CT5401
Spatial Tools for Water Resources Management

Microwave Remote-Sensing

Susan Steele-Dunne
Water Resources Management
Civil Engineering & Geosciences
TU Delft

s.c.steele-dunne@tudelft.nl

https://www.youtube.com/watch?v=UoIu0z8orC8

YouTube NL

NASA Launches Soil Moisture Mapper

NASA Jet Propulsion Laboratory

Subscribe 178,846

21,740

Outline

- **Introduction** to microwave remote sensing
- **Passive** microwave remote sensing
- **Active** microwave remote sensing
- **Guest speaker:**

  Robin van der Schalie (vandersat)

Exercise: Soil Moisture and precipitation in West Africa

Acknowledgements

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

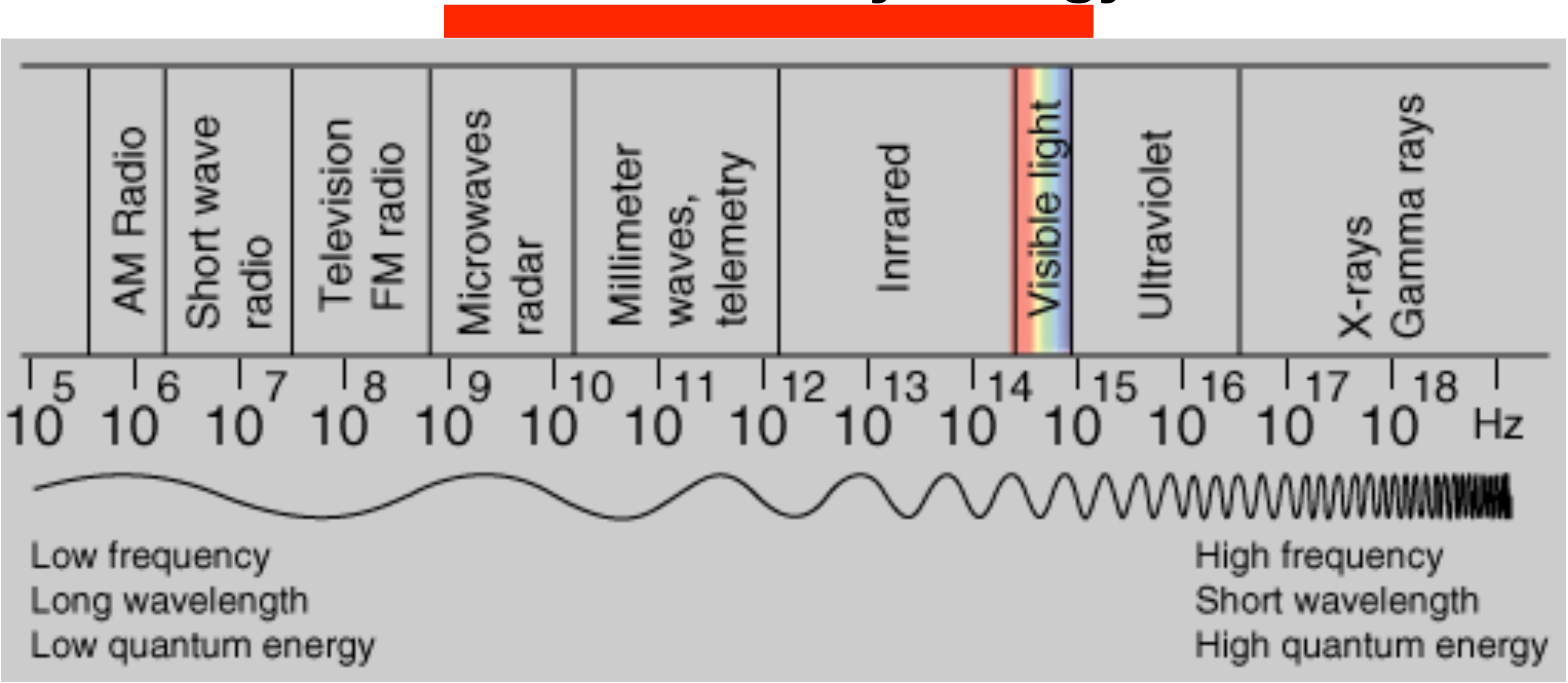
Introduction to Microwave Remote Sensing

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

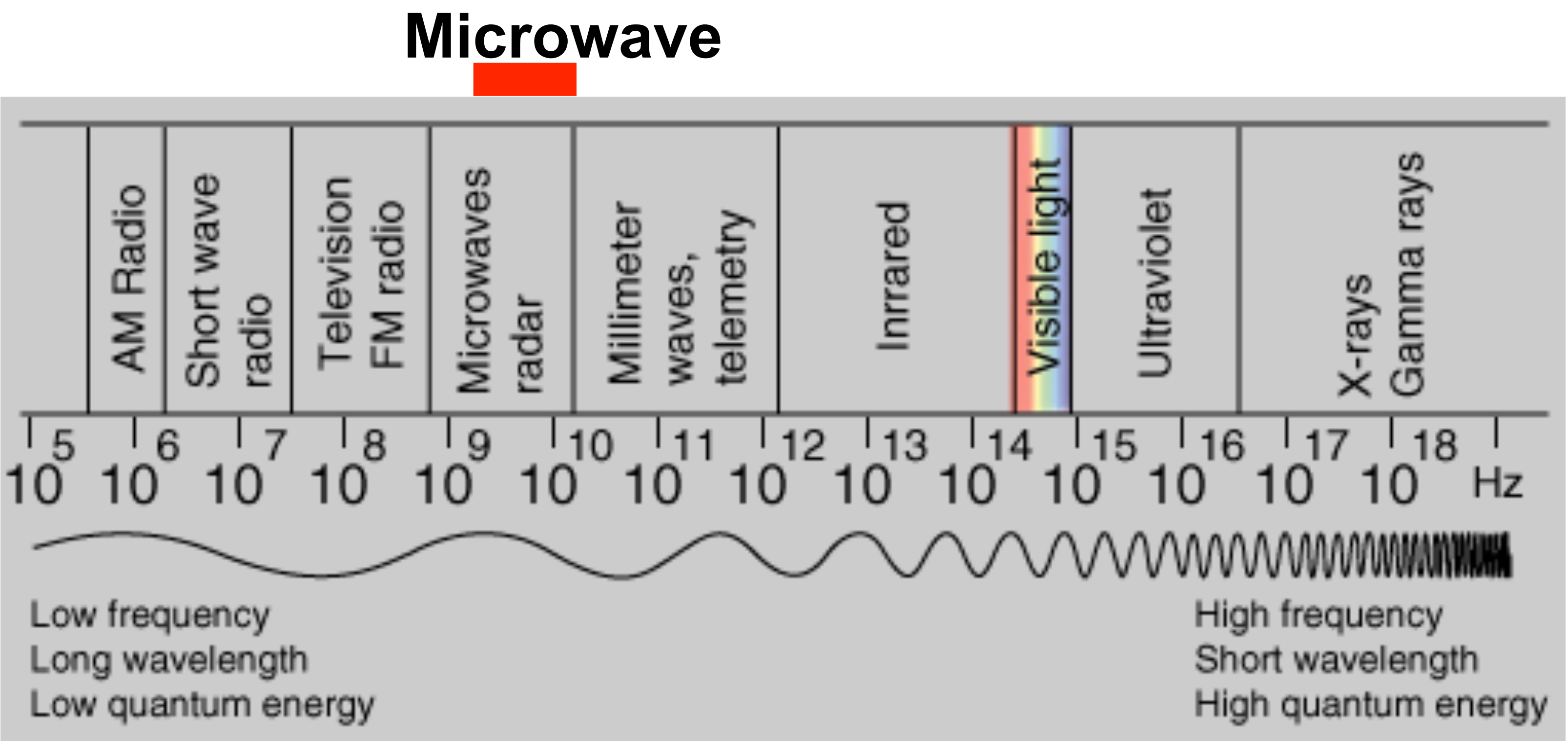
- List the advantages of MW remote sensing
- Discuss how MW remote sensing compliments VIS and IR remote sensing
- Define the dielectric constant and explain its significance in MW RS
- Discuss the differences between active and passive MW RS

Satellite principles: The Spectrum

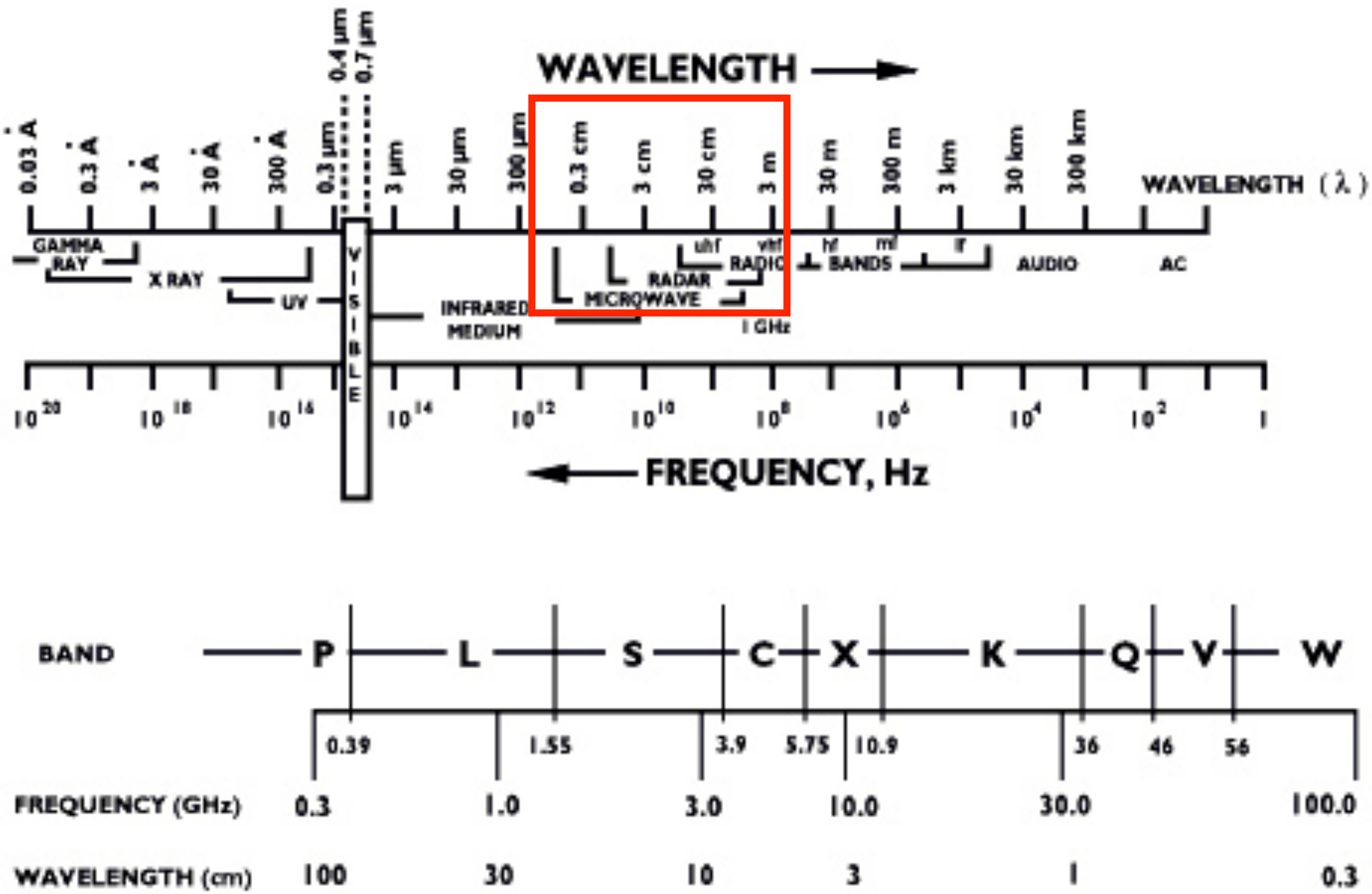
Most useful for hydrology



Satellite principles: The Spectrum



Microwaves have wavelengths of 0.1-100cm



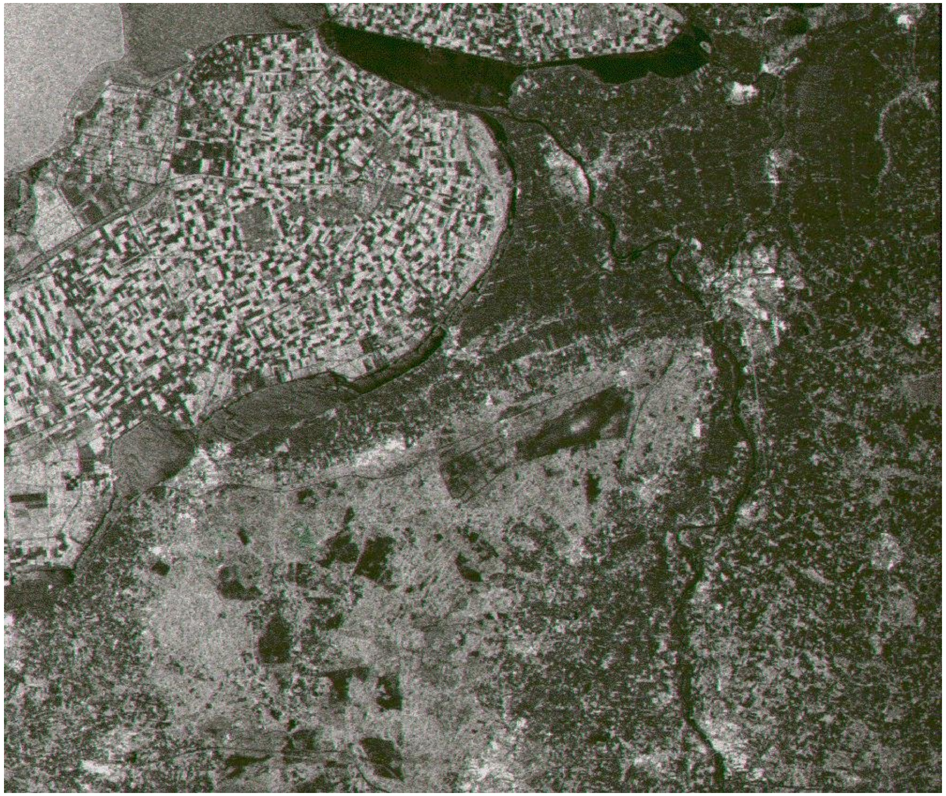
Source: ESA

Different microwave bands provide information about different object characteristics.

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

Do not need illumination from the sun

=> images can be acquired day and night!

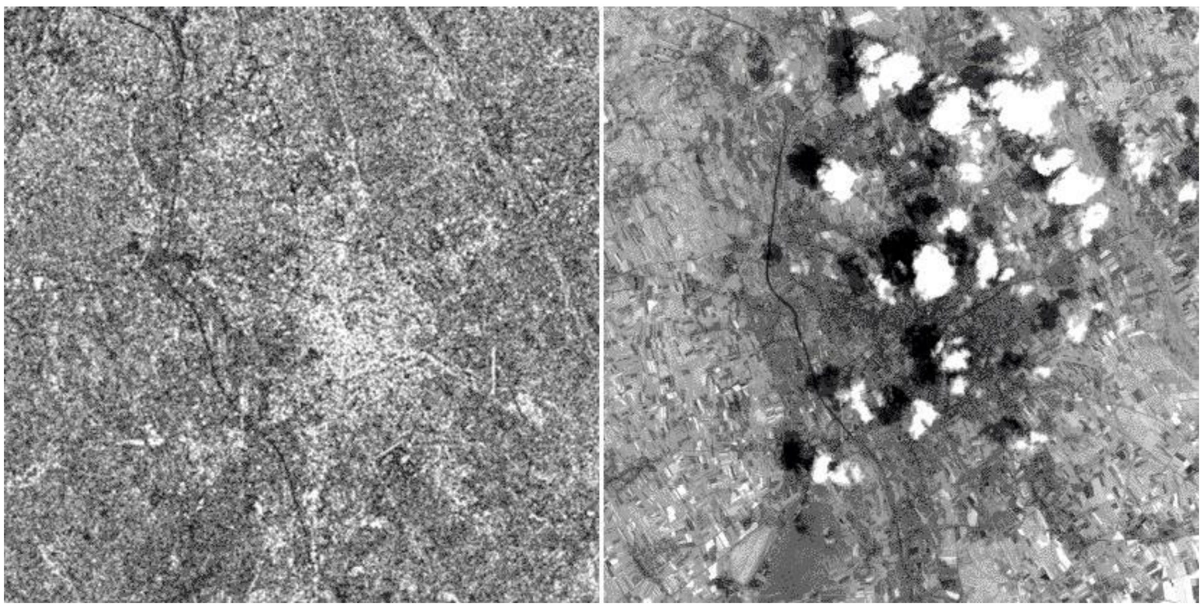


SAR image (ERS-1),
The Netherlands
02/08/1991 local time $\boxed{23:40}$
Source: ESA

Advantages of using microwave (λ = 1-100cm

Can penetrate clouds

& Independent of atmospheric effects like haze.



Udine, Italy

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

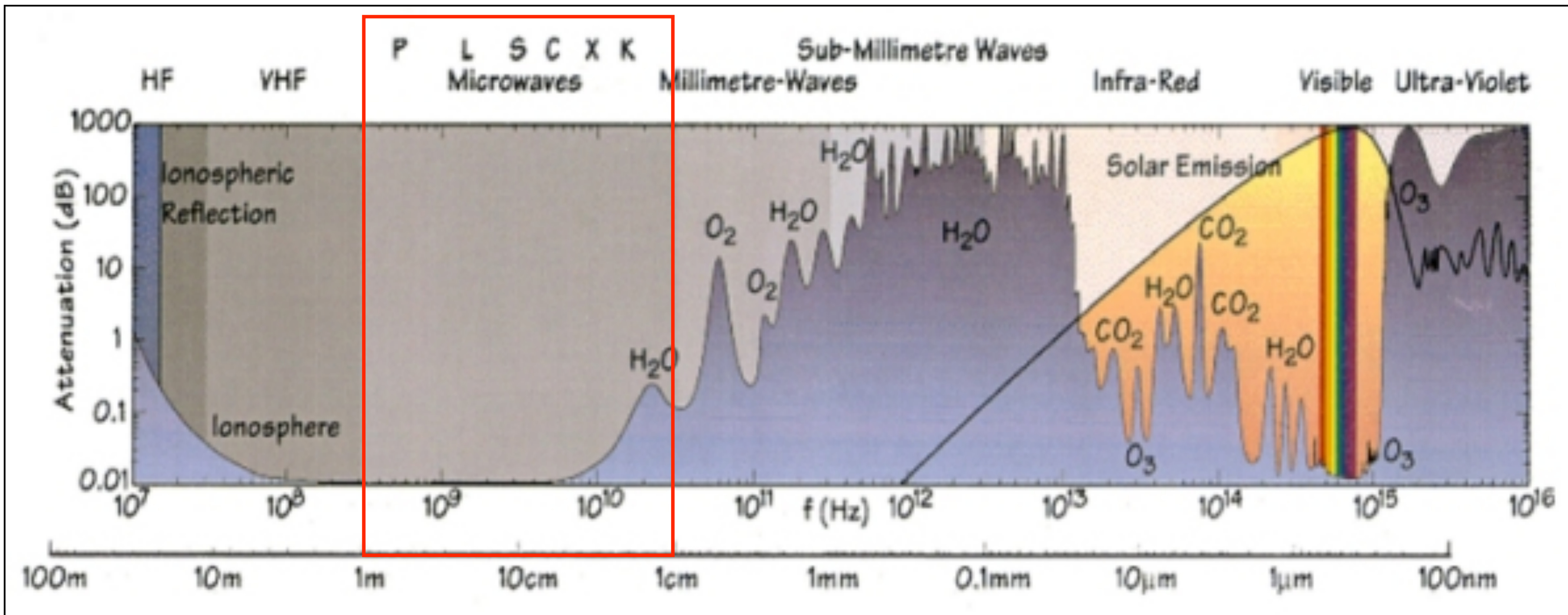
Landsat-5 (optical)
04/07/1993
9:14am(GMT)

Source: ESA

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

Can penetrate clouds

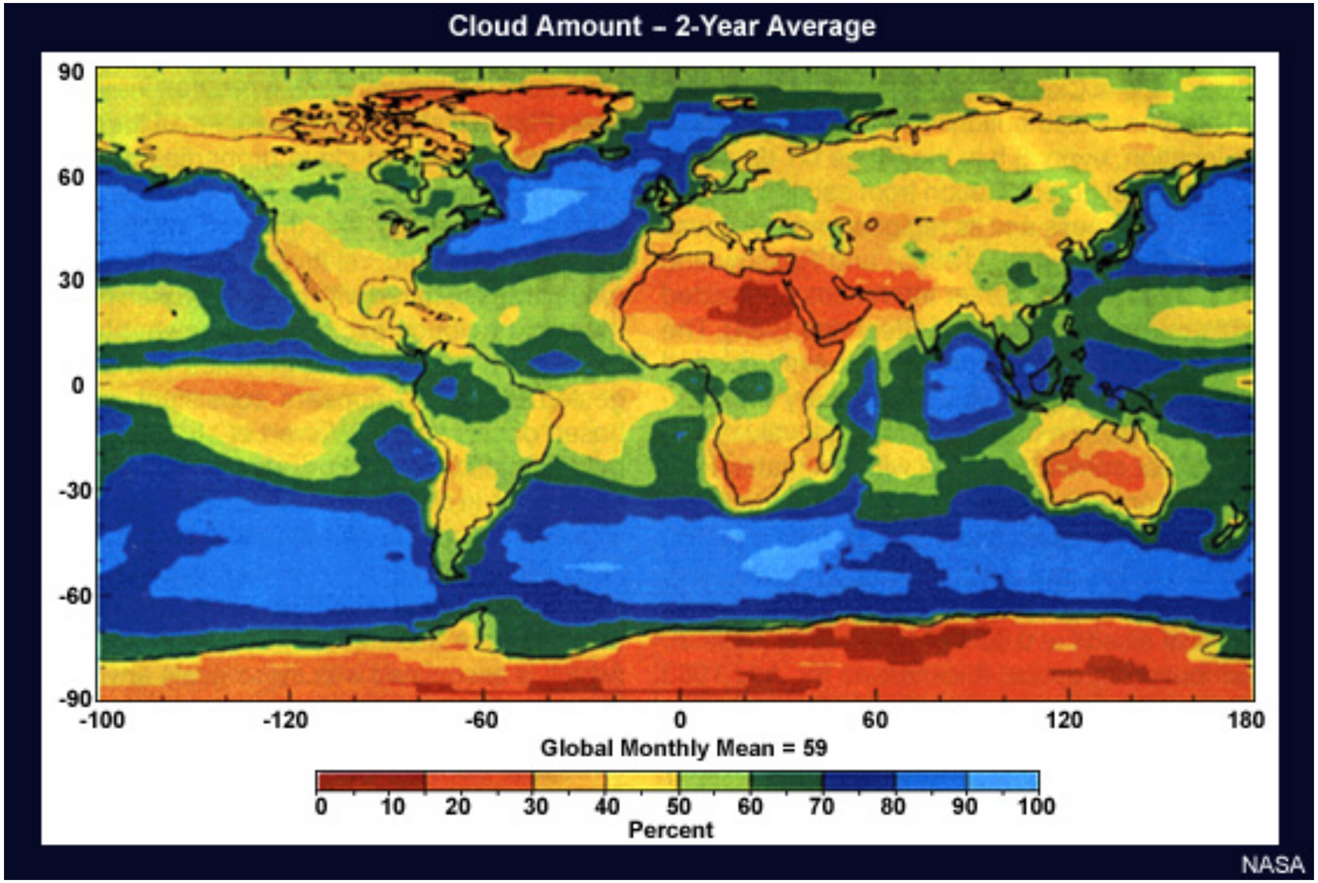
& Independent of atmospheric effects like haze.



Advantages of using microwave (λ = 1-100cm

Can penetrate clouds

& Independent of atmospheric effects like haze.



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

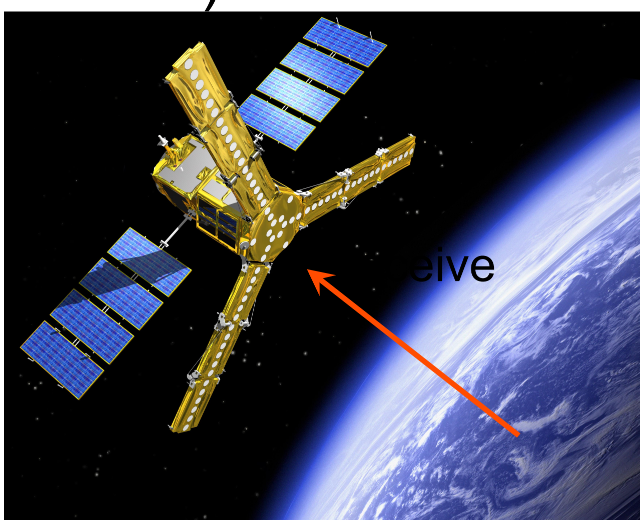
https://www.youtube.com/watch?v=y_jM_BxQGvE

Remote-sensing techniques

Passive

Employ natural sources of energy,

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

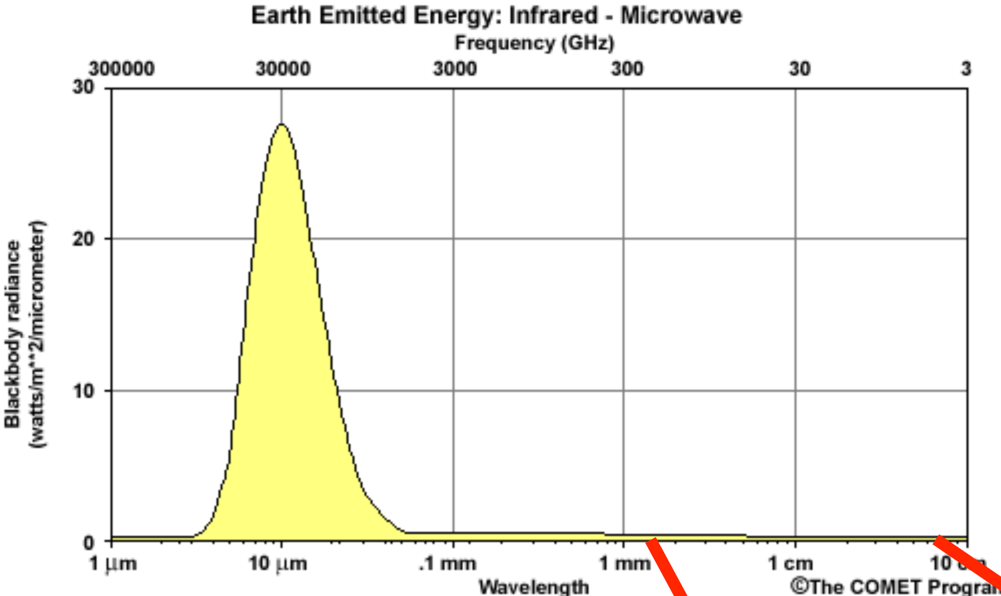


Active

Have their own source of energy.

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

Energy available to Passive MW sensors



Lower frequency

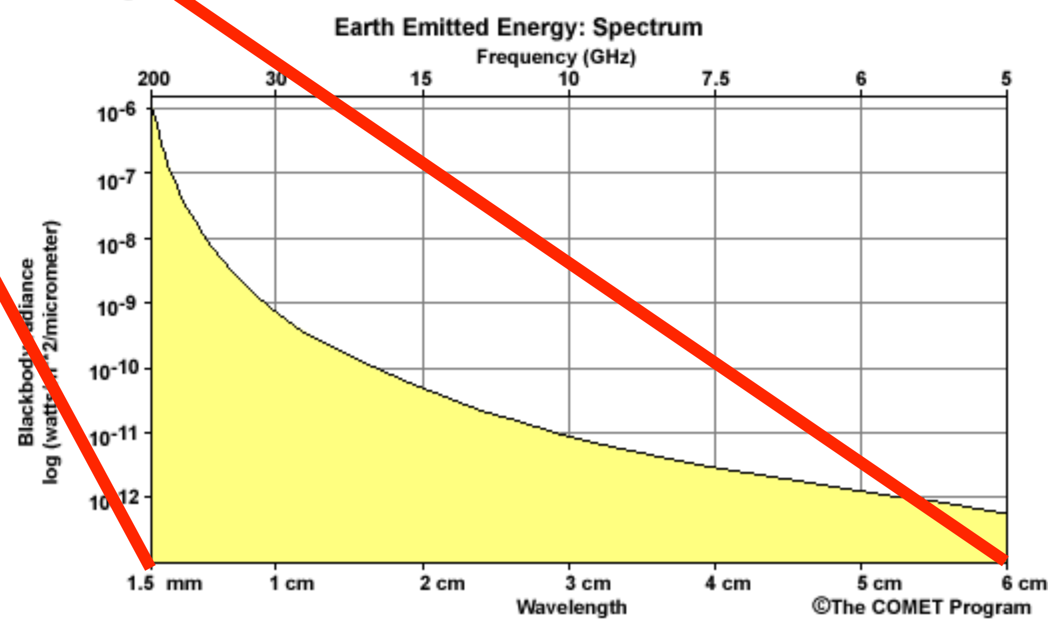
Less energy

Need a larger

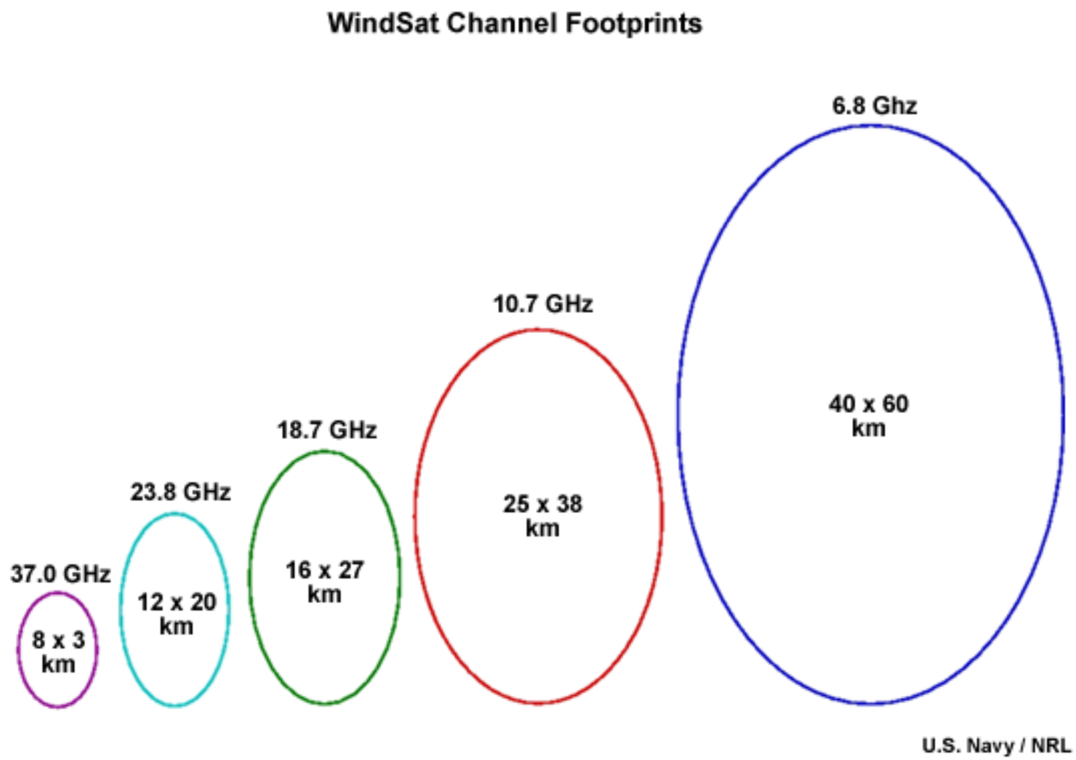
"field of view"

compared to VIS and IR

> 10km



Energy available to Passive MW sensors



Lower frequency

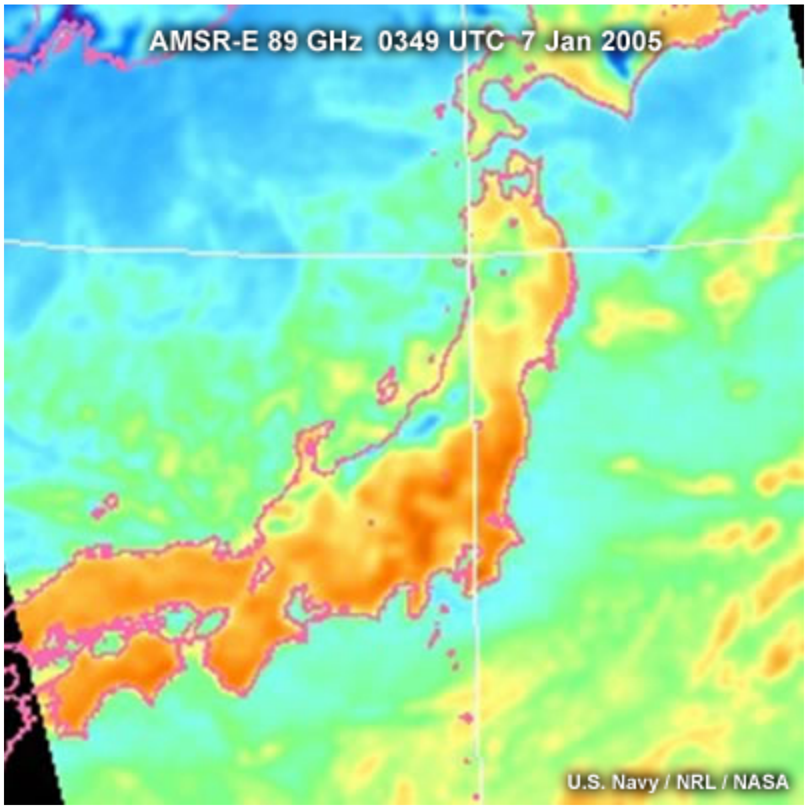
Longer wavelength

Less energy

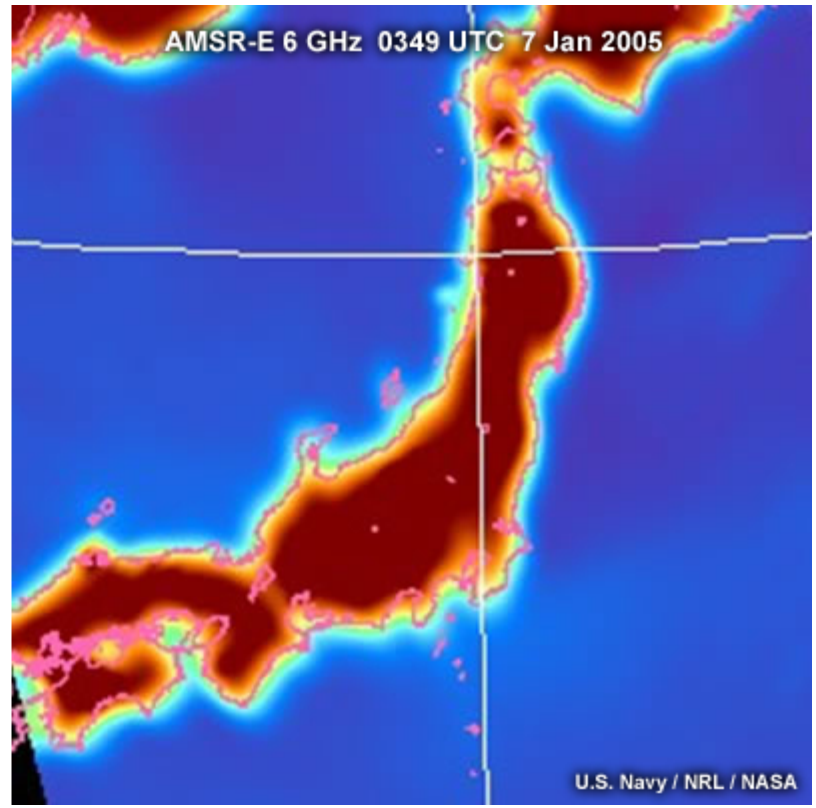
=> Need larger field of view!

