Remote Sensing Glossary
SPR2009
METEO-GEOSC-GEOG-EE 597K

REMOTE SENSING GLOSSARY

updated (but *unedited*)

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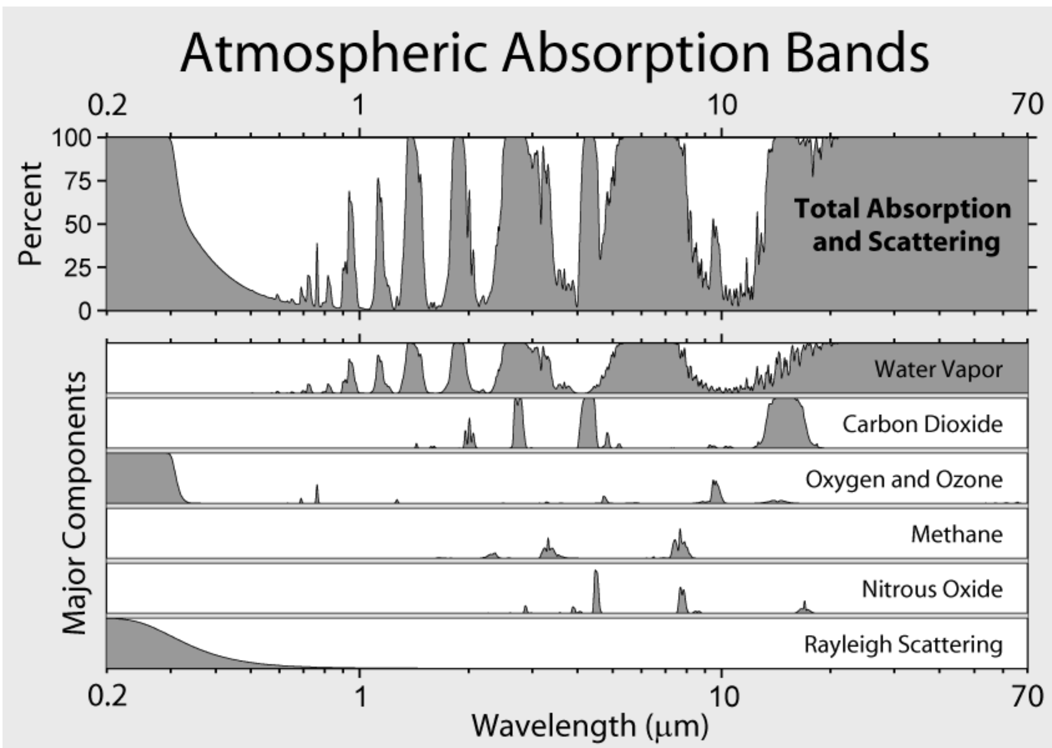
A

Absorption: the electromagnetic process in which radiant incidence is absorbed and converted into other forms of energy (i.e. heat) by the medium. This occurs when irradiance of the same frequency as the resonant frequency of an atom or molecule excites the medium to the point of stimulation. The atom or molecule will then emit a photon of longer wavelength in the form of heat. Usually absorption is shown with absorption bands which are ranges of wavelengths within which the irradiance is absorbed by the particular medium (i.e. H_2O, CO_2, N_2O, etc.). [see Elachi and Zyl (2006), Introduction to the Physics and Techniques of Remote Sensing, 3nd ed., 399 pp., Wiley & Sons Inc. New Jersey] The following absorption bands are courtesy of http://www.globalwarmingart.com/wiki/Image:Atmospheric_Absorption_Bands_png.



Absorption Band: Bands in the electromagnetic spectrum that are absorbed by a given medium[1]. In relation to the earth's atmosphere, there are certain gases that have tendencies to absorb large amount of radiation at given wavelengths. However, other electromagnetic wavelengths are not affected at all by these same gases. Areas where there is a large amount of absorption are termed absorption bands, while areas of low absorption are termed atmospheric windows.

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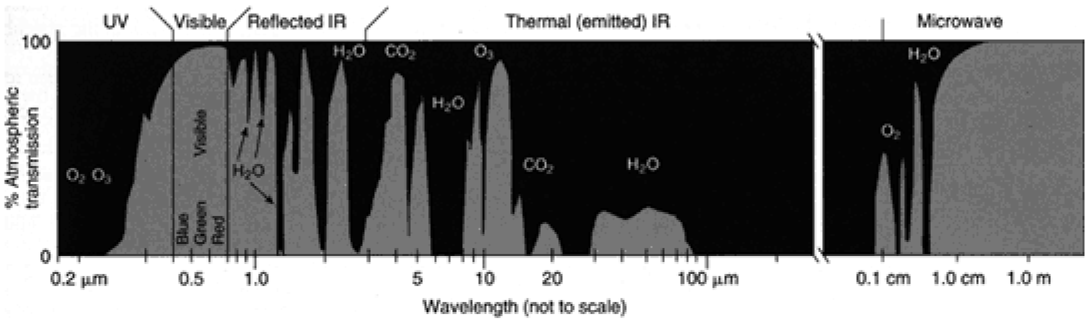

Figure 1 – Diagram of absorption bands and atmospheric windows, with bands represented by the gas causing the absorption. Image is from NASA[1].

Knowledge of atmospheric bands is key to remote sensing. Certain wavelengths are not studied using satellites due to the high absorption of the atmosphere, while other wavelengths are heavily exploited for their low levels of absorption. Common gases that contribute to these bands are methane, nitrous oxide, oxygen, ozone, carbon dioxide, and water vapor[2], as represented in figure 2.

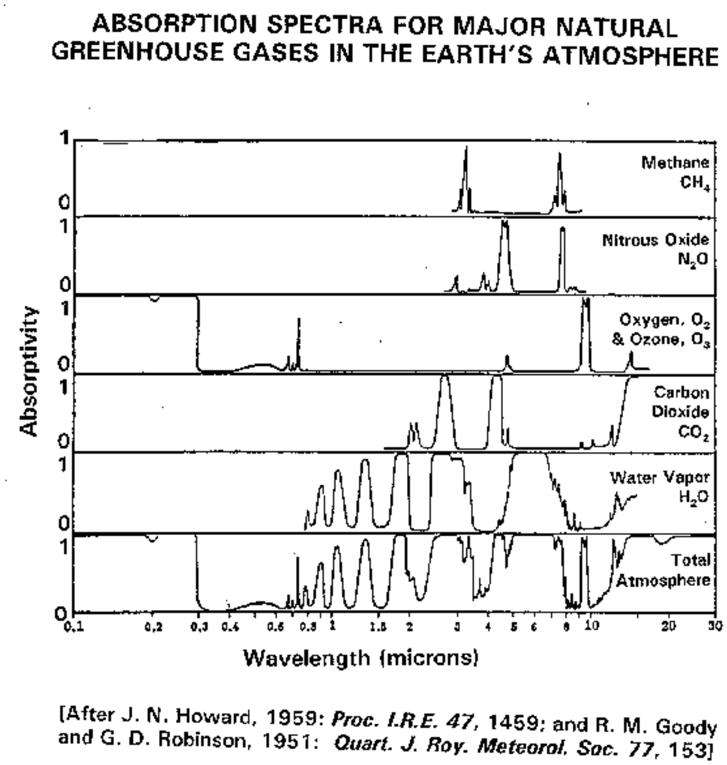

Figure 2 – Atmospheric absorption band gases based on absorptivity values from 0 to 1. Image from Iowa State University[2].

1. "Remote Sensing: Feature Articles." NASA Earth Observatory: Home. 12 Apr. 2009 <http://earthobservatory.nasa.gov/Features/RemoteSensing/remote_04.php>.

2. "Greenhouse Gas Absorption Spectrum." IITAP Home Page. 12 Apr. 2009 <http://www.iitap.iastate.edu/gccourse/forcing/spectrum.html>.

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Absorption Coefficient

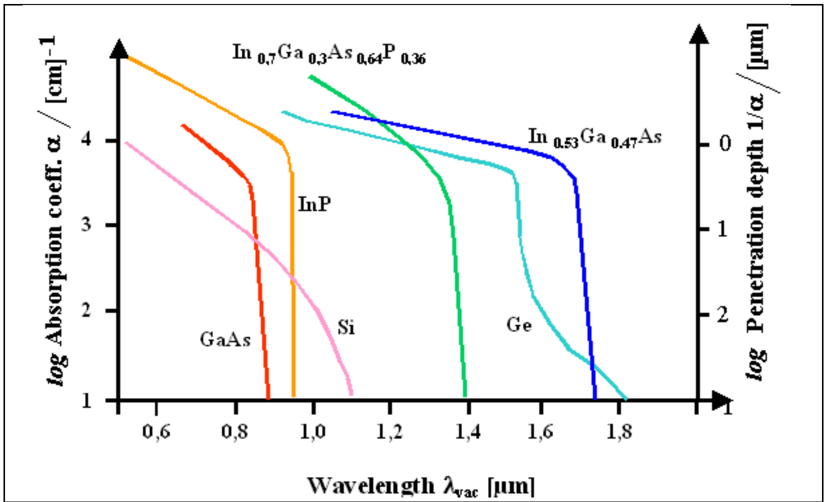
In general, the extinction and absorption coefficients are parameters defining how strongly a substance absorbs or lets through (transmits) at a given wavelength. The absorption coefficient describes a fraction of a beam of radiation that is absorbed in passing through a unit length of absorbing material.

The *Absorption coefficient* determines how far into a material light of a particular wavelength can penetrate before it is absorbed. If a material has a low *absorption coefficient*, light is being poorly absorbed, and if the material is thin enough it will appear transparent to that wavelength. The *absorption coefficient* also depends on the material and on the wavelength of light which is being absorbed.

The band-band absorption process is described by Beer's Law, which describes the reduction of radiation through a medium due to a linear relationship between the energy extinction and concentration of absorber/scatters in a medium.
It describes the intensity of light at a depth z: $I(z) = Io * \exp - \alpha * z$
With Io = intensity at $z = 0$ and $\alpha = \alpha(hv)$ = the *absorption coefficient* of the material
This equation shows that the *absorption coefficient* is a function of the E energy (hv) of the photons.

-When hv is less than emission, the material is transparent and α is small.
When hv is greater than emission, absorption should be strong.

The following diagram shows the absorption coefficients of major semiconductors. The absorption coefficient changes by 4-5 orders of magnitude around the band energy, and in direct semiconductors the chance is harder than in indirect semiconductors.



http://www.techfak.uni-kiel.de/matwis/amat/semi_en/kap_5/backbone/r5_2_2.html

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Active Sensing: A remote sensing system, which measures sources of energy or radiation by providing its own energy source for illumination.

The sensor rather emits energy in order to scan objects and areas, so that a passive sensor can detect and measure the radiation reflected from the target.

The system can be described as either an imaging (Ex:RADAR) or non-imaging system (Ex: altimeters). Non-imaging systems take measurements in one linear dimension as compared to the two-dimensional done by imaging sensors. An altimeter transmits microwave pulses and measures the round trip time delay to targets to determine their distance from the sensor. Generally an altimeter measures from nadir and can measure height or elevation.

The simplest example of an imaging active sensor is **radar**, used by police to measure the speed of vehicles. The radar pulses, microwave radio signals toward the vehicles and detects the backscattered portion of the signal. The strength of the backscattered angle is measured in relation to the speed of the target to discriminate between different targets and their transmitted and reflected signals.

1.The sensor first emits radiation in the direction toward the target of investigation.
2. Radiation becomes reflected by the target and is measured by the sensor.
3. Measures either the angle of reflection, or the time it takes for the energy to return.

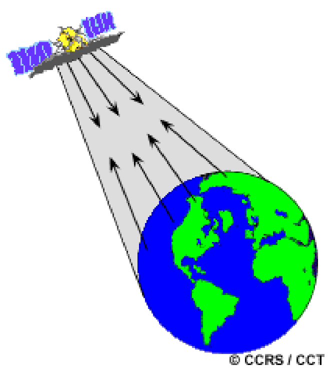

Figure 1: An example of an active sensor sending out radiation and collection the reflected energy.[1]

It is important to note that depending on the target source, different kinds of reflectance can take place. However, important information can still be gleaned from areas with a lot of noise and scattering. See Figure 2:

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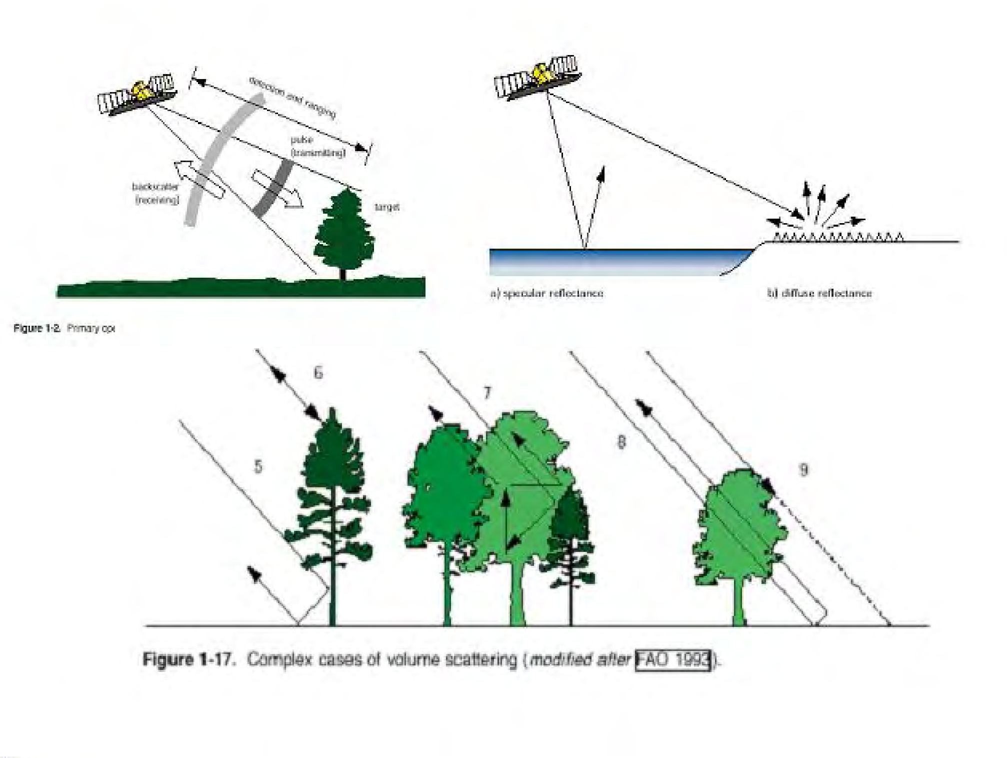

Figure 2: Demonstrates the different type of reflection that can take place based on the target surface. Reflectance can range from specular to diffuse or direct, to backscattered.[(2)]

Advantages

- Able to obtain data at anytime, regardless of the time of day or season.
- Unobtrusive.
- Systematic collection reduces sampling bias.
- Can provide data over large areas.

Disadvantages

- Require large amounts of energy to generate high-resolution images.
- Sensors can become uncalibrated.
- Expensive and hard to maintain
- Inherent trade-offs (spectral, spatial, temporal resolutions, signal infidelity)

Figure 3: SAR image of Death Valley. Courtesy of NASA.[(3)]

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Applications:

- Can be used to examine wavelengths not provided by the sun (Ex: microwaves)
- Help to better control the way a target is illuminated.
- Analyze climate change, depth, speed, and height information.
- Hazard Assessment.
- Natural Resource Management.

Examples:

- Radar (RADARSAT, SRTM, ERS)
- Laser fluorosensor (LIDAR): used to measure concentrations of chemicals in the atmosphere.
- Synthetic Aperture radar (SAR): used to produce digital elevation models (DEM) for GIS.
- Scatterometers: used to make precise quantitative measurements on the amount of energy backscattered.

Sources:
(1) Canada Centre for Remote Sensing Tutorial. Accessed 11 Feb. 2008.
http://www.ccrs.nrcan.gc.ca/resource/tutor/fundam/chapter1/06_e.php

(2) Chevron Sensor Tutorial. Accessed 11 Feb. 2008.
http://www.es.ucsc.edu/~hyperwww/chevron/pas_act.html

(3)Source: Canada Centre for Remote Sensing Tutorial. Accessed 11 Feb. 2008.
http://www.nasaimages.org/luna/servlet/detail/nasaNAS~4~4~9384~111121:Color-Image-of-Death-Valley,-Califo

Active Gain Control
Definition: Active gain control (AGC, sometimes called automatic gain control) is a way of autonomously managing the gain of a receiving device such that the resulting amplitude always falls within a desired range[1]. In remote sensing, AGC is necessary to account for widely varying received power levels due to atmospheric obstructions, surface reflectivity variances, and lifetime varying transmitting power levels (where a transmitter is used). In an AGC circuit, the gain of the receiving system is slowly varied until the average received power level falls within a desired amplitude range, usually where the rest of receiver functions best. Without AGC, the rest of the receiver can become saturated with high level incoming signals and/or completely loose weak incoming signals.

References
http://www.eecg.toronto.edu/~kphang/papers/2001/martin_AGC.pdf

Aerosol Optical Depth

Aerosol optical depth (AOD) is a measure of direct radiative forcing through analysis of the extinction of radiation by scattering of aerosols and the absorption of radiation in a column of atmosphere. Aerosol optical depth is based upon the aerosol concentration in a column of atmosphere and can be determined by pointing instruments, such as sunphotometers, at the sun. But AOD is not directly observed; it is the difference between total optical depth and radiative components including Rayleigh scattering, extinction, absorption, and cloud contamination (World Data Centre for Aerosols, 2009). AOD is inversely related to wavelength; AOD is small for longwave radiation and large for shortwave radiation. Aerosol optical depth typically ranges from 0.02 to 0.2 (AMS Glossary). Aerosol optical depth is highly dependent on wind patterns, climate, and other changing meteorological conditions. In general, the higher the aerosol optical depth, the more hazardous the atmosphere becomes for inhabitants.

The MODIS aerosol product measures aerosol optical depths over land and ocean. MODIS is able to derive aerosol optical thickness over land due to the blue channel on MODIS (not present on AVHRR). Aerosol satellite data from GMS-5 and TOMS can also be used to determine aerosol optical depth (Jietai, 1999). Ground based observations aide in the calibration of remote sensing instruments and can confirm calculations of the Angstrom exponent, which is determined from the aerosol optical depth and is a measure aerosol size distribution.

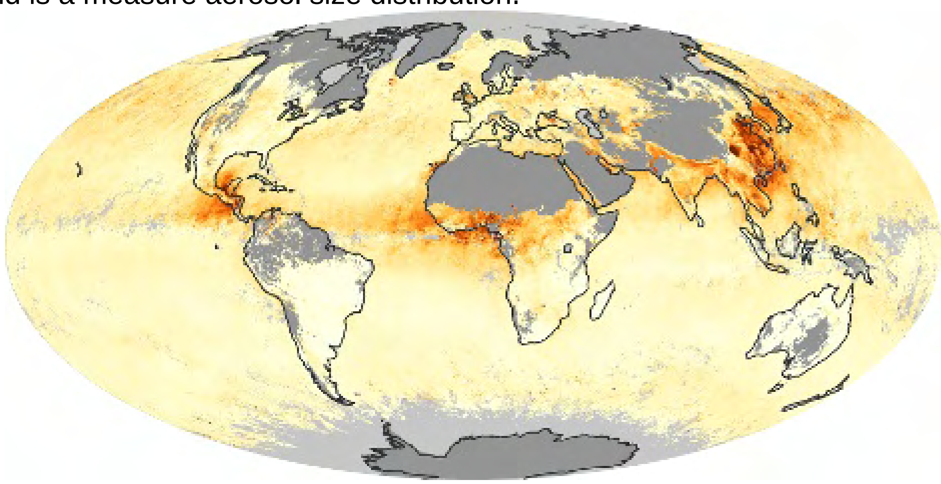

Figure 1 shows the global aerosol optical depth amounts for April 2005. The pale yellow represents aerosol optical depths less that 0.1 while the red-brown represents aerosol optical depths of 1. This image is from MODIS on the Terra satellite (Remer, 2009).

References

American Meteorological Society. "Aerosol Optical Depth". http://amsglossary.allenpress.com/glossary/search?id=aerosol-optical-depth1

Jietai, Zhang Junhua Mao. "Remote Sensing Aerosol Optical Depth from Space and Ground". 1999. http://www.gisdevelopment.net/aars/acrs/1999/ps6/ps61220.asp

Remer, Lorraine. Aerosol Optical Thickness Image. 2009. http://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MODAL2_M_AER_OD

World Data Centre for Aerosols. "Aerosol Optical Depth". 2003. http://wdca.jrc.ec.europa.eu/data/parameters/data_AOD.html

Albedo

Albedo is a measure of reflectance occurring at an object. It is the ratio between reflected to incident electromagnetic radiation (Wikipedia, 2009). Albedo is measured on a scale from 0 to 1. For example, an albedo measure of 0.3 indicates that 30% of light is being reflected back to space. The average albedo of Earth is approximately 0.3; clouds reflect a portion of sunlight back to space and contribute to average global albedo.

Fresh snow has an albedo of 0.9 (90% of light reflected back) whereas charcoal has an albedo of 0.04 (4% of light reflected back). An ideal black body will absorb all radiation, 0% albedo, while an ideal white body will reflect all radiation, 100% albedo. Albedo depends on surface properties as well as direction and distribution of incoming radiation. Albedos, in combination with bidirectional reflectance distribution functions (BRDF), can accurately characterize scattering properties of the surface. Typically, brighter surfaces (e.g. ice) have higher albedos than dark surfaces (e.g. ocean).

Albedo is an important property in the maintenance of earth's climate and radiation balance. Changes in albedo cause temperature, wind, ocean current, and precipitation fluctuations (Budikova, 2008). When the icy surfaces at the poles begin to dissipate, less energy will be reflected back to space, more sunlight is absorbed, and the poles may become warmer. Albedo values are largely dependent on surface shapes and properties; deciduous tree have a 0.15 to 0.18 albedos while coniferous trees have a 0.09 to 0.15 albedos. Albedo is also dependent on radiation changes due to aerosol direct and indirect effects; aerosols serve to both cool and warm localized sections of the atmosphere.

Table 1: Reflectivity values of various surfaces

Surface	**Details**	**Albedo**
Soil	Dark & wet versus	0.05 -
	Light & dry	0.40
Sand		0.15 – 0.45
Grass	Long versus	0.16 -
	short	0.26
Agricultural crops		0.18 – 0.25
Tundra		0.18 – 0.25
Forests	Deciduous	0.15 – 0.20
	Coniferous	0.05 – 0.15
Water	Small zenith angle versus	0.03 – 0.10
	Large zenith angle	0.10 – 1.0
Snow	Old	0.40 -
	Fresh	0.95
Ice	Sea	0.30 – 0.45
	Glacier	0.20 – 0.40
Clouds	Thick	0.60 – 0.90
	Thin	0.30 – 0.50

Sources: Oke, 1998; Ahrens, 2001

Figure 1 is a table listing the details and albedos of common surface and agricultural crops. A large range of albedos exist on Earth (Budikova, 2008).

The albedo cannot be observed directly; a BDRF model must translate the data into directional-hemispherical reflectance and bi-hemispherical reflectance (Wikipedia, 2009). The albedo of Earth's surface can be observed with remote sensing instruments such as MODIS on Terra and Aqua satellites. The International Satellite Cloud Climatology Project (ISCCP) has been collecting albedo data since 1983 (Budikova, 2008). The MODIS BRDF and Albedo Product is a MODIS Standard Data Product that has been collecting data since 2000 (Schaaf, 2004). Also, Global Albedo, BRDF Model Parameters, and Nadir-BRDF Adjust Reflectance Projects outputs are produced every 16 days. The output uses 1km spatial resolution and is archived at the EROS data Center. These products are also used as Climate Modeling Grid products with a 0.05 degree spatial resolution. Albedo maps produced with a one minute resolution are created from the Filled Land Surface Albedo Product by the MODIS atmosphere team (Schaaf, 2004).

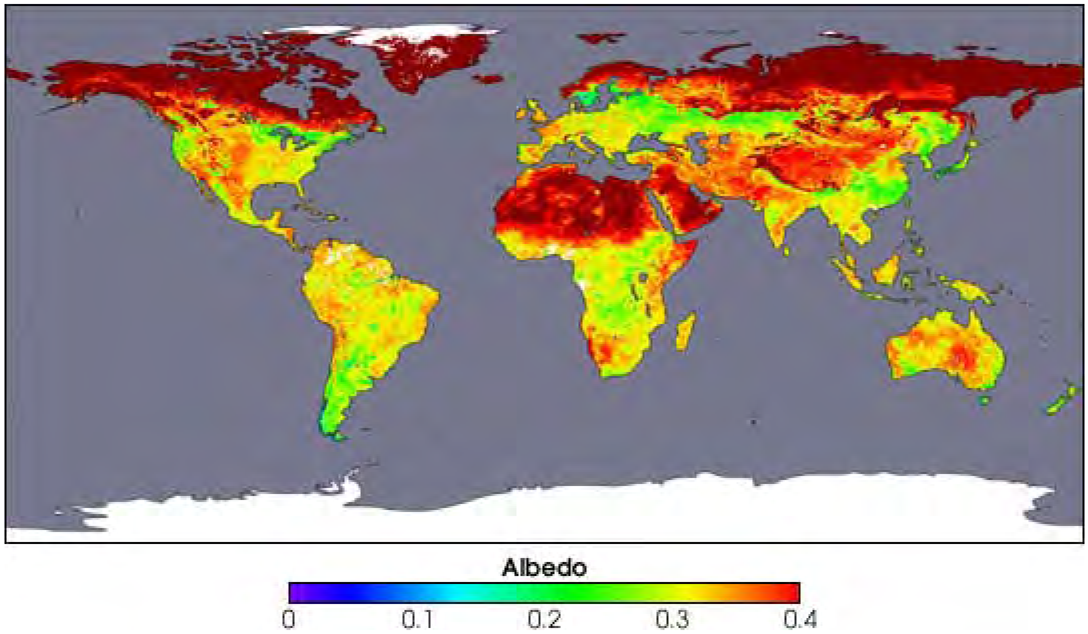

Figure 2 is an images of Earth's albedo from MODIS. This image was produced using data composited over a 16-day period, from April 7-22, 2002 (Schaaf, 2008).

References

Budikova, Dagmar. Encyclopedia of Earth. "Albedo". 2008. http://www.eoearth.org/article/Albedo

Earth Observatory. Global Albedo. 2008 http://images.google.com/imgres?imgurl=http://earthobservatory.nasa.gov/images/imagerecords/2000/2599/modis_albedo.jpg&imgrefurl=http://earthobservatory.nasa.gov/IOTD/view.php%3Fid%3D2599&usg=__WXjBv6Enxq5k95UYDn4qmiDFLYo=&h=313&w=540&sz=45&hl=en&start=7&tbnid=4etm1YkaeDh3HM:&tbnh=77&tbnw=132&prev=/images%3Fq%3DMODIS%2Balbedo%26gbv%3D2%26hl%3Den%26safe%3Doff%26sa%3DG

Schaaf, Crystal. MOD43 BRDF/Albedo MODIS Product. 2004. http://www-modis.bu.edu/brdf/product.html

Wikipedia. "Albedo". 2009. http://en.wikipedia.org/wiki/Albedo

Angle of incidence: The measure of deviation of a ray from a line directly perpendicular to the surface of some medium (this perpendicular line is often called the normal of the surface). This ray can be formed by any type of wave (acoustic, optical, microwave, X-ray, etc). The concept of the angle of incidence is nicely illustrated in Figure 1. The angle of incidence at which light is totally reflected internally on a particular medium is called the critical angle. Two other angles that are often used to refer to the incidence of beams are the angle of reflection (changing of direction of a wave at the interface between it and a particular medium so that the wave propagates back in the direction from which it came) and the angle of refraction (used to describe the angles of incidence and reflection of waves passing through a boundary between two media, such as water or glass). The grazing angle, or the angle between the ray in question and the medium that it is bouncing off of, is often used as opposed to the angle of incidence in quantifying the angular properties of an incoming wave. However, it is important to distinguish between the grazing angle and angle of incidence in an analysis.

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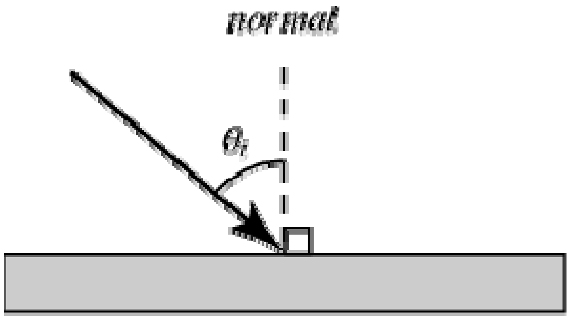


Figure 1: Shows an incoming ray intersecting a medium at a point, and the angle of incidence is drawn from the surface normal to the incoming ray (Weisstein 2007).

References:
Weisstein, Eric. "Angle of Incidence." Science World. Wolfram Research. <http://scienceworld.wolfram.com/physics/AngleOfIncidence.html>.

Atmospheric Correction
Atmospheric correction eliminates effects of absorption of scattering of radiation by atmospheric particles in satellite imagery. Atmospheric haze effects are diminished by rescaling each frequency band to a pixel value of zero in the IR and NIR bands; water is usually absorbent in the IR and NIR wavelengths. By removing atmospheric particle disturbances, surface reflectance can accurately be uncovered. Atmospheric correction allows for substitution using data from various platforms, more reliable results, and improved spatial definition of objects and edges (NCAVEO, 2005).
Image 1 (Image 2) is a satellite image without (with) atmospheric correction

Image 1

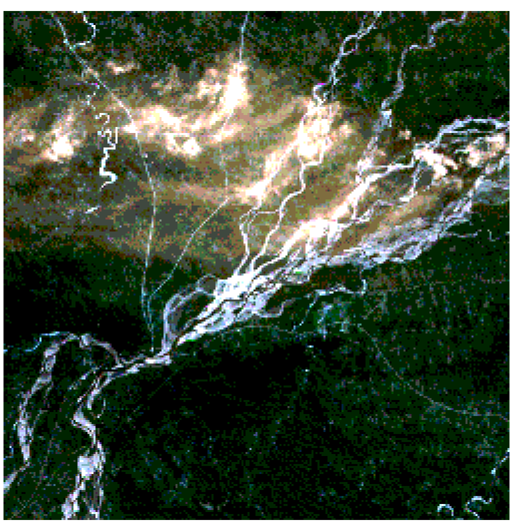
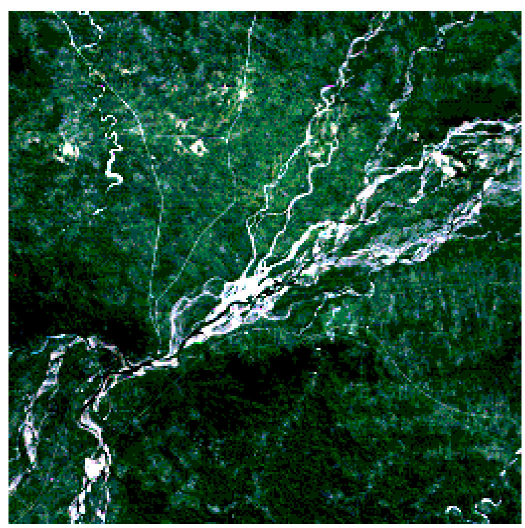


Image 2



Atmospheric correction converts the top of the atmosphere radiance to ground-leaving radiance (NCAVEO, 2005). Atmospheric correction allows for comparison of multi-temporal images with changes in the earth's surface rather than changes in the atmosphere with time. Also, with this

technique, multi-sensor images can be compared at similar spectral bands (Satellite Imaging Corporation, 2009). Software exists to enable atmospheric correction in both flat and mountainous areas. Atmospheric correction is used to reveal the changes in chlorophyll (and other oceanic properties) in the ocean. The atmosphere produces 80-90% of the radiance retrieved by a satellite whereas the ocean produces 10-20% of the radiance retrieved by a satellite (Boynton, 2009). In case of ocean, sun glint and white caps must also be accounted for in atmospheric correction models (Boynton, 2009). See Gordon and Wang (1994) for more information. In addition to ocean observations, atmospheric correction is also important for observations such as forest damage monitoring, surface temperature mapping, harvest estimations, and erosion monitoring (Satellite Imaging Corporation, 2009).
There are bidirectional and empirical models for doing atmospheric correction on an image (Wikipedia, 2008). There are two main steps in atmospheric correction algorithms. First, the atmospheric optical characteristics are estimated through direct measurements or theoretical models (Fallah-Adl, 1995). The optical characteristics in combination with radiative transfer models lead to atmospheric correction results (Fallah-Adl, 1995). Next, inversion procedures are used to correct remotely sensed imagery to uncover surface reflectance. (Fallah-Adl, 1995). Unfortunately, atmospheric correction can only be applied to high spatial resolution images (ie from Landsat TM, ASTER, Quickbird).

Image 3 (Image 4) illustrates a scene with (without) Atmospheric and Topographic Correction for Satellite Imagery (ATCOR) from the Satellite Imaging Corporation.

Image 3

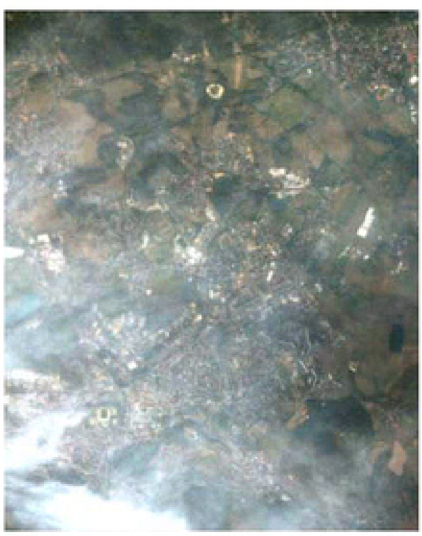


Image 4

References

Boynton, Chris. “Radiative Transfer Theory, Atmospheric Correction, and Ocean Color”. 2009. http://www.physics.miami.edu/~chris/envr_optics.html
Fallah-Adl, Hassan. “Atmospheric Correction”. 1995. http://www.umiacs.umd.edu/labs/GC/atmo/
Network for Calibration and Validation of Earth Observation data. “Atmospheric Correction”. Southampton: 2005. http://www.ncaveo.ac.uk/special_topics/atmospheric_correction/
Satellite Imaging Corporation. “Atmospheric/Topographic Correction for Satellite Imagery. 2009. http://www.satimagingcorp.com/svc/atcor.html
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Atmospheric Window: Refers to the part of the electromagnetic spectrum where absorption is low and radiation can be transmitted through the atmosphere with relatively little interference.

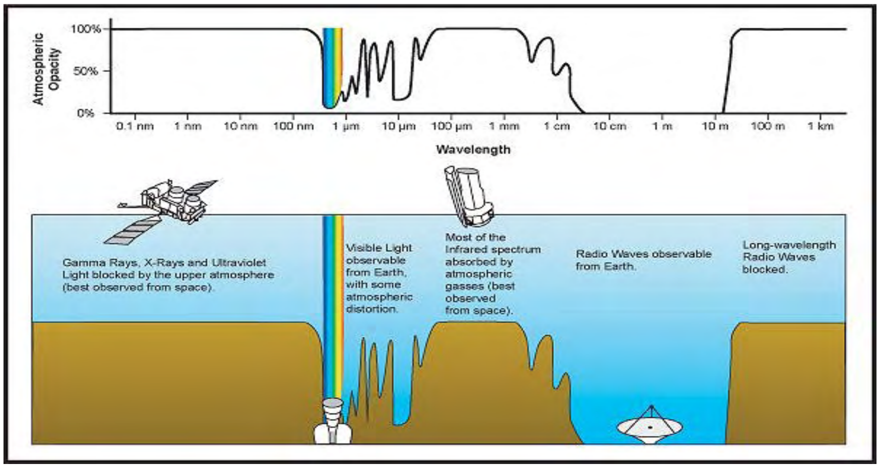


Figure 1: Electromagnetic spectrum shows that the Infrared wavelengths have very high transparency, and thus most radiant energy produced from the earth is here. Source: http://www.ipac.caltech.edu/Outreach/Edu/Windows/irwindows.html

Most thermal remote sensing occurs in atmospheric windows in the thermal IR part of the EM spectrum, where atmospheric absorption is low (8-13 um). These windows suffer from carbon dioxide and water vapor absorption. The 3-5μm window is another large atmospheric window contaminated with solar reflective energy.

Greenhouse gases all have different absorption characteristics based on their chemical properties. Gases such as CO2 and CH4 absorb at longer wavelengths due to the presence of relatively long C-H and carbonyl bonds. Without these atmospheric windows, the Earth would become much too warm to support life, and they thus allow for enough energy to radiate out into space to avoid overheating.

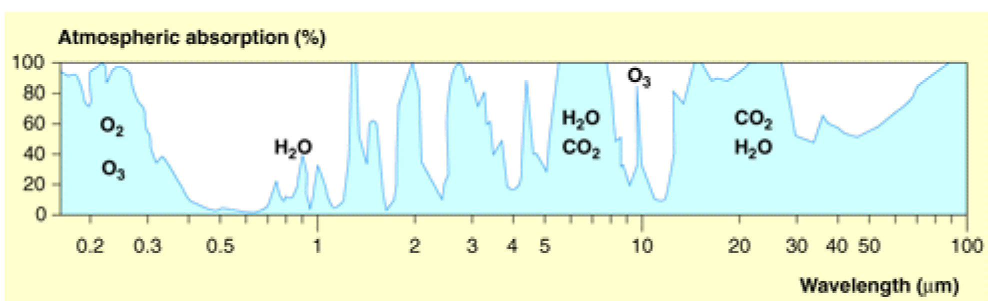


Figure 2: Spectrum showing the various greenhouse gases that absorb at different wavelengths.
Source: http://www.eduspace.esa.int/eduspace/subtopic/images/07-atmosvindue.gif

Figure: Table of specific bands in the electromagnetic spectrum where absorption is low. These are known as the atmospheric windows.

Spectral Windows where there is low absorption:

VIS & IR bands (in μm)	
0.3-0.9 (vis)	2.0-2.4
1.0-1.1	3.5-4.0
1.2-1.3	4.6-4.9
1.5-1.8	8.0-13.0
Microwave/Radio bands (in GHz)	
0.1-15	140-160
25-35	230-250
80-100	260-290

From 100 MHz-0.1GHz relatively low attenuation.

Source: Bamber, Jonathon. "An Introduction to Remote Sensing". Accessed Feb 26, 2009. http://www.ggy.bris.ac.uk/personal/JonathanBamber/teaching/rsp/rsp%20lectures%20with%20figs.htm

Atmospheric Window: It refers to the relatively transparent wavelength regions of the atmosphere.

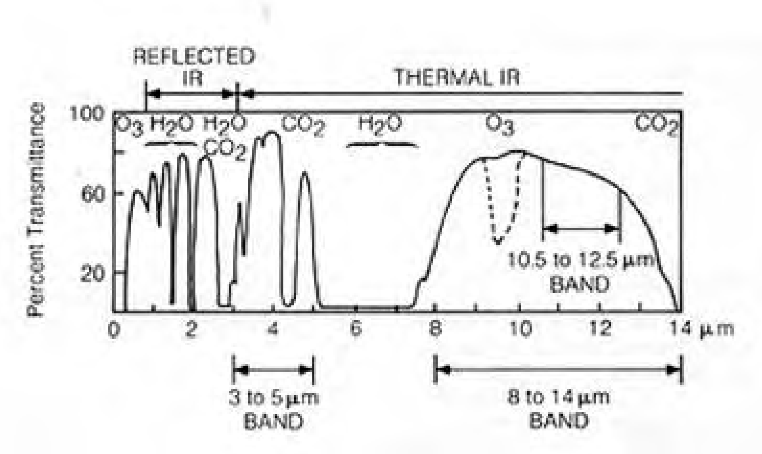
Atmospheric absorption reduces the number of spectral regions that we can work with in observing the Earth. It affects our decision in selecting and designing sensor. We have to consider

1) the spectral sensitivity of sensors available;

2) the presence and absence of atmospheric windows;

3) the source, magnitude, and spectral composition of the energy available in these ranges.

For the third point, we have to base our decision of choosing sensors and spectral regions on the manner in which the energy interacts with the target under investigation.



Most thermal remote sensing occurs in atmospheric windows in the thermal IR part of the EM spectrum, where atmospheric absorption is low.
These windows suffer from carbon dioxide and water vapor absorption. The 3-5µm window is contaminated with solar reflective energy as well during daylight hours

Applications?
Since the IR region is imperative to measuring what goes on in the atmosphere and land, remote sensing devices have be calibrated to receive measurements from these bandwidths. For example, AVHRR (see figure).

Application of Remote Sensing: Infrared radiometers:

band	wavelength	function
1	0.58-0.68	cloud discrimination
2	0.725-1.0	surface water boundaries
3	3.55-3.93	atmospheric corrn. to temps.
4	10.3-11.3	temperature mapping
5	11.5-12.5	atmospheric corrn. to temps.

Figure: Table shows wavelengths which correspond to where absorptio is low, measured by
AVHRR onboard the TIROS N and NOAA 6-13 satellites. For example we wanted to look at sea surface temperatures, measuring in band 4 would allow us to discriminate between clouds over the ocean because the albedo differs from water in the infrared bands.

Source: Bamber, Jonathon. "An Introduction to Remote Sensing". Accessed Feb 26, 2009.
http://www.ggy.bris.ac.uk/personal/JonathanBamber/teaching/rsp/rsp%20lectures%20w%20figs.htm

Other Satellites that take measurements in IR:

- Along-Track Scanning Radiometer (ATSR) aboard the European Remote Sensing Satellite (ERS-2),
- The Geostationary Operational Environmental Satellite (GOES) Imager,

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- Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA Earth Observing System (EOS) Terra and Aqua satellites.

+ These satellites provide high resolution and very accurate measurements, for long periods of time.
- However, they are obscured by clouds and require atmospheric corrections.

Attenuation
Attenuation is the gradual reduction in intensity of a transmitted quantity, often as a function of distance. The term applies mainly to electromagnetic and acoustic waves. Attenuation is caused primarily through the processes of scattering and absorption. The intensity of the electromagnetic radiation is not diminished due to the attenuation due to the inverse-square law.

In theory, a plane wave with a single frequency in a vacuum will propagate forever without a loss in intensity. A spherical wave, however, results in a decrease in intensity as the wave propagates. The further a wave propagates away from the source, the more molecular and particulate matter it will pass through. As a result, areas close to the source of the wave are generally less attenuated than areas far away from the source.

Attenuation of a plane wave passing through the atmosphere results from natural properties and loading conditions. The amount of attenuation through a medium can be quantified through an attenuation coefficient. The amplitude of a decaying plane wave is characterized by a function of exponential decay, where the attenuation coefficient is a unit with dimensions of inverse length.

Attenuation is measured in units of decibels per unit length (e.g. dB/km). The computation of attenuation, in decibels, is given as 10 times the log of the input intensity over the output intensity in watts (Figure 1). Propagation through a homogenous medium can be characterized by the attenuation constant.

$$\text{Attenuation(dB)} = 10 \times \log_{10}\left(\frac{\text{Input intensity(W)}}{\text{Output intensity(W)}}\right)$$

Eq. 1: Computation of attenuation as a function of input and output intensity

In satellite remote sensing, attenuation is an important concept for telecommunications. To communicate with a satellite and for a satellite to communicate with a base station, the range of the signal must be considered. Attenuation limits the range of the signal, often via radio waves. Of course, the amount of attenuation can vary widely and depends greatly on the type of the atmosphere in which the radiation is passing through.

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When taking scientific studies based on satellite measurements, attenuation must also be considered in order to account for the signal loss through a particular medium. Often algorithms may be applied to account for the attenuating effects of the atmosphere.

Detwiler, James. "What is a GIS?" GEOG 485. University Park, PA. 5 Sept. 2008.
Helen Couclelis, "Geographic information systems", in AccessScience@McGraw-Hill, http://www.accessscience.com, DOI 10.1036/1097-8542.757430
"sound." Encyclopædia Britannica. 2009. Encyclopædia Britannica Online. 06 Apr. 2009 <http://www.britannica.com/EBchecked/topic/555255/sound>.

AVHRR: Advanced Very High Resolution Radiometer. It is the primary sensor system and a multispectral scanning radiometer carried on the TIROS meteorological satellites. The system was first launched in 1978 as a four-channel radiometer, and has had two updates over the past 30 years. The most recent instrument, the AVHRR/3, was launched in May 1998 as part of the NOAA-15 satellite.
At the onset of the AVHRR project, it was anticipated that the instrument would only be used for observing cloud patterns, however, it was later discovered that the sensors were capable of gathering data on many other phenomena and characteristics of the Earth's surface, such as sea surface temperatures, sea ice concentrations, and land cover types.
The AVHRR/3 is an imaging system in which a small field of view is scanned across the earth from one horizon to the other by continuous 360 degree rotation of a flat scanning mirror. The current instrument consists of six detectors (three solar channels in the visible near-infrared region, three channels in the thermal infrared), each for a different portion of the electromagnetic spectrum, that record the amount of visible and infrared radiation emitted and/or reflected from the Earth's surface and atmosphere. However, only five of these six channels are broadcast to the ground at any given time, as two of the channels are unable to operate simultaneously (see Figure 1 below). The detectors are designed to operate within specification for a period of three years in orbit. The three channels operating within the infrared region of the spectrum (channels 3A/3B, 4, 5) are used for detecting heat (thus temperature) from land, water, and clouds. Channels 1 and 2 are used for imaging the Earth's surface, specifically cloud patterns and land-water boundaries. The AVHRR instrument is capable of recording pixel information for areas of 1.1 square kilometers.
The AVHRR/3 instrument broadcasts at 6 channels, seen in the table below:

AVHRR/3 Channel Characteristics			
Channel Number	Resolution at Nadir	Wavelength (um)	Typical Use
1	1.09 km	0.58 - 0.68	Daytime cloud and surface mapping
2	1.09 km	0.725 - 1.00	Land-water boundaries
3A	1.09 km	1.58 - 1.64	Snow and ice detection
3B	1.09 km	3.55 - 3.93	Night cloud mapping, sea surface temperature
4	1.09 km	10.30 - 11.30	Night cloud mapping, sea surface temperature
5	1.09 km	11.50 - 12.50	Sea surface temperature

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Figure 1: AVHRR/3 channel characteristics and broadcast wavelengths (NOAA Satellite and Information Service)

The AVHRR/3 instrument is composed of five modules:

- Scanner module
- Electronics module
- Radiant cooler module
- Optical subsystem
- Baseplate unit

Figure 2: European Space Agency: Meteorological

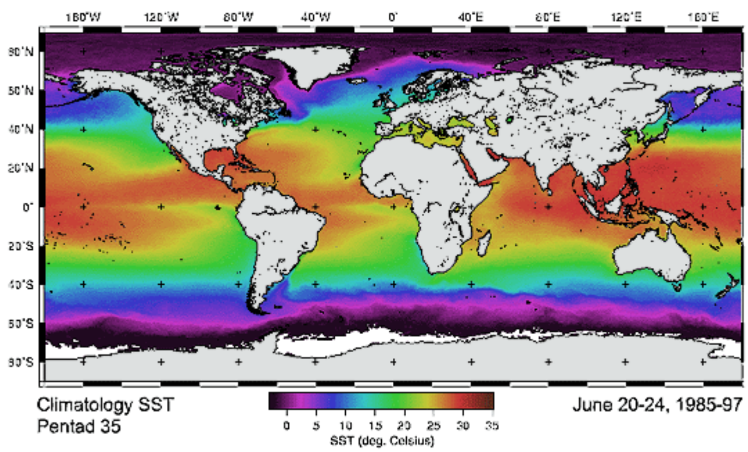

Figure: This image shows sea surface temperature averages from the month of June ranging from 1985 to 1997. The AVHRR instrument was originally meant to take data from cloud patterns and provide images based on that data, but it was quickly realized that the instrument was capable of sensing and imaging many more Earth surface characteristics.

Figure 3: United States Geological Survey

REFERENCES:

"Advanced Very High Resolution Radiometer/3 (AVHRR/3)." NOAA KLM User Guide. National Climatic Data Center. <http://www2.ncdc.noaa.gov/docs/klm/html/c3/sec3-1.htm>.

“Advanced Very High Resolution Radiometer – AVHRR.” NOAA Satellite and Information Service. National Environmental Satellite, Data and Information Service. <http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html>.

Hastings, David A., and William J. Emery. "The Advanced Very High Resolution Radiometer (AVHRR): A Brief Reference Guide." National Environmental Satellite, Data, and Information Service. National Oceanic and Atmospheric Administration. <http://www.ngdc.noaa.gov/ecosys/cdroms/AVHRR97_d1/avhrr2.htm>.

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B

Bandwidth – Is a broadly used term in many fields, for example digital communication, signal processing, and analog communications just to mention a few. It can refer to the total range of signals or the limit applied on the band the signal may occupy. [i]

When used in digital communications and processing it refers to the number of bits per second manipulated or transferred. In network communications transfer rates are in excess of 100 GB in some cases. Processing of data is referenced in frequency which is the multiplicative inverse of the bit rate.

In analog signal processing , signals not digitized, it is the measure of the frequency range of signals being processed. A couple of examples are filters, mixers, multipliers, and amplifiers. [ii]

It remote sensing of earth systems data is often transferred wirelessly from a platform to a receiving station. Bandwidth in this situation refers to the frequency range that has been allocated for that signal. A center frequency is the operating frequency and the bandwidth is the range between the upper and lower limits.[iii] Having this restriction does not allow for unlimited transfer of data so it may be digitized and compressed to increase the total data transferred within the same bandwidth.

Beer-Lambert Law- An equation that describes the absorption of light in a medium, based on the properties of that medium. As such, this law can be used describe the attenuation of radiation in the atmosphere. Thus, the Beer-Lambert Law, also known as Beer's Law has applications to remote sensing. The Beer-Lambert Law is expressed in the following equation:

$$A = \varepsilon bc$$

where A is the **absorbance** which is equal to

$$A = \log_{10}\left(\frac{p_o}{p}\right),$$

ε is the **molar absorbtivity,** b is the **path length**, and c is the concentration of the medium. As a result, absorbance increases with as path length, concentration, or molar absorbtivity increases. In remote sensing, it is important to calculate the absorbance in order to understand the attenuation of radiation between the target and the sensor.

Bidirectional Reflectance Distribution Function
The bidirectional reflectance distribution function (BRDF; $f(w_i,w_o)$) is a 4-dimensional function used to characterize the interactions of light reflecting at an opaque surface. Objects appear differently when viewed from varying illumination and viewing angles.

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BRDF is used in remote sensing to correct for illumination and angle effects, derive albedo, classify land cover, cloud detection, and atmospheric correction (Zucht, 2006). Also, it provides a boundary condition for all atmospheric radiative transfer problems (Zucht, 2006). BRDF depends on wavelength along with physical and optical surface properties. Some of these surface properties include multiple scattering, transmission, reflection, absorption, and emission. The units of BRDF is steradians $^{-1}$, where steradians describes solid angles. W_i is the incoming light direction and w_o is outgoing light direction (Wikipedia, 2009). Both w_i and w_o are defined with respect to the surface normal, n. BRDF describes reflectance as a function of both illumination geometry and viewing geometry. BRDF is a ratio between radiance reflected along w_o and irradiance incident on the surface along w_i. BRDF becomes 4-dimensional because both w_o and w_i have individual azimuth (θ) and elevation (φ) angles (Wikipedia, 2009).

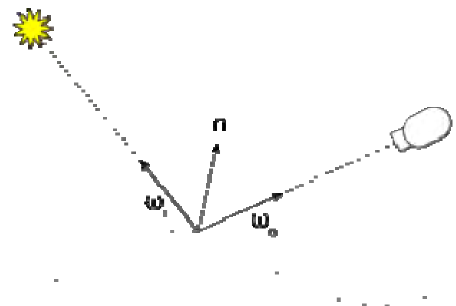
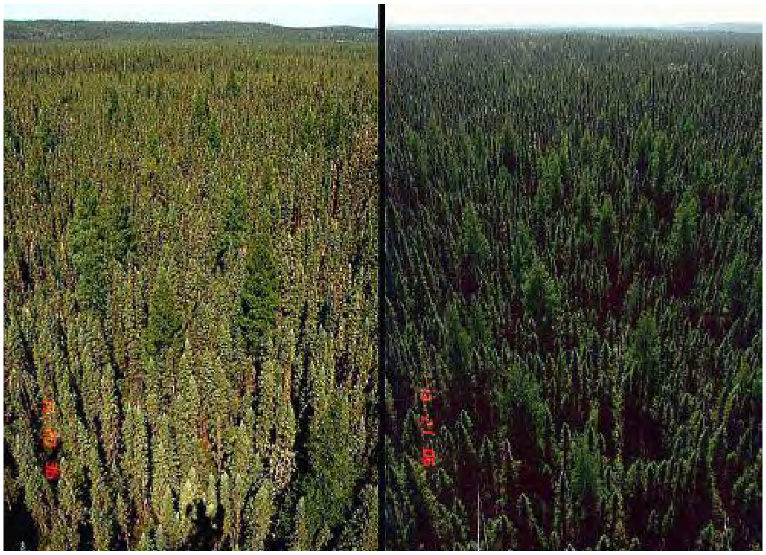


Figure 1 represents the key measurements in a BRDF calculation. w_i is the incoming light direction, w_o is the outgoing light direction, and n is the surface normal to which both w_i and w_o are defined.

