BHARATHIDASAN UNIVERSITY
Tiruchirappalli - 620 024
Tamil Nadu, India

Programme : 6 year Integrated M.Tech in Geological Technology and Geoinformatics

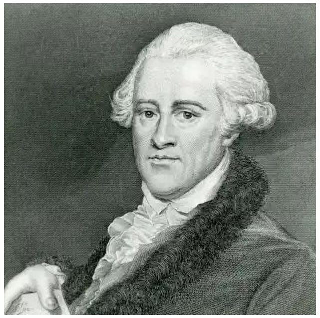
Course title : Principles of Remote Sensing
Course code : MTGT 0304

UNIT - IV

Thermal & Microwave Remote Sensing

D.Ramesh, Ph.D
Associate Professor, Dept. of Remote Sensing

History of Thermal Remote Sensing



The German-British astronomer Sir Frederick William Herschel (1738-1822) discovered the **infrared portion** of the electromagnetic spectrum in 1800.

Herschel discovered the existence of infrared by passing sunlight through a glass prism. As sunlight passed through the prism, it was dispersed into a rainbow of colors called a spectrum. A spectrum contains all of the visible colors that make up sunlight. Herschel measured the amount of heat in each color using thermometers with blackened bulbs to measure the various color temperatures.

He noticed that the temperature increased from the blue to the red part of the visible spectrum. He, then placed a thermometer just beyond the red part of the spectrum in a region where there was no visible light and found that the temperature was even higher! Herschel realized that there must be another type of light beyond the red, which we cannot see. This type of light became known as **infrared**.

American, Langley invented the bolometer in 1880 that was able to obtain measurable temperature variations of 1 / 10,000 °C.

In World War – I, S. O. Hoffman could detect men at 120 m and aircraft.

In the 1930s, Germany developed the Kiel system for discriminating between bombers and night fighters.

The single most important development in infrared technology was the development of the detector element by nations at war during World War II. Early infrared detectors were lead salt photo detectors.

Now we have very fast detectors consisting of mercury-doped Germanium (Ge:Hg), Indium antimonite (InSb) and other substances that are very responsive to infrared radiation. We also have computers to rapidly process and display the thermal radiometric measurements.

In 1968, the US government declassified thermal infrared remote sensing systems that did not exceed a certain spatial resolution and temperature sensitivity.

Characteristics of Modern day Photon detectors

Mercury – doped germanium	Ge : Hg	3 -14 µm
Indium antimonite	InSb	3 - 5 µm
Mercury cadmium telluride	HgCdTe (MCT), or Trimetal	8 - 14 µm

Present day systems are capable of temperature resolution on the order of 0.1°C.

The first declassified satellite remote sensor data were collected by the U. S. Television IR Operational Satellite (TIROS) launched in 1960. The coarse resolution thermal infrared data were ideal for monitoring regional cloud patterns and frontal movement.

NASA launched the Heat Capacity Mapping Mission (HCCM) in 1978 that obtained 600 x 600 m spatial resolution thermal infrared data (10.5 - 12.6 μm) both day (1:30 pm) and night (2:30 am). This was one of the first scientifically oriented (geology) thermal infrared systems.

NASA's Nimbus 7 launched in 1978 had a Coastal Zone Color Scanner (CZCS) that included a thermal infrared sensor for monitoring sea-surface temperature.

In 1980, NASA and the Jet Propulsion Laboratory developed the thermal infrared multispectral scanner (TIMS) that acquires thermal infrared energy in six bands at wavelength intervals of <1.0 μm.

Landsat Thematic Mapper 4 and 5 sensors were launched in 1982 and 1984, respectively, and collected 120 x 120 m thermal infrared data (10.4 - 12.5 μm) along with two bands of middle infrared data.

Today, the NOAA Geostationary Operational Environmental Satellite (GOES) collects thermal infrared data at a spatial resolution of 8 x 8 km for weather prediction. Full-disk images of the earth are obtained every 30 minutes both day and night by the thermal infrared sensor.

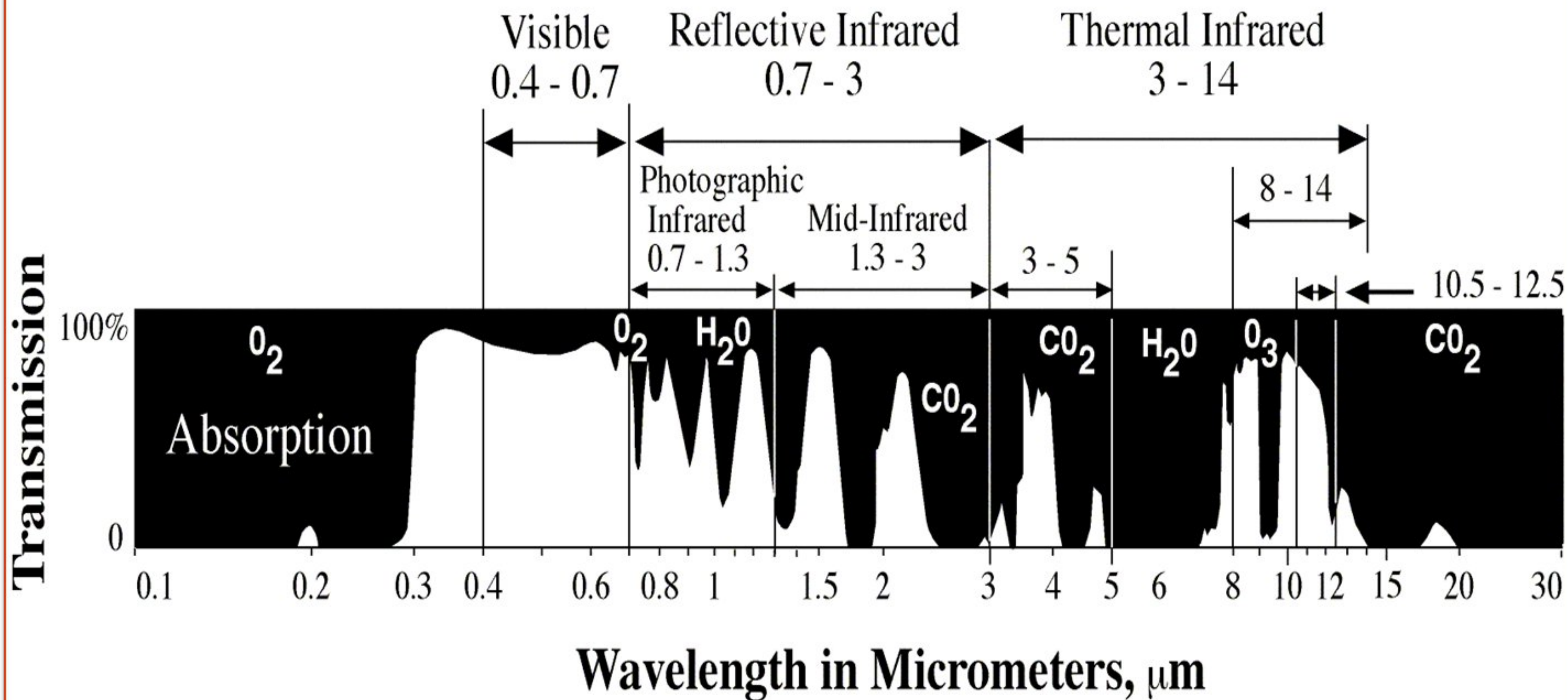
Thermal infrared energy is emitted from all objects that have a temperature greater than absolute zero. Therefore, all features (Sun, vegetation, soil, rocks, water, and even humans) emit thermal infrared electromagnetic radiation.

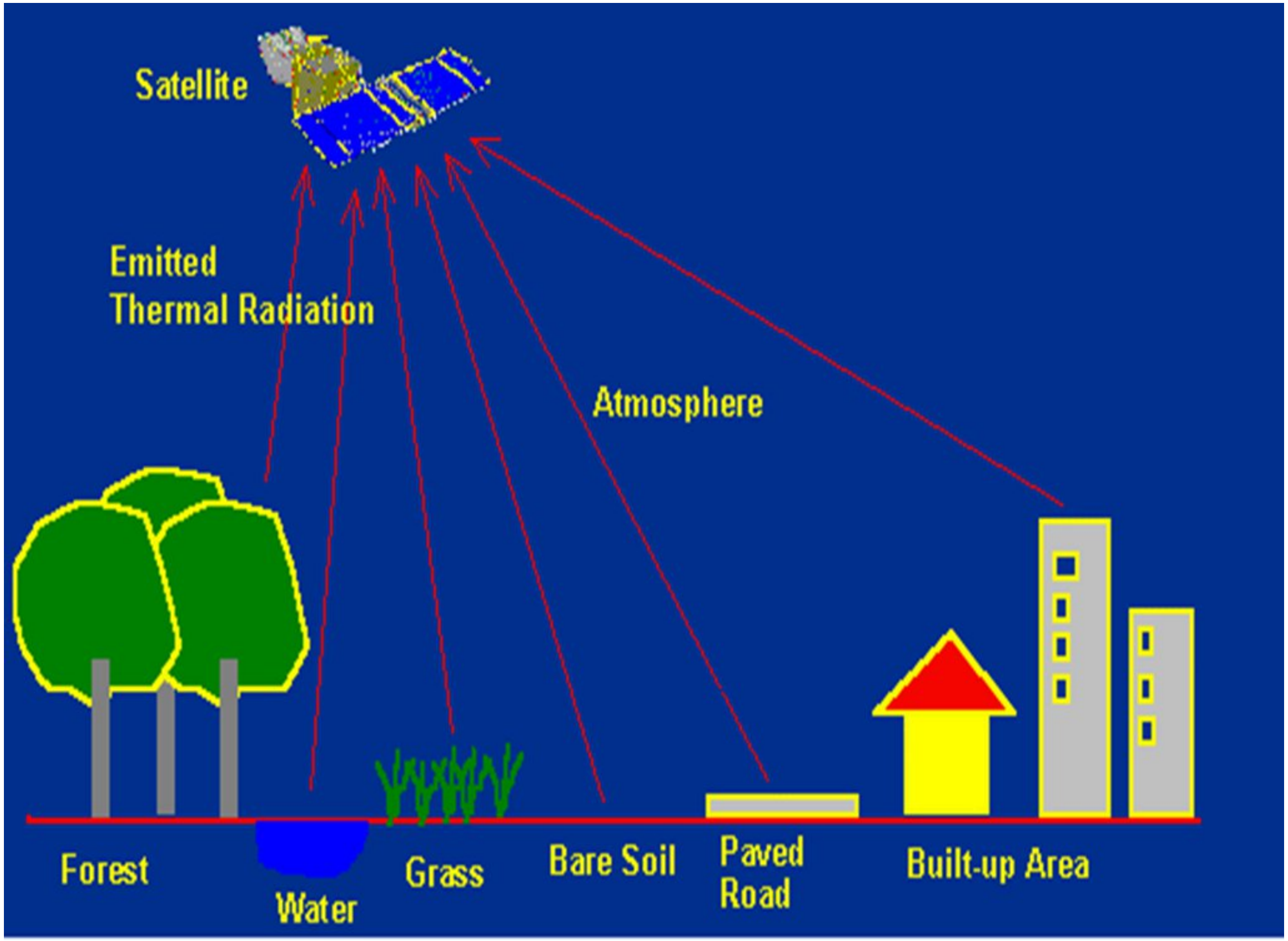
Humans sense thermal energy primarily through the sense of touch. Our eyes cannot detect differences in thermal infrared energy because they are only sensitive to short wavelength (visible region 0.4 μm to 0.7 μm).

Our eyes are not sensitive to the reflective infrared (0.7 - 3.0 μm) or thermal / far infrared energy (3.0 - 14 μm). Fortunately, engineers have developed detectors that are sensitive to thermal infrared radiation.

