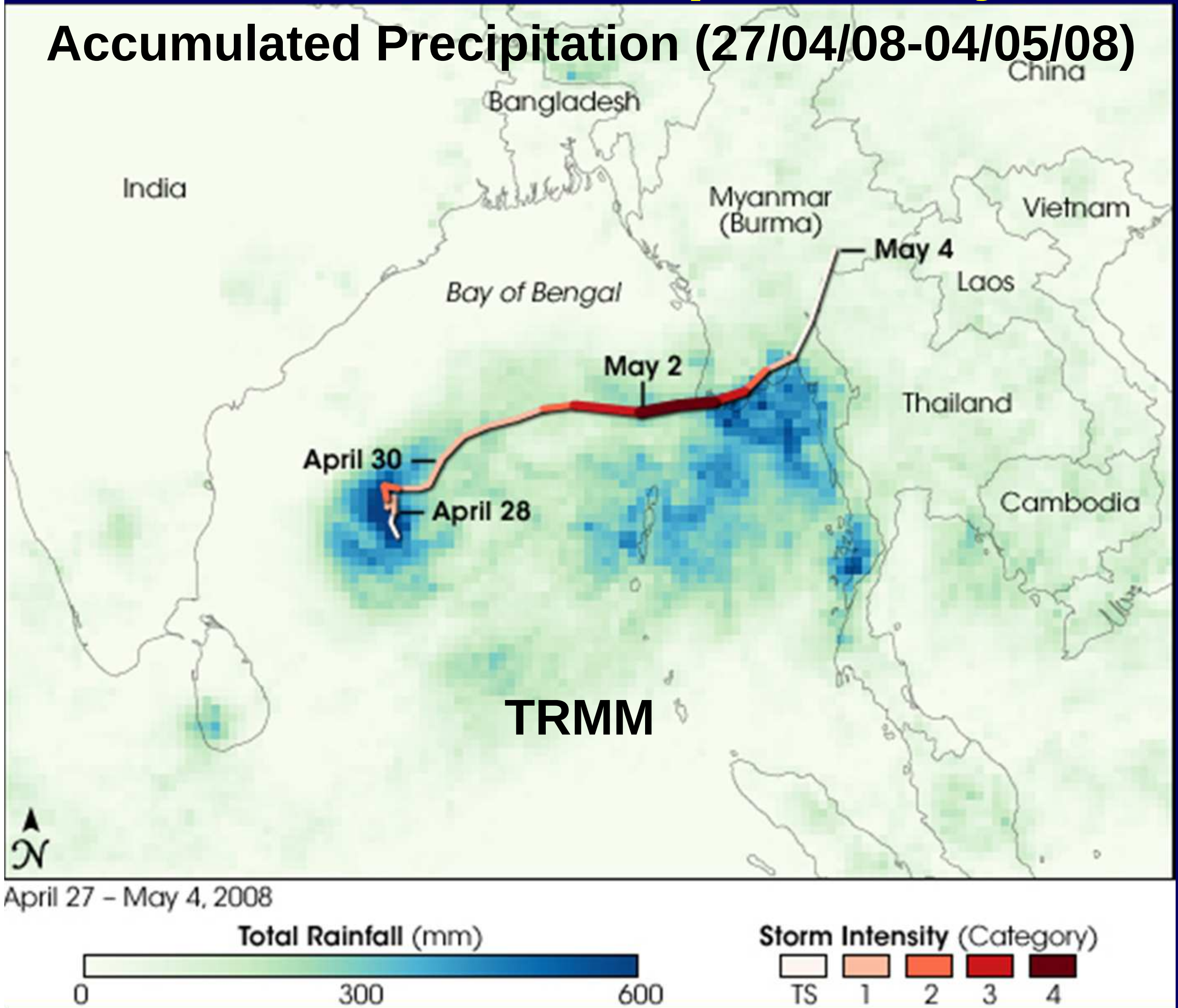
Land surfaces
Snow Cover - white/grey
land (non-desert) - grey/brown
Deserts - light green

Clouds/precipitation
Scattering (by cloud ice) - yellow
Emission (over water) - black

Other Surfaces
Polar snow /ice- white/yellow
Sea ice - green/brown

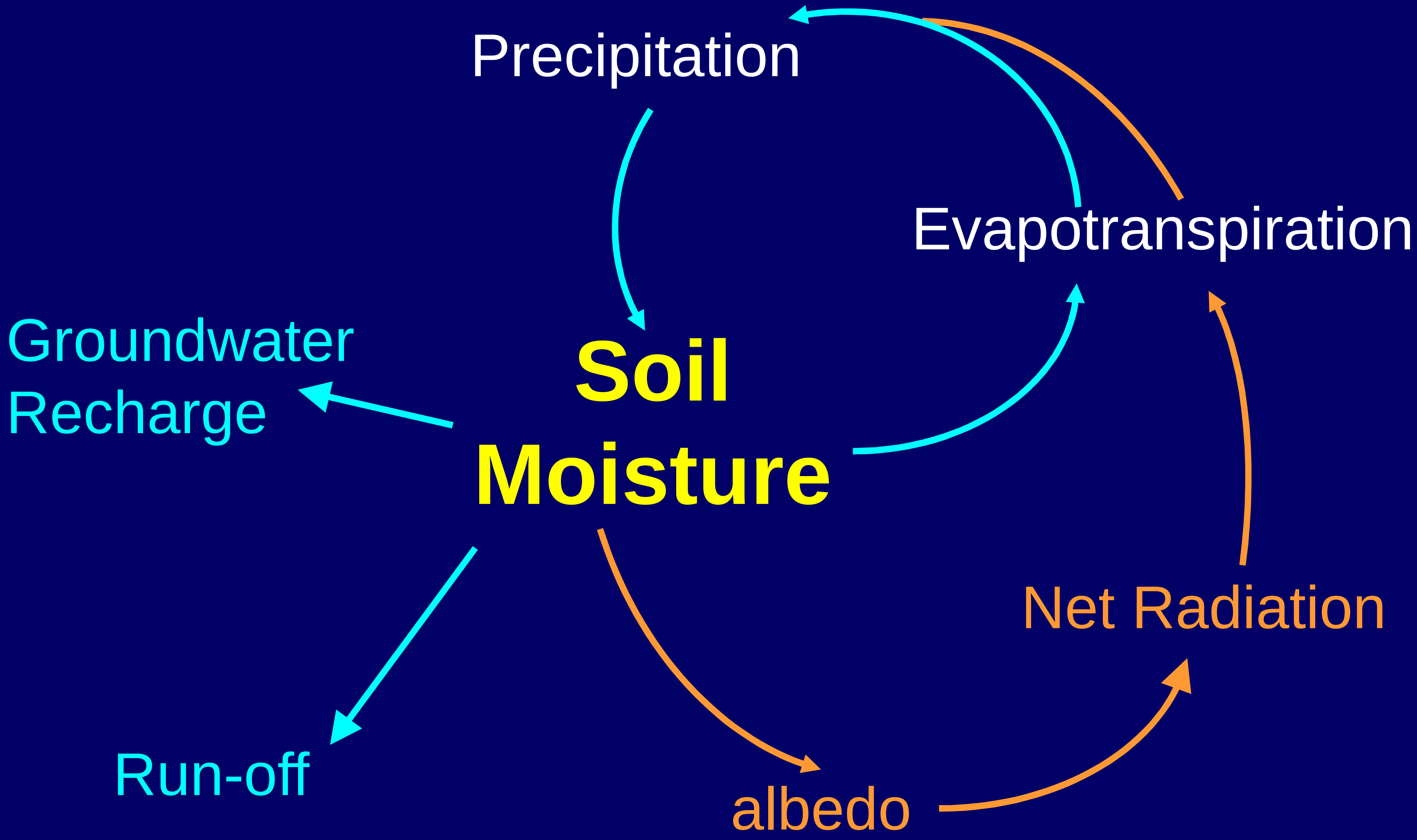
Passive Microwave Remote-Sensing: Precipitation

Impact of Cyclone Nargis



http://earthobservatory.nasa.gov

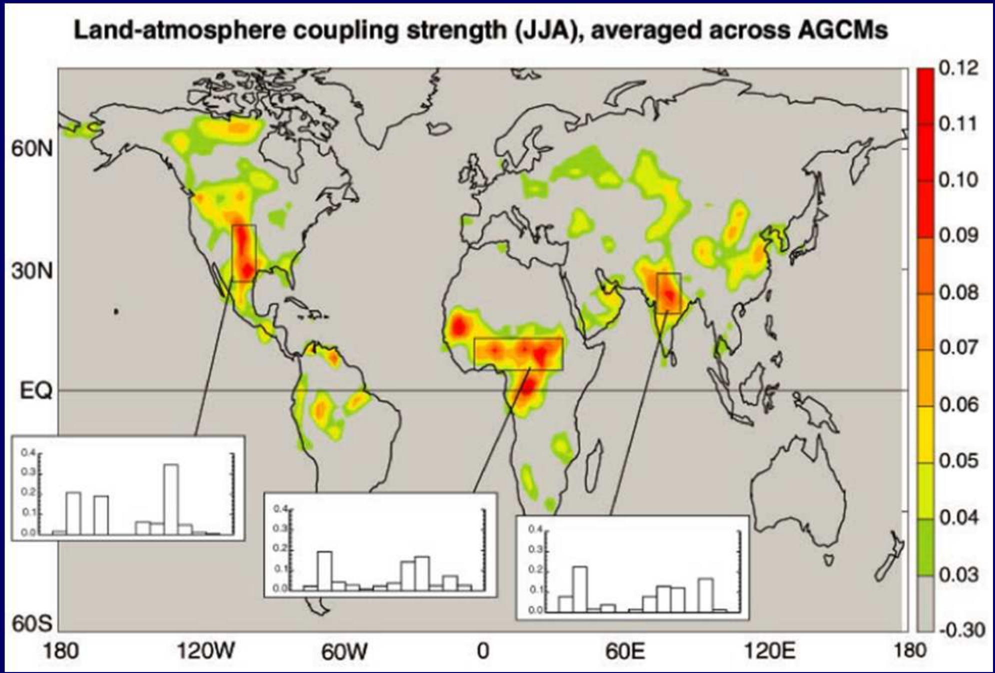
Soil moisture in hydrology



Soil Moisture: Hydroclimatology

Seasonal prediction of precipitation

Koster et al. (2004)



Agriculture

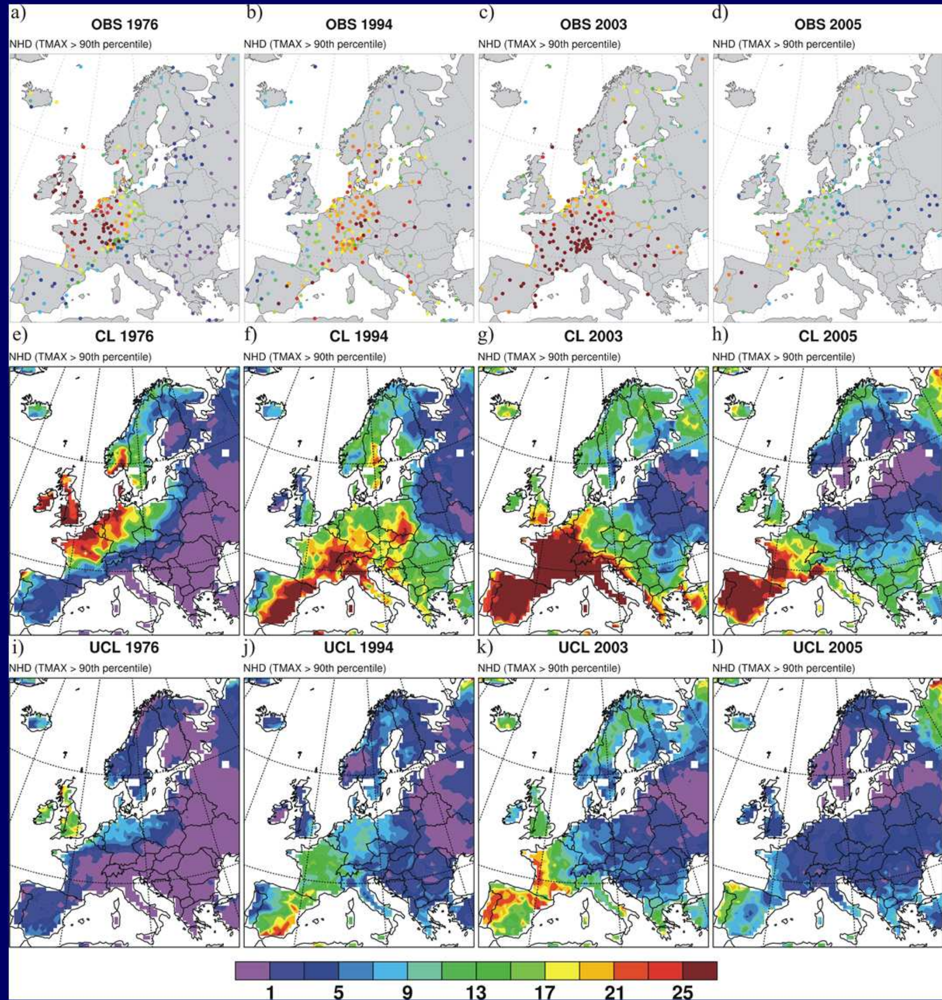
Water Resources Management

Power supply

Drought => Famine

Duration and magnitude of heatwaves

Fischer et al. (2007)



Public Health

Significant economic and societal impact

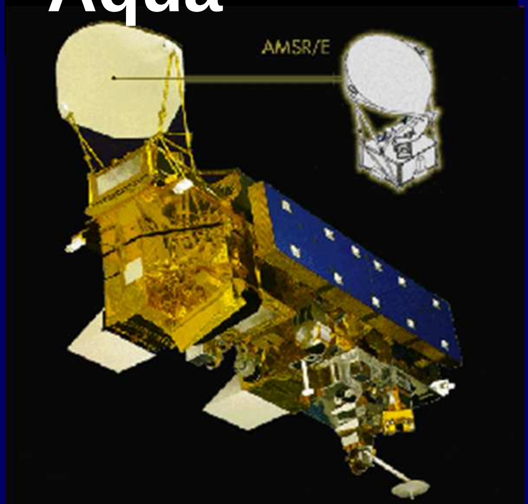
Soil Moisture Remote-Sensing

Past | **Future**

[4]

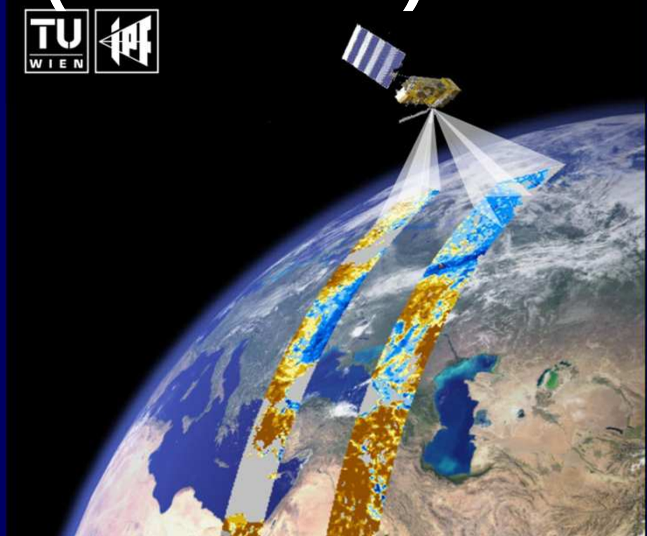
[3]

AMSR-E on Aqua



[5]

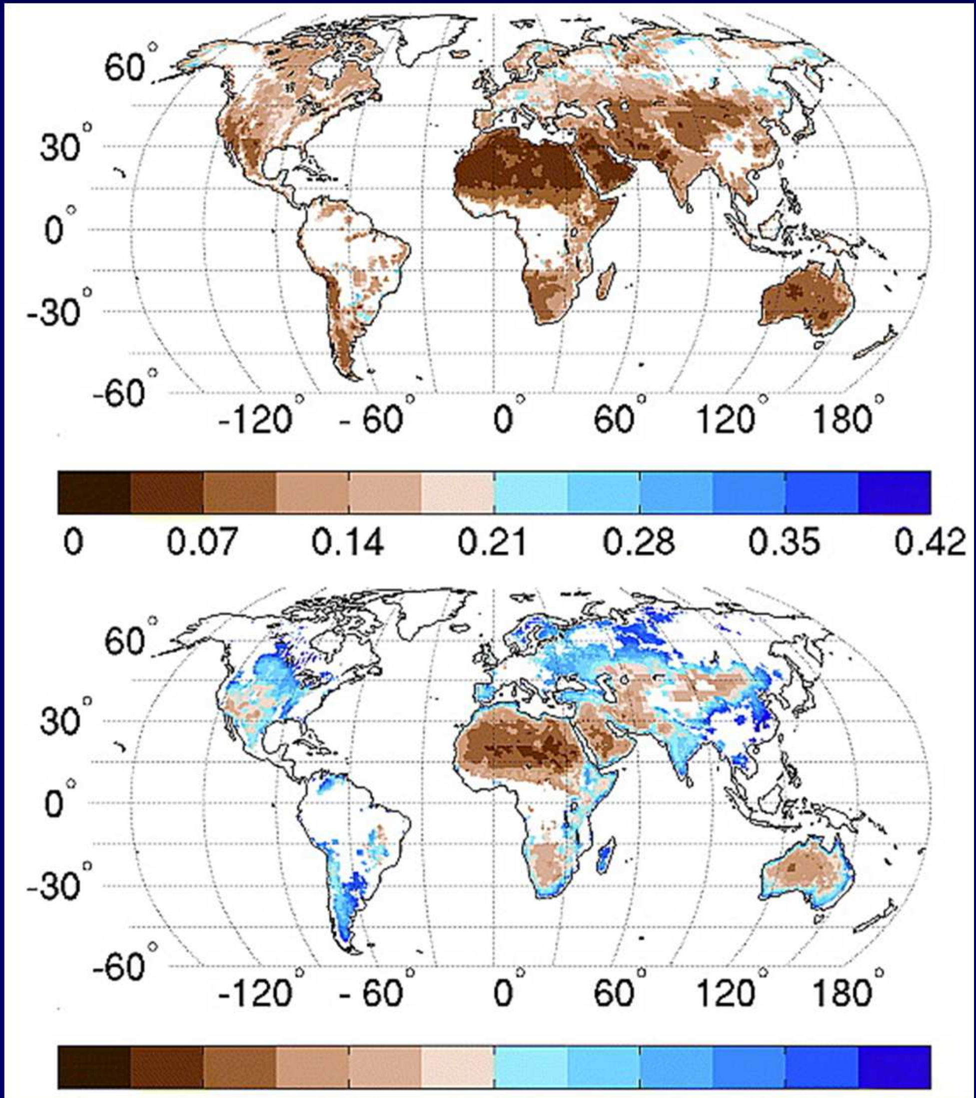
ASCAT on MetOP (2006-2020)



[6]

[7]

Passive Microwave Remote-Sensing: Soil Moisture



Average surface soil moisture from (top) AMSR-E (June 2002–May 2006) and (bottom) SMMR (January 1979–August 1987). (Reichle et al. (JGR,2007))

AMSR-E

Advanced Microwave Scanning Radiometer for the Earth Observing System

X-band (10.7GHz) , (C-band had too much RFI)

Effective resolution ~50km

SMMR

Scanning Multichannel Microwave Radiometer

C-band (6.6 GHz)

Effective resolution ~120km

SMOS: Why L-band?

Dielectric constant of water

$$\varepsilon = 80$$

Greater Δε between wet and dry at lower frequencies

Δε results in ΔT_B of ~100K

=> ***detectable***!

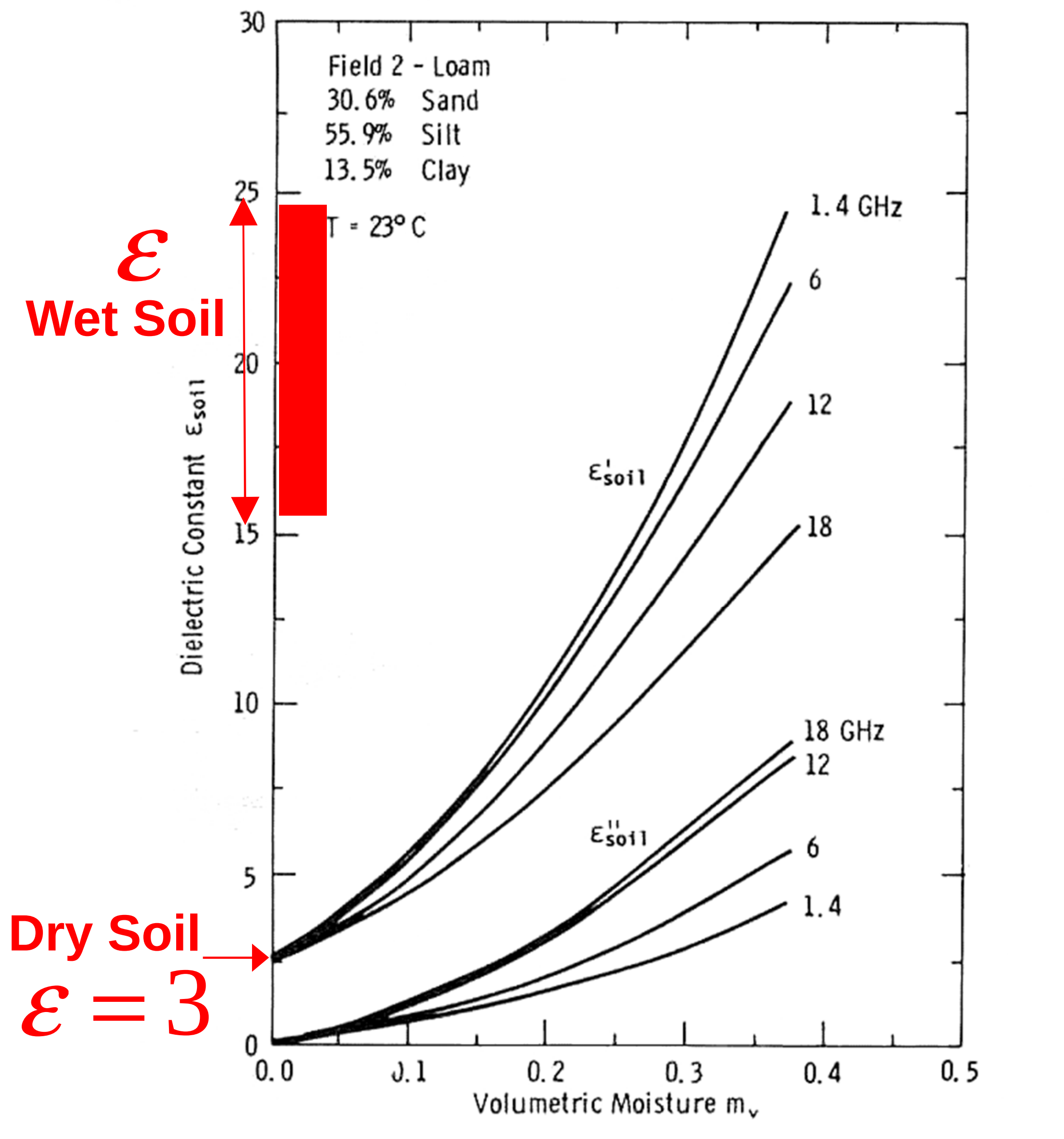
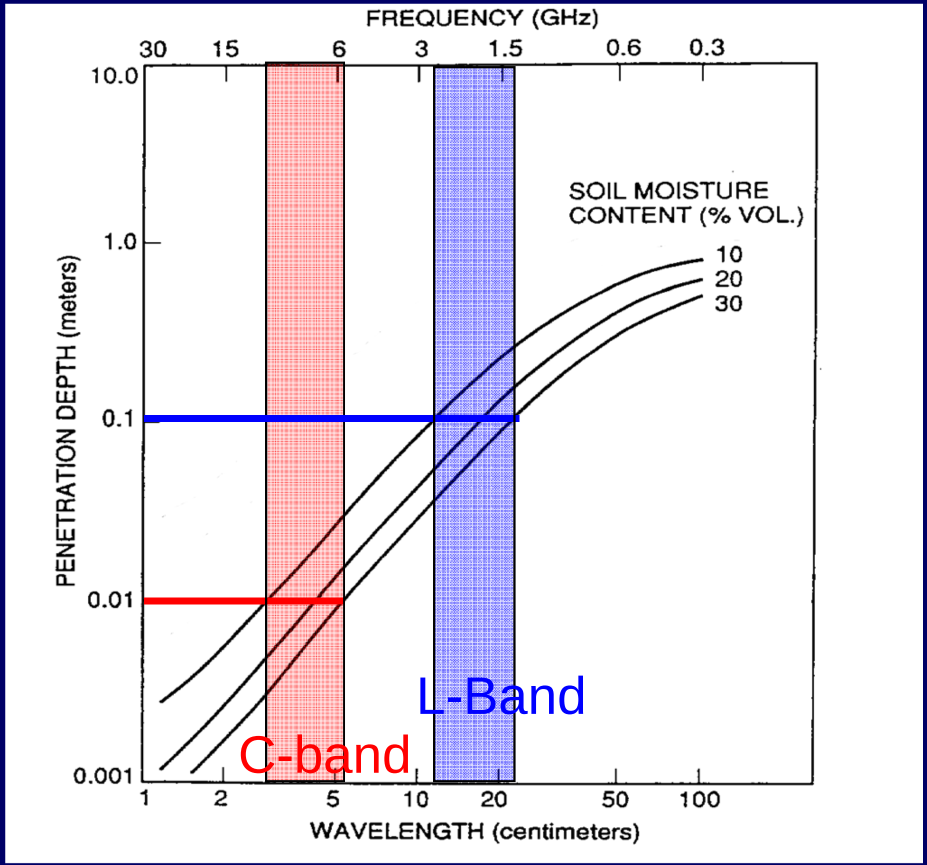


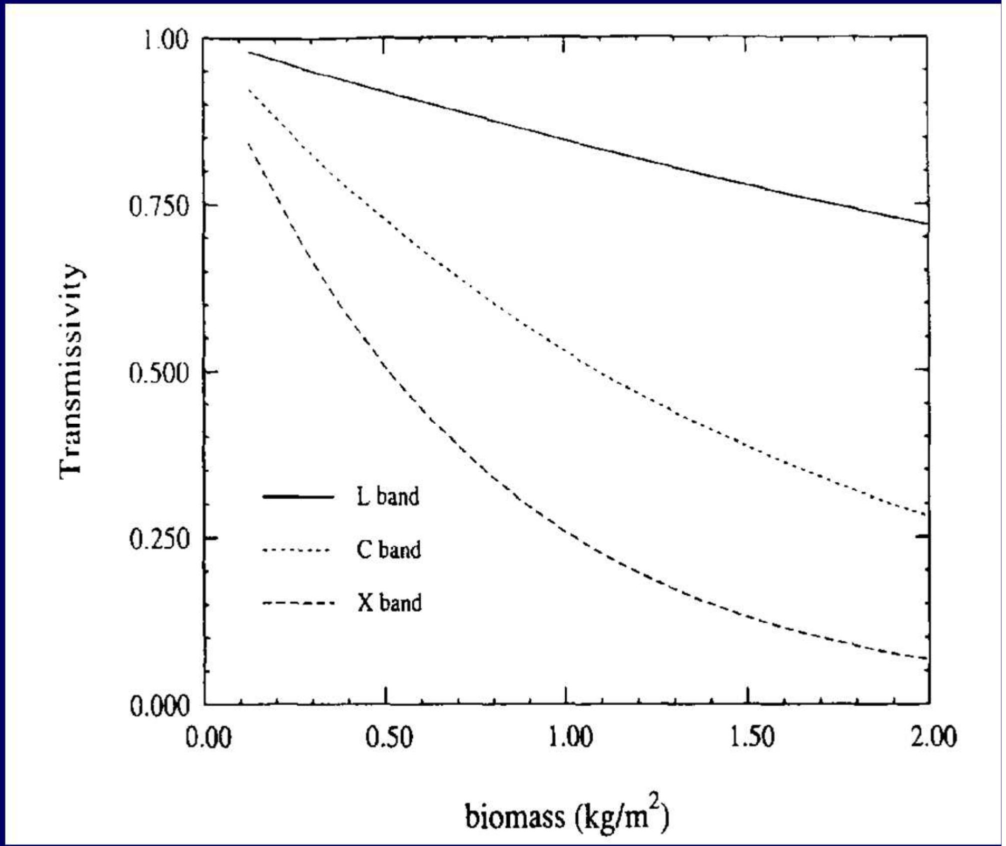
Fig. E.52 Measured dielectric constant as a function of volumetric moisture content for a loamy soil at four microwave frequencies.

SMOS: Why L-band?

