Chapter 8. Remote sensing

8.1 Introduction

What is remote sensing? One can describe remote sensing in different ways. It is a method to get information about phenomena without being in contact with it. One can also use wavelengths beyond the human vision, i.e. often are observations made in the infra-red wavelength region. One can also use several platforms, such as satellites, balloons, aircraft and space shuttles. The methods used can be both passive and active. There are several advantages with remote sensing and some capabilities are unique:

** A global coverage is possible*
** It is non-intrusive*
** One can use multiple scales*
** Wide spectral range, such as UV, visible, infra-red, thermal and microwave.*
** Repetitive coverage, which is perfect for environmental monitoring.*

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8.2 Remote sensing

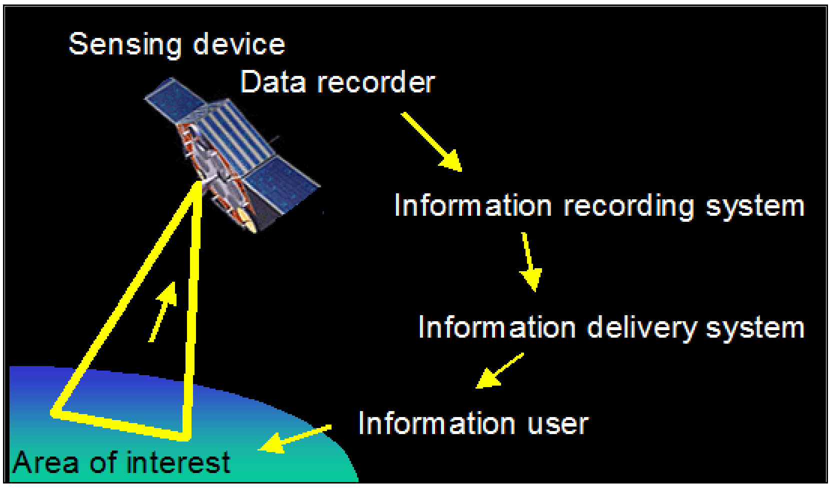
One can divide the field into two parts depending if the detection is Active or Passive. As examples of *Active* detection we have for instance:

1. Luminescence / fluorescence
2. RADAR
3. SONAR

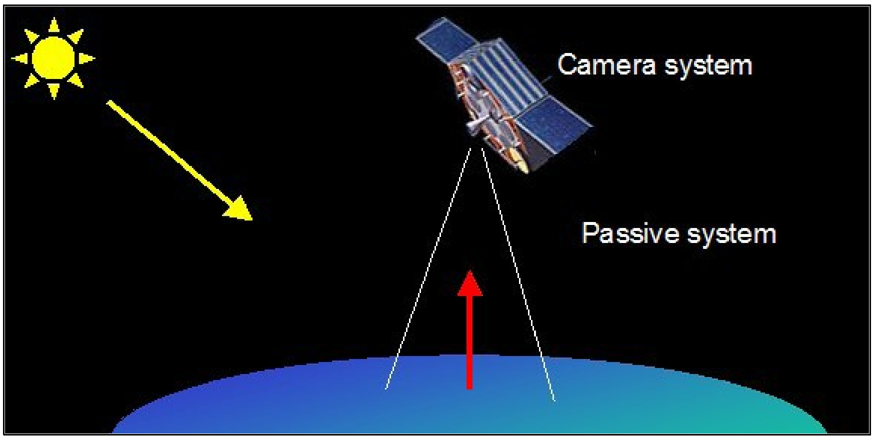
Passive detection can be:

1. Aerial photography
2. Multi-spectral sensing
3. Hyper-spectral sensing
4. Fraunhofer Line Detection

Thus, we can conclude, Remote sensing deals with detection of the atmosphere, oceans, or land surface, and the principles of recording is seen below.

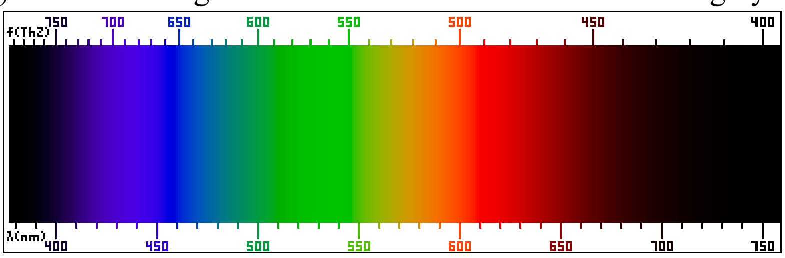


The user needs information about an area of interest of the Earth. Starts the sensing device of the satellite that records data and sends it to an information recording system. It delivers the data to the user who can study the information.

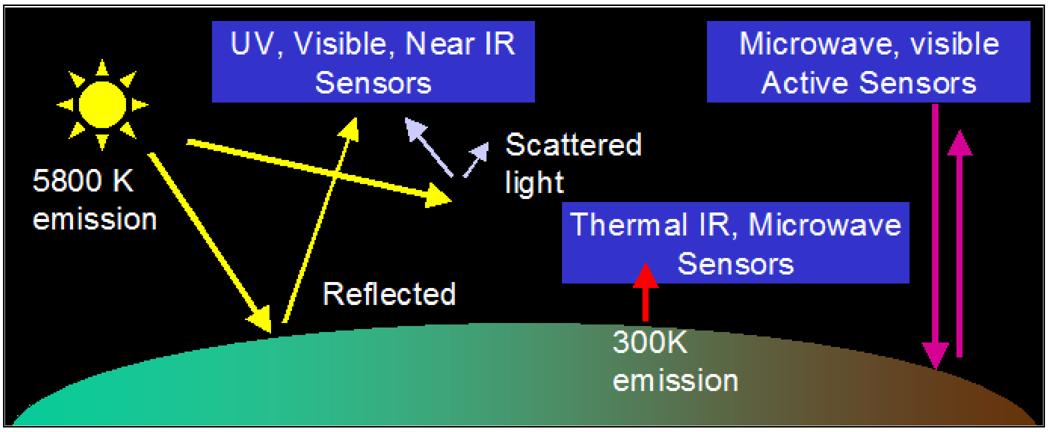


As we also can see that in this way we perform passive detection, studying the Earth via light coming from the Earth, enlightened by the Sun.
The recordings are performed in various wavelength areas such as:

a) The ultraviolet region where $\lambda < 400$ nm = 0.4 μm.
b) The visible region where 380 nm < λ < 750 nm or roughly 0.4 μm< λ < 0.7 μm.



c) Reflected IR, 0.7 mm< λ < 2.8 mm.
d) Thermal, emitted IR 2.4 mm< λ < 20 mm.
e) Microwave radiation 1 cm< λ < 1 m.



