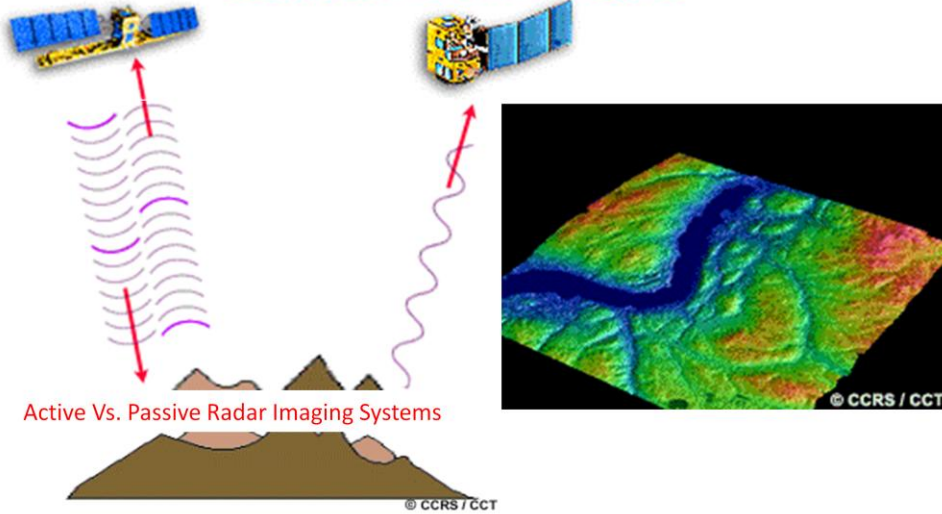


Lecture 19: RADAR Principles



Radar principles Chapter 9
Radar satellites
Radar interferometry
SRTM

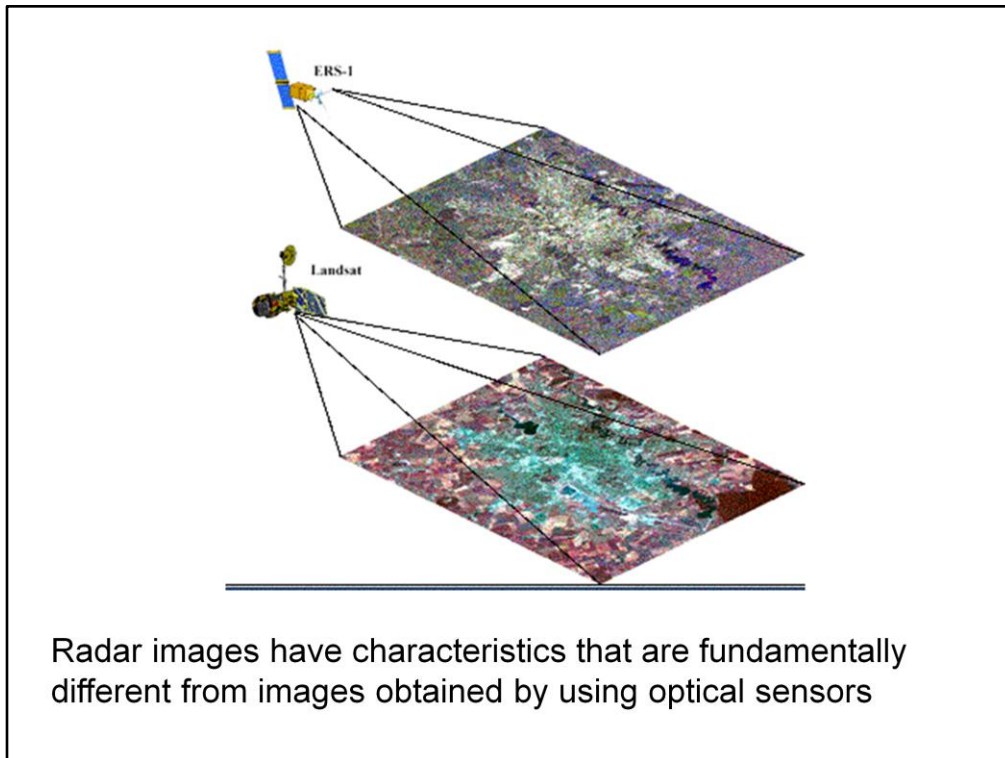
February 13, 2012

Advantages of Radar/Microwave Instruments

1. All weather: cloud and smoke penetration
2. **Active systems:** Day or night instruments
3. No requirement for sun synchronous observations
4. Spatial patterns can be interpreted like optical images

Disadvantages for Radar/Microwave Instruments

1. World is less well understood in mm and cm ranges
2. Visual interpretation complex because of the look angle geometry
3. More complex to process for physical units (Navier-Stokes equations for fluid mechanics)



Radar images have certain characteristics that are fundamentally different from images obtained by using optical sensors such as Landsat, SPOT or aerial photography. These specific characteristics are the consequence of the imaging radar technique, and are related to radiometry ([speckle](#), texture or geometry).

During radar image analysis, the interpreter must keep in mind the fact that, even if the image is presented as an analog product on photographic paper, the radar "sees" the scene in a very different way from the human eye or from an optical sensor; the grey levels of the scene are related to the relative strength of the microwave energy backscattered by the landscape elements.

Shadows in radar image are related to the oblique incidence angle of microwave radiation emitted by the radar system and not to geometry of solar illumination. The false visual similarity between the two types of images usually leads to confusion for beginners in interpretation of radar images.

Elements of interpretation of radar imagery can be found in several publications for example, in "The use of Side-Looking Airborne Radar imagery for the production of a land use and vegetation study of Nigeria" (Allen, 1979).

Grey levels in a radar image are related to the microwave backscattering properties of the surface. The intensity of the backscattered signal varies according to roughness, dielectric properties and local slope. Thus the radar signal refers mainly to geometrical properties of the target.

In contrast, measurements in the visible/infrared region use optical sensors where target response is related to colours, chemical composition and temperature.

The following parameters are used during radar imagery interpretation:

- tone
- texture
- shape
- structure
- size.

Several principles of photo-interpretation can be used for radar imagery interpretation and we can distinguish three steps:

- *photo reading*: this corresponds to boundaries recognition on the basis of the previously listed parameters.

- *photo analysis*: this corresponds to the recognition of what is within the boundaries previously identified.

- *deductive interpretation of image*: At this stage, the interpreter uses all his thematic knowledge and experience to interpret the data.

Before describing texture, we can propose the following definitions:

- *Tone*

Radar imagery tone can be defined as the average intensity of the backscattered signal. High intensity returns appear as light tones on a positive image, while low signal returns appear as dark tones on the imagery.

- *Shape*

It can be defined as spatial form with respect to a relative constant contour or periphery, or more simply the object's outline. Some features (streets, bridges, airports...) can be distinguished by their shape. It should be noted that the shape is as seen by the oblique illumination: slant range distance of the radar.

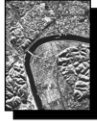
- *Structure*

The spatial arrangement of features throughout a region with recurring configuration.

- *Size*

The size of an object may be used as a qualitative recognition element on radar imagery. The size of known features on the imagery provides a relative evaluation of scale and dimensions of other terrain features.

Keywords: ESA European Space Agency - Agence spatiale europeenne, observation de la terre, earth observation, satellite remote sensing, teledetection, geophysique, altimetrie, radar, chimique atmosferique, geophysics, altimetry, radar, atmospheric chemistry.



RADAR Wavelengths and Frequencies used in Active Microwave Remote Sensing Investigations

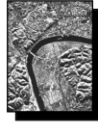
| <i>Band Designations (common wavelengths shown in parentheses)</i> | <i>Wavelength (λ) in cm</i> | <i>Frequency (ν) in GHz</i> |
|----------------------------------------------------------------------------|----------------------------------------------------|------------------------------------------------|
| K | 1.18 - 1.67 | 26.5 to 18.0 |
| K_a (0.86 cm) | 0.75 - 1.18 | 40.0 to 26.5 |
| K_u | 1.67 - 2.4 | 18.0 to 12.5 |
| X (2.0 and 3.2 cm) | 2.0 - 3.8 | 12.5 - 8.0 |
| C (7.5, 6.0 cm) | 3.8 - 7.5 | 8.0 - 4.0 |
| S (8.0, 9.6, 12.6 cm) | 7.5 - 15.0 | 4.0 - 2.0 |
| L (23.5, 24.0, 25.0 cm) | 15.0 - 30.0 | 2.0 - 1.0 |
| P (68.0 cm) | 30.0 - 100 | 1.0 - 0.3 |

Where $C = v\lambda$

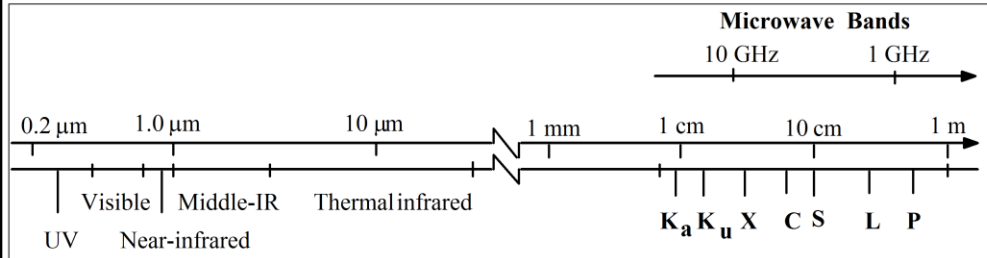
$$\lambda = c/\nu$$

Jensen, 2000

K band radars mostly used for atmospheric observations for weather; X, C, S, L, and P used for terrestrial observations



Active Microwave (RADAR) Commonly Use Frequencies

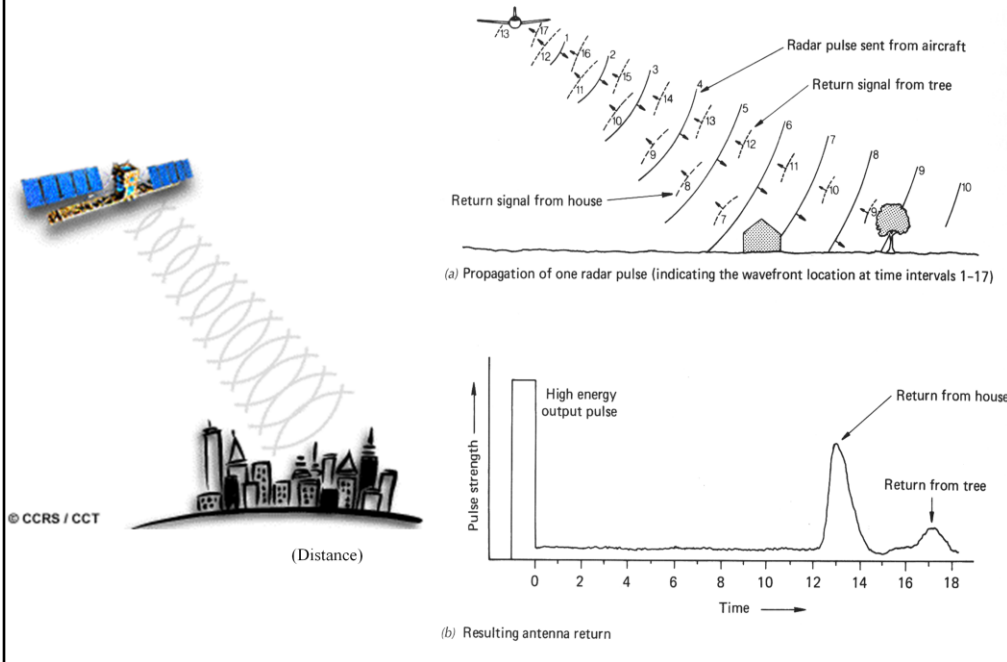


A **pulse** of electromagnetic radiation is emitted by the transmitter through the antenna. It is of a specific wavelength and duration (i.e., it has a **pulse length** measured in microseconds (μsec), a **polarization** (vertical, horizontal, cross), and wavelengths measured in mm or cm).