Observe more of soil column

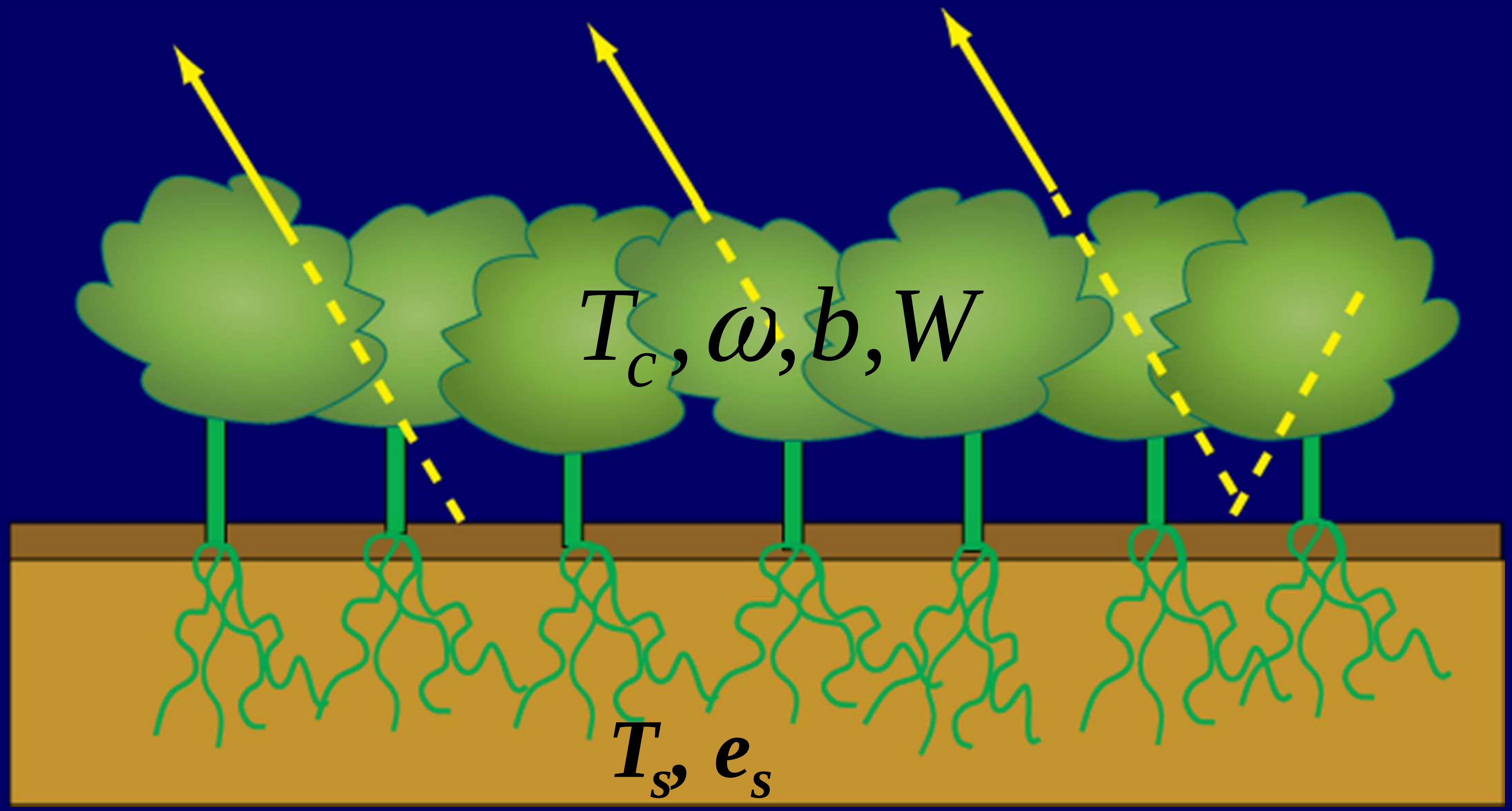


Can 'see' through denser vegetation



Microwave Remote-Sensing

$$T_B = T_s e_s \exp(-\tau) + T_c(1-\omega)(1-\exp(-\tau)) + T_C \rho_S \exp(-\tau)(1-\omega)(1-\exp(-\tau))$$



Passive Microwave Remote-Sensing: Soil Moisture

T_B , the brightness temperature from a vegetated surface:

$$T_B = T_s e_s \exp(-\tau) + T_c(1-\omega)(1-\exp(-\tau)) + T_c \rho_s \exp(-\tau)(1-\omega)(1-\exp(-\tau))$$

e_s is the soil emissivity, related to soil reflectivity by ($e_s = 1 - \rho_s$)

T_s is the surface temperature (assume vegetation and soil temperatures are equal)

τ is the vegetation opacity along the viewing path

$$\tau = \frac{bW}{\cos\theta}$$

θ is the incidence angle

b is a vegetation coefficient
depends on (frequency, vegetation type)

W is the vegetation water content

ω is the vegetation scattering albedo

Passive Microwave Remote-Sensing: Soil Moisture

T_B , the brightness temperature from a vegetated surface:

$$T_B = T_s e_s \exp(-\tau) + T_c(1-\omega)(1-\exp(-\tau)) + T_C \rho_S \exp(-\tau)(1-\omega)(1-\exp(-\tau))$$

e_s is the soil emissivity, related to soil reflectivity by ($e_s = 1 - \rho_s$) role of soil moisture

T_s is the surface temperature (assume vegetation and soil temperatures are equal)

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Passive Microwave Remote-Sensing: Soil Moisture

T_B , the brightness temperature from a vegetated surface:

$$T_B = T_s e_s \exp(-\tau) + T_c (1-\omega)(1-\exp(-\tau)) + T_C \rho_S \exp(-\tau)(1-\omega)(1-\exp(-\tau))$$

e_s is the soil emissivity, related to soil reflectivity by ($e_s = 1 - \rho_s$) role of soil moisture

$e_s = e_s$ (dielectric constant, incidence angle)

dielectric constant is a strong function of soil moisture ….

SMOS Retrieval

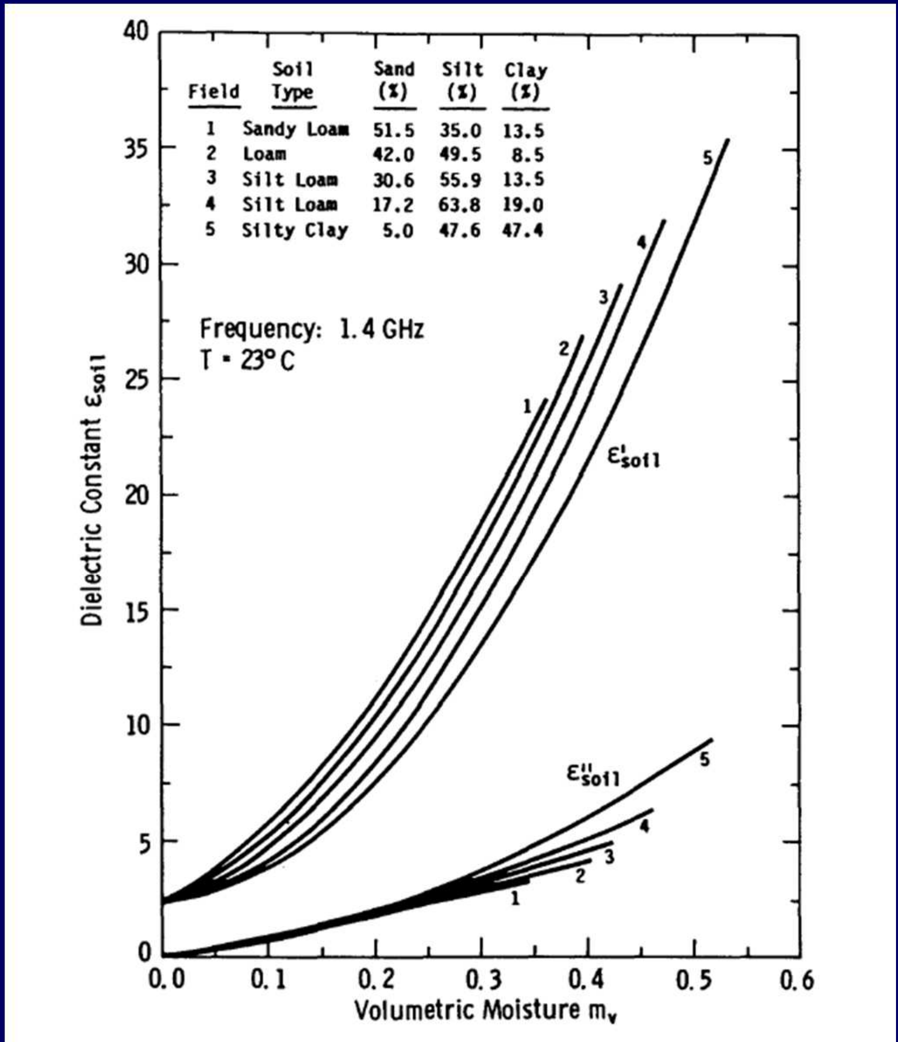
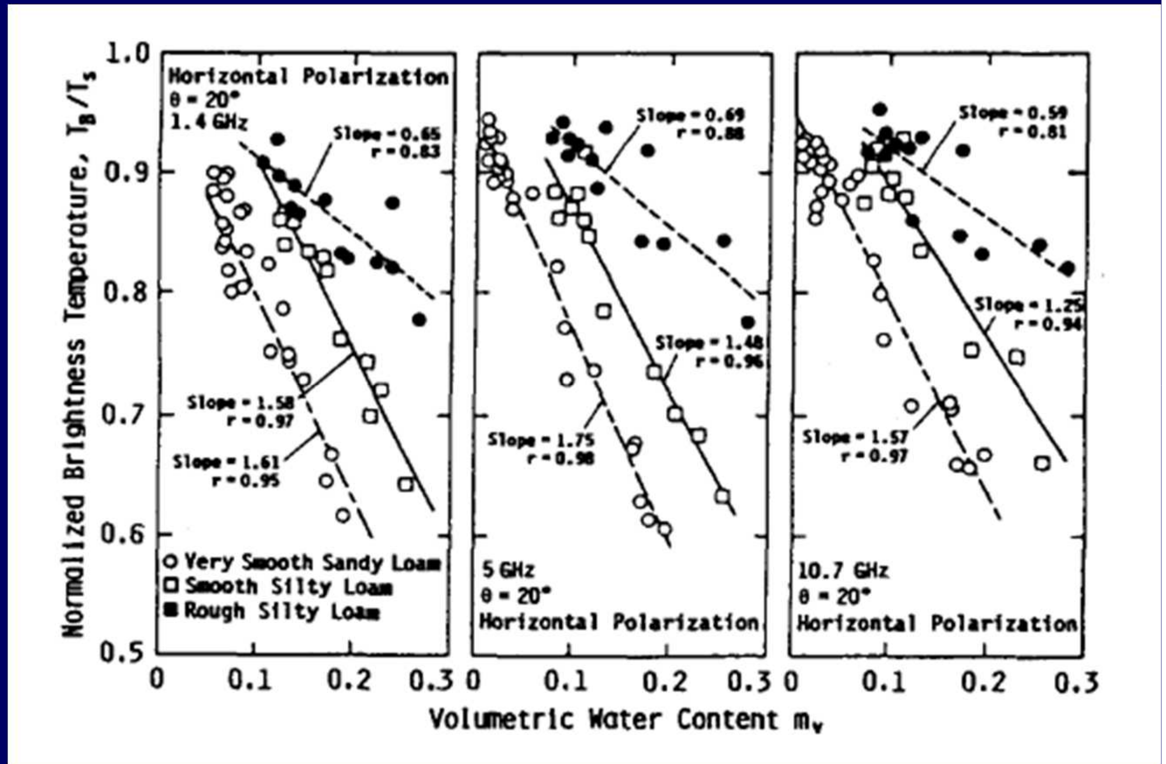
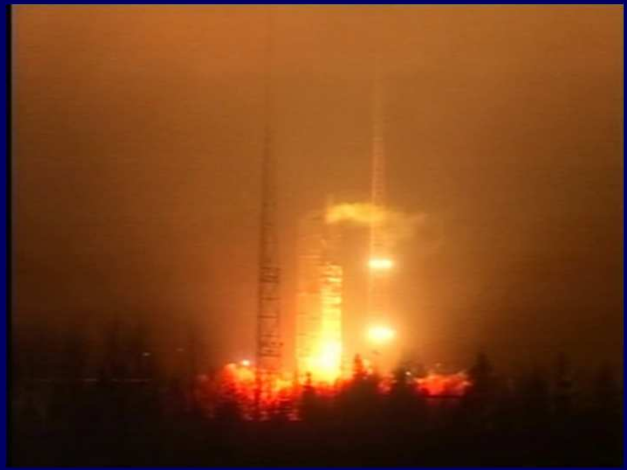


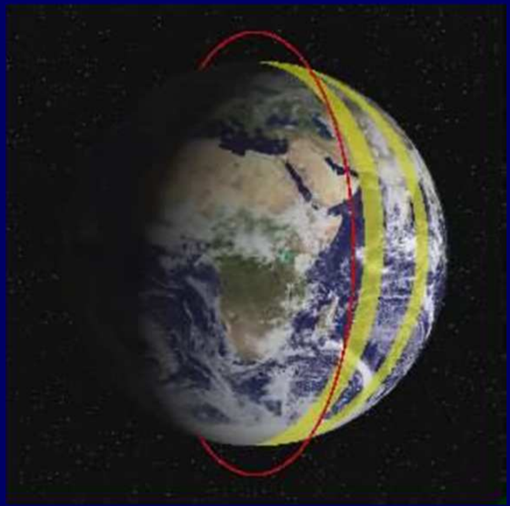
Fig. 2. Dielectric constant as a function of volumetric soil moisture for five soils at 1.4 GHz. Smooth curves were drawn through measured data points. (From Ulaby et al. (1986). Reproduced with permission, *Microwave Remote Sensing: Active and Passive, Vol. III: From Theory to Applications*, by Fawwaz T. Ulaby, Richard K. Moore, Adrian K. Fung. © 1986, Artech House, Inc., Norwood, MA.)

Need to account for differences in:
1) soil texture
2) roughness
3) vegetation



SMOS mission


[8]


[9]

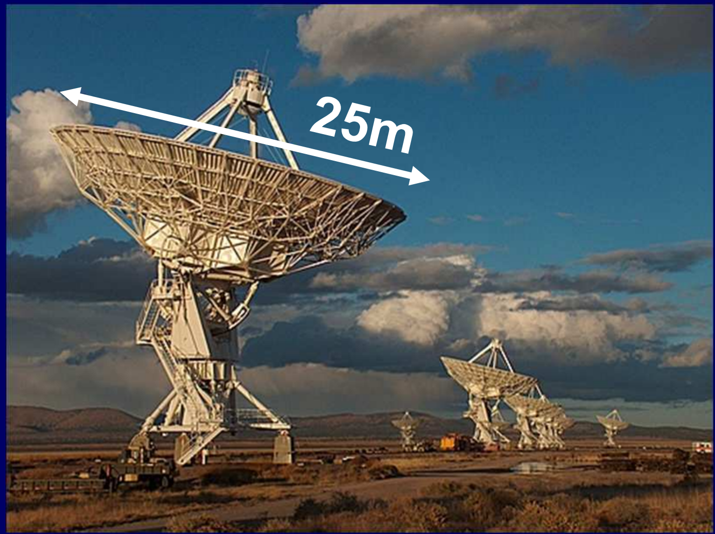
Launched 2 November 2009

Duration	Minimum 3 years
Frequency	L-band (21 cm-1.4 GHz)
Spatial resolution	35 km at centre of FOV
Radiometric resolution	0.8 - 2.2 K
Angular range	0-55 degrees
Temporal resolution	3 days revisit at Equator

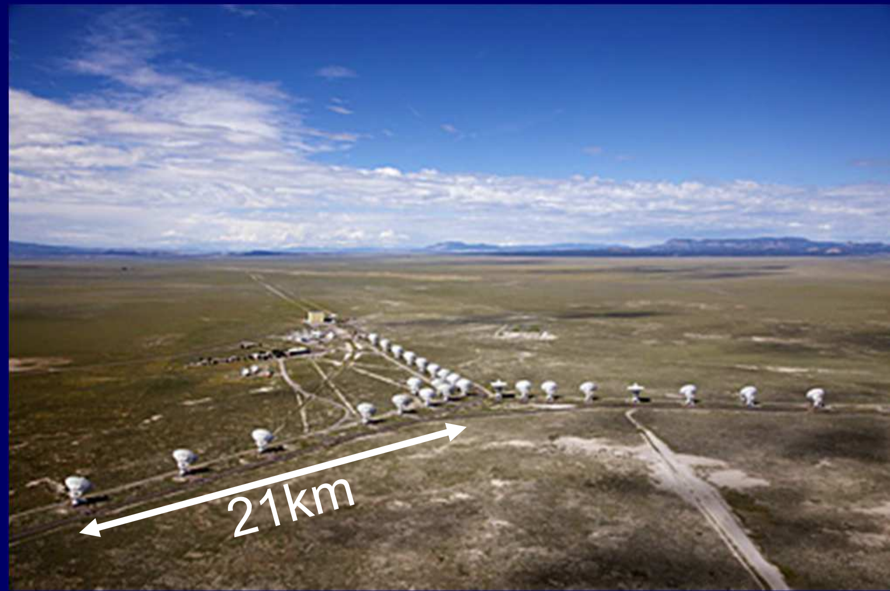
Sun-synchronous, dawn/dusk, at altitude 758 km. 06.00 hrs local solar time at ascending node.

SMOS mission

"Very Large Array", New Mexico

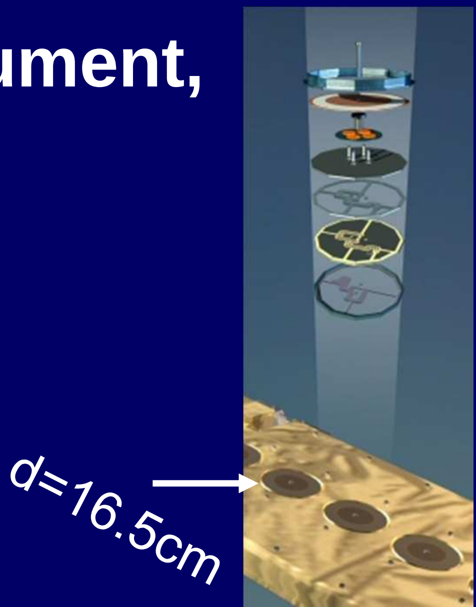


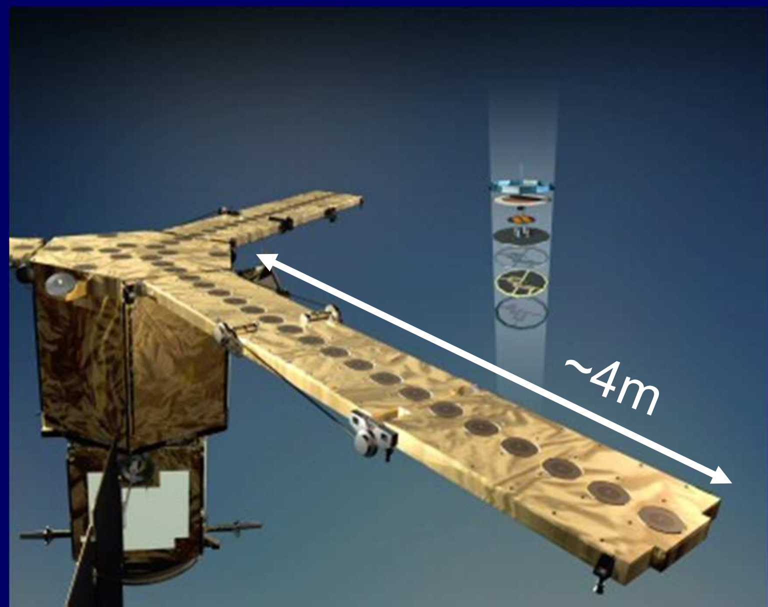
[10]



[11]

MIRAS instrument, SMOS

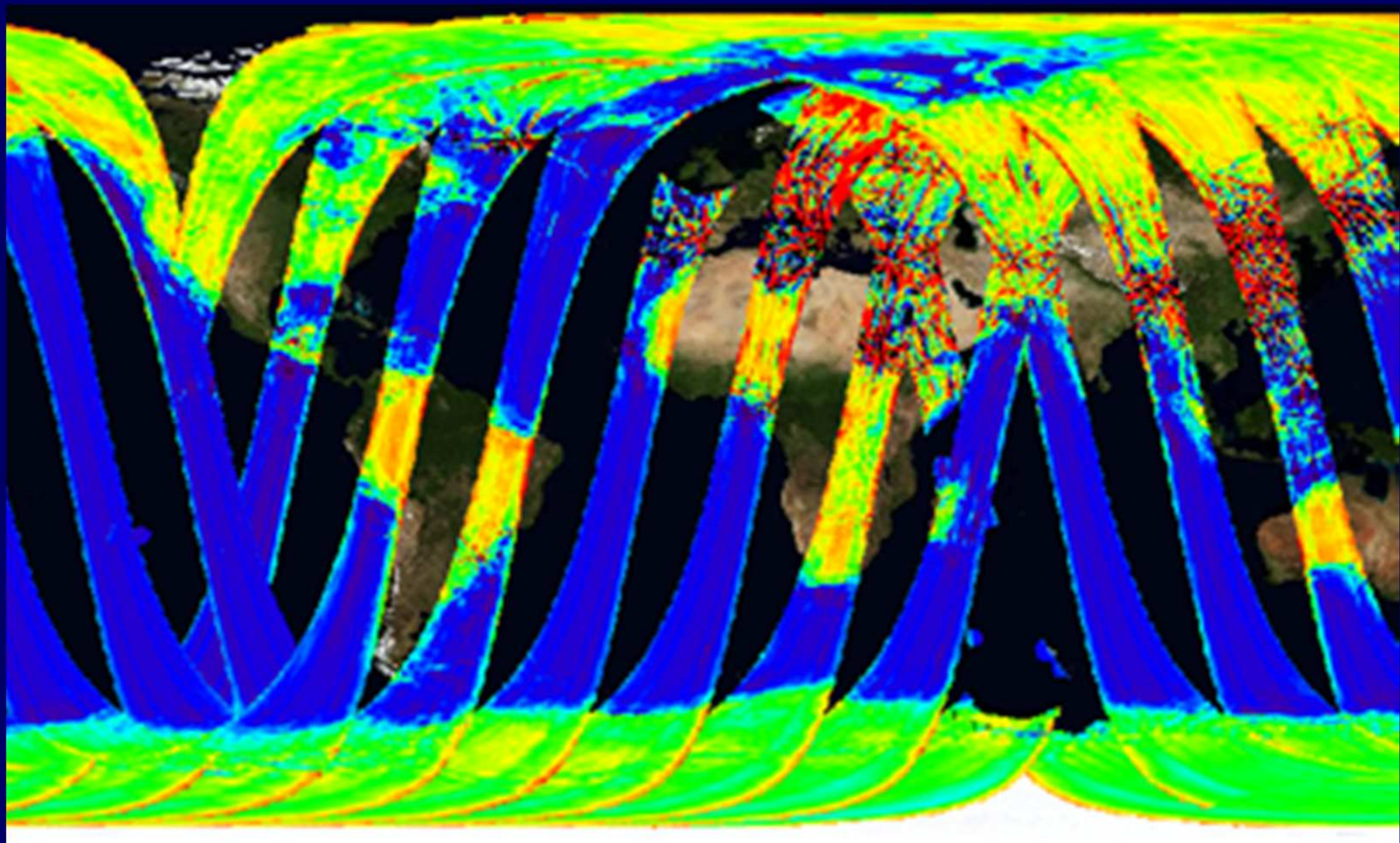




[12]

SMOS mission

First data received! **20 November 2009**

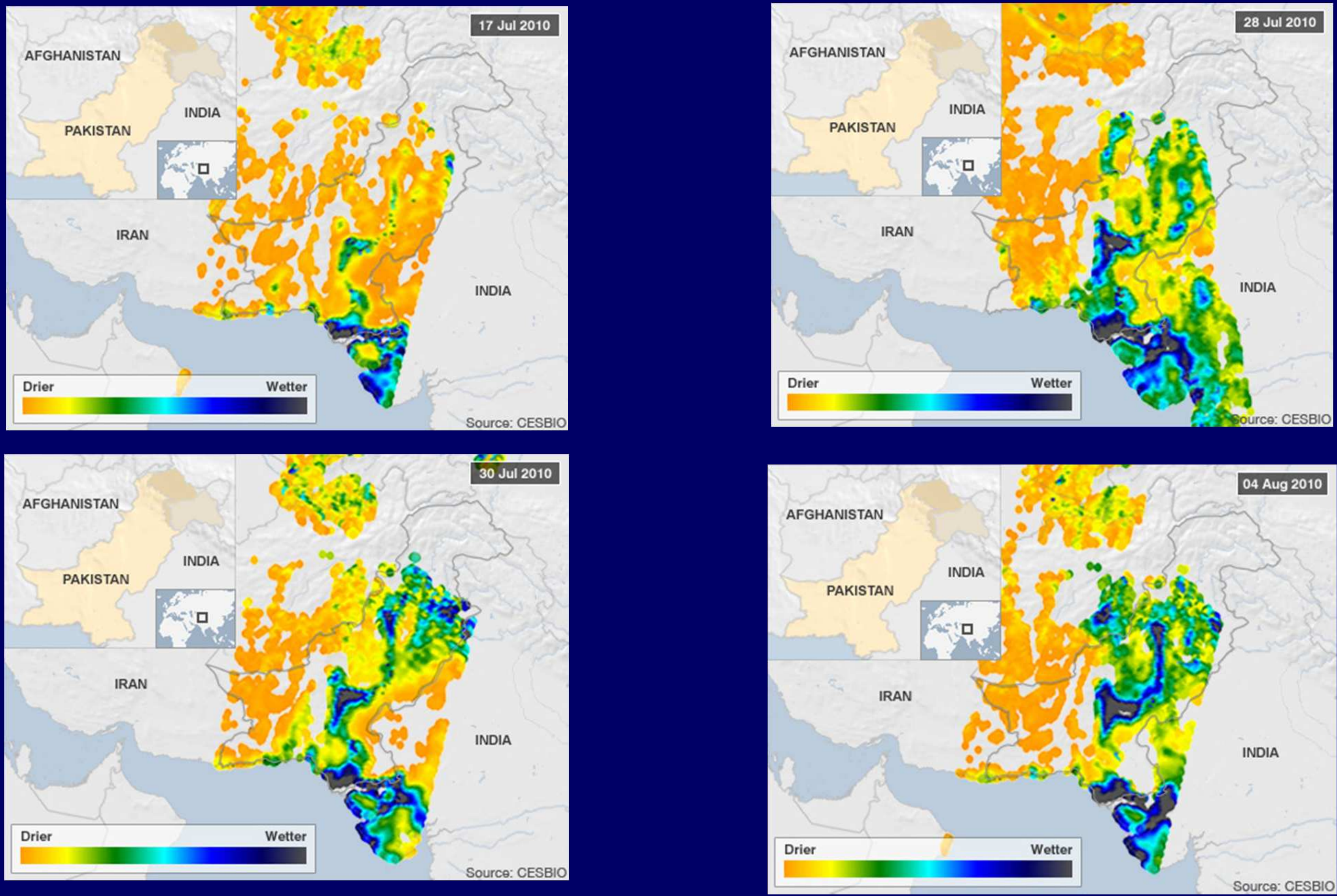


Blue = low, Red = high brightness temperature

BBC NEWS

BBC, 17th August 2010

"SMOS satellite tracks Pakistan floods"

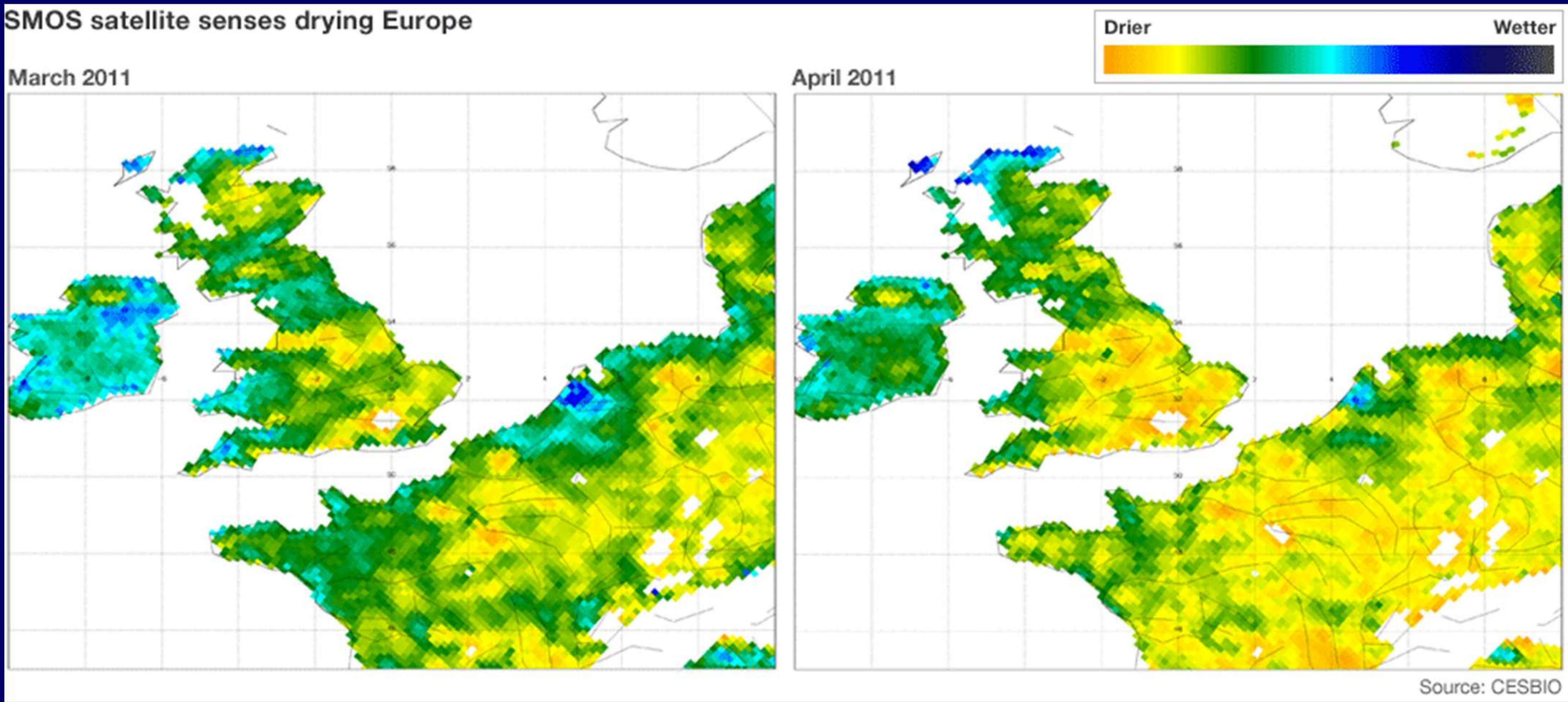


http://www.bbc.co.uk/news/science-environment-10991541

BBC NEWS

BBC, 9th May 2011

“Soils of UK and Europe drying out”