Here we can see the different techniques used, both passive and active recording of phenomena under investigation. As we have seen earlier, the emitted radiation from the Earth is found in the IR and microwave wavelength regions due to the temperature of the Earth.

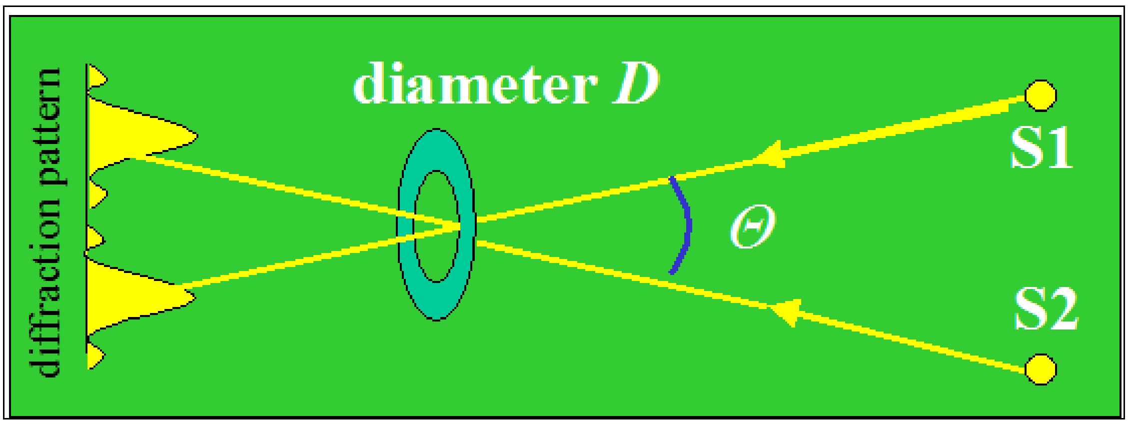
8.3 Resolution

When working with different types of sensors, one often discusses resolution. However, there are various types, such as;

a) spatial
b) spectral
c) temporal
d) radiometric

Resolution is often discussed parallel to *resolving power*. What do we mean with resolution? Resolution is defined to the ability to distinguish between signals S1 and S2 that are spatially or spectrally similar, and close with respect to distance, angle or wavelength.

Rayleigh criterion



When looking at two objects S1 and S2 close to each other under an angle θ_C, the objects are fully resolved when

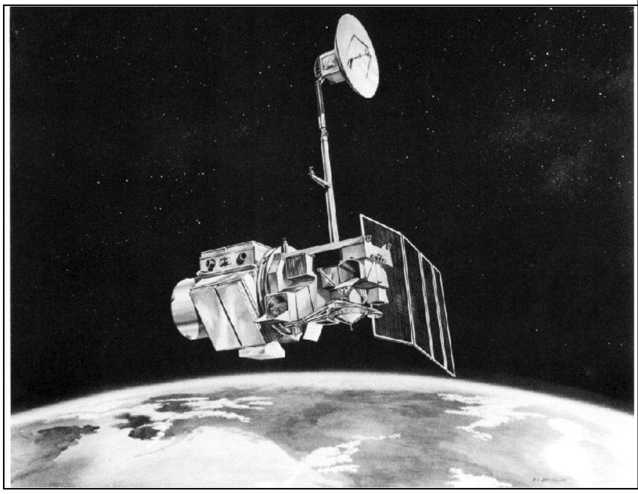
$\theta_C = 1.22\lambda/D$

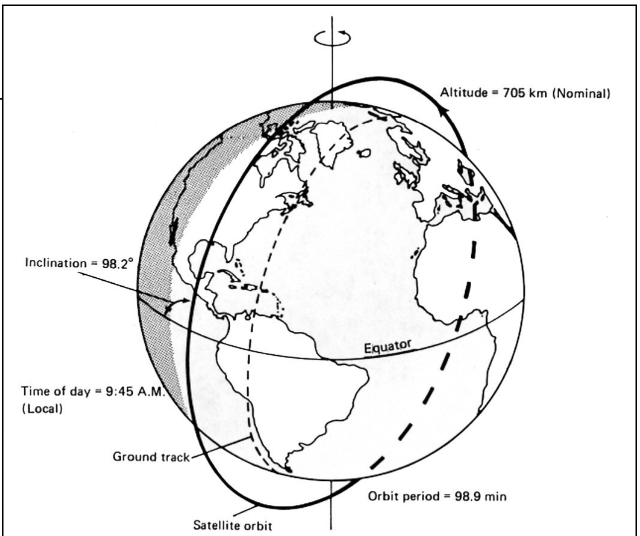
Here *D* stands for the diameter of the apparatus opening, and λ for the wavelength.

Example
If we look at two objects close to each other at a wavelength of 500 nm and suppose the opening of our iris is 5 mm. What is the minimum angle we observe the the objects under in radians?

Solution
The Rayleigh criterion gives $\theta_C = 1.22\ \lambda/D = 1.22 \times 500 \times 10^{-9} / 5 \times 10^{-3}$ rad = 1.2×10^{-4} rad. This angle is quite small. We can calculate it in degrees as well: $\theta_C = 1.2 \times 10^{-4}$ rad x $360^o/2\pi$ = 0.0070^o.

8.4 Landsat



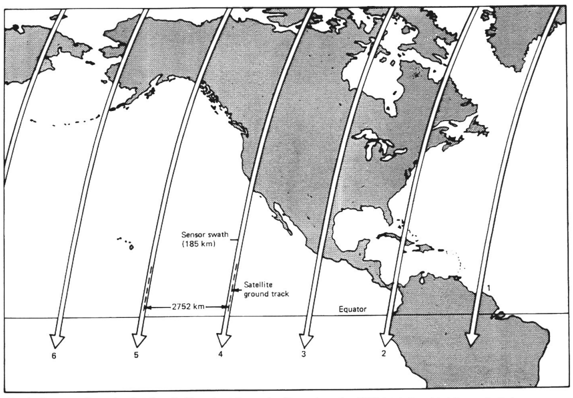


Sun-synchronous orbit of Landsat-4 and -5. (Adapted from NASA diagram.)