Jensen, 2000

Note that this is a log scale and not linear. Know size scale for K, X, C, L, and P bands

RADAR Principles



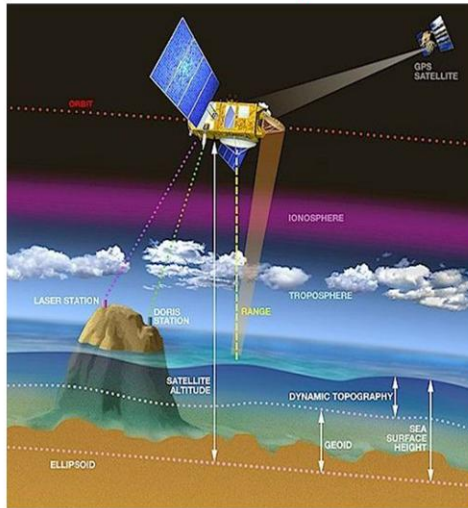
Slant range (SR) is distance between transmitter and object

$$SR = ct/2$$

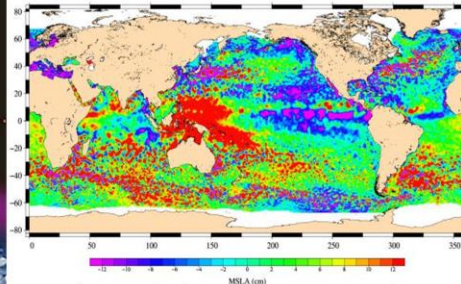
c = speed of light

t = time between transmission and echo reception

Radar Altimetry



DUACS Map of Sea Level Anomaly - Jason2+Jason1



Tandem Mission of Jason -1 and -2 Brings Ocean Currents Into Sharper Focus April 2009

The return measures: surface height, amplitude and waveform, from this we can measure **wave height and wind speed** over the oceans, and more generally, the backscatter coefficient and surface roughness for most surfaces from which the signal is reflected.

7

The principle is that the altimeter emits a radar wave and analyses the return signal that bounces off the surface. Surface height is the difference between the satellite's position on orbit with respect to an arbitrary reference surface (the Earth's centre or a rough approximation of the Earth's surface: the reference ellipsoid) and the satellite-to-surface range (calculated by measuring the time taken for the signal to make the round trip). Besides surface height, by looking at the return signal's amplitude and waveform, we can also measure wave height and wind speed over the oceans, and more generally, backscatter coefficient and surface roughness for most surfaces off which the signal is reflected.

If the altimeter emits in two frequencies, the comparison between the signals, with respect to the frequencies used, can also generate interesting results (rain rate over the oceans, detection of crevasses over ice shelves, etc).

To obtain measurements accurate to within a few cms over a range of several hundred kms requires an extremely precise knowledge of the satellite's orbital position. Thus several locating systems are usually carried onboard altimetry satellites. Any interference with the radar signal also needs to be taken into account. Water vapor and electrons in the atmosphere, sea state and a range of other parameters can affect the signal round-trip time, thus distorting range measurements. We can correct for these interference effects on the altimeter signal by measuring them with supporting instruments, or at several different frequencies, or by modelling them. Altimetry thus requires a lot of information to be taken into account before being able to use the data. Data processing is also a major part of altimetry, producing data of different levels optimized for different uses at the highest levels.

Who measures this?

There are four altimetry satellites currently in service:

- Two satellites - Jason-1 (CNES and NASA) and Jason-2 (CNES, Eumetsat, NASA and NOAA) have a short repeat cycle (10 days), to enable observing the same spot on the ocean frequently but with relatively widely-spaced ground tracks (315 kms at the equator). Jason-2 is on the same orbit as their predecessor, Topex/Poseidon (1992-2005; NASA), while Jason-1 has been shifted on a new orbit, in tandem with Jason 2, with a 5-day time lag.
- One satellite - Envisat (ESA) has a longer repeat cycle (35 days) but tighter ground track spacing (90 kms at the equator), and another one, ERS-2, on the same track with a small time-lag (but no longer any onboard recorder).

This image is the first global map of ocean surface topography produced with data from the new interleaved tandem mission of the Jason-1 and Ocean Surface Topography Mission (OSTM)/Jason-2 satellites.

In January 2009, Jason-1 was established on opposite side of earth from Jason-2 (5 day cycle offset). It takes 10 days to cover the globe and return to a site over the ocean. So, in this new tandem configuration, Jason-1 flies over the same region of the ocean that OSTM/Jason-2 flew over five days earlier.

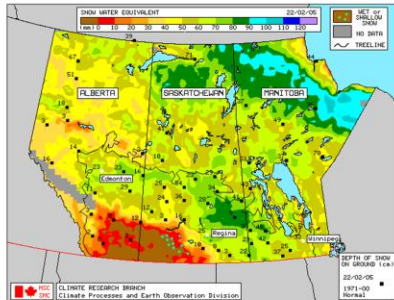
Working together, the two spacecraft measure the surface topography of the ocean twice as often as was possible with one satellite. Combining data makes it possible to map smaller, more rapidly changing features. This image shows sea-level anomaly data from the first 14 days of the joint mission for, the period beginning on Feb. 20-Mar 2, 2009. An anomaly is a departure from a long term average value.

Red and yellow are regions where sea levels are higher than normal. Purple and dark blue show where sea levels are lower. A higher-than-normal sea surface is usually a sign of warm waters below, while lower sea levels indicate cooler than normal temperatures. The small-sized patches of highs and lows are ocean eddies, the storms of ocean weather that carry most of the energy of ocean circulation. These are not well observed with only one satellite.

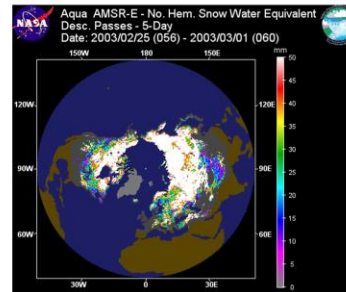
Snow: Remote Sensing/Satellite Capabilities

Snow Depth/Snow Water Equivalent

- passive microwave – only proven satellite technique for SWE retrieval; also hyperspectral (research grade)
- historical record back to 1978 (SMMR, SSM/I) available in consistent 25 km grid format
- requires regionally-tuned algorithms to take into account landscape effects, variation in physical properties → validation is a challenge!
- On-going research into SWE retrieval from active microwave (SAR) – offers higher spatial resolution capability



SSM/I SWE map for Canadian prairie region
(produced by MSC weekly for 15+ years)



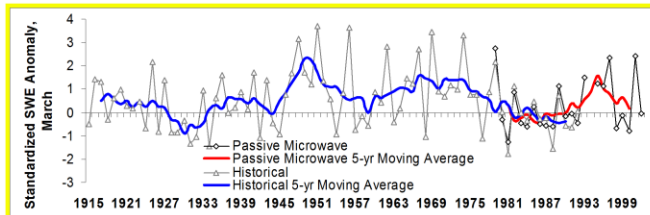
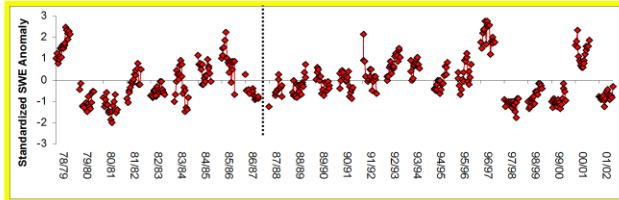
Global SWE map from AMSR-E
(limited validation)

Climate Research Applications of Passive Microwave SWE

- Availability of SMMR and SSM/I in consistent gridded format (EASE-Grid) → 25 winter seasons (1978/79 – 2002/03)
- Investigation of spatial and temporal variations in snow cover in relation to climate/atmospheric circulation
- Evaluation of climate model snow cover outputs – GCM, RCM



Winter season (DJF) SWE anomalies produced from passive microwave satellite data time series. Dashed line denotes transition from SMMR to SSM/I.



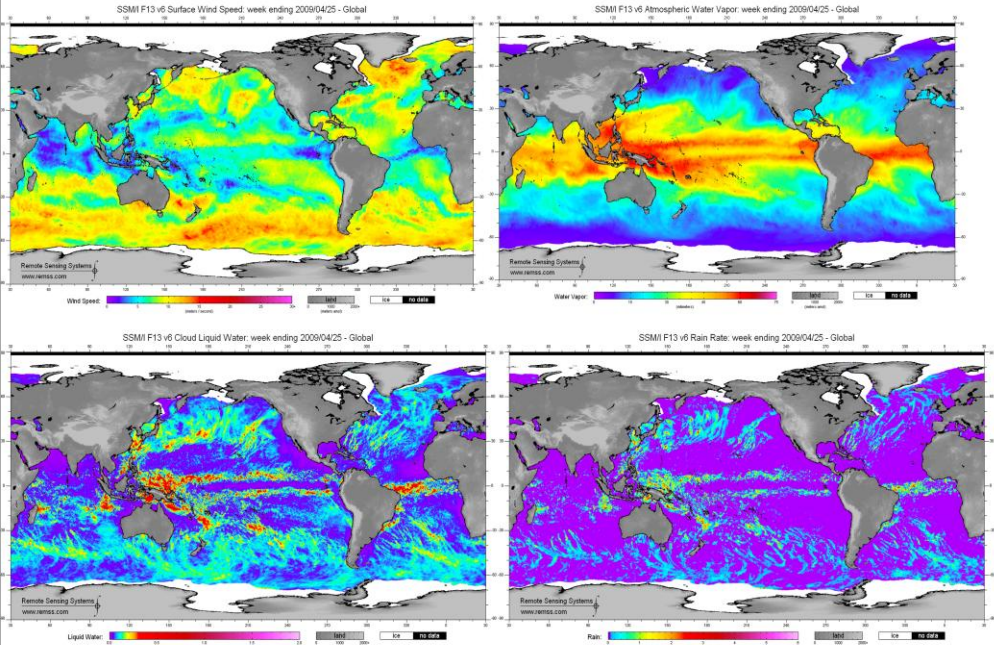
Merging Conventional (1915-1992) and Passive Microwave (1978 – 2002) Time Series

Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR)

Data designed to provide a consistent time series of sea ice concentrations (the fraction, or percentage, of ocean area covered by sea ice) spanning the coverage of several passive microwave instruments. Data set is generated from brightness temperature data derived from Nimbus-7 satellite.

