AOSC400-2015
October 27, Lecture # 15

Principles of Remote Sensing

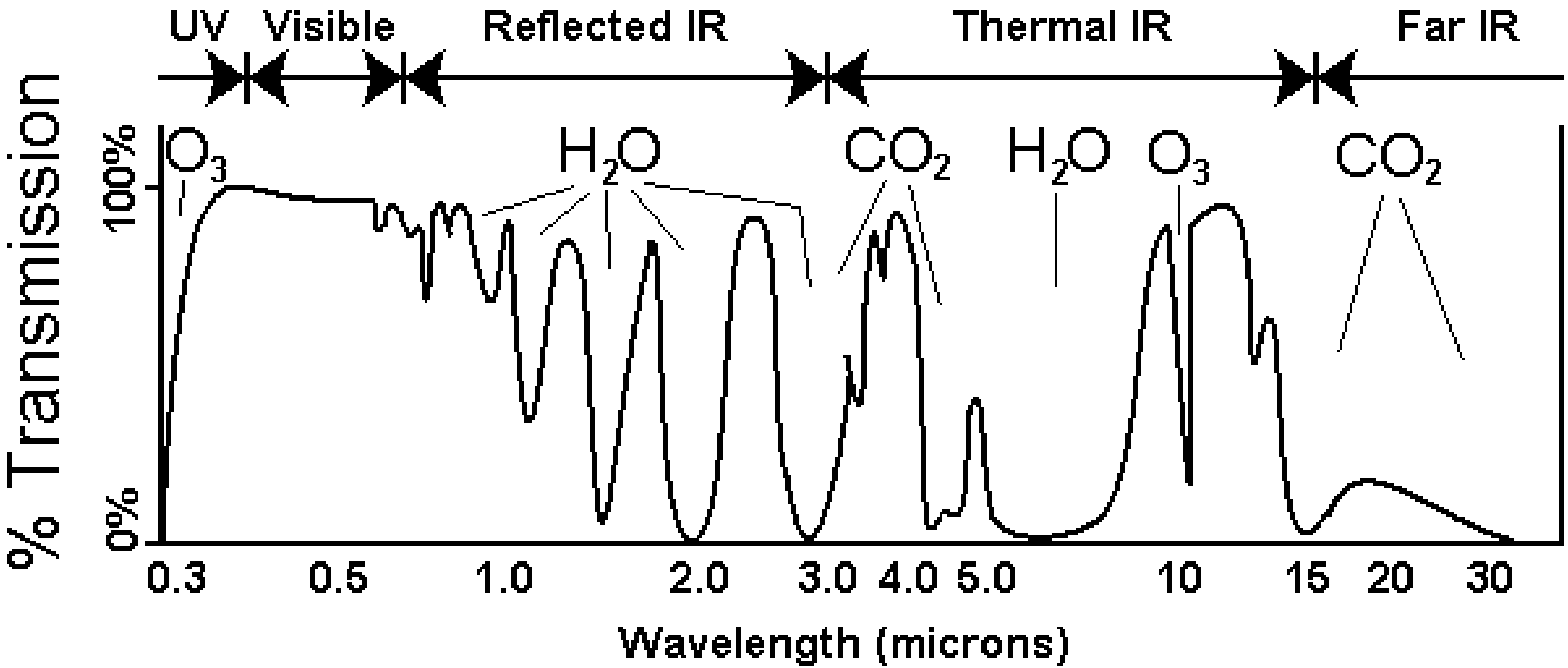
- Remote Sensing Methods
- Passive and active sensors
- Absorption spectrum in microwave
- Principles of MW radiometry
- Polarized waves
- Microwave Instruments of focus
- Solution of the transfer equation for a non-scattering atmosphere in MW

*Sources of information used for this lecture are listed in updated Syllabus.

Spectral Intervals in (VIS, IR, MW) of interest in Remote Sensing

Several spectral regions are considered useful for remote sensing from satellites.

- Windows to the atmosphere (regions of minimal atmospheric absorption) exist near 4 µm, 10 µm, 0.3 cm, and 1 cm *(see next slide).*
- Infrared windows are used for sensing the temperature of the earth surface and clouds, while microwave windows help to investigate the surface emissivity and the liquid water content of clouds.