BRDF's conserve energy and obey Helmholtz reciprocity. Helmholtz reciprocity. Helmholtz reciprocity (also known as Helmholtz Stereopsis) analyzes surface reflectance symmetry. The relationship between surface reflectance symmetry from an image can provide information about the intensity of corresponding pixels (Zickler, 2006). BRDF's can be observed with calibrated cameras and lightsources or simulated using models (Wikipedia, 2009). Some of the models using BRDF include the Lambertian model, Lommel-Seeliger model, Phong-reflectance model, and the Oren-Nayar model (Wikipedia, 2009). Examples of BRDF in remote sensing applications include Combined Aqua and Terra Processing, Global MODIS White-Sky Albedo and Nadir BRDF – Adjusted Reflectance (NBAR), and determining global albedos using AVHRR data and land cover BRDF parameters (Schaaf, 2003). These products are mainly used to create global albedo images (Schaaf, 2003).

BRDF models and products account for the fact that images look differently depending on the viewing angle and environmental conditions. To illustrate the differences in appearance depending on sun and surface position and optical properties, four images are shown below



This is a black spruce forest in the BOREAS experimental region in Canada. Left: backscattering (sun behind observer), note the bright region (hotspot) where all shadows are hidden. Right: forwardscattering (sun opposite observer), note the shadowed centers of trees and transmission of light through the edges of the canopies. Photograph by Don Deering. Figure and caption courtesy of Lucht, 2006.

A soybean field. Left: backscattering (sun behind observer). Right: forwardscattering (sun opposite observer), note the specular reflection of the leaves. Photograph by Don Deering. Figure and caption courtesy of Lucht, 2006.

References
Lucht, Wolfgang. “BRDF Explained”. 2006. http://www-modis.bu.edu/brdf/brdfexpl.html
Schaaf, Crystal. “BRDF and Remote Sensing”. 2003. http://www-modis.bu.edu/brdf/brdf.html
Wikipedia. “Bidirecitonal Reflectance Distribution Function”. 2009.
http://en.wikipedia.org/wiki/Bidirectional_reflectance_distribution_function
Zickler, Todd. “Helmholtz Stereopsis”. 2006. http://www.eecs.harvard.edu/~zickler/helmholtz.html

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Blackbody – A blackbody is a theoretical object that absorbs and radiates energy at the maximum possible rate per unit area at each wavelength for a given temperature. Emitted blackbody radiation (M_λ) can be calculated from temperature with the *Stefan-Boltzmann law*.

R., Jensen, John. Remote sensing of the environment an earth resource perspective. Upper Saddle River, NJ: Pearson Prentice Hall, 2007.

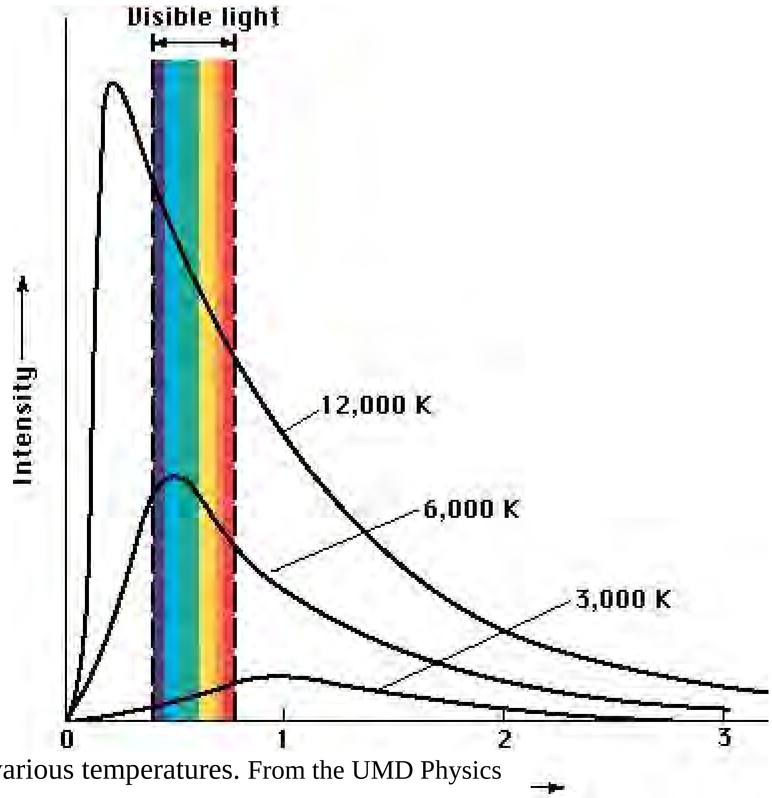

Figure 1: Blackbody curve at various temperatures. From the UMD Physics Department (http://www.physics.umd.edu/courses/Phys401/bedaque06/blackbody_curves.jpg)

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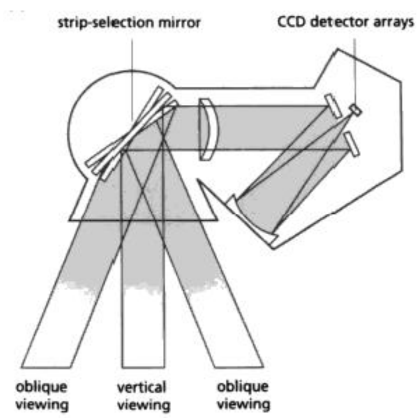
C

Charge-coupled devices (CCDs)
Charge-coupled devices (CCDs) are used in remote sensing instruments, scanners and cameras. They are tiny light-sensitive diodes/capacitors which convert photons into electrons; they create electrical charge proportional to light that hits them. In remote sensing instruments and pushbroom systems, they are lined up in the thousands in a linear array and used to measure radiation from the ground. An optical system directs radiation to the arrays.



Optical systems direct radiation to the CCD detector arrays (Drury, 2001, p42.)

The photoactive region of the CCD is an epitaxial layer of silicon. CCDs are mounted on silicon wafers. When light is projected onto the array, capacitors absorb the charge, and can transfer its charge to its neighbors. This is controlled by a control circuit. The last capacitor in the array sends the charge to a charge amplifier where it is turned into a voltage. This process is repeated thousands of times, with the charge varying in relation to the amount of light absorbed, and the 'image' turned into digital form.
To improve the signal to noise ration, a clocking scheme combined the charges collected by groups of neighboring CCD pixels (pixel binning). When the finite charge capacity of each capacitor is reached, saturation occurs where excess charge flows into adjacent device structures.
CCDs were conceived in 1970 at Bell Labs; 3 years later the Jet Propulsion Lab initiated a 'scientific grade' large array CCD program. The first astronomical CCD image was created in 1974. Today, material scientists still seek to create the perfect CCD which has perfectly uniform response, is noiseless, has unlimited dynamic range, completely understandable characteristics and 100% quantum efficiency.

References
Stephen A. Drury, *Image Interpretation in Geology,* Routledge, 2001, p.42.
Molecular Expressions, *Concepts in Digital Imaging Technology, http://micro.magnet.fsu.edu/primer/digitalimaging/concepts/concepts.html*
Greg Bothun, *CCDs for Material Scientists*, http://zebu.uoregon.edu/ccd.html
Wikipedia, *Charge-coupled device*, http://en.wikipedia.org/wiki/Charge-coupled_device

D

Density Slicing

A method of digital data interpretation in which information from an individual band is enhanced is known as density slicing. Density slicing (also known as double threshold) is a classification technique using computer processing of digital data. The range of brightness of an image is divided into sub-intervals. The enhancement procedure may be applied to one band or a multi-band image. The method works best if the range of brightness values covers a single band of frequencies. Each interval is then assigned a color. The intervals may be defined based on the application.

The typical range of density slicing is two degrees Celsius for thermal imagery. The original imagery is typically black and white, whereas the imagery after the density slicing is in color. Density slicing allows the user to define sub-intervals for characterizing the data. The advantage of density slicing is that it allows one to gain a greater degree of variability of brightness within the remotely sensed image compared to the original image (e.g. black and white imagery).

The range of input pixel values is assigned a single output pixel value in a density sliced image. The range of pixel values may be defined by the user. If each interval range corresponds to a different color, the result is called a pseudo-color image. Often, density slicing is most effective when the value of particular pixels have significance to a physical variable. Sometimes it is most effective for the user if a particular range of values of intensity may be isolated within the image. In some applications this technique is quite effective (see Figure 1). Density slicing is commonly applied in the medical profession. An example of a density slice image is a Magnetic Resonance Imaging (MRI) scan.

In satellite remote sensing, density slicing is an important technique for classification of remote sensed images. For images over the ocean, thermal infrared imagery may be density sliced to determine sea surface temperature. Alternatively, vegetation imagery over land may be applied with density slicing to classify the vegetation index. Density slicing is also widely used to generate image masks, in which further image processing can be facilitated. Density slicing is not always an acceptable means of producing a classification map though, because contribution from the distribution may be limited by criteria specified by the user.

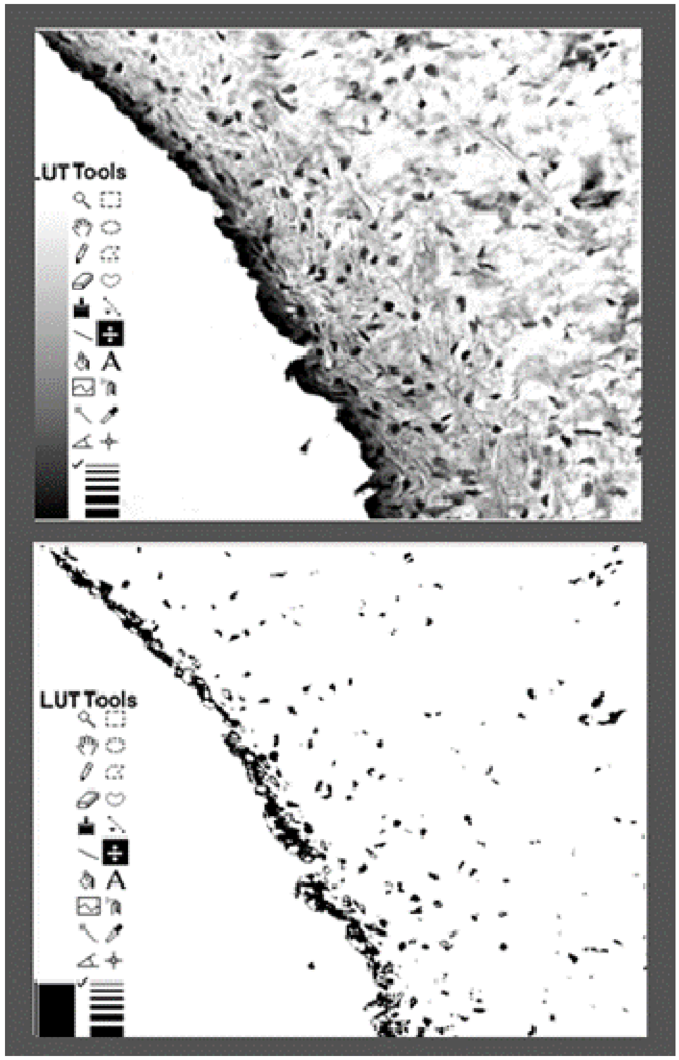


Fig. 1: Density slicing of remotely-sensed imagery (courtesy of UChicago BSD)

Rees, W. G. Physical Principles of Remote Sensing (Topics in Remote Sensing). New York: Cambridge UP, 2001.

"Remote Sensing Tutorial Page 1-12a." The Remote Sensing Tutorial. 07 Apr. 2009 <http://rst.gsfc.nasa.gov/Sect1/Sect1_12a.html>.

"Glossary of remote sensing terms." Density Slicing. Natural Resources Canada. 12 Apr. 2009 <http://www.ccrs.nrcan.gc.ca/glossary/index_e.php?id=127>.

Depolarized: Eliminating the polarization of waves of radiation. In doing so, the radiation observed is scattered in multiple directions; this is opposite to polarizing an object, in which the radiation is organized into one wave plane. This is important in remote sensing when dealing with uneven surfaces such as the ocean. Lukert and Blanchard, 1988[1], note the need for polarized measurements when dealing with

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Synthetic Aperture Radar (SAR). When polarized data is used, side lobe interference is quite prevalent, but it is reduced when using the 'random' scattering of depolarized radiation. Therefore, depolarized radiation cannot be ignored in remote sensing, and is an important consideration for maximizing the usage of sensors.

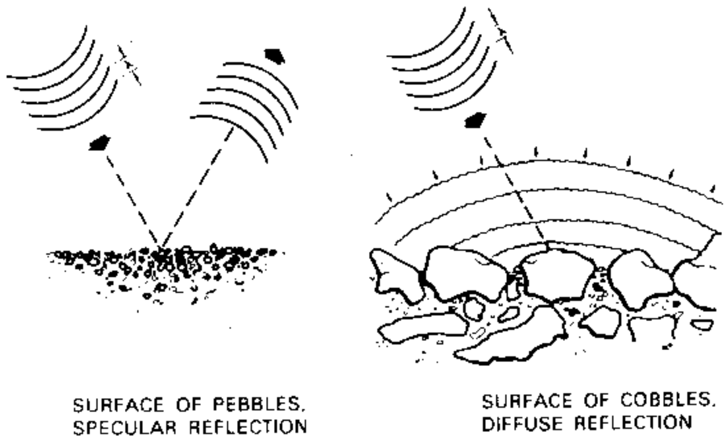

Figure 1 – Schematic image of radar energy striking different surfaces. Given the differences in reflection off a surface, it is often important for a sensor to be able to receive depolarized data. Image from the Food and Agriculture Organization of the United Nations[2].

1. Lukert, D. H., and A. J. Blanchard. "Azimuth depolarization ambiguities in Synthetic Aperture Radar." International Journal of Remote Sensing 9 (1988): 527-42.

2. "The application of remote sensing technology to marine fisheries: an introductory manual." FAO: FAO Home. 17 Apr. 2009 <http://www.fao.org/docrep/003/t0355e/T0355E02.HTM>.

Diffraction
Definition: Diffraction is the bending of electromagnetic energy around an object such that the direction of propagation of a portion of the energy is no longer parallel to the initial direction of propagation[1]. Diffraction is also seen when a plane wave encounters a surface with a slit or hole on the order of a wavelength.

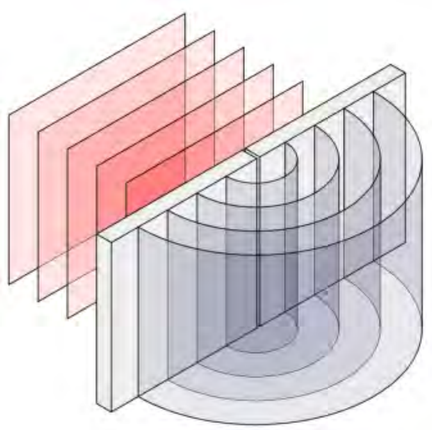

Figure 2: Diffraction of a plane wave when encountering a slit in a material[2].

References
[1] http://micro.magnet.fsu.edu/optics/lightandcolor/diffraction.html
[2] http://upload.wikimedia.org/wikipedia/commons/thumb/6/6e/Diffraction_through_Slit.svg/600px-Diffraction_through_Slit.svg.png

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Digital Elevation Model (DEM)

A digital elevation model (DEM) is a digital representation of topography in three dimensions, created from DEM data. DEM data are in the form of arrays of regularly spaced elevation points; these raster files can also be expressed in triangular irregular network formats. DEMs are referenced to Universal Transverse Mercator (UTM) projections or other geographic coordinate systems. The most common DEM files are from the USGS. DEMs are used in a variety of applications ranging from geographic information science/systems to flight simulations.

The USGS uses interpolation from vectors or digital line graph hypsographic and hydrographic data to collect DEMs. Discontinued methods include the Gestalt Photo Mapper II, manual profiling from photogrammetric stereomodels, and interpolation from digitized contours. Remote sensing is rapidly replacing land surveying as the most common way to create DEMs. The most modern techniques include LIDAR, Real Time Kinematic GPS and InSAR, but hypsographic and hydrographic techniques are considered the most accurate.

DEM files are classified by the ground spacing between grid points based on latitude-longitude. For example, USGS uses 1 degree, 30 minute and 7.5 minute DEMS. For the 1 degree DEM, the ground spacing between grid points is 3 arc seconds or 90 meters. 1 degree DEM is also known as 1:250,000 scale DEM. The 7.5 minute DEM is the most accurate. USGS DEMs are referenced to the geographic coordinate systems NAD27 or NAD 83, with the exception of 1 degree data which are referenced to the horizontal datum of the WGS (World Geodetic Survey) 1972. Root mean square error is used to derive data accuracy and qualifies how accurate elevation and morphology is at each pixel.

DEM data can be read by many different types of software, such as ArcGIS, VTbuilder and USGS freeware. The USGS is in the process of converting DEM formats to Spatial Data Transfer Standard (SDTS) formats due to the ease of data transfer and improved quality the latter format provides.

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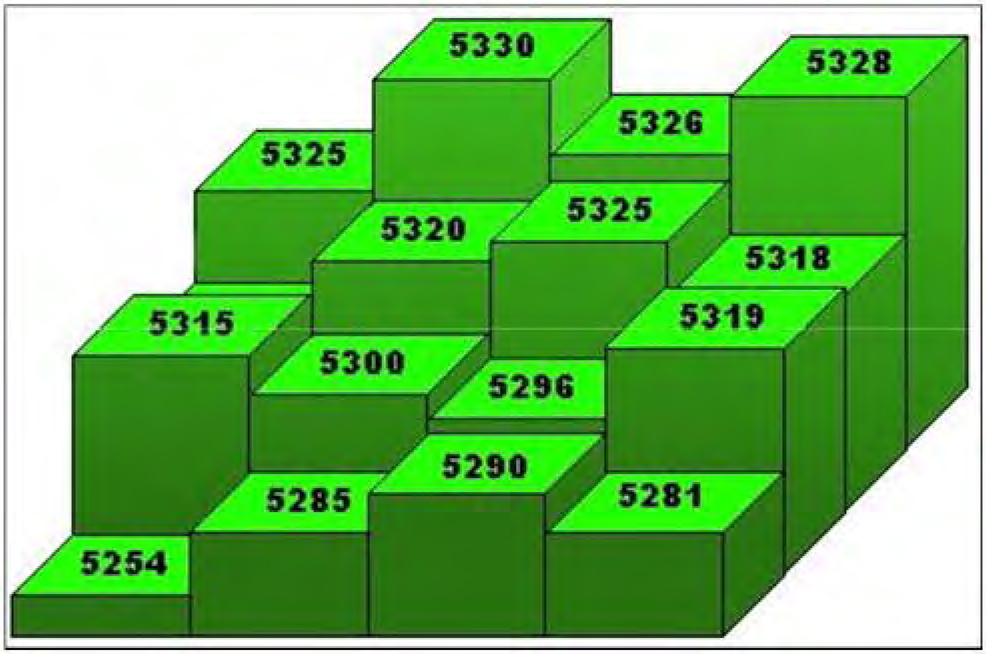
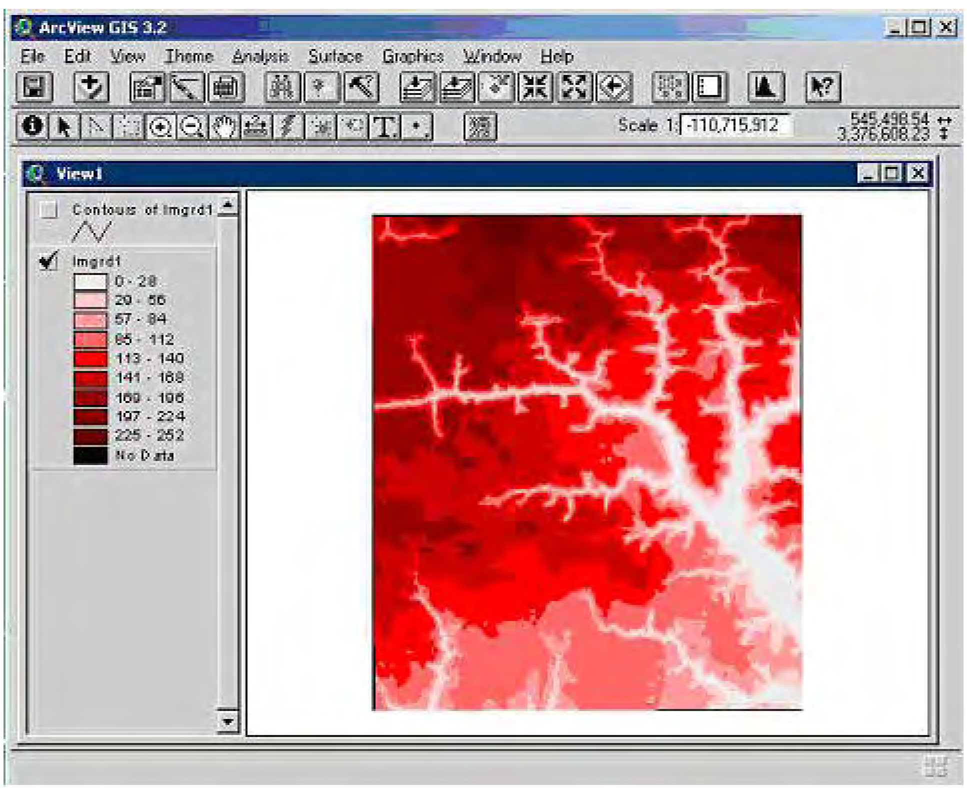


This image shows the concept behind raster DEM data – each ‘cell’ that a data point is applied to has an elevation value.

Image from Brigham Young University Geospatial Data Acquisition (http://emrl.byu.edu/gsda/data_dem_overview.html).



USGS DEM read in ArcView GIS
Image from GeoCommunity (http://data.geocomm.com/dem/sdts2dem_demo.html)

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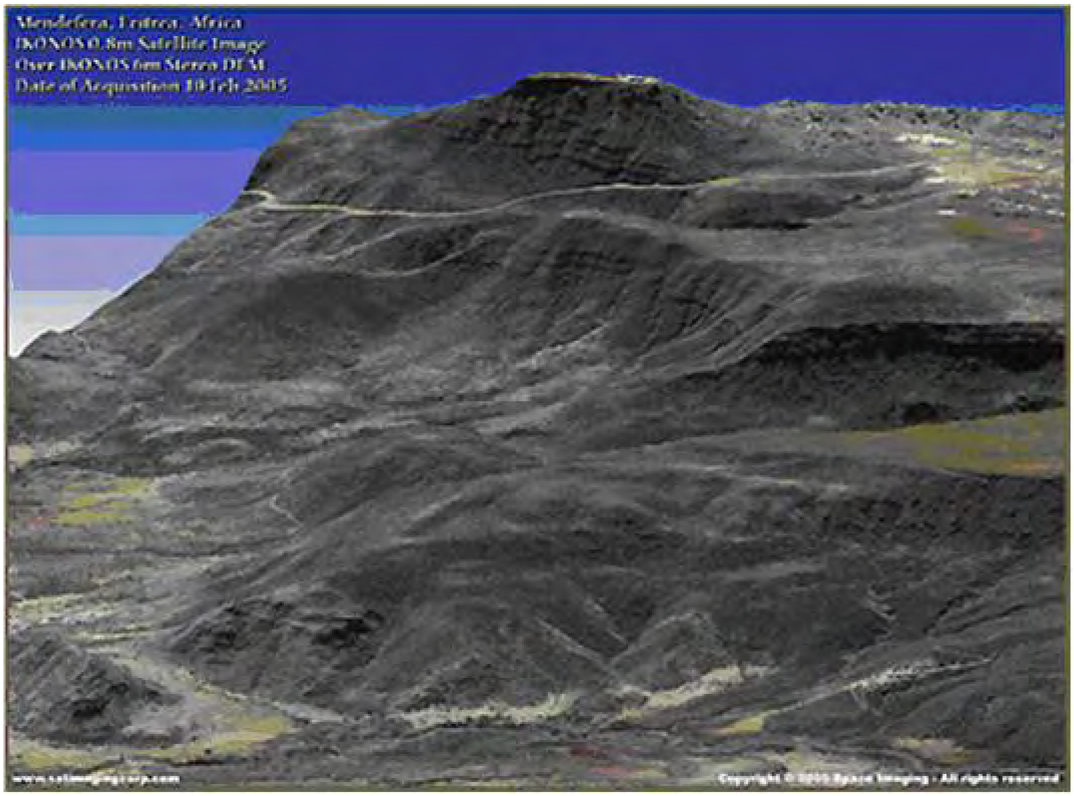

This image is a DEM of Eritrea, Africa, based on data from the IKONOS satellite.
Image from Satellite Imaging Corporation (http://www.satimagingcorp.com/svc/dem.html)

References

Brigham Young University, Environmental Modeling Research Laboratory, Data Acquisition, http://emrl.byu.edu/gsda/data_dem_overview.html
GeoCommunity, *Using USGS DEMS in ArcView GIS* , http://data.geocomm.com/dem/sdts2dem_demo.html
Satellite Imaging Corporation, *Digital Elevation Models*, http://www.satimagingcorp.com/svc/dem.html
USGS,*US GeoData Digital Elevation Models*, http://egsc.usgs.gov/isb/pubs/factsheets/fs04000.html
Virtual Terrain Project, *Data Sources: DEM*, http://www.vterrain.org/

Doppler Shift

The Doppler shift is a change in the frequency of EM or other waves caused by the relative motion between the source and the director. It is used in the generation of synthetic-aperture radar images.

Johann Christian Doppler (1803 – 1853) is the man who first realized the Doppler shift. The Doppler shift is an effect that is associated with any wave phenomena (including sound waves).

The Doppler shift was originally studied in the visible part of the EM spectrum. Today, it is applied to EM waves in all portions of the spectrum. And because of the inverse relationship between frequency and wavelength, the Doppler shift can also be described in terms of wavelength.

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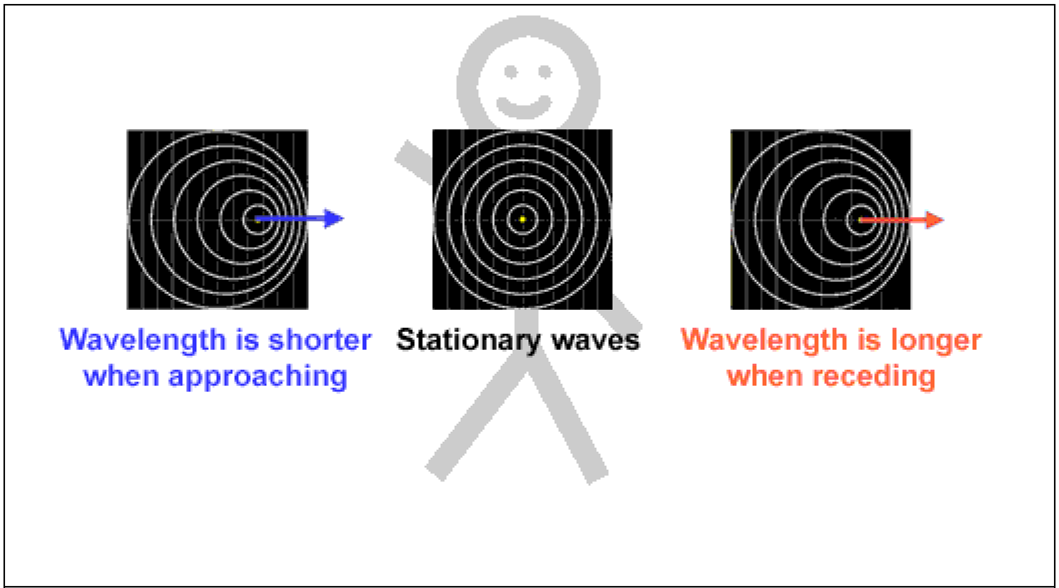
Light from moving objects will appear to have different wavelengths, depending on the relative motion of the source and the observer. An object approaching will appear to have short blue waves, and an object that is receding will appear to have long red waves. This is also called a redshift and a blueshift.



http://www.astrocappella.com/background/doppler_background.shtml

A real-life example of the Doppler shift is when an ambulance drives by, you often will hear the siren's pitch change as the vehicle drives towards and then away from you. First the pitch becomes higher, and then becomes lower. This is due to the shift in frequency of the sound waves, as illustrated in the image above.

Today, the techniques of the Doppler shift play a major role in radar, communications, and navigation systems. Doppler radars are used to measure the speeds of cars (in police radar guns), to open supermarket doors, and to monitor the weather. Doppler techniques are also used by astronomers to determine the velocity of distant stars and galaxies relative to the earth.

How does Doppler shift work in Radar?
When NASA sends pure microwave signals derived from an atomic clock to distant satellites traveling in space, the spacecraft receives the Doppler shifted microwave signals from earth and then will re-transmit them back toward earth. This process doubles the relative Doppler shift, as well as carrying commands to the satellite and data in the return signals. Weather forecasters often use the Doppler weather surveillance radar (WSR 88D) or NEXRAD. The following image is a Doppler radar. Rainfall intensity, wind speed and direction are measured from the intensity of the reflected wave, and the Doppler shift.

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http://www.jamstec.go.jp/cruisedata/mirai/e/eq_meteorological.html

Ducting

Definition: Ducting is the trapping of electromagnetic waves in the earth's atmosphere. It occurs when the atmosphere has strongly varying refractivity versus height. Under these conditions, a wave propagating at a small angle along the surface of the earth will bend away from the upper atmosphere back towards the earth's surface and remain propagating along the surface.

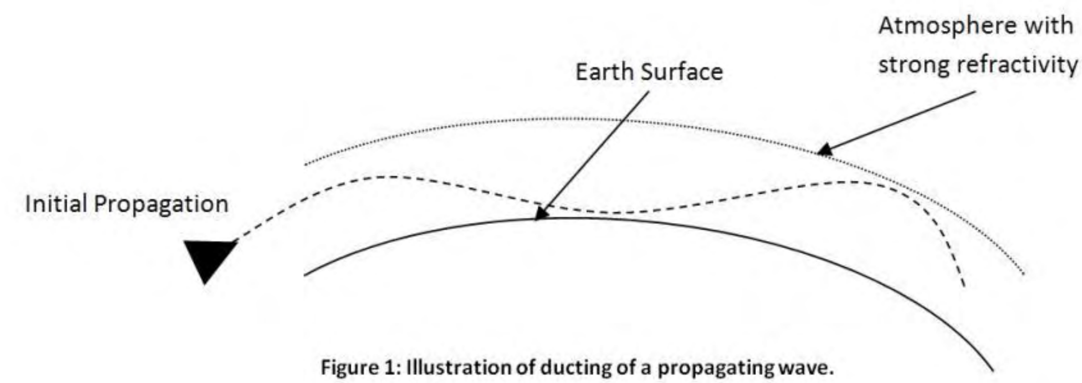

Figure 1: Illustration of ducting of a propagating wave.

References

[1] B. W. Atkinson and M. Zhu, "Coastal effects on radar propagation in atmospheric ducting conditions." *Meteorological Applications*, Vol. 13. No. 1, pp. 53-62, Mar. 2006.

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E

Electromagnetic Spectrum
Continuous sequence of electromagnetic energy arranged according to wavelength or frequency. The spectrum extends from low energy microwaves and infrared light to the visible part of the spectrum (red, orange, yellow, green, blue and violet), and then to more energetic forms of light such as ultraviolet and x-rays. The following diagram displays the range wavelengths in the spectrum with a comparative scale of objects for size. Although some radiations are marked as N for No in the diagram, some waves do penetrate through the atmosphere, although extremely minimal compared to other radiations.

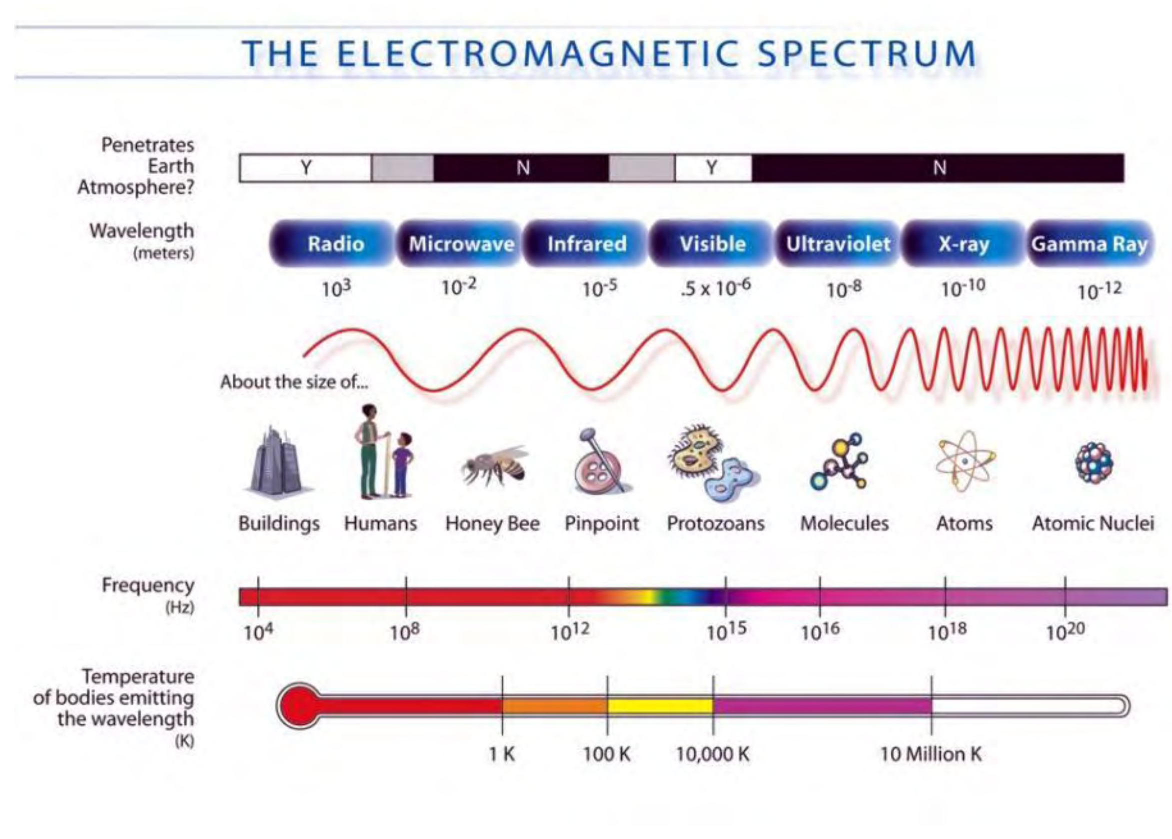

Image from NASA.gov

The visible part of the spectrum (.4 - .7 microns) can be further subdivided according to color, with red at the long wavelength and violet at the short wavelength end, as illustrated below.

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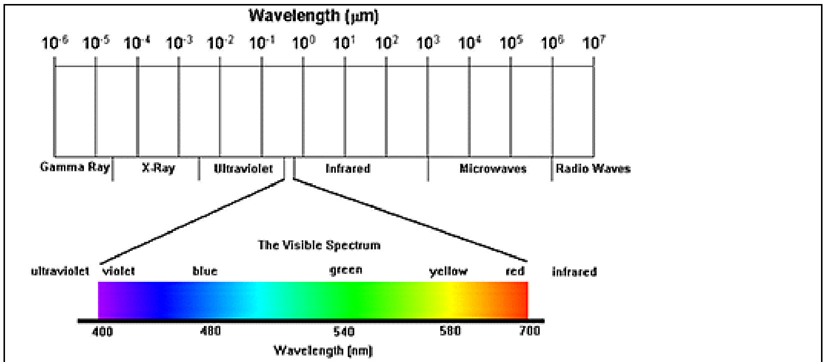
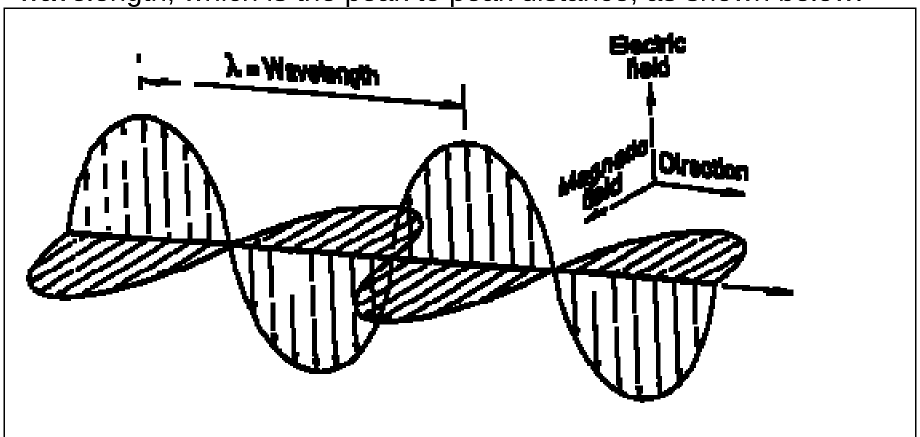


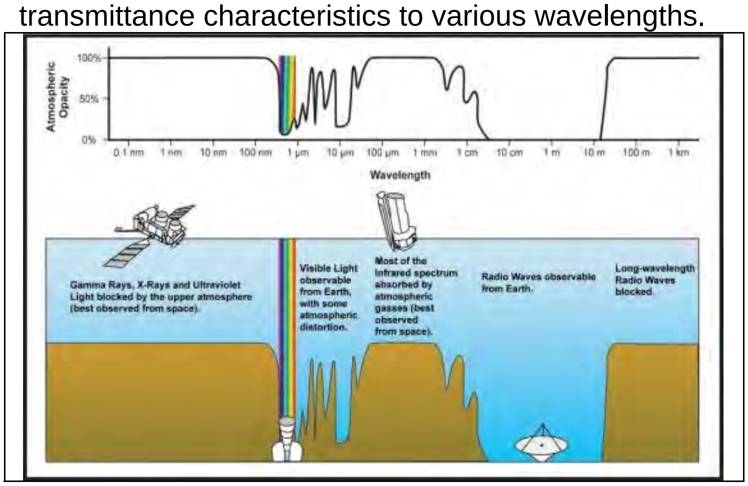
http://www.daviddarling.info/encyclopedia/V/visible_light.html

Electromagnetic (EM) energy can be described as waves of electromagnetic and magnetic energy moving together through space. EM energy is emitted by natural sources like the Sun and the Earth. EM energy passes through space at the speed of light in the form of sinusoidal waves. The behavior of EM radiation depends on its wavelength, which is the peak to peak distance, as shown below.



http://www.geo.mtu.edu/rs/back/spectrum/

EM radiation interacts with matter in different waves in different parts of the spectrum. Depending on the wavelength, atmospheric transmittance (or opacity) behalves different to various wavelengths of EM radiation. The following image describes the transmittance characteristics to various wavelengths.



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http://www.answers.com/topic/electromagnetic-spectrum

Emissivity – Emissivity (ε) is the ratio between the actual real world radiance of a selective radiating body (M_r) and a blackbody at the same kinetic temperature in Kelvin. Valid values of emissivity are greater than zero and less than one for all selectively radiating bodies. The emissivity also changes depending on the wavelength considered.

$$\varepsilon = \frac{M_r}{M_b}$$

See: R., Jensen, John. Remote sensing of the environment an earth resource perspective. Upper Saddle River, NJ: Pearson Prentice Hall, 2007.

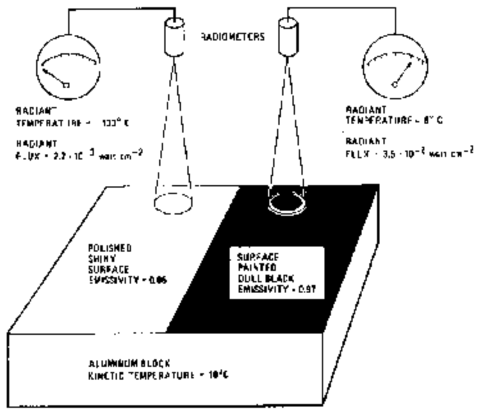

Figure 3: The Aluminum Block at a single kinetic temperature has two different surfaces which have two different emisivities. Each surface gives off a separate radiant temperature.

From : Butler, M.J.A, M.-C Mouchot, V. Barale, and C. LeBlanc. The application of remote sensing technology to marine fisheries: an introductory manual. Rome: Food and Agriculture Organization of the United Nations, 1988.

Endmember (spectral): the basic spectral components of a spectral mixture that often represent the “pure” features/materials in an image scene. Most image pixels from satellite-based sensors are composed of a spectral mixture of endmembers (i.e.—represent more than a single feature/material) due to their coarse spatial resolution. Various techniques of spectral mixture analysis (SMA) are often used to estimate the proportion of a pixel represented by each endmember (e.g.—50% deciduous forest, 25% evergreen forest, 25% grass). For instance, a linear mixture model would assume that the mixed spectral response from a pixel would be a linear combination of the pixel’s endmembers.

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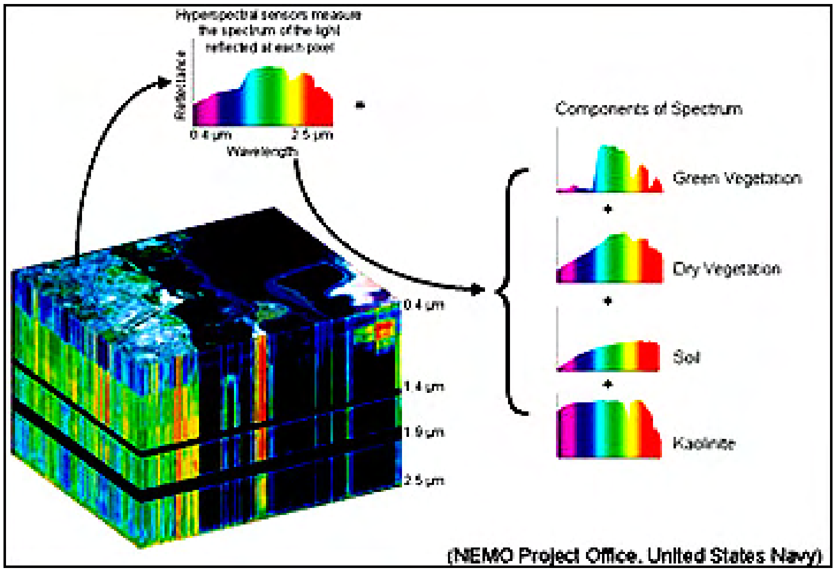

Figure 1: Example of spectral endmembers (4 spectra on the right) that combine into a spectral mixture based on the proportion area they represent within a pixel.
Source: http://rst.gsfc.nasa.gov/Sect13/Sect13_9.html

Sources
Adams, J. B. and A. R. Gillespie. 2006. Remote Sensing of Landscapes with Spectral Images: A Physical Modeling Approach. Cambridge University Press, New York, NY.
Lillesand, T., R. Kiefer, and J. Chipman. 2008. Remote Sensing and Image Interpretation. John Wiley & Sons Inc., Hoboken, NJ.
Remote Sensing Tutorial
http://rst.gsfc.nasa.gov/Sect13/Sect13_9.html

Enhanced Vegetation Index (EVI): a modified version of the popular Normalized Difference Vegetation Index (NDVI) that tries to minimize soil background effects and atmospheric scattering. EVI has been found to perform better in high biomass areas (e.g.—tropical forests) where NDVI tends to saturate. It is given by:

$$EVI = \frac{r_{NIR} - r_{Red}}{r_{NIR} + C_1 r_{Red} - C_2 r_{Blue} + L} \times G$$

where **r** is a surface reflectance measure (atmospherically corrected or partially corrected), **G** is a gain factor, **L** is a canopy background adjustment, and **C1/C2** are aerosol resistance term coefficients (use blue band to correct for aerosol effects in red band). For the MODIS vegetation indices product, the values used are: **L** = 1, **C1** = 6, **C2** = 7.5, and **G** = 2.5.

Sources
Lillesand, T., R. Kiefer, and J. Chipman. 2008. Remote Sensing and Image Interpretation. John Wiley & Sons Inc., Hoboken, NJ.
RangeView: EVI
http://rangeview.arizona.edu/Glossary/evi.html
Terrestrial Biophysics & Remote Sensing Lab
http://tbrs.arizona.edu/cdrom/VI_Intro/VI_MOD_VI.html

Error Matrix: a matrix used to show the classification accuracy of an image classification procedure (e.g.—supervised/unsupervised classification). It is also often termed a confusion matrix or contingency table. The matrix compares the known validation data with the results of an automated classification. The columns represent the actual number of pixels within the known feature types (obtained from the validation data) while the rows show the number of pixels classified into the feature types by the procedure. From the matrix, it is easy to obtain important classification performance statistics such as producer accuracy, user accuracy, and overall accuracy. Producer accuracy represents the probability that a reference sample will be correctly mapped (i.e.—error of omission measure) while consumer accuracy is the probability that the classification of a sample pixel actually matches what it is (i.e.—error of commission measure). The numbers in the main diagonal of the matrix are all the pixels that were correctly classified while the numbers outside the diagonal are either commission or omission errors.

TABLE 7.3 Error Matrix Resulting from Classifying Training Set Pixels

	Training Set Data (Known Cover Types)[a]						
	W	S	F	U	C	H	Row Total
Classification data							
W	480	0	5	0	0	0	485
S	0	52	0	20	0	0	72
F	0	0	313	40	0	0	353
U	0	16	0	126	0	0	142
C	0	0	0	38	342	79	459
H	0	0	38	24	60	359	481
Column total	480	68	356	248	402	438	1992

Producer's Accuracy	User's Accuracy
W = 480/480 = 100%	W = 480/485 = 99%
S = 052/068 = 76%	S = 052/072 = 72%
F = 313/356 = 88%	F = 313/353 = 87%
U = 126/248 = 51%	U = 126/142 = 89%
C = 342/402 = 85%	C = 342/459 = 74%
H = 359/438 = 82%	H = 359/481 = 75%

Overall accuracy = (480 + 52 + 313 + 126 + 342 + 359)/1992 = 84%

[a]W, water; S, sand; F, forest; U, urban; C, corn; H, hay.

Figure 1: Example error matrix for a land cover classification.
Producer accuracy: # in main diagonal within each column / column total
User accuracy: # in main diagonal within each column / row total
Overall accuracy: sum of # in main diagonal / row total of column totals
Source: (Lillesand et al. 2008)

<u>Sources</u>

Lillesand, T., R. Kiefer, and J. Chipman. 2008. Remote Sensing and Image Interpretation. John Wiley & Sons Inc., Hoboken, NJ.

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EVI: Enhanced Vegetation Index (EVI) is an 'optimized' index designed to enhance the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmosphere influences. EVI is computed following this equation:

$$EVI = 2.5 \times \frac{(NIR - RED)}{(NIR + C1 \times RED - C2 \times Blue + L)}$$

where NIR/red/blue are atmospherically-corrected or partially atmosphere corrected (Rayleigh and ozone absorption) surface reflectance, L is the canopy background adjustment that addresses non-linear, differential NIR and red radiant transfer through a canopy, and C1, C2 are the coefficients of the aerosol resistance term, which uses the blue band to correct for aerosol influences in the red band. The coefficients adopted in the MODIS-EVI algorithm are; L=1, C1 = 6, C2 = 7.5, and G (gain factor) = 2.5. Whereas the NDVI is chlorophyll sensitive, the EVI is more responsive to canopy structural variations, including leaf area index (LAI), canopy type, plant physiognomy, and canopy architecture. The two VIs complement each other in global vegetation studies and improve upon the detection of vegetation changes and extraction of canopy biophysical parameters.

Reference:
http://www.wikipedia.org
http://earthobservatory.nasa.gov

Extinction Coefficient

In general, the extinction and absorption coefficients are parameters defining how strongly a substance absorbs or lets through (transmits) at a given wavelength.

The extinction coefficient is the fraction of light lost to scattering and absorption per unit distance in a participating medium. In electromagnetic terms, it can be explained as the decay, or damping of the oscillation amplitude of the incident electric field.

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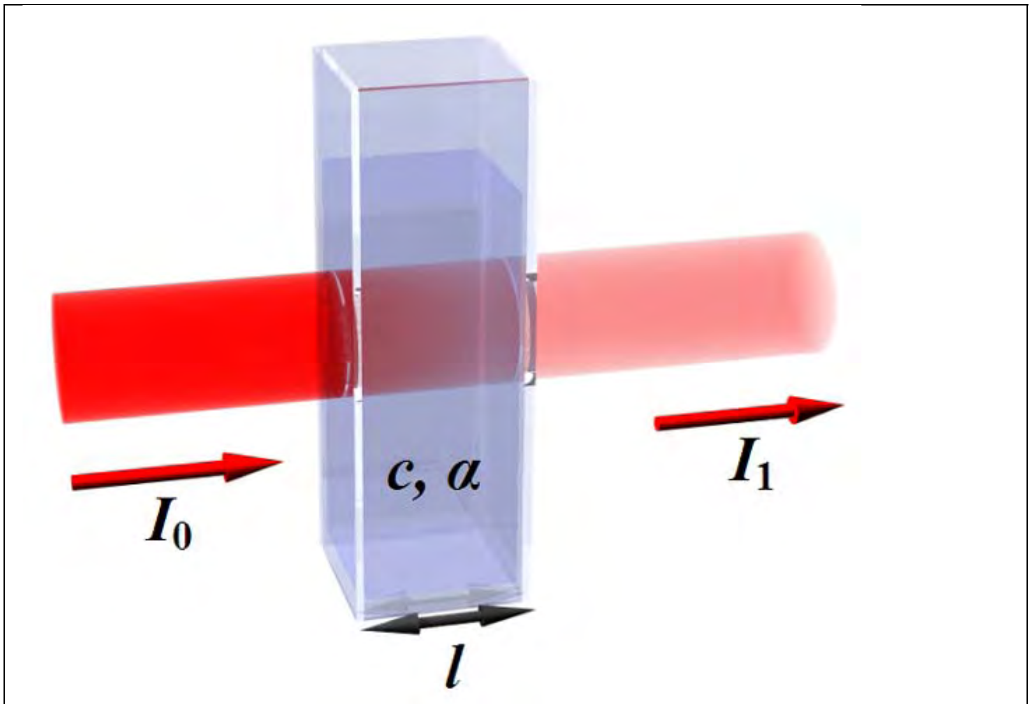
The velocity of propagation of a electromagnetic wave through a solid is given by the refractive index N = n – ik, were n is the real part and k is the extinction coefficient.

The attenuation of sun's energy that's due to absorption and scattering by specific atmospheric molecules and aerosols is called extinction. Extinction is expressed as the atmosphere's optical thickness, which is the integrated value of the extinction coefficient at each altitude by the atmospheric thickness. This indicates the magnitude of absorption and scattering.

Beer's Law describes the reduction of radiation through a medium due to a linear relationship between energy extinction and the concentration of absorber/scatters in a medium. In this law, -ρKI *ds, where ρ is the density of absorbers/scatters, K is the extinction coefficient, I is the incident radiation in a specific range of wavelengths, and ds is the path length.

The following diagram depicts Beer's Law and the extinction coefficient for how much is lost due to scattering, where Io is the intensity of light being transmitted, α is the absorption coefficient, l is the length (ds in the equation above).



http://dbpedia.org/page/Beer-Lambert_law

F

False Color Imagery

A false color image is such that the colors depicted in the image differ from that which would be observed in real life. False color images typically depict intensities of wavelengths outside of the visible spectrum. Therefore, unlike a photograph, a false color image may not always portray the ocean as blue, grass as green, or soil as brown. This type of imagery allows one to visualize wavelengths beyond that which the human eye can detect. Wavelengths outside of the visible spectrum, such as in infrared and ultraviolet, are captured in detectors and used to produce false color imagery. This imagery provides data about spectral bands based on a given color scheme assigned by the user. For example, the Chandra X-ray Observatory uses false color to depict x-ray emissions, where variations in color shading represent variations in densities of hot gas. In satellite remote sensing, false color imagery is generated using digital image processing techniques. The color scheme is typically defined to emphasize certain features in the spectral band data. Landsat 7 satellite imagery is a widely used application of false color. The three sensor of Landsat 7, the Enhanced Thematic Mapper (or ETM+), contains ranges of wavelengths each assigned a specific color scheme: red corresponds to near infrared (ETM+ band 4), green corresponds to red (ETM+ band 3), and blue corresponds to green (ETM+ band 2). In short, RGB translates to NRG (see Figure 1).

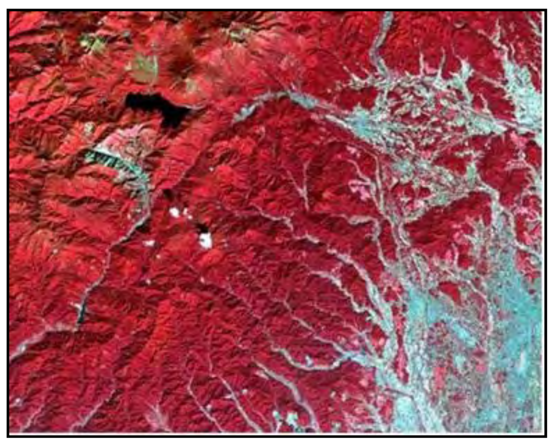


Fig. 1: *False color imagery using Landsat 7 ETM+ bands 4, 3, 2 (courtesy of NASA GSFC)*

A variation of false color imagery is known as pseudo-color imagery. In this technique, a grayscale image is used where each pixel value in a table is assigned a corresponding color value. The color value is typically determined to complement features in the imagery and aid the user. For example, vegetation may be purposely chosen to be green and river water kept blue, even though the wavelength range does not correspond with green or blue in the visible spectrum. A common application of pseudo-color imagery is MRI scanned images.