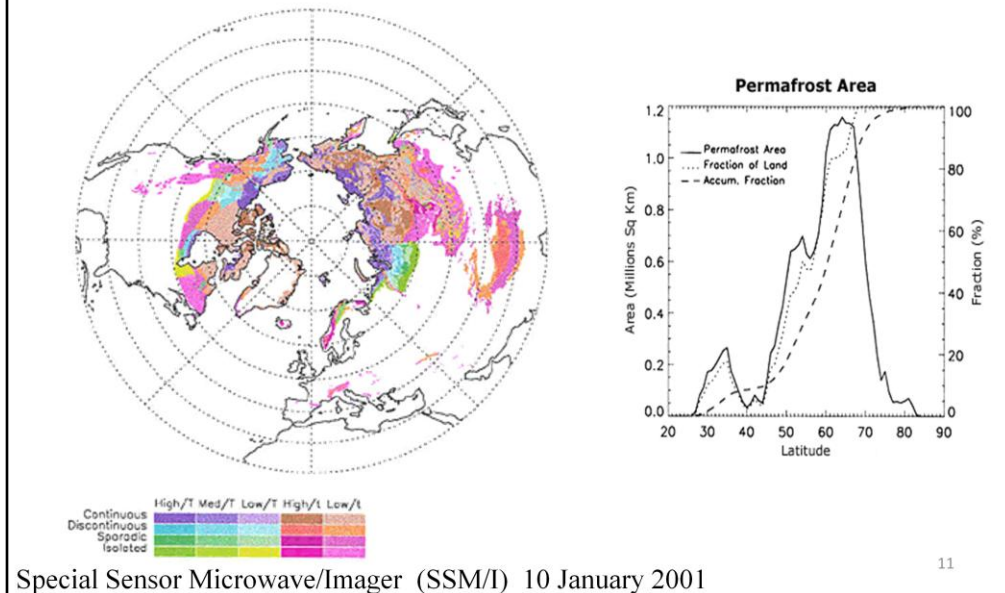
Special Sensor Microwave/Imager (SSM/I)

Weekly Composite SSM/I Images for week ending April 25, 2009



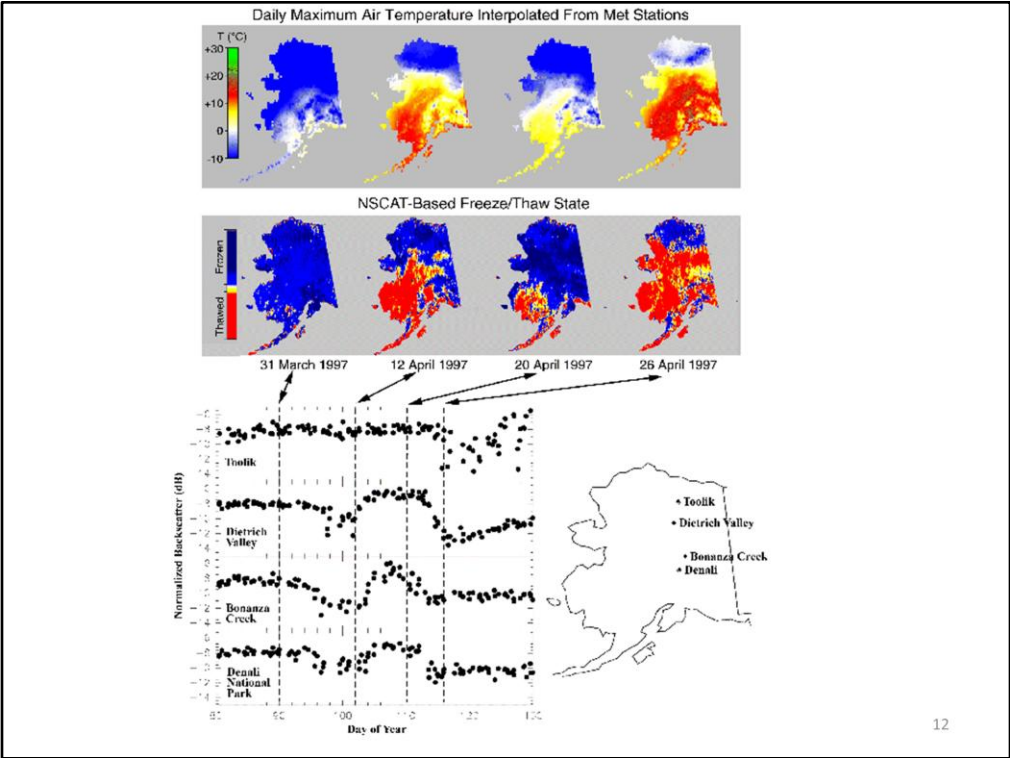
Special Sensor Microwave/Imager (SSM/I) on DMSP Satellite

Global Snow Depth Mapping: DMSP Satellite



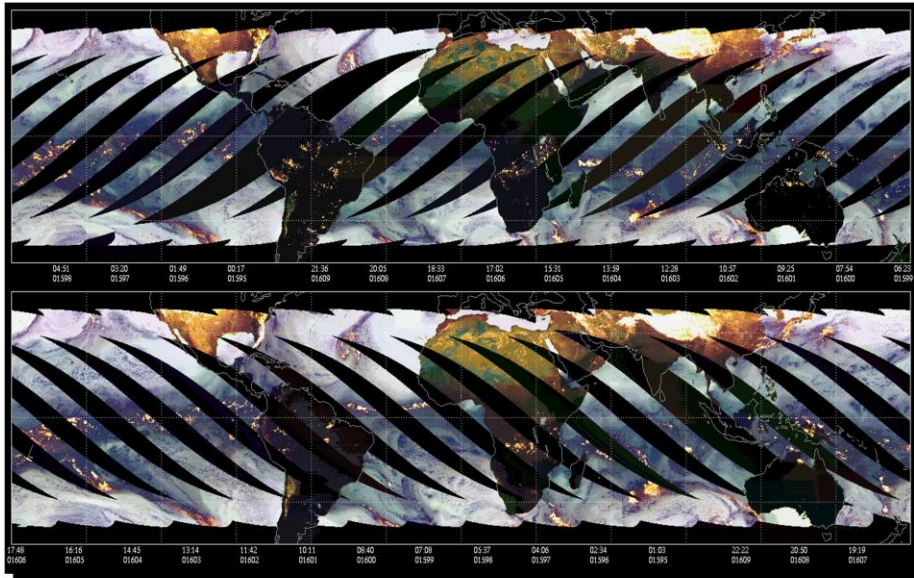
Permafrost regions occupy approximately 22.79 million square kilometers (about 24 percent of the exposed land surface) of the Northern Hemisphere ([Zhang et al. 2003b](#)). Permafrost occurs as far north as 84°N in northern Greenland, and as far south as 26°N in the Himalayas. Because reliable data on hemispheric-scale permafrost extent have only recently become available, this site provides just a snapshot of current permafrost conditions rather than time-series data.

IPA map: Distribution of permafrost and ground ice in the Northern Hemisphere, based on the EASE-Grid version of the International Permafrost Association map. "High," "Med," and "Low" refer to ice content, and "T" and "t" refer to thick and thin overburden, respectively. Image courtesy International Permafrost Association, supplied by Tingjun Zhang, National Snow and Ice Data Center, University of Colorado, Boulder.



Tropical Rainfall Measurement Mission (TRMM)

Passive Microwave Imager (TMI) Data on TRMM 9 March 1998

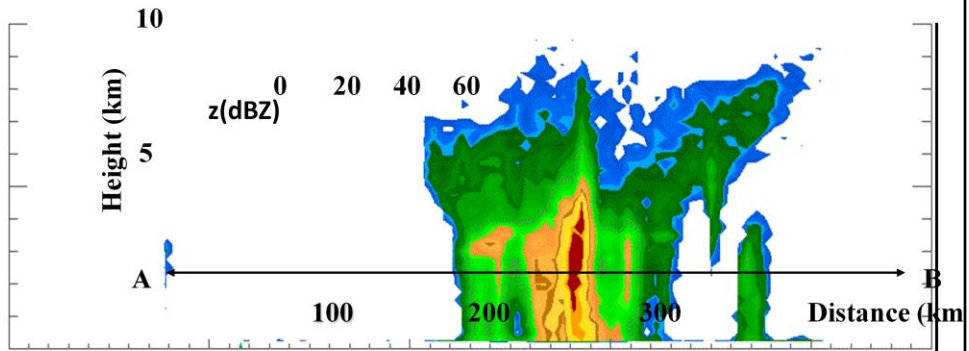
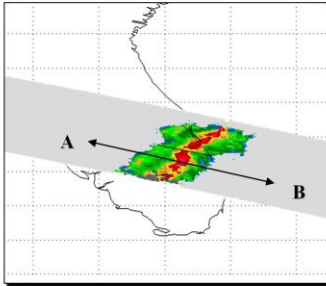