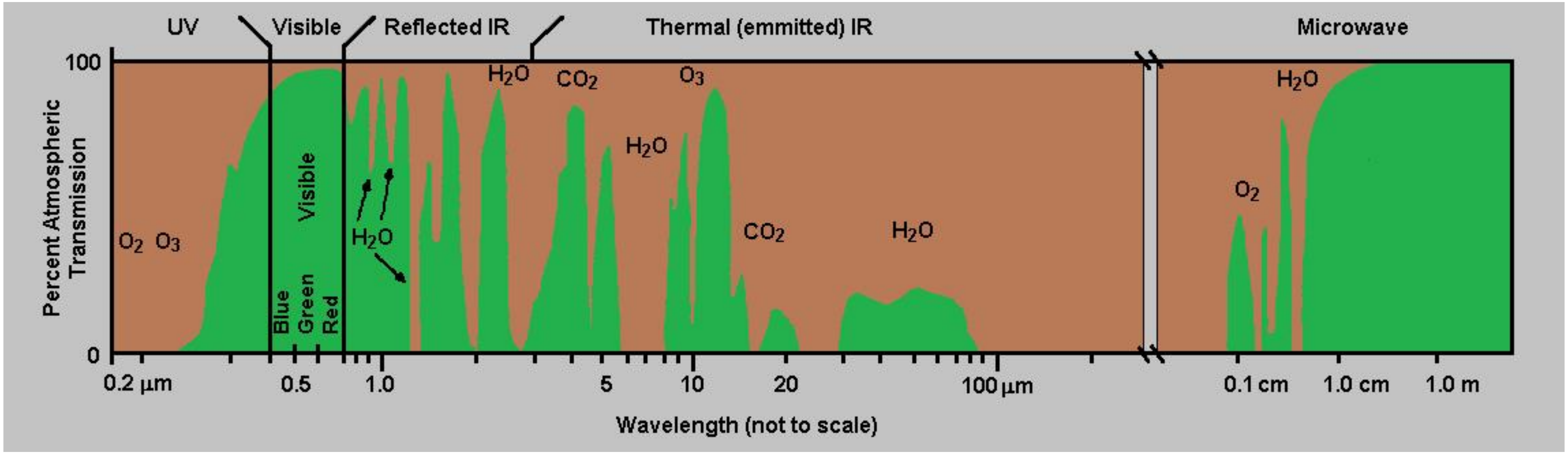


High transmission means low absorption. There is significant transmission of radiation at 0.5 microns, 2.5 microns, and 3.5 microns, but a great deal of atmospheric absorption at 2.0, 3.0, and about 7.0 microns.

Absorption bands

The CO_2 and O_2 absorption bands at 4.3 μm, 15 μm, 0.25 cm, and 0.5 cm are used for temperature profile retrieval

The water vapor absorption bands near 6.3 μm, beyond 18 μm, near 0.2 cm, and near 1.3 cm are sensitive to the water vapor concentration in the atmosphere
(see next slide).


UV
Visible
Reflected IR
Thermal (emmitted) IR
Microwave
Percent Atmospheric Transmission
100
0
O_2 O_3
Visible
Blue
Green
Red
H_2O
H_2O
CO_2
O_3
H_2O
CO_2
H_2O
O_2
H_2O
0.2 µm
0.5
1.0
5
10
20
100 µm
0.1 cm
1.0 cm
1.0 m
Wavelength (not to scale)

Remote Sensing Methods

There are two types of remote sensing instruments:

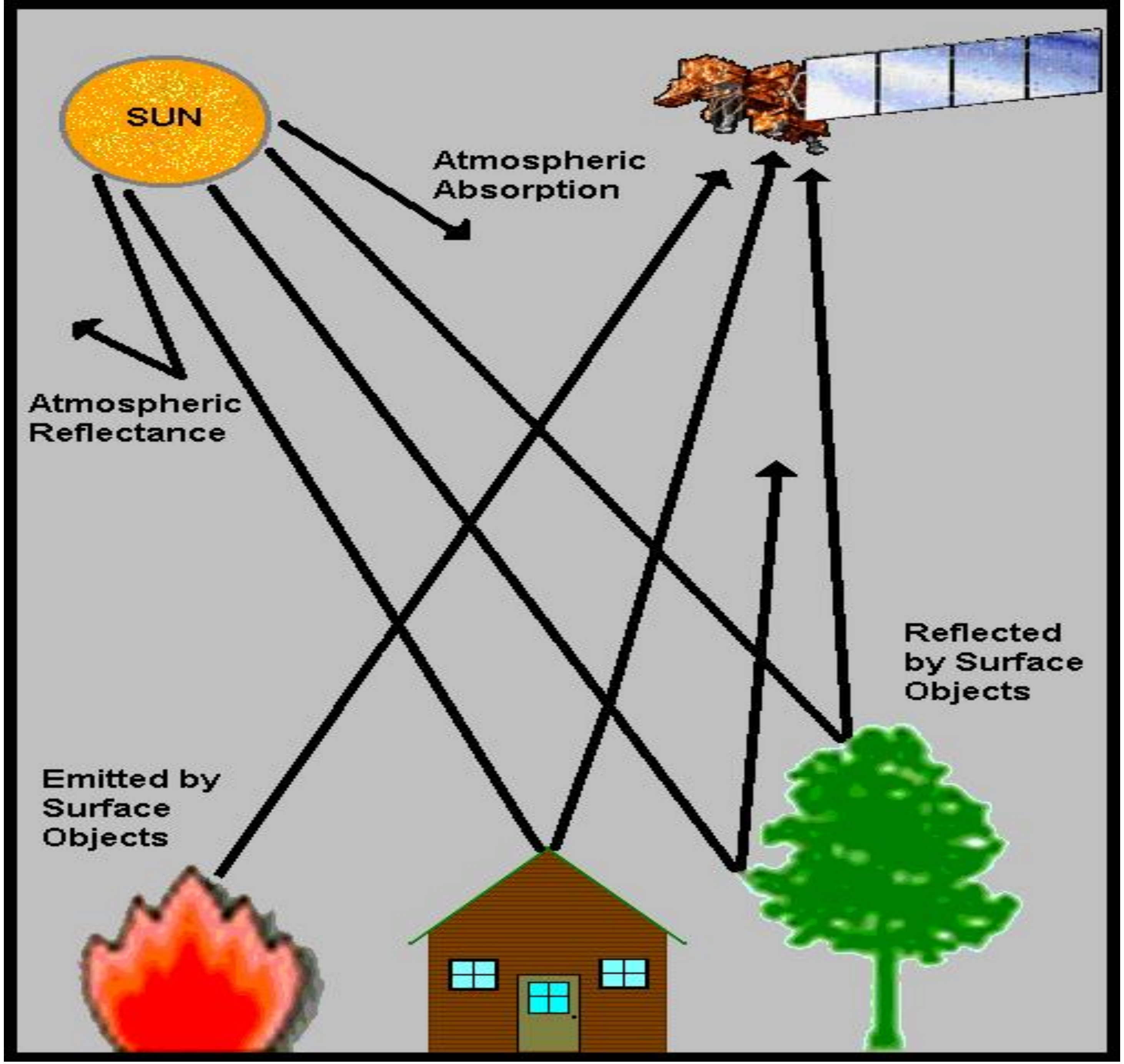
- Passive
- Active

- Passive instruments detect natural energy that is reflected or emitted from the observed scene. Reflected sunlight is the most common external source of radiation sensed by passive instruments.
- Active instruments provide their own energy to illuminate the scene they observe.

Passive Remote Sensing by Satellites

Monitoring of radiation emitted by and reflected from the Earth system by satellite-borne radiometers provides information on weather and climate. Fields that are currently routinely monitored from space include: temperature, cloud cover, cloud droplet concentrations and sizes, rainfall rates, humidity, radiative fluxes, surface wind speed and direction, **concentrations of trace constituents and aerosols,** and lightning. Discussed will be just a few of the many applications of remote sensing in **atmospheric science.**

Passive Remote sensing



Examples of passive remote sensors:

Radiometer

An instrument that quantitatively measures the intensity of electromagnetic radiation in some band of wavelengths in the spectrum. Usually a radiometer is further identified by the portion of the spectrum it covers; for example, visible, infrared, or microwave.