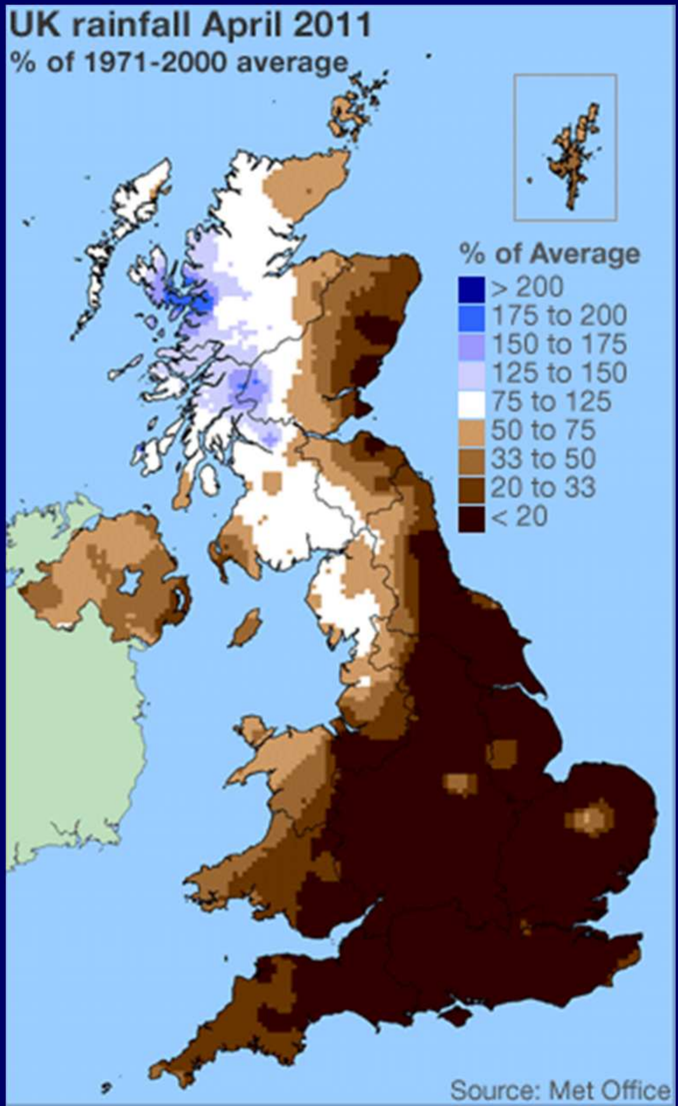


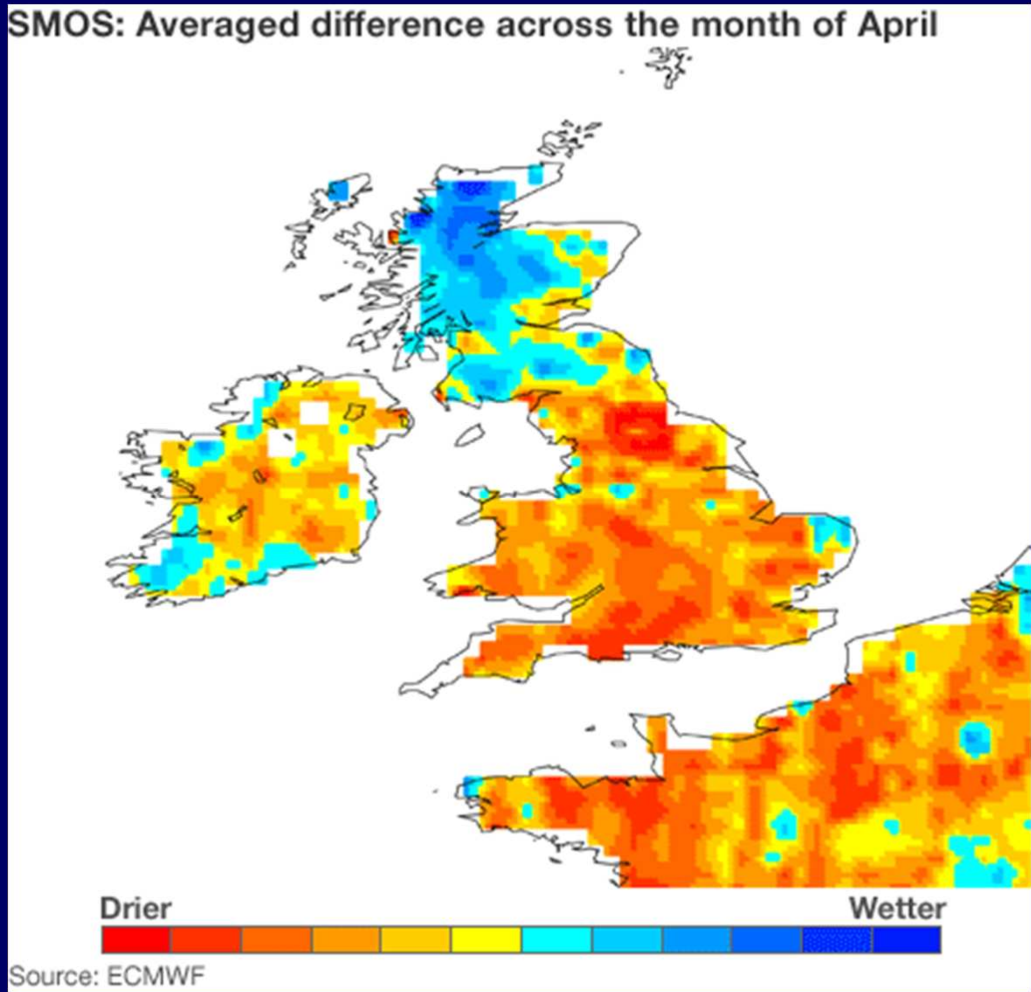
http://www.bbc.co.uk/news/science-environment-13338174

BBC NEWS

BBC, 9th May 2011

"Soils of UK and Europe drying out"





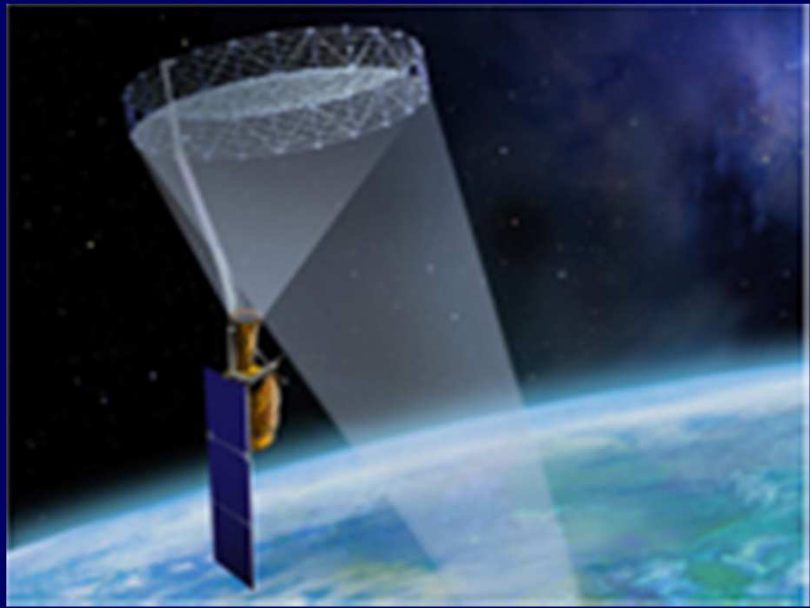
http://www.bbc.co.uk/news/science-environment-13338174

Next Step:
Combined Active and Passive

SMOS
Soil Moisture & Ocean Salinity Mission

ESA
Launch date: November 2009
Revisit time: 2-3 days
Observations:
35km Radiometer 1.4GHz (H+V)

http://www.esa.int/esaLP/LPsmos.html



SMAP
Soil Moisture Active-Passive Mission

NASA
Launch date: 2014<
Revisit time: 2-3 days
Observations:
40km Radiometer 1.4GHz (H+V)
3km Radar (1.26 H GHz, 1.29 V GHz)

http://smap.jpl.nasa.gov/

Passive Microwave Remote Sensing

Summary

Passive MW sensors measure brightness temperature.

At MW frequencies, $T_b < T_{physical}$, depending on emissivity.

Microwave emissivity varies considerably by surface type and condition, => passive microwave remote sensing has many applications including polar mapping, and measuring precipitation and soil moisture.

Active Microwave Remote Sensing

Learning objectives

By the end of this section, you will be able to:

1) Explain the difference between the main types of active MW sensors

2) List examples of each of the sensor types

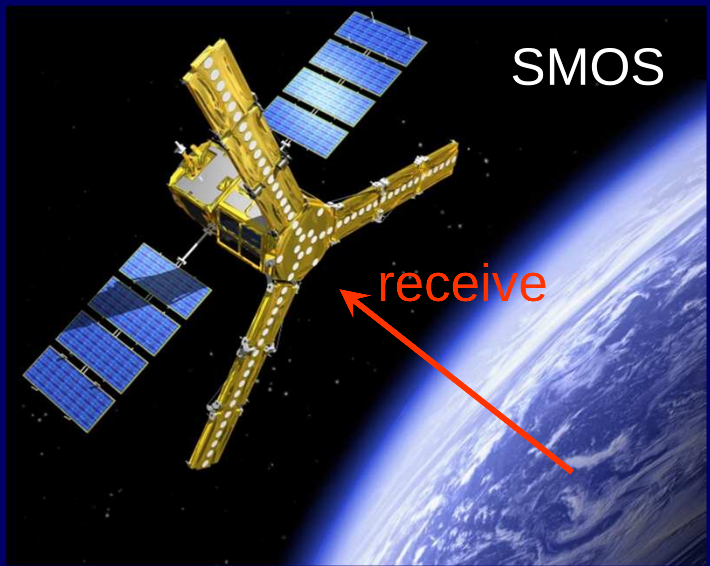
3) Describe how active microwave remote sensing can used to estimate water levels, soil moisture and address many problems in water resources management

Remote-sensing techniques

Passive

Employ natural sources of energy,

e.g. the sun (optical) or the earth itself (MW).



[3]

Active

Have their own source of energy.

In lasers, this source is optical.
In radar, this source is MW.

[4]

Active Microwave Sensor types

Non-imaging radar sensors

Take measurements in one linear dimension.

Examples:
1) radar altimeters
(measure distance)

2) scatterometers
(measure surface properties)

[4]

Imaging radar sensors

Take two-dimensional measurements.

Examples:
1) Real aperture radar (RAR)

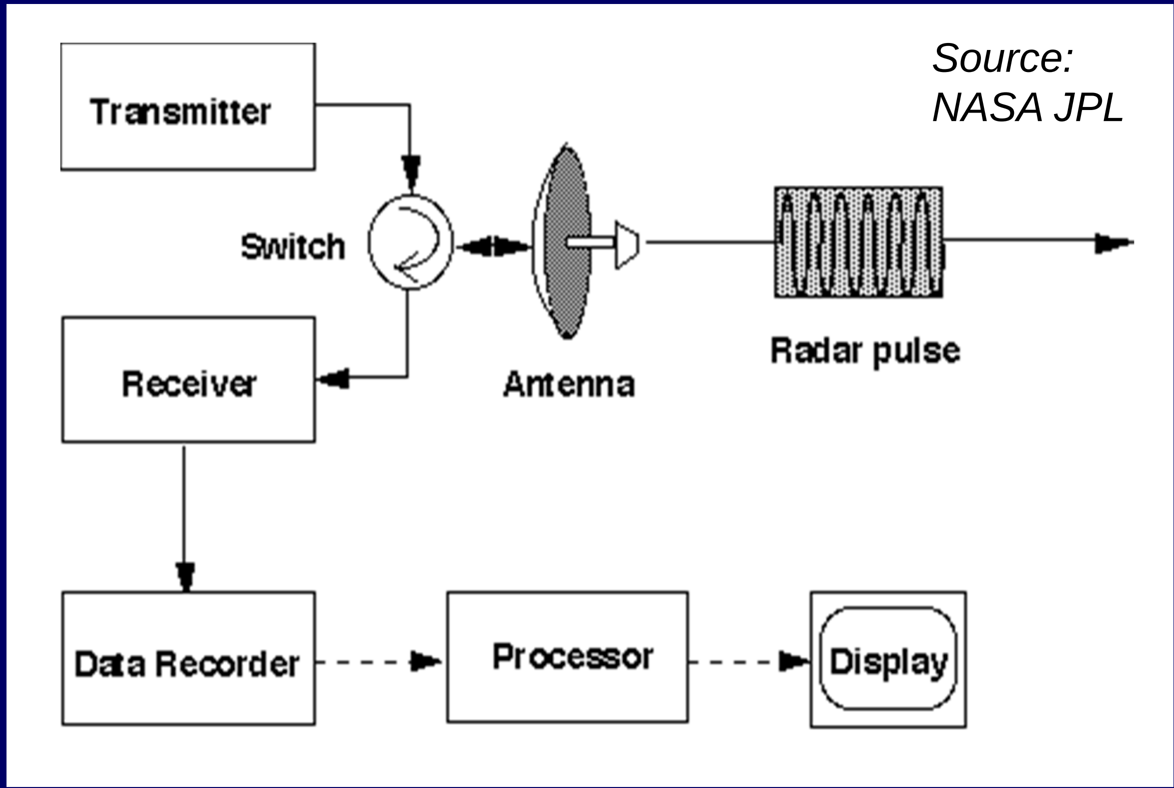
2) Synthetic aperture radar (SAR)

Components of a radar system

Antenna:
The microwave signals from the transmitter are bundled into a *beam*.

The antenna then *emits* the signal in a beam towards the Earth's surface, and *receives* the backscattered signal from the Earth's surface.

Transmitter:
Generates the microwave signal, and *transmits* it to the antenna

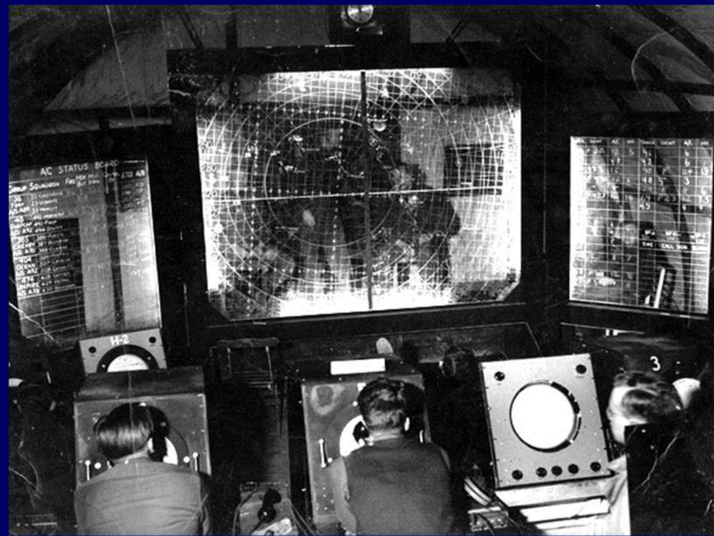


Receiver:
Accepts the backscattered signal from the antenna, *filters and amplifies* it as required by the recorder.

Recorder:
Stores the received signal

RADAR – Radio Detection And Ranging.

Radar techniques were originally developed for military applications.



[13]

[14]

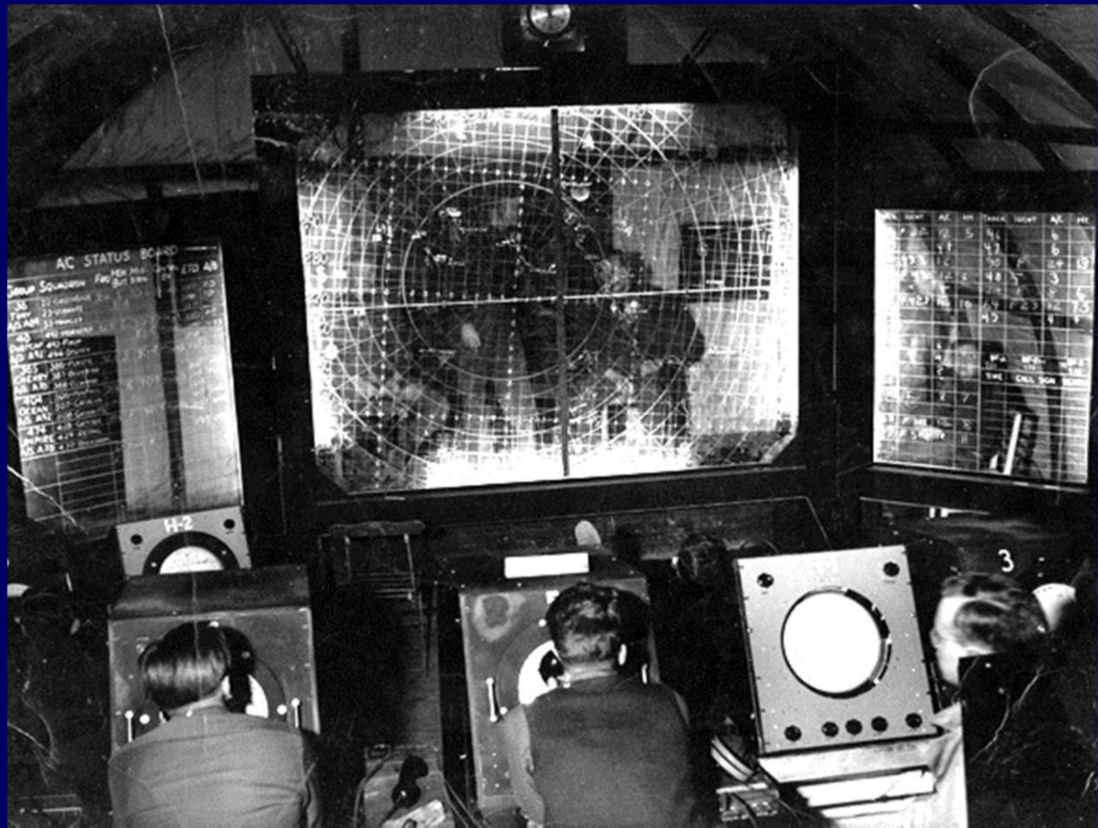
Surface search radar display found on ships

[15]

Radar tower
Heathrow airport

Radar Ranging

Developed during WWII,
to track incoming aircraft.



[13]

If a short microwave pulse is transmitted towards and reflected by a target, the distance $\boldsymbol{R}$ to the target is given by:

$$R = \frac{ct}{2}$$

where

$\boldsymbol{c}$ is the speed of light in the medium

$\boldsymbol{t}$ is the time taken for the signal to reach the target and return to the transmitter.

Radar Altimetry

Altimeters use ranging to measure surface topography

$$h = \frac{ct}{2}$$

c is the speed of light in the medium

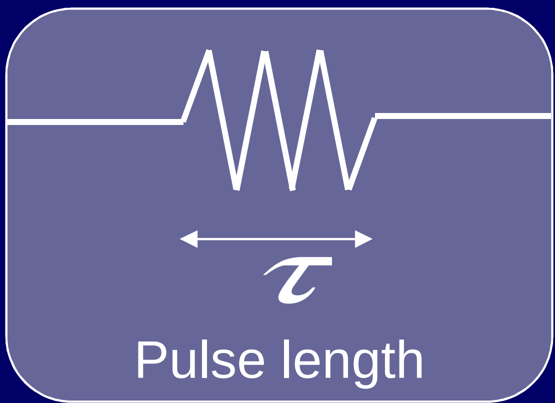
t is the time delay between transmitted and received signals

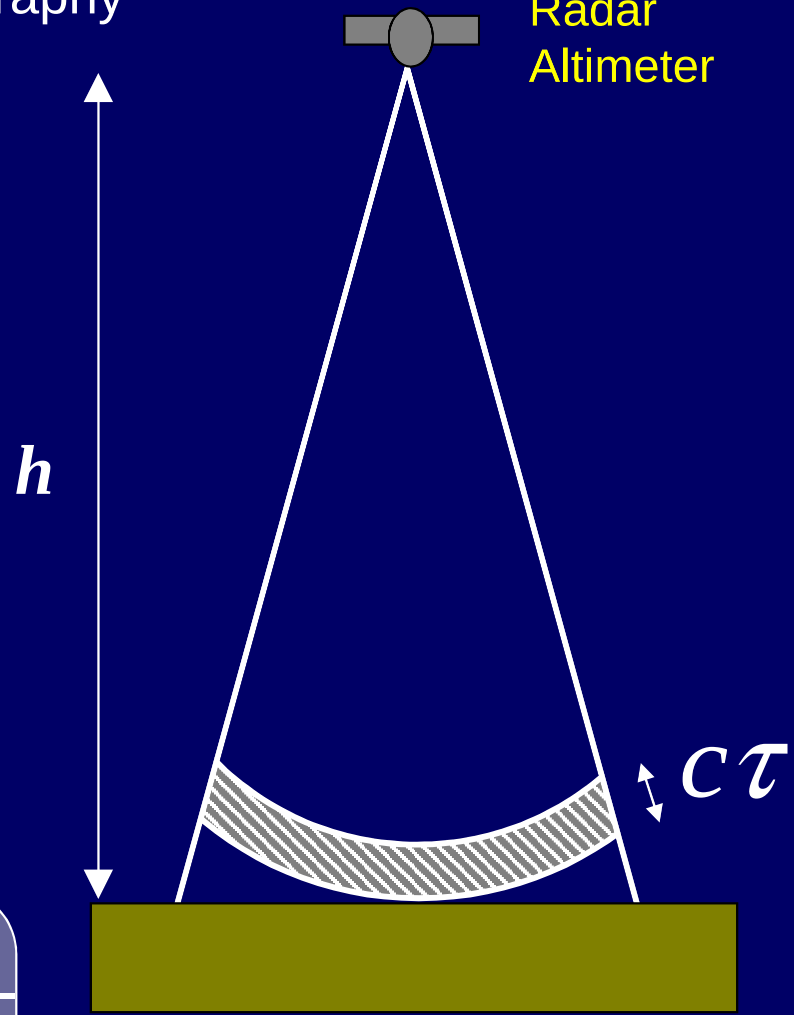
The accuracy with which the distance can be measured is given by:

$$\Delta h = \frac{c\tau}{2} = \frac{c}{2B}$$

where B is the bandwidth of the pulse,

$$B = \frac{1}{\tau}$$



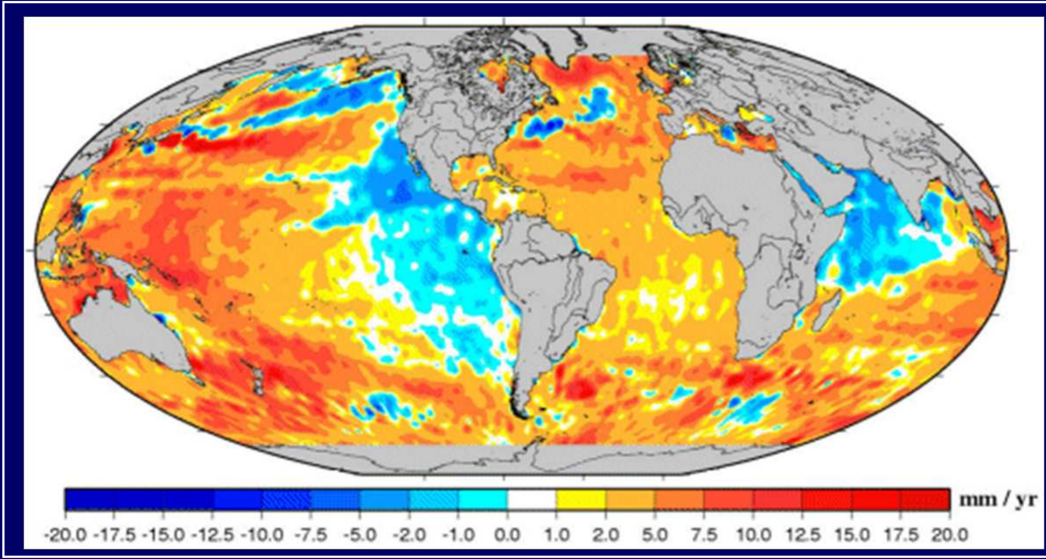


Some radar altimetry missions

Mission	Agency	Launch	Altitude (km)	Frequency	Revisit Time (days)	Inclination	Error Budget Range	Error Budget Orbit
Past								
Geosat	US Navy	1985	800	Ku	17	108	4cm	30-50cm
ERS-1	ESA	1991	785	Ku	35	98.5	3cm	8-15cm
Topex-Poseidon	NASA	1992	1336	Ku, C	10	66	2cm	2-3cm
Current								
ERS-2	ESA	1995	785	Ku	35	98.5	3cm	7-8cm
GFO	NOAA/ US Navy	1998	800	Ku	17	108	3-5cm	?
Jason-1	CNES/ NASA	2001	1336	Ku,C	10	66	2cm	2-3cm
Envisat	ESA	2002	800	Ku,S	35	98.5	2-3cm	2-3cm

(Ku=13.6GHz, C=5.3GHz, Ka=35GHz)

Mean sea level observations



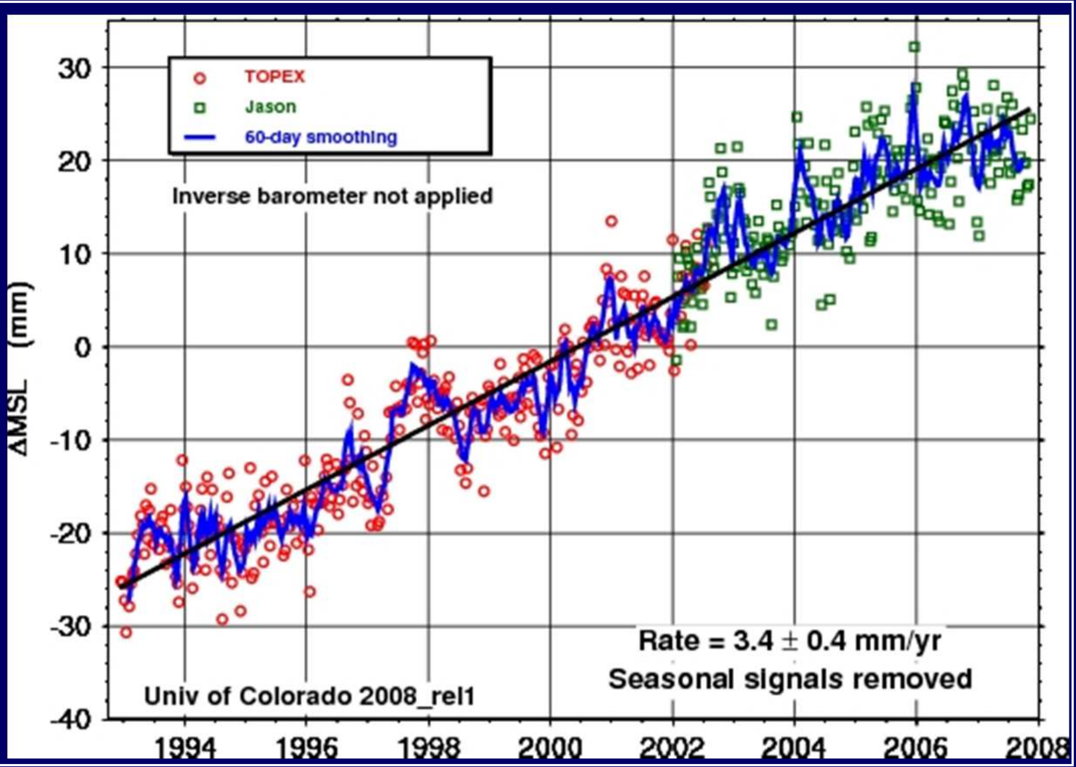
Mean Sea Level trends computed from altimetry, from January 1993 to 2005.