Energy available to Passive MW sensors

5km FOV



50km FOV

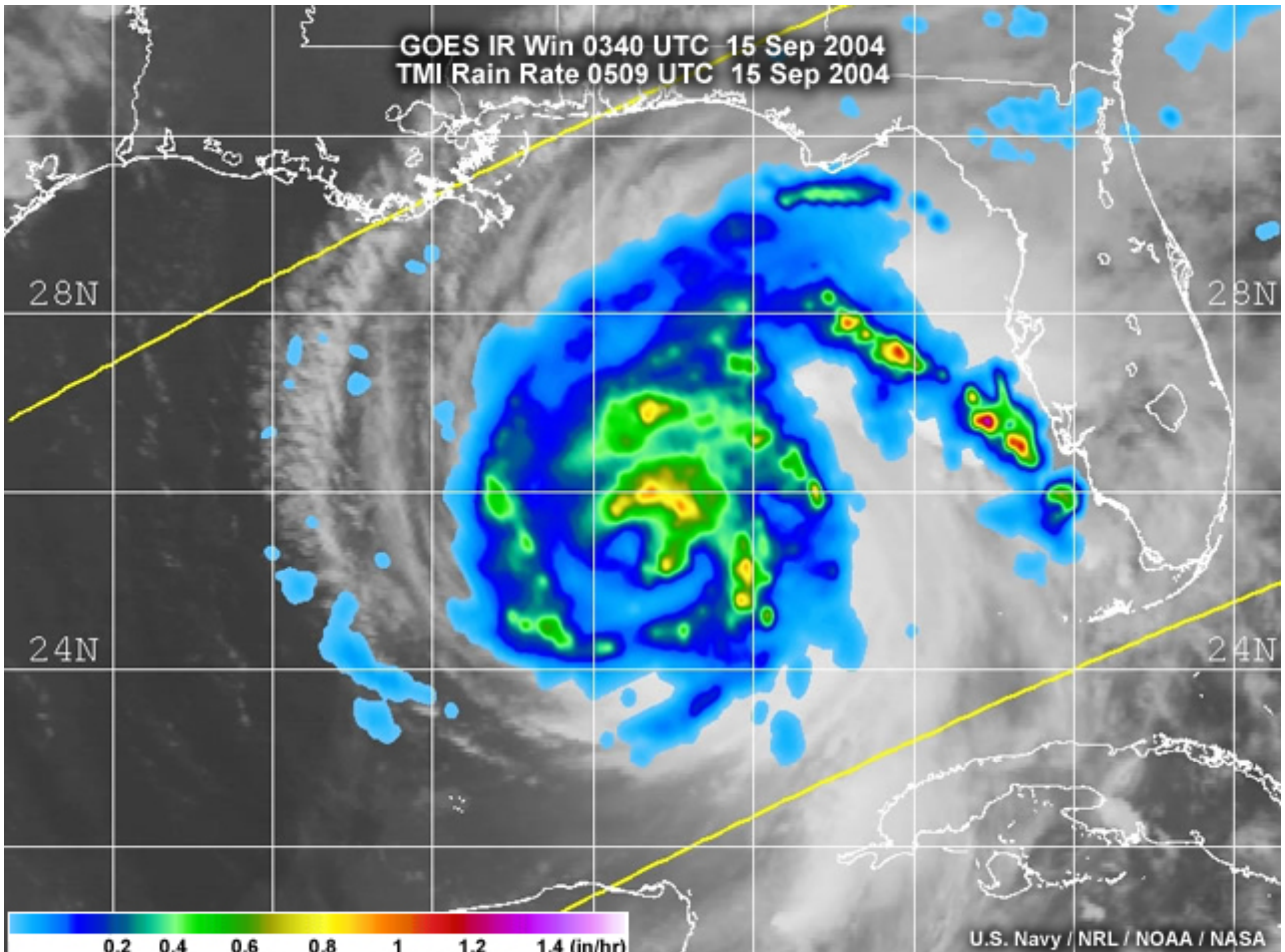


Effect of changing field-of-view on image quality

Influence of water on signal along coastline

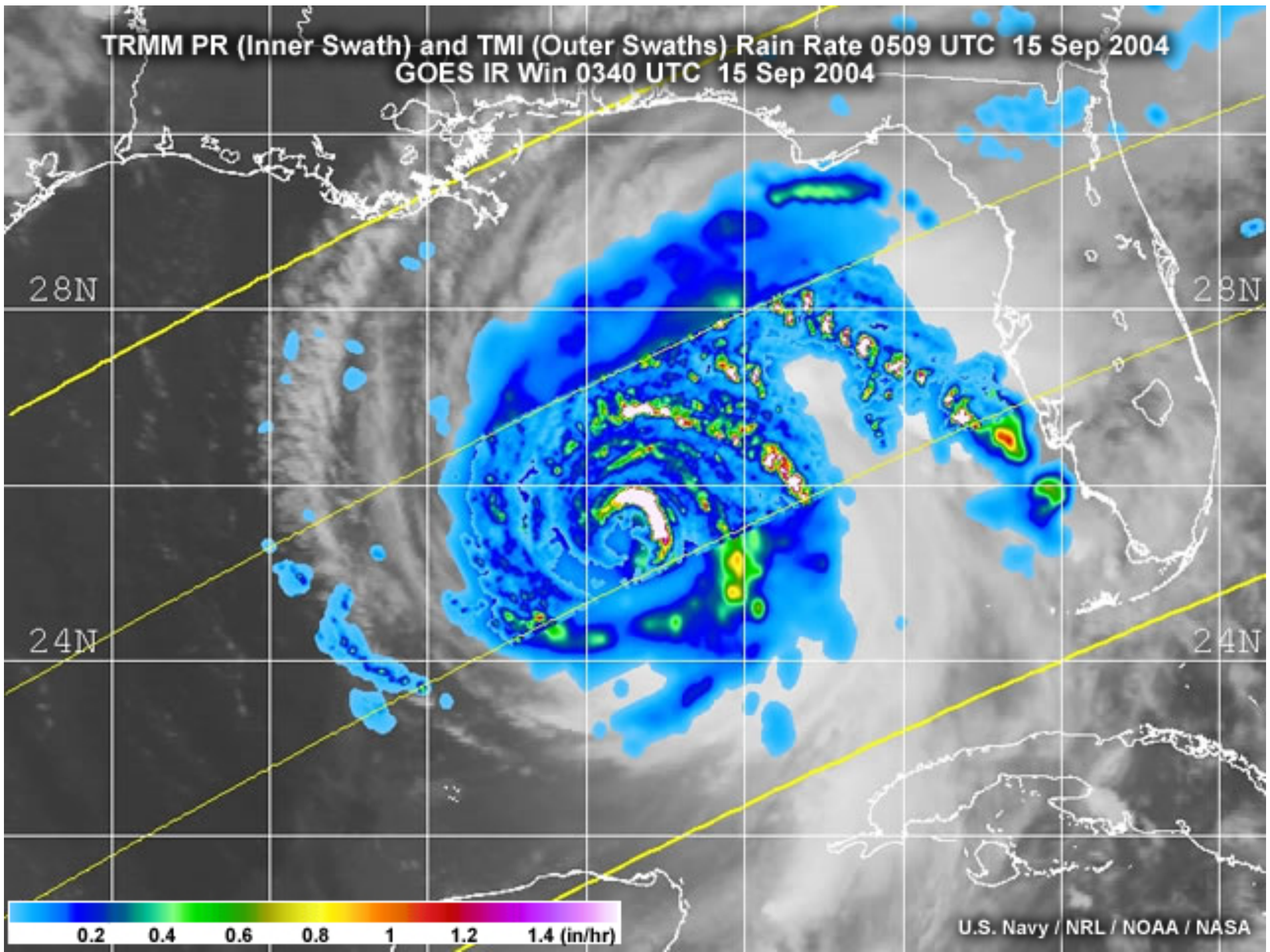
Active v. Passive Precipitation Sensing

TRMM (passive) microwave imager



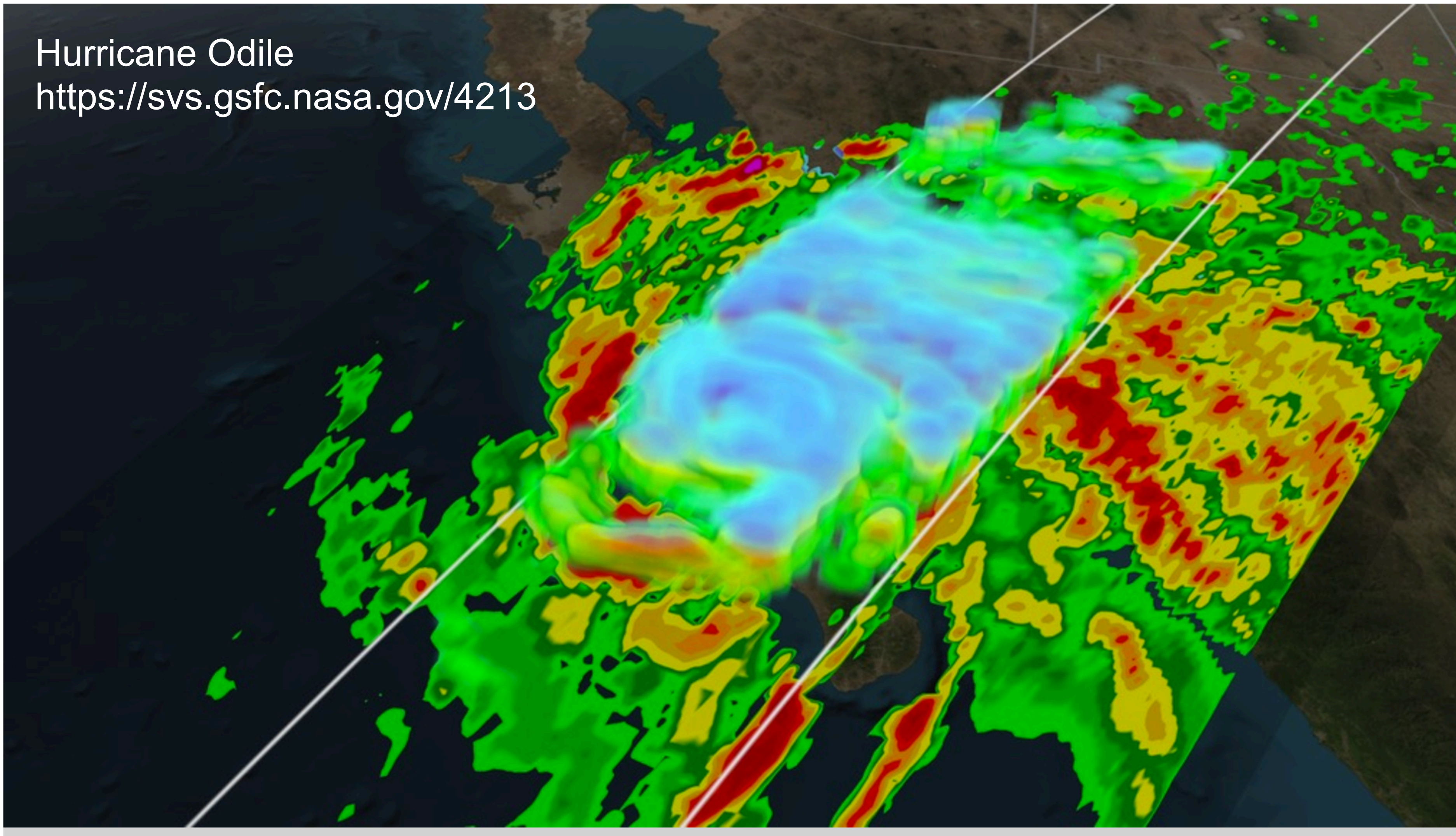
Active v. Passive Precipitation Sensing

TMI + TRMM Precipitation Radar

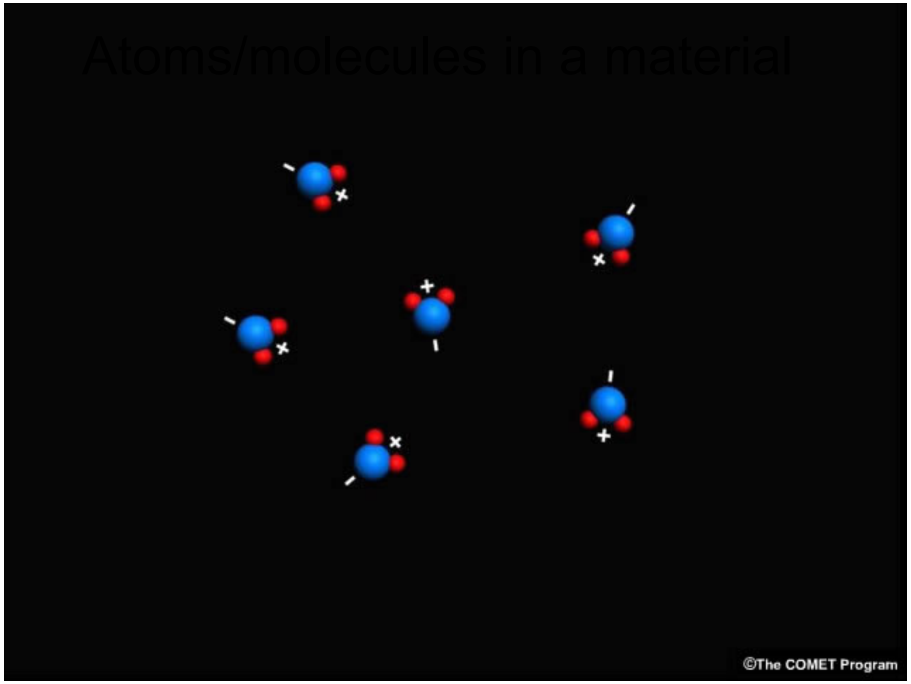


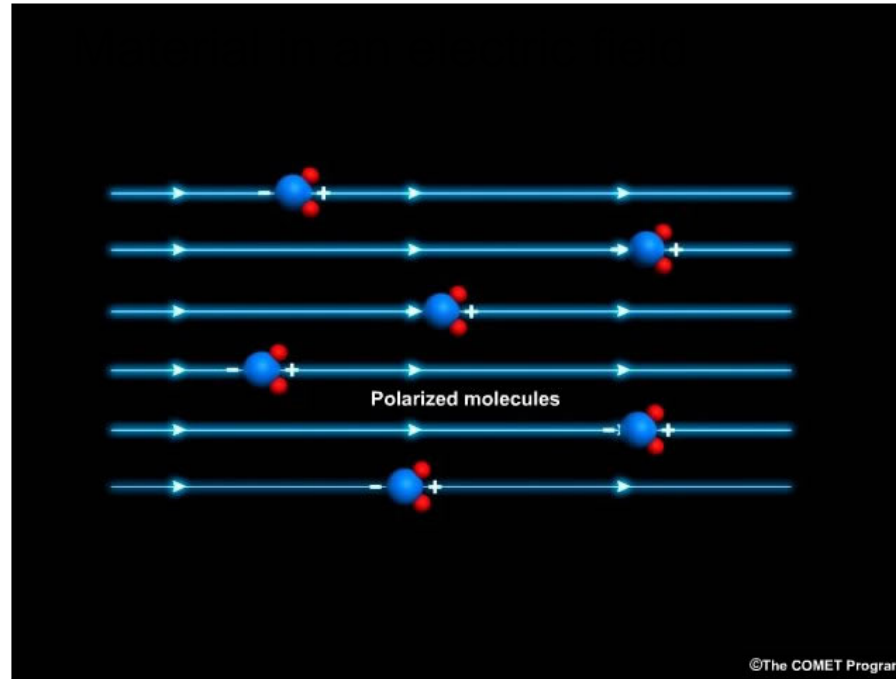
Active v. Passive Precipitation Sensing

Global Precipitation Measurement Mission



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

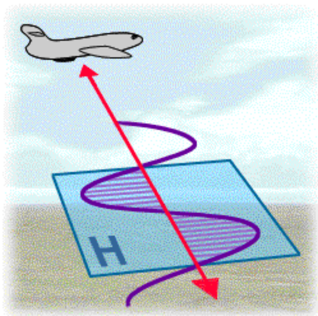
The Dielectric Constant and Emissivity

Dielectric Constants for Various Materials

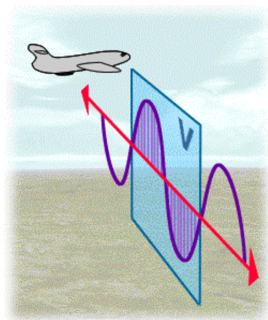
Common naturally occuring materials	Typical Dielectric Constants between ~1 to 100 GHz ε'
Air, vacuum	1.00059, 1.0 (by definition)
Ice (fresh, sea)	3.2, 4-8
Snow (dry, wet)	1.3-1.6, 1.4-1.9
Permafrost	4-8
Water (fresh)	80 (20°C, <3 GHz), ↓15-25 (~3 GHz) and decreasing with frequency
Sea water	78 (20°C,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

Polarization

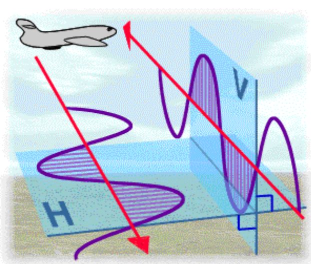
HH



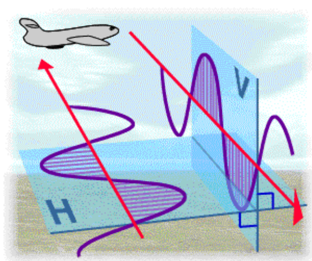
VV



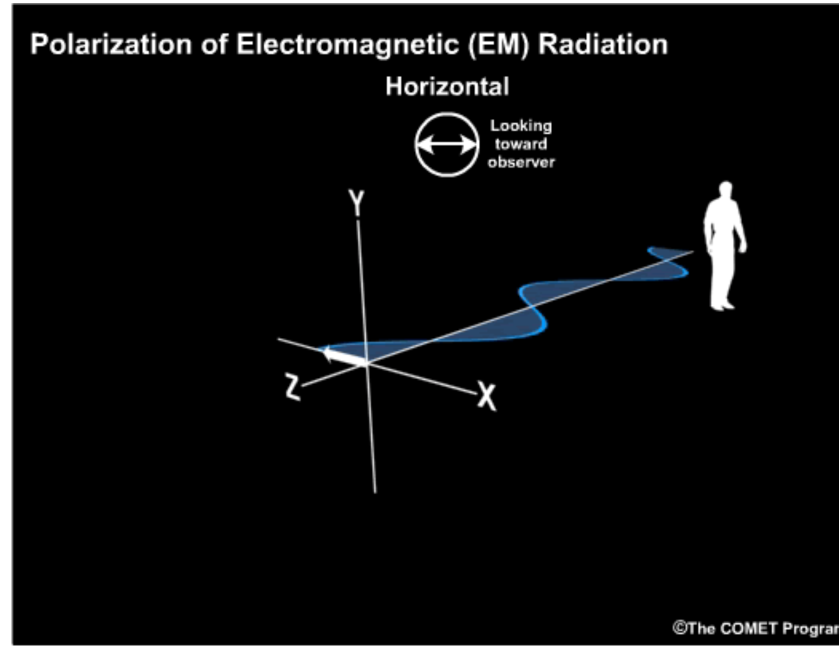
HV

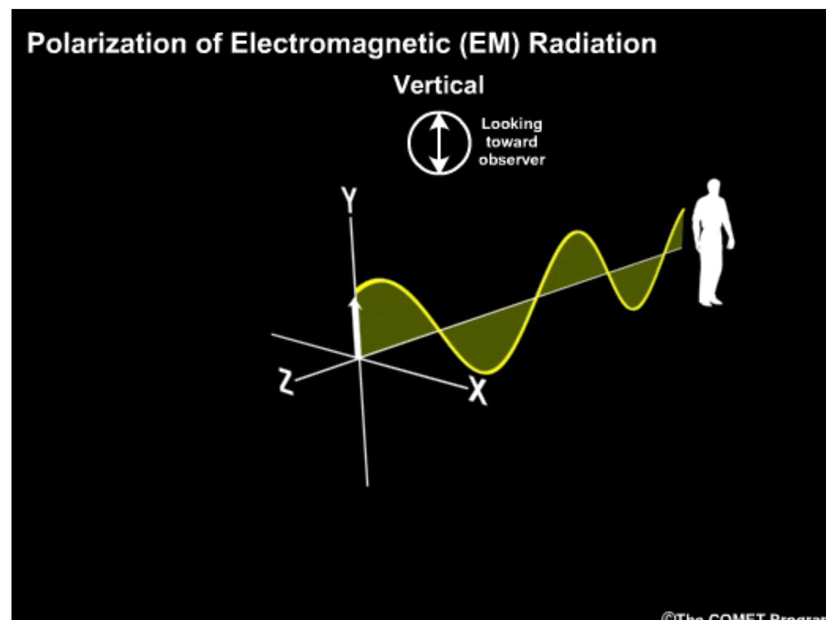


VH

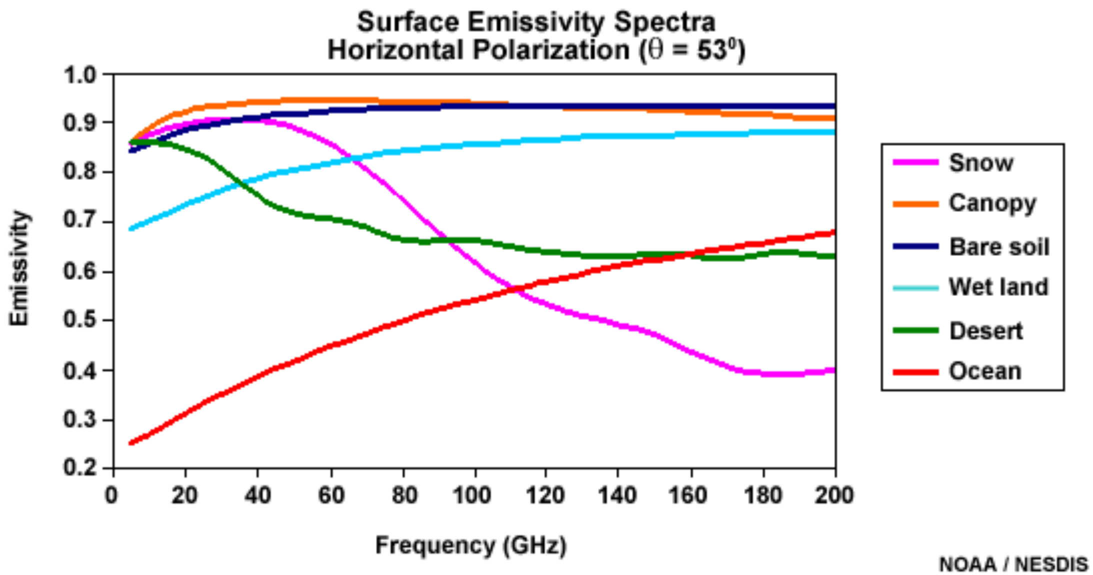


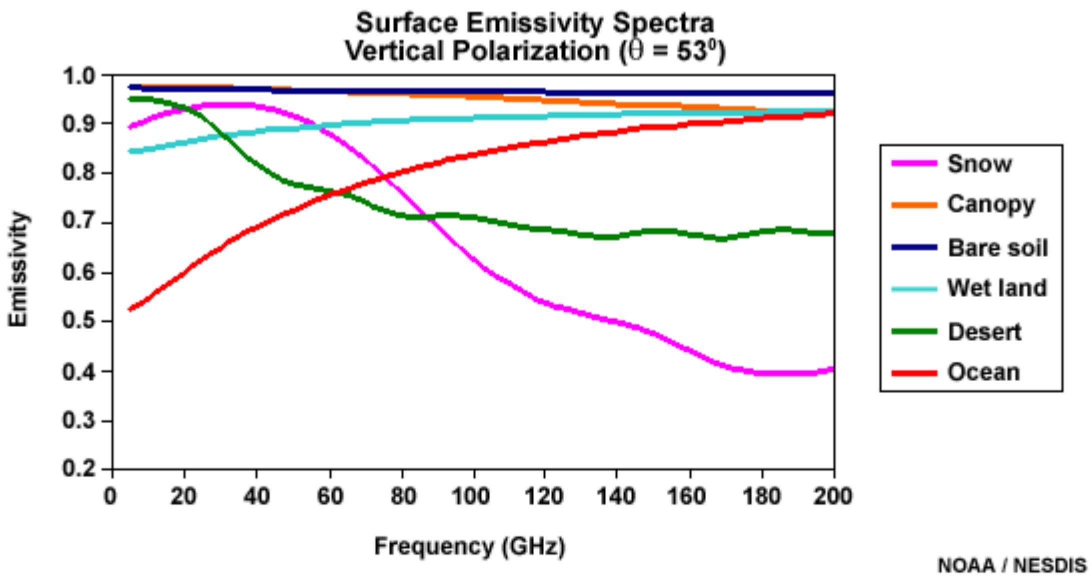
Source: CCRS



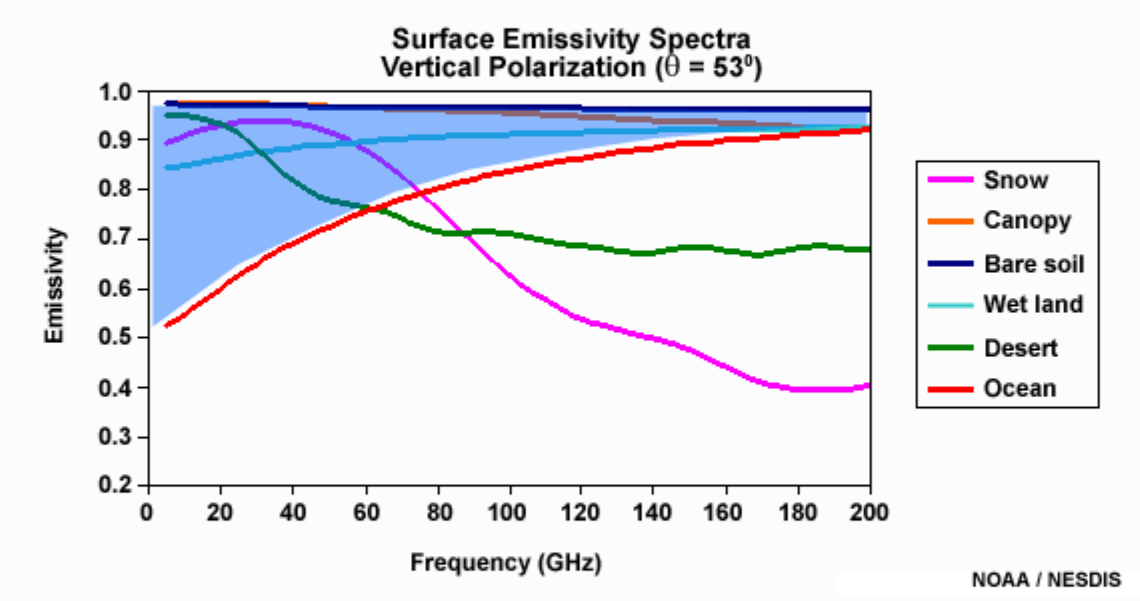


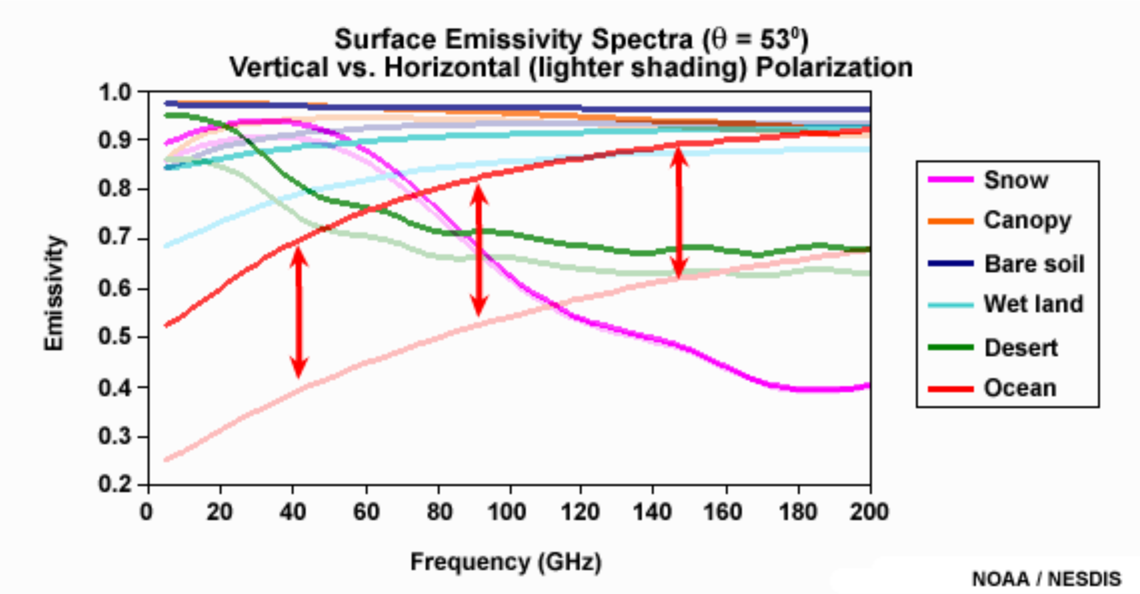
Polarization





Polarization





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**
- Different frequencies, **polarizations**

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 $\frac{hf}{kT} << 1$

$$B_f = \frac{2f^2kT}{c^2}$$

$$\boxed{B_f \propto T}$$

Passive Microwave Remote-Sensing

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

All other materials are grey bodies (emissivity <1)

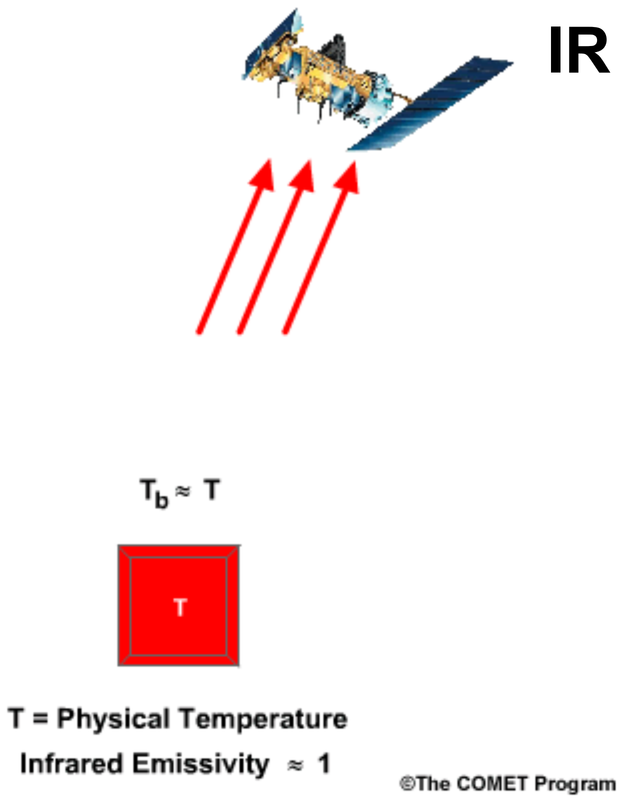
Brightness temperature

$$T_B = e\,T$$

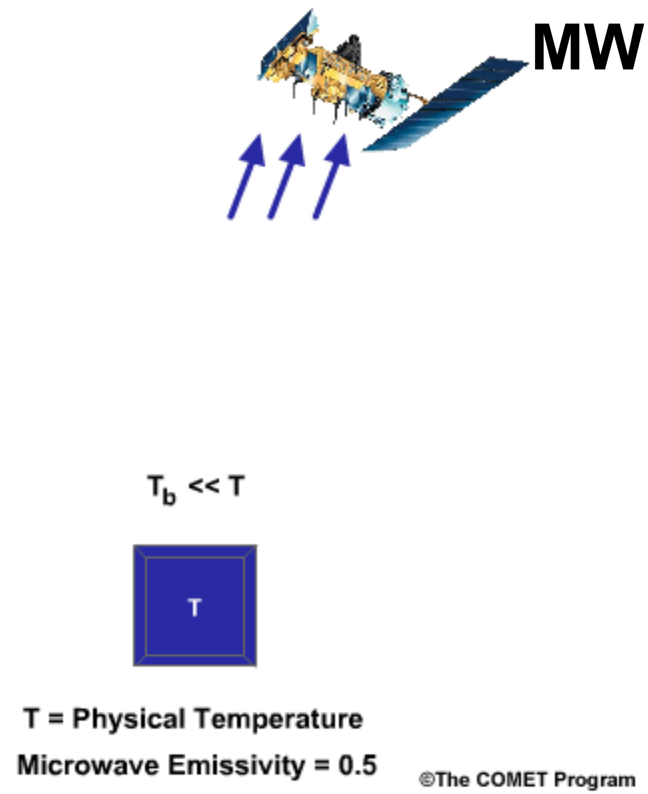
T_B is the temperature a blackbody would have to have the same brightness (at some frequency f) as a grey body with emissivity e and temperature T.

Passive Microwave Remote-Sensing

Infrared v Microwave Temperature



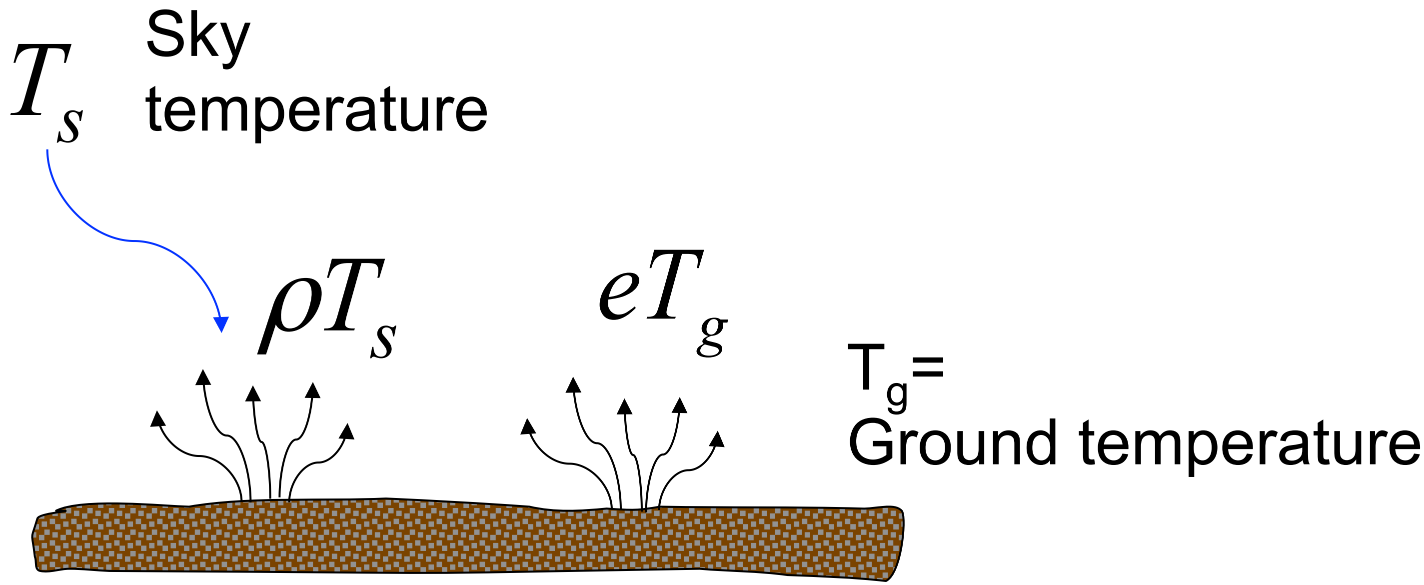
Little reflection or scattering



Dielectric effect

=> Reflection, scattering

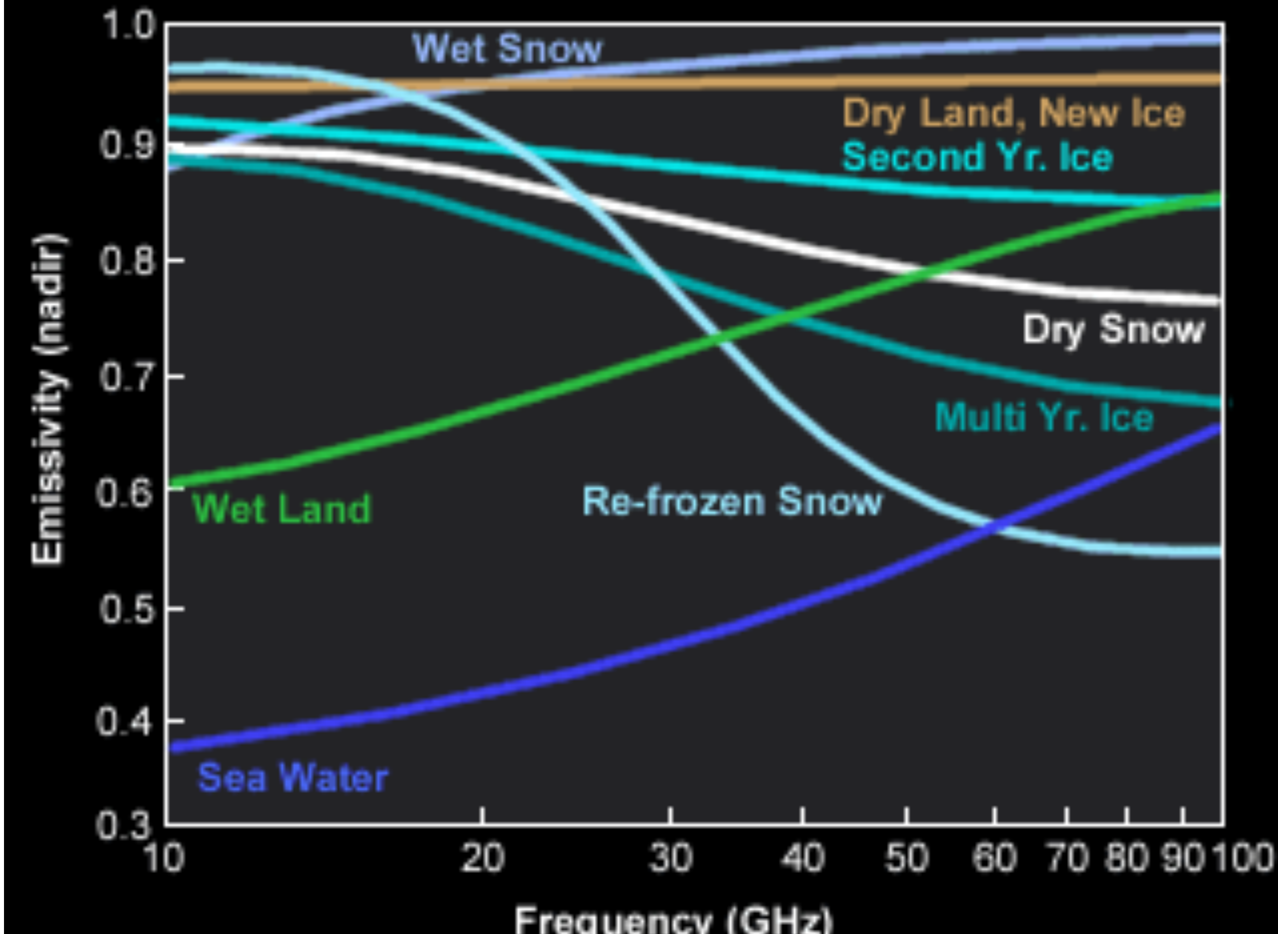
Passive Microwave Remote-Sensing



$$T_b = \rho T_s + eT_g$$

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

Passive Microwave Remote-Sensing



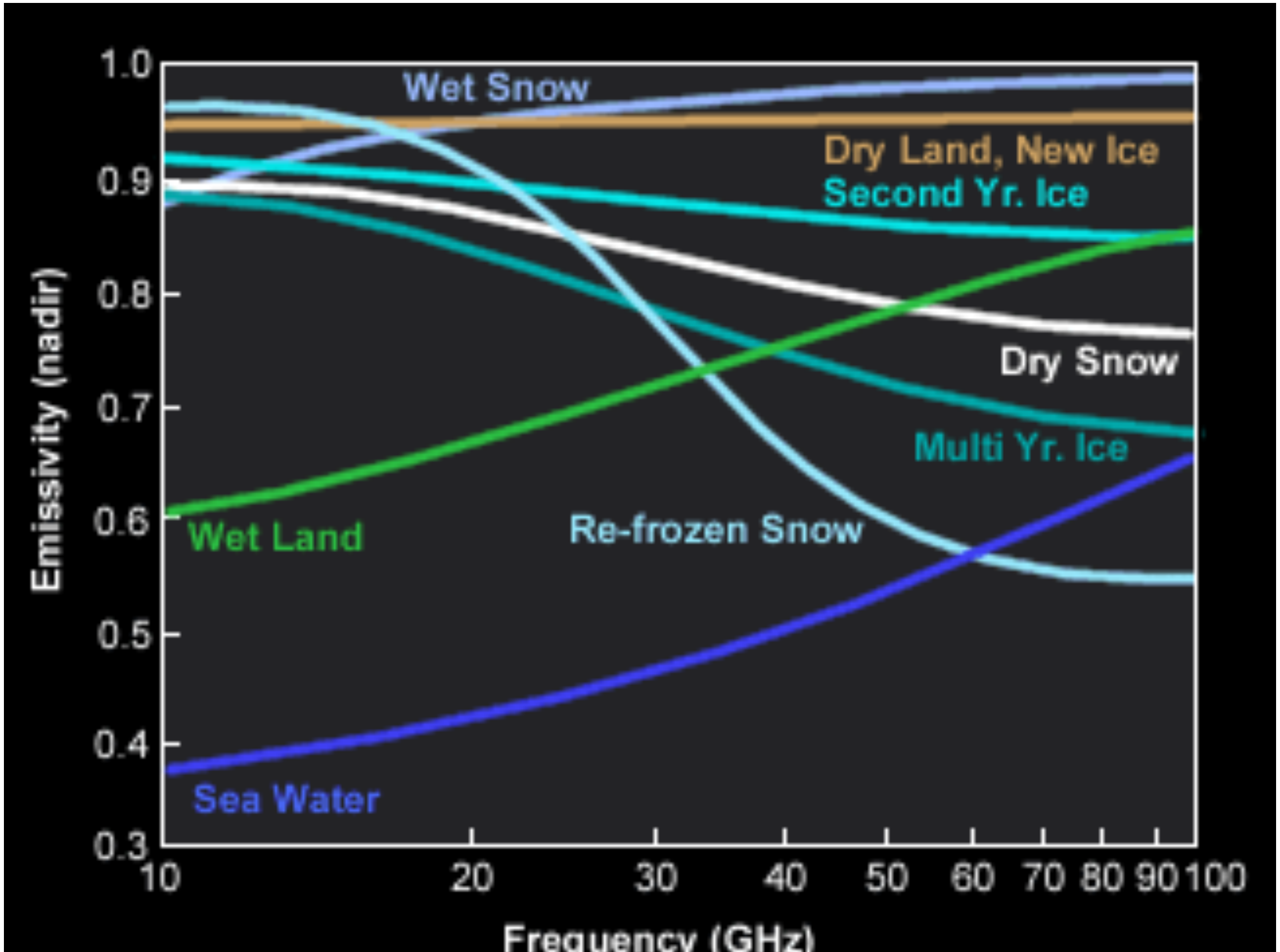
Surface emissivity at nadir as a function of frequency for scattering materials (aged sea ice and snow cover) and absorption materials (water, wet and dry soil and new sea ice).