"Landsat 7 Compositor." The Landsat Program. National Aeronautics and Space Administration. 12 Apr. 2009 <http://landsat.gsfc.nasa.gov/education/compositor/>.

"Remote Sensing Tutorial Page 1-8." The Remote Sensing Tutorial. National Aeronautics and Space Administration. 12 Apr. 2009 <http://rst.gsfc.nasa.gov/Sect1/Sect1_8.html>.

"Chandra :: Photo Album :: Chandra Images & False Color." The Chandra X-ray Observatory Center :: Gateway to the Universe of X-ray Astronomy! Harvard-Smithsonian Center for Astrophysics. 12 Apr. 2009 <http://chandra.harvard.edu/photo/false_color.html>.

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Fluorescence
Definition: The process of molecular absorption of a photon of relatively high energy and reemission at lower energy (longer wavelength)[1]. For example, an object may absorb a photon in the ultraviolet part of the spectrum and emit a photon in the red portion of the spectrum (sometimes with a time lag). A measure of fluorescence is often useful for an indication of plant heath and photosynthetic activity[2].

References

[1] http://chemistry.rutgers.edu/grad/chem585/
[2] J. A. Lopez, et. al. "Remote sensing of chlorophyll fluorescence for estimation of stress in vegetation..." *IEEE International Geoscience and Remote Sensing Symposium*, 2007, pp. 3769-3772, July 2007.

Fourier Transform Spectrometer (FTS)- A spectrometer that generally uses infrared radiation to provide high resolution measurements. Most FTS use an adapted form of the ***Michaelson Interferometer*** in their designs.

A FTS works by dividing a beam of light from a source through a beam splitter where the resulting beams are sent to two mirrors. The mirrors reflect the split beams back to the beam splitter where they interfere with each other and are deflected to a detector. The signal recorded depends on the wavelength of the light as well as the optical path difference between the beam splitter and the two mirrors. One of the mirrors is moved horizontal to the source beam, thus changing the optical path of light traveling to that mirror. This change in the mirror's position results in an alternation of detected signal. Depending on the original properties of the source radiation, the spectrum can then be recovered by processing the output with a Fourier transform. An example of a Fourier Transform Spectrometer is the ***Tropospheric Emission Spectrometer (TES).***

[See: "What is a Fourier Transform Spectrometer" , National Institute of Standards and Technology, http://physics.nist.gov/Divisions/Div842/Gp1/fts_intro.html ; and "Fourier Transform Spectrometer", Wolfram Science World, http://scienceworld.wolfram.com/physics/FourierTransformSpectrometer.html]

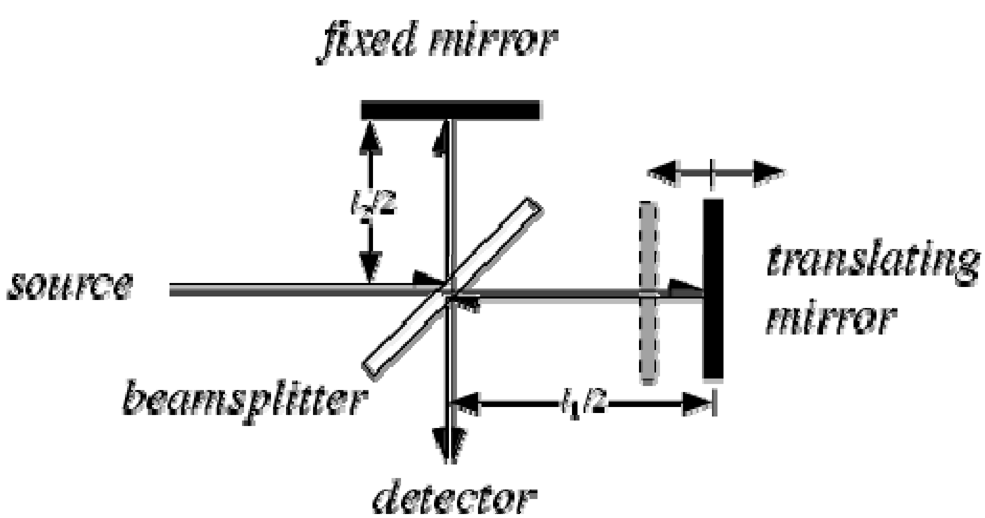
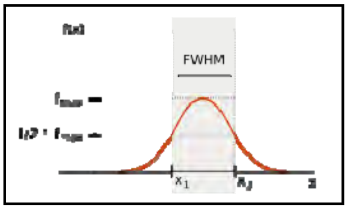


Figure 1 – Schematic of the basic interferometer used in most FTS.

Full Width Half Maximum – Wikipedia gives the definition of Full Width Half Maximum (FWHM) as expression of the extent of a function, given by the difference between the two extreme values of the independent variable at which the dependent variable is equal to half of its maximum value.[iv] As shown in Figure 1



It can be applied to the duration of pulse waveforms and spectral width of sources and is also used frequently as a definition of spectral resolution.

In an object that does not have sharp edges for example, in an image of the star the star appears as a blurred object with a Gaussian distribution. The use of FWHM allows a location for that star in the image to be determined.[v] As shown in Figure 2[vi]

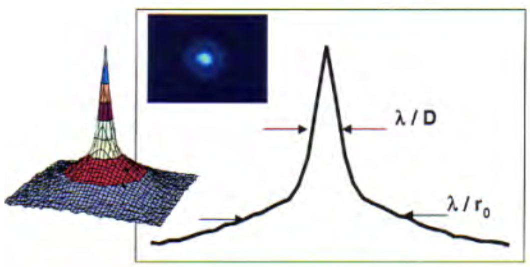


Figure 4 Graphic from EE477 Notes

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G

Geographic Information Systems (GIS)

A geographic information system is a computer-based technology used for the storage, manipulation, and analysis of geographically referenced information. Geographic information systems, or GIS, has five main components: software, hardware, data (spatial), procedures, and people.

GIS data may be represented through one of two data models: raster and vector data models. Data models refer to the method in which geographic information is stored as a data layer. Raster data type is represented in grid form. In other words, raster data consist of rows and columns of cells with each cell assigned a single value. Vector data consists of geometric primitives such as points, lines, and polygons to represent features in a landscape. (see Figure 1)

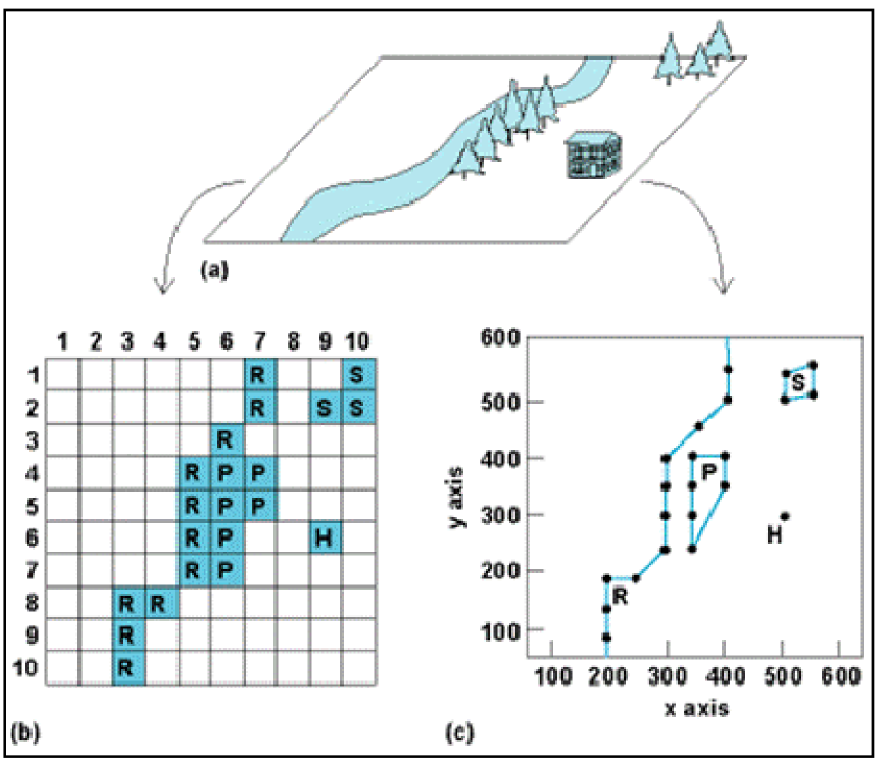

Fig. 1: *Comparison of raster (b) and vector (c) data models to represent real data (a) (courtesy of James Detwiler)*

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An advantage of GIS is its utility in determining relationships between spatial features. Relationships such as adjacency, connectivity, and containment can easily be quantified in GIS analysis. The branch of geometry which refers to the spatial relationships between geometric objects is known as topology.

GIS has significant importance for applications with remotely-sensed imagery. With the increased availability of orthorectified satellite (and aerial) imagery, there is a tremendous amount of spatial data which may be analyzed through GIS. Overlays of spatial information provide an analysis of relationships between features which would prove difficult without use of GIS. As satellite imagery becomes more openly available the applications of remotely-sensed data with GIS will only continue to become more widespread.

Detwiler, James. "What is a GIS?" GEOG 485. University Park, PA. 5 Sept. 2008.

Helen Couclelis, "Geographic information systems", in AccessScience@McGraw-Hill, http://www.accessscience.com, DOI 10.1036/1097-8542.757430

"GIS." Encyclopædia Britannica. 2009. Encyclopædia Britannica Online. 05 Apr. 2009 <http://www.britannica.com/EBchecked/topic/1033394/GIS>.

Geostationary – A geostationary orbit is one where the period of the satellite's rotation is the same as the Earth's . Essentially this means that to an observer on the surface of the earth, the satellite appears to be at a fixed position in the sky. Geostationary orbits must be close to 22, 236 miles above the equator in order to have a period of 1436 minutes, or almost exactly one sideral day. A satellite at that altitude must be traveling at approximately 3.07km/s. The space above the equator at this altitude is highly coveted, as there is a limited amount.

See: "Geostationary Orbit ; Steve Sque, University of Exeter." Physics at Exeter. 27 Mar. 2006. 08 Mar. 2009 <http://newton.ex.ac.uk/research/qsystems/people/sque/physics/geostationary-orbit/>.

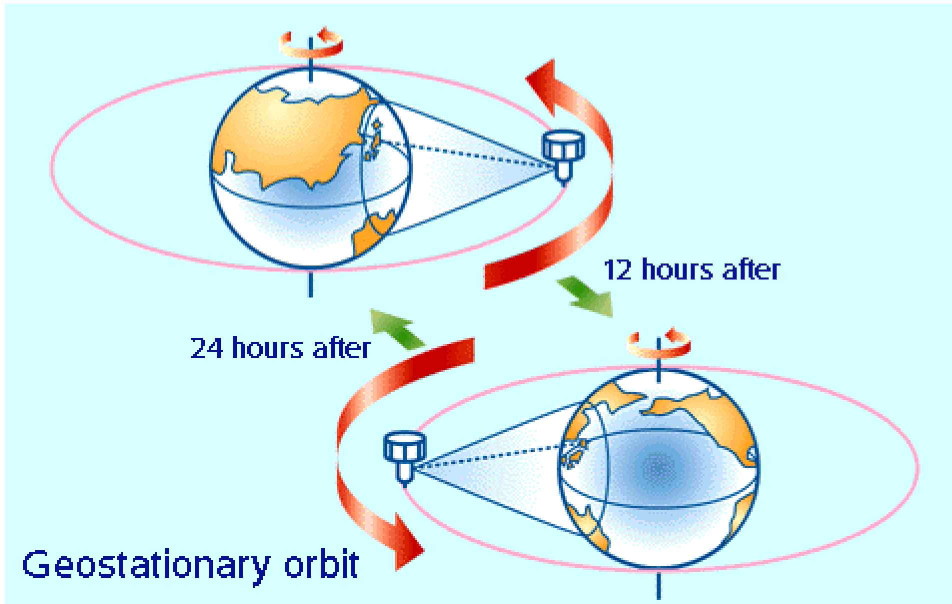

Figure 5: What a geostationary orbit looks like. From Diana Engle, PhD.

Engle, Diana. "Geostationary Orbits." Geostationary Orbits. The Data Discovery Toolkit and Foundry. 08 Mar. 2009 <http://www.newmediastudio.org/DataDiscovery/Hurr_ED_Center/Satellites_and_Sensors/Geostationary_Orbits/Geostationary_Sat.html>.

Global Position System (GPS): A constellation of 24 satellites, operated by the United States Air Force 50th Space Wing[1], which is primarily used for precise measurements of location and time for a given receiver anywhere on the planet.

Figure 1 – Artistic rendering of a GPS satellite in space, in orbit around the earth. Image from the US Government GPS Information Page[2].

GPS is part of the Global Navigation Satellite System (GNSS), with satellites initially launched in 1978. Two blocks of GPS satellites have been operated: Block I (1978-1989) and Block II (1989-present). These satellites were developed initially for military use, and were not made fully operational to the public until 1993. From 1993 to 2000, these satellites operated with selective availability to the public, which purposely degraded the accuracy of the system to maintain a military advantage for the United States military. By setting selective availability to zero (i.e. discontinuation), accuracy on the spatial scale improved from an error of ~100 meters to errors of ~ 30 meters.

GPS satellites orbit in 6 major orbits, which each orbit containing 4 satellites. The satellites orbit at 20,200 km, and complete two orbits per sidereal day.

Figure 2 – Schematic diagram of the 24-satellite/6 orbital pattern constellation. Image from Peter H. Dana through Kenneth E. Foote (University of Colorado)[3].

This allows for an individual satellite to pass over a particular geographic location at the same time of day based on the suns orbit (i.e. the satellite can pass over one location when the sun is at its maximum intensity each day). These orbital patterns allow for at least 4 satellites to be within the receivers 'visible' range at any point in time. To calculate the user's position, the receiver will 'listen' for the continuous signal emitted by the satellite, which includes the precise time and location of the satellite. GPS satellites operate primarily in two wavelengths: L1 (1575.42 MHz) and L2 (1227.60 MHz)[3]. Using this, the receiver computes a sphere around the satellite upon which the user is located. When four spheres (from four satellites) are combined using trilateration[4], the user's latitude, longitude, altitude, and time can be accurately computed.

GPS satellites are subject to several sources of error. In the atmosphere, dispersion in the ionosphere and humidity in the troposphere are of particular interest. Changes in ionospheric dispersion are relatively slow, and can therefore be corrected as need be. However, tropospheric humidity changes can effect wave propagation on a short time scale, making errors difficult to overcome. In addition, relativity affects the rate at which the clocks on-board keep time. To overcome this effect, the United States Air Force 2nd Operations Squadron operates four operational control segments[5] which are used to correct the time of the clocks on each satellite along with orbital location.

1. "Los Angeles Air Force Base - Fact Sheets." Los Angeles Air Force Base - Home. 12 Apr. 2009 <http://www.losangeles.af.mil/library/factsheets/index.asp>.

2. Global Positioning System. US Government. 12 Apr. 2009 <http://www.gps.gov/systems/gps/index.html>.

3. "The Global Positioning System." University of Colorado at Boulder. 1 May 2000. 12 Apr. 2009 <http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html>.

4. How-GPS-Works - Home Page. 12 Apr. 2009 <http://www.how-gps-works.com/>.

5. "GPS Success Story." Software Engineering Institute | Carnegie Mellon. 12 Apr. 2009 <http://www.sei.cmu.edu/programs/acquisition-support/success/gps.html>.

GOES: **G**eostationary **O**perational **E**nvironmental **S**atellite is a geostationary orbiting, continuous monitoring, weather satellite system produced by NOAA, used for short-range warning and data analysis.

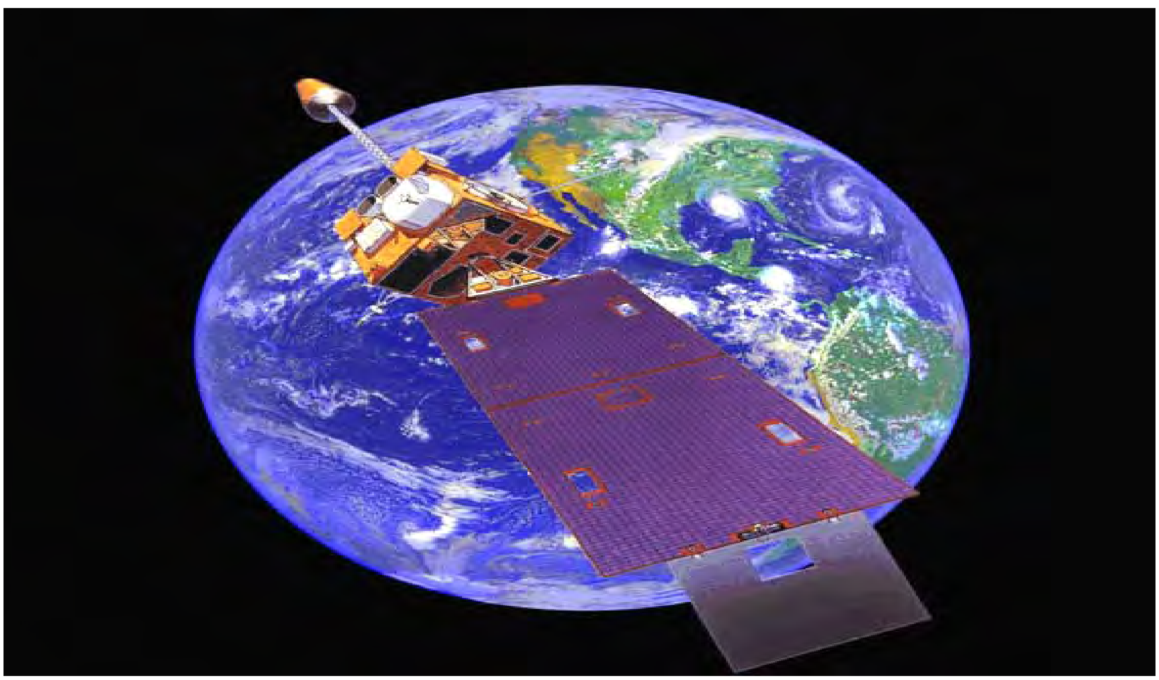

Figure 1: Example GOES-10 Satellite orbiting the earth.
Source: http://library01.gsfc.nasa.gov/gdprojs/images/goes_2.jpg

NASA launched the first GOES satellite for NOAA in 1975 and followed it with another in 1977. Currently, the United States is operating GOES-11 and GOES-12. GOES-13 is being stored in orbit as a replacement for GOES-12 (EAST) or GOES-11 (WEST) in the event of failure. GOES-11 just recently replaced GOES-10 in 2008. GOES-12 is positioned at 75 W longitude and the equator, while GOES-11 is positioned at 135 W longitude and the equator. This allows for the two satellites to operate together and produce a “full-face” picture of earth, day and night.

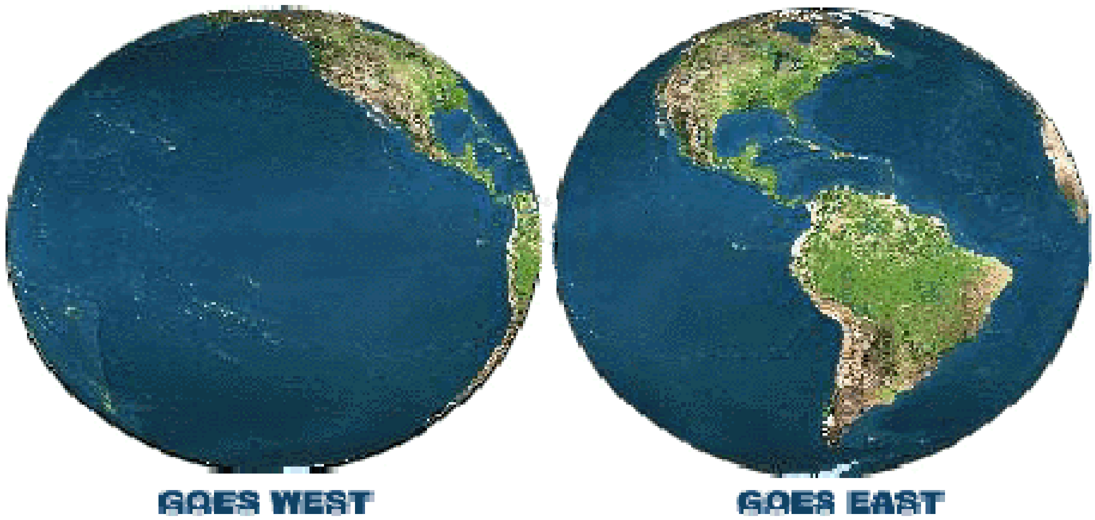

Figure 2: Coverage of area by each GOES satellite in use today. Coverage extends approximately from 20W longitude to 165 E longitude.
Source: NOAA Satellite Information

The satellites carry two main instruments, the *imager* and the *sounder*. The imager is a 5-channel imaging radiometer (1 visible and 4 infrared) that senses radiant and reflected solar energy from the Earth's surface and atmosphere. The Sounder provides data to determine the vertical temperature and moisture profile of the atmosphere, surface and cloud top temperatures, and ozone distribution. Other instruments onboard include a search and rescue transponder, a data collection and relay system and a space environment monitor.

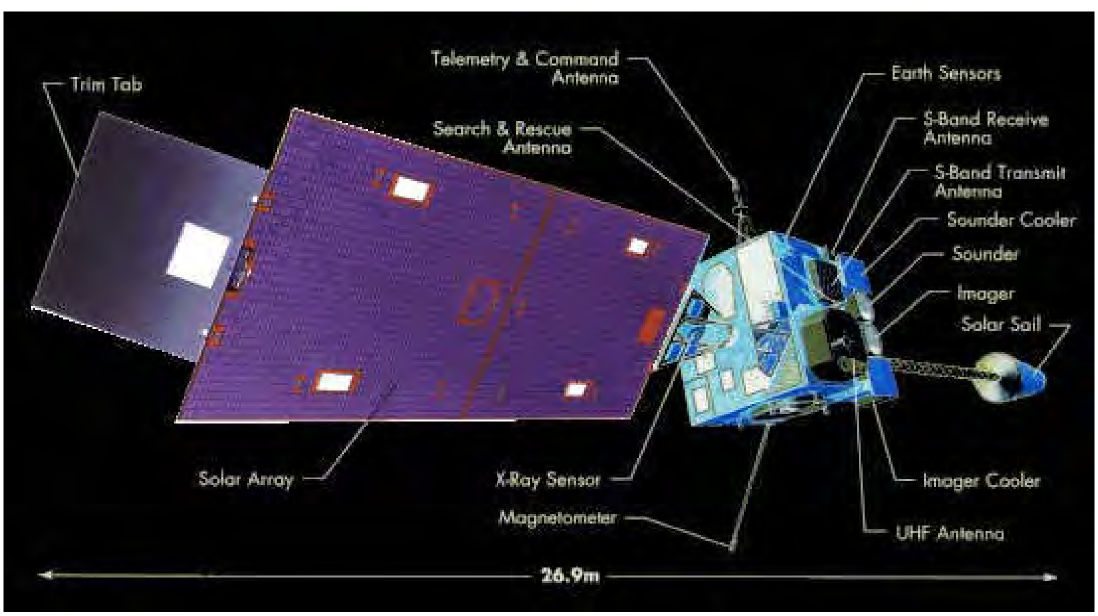

Figure 3: GOES satellite and its associated instruments.
Source: http://www.weathertap.com/guides/satellite/satellite-tutorial.html

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Why use the GOES?
The GOES satellites follow a geosynchronous orbit, meaning that they orbit the equatorial plane of the Earth at a speed matching the Earth's rotation over one position on the surface. The satellites are stationed about 35,800 km (22,300 miles) above the Earth, allowing them to view the entire earth.

- Due to the positioning of the satellites, they are able to view and track atmospheric phenomena associated with severe weather such as tornadoes, floods, and hurricanes.
- GOES satellite imagery is used to estimate rainfall during thunderstorms and hurricanes for flash flood warnings, as well as estimates snowfall accumulations and overall extent of snow cover.
- Satellite sensors detect ice fields and map the movements of sea and lake ice. Thus long-range Climatology analysis can be done using this data.

The GOES satellite transmits data every 15 minutes, making its images relatively accurate. However, under sever weather events, data may be transmitted more often to ensure precise tracking of weather phenomena.

Due to the 5-channel radiometer, different images can be produced depending on whether you are in the visible, long wave IR, shortwave IR, split-window IR, or water vapor. Each type of imagery can provide valuable information and its resolutions may have different trade-offs. For example, GOES satellites generally have a greater temporal resolution, while the spatial resolution is more coarse. However, in the Visible spatial resolution is approximately 1km, while the spatial resolution of the remaining sensors range from 4km to 8km depending on the sensor.

Due to end of life fuel conditions, GOES-10 will cease to operate in December of 2009.

Figure 4: Example GOES visible image of Hurricane Katrina.
Source: antwrp.gsfc.nasa.gov

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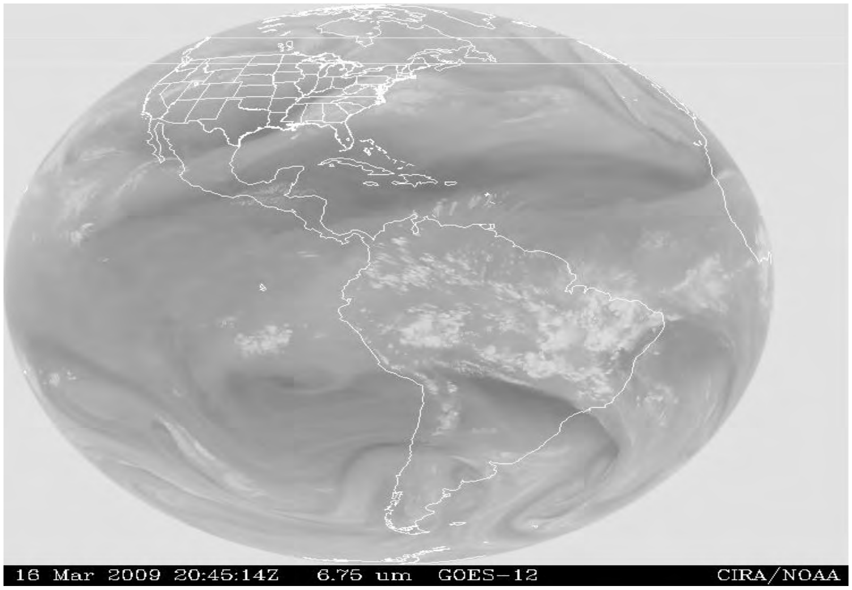

Figure 5: Example of "full-disk" water vapor image. (Both East and West satellites combined).
Source: http://goes-rap.cira.colostate.edu/GOES-12/GEMS/Original/JPEG/Current/fulldisk_c03.jpg

Sources:
WeatherTAP Satellite Tutorial. Accessed March 17 2008.
http://www.weathertap.com/guides/satellite/satellite-tutorial.html

NOAA Satellite Information. "Basic Information" Accessed March 17 2008.
http://www.oso.noaa.gov/goes/inrstat/G10_RegStats.asp

GPS Radio Occultation:

Remote sensing technique used for monitoring atmospheric properties. It relies on the detecting the modification of a radio signal going through the atmosphere.
A specific occurrence of that technique using GPS satellites as a source and Low Earth Orbit satellites as receivers is presented here. Figure 6 illustrates that set up.

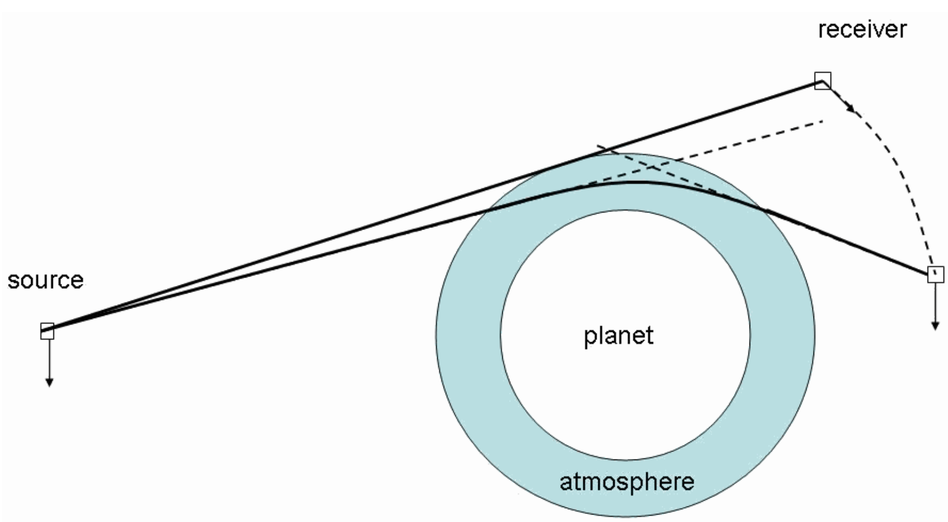

Figure 6. GPS Radio Occultation set up.

As can be seen on the figure above, the receiver is going to receive a bended signal. That bending angle is going to provide the information necessary to describe the atmosphere. The bending angle is computed by using the Doppler shift of the received signal. Data from several GPS transmitters can be used to establish the precise positions and velocities of the GPS and LEO satellites and to calculate the expected Doppler shift in the absence of bending angle. Each GPS satellite continuously transmits right-hand circularly polarized signals at two L band frequencies, 1575.42 MHz (L1) and 1227.6 MHz (L2), corresponding to wavelengths of 19.0 cm and 24.4 cm, respectively. These are modulated at frequency of 10.23 MHz by a pseudo-random precision ranging code (P code). The L1 carrier signal is also modulated at a frequency of 1.023 MHz by a coarse/acquisition (C/A) ranging code. In order to make full use of the atmospheric information contained in these signals, a GPS receiver operating in LEO must be able to measure the phase and amplitude of the L1 and L2 carrier signals. Comparison of L1 and L2 phase measurements forms the basis for separating atmospheric and ionospheric contributions to the bending.

From the bending angle, knowing the position of transmitter and receiver, the atmospheric refractive index can be inferred. In order to derive properly atmospheric properties from retrieved bending angles, it is necessary to understand how these properties influence *n.* There are 4 main influences that are, in order of importance: the dry neutral atmosphere, water vapor, free electrons in the ionosphere and particulates (primarily liquid water). An example of atmospheric bending as a function of ray path tangent height is shown in Figure 7.

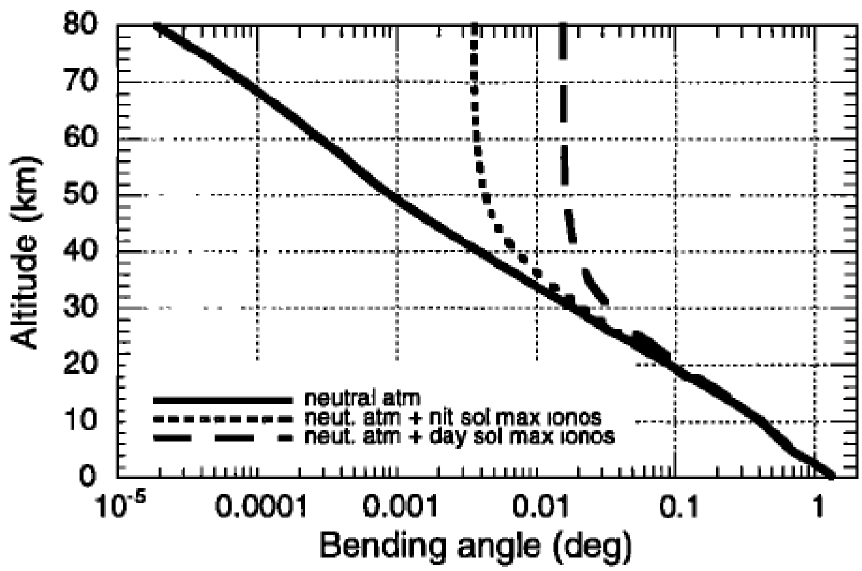

Figure 7. Atmospheric and ionospheric bending for limb ray paths plotted as a function of ray path tangent height. Calculations are based on US Standard Atmosphere.

Once the relative importance of all those factors is determined, there are other mechanisms affecting the received signal that must be accounted for. The dominant attenuation mechanism is defocusing, which occurs when rapidly changing vertical refractivity gradients cause adjacent, nearly parallel rays entering the atmosphere to bend differentially and diverge, reducing (or sometimes enhancing) signal intensity at the receiver.

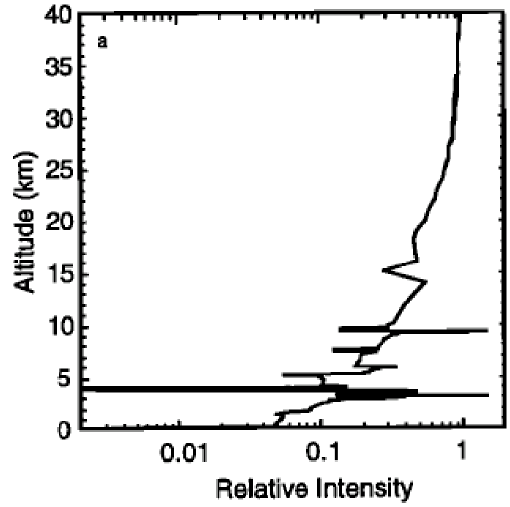

Figure 8. Variation of defocusing factor M with altitude.

Other more traditional error corrections have to be included to finalize the signal processing and obtain accurate profiles. Once this is done, with 24 GPS satellites, a single GPS receiver in a near polar orbit at 800 km will observe over 500 occultations per day, distributed fairly uniformly about the globe. Figure 9 gives an idea of the coverage obtained by the GPS Radio Occultation technique.

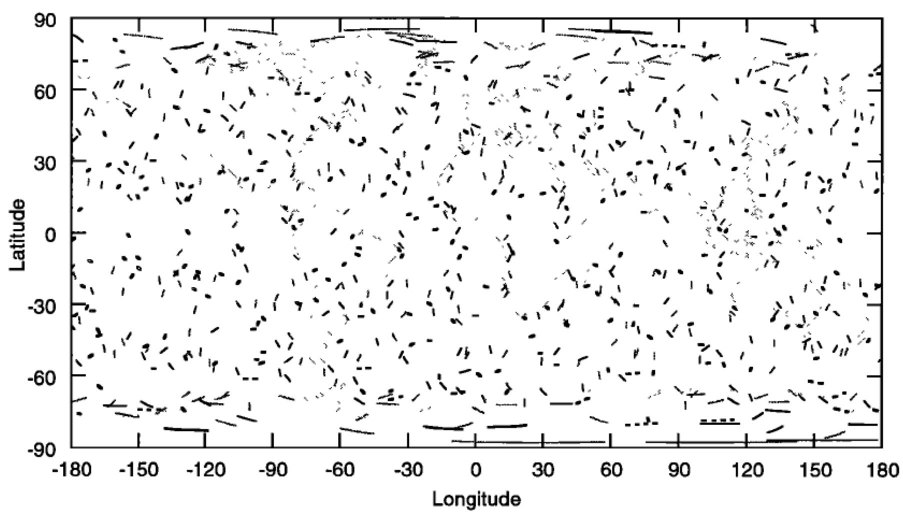

Figure 9. Distribution of occultations observed in 9 days by a polar orbiter at 800 km altitude viewing 24 satellites.

The technique as been tested during a few missions (FORMOSAT-3, CHAMP, GRACE) and interesting results were obtained. It could be applied to weather forecasting, climate study, stratosphere-troposphere exchange, polar regions study, atmospheric boundary layer monitoring and small scale waves and turbulences.

References:

- Wikipedia: http://en.wikipedia.org/wiki/Radio_occultation
- *Kursinski et al.*, Observing Earth's atmosphere with radio occultation measurements using the Global Positioning System, Journal of geophysical research: Atmospheres, 1997, vol:102, iss:D19, pg:23429 -23465

Ground truth: A common way to correct data taken at a distance (aerial photography, cartography, meteorology, satellite imagery, and many other mechanisms of remote sensing) to more closely correspond to data taken at the specific location in question. Collecting of ground-truth data allows the effective calibration of remotely sensed data, as well as aiding in the interpretation and analysis of whatever data is being collected by the remote sensor. One of the most common uses for ground truth is for atmospheric correction. Images taken from satellites (as well as data collected in the atmosphere and at the surface) are susceptible to a fair amount of distortion as a result of absorption in the atmosphere, so correction of these images and data is necessary for proper analysis to take place.
The process of ground truthing data is most often done at the site of the measurements, where various observations and measurements of the feature being sensed are collected, and these areas are called ground resolution cells. Developing a ground truth also involves taking geographic coordinates of the ground resolution cell with GPS technology and comparing those with the coordinates of the pixel being studied provided by remote sensing software to understand and analyze the location errors and how it may affect the analysis of that data.
There are two sources of error linked to ground truth in the classification of objects in images: errors of omission and errors of commission. An error of omission occurs when an object or a pixel is not classified at all in an image, although a classification scheme exists An error of commission occurs when an object or pixel is incorrectly classified in an image.

Reference:
NASA. "Ground Truth and Imaging Spectroscopy: Rationale for Surface Observations and Data Collection." Remote Sensing Tutorial: Collecting Data at the Surface. Goddard Space Flight Center, NASA. <http://rst.gsfc.nasa.gov/Sect13/Sect13_1.html>.

H

IS A LONELY LETTER ☹

I

Inclination

Inclination refers to the angle at which a celestial body is moving with respect to the plane of reference. Inclination is an important topic in remote sensing since it provides information about a satellite orbit's shape, position, and orientation with reference to the Earth's surface.

Computation of inclination is of significant importance in the field of astrodynamics. Inclination is given by the following equation (see Equation 1). The term h_z is the z-component of *h*, where *h* is the orbital momentum vector orthogonal to the orbital plane.

$$i = \arccos \frac{h_z}{|\mathbf{h}|}$$

Eq. 1: Inclination as a function of h_z and h

Inclination one of six orbital parameters as defined by Johannes Kepler to describe the size and shape of a celestial orbit. The other orbital parameters are eccentricity, semimajor axis, longitude of the ascending node, argument of periapsis, and mean anomaly at epoch. Every satellite orbit lies in an orbital plane which always runs through the center of the Earth. However, the orbital plane may be tilted any angle relative to the Earth's equator. The angle between the orbital plane and the equatorial plane may be between 0 and 180 degrees. This angle, as measured counterclockwise at the ascending node, is defined as the inclination (see Figure 1).

The inclination of a satellite is decided when the satellite is put into orbit and, yet, the inclination cannot be changed once in orbit. A satellite's inclination is often determined based on the function of the satellite. Depending on the area of interest, a satellite may be placed on an orbit of any inclination between 0 and 180 degrees.

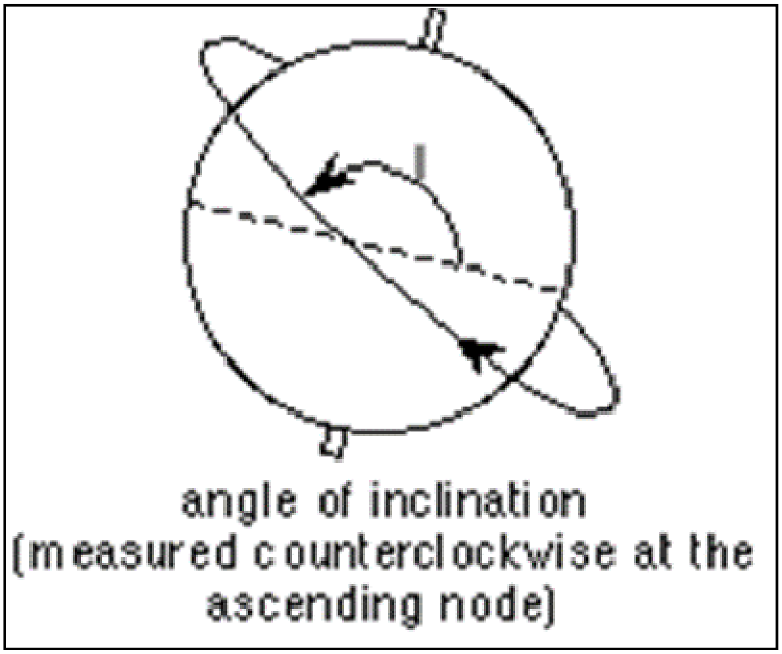

Fig. 1: Schematic diagram of the angle of inclination (courtesy of UNL CASDE)

An inclination of 0 degrees means that a satellite is located on the equatorial plane and rotating in the same direction as the Earth. An inclination of 90 degrees means that a satellite is rotating directly over the north and south poles of the Earth. Finally, an inclination of 180 degrees means that a satellite is located on the equatorial plane and rotating in the opposite direction as the Earth. This type of orbit is typically called a retrograde equatorial orbit.

In satellite remote sensing, inclination varies depending on the purpose of the satellite. Sun-synchronous satellites that have the same track throughout the year typically have inclinations as high as 98 degrees. Some satellites that conduct studies of the sun, such as SOHO, have inclinations as low as 28 degrees. Weather satellites generally have high inclinations between 45 and 90 degrees to be at an ideal location to monitor weather conditions.

"CASDE | Remote Sensing Glossary - I." CASDE | Virtual Nebraska. UNL. 12 Apr. 2009 <http://www.casde.unl.edu/glossary/i.php>.

"Remote Sensing Tutorial Page 1-8." The Remote Sensing Tutorial. National Aeronautics and Space Administration. 12 Apr. 2009 < http://rst.gsfc.nasa.gov/Intro/Part2_1a.html>.

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Imaging spectroscopy: Imaging spectroscopy (also spectral imaging, chemical imaging, or microspectroscopy) is similar to color photography, but each pixel acquires many bands of light intensity data from the spectrum, instead of just the three bands of the RGB color model. More precisely, it is the simultaneous acquisition of spatially coregistered images in many spectrally contiguous bands.

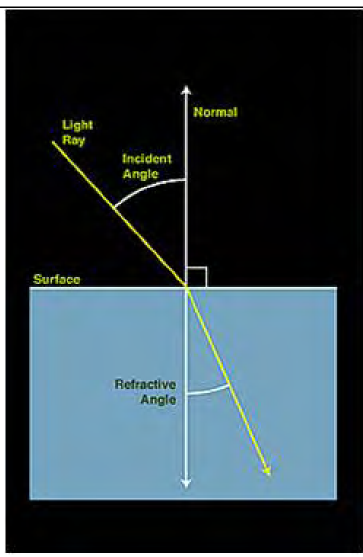
Some spectral images contain only a few image planes of spectral data, while others are better thought of as full spectra at every location in the image. To be scientifically useful, such measurement should be done using an internationally recognized system of units.

References:
http://speclab.cr.usgs.gov
http://www.wikipedia.org

Index of Refraction (n)
The index of refraction is a ratio of the wavelength or velocity of electromagnetic radiation in a vacuum to that in a substance. It is a measure of how much the speed of light is reduced inside a medium.

N = c / cn, where c is the speed of light in a vacuum (3 * 10 ^ 8) and cn is the speed of light in a substance

The index of refraction is directly related to Snell's Law. Snell's Law allows us to quantify the amount or degree of refraction between two medium. This law states that for a given frequency of light, the product of the index of refraction and the SINE of the angle between the ray of the incoming energy and the medium normal to the surface is constant. If you know the index of refraction of a medium n1 and n2, as well as the angle of incidence, it is possible to predict the amount of refraction in medium n2.



This image is courtesy of Dr. Lampkin's 362 Slides.

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InSAR: Interferometric Synthetic Aperture Radar. SARs transmit (i.e.—active remote sensor) and receive microwave signals and can operate during cloudy conditions and without daylight. InSAR compares two or more SAR images and determines if there are any phase differences in the returning microwave signals. Phase differences can be used to measure surface deformation or elevation depending on the InSAR technique. A phase shift (see Figure 1) is measured in radians and the term fringe is used to describe an entire 2π cycle. An interferogram (see Figure 2) is usually produced to visualize the interference fringes. By analyzing phase shifts that are only a small fraction of the signal wavelength, it is possible to measure displacements to millimeter accuracy. The main SAR satellite platforms include the European Remote Sensing Satellite (ERS) 1/2, Japanese Earth Resources Satellite (JERS) 1, Radarsat, and the Environmental Satellite (Envisat).

- Repeat-pass InSAR: 2 SAR images are taken at different times, coregistered, and then used to determine phase differences between coherent points in the 2 images. If nothing has happened between 2 SAR images taken from the same position/location and of the exact same terrain, they should show no phase differences. Therefore, if the phases have shifted, something has happened to the surface (e.g.—deformation).
- Single-pass InSAR: 2 SAR images taken at the same time from slightly different positions. Provides topographic modeling capabilities (DEM generation).

A general diagram of the InSAR process is shown in Figure 3. A_i represents the position of the satellite for the first SAR image and A_j represents the satellite position for the second image. In this example, the interferogram of phase differences generated by the combination of the 2 images could be the result of several factors: topography ($z(y)$), surface displacement in the look/line-of-sight direction (θ), and separation in space between the two observations (termed the baseline, B). The effect of topography on the phase is proportional to the baseline and can be used to derive DEMs. To determine surface displacement, the contribution of topography and the baseline must be eliminated. The baseline effects can be modeled and eliminated while a DEM is required to remove the topographic effects. The DEM can either come from an independent source (e.g.—SRTM) or can be derived by a third SAR image (i.e.—3 pass method) that is taken very close in time and distance to one of the other observations. Once the baseline and topography contributions are removed from the interferogram, the fringes only represent displacement in the look direction.

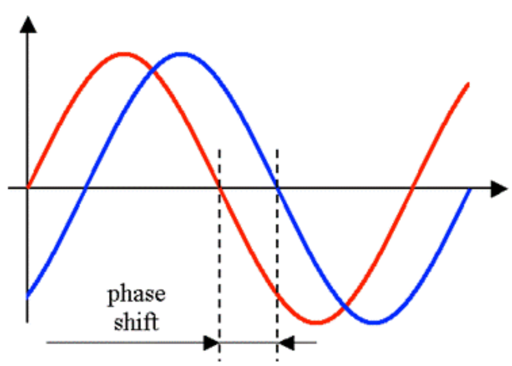

Figure 1: Example of a phase shift in a returning SAR signal. InSAR can be used to analyze phase differences between 2 SAR images to model topography and determine displacements. Source: http://en.wikipedia.org/wiki/Image:Phase_shift.png

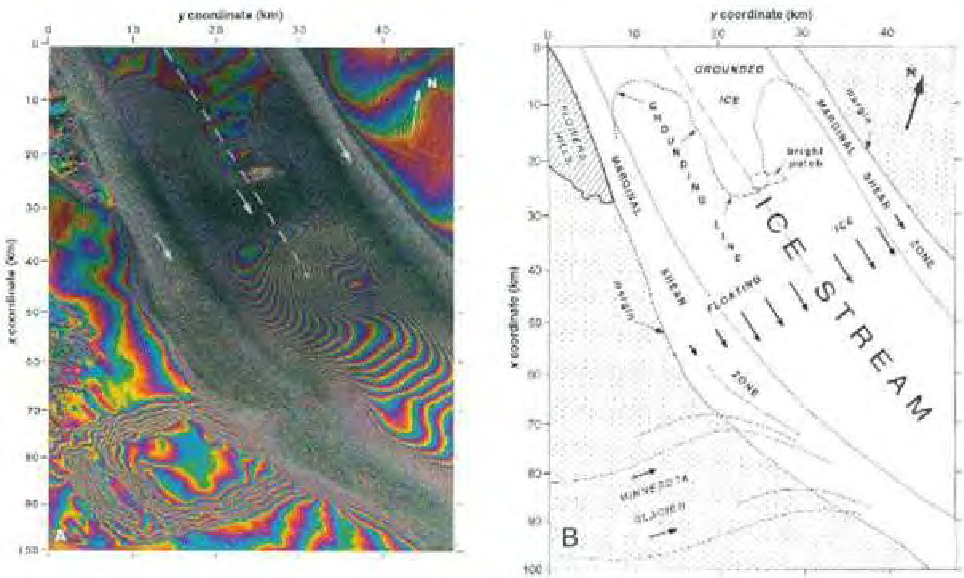

Figure 2: Example of a typical interferogram produced from determining phase differences between 2 SAR images. The interferogram correctly delineates the grounding line of the Rutford Ice Stream, Antarctica. A fringe going from blue→yellow→red→blue is a 2.8 cm displacement in the look direction. Source: (Goldstein et al. 1993)

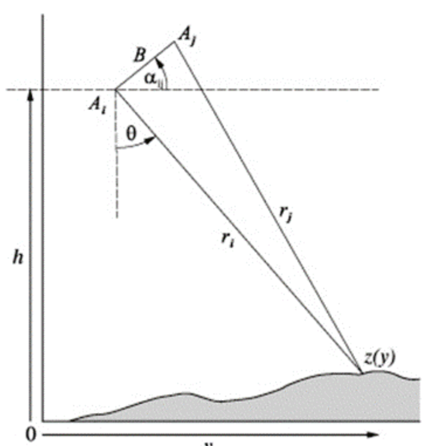

Figure 3: Diagram showing typical process for determining InSAR measurements. Source: (Bamber and Rivera 2007)

Sources

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Li, S., C. Benson, R. Gens & C. Lingle (2008) Motion patterns of Nabesna Glacier (Alaska) revealed by interferometric SAR techniques. Remote Sensing of Environment, 112, 3628-3638.

Massonnet, D. & K. L. Feigl (1998) Radar interferometry and its application to changes in the earth's surface. *Reviews of Geophysics,* 36**,** 441-500.

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L

Lambertian Surface

A surface is called 'lambertian' when the body reflection obeys Lambert's cosine law. It is named after Johann Heinrich Lambert, from his Photometria book that was published in 1760.

The Lambert's cosine law says that the amount of light emitted from a surface in different directions is proportional to the cosine of the angle between the direction and the surface normal (Cowan, Lambertian). A lambertian surface is when the distribution of radiant energy leaving a surface is equal in all directions. Therefore the luminance or brightness of a lambertian surface is constant regardless of the angle from which it is viewed. A lambertian surface is a perfectly diffusing surface. Many natural surfaces are close to lambertian at directions close to perpendicular, but most depart from Lambert's law when seen at low angles.

Figure 1

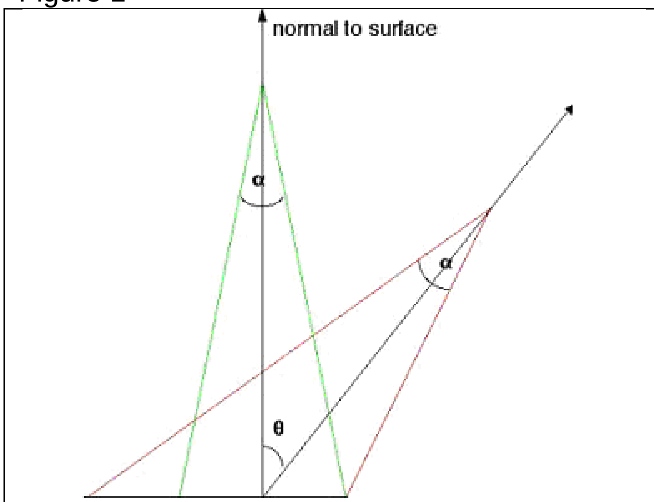
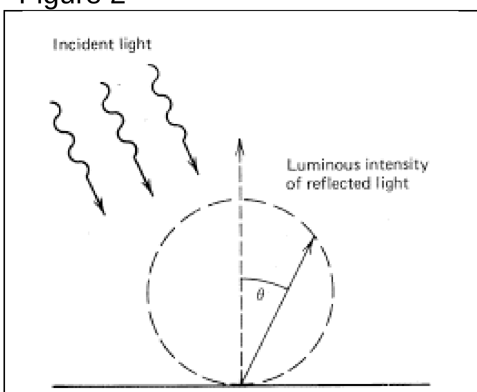


Figure 1 shows how a surface is viewed, directly downward or normal to the surface within a specific solid angle on a surface. (http://www.physics.uc.edu/~sitko/LightColor/8-Measuring/Measurement.htm)

Figure 2



In this figure, the circle indicates the strength of scattering in that direction, and the pointed arrow represents the strength of light in the direction the arrow points. (http://www.physics.uc.edu/~sitko/LightColor/8-Measuring/Measurement.htm)
If this surface were lambertian, than each point would scatter light following Lambert's law.