(Source: Legos/CNRS, France)

Mean Sea Level variation computed from altimetry

(Source: http://sealevel.colorado.edu)

Leuliette, E. W, R. S. Nerem, and G. T. Mitchum, 2004. Calibration of TOPEX/Poseidon and Jason altimeter data to construct a continuous record of mean sea level change. *Marine Geodesy*, **27**(1-2), 79-94.



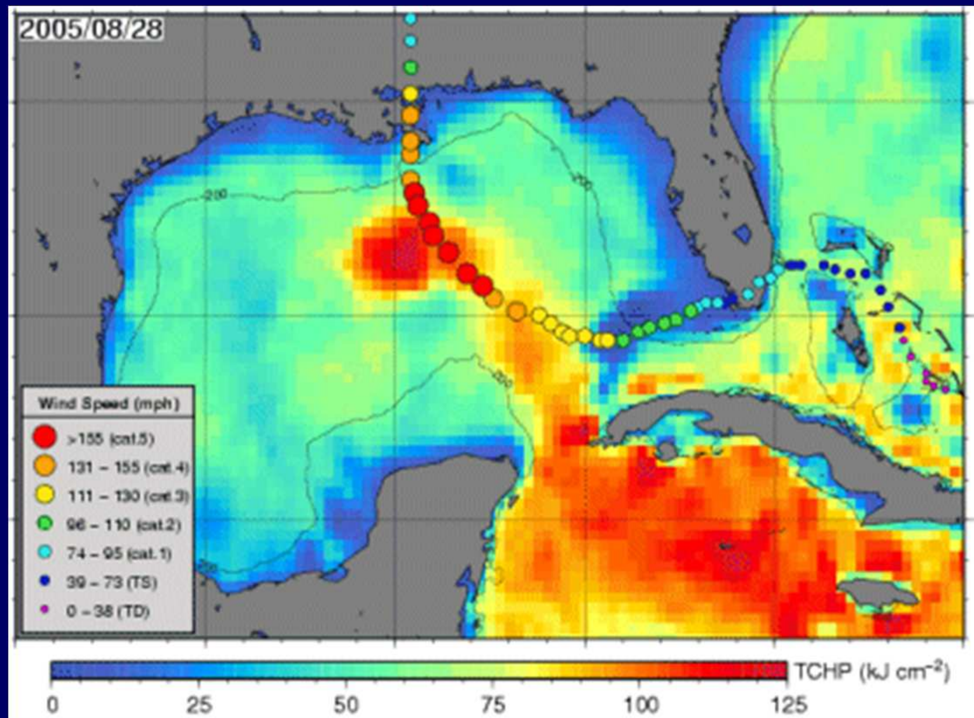
Sea surface height anomalies

Warm ocean currents and eddies → Increased sea surface heights

↓ ↓

Intensification of hurricanes Observe with radar altimetry!

Hurricane Katrina



Tropical Cyclonic Heat Potential computed from altimetry on 28 August 2005, with Hurricane Katrina's trajectory and intensity overlaid.

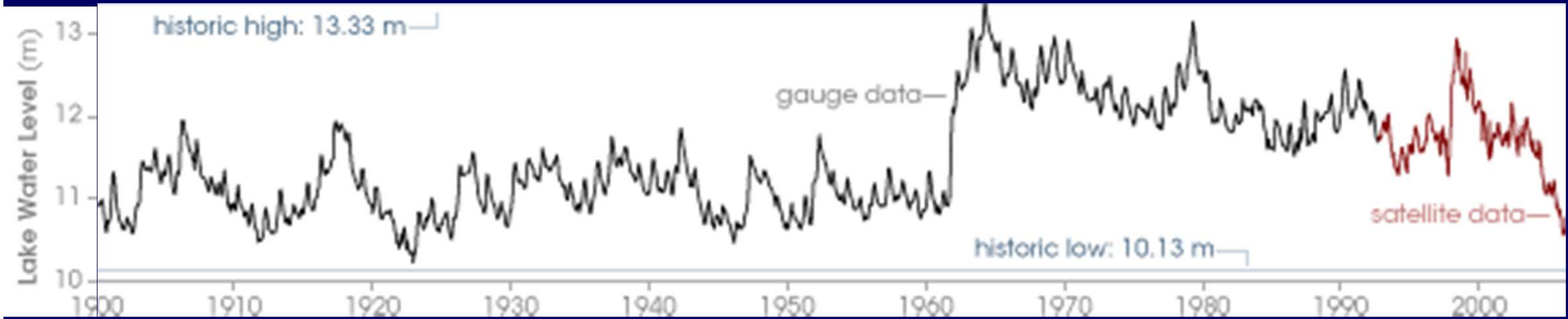
Katrina's intensification seems to coincide with its crossing over the Loop Current.

(Credits NOAA/AOML)

Lake level monitoring

Lake Victoria

- Borders Kenya, Uganda, Tanzania
- Food, transport,energy for 30 million people
- 3rd largest lake in the world
- Surface Area 68,870 km2
- Mean depth: 40.0 m

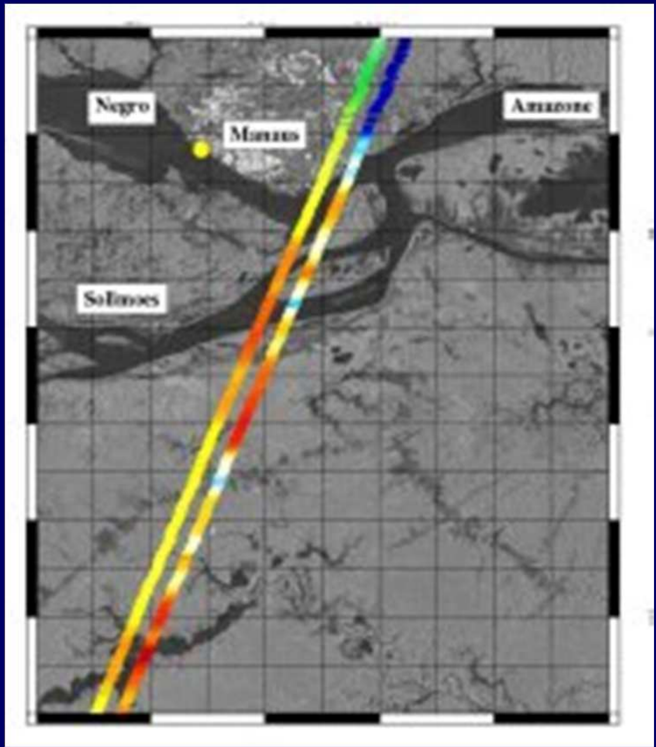


Lake level data from the TOPEX-Poseidon and Jason-1 satellites (red) augment gauge data at Jinja, Uganda (black). (Graph by Robert Simmon, based on data provided by the USDA Foreign Agricultural Service.)

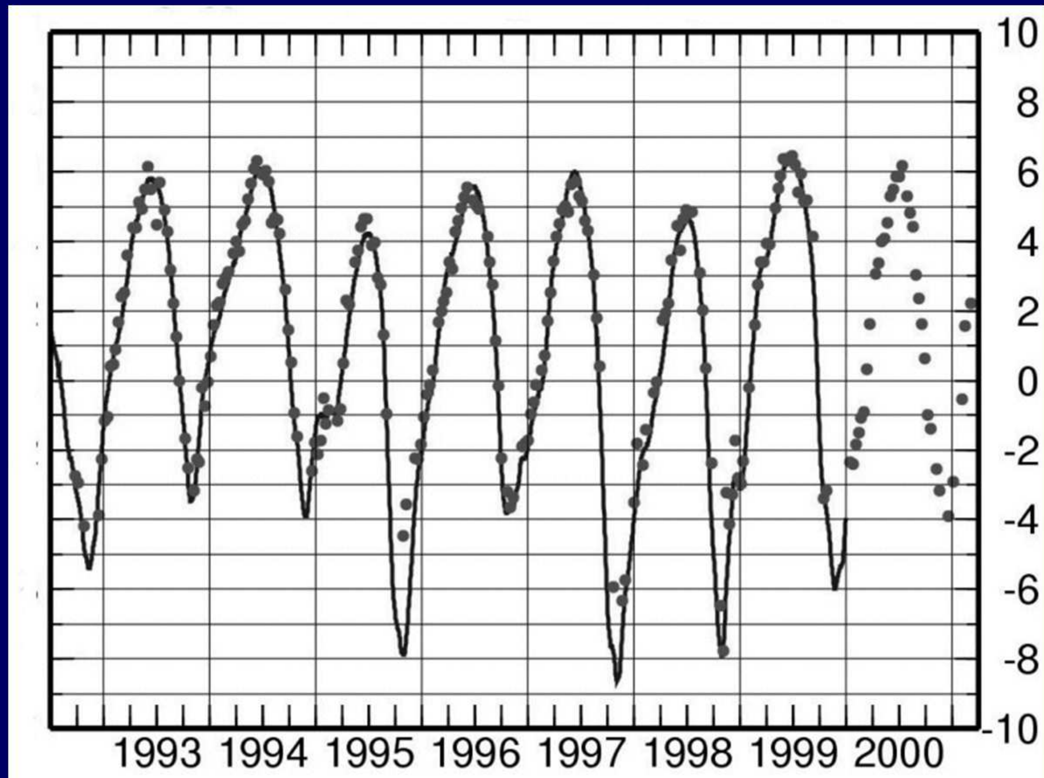
Source: earthobservatory.nasa.gov

River level monitoring

Mean water level variations at Manaus, Amazon River, from Topex/Poseidon



Topex/Poseidon track 63 shown in the area of the Amazon and Rio Negro rivers in the upper Amazon basin.



Water level time series in the Amazon for Topex/Poseidon track 63 (3.21°S-3.14°S), in metres. In-situ data from the Manaus station are shown as dots.

Land and Ice Sheet Topography

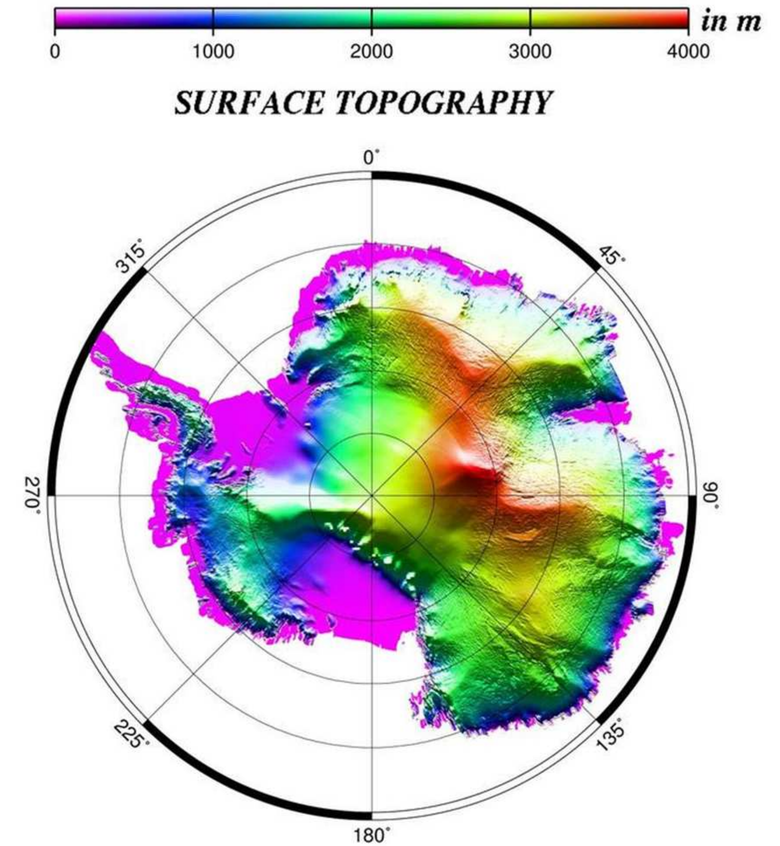
Challenges over land:

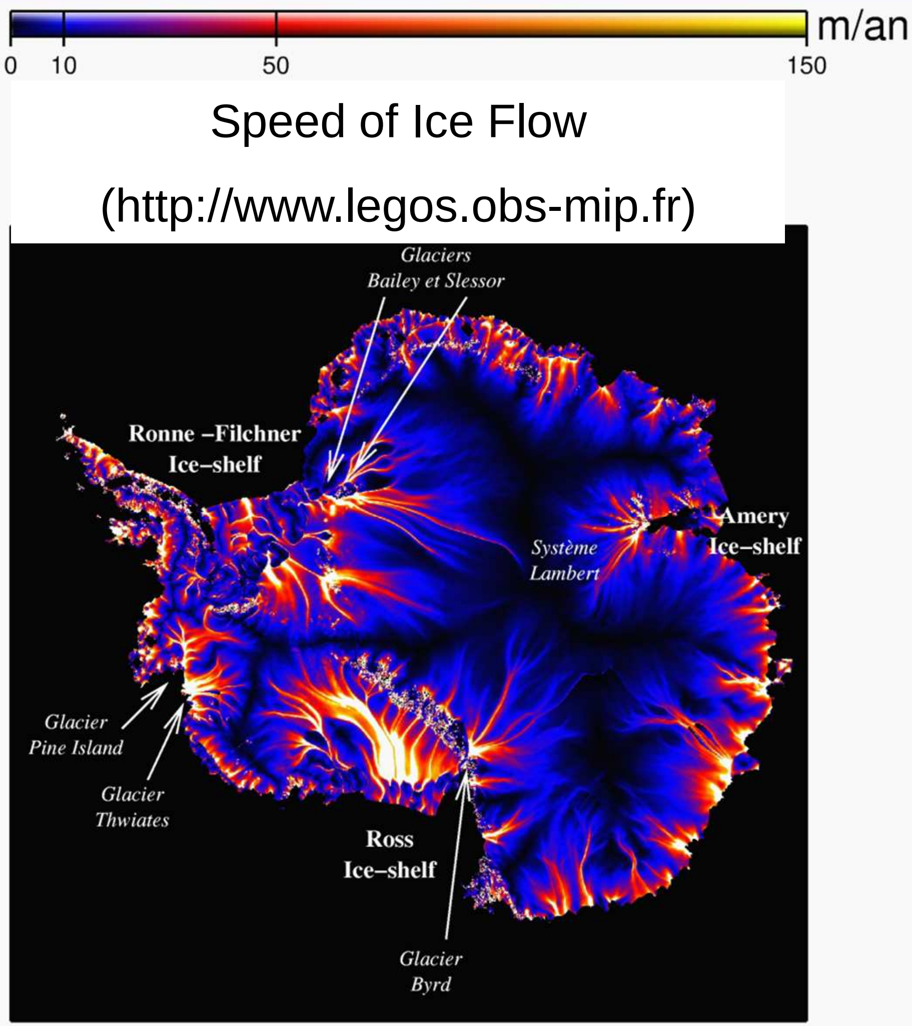
1) Loss of track

2) Slope-induced error

Limited to ‘flat’ areas

Elevation map of Antarctic Ice Sheet from ERS-1 data (http://www.legos.obs-mip.fr)





Speed of Ice Flow

(http://www.legos.obs-mip.fr)

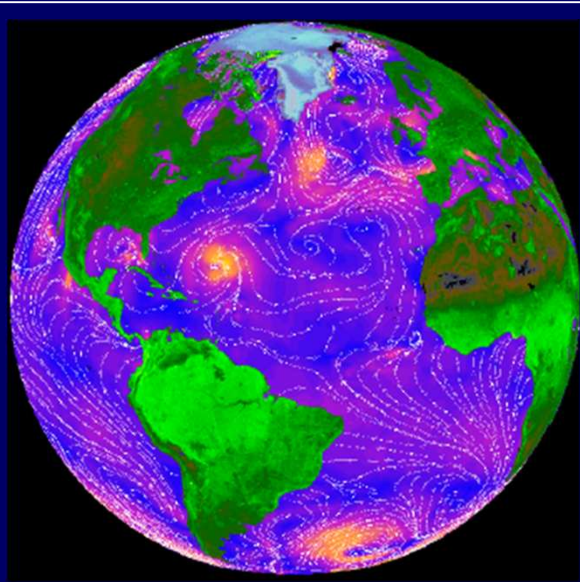
Non-Imaging Radar: Scatterometers

Scatterometry:

Measures the properties of surfaces (e.g. land and ocean) and volumes (vegetation canopy) based on backscattering cross-section of the surface area illuminated by the antenna.

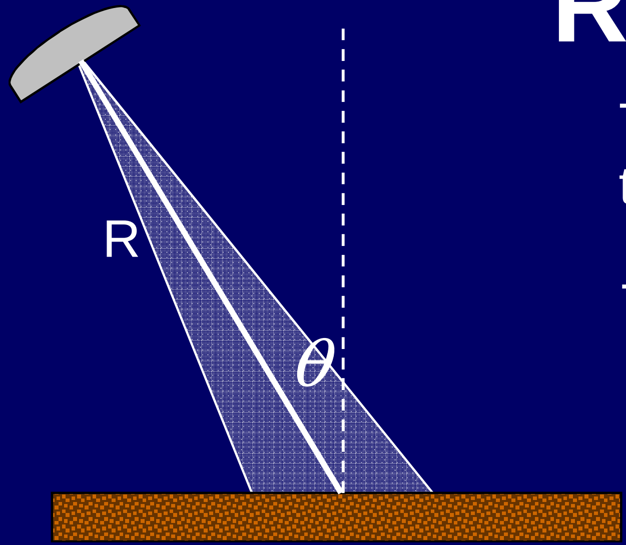
Originally developed to map wind speed and direction over oceans.

Over land, scatterometry can tell us about soil moisture content, roughness and texture, as well as vegetation structure.



Wind directions and velocities over the ocean as from QuikSCAT (NASA JPL)

Radar Equation



The surface acts like a transmitter, transmitting this backscattered power back to the antenna

The power received at the antenna is given by:

$$P_r = \frac{G P_t S \sigma A}{(4\pi)^2 R^4} \cos\theta$$

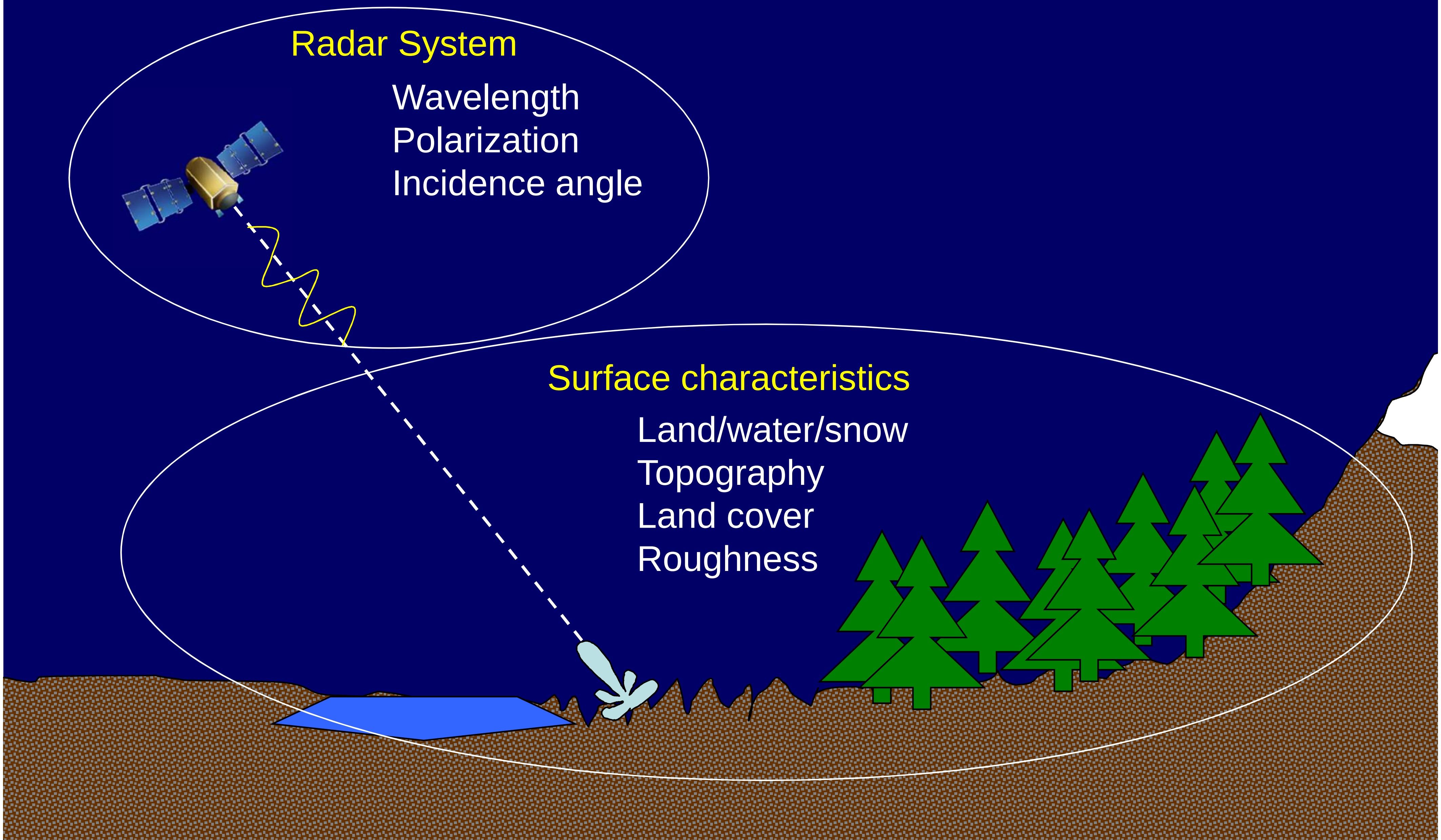
Radar System Properties

- G is the antenna gain. $G = \frac{\eta 4\pi A}{\lambda^2}$
- λ is the wavelength
- P_t is the transmitted energy
- A is the area of the antenna, η is its efficiency.

Geometry & Surface Characteristics

- σ is the backscatter cross section
- R is the range (distance) from the sensor to the object.

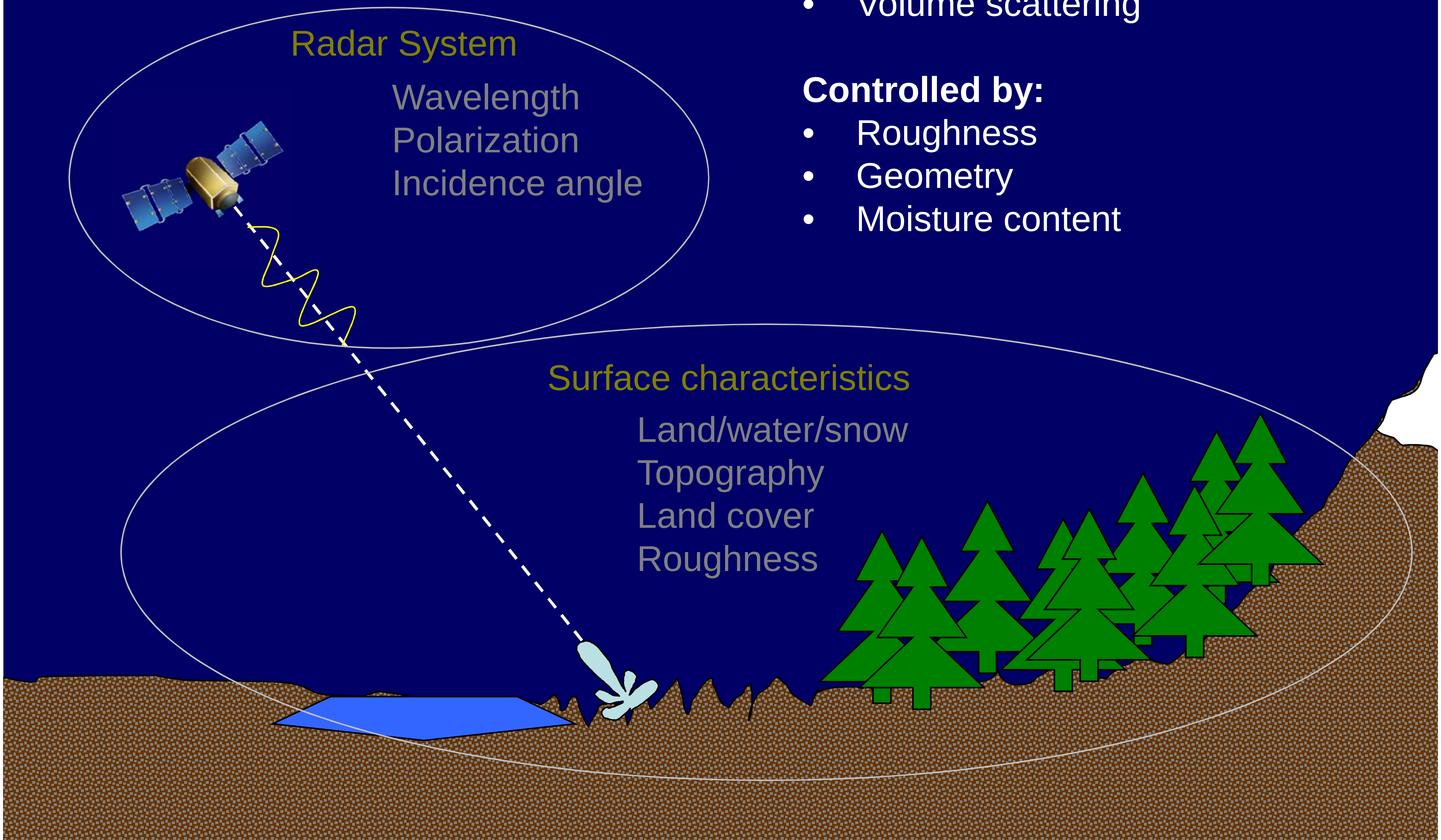
Backscatter cross section, σ



Backscatter cross section, σ

Two types of scattering:
- Surface scattering
- Volume scattering

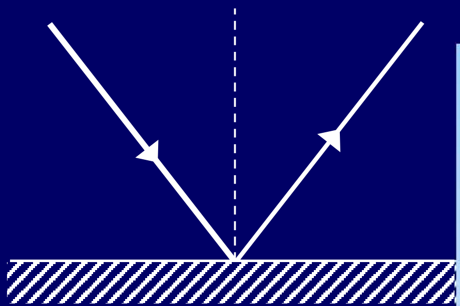
Controlled by:
- Roughness
- Geometry
- Moisture content