Adapted from Dr. Norman C. Grody

Passive Microwave Remote-Sensing

Ice

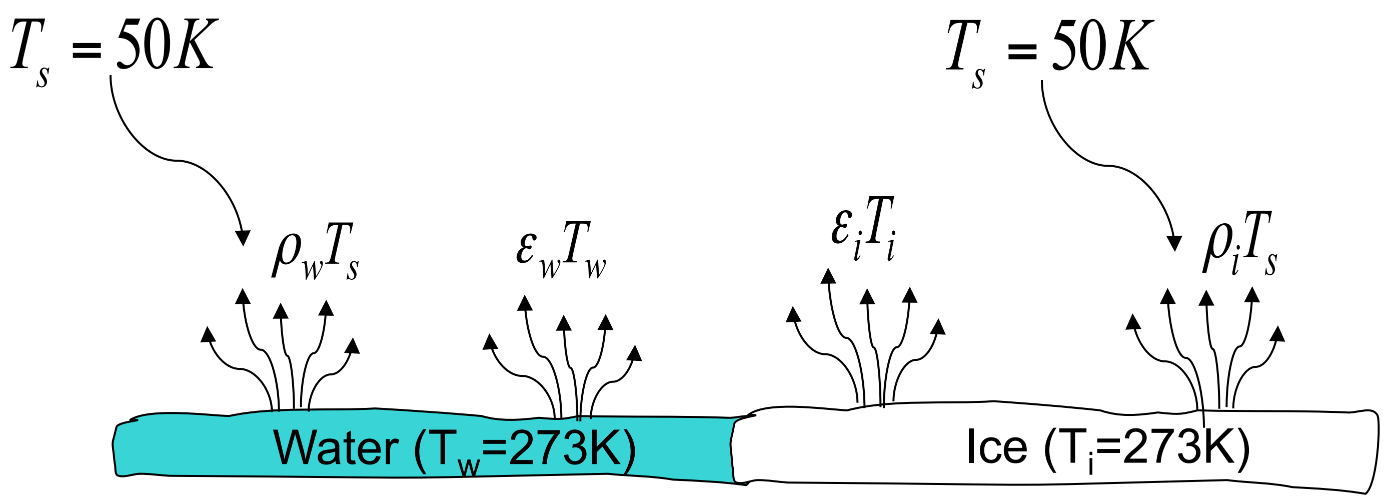
Water



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: Polar Mapping



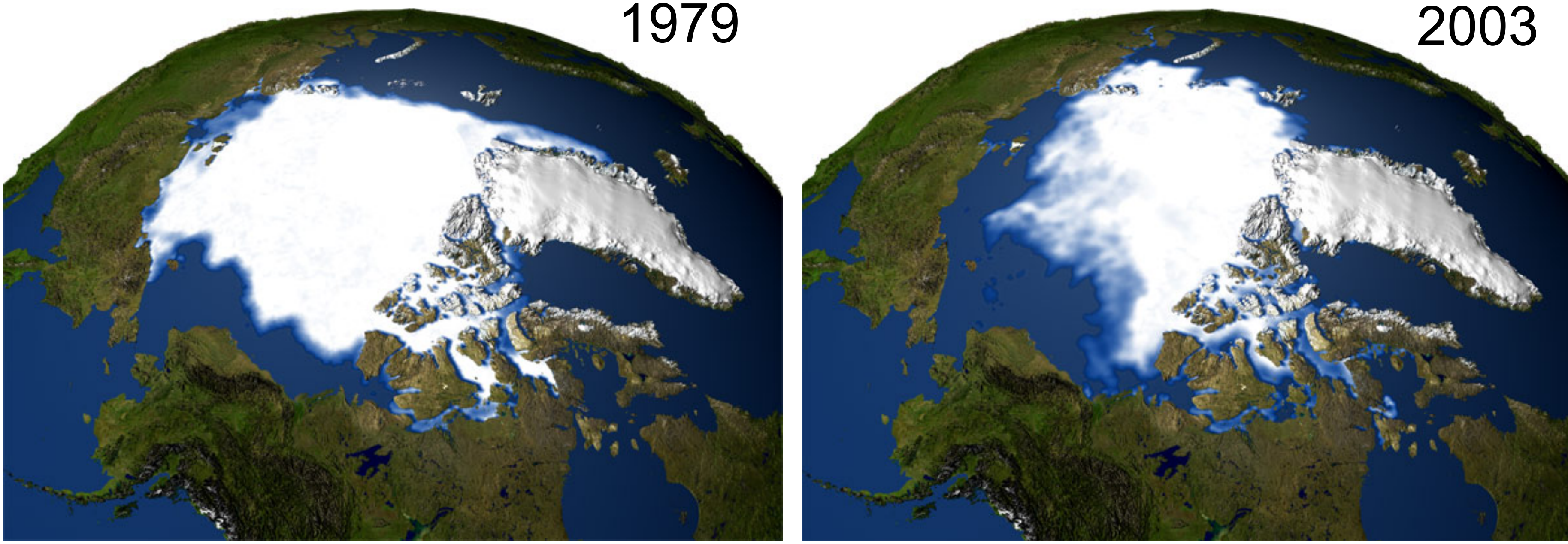
$$T_{b,w} = T_s + e_w(T_w - T_s) \qquad T_{b,i} = T_s + e_i(T_i - T_s)$$

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

	Dielectric constant	Emissivity
water	80	0.36
Ice	3	0.93

$$\Delta T_b = 127K$$

Passive Microwave Remote-Sensing: Polar Mapping



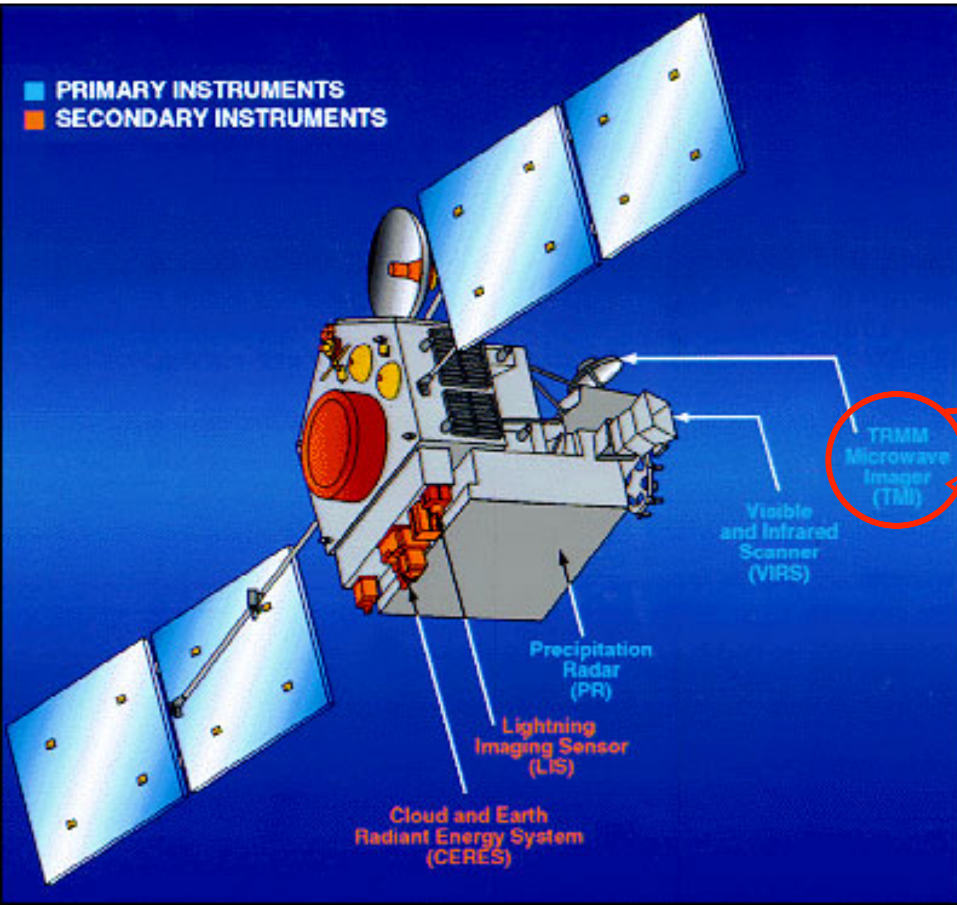
Arctic perennial sea ice has been decreasing at a rate of 9% per decade.

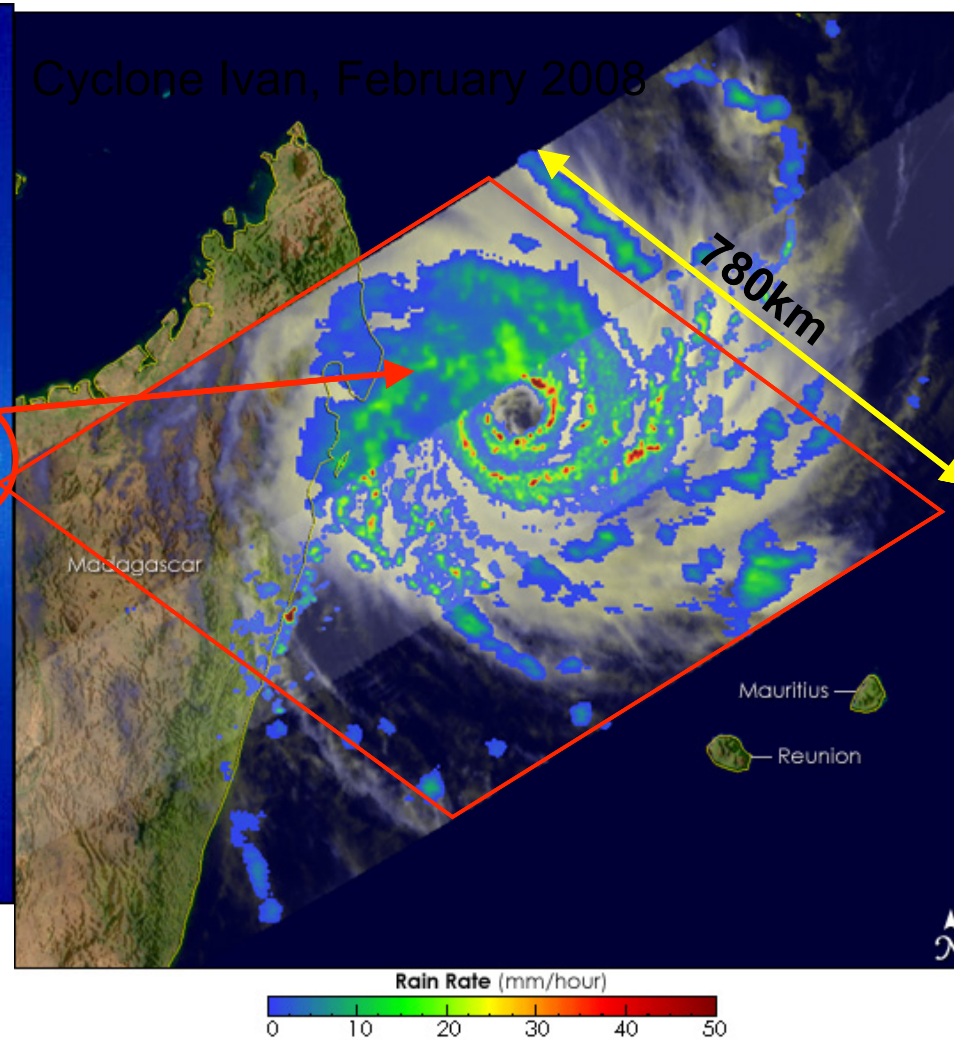
Special Sensor Microwave Imager (SSMI).

Credit: NASA

Passive Microwave Remote-Sensing: Precipitation

Tropical Rainfall Measuring Mission (NASA/NASDA)





Passive Microwave Remote-Sensing: Precipitation

Tropical Rainfall Measuring Mission (NASA/NASDA)

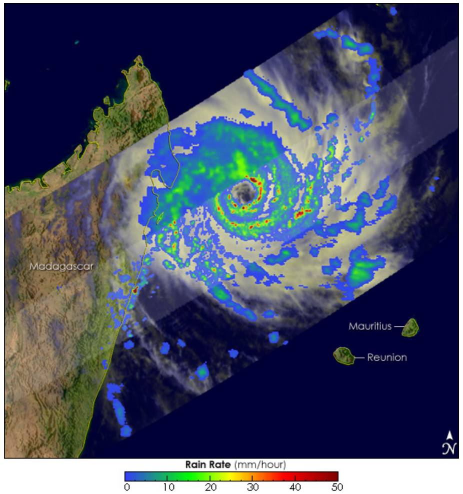
<u>TRMM Microwave Imager (TMI)</u>

•Microwave Radiometer

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

=>Range of resolutions & penetration depths

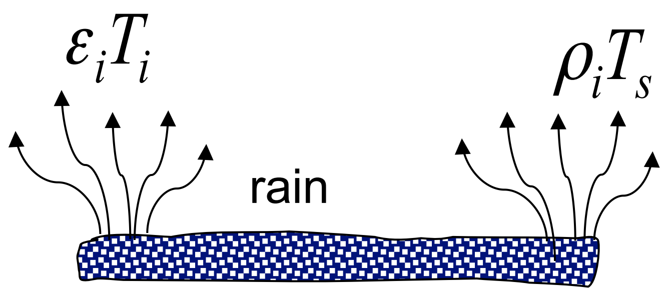
•Measures ***integrated column precipitation***

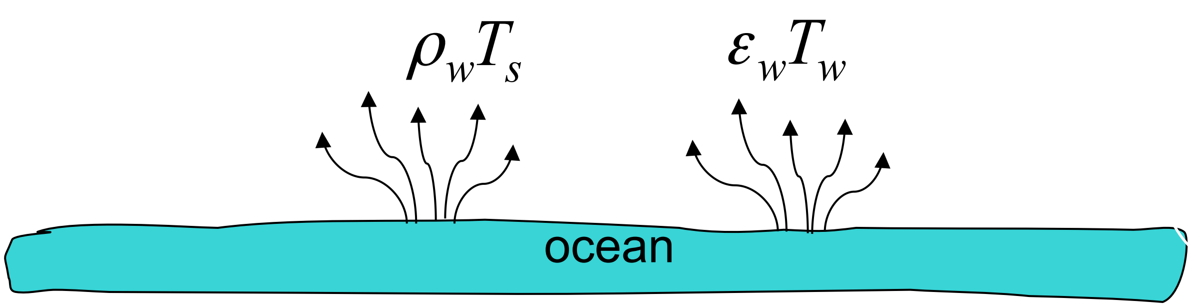


Passive Microwave Remote-Sensing: Precipitation

Tropical Rainfall Measuring Mission (NASA/NASDA)

TRMM Microwave Imager works best over oceans:



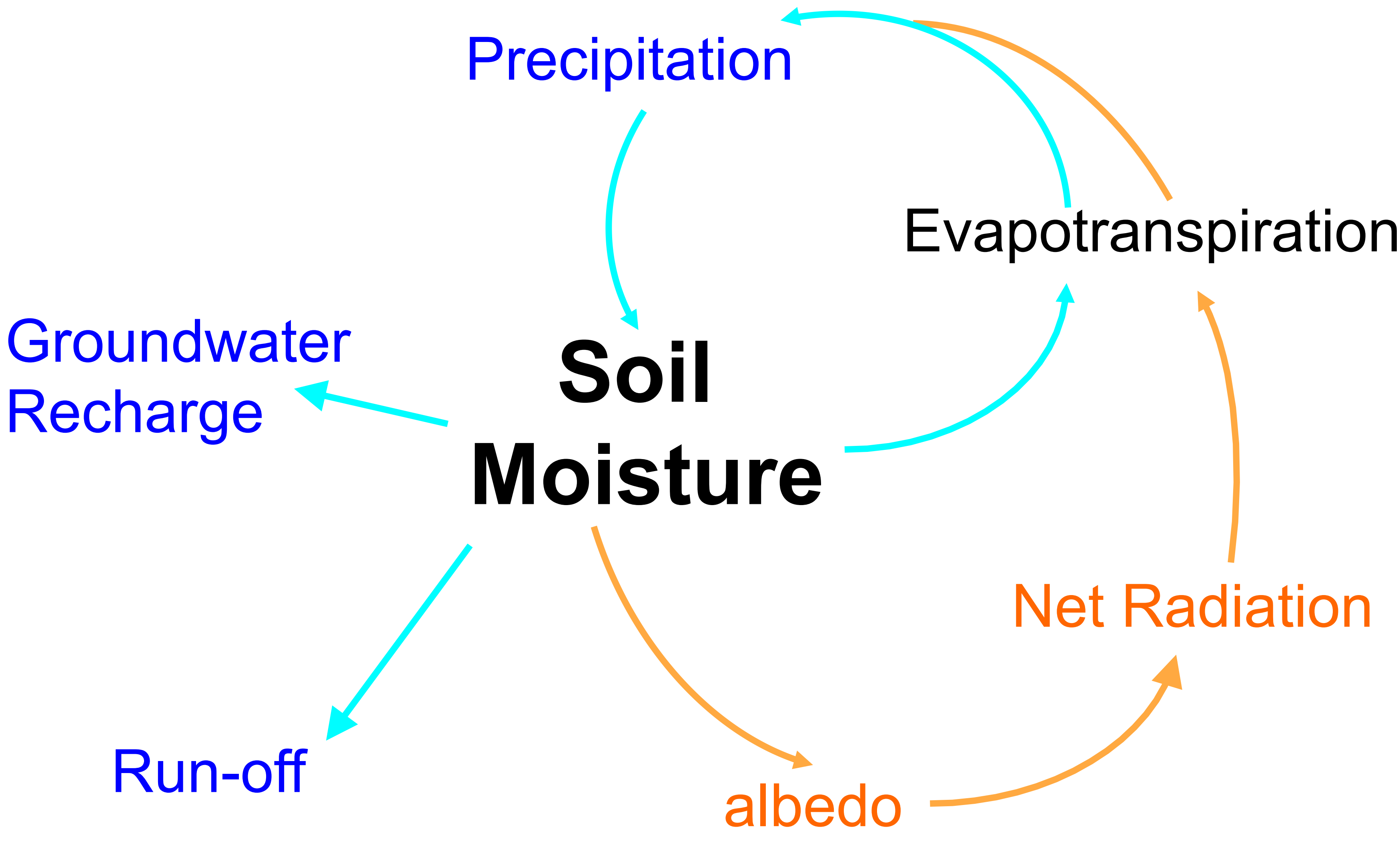


Remember low emissivity of sea water?
- Oceans appear "cold".

Raindrops appear "warm"

=> more raindrops make scene "warmer".

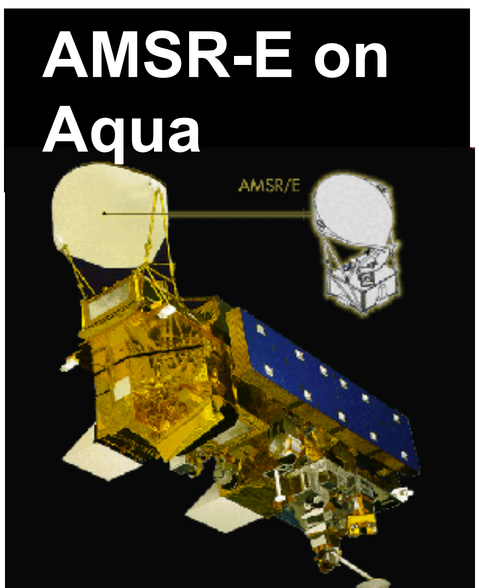
Soil moisture in hydrology



Soil Moisture Remote-Sensing

1990+

Current SOTA



Passive Microwave Remote-Sensing: Why L-band for Soil Moisture?

Dielectric constant of water

$$\varepsilon = 80$$

Greater Δε between wet and dry at lower frequencies

Δε results in ΔT_B of ~100K

=> ***detectable***!

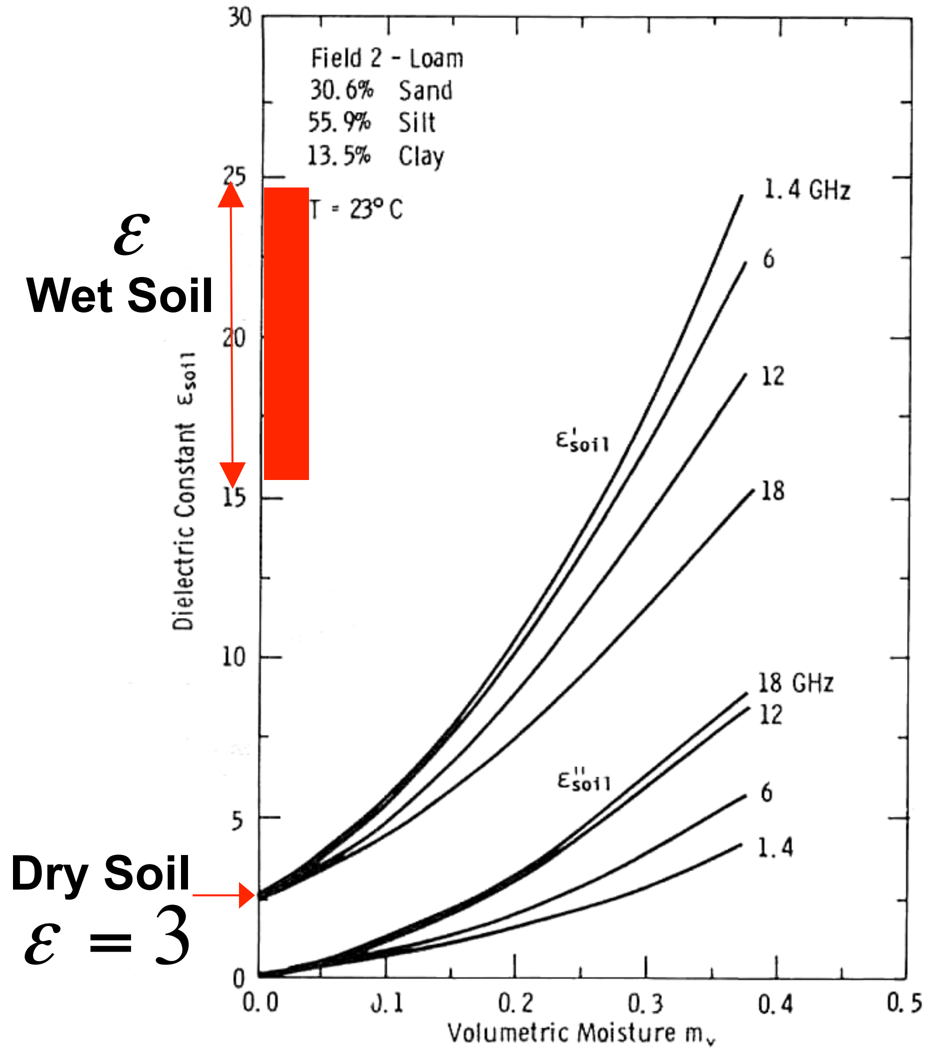


Fig. E.52 Measured dielectric constant as a function of volumetric moisture content for a loamy soil at four microwave frequencies.

Passive Microwave Remote-Sensing: Why L-band for Soil Moisture?

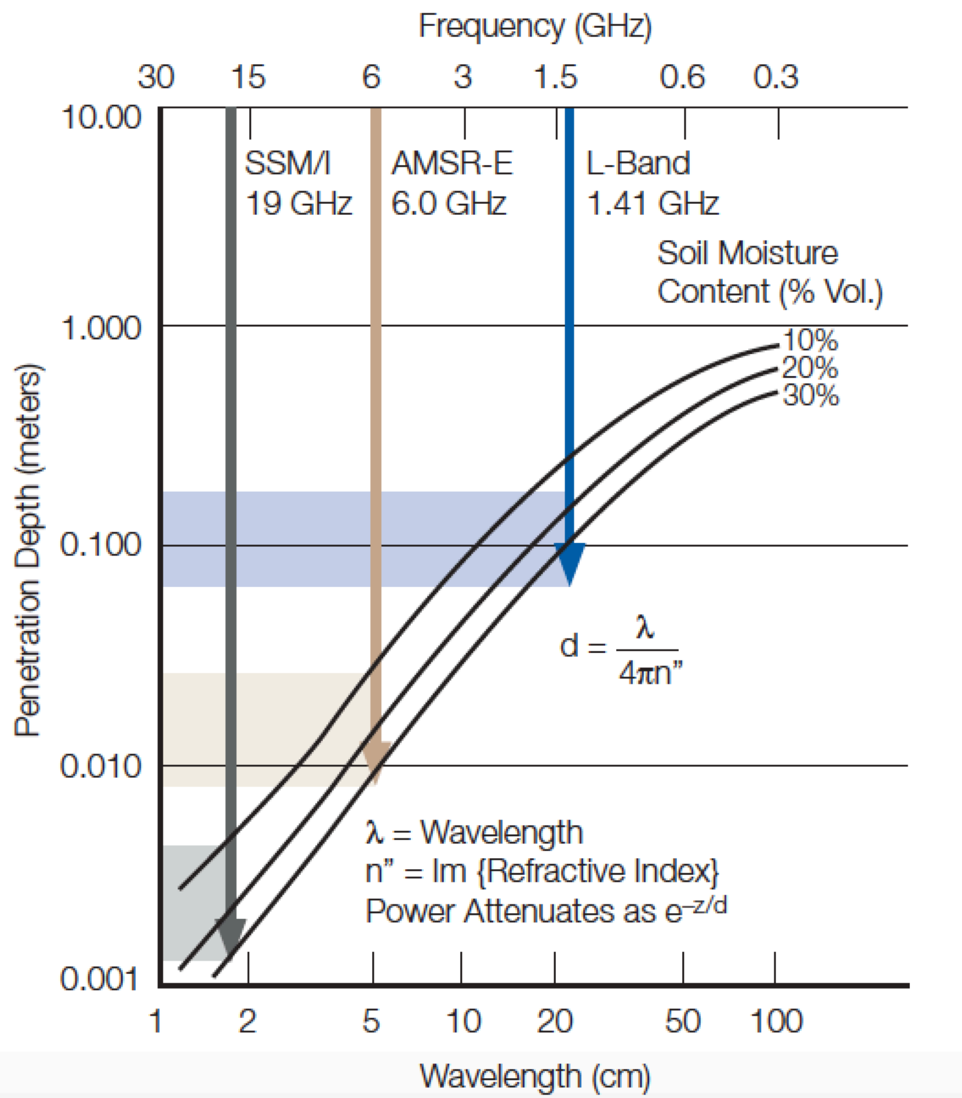


Figure 31. L-band TB observations are sensitive to emission from deeper in the soil than at higher frequencies (adapted from Njoku and Kong 1977). Soil moisture curves are given for 10, 20, and 30% (or in absolute units, 0.10, 0.20, 0.30 cm3/cm3). **(SMAP Handbook)**

Passive Microwave Remote-Sensing: Why L-band for Soil Moisture?

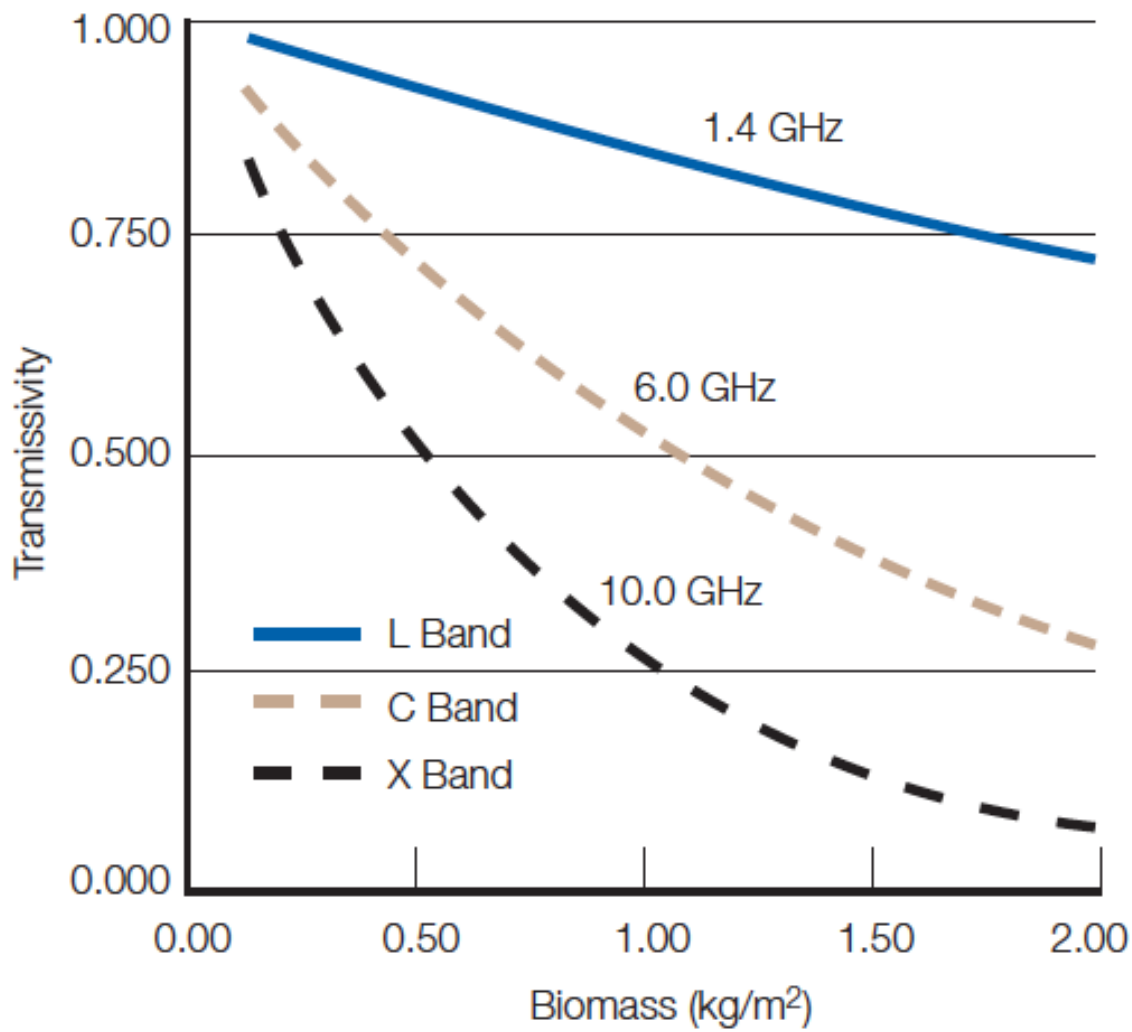
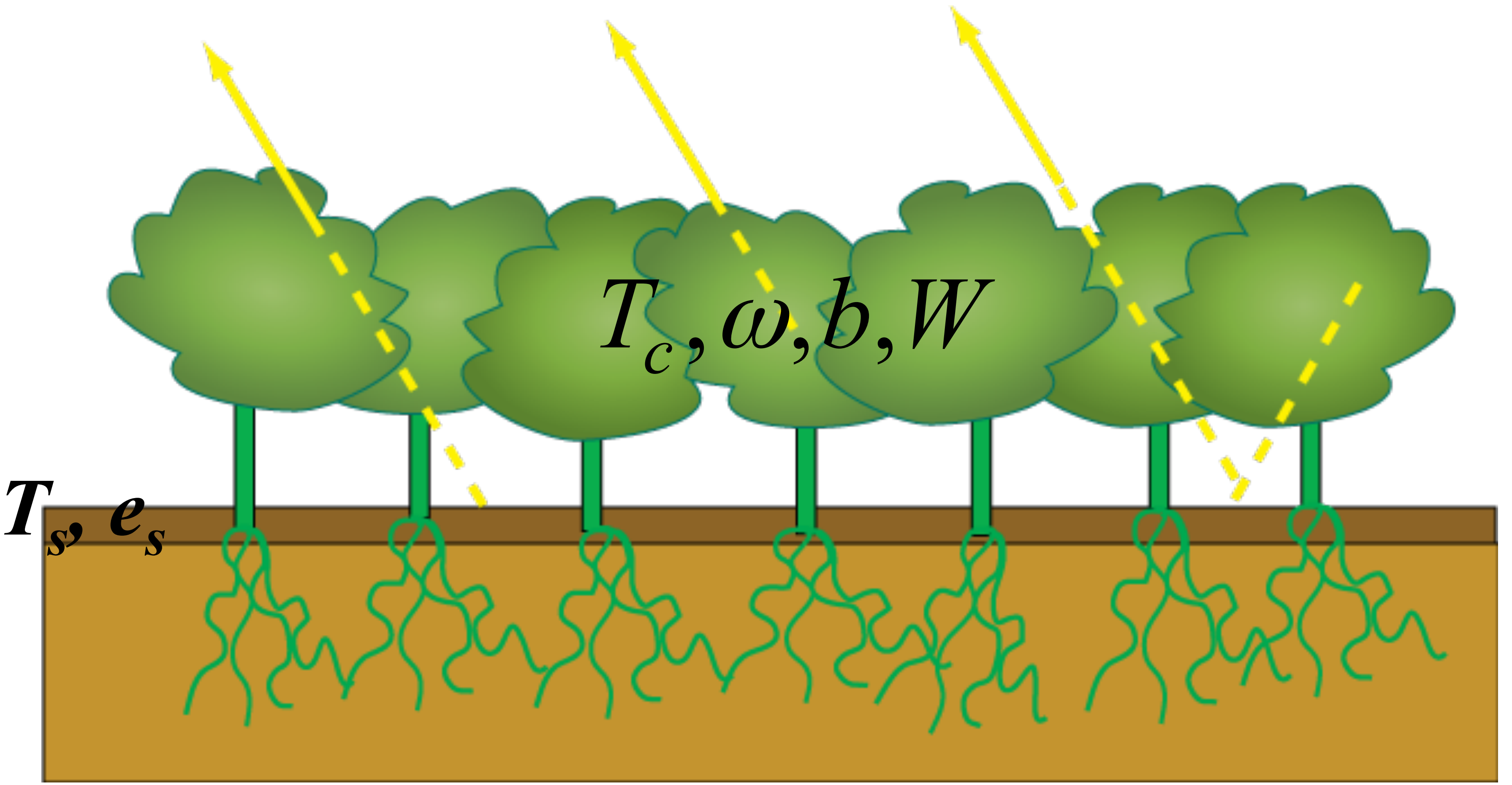


Figure 30. Vegetation transmissivity to soil emission at L-band frequencies (1.4 GHz) is much higher than at C- (6 GHz) or X-band (10 GHz) frequencies. (Adapted from Ulaby et al. 1996.) (**SMAP Handbook)**

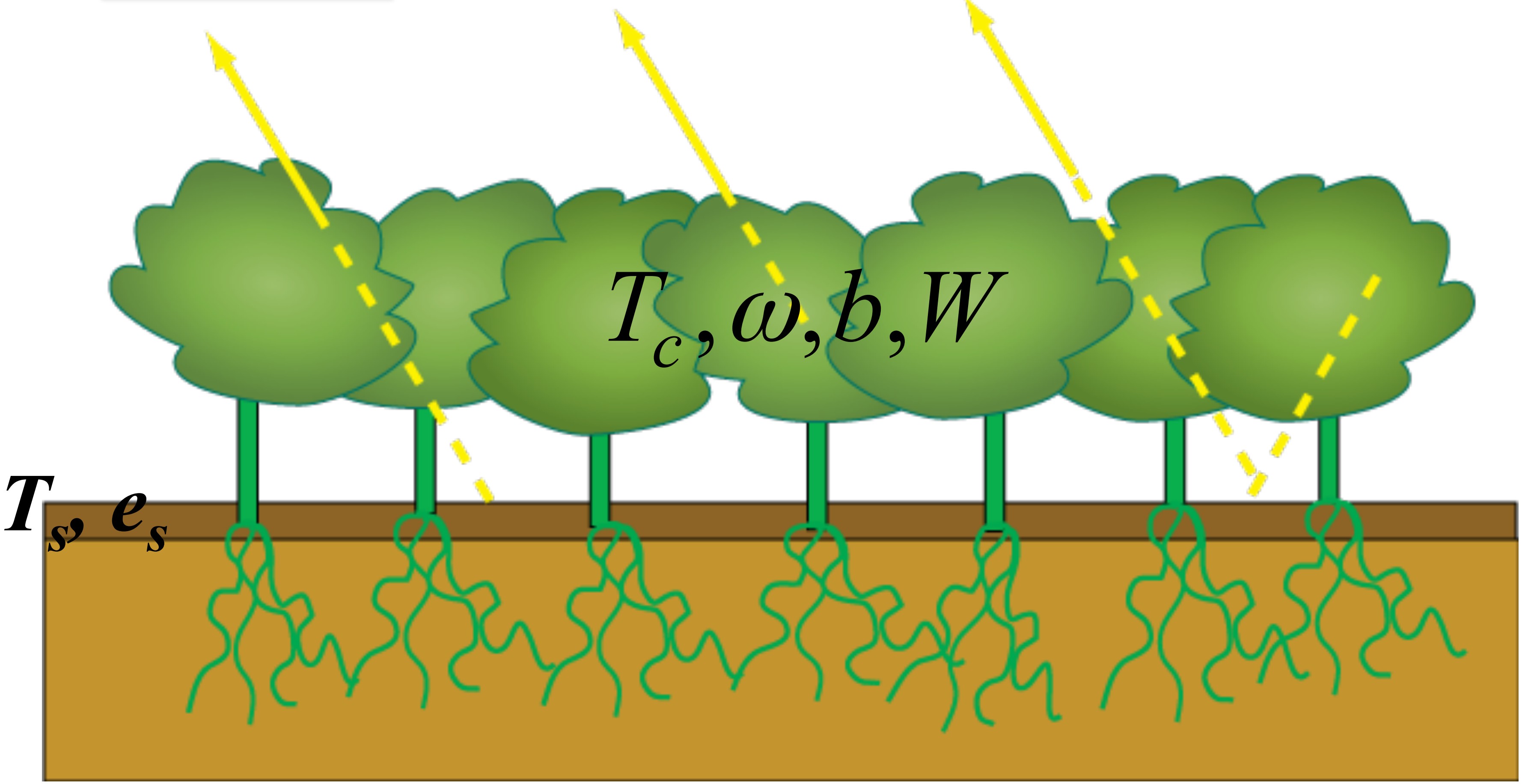
Passive Microwave Remote-Sensing: Tau-omega model

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



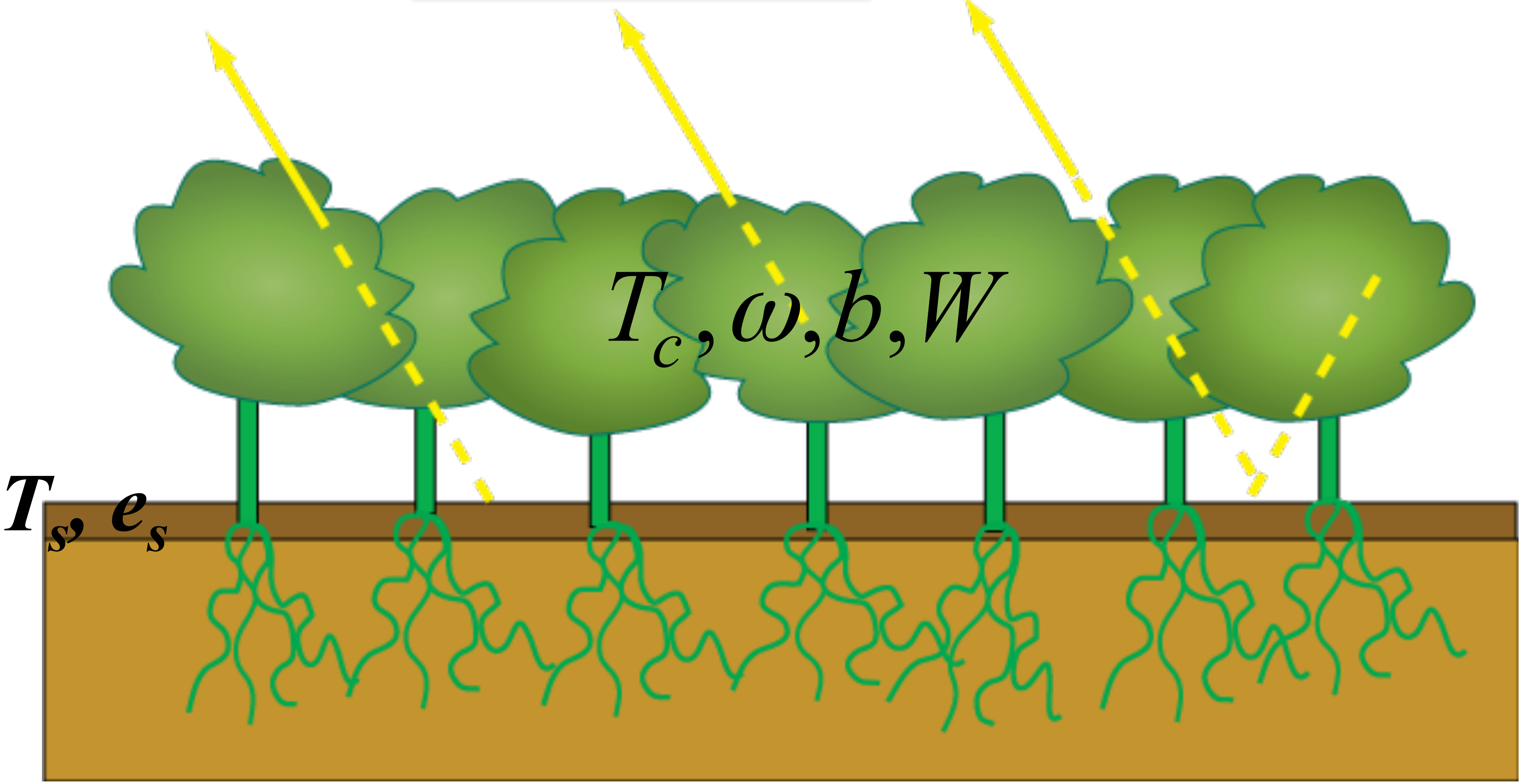
Passive Microwave Remote-Sensing: Tau-omega model