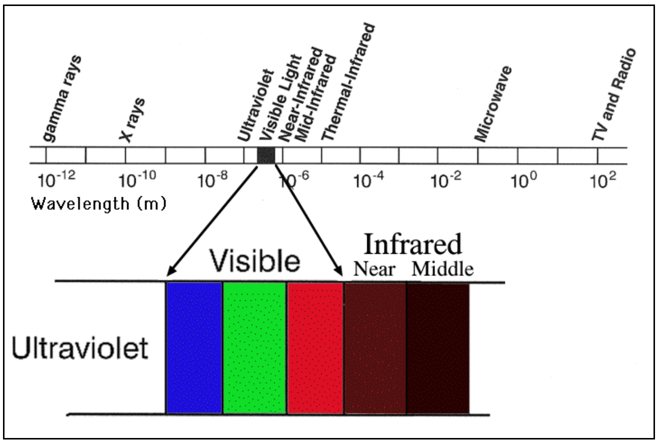
The primary mission of the Landsat Project is to ensure a collection of consistently calibrated Earth imagery. Landsat's Global Survey Mission is to establish and perform a data acquisition strategy that ensures repetitive acquisition of observations over the Earth's land mass, coastal boundaries, and coral reefs; and to ensure the data acquired are of maximum utility in supporting the scientific objectives of monitoring changes in the Earth's land surface and associated environment.

The Landsat program has a long history of providing satellite remote sensing information to the World, over 29 years. The first seven Landsat spacecraft have collected the longest continuous space-based remote sensing dataset ever.

The Landsat satellites operated around the globe covering it with slight distance changes at a height above the Earth of 706 km. The orbit period is around 80 minutes. It operates in wide wavelength regions as shown below. Recordings are made in the blue, green, red, near infrared and the middle infrared wavelength regions.

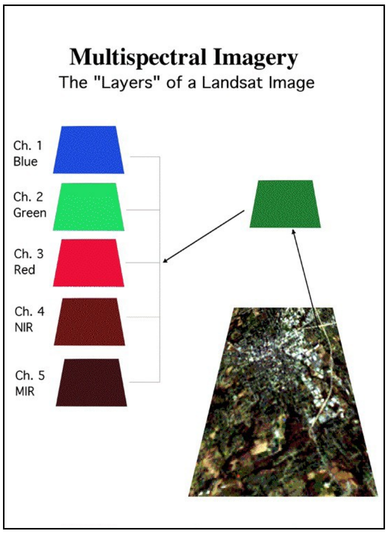


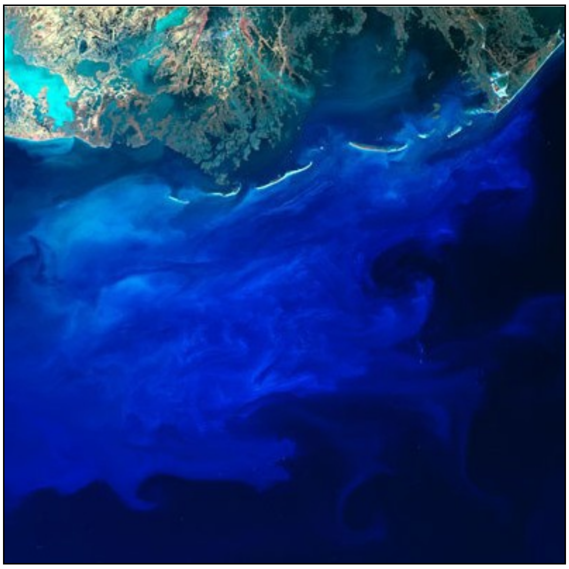
Spacing between adjacent Landsat-4 or -5 orbit tracks at the equator. The earth revolves 2752 km to the east at the equator between passes. (Adapted from NASA diagram.)



Since it operates in many different wavelength regions one can extract useful information regarding forests, seas etc.

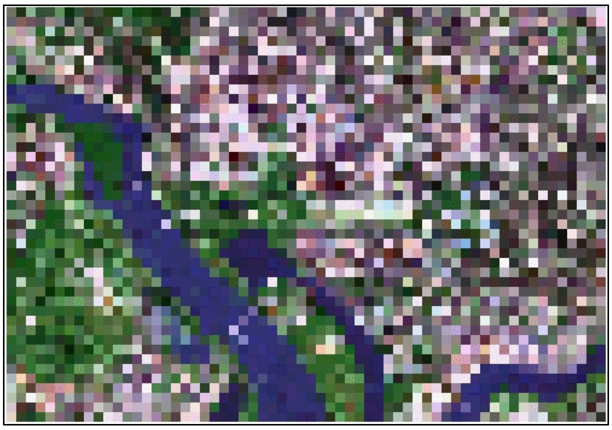
Below is shown how the system works how the data is put together to obtain information about the surface of the Earth.

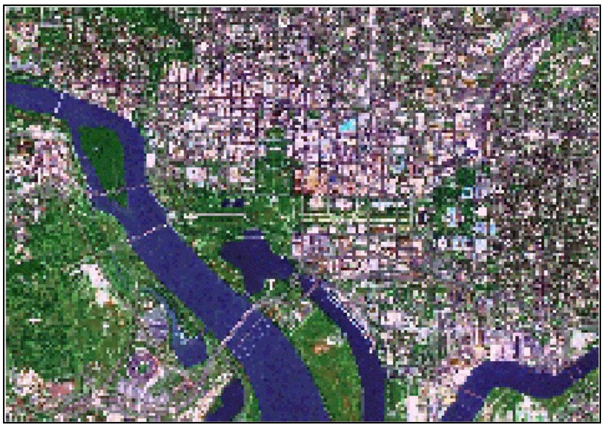




Landsat 7's blue band can observe some distance into the coastal water, which makes silt or mud appear blue. Here it is flowing off of the coast of Louisiana and into the Gulf of Mexico. The brightness and shade of blue depend on the density of the silt and the depth of the silt carrying currents in the water. If one looks in detail one can see small bright dots in the scene that are fishing boats and oil platforms.

By making observations simultaneously in different wavelength regions we can store the rather complex information in a simpler way.





Resolution 100 m **Resolution 30 m**

The resolution of the images has been constantly improving. Above is shown the same image at different resolutions.

Example

A satellite is positioned at the height 36 x 10^6 m above the Earth. The camera has an opening diameter of 45 cm. It is operating at the wavelength 1.5 µm. Calculate the instruments maximum resolution.