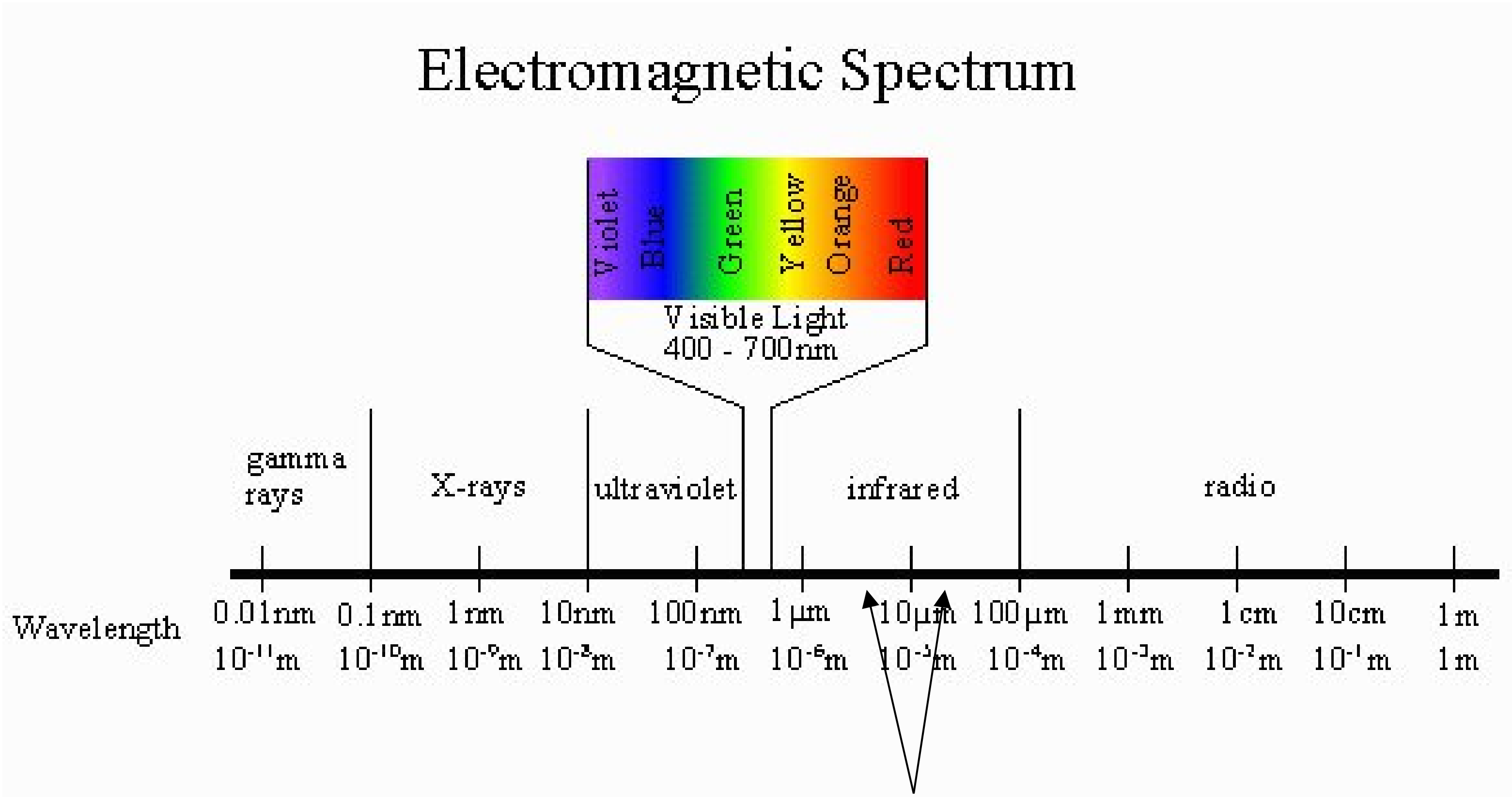
These thermal infrared sensors allow us to sense a previously invisible world of information as they monitor the thermal characteristics of the earth surface.

Atmospheric Windows in the Electromagnetic Spectrum




Satellite
Emitted
Thermal Radiation
Atmosphere
Forest
Water
Grass
Bare Soil
Paved
Road
Built-up Area

Thermal Infrared Spectrum



Thermal IR

Infrared (IR) waves:

- Near IR : 0.7 to 1.3 µm
- Mid IR : 1.3 to 3 µm
- Thermal IR: 3 to 14 µm

Most remote sensing applications make use of the 3 to 5 and 8 to 14 micrometer range (due to absorption bands).

The main difference between thermal infrared and near infrared is that thermal infrared is emitted energy, whereas the near infrared is reflected energy, similar to visible light.


sierra pacific innovations

Principles of Emitted Radiation

The amount of radiation emitted by an object is determined primarily by its:

- internal temperature and
- emissivity

EMR and Temperature

- The temperature of the Sun is approximately 6000 degrees Kelvin.

- For the sake of simplicity we assume that the Sun absorbs and radiates energy at the maximum possible rate, per unit area, at each wavelength, for a given temperature.

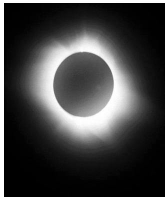
- We assume that the Sun is a “blackbody”.

Wien's Displacement Law

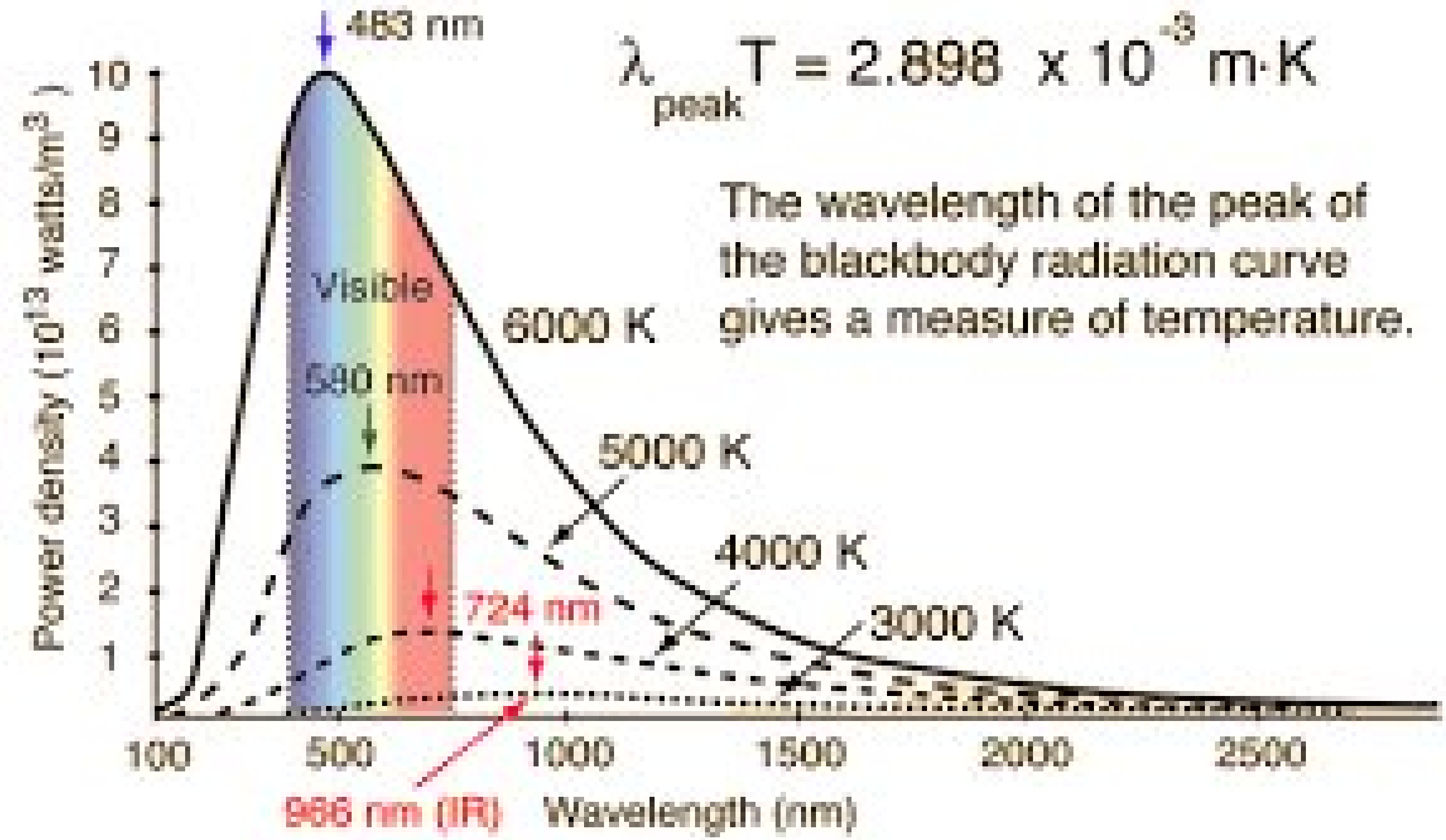
The relationship between the true temperature of a blackbody (T) in degrees Kelvin and its peak spectral exitance or dominant wavelength (λmax) is described by Wien's displacement law:

$$\lambda_{max} = \frac{k}{T} = \frac{2898\ \mu m\ ^{\circ}K}{T}$$

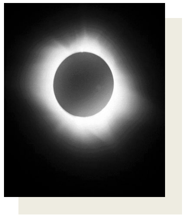
where k is a constant equaling 2898 μm °K.



Wien's Displacement Law



Stephen - Boltzmann Law



The total spectral radiant flux exitance (Fb) measured in watts m^2 leaving a blackbody is proportional to the fourth power of its temperature (T). This is the Stefan-Boltzmann law and is expressed as:

$$Mb = \sigma T4$$

where k is the Stefan-Boltzmann constant equaling 2898 mm °K, and T is temperature in degrees Kelvin.

The total radiant exitance is the integration of all the area under the blackbody radiation curve.

EMR and Temperature

- Wien's Displacement Law shows that much of the Sun's EMR (light) is converted to longer wavelength thermal infrared EMR (radiant heat) upon interaction with the Earth's Surface.

- Much of the emitted thermal radiation is trapped by the atmosphere creating a habitable planet for us (otherwise Earth's average ambient temperature would be below zero degrees Celcious).

A body's temperature can be expressed by two temperatures:

the internal or **kinetic temperature** (from the kinetic motion of its atoms) as measured by an inserted thermometer, T_k. The second is the **external temperature** measured by its emitted radiation, T_R. **The radiant flux F_B** (rate of flow of EM energy, commonly measured as Watts per square centimeter) emanating from a blackbody is related to its internal (kinetic) temperature T_k(temperature in Kelvin units) by the Stefan-Boltzmann Law.

Thermal Infrared Remote Sensing

- Electromagnetic radiation exiting an object = **Radiant Flux** (Φ, Watts)
- Amount of energy exiting an object = **Radiant temperature** (T Rad)
- For most objects there is a strong correlation between Kinetic temperature and the radiant flux.
- Radiant temperature is always less than the true kinetic temperature, due to Emissivity

Emissivity

Emissivity is the ratio between the radiant flux (M_r) from a real object and an ideal blackbody (M_b) at the same temperature.

$$\varepsilon = Mr / Mb$$

Emissivity

ε is less than but never quite equal to 1

ε varies between 0 and somewhat less than 1.

Why is it important to know about emissivity when conducting a thermal infrared remote sensing investigation?

because 2 objects lying next to each other on the ground could have the same true kinetic temp but have different apparent temps when sensed by a thermal radiometer simply because their emissivities are different.

Emissivity

- **Emissivity** varies with…
  - Color (darker has higher E)
  - Surface Roughness (greater has higher E)
  - Moisture Content (greater has higher E)
  - Compaction (greater has higher E)
  - Field of View (variable)
  - Wavelength (variable)
  - Viewing Angle (variable)

Emissivity

Granite	0.86
Basalt, rough	0.95
Human Skin	0.98
Water	0.92 – 0.99
Concrete	0.71 – 0.90
Vegetation	0.96 – 0.98
Rocks	0.78 – 0.86
Snow	0.83 – 0.85
Rusty Steel	0.70
Aluminum	0.05 – 0.08

Kinetic Heat, Temperature, Radiant Energy and Radiant Flux

- The energy of particles of matter in random motion is called kinetic heat (also referred to as internal, real, or true heat).
- All objects having a temperature above absolute zero (0 °K; -273.16 °C; -459.69 °F) exhibit this random motion.
- When these particles collide they change their energy state and emit EM radiation as previously discussed.

Kinetic Heat, Temperature, Radiant Energy and Radiant Flux

- The amount of heat can be measured in calories (the amount of heat required to raise the temperature of 1 g of water 1°C).
- We can measure the True Kinetic Temperature (T_{kin}) or concentration of this heat using a thermometer.
- We perform this in situ (in place) temperature measurement when we are ill. We can also measure the true kinetic internal temperature of soil or water by physically touching them with a thermometer.

Kinetic Heat, Temperature, Radiant Energy and Radiant Flux

- Fortunately for us, an object's internal kinetic heat is also converted to radiant energy (often called external or apparent energy).

- The electromagnetic radiation exiting an object is called radiant flux (Φ) and is measured in watts. The concentration of the amount of radiant flux exiting (emitted from) an object is its radiant temperature (Trad).

Kinetic Heat, Temperature, Radiant Energy and Radiant Flux

- There is usually a high positive correlation between the true kinetic temperature of an object (T_{kin}) and the amount of radiant flux radiated from the object (T_{rad}).
- Therefore, we can utilize radiometers placed some distance from the object to measure its radiant temperature which hopefully correlates well with the object's true kinetic temperature.
- **THIS IS THE BASIS OF THERMAL INFRARED REMOTE SENSING.**

Kinetic Heat, Temperature, Radiant Energy and Radiant Flux

- Unfortunately, the relationship is not perfect, with the remote measurement of the radiant temperature always being slightly less than the true kinetic temperature of the object.
- This is due to the emissivity of the object.

Emissivity and Temperature (again)

- "good absorbers are good emitters and good reflectors are poor emitters" (Kirchoff's Radiation Law)

otherwise said as:

absorptance = emissivity

we then may assume transmittance = 0

so that

Radiance + Emissivity = 1

Radiance + Emissivity = 1

- this relationship is imp. b/c it describes why objects appear as they do on thermal IR imagery.
- i.e., b/c the terrain theoretically does not lose any incident energy to transmittance, all energy leaving the object must be accounted for by the relationship b/t reflectance and emissivity.

Emissivity and Temperature (again)

- knowing the emissivity of an object allows us to modify the Stephan-Boltzman Law to have the recorded apparent radiant temp better = the true kinetic temp:
- Radiant flux of a real object (as opposed to a blackbody) = Emissivity X the Stephan-Boltzman Constant X true kinetic temperature to the fourth power.

$$M_r = \varepsilon \sigma T_{kin}^4$$

$$M_r = \varepsilon \sigma T_{kin}^{4}$$

- this equation takes into account the temp of the object and its emissivity to create a more accurate estimate of the radiant flux exiting an object and recorded by the thermal IR sensor

Thermal infrared remote sensing systems generally record the apparent radiant temperature, Trad, of the terrain rather than the true kinetic temperature, Tkin.