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



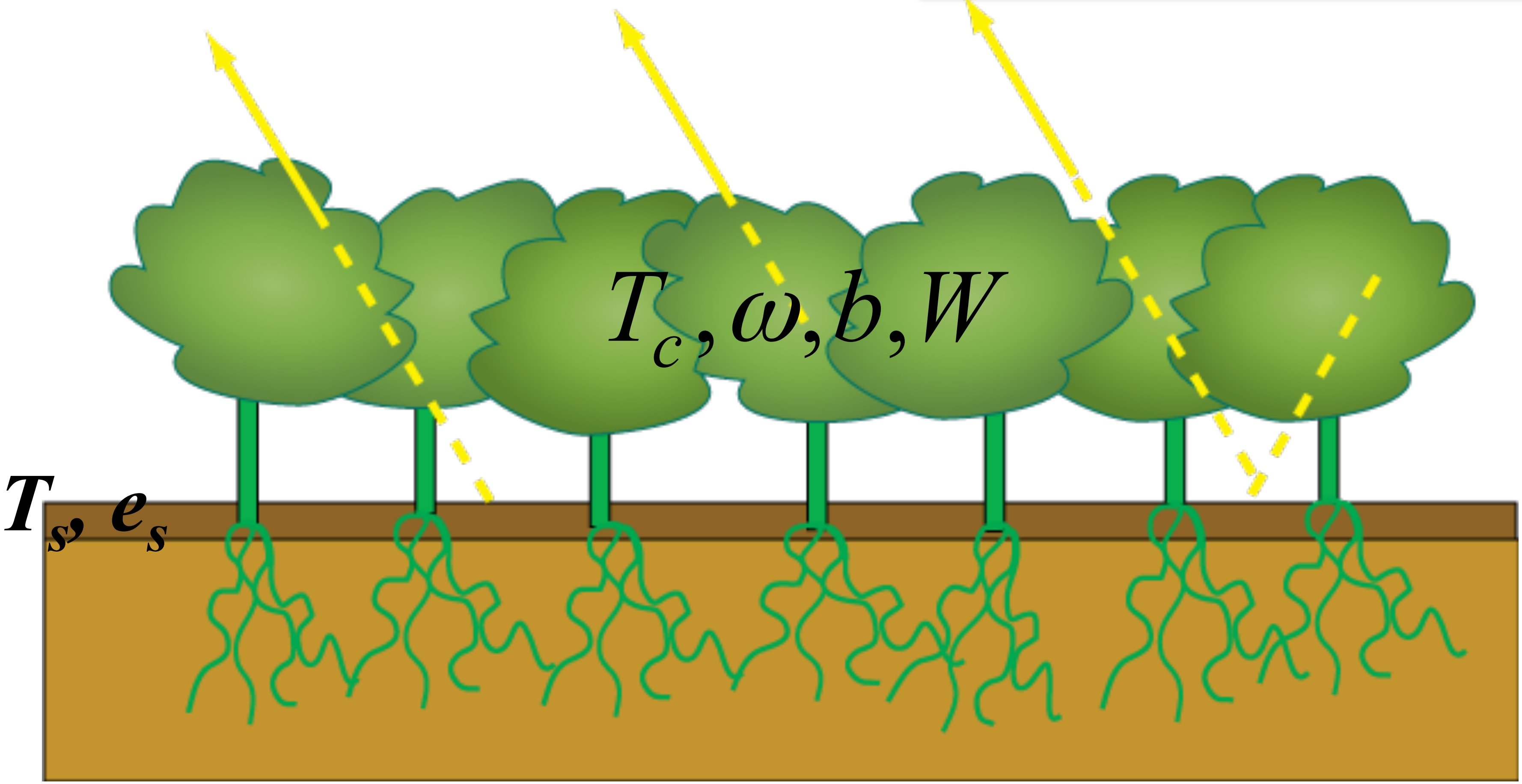
Passive Microwave Remote-Sensing: Tau-omega model

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



Passive Microwave Remote-Sensing: Tau-omega model

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



Passive Microwave Remote-Sensing: Tau-omega model

Temperature

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

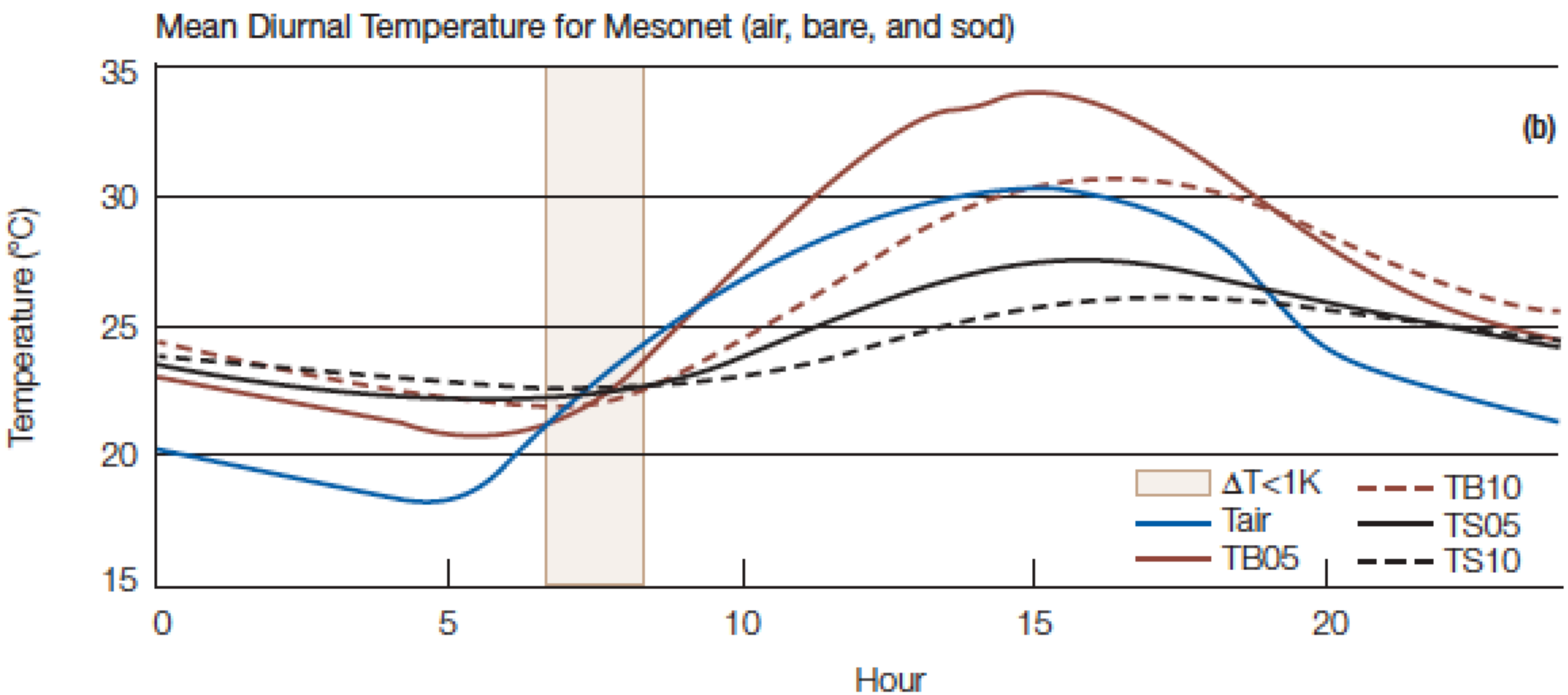


Figure 32. Soil temperature as a function of time based on June 2004 Oklahoma Mesonet data: (a) vertical profiles for a sod-covered site and (b) the mean soil temperatures for bare soil (TB05 at 5 cm below the surface, TB10 at 10 cm below the surface), and sod (TS05, TS10). The shaded region identifies the period of the day when these effects result in less than 1 °C difference among the four temperatures (T. Holmes, personal communication).

(SMAP Handboo

Passive Microwave Remote-Sensing: Tau-omega model

Emissivity

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

$$e_s = 1 - \rho_s$$

Soil Emissivity = 1 - Soil Reflectivity

Soil reflectivity depends on:

- ***Soil dielectric constant***
- ***Soil roughness***
- Incident angle
- Polarization

Passive Microwave Remote-Sensing: Tau-omega model

Soil dielectric constant

Dielectric mixing model

e.g. Dobson et al. (1985), Wang and Schmugge (1980), Mironov et al. (2009)

Soil dielectric constant depends on:

Soil moisture

Soil texture

Frequency

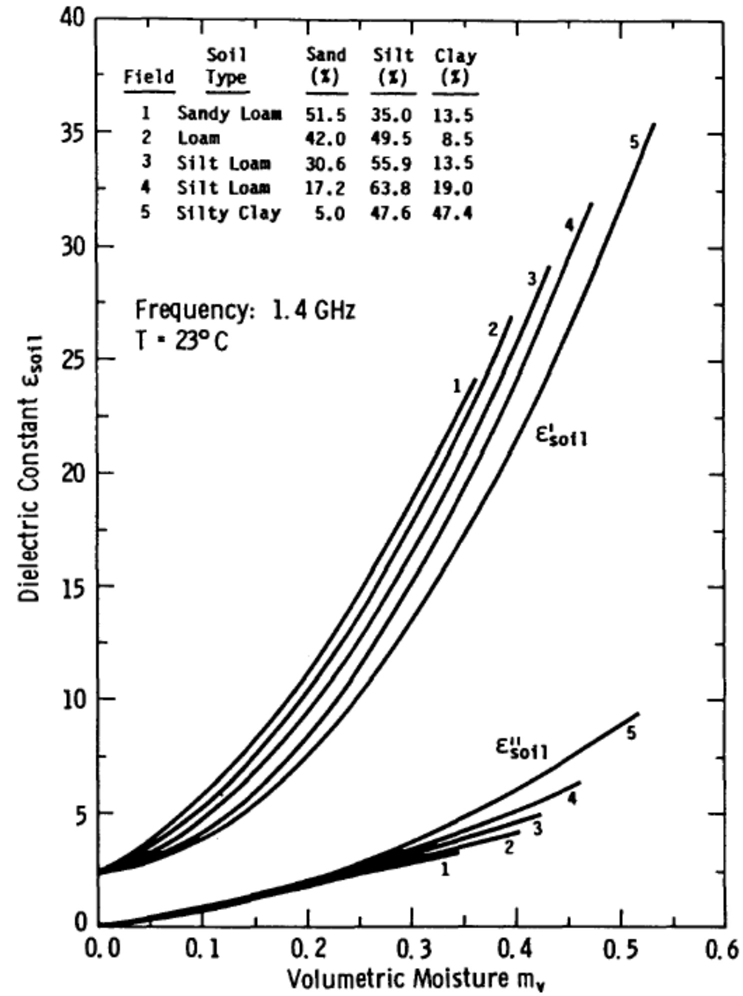


Fig. 2. Dielectric constant as a function of volumetric soil moisture for five soils at 1.4 GHz. Smooth curves were drawn through measured data points. (From Ulaby et al. (1986). Reproduced with permission, *Microwave Remote Sensing: Active and Passive, Vol. III: From Theory to Applications*, by Fawwaz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

Passive Microwave Remote-Sensing: Tau-omega model

Soil dielectric constant

The **smooth reflectivity** is calculated using the **Fresnel equations**:

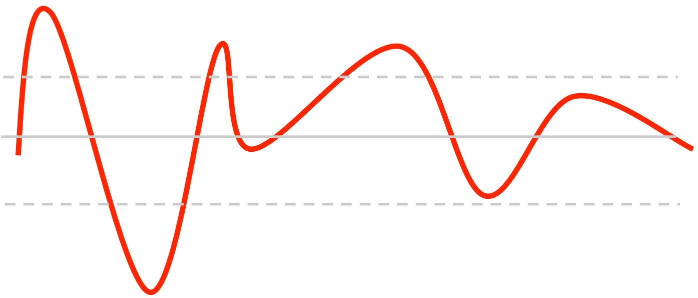
$$\rho_H(\theta) = \left| \frac{\cos\theta - \sqrt{\varepsilon - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon - \sin^2\theta}} \right|^2$$

$$\rho_V(\theta) = \left| \frac{\varepsilon\cos\theta - \sqrt{\varepsilon - \sin^2\theta}}{\varepsilon\cos\theta + \sqrt{\varepsilon - \sin^2\theta}} \right|^2$$

Where ε is the soil dielectric constant!

Passive Microwave Remote-Sensing: Tau-omega model

Soil roughness



Roughness correction:

e.g. Choudhury et al. (1979)

$$\rho_{rough}(\theta) = \rho_{smooth}\theta \exp(-h\cos^2\theta)$$

where

$$h \propto \sigma^2$$

Variance of height distribution

Factors affecting SM retrieval






Passive Microwave Remote-Sensing: Tau-omega model

Emissivity

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

$$e_s = 1 - \rho_s$$

Soil Emissivity = 1 - Soil Reflectivity

Soil reflectivity depends on:

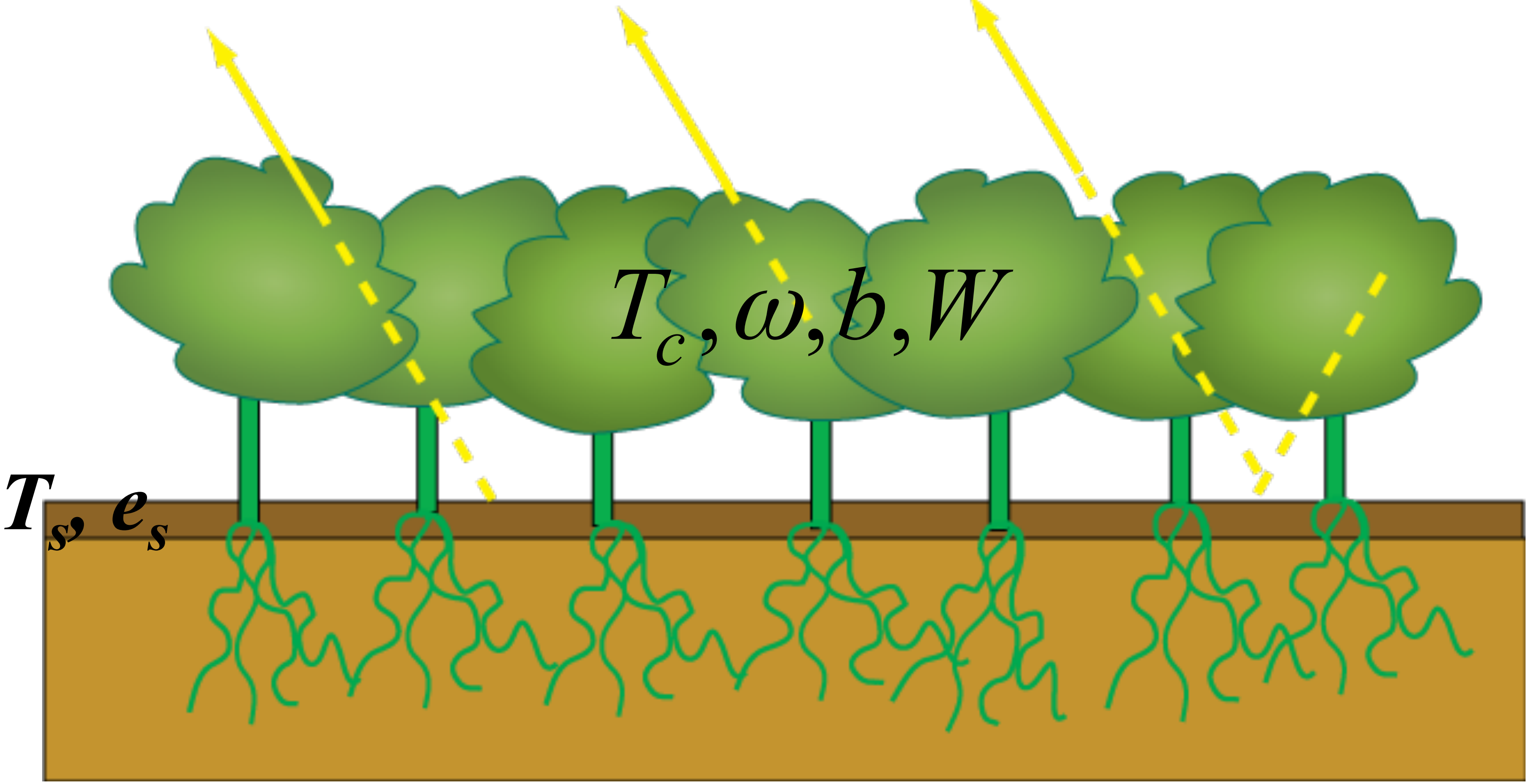
- ***Soil dielectric constant***
- ***Soil roughness***
- Incident angle
- Polarization

Factors affecting SM retrieval

Passive Microwave Remote-Sensing: Tau-omega model

Vegetation

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



Passive Microwave Remote-Sensing: Tau-omega model

Vegetation

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

T_c Canopy temperature

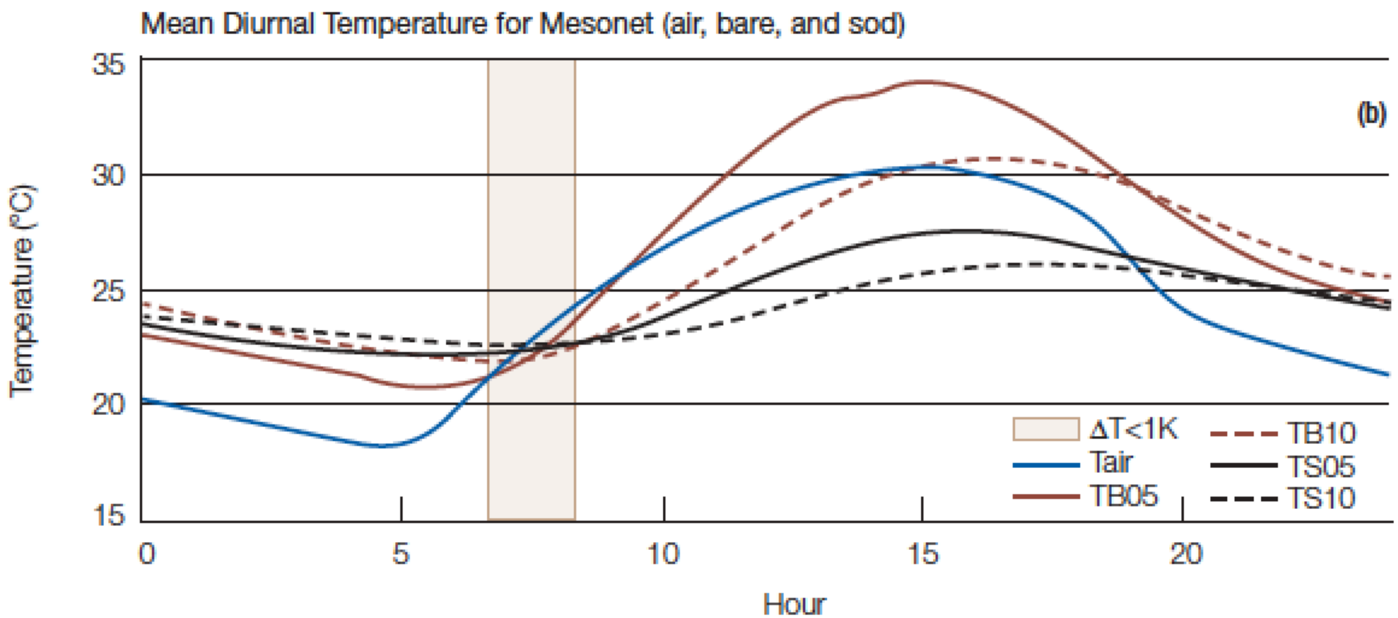


Figure 32. Soil temperature as a function of time based on June 2004 Oklahoma Mesonet data: (a) vertical profiles for a sod-covered site and (b) the mean soil temperatures for bare soil (TB05 at 5 cm below the surface, TB10 at 10 cm below the surface), and sod (TS05, TS10). The shaded region identifies the period of the day when these effects result in less than 1 °C difference among the four temperatures (T. Holmes, personal communication).

(SMAP Handboo

Passive Microwave Remote-Sensing: Tau-omega model

Vegetation

$$T_B = T_s e_s \exp\left(-\boxed{\tau}\right) + \boxed{T_c}(1-\boxed{\omega})(1-\exp(-\boxed{\tau})) + \boxed{T_c}\rho_s \exp(-\boxed{\tau})(1-\boxed{\omega})(1-\exp(-\boxed{\tau}))$$

τ Vegetation opacity

τ =b*VWC*secθ

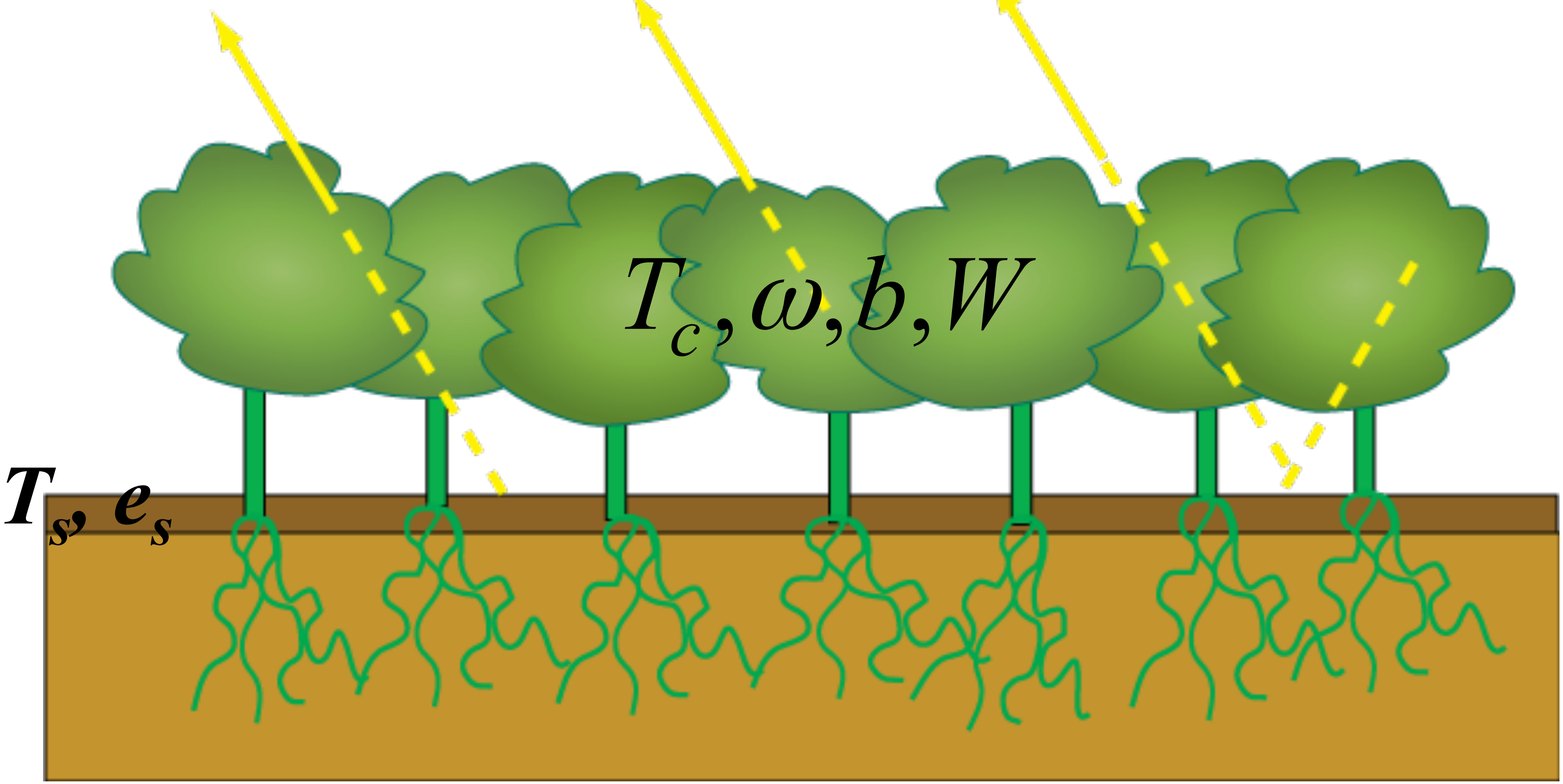
b depends on vegetation type, frequency & polarization

VWC is vegetation water content

ω Vegetation single scattering albedo ≈ 0

Passive Microwave Remote-Sensing: Tau-omega model

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



Passive Microwave Remote-Sensing: Tau-omega model

Surface heterogeneity

Forest

Different crops

Urban areas

Open water

Irrigated agriculture

Snow

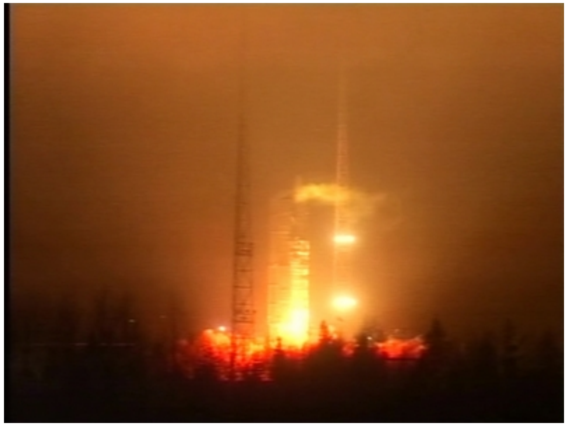
Passive Microwave Remote-Sensing: Ancillary data

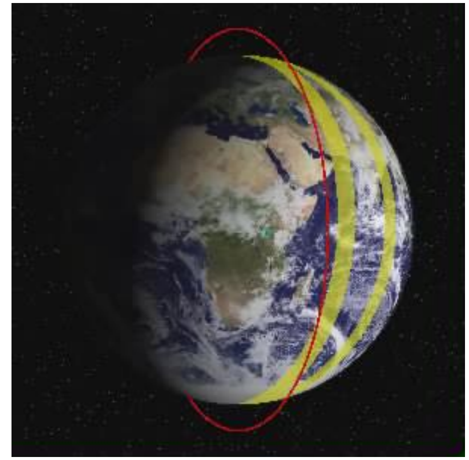
Static
- Land/water/forest/urban/mountain mask
- Elevation
- Slope
- Permanent water fraction
- Soil texture (sand/clay fraction)

Dynamic
- Land cover
- Surface roughness
- Precipitation
- Vegetation parameters
- Effective soil temperatures

Parameters of tau-omega model
Flags

SMOS mission



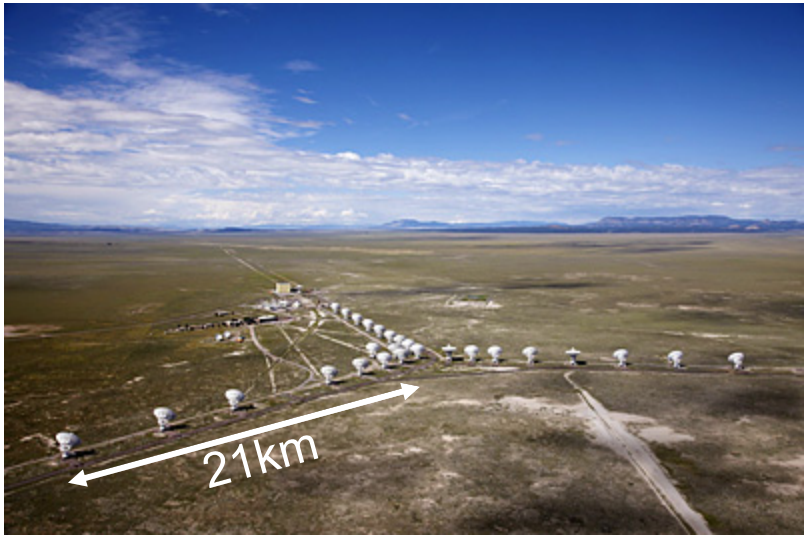


Launched	2 November 2009
Duration	Minimum 3 years
Frequency	L-band (21 cm-1.4 GHz)
Spatial resolution	35 km at centre of FOV
Radiometric resolution	0.8 - 2.2 K
Angular range	0-55 degrees
Temporal resolution	3 days revisit at Equator

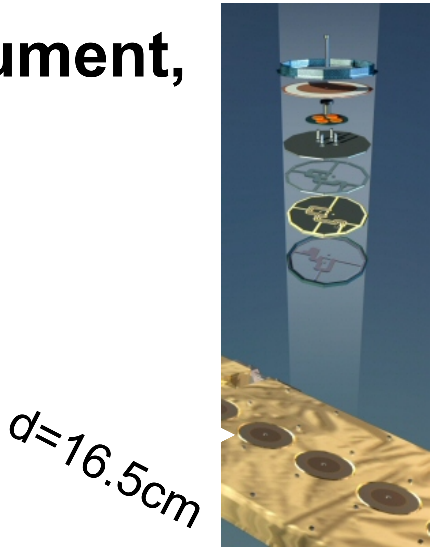
Sun-synchronous, dawn/dusk, at altitude 758 km. 06.00 hrs local solar time at ascending node.

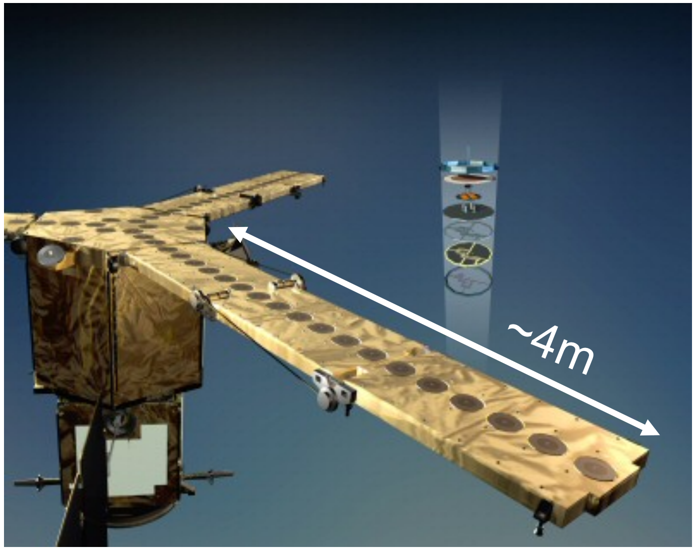
Passive Microwave Remote-Sensing: SMOS

"Very Large Array", New Mexico



MIRAS instrument, SMOS





Passive Microwave Remote-Sensing: SMOS

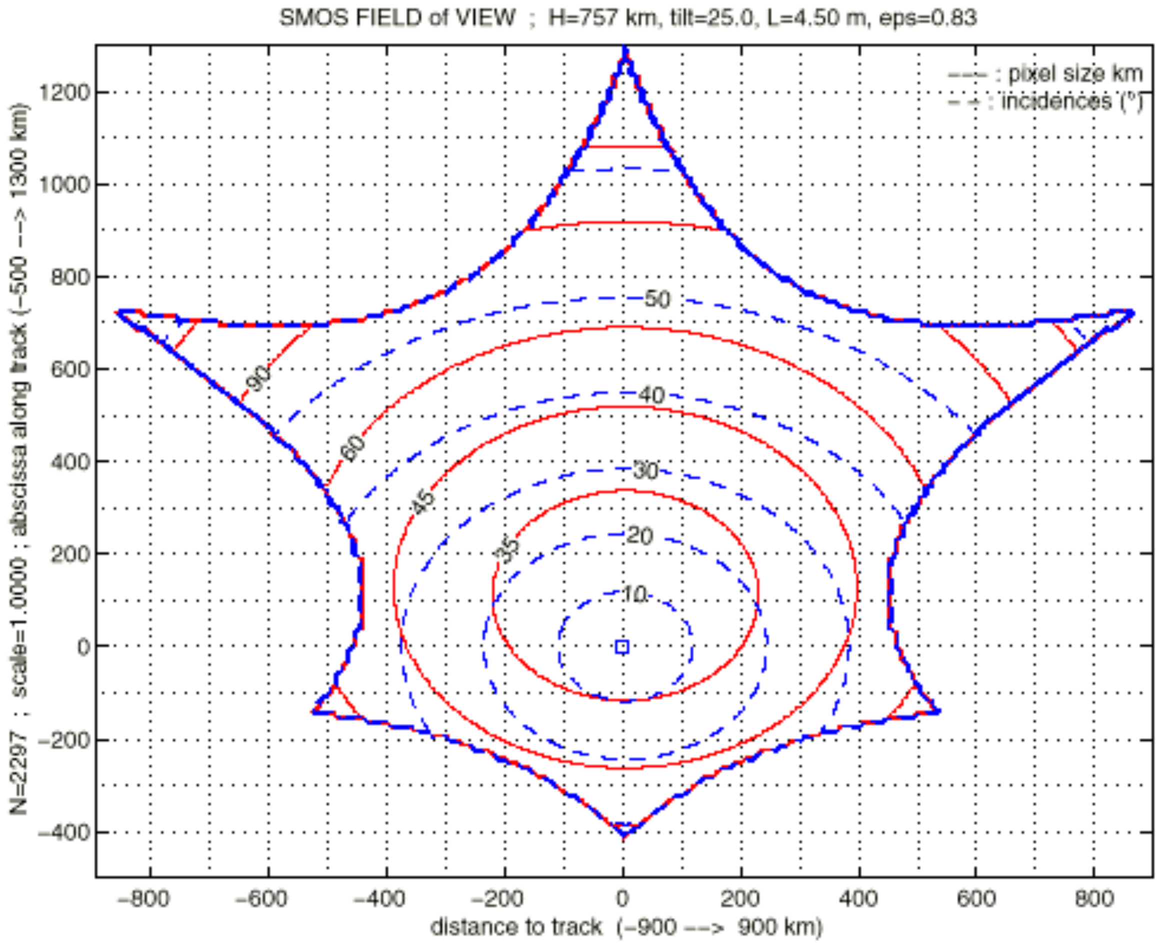
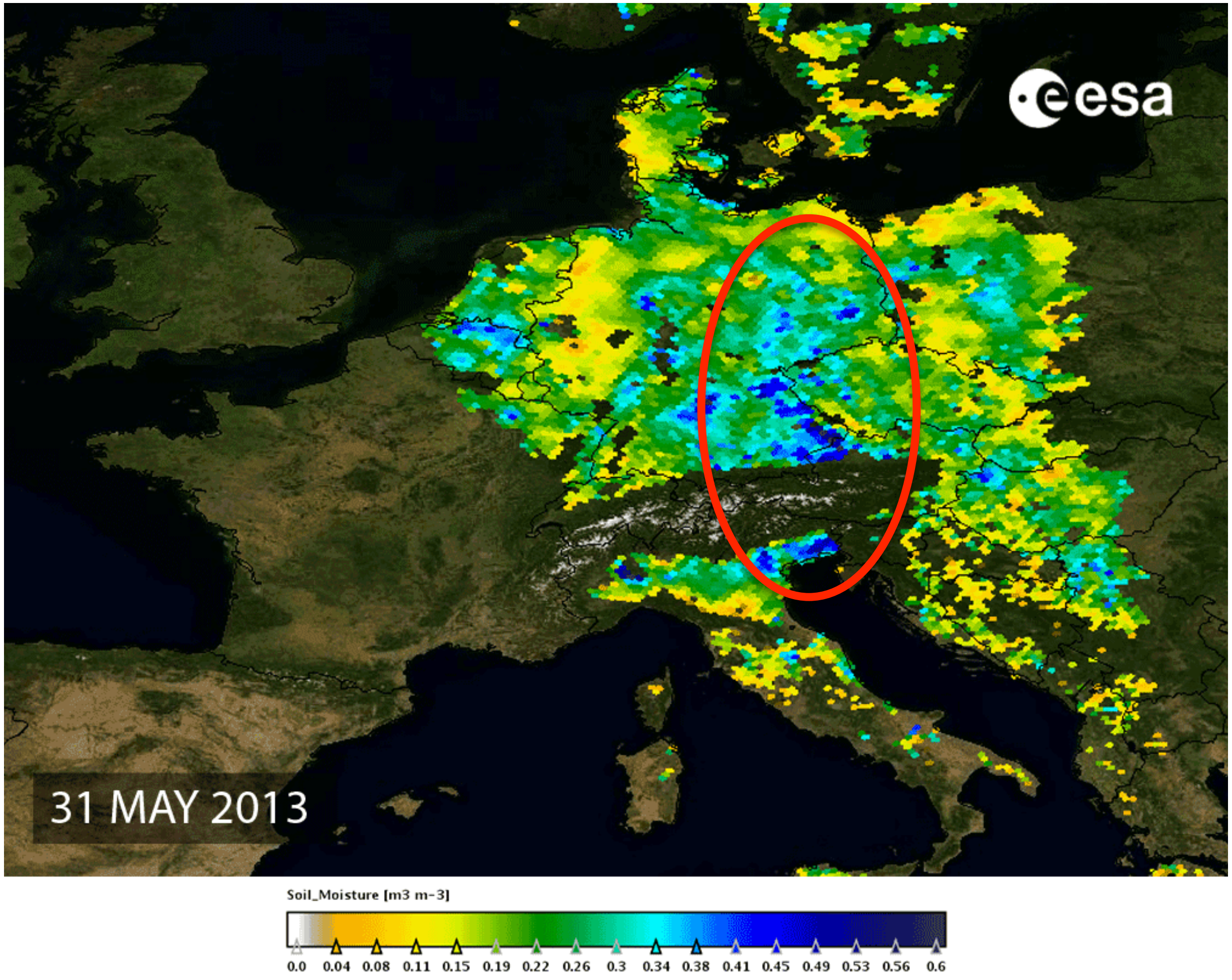


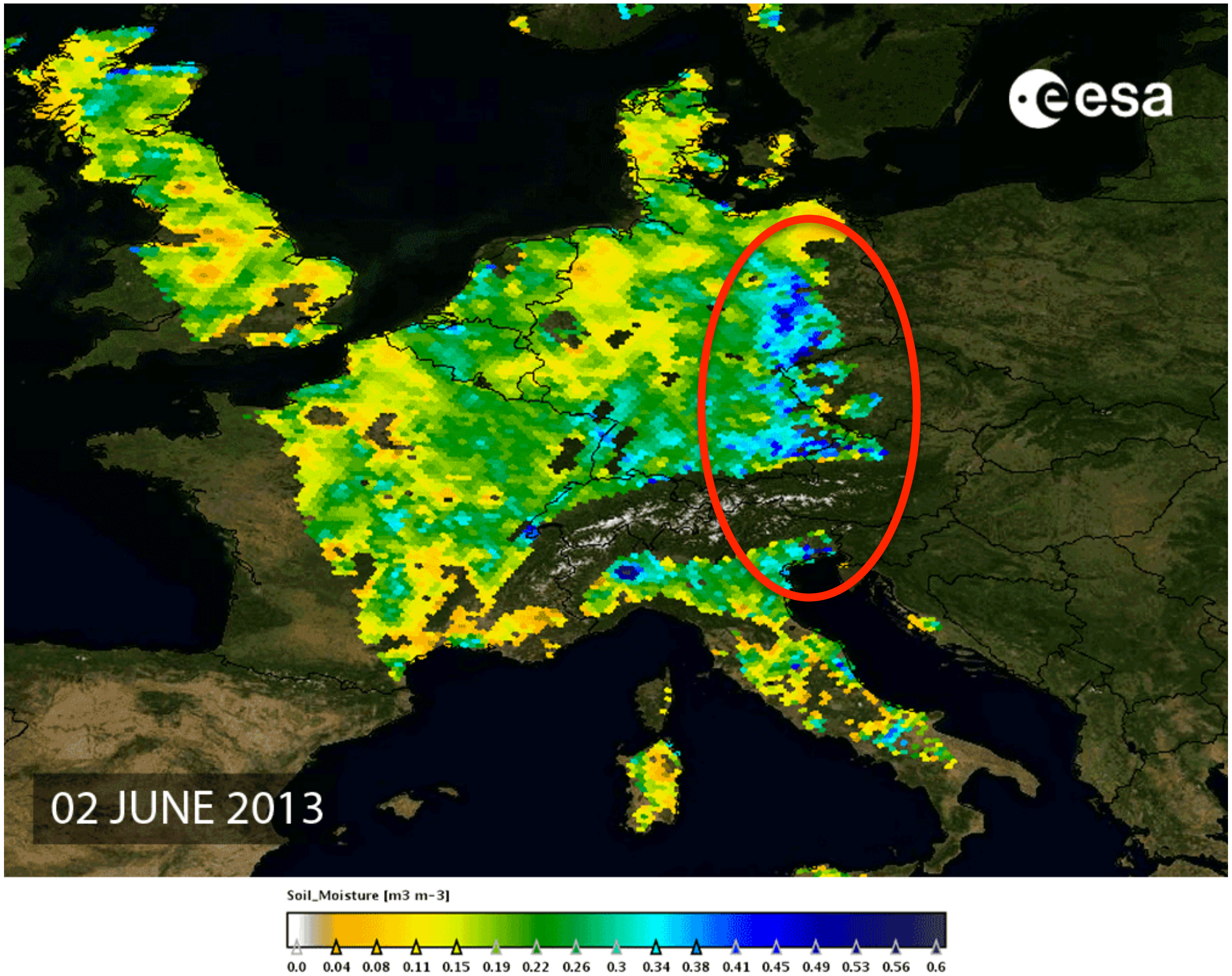
Figure 212-1: SMOS FOV for configuration parameters specified in the title. Contours of equal incidence angle and ground resolution are indicated. The subsatellite point H is shown by a square. The angular resolution Dq was taken equal to 0.8 x l / r (l=wavelength, r = length of antenna arms), which is on the pessimistic side.