Imaging Radiometer

A radiometer that includes a scanning capability to provide a two-dimensional array of pixels from which an image may be produced is called an imaging radiometer. Scanning can be performed mechanically or electronically by using an array of detectors.

Spectrometer

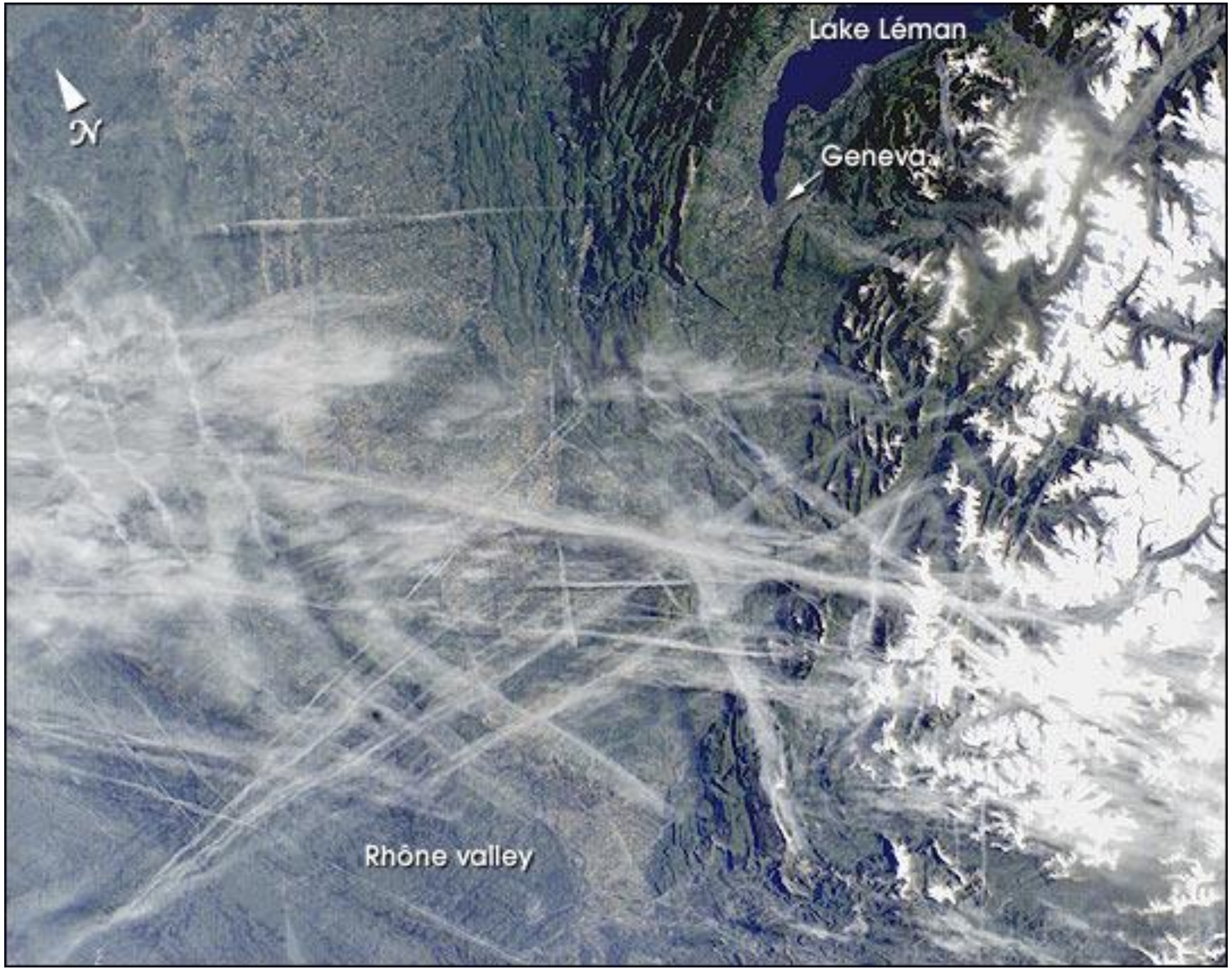
A device designed to detect, measure, and analyze the spectral content of the incident electromagnetic radiation is called a spectrometer. Conventional, imaging spectrometers use gratings or prisms to disperse the radiation for spectral discrimination.