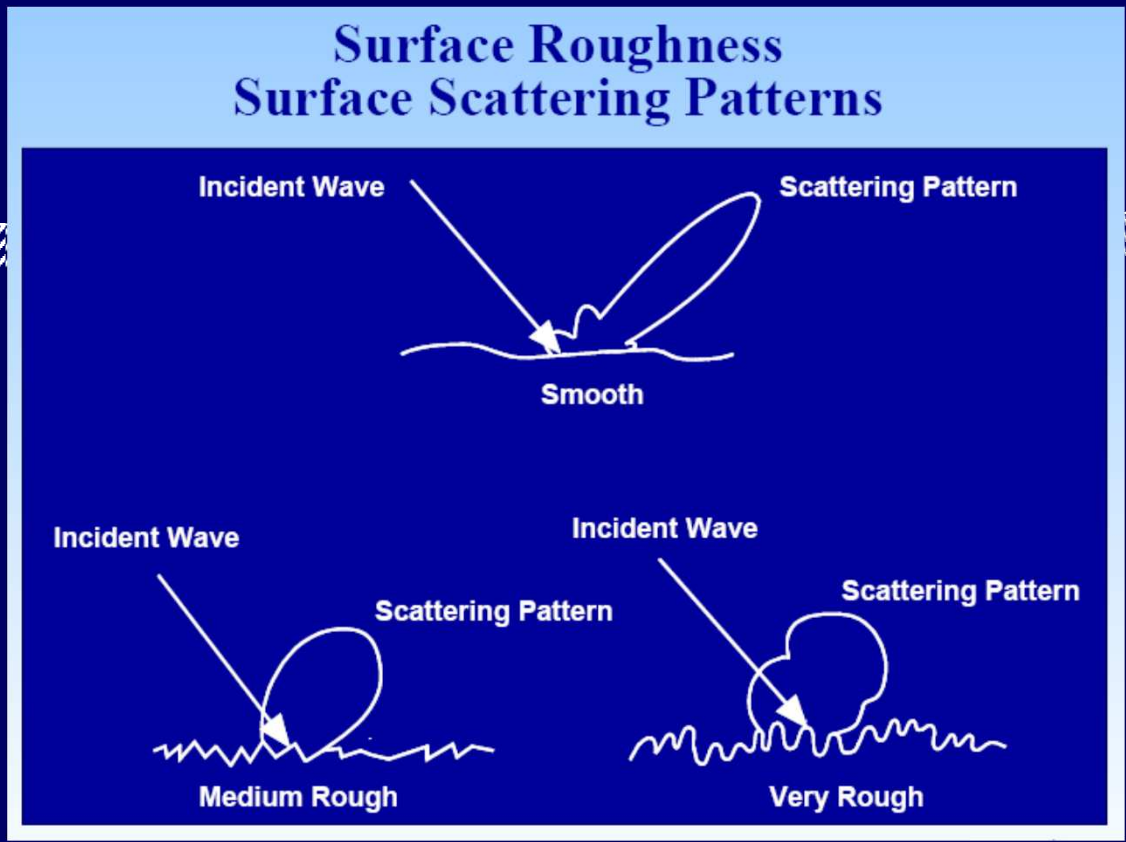


Backscatter cross section, σ – Surface scattering

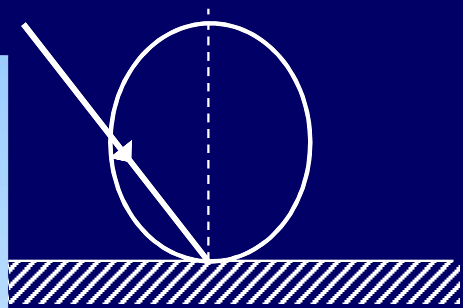
Roughness

“Smooth”
Specular scattering





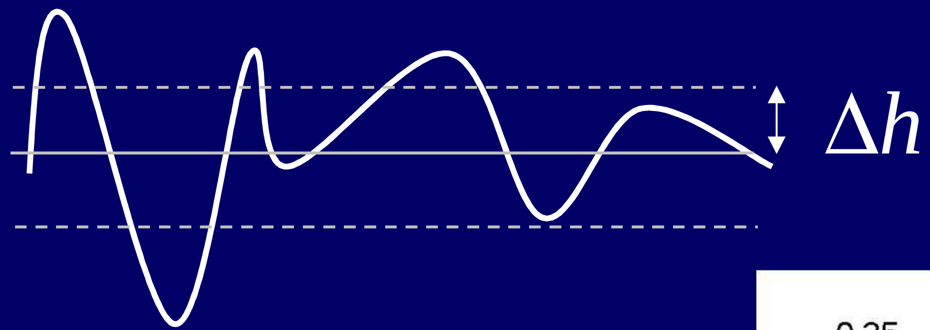
“Rough”
Lambertian scattering



Source:CCRS

Backscatter cross section, σ – Surface scattering

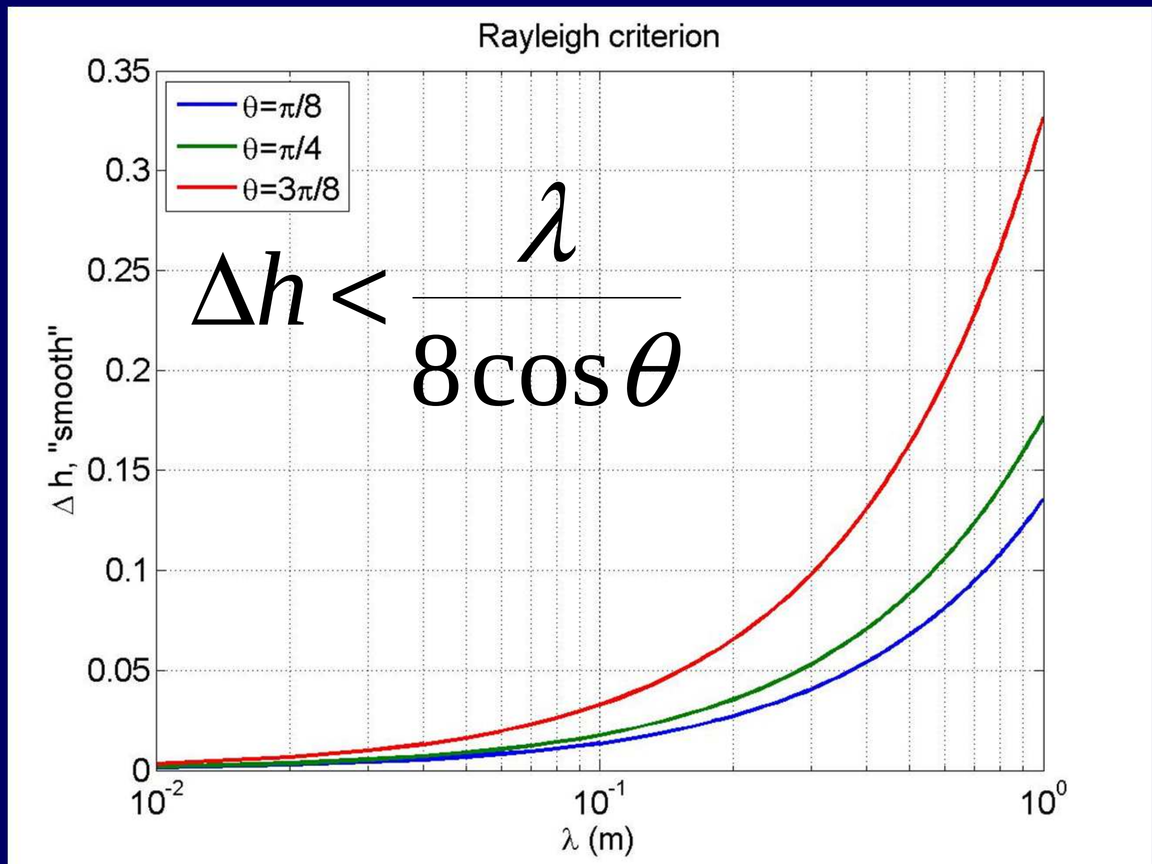
Roughness



Δh = root mean square variation in surface height

Surface is "smooth" if
$\Delta h << \lambda$

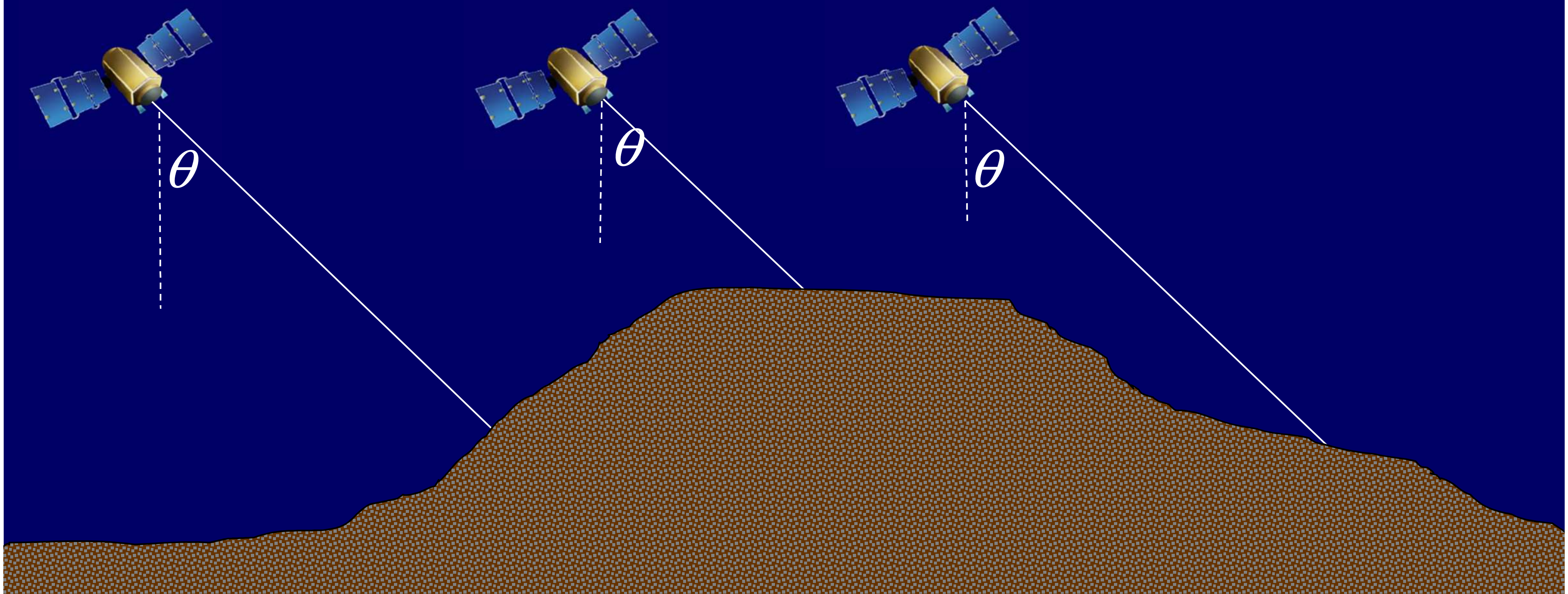
e.g. Rayleigh criterion



$$\Delta h < \frac{\lambda}{8\cos\theta}$$

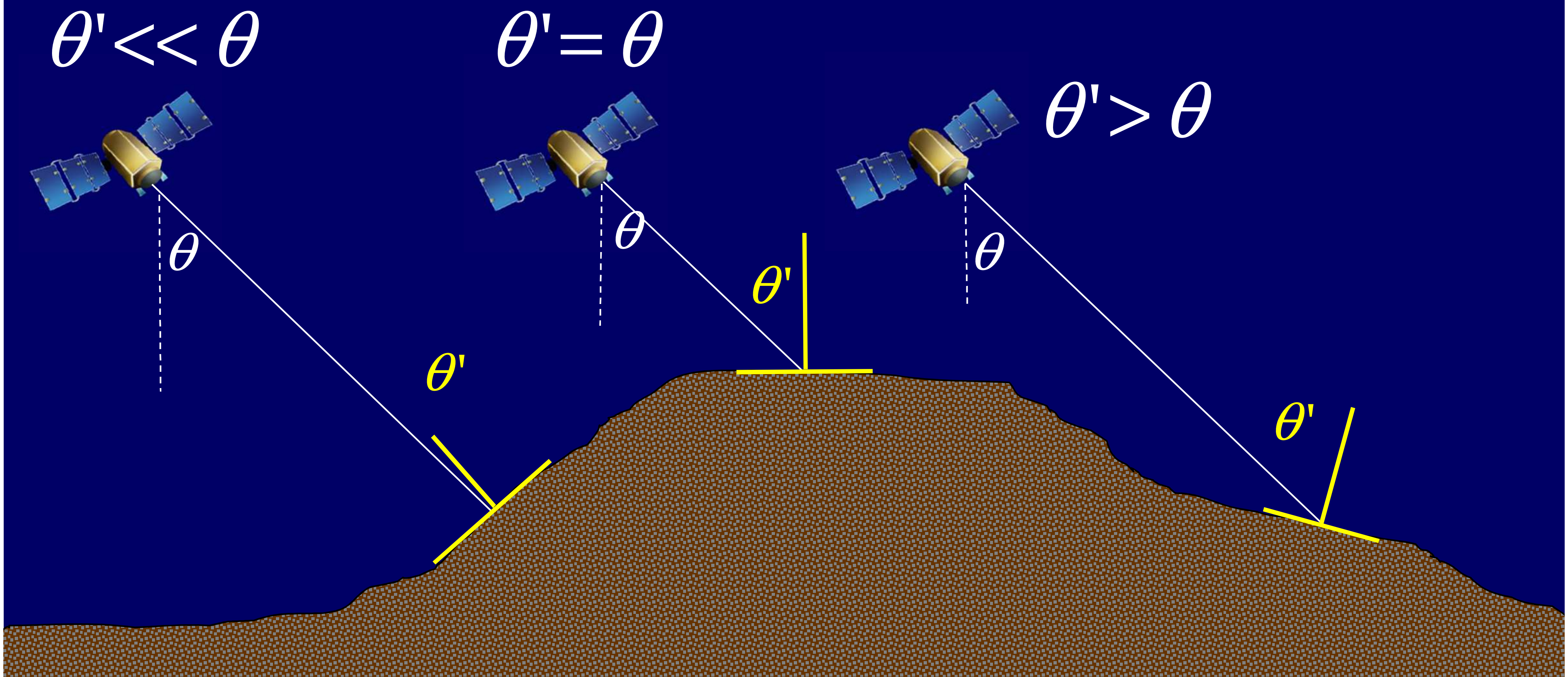
Backscatter cross section, σ – Surface scattering

Geometry - Local Incidence Angle



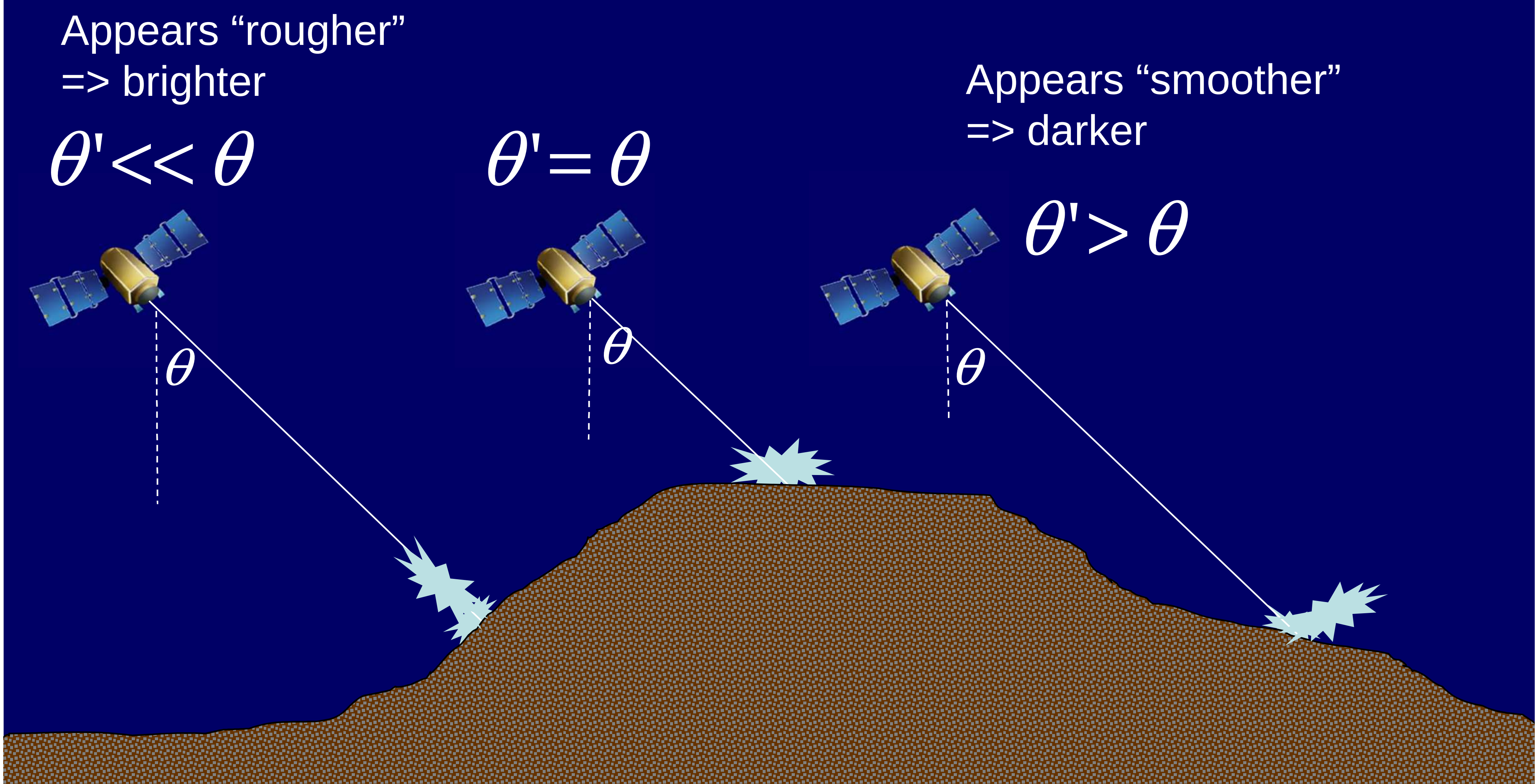
Backscatter cross section, σ – Surface scattering

Geometry - Local Incidence Angle



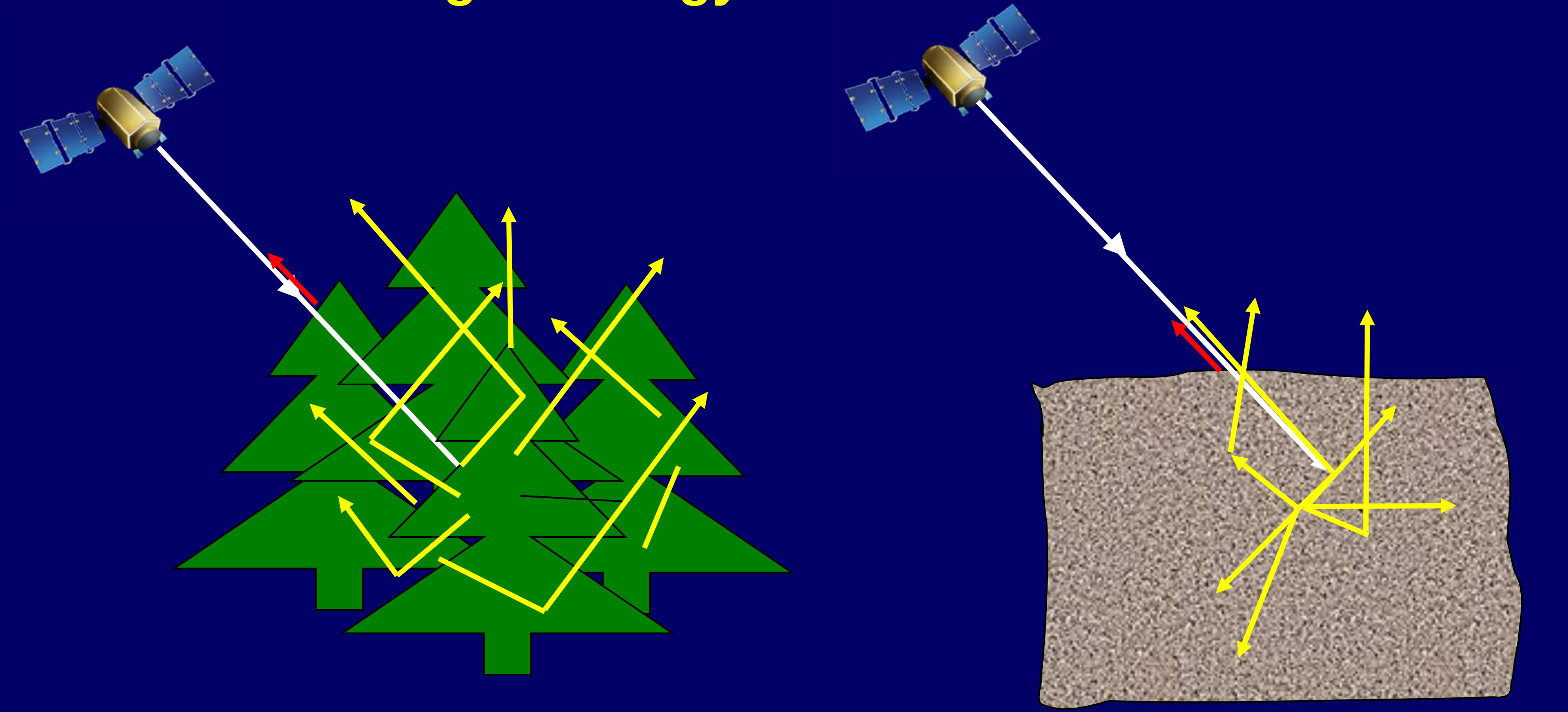
Backscatter cross section, σ – Surface scattering

Geometry - Local Incidence Angle



Backscatter cross-section, σ – Volume scattering

Scattering of energy within a medium/ volume



Effect on backscatter cross-section depends on amount scattered towards antenna

Backscatter cross-section, σ – Volume scattering

Dielectric Constant

Fundamental parameter of natural materials, relating to its electrical properties:

$$\varepsilon = \varepsilon' + j\varepsilon''$$

Real component
aka "dielectric constant"

Imaginary component
aka "lossy component"

It affects the reflective and emissive properties of a medium

High dielectric constant => reflective => more surface scattering

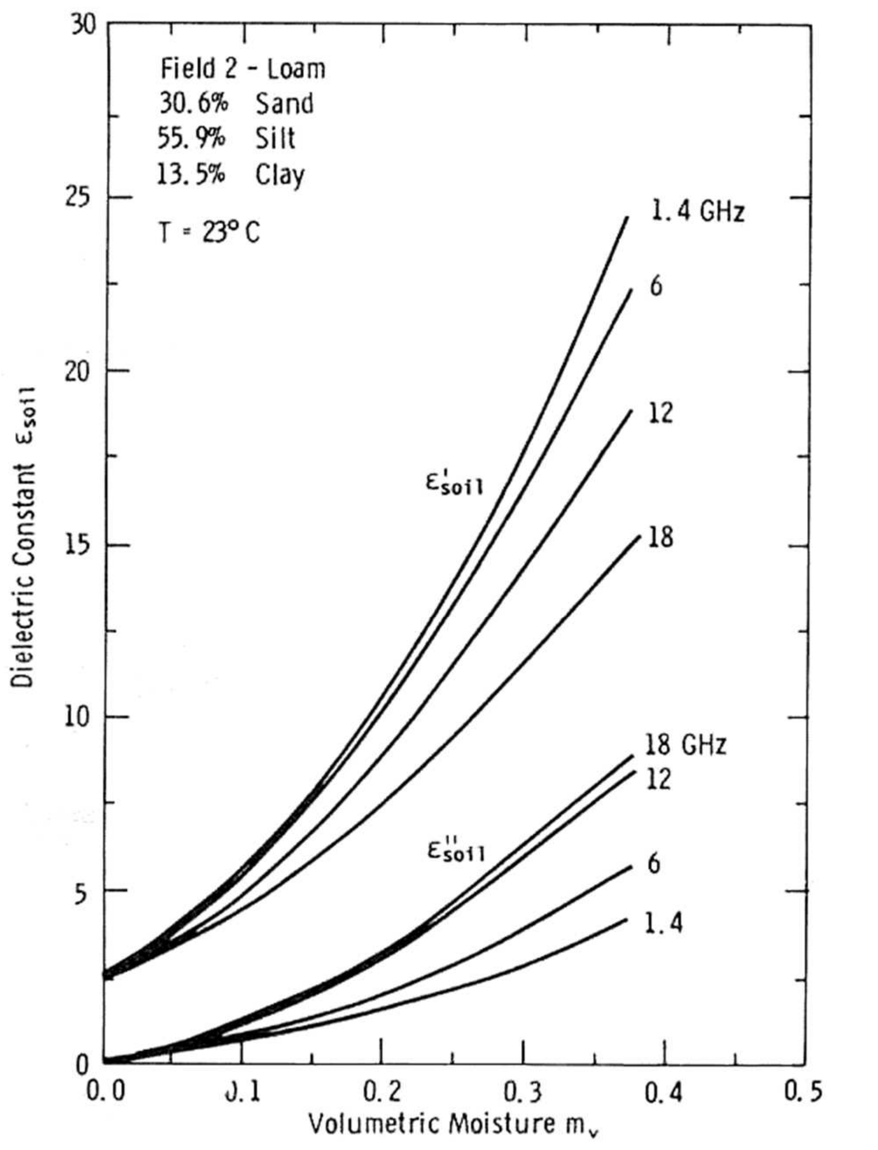


Fig. E.52 Measured dielectric constant as a function of volumetric moisture content for a loamy soil at four microwave frequencies.

Backscatter cross-section, σ – Volume scattering

Penetration Depth

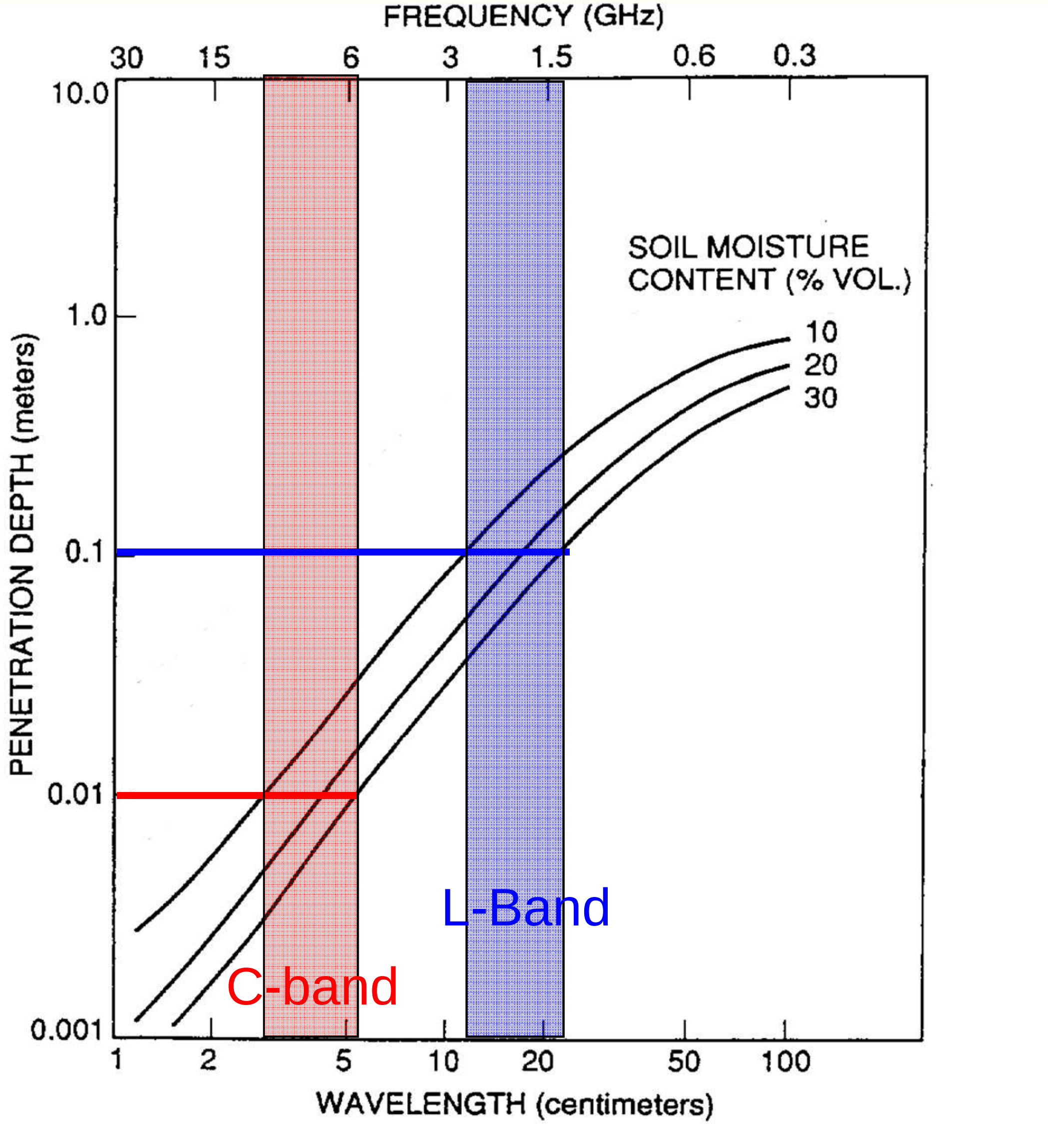
Depth at which power of wave is reduced to 1/e times its original value.

$$L_p = \frac{\lambda\sqrt{\varepsilon'}}{2\pi\varepsilon''}$$

Higher penetration depth:
Pure ice, older sea ice, dry soil

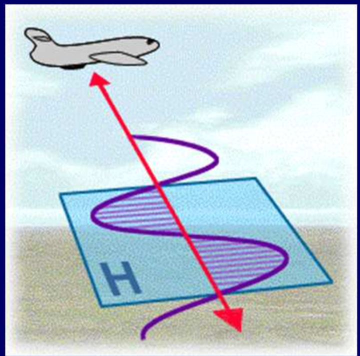
Wetter soils more reflective, lower penetration depth.