Solution

We use the Rayleigh criterion to solve the problem. The minimum angle to appear between two adjacent points on Earth is

$$\theta = 1.22\frac{\lambda}{D} = 1.22\frac{1.5x10^{-6}}{45x10^{-2}}\text{ rad} = 4.07x10^{-6}\text{ rad}$$

(2π rad = 360^{o}). Let the distance between the two adjacent objects be x, and use $\theta = x/H$ where H = 36 x 10^6 m. We get $x = H$ x θ = 36 x 10^6 x 4.07 x 10^{-6} m ≈ 150 m.
In the above example we see that if we increase the opening of the instrument 5 times, we can observe objects of the size 150/5 m = 30 m just as in the picture above.

Example

A Landsat satellite is positioned at the height 705 km above the Earth. The camera has an opening diameter of 45 cm. It is operating at the wavelength 1.5 μm. Calculate the instruments maximum resolution.

Solution

We use the Rayleigh criterion as above to solve the problem. The minimum angle to appear between two adjacent points on Earth is

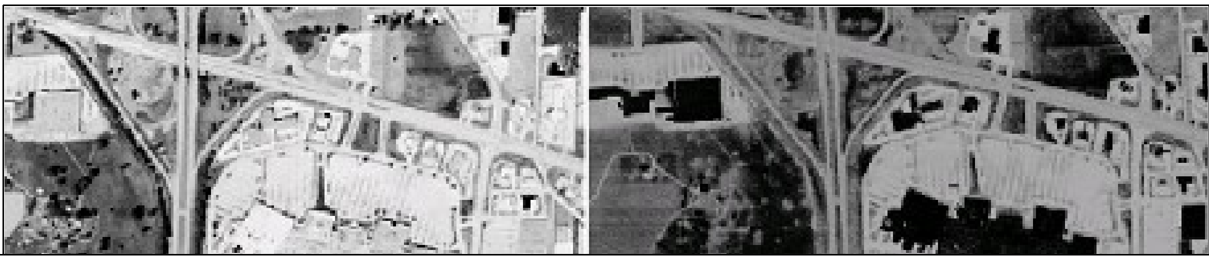
$\theta = x/H$ so, $x = H \times \theta = 705 \times 10^3 \times 4.07 \times 10^{-6}\ m \approx 3$ m

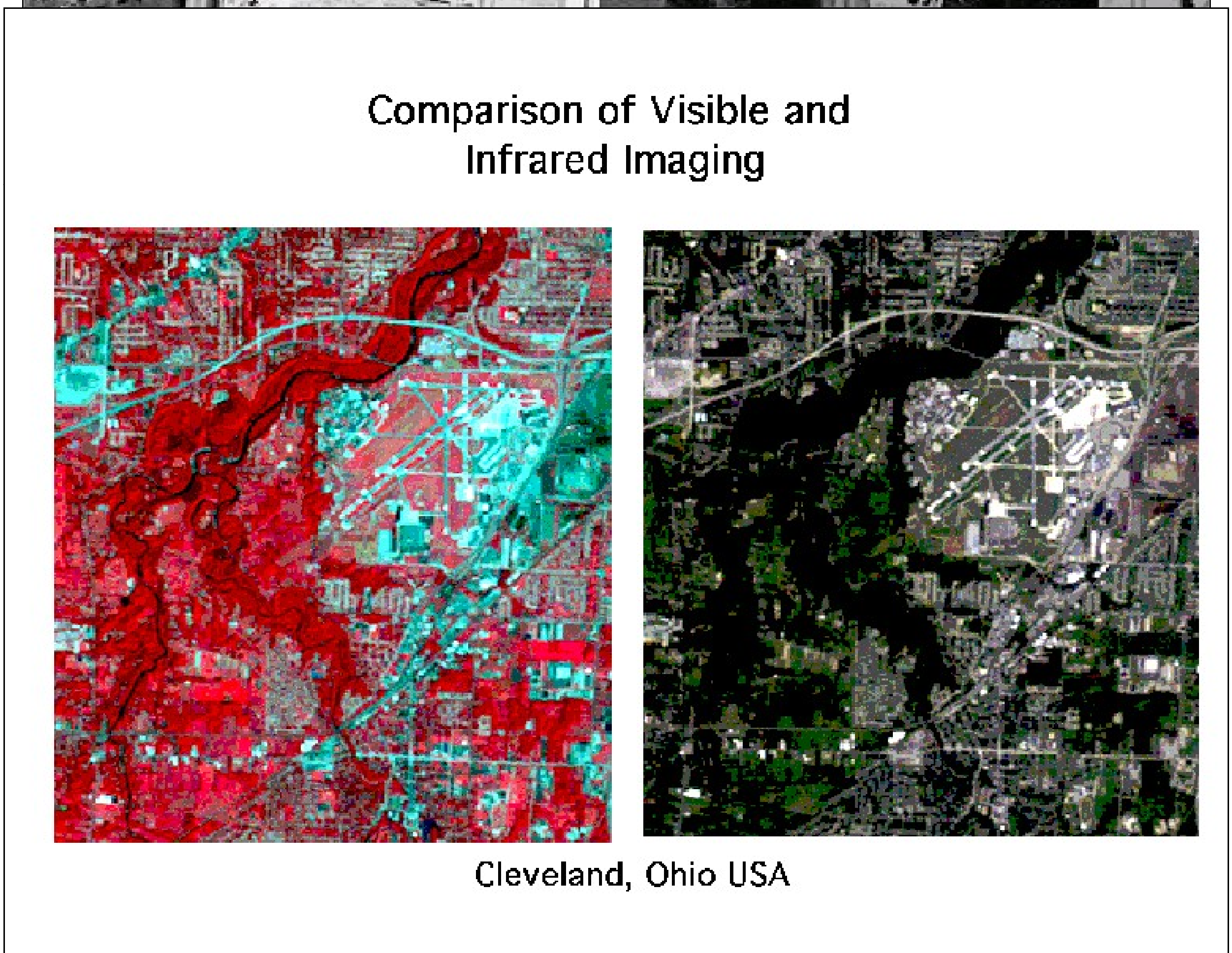
Earthshots is an ebook of before-and-after Landsat images (1972-present), showing recent environmental events and introducing remote sensing. Earthshots comes from the U.S. Geological Survey's EROS Data Center, the world's largest archive of earth science data and the official National Satellite Land Remote Sensing Data Archive.