Figure 3

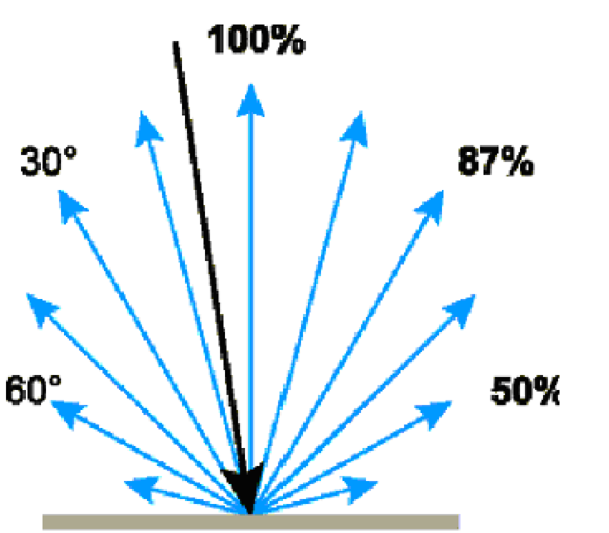


Figure 3 shows that a reflection from a diffuse Lambertian surface obeys the cosine law by equally distributing reflected energy in proportion to the cosine of the reflected angle. This surface radiates equally at 0 and 60 degrees. And since a radiance detector would see twice as much surface area in the same solid angle for the 60 degrees case, the average reflection would be half the magnitude of the reflection in the 0 degree case. (Principles of light measurement: http://www.anees.com/6.html)

Figure 4

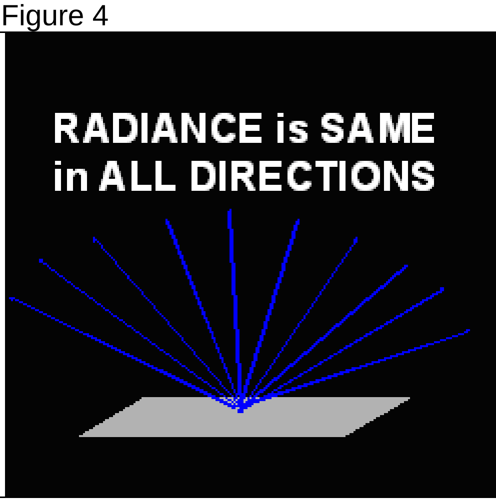


Figure 4 is courtesy of Derrick Lampkin's 362 slides describing how radiance is the same in all directions for a Lambertian surface.

It is also very important to note that all blackbodies are lambertian sources. The radiance of a blackbody is not a function of direction, and therefore a blackbody would be a perfect lambertian radiator.

Works Cited:

Cowan, Bill. Lambertian Surfaces. June 2007, Spring lecture notes. http://www.cgl.uwaterloo.ca/~wmcowan/teaching/cs488/pdf/lambertian.pdf

University of Cincinnati, Physics department. Light Measurement. Chapter 8. http://www.physics.uc.edu/~sitko/LightColor/8-Measuring/Measurement.htm

Principles of Light Measurement: http://www.anees.com/6.html

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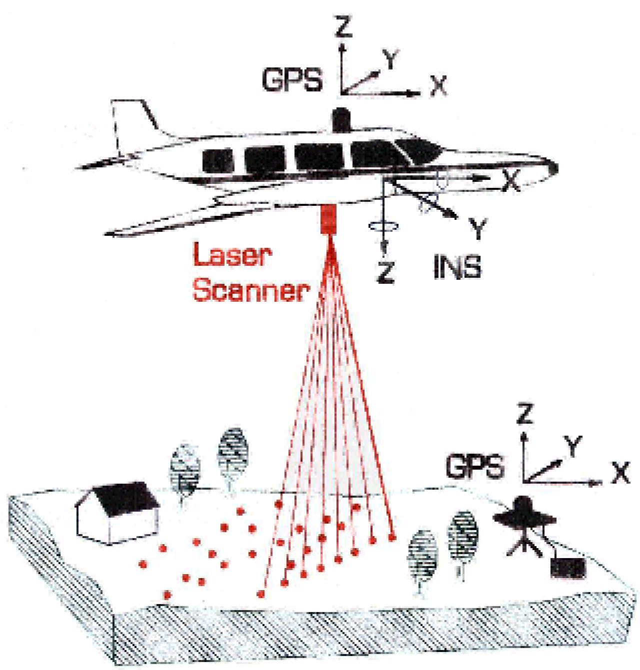
Laser altimetry: A method of automatically determining height or elevation of a particular terrain from an aircraft or a satellite. Laser altimetry is also known as airborne laser mapping, LIDAR mapping, or airborne laser scanning. Along with stereo-photogrammetry and airborne synthetic aperture radar interferometry, it is one of the most important and common means of building three-dimensional maps and images of terrain. The instrument that performs this measurement, a laser altimeter, is operated in a helicopter, airplane, or a satellite. The instrument releases a laser pulse which travel to the terrain surface and then are reflected back to the instrument, which gives information about how much time it took for the pulse to return to the instrument. Using the time it took for the pulse to return to the instrument, the elevation of the terrain below the instrument is calculated while taking the speed of light into account.
There are two major things that need to be taken into account to determine the exact three-dimensional coordinates (latitude, longitude and elevation) of any spot on the surface that is hit by a laser pulse from the laser altimeter. First, the exact location of the aircraft when the pulse was emitted is necessary information, and second, it is necessary to know which Cartesian direction the laser altimeter was pointing when the pulse was emitted. These measurements are collected and corrected using GPS receivers and INS (Internal Navigation System) instruments onboard the aircraft or satellite where the laser altimeter is making measurements. With these corrections in place, laser altimetry is an effective means of collecting elevation data with an average vertical error of less than 10 centimeters and horizontal error of less than 20 centimeters. In order to create a three-dimensional map or image of the Earth's surface, between 2,000 and 100,000 range measurements per second are performed, each to a different spot on the surface, to ensure complete coverage of an area of terrain that is being mapped. The laser beam is scanned in a linear fashion across the line on which the aircraft is flying. This process is repeated over and over again as the aircraft flies in a linear pattern over the terrain, thus gathering strips of elevation data from the surface. Depending on the laser altimeter used and the altitude of the aircraft and operational laser altimeter, above ground spot sizes of 20 centimeters to 25 meters and strip widths of 50 meters to 9 kilometers can be achieved.



References:
1) "Laser Altimetry." GeoLas Consulting: Laser Altimetry. 2006. GeoLas Consulting. <http://www.geolas.com/Pages/laser.html>.
2) NASA. "The Geoscience Laser Altimeter System." The Geoscience Laser Altimeter System: The Next Generation Space Lidar. 2007. Goddard Space Flight Center, NASA. <http://glas.gsfc.nasa.gov/>.
Figure 1: This figure shows the principles of laser altimetry from

an airplace quite simply, including the GPS recievers on the ground and on the plane, the INS navigation device, and points on the ground which are detected and scanned by the altimeter (GIS Development).

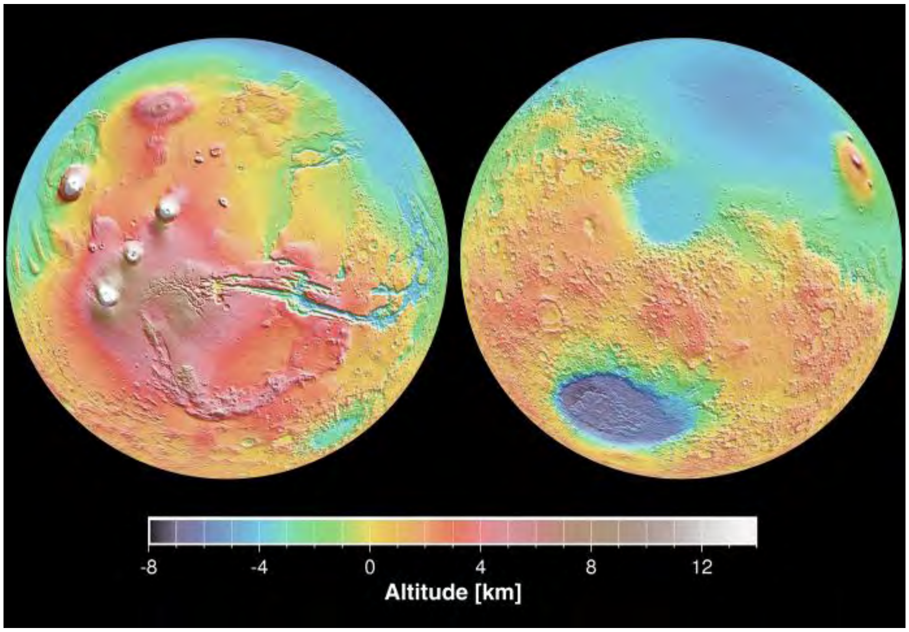


Figure 2: Laser altimetry has been done of the Martian surface in addition to measurements taken on Earth. Altitude is clearly shown in this image from NASA (Mars Program, Jet Propulsion Laboratory, NASA).

LIDAR

LIDAR, or LIght Detection And Ranging is a remote sensing system used to collect topographic data. LIDAR technology uses a laser and a sensor to transmit and receive pulses from reflected surfaces. LIDAR data is collected with aircraft-mounted lasers capable of recording elevation measurements at a fast rate of 2000 to 5000 pulses per second, with a vertical precision of 6 inches. The LIDAR laser beam travels 186,282 miles per second, extremely far fast! During the aircraft flight, the LIDAR sensor pulses a narrow frequency beam toward the earth through an opening in the bottom of the aircraft's center structure or fuselage. The LIDAR then records the time difference between the release of the laser beam and the return of the laser signal to the aircraft. LIDAR started in the pre-laser times of the 1930s with searchlight beams, and then quickly evolved to modern LIDARS using nano-second laser pulses.

The cosine effect applies to LIDAR in the same way it applies to Radar. This simply means the measured speed of the beam is directly related to the cosine of the angle between the LIDAR gun and the target's direction of travel. This effect refers to the angle of the target vehicle (aircraft) in relation to the aircraft where the LIDAR is mounted.

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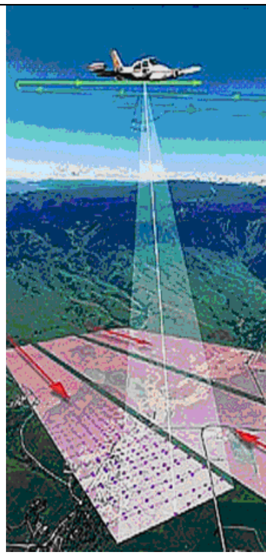
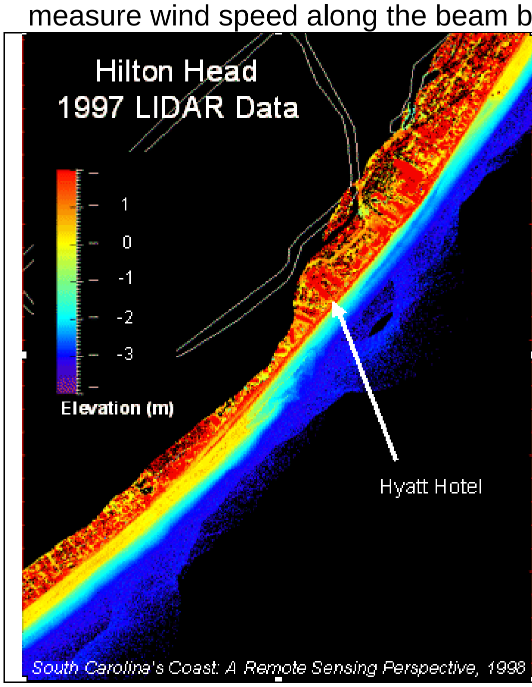
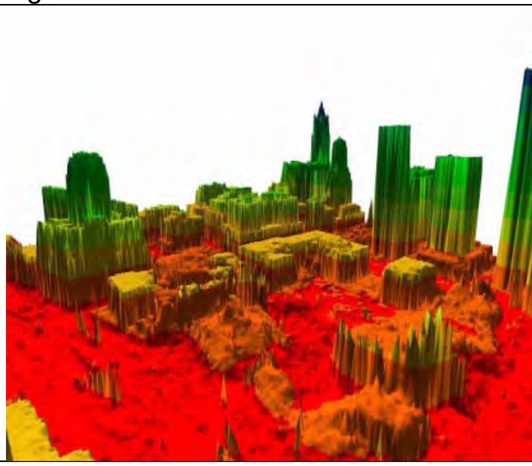
	This is courtesy of the Natural Resources Conservation Service (NRCS), http://www.wy.nrcs.usda.gov/wygis/lidar.html This image shows a LIDAR laser beam being sent out from an aircraft and the ground swath as seen from above.

LIDAR is being used by the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA) scientists to document topographic changes along shorelines. Figure 2 depicts LIDAR data being used to document topographic changes in Hilton Head, South Carolina, from 1997. LIDAR is also very beneficial to Natural Resource Management because of its easy creation of highly accurate Digital Elevation Models (DEMS), as well as cost effective data collection in covering a larger area in less time. Policemen also use LIDAR to record both the distance and the speed when issuing speeding tickets. The first LIDARs were used for meteorological uses in studying atmospheric composition, structure, clouds and aerosols. There are also specific kinds of LIDAR such as the elastic backscatter LIDAR used for the studies of aerosols and clouds, and the Doppler LIDAR that is used to measure wind speed along the beam by measuring the frequency shift.

	Figure 2 depicts LIDAR data being used to document topographic changes in Hilton Head, South Carolina, from 1997. This is courtesy of NOAA, http://www.csc.noaa.gov/products/sccoasts/html/tutlid.htm

As the LIDAR sensor collects data points, the location of the data are simultaneously recorded by the Global Positioning System (GPS) sensor that is also mounted on the aircraft. This allows retrieval of accurate longitude, latitude and elevation positions for every data point. These data points allow easy generation of high precision DEMs of the ground surface.

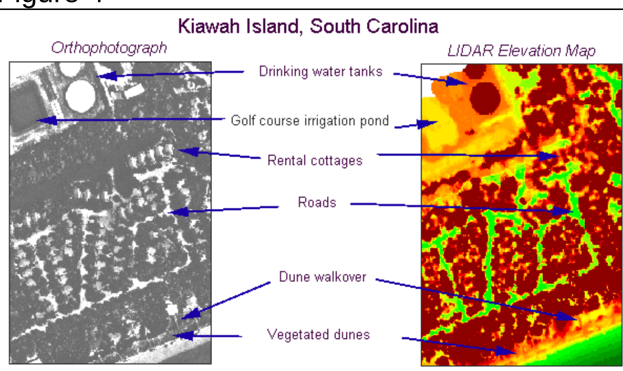
Figure 3



This is a 3D LIDAR image of the Ground Zero site after 9/11. LIDAR provided elevation data that enabled emergency managers to assess damage through the smoke. It was also used to determine changes in the rubble pile and create 3-D digital elevation models showing the extent of devastation. (http://www.loc.gov/exhibits/911/911-maps.html)

Sometimes LIDAR data is easiest to interpret when examined alongside additional data such as aerial photography. Comparing data makes it easier to identify features such as houses, roads, vegetation and irrigation.

Figure 4



This image is courtesy of NOAA's About Lidar Data site. It demonstrates a comparison of Lidar elevation data to an orthophotograph.

The final image results from LIDAR data typically take weeks to produce, whereas regular ground-based methods typically take months or even years. The first acre of LIDAR flight data is expensive, because of the high quality equipment and LIDAR technology is available through a number of sources.

Works Cited

NOAA: About Lidar Data. http://www.csc.noaa.gov/products/sccoasts/html/tutlid.htm

Department of Agriculture: Natural Resources Conservation Service. Wyoming Statewide LIDAR effort. http://www.wy.nrcs.usda.gov/wygis/lidar.html

Library of Congress, Geography and Map Division: Witness and Response 9/11. http://www.loc.gov/exhibits/911/911-maps.html

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Limb Observation- A limb observation (or "limb view") occurs when a sensor collects information with a field of view that is roughly parallel to the Earth's surface. As such, the sensing system focuses on the Earth's horizon as it orbits. This is different than nadir sensing, in which the sensing system is focused downward, directed towards the Earth's surface.

Limb sensing techniques are useful because they allow for increased resolution in a vertical cross section of atmospheric constituents when compared with nadir viewing. However, because the atmosphere at the horizon, or limb, is generally far from the instrument there is increased attenuation of radiation along the sensor's field of view. Many atmospheric sensing systems are capable of both limb and nadir viewing because of these tradeoffs. [see "Microwave Limb Sounder", http://mls.jpl.nasa.gov/index.shtml]

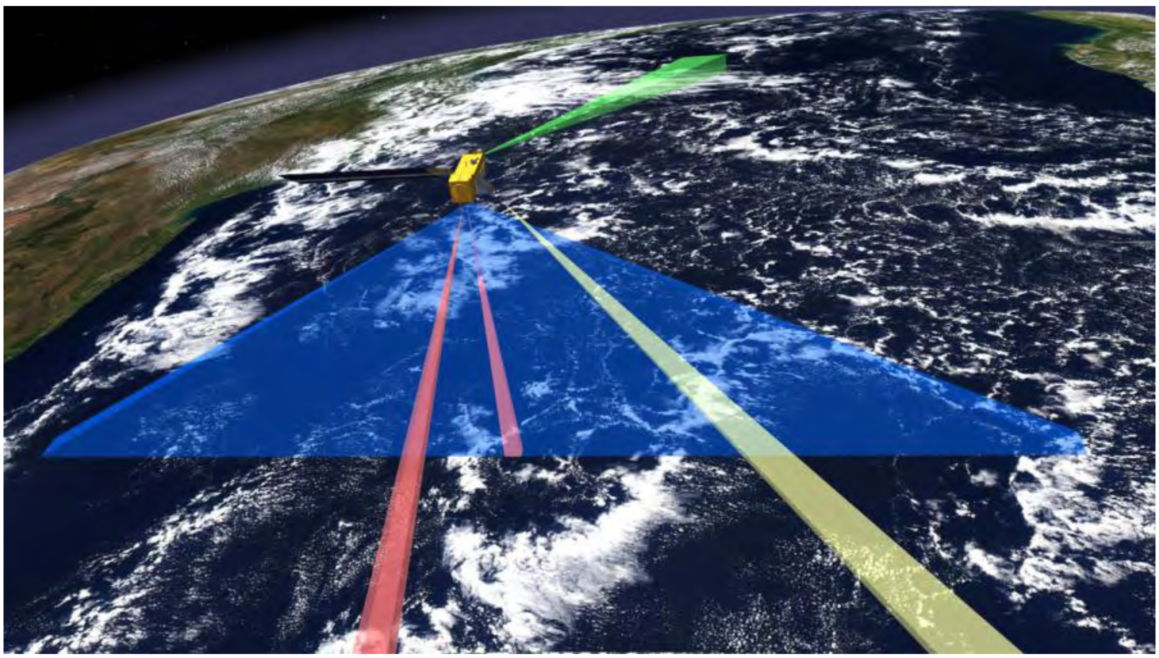

Figure 1 – The NASA Aura satellite, illustrating different viewing techniques by its instruments. The green and yellow paths show limb observation fields of view.

Line-of-sight Propagation
Line-of-sight propagation (also known as tropospheric propagation or space waves) is a term used to describe electromagnetic waves that travel in a straight line. These waves may be diffracted by the atmosphere but generally do no travel over the horizon. Line-of-sight propagation is highly directional and relies on a narrowly focused beam of radiation to communicate between a transmitter and a receiver. Therefore, when there are no obstructions between the transmitter and receiver they are said to be in "line-of-sight" with each other.

When there is a line-of-sight path between a transmitter and a receiver, the loss in propagation is free-space attenuation. Free-space attenuation is equivalent to 6 decibels per octave of distance between the transmitter and the receiver. The line-of-sight path is not necessarily the optical line of sight. For frequencies between approximately 1 and 30 MHz, the wave path may be diffracted due to layers of the atmosphere. The diffraction allows waves to follow the Earth's curvature allow deflected straight lines or quasi-curved paths.

Satellites must consider line-of-sight propagation to account for obstructions which may prevent an electromagnetic wave from reaching its destination. The distance covered by the radiation is calculated based on the travel time of the wave. The maximum range of a line-of-sight from a land-based transmitter is dependant on the curvature of the earth (Figure 1). This distance in which ground-based transmitters may propagate waves is typically around 100 kilometer, from horizon to horizon (see Figure 1). Examples of line-of-sight propagation include radar, satellite, and FM radio.

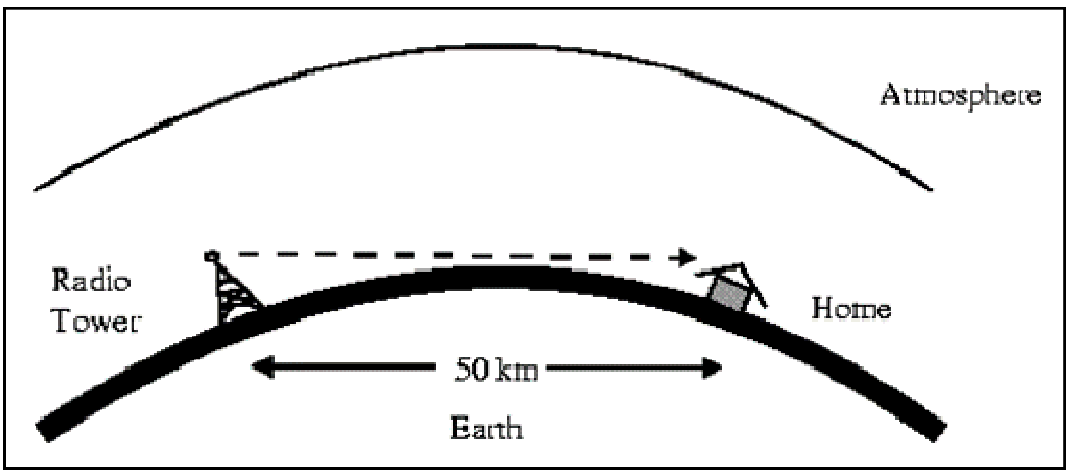

Fig. 1: Line-of-sight propagation for ground-based transmitters
(courtesy of www.accessscience.com)

Line of sight propagation is an important consideration for calculating the travel time for electromagnetic radiation, such as radio waves. For applications such as RADAR and LiDAR, an accurate measurement of time is essential for proper results. Line of sight propagation may influence radiation to take multiple paths to a target. For this reason, line of sight propagation must be taken into account for instruments detecting electromagnetic radiation over large distances.

Helen Couclelis, "Geographic information systems", in AccessScience@McGraw-Hill, http://www.accessscience.com, DOI 10.1036/1097-8542.757430

"Inside line-of-sight propagation." Urgent Communications Magazine Online | Formerly MRT Magazine. 07 Apr. 2009 <http://urgentcomm.com/mag/radio_inside_lineofsight_propagation/>.

"line-of-sight microwave link." Encyclopædia Britannica. 2009. Encyclopædia Britannica Online. 07 Apr. 2009 <http://www.britannica.com/EBchecked/topic/342021/line-of-sight-microwave-link>.

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Luminance: A measure of the luminous intensity per unit area of light traveling in a given direction. This differs from illuminance, which is the total luminance flux on a surface, per unit area. It is a description of the amount of light that passes through or emitted from a particular area, and falls within a particular solid angle (which is an angle in three-dimensional space that an object subtends at a point). It can be quantified in units of candela per square meter. The candela is the SI base unit for luminance, and it gets its name from the observation that the common candle emits light equivalent to one candela unit.

Luminance characterizes emission or reflection of light from flat, diffuse surfaces. As a result, luminance is an indicator of how much light power will be perceived by the eye or another sensor viewing the surface being illuminated from a particular angle of view (and thus an indication of how bright the particular surface will appear).

For an ideal optical system, the input luminance is equal to the output luminance (or, the image seen is equal in brightness to the surface itself), which makes luminance an invariant in geometric optical systems. But, for real systems, the output luminance is at the very most equal to the input luminance (the image is never actually as bright as or brighter than the source surface).

Luminance can be quantified in the following equation:

$$L_v = \frac{d^2F}{dA\,d\Omega\,\cos\theta}$$

Where:
L_v is the luminance (cd/m^2),
F is the luminous flux or luminous power (lm),
θ is the angle between the surface normal and the specified direction,
A is the area of the surface (m^2), and
Ω is the solid angle (sr).

References
Halstead, Charles P. "Brightness, Luminance, and Confusion." Information Display. Mar. 1993. <http://www.crompton.com/wa3dsp/light/lumin.html>.
Equations found using Wikipedia definition of “Luminance”
http://en.wikipedia.org/wiki/Luminance

M

MEO (Medium Earth Orbit): Between LEO and GEO

Examples: GPS satellites, Molniya (Russian) communications satellites[vii]

Altitude ranges from a few hundred miles to a few thousand with orbital periods from ~2 to 12 hours. Orbital eccentricity can be near 0 or nearly circular to highly elliptical. Communications with the satellites does not require as high a power nor as large an antenna as do satellites in higher orbits. The more elliptical orbits allow the satellite to travel slower when in apogee so this allows for prolonged periods in the same region of the 'sky' resulting in less antenna adjustment being required. [viii] Several satellites placed into the same orbital pattern will allow for one of them to be in apogee segment of the orbit almost continuously.

An elliptical orbit graphic[ix]

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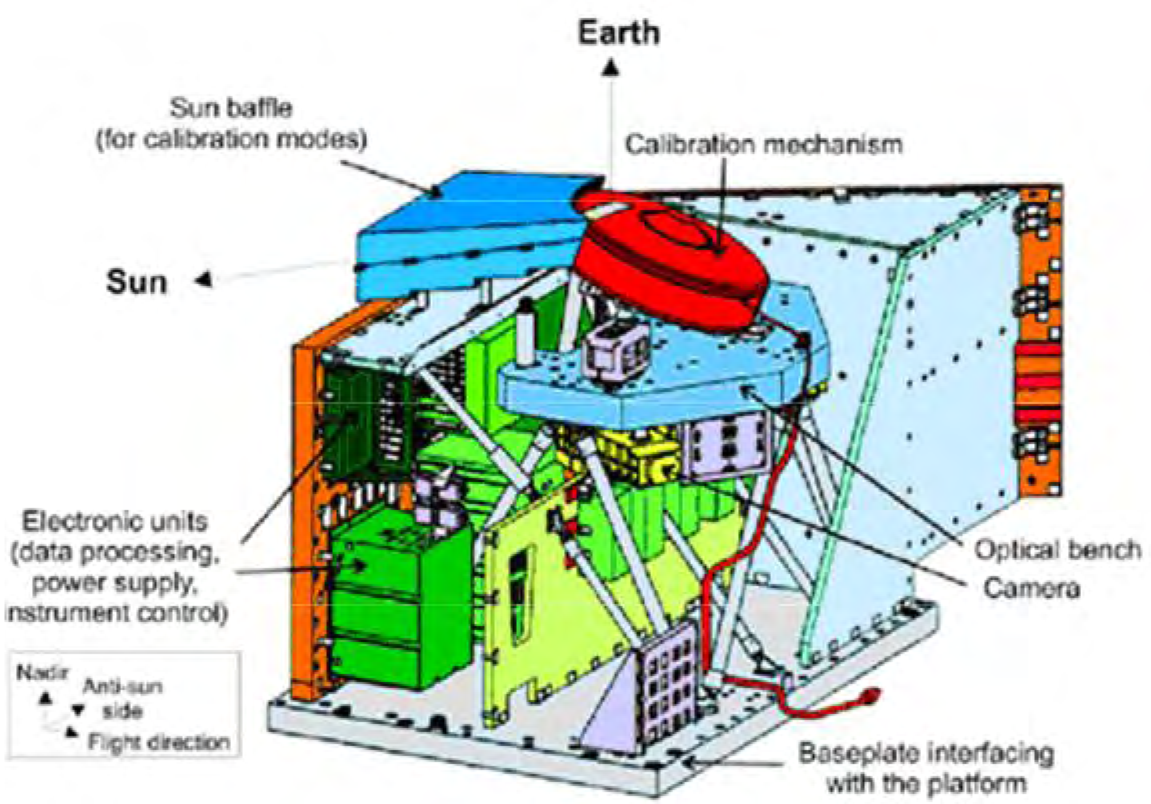
Medium Resolution Imaging Spectrometer – MERIS

MERIS is a medium-spectral resolution imaging spectrometer that operates over 15 spectral bands in visible and near IR. It is an instrument onboard the European Space Agency's environmental research satellite ENVISAT-1 which was launched in 2002. It was developed by France primarily for ocean observations but has other applications that will be outlined.

MERIS is a pushbroom system where linear 2D CCD arrays provide spatial sampling across track (0.26km at nadir and 0.39km at swath extremities). One dimension resolves ground pixels across flight direction. The other dimension resolves the incoming radiation into the 15 bands. The satellite's movement scans along track (~0.29km). It has 5 optical modules arranged in a fan shaped configuration. It takes about 3 days to cover the planet.

MERIS has a spectral coverage of 0.412-1.05 micrometers. Over a 1,150 km swathwidth, its full ground resolution is 300, operated on request for coast or land observations, while its reduced resolution is 1200m, used for open ocean observation. The instrument field of view: 68.5 degrees. The bandwidth is programmable between 0.0025-0.03 micrometers.



This figure shows the components of MERIS.
(Bezy et al., 2000, http://www.mumm.ac.be/Assets/OceanColour/Pages/MERIS_sensor.gif)

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Applications:
MERIS is capable of detecting low levels of radiation from the ocean but also has a high dynamic range that allows it to detect bright objects like clouds. There are 3 main mission objectives split into ocean, atmosphere and land:

> *Ocean*: monitoring chlorophyll, suspended matter, ocean color, pollution, coastal erosion and sea ice.
> *Atmosphere*: monitoring cloud distribution and altitude, aerosols, water vapor column content.
> *Land*: Monitoring vegetation, agriculture, inland waters, snow and ice distribution.

MERIS image showing dark green phytoplankton caused by upwelling along the west coast of Africa near Mauritania. MERIS can detect chlorophyll concentrations as low as 0.01 microgram, or 1/100 000 000 of a gram, per litre.
(European Space Agency, 2002 http://www.esa.int/esaEO/ESACGIF18ZC_index_1.html)

The channels used for such data acquisition are shown in the table below. MERIS has great potential as an ice sheet research tool because it can provide more detail on ice sheet characteristics than was previously possible using poorer resolution sensors.

Channel	Centre Wavelength ± Bandwidth (nm)	Application
1	412.5 ± 10	Yellow substance and detrial pigments

2	442.5 ± 10	Chlorophyll absorption maximum
3	490 ± 10	Chloropyll and other pigments
4	510 ± 10	Suspended sediment, red tides
5	560 ± 10	Chlorophyll absorption minimum
6	620± 10	Suspended sediment
7	665± 10	Chlorophyll absorption and fluorescence reference
8	681.25 ± 7.5	Chlorophyll fluorescence peak
9	708.75 ± 10	Fluorescence reference, atmospheric corrections
10	753.75 ± 7.5	Vegetation, cloud
11	760.625 ± 3.75	Oxygen absorption R-branch
12	778.75 ± 15	Atmosphere corrections
13	865 ± 20	Vegetation, water vapour reference
14	885 ± 10	Atmosphere corrections
15	900 ± 10	Water vapour, land

Table 1: Specification of the 15 MERIS channels recommended by the Science Advisory Group. (http://wdc.dlr.de/sensors/meris/)

References:
Bézy J.-L., S. D. and M. Rast, *MERIS - A new generation of ocean colour sensor onboard Envisat*. ESA bulletin 103: 48-56, 2000.
European Space Agency, *ESA Earthnet: The Medium Resolution Imaging Spectrometer Instrument*, http://envisat.esa.int/instruments/meris/
Massom, R., and Lubin, D., *Polar Remote Sensing Volume II: Ice Sheets*, Springer-Praxis, Chichester, UK, 2006.
MUMM-BMM-UGMM Optical Remote Sensing Research and Application, *MERIS, http://www.mumm.ac.be/OceanColour/Sensors/meris.php*
The World Data Center for Remote Sensing of the Atmosphere, *MERIS*, http://wdc.dlr.de/sensors/meris/

Micropulse Lidar Network
Micropulse Lidar Network (MPLNET) is a NASA network of Micro-Pulse Lidar systems used to measure cloud and aerosol structure at various heights in the atmosphere. It was originally developed by NASA Goddard Space Flight Center in the early 1990's.

Observations taken continuously by firing a short pulse of 523 or 527nm laser light and measuring signal return time provide information about aerosol and cloud property changes throughout time (Belcher, 2007). MPLNET provides information about clouds and aerosols taken from the ground in order to validate cloud and aerosol data from satellites. Examples of satellites that use MPLNET for validation include GLAS, MISR, TOMS, and space-based LIDARS on ICESat and CALIPSO (Belcher, 2007). Field missions also use MPLNET data to aide in their scientific endeavors. ICEALOT, the International Chemistry Experiment in the Arctic Lower Troposphere, occurred in the North Atlantic and Arctic from March through May 2008. The ICEALOT mission used MPLNET data to gather continuous cloud and aerosol information.
MPLNET sites are generally co-located with AERONET sites to provide aerosol and cloud information at various atmospheric layers. Aerosol and cloud information allow for the calculation or measurement of optical depth, single scatter albedo, size distribution, aerosol and cloud heights, planetary boundary layer structure, and radiative profiles (Belcher, 2007). AERONET sites have been coordinated with MPLNET sites at Cart_Site, GSFC, Dunhuang, Skukuza, CRYSTAL_FACE, SERC, NCU_Taiwan, Roosevelt_Roads, Mongu, Abracos_Hill, and Monterey. All MPLNET data followed the structure of AERONET data and is in netCDF format.

Figure 1 illustrates the locations of MPLNET sites across the world from 2000 to 2009. This image is provided courtesy of Goddard Space Flight Center. http://mplnet.gsfc.nasa.gov/data.html

Specifying a site provides in depth information about the data collected at each site. Longitude, latitude, and elevation are provided for each site. A shortcut is provided to browse desired archived data. A vertical backscatter visual with respect to time is provided as well as plots for layer heights and classification, aerosol properties, cloud properties, and polar stratospheric cloud properties. Options to create plots with Level 1, Level 1.5, Level 2, and Level 3 data are present at each site (however not all sites has data available at each level). Level 1 data is real time data; level 2 data is quality assured, but not real time; level 3 is reprocessed data (Belcher 2007). Level 1.5a includes MPL Calibration Values, Aerosol Vertical Structure, Layer Averaged Aerosol Extinction-to Backscatter Ratio, Aerosol backscatter, extinction, and optical depth profiles, and Cirrus Flag (Belcher, 2007). Level 1.5b includes Planetary Boundary Layer heights, cloud base and top heights and multiple layers, highest aerosol layer height, and Vertical Feature Mask. Skew-Ts are also provided as well as GOES aerosol information.

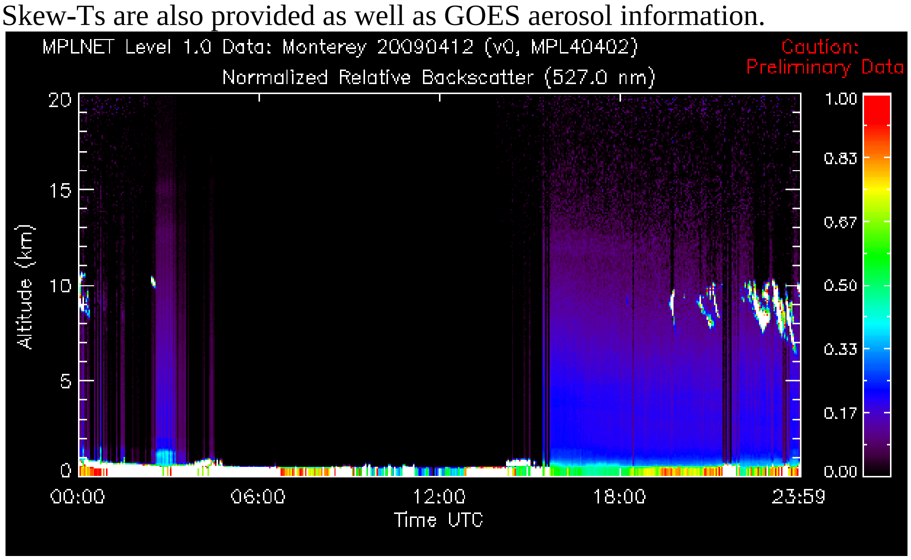

Figure 2 illustrates the normalized relative backscatter with altitude over the time period of one day at Monterey, CA. The intensity of the backscattered in indicated with a color bar (red is highest reflectivity). http://mplnet.gsfc.nasa.gov/data.html

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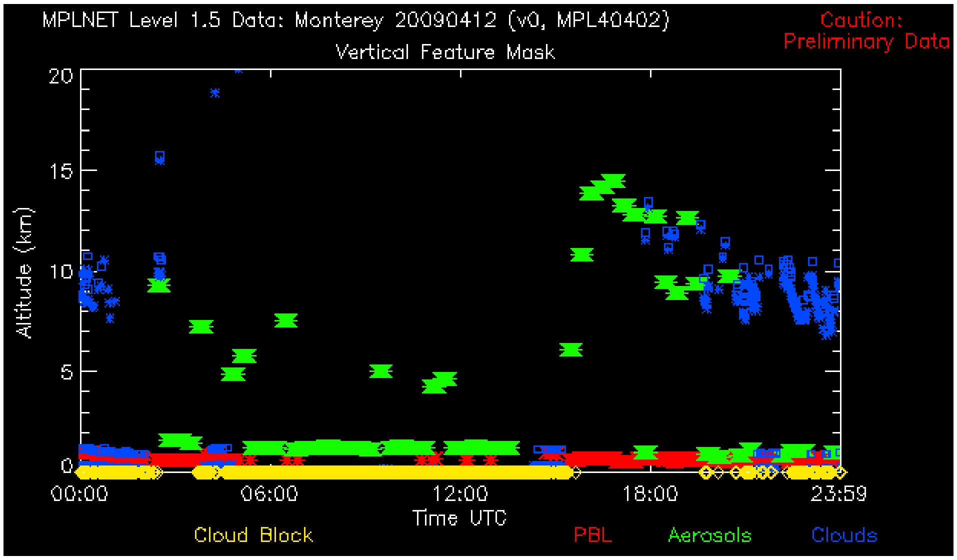

Figure 3 is a level 1.5 cloud heights and classification plot for Monterey, CA on April 12, 2009. http://mplnet.gsfc.nasa.gov/data.html

References

Belcher, Larry. "MPLNET- NASA Goddard Space Flight Center". 2007. http://mplnet.gsfc.nasa.gov/

Mars Orbiter Camera (MOC)

The Mars Orbiter Camera falls in the category of visible/infrared imaging sensors. It was launched in November 1996 on the Mars Global Surveyor (MGS) spacecraft which reached Mars in September 1997. The mapping orbit of the spacecraft is at altitudes at periapsis and apoapsis of 370km and 435km and a period of 117 minutes. It scanned the planet in 2.5km wide strips and sent back more than 240,000 images. It ceased operation in November 2006.

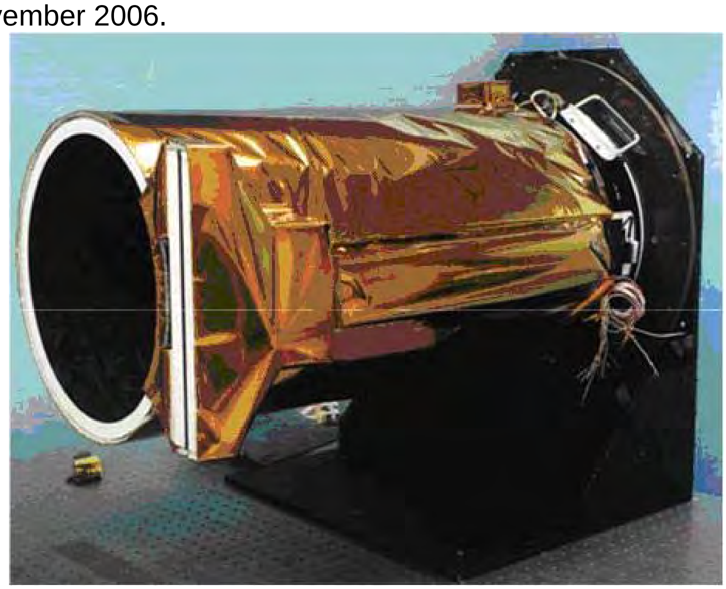

Photo from Malin Space Science Systems (www.msss.com/mgs/moc)

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General statistics:

Pushbroom system with 3 components:

-wide angle (140 degree) camera for selective moderate resolution images (280m/pixel) in blue and red

-narrow angle (0.4 degree) camera for very selective high resolution images (1.4m/pixel)-standard global coverage (7.5km/pixel)

12 MB buffer used to store images between acquisition and transmission to Earth

Mass: 23.6 kg

Power consumption: 6.7W standby; 18.7 during acquisition

Narrow-angle camera statistics:

Optics:35cm aperture

Telescope: f/10 Ritchie-Cretien telescope

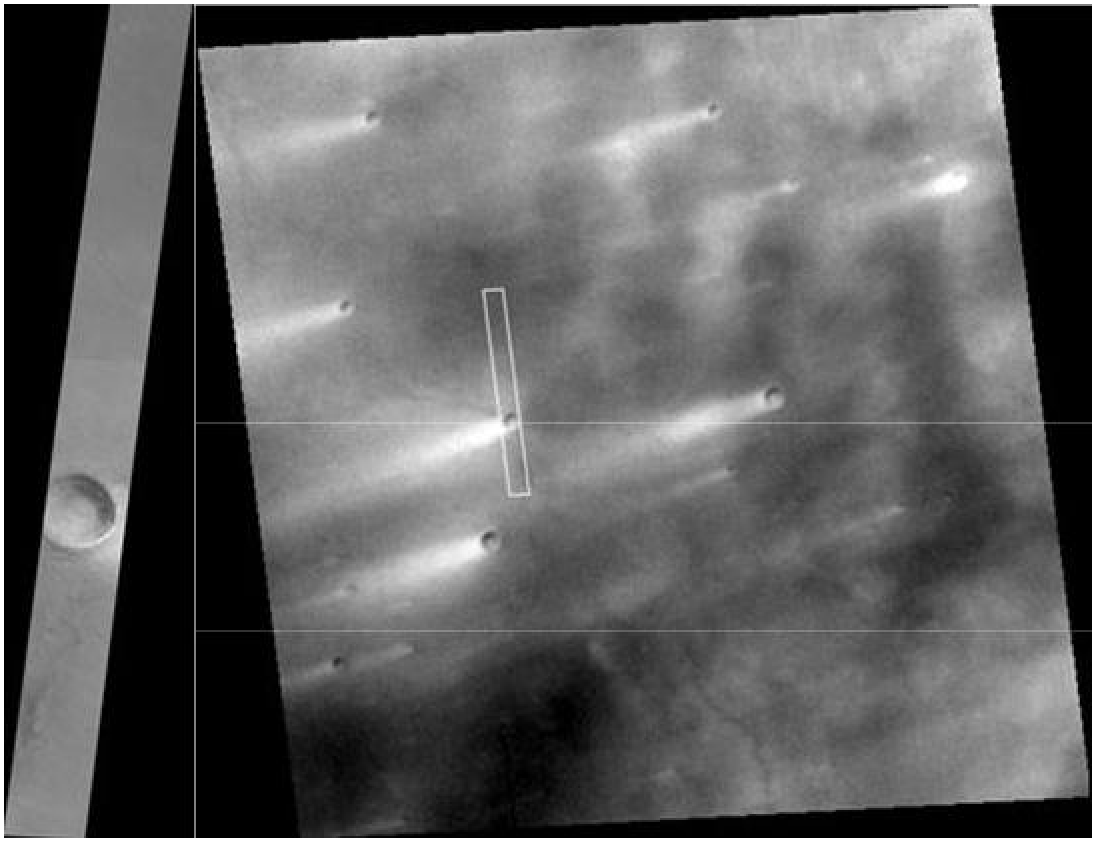
2048 element CCD detector array

Passband: 0.5 to 0.9 micros

Maximum resolution: 1.3 meters per pixel on the surface

Exposure time: 0.44 milliseconds at spacecraft ground track velocity of 3km/s

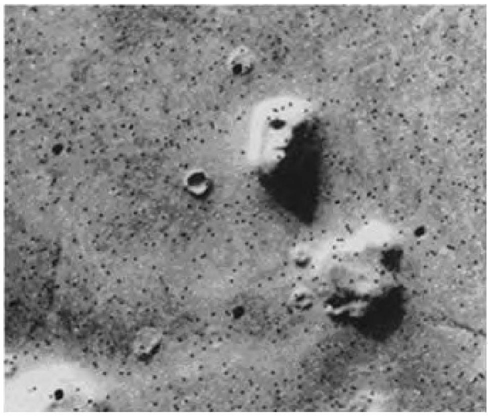
MOC image of Crater with bright streak in Syrtis Major



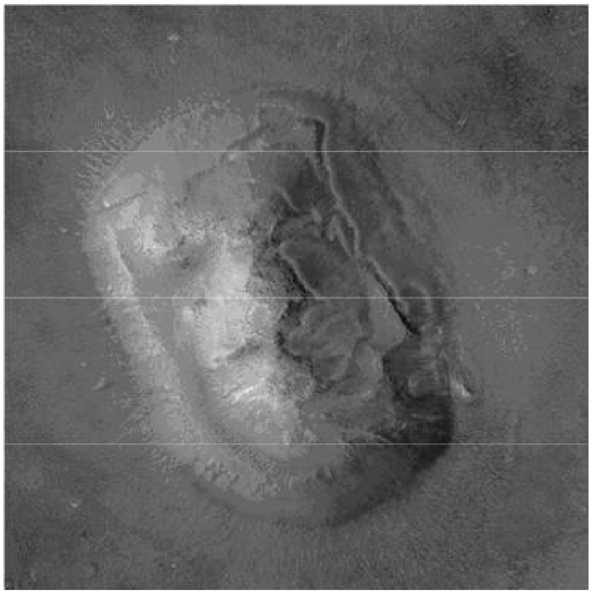
Left: MOC narrow-angle image M23-02058
Right: MOC red wide-angle context image M23-02059
Photos from Malin Space Science gallery (http://www.msss.com/moc_gallery)

One of the more intriguing aspects of Mars examined by the MOC was the 'Face on Mars'. In 1976, Viking 1 sent a photograph of what we now believe is a butte/mesa in the

Martian region of Cydonia which looked like a huge face. This 'face' became a focus of pop culture and pop science and the subject of alien and conspiracy theories. On April 5th, 1998, the MOC was flown over Cydonia and photos 10 times sharper than the original Viking image were sent back to Earth. They revealed a natural landform. On April 8th, 2001, the MOC took a second look and verified the formation was natural. This showed the power of resolution – the MOC photos were 1.56 meters/pixel, while Viking's were 43 meters/pixel. The ability to point spacecraft at specific features was also demonstrated.



1976 Viking Photo
Photo from http://www.msss.com/mars_images/moc/extended_may2001/face/1976pio.html



April 2001 MOC image E03-00824
Photo from http://www.msss.com/mars_images/moc/extended_may2001/face/index.html

References:
Malin Space Science Systems, www.msss.com/mgs/moc
NASA, *Nasa Captures New Images of the Face on Mars,* May 24th 2001, http://science.nasa.gov/headlines/y2001/ast24may_1.htm
Charles Elachia and Jakob van Zyl, *Introduction to the Physica and Techniques of Remote Sensing,* 2006, John Wiley and Sons, Inc, New Jersey.

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MLS:
The Microwave Limb Sounder (MLS) experiments measure naturally-occurring microwave thermal emission from the limb (edge) of Earth's atmosphere to remotely sense vertical profiles of atmospheric gases, temperature, pressure, and cloud ice. The overall objective of these experiments is to provide information that will help improve our understanding of Earth's atmosphere and global change.
The first MLS experiment in space (UARS MLS) was on NASA's Upper Atmosphere Research Satellite (UARS) launched 12 Sept 1991. After March 1994, the UARS MLS measurements became increasingly intermittent due to conserving satellite power and the MLS scan mechanism lifetime. The last data were obtained on 25 August 2001 (for more information go to UARS MLS data).
The second (EOS MLS) is on the NASA Earth Observing System (EOS) Aura mission launched 15 July 2004. EOS MLS began full-up atmospheric science observations on 13 August 2004, with excellent performance to date in all portions of the instrument. Data are now publicly available (for information go to EOS MLS data).
The scientific priorities and objectives of the MLS investigation are to improve understanding of the following processes and parameters vital to global change research and environmental policy:

Chemistry of the lower stratosphere and upper troposphere — MLS measures lower stratospheric temperature and concentrations of H2O, O3, ClO, BrO, HCl, OH, HO2, HNO3, HCN, and N2O, for their effects on (and diagnoses of) ozone depletion, transformations of greenhouse gases, and radiative forcing of climate change. These measurements will be especially valuable for diagnosing the potential for severe loss of Arctic ozone during the critical period following the turn of the century when an abundance of stratospheric chlorine will still be high, and slight cooling of the stratosphere could exacerbate ozone loss due to chlorine chemistry. The measurements will help determine whether the stratosphere is responding as expected to the effects of the Montreal Protocol agreements for phasing out ozone-depleting substances. MLS also measures upper tropospheric H2O, O3, CO, and HCN for their effects on radiative forcing of climate change and for diagnoses of exchange between the troposphere and stratosphere.

Chemistry of the middle and upper stratosphere — MLS observes the details of ozone chemistry by measuring many radicals, reservoirs, and source gases in chemical cycles which destroy ozone. This set of measurements will provide stringent tests on the understanding of global stratospheric chemistry, will help explain observed trends in ozone, and can provide early warnings of any changes in the chemistry of this region.

Water in the upper troposphere— the Upper Atmosphere Research Satellite

(UARS) has demonstrated the MLS capability of measuring upper tropospheric water vapor profiles, knowledge of which is essential for understanding climate variability and global warming but which previously has been extremely difficult to observe reliably on a global scale. MLS is unique in its ability to provide these measurements in the presence of tropical cirrus, where important processes affecting climate variability occur. MLS also provides unique measurements of cirrus ice content. The simultaneous MLS measurements of upper tropospheric water vapor, ice content, and temperature, under all conditions and with good vertical resolution, will be of great value for improving our understanding of processes (such as El Niño) affecting the distribution of atmospheric water, climate variability, and tropospheric-stratospheric exchange. The simultaneous measurements of dynamic tracers CO and N2O enhance the value of this data set by helping identify source regions of the air masses being observed.

http://mls.jpl.nasa.gov/
http://en.wikipedia.org/
http://www.nasa.gov/

MODIS

Definition: MODIS[1] (Moderate Resolution Imaging Spectroradiometer) is an instrument currently aboard two satellites, Terra (launched 1999) and Aqua (launched 2002). MODIS is a multispectral measurement device with 36 bands ranging from 405nm to 14.385µm. It has imaging resolutions ranging from 250 meters to 1 km with a cross-track swath dimension of 2330 km, allowing a very large field of view. MODIS produces daily data products such as ocean chlorophyll, aerosol product, vegetation, and cloud activity.

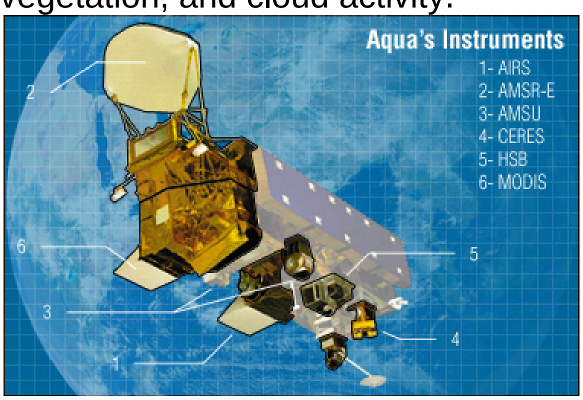

Figure 10: The Aqua satellite, carrying the MODIS instrument[2].

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Figure 11: MODIS image of the day (April 27, 2009), comprised of three bands in the optical wavelength range (corresponding to red, green, and blue). This image illustrates the sediment in the Gulf of Mexico[1].

References

[1] http://modis.gsfc.nasa.gov/
[2] http://aqua.nasa.gov/

Multispectral Scanner: A multispectral scanner is a remote sensing platform with the ability to scan in several wavelengths simultaneously[1]. In doing so, multiple images of a singular location can be achieved at the same time. In addition, specific traits of certain areas can be isolated for analysis. For example, in figure 1, an image of Karshi, Uzbekistan is presented using Landsat 7.

Figure 1 – Karshi, Uzbekistan, as seen using Landsat 7. This image is a combination of EMI bands 1, 2, and 3, which are used to isolate agricultural fields (brown and green) and urban environments (white). Image from NASA[2].

Using specific bands (in this case 1, 2, and 3), specific features such as urban environments and agricultural regions can be isolated using coloration. This is one of the key traits of multispectral sampling; i.e. one can isolate specific areas of study using multiple bands. Multispectral scanning was first introduced with Landsat, and this satellite system is still the primary multispectral scanner in space.

Multispectral scanners such as Landsat 7 allow for the detection of vegetation changes, land uses, and fires, such as in figure 2.

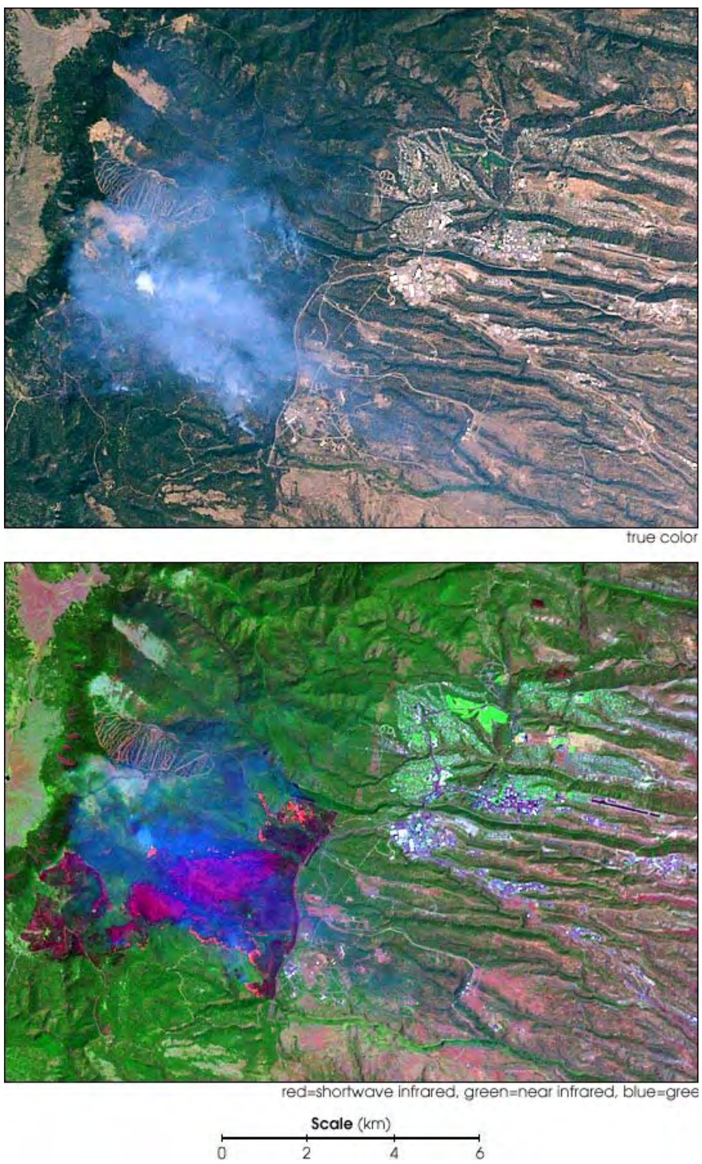

Figure 2 – Landsat 7 images of fires near Los Alamos. The upper image is a visible satellite image, while the bottom image is a conglomerate of visible imagery along with infrared imagery highlighted in red and green. This allows the user to pinpoint the location of fires. Image from NASA[3].