Required penetration depth determines design λ

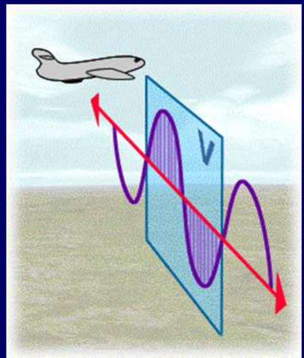


Backscatter cross-section, σ – Volume scattering

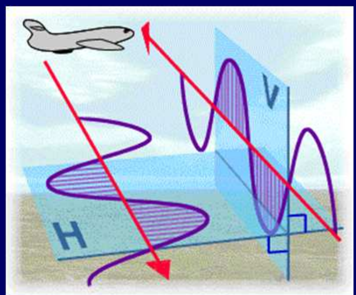
HH



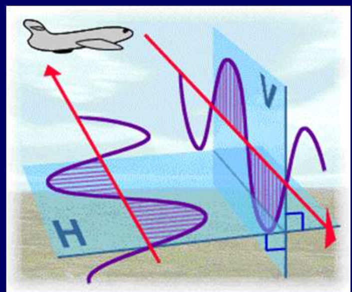
VV



HV

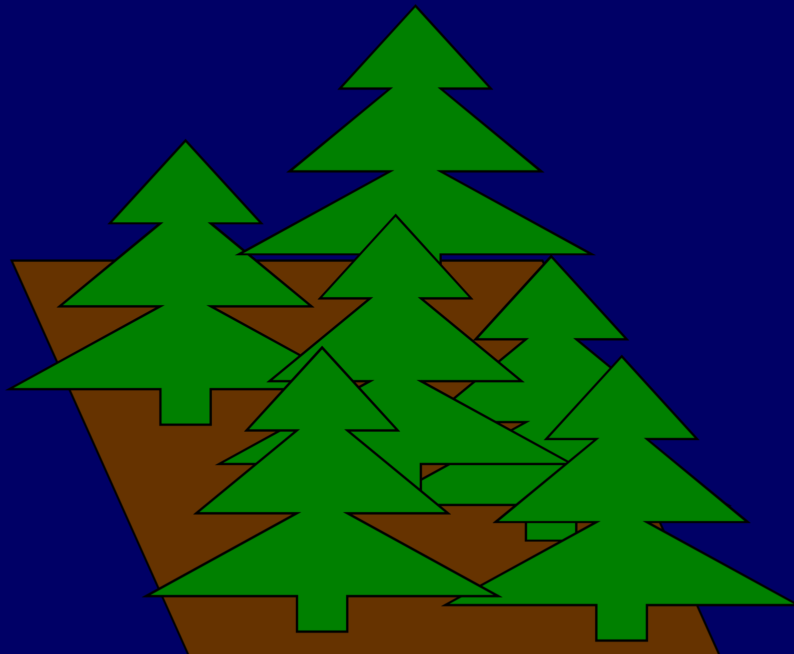


VH

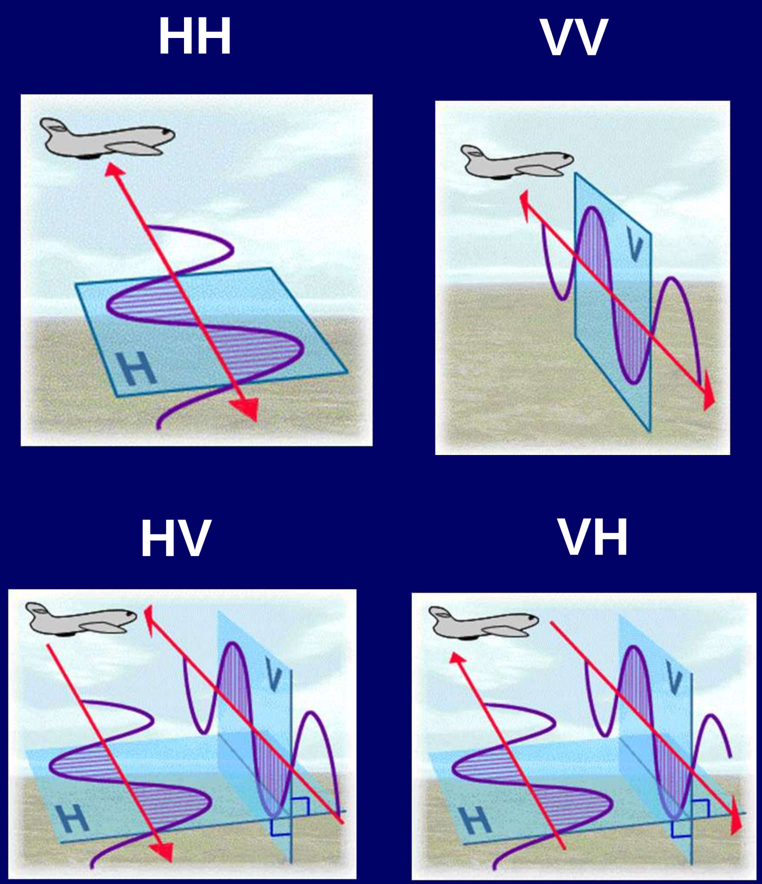


Source: CCRS

Polarization

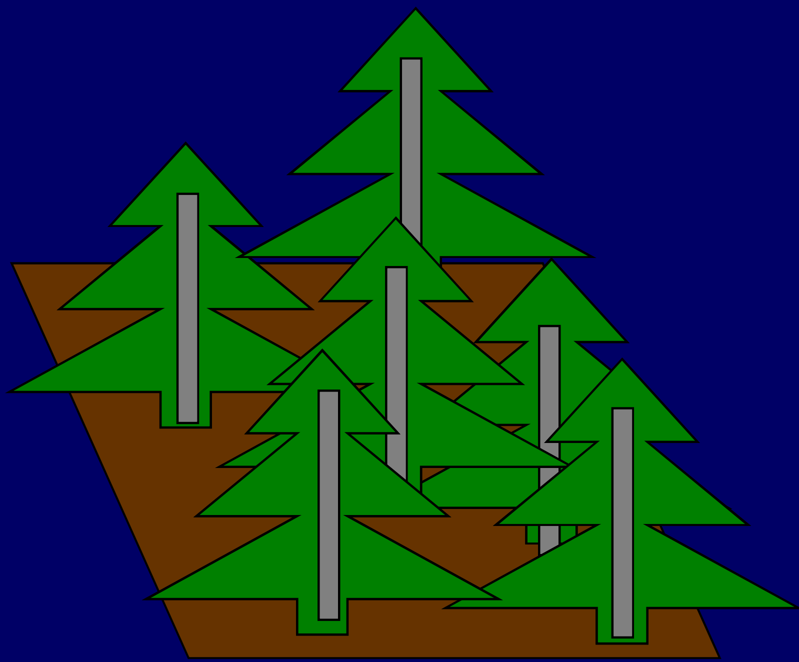


Backscatter cross-section, σ – Volume scattering

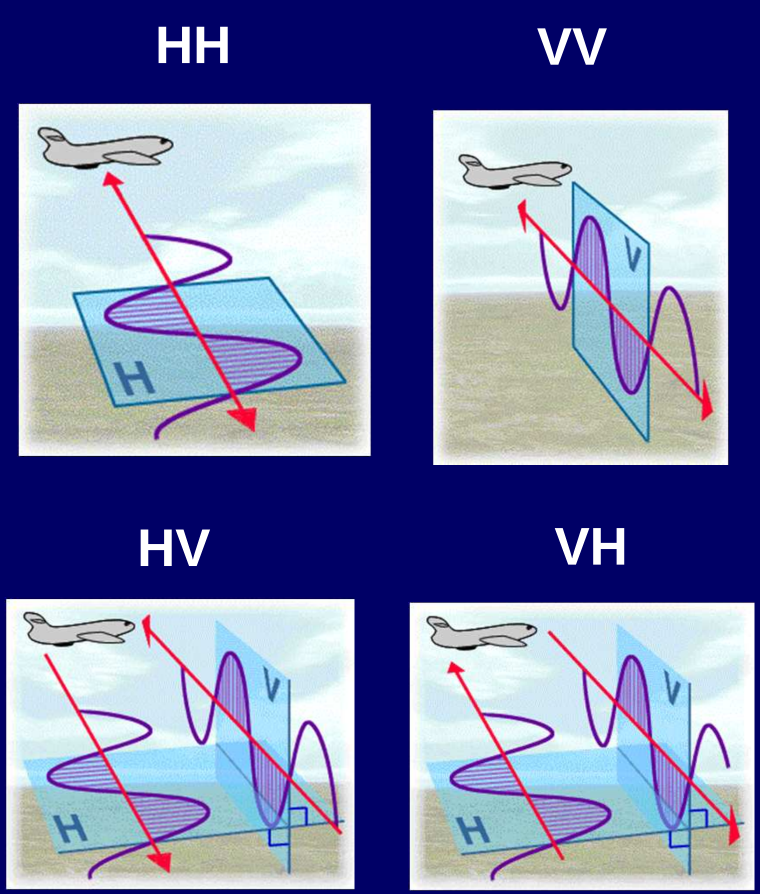


Source: CCRS

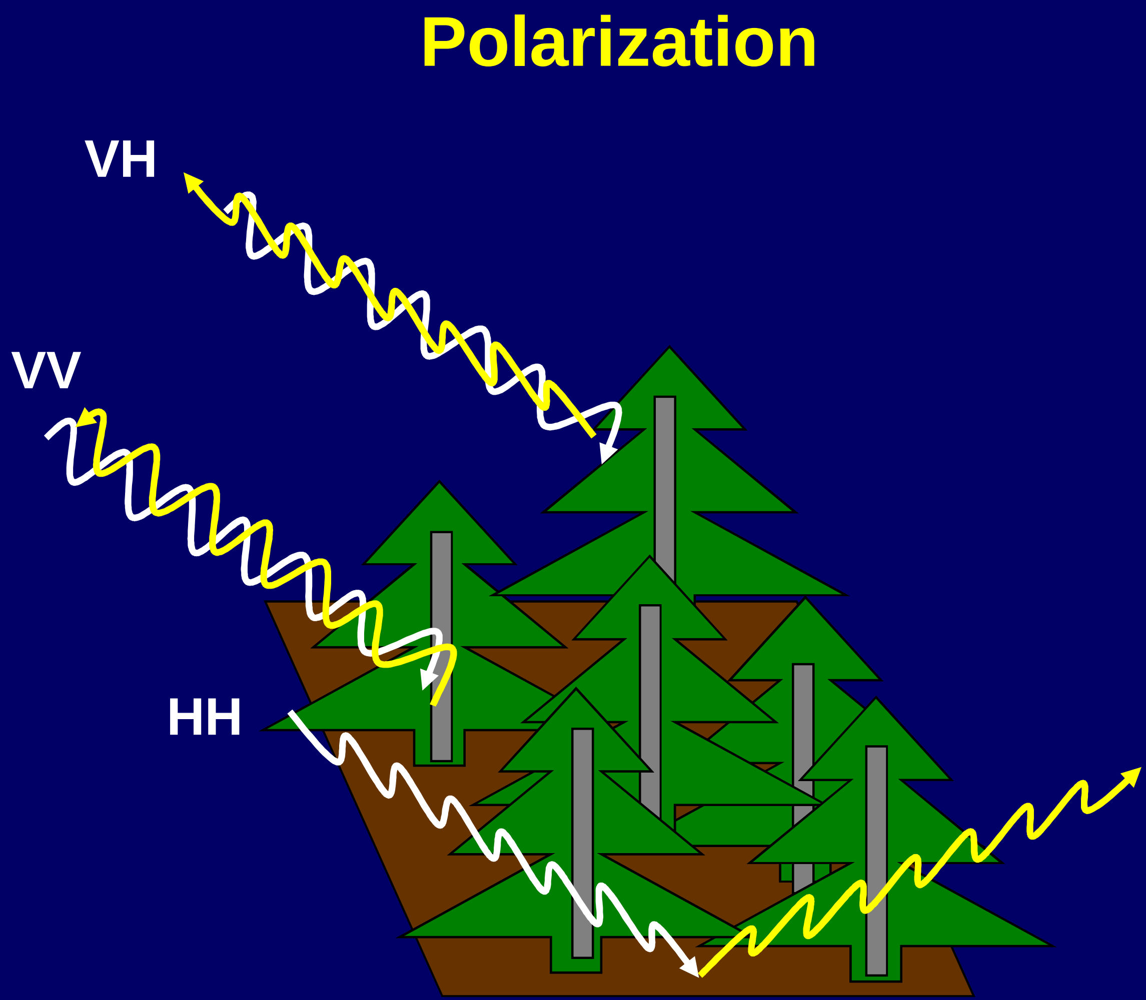
Polarization



Backscatter cross-section, σ – Volume scattering



Source: CCRS



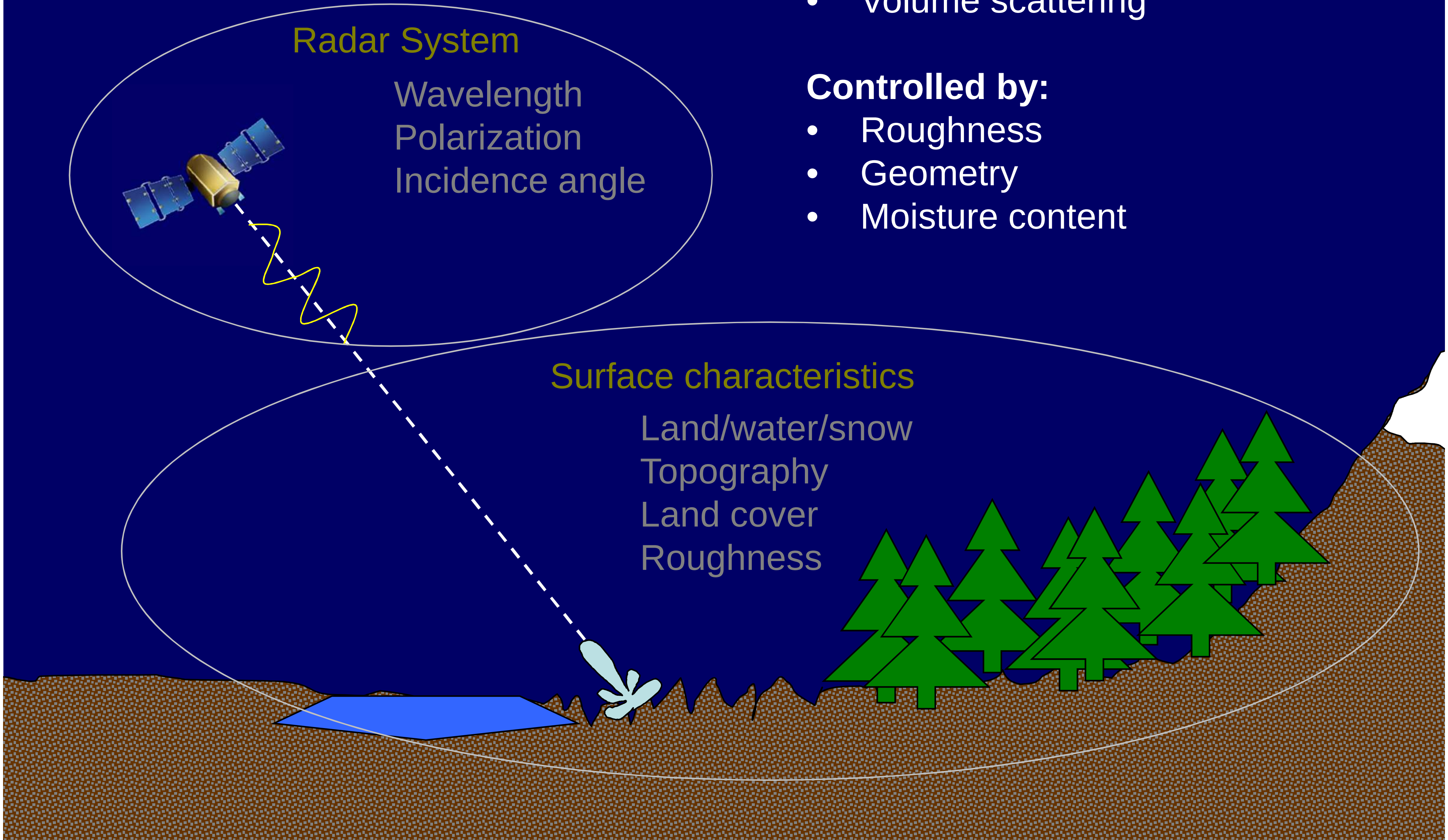
Backscatter cross section, σ

Two types of scattering:

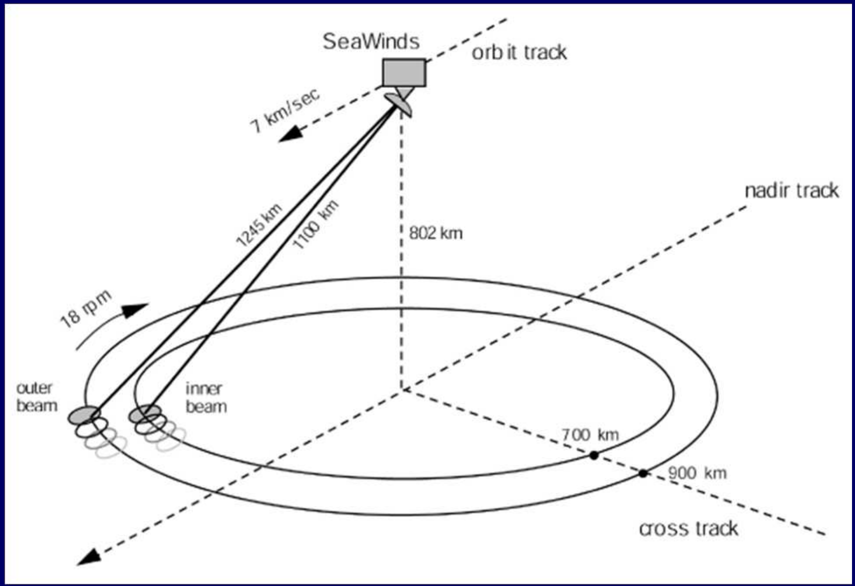
- Surface scattering
- Volume scattering

Controlled by:

- Roughness
- Geometry
- Moisture content



Scatterometry: SeaWinds on Quikscat



Launch: June 1999, NASA

Polar orbiting,
sun synchronous,
altitude 803km

1800km swath

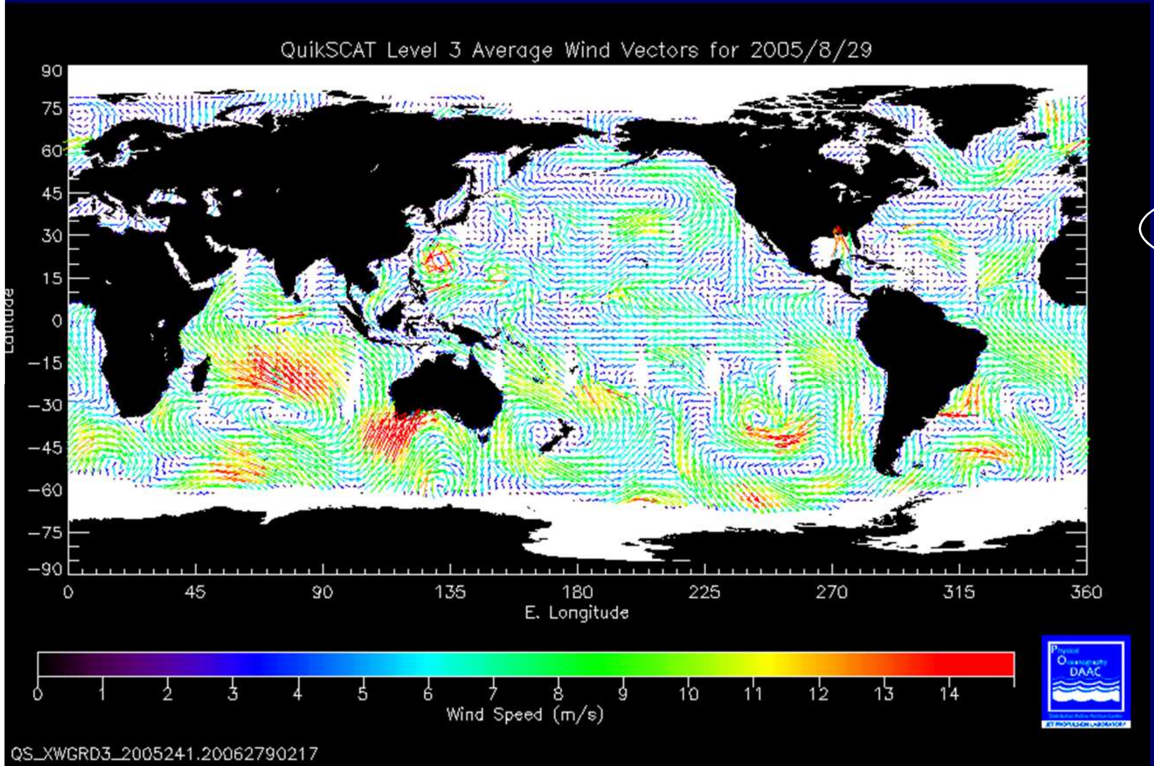
Pencil beam antenna, two beams

Frequency 13.4GHz

Wind speed and direction

Resolution 25km

Wind speed accuracy 3-20ms^{-1} ±2ms^{-1}



http://winds.jpl.nasa.gov/

Scatterometry: SeaWinds on Quikscat

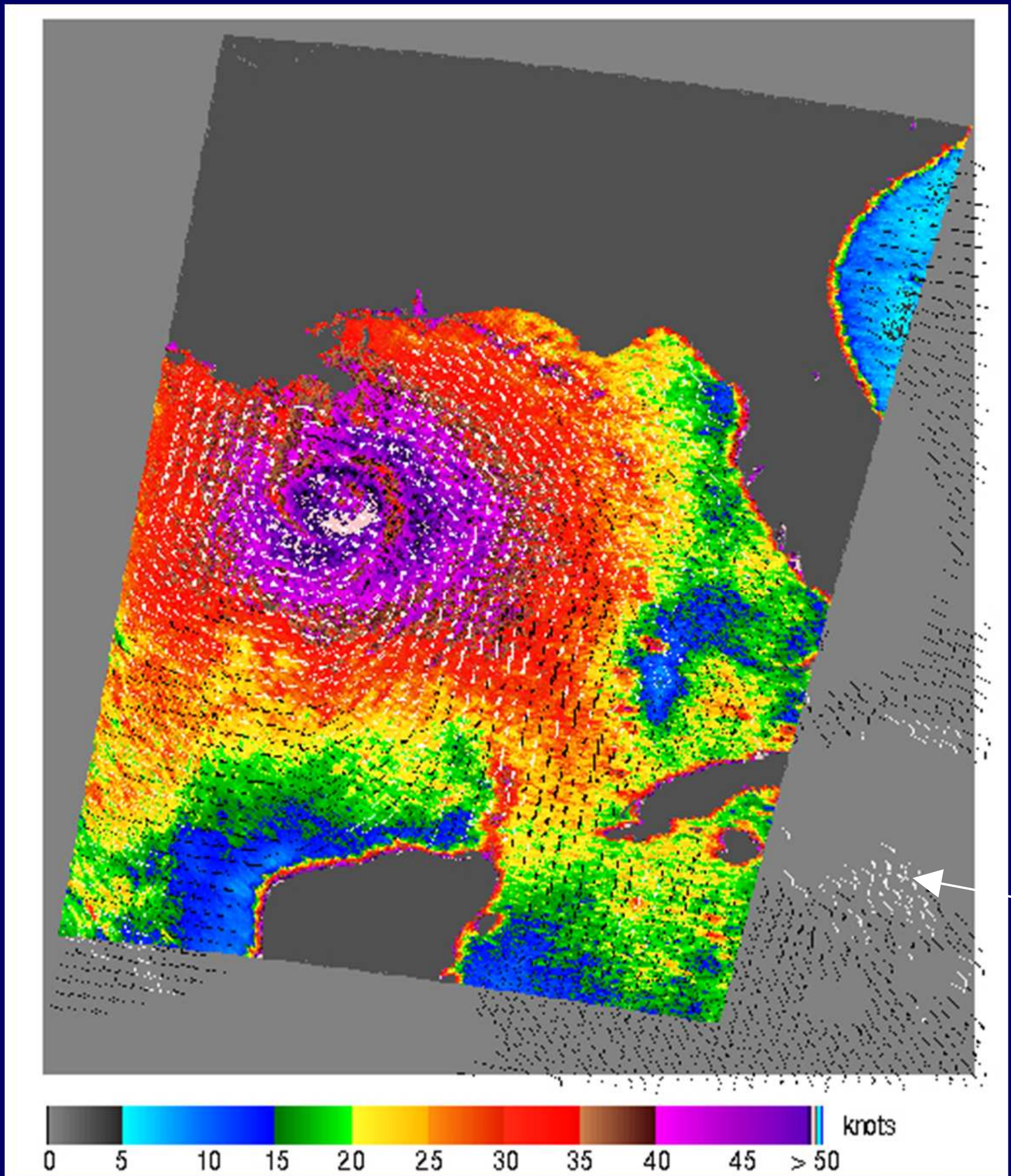


Image Credit: NASA JPL

Hurricane Katrina (Category 4)

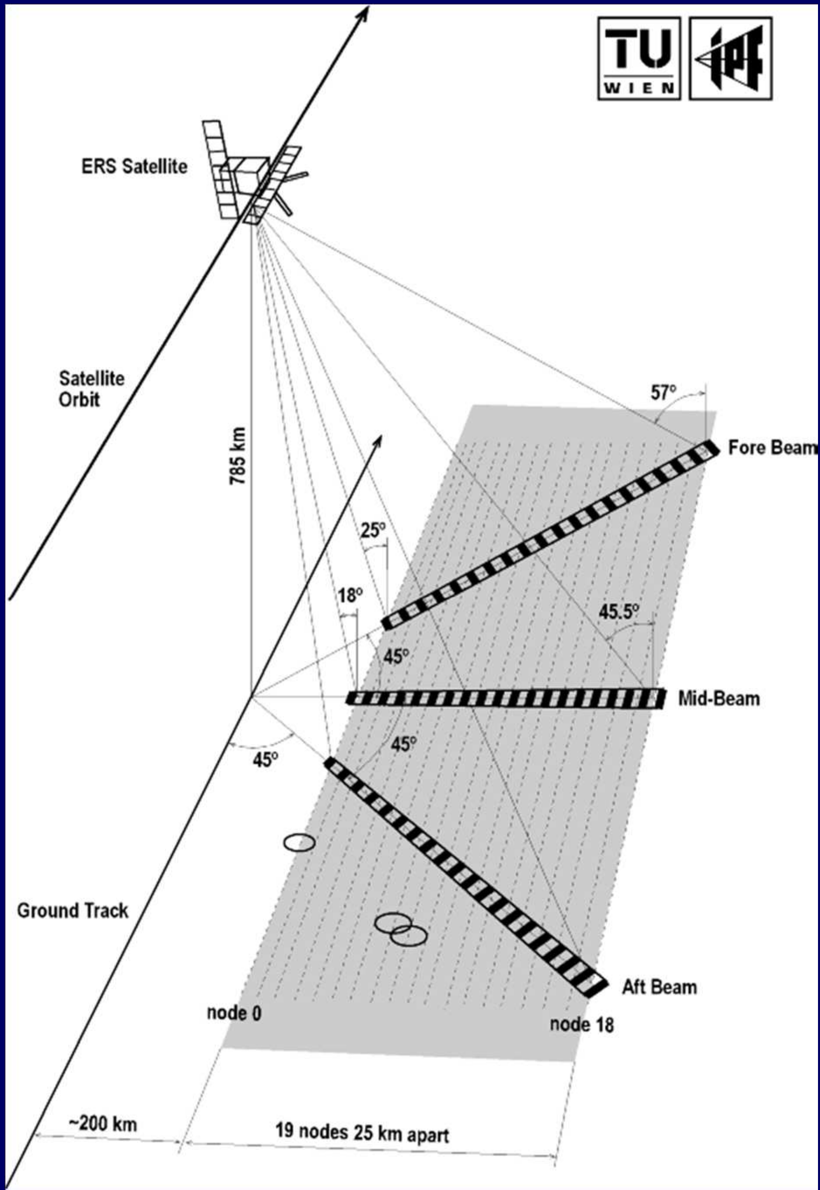
Quikscat, August 29, 2005

Intensity of storm makes accurate measurements difficult.