Change discrimination

Using different wavelengths when studying an object can also give useful information. In some cases a Geostationary satellite can make recordings on daytime as well as during the night. In the latter case the use of infra-red detection is vital.

In the picture below we can see a drastic change when looking at the same region exposed in daylight as well as during the night with thermal detection.





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8.5 Geostationary Operational Environmental Satellite – GOES

A geostationary satellite operates at a certain height above the surface of the Earth. We can ask the question of how large this height is? In order to derive the height we meed to use the force of gravity and the centripetal force.

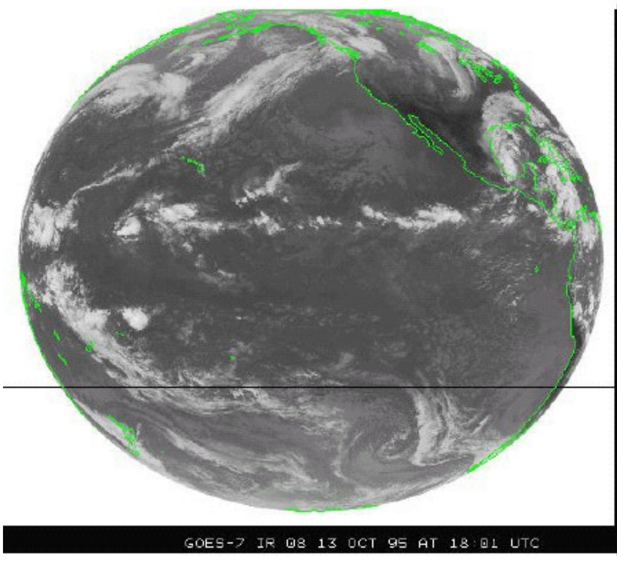
The acceleration of an orbiting object around the Earth (Mass M) at a distance r from the centre of the Earth is (G is the gravitational constant):

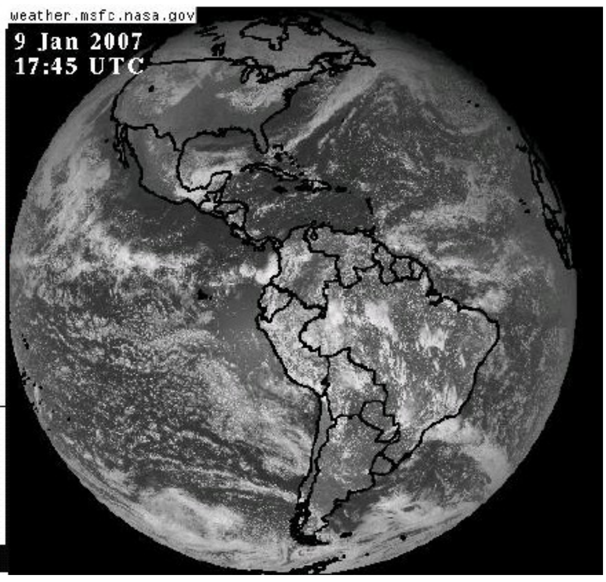
$$a = \frac{GM}{r^2}$$

Now we have $\omega = 2\pi f = 2\pi/T$, where T stands for the orbiting period, i.e. $T = 24$ hours.
The centripetal acceleration is $a_C = r\omega^2$ with the above definitions.
Putting these accelerations equal, we obtain:

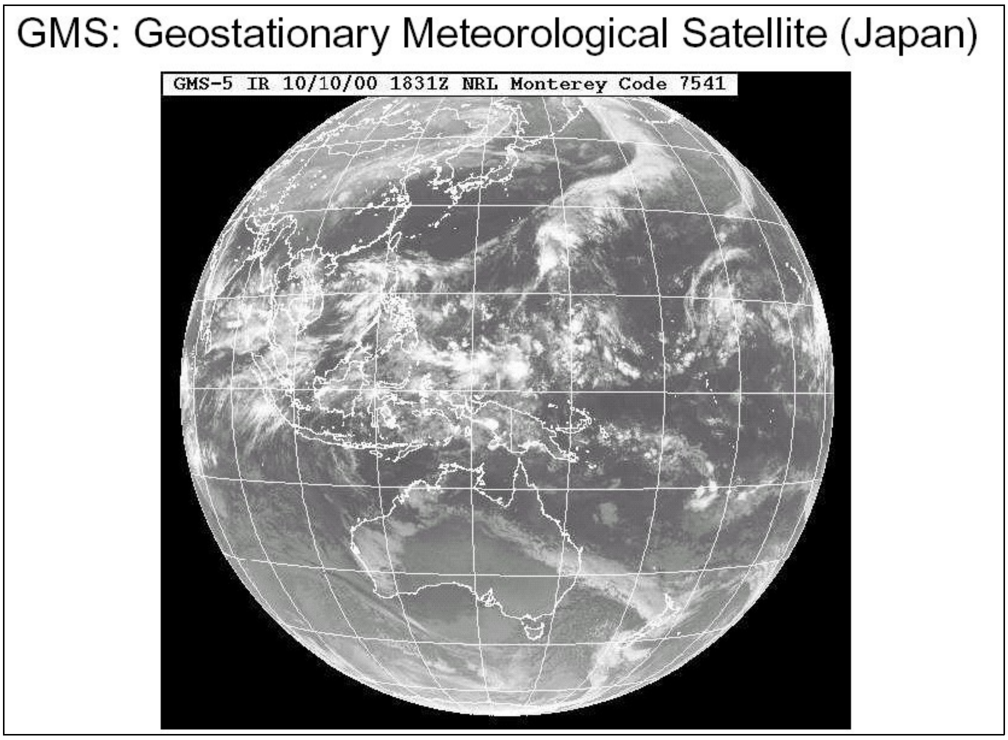
$$r = \left(\frac{GM}{\omega^2}\right)^{1/3}$$