If we assume that the incorporation of emissivity in the previous equation has improved our measurement to the point that:

$M_r = \varepsilon \sigma T_{kin}^4$ and we assume that

$M_b = \sigma T_{rad}^4$ and

$M_r = M_b$ then

$$\boldsymbol{\sigma T_{rad}^4 = \varepsilon \sigma T_{kin}^4}$$

$$\sigma T_{rad}^{4} = \varepsilon\sigma T_{kin}^{4}$$

Therefore, the radiant temperature of an object recorded by a remote sensor is related to its true kinetic temperature and emissivity by the following relationship:

$$T_{rad} = \varepsilon^{1/4} T_{kin}$$

$$T_{rad} = \varepsilon^{1/4} T_{kin}$$

or, solving for ε:

$$\varepsilon = \{T_{rad} / T_{kin}\}^4$$

Emissivity and Temperature (again)

- The apparent radiant temperature = emissivity to the negative fourth power X true kinetic temperature
- Therefore, we want to know the emissivity as precisely as possible in order to calculate the true kinetic temperature.

MATERIAL	ε	True Kinetic Temp		Radiant Temp	
		T_{kin}		$T_{rad} = \varepsilon^{1/4} T_{kin}$	
		K	°C	K	°C
blackbody	1	300	27	300.0	27
distilled water	.99	300	27	299.2	26.2
rough basalt	.95	300	27	296.2	23.2
vegetation	.98	300	27	298.5	25.5
dry loam soil	.92	300	27	293.8	20.8

Thermal or Heat Capacity (C)

- The quantity of heat required to raise the temperature of one gram of a material by one degree C or K.

- Water has a high heat capacity (1 cal / (gram deg C)). Soil, rocks, and building materials have low heat capacities.

Thermal Conductivity (K)

- Rate at which a substance transfers heat through it
- measured as calories per cm per second per °C difference in temp (cal cm^{-1} sec^{-1} $°C^{-1}$)
- Most natural materials have low thermal conductivities.

Thermal Inertia (P)

The resistance of a material to temperature change, indicated by the time dependent variations in temperature during a full heating/cooling cycle (a 24-hour day for Earth).

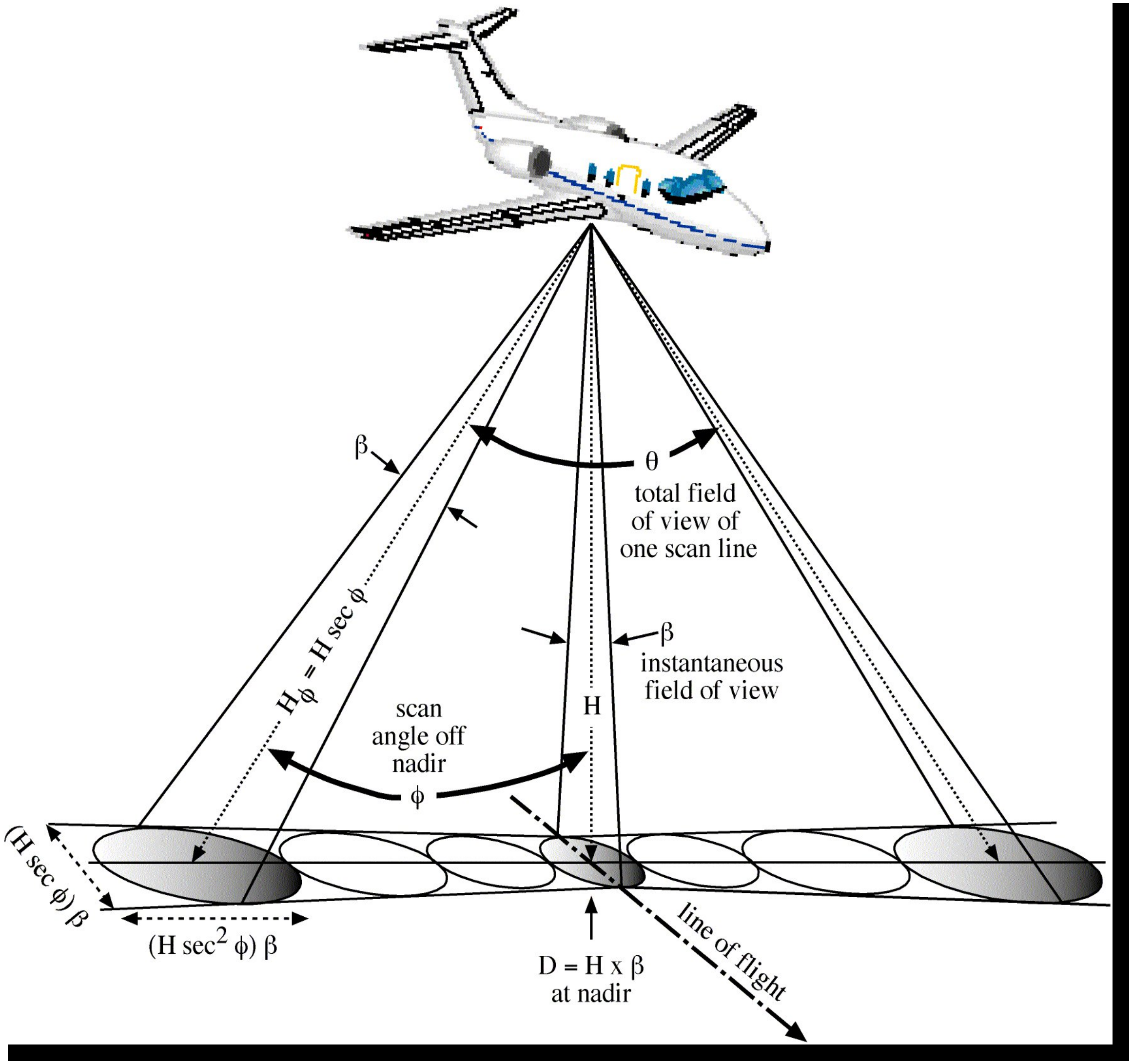
THERMAL INFRARED

DATA COLLECTION

Thermal Sensor Constraints

- Ground Resolution Cell Size (D)
- Ground Resolution Cell Size (D) = height above ground level in meters (H) x the instantaneous field of view in milliradians (ß)

Ground Resolution Cell Size Along a Single Across-Track Scan



Thermal Sensor Constraints

- There is a trade-off between spatial and spectral resolution, especially in thermal remote sensing.

Thermal Sensor Constraints

- Inverse Square Law:
  - The intensity of thermal radiation emitted from a point source varies as the inverse square of the distance between the source and the detector.
- “Twice the distance, One fourth the intensity”
- Can be countered by increasing the Ground Resolution Cell Size (D)

Most thermal infrared remote sensing investigations try to maintain good radiometric and spatial resolution by:

selecting a fairly large IFOV such as 2.5 mrad, and flying at a relatively low altitude to obtain smaller pixel sizes.

Unfortunately, at lower altitudes, the high spatial resolution may be outweighed by the fact that more flight lines are required to cover the area compared to more efficient coverage at higher altitudes with larger pixels.

The pixel size and the geographic size of the survey are considered, objectives are weighed, and a compromise is reached. Multiple flight lines of aircraft MSS data are difficult to mosaic.

Thermal Radiometric Calibration

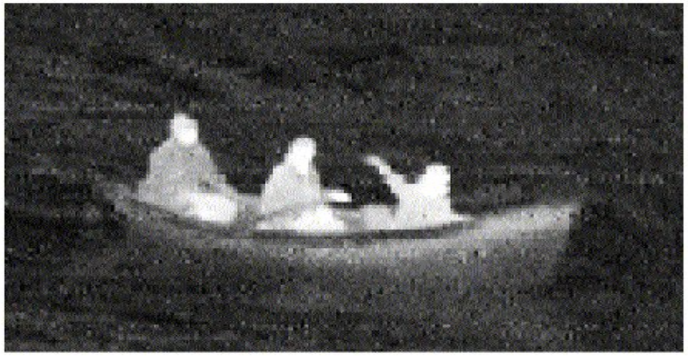
To use the thermal infrared remote sensor data for practical purposes such as temperature mapping, it is necessary to calibrate the brightness values stored on the digital tape to temperature values. This radiometric calibration may be performed using

- internal blackbody source referencing, or
- external empirical referencing based on in situ data collection.

Forward-Looking IR Systems

- For decades, the military organizations throughout the world have funded the development of FLIR type systems that look obliquely ahead of the aircraft and acquire high-quality thermal infrared imagery, especially at night.

- FLIR systems collect the infrared energy based on the same principles as an across-track scanner previously discussed, except that the mirror points forward about 45˚ and projects terrain energy during a single sweep of the mirror onto a linear array of thermal infrared detectors.

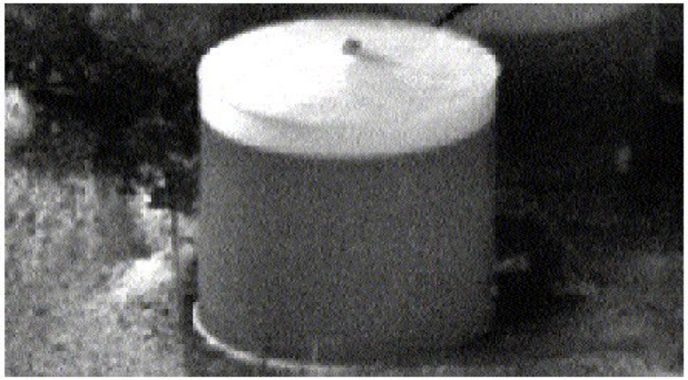


a.

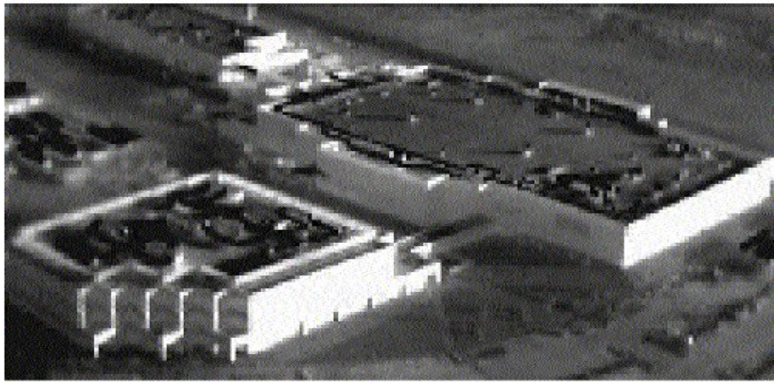
b.

c.

d.

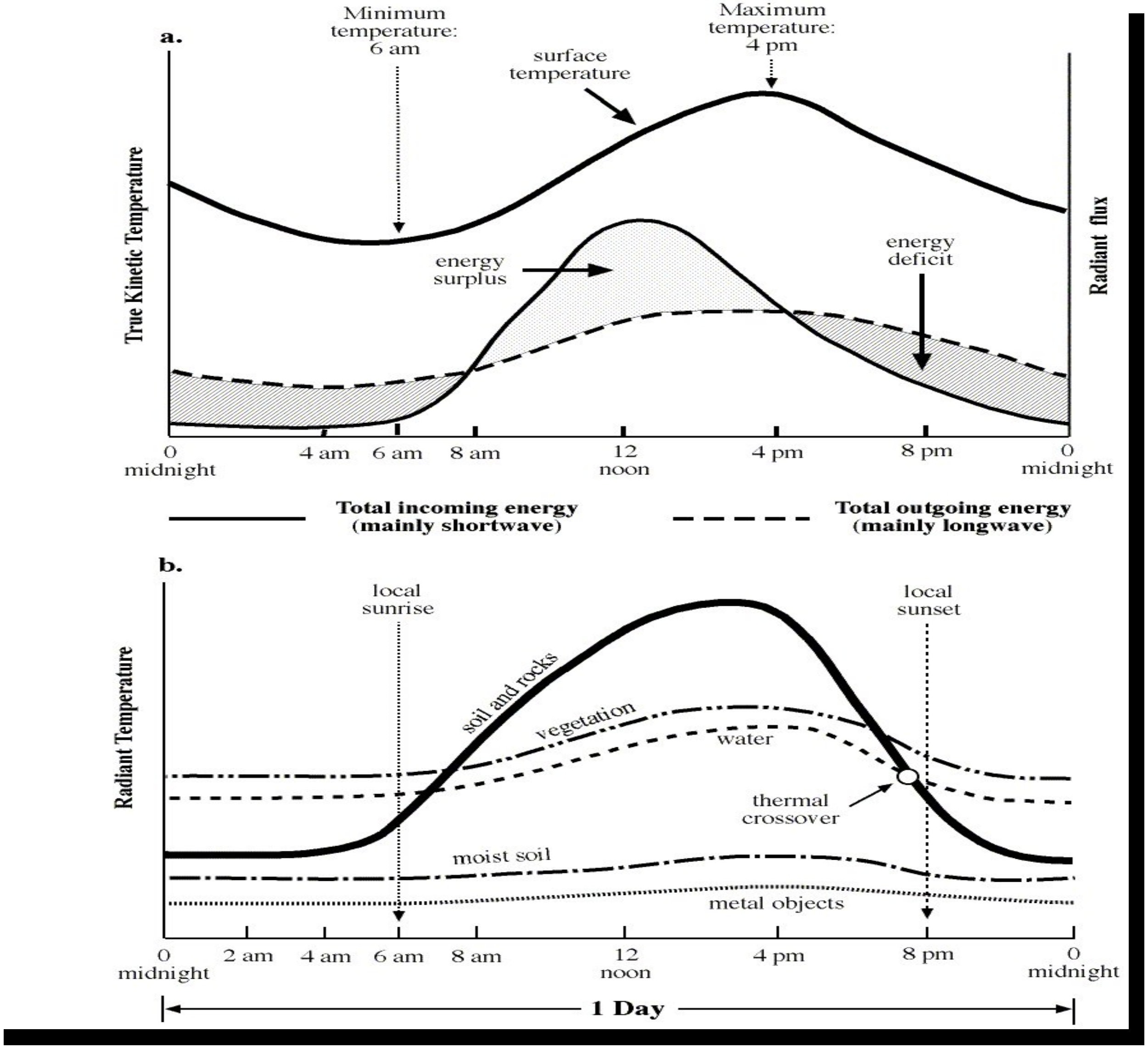


e.



f.