Barbs show wind direction

White barbs=heavy rainfall

Scatterometry: Soil Moisture



Wind scatterometers:

ERS-1, ERS-2 (1991-present)

MetOp satellites (2006-2020)

Backscatter measurements

Global soil moisture (25-50km)
(surface soil degree of saturation,
Soil water index (profile))

http://www.ipf.tuwien.ac.at/

Scatterometry: Soil Moisture

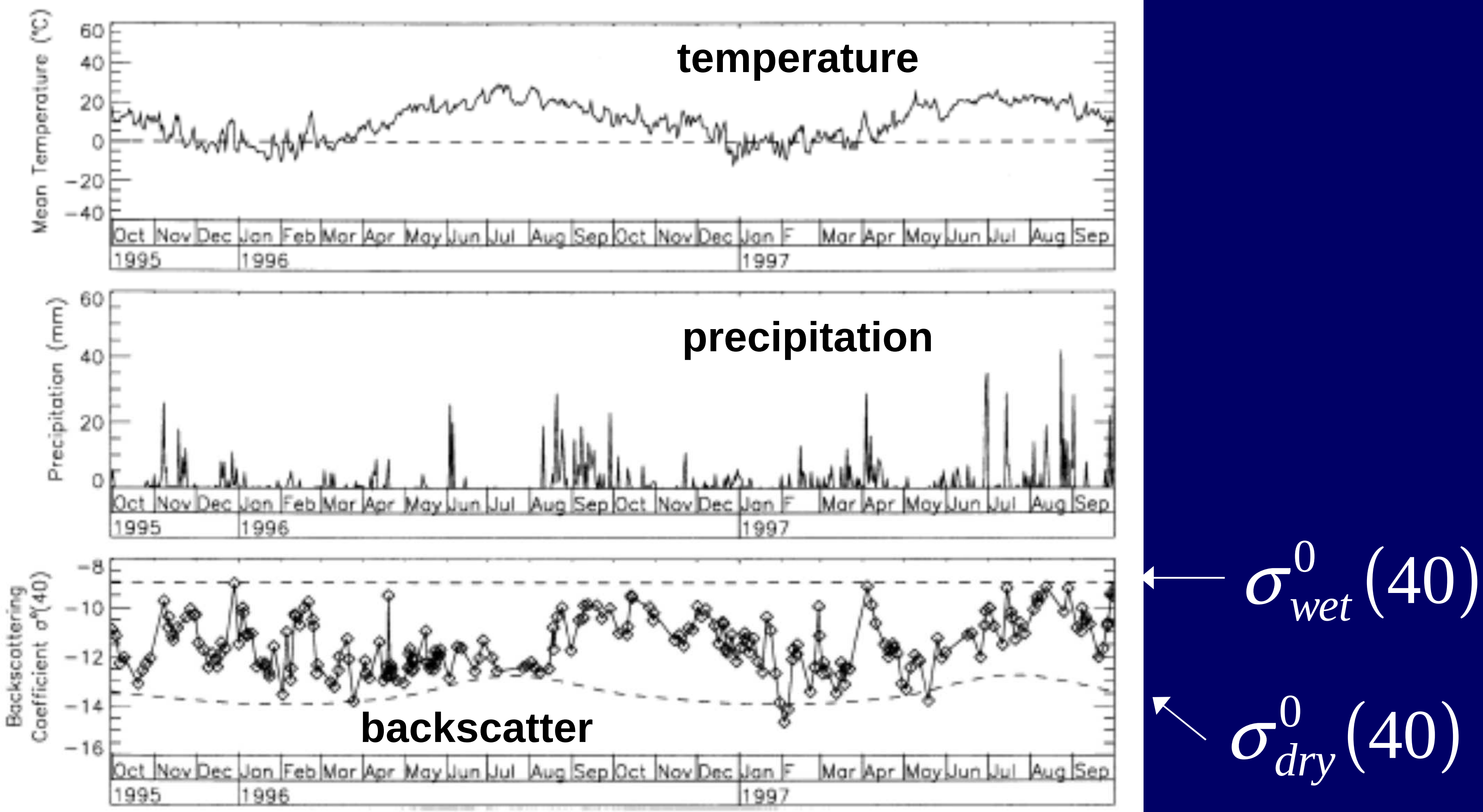


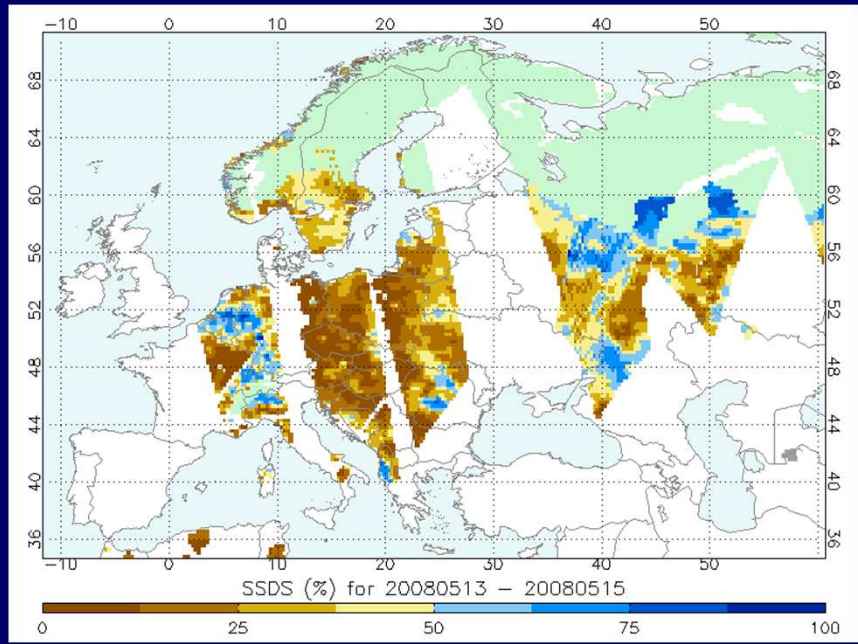
Figure 3. Time series of mean temperature, precipitation, and $\sigma^0(40)$ for the station Simferopol (33.98°E, 45.02°N) for the period October 1995 to September 1997. In the bottom figure the backscattering coefficient of a dry and wet surface, $\sigma^0_{dry}(40,t)$ and $\sigma^0_{wet}(40)$ are indicated by dashed lines.

Wagner et al. (1999)

Scatterometry: Soil Moisture

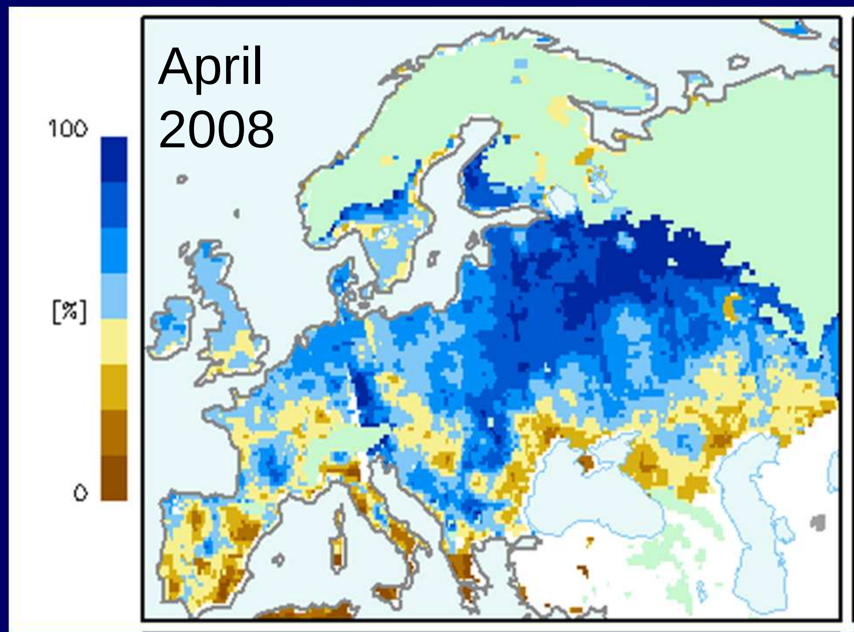
Surface soil degree of saturation (SSDS):

$$m_s(t) = \frac{\sigma^0(40,t) - \sigma^0_{dry}(40,t)}{\sigma^0_{wet}(40,t) - \sigma^0_{dry}(40,t)}$$



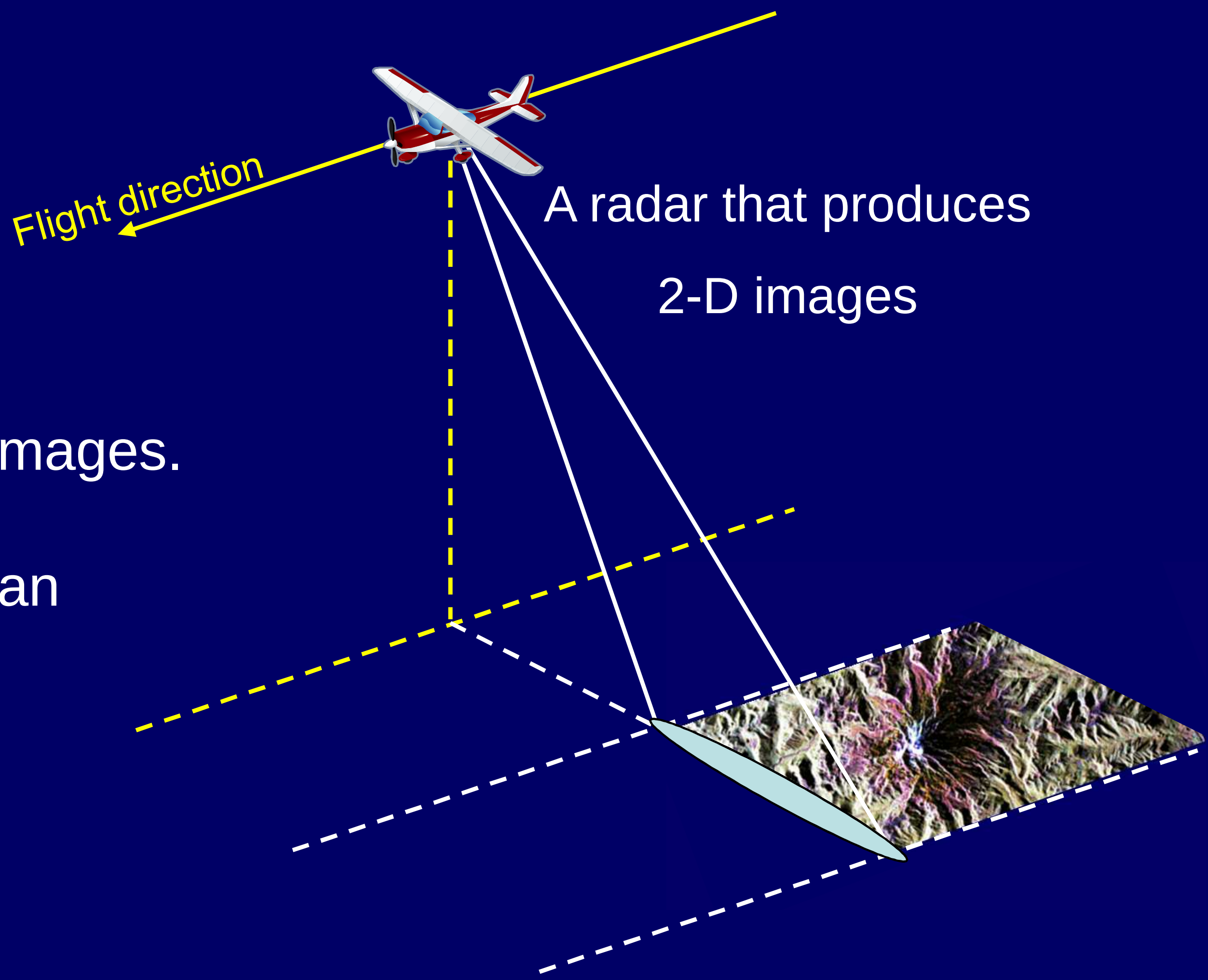
Soil Water Index (SWI):

$$SWI(t) = \frac{\sum_i m_s(t_i) e^{-(t-t_i)/T}}{\sum_i e^{-(t-t_i)/T}}$$



http://www.ipf.tuwien.ac.at/

Imaging Radar



A radar that produces 2-D images.

Pulses are much shorter than
in scatterometer.

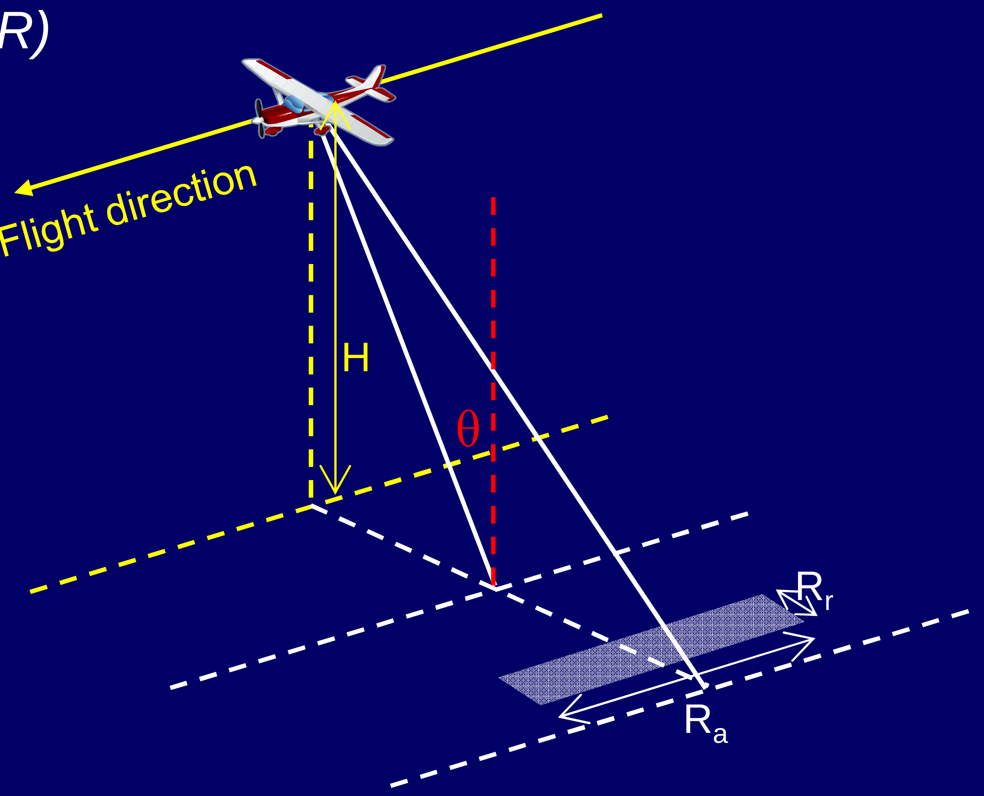
Two types:

1) Real Aperture Radar

2) Synthetic Aperture Radar

Imaging Radar: Real Aperture Radar

aka Side-looking radars (SLR)
or side-looking airborne radars (SLAR)



Resolution

Range (Across-track dimension)

$$R_r = \frac{ct_p}{2\sin\theta}$$

Azimuth (Along-track dimension)

$$R_a \approx \frac{H\lambda}{L\cos\theta}$$

Azimuth resolution proportional to height
=> limited use in spaceborne systems

c= speed of light
t_p= length of radar pulse
L = antenna length
H=altitude
θ= incidence angle

Imaging Radar: Synthetic Aperture Radar

Uses relative motion of platform to simulate a longer aperture (antenna).

Target is illuminated by several pulses.

Range is different for each pulse

$\Rightarrow$phase is different for each pulse

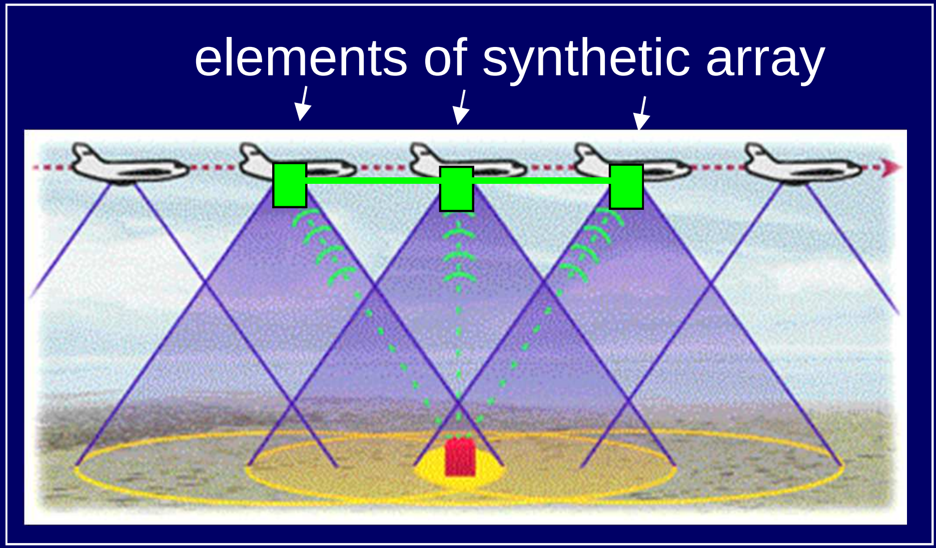
$\Rightarrow$Doppler effect

Use signal processing to account for difference in phase

Synthetic array increases azimuth resolution:

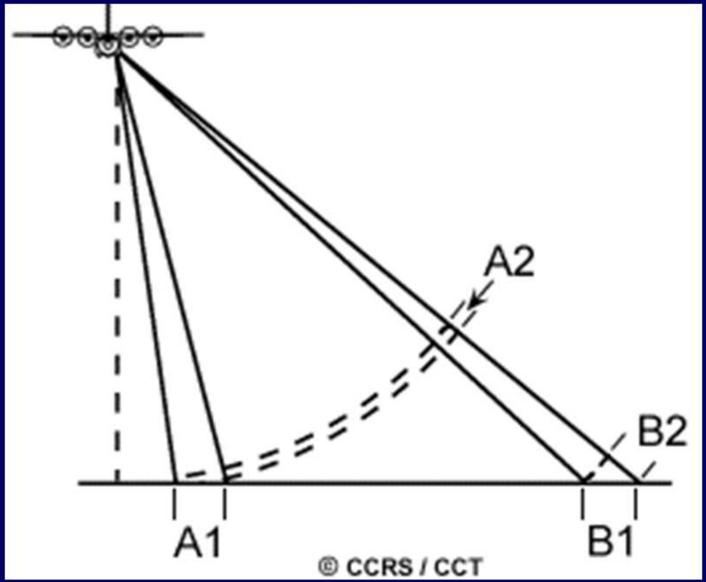
$$R_a \approx \frac{L}{2}$$

Independent of altitude!



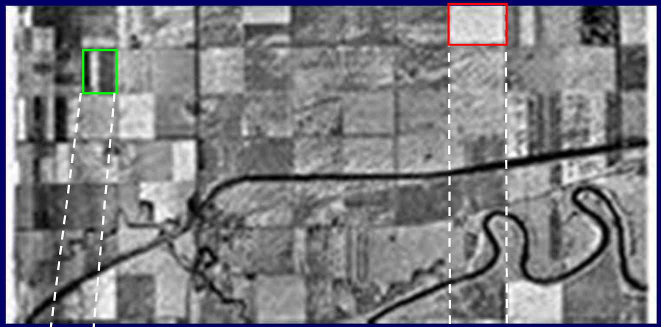
[16]

Imaging Radar: Slant-range distortion



In radar image
|A2|<<|B2|

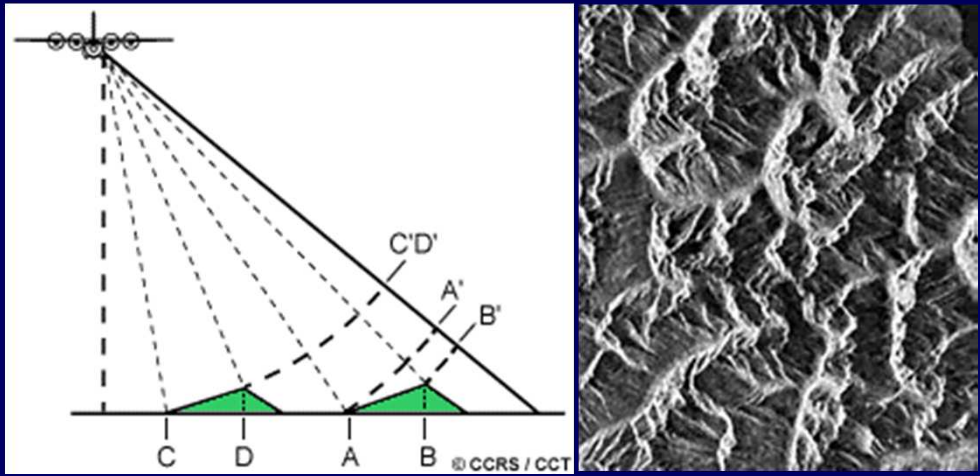
On the ground |A1| = |B1|



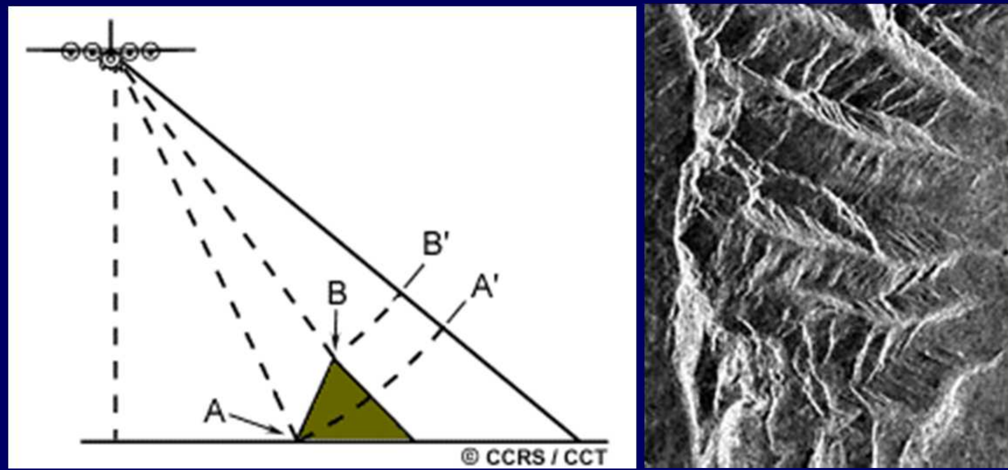
Solution:
Trigonometry!

Source: CCRS

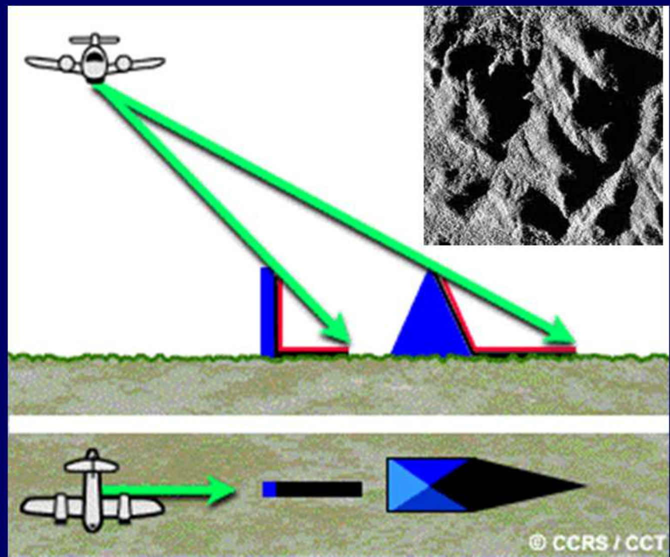
Imaging Radar: Relief displacement



Foreshortening



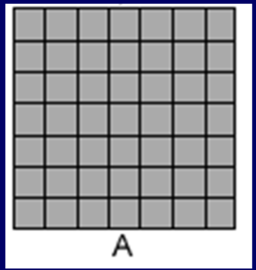
Layover



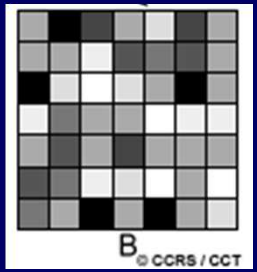
Radar Shadow

Source: CCRS

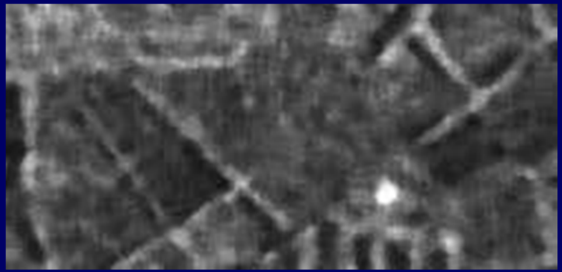
Imaging Radar: Speckle (SAR)

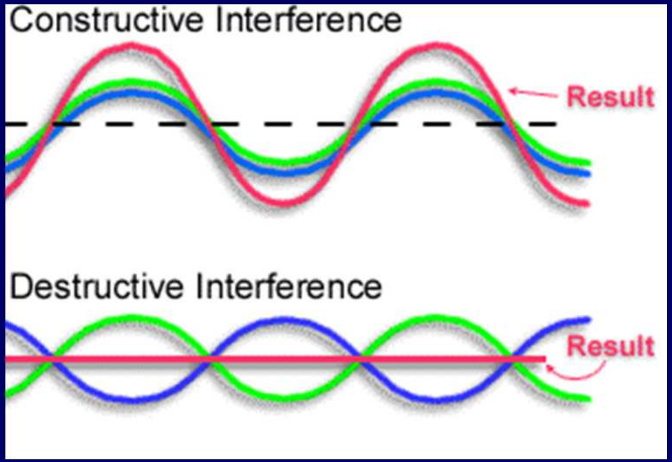


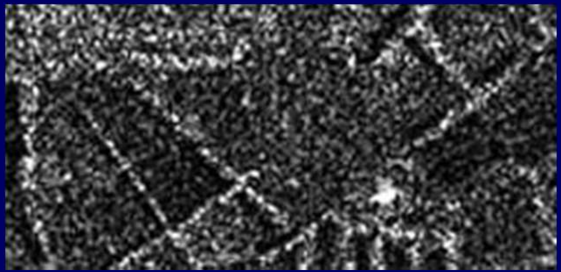
Interference between backscattered microwaves



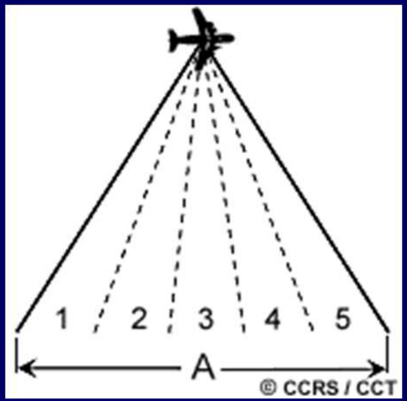
'salt and pepper'

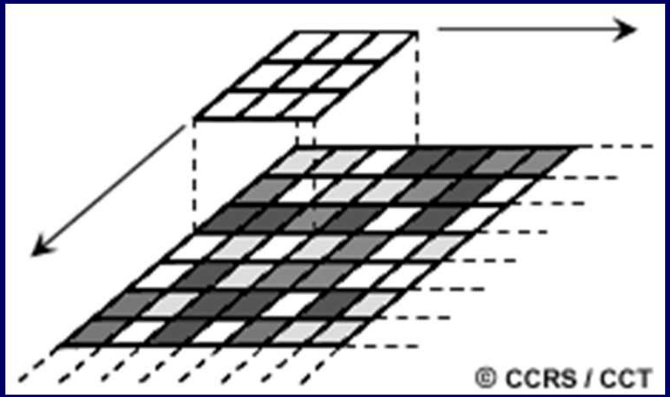






Solutions:



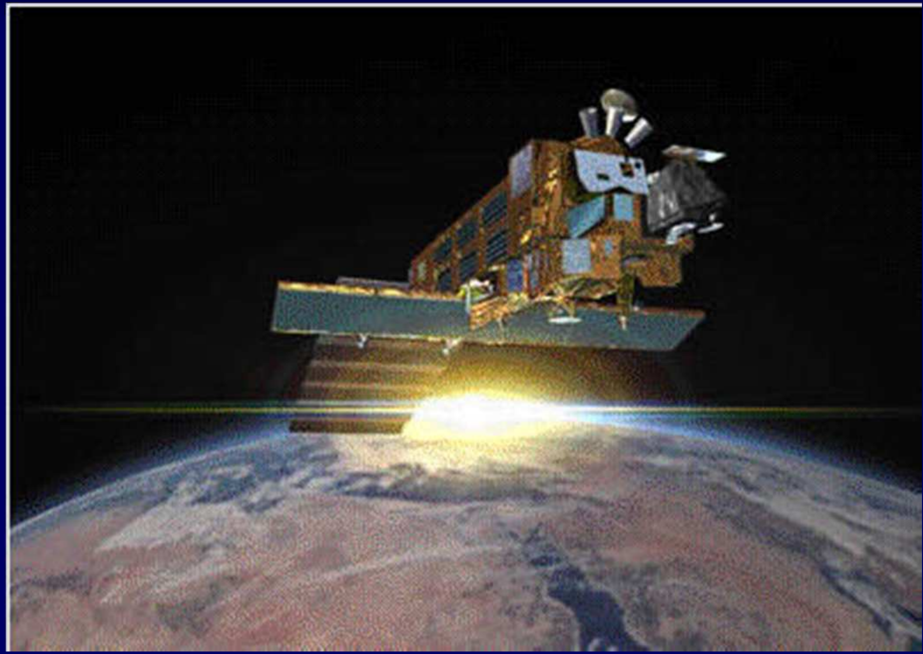


Multi-look processing

Spatial filtering

Source: CCRS

SAR Applications: ASAR



Agency: ESA

Platform: Envisat

C-band, 5 polarization modes

Spatial Resolution:

Image, wave and alternating polarization modes: 30m

Wide Swath Mode: 150m

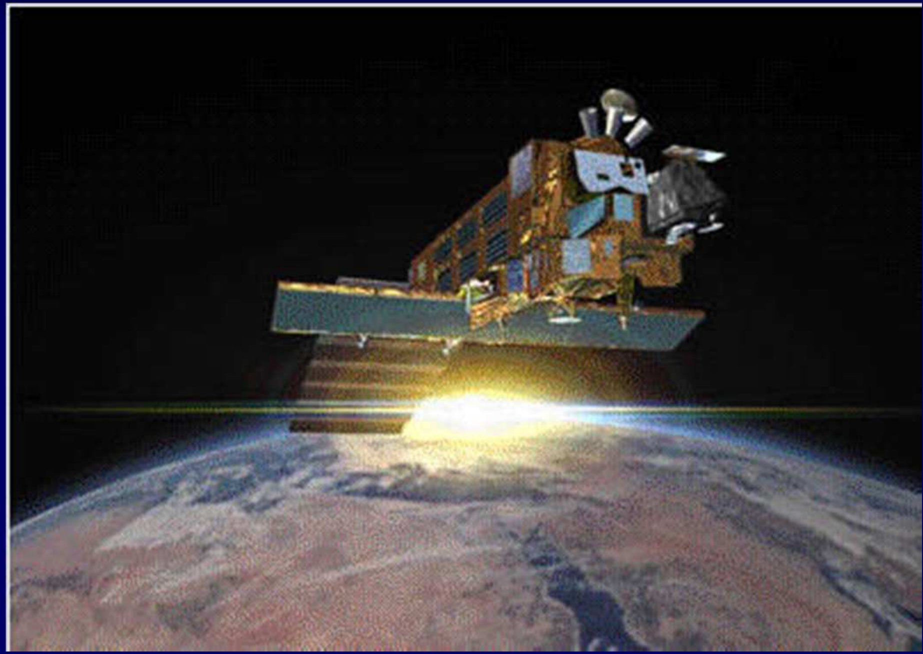
Global monitoring model : 1000m

Swath width:

Image and alternating polarisation modes: up to 100km
Wave mode: 5km,

Wide swath and global monitoring modes: 400km or more

SAR Applications: ASAR



Oceans & Coast

Wave Characteristics
Ocean Fronts
Coastal Dynamics
Oil Slicks and ShipTraffic

Land

Global Vegetation Monitoring
Forestry
Geology and Topography
Agriculture
Flooding, Hydrology and Water Management
Urban Studies

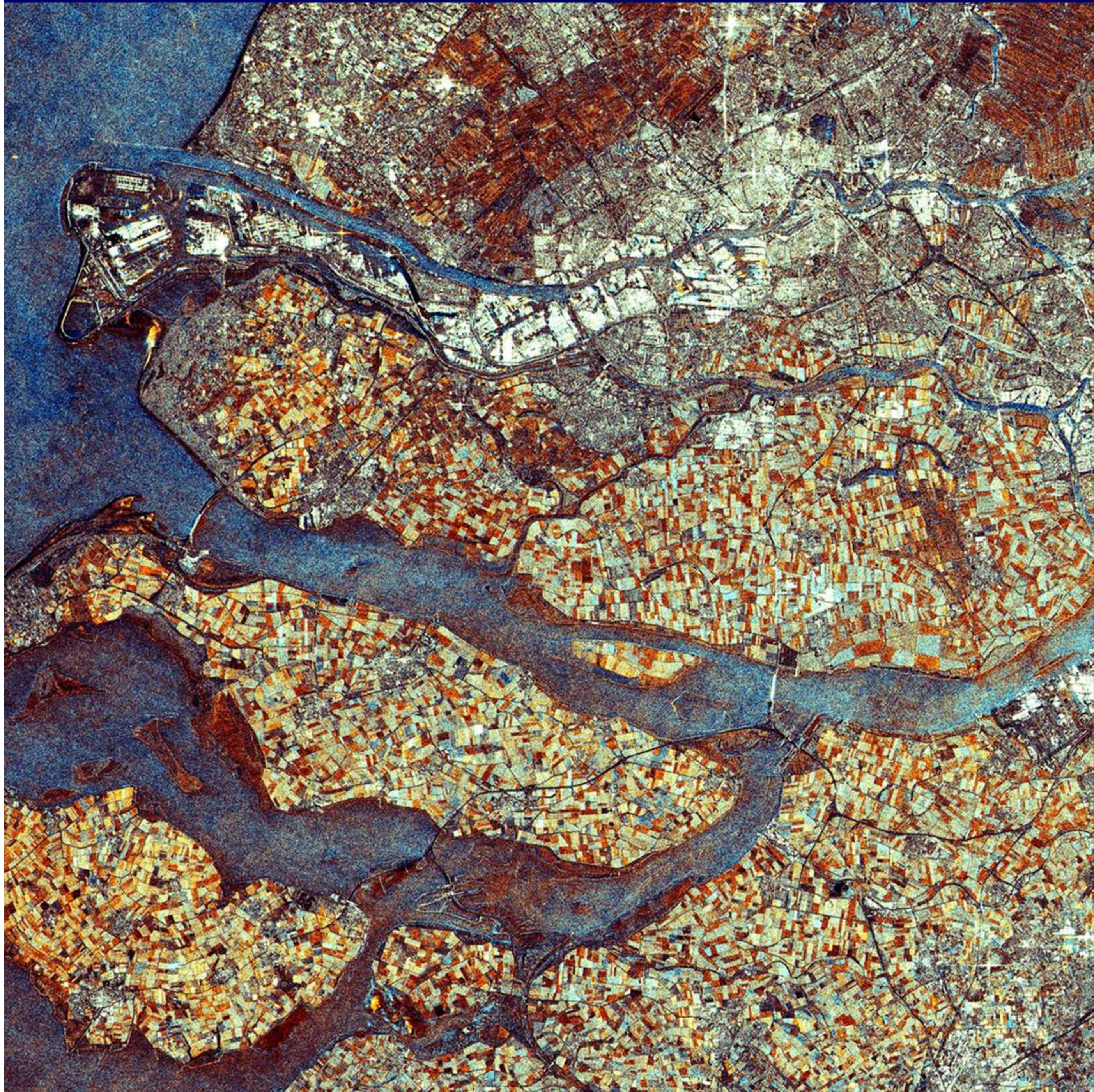
Natural Disasters

Volcanic activity
Earthquakes
Land subsidence

Snow and Ice

monitoring the ice extent and the boundaries of ice sheets
mapping the motion of ice sheets and glaciers
sea ice mapping & navigation
snow cover

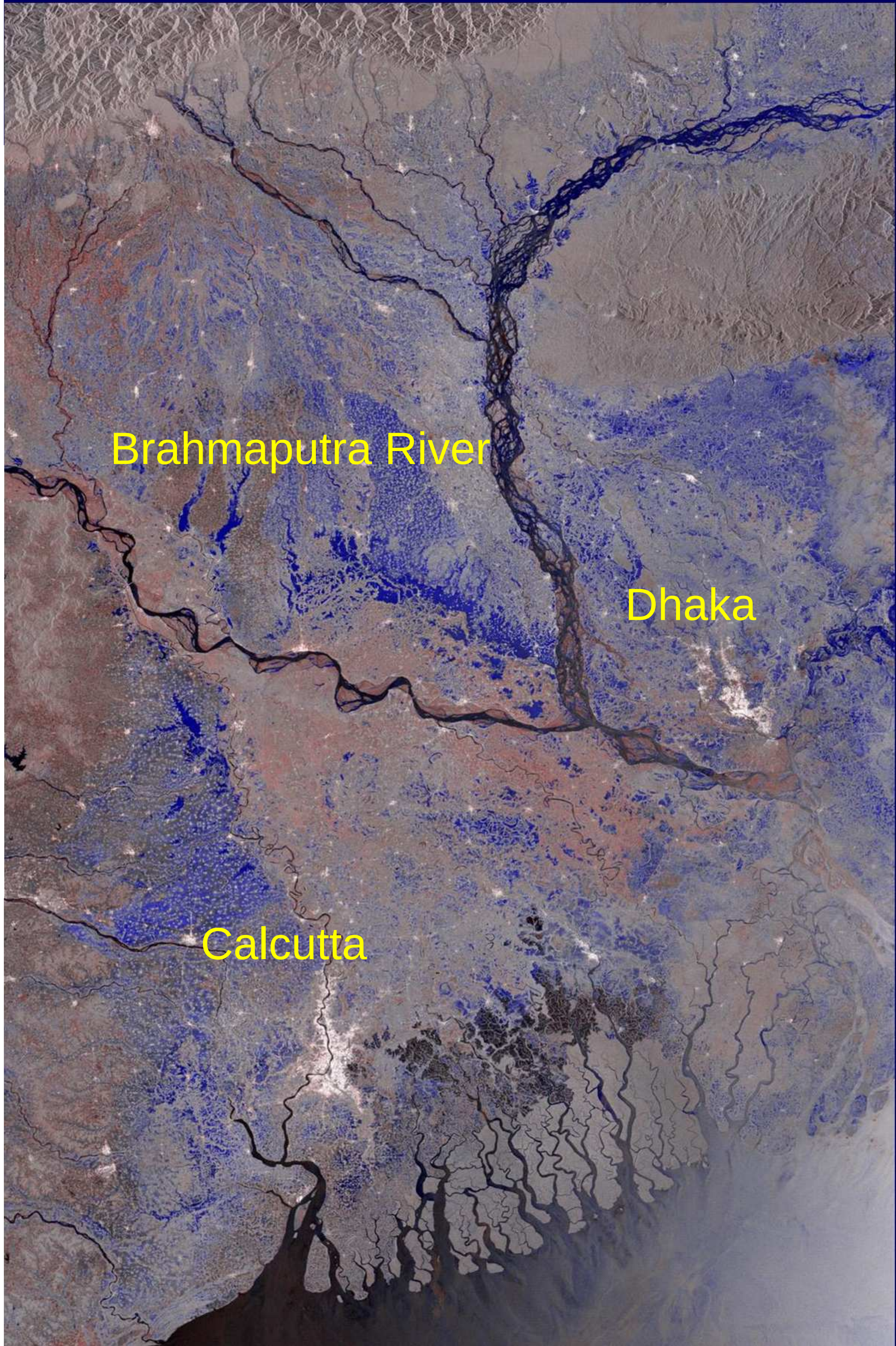
SAR Applications: ASAR



Envisat ASAR
Image mode
$\Rightarrow$resolution of 12.5 m.

Agriculture
Flooding,
Hydrology
Water Management
Urban Studies

Source: ESA



Applications:

ASAR

Mapping flood extent

Composite of two ASAR images from 26 July 2007 (before) 12 April 2007(after).

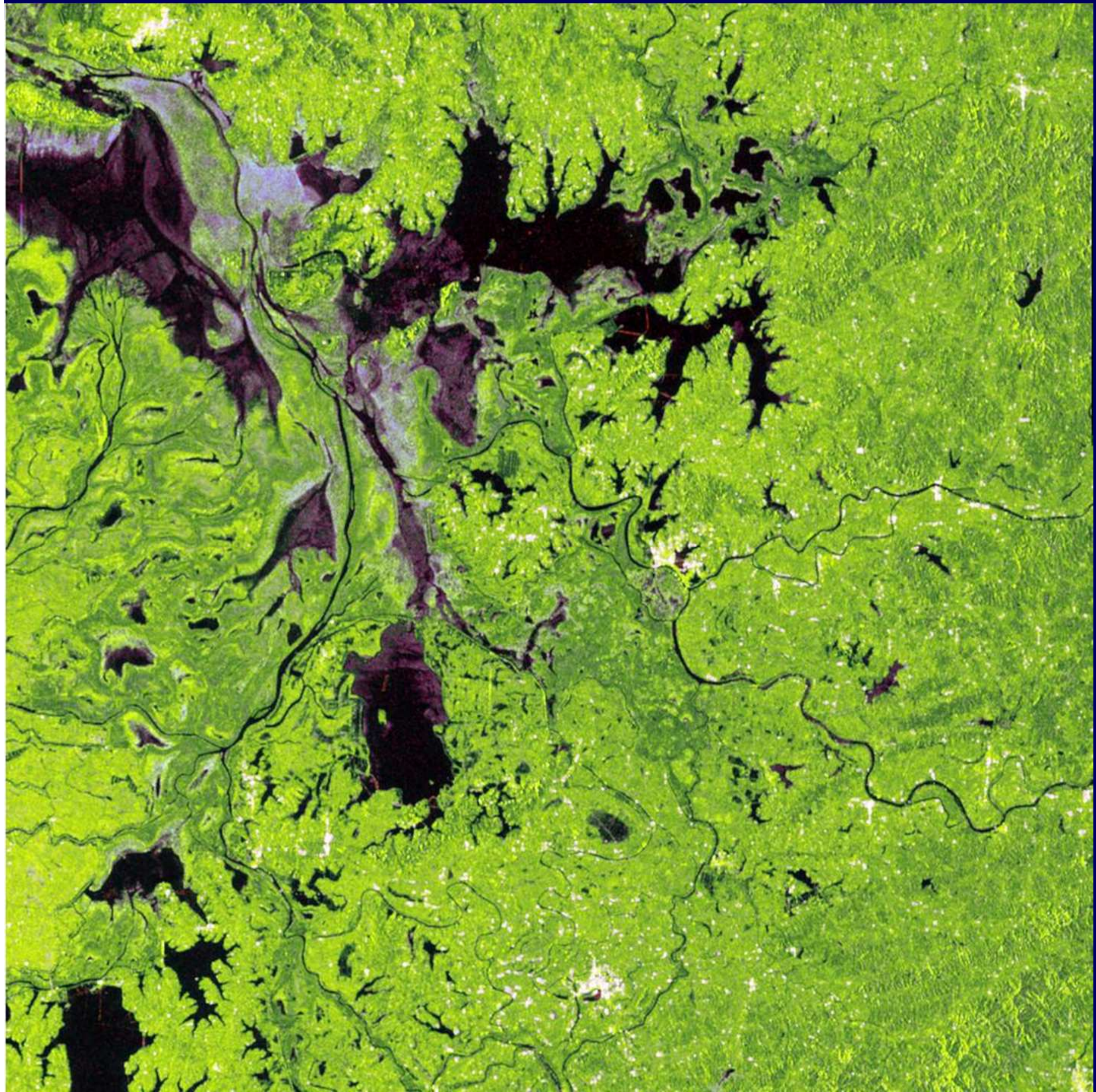
Black and white = no change

Blue are potentially flooded spots.

Red may also indicate flooding, but could also be related to agricultural practices.

Source ESA

ASAR: Monitoring lake and wetland extent



Patchy waters of Poyang Lake, 29 December 2005.

One of China's most important rice-producing regions.

Challenges:
Massive seasonal changes in water level,
Regular severe floods.

Shrinks from 3500km to 1000km in dry season.

Wetlands significant for migrating birds.

[17]

Alternating Polarisation (AP) mode = simultaneous acquisition of data in two radar polarisations to gather added detail. Resolution= 75 m, image width = 82.3 km.

Active Microwave Remote-Sensing

Summary:

In active MW remote sensing, a sensor transmits and receives a signal.

We can measure how long it takes for the signal to return = Altimetry. Information on surface topography.

We can look at the change in the signal (backscatter) and infer information about the surface properties

Assignment 6: Soil Moisture Retrieval from Active MW Remote Sensing

Analyze soil moisture products derived from ERS Wind Scatterometer data

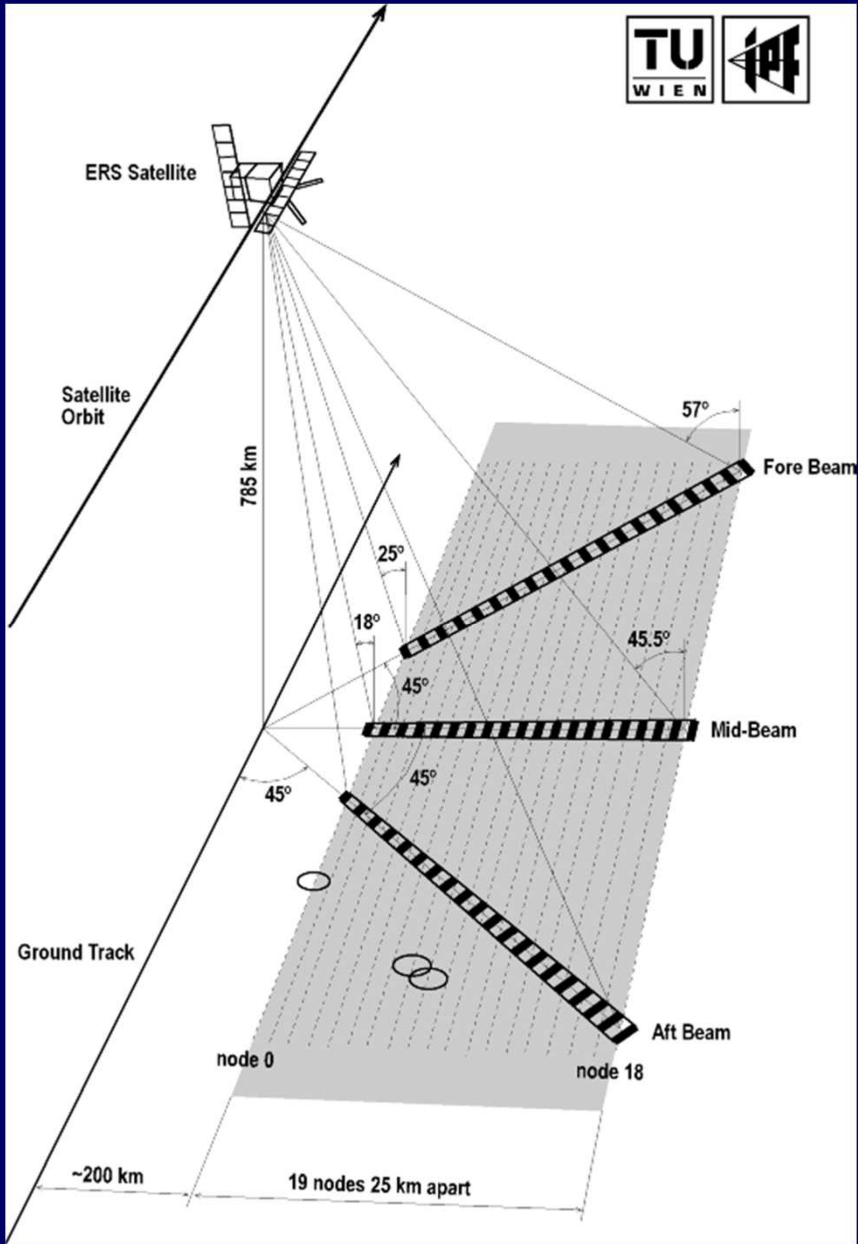
Issue to consider: Revisit time, change detection approach

What can we resolve given this revisit time? Individual storms? Seasonal cycle?

$\Rightarrow$ What kinds of applications is this data product useful for? What applications need more frequent observations?

$\Rightarrow$ Potential sources of uncertainty

Scatterometry: Soil Moisture



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MetOp satellites (2006-2020)

Backscatter measurements

Global soil moisture (25-50km)
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http://www.ipf.tuwien.ac.at/

Scatterometry: Soil Moisture

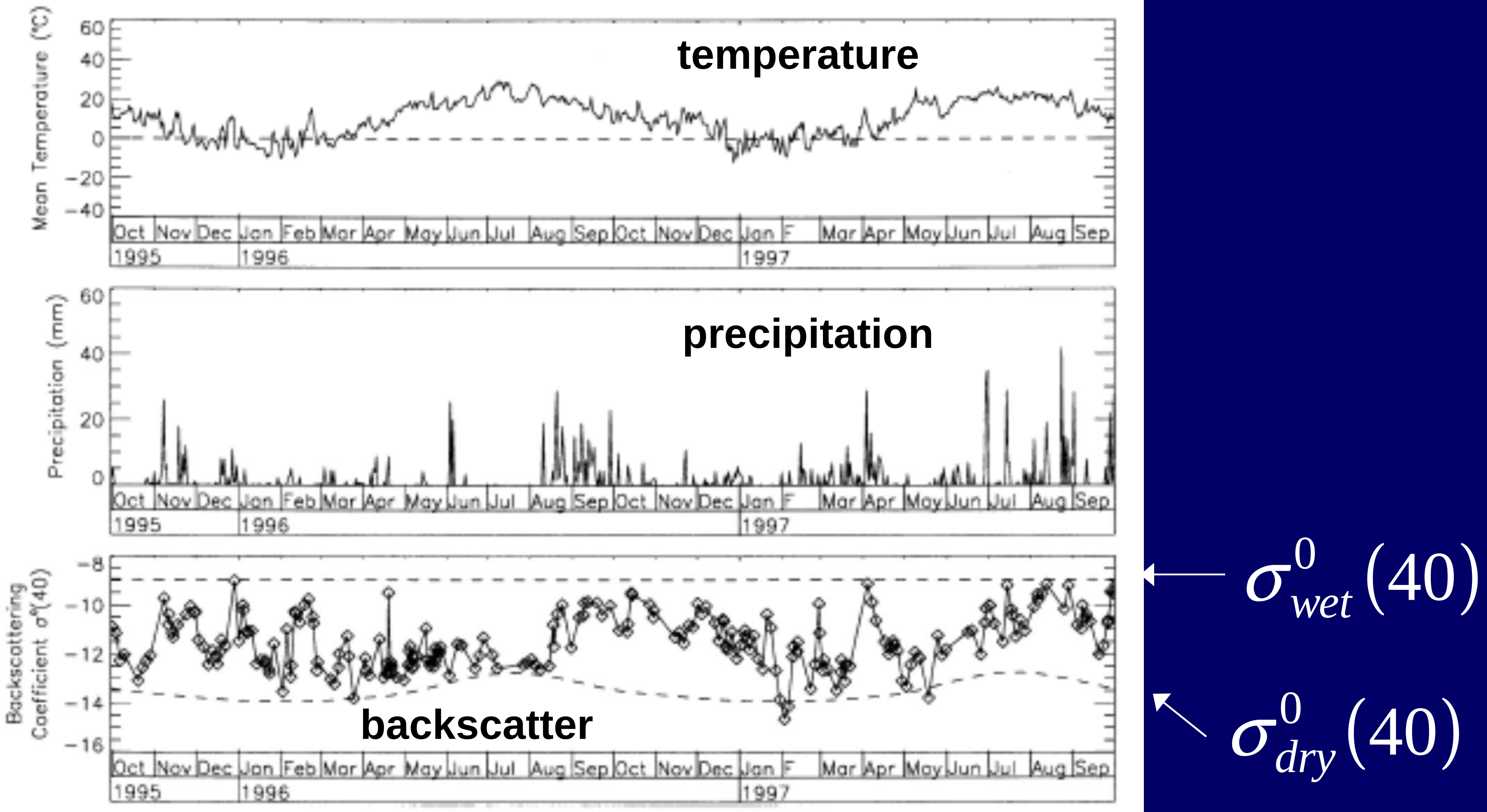


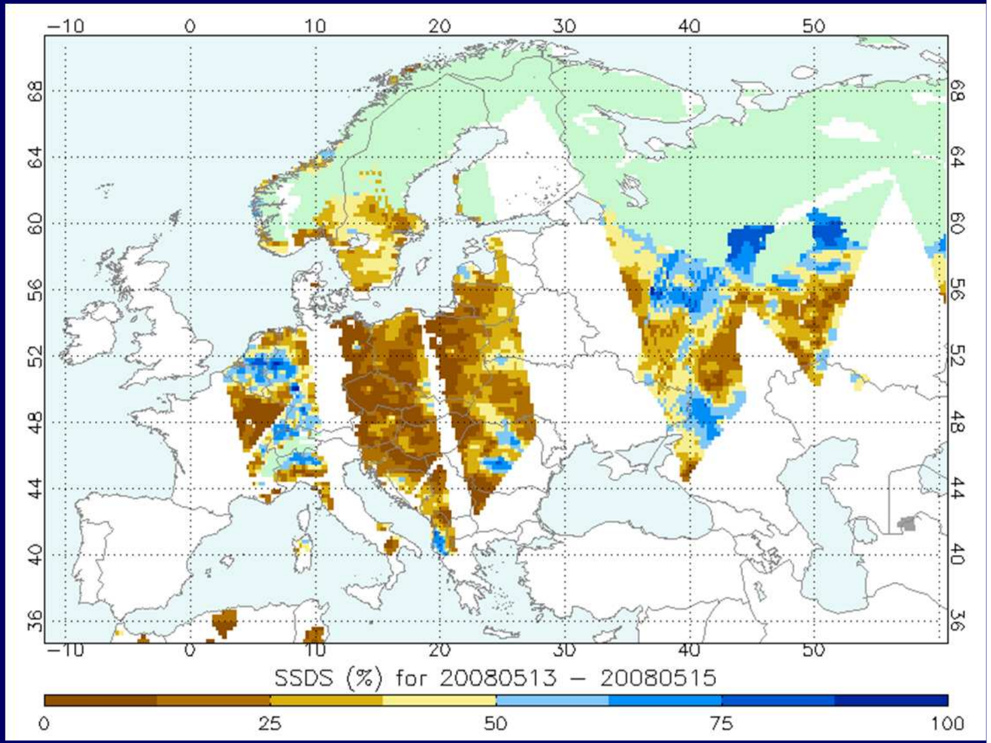
Figure 3. Time series of mean temperature, precipitation, and $\sigma^0(40)$ for the station Simferopol (33.98°E, 45.02°N) for the period October 1995 to September 1997. In the bottom figure the backscattering coefficient of a dry and wet surface, $\sigma^0_{dry}(40,t)$ and $\sigma^0_{wet}(40)$ are indicated by dashed lines.

Wagner et al. (1999)

Scatterometry: Soil Moisture

Surface soil degree of saturation (SSDS):

aka Relative Surface Wetness



$$m_s(t) = \frac{\sigma^0(40,t) - \sigma^0_{dry}(40,t)}{\sigma^0_{wet}(40,t) - \sigma^0_{dry}(40,t)}$$

http://www.ipf.tuwien.ac.at/

Scatterometry: Soil Moisture

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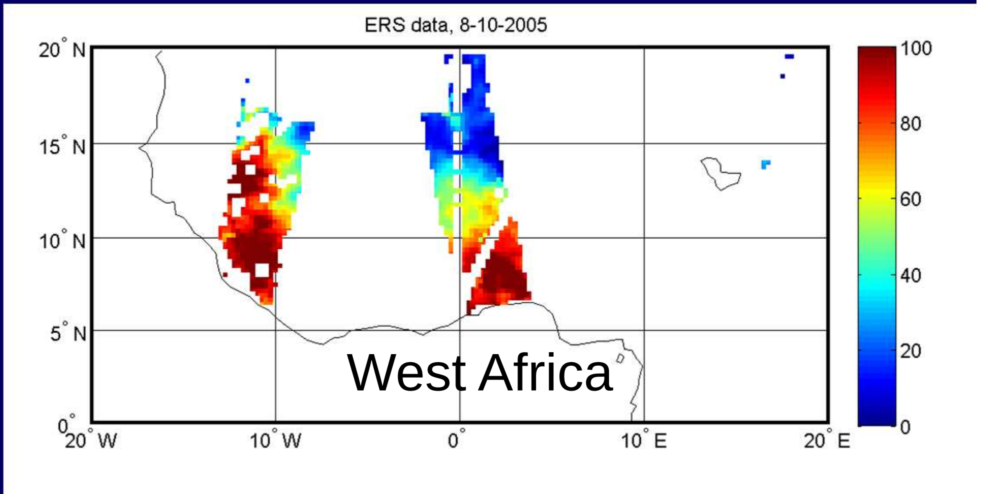
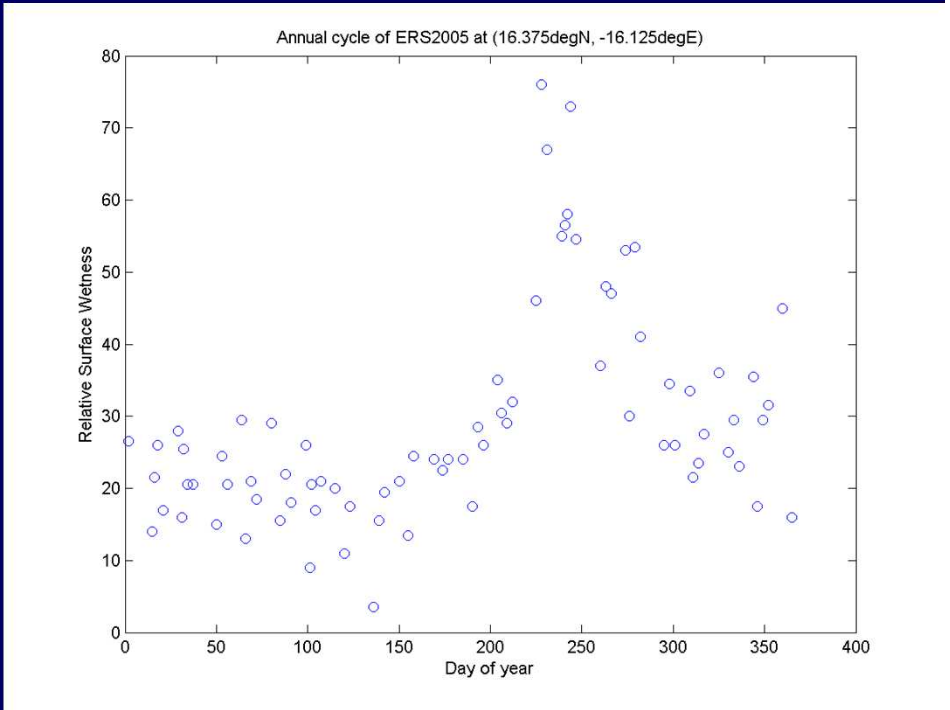


$$m_s(t) = \frac{\sigma^0(40,t) - \sigma^0_{dry}(40,t)}{\sigma^0_{wet}(40,t) - \sigma^0_{dry}(40,t)}$$



Sources images

[1] The Electromagnetic Spectrum, source: HyperPhysics Georgia State University, image courtesy of C.R. Nave
[2] Atmospheric attenuation on the EM spectrum, source: ESA
[3] Soil Moisture Ocean Salinity (SMOS) satellite, source: ESA
[4] European Remote Sensing (ERS) satellite, source: ESA
[5] Aqua satellite, source: NASA
[6] Soil Moisture from ASCAT, source: TU Wien
[7] Soil Moisture Active Passive (SMAP), source: NASA
[8] Launch of SMOS satellite, source: ESA
[9] Polar orbit, source: Creative Commons/Wikipedia
[10] Very Large Array (VLA), Magdalena, New Mexico; photo courtesy of Richard Ryer
[11] Very Large Array (VLA), Socorro, New Mexico; source: NRAO/AUI/NSF
[12] The SMOS instrument, source: ESA
[13] Radar during World War II, source: War History Online
[14] Radar screen, source: Wikimedia Commons
[15] Heathrow Airport radar tower, photo courtesy of David Monniaux
[16] Synthetic Aperture Radar (SAR), source: Wikimedia Commons/Rcs ivan
[17] Poyang Lake, China; source: redOrbit.com