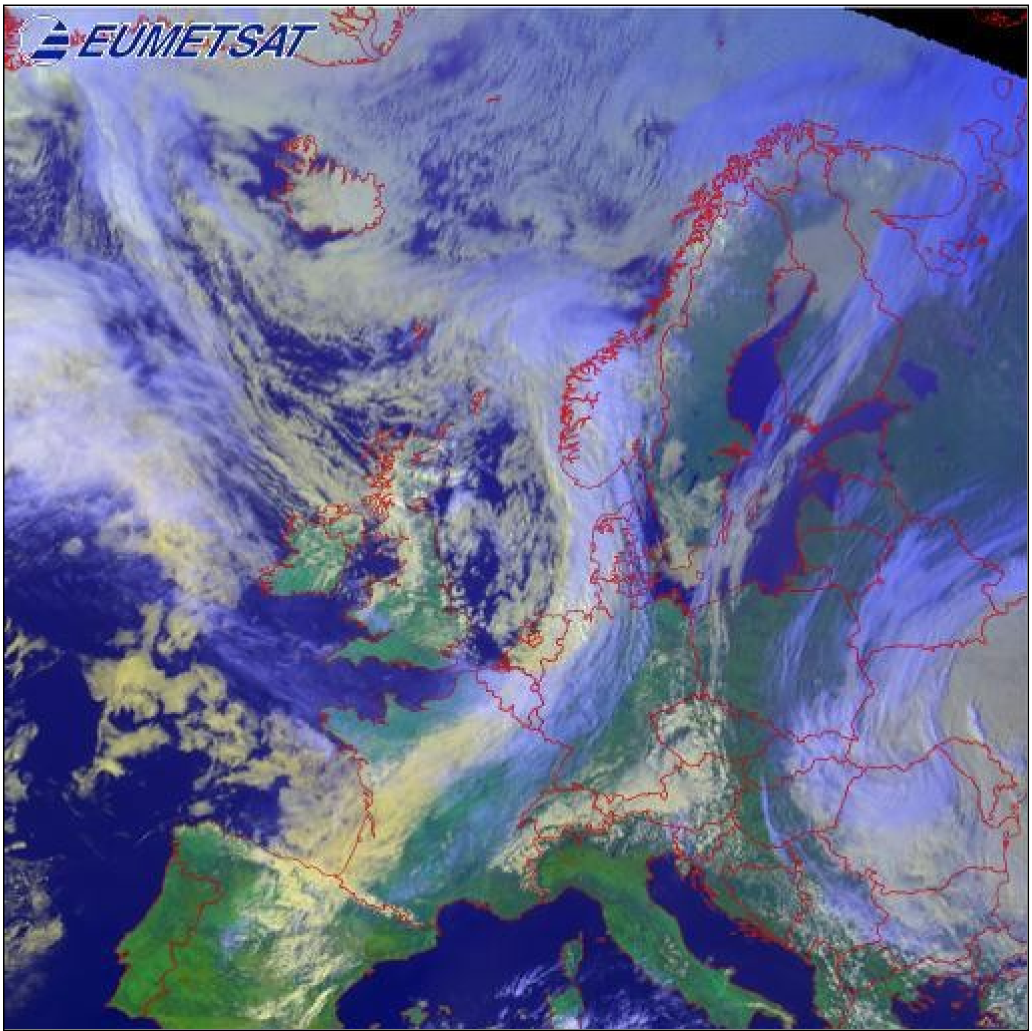
With $M = 5.972\text{x}10^{24}$ kg, $G = 6.67428\text{x}10^{-11}$ m^2/kgs^2 and R = 6378 km, we get r = 42,164 km and H = 35,790 km above the surface of the Earth.
Below are shown views from the GOES satellites, West view in IR and East view in visible.





Another satellite view from the Japanese GMS satellite is shown below.

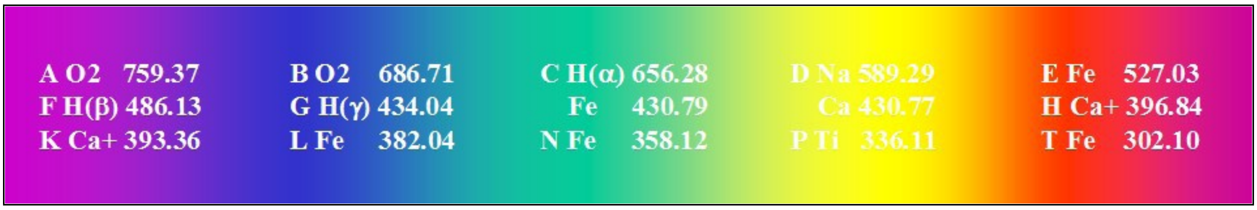




The weather satellites provides information continuously. There are many sites where these types of pictures are available such as at SMHI:
http://www.smhi.se

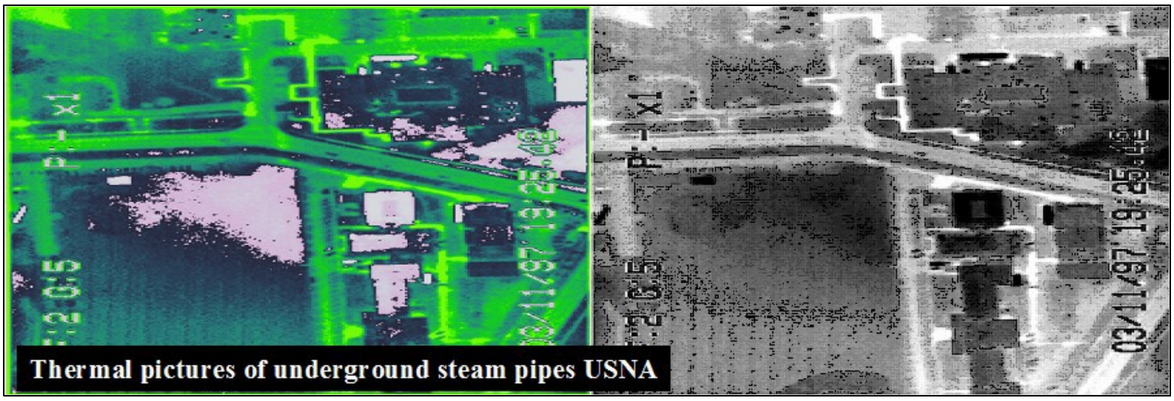
Fraunhofer measurements

Satellites as well as ground stationed observatories provides information of intensities of several abundant atoms and molecules of atmospheric spectra, such as the Fraunhofer lines. An English chemist and optician, W. Wollaston already in 1802 observed dark (absorption) lines of the solar spectrum. In 1814, Fraunhofer studied the solar absorption lines very thoroughly and denoted them with A, B, C, D etc. He soon found more lines and started to use a, b, c, etc, He also needed to extend the work since he later looked at higher resolution and saw doublets, i,e D1 and D2 etc.
Below we see the solar spectrum with Fraunhofer lines,