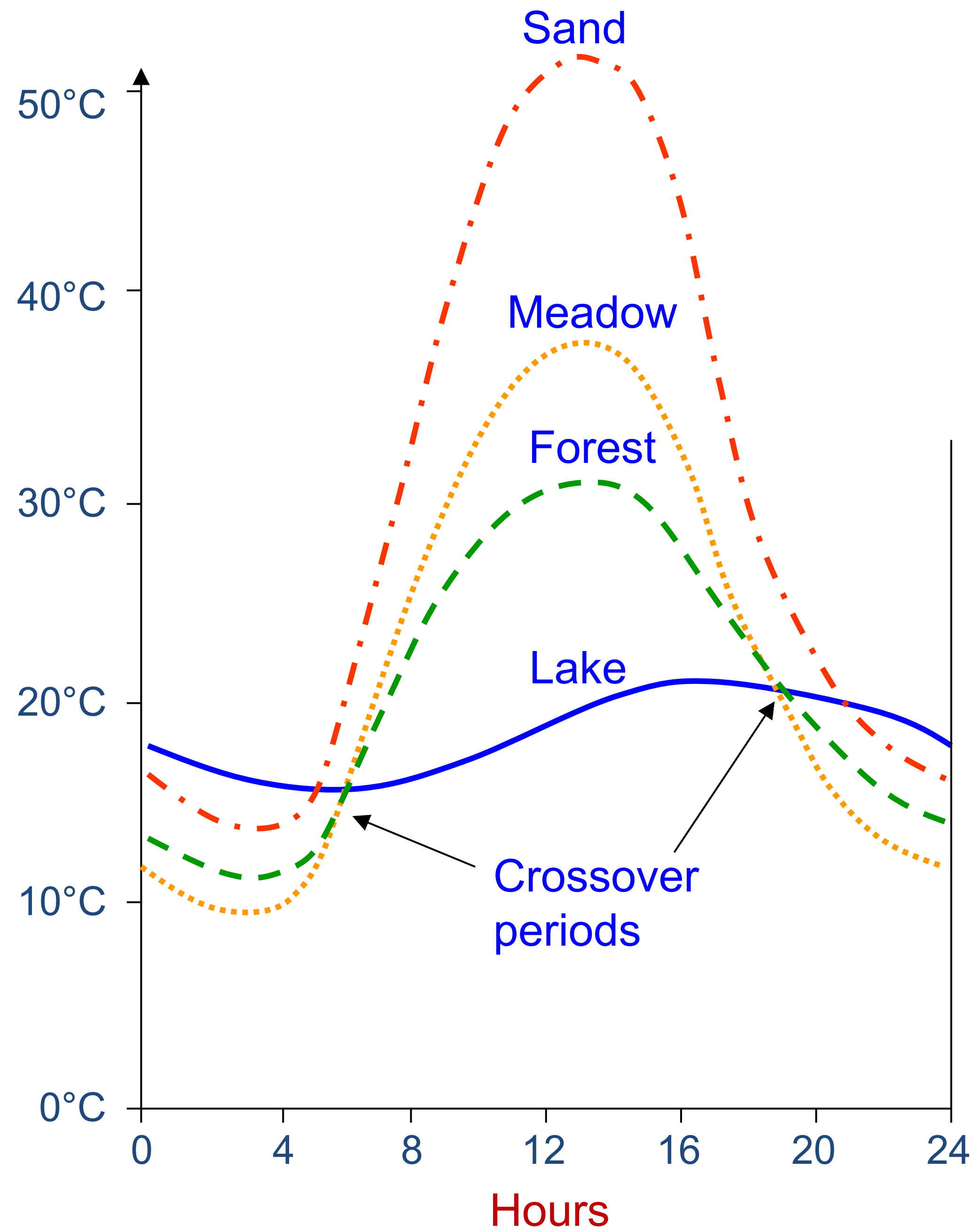
- FLIR examples



Effect of Time of Day on Temperature

Variations in radiant temperature

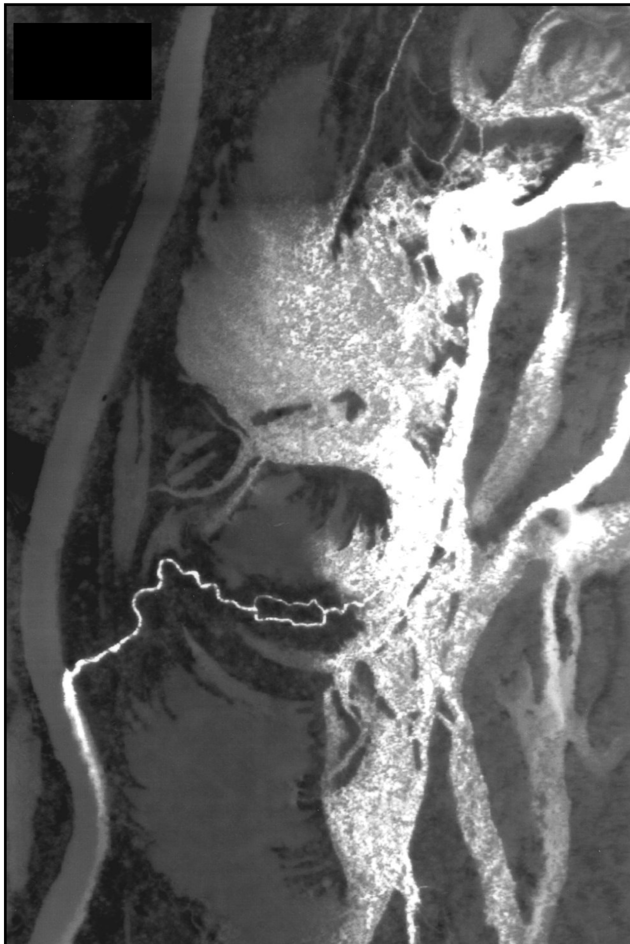
Variations in radiant temperature of four materials for a diurnal cycle.



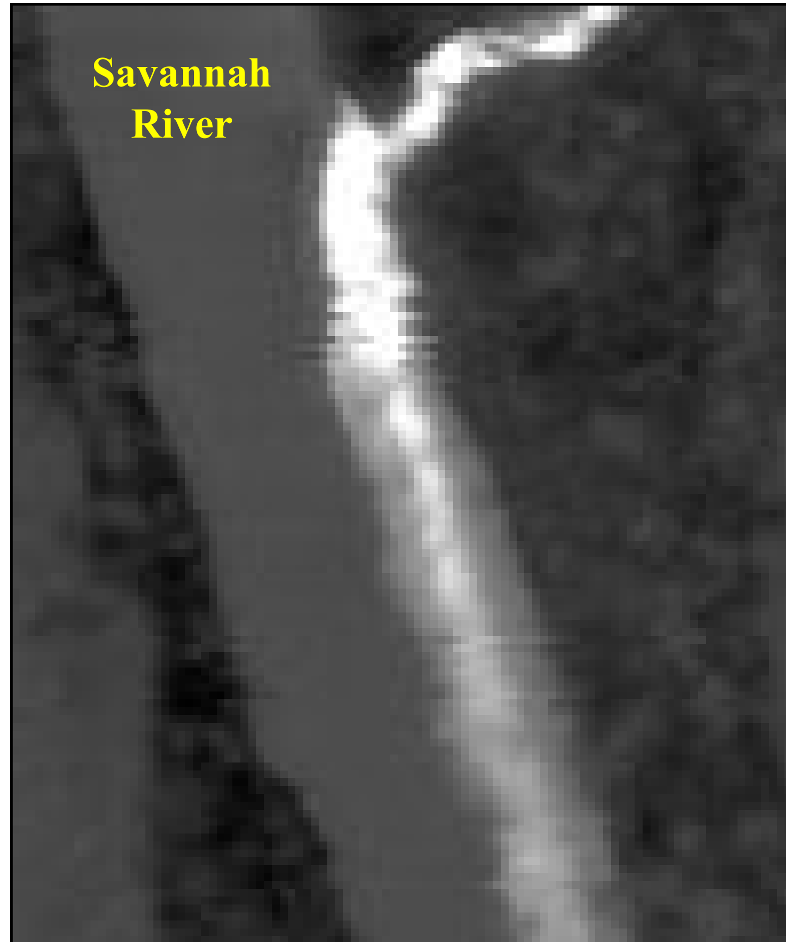
Day and night thermal images

Day and night thermal IR images (8 to 14 μm). Image-acquisition times were 11:25 am (top) and 12:20 am (bottom).

Pre-dawn Thermal Infrared Image of Effluent Entering the Savannah River Swamp System

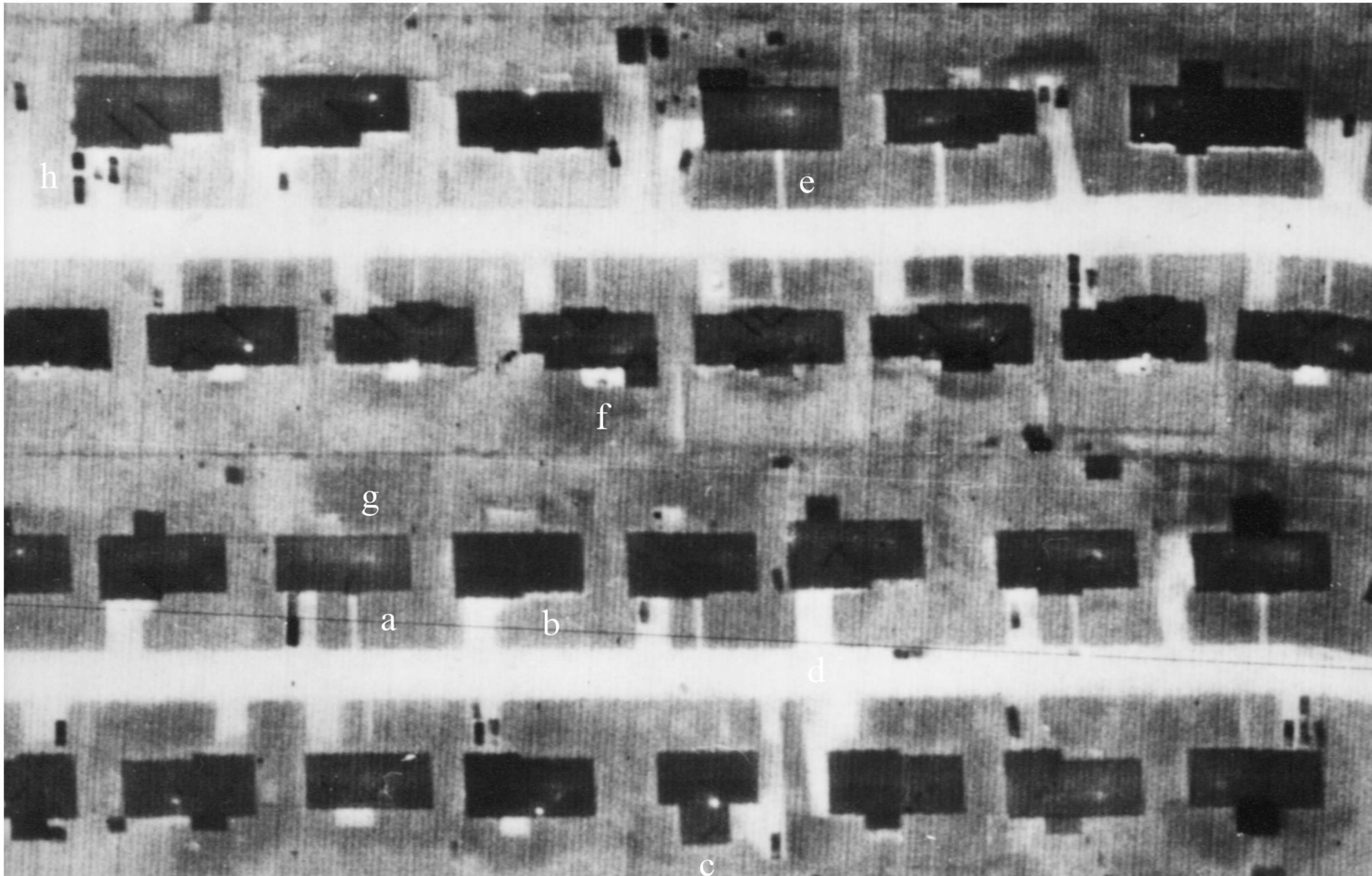


2x reduction



March 31, 1981
4:28 am; 3 x 3 m

Pre-dawn Thermal Infrared Image of a Residential Subdivision in Forth Worth, Texas



250 m AGL1 mrad IFOV6:45 am Jan 10, 19800.25 x 0.25 m

Microwave Remote Sensing

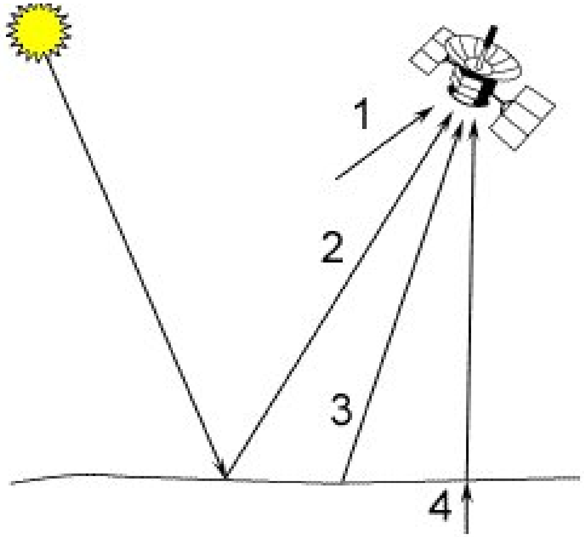
Microwave sensing encompasses both active and passive forms of remote sensing. Microwave portion of the spectrum covers the range from approximately 1cm to 1m in wavelength.