1. "Technical Details." The Landsat Program. 17 Apr. 2009 <http://landsat.gsfc.nasa.gov/about/mss.html>.

2. "Images." The Landsat Program. 17 Apr. 2009 <http://landsat.gsfc.nasa.gov/images/archive/c0015.html>.

3. "Visible Earth: Los Alamos Fires From Landsat 7." Visible Earth: Home. 17 Apr. 2009 <http://visibleearth.nasa.gov/view_rec.php?id=15421>.

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N

Nadir
Nadir is the direction pointing below a location; the direction opposite the nadir is referred to as zenith. The nadir is the local vertical direction that points towards the force of gravity at a particular location. These general definitions are applied to remote sensing principles; nadir is the downward viewing angle of a satellite. If a satellite is not looking directly downward, the satellite is then experiencing limb viewing angles (as illustrated in Figure1).

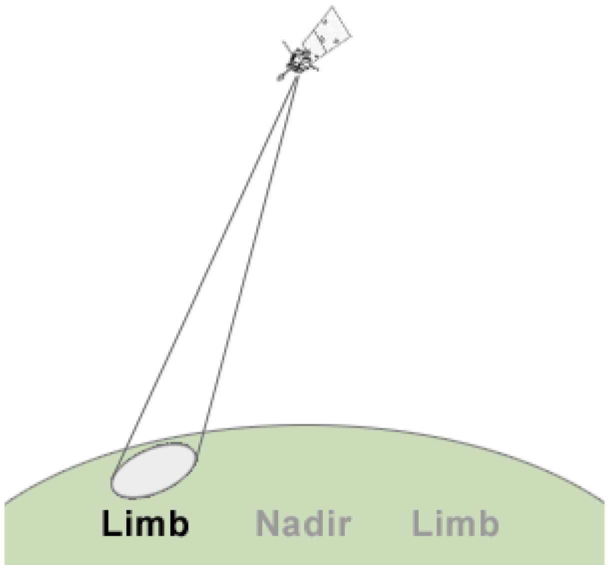

Figure 1 represents the nadir and limb viewing angles of a satellite. The nadir angle is directly below the satellite, while the limb angles are not directly below the satellite but rather offset to both sides.

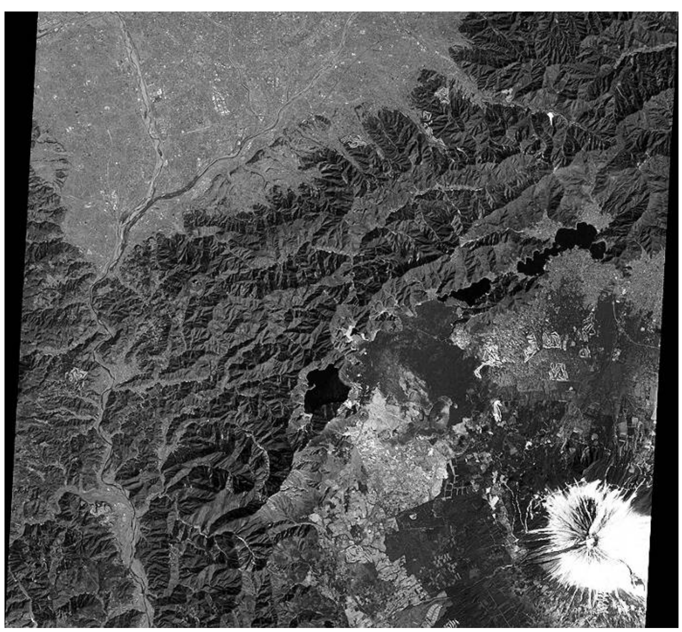

Figure 2 is a nadir image of Mt. Fuji observed by the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) on ALOS satellite “Daichi” on February 14, 2006.

References
Wikipedia. “Nadir”. 2009. http://en.wikipedia.org/wiki/Nadir
Japan Aerospace Exploration Agency. “ALOS Daichi Satellite”. 2006.
http://images.google.com/imgres?imgurl=http://old.mfb geo.com/pic/pic_news/20060215_alos-prism_fuji-nadir.jpg
Jasmin, Tommy. “Remote Sensors and Data Collection”.
http://www.ssec.wisc.edu/sose/pirs/pirs_m2_footprint.html

Near Infrared (NIR): In reference to the infrared spectrum (0.7-350 µm), near infrared (NIR) refers to 0.7-5 µm range[1]. This range is the shortest wavelengths measured in the infrared before transitioning into the visible spectrum.

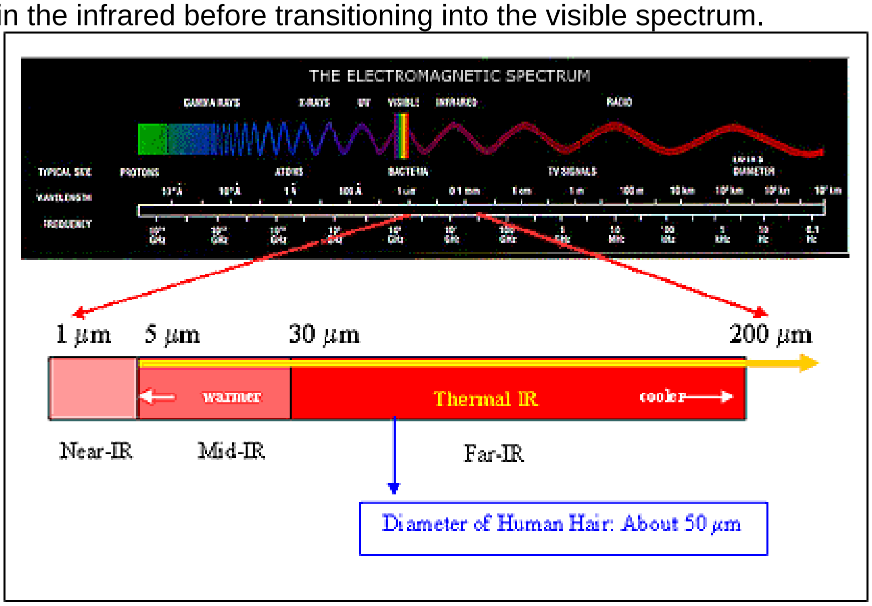

Figure 1 – Image of the electromagnetic spectrum, with a focus on the infrared range. Note that the near-IR range is closest to the visible range. Image source is NASA JPL[2].

One use of NIR in remote sensing is studying plant life. Given the structure of plant life, incoming radiation is strongly reflected in green (visible wavelength) from chlorophyll, and in the NIR from cell wall structure[3]. Utilizing this knowledge, the Normalized Difference Vegetation Index (NDVI) was developed to compare healthy vegetation to unhealthy vegetation and clear regions[4]. Changes in energy reflectance, as seen in figure 2, allow satellites to measure differences in vegetation within a region using NIR sensors.

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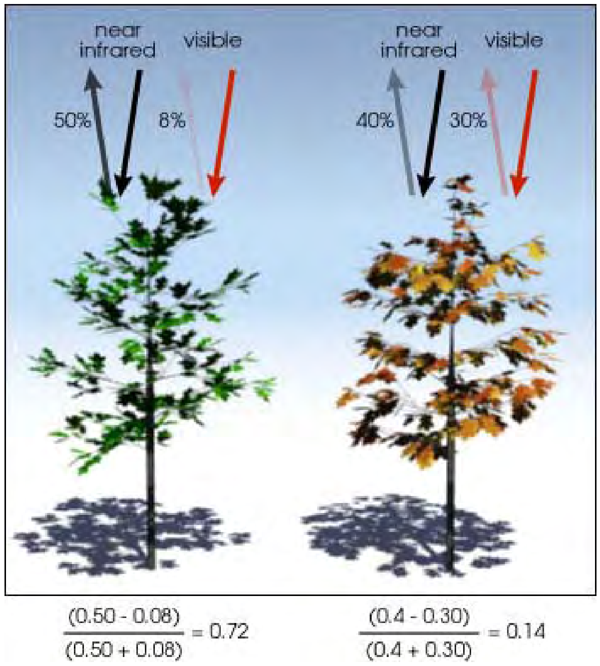


Figure 2 – Diagram showing the differences in reflected electromagnetic energy by vegetation health. Image is from the Department of Biology at Duke University[4].

1. "Near, Mid and Far-Infrared." Infrared Processing and Analysis Center. 12 Apr. 2009 <http://www.ipac.caltech.edu/Outreach/Edu/Regions/irregions.html>.

2. "Field Guide: What Is Infrared?" IPAC. 12 Apr. 2009 <http://ipac.jpl.nasa.gov/spitzersite_backup.20031218/Media/guides/ir.shtml>.

3. "The Electromagnetic Spectrum." The Soonet BBS. 12 Apr. 2009 <http://hosting.soonet.ca/eliris/remotesensing/bl130lec3.html>.

4. "NDVI: Brief Description and History." Duke Department of Biology. 12 Apr. 2009 <http://www.biology.duke.edu/bio265/jmu/BriefDescriptionandHistory.htm>.

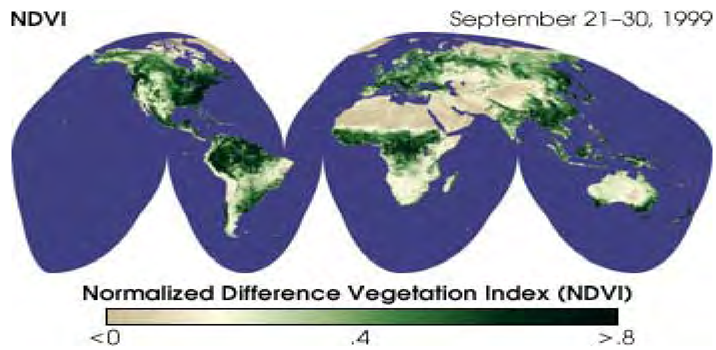
NDVI: The normalized difference vegetation index is the remote sensing way of measuring whether vegetation is alive or dead based on information from the visible (red) and near infrared bands. It is defined as:

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})}$$

Values can range from -1 to 1, where 0 indicates stress, dying, or no vegetation and 1 indicates healthy green, complete vegetation.

Values can be subdivided to evaluate more distinct classification. Very low values of NDVI (0.1 and below) correspond to barren areas of rock, sand, or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate temperate and tropical rainforests (0.6 to 0.8). (Source: NASA Earth Observatory).

Figure 1: An example satellite NDVI map to show the density of plant growth across the globe. Source: NASA Earth Observatory.



Why use different bands?
Vegetation appears differently in the thermal and infrared wavelengths. By comparing these two values, an average vegetation value can be devised. These wavelengths are determined by evaluating the leaf-cell structure. Pigments which affect the amount of reflected light are found in the visible spectrum. For example Chlorophyll-a (the green we see in plants) has a maximum absorption ~0.450 and 0.650 µm. On the other hand, red leaves or stressed vegetation have pigments called Anthocyanins which have absorption closer to the near infrared bands.

Additionally, the mesophyll segment of a leaf reflects at cell wall/air interfaces, causing strong reflectance in the near infrared part of the spectrum. Thus, by being able to see distinct differences of plants in two different bands allows for a better normalized calculation.

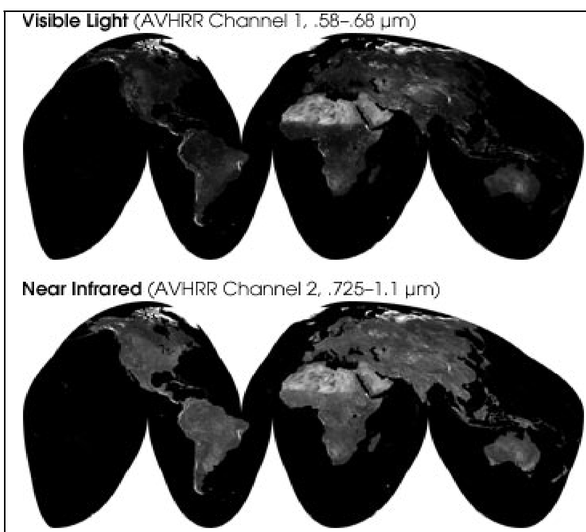


Figure 2: Difference in vegetated areas seen by different wavelengths. In visible light, vegetated areas are very dark, while desert regions are light. At near-infrared wavelengths, the vegetation is brighter and deserts are about the same.
Source: NASA

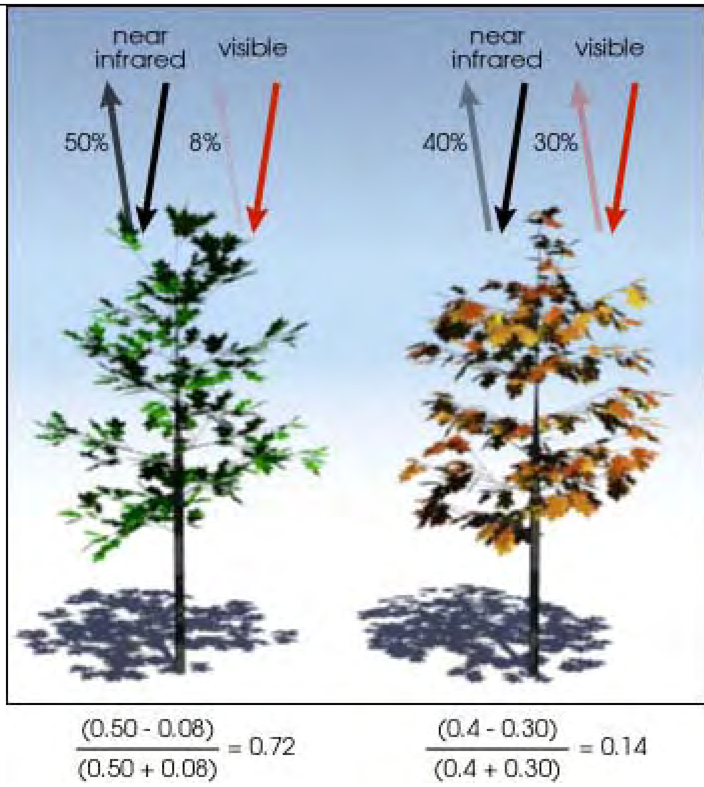


Figure 3:
Healthy vegetation absorbs most of the visible light that hits it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light.
Source: NASA Observatory

Applications:
NDVI has been found to be useful for continental or global scale vegetation monitoring because it can compensate for changing illumination conditions, surface slope, and viewing aspect. NDVI can be used to detect seasonal changes in green biomass, but can also be used to detect changes to human activities (logging) or natural disturbances such as wild fire.

NDVI does have some drawbacks. It is sensitive to a number of variables such as clouds, atmospheric composition (water vapor and aerosols) and soil moisture.

The most popular and used satellite instrument for collecting NDVI is NOAA's AVHRR satellite. It is sensitive to wavelengths from .55 to .7 um and .73-1 um, both of which are idealized in the NDVI calculation. AVHRR's detectors measure the intensity of light being reflected from the different bands.

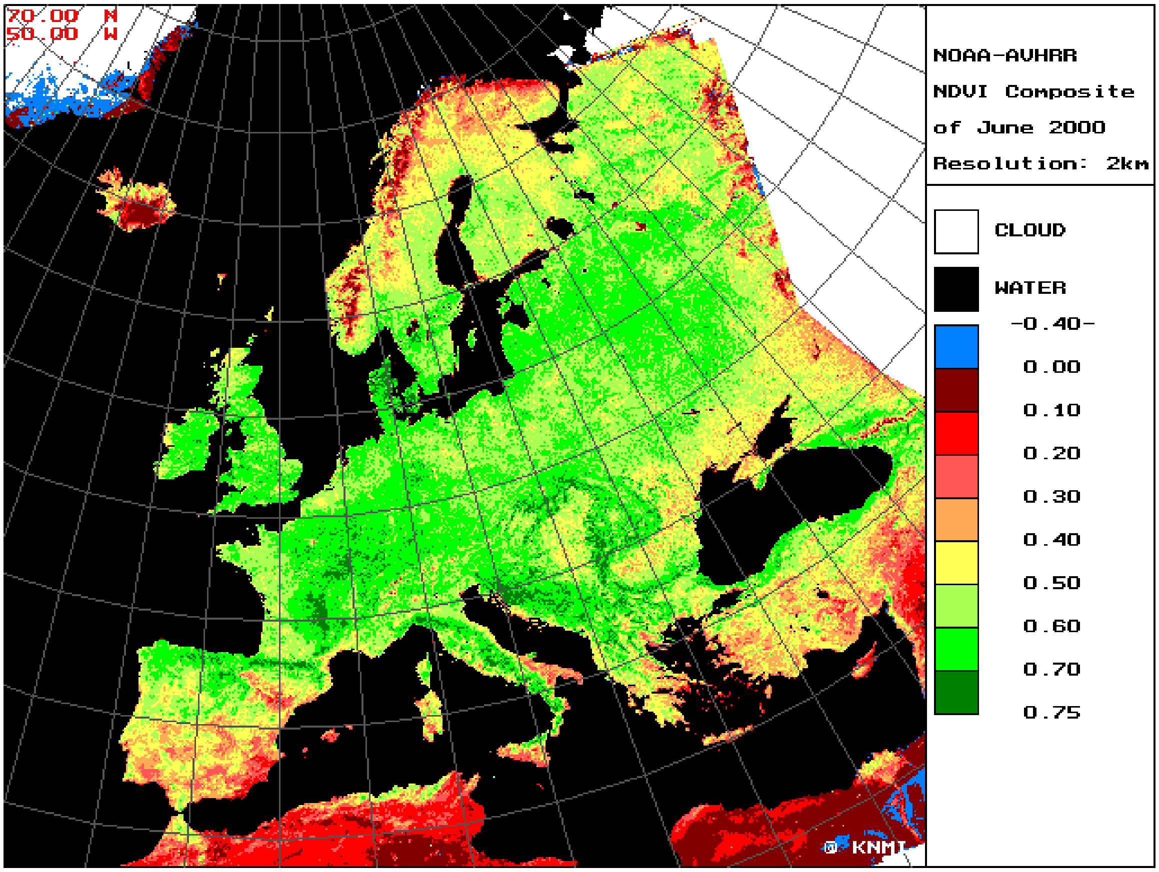


Figure 4: Example of NDVI from AVHRR of Europe in June 2000
Source: http://www.knmi.nl/onderzk/applied/sd/en/AVHRR_archive_KNMI.html

In general, if there is much more reflected radiation in near-infrared wavelengths than in visible wavelengths, then the vegetation in that pixel is likely to be “alive” and may contain some type of forest. If there is very little difference in the intensity of visible and near-infrared wavelengths reflected, then the vegetation is probably sparse and may consist of grassland, tundra, or desert.

The Landsat thematic mapper (LTM) is also used to calculate NDVI, but because its band wavelengths differ (uses bands 3 and 4), it is most often used to create images with greater detail covering less area. MODIS also has an NDVI system.

Sources:

Land Surface Characteristics. Accessed Feb 27, 2008.
http://www.calmit.unl.edu/storm/newpage31.htm

Chesapeake Bay and Mid-Atlantic from Space. “RS Principles”. Accessed Feb 27 2008.
http://chesapeake.towson.edu/data/all_ndvi.asp)

Normalized Burn Ratio (NBR): the most common remote sensing measure used to quantify wildfire burn severity across landscapes. The mid-infrared (MIR) and near-infrared (NIR) respond in different directions to increases in fire effects and therefore provide an opportunity to construct a unique measure of burn severity given by: NBR = (NIR – MIR) / (NIR + MIR). Landsat TM and ETM+ imagery are most often used when calculating NBR, where NIR corresponds to Band 4 (0.76µm - 0.90µm TM; 0.78µm – 0.90µm ETM+) and MIR to Band 7 (2.08 – 2.35 µm TM; 2.09 – 2.35 µm ETM+).

To better distinguish burned/unburned areas and classify burn severity, a bi-temporal approach (NBRpre – NBRpost) is frequently used to calculate a "differenced" NBR (dNBR). There are two different methods for calculating dNBR: the initial assessment method that uses a post-fire image from immediately after a fire and the extended assessment that uses an image from the following growing season. The dNBR index is thought to represent the magnitude of change where positive and higher numbers indicate increasing burn severity while lower negative numbers are interpreted as increased post-fire "greenness" compared to pre-fire vegetation conditions. Values are often scaled and range from -550 to +1350 in burned areas with values around zero interpreted as no change. To determine burn severity classes (e.g.—low, medium, high) and produce a thematic burn severity map, dNBR thresholds are created based on the ecological setting of the fire.

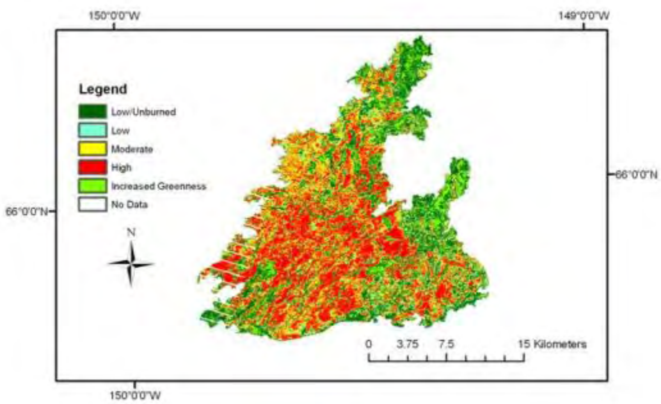


Figure **1**: Example classified dNBR burn severity map.
Source: MTBS (http://mtbs.gov)

<u>Sources</u>

Key, C. and N. Benson. 2006. FIREMON: Burn Severity Landscape Assessment.1-55.
Lopez-Garcia, M. and V. Caselles. 1991. Mapping burns and natural reforestation using Thematic Mapper data. Geocarto International 6:31-37.
Monitoring Trends in Burn Severity (MTBS) http://mtbs.gov
van Wagtendonk, J. W., R. R. Root, and C. H. Key. 2004. Comparison of AVIRIS and Landsat ETM+ detection capabilities for burn severity. Remote Sensing of Environment 92:397-408.
White, J. D., K. C. Ryan, C. C. Key, and S. W. Running. 1996. Remote sensing of forest fire severity and vegetation recovery. International Journal of Wildland Fire 6:125-136.

NDWI: The Normalized Difference Water Index (NDWI) (Gao, 1996) is a satellite-derived index from the Near-Infrared (NIR) and Short Wave Infrared (SWIR) channels that reflects changes in both the water content (absorpation of SWIR radiation) and spongy mesophyll in vegetaion canopies.

NDWI is expressed as

$$NDWI = \frac{(\rho_{NIR} - \rho_{SWIR})}{(\rho_{NIR} + \rho_{SWIR})}$$

Gao (1996) produced NDWI from MODIS (Moderate Resolution Image Spectroradiometer) sensor data. According to his findings, NDWI is a good indicator for vegetation liquid water and is less sensitive to atmospheric scattering effects than NDVI (Normalized Difference Vegetation Index). MODIS NDWI has been used to detect and monitor the moisture condition of vegetation canopies over large areas (e.g. Delbart et al. 2005) and tested as a drought indicator (Gu et al. 2008).

Reference:
http://edo.jrc.ec.europa.eu/
GAO B. C., NDWI : A normalized difference water index for remote sensing of vegetation liquid water from space, *Remote sensing of environment*, 1996, vol. 58, pp. 257-266

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O

Object-Oriented Classification: a new set of methods for identifying and classifying objects/features in a multispectral image using both spectral and spatial patterns. Instead of just classifying single pixels, object-oriented classification assumes that an image is made up of homogenous patches that are larger than single pixels. Most object-oriented methods include 2 basic steps: (1) the segmentation of an image into objects at a spatial level specified by the analyst and (2) the classification of the objects. The classification involves not only pixel spectral properties, but also object shapes and the relationship between objects. Thematic maps created by object-oriented methods are often smoother and cleaner than those produced by traditional supervised/unsupervised classification techniques.

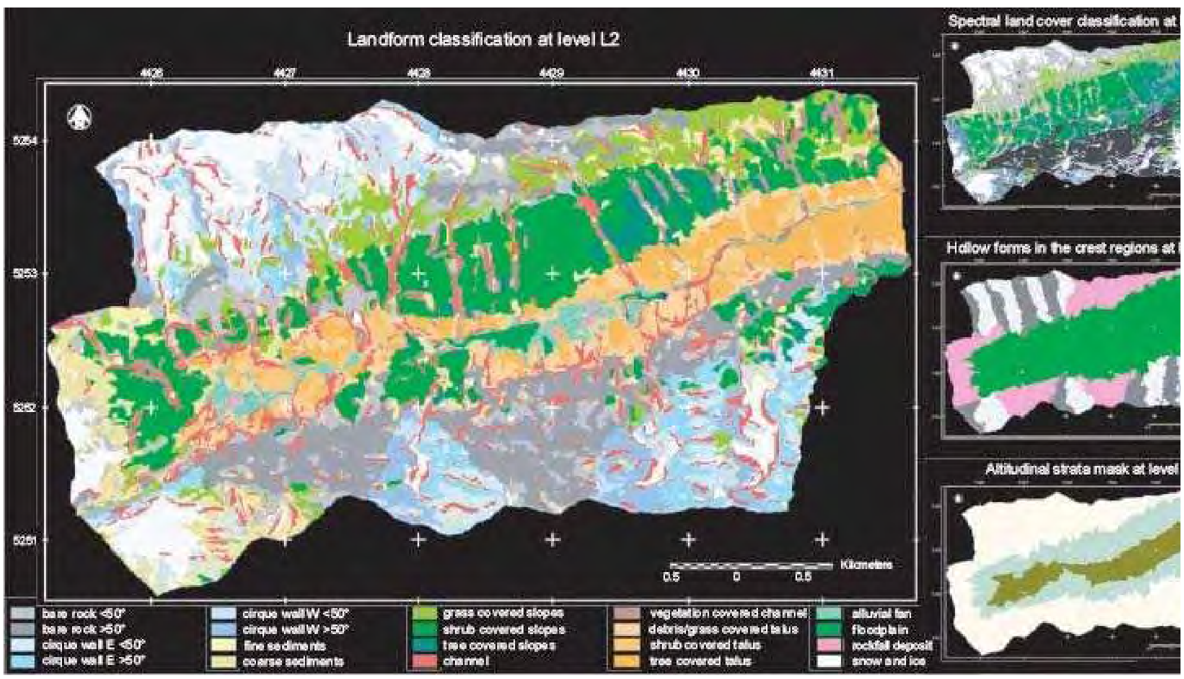


Figure 1: Example object-oriented classification of alpine landforms at 4 different spatial levels of object segmentation
Source: http://folk.uio.no/njs/Schneevoigt_proj.html

Sources
Lillesand, T., R. Kiefer, and J. Chipman. 2008. Remote Sensing and Image Interpretation. John Wiley & Sons Inc., Hoboken, NJ.
Object based alpine landform classification
http://folk.uio.no/njs/Schneevoigt_proj.html

Orbital Node

Definition: An orbital node is a point at which an object crosses a plane of reference[1]. Typically, nodes are used to describe when a satellite crosses the equator. The ascending node is when the satellite leaves the southern hemisphere and enters the northern hemisphere. The descending node is when the opposite occurs. The nodes are usually described by their earth longitudinal positions, and can vary at each orbit.

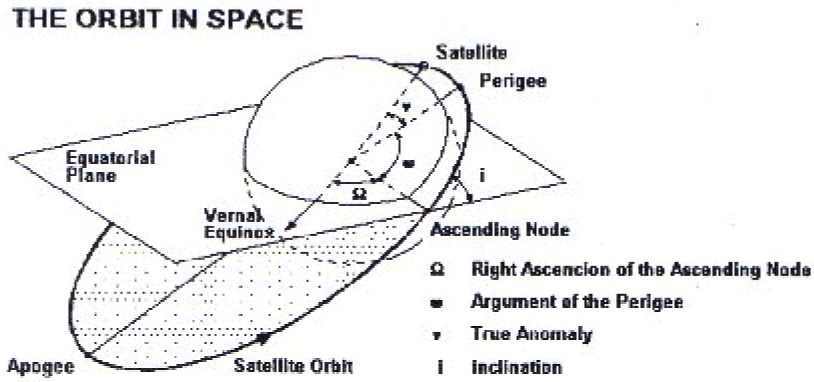


Figure 12: Illustration of the ascending node in a satellite orbit. The descending node occurs behind the planet[2].

References
[1] http://www2.jpl.nasa.gov/basics/bsf5-1.html
[2] http://www.satcom.co.uk/images/Presentations/rpcstl3s1b.gif

Orthorectification

Maria Zatko

Very high resolution satellite imagery is taking the place of tasks previously requiring aerial photography. However, the angles and scales of satellite images must be corrected to achieve accurately scaled and proportioned images. Geometrically adjusted satellite images account for sensor orientation, terrain relief, lens distortion, camera tilt, earth shape and rotation, sensor orbit and altitude variation, and sensor systematic error (Okeke, 2009). An image adjusted by an orthorectification model can be used to measure actual distances, angles, and areas because the scale of the adjusted image is uniform (Wikipedia, 2009). Image 1 illustrates the differences between an unprocessed image (right) and an orthorectified image (left).

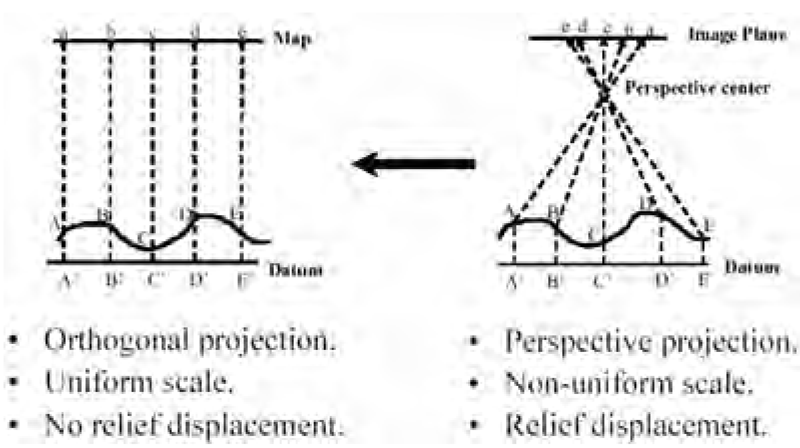


Image 1 courtesy of Dr. F.I Okeke of the Department of Geoinformatics and Surveying at the University of Nigeria. http://www.gisdevelopment.net/technology/ip/fio_1.htm.

To understand orthorectification, consider a nadir angle satellite looking at a flat scene. An off-nadir angle satellite looking at the flat scene will create a distorted longitude and latitude image of the scene. “Roll” is the term given to rotation along the y-axis; “pitch” is the term given to rotation along the x-axis; and “yaw” is the term given to rotation about the optical axis (Image Registration and Fusion Systems, 2009). Orthorectification accounts for the longitude and latitude distortion due to offsets in roll, pitch, and yaw (Image Registration and Fusion Systems, 2009). Orthorectification treats the image as if the roll, pitch, and yaw were all zero (Image Registration and Fusion Systems, 2009). Small distortions arise from the orthorectification image conversion; bridges and buildings may appear bent and distorted with orthorectification but can be corrected with proper models. Orthorectified images can be used for resource management, municipal planning, cadastral mapping, and geographic information systems (Okeke, 2009). Image 1 represents the flat scene as seen by a nadir-looking satellite. Image 2 represents the flat scene when the satellite experiences a 30º roll, 60º pitch, and 30º yaw. Image 3 is the orthorectification of Image 2.

Image 1

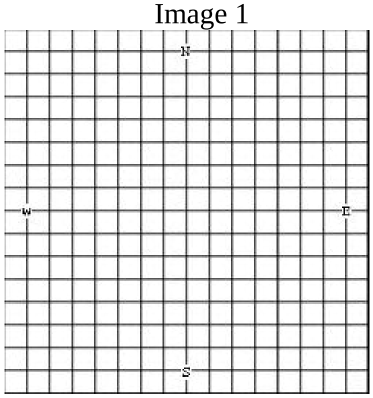


Image 2

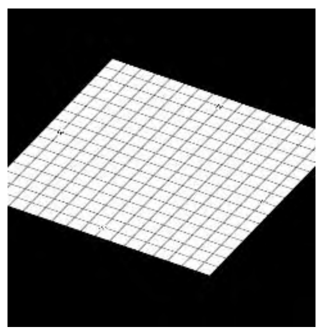
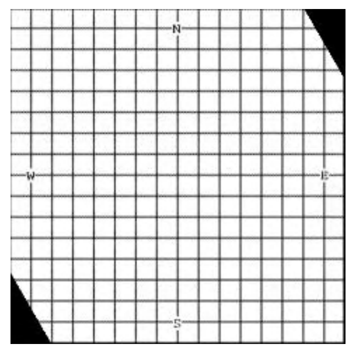


Image 3



There are two types of orthorectification approaches: parametric and non-parametric. In the parametric approach, interior and exterior parameters are required. In the non-parametric approach, only control-points are known. Many commercial software products contain orthorectification imagery techniques including Erdas Imagine, PCI Geomatics, ENVI, ZI Imagine, LH System, and TNT products (Okeke, 2009). These software products support imaging satellites including Landsat, SPOT, IRS, AVHRR, ASTER, Ikonos, and Quickbird. Automatic or semi-automatic orthorectification techniques are being developed by the EPA (Snonecker, 2005).

References:

Image Registration and Fusion Systems. 2009. http://www.imgfsr.com/ifsr_or.html.

Okeke, F.I. “Review of Digital Image Orthorectification Techniques”. GIS Development. 2009. http://www.gisdevelopment.net/technology/ip/fio_1.htm.

Slonecker, Terrence E. “Automatic Imagery Ortho-Rectification Pilot”. October, 2005. http://www.epa.gov/geoss/ami/ortho.html.

Wikipedia. “Orthophoto”. February, 2009. http://en.wikipedia.org/wiki/Orthophoto.

P

Path Radiance – Path Radiance is a measurement of intensity of the energy that falls within a specific solid angle and is measured in watts per meter squared per steradian from a specific direction or path in a remote sensing system.
See: R., Jensen, John. Remote sensing of the environment an earth resource perspective. Upper Saddle River, NJ: Pearson Prentice Hall, 2007.

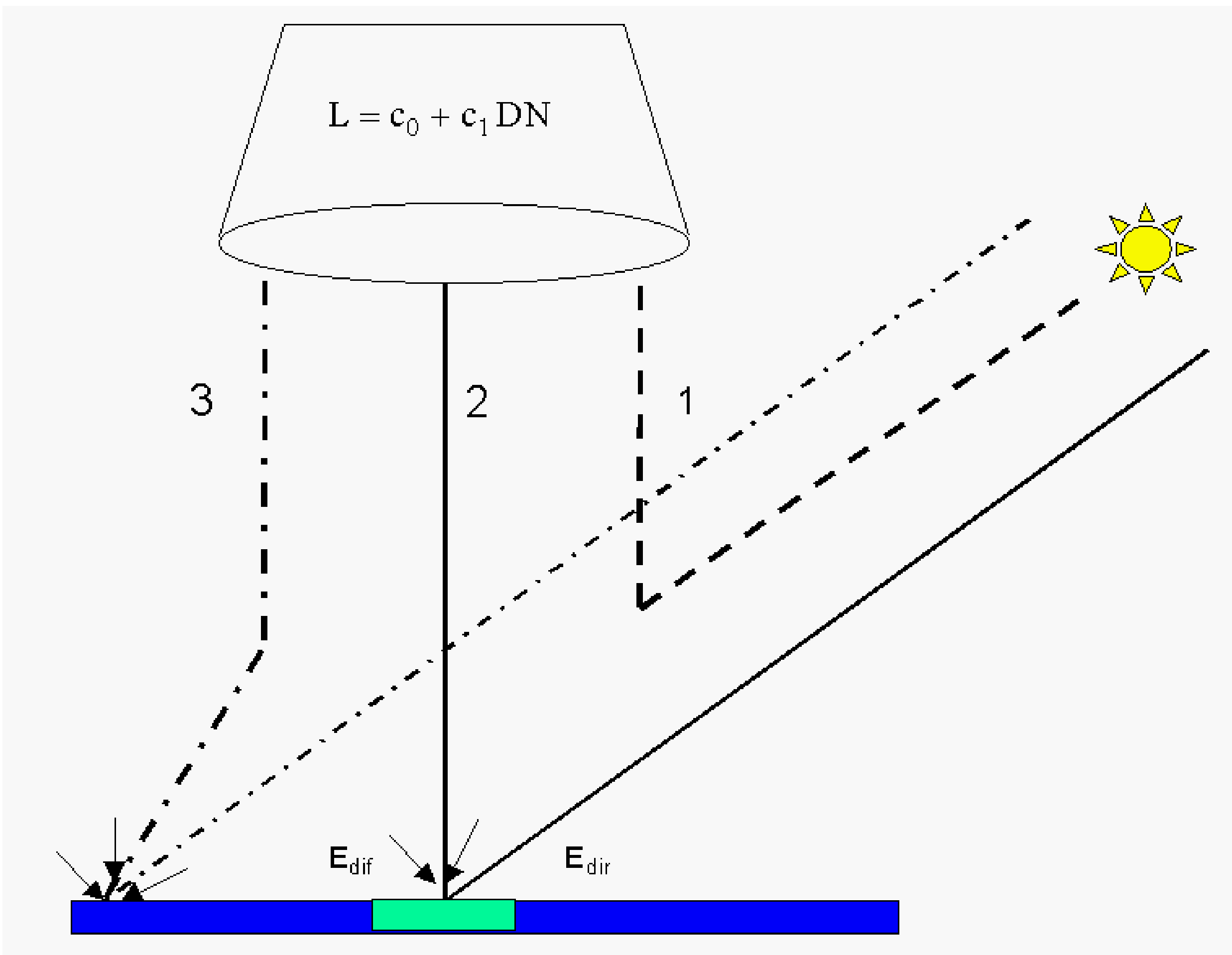


Figure 13: An Image showing three separate paths of radiance. From ReSe Applications, a spinoff from the University of Zurich. http://www.rese.ch/atcor/atcor3/img/atcor2_rad_comp.gif

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Photogrammetry: The first remote sensing technology ever developed (can be dated back to the mid-nineteenth century) that uses photographs in order to determine geometric properties of objects on the ground. This rudimentary version of remote sensing is practically as old as the art of photography. If the scale of the photograph being examined is known, the distance between two points which lay on a surface parallel to the photographic image plane can be determined by measuring their distance on the image.

The fundamental principle used in photogrammetry is triangulation, which is the process of determining the location of a point by measuring angles from known points based on either end of a fixed baseline, rather than measuring the distances between the points directly. The intersection of these known points is what determines the three-dimensional location of a point.

With 3-D image referencing in photographs and LIDAR technologies, photogrammetry has become an obsolete technology. However, it is still important to understand the basis of photogrammetry in the fields of optics and projective geometry.

Figure 1: This shows a simple representation of how images are collected from an airplane collecting image data. It shows GPS capabilities in the x, y, and z directions as well as the functions of the laser scanner that collects photo data (University of Cape Town Department of Geomatics).

References:
"The Basics of Photogrammetry." Photogrammetry. 2007. Geodetic Services, Inc. <http://www.geodetic.com/Whatis.htm>.

Photometer

A photometer is an instrument used to measure light intensity in the visible range of the electromagnetic spectrum. There are two types of photometers, as follows: laboratory photometers and portable photometers. Laboratory photometers have a fixed position which allows for high accuracy. Alternatively, portable photometers are mobile – often used in field studies – and consequently have less accuracy.

Objects further from the source emit radiation such that the illuminance is less than if the object were close to the source. Illuminance decreases proportionally to the inverse of distance squared. Photometers use this concept to measure the relative intensity of light emitted from a source.

The instrument operates by converting an electric current into a mechanical indication. Often the source of the current is a selenium cell. This type of photometer is called a photoelectric photometer. Since the instrument generates its own current when there is incident light, this type of photometer may be used either as a laboratory photometer or a portable photometer.

Quite simply, a photoelectric photometer is composed of an iron plate. The plate is often circular and coated with a layer of selenium and gold or platinum. A highly conductive metal film is applied to the outer edge of the plate. Attached to this terminal is a microammeter or galvanometer, which induces a current through the device once light reaches the selenium layer (Figure 1).

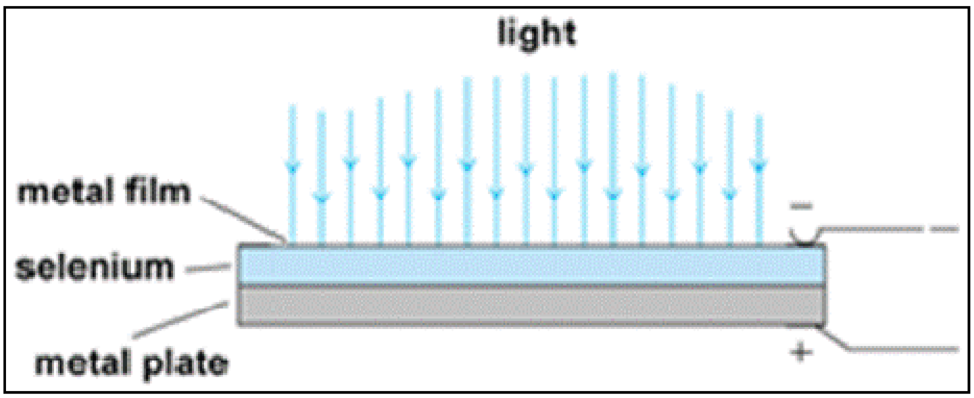

Fig. 1: Schematic of the barrier-layer photocell of a photoelectric photometer

Photometers are used in a wide variety of applications. In photography, photometers help photographers measure glare and color variations from the light source. Another practical application of photometers is used in the paint industry to objectively characterize the color of paint. Other devices which utilize photometers are spectrographs, telescopes, and densitometers. Visual photometers, though used in laboratories to demonstrate photometric principles, have often been replaced by more advanced physical methods in recent years.

G. A. Horton, "Photometer", in AccessScience@McGraw-Hill, http://www.accessscience.com, DOI 10.1036/1097-8542.510800

"Photometer." Encyclopædia Britannica. 2009. Encyclopædia Britannica Online. 05 Apr. 2009 <http://www.britannica.com/EBchecked/topic/458005/photometer>.

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Planck's law: The spectral radiance of electromagnetic radiation at each wavelength from a blackbody at a temperature indicated by *T*. The law can be defined as a function of frequency *v* using the following equation:

$$I(\nu,T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}}-1}.$$

Where:
I is the spectral radiance of the surface;
v is the frequency (Hz);
T is the temperature of the blackbody (K);
h is the Planck constant, which is 6.626068 × 10^{-34} m^2 kg / s (joules per second);
c is the speed of light (m/s);
e is the base of the natural logarithm; and
k is the Boltzmann constant, which is 1.3806503 × 10^{-23} m^2 kg s^{-2} K^{-1} (joules per Kelvin).
This is a definition of the amount of emitted power per unit area of emittance surface, per unit solid angle, and per unit frequency. Planck's law can also be written as a function of wavelength λ:

$$I'(\lambda,T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda kT}}-1}.$$

Where *I'* is the equivalent of *I* in the equation for Planck's law as function of frequency. The German physicist Max Planck introduced this law in 1900 as a mechanism for improving on the Wien approximation, which describes the short wavelength/high frequency spectrum of thermal emission from objects. Planck found that his function was capable of describing thermal emission from objects at both short and long wavelengths. Planck considered the possible ways of distributing electromagnetic energy over the different modes of charged oscillators in matter when building the derivation of the law. The law was further developed and publicized once Planck assumed that the energy of these oscillators was limited to a set of integer multiples of a fundamental unit of energy, *E*, proportional to the frequency of oscillation: $E = h\nu$. Planck's law is only applicable for surfaces that are producing many photons capable of being measured in the visible spectrum. Ribaric and Sustersic (2008) provide a decent example of this principle: a black body at room temperature (roughly 300 K) with one square meter of surface area will emit a photon in the visible range once about every thousand years or so, meaning that for most practical purposes, a black body at room temperature does not emit in the visible range.

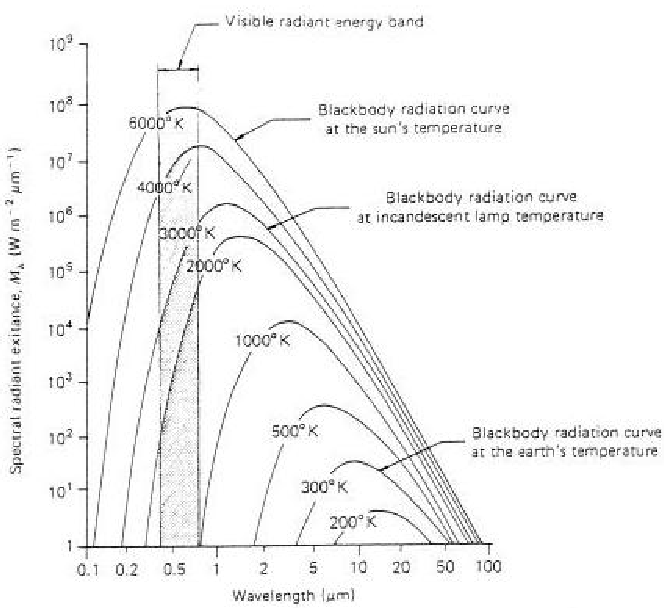

Figure 1:

This graph shows the relationship between the spectral distribution of energy radiated from blackbodies of various temperatures (Bamber 2007).

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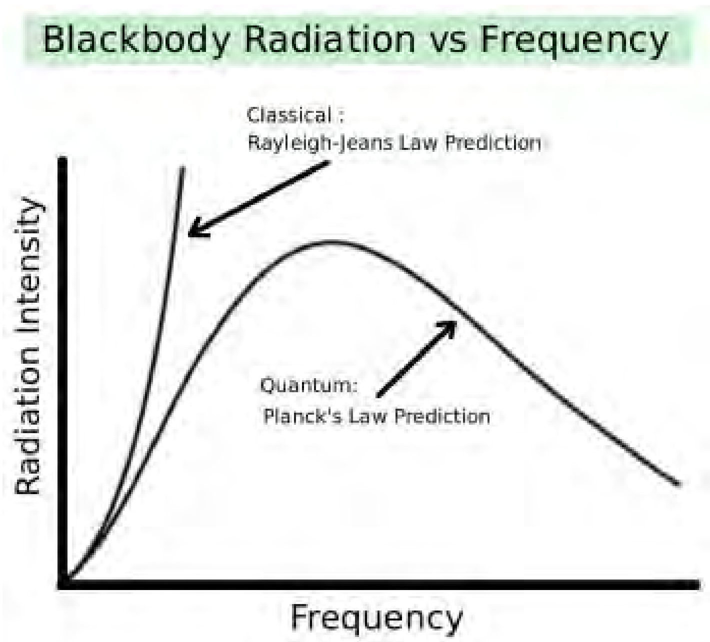


Figure 2:
This diagram shows the somewhat incomplete nature of the Rayleigh-Jeans Law, which only was able to fit data with a long wavelength and low frequency, compared to Planck's Law, which was an all-encompassing mechanism for quantifying experimental data regardless of wavelength and frequency parameters.

References:
1) Rybicki, G. B.; Lightman, A. P. (1979), *Radiative Processes in Astrophysics*, New York: John Wiley & Sons

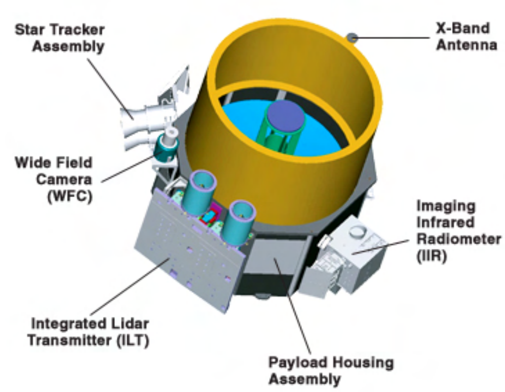
2) Weisstein, Eric. "Planck's Law." Science World. Wolfram Research. <http://scienceworld.wolfram.com/physics/PlancksLaw.html>.

Platforms

A platform is a structure that is used to carry a sensor. In remote sensing, the satellite is typically the platform. However, aircraft, balloons, and ground based vehicles can also serve as platforms in remote sensing. Platforms are dependent upon the altitude required to give the desired ground resolution as well as the sensor instantaneous field of view.

Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) provides a good example of a platform. CALIPSO flies in A-train formation and uses lidar to measure aerosols and clouds in the atmosphere.

Image 1



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CALIPSO is the platform which contains several remote sensing instruments. The instruments include Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), Wide Field Camera (WFC),and Imaging Infrared Radiometer (IIR).
Other examples of platforms include TERRA, which includes and TOMS-AI
ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer)
CERES (Clouds and the Earth's Radiant Energy System)
MISR (Multi-angle Imaging SpectroRadiometer)
MODIS (Moderate-resolution Imaging Spectroradiometer)
MOPITT (Measurements of Pollution in the Troposphere)

References
Canada Centre for Remote Sensing. "Glossary of Remote Sensing Terms". 2008. http://www.ccrs.nrcan.gc.ca/resource/tutor/planet/4_3_e.php
NASA. "CALIPSO". 2009. http://www-calipso.larc.nasa.gov/
Wikipedia. "CALIPSO". 2009 http://en.wikipedia.org/wiki/CALIPSO

Photomultiplier tube:
Also known as PMT. Instrument used in the UV, visible and near IR to strongly amplify light signals. It relies on two physic principles: the photoelectric effect and the secondary emission. The incoming photon is converted in an electron through a photocathode. That electron is then multiplied as it is focused onto many dynodes in a vacuum tube. Finally these are collected on an anode at the end of the tube. That process is illustrated on Figure 14.

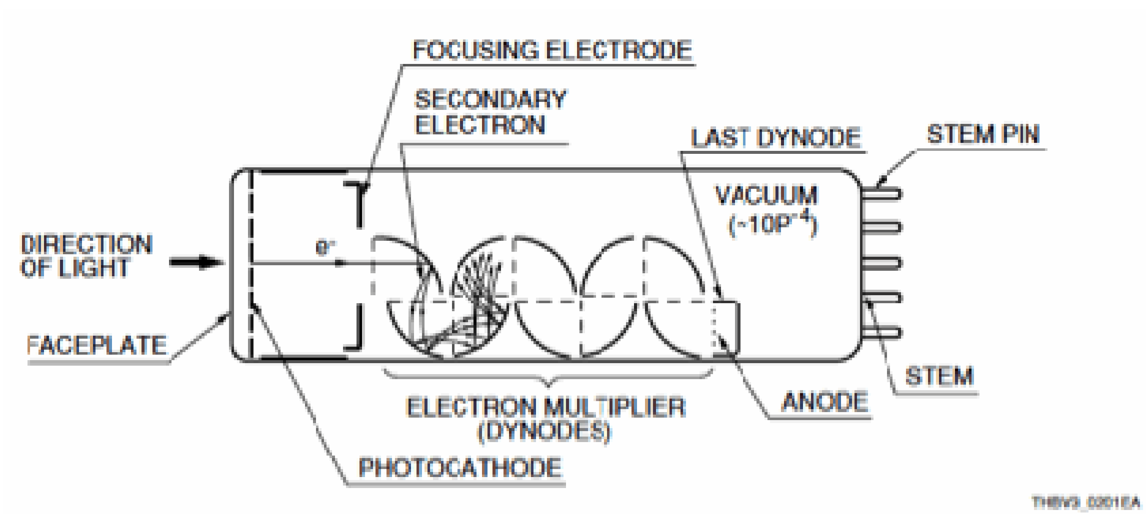

Figure 14. Construction of a PMT.

The first photomultiplier demonstration occurred in the early 1930's. Since then, the main modifications were on the materials used for the photocathode and dynodes, since the gain and frequency range of the device only depend on that. It can be noted that different geometries exist (circular for instance), the construction remains the same for all PMTs.

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Photocathode:
Converts incident photons into electrons.
The photoelectric effect was discovered in 1887 by Hertz through experiments exposing a negative electrode to UV radiation.
A photocathode is a semiconductor. This means that it can be described by a band model, as shown in Figure 15. The incident photon will transfer part or all his energy (*hv*) to an electron in the material. If the energy of the excited electron is above the energy gap (EG), it will diffuse toward the surface. If that same energy is higher than the vacuum level (or specific gas level when the semiconductor is not in a vacuum) it will be emitted out of the material. The vacuum level is always lower than any other gas level, that's why PMTs use vacuum tubes.
The choice of semiconductor material will determine the spectral range of the device (depending on its energy gap and vacuum level).