Temperature measurements

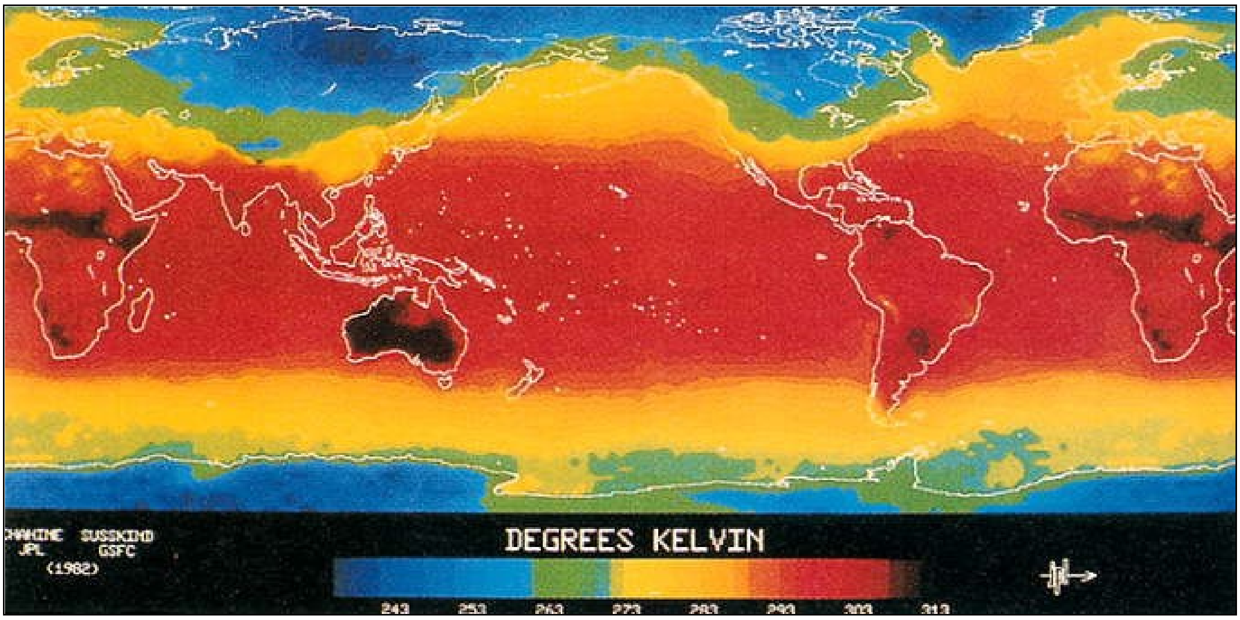
Thermal IR deals with the Far IR region of the EM spectrum, wavelengths between 2.4 and 20 µm, whereas most Thermal IR scanners use wavelengths between 8 and 15 µm.


Thermal pictures of underground steam pipes USNA

There are several types of sensors that can be used and that are rather fast, with measurement times around 0.5 s. Many instruments are based on measuring IR intensities and comparing with the Planck black body radiation curve. They have often a set of interference filters for different wavelengths, After data collection the instrument compares with the Planck curve and determines the temperature. Many instruments have an accuracy around 0.5^{o}C.

Their size can be fairly small. Sometimes they have to bee cooled to have the best performance.

By using the thermal radiation from the Earth one can map the temperature rather accurately.



Above is shown a picture where the various temperatures all over the World can be seen in detail.

The figure below shows the complex transmission/absorption of the atmosphere. As we have seen earlier there are just minor absorption in the visible region. Below 300 nm the ozone and oxygen molecules absorbs the incident light. A lot of absorption at higher wavelengths are due to water, oxygen and carbon dioxide,

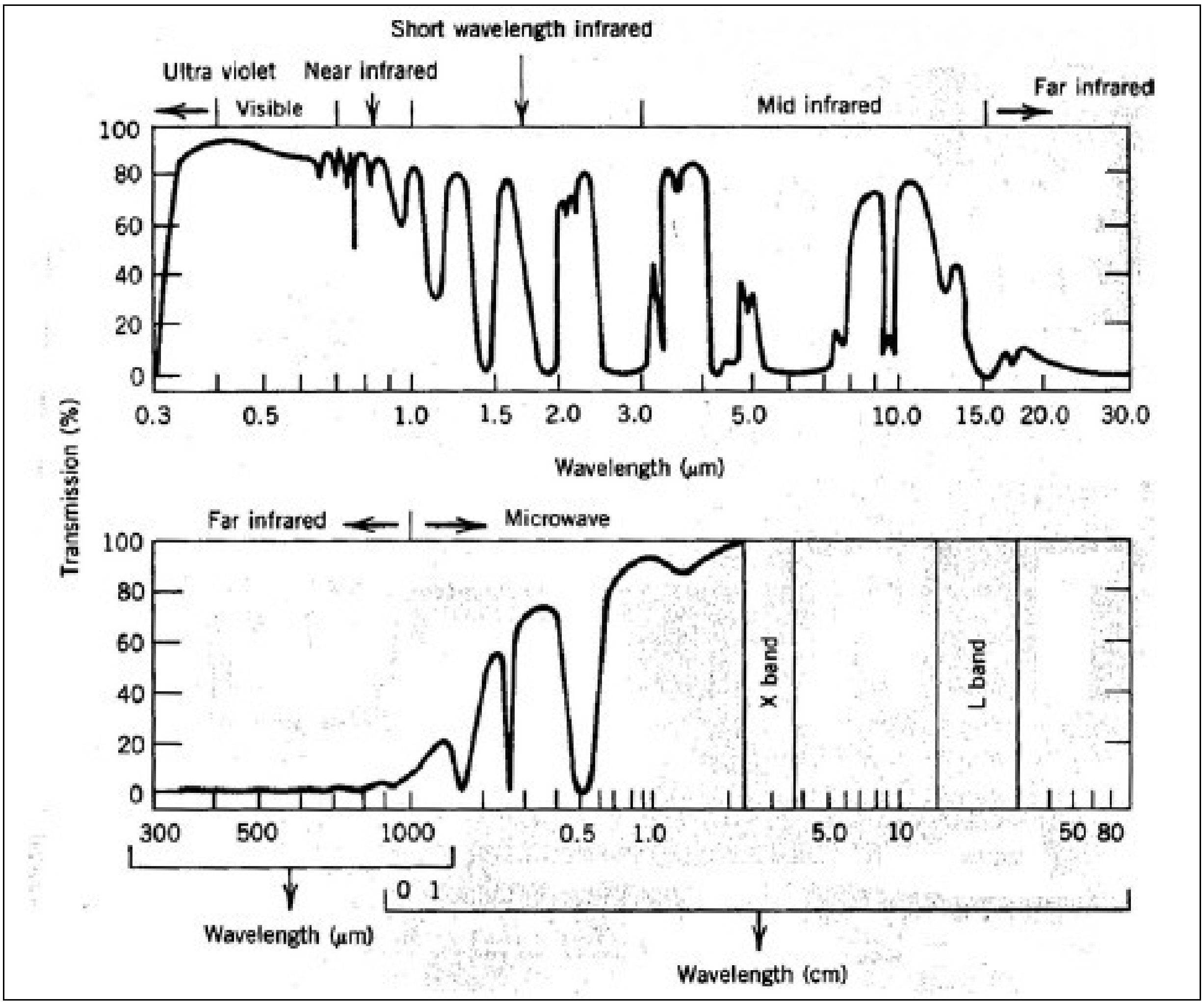
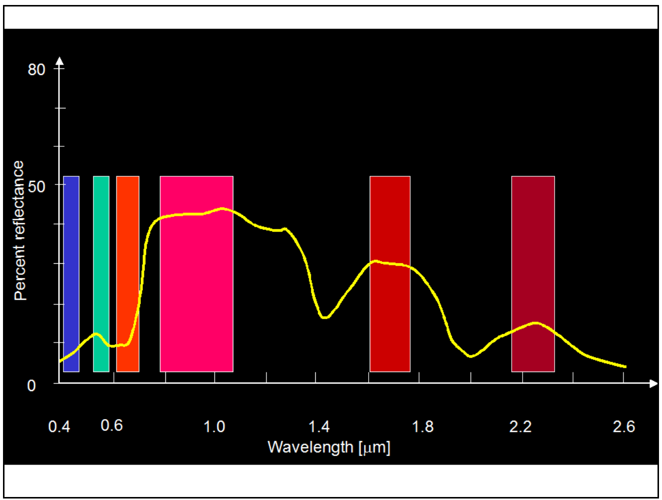