Because of their long wavelengths, compared to the visible and infrared, microwaves have special properties that are important for remote sensing. ***Longer wavelength microwave radiation can penetrate through cloud cover, haze, dust, and all but the heaviest rainfall*** *as the longer wavelengths are not susceptible to atmospheric scattering which affects shorter optical wavelengths.*

This property allows detection of microwave energy under almost all weather and environmental conditions so that data can be collected at any time.

Passive microwave sensing is similar in concept to thermal remote sensing. All objects emit microwave energy of some magnitude, but the amounts are generally very small. A passive microwave sensor detects the naturally emitted microwave energy within its field of view. This emitted energy is related to the temperature and moisture properties of the emitting object or surface.

Passive microwave sensors are typically radiometers or scanners and operate in much the same manner as systems discussed previously except that an antenna is used to detect and record the microwave energy.



The microwave energy recorded by a passive sensor can be emitted by the atmosphere (1), reflected from the surface (2), emitted from the surface (3), or transmitted from the subsurface (4).

Because the wavelengths are so long, the energy available is quite small compared to optical wavelengths. Thus, the fields of view must be large to detect enough energy to record a signal. Most passive microwave sensors are therefore characterized by low spatial resolution.

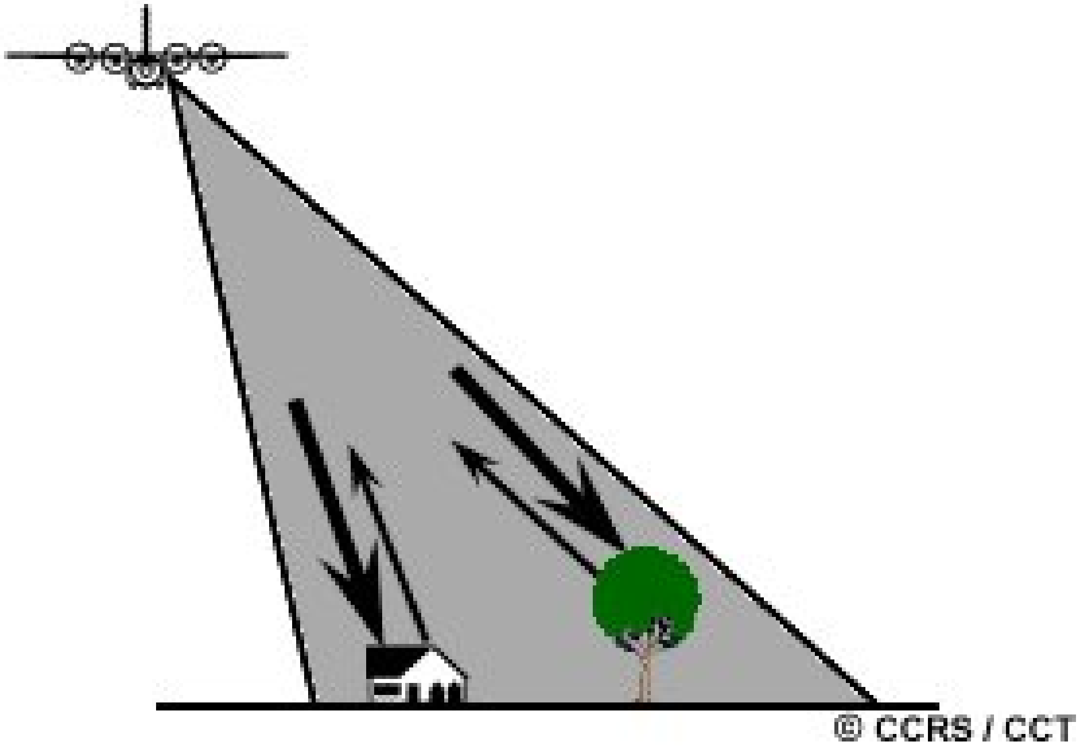
Applications of passive microwave remote sensing include meteorology, hydrology, and oceanography. By looking "at", or "through" the atmosphere, depending on the wavelength, meteorologists can use passive microwaves to measure atmospheric profiles and to determine water and ozone content in the atmosphere.

Hydrologists use passive microwaves to measure soil moisture since microwave emission is influenced by moisture content. Oceanographic applications include mapping sea ice, currents, and surface winds as well as detection of pollutants, such as oil slicks.

Active microwave sensors provide their own source of microwave radiation to illuminate the target. Active microwave sensors are generally divided into two distinct categories: ***imaging*** *and* ***non-imaging****.*

The most common form of imaging active microwave sensors is RADAR. RADAR is an acronym for ***RA****dio* ***D****etection* ***A****nd* ***R****anging, which essentially characterizes the function and operation of a radar sensor.*

The sensor transmits a microwave (radio) signal towards the target and detects the backscattered portion of the signal. The strength of the backscattered signal is measured to discriminate between different targets and the time delay between the transmitted and reflected signals determines the distance (or ***range****) to the target.*


© CCRS / CCT

Non-imaging microwave sensors

include ***altimeters*** *and* ***scatterometers****. These are profiling devices which take measurements in one linear dimension, as opposed to the two-dimensional representation of imaging sensors.*

Radar altimeters transmit short microwave pulses and measure the round trip time delay to targets to determine their distance from the sensor. Generally altimeters look straight down at nadir below the platform and thus measure height or elevation (if the altitude of the platform is accurately known).

Radar altimetry *is used on aircraft for altitude determination and on aircraft and satellites for topographic mapping and sea surface height estimation.*

Scatterometers *are also generally non-imaging sensors and are used to make precise quantitative measurements of the amount of energy backscattered from targets. The amount of energy backscattered is dependent on the surface properties (roughness) and the angle at which the microwave energy strikes the target. Scatterometry measurements over ocean surfaces can be used to estimate wind speeds based on the sea surface roughness.*

Ground-based scatterometers are used extensively to accurately measure the backscatter from various targets in order to characterize different materials and surface types. This is analogous to the concept of spectral reflectance curves in the optical spectrum.

Active Microwave sensing

As with passive microwave sensing, a major advantage of radar is the capability of the radiation to penetrate through cloud cover and most weather conditions. Because radar is an active sensor, it can also be used to image the surface at any time, day or night. These are the two primary advantages of radar: ***all-weather*** *and* ***day*** *or* ***night*** *imaging capability.*

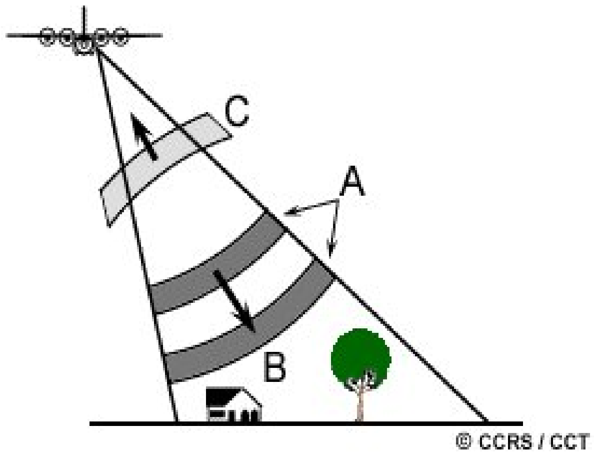
Because of the fundamentally different way in which an active radar operates compared to the passive sensors, a radar image is quite different from and has special properties unlike images acquired in the visible and infrared portions of the spectrum. Because of these differences, radar and optical remote sensing data can be complementary to one another as they offer different perspectives of the Earth's surface providing different information content.

History

The first demonstration of the transmission of radio microwaves and reflection from various objects was achieved by Hertz in 1886. Shortly after the turn of the century, the first rudimentary radar was developed for ship detection.

In the 1920s and 1930s, experimental ground-based pulsed radars were developed for detecting objects at a distance. The first imaging radars used during World War II had rotating sweep displays which were used for detection and positioning of aircrafts and ships. After World War II, side-looking airborne radar (SLAR) was developed for military terrain reconnaissance and surveillance where a strip of the ground parallel to and offset to the side of the aircraft was imaged during flight.

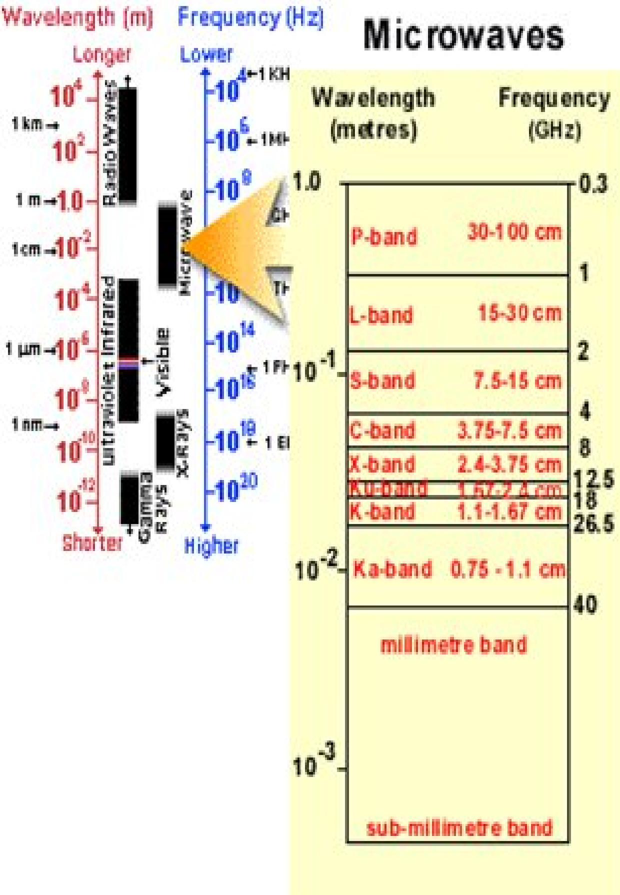
In the 1950s, advances in SLAR and the development of higher resolution synthetic aperture radar (SAR) were developed for military purposes. In the 1960s these radars were declassified and began to be used for civilian mapping applications. Since this time the development of several airborne and spaceborne radar systems for mapping and monitoring applications use has flourished.



***Radar** is basically a ranging or distance measuring device. It consists fundamentally of a transmitter, a receiver, an antenna, and an electronics system to process and record the data.*

*The transmitter generates successive short bursts (or **pulses** of microwave (A) at regular intervals which are focused by the antenna into a beam (B). The radar beam illuminates the surface obliquely at a right angle to the motion of the platform. The antenna receives a portion of the transmitted energy reflected (or **backscattered**) from various objects within the illuminated beam (C).*

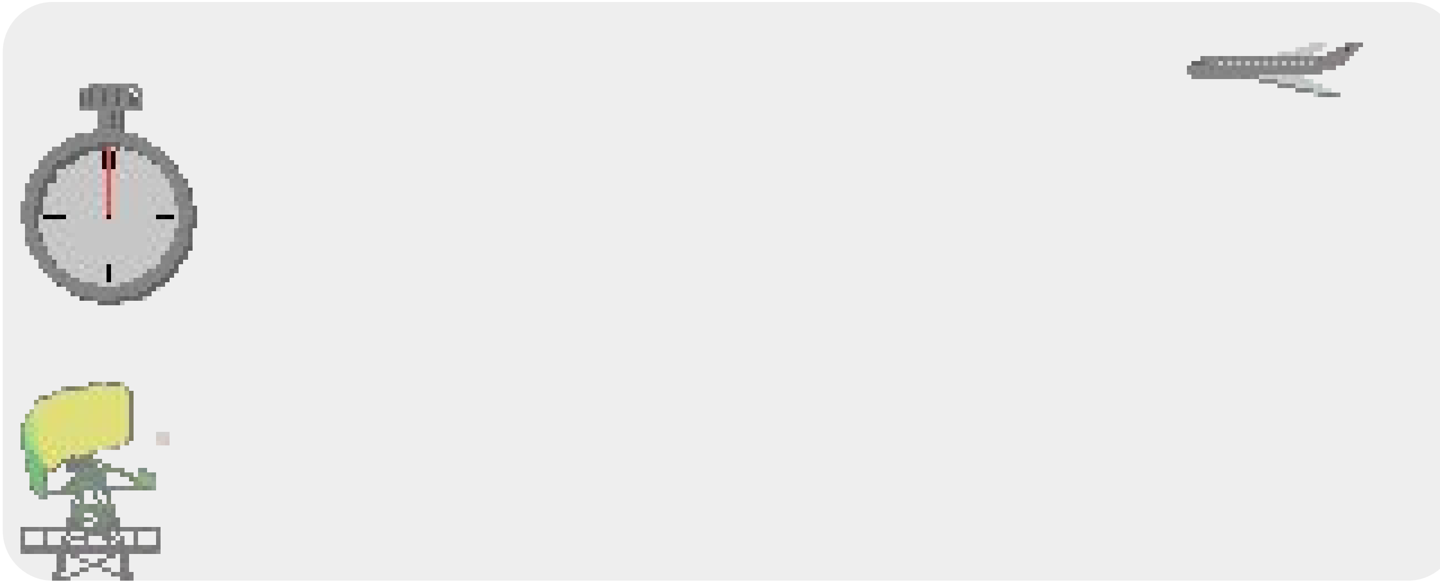
By measuring the time delay between the transmission of a pulse and the reception of the backscattered "echo" from different targets, their distance from the radar and thus their location can be determined. As the sensor platform moves forward, recording and processing of the backscattered signals builds up a two-dimensional image of the surface.