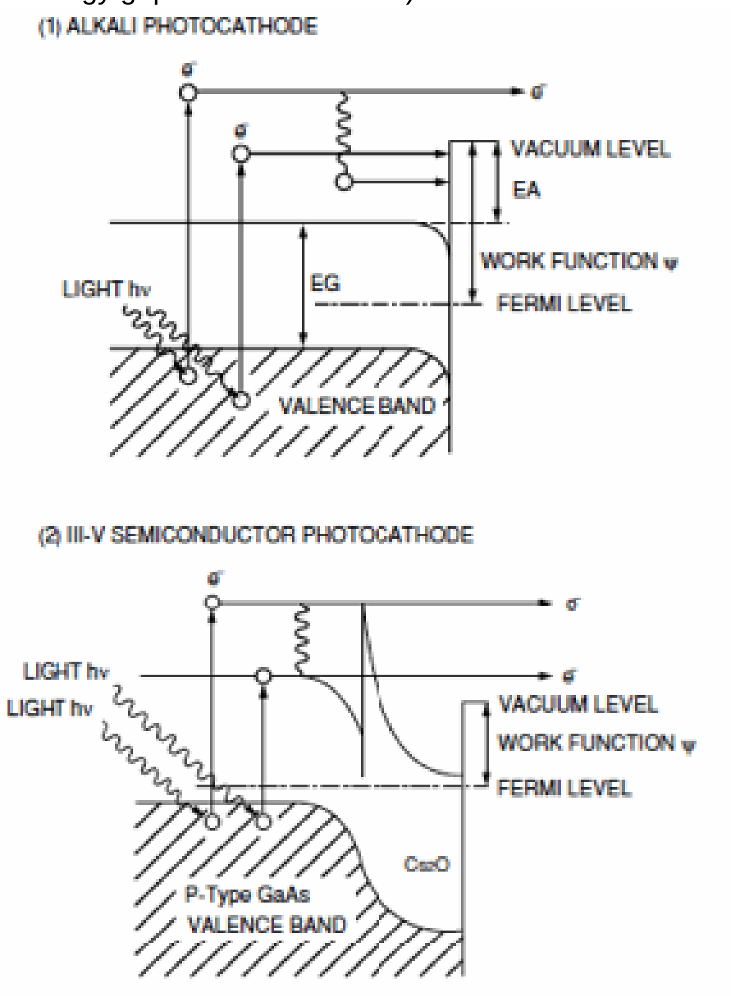

Figure 15. Photocathode band models.
Photocathodes can be classified by photoelectrons emission process into a reflection mode and a transmission mode. The transmission mode photocathode is usually deposited as a thin film on a glass plate that is optically transparent. The reflection mode photocathode is usually formed on a metal plate.

Dynode:
Also known as electron multiplier. When an electron hits a dynode, it results in the emission of more electrons (from 10 to 100).
Major secondary emissive materials used for dynodes are alkali antimonide, beryllium oxide (BeO), magnesium oxide (MgO), gallium phosphide (GaP)… These materials are coated onto a substrate electrode made of nickel, stainless steel, or copper-beryllium alloy. Figure 16 shows a model of the secondary emission multiplication of a dynode.

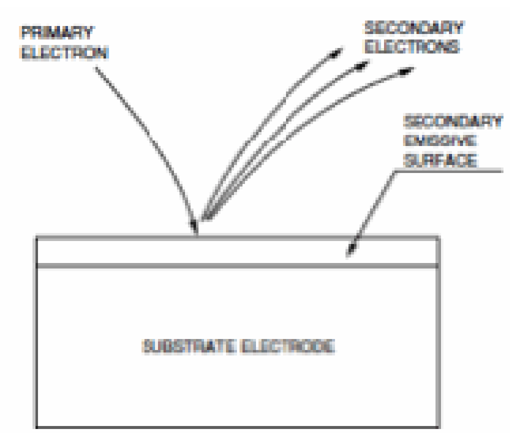

Figure 16. Secondary emission of a dynode.

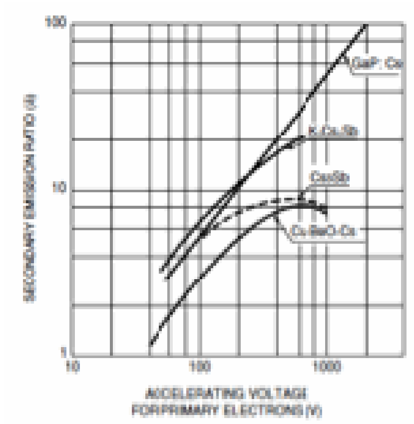

Figure 17. Secondary emission ratio.

The multiplication factor of each dynode, also called secondary emission ratio, depend on the initial accelerating voltage of the primary electron (Figure 17). When picking a dynode, its gain, time response and linearity are as important as the secondary emission ratio.

Polar Orbit: A satellite which orbit passes directly or nearly directly over each pole. This type of near-earth orbit, at an elevation of 700-1000 km [1, 2], is generally sun-synchronous[1]. Orbit times are roughly 100 minutes, substantially shorter than wider orbital paths[2]. Due to the nature of a polar orbit, the rotation of the planet cannot be used to power the satellites orbit. Given this, polar orbiters tend to have a shorter lifetime and require a great deal of power to be provided when putting the satellite into orbit[3].

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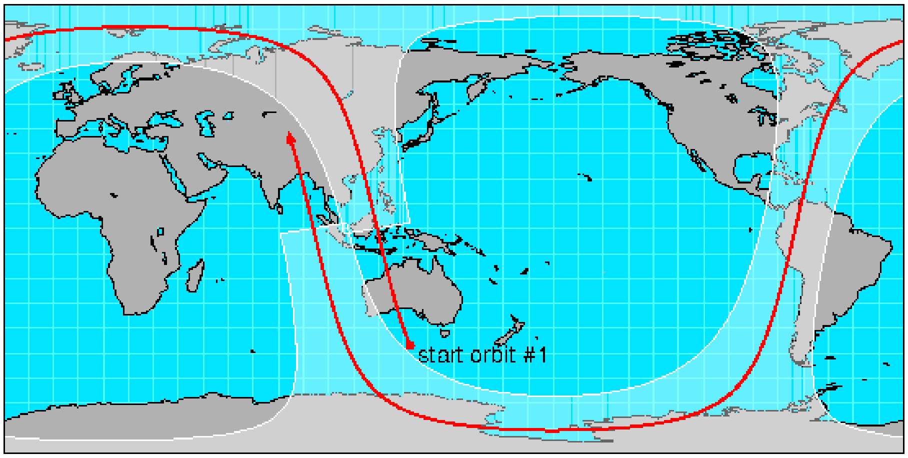

Figure 1 – Schematic of a polar orbiting satellite. This orbit will continue to retrograde westward with time, allowing nearly the entire earth to be sampled over a given time. Image from News Media Studio[4].

Polar orbits have some very distinct advantages. High-resolution imagery is much easier to achieve given the lower altitude of orbit. For this reason, the United States Air Force Surveillance Satellites take advantage of this type of orbit pattern with their Defense Meteorological Satellite Program (DMSP)[5]. Figure 2 provides an excellent example of how multiple passes with satellites can be combined to form a single mosaic image.

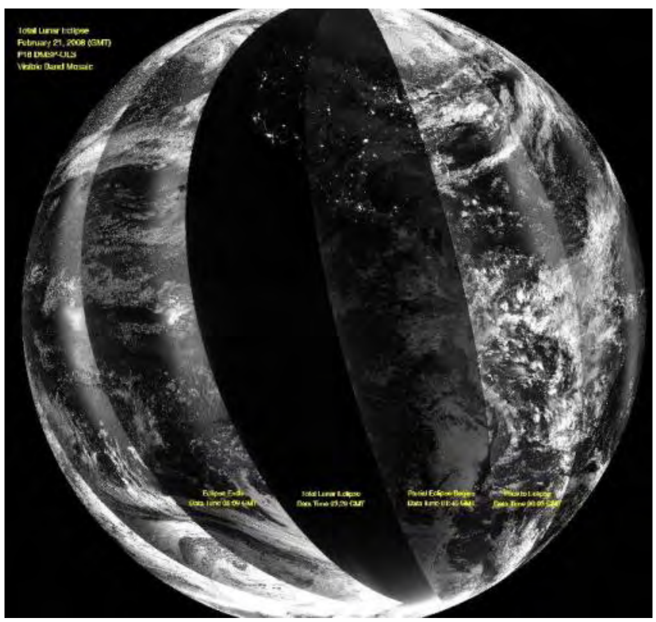

Figure 2 – DMSP visible satellite image during a lunar eclipse in 2008. Of particular note is the individual 'slices' of imagery, with each piece representing a satellite pass over a particular region. Image is from NOAA National Geophysical Data Center[6].

Another popular program which uses polar orbiting to its advantage is NPOESS, or The National Polar-orbiting Operational Environmental Satellite System. This satellite constellation monitors the climate and the near-space environment, which is of particular interest near the poles in studying aurora[7].

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1. "Satellite Orbits." NASA. 12 Apr. 2009 <http://asdwww.larc.nasa.gov/SCOOL/orbits.html>.

2. "Polar Orbiting Satellites." Educational Web Sites. 12 Apr. 2009 <http://www.phy6.org/Education/wlopolar.html>.

3. "Polar orbit." 12 Apr. 2009 <http://www.centennialofflight.gov/essay/Dictionary/POLAR_ORBIT/DI154.htm>.

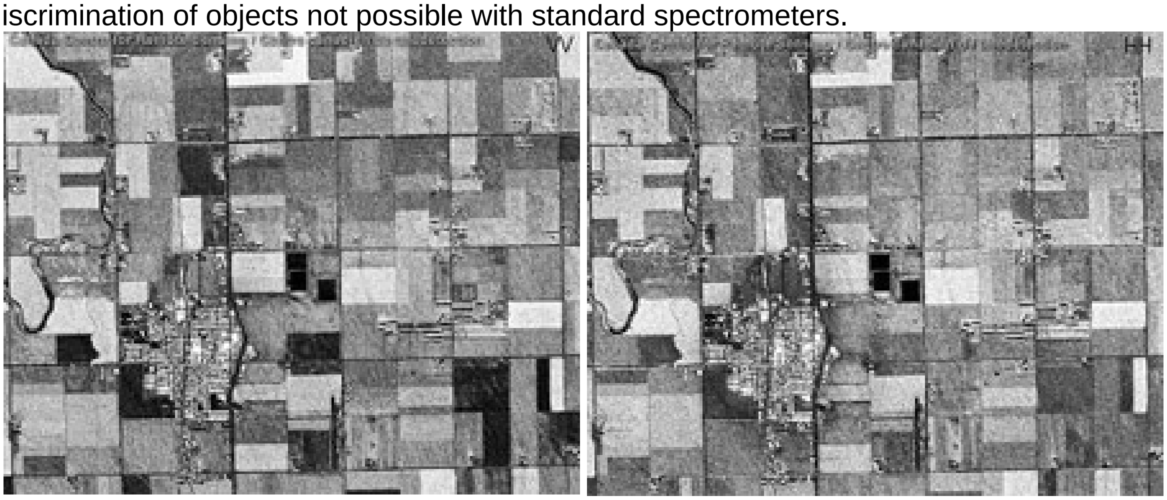
4. "Polar Orbits." Welcome! 12 Apr. 2009 <http://www.newmediastudio.org/DataDiscovery/Hurr_ED_Center/Satellites_and_Sensors/Polar_Orbits/Polar_Orbits.html>.

7. "NOAA/NGDC - Earth Observation Group - Defense Meteorological Satellite Program, Boulder." USDOC/NOAA/NESDIS/National Geophysical Data Center (NGDC) Home Page. 12 Apr. 2009 <http://www.ngdc.noaa.gov/dmsp/>.

6. DMSP Total Lunar Eclipse. 12 Apr. 2009 <http://www.affrc.go.jp/apan/emwg/images/F1620080221.lunar_eclipse.lo_res.w_text.vis.jpg>.

7. NPOESS. 12 Apr. 2009 <http://www.npoess.noaa.gov/>.

Polarimetry
Definition: Polarimetry is the sensing and discrimination of the polarization of incoming electromagnetic (EM) waves in order to differentiate objects and structures. Because objects scatter EM radiation of different polarizations in varying degrees of intensity, observing the polarization sensitivity of these objects can reveal properties and allow discrimination of objects not possible with standard spectrometers.



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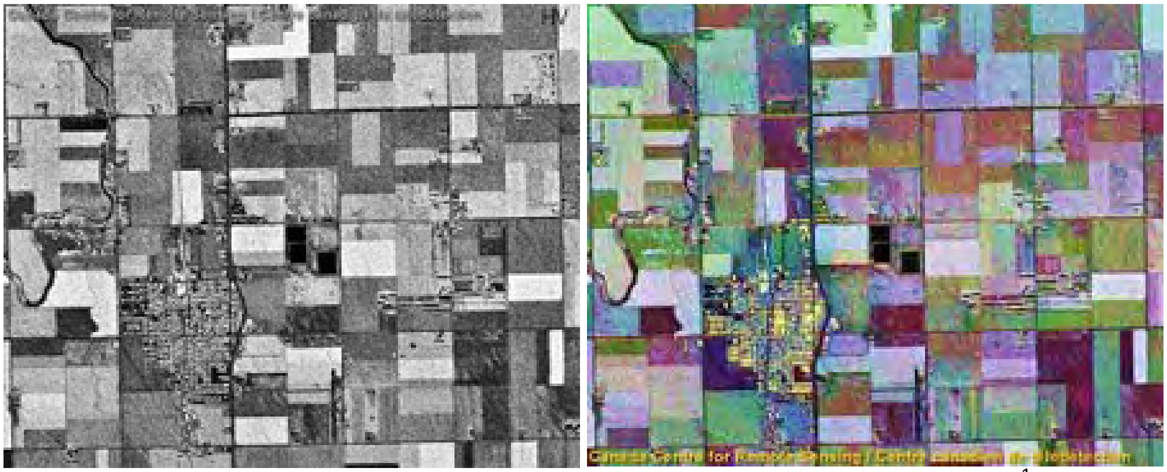

Figure 18: Polarimetric imaging or an agricultural area with varying polarizations[1].

References

[1] http://www.ccrs.nrcan.gc.ca/resource/
[2] http://earth.esa.int/polsarpro/tutorial.html

Polarization: the property of an electromagnetic wave, such as visible light, describing the direction in which the electric field oscillates relative to the direction of its propagation (see figure 1).

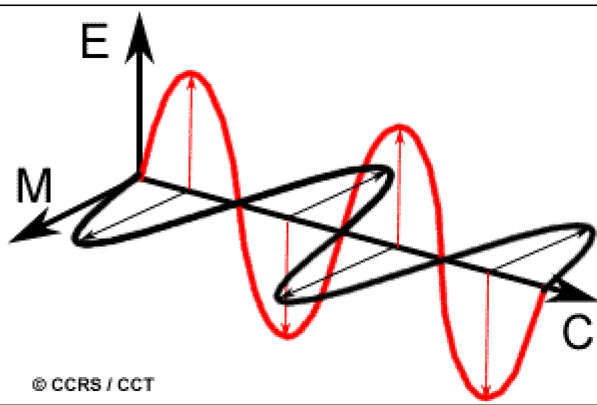

Figure 1 - Schematic of electromagnetic radiation showing the electric field orientation (red) relative to the direction of propagation (C).
[http://www.ccrs.nrcan.gc.ca/glossary/index_e.php?id=3089]

Polarization can be linear, circular, or elliptical in nature. The type of polarization is determined by the magnitudes of the perpendicular components of the electric field and the phase difference between them.

- Linear polarization results from a constant electric field vector where the perpendicular components of the electric field are in phase.
- Circular polarization results from equal magnitudes of the perpendicular electric field components but a 90 degree phase shift between the two.

- Elliptical polarization results from non-equal magnitudes of the perpendicular electric field components as well as a non-zero phase difference.

While most natural light is non-polarized, meaning that there is no favored orientation of the electric field vector, most reflected light is at least partially polarized.

Light may also be polarized using a filter. Polarizing filters transmit light with only one component of electric field vector oscillation while absorbing light with any other oscillation component (see figure 2). The resulting radiation is fully-polarized. This method is used in polarizing sunglasses to reduce the amount of glare by absorbing all reflected light of a particular polarization. Such filtering is an effective method of measuring the degree of polarization in electromagnetic radiation.

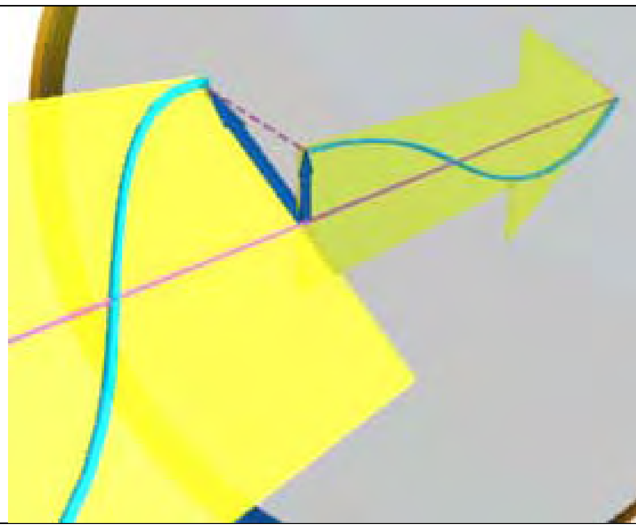

Figure 2 – Conceptual diagram of a polarizing filter. Light with an electric field oscillating in a diagonal plane (yellow) is filtered, transmitting only light with a vertical oscillation. [http://www.colorado.edu/physics/2000/polarization/polarizationII.html]

The polarization of radiation that is scattered from Earth surfaces as well as atmospheric constituents is related to the scattering medium. As such, in remote sensing, polarimetry is frequently used to identify atmospheric and terrestrial materials based on the polarization observed in emitted or reflected radiation.

SOURCES:

"Polarization of Light." The Columbia Encyclopedia, 6th Edition. 2008. *Encyclopedia.com.* 15 Feb. 2009 <http://www.encyclopedia.com>.

"Polarization." Glossary of Remote Sensing Terms. 2005. *Canada Centre for Remote Sensing*. 15 Feb. 2009 <http://www.ccrs.nrcan.gc.ca/glossary/index_e.php?id=681>

"Polarization." Physics 2000. *The University of Colorado*. 15 Feb. 2009. <http://www.colorado.edu/physics/2000/polarization/index.html>
Staples, G. C. and Hornsby, J.. "Turning the Scientifically Possible into the Operationally Practical: RADARSAT-2 Polarimetry Applications." 2002. Geocommunity Geoimaging Feature. < http://imaging.geocomm.com/features/rsi1102/index.html>

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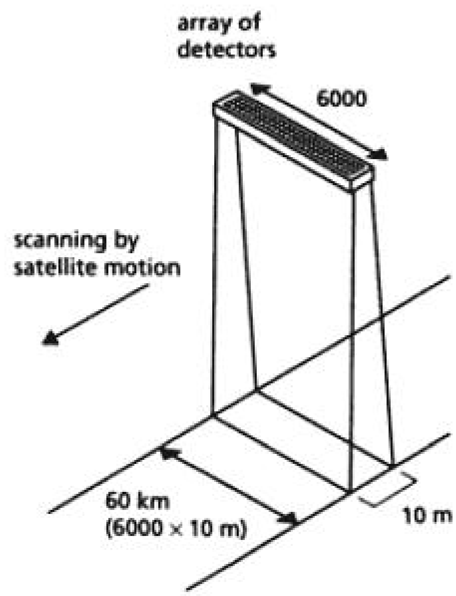
Pushbroom

The term pushbroom is used to refer to scanners that move 'along-track'. Sensors are lined up in arrays which capture data as the satellite moves forward like reading strips coming out of a fax machine, or like sweeping a broom across the floor, hence the name. This is in contrast to 'whiskbroom', or 'across-track', scanners than scan from side to side.



CCD Arrays are swept across the surface analogous to a broom sweeping across the floor. (Image from Drury, 2001, p42.)

Pushbroom systems use radiation sensitive charge-coupled devices (CCDs) as detectors. Spatial resolution of pushbroom systems depend on CCD size, optics and elevation. The spectral resolution depends on the time each CCD receives radiant energy. CCDs respond to wavelengths up to 2.4 microns and can monitor the full VIR and NIR range, providing better signal to noise ratios than line-scanners. The pushbroom method provides better radiometric and spatial resolution than whiskbroom scanners, but require more complicated calibration due to the large number of detectors. Pushbroom systems have the added benefit of being lighter because it does not require electromechanical components to move it from side to side.

Early pushbroom systems include the high resolution visible (HRV) scanners on the1986 French SPOT-1 spacecraft and the Modular Optico-electronic Multispectral Scanner (MOMS) on the STS-7 and 11 shuttles. Well known pushbroom systems include THEMIS, ASTER, EROS-A1, TLS and so on. Even the Hubble Space Telescope uses CCD detectors to capture astronomical scenes.

References
AmesRemote, Section 2: Acquiring Remote Sensing Data *http://www.amesremote.com/section2.htm*
NASA, *Technical and Historical Perspectives of Remote Sensing: Other Remote Sensing Systems – MOMS and SPOT,* http://rst.gsfc.nasa.gov/Intro/Part2_22.html
Stephen A. Drury, *Image Interpretation in Geology,* Routledge, 2001, p.42.

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RADAR – RADAR (radio detection and ranging) is based on the transmission of long wavelength microwaves (from 3cm – 25cm) through the atmosphere and then recording the backscatter as the waves reflect back off of objects in their path. RADAR can be used to figure out an object's size and distance.
See: R., Jensen, John. Remote sensing of the environment an earth resource perspective. Upper Saddle River, NJ: Pearson Prentice Hall, 2007.

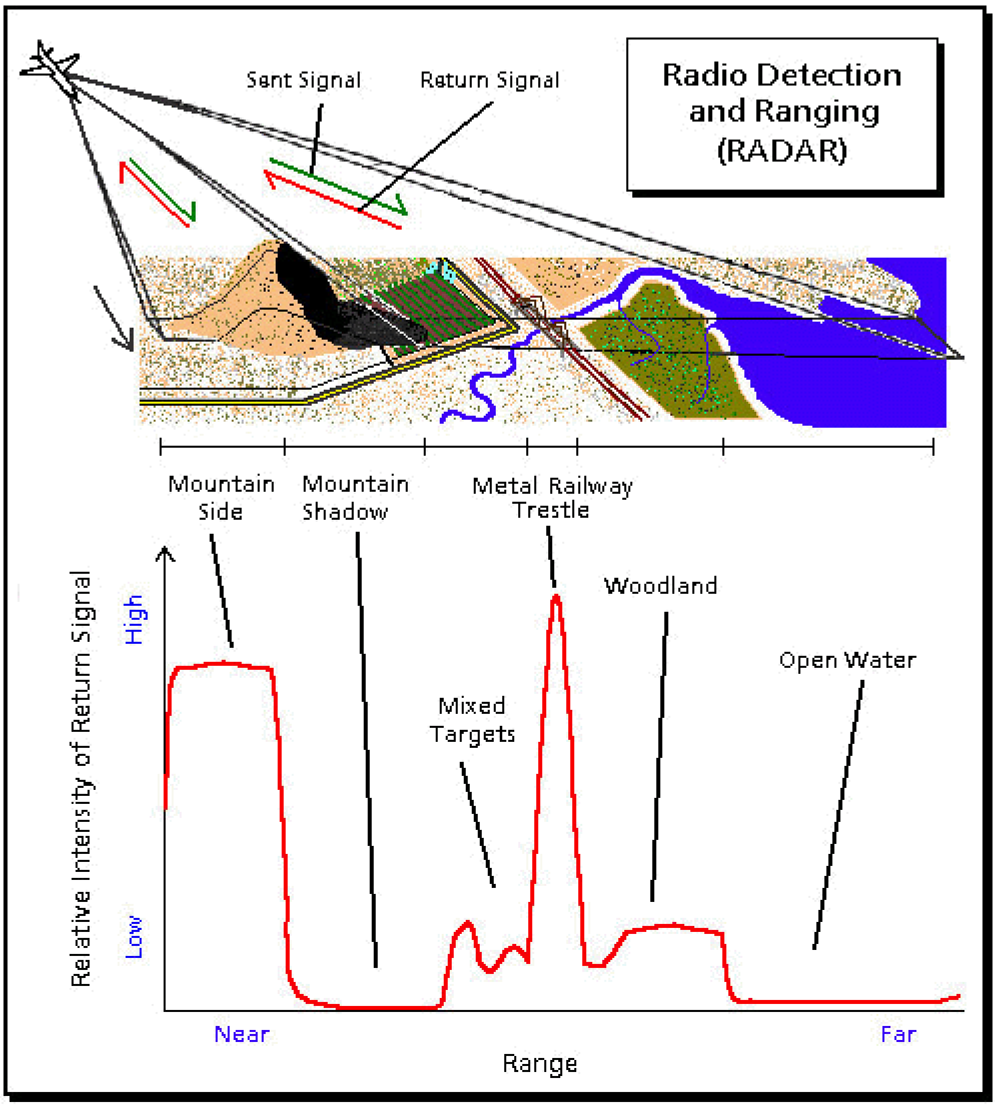

Figure 19: Example of a RADAR system from the Rice University department of Earth Sciences, http://earth.rice.edu/mtpe/geo/geosphere/topics/remotesensing/25_radar.html

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Radiant Temperature: the concentration of the amount of radiant flux from an object. It is the basis of *thermal* remote sensing and is measured by thermal radiometers.

Mathematically, Radiant temperature is the kinetic temperature multiplied by the emissivity to the one-fourth power.

Thermal remote sensing is the measurement of the energy of particles of matter in random motion through kinetic interactions (random collisions of particles). Kinetic energy is measure by the heat energy of these interactions is the objects true kinetic temperature T_{kin}.. We can measure the true kinetic temperature (T_{kin}) using a thermometer. It is important to note that in the thermal wavelengths, objects do not transmit well (t=0), and Kirchoffs law allows us to state that "good absorbers are good emitters".

When these particles collide they change their energy state and emit electromagnetic radiation called radiant flux (watts). The concentration of the amount of radiant flux exiting (emitted from) an object is its radiant temperature (T_{rad}).

*There is usually a high 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.

Figure 1: Example of a thermal radiometer measuring radiant flux of an emitting object. Source: http://www.ucol.mx/ciiv/geochem/thermal_en.htm

In general, thermal radiometers, which measure the objects radiant temperature can be used as a proxy for the objects true kinetic temperature.

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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 a thermal property called emissivity, which can be used to help correct the calculationof the radiant temperature:
$T_R = \varepsilon^{1/4} T_R$

Why is Emissivity so important?
Emissivity can be influenced by a number of factors:

- Color (dark objects absorb and emit more)
- Surface roughness (the rougher the surface, the greater the area and greater potential for absorption)
- Moisture Content(water has high emissivity)
- Field of view
- Wavelength
- View Angle

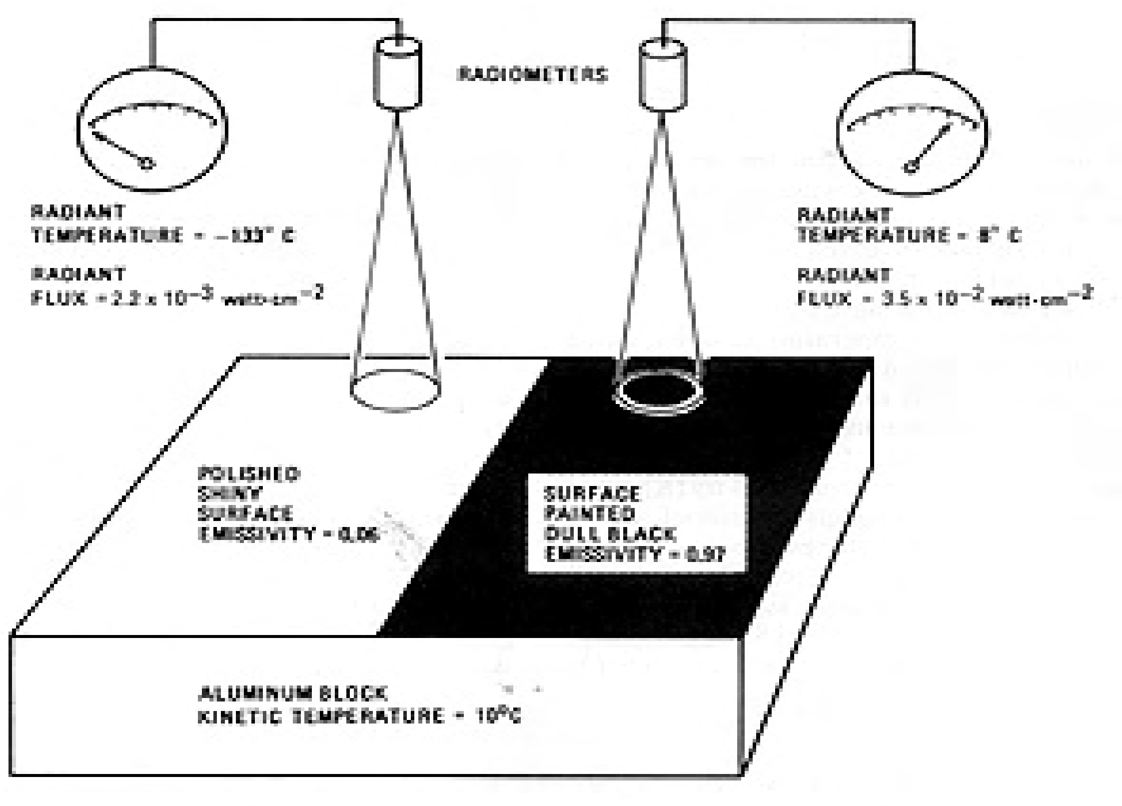

Figure 2: The radiant temperature is significantly higher for a blackened surface (high ε) than for a shiny surface (lower ε), even if the two materials are at the same kinetic temperature.
Source: F. F. Sabins, Jr., Remote Sensing: Principles and Interpretation. 2nd Ed., © 1987.; Remote Sensing Tutorial Accessed March 1 2009
http://rst.gsfc.nasa.gov/Sect9/Sect9_2.html

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If an objects radiant and kinetic temperatures are known, applying the Stefan-Boltzmann law for the thermal can estimate emissivity of an object:

$$\varepsilon = (T_R / T_k)^4$$

Also, the radiant flux is equal to:

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

Applications:

In the thermal wavelengths, another law called Wiens displacement law, can be applied. It gives us information on the dominant wavelength (λ_{max}), which provides valuable information on choosing which part of the thermal spectrum we might want to sense in. For example, if we are looking for 800 ˚K forest fires that have a dominant wavelength of approximately 3.62 µm then the most appropriate remote sensing system might be a 3-5 µm thermal infrared detector.

- MODIS band 20-25 are in 3-5 µm.

"If we are interested in soil, water, and rock with ambient temperatures on the earth's surface of 300 ˚K and a dominant wavelength of 9.66 µm, then a thermal infrared detector operating in the 8 - 14 µm region might be most appropriate.

- Landsat image thermal band (6) is in 10.4-12.5 µm
- ASTER band 12 and 13 are in 8 - 14 µm
- MODIS band 29-30 and 31-32 are in 8 - 14 µm"

Source: Thermal Infrared Remote Sensing Powerpoint. Accessed March 1 2009
www.utsa.edu/lrsg/Teaching/EES5053-06/L7-therm.ppt

The thermal state of a material is very sensitive to the time of day (or night). To track this change, the change in radiant temperature during a diurnal heating cycle proves to show variation with the materials involved. Changes in temperature during the cycle depend on the thermal properties of each material. (See Figure 3)

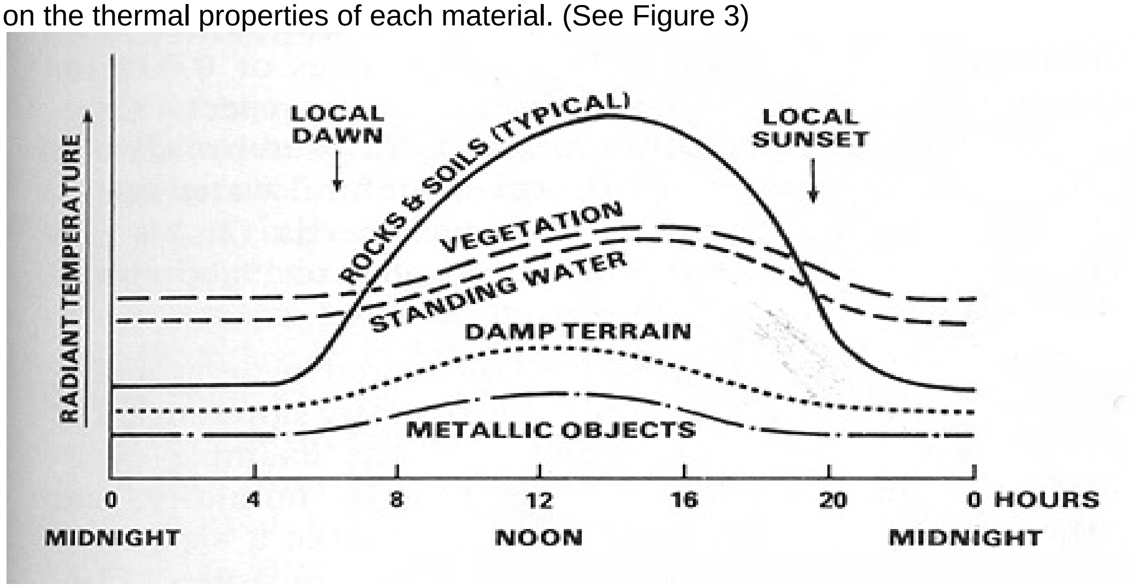

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Figure 3: Changes in radiant temperatures of five surface-cover types during a 24-hour thermal cycle.
Source: http://rst.gsfc.nasa.gov/Sect9/Sect9_4.html

A few of NASA's thermal satellites include:
- Landsat systems (MSS, TM, ETM+)
- ETM+ has a 60 m band at 10.5-12.5 µm)
- TRMM
- CERES
- EOS Terra (Dec. 1999)
- CERES, MODIS, ASTER, MOPITT
- EOS Aqua (May 2002)
- AIRS, CERES, MODIS
- EOS Aura (July 2004)
- HIRDLS, TES

Additional Sources:
Remote Sensing Glossary. Accessed March 1 2009.
http://www.ldeo.columbia.edu/res/fac/rsvlab/glossary.html

Radiometric Resolution – Radiometric resolution is the sensitivity of an instrument to different levels of radiant flux received, emitted, or backscattered from whatever object the instrument is receiving flux from. Radiometric resolution defines the number of signal levels that can be reported by the instrument, called a *digital number*.

See: R., Jensen, John. Remote sensing of the environment an earth resource perspective. Upper Saddle River, NJ: Pearson Prentice Hall, 2007.

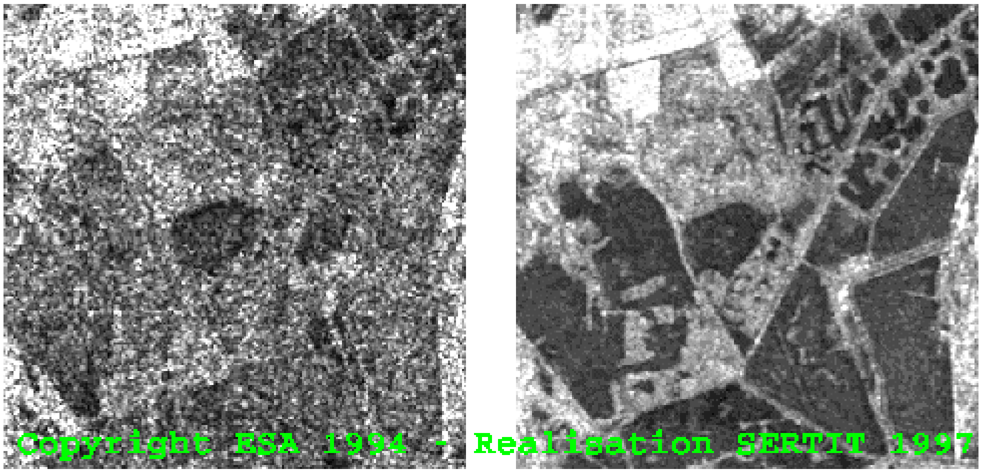

Figure 20: An Image from the European Space Agency showing how radiometric resolution can dramatically affect the usability of information received from an instrument. From: http://earth.esa.int/workshops/ers97/papers/laugier/

Random and Systematic errors:

Errors affecting any measurements. Repeating the measurements usually reveals random errors. It does not, however, reveals systematic errors.
For instance, small disturbances to the instrument (such as mechanical vibration), problems of resolution induce random errors. Miscalibration of the instrument is a source of systematic errors.

Figure 21 gives an illustration of the difference between random and systematic errors. Here, accurate measurements are shots that arrive close to the center. However, in most real situations, we do not know the true value of the measured quantity. Figure 22 gives a better illustration of a real set of measurements.

The difference between random and systematic errors is not always clear. For instance your instrument may be tilted compared to what you are looking at. If that tilt stays the same during all the measurements it will induce a systematic error. But if that tilt changes (because the instrument support is unstable for instance), then it creates a random error.

The treatment of random errors can be performed by statistical means (average, standard deviation…). However, systematic errors are difficult to evaluate or even to detect. A good calibration will eliminates some most of the systematic errors, but may not always be sufficient. Those errors have to be anticipated and must always be much less than the required precision.

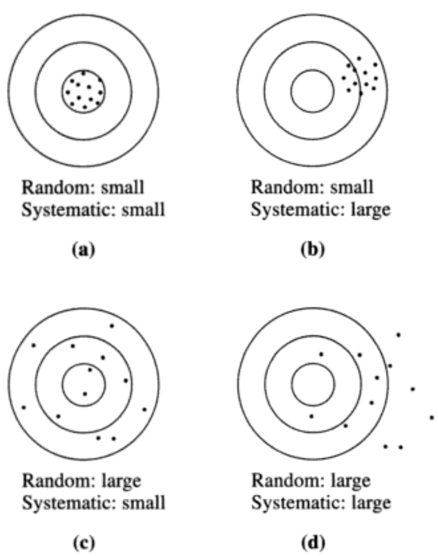

Figure 21. Random and systematic errors in target practice. (a) Because all shots arrived close to one another, we can tell the random errors are small. Because the distribution of shots is centered on the target, the systematic errors are also small. (b) The random errors are still small, but the systematic ones are much larger – the shots are systematically off-center toward the right. (c) Here, the random errors are large, but the systematic ones are small – the shots are widely scattered but not systematically off-center. (d) Here the random and systematic errors are large.

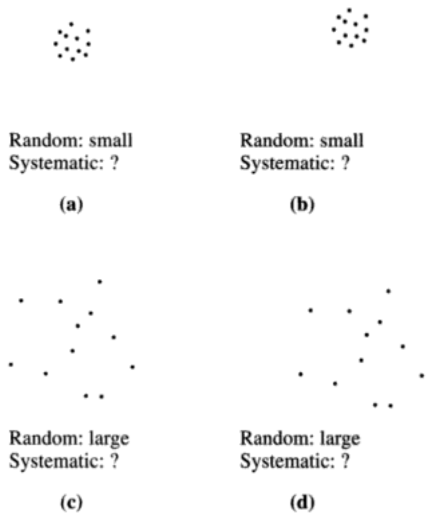

Figure 22. The same experiment as in Figure 1 redrawn without showing the position of the target. This situation corresponds closely to the one in most real experiments, in which we do not know the true value of the quantity being measured. Here, we can still asses the random errors easily, but cannot tell anything about the systematic ones.

References:

- John Robert Taylor (1999). *An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements*. University Science Books. p. 94, §4.1. ISBN 093570275X.
- Wikipedia.

Rayleigh Scattering: The scattering of electromagnetic radiation by particles with dimensions much smaller than the wavelength of the radiation.

$$r \ll \lambda \text{ or when } x \ll 1$$

Where x is the size of the scattering particle using $x = 2\pi r/\lambda$.

Scattering is a very complex process where incoming energy can be re-directed several times within a medium-often reducing its magnitude in an unpredictable fashion. The relative size of the incident radiant energy (defined by its wavelength) and the particle size of the medium can be defined into 3 distinct categories, where Rayleigh represents the molecular scattering of the gases in the atmosphere.

Rayleigh Scattering is applicable to scattering of:

- UV and visible radiation by air molecules (N_2,O_2…)
- Infra-red radiation by small aerosols
- Microwave radiation by cloud and rain drops.

Also, Scattering is dependent upon 3 variables.

- ✓ The size of the particle,
- ✓ the wavelength of incident radiation
- ✓ the complex refractive index $m = n + i k$

Where n is responsible for scattering, the imaginary part, and k is responsible for absorption, the real part. Both of these depend on wavelength.

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Lord Rayleigh calculated the scattered intensity from dipole scatterers much smaller than the wavelength to be:

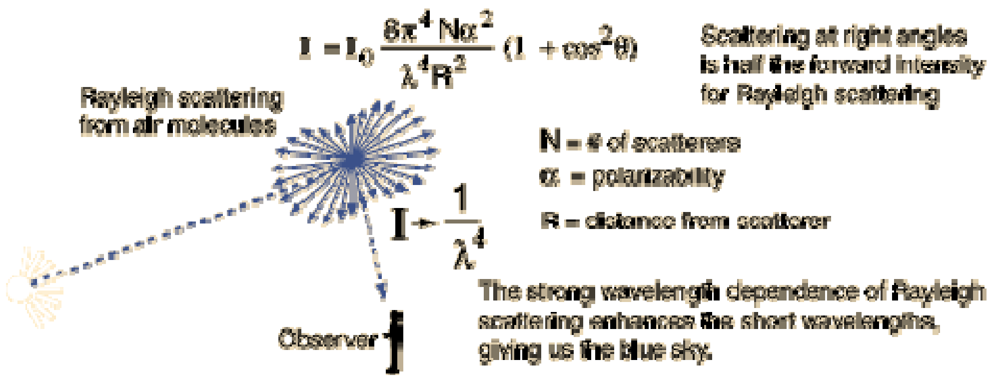

Figure 1: Amount of Scattered radiation due to particles much smaller than incident wavelengths.
Source: http://hyperphysics.phy-astr.gsu.edu/Hbase/atmos/blusky.html

Rayleigh scattering can be considered to be *elastic* scattering since the photon energies of the scattered photons is not changed.

Applications:
Light from the sun is made up of the colors in the rainbow, which correspond to different wavelengths of radiation. The blues are made up of short wavelengths and the reds of longer wavelengths. Rayleigh Scattering is what gives sky its blue color, and at sunset its red color.

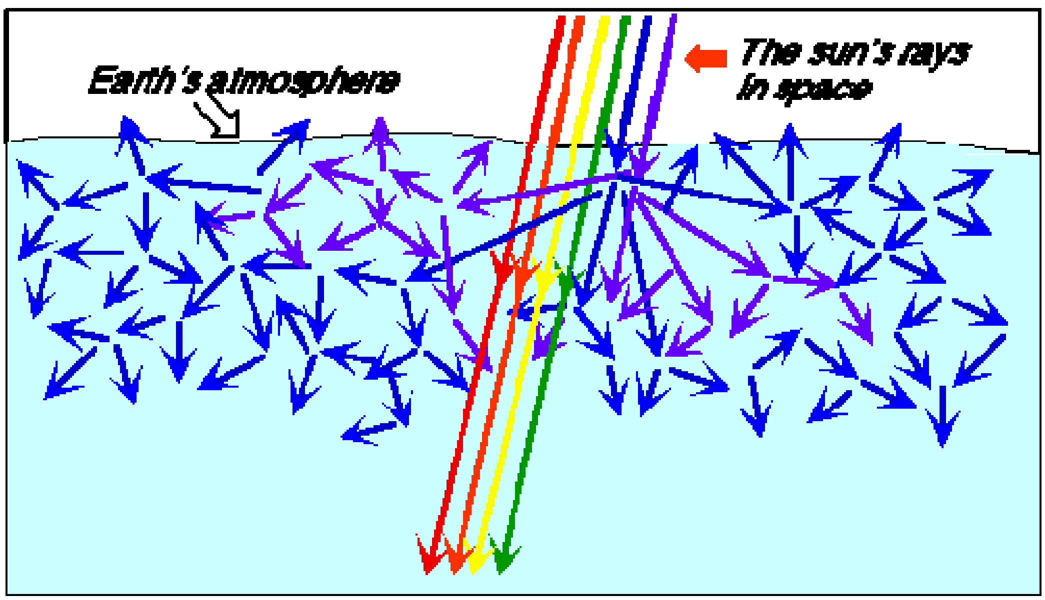

Figure 2: Reds, oranges and yellows are scattered more at longer distances or larger particles (aerosols). Blues are scattered at shorter wavelengths causing the sky to be blue.

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Source: http://www.srrb.noaa.gov/highlights/redsky/page3.html

Rayleigh scattering increases with decreasing (shorter) wavelengths, causing the preferential scattering of blue light (blue sky effect); however, the red sky tones at sunset and sunrise result from significant absorption of shorter wavelengths and much larger travel paths for the suns rays.

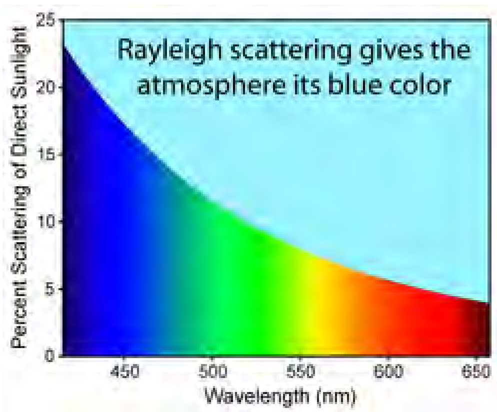


Figure 3: Depiction of greatest scattering concentration of blue light in the visible part of the electromagnetic spectrum.
Source: http://en.wikipedia.org/wiki/File:Rayleigh_sunlight_scattering.png

The atmosphere's molecules are able to scatter light better in this band of the spectrum because the electromagnetic field of the light waves induces electric dipole moments in the molecules.

Since this maximum scattering of the atmosphere occurs at short wavelengths, one may wonder why we don't see more violet light? The suns emission spectrum varies at different wavelengths, and at the violet wavelengths, much is absorbed by the high atmosphere. Also, human eyes are more sensitive to blue light.

"Additionally, blue light is twice as likely to be absorbed at greater distances, often leaving yellow, red and orange colors for sunsets. When the air is clear the sunset will appear yellow, because the light from the sun has passed a long distance through air and some of the blue light has been scattered away. If the air is polluted with small particles, the sunset will be redder". Source:
http://math.ucr.edu/home/baez/physics/General/BlueSky/blue_sky.html

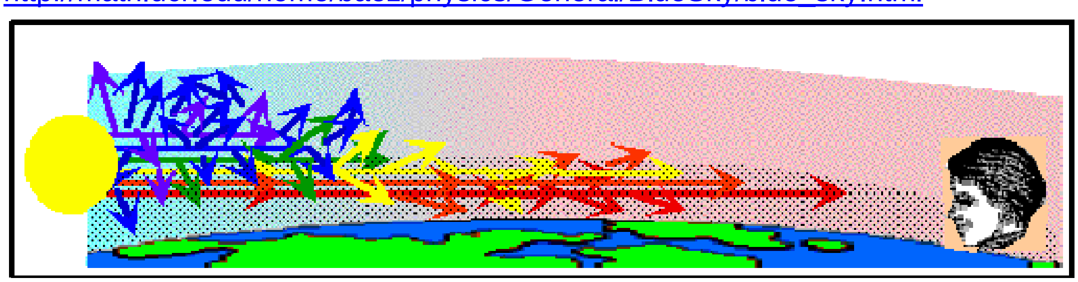


Figure 4: Red is scattered more at longer wavelengths which is why the sunsets are often red..
Source: http://www.srrb.noaa.gov/highlights/redsky/page3.html

Practical applications of Rayleigh scattering include:

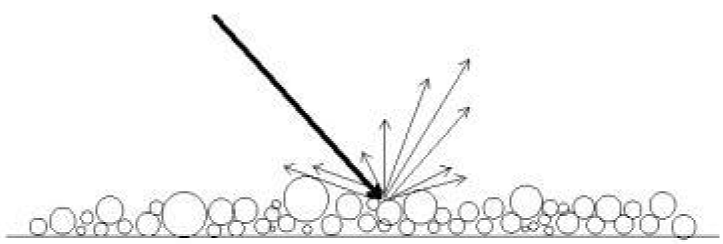
- Lidar
- weather radar
- remote sounding of cloud water.

Additional Sources:
Remote Sensing Tutorial.Goddard Space Center. Accessed March 5, 2009.
http://rst.gsfc.nasa.gov/Intro/Part2_4.html

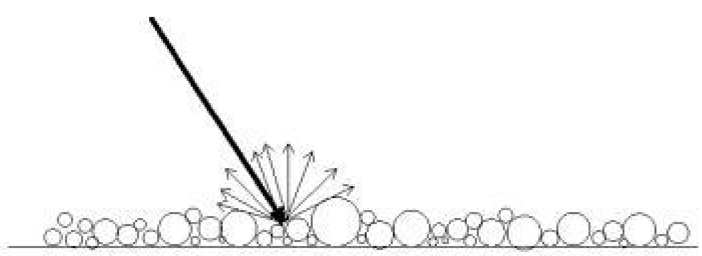
Hulst, Hendrick. Light Scattering by Small Particles. Page 88.

"Rayleigh Scattering". University of Texas. Accessed March 5, 2009.
http://farside.ph.utexas.edu/teaching/em/lectures/node97.html

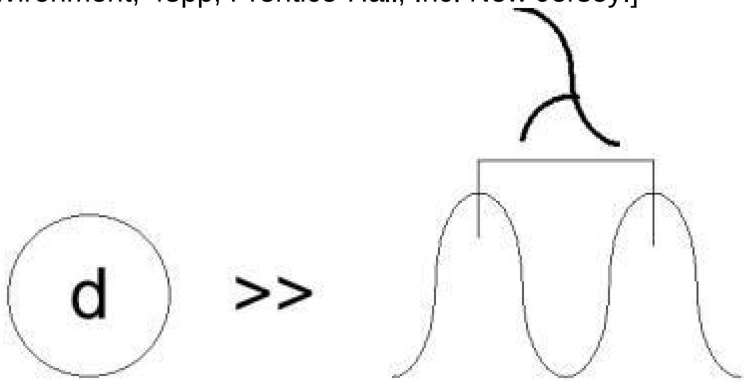
Reflection, Diffuse: when radiant incidence on a rough surface (i.e. λ < surface roughness); the radiant exitance is reflected in all directions i.e. no mirror image, but with a general "trend." A good example of this is when you shine a flashlight on white paper. The reflected light is diffused in many directions rather than reflecting in a single direction. [see Jensen, John (2000), Remote Sensing of the Environment, 44pp, Prentice-Hall, Inc. New Jersey.]



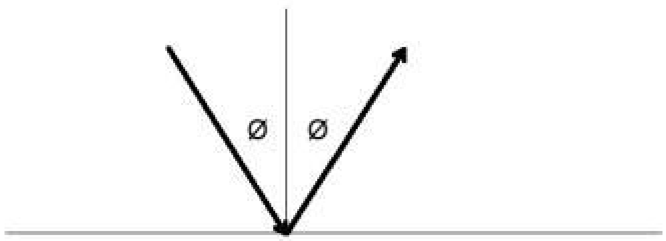
Reflection, Lambertian: when radiant incidence on a *perfectly rough* surface; the radiant exitance is constant for any angle of reflection to the surface. [see Jensen, John (2000), Remote Sensing of the Environment, 44pp, Prentice-Hall, Inc. New Jersey.]



Scattering, Non-selective: This type of scattering deals with particles that are larger than ten times the wavelength of the incident radiation and is not dependant on the wavelength of the radiation- all bands are scattered. Non-selective scattering takes place in the lowest part of the atmosphere where various elements such as water vapor, ice crystals, and sea salt exist. [see Jensen, John (2000), Remote Sensing of the Environment, 43pp, Prentice-Hall, Inc. New Jersey.]



Reflection, Specular: when radiant incidence with angle Ø is reflected off a *mirror* smooth surface such that the radiant exitance has an angle of Ø as well. A good example of this is sunglint on smooth ocean surfaces. [see Jensen, John (2000), Remote Sensing of the Environment, 44pp, Prentice-Hall, Inc. New Jersey.



Remote Sensing, Passive Microwave: Data is recorded in the form of a brightness temperature which is dependent upon both the temperature of the object and the emissivity of the object (which in itself is dependent on the temperature). See Planck's Law: $S(\lambda) = 2\pi ckT/\lambda^4$.

Remote sensing using passive microwave systems require relatively large spatial resolutions because the upwelling radiation is so weak the sensor has to use a large area in order to generate a sufficient amount of data from the microwave emission. Also, the spectral resolution has to be similarly large so that enough upwelling energy is available to be recorded.

Passive microwave remote sensing is especially useful when one wants to see the effects or concentration of nearly anything water related (i.e. soil moisture, ice water content, precipitation, etc.). [see Elachi and Zyl (2006), Introduction to the Physics and Techniques of Remote Sensing, 3nd ed., Ch. 6, Wiley & Sons Inc. New Jersey.] Image courtesy of NASA.