Many such instruments are carried on satellites.

Due to their complexity, clouds are difficult to model

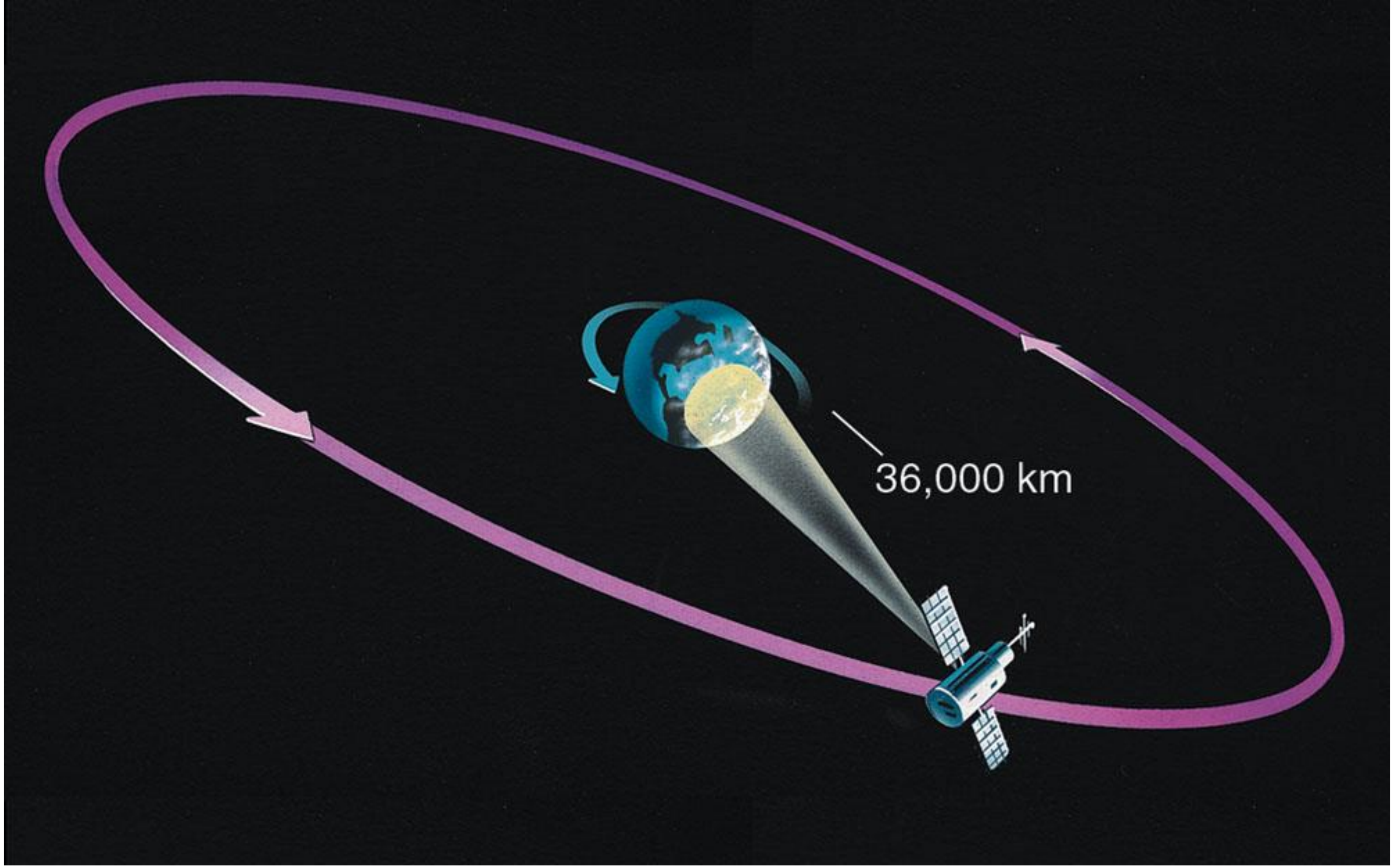
Satellites are useful for studying clouds.