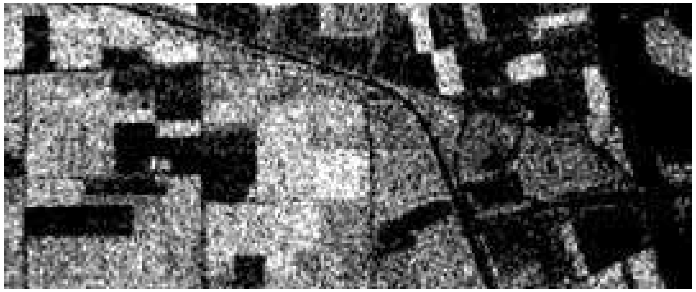


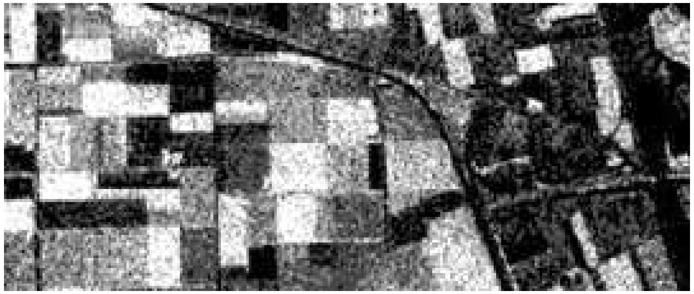
While we have characterized electromagnetic radiation in the visible and infrared portions of the spectrum primarily by wavelength, microwave portions of the spectrum are often referenced according to both ***wavelength*** *and* ***frequency****.*

The ***microwave region of the spectrum*** *is quite large, and there are several wavelength ranges or bands commonly used which given code letters during World War II, and remain to this day.*

Ka, K, and Ku bands*: very short wavelengths used in early airborne radar systems but uncommon today.*
X-band: *used extensively on airborne systems for military reconnaissance and terrain mapping.*
C-band: *common on many airborne research systems (CCRS Convair-580 and NASA AirSAR) and spaceborne systems (including ERS-1 and 2 and RADARSAT).*
S-band: *used on board the Russian ALMAZ satellite.*
L-band: *used onboard American SEASAT and Japanese JERS-1 satellites and NASA airborne system.*
P-band: *longest radar wavelengths, used on NASA experimental airborne research system.*



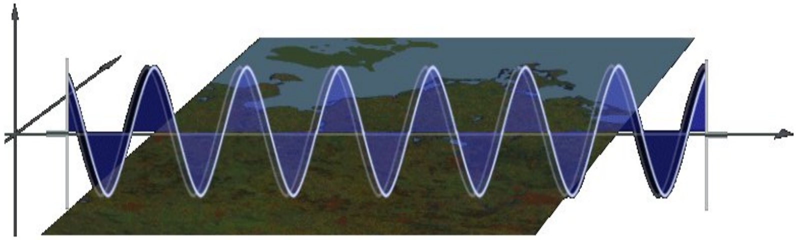


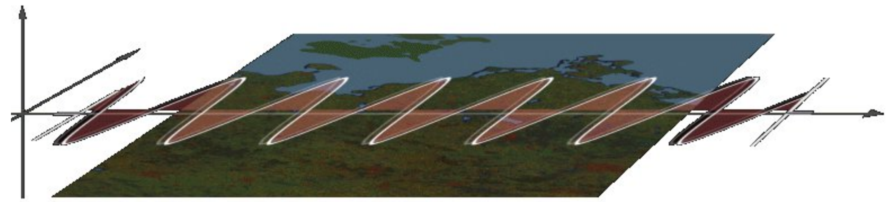


Two radar images of the same agricultural fields

Each image having been collected using a different radar band. The one on the top was acquired by a C-band radar and the one below was acquired by an L-band radar.

You can clearly see that there are significant differences between the way the various fields and crops appear in each of the two images. This is due to the different ways in which the radar energy interacts with the fields and crops depending on the radar wavelength.





Vertically polarisised electric field

Microwave energy, the ***polarization*** *of the radiation is also important. Polarization refers to the orientation of the electric field. Most radars are designed to transmit microwave radiation either* ***horizontally polarized (H)*** *or* ***vertically polarized (V)***. *Similarly, the antenna receives either the horizontally or vertically polarized backscattered energy, and some radars can receive both.*

These two polarization states are designated by the letters ***H for horizontal****, and* ***V, for vertical****. Thus, there can be four combinations of both transmit and receive polarizations as follows:*

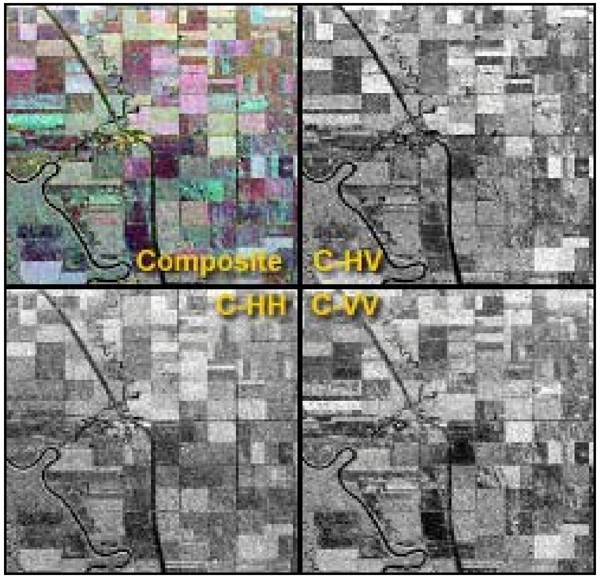
HH - for horizontal transmit and horizontal receive,
VV - for vertical transmit and vertical receive,
HV - for horizontal transmit and vertical receive, and
VH - for vertical transmit and horizontal receive.

The first two polarization combinations are referred to as ***like-polarized*** *because the transmit and receive polarizations are the same. The last two combinations are referred to as* ***cross-polarized*** *because the transmit and receive polarizations are opposite of one another.*

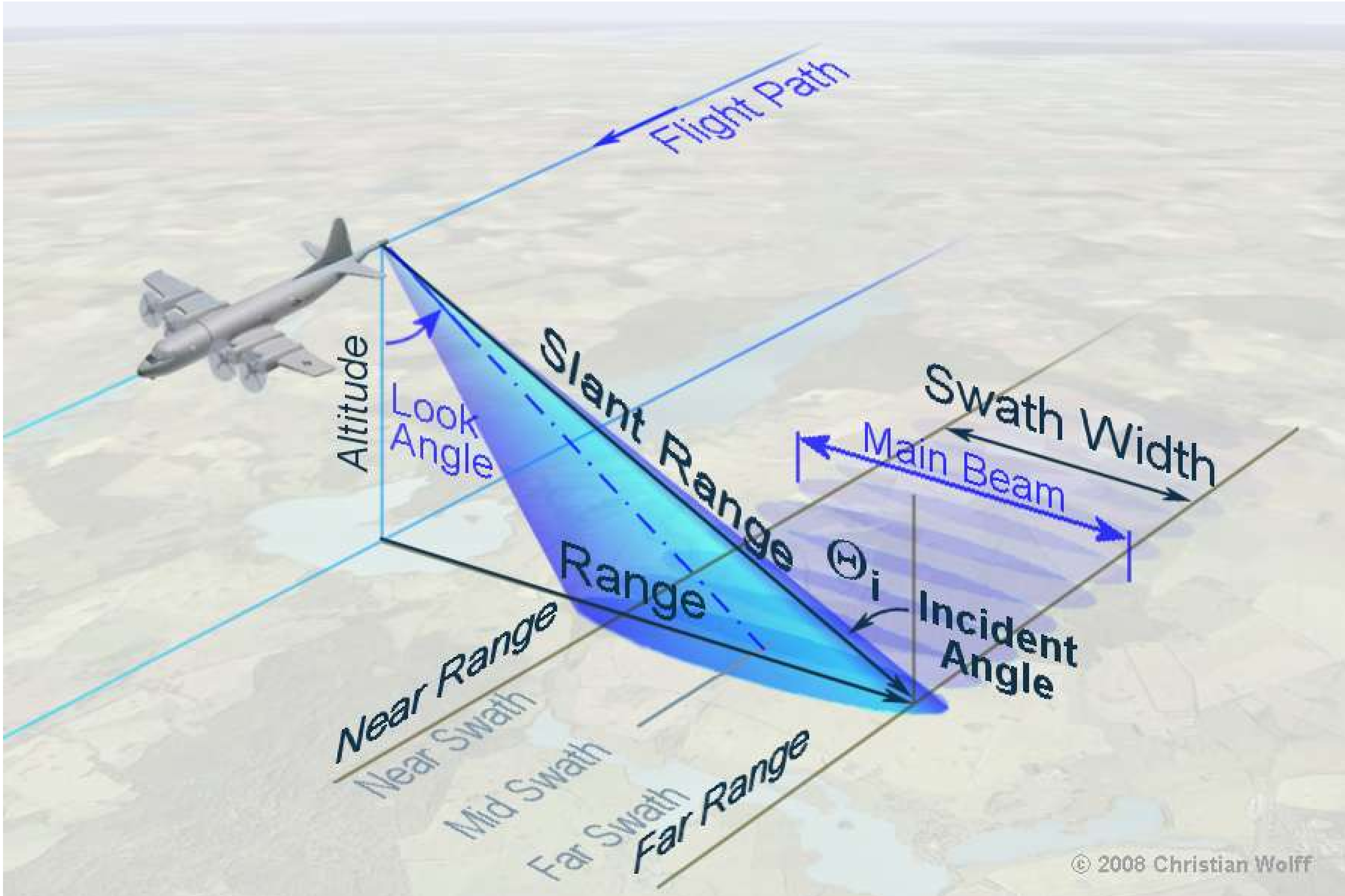
*These **C-band images** of agricultural fields*

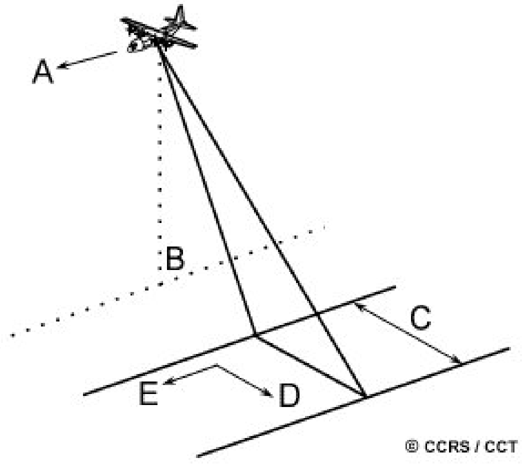
The bottom two images are like-polarized (HH and VV, respectively), and the upper right image is cross-polarized (HV). The upper left image is the result of displaying each of the three different polarizations together, one through each of the primary colours (red, green, and blue).

Similar to variations in wavelength, depending on the transmit and receive polarizations, the radiation will interact with and be backscattered differently from the surface. Both wavelength and polarization affect how a radar "sees" the surface. Therefore, radar imagery collected using different polarization and wavelength combinations may provide different and complementary information about the targets on the surface.