10.7 GHz (X band, ~3cm) frequency provides a linear response to rainfall

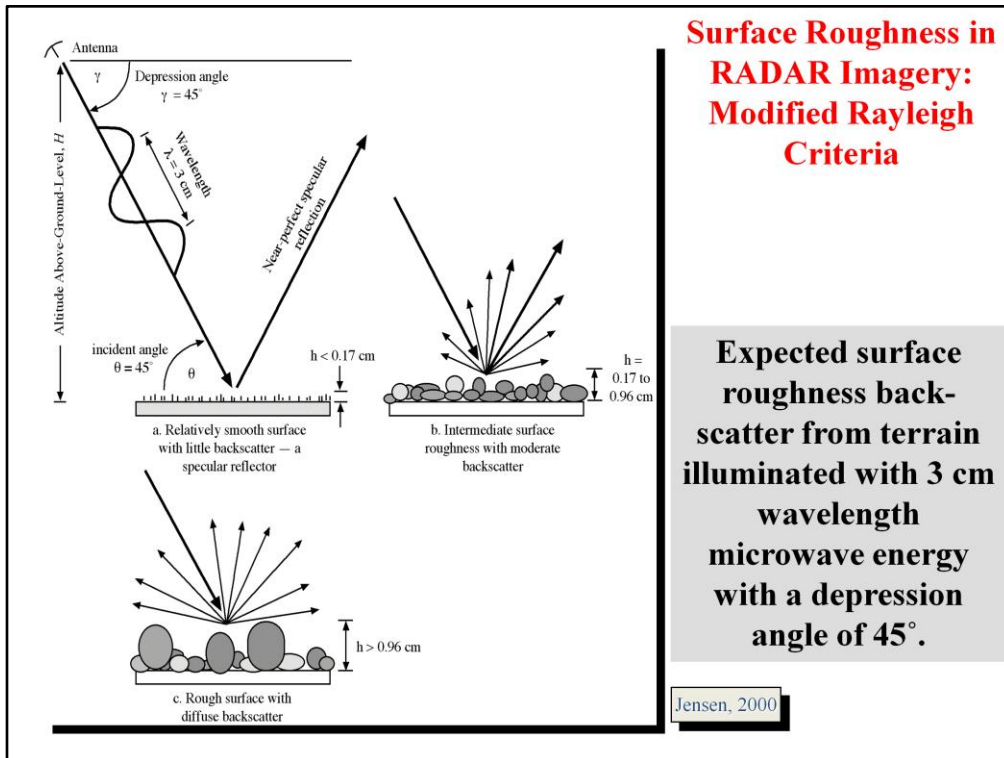
13
Jensen 2000

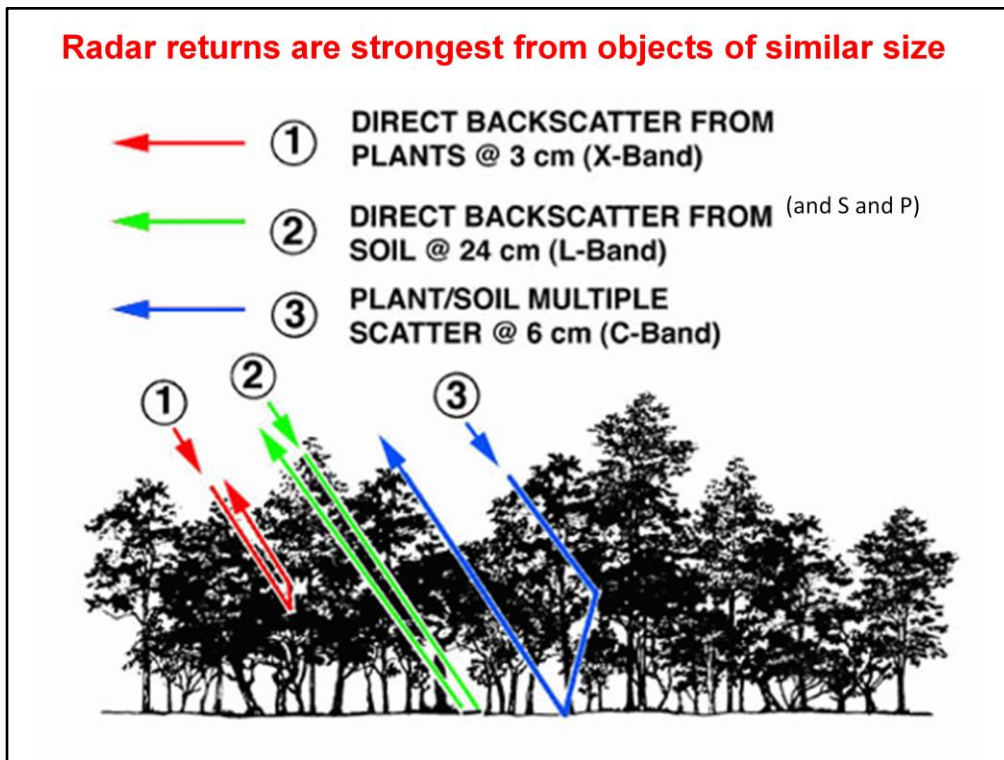
TMI computes surface rain, convective surface rain, and profiles of hydrometeors (cloud liquid, cloud ice, water vapor, etc.) at 14 vertical levels. A passive microwave sensor that measures five frequencies: 10.7 (45 km spatial resolution), 19.4, 21.3, 37, and 85.5 GHz (5 km spatial resolution). It has dual polarization at four of the frequencies. Swath width is 487 miles (780 km). The 10.7 GHz (X band, ~3cm) frequency provides a linear response to rainfall.

TRMM Precipitation Radar (PR) data obtained on March 9, 1998



Along-track cross-section of TRMM Precipitation Radar data obtained on March 9, 1998

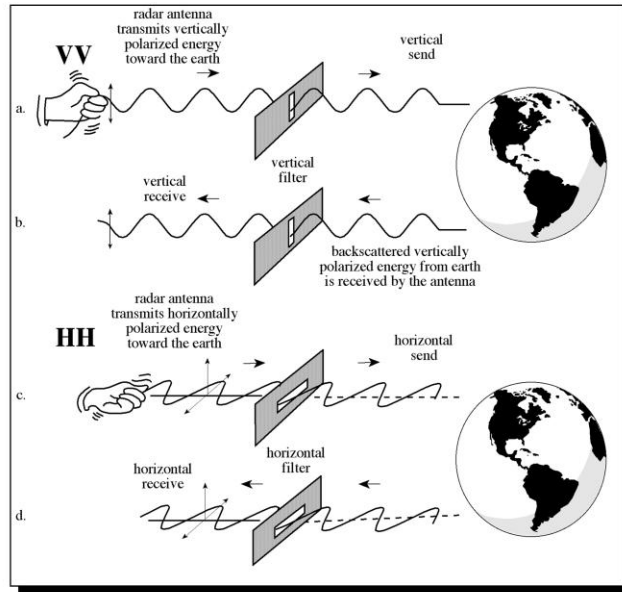




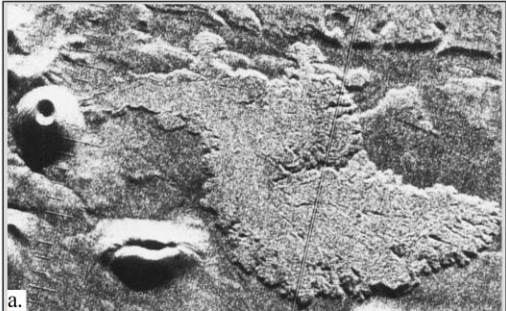
Radar signals can be generated at several different wavelengths, which is useful because the energy has an ability to travel through vegetation or soil to different amounts that are controlled by the dielectric constant of the material. As this diagram shows, short wavelength radar (2 cm) will be reflected from the tops of trees. Long wavelength radar (24 cm) data will normally go right down to the ground and be reflected off of the surface. Intermediate wavelength radars (say, 6 cm) will sometimes experience multiple scattering events within the canopy.

If we had a set of different wavelength radar images over a forest, it should be possible to use this changing penetration capability to study the structure of the trees and the total amount of material ("biomass") in the forest.

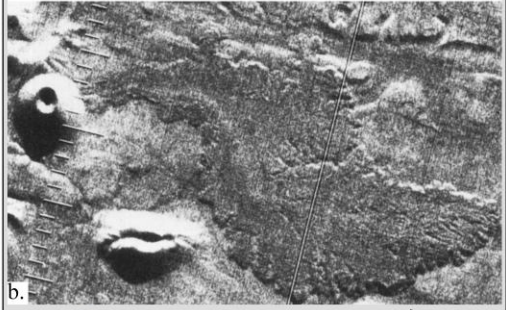
Polarization



Polarization



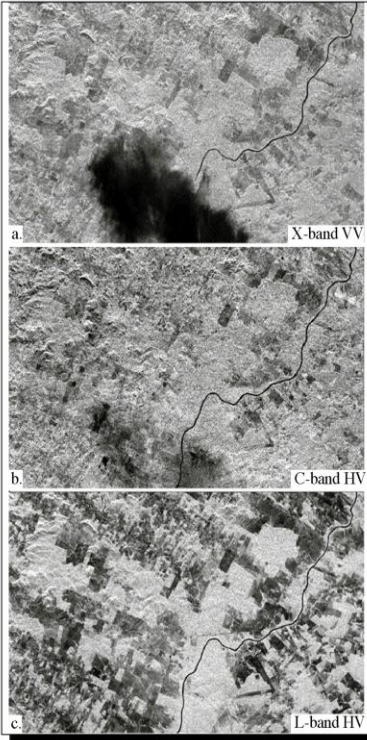
a.
K_a - band, HH polarization ↓ look direction



b.
K_a - band, HV polarization → N

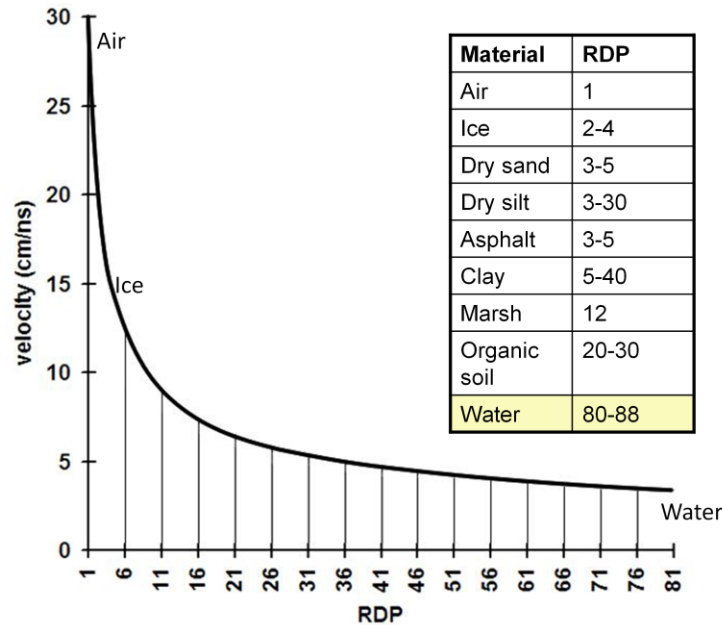
Jensen, 2000

**SIR-C/X-SAR Images of
part of Rondonia, Brazil,
April 10, 1994**



Jensen, 2000

Relative dielectric constant (=dielectric permittivity) is inversely related to radar travel velocity

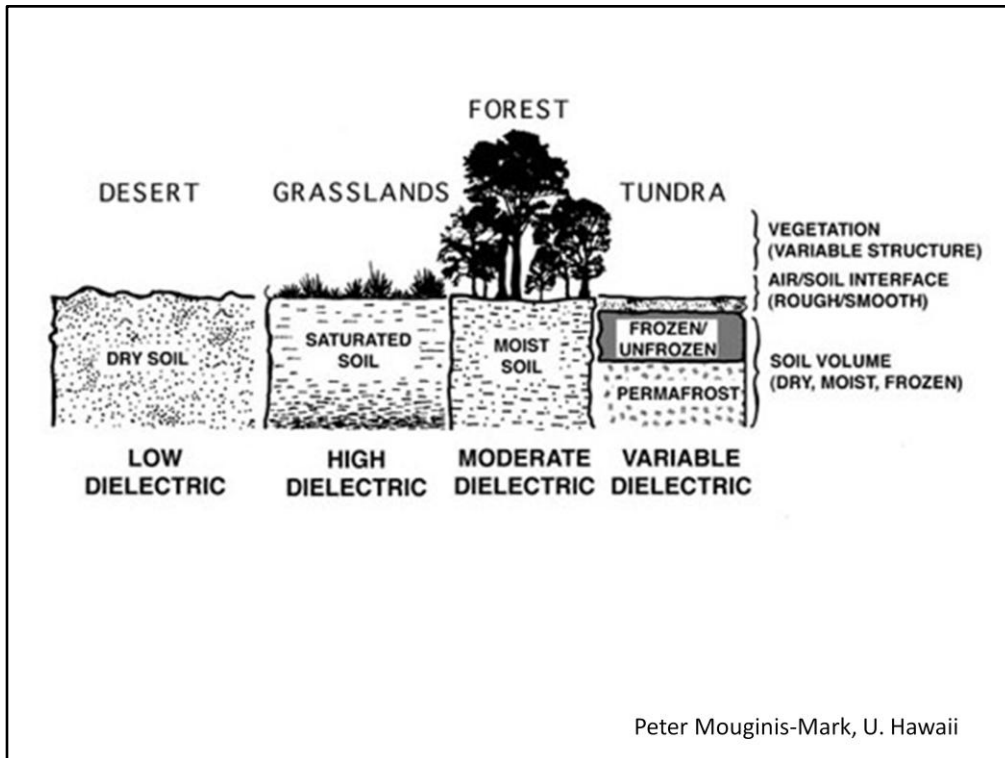


Relative dielectric permittivity (also called the “dielectric constant”) is inversely related to radar travel velocity.