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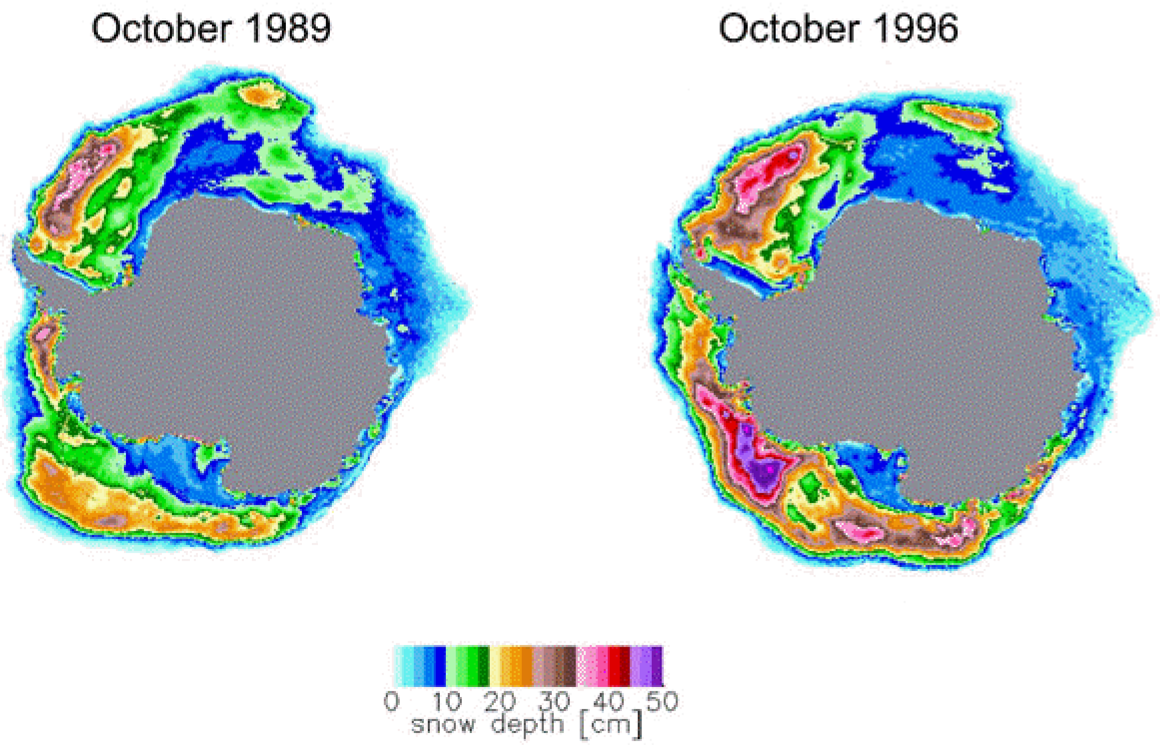

Refraction: The bending of a wave as it passes from substances of different densities to another. The bending of light results in a change of wave speed and direction. The amount of bending depends on the indices of refraction and the angles at which the energy is incoming. Waves can be of any type; electromagnetic, sound, light, etc…

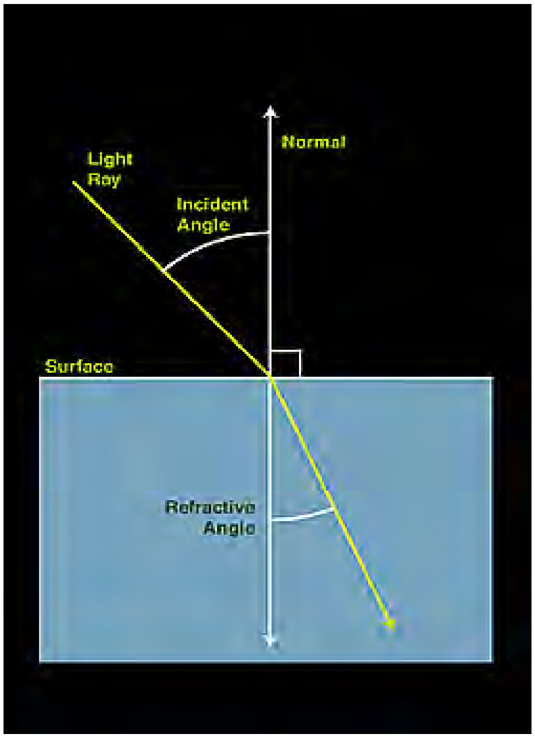

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Figure 1: Angles of Incidence and Refraction (2D)
(Lampkin Powerpoint via http://www.ps.missouri.edu/rickspage/refract/Fig4b.jpg)

Refraction within a medium is most important because it helps to describe the medium at which energy is incident on. Depending on the medium, the amount of absorption, transmission, and scattering can be determined, which all are components of the radiation budget.

- Can be Quantified using *Snell's law* to get the *Index of Refraction*.

  - *Index of Refraction* is the speed of light in a vacuum divided by the speed of light in the medium.

    $$n = c / c_n$$

    Where c= speed of light in vacuum (3x10^8 m/s)
    c_n = speed of light in a substance

Indices must be greater than or equal to 1.

Some typical Values:

Vacuum 1.000	Ethyl alcohol 1.362
Air 1.000277	Ice 1.31
Water 1.333	Diamond 2.419

  - *Snell's Law* allows us to quantify the amount or degree of refraction between two medium. In 1621, Dutch physicist Willebrord Snell determined the angular relationships of light passing from one medium to another. The law states that for a given frequency of light, the product of the index of refraction and the SINE of the angle between the ray of the incoming energy and the medium normal to the interface are constant.

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

Where:
n_1 is the refractive index of the refractive medium
theta$_1$ is the incident angle between the light ray and the normal to the medium.
n_2 is the refractive index of the refractive medium
theta$_2$ is the angle of refraction

Thus, if you know the index of refraction of a medium as well as the angle of incidence, it is possible to predict the amount of refraction in medium n_2

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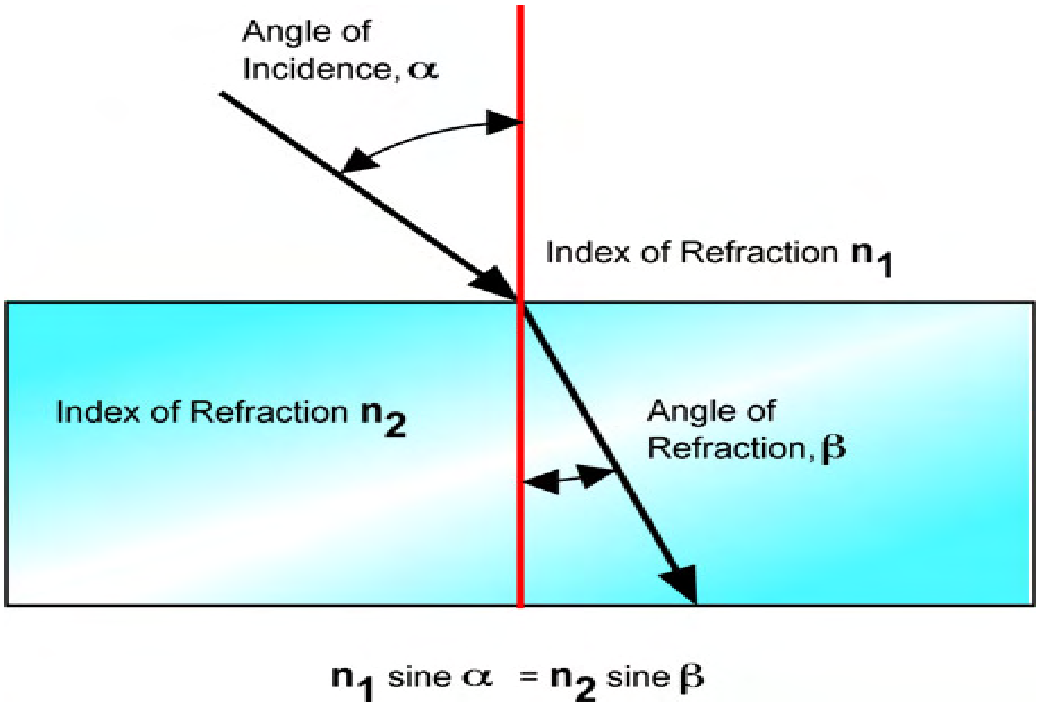


Figure 2: Image of refraction indices with respect to mediums and angles
(http://www.datasync.com/~wizard/Lasers/Refraction348.jpg)

Understanding Refraction:

- Wavelengths slow down upon entering a medium of higher index of refraction.
- If the incident medium has a larger index of refraction, than the angle with the normal is increased.
- Energy bends inward (toward the surface normal) when entering a medium of higher index of refraction. (Fig3)
- Energy bends outward when entering a medium of lower index of refraction.

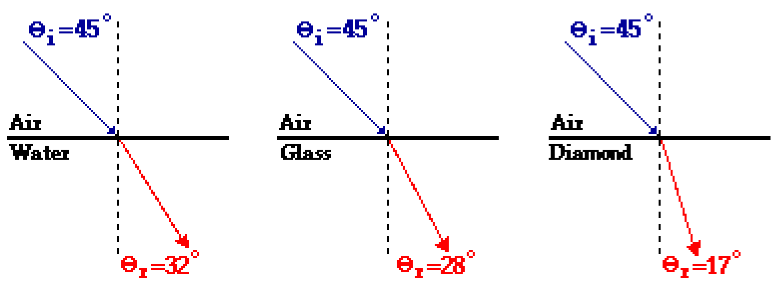


Figure 3: The angle of refraction is dependent upon the index of refraction for which the medium is entering. As the refractive index becomes larger than air, the angle of refraction becomes smaller.
(http://www.glenbrook.k12.il.us/gbssci/Phys/Class/refrn/u14l2a.html)

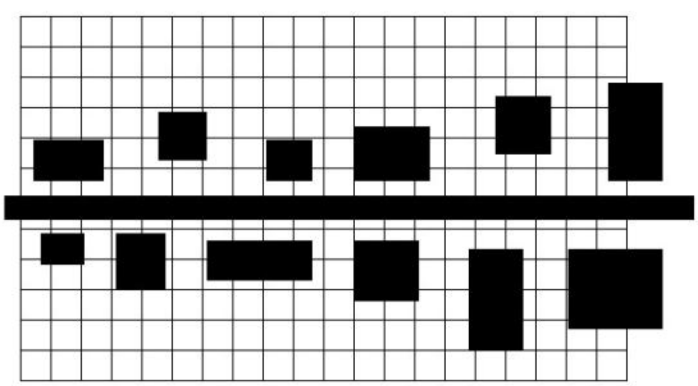
** Note: When energy moves from a dense to less dense medium, Snells law cannot be used to calculate the refracted angle. Before this ray "Internally reflects", the energy refracts at the critical angle, which can be found by substituting 90degrees for the angle of refraction. Thus, the critical angle is equal to the SINE inverse of medium 2 divided by medium 1. When Theta 1 is greater than the critical angle, the energy undergoes *total internal reflection*. (http://theory.uwinnipeg.ca/physics/light/node5.html)

Applications:

- Refraction is seen when looking into a bowl of water because airs refractive index is less than waters.
- Refraction is responsible for rainbows, mirages and Fata Morgana. These are caused by the change of the refractive index of air with temperature.
- It is important to know the refractive index, because in the earth's atmosphere, composition, temperature, and humidity can affect the density of a medium.
- Used as one component of the radiation budget, and in determining the amount of incident energy from one to source to another.

Source: National Aeronautics and Space Administration (Content source); Peter Saundry (Topic Editor). 2008. "Refraction." In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). [First published in the Encyclopedia of Earth January 3, 2007; Last revised August 22, 2008; Retrieved January 19, 2009]. <http://www.eoearth.org/article/Refraction>

Resolution, Spatial: the smallest angular/linear separation between two objects that can be resolved by the sensor. The nominal spatial resolution is the ground-projected instantaneous-field-of-view (IFOV) at nadir (10 x 10m, 30 x 30m, 1 x 1km, etc.). The general rule for "adequate" spatial resolution is the ability for the sensor to resolve features less than one half of the size of the feature of interest—if you wanted to count the number of houses in a suburb, you would need a spatial resolution of less than half the size of the smallest house in the vicinity. The following example shows a spatial resolution of about 3 meters. This resolution would certainly be adequate if one wanted to count the number of houses on this particular street. [see Jensen, John (2000), Remote Sensing of the Environment, 15pp, Prentice-Hall, Inc. New Jersey.]



S

SAA – Southern Atlantic Anomaly is an area where the inner Van Allen radiation belt makes its closest approach to the earths surface. The tilt and offset of the earths magnetic field an area in the South Atlantic ocean is the closest to the radiation belt and an area in the northern Pacific is the furthest. This allows cosmic rays and charged particles to reach lower into the earths atmosphere, as shown in Figure 1.[x] This requires that satellites and space craft pass through this area if the orbit includes this anomaly and the strong radiation effects must be accounted for in the design of a satellite or spacecraft. The International Space Station, orbiting with an inclination of 51.6°, required extra shielding to deal with this problem. The Hubble Space Telescope does not take observations while passing through the SAA.[xi]

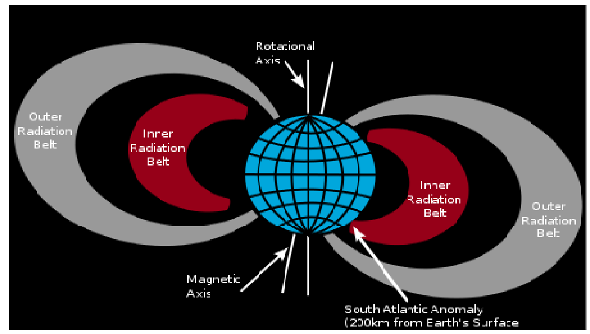


Figure 23 Van Allen radiation belts and the SAA

It can affect the communications with satellites, aircraft, spacecraft including both the International Space Station and the Space Shuttle. SWIFT satellite and others that have detectors in the X-ray band may even have to disable the equipment while in the SAA to prevent damage. Figure 2 shows the SAA in red, and the light shaded green regions are the auroral zones near the poles.

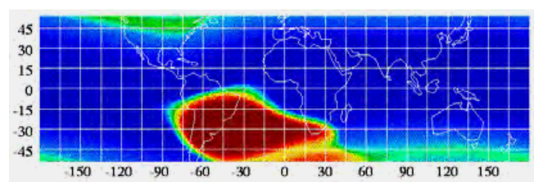
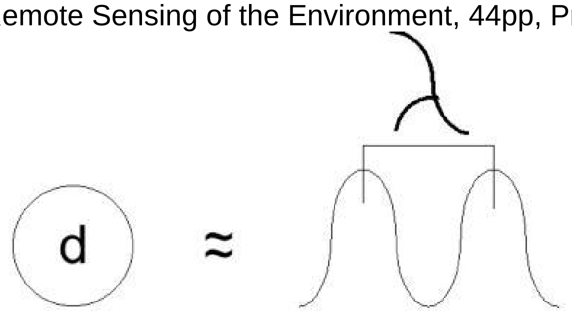
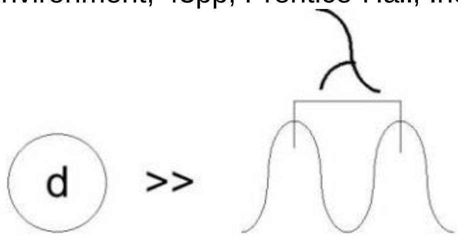


Figure 2 ROHSAT Image of SAA

Scattering, Mie: This type of scattering deals with particles that are approximately [0.1 to 10 times] the same size of the wavelength of incident radiation being scattered. Also, Mie scattering takes place in the lower part of the atmosphere where many spherical particles exist. The main contributors to this type are dust and pollution- higher concentrations of these particles yield more scattering of violet and blue light allowing more orange and red light to be seen making gnarly sunsets. [see Jensen, John (2000), Remote Sensing of the Environment, 44pp, Prentice-Hall, Inc. New Jersey.]



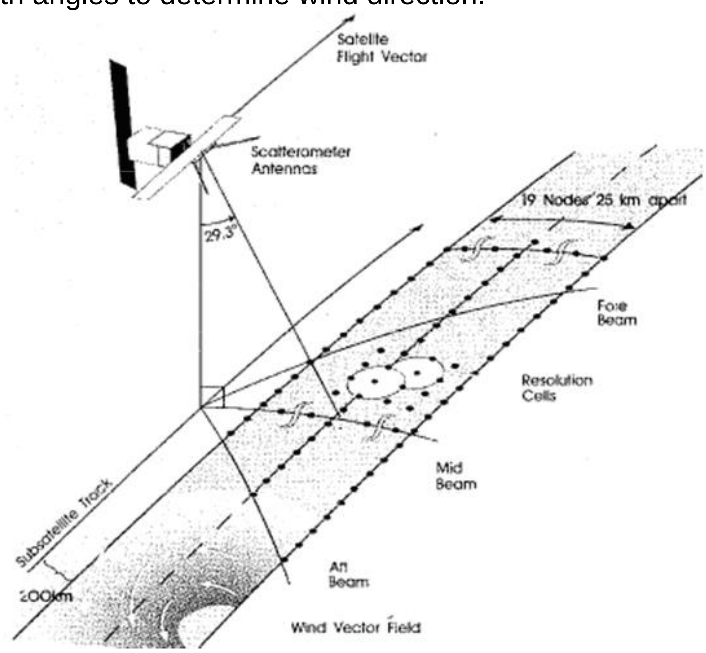
Scattering, Non-selective: This type of scattering deals with particles that are larger than ten times the wavelength of the incident radiation and is not dependant on the wavelength of the radiation- all bands are scattered. Non-selective scattering takes place in the lowest part of the atmosphere where various elements such as water vapor, ice crystals, and sea salt exist. [see Jensen, John (2000), Remote Sensing of the Environment, 43pp, Prentice-Hall, Inc. New Jersey.]



Scatterometer

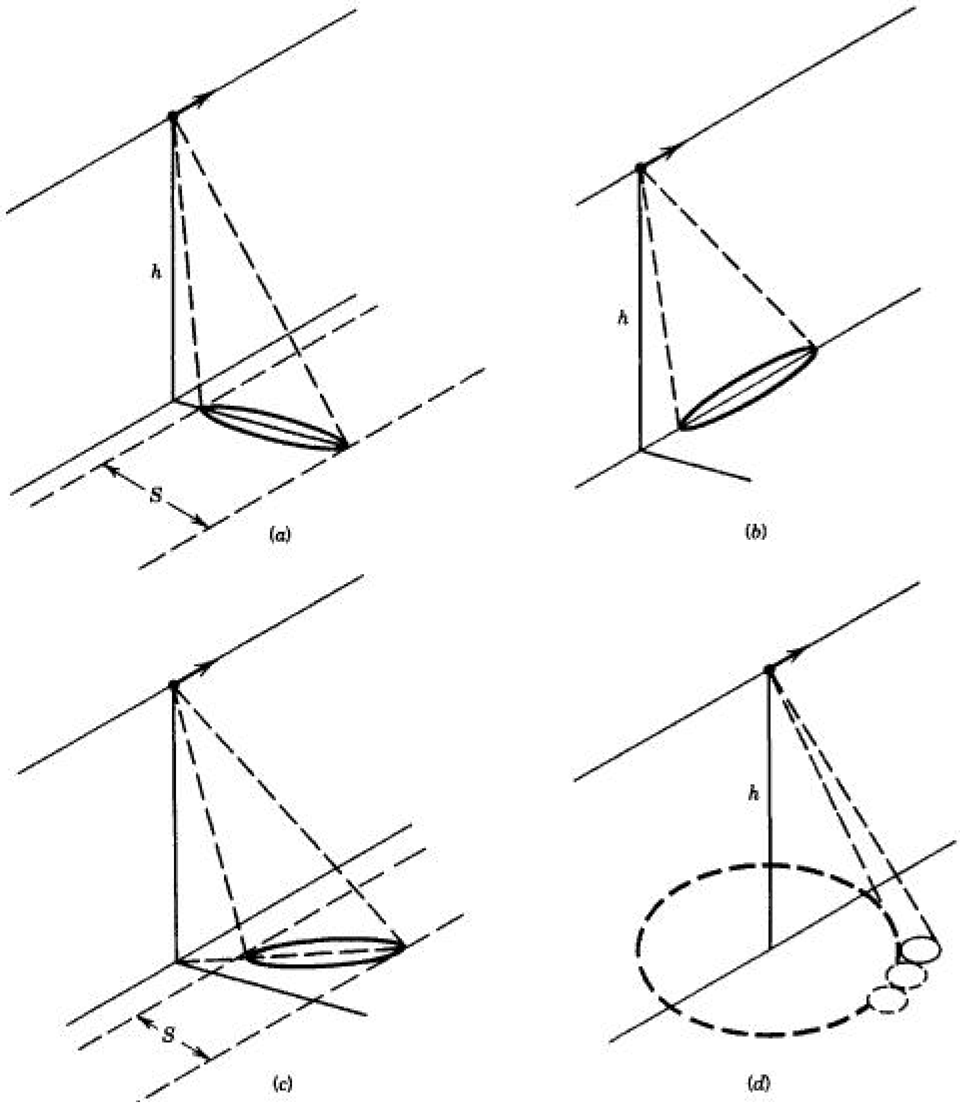
Scatterometers are radar sensors used to study average scattering properties over large spatial scales. They provide the backscattering cross section of a surface area illuminated by the sensor antenna. Microwave pulses are directed at the earth's surface and the reflected energy is measured. The background noise is subtracted from the signal and noise measurement to determine the backscatter signal power. Sigma -0, the normalized radar cross section, is then determined from the signal power measurement using a distributed target radar equation. Not surprisingly, they have a large footprint.

The principle behind scatterometers lies in the fact that the strength of radar backscatter is proportional the surface capillary and small gravity wave amplitude (Bragg scattering), which are related to near-surface wind speed. The radar backscatter can be measured at different azimuth angles to determine wind direction.



Scatterometer operation. Image from Wikipedia Commons, originally from U.S. National Oceanic and Atmospheric Administration (http://en.wikipedia.org/wiki/File:Scattometer_principle.GIF).

In a scatterometer, the electronics system contains a transmitter, receiver and digital signal processor. These generate the microwave pulses which are sent to earth by the antenna subsystem. The pulses are reflected by surfaces as backscatter, which are detected by the antenna and converted into digital form by the electronics system. The command and data system collects data on the location and instrument conditions to facilitate the operation of the instrument by the command center on the ground. Several different configurations for sensing are possible, as shown in the accompanying figure from Charles Elachi and Jakob van Zyl, 2006. -



Scatterometer patterns: Top left, A) side looking fan-beam scatterometer allows sensing of a wide swath; Top right, B) forward looking fan beam scatterometer allows measurement only along the flight path but for a variety of incidence angles; Bottom left, C) the tilted fan beam allows wide swath sensing and multiple look direction measurement; Bottom right, D) scanning pencil beam provides backscatter measurement at a constant angle and dual look direction over a wide swath. (Charles Elachi and Jakob van Zyl, 2006.)

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Scatterometer radar signals can penetrate the surface and observe subsuficial/ subcanopy features. Scatterometers used in studying near surface winds over oceans, polar ice, vegetation, soil moisture and unusual weather such as hurricanes. NASA's Scatterometer Climate Record Pathfinder (SCO) project produces data time series to assist in climate studies of the Earth's cryosphere and biosphere. Some scatterometer satellites include Seasat, which carries a Ku-band scatterometer (SASS); the European Space Agency's Earth Remote Sensing 1 and 2 C-band missions; the NASA Scatterometer (NSCAT) mission; Seawinds on QuikSCAT, and Seawinds on ADEOS-II/Midori2. NASA produces datasets consisting of time series of enhanced resolution images made by scatterometers using the Scatterometer Image Reconstruction (SIR) and SIR with filtering algorithms.

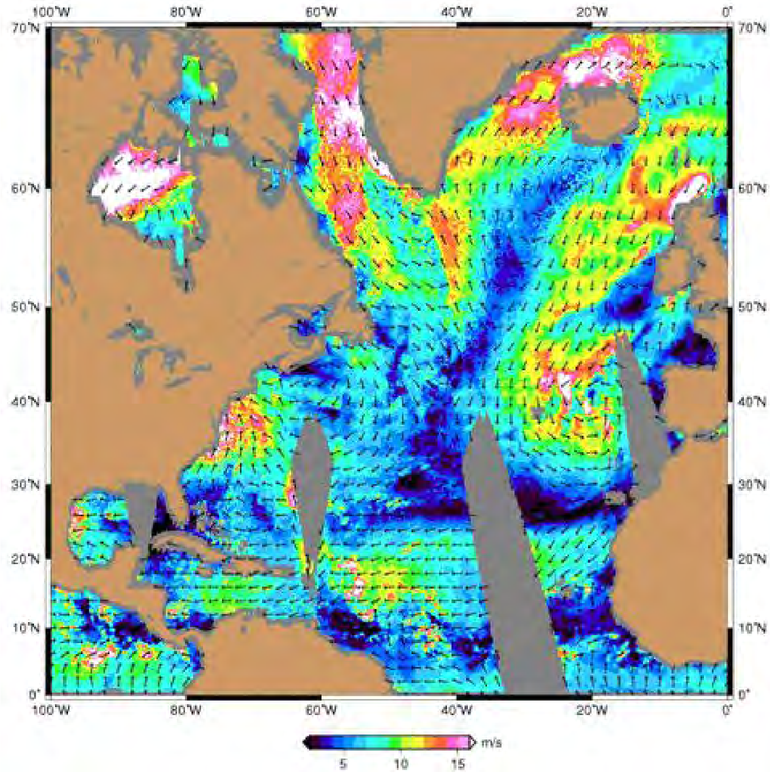

Image of Wind speed data from QuikScat scatterometer, aboard SeaWinds during Hurricane Isabel in 2003.
Image from Aviso/Nasa/JPL http://www.aviso.oceanobs.com/en/applications/atmosphere-wind-and-waves/hurricanes/isabel-2003/index.html

References
Charles Elachia and Jakob van Zyl, *Introduction to the Physica and Techniques of Remote Sensing,* 2006, John Wiley and Sons, Inc, New Jersey.
NASA Scatterometer Climate Record Pathfinder (Center for Remote Sensing – BYU), http://www.scp.byu.edu/
Wikipedia Commons, http://en.wikipedia.org/wiki/NASA_Scatterometer
Aviso, *Isabel 2003*, http://www.aviso.oceanobs.com/en/applications/atmosphere-wind-and-waves/hurricanes/isabel-2003/index.html
NASA, *Sea Winds Scatterometer,* http://winds.jpl.nasa.gov/aboutScat/sws_dwg.cfm

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Schlieren Imaging:

Optical process used to visualize local density variation in a fluid. It was first developed in 1964 by a German physicist August Toepler to study supersonic motion.

The basic principle can be described as follows (Figure 24). The light from a collimated source is shining behind a target object. The collimated light is focused with a lens. A razor blade is placed at the focal point, positioned to block half the light. In flow of uniform density this would simply make the image half as bright. However, density gradients due different factors (pressure gradients, temperature gradients…) distort the beam. That distorted beam focuses imperfectly, and parts which have focused in an area covered by the razor blade are blocked.

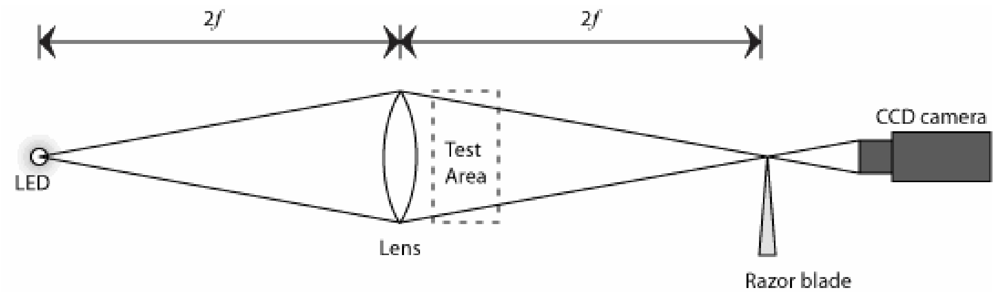

Figure 24. A simple Schlieren imaging set up.

The razor blade could be replaced by a colored "bullseye" target, resulting in Rainbow Schlieren which can assist in visualizing the flow. The result is a set of lighter and darker patches corresponding to positive and negative density gradients in the direction normal to the razor blade. Figure 25 (a) and (b) shows example of results that can be obtained with the Schlieren technique.

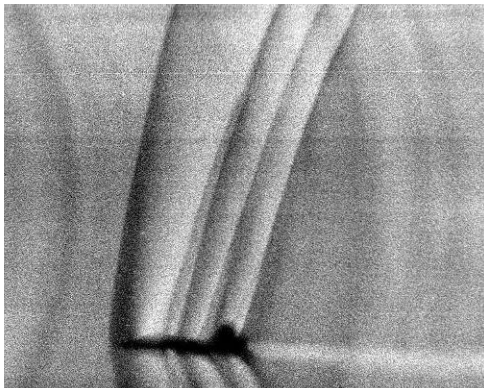

Figure 25. (a) Shock waves produced by a T-38 Talon during flights.

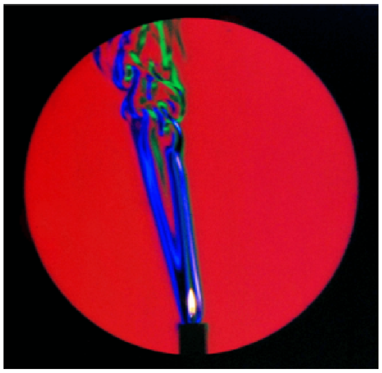

Figure 26. (b) Color Schlieren imaging of the thermal plume from a burning.

Refererences:

- Wikipedia: Shlieren Photography.
- *Schlieren and Shadowgraph Techniques: Visualizing Phenomena in Transparent Media*, by Gary S. Settles
- *Electrical Breakdown and Discharges in Gases, Macroscopic Processes and Discharges*, Kunhardt E.E. and Lawrence H.L., NATO ASI Series, Series B: Physics, Vol. 89b.

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Selective Availability

Selective availability is a function in the Global Positioning System (GPS) navigation system which is currently disabled. The feature was intentionally developed to degrade the signal transmitted from the GPS satellites to civilian GPS receivers. The GPS signal was degraded in selective availability by introducing random errors in the signal.

The GPS receiver is composed of an antennae and a clock (crystal oscillator). In present day, the actual OEM GPS receiving unit is quite small, measuring 1.5 by 1.7 cm. The number of channels of the GPS unit specifies how many satellites the GPS can monitor simultaneously at any given time. Although originally limited to five channels, the GPS units today typically have between 12 and 20 channels. The technique of transmitting data is via a pseudo-random sequence encoded and sent by the satellite which in then decoded by the GPS receiver. Selective availability alters the signal transmitted by the satellite such that positional errors are automatically introduced once the signal had been decoded by the GPS receiving unit.

Selective availability was originally implemented by the United States military to prevent enemy troops from intercepting GPS signals and using positional information for their own advantage. United States military GPS receivers, however, were enabled with the encryption to correctly obtain an accurate signal. Selective availability was temporarily disabled during the early 1990’s for the Gulf War since many troops within the United States military were using commercial GPS receivers. With increasing use of commercial-grade GPS receivers in the late 1990’s, there was an increased need for high accuracy in civilian GPS units.

On May 1, 2000, selective availability was officially turned off by President Clinton upon recommendation by the Secretary of Defense. The reason for discontinuing selective availability was to improve scientific interests, transportation safety, and commercial enterprise, as outlined by President Clinton in a formal statement released by the White House on May 1, 2000.

Selective availability introduces a significant error source which affects the accuracy of positional measurement. When selective availability is turned on, typical positional errors are 10 meters (32 feet) horizontally and 30 meters (98 feet) vertically. Compared to other sources of error, selective availability is one of the largest GPS error sources, after ionospheric noise and position dilution of precision (Figure 1).

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GPS ERROR SOURCES

ERROR SOURCE	TYPICAL RANGE ERROR	DGPS (CODE) RANGE ERROR <100 KM REF-REMOTE
SV CLOCK	1 M	
SV EPHEMERIS	1 M	
SELECTIVE AVAILABILITY	10 M	
TROPOSPHERE	1 M	
IONOSPHERE	10 M	
PSEUDO-RANGE NOISE	1 M	1 M
RECEIVER NOISE	1 M	1 M
MULTIPATH	0.5 M	0.5 M
RMS ERROR	15 M	1.6 M
ERROR * PDOP=4	60 M	6 M

PDOP=Position Dilution of Precision (3-D) 4.0 is typical

Fig. 1: *Comparison of raster (b) and vector (c) data models to represent real data (a) (courtesy of James Detwiler)*

Detwiler, James. "What is a GIS?" GEOG 485. University Park, PA. 5 Sept. 2008.

Helen Couclelis, "Geographic information systems", in AccessScience@McGraw-Hill, http://www.accessscience.com, DOI 10.1036/1097-8542.757430

"GIS." Encyclopædia Britannica. 2009. Encyclopædia Britannica Online. 05 Apr. 2009 <http://www.britannica.com/EBchecked/topic/1033394/GIS>.

Signal to Noise Ratio (SNR):

Ratio of a signal power to the noise power corrupting that signal. It is an indication of the purity of a signal. The higher a SNR is, the less the observed signal is corrupted by its background. It has application in characterizing every measurement devices, whether it is electrical, optic or acoustic. The SNR can be written as follows.

$$SNR = P_{signal}/P_{noise} = (A_{signal}/A_{noise})^2$$

$$SNR(dB) = 10log(P_{signal}/P_{noise}) = 20log(A_{signal}/A_{noise})$$

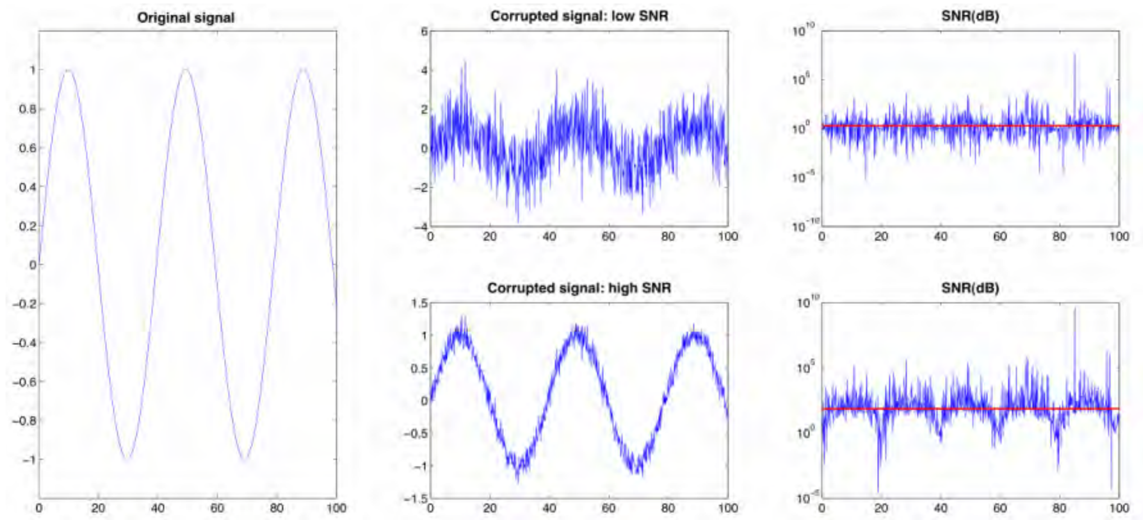

Figure 27. Simple illustration of a signal affected by noise and its SNR.

Figure 27 gives an example of a signal affected by different level of noise and the related SNR.
For image processing, the SNR has a slightly different meaning. It is defined as the ratio between the net signal value and the RMS noise. The net signal value is the difference between the average signal and background, and the RMS noise is the standard deviation of the signal value.

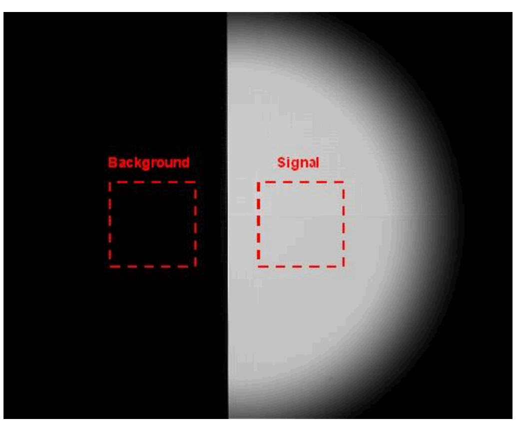

Figure 28. An operator arbitrarily defines a box area in the signal and background regions of a back-illuminated half moon or knife-edge test target. The data, (such as pixel intensity), is used to determine the average signal and background values.

References:

- Wikipedia: http://en.wikipedia.org/wiki/Signal-to-noise_ratio

Slit Spectrograph:

A spectrograph is an instrument breaking an incoming wave into its frequency spectrum. A slit spectrograph is used to observe natural phenomena whose scale and background are too large for a standard spectrograph. The slit not only selects a given field of view, it also increases the resolution by diffracting the incoming light. The rest of the instruments consist in a concave mirror used to collimate the light on a diffraction grating (used to produce the spectrum), and a set of lenses to focus the light on the detector (often preceded by an image intensifier). Figure 1 gives a good description of the instrument. Figure 2 shows an example of results obtained with a slit spectrograph to observe sprites.

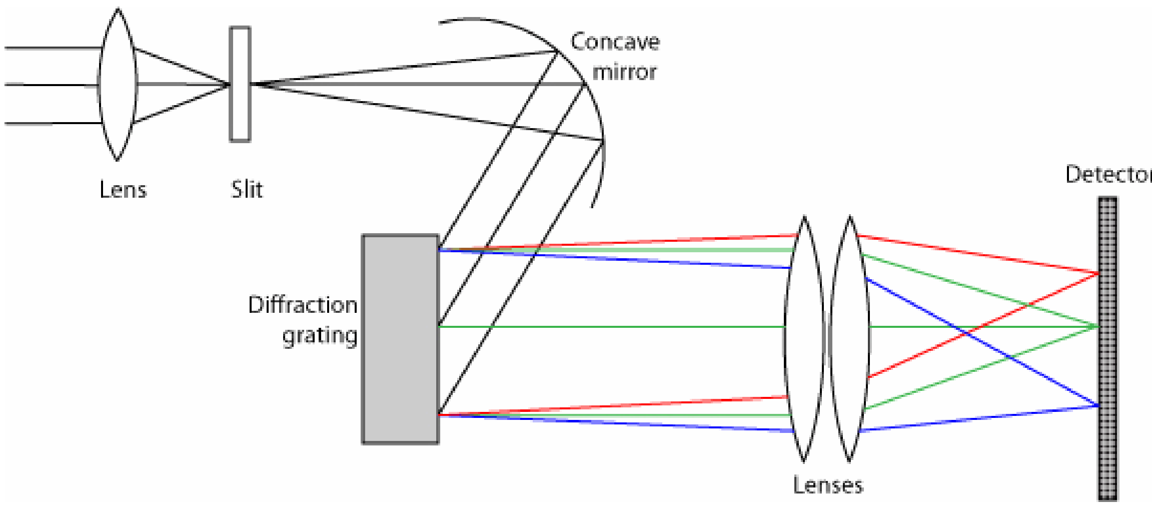

Figure 29. Slit spectrograph diagram.

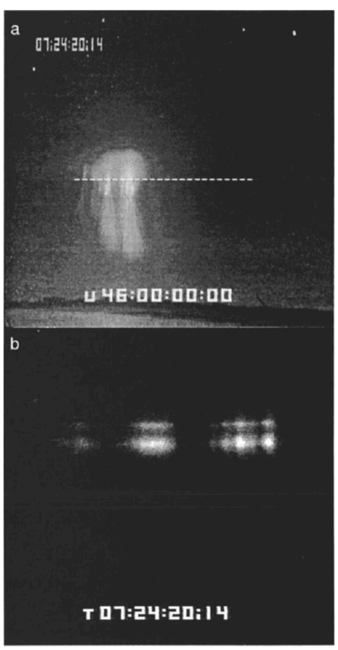

Figure 30. Example of a slit spectrograph acquisition. (a) Image of a sprite: the dashed line represent the position of the slit relative to the sprite. (b) Corresponding sprite spectra.

References:

- D. L. Hampton, M. J. Heavner, E. M. Wescott, and D. D. Sentman. Optical spectral characteristics of sprites. *Geophysical Research Letters*, 23(1):89–92, January 1996.
- S. B. Mende, R. L. Rairden, and G. R. Swenson. Sprite spectra; N_2 1 PG band identification. *Geophysical Research Letters*, 22(19):2633–2636, October 1995.

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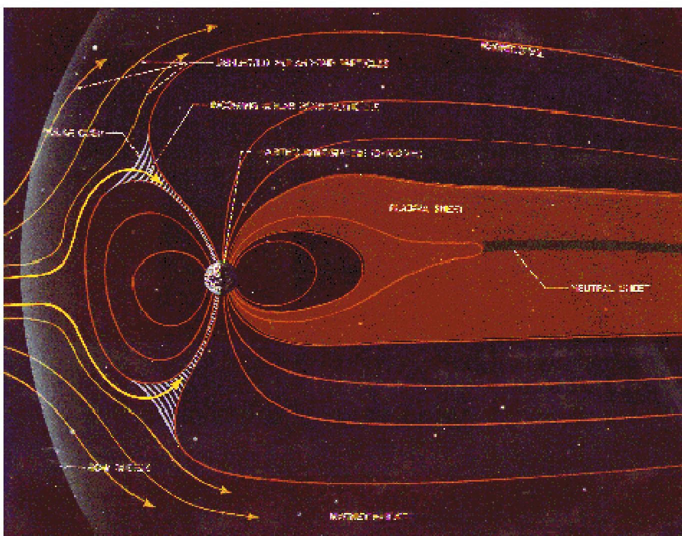
Solar Flux
Definition: The amount of solar energy incident on a surface (usually the earth's surface). Often needed for accurate remote sensing of data products[1]. Solar flux varies daily and on longer time scales, and can impact earth and satellite communications[2]. Measured in *power/area*, often in *watts / m^2* over a certain bandwidth or at a specific wavelength or frequency.

References

[1] http://acdb-ext.gsfc.nasa.gov/Data_services/merged/sbuv.alg_cal.html
[2] http://www.ngdc.noaa.gov/stp/SOLAR/FLUX/flux.html

Solar Wind – is a stream of charged particles, a plasma, ejected from the sun consisting mostly of electrons and protons. The particles can escape the effects of solar gravity due to the high temperature of the corona and a high kinetic energy level. The process by which the particles achieve the high energy level is not completely understood.[xii] They travel at speeds of 300 to 800 km per second with gusts in excess of 1000 km per second.[xiii] First direct observation of the solar winds was made by the Soviet satellite Luna 1.[xiv]



Solar winds are divided into two components referred to as the slow and fast solar winds. With the slow winds originating in the equatorial regions of the sun and the fast winds from the polar regions. Occasionally there are Coronal Mass Ejections that occur when large amounts of magnetic energy are released from the sun and may occur in conjunction with a flare but not always. This burst of ionizing radiation when it interacts with the magnetic field surrounding earth can create large fluctuations in the electromagnetic spectrum. As a result satellites can fail and can even damage systems on earth. One Storm in 1989 caused a failure of the Hydro-Quebec electric power system effecting over 6 million people in Canada and the United States.[xv]

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Solid Angle- A three dimensional angle that can be described as measuring the amount of field of view from a specific point that is occupied by an object. A solid angle is proportional to the surface area of an object projected on a sphere that is centered at the point the object is viewed from. The unit of measurement for solid angle is the steradian (sr). The solid angle a sphere occupies as viewed from a point within the sphere is 4π sr.

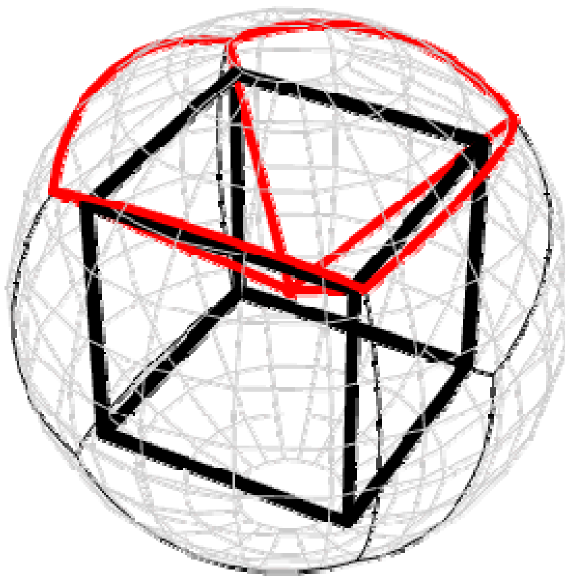
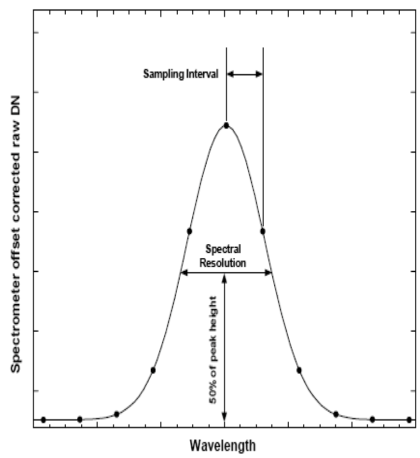


Figure 1 – The solid angle of a side of the black cube from its center is shown as the area on the sphere contained between the red lines.

Solid angles are important in remote sensing because they can be used to describe a sensor's beam. As such, a nadir-viewing instrument's footprint can be described in terms of solid angle. [see "Solid Angle". Wolframm Math World. http://mathworld.wolfram.com/SolidAngle.html]

Spectral Window- A band of the electromagnetic spectrum that allows for maximum transmission with the least amount of attenuation through a specific medium. Spectral windows vary depending upon the atmospheric constituent or surface property being studied. For instance, in analyzing ozone, one would utilize a different spectral window than when analyzing methane, in that these gases interact differently with different wavelengths of radiation. If the wrong spectral window is chosen, the observed radiation may not have been affected by the target medium, preventing any useful analysis. Furthermore, the wrong spectral window could lead to unwanted attenuation by other media within the beam such as water vapor or other gases.

Spectral Resolution – Has several definitions and one is the full width half maximum of measurement of an instruments response to a monochromatic source.[xvi] As shown in Figure 1. However this definition is also utilized to analyze the quality of an image when it does not have sharp edges.



Another definition is the range of wavelengths seen by a particular sensor. The smaller this range, the more specific the information the sensor can provide.[xvii]

The ability to distinguish two spectral features close to one another; the smallest difference in wavelength between two such distinguished features.[xviii]

Figure 31 Full Width Half Maximum

One additional definition the width of spectral bands that a satellite imaging system can detect. Often satellite imaging systems are multi-spectral meaning that they can detect in several discrete bands, it is the width of these bands that spectral resolution refers too. The narrower the bands, the greater the spectral resolution.[xix]

Spectral Response Functions

Spectral response functions (SRF) describe instrument or material sensitivity to different wavelengths of monochromatic light. These wavelengths are distinguished from one another due to differences in energy. Scanning monochromators or tunable lasers (Milton, 2004) are used to determine SRFs. All remotes sensing instruments (e.g. MODIS, ASTER) have individualized spectral response functions.

The data analysis homework from Meteo597K earlier this semester proves helpful in describing spectral response functions. Spectral response functions from the ASTER sensor transform library spectra for vegetation, water, and minerals into multispectral data. The figures below overlay library spectra with ASTER spectral response functions for calcite, decidous trees, and tap water. These figures illustrate the wavelengths in which ASTER can obtain data across the electromagnetic spectrum. There is only one spectral response function for ASTER but each library spectrum exhibits reflectance responses at different wavelength.

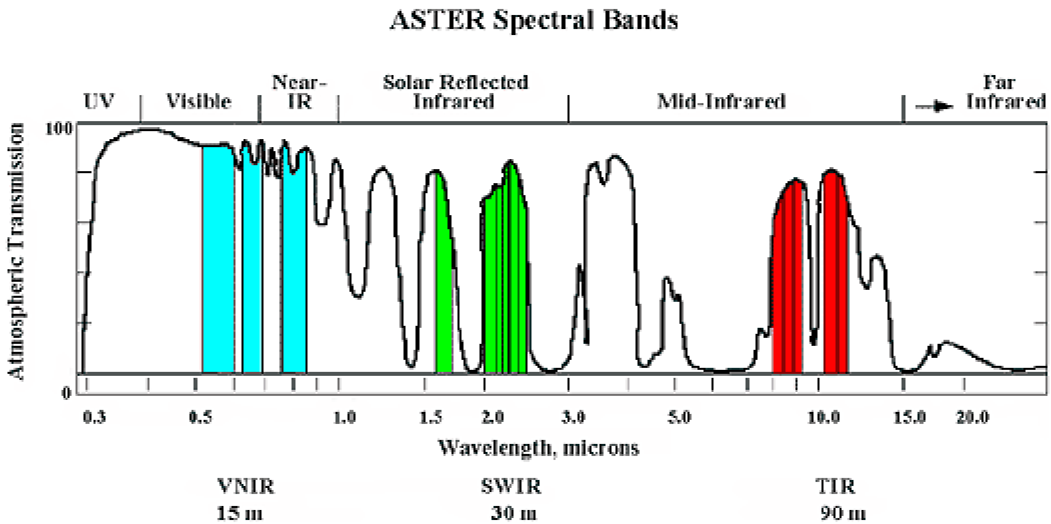


Figure 1 illustrates the 14 spectral bands of ASTER. The colored areas indicate the wavelengths over which each band is active. VNIR is the very near infrared portion of ASTER. SWIR is the shortwave infrared portion of ASTER. TIR is the thermal infrared portion of ASTER.

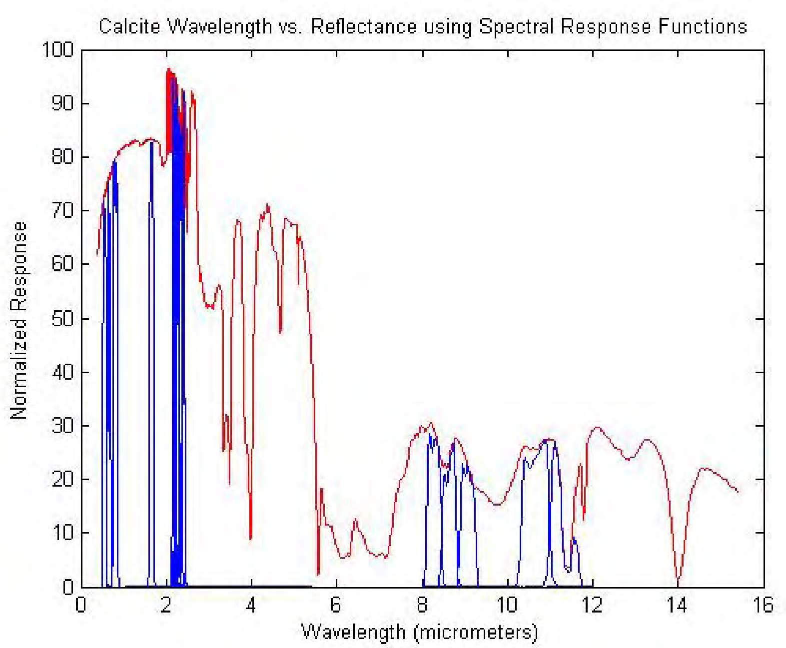


Figure 2 overlays the ASTER spectral response functions on the calcite library spectra. The spectral response functions at each wavelength over 14 bands were multiplied by reflectance to create the 14 blue segments in graph above. The calcite library spectrum is shown in maroon. This graph illustrates the gaps in ASTER data analysis on the calcite library spectra; only data within the blue bands can be analyzed (Zatko, 2009).

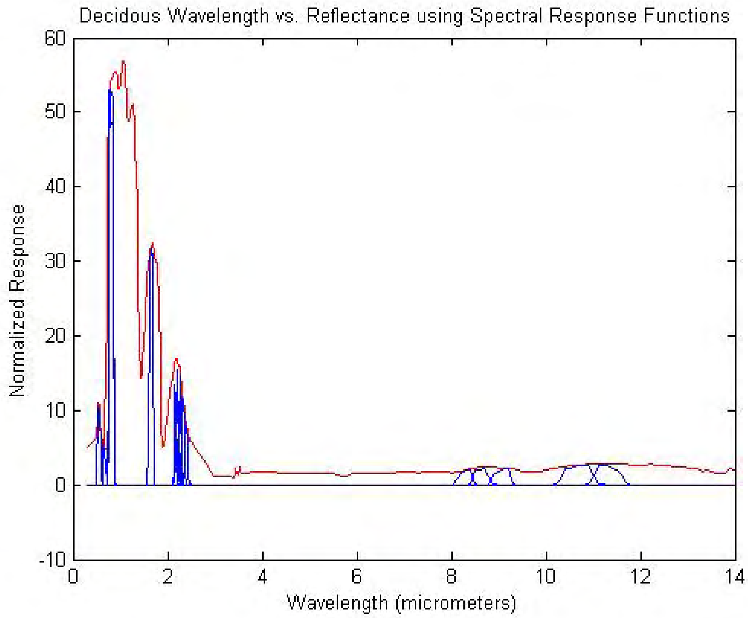


Figure 3 overlays the ASTER spectral response functions on the decidous library spectra. The spectral response functions at each wavelength over 14 bands were multiplied by reflectance to create the 14 blue segments in graph above. The decidous library spectrum is shown in maroon. This graph illustrates the gaps in ASTER data analysis on the decidous library spectra; only spectral data within the blue bands can be analyzed (Zatko, 2009).