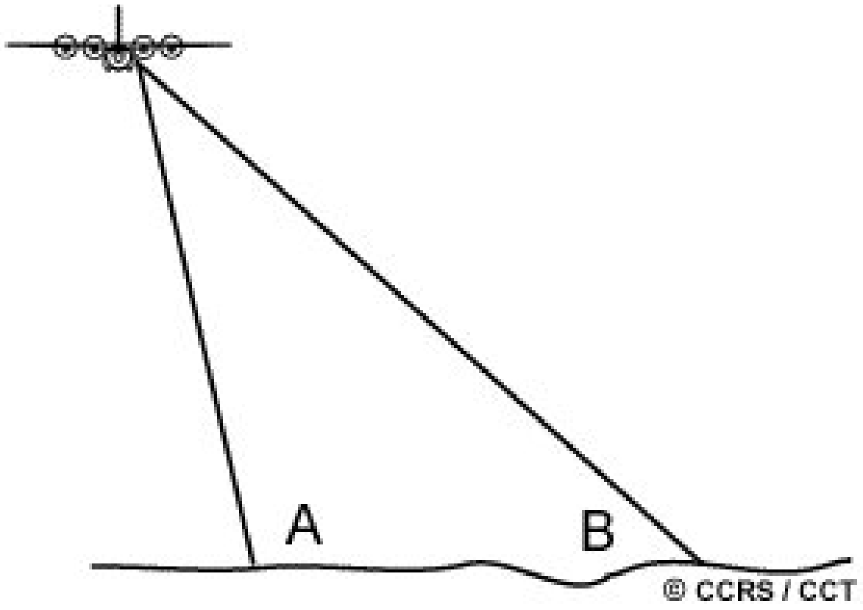


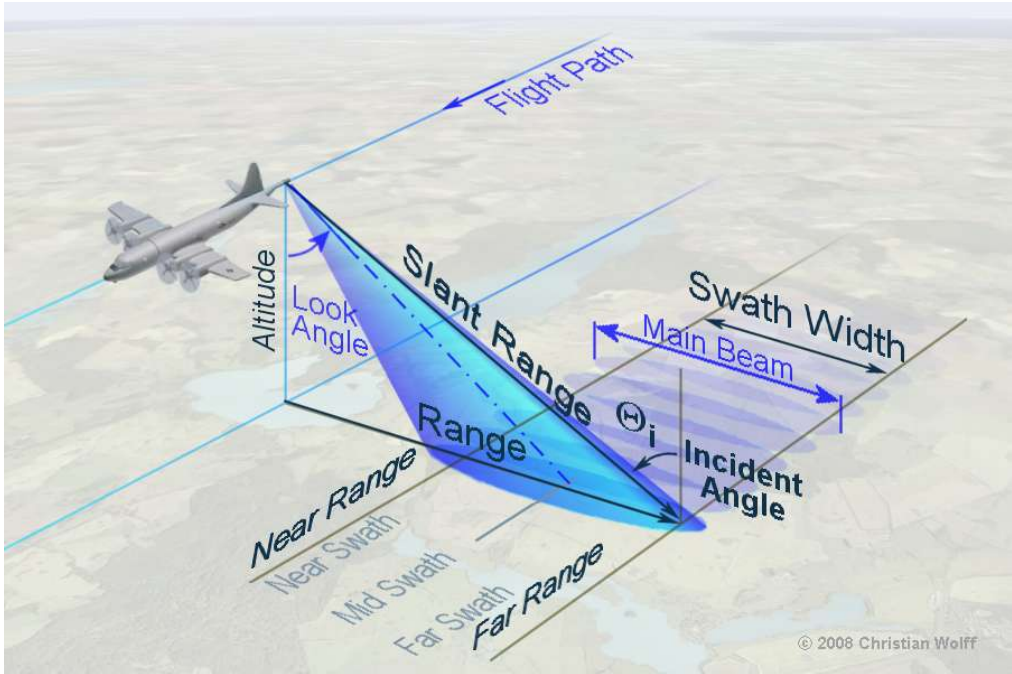
C-band images


Flight Path
Altitude
Look
Angle
Slant Range
Swath Width
Main Beam
Range
Θ_i
Incident
Angle
Near Range
Near Swath
Mid Swath
Far Swath
Far Range
© 2008 Christian Wolff



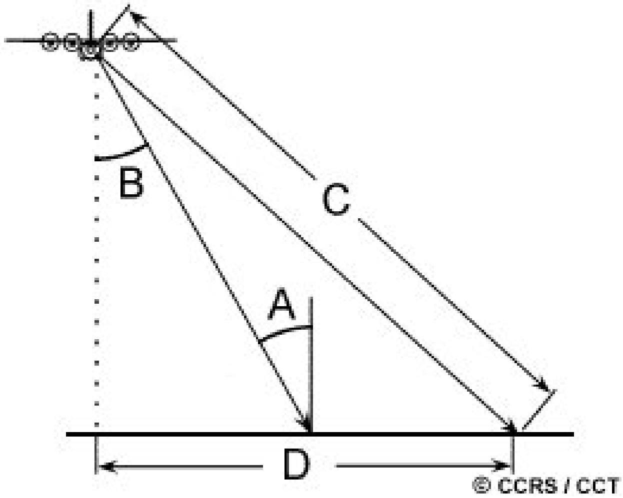
The imaging geometry of a radar system is different from the framing and scanning systems employed for optical remote sensing. Similar to optical systems, the platform travels forward in the ***flight direction (A)*** *with the* ***nadir (B)*** *directly beneath the platform. The microwave beam is transmitted obliquely at right angles to the direction of flight illuminating a* ***swath (C)*** *which is offset from nadir.* ***Range (D)*** *refers to the across-track dimension perpendicular to the flight direction, while* ***azimuth (E)*** *refers to the along-track dimension parallel to the flight direction. This side-looking viewing geometry is typical of imaging radar systems (airborne or space borne).*

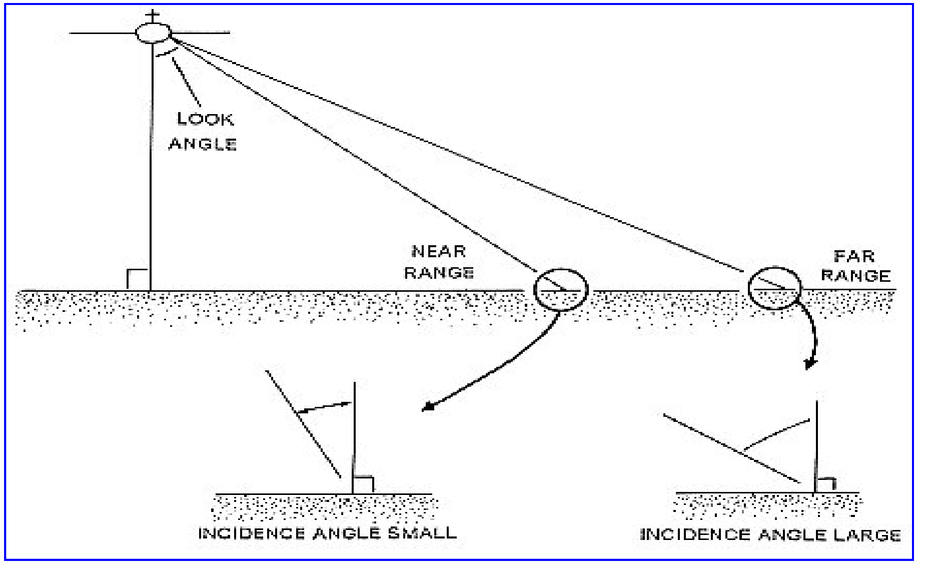




Near range

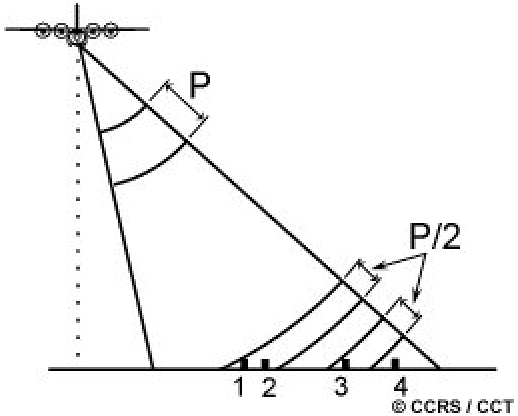
The portion of the image swath closest to the nadir track of the radar platform is called the near range (A) while the portion of the swath farthest from the nadir is called the far range (B).



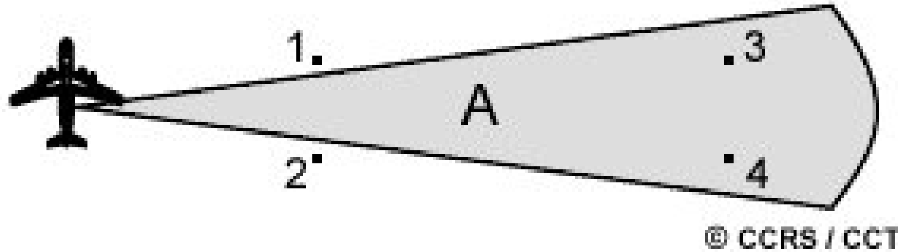


Incidence angle

The incidence angle is the angle between the ***radar beam and ground surface (A),*** *which increases from near to far range. The* ***look angle (B)*** *is the angle at which the radar "looks" at the surface. In the near range, the viewing geometry may be referred to as being steep, relative to the far range, where the viewing geometry is shallow. At all ranges the radar antenna measures the radial line of sight distance between the radar and each target on the surface. This is the* ***slant range distance (C)****. The* ***ground range distance (D)*** *is the true horizontal distance along the ground corresponding to each point measured in slant range.*



Unlike optical systems, a radar's spatial resolution is a function of the specific properties of the microwave radiation and geometrical effects. If a Real Aperture Radar (RAR) is used for image formation (as in Side-Looking Airborne Radar) a single transmit pulse and the backscattered signal are used to form the image. In this case, the resolution is dependent on the effective length of the pulse in the slant range direction and on the width of the illumination in the azimuth direction. The ***range or across-track resolution*** *is dependent on the length of the pulse (P). Two distinct targets on the surface will be resolved in the range dimension if their separation is greater than half the pulse length. For ex. targets 1 and 2 will not be separable while targets 3 and 4 will. Slant range resolution remains constant, independent of range. However, when projected into ground range coordinates, the resolution in ground range will be dependent of the incidence angle. Thus, for fixed slant range resolution, the ground range resolution will decrease with increasing range.*

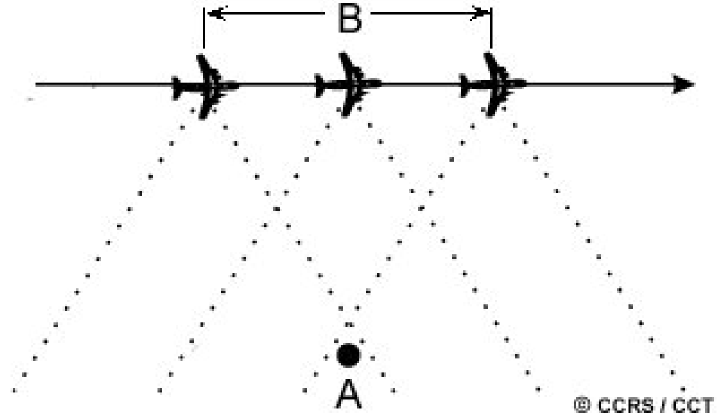


The **azimuth or along-track resolution** is determined by the angular width of the radiated microwave beam and the slant range distance. This **beam width (A)** is a measure of the width of the illumination pattern. As the radar illumination propagates to increasing distance from the sensor, the azimuth resolution increases (becomes coarser).

In this illustration, targets 1 and 2 in the near range would be separable, but targets 3 and 4 at further range would not. The radar beam width is inversely proportional to the antenna length (also referred to as the aperture) which means that a longer antenna (or aperture) will produce a narrower beam and finer resolution.

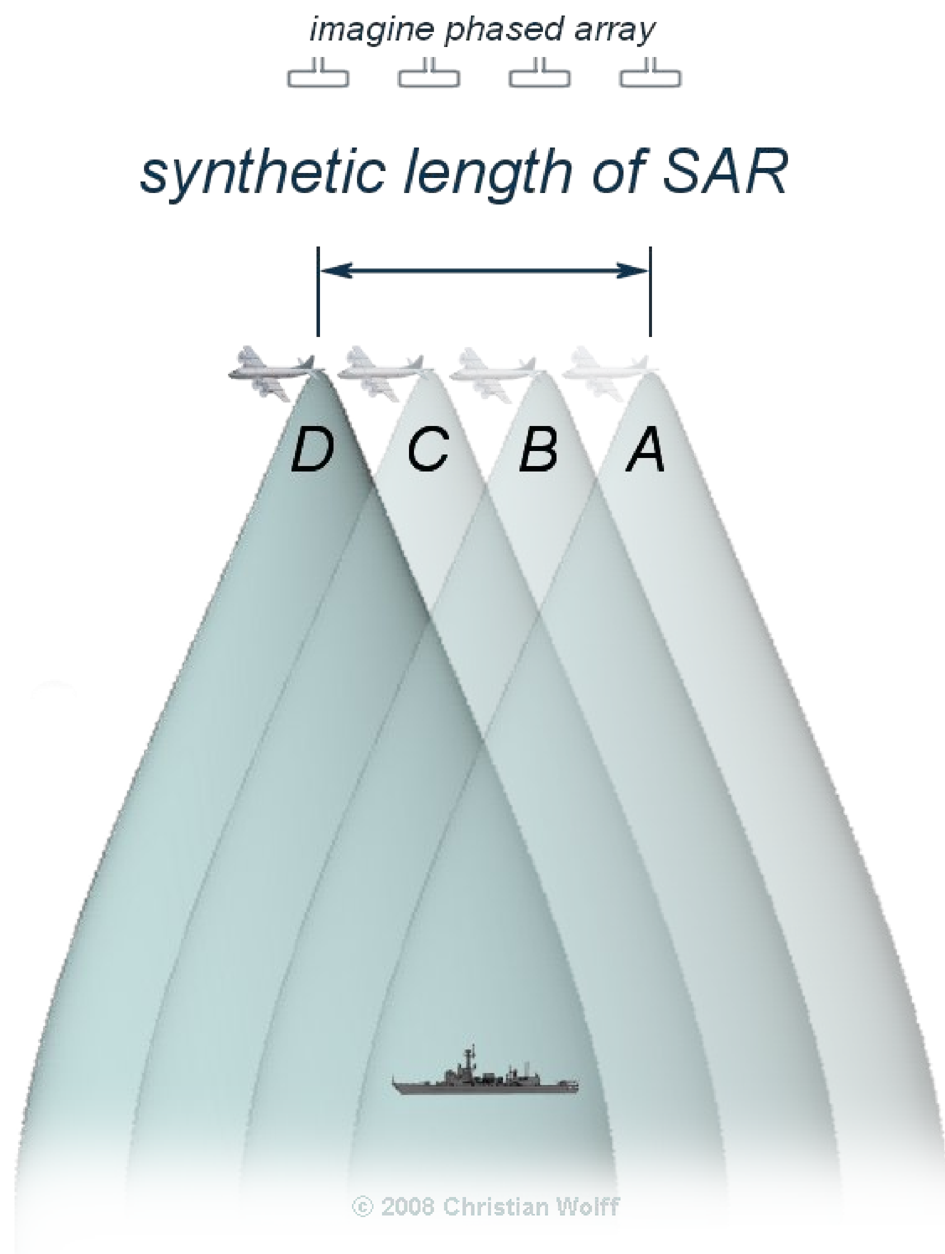
Finer azimuth resolution can be achieved by increasing the antenna length. However, the actual length of the antenna is limited by what can be carried on an airborne or space borne platform.