RDP is the ratio of a material's electrical permittivity to the electrical permittivity in a vacuum (defined as equal to 1). Relative dielectric permittivities of materials vary somewhat with composition, but the greatest factor affecting RDP is **moisture content** and its distribution. Bulk density, porosity, physical structure and temperature will all affect the moisture content, but by themselves are not the controlling factor, as they all affect moisture in some fashion.

RDP it is mostly a measurement of how effectively an electromagnetic wave can move through a medium, and therefore is more a measure of velocity rather than overall ability to transmit energy. For instance, the RDP of fresh water is very high (about 80), and radar energy can easily be transmitted through ice without being attenuated. A bed of peat, which is composed almost wholly of organic material and fresh water, also has a high RDP but will also allow radar transmission to great depths, but at much slower speeds than in saturated sand or other materials. The relative dielectric permittivity of air, which exhibits only negligible electromagnetic polarization, is approximately 1.0003, and is usually rounded to one. The RDP of many naturally occurring dry materials, varies only between about 3 and 5. But just a small amount of water causes the RDP to increase.

An important property of a dielectric is its ability to support an electrostatic field while dissipating minimal energy in the form of heat. The lower the *dielectric loss* (the proportion of energy lost as heat), the more effective is a dielectric material. Another consideration is the *dielectric constant*, the extent to which a substance concentrates the electrostatic lines of flux.



Different vegetation types (e.g., desert, grasslands, forests or frozen tundra) will all have different backscatter properties. In addition, the basic reflectivity of the soil, called the "dielectric constant" will change depending on the amount of water that the soil contains. Dry soil has a low dielectric constant, so that little radar energy will be reflected. Saturated soil will have the opposite effect, and will be a strong reflector. Moist and partially frozen soils will have intermediate values.

Thus, if we keep the radar incidence angle constant, we can use radar to study large differences in moisture content of the soil. This is often done in deserts (looking for subsurface water) or in tropical rain forests (looking for flooded rivers beneath the tree canopies).

C-Band HH Polarization Image, March 12, 1998. Dry Snow Pack Conditions



Eastern Ontario, Canada

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CV-580 C-Band HH polarization image of Casselman study site. March 12, 1998. Dry snow pack conditions

Microwave sensors have all weather imaging capabilities and are sensitive to changes in the dielectric constant within a snow pack. Airborne polarimetric C-band SAR data was collected on [December 1, 1997, March 6 and 12, 1998](#), over two study areas in Eastern Ontario, Canada. Field measurements of snow pack properties and weather conditions were gathered along flight lines over ploughed agriculture fields during each airborne data acquisition. The multi-temporal polarimetric data were analyzed with respect to changes in the SAR polarimetric signatures and polarimetric parameters as a function of changing snow pack conditions. Polarimetric SAR information of derived snow parameters can identify snow state and structure.

Horizontal polarizations may underestimate snow extent during early winter [when snow is clean], but provide the best overall estimates as winter progresses.

Dry snow has more backscatter than wet snow

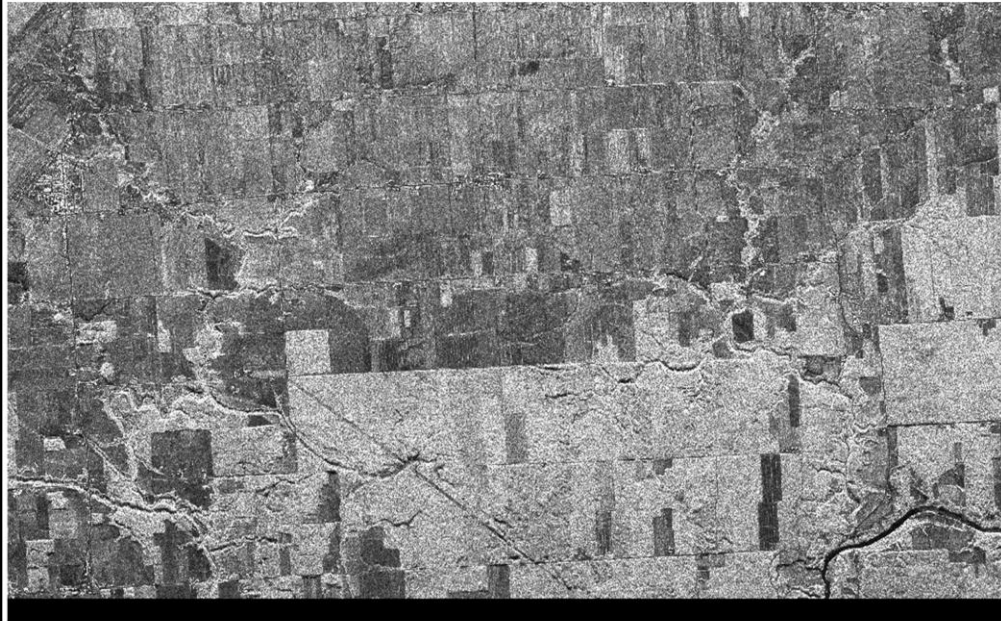
Snow is more reflective at short (ka) wavelengths

Snow has low backscatter at longer wavelengths (X, C, L, S, P)

Results show some microwave parameters are more sensitive to changes in snow pack parameters, and respond differently to various snow conditions. A number of SAR parameters (linear polarizations, pedestal height, co-polarimetric plots, total power) exhibited significant differences between snow structure in wet/dry snow conditions.

Other parameters, such as the co-polarized phase difference and the linear ratio values, remained unchanged between the image dates. SAR polarimetric parameters provide information on snow state (wet/dry) and structure within the snow pack; conditions which complicate the extraction of Snow Water Equivalent measurements from passive microwave data.

C-Band VV Polarization March 12, 1998. Dry Snow Pack Conditions



23

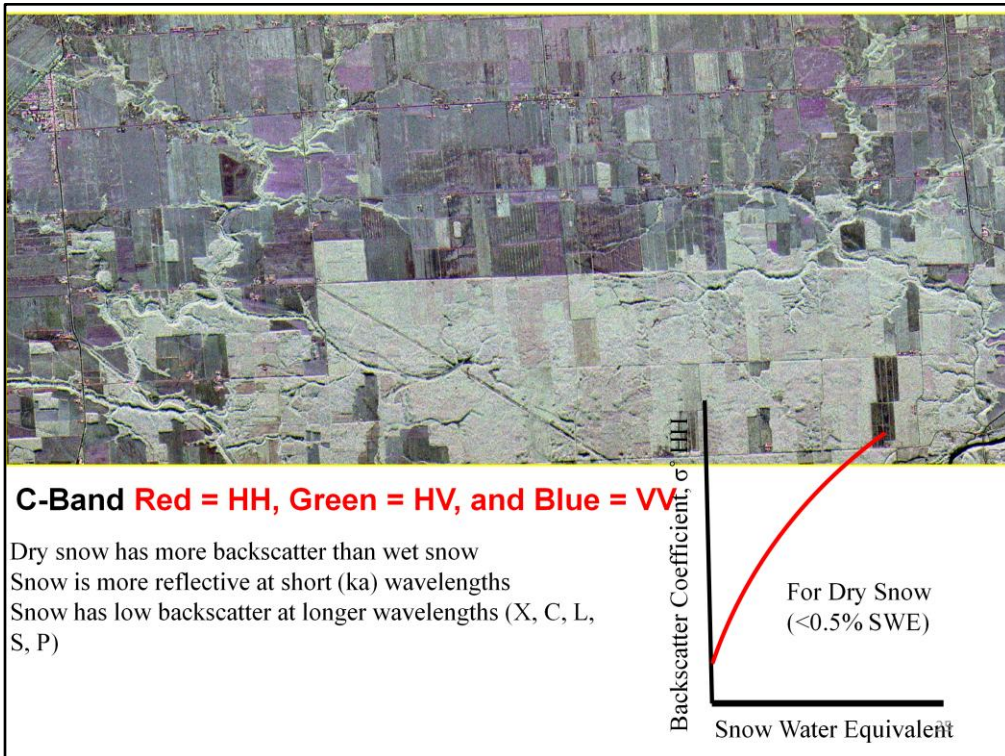
CV-580 C-Band VV polarization image of Casselman study site. March 12, 1998. Dry snow pack conditions
Vertical polarization tends to overestimate SWE over bare frozen ground and desert soils.

C-Band HV Polarization March 12, 1998. Dry Snow Pack Conditions

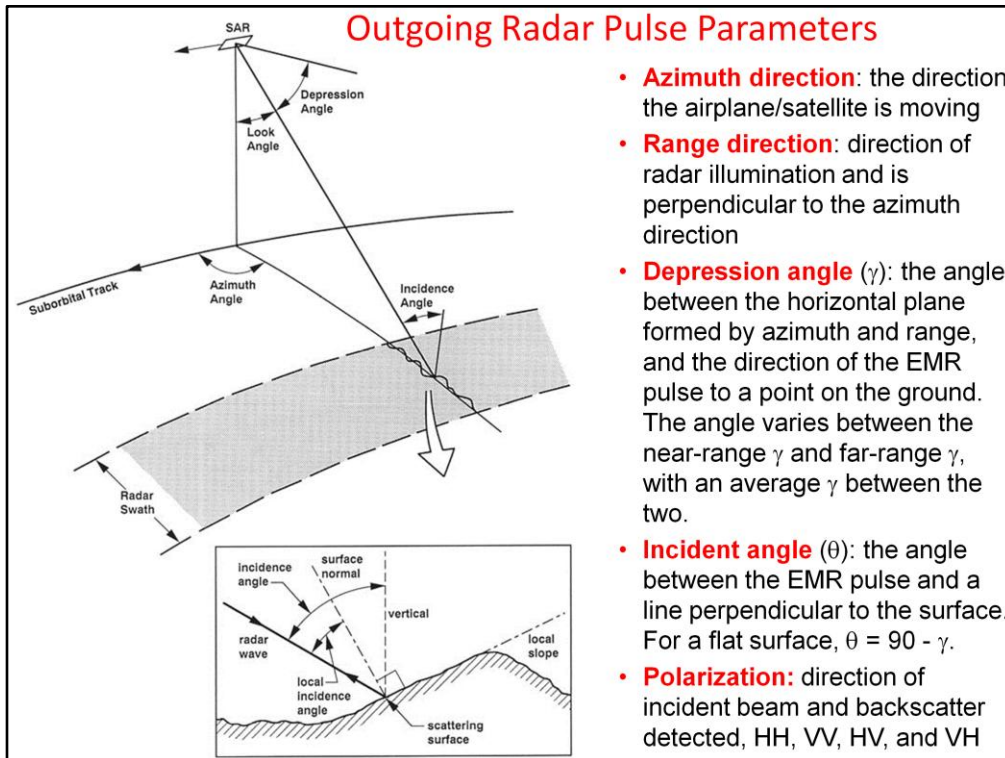


24

CV-580 C-Band HV polarization image of Casselman study site. March 12, 1998. Dry snow pack conditions