Monitoring soil moisture with SMOS



http://www.esa.int/spaceinimages/Images/2013/06/Soil_moisture_from_SMOS

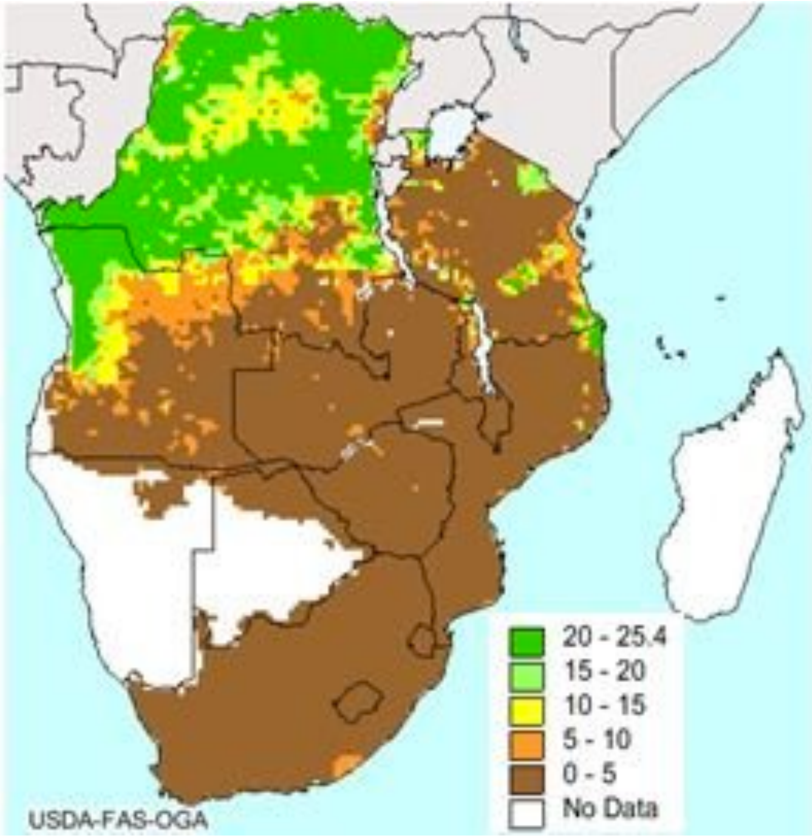
Monitoring soil moisture with SMOS

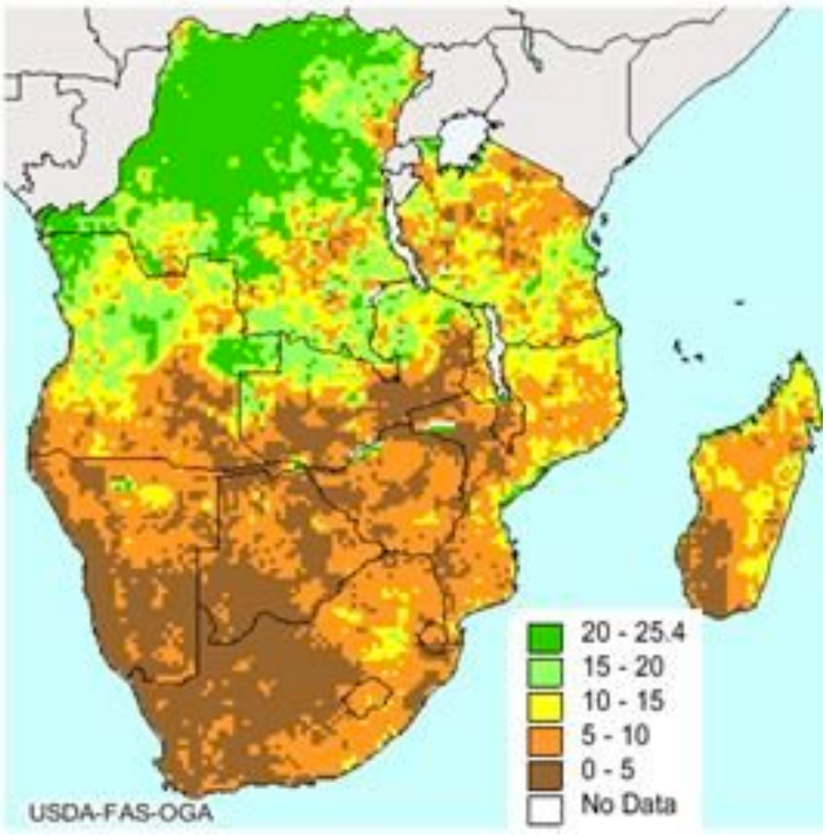


http://www.esa.int/spaceinimages/Images/2013/06/Soil_moisture_from_SMOS

SMOS boosts soil moisture mapping

Soil moisture in southern Africa in mid-April 2014.



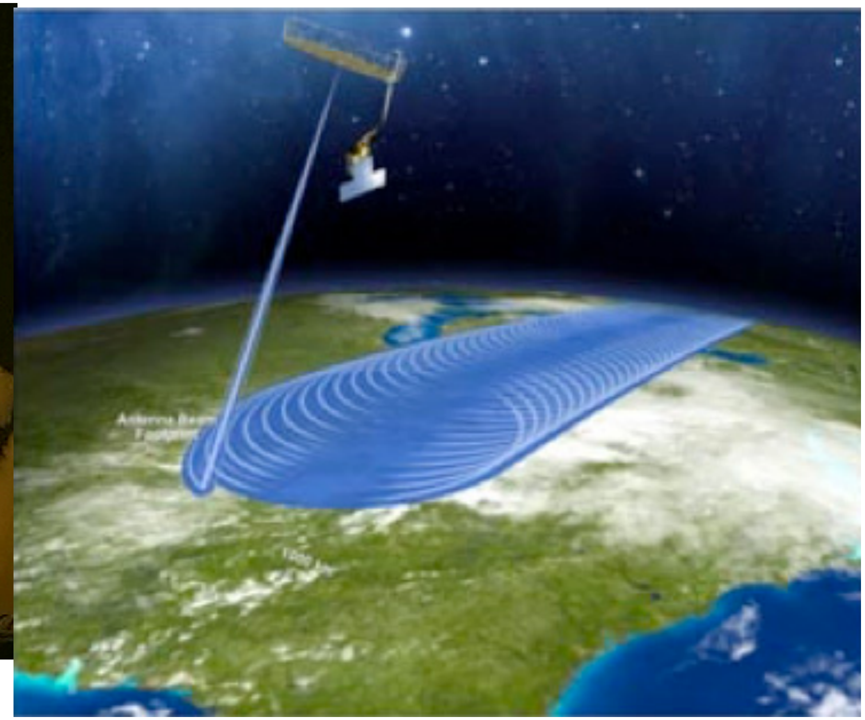


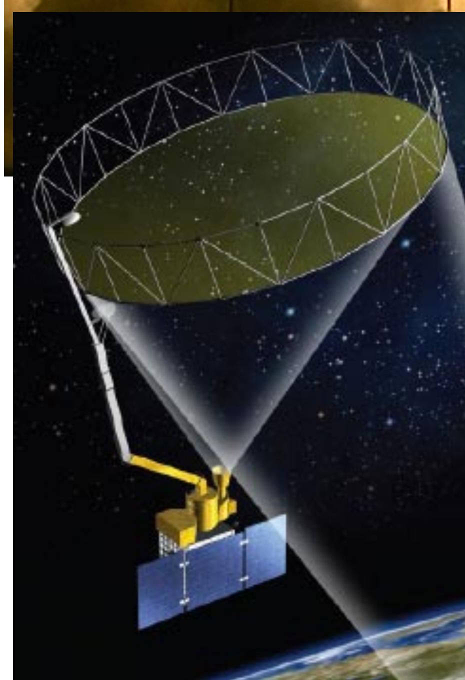
Rain gauges only

Includes SMOS ***assimilation***

http://www.esa.int/spaceinimages/Images/2014/05/SMOS_boosts_soil_moisture_mapping

NASA's Soil Moisture Active Passive (SMAP)

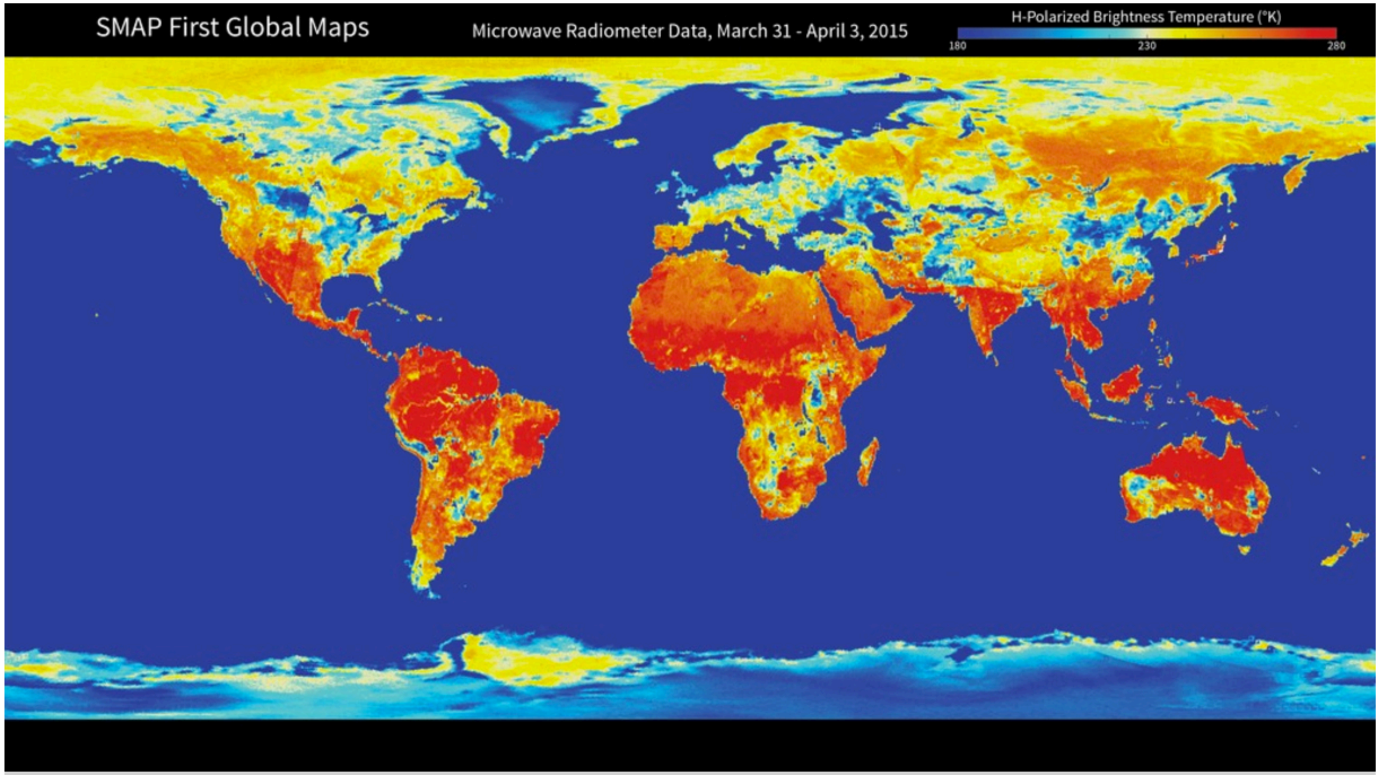




- Launched 31 January 2015
- Duration >3 years
- Frequency 1.4GHz (radiometer), 1.21GHz (radar)
- Incidence angle (40 deg)
- Temporal resolution (3 days at equator)
- Revisit time: 6AM/6PM

NASA Soil Moisture Mission Produces First Global Maps

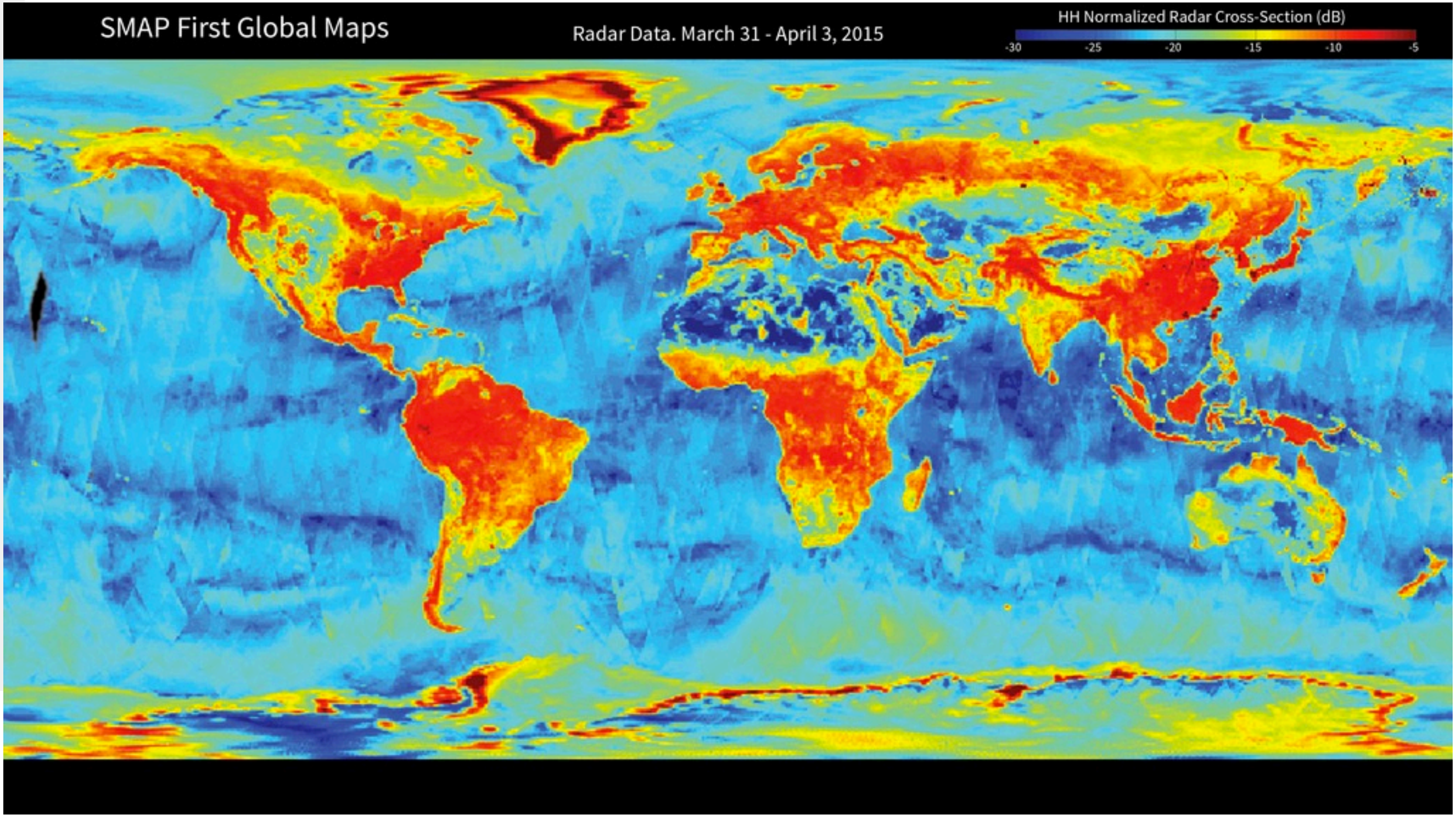
on April 21, 2015



https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=30596

NASA Soil Moisture Mission Produces First Global Maps

on April 21, 2015



https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=30596

NEWS I July 10, 2015

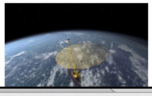
SMAP Team Investigating Radar Instrument Anomaly

Updated - Aug. 5, 2015 at 2 p.m. PDT / 5 p.m. EDT

The JPL SMAP mission team continues to troubleshoot the anomaly that occurred on SMAP's radar instrument on July 7. The radar remains in safe mode. SMAP's radiometer instrument continues to operate nominally and is collecting valuable science data.

De
vol
bo
Ea
ins
po

Featured Resources



SMAP GLOBE program

smap.jpl.nasa.gov/news/1247/

Jet Propulsion Laboratory
California Institute of Technology

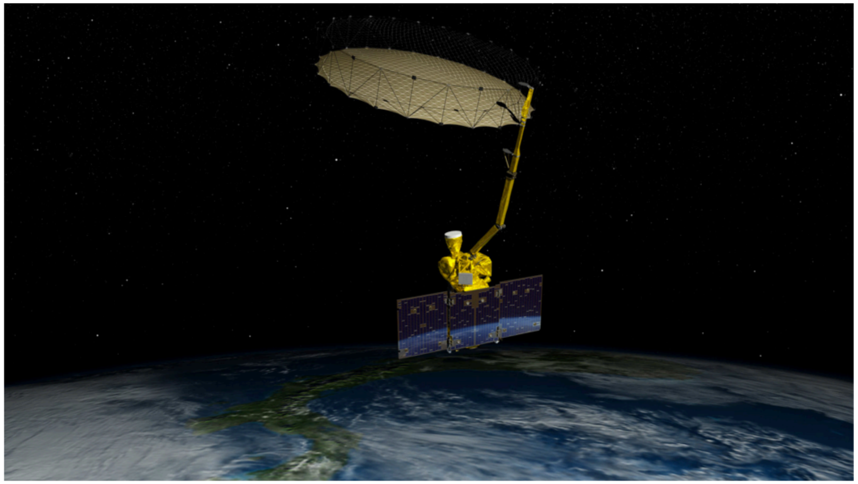
SMAP SOIL MOISTURE ACTIVE PASSIVE

search

Mission Observatory Science Data Multimedia Education News & Events

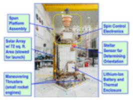
NEWS I September 2, 2015

NASA Soil Moisture Radar Ends Operations, Mission Science Continues

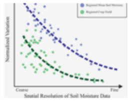


NASA's Soil Moisture Active Passive (SMAP) mission is producing high-quality global maps of soil moisture to track water availability around our planet and guide policy decisions. Credit: NASA/JPL-Caltech

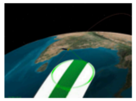
Featured Resources



SMAP Observatory Labeled 2



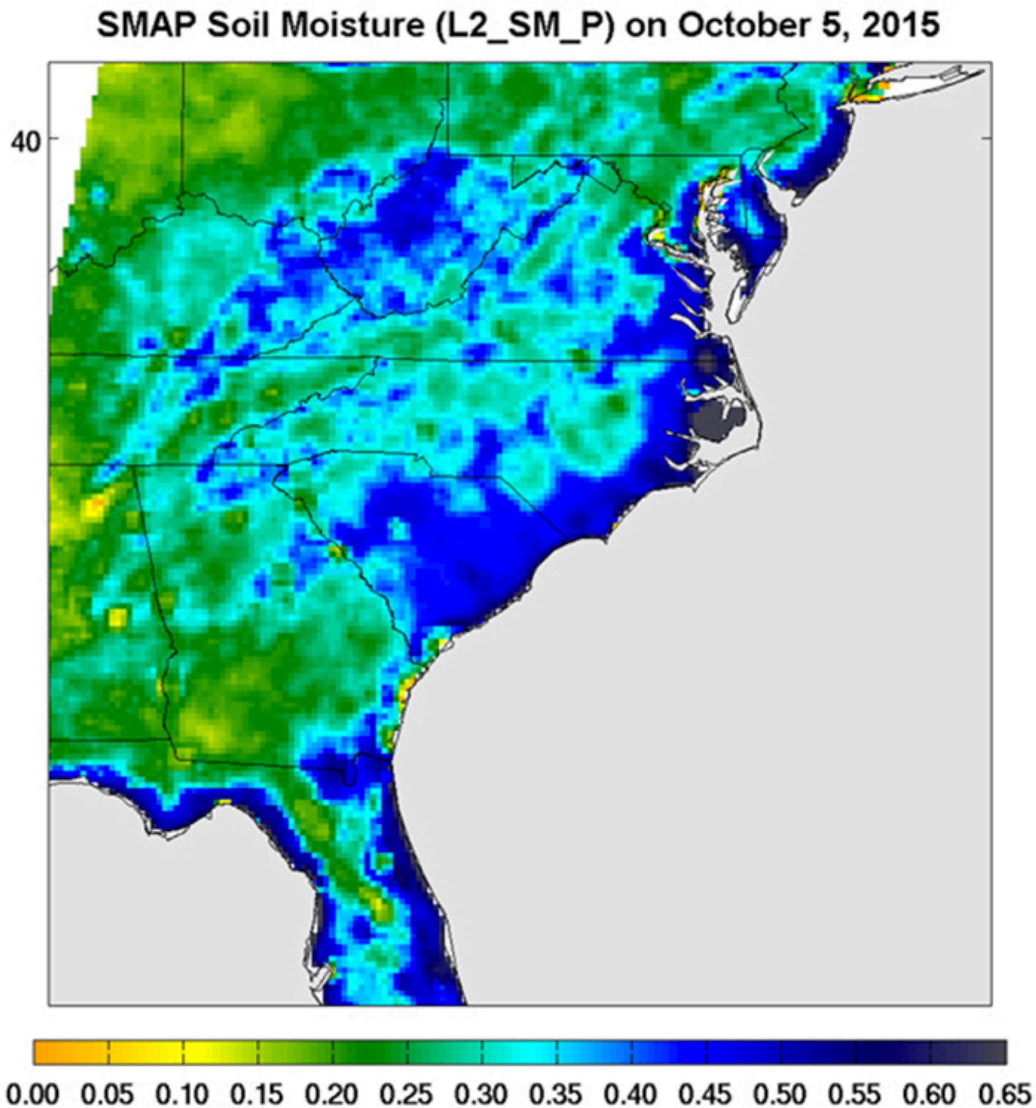
Graph of Variation of Domain-Averaged Soil Moisture



Swath Path 1

› more resources

Devastating Carolina Floods Viewed by SMAP

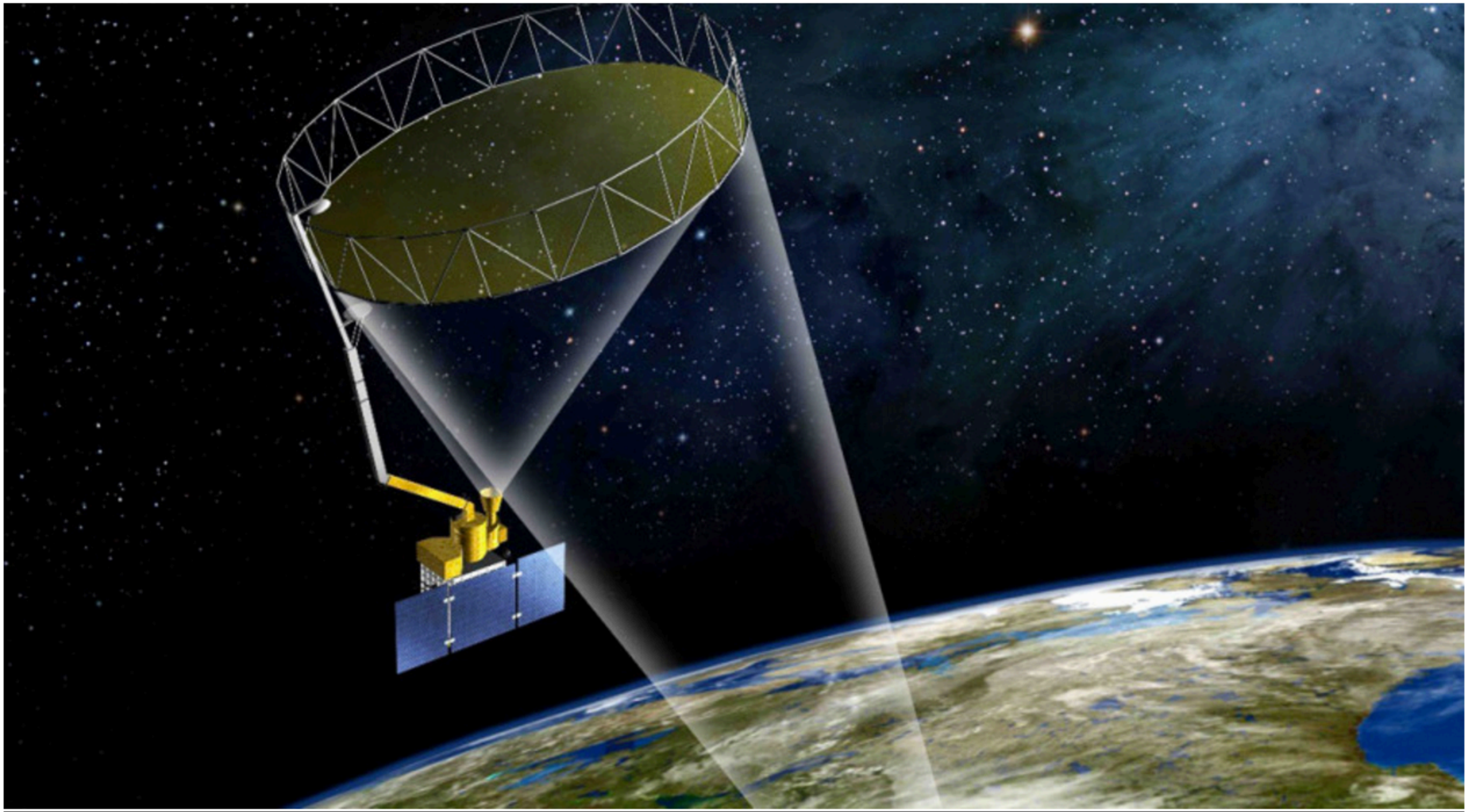


- 17 deaths
- 1000-year storm
- 14 dams failed
- Large-scale flooding

http://www.jpl.nasa.gov/spaceimages/details.php?id=pia20001

NASA Focused on Sentinel as Replacement for SMAP Radar

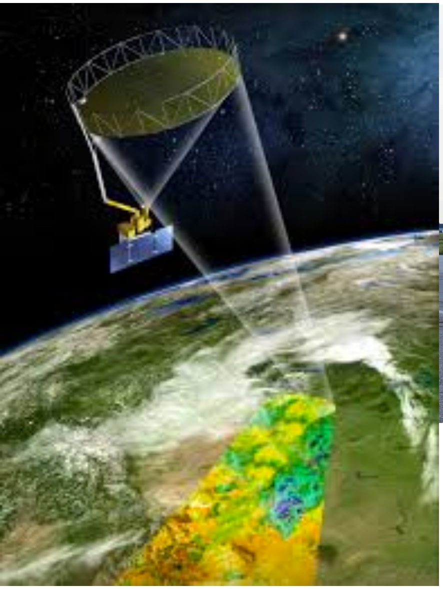
by **Dan Leone** — November 27, 2015



Sentinel's C-band radar is not the only radar flying in space — or even the closest substitute for the lost SMAP L-band radar — but it is the only one that will trail SMAP (artist's concept above) closely enough to gather timely radar images of the swath of Earth SMAP covers. Credit: NASA

http://spacenews.com/nasa-focused-on-sentinel-as-replacement-for-smap-radar/

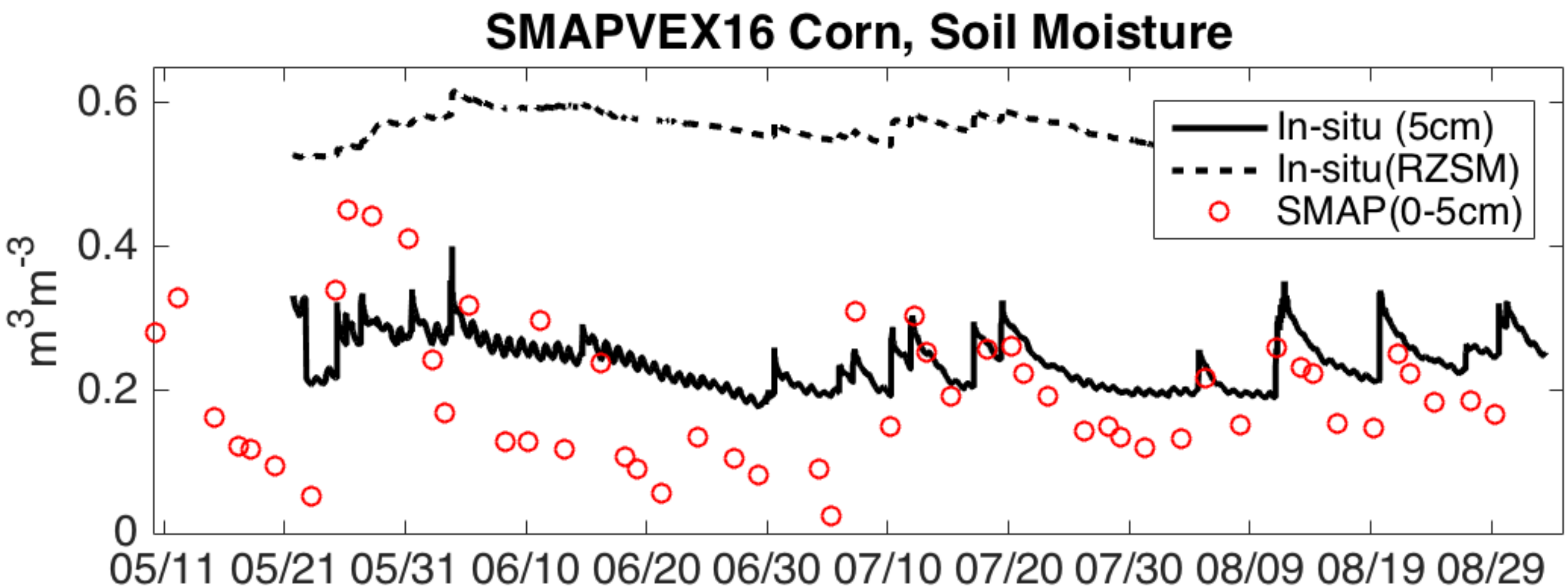
TU Delft @ SMAPVEX16!

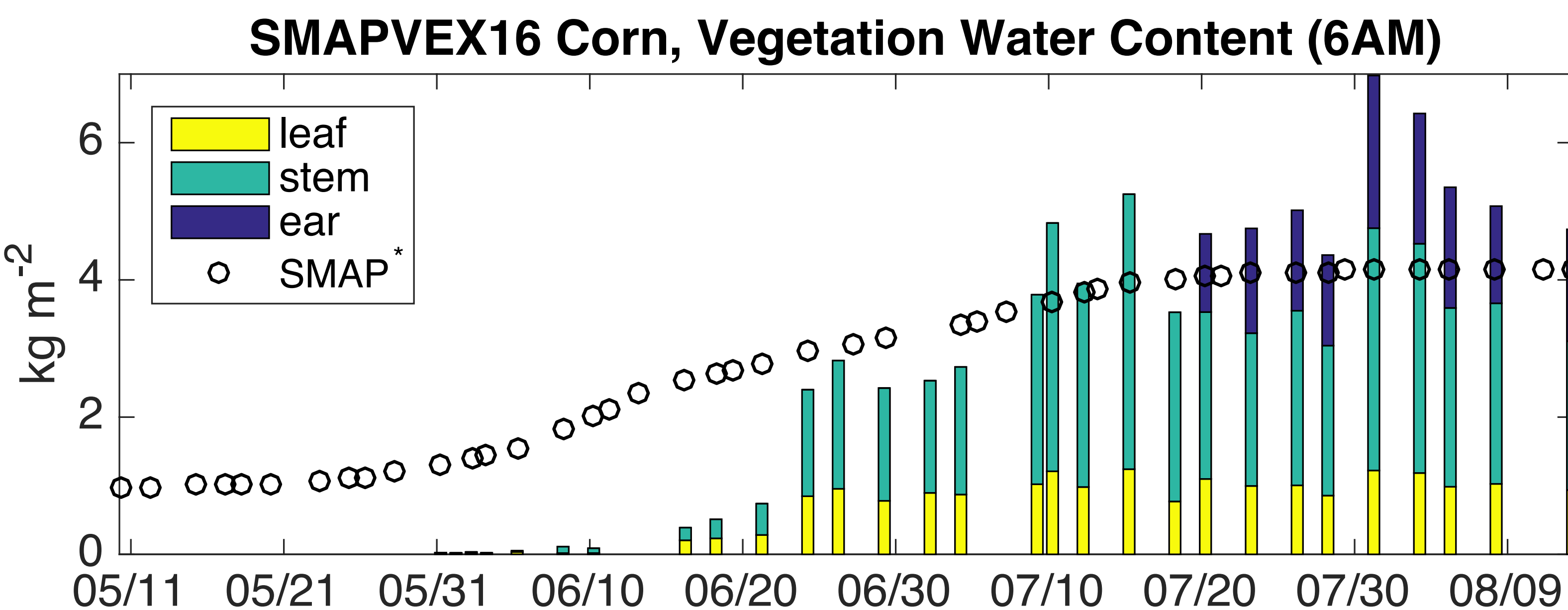






TU Delft @ SMAPVEX16!





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

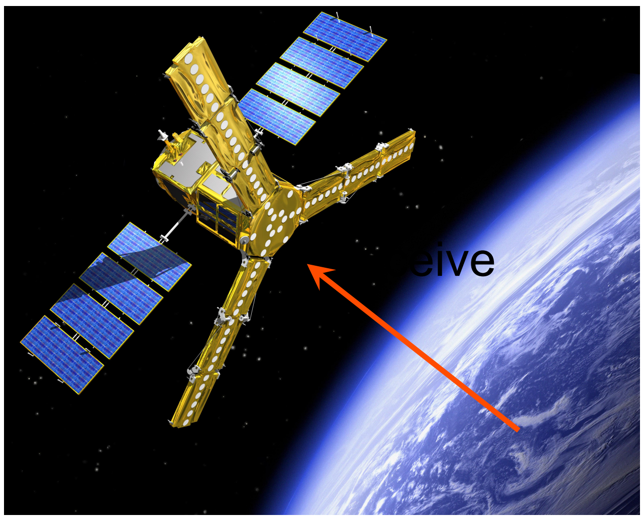
3) Describe how active microwave remote sensing can used to estimate water levels, soil moisture and address many problems in water resources management

Remote-sensing techniques

Passive

Employ natural sources of energy,

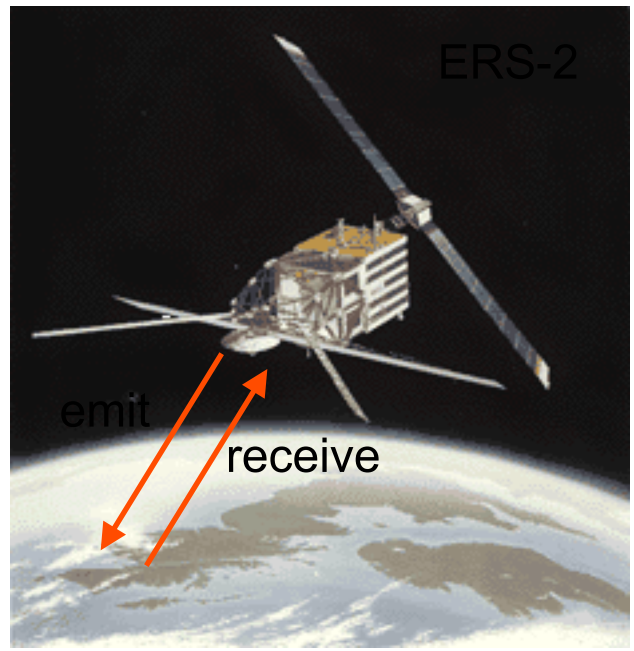
e.g. the sun (optical) or the earth itself (MW).



Active

Have their own source of energy.

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



Active Microwave Sensor types

Non-imaging radar sensors

Take measurements in one linear dimension.

Examples:
1) radar altimeters
(measure distance)

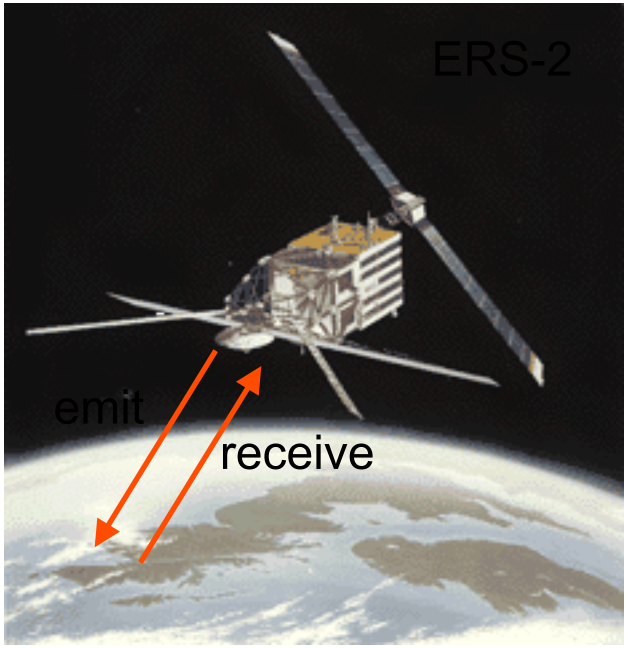
2) scatterometers
(measure surface properties)

Imaging radar sensors

Take two-dimensional measurements.