For airborne radars, antennas are usually limited to one to two meters; for satellites they can be 10 to 15 meters in length. To overcome this size limitation, the forward motion of the platform and special recording and processing of the backscattered echoes are used to simulate a very long antenna and thus **increase azimuth resolution**.



*As a **target (A)** first enters the radar beam (1), the backscattered echoes from each transmitted pulse begin to be recorded. As the platform continues to move forward, all echoes from the target for each pulse are recorded during the entire time that the target is within the beam. The point at which the target leaves the view of the radar beam (2) some time later, determines the length of the simulated or **synthesized antenna (B)**.*

*Targets at far range, where the beam is widest will be illuminated for a longer period of time than objects at near range. The expanding beam width, combined with the increased time a target is within the beam as ground range increases, balance each other, such that the resolution remains constant across the entire swath. This method of achieving uniform, fine azimuth resolution across the entire imaging swath is called **synthetic aperture radar**, or **SAR**. Most airborne and space borne radars employ this type of radar.*


imagine phased array
synthetic length of SAR
D
C
B
A
© 2008 Christian Wolff

*A **S**ynthetic **A**perture **R**adar (**SAR**), or SAR, is a coherent mostly airborne or space borne side looking radar system which utilizes the flight path of the platform to simulate an extremely large antenna or aperture electronically, and that generates high-resolution remote sensing imagery.*

Over time, individual transmit / receive cycles are completed with the data from each cycle being stored electronically. The signal processing uses magnitude and phase of the received signals over successive pulses from elements of a synthetic aperture. After a given number of cycles, the stored data is recombined (taking into account the Doppler effects inherent in the different transmitter to target geometry in each succeeding cycle) to create a high resolution image of the terrain being over flown

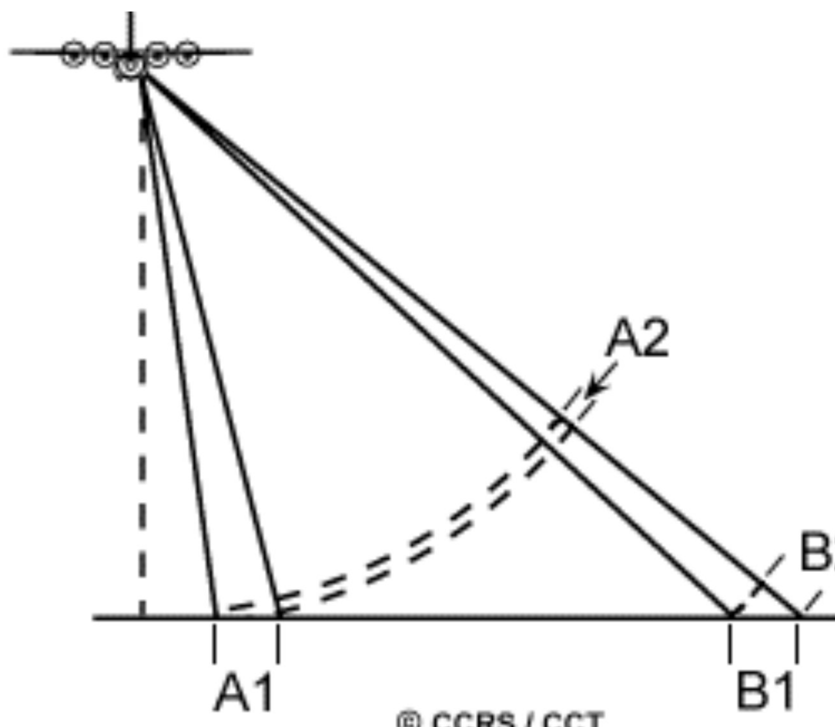
The SAR-processor stores all the radar returned signals, as amplitudes and phases, for the time period T from position A to D. Now it is possible to reconstruct the signal which would have been obtained by an antenna of length $v \cdot T$, where v is the platform speed. As the line of sight direction changes along the radar platform trajectory, a synthetic aperture is produced by signal processing that has the effect of lengthening the antenna. Making T large makes the „synthetic aperture" large and hence a higher resolution can be achieved.

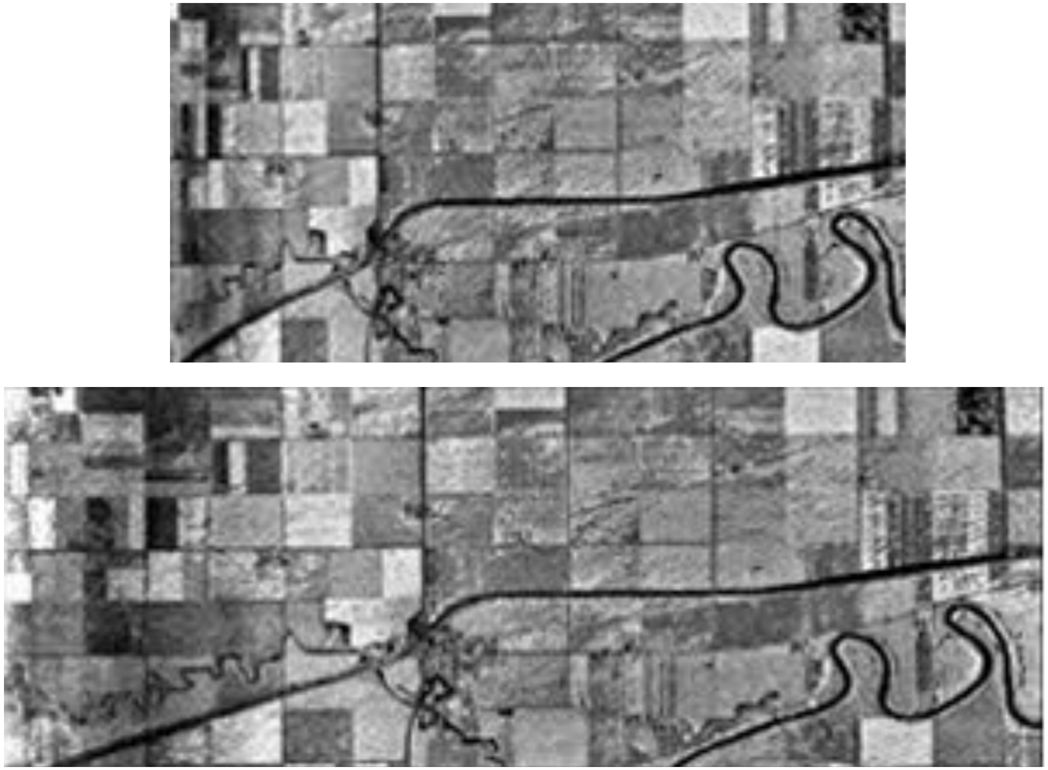
As a target (like a ship) first enters the radar beam, the backscattered echoes from each transmitted pulse begin to be recorded. As the platform continues to move forward, all echoes from the target for each pulse are recorded during the entire time that the target is within the beam. The point at which the target leaves the view of the radar beam some time later, determines the length of the simulated or synthesized antenna. The synthesized expanding beamwidth, combined with the increased time a target is within the beam as ground range increases, balance each other, such that the resolution remains constant across the entire swath.

Radar Image Distortions

As with all remote sensing systems, the viewing geometry of a radar results in certain geometric distortions on the resultant imagery. However, there are key differences for radar imagery which are due to the side-looking viewing geometry, and the fact that the radar is fundamentally a distance measuring device. ***Slant range scale distortion*** *occurs* ***because the radar is measuring the distance to features in slant-range rather than the true horizontal distance along the ground****.*

This results in a varying image scale, moving from near to far range. Although targets A1 and B1 are the same size on the ground, their apparent dimensions in slant range (A2 and B2) are different. This causes targets in the near range to appear compressed relative to the far range. Using trigonometry, ground-range distance can be calculated from the slant-range distance and platform altitude to convert to the proper ground-range format.



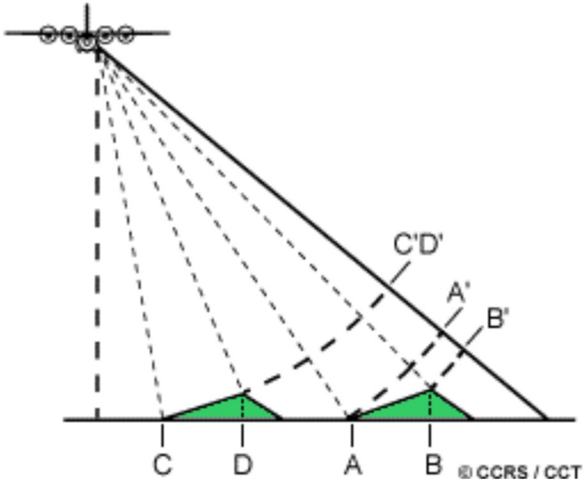


***This conversion comparison** shows a radar image in slant-range display (top) where the fields and the road in the near range on the left side of the image are compressed, and the same image converted to ground-range display (bottom) with the features in their proper geometric shape*

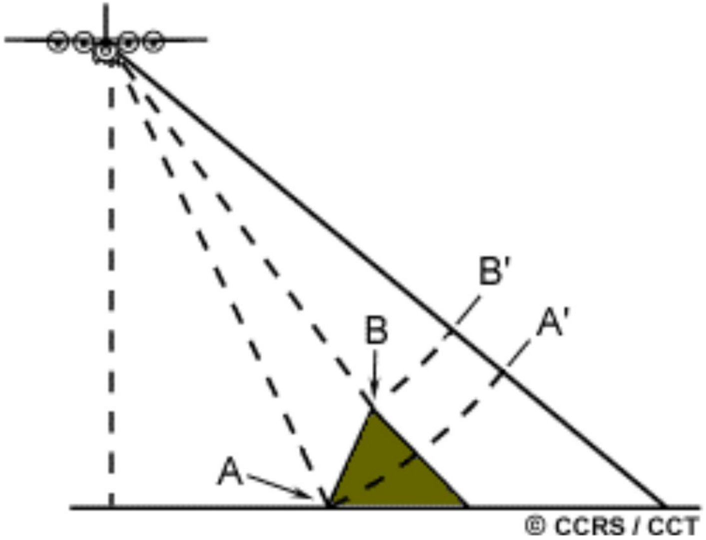
*Radar images are also subject to geometric distortions due to **relief displacement**.*

This displacement is one-dimensional and occurs perpendicular to the flight path. However, the displacement is reversed with targets being displaced towards, instead of away from the sensor.

*Radar **foreshortening** and **layover** are two consequences which result from relief displacement.*



*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. As, 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').*



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*

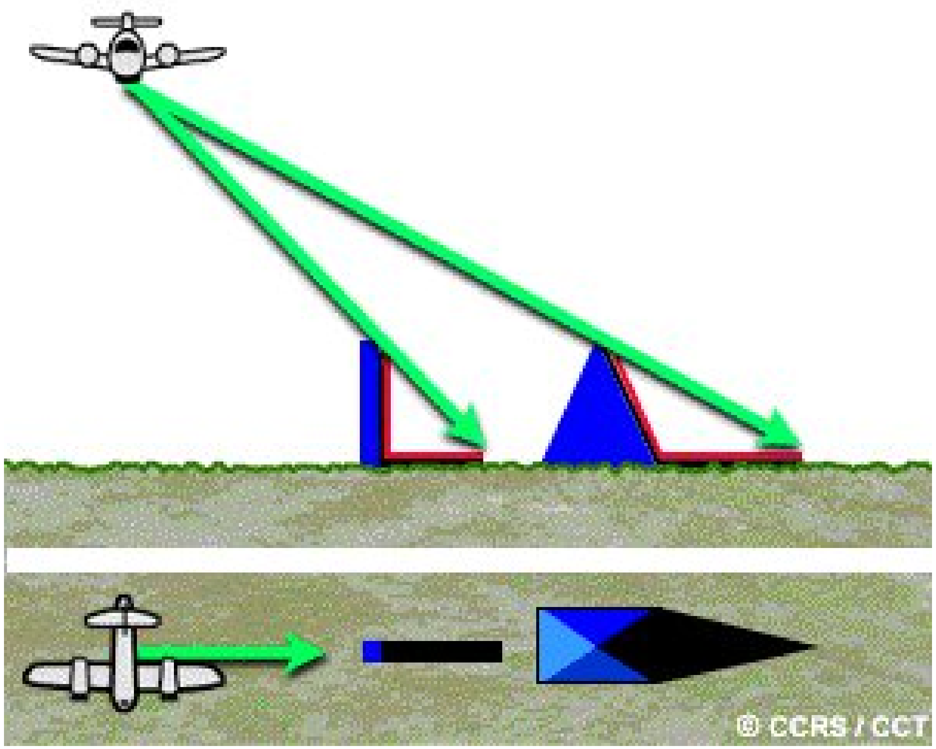
*Both foreshortening and layover result in **radar shadow**. Radar shadow occurs when the radar beam is not able to illuminate the ground surface.*

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.*



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