C-band Multi-polarization composite image of Casselman study site. March 12, 1998. Dry snow pack conditions.
 Red = HH, Green = HV, and Blue = VV



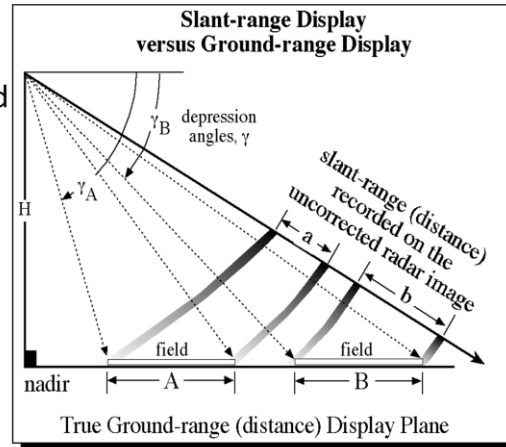
Geometry of radar image acquisition. The depression angle is complementary to the look angle; from satellite, incidence angle may be affected by planetary curvature. Local incidence angle may be affected by local topography.

Slant-Range vs. Ground-Range

- **Slant-range (SR) distance** is the *straight-line distance* between the transmitter and the object.
- **Ground-range (GR) distance** is the *horizontal distance* between the transmitter and the object.
- We can easily convert between the two:

$$GR = \sqrt{SR^2 - H^2}$$

$$GR = H \sqrt{\frac{1}{\sin^2 \gamma} - 1}$$



Radar imagery has than that produced by most conventional remote
sensor systems (cameras, multispectral scanners or area-array detectors).

- Uncorrected radar imagery is displayed in what is called **slant-range geometry**, i.e., it is based on the actual distance from the radar to each of the respective features in the scene.

It is possible to **convert the slant-range display** into the true **ground-range display** on the x-axis so that features in the scene are in their proper planimetric (x,y) position relative to one another in the final radar image.

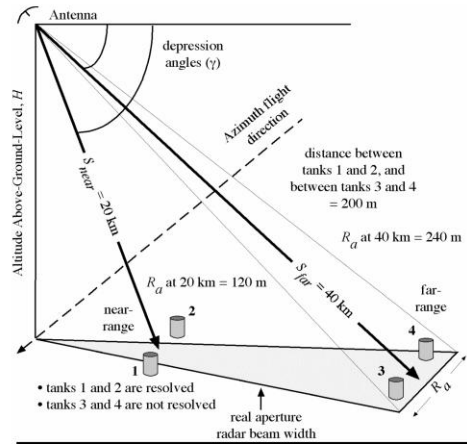
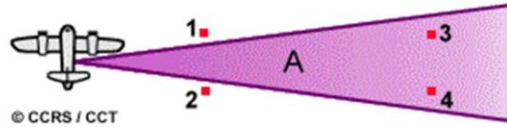
Spatial Resolution of SLAR

Azimuth resolution (along-track)

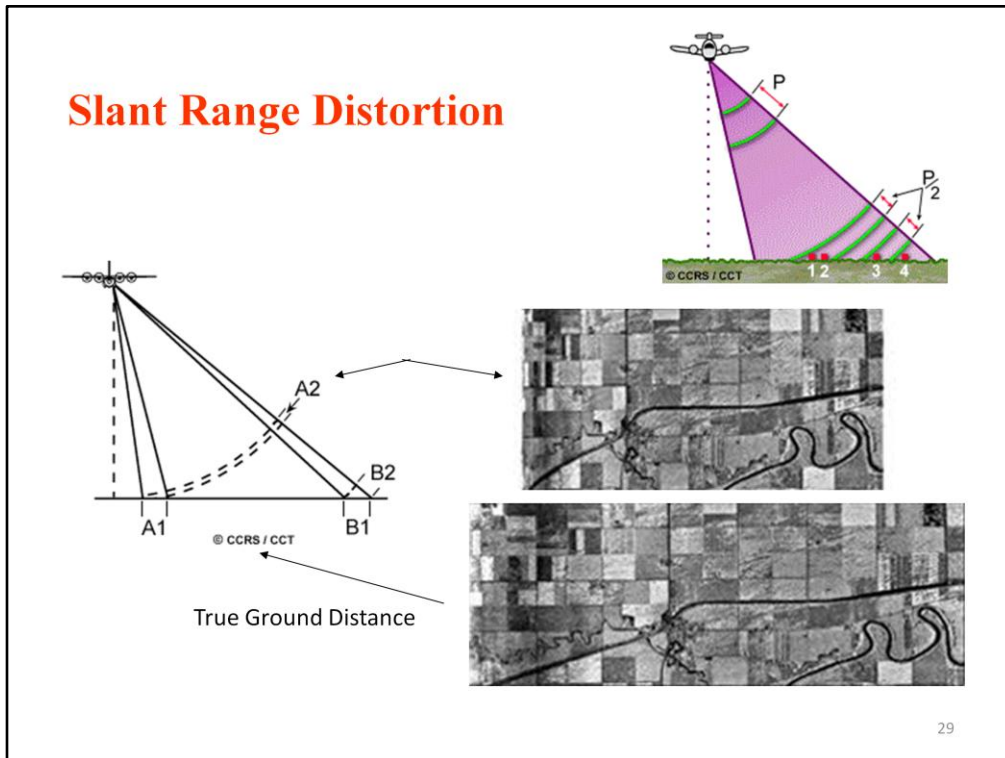
- Width of the terrain strip the radar beam illuminates
- The width is proportional to the wavelength of the EMR and inversely proportional to the antenna length:

$$R_a = \frac{S \cdot \lambda}{L} \quad R_a = \left(\frac{H}{\sin \gamma}\right) \cdot \frac{\lambda}{L}$$

- R_a = azimuth resolution
- S = slant-range distance to the point of interest
- λ = wavelength of EMR
- L = antenna length
- it can be set as a function of the height (altitude) of the radar and the depression angle γ



SLAR = Side Looking Airborne Radar A real aperture radar system (RAR), also known as a “brute force radar”. SLAR operates with an antenna that has a discrete physical length, a long (about 5-6 m) antenna. (Aperture is analogous to Field of View.) For a SLAR radar this is *usually* shaped as a section of a cylinder wall. This type produces a beam of non-coherent pulses and uses its length to obtain the desired resolution (related to angular beamwidth) in the azimuthal (flight line) direction.

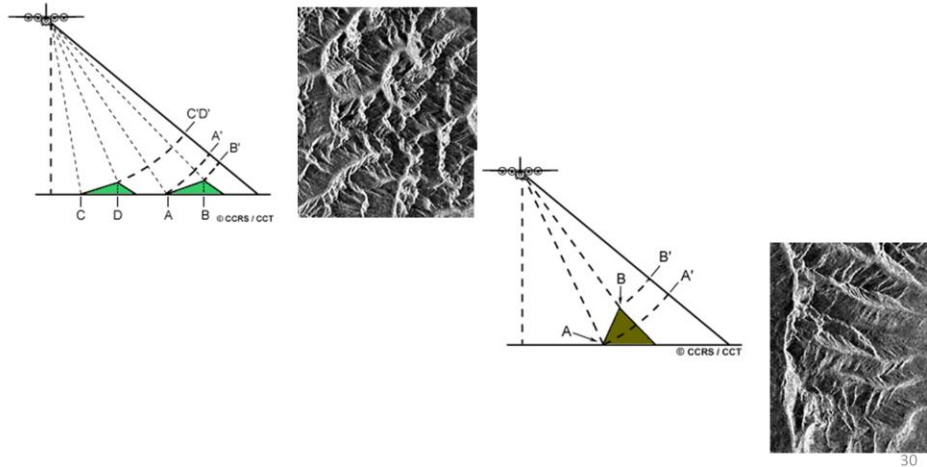


When the radar beam reaches the base of a tall feature tilted towards the radar (e.g. a mountain) before it reaches the top **foreshortening** will occur. Again, because the radar measures distance in slant-range, the slope (A to B) will appear compressed and the length of the slope will be represented incorrectly (A' to B'). Depending on the angle of the hillside or mountain slope in relation to the incidence angle of the radar beam, the severity of foreshortening will vary. Maximum foreshortening occurs when the radar beam is perpendicular to the slope such that the slope, the base, and the top are imaged simultaneously (C to D). The length of the slope will be reduced to an effective length of zero in slant range (C'D'). The figure below shows a radar image of **steep mountainous terrain** with severe foreshortening effects. The foreshortened slopes appear as bright features on the image.

Layover occurs when the radar beam reaches the top of a tall feature (B) before it reaches the base (A). The return signal from the top of the feature will be received before the signal from the bottom. As a result, the top of the feature is displaced towards the radar from its true position on the ground, and "lays over" the base of the feature (B' to A'). **Layover effects** on a radar image look very similar to effects due to foreshortening. As with foreshortening, layover is most severe for small incidence angles, at the near range of a swath, and in mountainous terrain.

Both foreshortening and layover result in **radar shadow**. Radar shadow occurs when the radar beam is not able to illuminate the ground surface. Shadows occur in the down range dimension (i.e. towards the far range), behind vertical features or slopes with steep sides. Since the radar beam does not illuminate the surface, shadowed regions will appear dark on an image as no energy is available to be backscattered. As incidence angle increases from near to far range, so will shadow effects as the radar beam looks more and more obliquely at the surface. This image illustrates **radar shadow effects** on the right side of the hillsides which are being illuminated from the left.