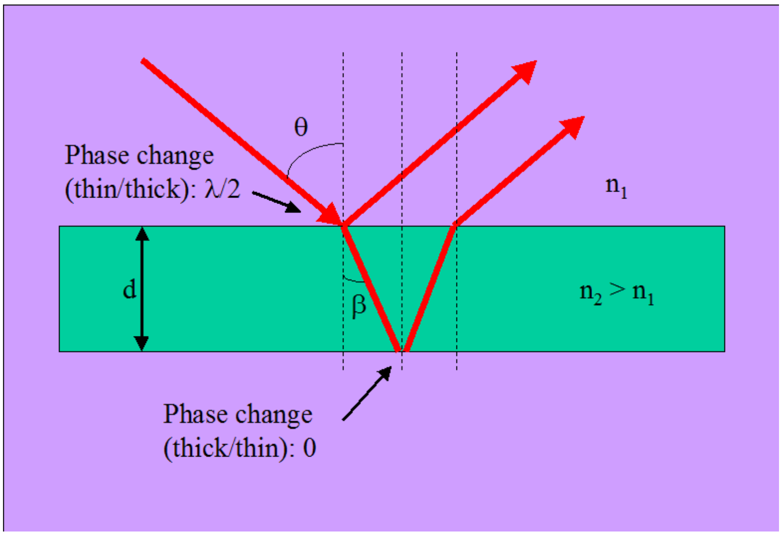
Figure from Elachi, C., Introduction to the Physics and Techniques of Remote Sensing, John Wiley & Sons, New York, 1987.



In remote sensing, one often uses several bands for detection, just like the picture above, where three bands in the visible, blue, green and red are used as well as three bands in the infrared wavelength region. More often more bands than six are being used nowadays.

Interference filters

In order to select various bands one can use small spectrometers or interference filters. An interference filter can be designed to give maximum transmission at certain wavelengths, as well as band widths. Let us look at a thin film of a material with refractive index n_2 in a surrounding with refractive index n_1 (often air with $n_1 = 1$). Observe that maximum transmission corresponds to minimum in reflection!



Optical path difference + phase difference = Condition for minimum in reflection

$2n_2\, d \cos\beta + (0 + \lambda/2) = m(\lambda + 1/2)$

If the light is coming at normal incidence ($\theta = 0$), we have: $2n_2 d = m\lambda$, $m = 1, 2, \ldots$

Let us select the thinnest film, with $m = 1$ leading to $2n_2 d = \lambda$. Thus we can construct a filter that transmits a desired wavelength for a given thickness.

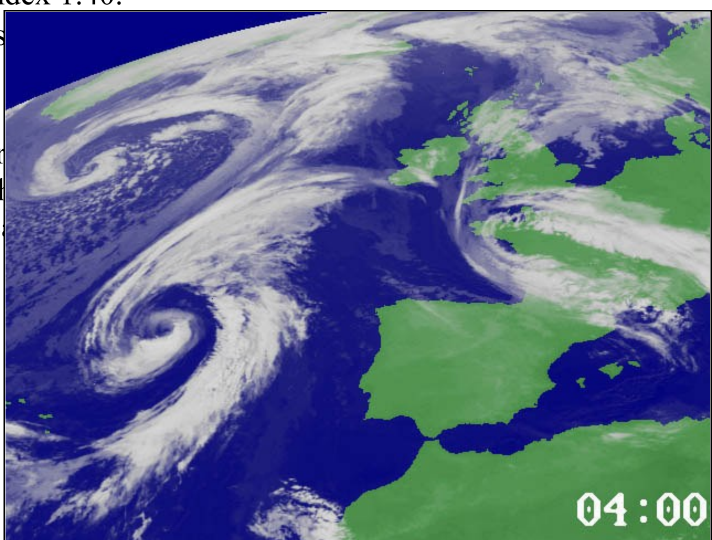
Example

Build an interference filter that has a maximum transmission at 600 nm. Use a material with refractive index 1.40.

Solution Us … nd $d = 214$ nm

Meteostat

ESA has for … Meteosat geostationary satellites. Th … ond Generation (MSG) satellite bec … highly detailed imagery of Europe, the … by meteorologists.



Pictures of this kind can be seen at:
http://www.esa.int/esaMI/MSG/SEMQSCULWFE_0.html