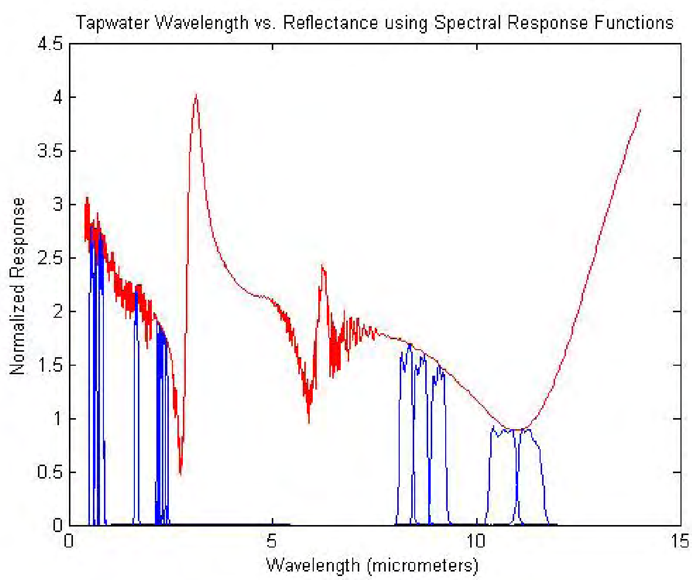


Figure 4 overlays the ASTER spectral response functions on the tap water library spectra. The spectral response functions at each wavelength over 14 bands were multiplied by reflectance to create the 14 blue segments in graph above. The tap water library spectrum is shown in maroon. This graph illustrates the gaps in ASTER data analysis on the tap water library spectra; only spectral data within the blue bands can be analyzed (Zatko, 2009).

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ASTER has 14 bands of information according to the following table:

Instrument	**VNIR**	**SWIR**	**TIR**
Bands	1-3	4-9	10-14
Spatial resolution	15m	30m	90m
Swath width	60km	60km	60km
Cross track pointing	±318km (24 deg)	±116km 8.55 deg)	±116km (8.55 deg)
Quantisation (bits)	8	8	12

Table courtesy of Geoscience Australia

References
Australian Government; Geosciences Australia. ASTER - Advanced Spaceborne Thermal Emission and Reflection Radiometer. 2009. http://www.ga.gov.au/remote-sensing/satellites-sensors/aster.jsp
Fantle, Matt. 597 Data Analysis Homework. 2009. https://cms.psu.edu/section/default.asp?id=MRG-081015-141648-msf17

Milton, Edward J. “Estimating the spectral response function of the CASI-2”. Nottingham, UK, Remote Sensing and Photogrammetry Society. 2004. http://eprints.soton.ac.uk/9188/.

Zatko, Maria. Remote Sensing 597K Data Analysis homework. 2009.

SRTM: The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale from 56°S to 60 °N to generate the most complete high-resolution digital topographic database of Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. The technique employed is known as Interferometric Synthetic Aperture Radar.

The elevation models derived from the SRTM data are used in Geographic Information Systems. They can be downloaded freely over the internet, and their file format (.hgt) is supported by several software developments.

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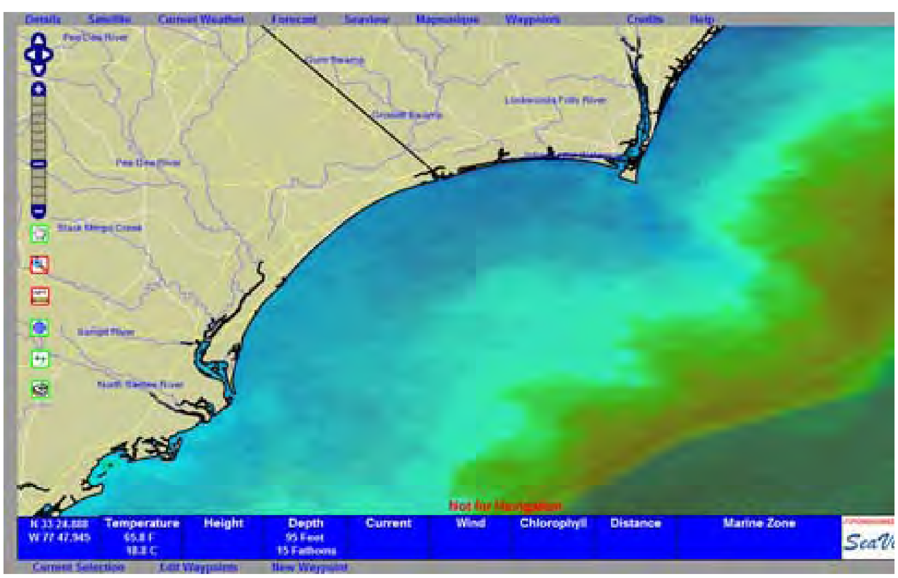
SRTM is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA).

http://www.nasa.gov/
http://en.wikipedia.org/
http://srtm.usgs.gov/

SST: Sea surface temperature is the water temperature close to the surface.

In practical terms, the exact meaning of *surface* varies according to the measurement method used. A satellite infrared radiometer indirectly measures the temperature of a very thin layer of about 10 micrometres thick (referred to as the *skin*) of the ocean which leads to the phrase *skin temperature* (because infrared radiation is emitted from this layer). A microwave instrument measures subskin temperature at about 1 mm. A thermometer attached to a moored or drifting buoy in the ocean would measure the temperature at a specific depth, (e.g. at 1 meter below the sea surface) — this temperature during the day is called temperature of the warm layer. The measurements routinely made from ships are often from the engine water intakes and may be at various depths in the upper 20 m of the ocean. In fact, this temperature is often called sea surface temperature, or foundation temperature. Note that the depth of measurement in this case will vary with the cargo aboard the vessel.



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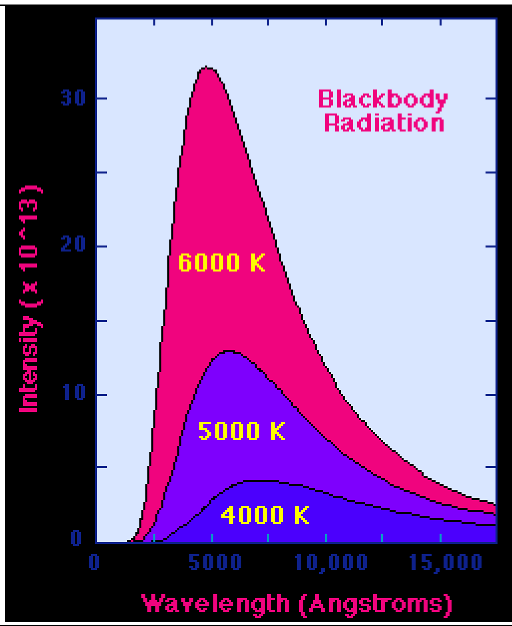
Reference:
http://sst-offshore.com
http://wikipedia.org
http://www.sstcharts.com/

Stefan Boltzmann's Law

Stefan-Boltzmann's Law, Plank's law and Wien's law are all related in that they pertain to blackbody radiators. A blackbody radiator is both a perfect emitter and absorber.

In basic terms, Stefan Boltzmann's law gives the total energy being emitted at all wavelengths by a blackbody (which is also correspondent to the area under the Planck Law curve).



This figure shows radiation emitted by a blackbody. The area under Plank's curve is equal to the energy emitted that's represented by Stefan Boltzmann's Law. Credit is given to http://csep10.phys.utk.edu/astr162/lect/light/radiation.html

Mathematically, Stefan Boltzmann's law describes that the energy radiated by a blackbody radiator is proportional to the fourth power of the absolute temperature. Or in equation form:
$E = \sigma T^4$, where $\sigma = 5.678$ e -8 watt/ m^2K^4.

For hot objects other than ideal radiators, the law is expressed in the form:

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$\frac{P}{A} = e * \sigma * T^4$, where e is the emissivity of the object, = 1 for an ideal radiator. The Stefan-Boltzmann relationship is also related to the energy density in radiation in a given volume of space.

Sun Synchronous - A sun synchronous orbit is a polar orbit (i.e. the orbit will cross the north and south poles) when the orbiting satellite passes the equator and all other latitudes at the same local time every day. For example, a sun synchronous satellite could measure cloud cover over Chicago at 3:00pm each day. In a sun synchronous orbit, the satellite must rotate 1 degree eastward to keep up with the Earth's revolution around the sun.
See: "Sun synchronous orbit." U.S. Centennial of Flight Commission. 08 Mar. 2009 <http://www.centennialofflight.gov/essay/Dictionary/SUN_SYNCH_ORBIT/DI155.htm>.

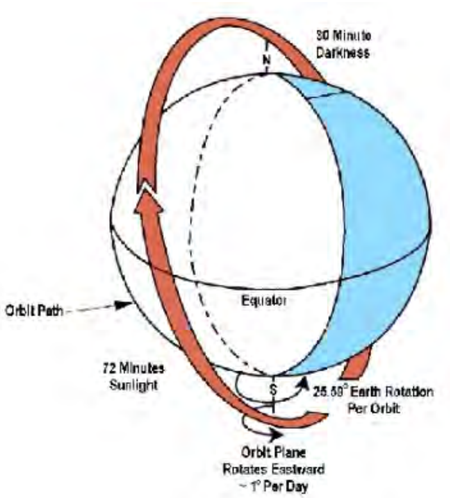

Figure 32: Sun Synchronous Orbit. From: http://www.centennialofflight.gov/essay/Dictionary/SUN_SYNCH_ORBIT/DI155G1.htm

Supervised Classification: a common method for identifying and classifying objects/features in a multispectral image. Most supervised classification methods involve 3 main stages: a training stage, a classification stage, and an output stage. In the training stage, training areas within the image are used to determine the spectral pattern of the specific features (e.g.—land cover types) of interest. Several training pixels should used be used for each feature of interest since the spectral properties of a feature can vary depending on scene characteristics (shadows, topography, etc.), Then, in the classification stage, the image pixels are classified based on which feature they are most similar to in terms of spectral characteristics. This is commonly accomplished with some form of spectral pattern recognition (e.g.—minimum-distance-to-means classifier, parallelepiped classifier, Gaussian maximum likelihood classifier). Finally, the results of the classification are presented in the output stage, typically in the form of a thematic map.

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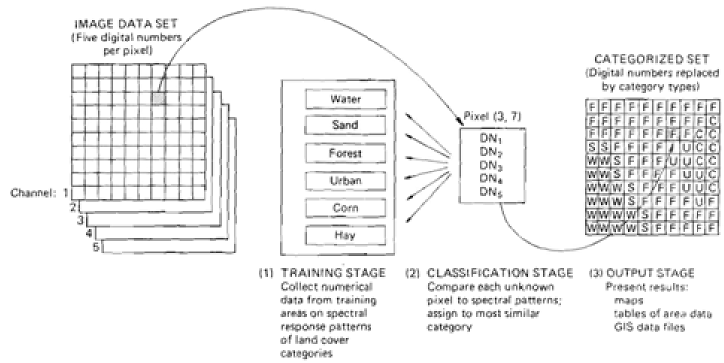
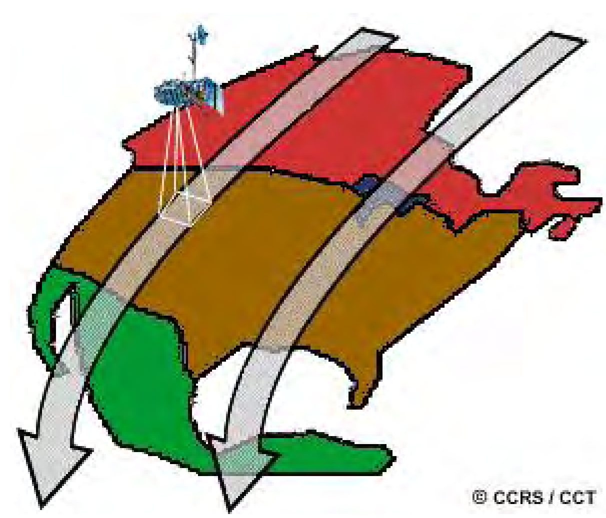


Figure 1: Typical steps and workflow for supervised classification.
Source: (Lillesand et al. 2008)

Sources
Lillesand, T., R. Kiefer, and J. Chipman. 2008. Remote Sensing and Image Interpretation. John Wiley & Sons Inc., Hoboken, NJ.

Swath

Swath is a measure of the surface, usually given in terms of width, which a sensor analyses as it moves over the Earth. It is used to describe the physical sensing range of satellite instruments, for example, 'a swath of 32 km'. Space instruments have swaths that range from tens to hundreds of kilometers. The combination of a satellite orbit and the rotation of the earth allow an instrument's swath to cover a different area with each consecutive pass. This is how satellites obtain global coverage of the Earth. Satellites are designed to retrace swath tracks over period of time. Swaths which are adjacent can overlap, especially in the cases of satellites in polar orbit.



This cartoon shows satellite swath during different passes.
Image from Canada Centre for Remote Sensing, http://ccrs.nrcan.gc.ca/

Swath 'tracks' can vary from satellite to satellite. For instance, the NASA Scatterometer makes observations on both sides of its central satellite track. The 'nadir' gap separating these two observational swaths is 400km wide, and the bands themselves are 600 km wide. Other satellites, such as ERS-1 and 2, have scatterometers that only measure on one side.

Swath data is referred to as levels. Level 0 data is in power units (volts or amps); Level 1 data is in instrument specific units (eg backscatter); Level 2 data is in geophysical units (eg direction); Level 3 data is gridded on longitude-latitude axes.

References
Canada Centre for Remote Sensing, *Tutorial: Fundamentals of Remote Sensing Satellites and sensors*, http://ccrs.nrcan.gc.ca/

Florida State University, Center for Ocean-Atmosphere Prediction Studies, *What are Swaths?*, http://www.coaps.fsu.edu/~bourassa/scat_html/what_are_swaths.shtml

Synthetic Aperture Radar (SAR) – A satellite- or aircraft-borne that utilizes many continuous microwave pulses of a small antenna to simulate a larger antenna. Thus, the simulated antenna is as long as the flight path of the satellite or aircraft over the time the pulses were taken. This technique is highly useful in military and research applications as it provides a high resolution mapping of surface features.

In order to obtain accurate, high-resolution results with a SAR, one needs a **fully-coherent** transmitter, a powerful SAR processor, and precise knowledge of the flight path and velocity. The benefit of SAR is that it allows for imaging with a resolution so fine that it would take an impractically large real aperture. Furthermore, synthetic aperture radar is useful in most weather conditions and its resolution is not dependent on altitude. One application of SAR, is interferometric synthetic aperture radar (INSAR) used in geodesy and remote sensing with applications in tectonics, volcanism, and the generation of digital elevation maps (DEMS). [see: "What is Synthetic Aperture Radar", Sandia National Laboratories, http://www.sandia.gov/radar/whatis.html]

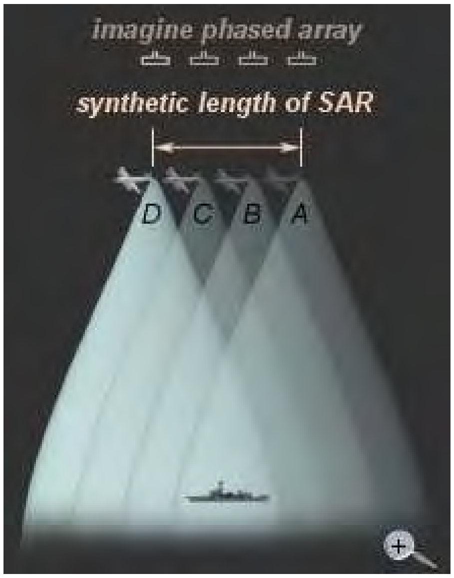


Figure 1 – A conceptual diagram of aircraft-born SAR.

T

Telemetry – one interpretation of could be measurement at a distance. Specifically it is the method of generation of an electrical signal that is proportional to the value being measured and transmitting to a distant station.[xx]

The term has its foundations in the early monitoring of electric power system distribution in 1912 in Chicago. Aerospace telemetry began in the 1930's with the use of radiosonde devices attached to tethered balloons transferring temperature, barometric pressure and humidity readings by radio to a ground station. [xxi]

Currently as applied to remote sensing: It is the transfer of data information by wireless or wired communications equipment.

Temporal Resolution: the frequency that a satellite system collects data for specified area over a period of time.

Temporal resolution of a sensor depends on a variety of factors:

- the satellite/sensor capabilities
- the swath overlap
- the latitude.

As a satellite revolves around the Earth, the sensor "sees" a certain portion of the Earth's surface. The area imaged on the surface, is referred to as the swath. Overlap in the imaging swaths increase with increasing latitude, causing regions near the poles to get sampled more frequently. The more frequently an area is captured, the better or finer the temporal resolution becomes.

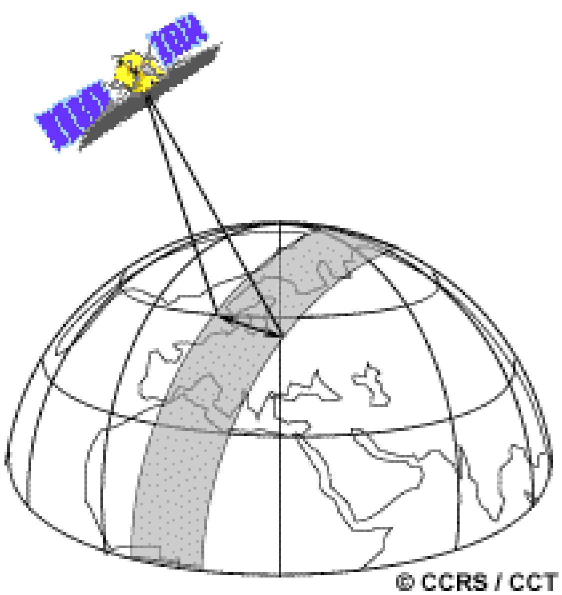
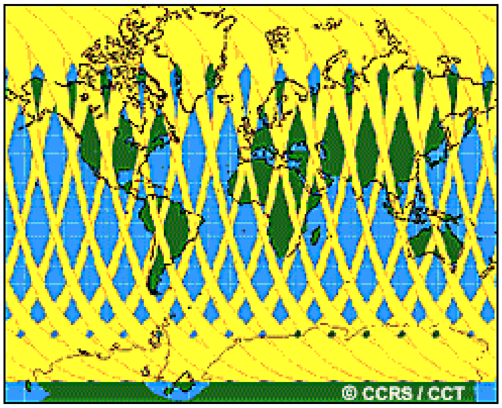


Figure 1: The overlap of many swatch paths. Temporal resolution will be higher at higher latitudes, due to the multiple overlaps of satellites in capturing data. Source: Canadian Center for Remote Sensing.

Figure 2: An example of an area swath capture. Source: Canadian Center for Remote Sensing



Additionally, the orbit a satellite follows can impact its ability to collect data. Some satellites at very high altitudes may follow a *geostationary orbit,* and will view the same portion of the earth at all times. These satellites can be used to collect data continuously, however if the satellite cannot depict through clouds or solar energy at night, there may be errors. On the other hand, *sun-synchronous orbits* cover each area of the world at constant local times. These types of satellites are most often used in collecting temporal data because of the consistent illumination conditions. Generally, these orbits also ascend on the shadowed side of the earth and descend on the sunlit side, where recording of reflected solar energy takes place.

The ability to collect imagery of the same area of the Earth's surface at different periods of time is one of the most important elements when choosing imagery. High temporal resolution images are generally used to identify spectral characteristics over a change time period.

Most often this type of resolution should be used when:

- persistent clouds offer limited clear views of the Earth's surface
- short-lived phenomena (floods, oil slicks, etc.) need to be imaged
- multi-temporal comparisons are required (e.g. the spread of a forest disease from one year to the next)
- the changing appearance of a feature over time can be used to distinguish it from near-similar features

Applications:

Sensors such as the AVHRR capture images more frequently than sensors such as the Landsat TM. Satellite imagery usually has a set temporal resolution. AVHRR data is often used to analyze trends of vegetation cover and conditions. AVHRR's data is often of very high resolution, so it must be supplemented with that of the LandSat data because of its finer resolution.

With most remote sensing images, comes the trade-offs of deciding what resolutions will best depict the quality of information needed from an image. When using high temporal resolution images, most often the spatial resolution is compromised. This tradeoff can be attributed to the finite speed of light. When a satellite sends out a signal to capture data over an area, by the time the signal is reflected back, the area may have undergone changes. Thus, the longer the light has to travel the lower the temporal resolution.

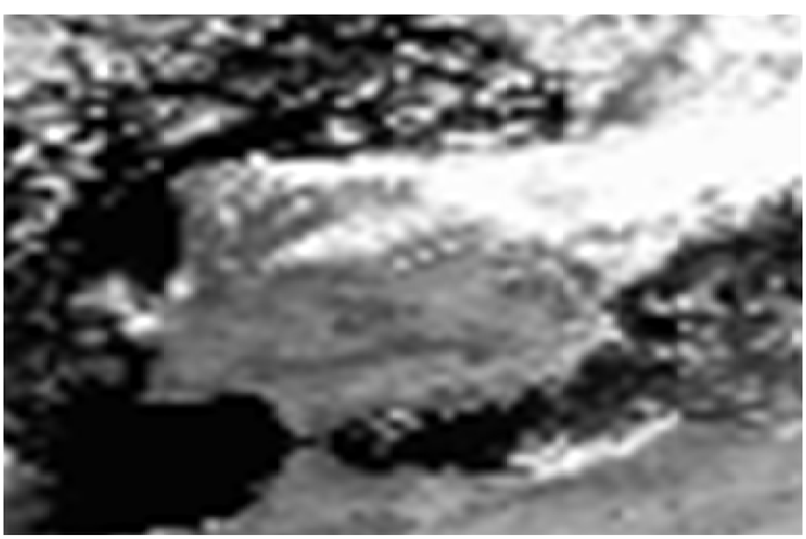


Figure 3: An example of high temporal resolution and low spatial resolution. Image displays monitoring of the atmospheric contaminants over a large area.
Source:
http://www.deimos-imaging.com/technology/remote-sensing
Ultimately, depending on the needs of a user,

the decisions of what resolutions and the specific qualities (time, area) which can impact an image should be defined in advance.

Sources:
Temporal Resolution. Accessed Feb 28 2008.
http://rangeview.arizona.edu/Glossary/tempres.html

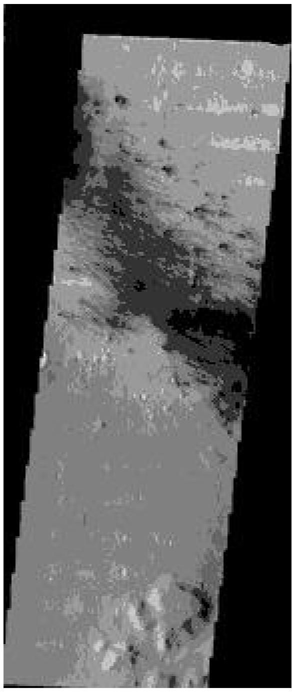
Canadian Center for Remote Sensing. Accessed Feb 28 2008.
http://www.ccrs.nrcan.gc.ca/resource/tutor/fundam/chapter2/06_e.php

THermal Emission Imaging System (THEMIS) & Spectrometer(TES)

The Thermal Emission Imaging System (not to be confused with NASA's Time History of Events and Macroscale Interactions during Substorms Mission) is an instrument consisting of two pushbroom spectrometers found onboard the Mars Odyssey spacecraft. The spacecraft was launched on April 7 2001 and arrived at Mars on October 24 2001. The primary Mars Odyssey mission was from February 2002 to August 2004, after which the extended mission started. The main goals are to determine if there was life on Mars, to characterize the climate, and prepare for human exploration of Mars. The main mission of THEMIS is to characterize hydrous mineral distribution by detecting heat radiated by minerals at the surface. The two other main science instruments were the Gamma Ray Spectrometer (GRS) and the Mars Radiation Environment Experiment (MARIE). A team of scientists under Dr. Phil Christensen of Arizona State University designed THEMIS.

Photo of THEMIS (NASA/JPL)

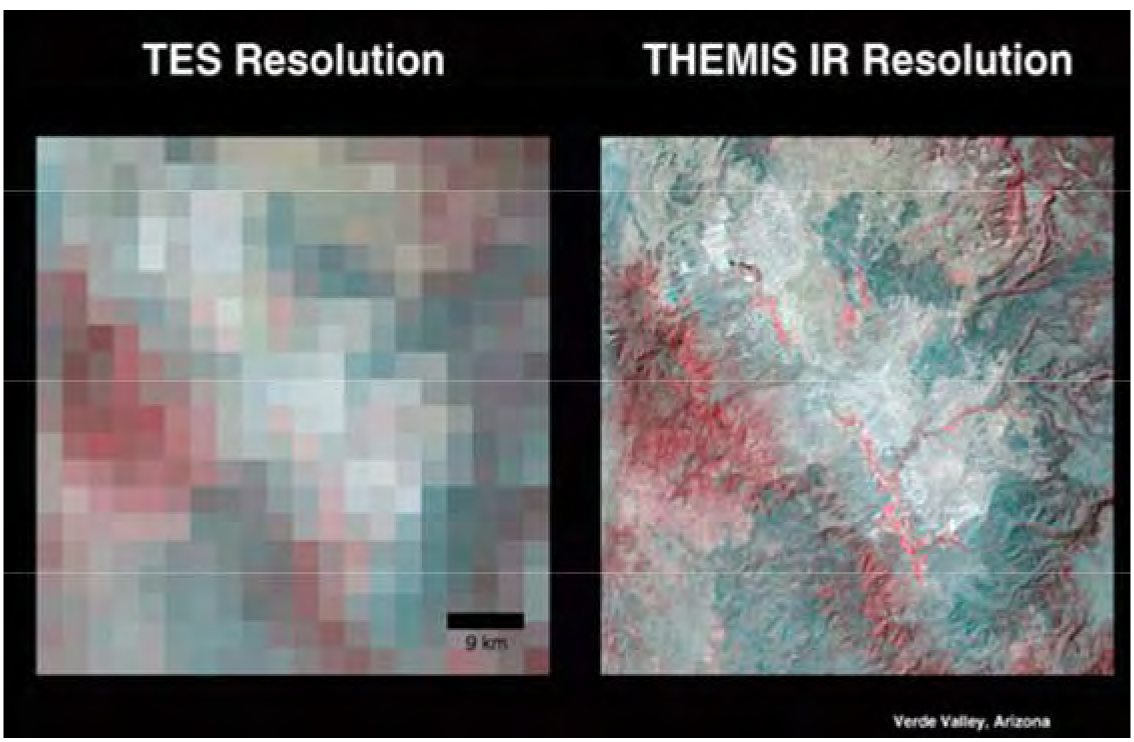
Of THEMIS' 2 spectometers, one operates in the visible (5 bands) and one operates in the thermal infrared (9 bands). Of the 9 thermal infrared bands, 8 are in the range of 6 to 13 microns, appropriate for detecting silicate spectra; the 9th band is used to monitor the atmosphere. The shortest infrared wavelength (6.78 microns) is measured twice to improve the signal to noise ratio. The resolution is 100m/pixel with a 32km swath. The multispectral capabilities of THEMIS allow active thermal spots and localized hydrothermal deposits to be detected. A similar technique is used by ASTER.



Statistics:
-Telescope: 3 mirror f/1.7 anastigmatic; 12 cm aperture; 20cm focal length
-Dichroic beam splitter separates the visible and infrared radiation.
-IR: 320x240 silicon microbolometer array
-4.6 degree field of view crosstrack by 3.5 degree downtrack
-Thermal infrared bands centered at 6.78,7.93,8.56, 9.35,10.21,11.04,11.79,12.57 and 14.88 microns.
-Mass: 12kg
-Power consumption: 12W

Left: THEMIS image of Gusev creater, Mars.
Image from NASA/JPL/ASU

THEMIS' spatial resolution is a great improvement on earlier thermal data obtained by the Thermal Emission Spectrometer (TES) during the Mars Global Surveyor mission. While THEMIS is multispectral with a high spatial resolution (100m/pixel) and low spectral resolution (9 IR bands), TES is hyperspectral with low spatial resolution (3x6km) and high spectral resolution (143 bands).



Comparison of TES and THEMIS resolution

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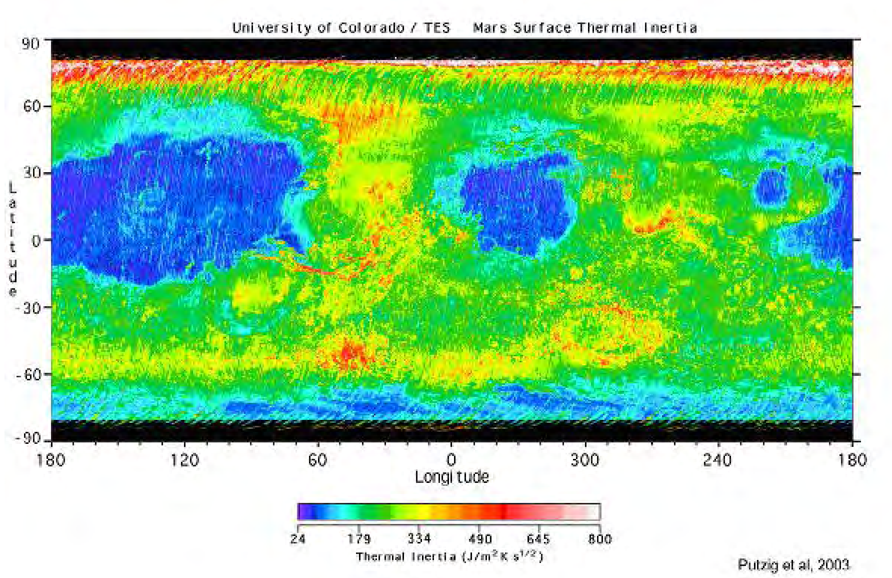
Image from NASA/JPL, http://mars.jpl.nasa.gov/odyssey/technology/tesvsthemis-image.html

Thermal Emission Spectrometer (TES)

TES was a thermal mapping instrument on the Mars Global Surveyor spacecraft, which launched in November 1996 and stopped transmitting in November 2006 after its battery ran out. The mapping phase of the mission was completed on 31 January 2001 and the spacecraft exceeded its expected lifetime. Like THEMIS, TES was designed under the lead of Dr. Phil Christensen. The goal of the TES mission was to measure the thermal energy emitted from Mars. Over 200 million infrared spectra were obtained during the mission. Some of the achievements of the mission included the first systematic study of Martian weather; characterization of the dark regions of Mars and the discovery of large areas of exposed bedrock.

TES, Image from ASU (http://tes.asu.edu/)



Mars Surface Colorized Thermal Inertia from TES data

Image from Putzig et al. 2005, http://lasp.colorado.edu/inertia/ti2003.html

For both TES and THERMIS, Arizona State University has a library of thermal infrared emission spectra for a variety of geologic materials. THEMIS is also the name of the Greek goddess of justice.

References:

Arizona State University, *Mars Odyssey Mission: THEMIS,* http://themis.asu.edu/

Arizona State University, *Mars Global Surveyor Thermal Emission Spectrometer*, http://tes.asu.edu/

Charles Elachia and Jakob van Zyl, *Introduction to the Physica and Techniques of Remote Sensing,* 2006, John Wiley and Sons, Inc, New Jersey.

NASA JPL, *2001 Mars Odyssey,* http://mars.jpl.nasa.gov/odyssey/

Putzig, N. E., M. T. Mellon, K. A. Kretke, and R. E. Arvidson, Global thermal inertia and surface properties of Mars from the MGS mapping mission, Icarus 173, 325-341, 2005.

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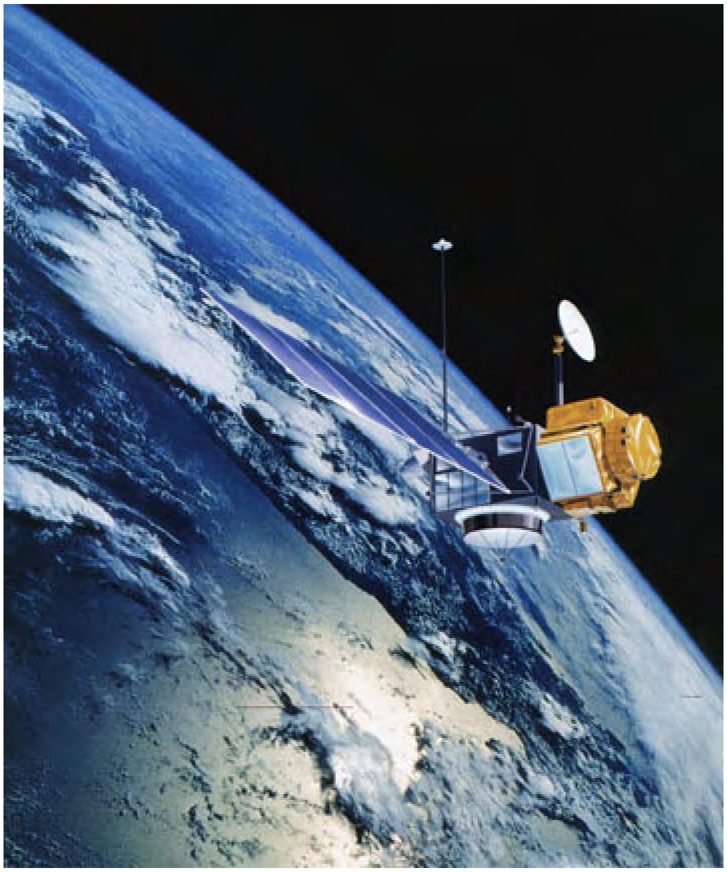
Topex/Poseidon: Launched in 1992, TOPEX/Poseidon was a joint satellite mission between NASA, the U.S. space agency, and CNES, the French space agency, to map ocean surface topography. The first major oceanographic research vessel to sail into space, TOPEX/Poseidon helped revolutionize oceanography by proving the value of satellite ocean observations.



While a three-year prime mission was planned, TOPEX/Poseidon delivered more than 10 years of data from orbit. In those years, the mission:

- Measured sea level with an unprecedented accuracy
- Mapped global tides for the first time
- Monitored effects of currents on global climate change and produced the first global views of seasonal changes of currents
- Monitored large-scale ocean features like Rossby and Kelvin waves and studied such phenomena as El Niño, La Niña, and the Pacific Decadal Oscillation

- Mapped basin-wide current variations and provided global data to validate models of ocean circulation
- Mapped year-to-year changes in heat stored in the upper ocean
- Improved our knowledge of Earth's gravity field

http://www.tsgc.utexas.edu/topex/
http://www.wikipedia.org

Transmissivity: A ratio of the amount of radiation that reaches a surface at a given angle[1]. The ratio is often computed using measurements (or estimates) of the total radiation striking a surface and the total amount of energy initially introduced into a system. Transmissivity is defined by Baigorria et al. as

$$\tau = \frac{H}{H_0} \times 100$$

Where H is the incoming solar radiation measured at the surface, H_o is the total incoming radiation from space, and τ is the transmissivity[2]. Transmissivity is of particular importance in remote sensing when active remote sensors are used. If the atmosphere has very low transmissivity for a given sensors wavelength, it will result in poor measurements due to power loss. For these reasons, transmissivity must be taken into account when considering instrumentation to study a given phenomena.

1. "Atmospheric transmissivity." APES - Agricultural Production and Externalities Simulator. 12 Apr. 2009 <http://www.apesimulator.it/help/models/solarradiation/Atmospheric_transmissivity.html>.
2. Baigorria GA, Villegas EB, Trebejo I, Carlos JF, Quiroz R (2004) Atmospheric transmissivity: distribution and empirical estimation around the Central Andes. Int J Climatol 24:1121–1136.

Traveling Wave Tube (TWT):
Device used to amplify radio frequency signals. They are two different kind of TWTs:
- Low power TWT: highly sensitive, low noise and wideband. Used as amplifiers in radar receivers.
- High power TWT: used as pre-amplifier for high power transmitters.

A TWT is able to reach gains of 40 dB with bandwidth larger than an octave (the upper frequency can be more than twice the lower frequency). Traditionally, TWTs have been designed for frequencies between 300 MHz to 500 GHz.
The design of the TWT is described in Figure 33.It is based on a vacuum tube. The electron gun produces an electron beam that propagates on the axis of the tube. The magnetic field generated on that same axis by surrounding magnets focus into a tight beam. The helix at the center of the tube is a coiled wire that provides a low impedance transmission line for the RF energy of the tube. The incoming RF signal induces a current in the helix. As shown in Figure 2, that helix, due to the Electric field created by

the current, causes a velocity modulation of the electron beam (called bunching of electrons). As it goes through the length of the helix, bunching becomes more and more important, inducing more and more current in the helix. The amplified current is eventually redelivered to an output waveguide at the end of the helix that will emit the amplified wave.

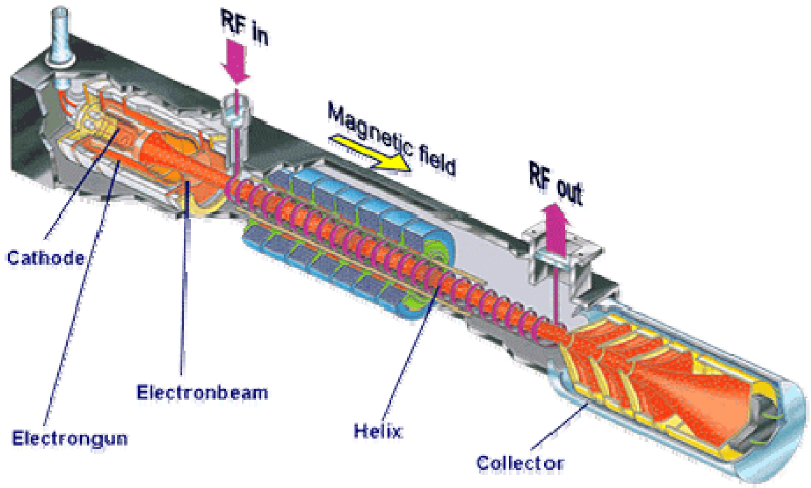


Figure 33. Diagram of a TWT.

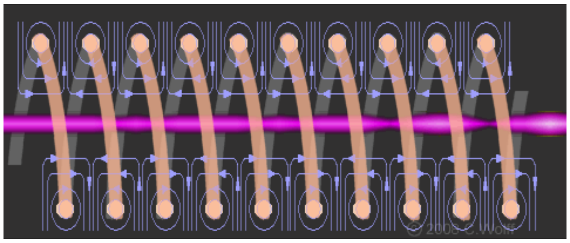


Figure 34.Electron beam bunching. The blue lines represent the electric field created by the current in the helix

TWTs are widely used in satellite transponders, where the input signal is very week and the output needs to be higher power.

References:

- Radar Tutorial
- J.R. Pierce, Theory of the Beam-Type Traveling-Wave-Tube. *Proceedings of the Institute of Radio Engineers*, Vol.35(2), 1947.
- NASA, Glenn Research Center website.

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Tropospheric Emission Spectrometer (TES)- A high spectral resolution Fourier Transform Infrared Spectrometer onboard NASA's Aura Satellite. Capable of both nadir and limb viewing, TES is designed to measure concentrations of ozone, carbon monoxide, water vapor, methane and their vertical profiles in the troposphere. Apart from these constituents, atmospheric temperature, surface temperature, land emissivity, effective cloud pressure and optical depth, as well as nitric acid may all be derived from TES radiance spectra. TES has a high spectral resolution of 0.1 cm^{-1} (for 4 second scans) and 0.025 cm^{-1} (for 16 second scans). The vertical resolution of TES-derived profiles depends on the constituent profile being derived and is determined by the averaging kernel for each scan. [see "Tropospheric Emission Spectrometer" http://tes.jpl.nasa.gov]

Figure 1 – The Tropospheric Emission Spectrometer before being added to the Aura Satellite.

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U

Unsupervised Classification: a common method for identifying and classifying objects/features in a multispectral image. Image pixels are clustered/classified according to the statistical properties of the spectral data. In contrast to supervised classification, this is done without user guidance or training data and the clusters formed from the analysis are simply spectral classes without a specific identity. It is up to the user to determine what the spectral classes actually represent. For instance, if a land cover classification is being performed, the user must decide which spectral classes represent deciduous forest, evergreen forest, shrub, barren land, etc. It is possible for two or more spectral classes to be identified as the same object/feature. Once the spectral classes are identified, a thematic map of the multispectral image can be produced. As with all image classification work, the results of the classification should be validated with ancillary data. Common statistical procedures for performing unsupervised classification include K-means and Iterative Self-Organizing Data Analysis Techniques A (ISODATA).

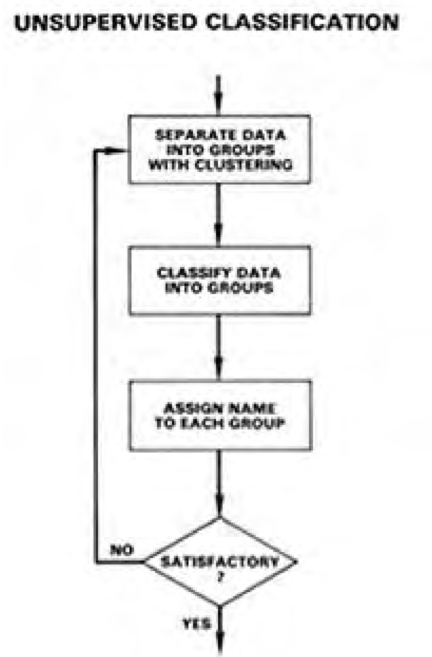

Figure 1: Typical workflow for unsupervised classification.
Source: http://rst.gsfc.nasa.gov/Sect1/Sect1_16.html

<u>Sources</u>

Adams, J. B. and A. R. Gillespie. 2006. Remote Sensing of Landscapes with Spectral Images: A Physical Modeling Approach. Cambridge University Press, New York, NY.
End to End Remote Sensing and Tutorial Page http://rst.gsfc.nasa.gov/Sect1/Sect1_16.html
Lillesand, T., R. Kiefer, and J. Chipman. 2008. Remote Sensing and Image Interpretation. John Wiley & Sons Inc., Hoboken, NJ.

V

Van Allen radiation belts - "The radiation belts are regions of high-energy particles, mainly protons and electrons, held captive by the magnetic influence of the Earth. They have two main sources. A small but very intense "inner belt" (some call it "The Van Allen Belt" because it was discovered in 1958 by James Van Allen of the University of Iowa) is trapped within 4000 miles or so of the Earth's surface.[xxii] The source of the particles is from cosmic radiation and Solar Winds.

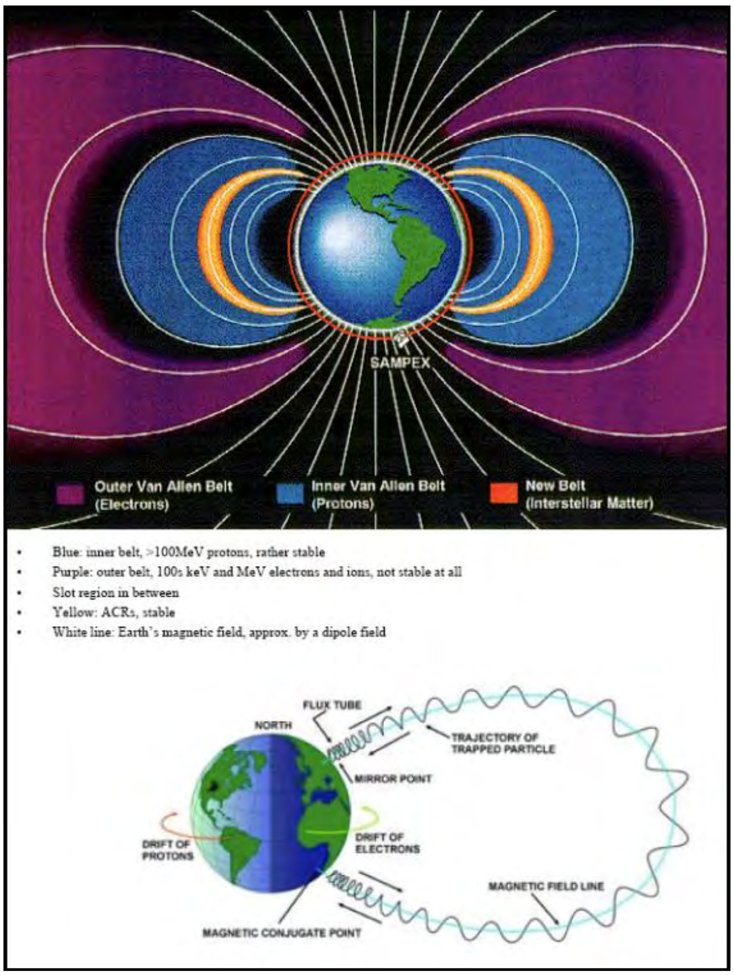

Figure 1 Van Allen Belts[xxiv]

Figure 1 shows a graphical representation of the radiation belts around earth.

Van Allen belts refer strictly to the earth system but other planets have been found to have radiation belts surrounding them.

Charge of the particles in this region can have energies exceeding 500 keV with fluxes of up to 9,4 x 10^9 particles per centimeter^2 per second. In the proton belt the kinetic energies can be over 400 MeV and can penetrate 143 mm of lead.[xxiii]

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VPI: Vegetation Productivity Indicator (VPI) is used to assess the overall vegetation condition and is a categorical type of difference vegetation index.

The VPI method was originally developed by C. Sannier (Sannier et al. (1), 1998) based on NOAA AVHRR data for a study area in Zambia, and later on implemented by Herman Eerens for Europe (for MARS-STAT) and Africa (MARS-FOOD / GMFS) (Boogaard et al., 2004) based on SPOT-VEGETATION data. It applies techniques commonly used in hydrology for the prediction of extreme events.

The VPI method is a a statistical distribution of the NDVI for each 10-day period of the year by applying techniques commonly used in hydrology for the prediction of extreme events. The VPI can be calculated based on DMP (Dry Matter Productivity) or NDVI values.

Reference:
http://gmfsgeonetwork.gim.eu
C. A. D. Sannier, J. C. Taylor, W. Du Plessis, K. Campbell, Real-time vegetation monitoring with NOAA-AVHRR in Southern Africa for wildlife management and food security assessment, *International Journal of Remote Sensing,* Volume 19, Issue 4 March 1998 , pages 621 - 639

W

Wavelength – a wavelength (λ) is the difference between successive peaks of a propagating wave. In a vacuum, wavelength of an electromagnetic wave can be calculated from a wave's frequency(number of oscillations per time) with the following equation.

$\lambda = \frac{c}{v}$ Where C is the speed of light and v is the frequency.

Waves also have many other properties including period, frequency, and amplitude.

From: Theo Koupelis and Karl F. Kuhn (2007). *In Quest of the Universe*. Jones & Bartlett Publishers.

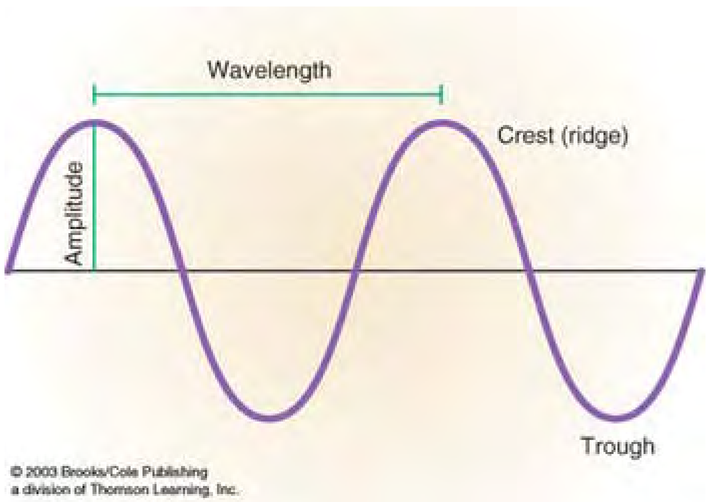

Figure 35: A picture of a wave showing its wavelength, from crest to crest.
From: The University of Wisconsin,
http://cimss.ssec.wisc.edu/satmet/modules/spectrum/wavelength.html

Wave propagation: Any of the ways in which waves travel through a particular medium. For electromagnetic waves, propagation (or movement) can occur both in a vacuum as well as in any material medium. Wave propagation is commonly conceptualized into two quantities: phase velocity and group velocity (speed) as they relate to energy/information propagation. A wave's velocity is mostly dependent on the density of the medium in which the wave is traveling through (from a remote sensing standpoint, this medium is typically the atmosphere or bodies of water that are detectable from space). Phase velocity is defined as:

$$v_p = \frac{\omega}{k},$$

Where v_p is the phase velocity, ω is the angular frequency of the wave (in radians/second), and *k* is the wave number (in radians/meter).

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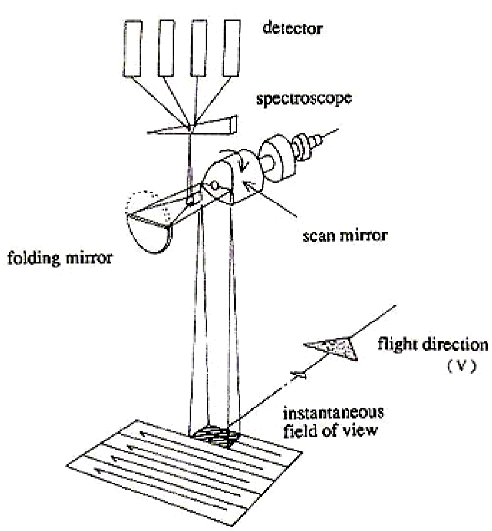
Group velocity is the speed of energy and information propagation and, for an electromagnetic wave, must be less than the speed of light. These two velocities are related in what is called a dispersion relationship where:

$$\omega = \Omega(k).$$

For waves propagating through the electromagnetic spectrum, the special case that $\Omega(k) = ck$ exists, which illustrates that all waves travel at the same speed c. Because of this characteristic of waves traveling through the electromagnetic spectrum, they are called non-dispersive waves. The dispersion relationship depends on the medium through which the wave propagate and on the type of waves. In the electromagnetic spectrum and in almost all other cases of wave propagation, a wave is mainly a movement of energy through a medium. Most often, the group velocity is the velocity at which the energy moves through this medium.

REFERENCES:
1) Dilbag Singh and S. K. Tomar, "Wave propagation in micropolar mixture of porous media" International Journal of Engineering Science, Volume 44, Issues 18-19 , November 2006, Pages 1304-1323.
2) Weisstein, Eric. "Wave Velocity." Science World. Wolfram Research. <http://scienceworld.wolfram.com/physics/WaveVelocity.html>.

Whisk-broom Sensor: This particular sensor uses a scanning mirror and linear arrays to resolve the objective. As the satellite passes over the earth, a rotating drum housing a mirror spins capturing each pixel (of determined spatial resolution) individually. The pixel data is then reflected off several mirrors into the objective aperture into the collimator. Following that, the data is reflected off a dispersing element, through a lens into an array. All of this is happening simultaneously, pixel by pixel. [see Jensen, John (2000), Remote Sensing of the Environment, 184pp, Prentice-Hall, Inc. New Jersey.]
Image courtesy of http://www.fas.org/irp/imint/docs/rst/Intro/2-10-2.jpg.



X

Y

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Z

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[i] http://searchenterprisewan.techtarget.com
[ii] http://searchenterprisewan.techtarget.com
[iii] Roddy, Dennis, Satellite Communications, 1996, MaGraw-Hill, New York.
[iv] http://en.wikipedia.org/wiki/Full_width_at_half_maximum retrieved 7 May 2009
[v] http://www.noao.edu/image_gallery/text/fwhm.html retrieved 7 May 2009
[vi] Kane, Timothy, Remote Sensing Platforms, 2008 PowerPoint, Kane's Computer.
[vii] Kane, Timothy, Remote Sensing Platforms, 2008 PowerPoint, Kane's Computer.
[viii] http://searchmobilecomputing.techtarget.com.
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[x] http://heasarc.gsfc.nasa.gov/docs/rosat/gallery/misc_saad.html, retrieved 6 May 2009
[xi] http://en.wikipedia.org/wiki/South_Atlantic_Anomaly, retrieved 6 May 2009
[xii] http://en.wikipedia.org/wiki/Solar_wind, retrieved on 5 March 2009
[xiii] Seeds, Michael A., Foundations of Astronomy, 9th Edition, 2007, Thompson, Brooks, Cole, Belmont, CA.
[xiv] Luna 1, http://nssdc.gsfc.nasa.gov, retrieved on 5 March 2009
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[xvi] ASD Technical Guide 3rd Ed. Section 2-1, Analytical Spectral Devices, Inc., retrieved 7 May 2009
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[xviii] http://lasp.colorado.edu/cassini/inst_desc/glossary.htm
[xix] http://maic.jmu.edu/sic/glossary.htm
[xx] Roddy, Dennis, Satellite Communications, 1996, MaGraw-Hill, New York.
[xxi] http://inventors.about.com/library/inventors/bltelemetry.htm.

[xxii] http://imagine.gsfc.nasa.gov/docs/ask_astro/
[xxiii] http://en.wikipedia.org/wiki/Van_Allen_radiation_belt
[xxiv] Kane, Timothy, Remote Sensing Platforms, 2008 PowerPoint, Kane's Computer.