Radar Distortions: foreshortening and layover

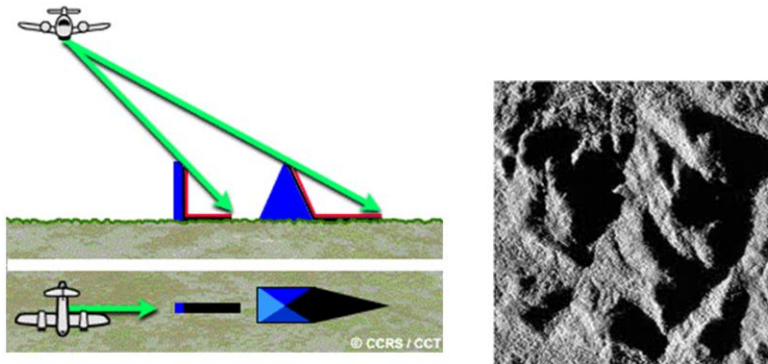


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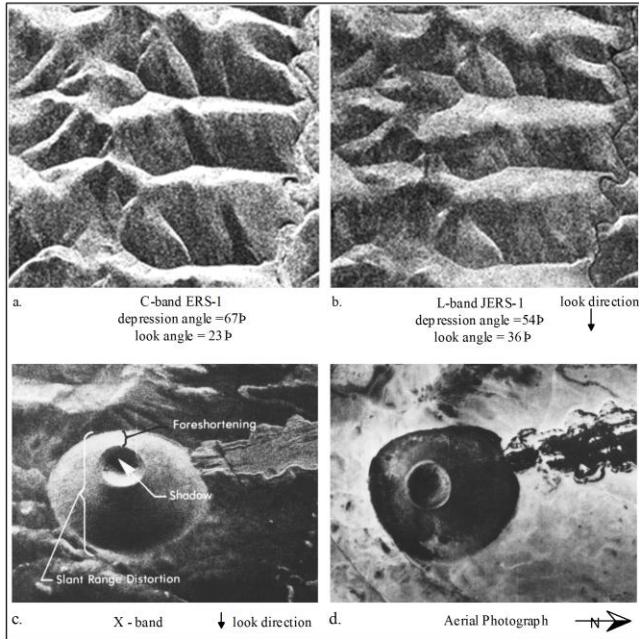
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Radar Shadow

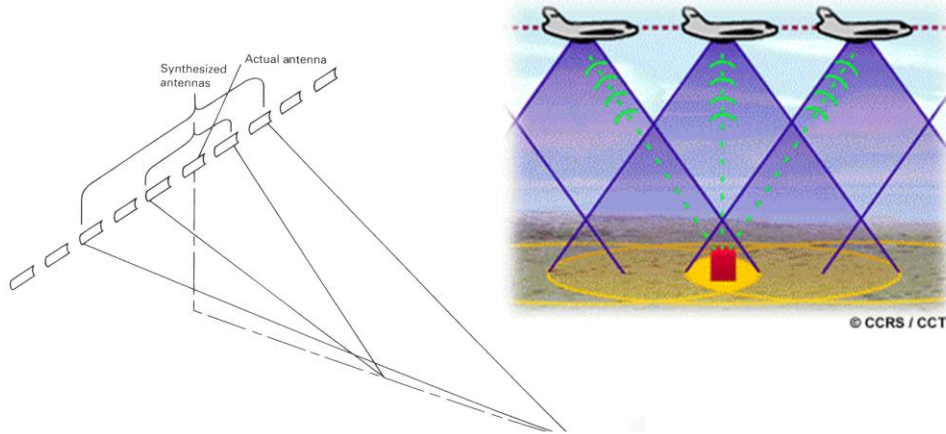


Red surfaces in image are completely in shadow. Black areas in image are shadowed and contain no information.

Geometric Distortions in RADAR



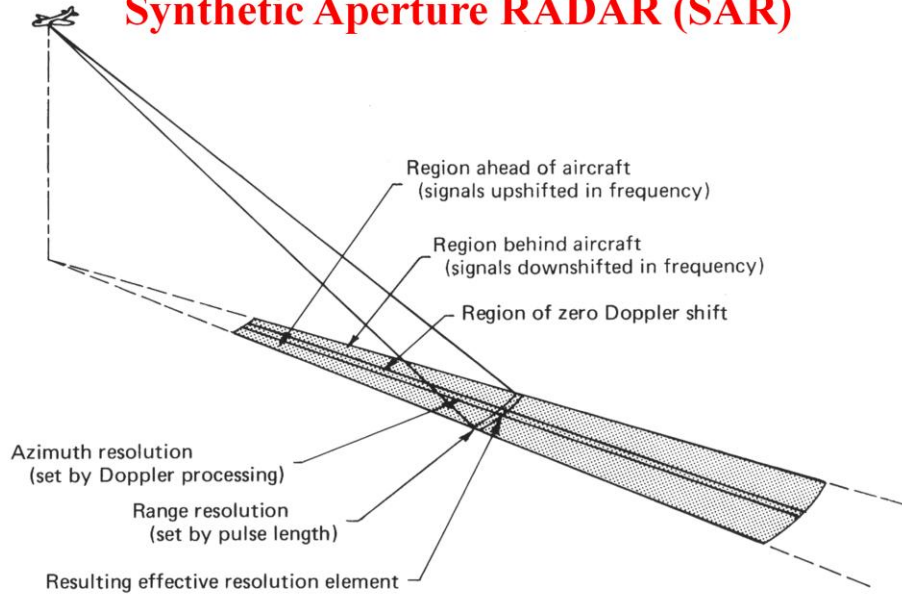
Synthetic Aperture RADAR (SAR)



A longer antenna is “synthesized” electronically by moving the same across the FOV. Recall that the azimuth resolution gets better with longer antennas in SLAR systems.

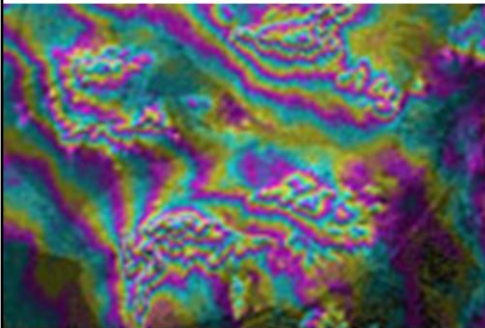
Remote sensing radars can be divided into two categories - real aperture and **synthetic aperture radars** (SAR). Real aperture radars transmit and receive microwave signals with a fixed length antenna. They are limited in their ability to produce resolutions fine enough for most remote sensing applications, simply because it is difficult to transport a very long antenna. To solve this problem synthetic aperture radars (SAR) were developed. SARs have physically shorter antennas, which simulate or synthesize very long antennas. This is accomplished through modified data recording and signal processing techniques.

Synthetic Aperture RADAR (SAR)

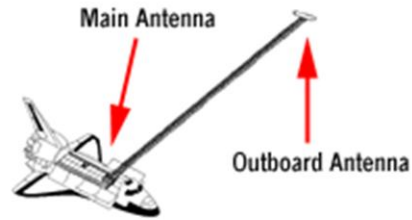


If we can detect the wavelength, we can measure the Doppler shift (lower frequency behind the detector, higher ahead of detector).

Radar Interferometry

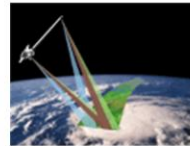


When two interferometric radar data sets are combined (or "interfered") the first product made is called an interferogram. (Portion of SIR-C interferogram of Fort Irwin, California)



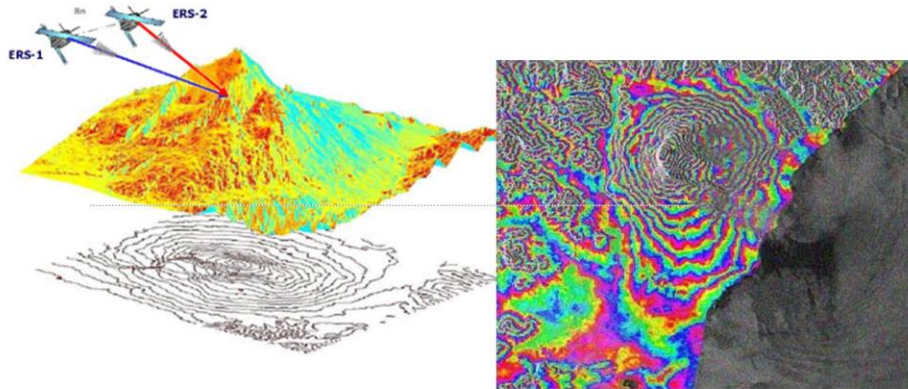
Reflected radar signals collected at two antennas, providing two sets of radar signals separated by a distance.

two images are taken from different vantage points of the same area.



To get two images from different vantage points, a **main antenna** was installed in Space Shuttle Endeavour's cargo bay. The main antenna both transmitted and received radar signals. Once the shuttle was in space, a **mast** was deployed from a canister that was attached to the main antenna truss. The mast extended out 60 meters (200 feet). At the end of the mast, an **outboard antenna** acted as the second vantage point and received radar signals.

Radar Interferometry



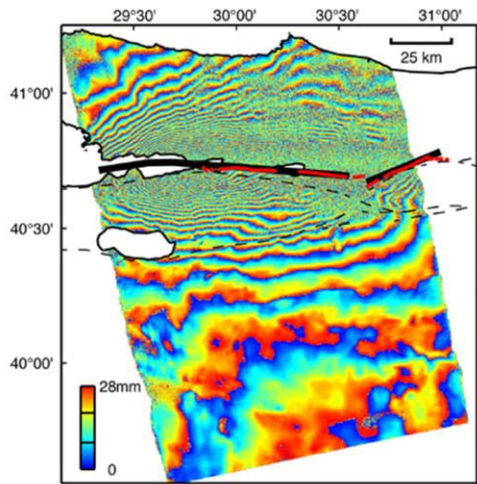
Interferogram of Mount Etna
derived from ERS-1 and ERS-2
Synthetic Aperture Radar data
1-2 August 1995

Differential interferometry involves taking at least two images (with addition of DEM), normally three images, of the same ground area. Passes 1 and 2 are used to form an interferogram of the terrain topography using the basic interferometric technique. Similarly, passes 2 and 3 produce a further interferogram of the same area.

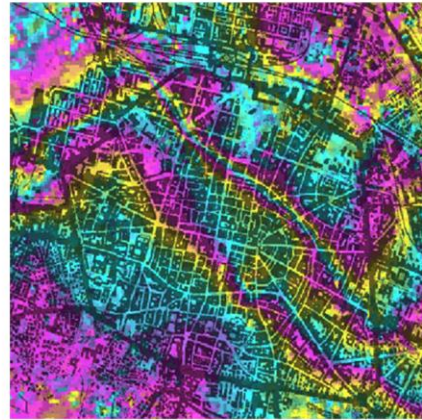
The two interferograms are then themselves differenced to reveal any changes that have occurred in the Earth's surface. Such changes could be the result of shifting geological faults or the buckling of the surface due to volcanic activity.