Examples:
1) Real aperture radar (RAR)

2) Synthetic aperture radar (SAR)

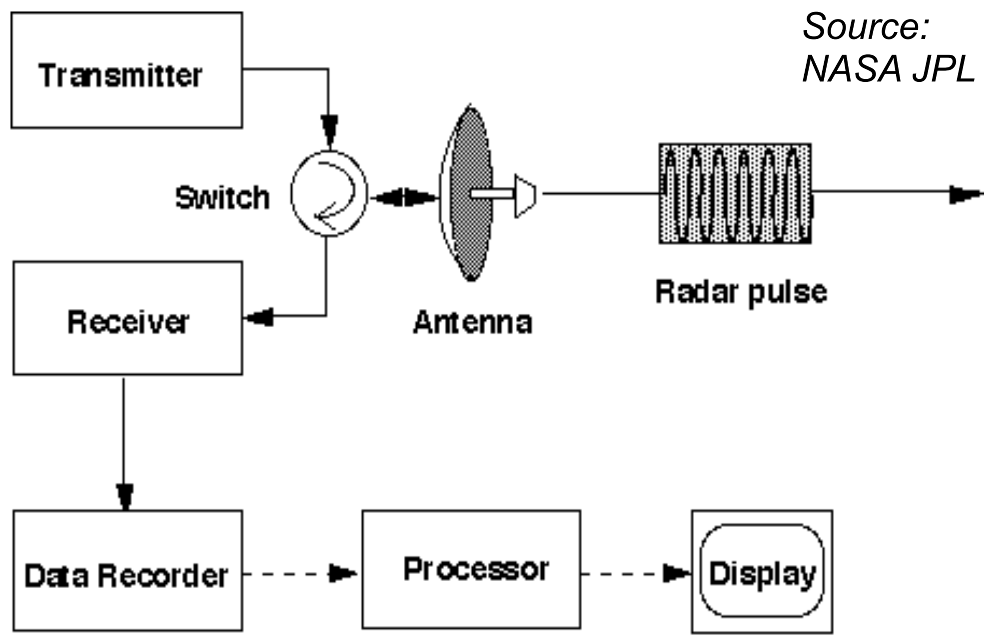


Components of a radar system

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

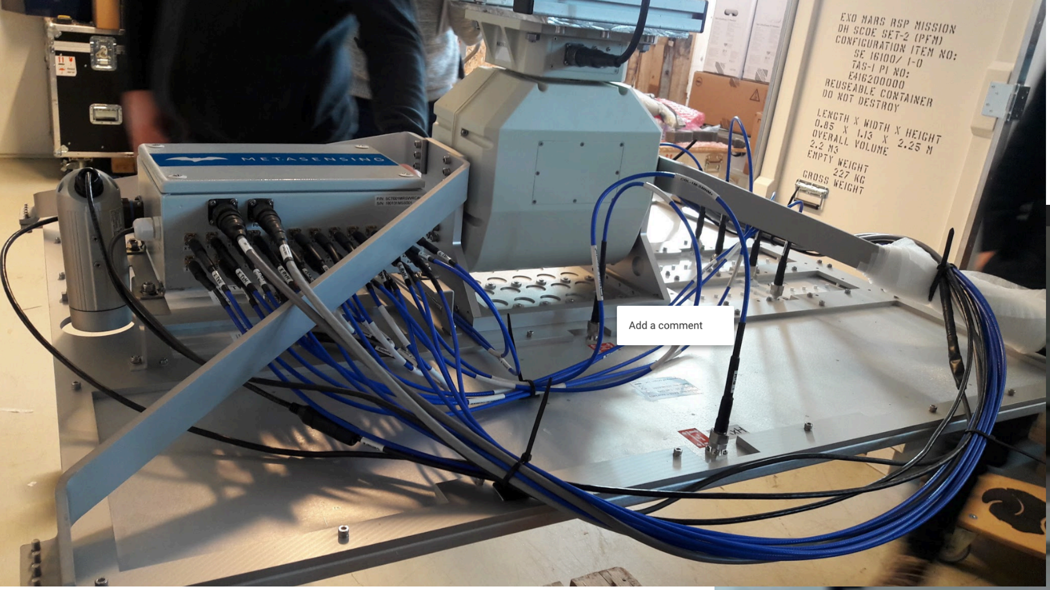


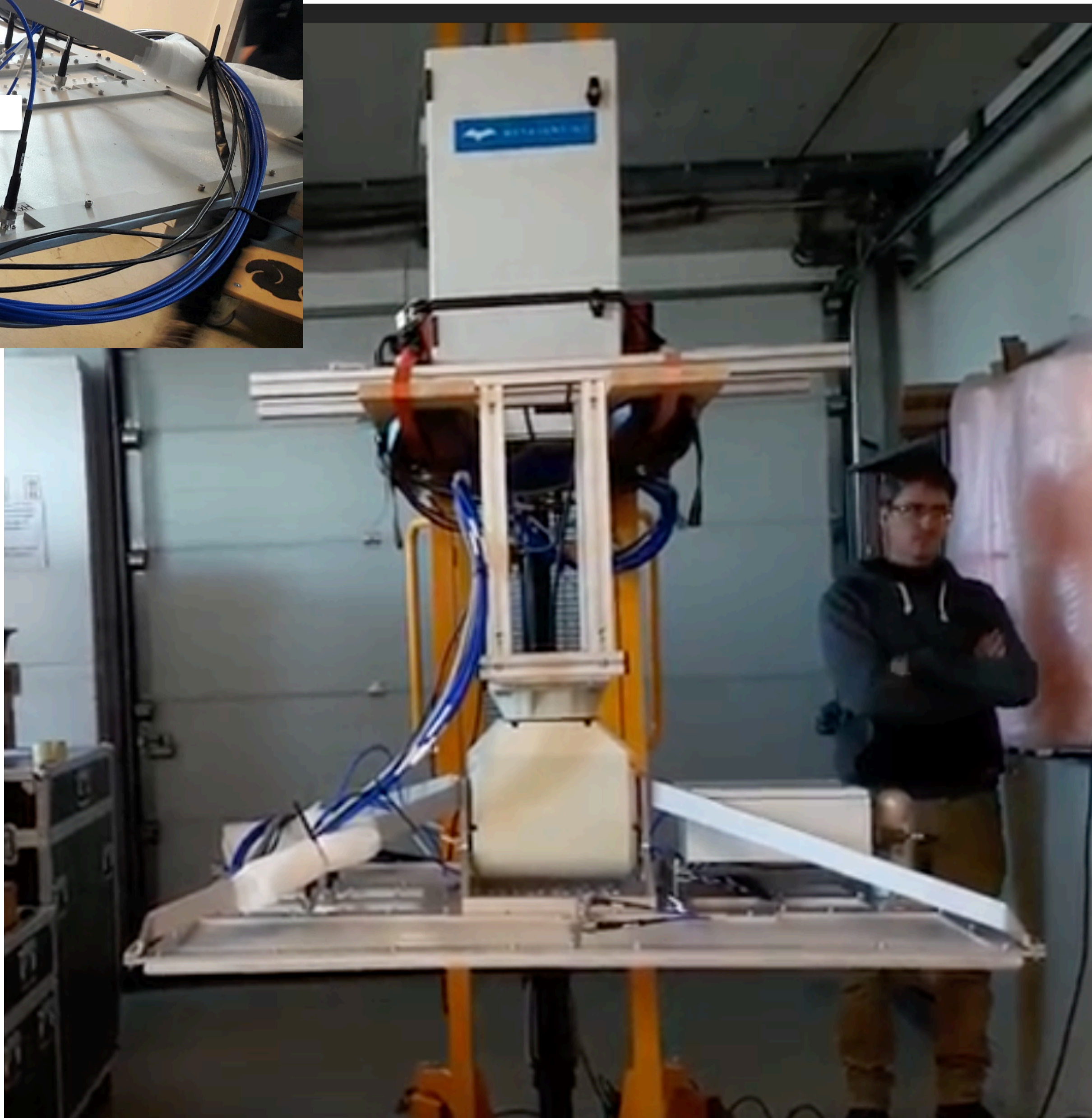
Source: NASA JPL

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

Recorder:
Stores the received signal

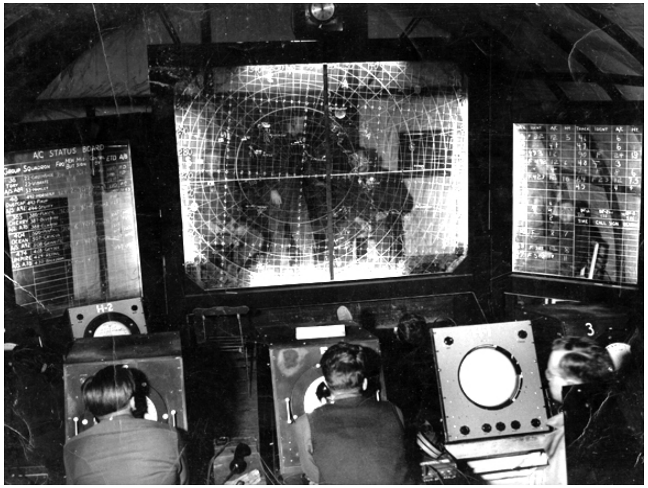
Components of a radar system





RADAR – Radio Detection And Ranging.

Radar techniques were originally developed for military applications.

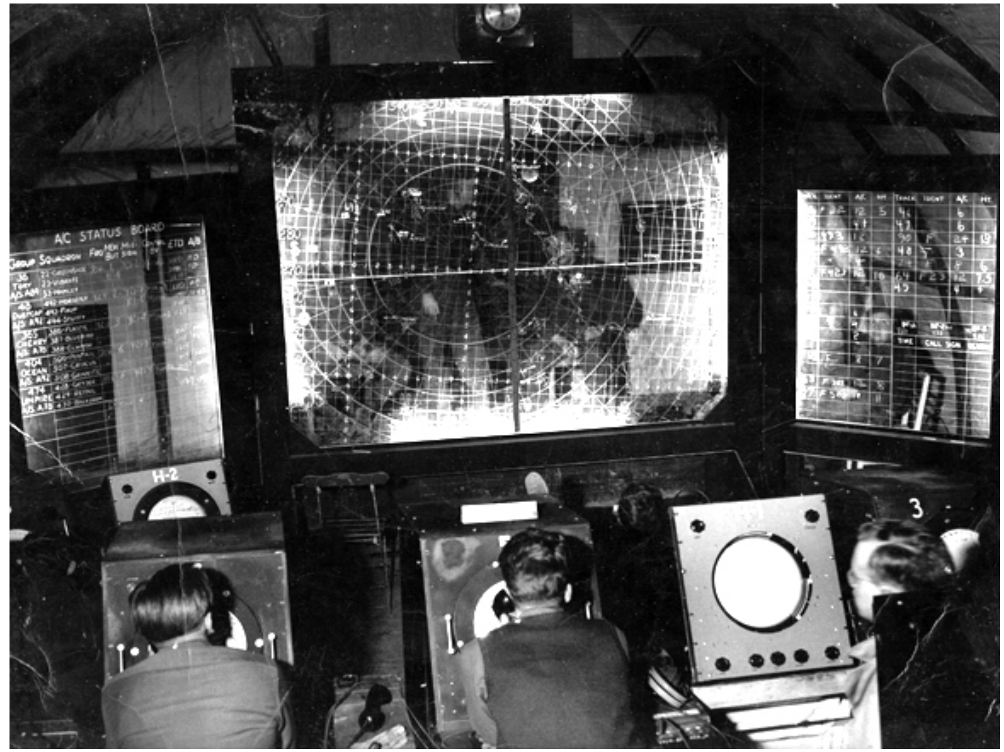


Surface search radar display found on ships

Radar tower
Heathrow airport

Radar Ranging

Developed during WWII,
to track incoming aircraft.



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

c is the speed of light in the medium
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

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

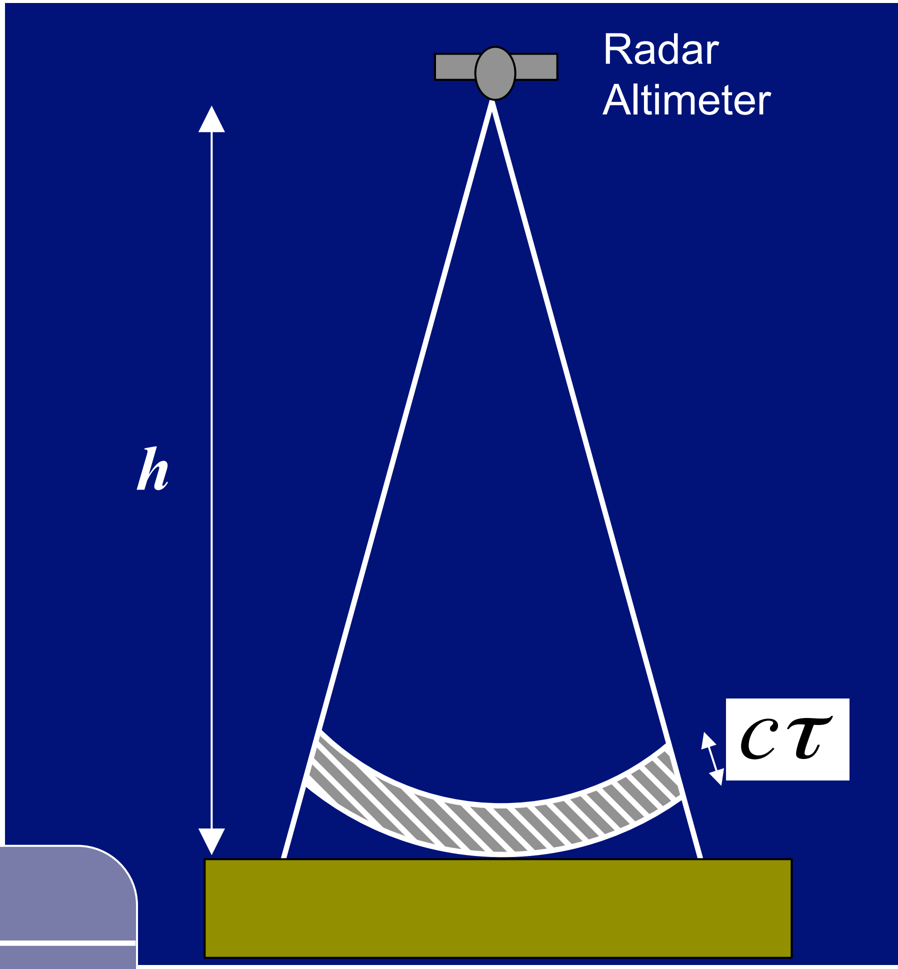
c is the speed of light in the medium
t is the time delay between transmitted and received signals

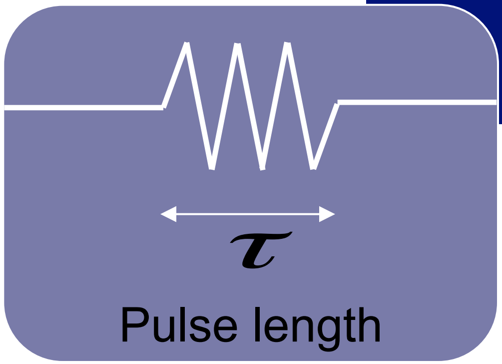
The precision with which the distance can be measured is given by:

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

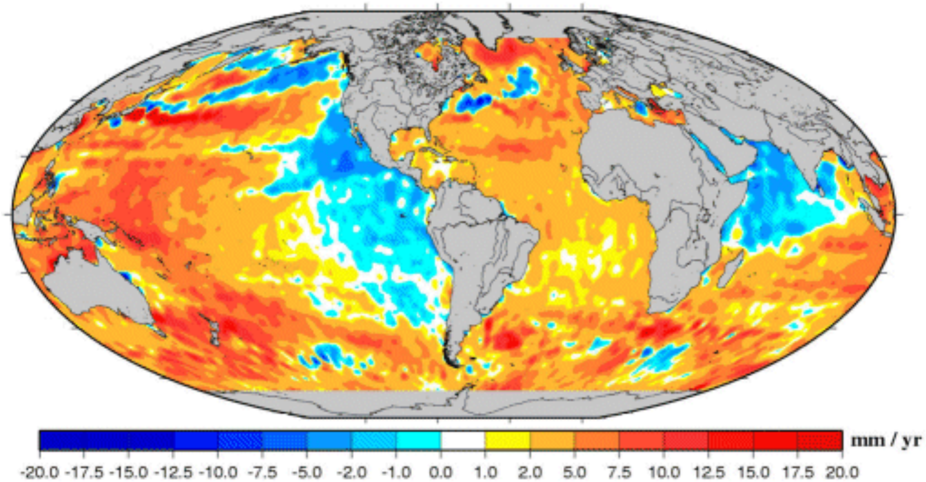
where B is the bandwidth of the pulse,

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





Mean sea level observations



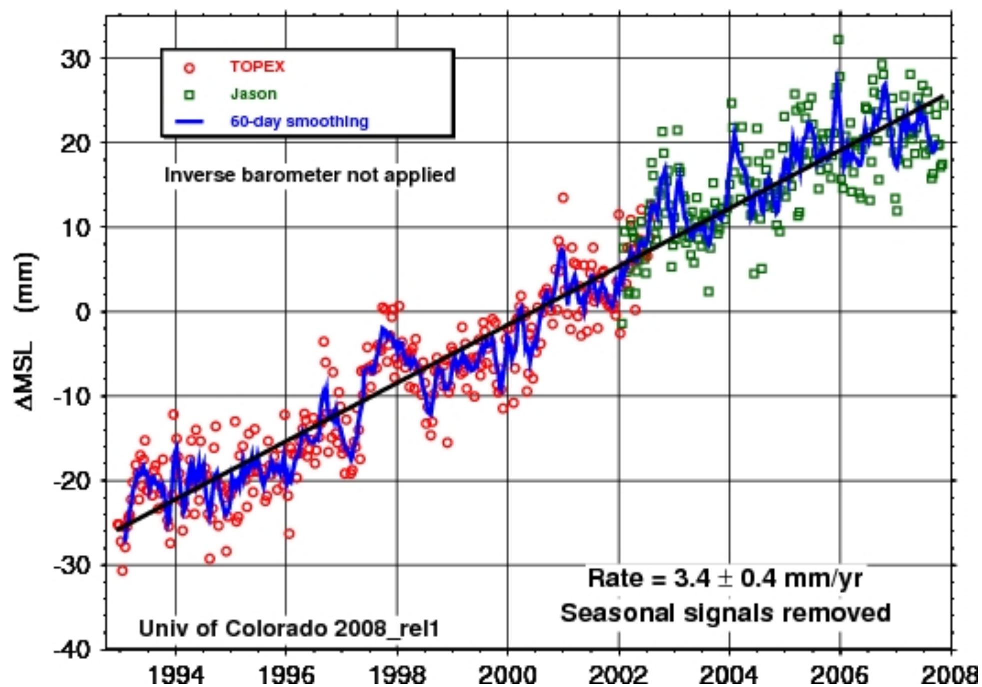
Mean Sea Level trends computed from altimetry, from January 1993 to 2005.

(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

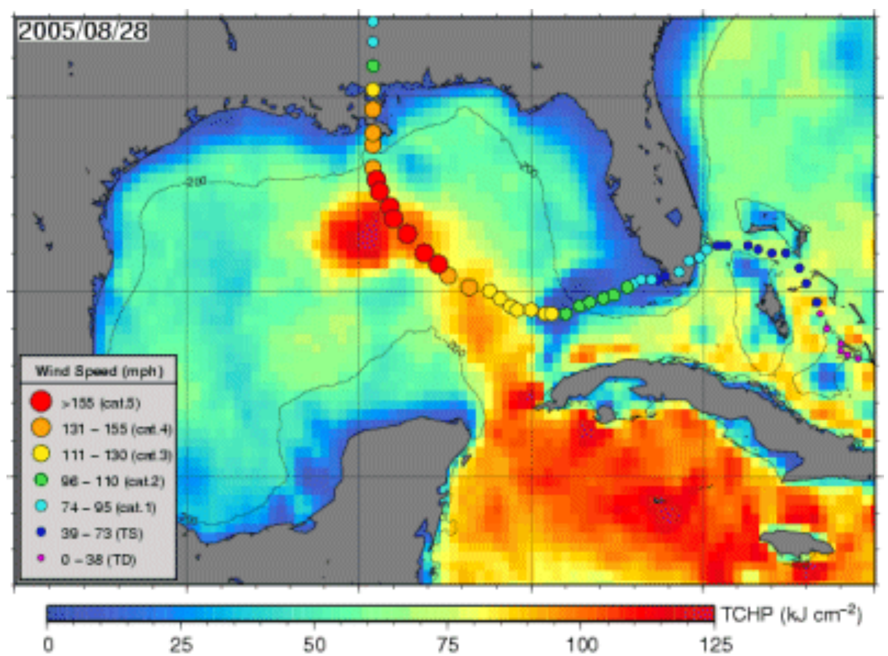
Observe with radar altimetry!

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])

Hurricane Katrina



Lake level monitoring

Lake Victoria

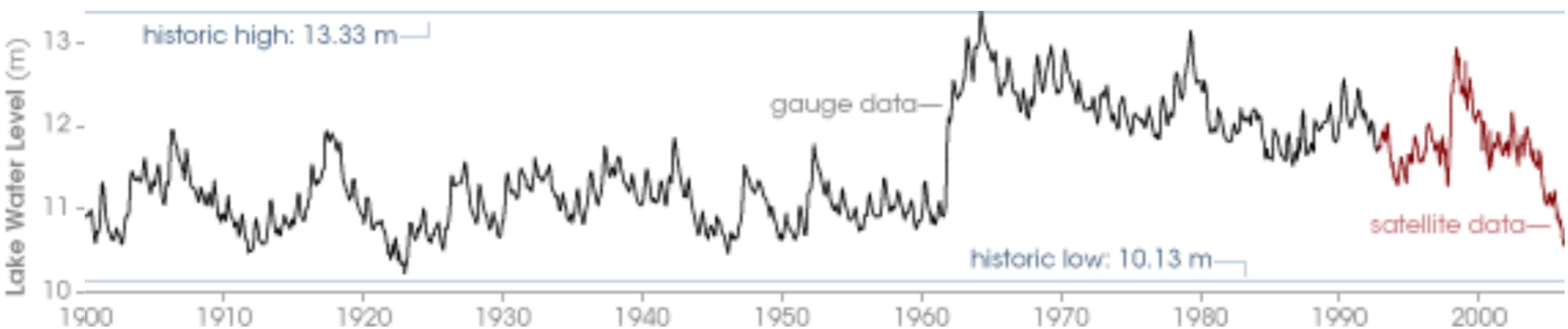
•Borders Kenya, Uganda, Tanzania

•Food, transport,energy for 30 million people

•3rd largest lake in the world

•Surface Area 68,870 km2

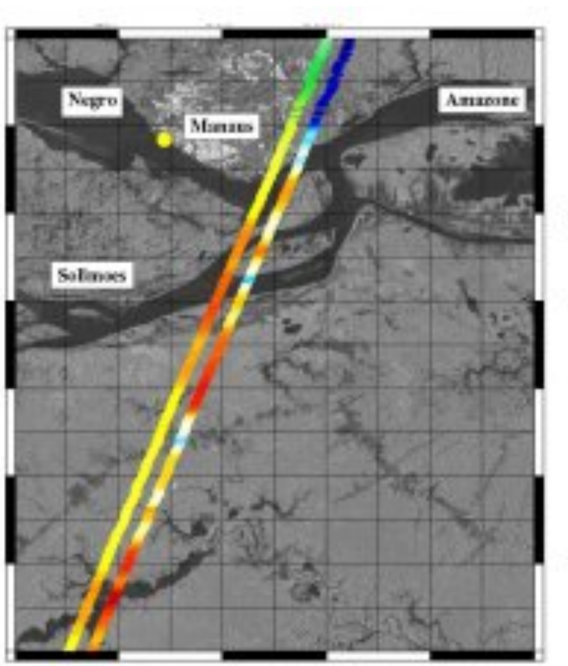
•Mean depth: 40.0 m



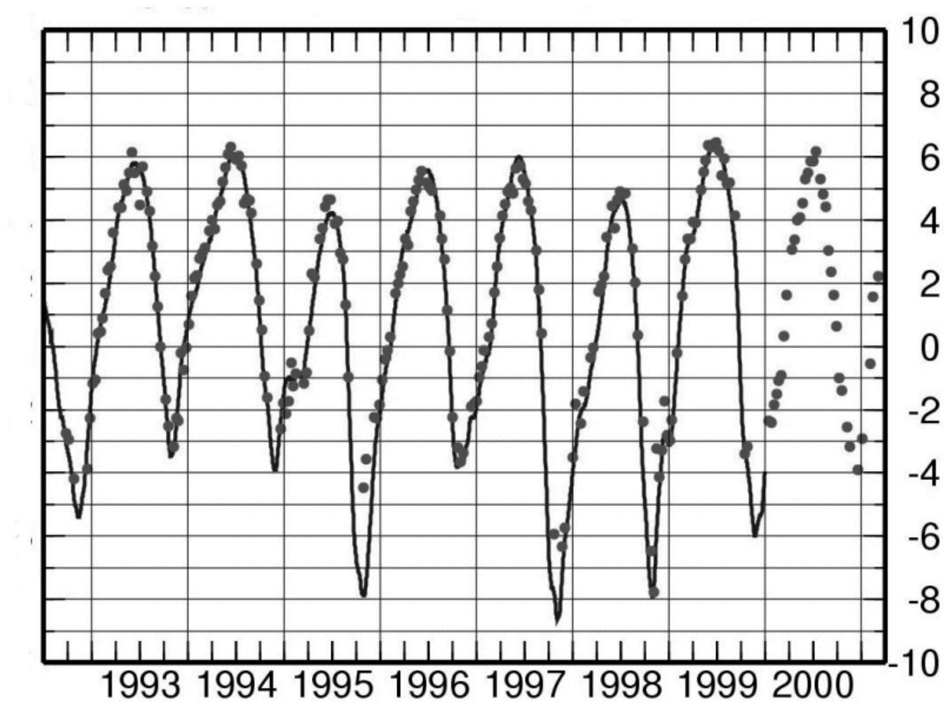
Lake level data from the TOPEX-Poseidon and Jason-1 satellites (red) augment gauge data at Jinja, Uganda (black). (Graph by Robert Simmon, based on data provided by the USDA Foreign Agricultural Service.)
Source: earthobservatory.nasa.gov

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.

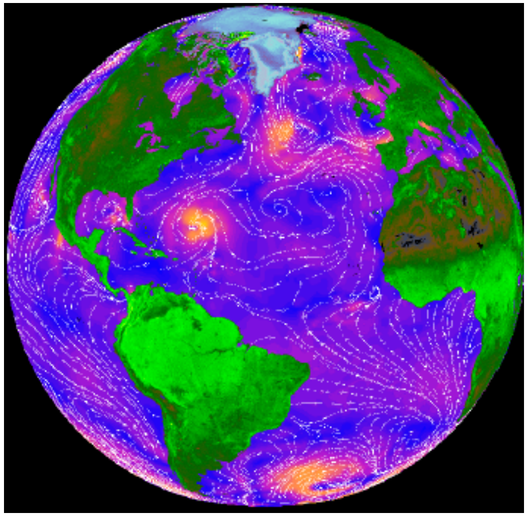
Non-Imaging Radar: Scatterometers

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.

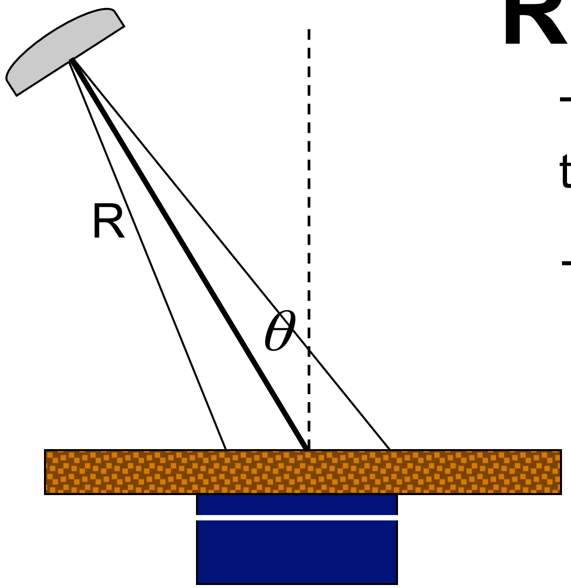
Originally developed to map wind speed and direction over oceans.

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. $G = \dfrac{\eta 4\pi A}{\lambda^2}$

λ is the wavelength

P_t is the transmitted energy

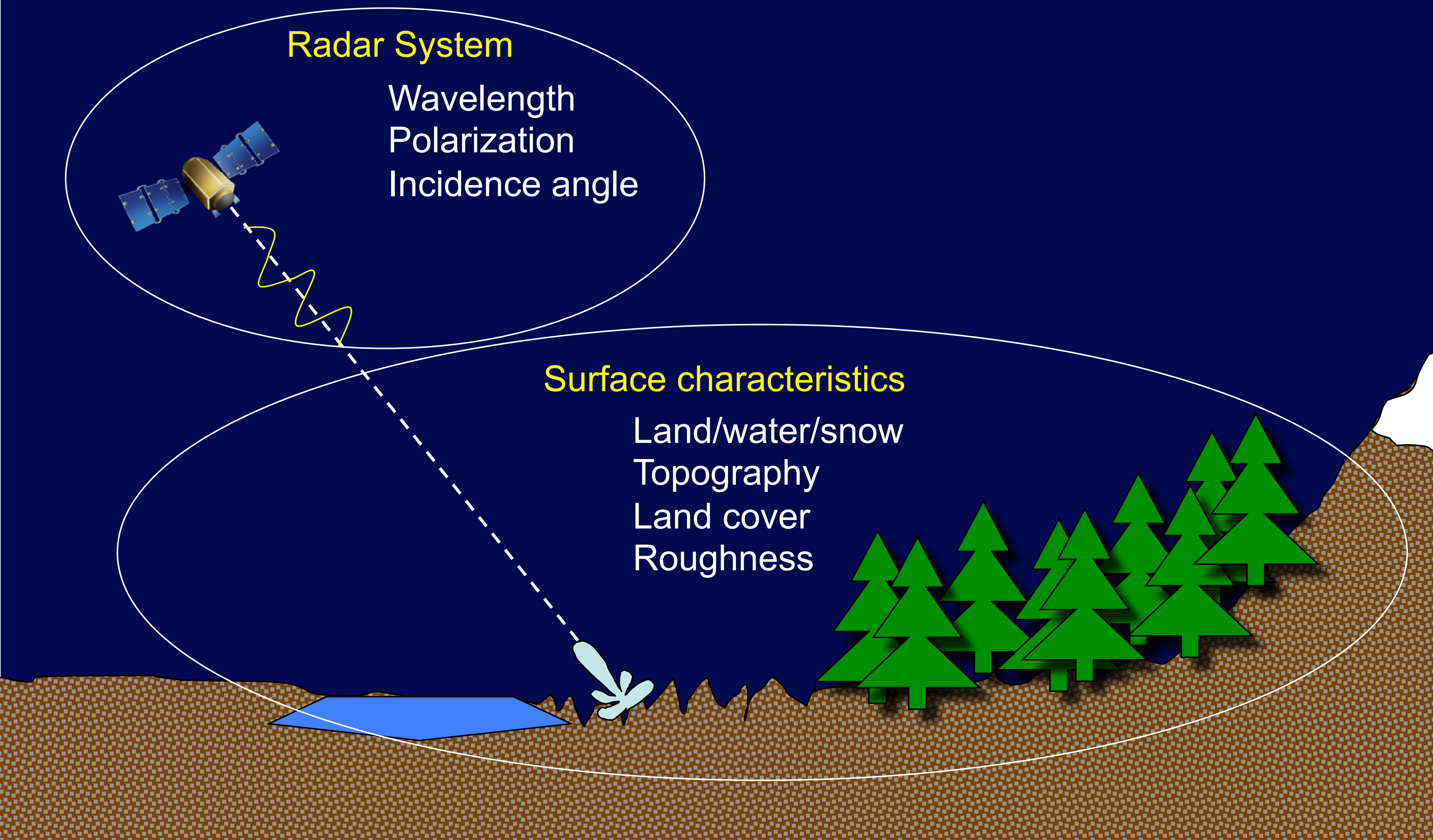
A is the area of the antenna, η is its efficiency.

Geometry
& Surface Characteristics

σ is the backscatter cross section

R is the range (distance) from the sensor to the object.

Backscatter cross section, σ



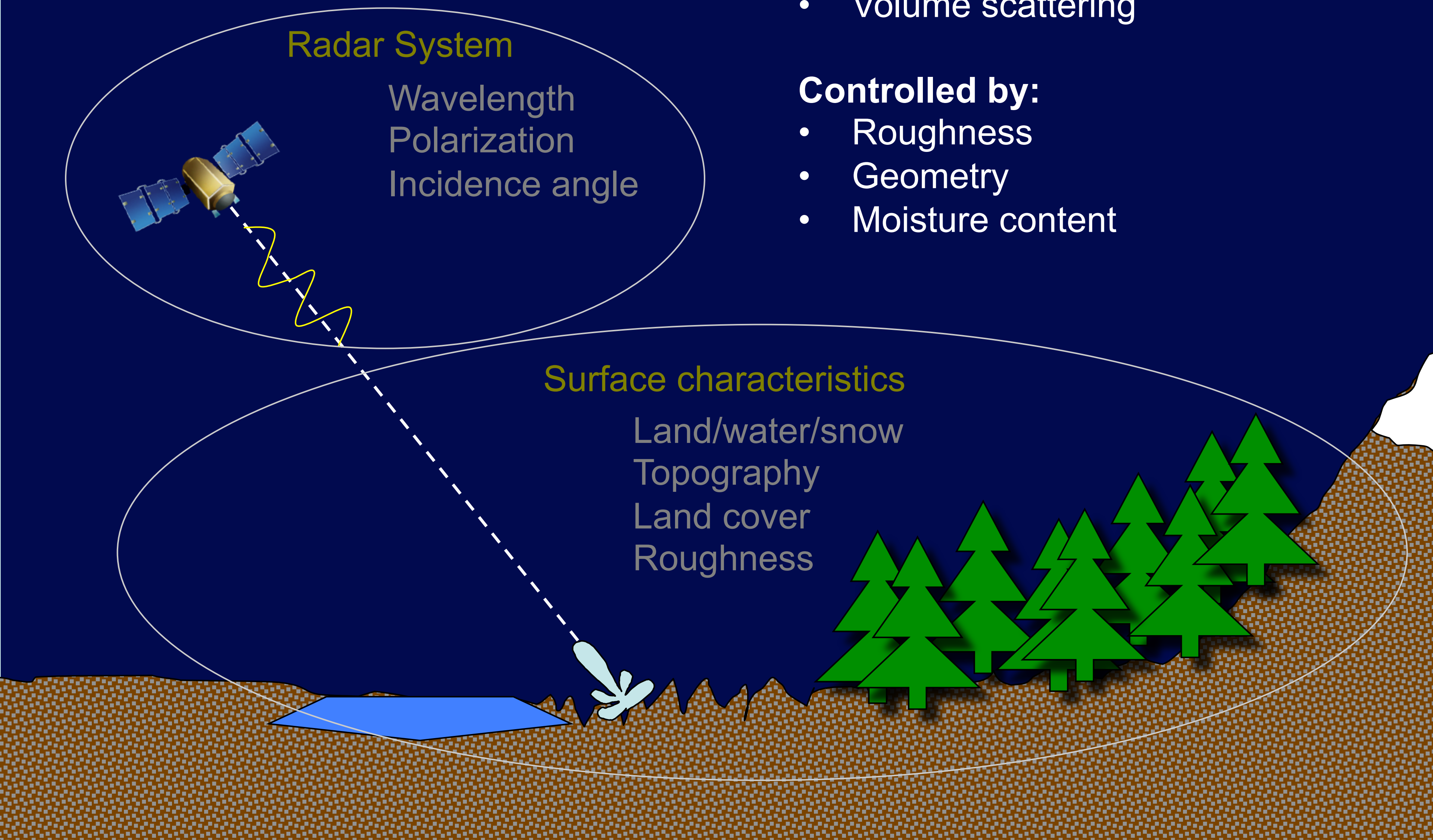
Backscatter cross section, σ

Two types of scattering:

- Surface scattering
- Volume scattering

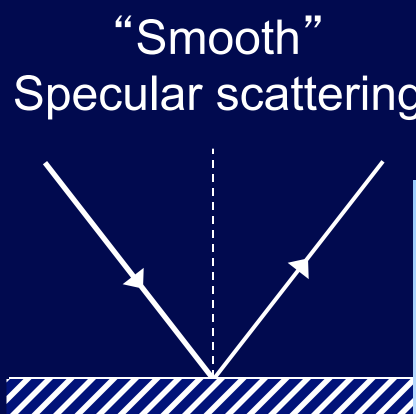
Controlled by:

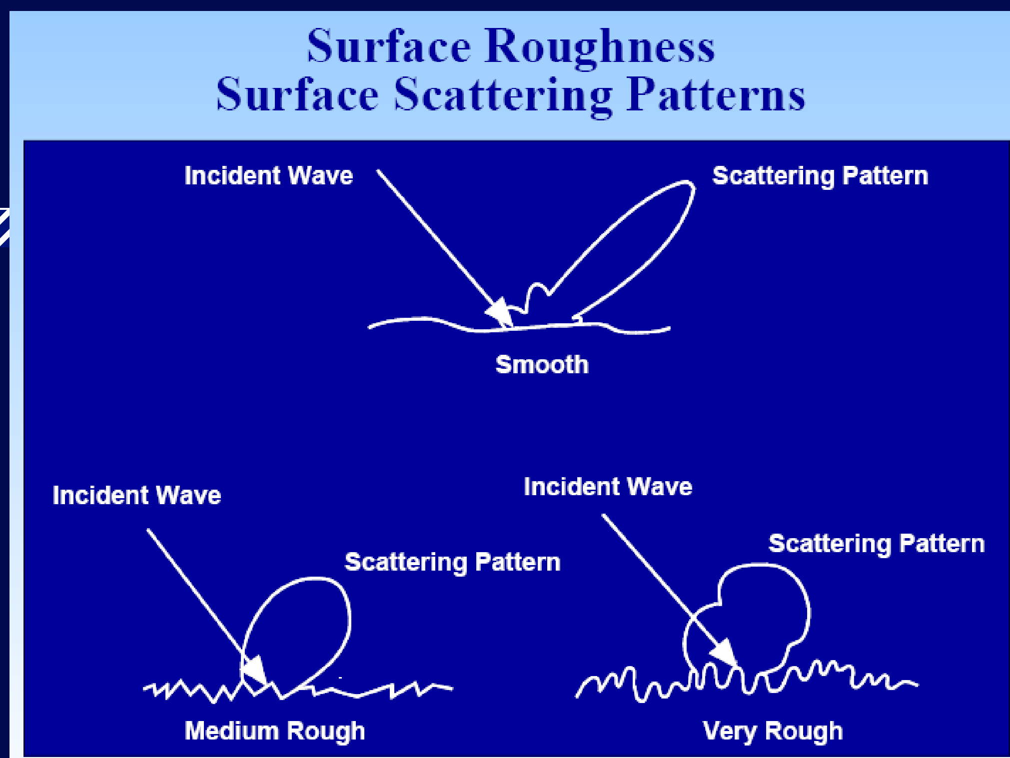
- Roughness
- Geometry
- Moisture content

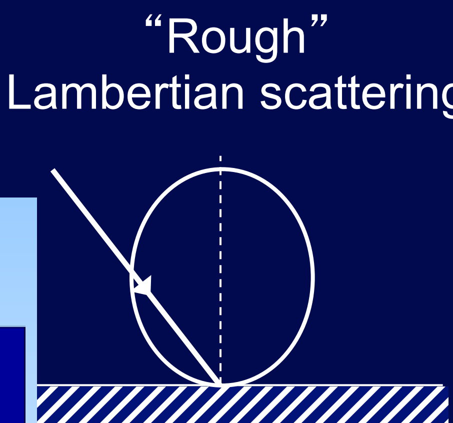


Backscatter cross section, σ – Surface scattering

Roughness



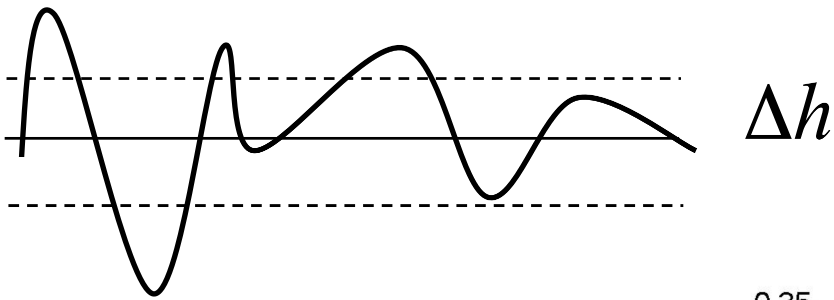




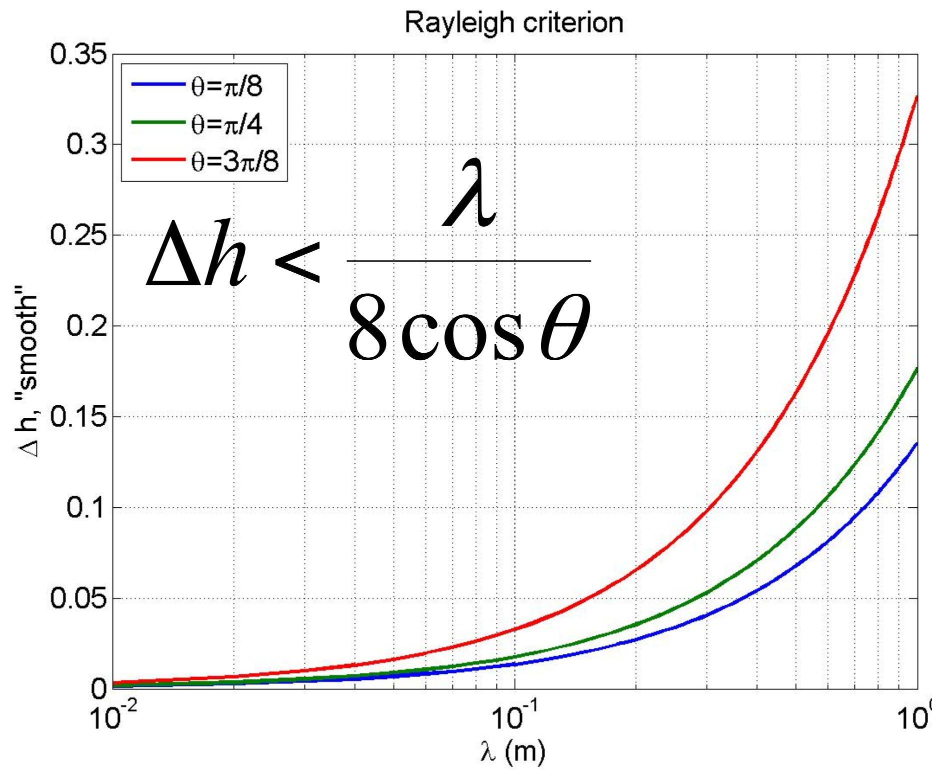
Source:CCRS

Backscatter cross section, σ – Surface scattering

Roughness



e.g. Rayleigh criterion



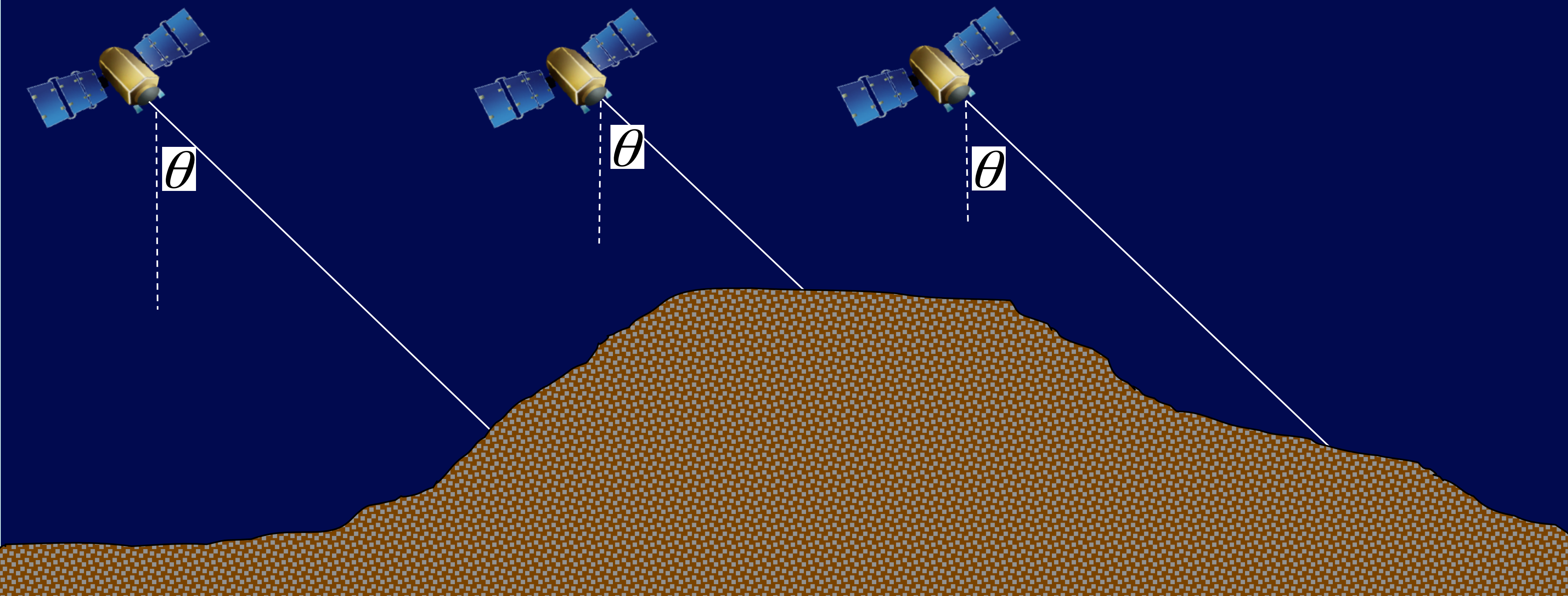
$$\Delta h < \frac{\lambda}{8\cos\theta}$$