In principle, the ERS SAR is sensitive to changes of the Earth's surface topography on a scale comparable to the radar wavelength, i.e. 5.6 cm

Change Detection Indicates Earthquake Movement and Subsidence



North Anatolian Fault
Near Istanbul, Turkey



Bologna, Italy

This image is an interferogram that was created using pairs of images taken by Synthetic Aperture Radar (SAR). The images, acquired at two different times, have been combined to measure surface deformation or changes that may have occurred during the time between data acquisition. The images were collected by the European Space Agency's Remote Sensing satellite (ERS-2) on 13 August 1999 and 17 September 1999 and were combined to produce these image maps of the apparent surface deformation, or changes, during and after the 17 August 1999 Izmit, Turkey earthquake. This magnitude 7.6 earthquake was the largest in 60 years in Turkey and caused extensive damage and loss of life. Each of the color contours of the interferogram represents 28 mm (1.1 inches) of motion towards the satellite, or about 70 mm (2.8 inches) of horizontal motion. White areas are outside the SAR image or water of seas and lakes. The North Anatolian Fault that broke during the Izmit earthquake moved more than 2.5 meters (8.1 feet) to produce the pattern measured by the interferogram. Thin red lines show the locations of fault breaks mapped on the surface. The SAR interferogram shows that the deformation and fault slip extended west of the surface faults, underneath the Gulf of Izmit. Thick black lines mark the fault rupture inferred from the SAR data. Scientists are using the SAR interferometry along with other data collected on the ground to estimate the pattern of slip that occurred during the Izmit earthquake. This then used to improve computer models that predict how this deformation transferred stress to other faults and to the continuation of the North Anatolian Fault, which extends to the west past the large city of Istanbul. These models show that the Izmit earthquake further increased the already high probability of a major earthquake near Istanbul.

Subsidence map of the urban area of Bologna from ERS differential interferometry. One colour cycle corresponds to a subsidence velocity of 1 cm/year starting from the stable base of the Appenini (in the south). Data processing by GAMMA.



Mission had X band, C-band, and L-band detectors on an instrument flown on the Space Shuttle

The SRTM data flight occurred Feb. 11-22, 2000 on STS-99 and successfully fulfilled all mission objectives. Following a lengthy calibration and validation phase the 9 terabytes of raw data were processed continent by continent into digital topographic maps, and the last data set was delivered to NGA in January, 2003.

Spaceborne Imaging Radar-C/X-Band Synthetic Aperture Radar ([SIR-C/X-SAR](#)) is a joint U.S.-German-Italian project that uses a highly sophisticated imaging radar to capture images of Earth that are useful to scientists across a great range of disciplines. The instrument was flown on two flights in 1994. One was on space shuttle Endeavour on mission STS-59 April 9-20, 1994. The second flight was on shuttle Endeavour on STS-68 September 30-October 11, 1994.

The SRTM data may be obtained through this URL: <http://dds.cr.usgs.gov/srtm/> and go to the directory where both version 1 and version 2 directories may be found. Please read the appropriate documentation, also found in the directories. 90m data.

USGS Digital Elevation Model (NED) for Continental US



Digital Topography from the Radar Mapping Mission

This anaglyph (stereoscopic view) of North America was generated entirely with data from the Shuttle Radar Topography Mission (SRTM). It is best viewed at or near full resolution with anaglyph glasses. For this broad view the resolution of the data was first reduced to 30 arcseconds (about 928 meters north-south and 736 meters east-west in central North America), matching the best previously existing global digital topographic data set called GTOPO30. The data were then resampled to a Mercator projection with approximately square pixels (about one kilometer, or 0.6 miles, on each side). Even at this decreased resolution the variety of landforms comprising the North American continent are readily apparent.

Active tectonics (structural deformation of the Earth's crust) along and near the Pacific - North American plate boundary creates the great topographic relief seen along the Pacific coast. Earth's crustal plates converge in southern Mexico and in the northwest United States, melting the crust and producing volcanic cones. Along the California coast, the plates are sliding laterally past each other, producing a pattern of slices within the San Andreas fault system. And, where the plates are diverging, the crust appears torn apart as one huge tear along the Gulf of California (northwest Mexico), and as the several fractures comprising the Basin and Range province (in and around Nevada).

Across the Great Plains, erosional patterns dominate, with stream channels surrounding and penetrating the remnants of older smooth slopes east of the Rocky Mountains. This same erosion process is exposing the bedrock structural patterns of the Black Hills in South Dakota and the Ozark Mountains in Arkansas. Lateral erosion and sediment deposition by the Mississippi River has produced the flatlands of the lower Mississippi Valley and the Mississippi Delta.

To the north, evidence of the glaciers of the last ice age is widely found, particularly east of the Canadian Rocky Mountains and around the Great Lakes. From northeastern British Columbia, across Alberta, Saskatchewan, and Manitoba to North Dakota and Minnesota, huge striations clearly show the flow pattern of the glaciers. And southwest of Lakes Michigan, Huron, and Erie, arcing ridges of sediment, called terminal moraines, show where glaciers dumped sediment at their melting ends.

In eastern Canada, New York, and New England, the terrain has been scoured by glaciers, and eroded by streams, particularly along fractures in the bedrock. In Labrador and Quebec, the Mistastin, Manicougan, and Clearwater Lakes meteor impact craters can also be seen. Further south, narrow curving ridges of upturned and eroded layered rocks form most of the Appalachian Mountains. In contrast, around the Caribbean Sea region (Yucatan, Florida, and the Bahamas), flat-lying, stable limestone platforms are common, while the most eastern islands of the Caribbean include active volcanoes along another convergence zone of tectonic plates.

This anaglyph was created by deriving a shaded relief image from the SRTM data, draping it back over the SRTM elevation model, and then generating two differing perspectives, one for each eye. Illumination is from the north (top). When viewed through special glasses, the anaglyph is a vertically exaggerated view of the Earth's surface in its full three dimensions. Anaglyph glasses cover the left eye with a red filter and cover the right eye with a blue filter.

Elevation data used in this image were acquired by the SRTM aboard the Space Shuttle Endeavour, launched on Feb. 11, 2000. SRTM used the same radar instrument that comprised the Spaceborne Imaging Radar-C/X-Band Synthetic Aperture Radar (SIR-C/X-SAR) that flew twice on the Space Shuttle Endeavour in 1994. SRTM was designed to collect 3-D measurements of the Earth's surface. To collect the 3-D data, engineers added a 60-meter (approximately 200-foot) mast, installed additional C-band and X-band antennas, and improved tracking and navigation devices. The mission is a cooperative project between NASA, the National Geospatial-Intelligence Agency (NGA) of the U.S. Department of Defense and the German and Italian space agencies. It is managed by NASA's Jet Propulsion Laboratory, Pasadena, Calif., for NASA's Earth Science Enterprise, Washington, D.C.

Location: 15 to 60 degrees North latitude, 50 to 130 degrees West longitude

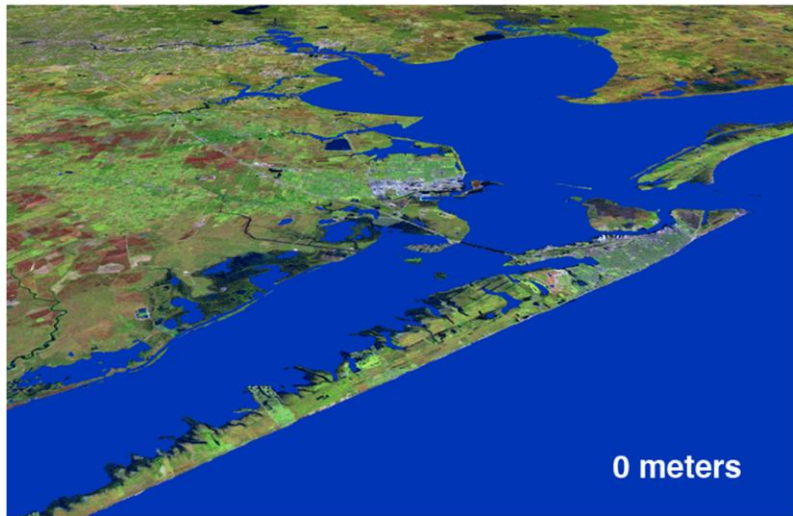
Orientation: North toward the top, Mercator projection

Image Data: Shaded SRTM elevation model

Original Data Resolution: SRTM 1 arcsecond (about 30 meters or 98 feet)

Date Acquired: February 2000

SRTM simulated view of the potential effects of storm surge flooding on Galveston and portions of south Houston



About the animation: This simulated view of the potential effects of storm surge flooding on Galveston and portions of south Houston was generated with data from the Shuttle Radar Topography Mission. Although it is protected by a 17-foot sea wall against storm surges, flooding due to storm surges caused by major hurricanes remains a concern. The animation shows regions that, if unprotected, would be inundated with water. The animation depicts flooding in one-meter increments.

About the image: The Gulf Coast from the Mississippi Delta through the Texas coast is shown in this satellite image from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) overlain with data from the Shuttle Radar Topography Mission (SRTM), and the predicted storm track for Hurricane Rita. The prediction from the National Weather Service was published Sept. 22 at 4 p.m. Central Time, and shows the expected track center in black with the lighter shaded area indicating the range of potential tracks the storm could take.

Low-lying terrain along the coast has been highlighted using the SRTM elevation data, with areas within 15 feet of sea level shown in red, and within 30 feet in yellow. These areas are more at risk for flooding and the destructive effects of storm surge and high waves.

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Location: 28 degrees North latitude, 23.5 degrees West longitude

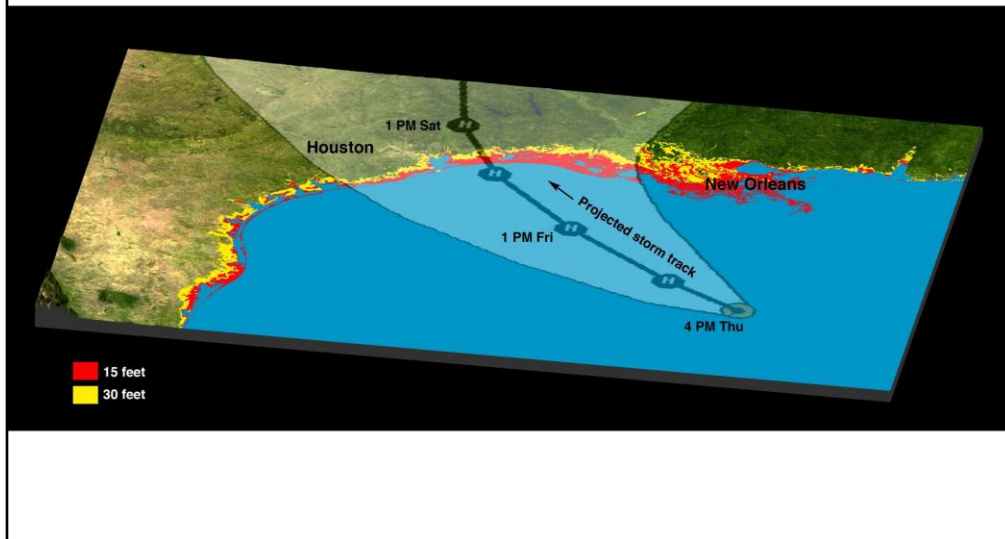
Orientation: North toward the top

Size: 890 by 1447 kilometers (552 by 897 miles)

Image Data: MODIS image and colored SRTM elevation model

Date Acquired: February 2000

SRTM Simulation of of storm surge flooding on Galveston and South Houston



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[Back to top](#)

What you should know about Sounder, Lidar, Radar and Microwave Data?

1. Measurement Principles: nomenclature, wavelengths (bands), polarization, scattering, backscatter, dielectric constant
2. How do these technologies work? How are signals transmitted?
3. Examples of unique measurements for each technology.
4. Radar Interferometry