Δh = root mean square variation in surface height

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

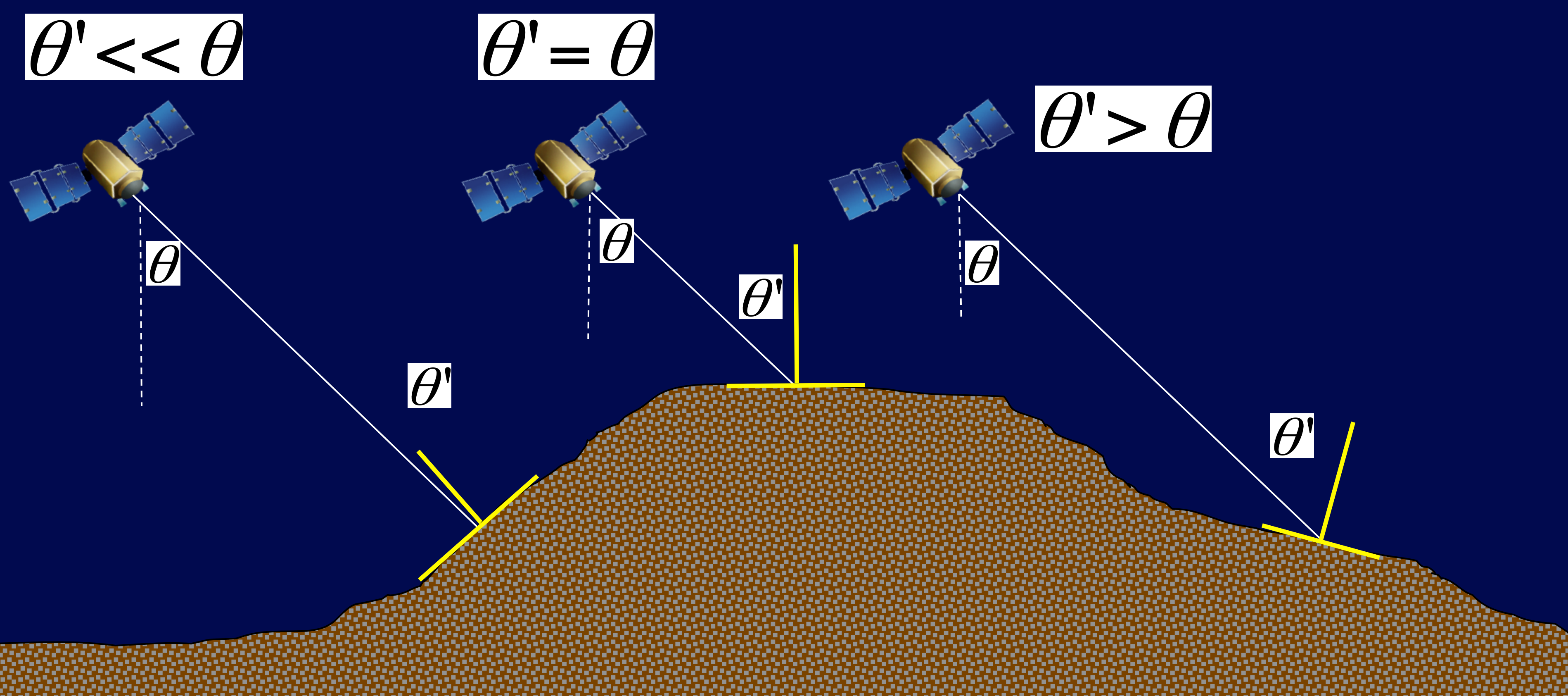
Backscatter cross section, σ – Surface scattering

Geometry - Local Incidence Angle



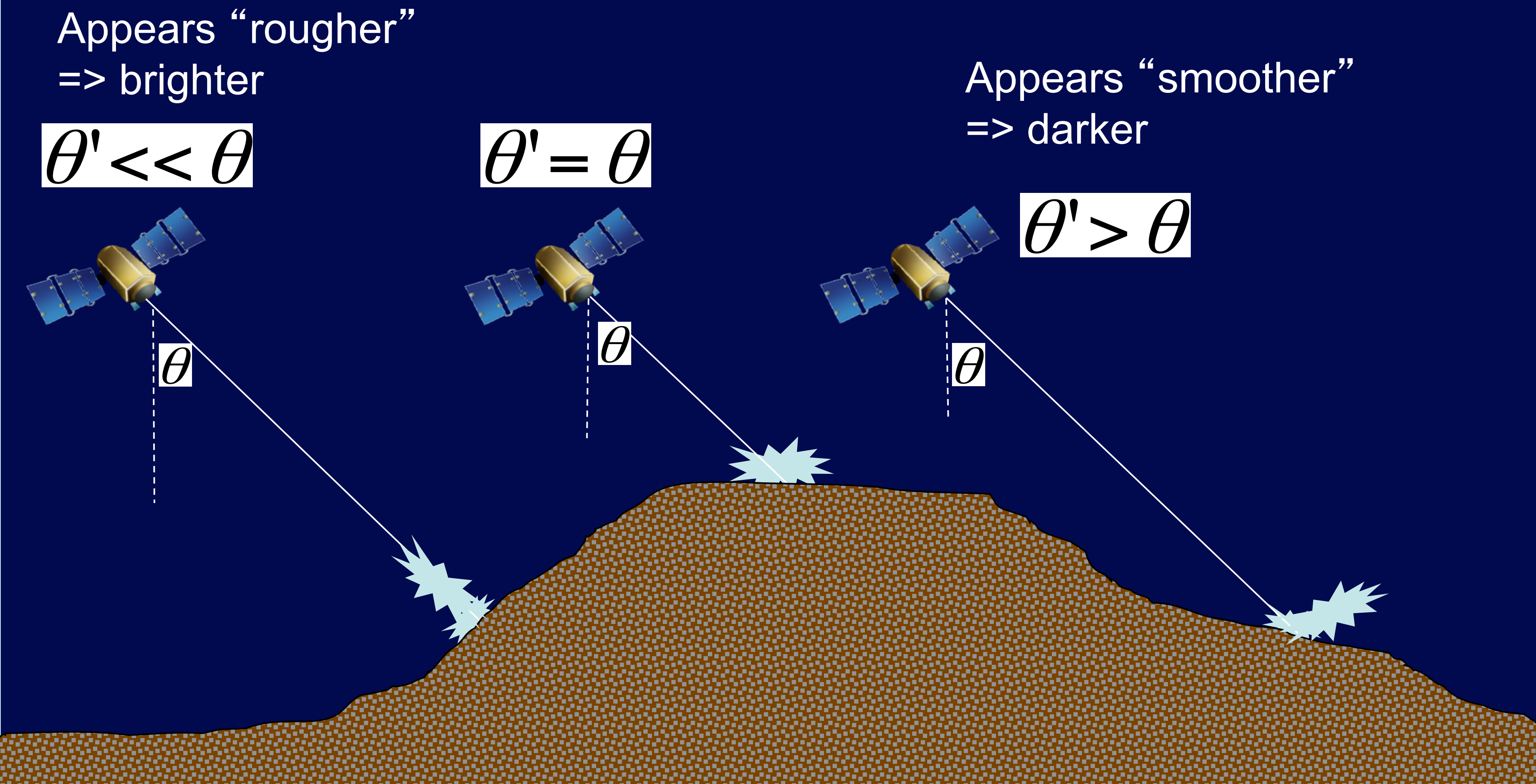
Backscatter cross section, σ – Surface scattering

Geometry - Local Incidence Angle



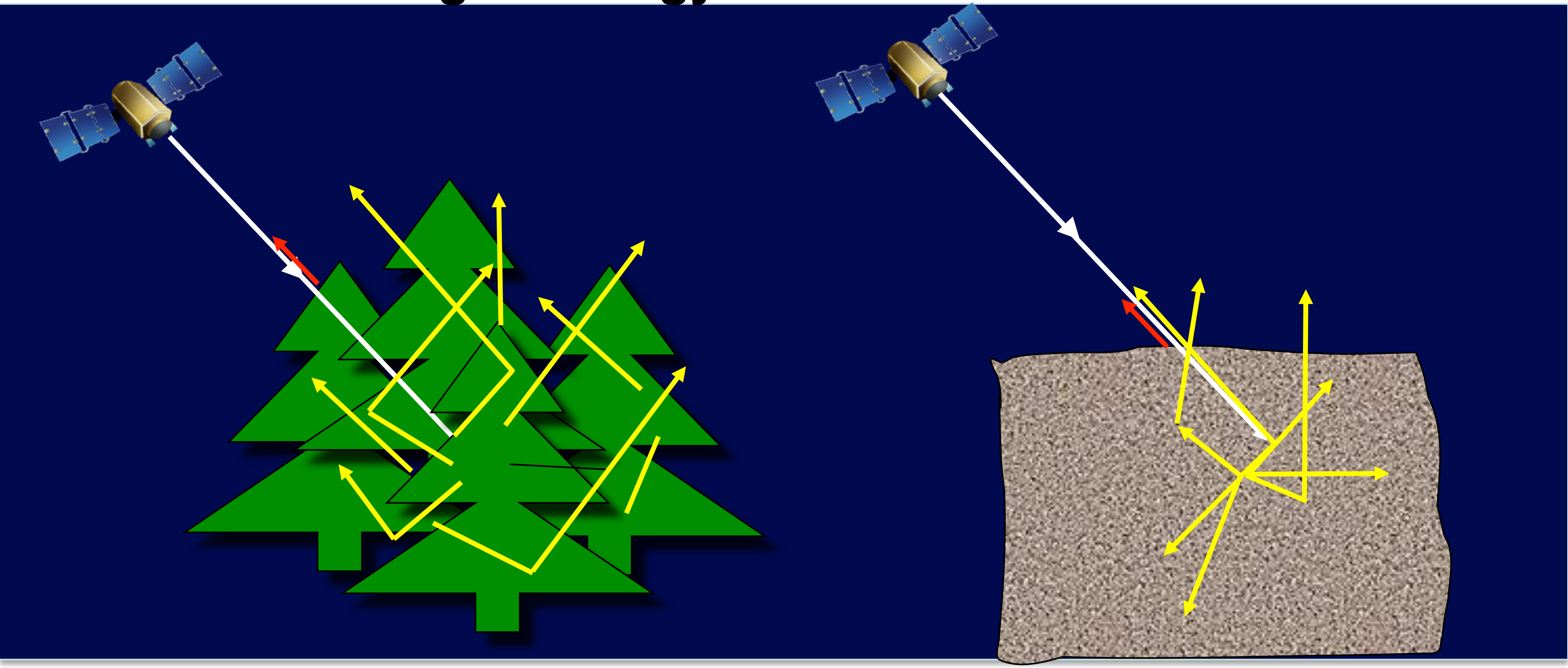
Backscatter cross section, σ – Surface scattering

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

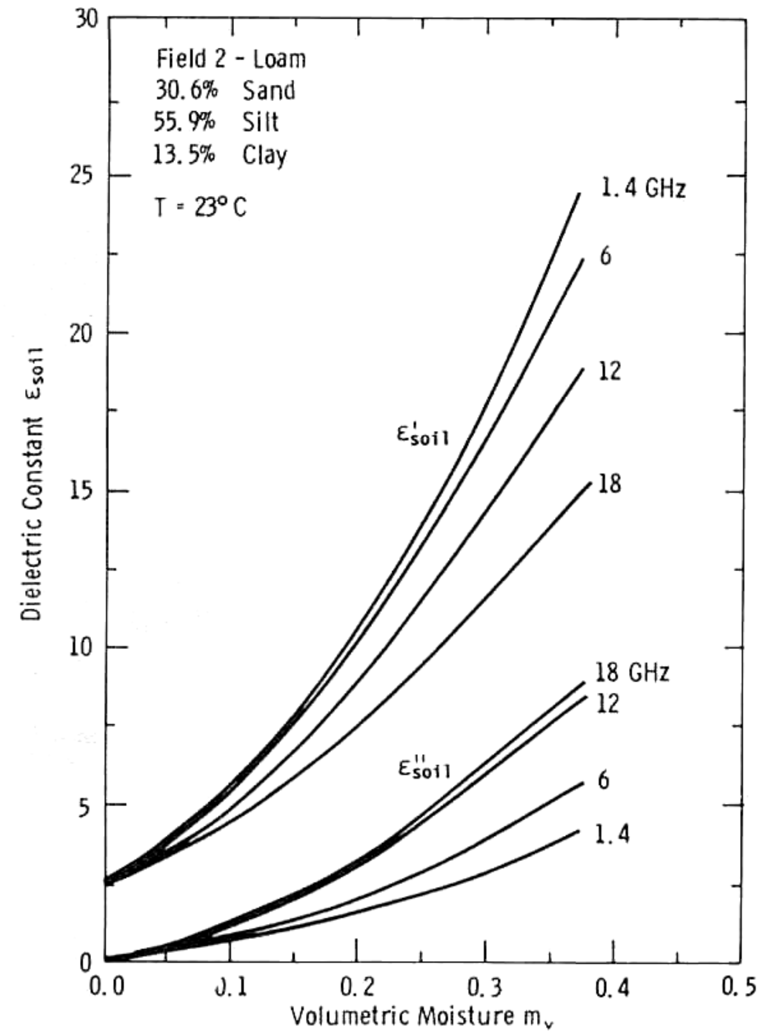


Fig. E.52 Measured dielectric constant as a function of volumetric moisture content for a loamy soil at four microwave frequencies.

Backscatter cross-section, σ – Volume scattering

Penetration Depth

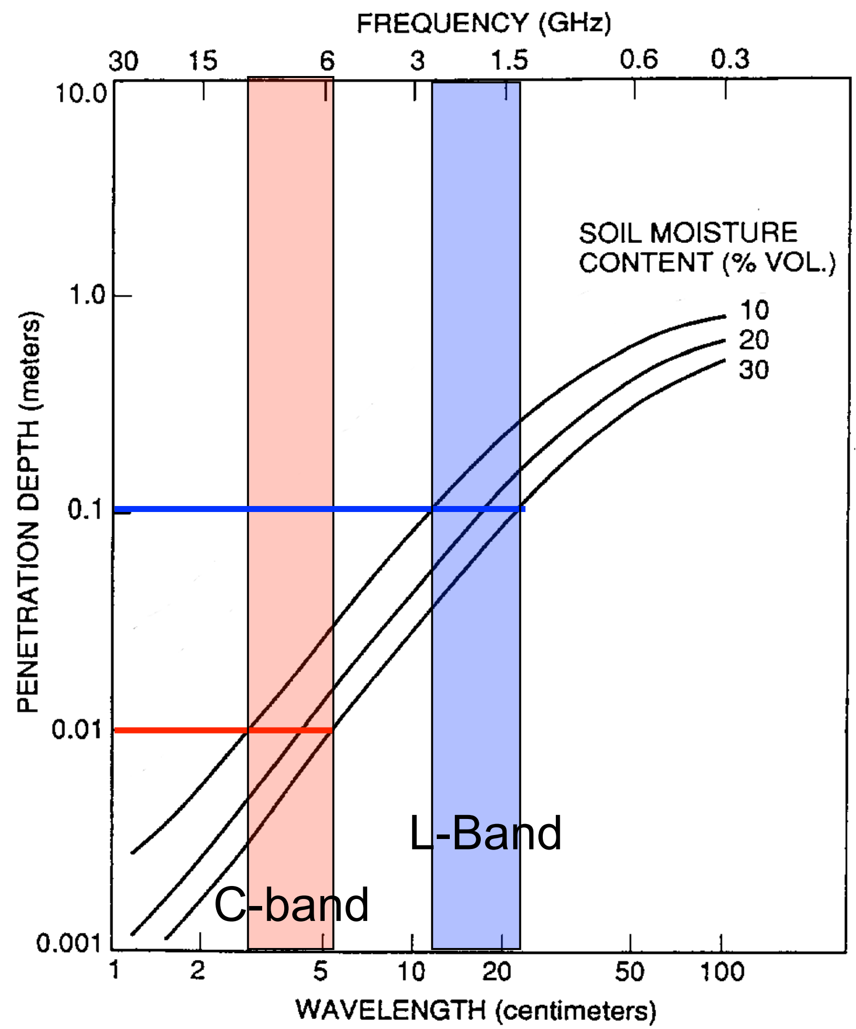
Depth at which power of wave is reduced to 1/e times its original value.

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

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

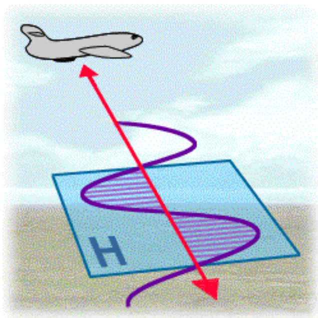
Wetter soils more reflective, lower penetration depth.

Required penetration depth determines design λ

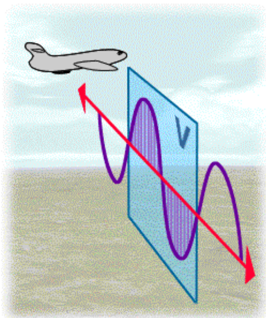


Backscatter cross-section, σ – Volume scattering

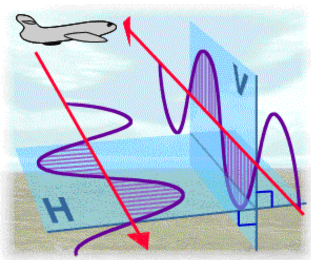
HH



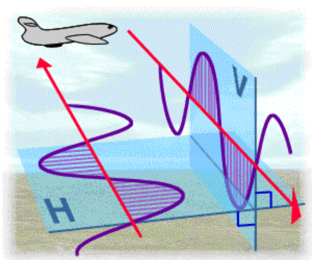
VV



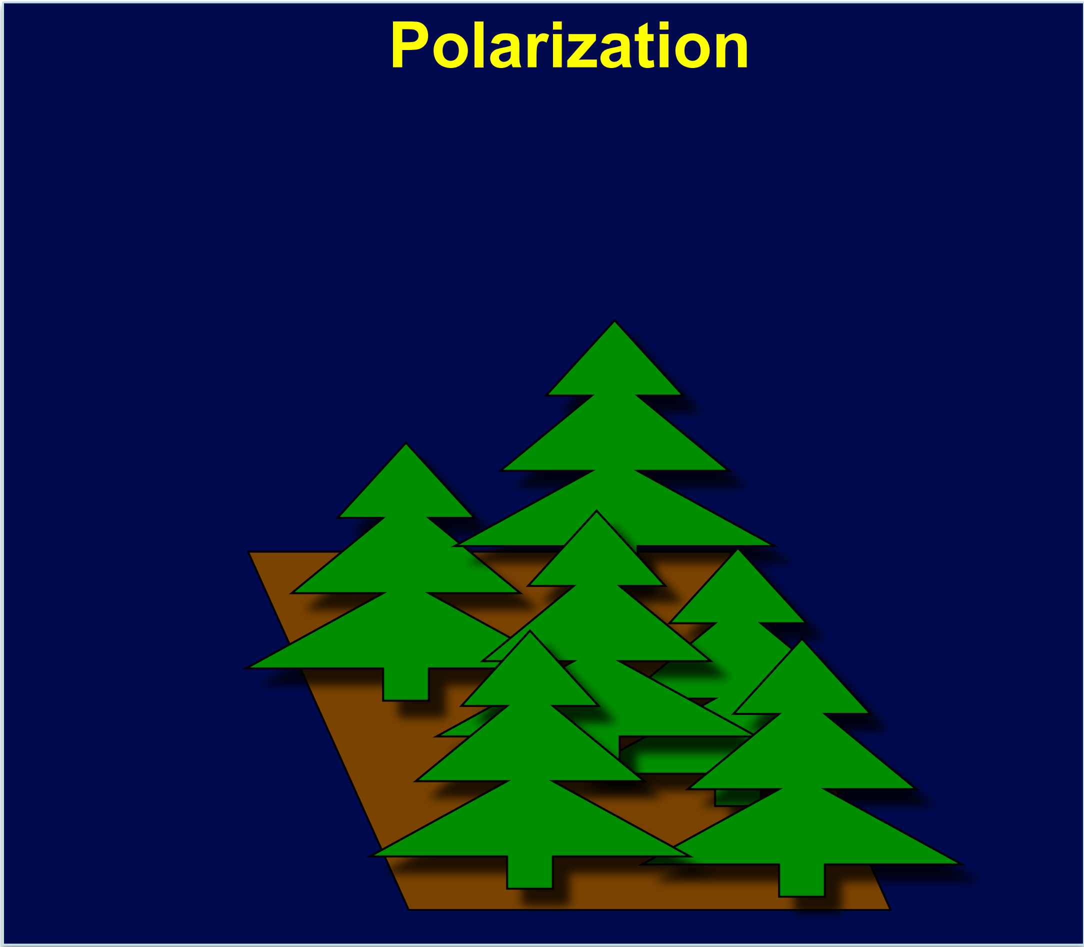
HV



VH

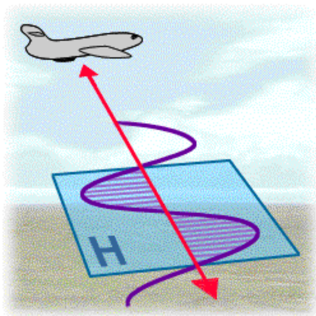


Source: CCRS

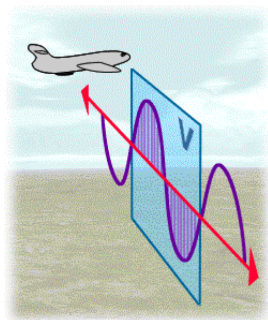


Backscatter cross-section, σ – Volume scattering

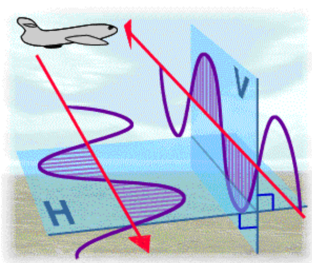
HH



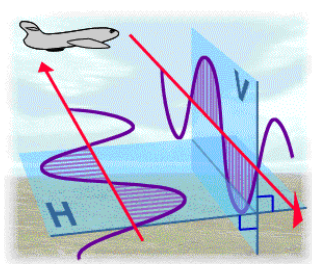
VV



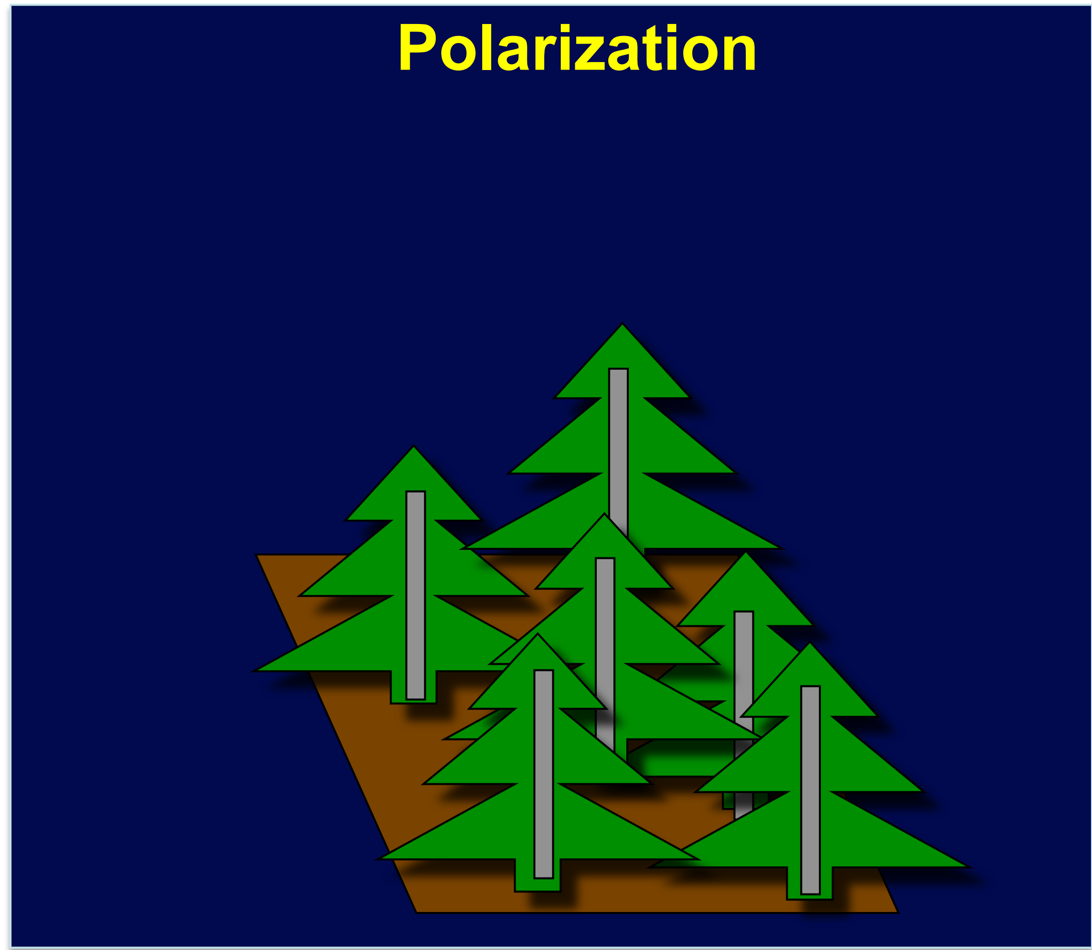
HV



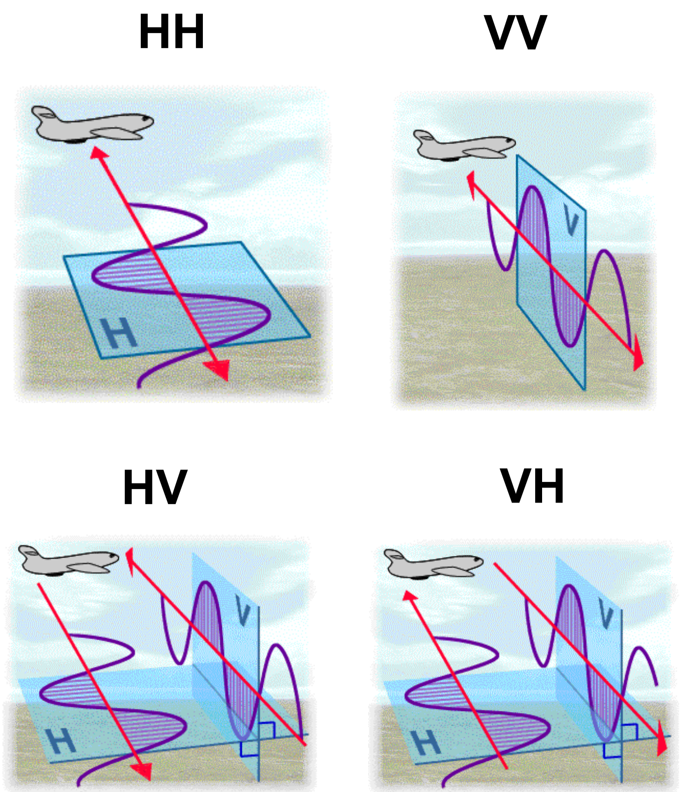
VH



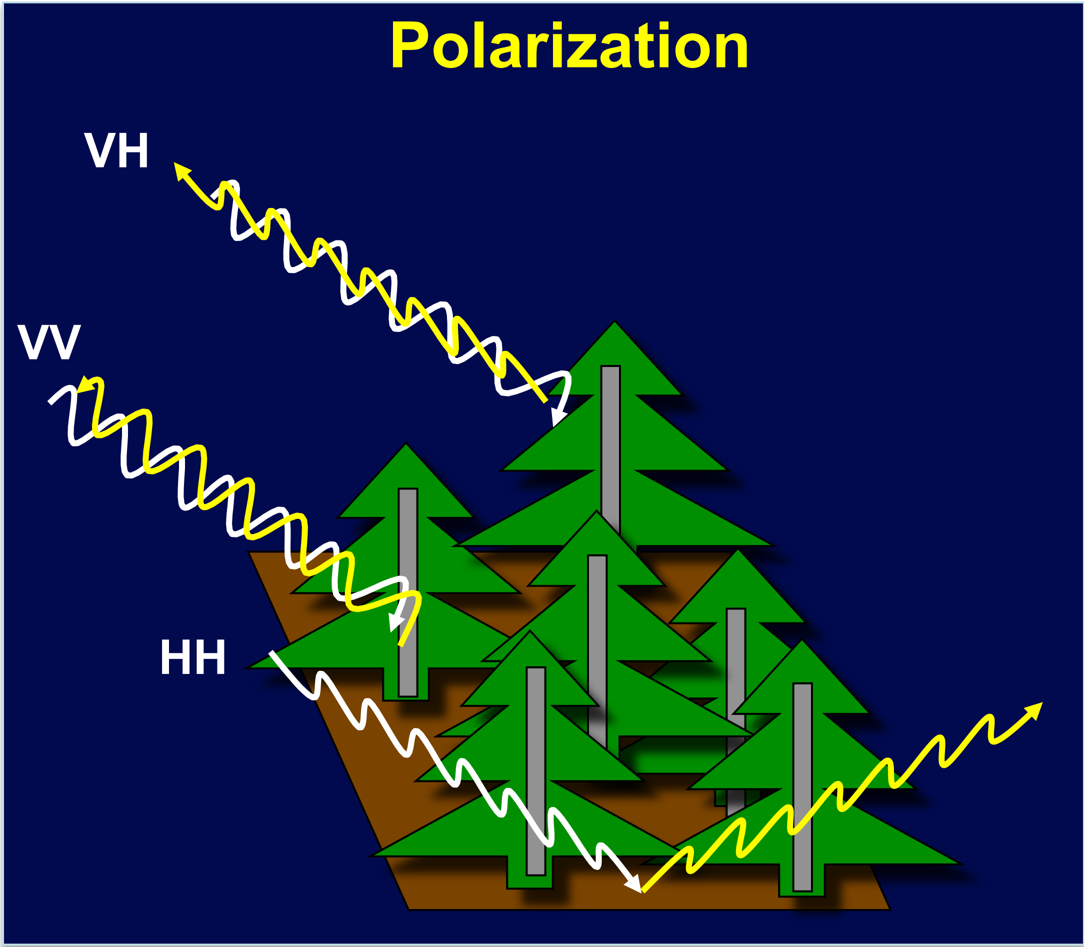
Source: CCRS



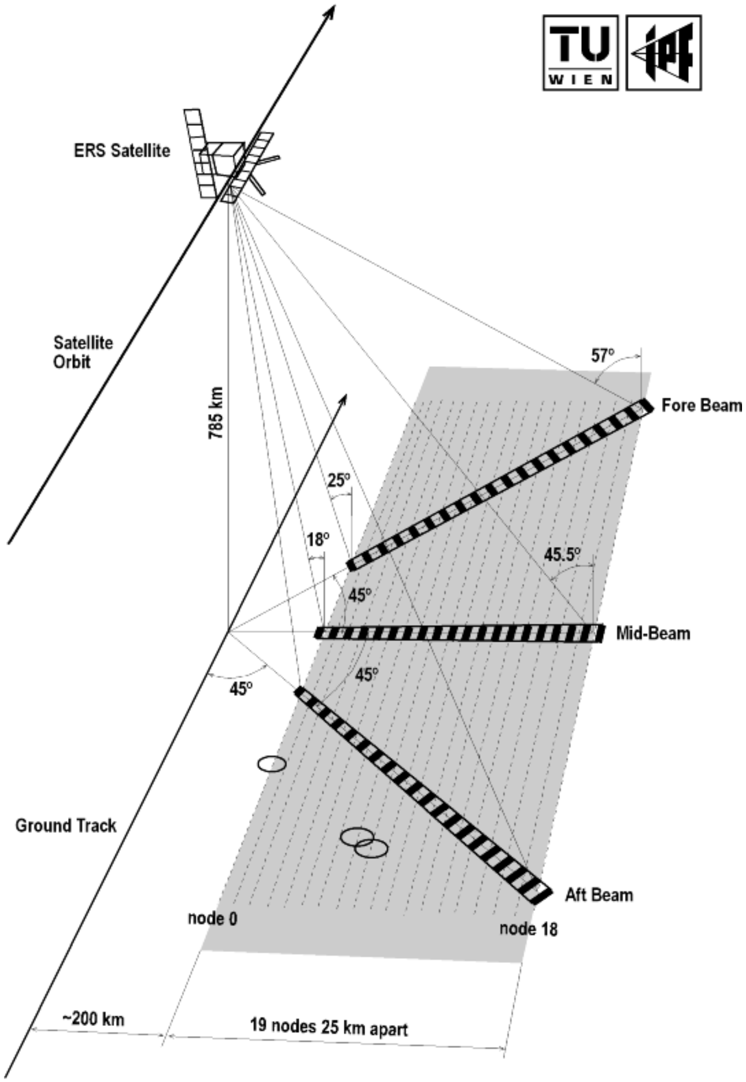
Backscatter cross-section, σ – Volume scattering



Source: CCRS



Scatterometry: Soil Moisture



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

Wind scatterometers:

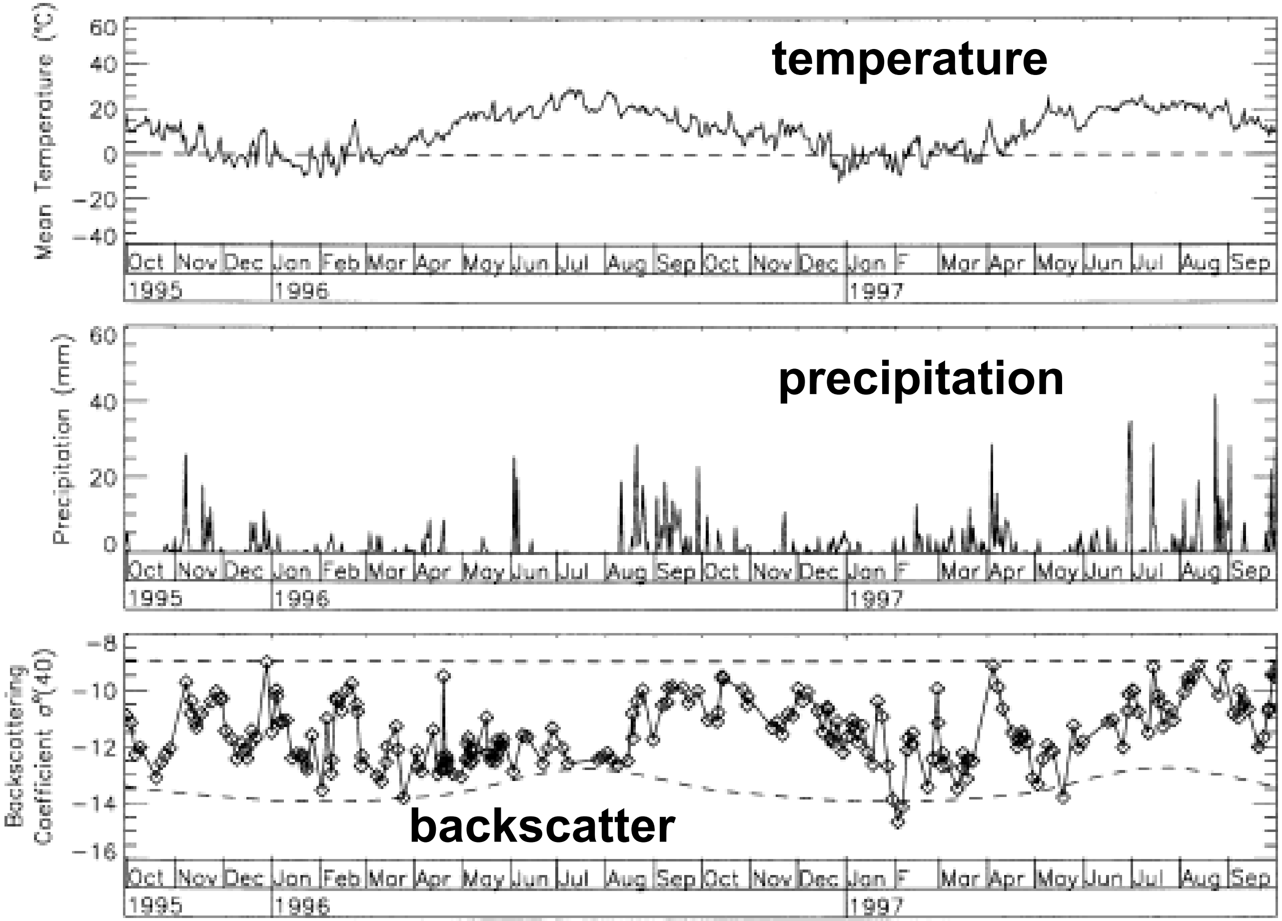
ERS-1, ERS-2 (1991-present)

MetOp satellites (2006-2020)

Backscatter measurements

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

Scatterometry: Soil Moisture



$$\sigma^0_{wet}(40)$$

$$\sigma^0_{dry}(40)$$

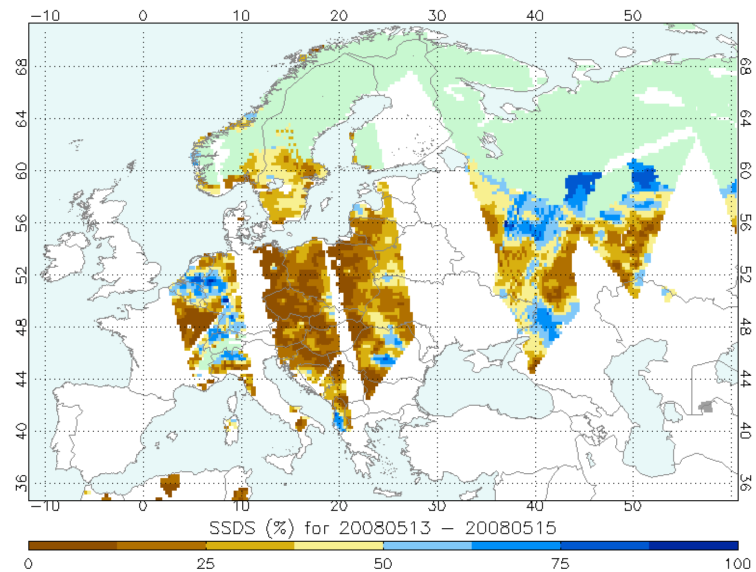
Figure 3. Time series of mean temperature, precipitation, and $\sigma^0(40)$ for the station Simferopol (33.98°E, 45.02°N) for the period October 1995 to September 1997. In the bottom figure the backscattering coefficient of a dry and wet surface, $\sigma^0_{dry}(40,t)$ and $\sigma^0_{wet}(40)$ are indicated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

Wagner et al. (1999)

Scatterometry: Soil Moisture

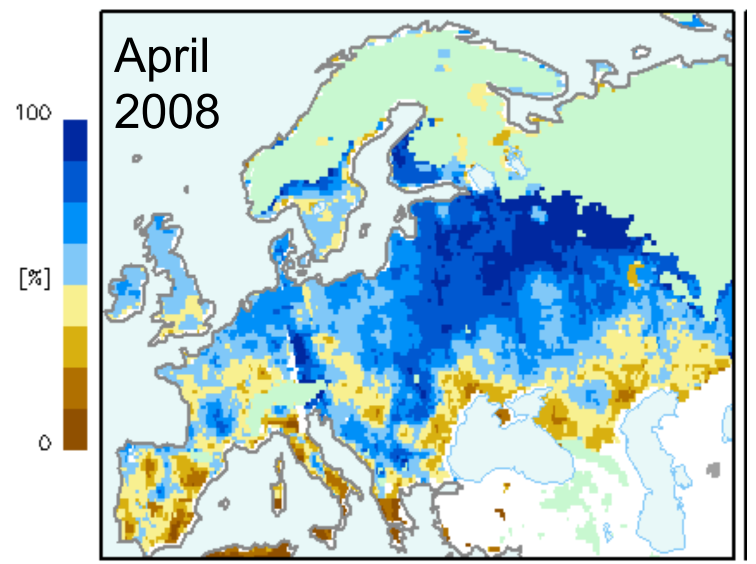
Surface soil degree of saturation (SSDS):

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



Soil Water Index (SWI):

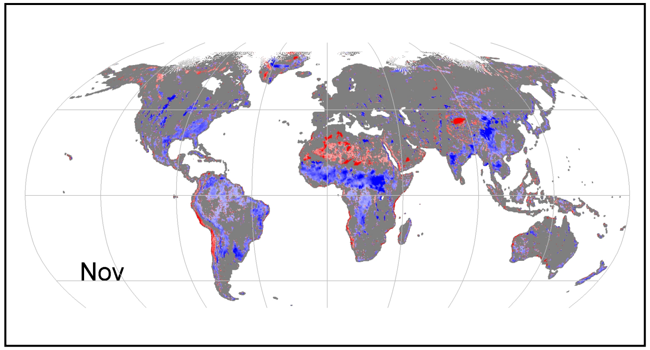
$$SWI(t) = \frac{\sum_i m_s(t_i) e^{-(t-t_i)/T}}{\sum_i e^{-(t-t_i)/T}}$$



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

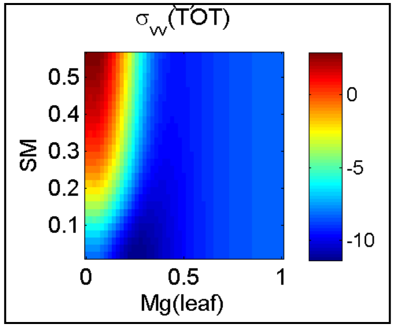
TU Delft: Water stress from radar

Difference between 10am/10pm in satellite radar measurements



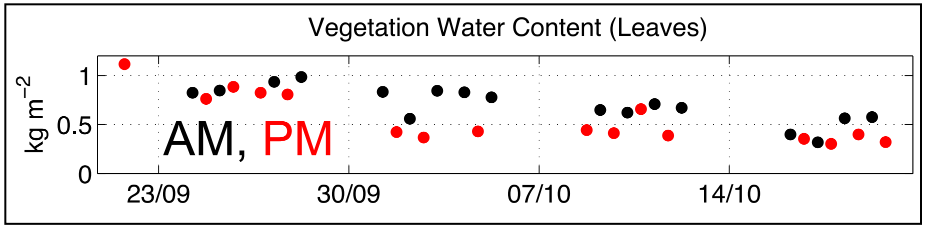
Friesen, ***Steele-Dunne***, van de Giesen 2012

Could be explained by variations in leaf moisture



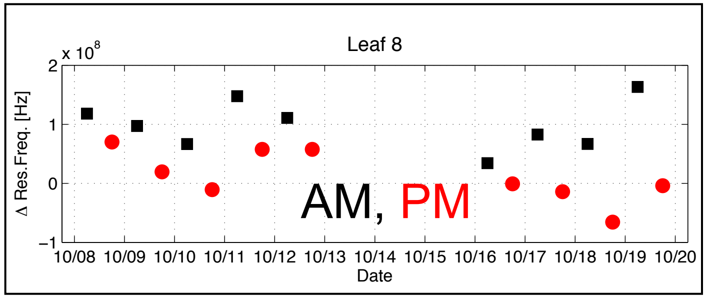
Steele-Dunne, Friesen, van de Giesen 2012

Leaf water content changes due to water stress



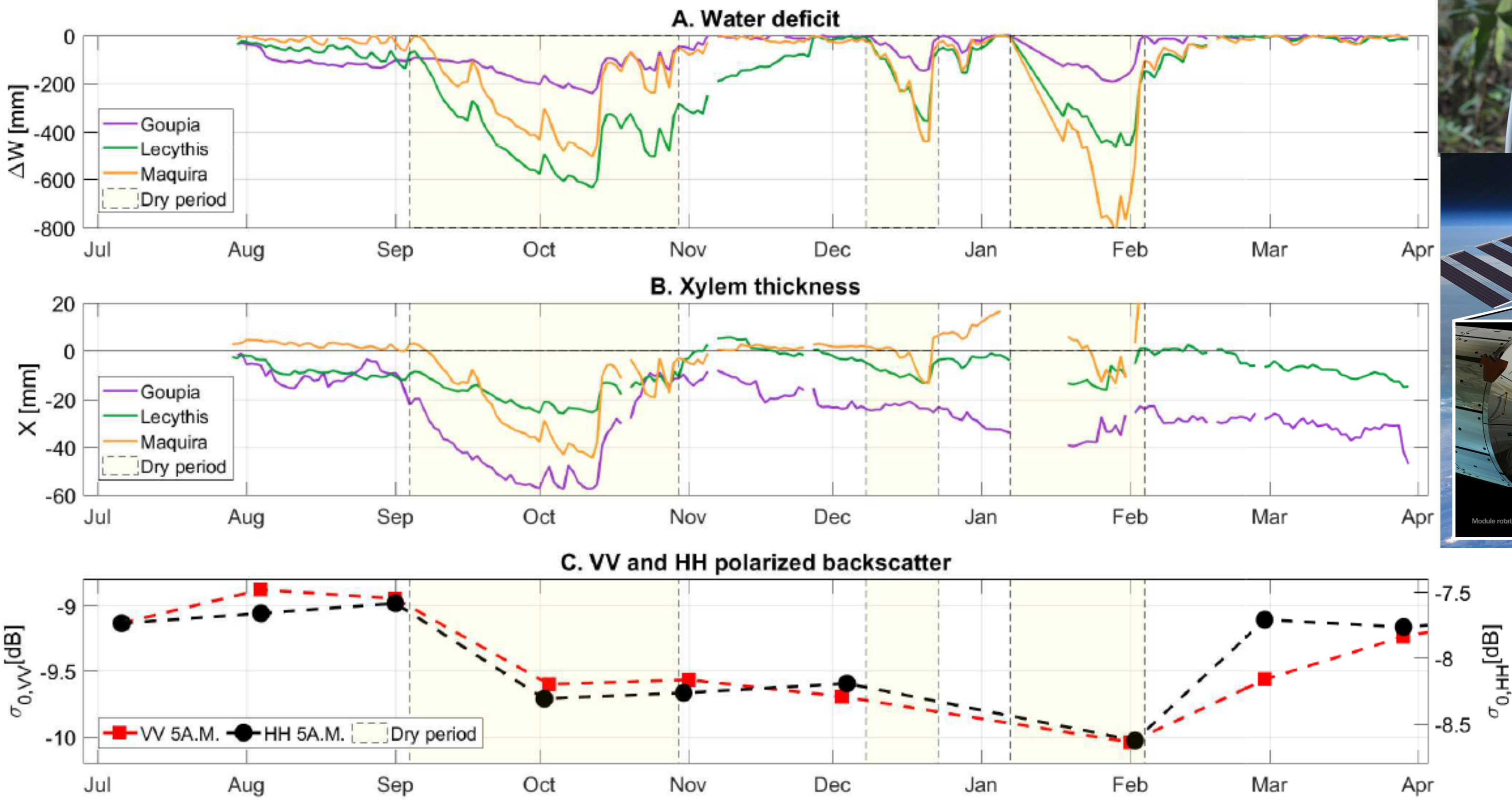
*Van Emmerik**, Steele-Dunne***, Judge, van de Giesen 2015a

Innovative sensor: leaf dielectric properties change due to stress



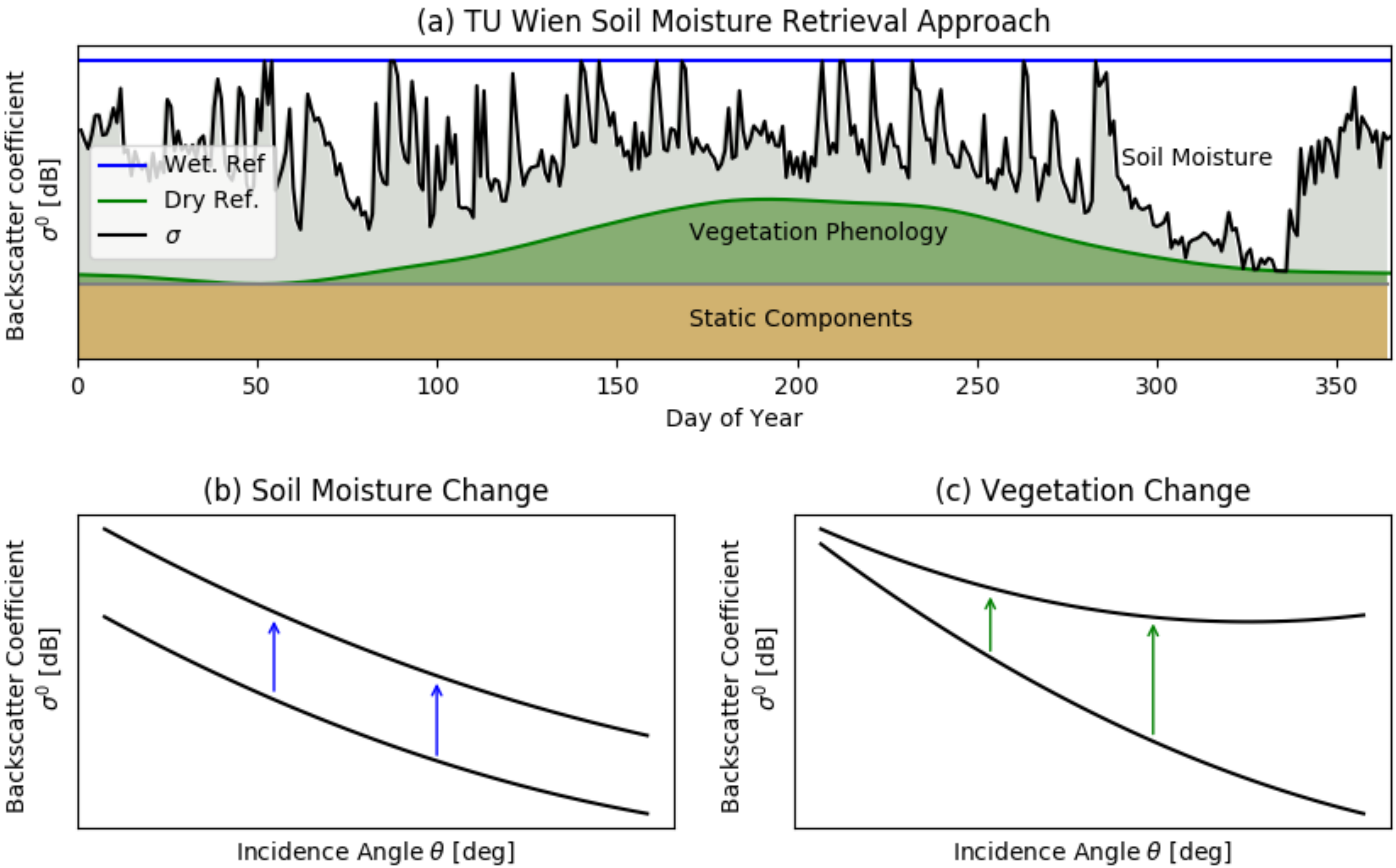
*Van Emmerik**, Steele-Dunne***, Judge, van de Giesen 2015b

Water Stress in the Amazon from ISS-RapidScat



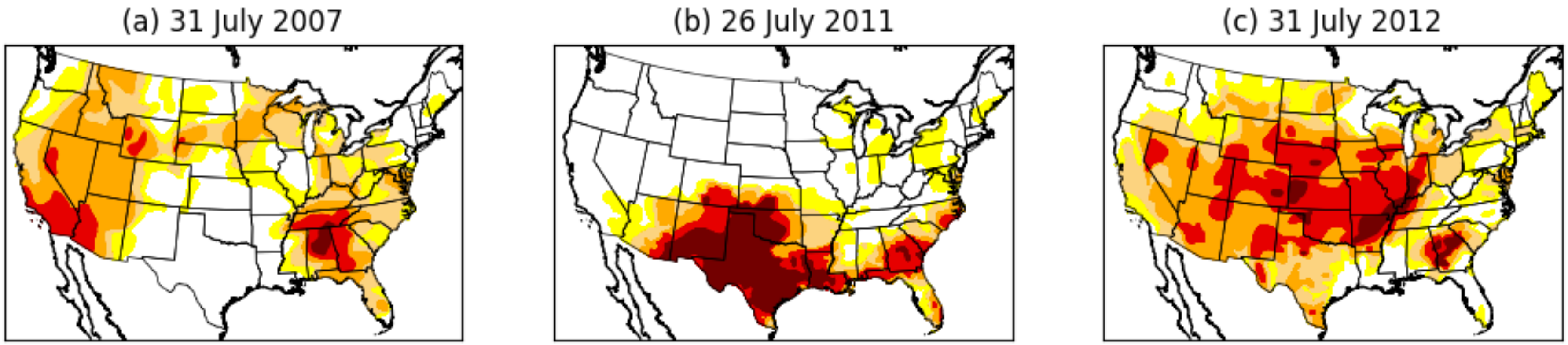
TUDelft UCONN UNICAMP

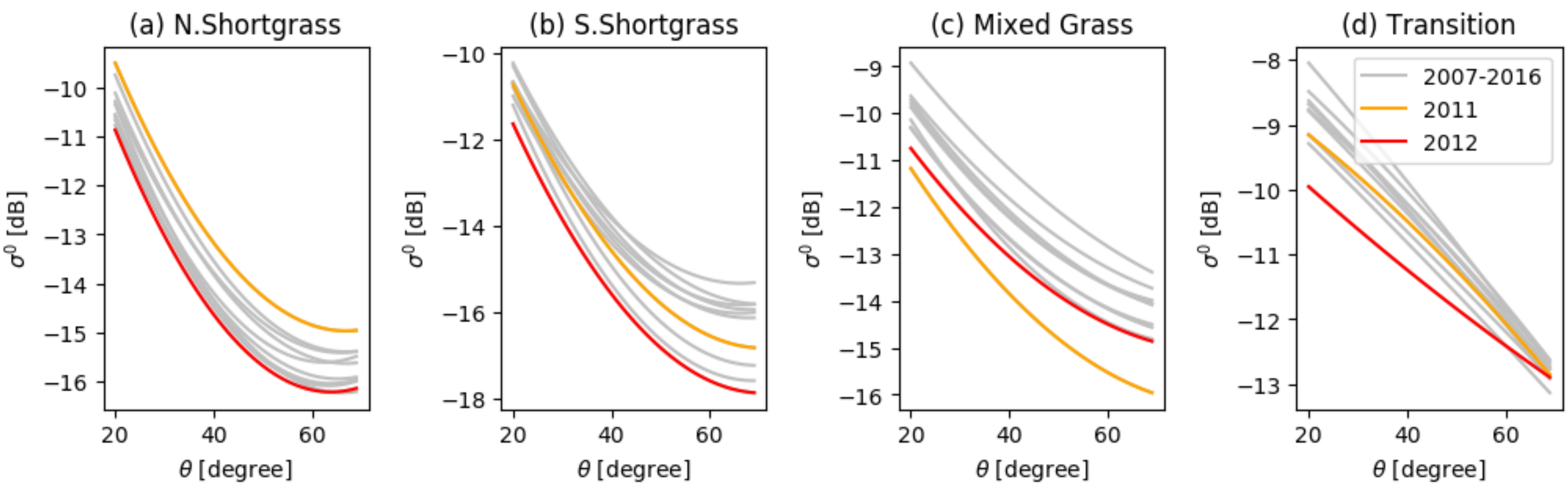
Vegetation using ASCAT



Steele-Dunne et al. (RSE 2018)

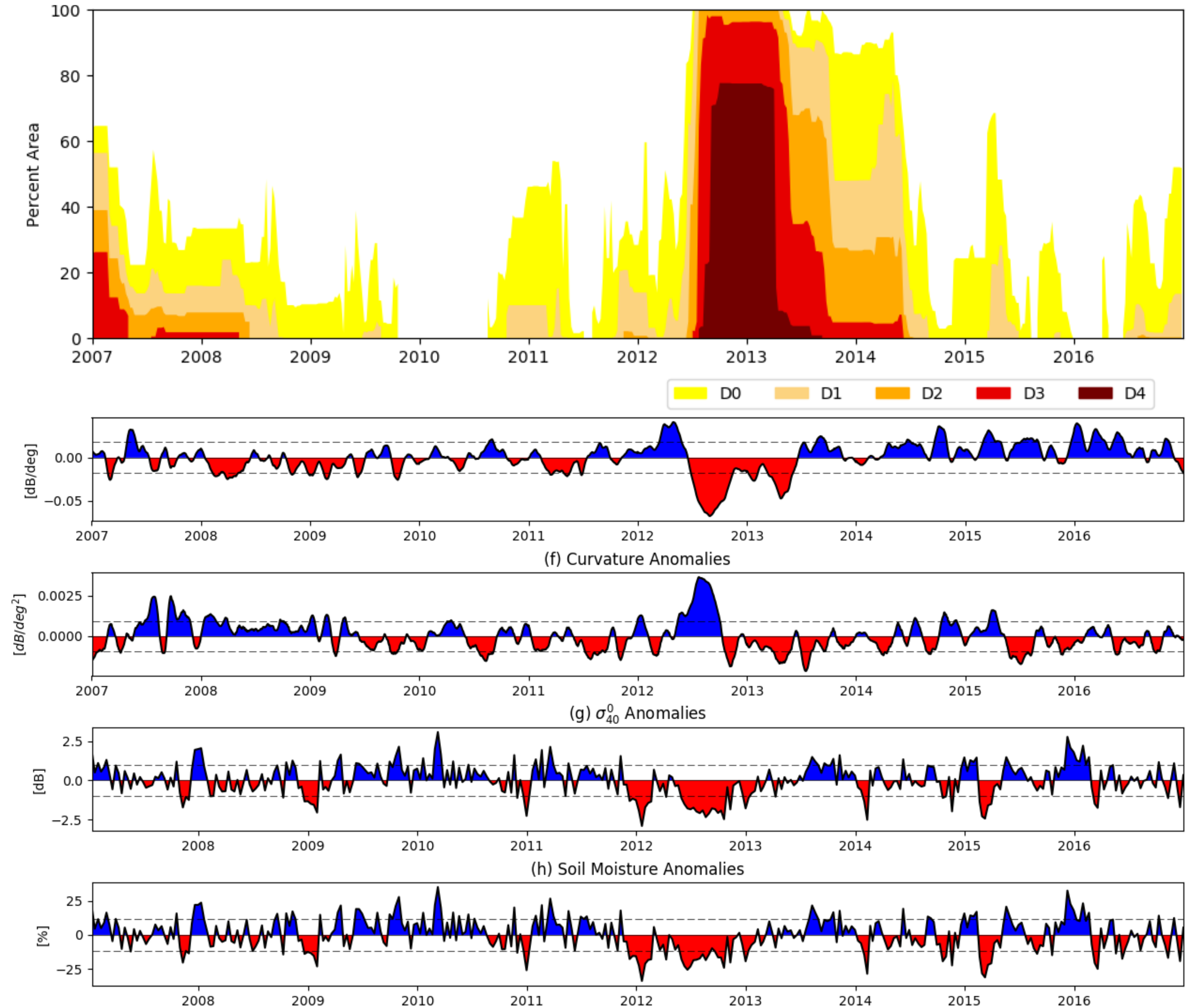
Drought impact on σ - θ relationship





Steele-Dunne et al. (RSE 2018)

Drought impact in Nebraska Sandhills

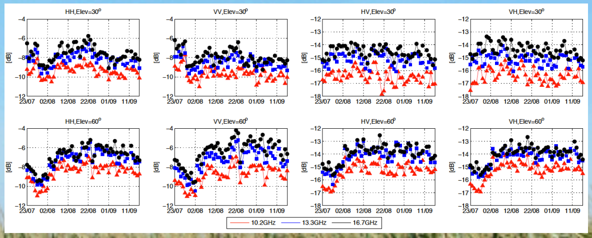


Steele-Dunne et al. (RSE 2018)

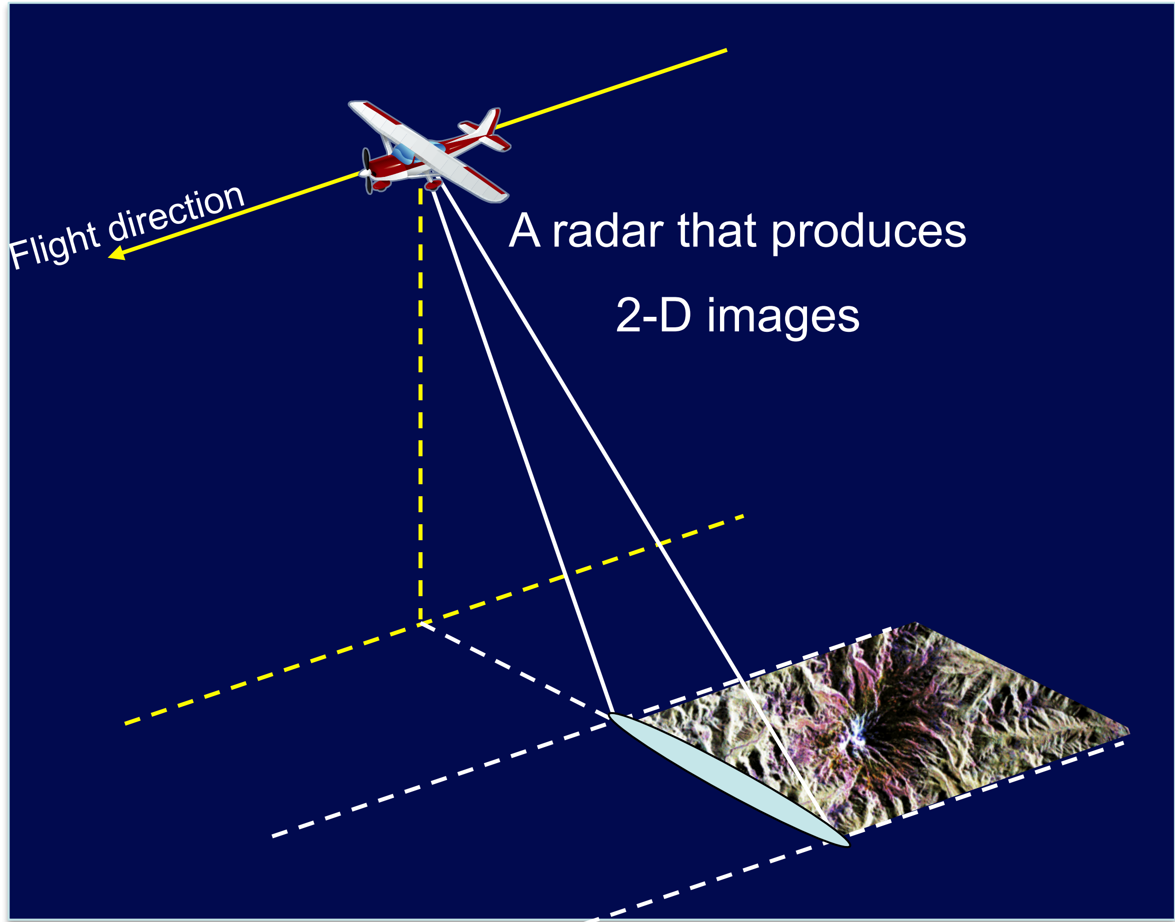
How thirsty are the crops?

Using radar to monitor canopy water dynamics

MSc. Project? - Contact:
Susan Steele-Dunne
(s.c.steele-dunne@tudelft.nl)



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

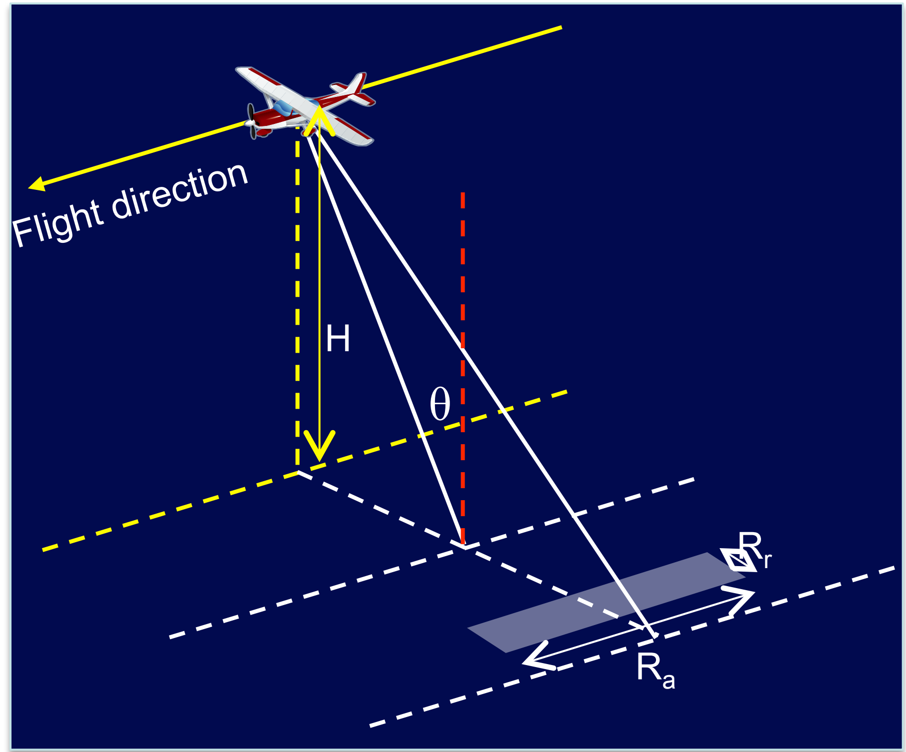
Range (Across-track dimension)

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

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

⇒phase is different for each pulse

⇒Doppler effect

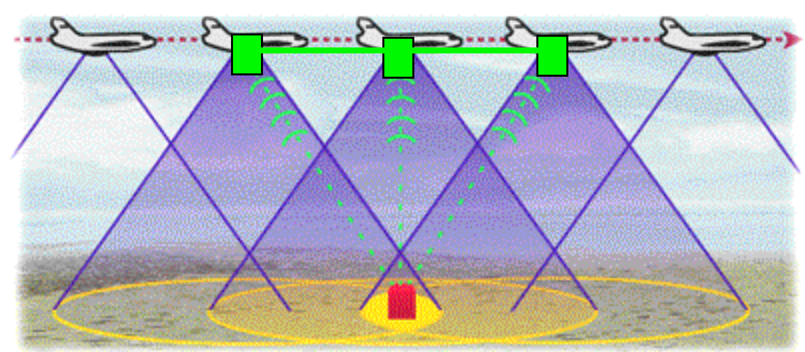
Use signal processing to account for difference in phase

Synthetic array increases azimuth resolution:

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

Independent of altitude!

elements of synthetic array



SAR Applications: Sentinel 1

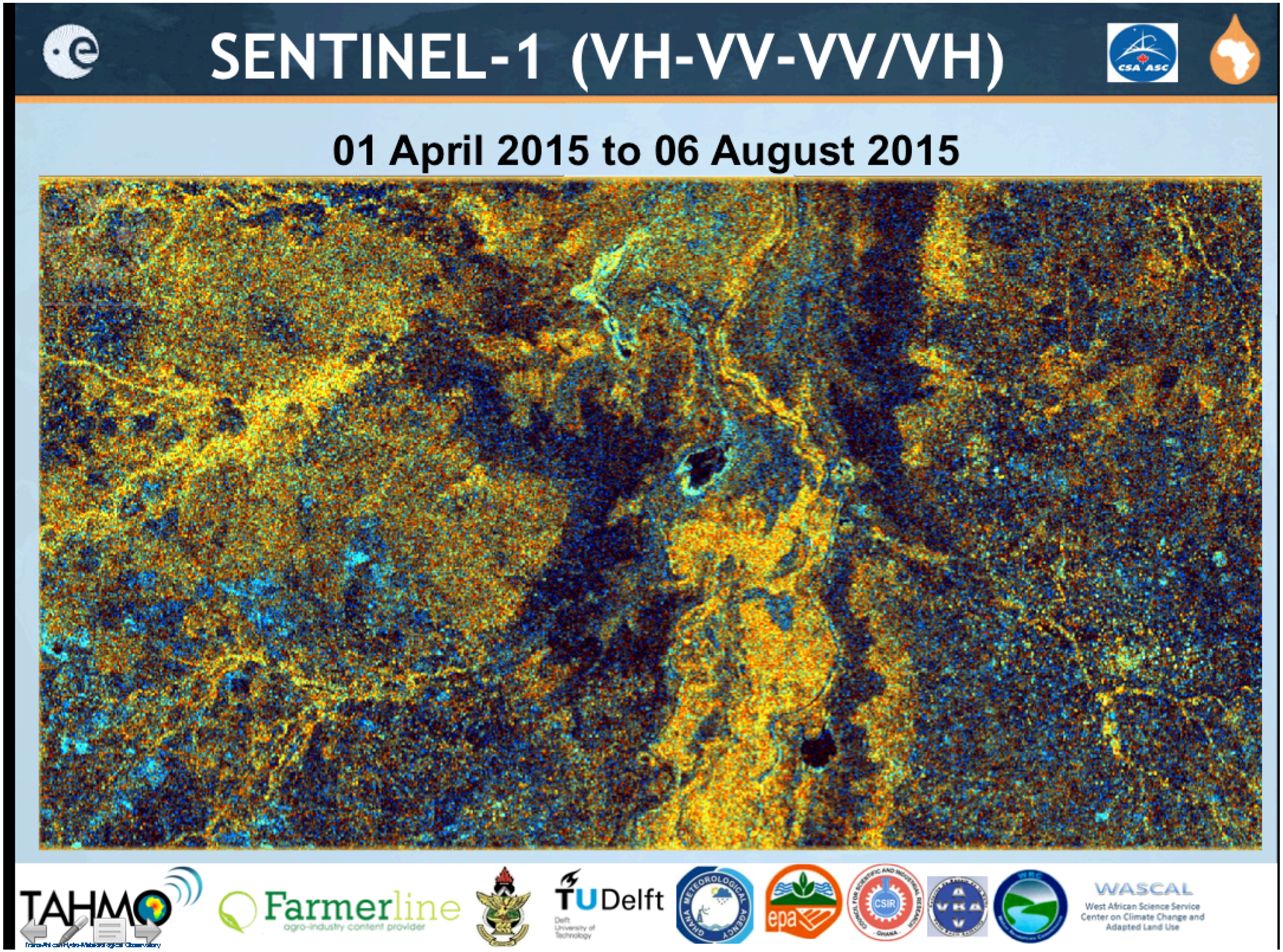
Oceans & Coast
- Wave Characteristics
- Ocean Fronts
- Coastal Dynamics
- Oil Slicks and ShipTraffic

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

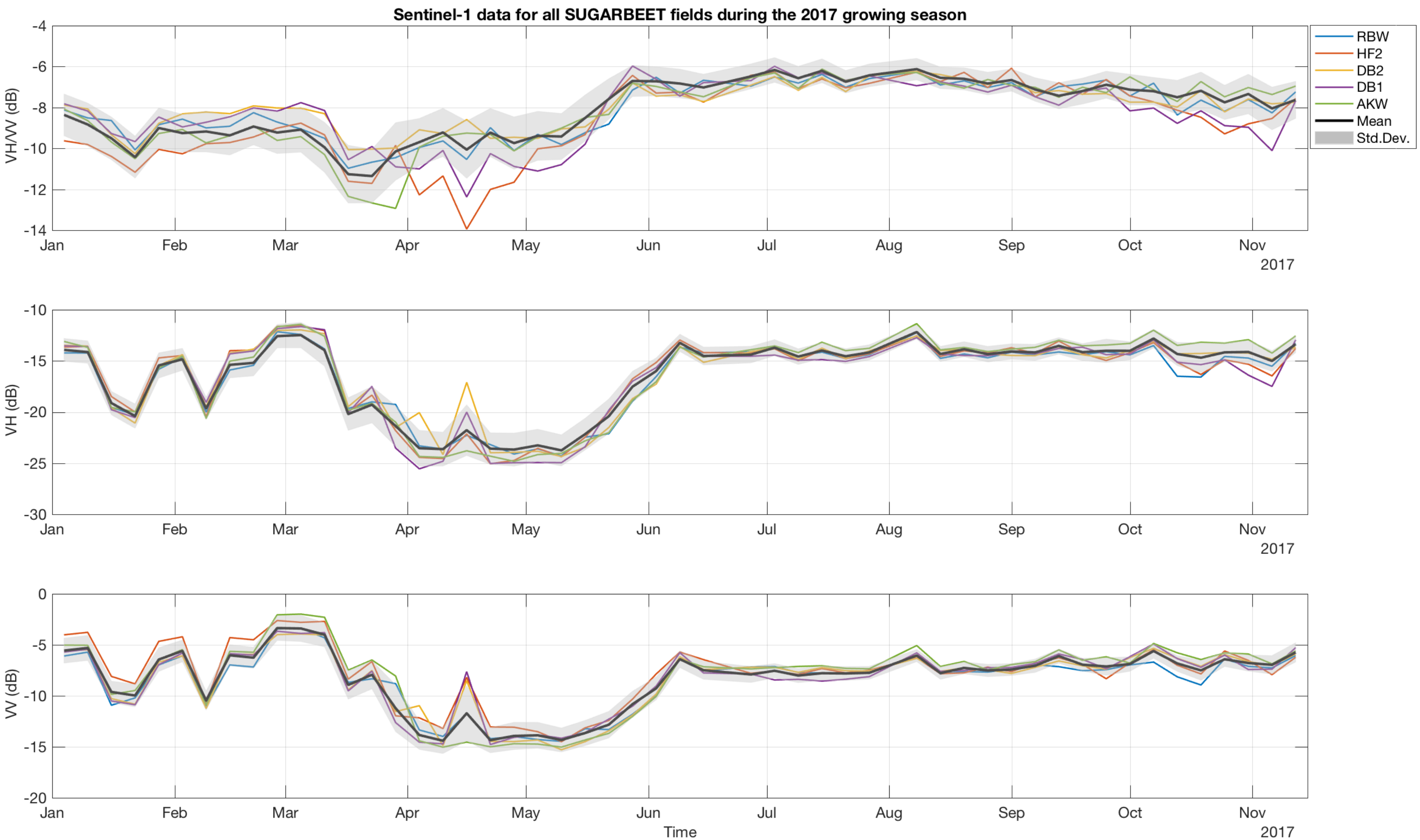
Natural Disasters
- Volcanic activity
- Earthquakes
- Land subsidence

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

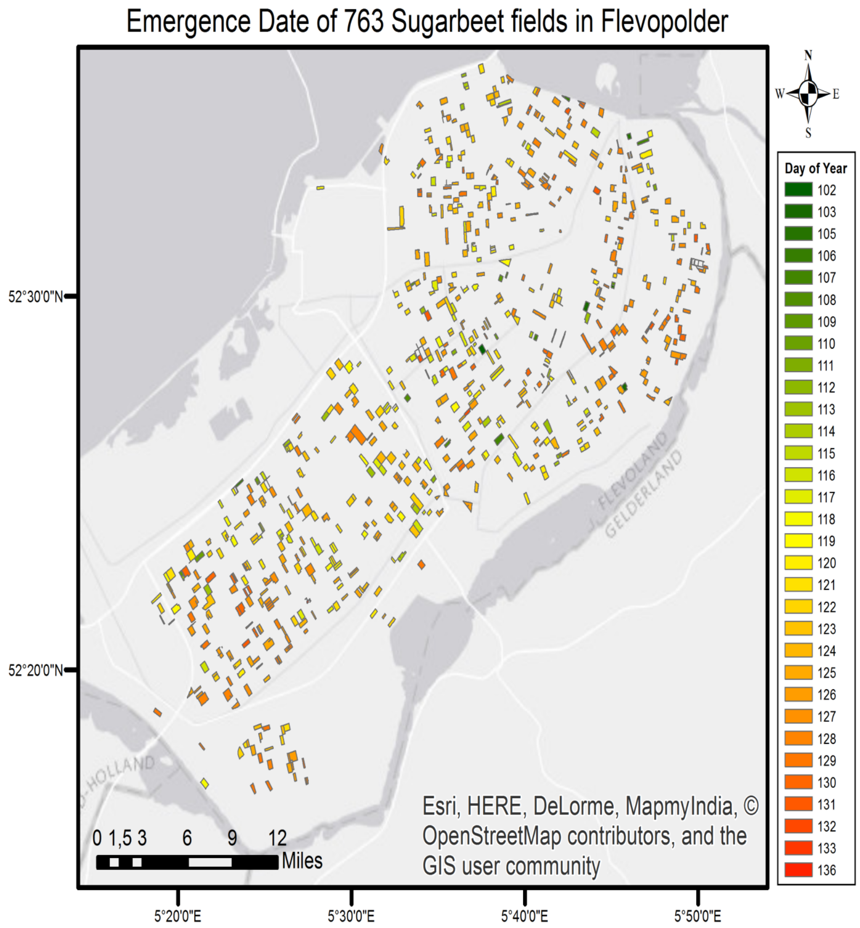
All-weather monitoring of the small reservoirs

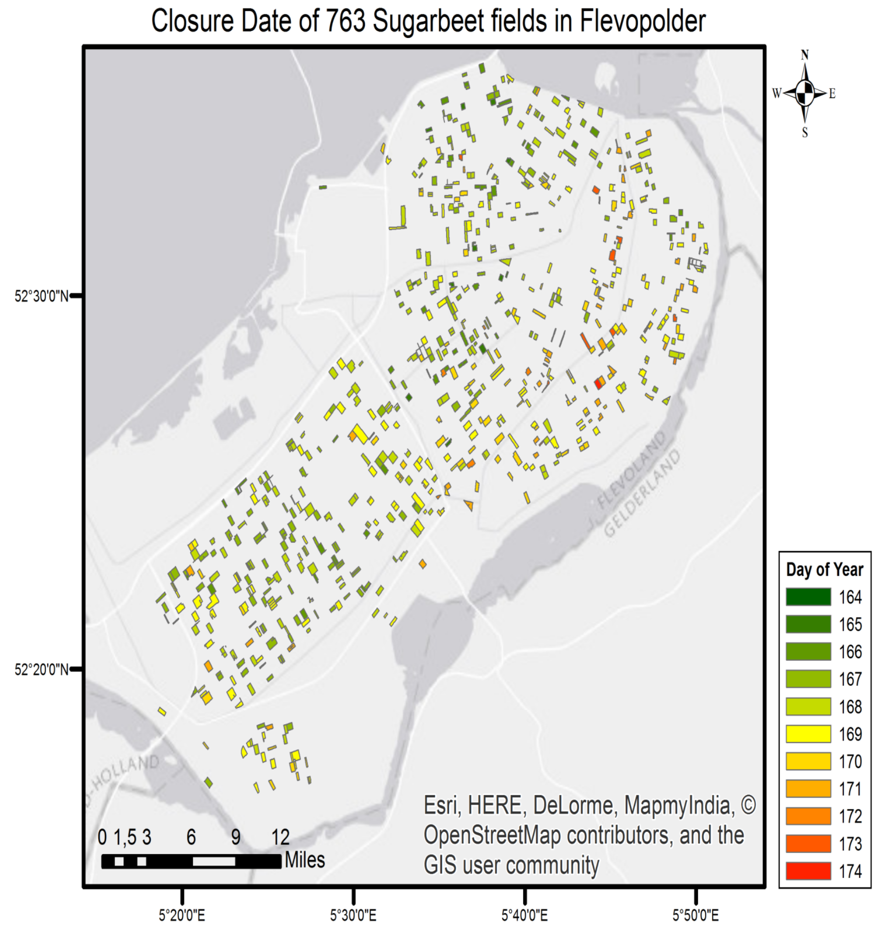


Agricultural Monitoring with Sentinel-1



Agricultural Monitoring with Sentinel-1





TUDelft

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