“Man made” clouds: Airplane Tracks

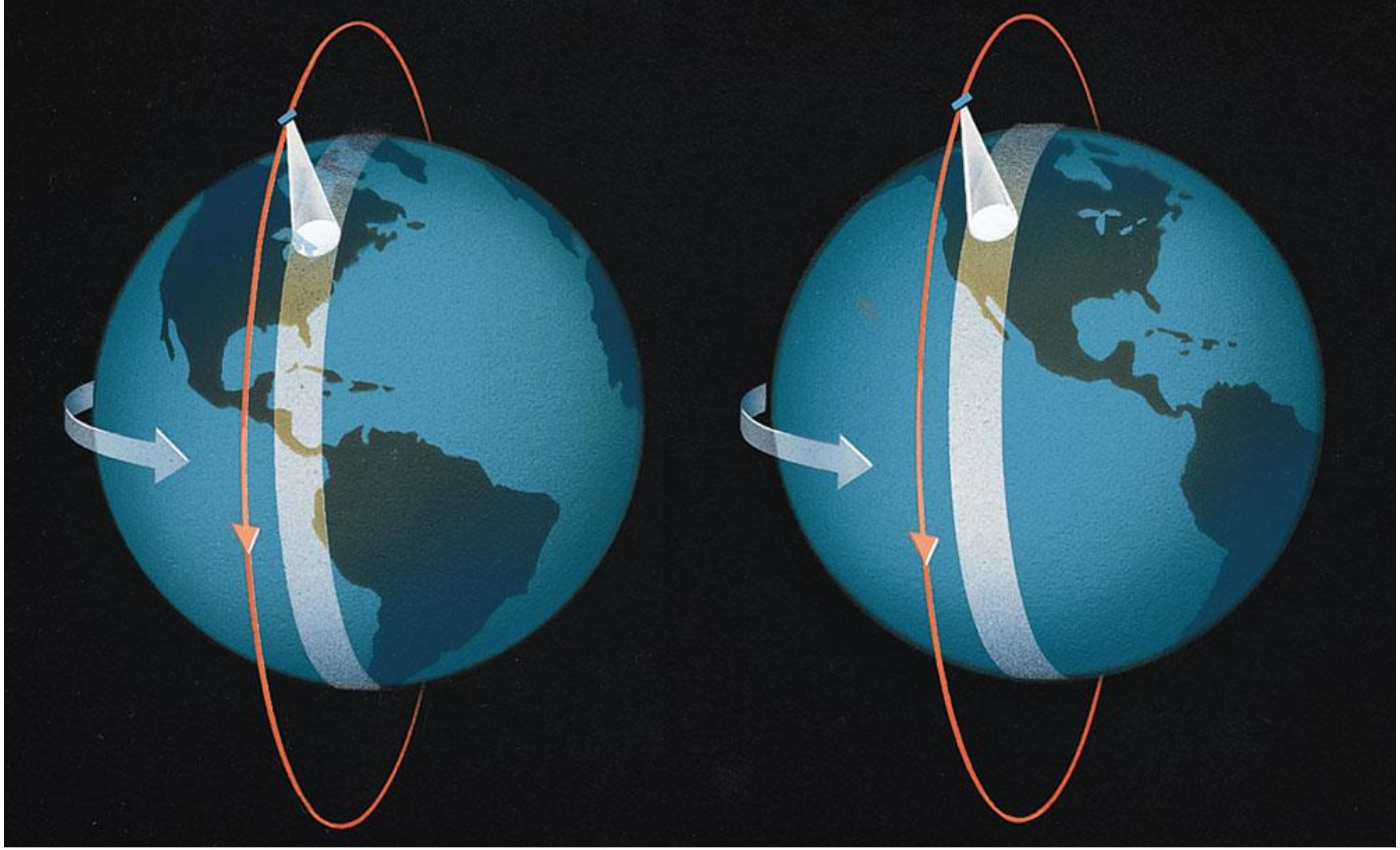


Cloud Observations from satellites

- Geostationary, polar orbiting
- Visible light provides a black and white picture of clouds
- Infrared approximates cloud temperature which infers height
- Satellites measure many other variables: sea surface temperatures, ozone, upper level features, snow cover, land cover



The geostationary satellite moves through space at the same rate that the earth rotates, so it remains above a fixed spot on the equator and monitors one area constantly.



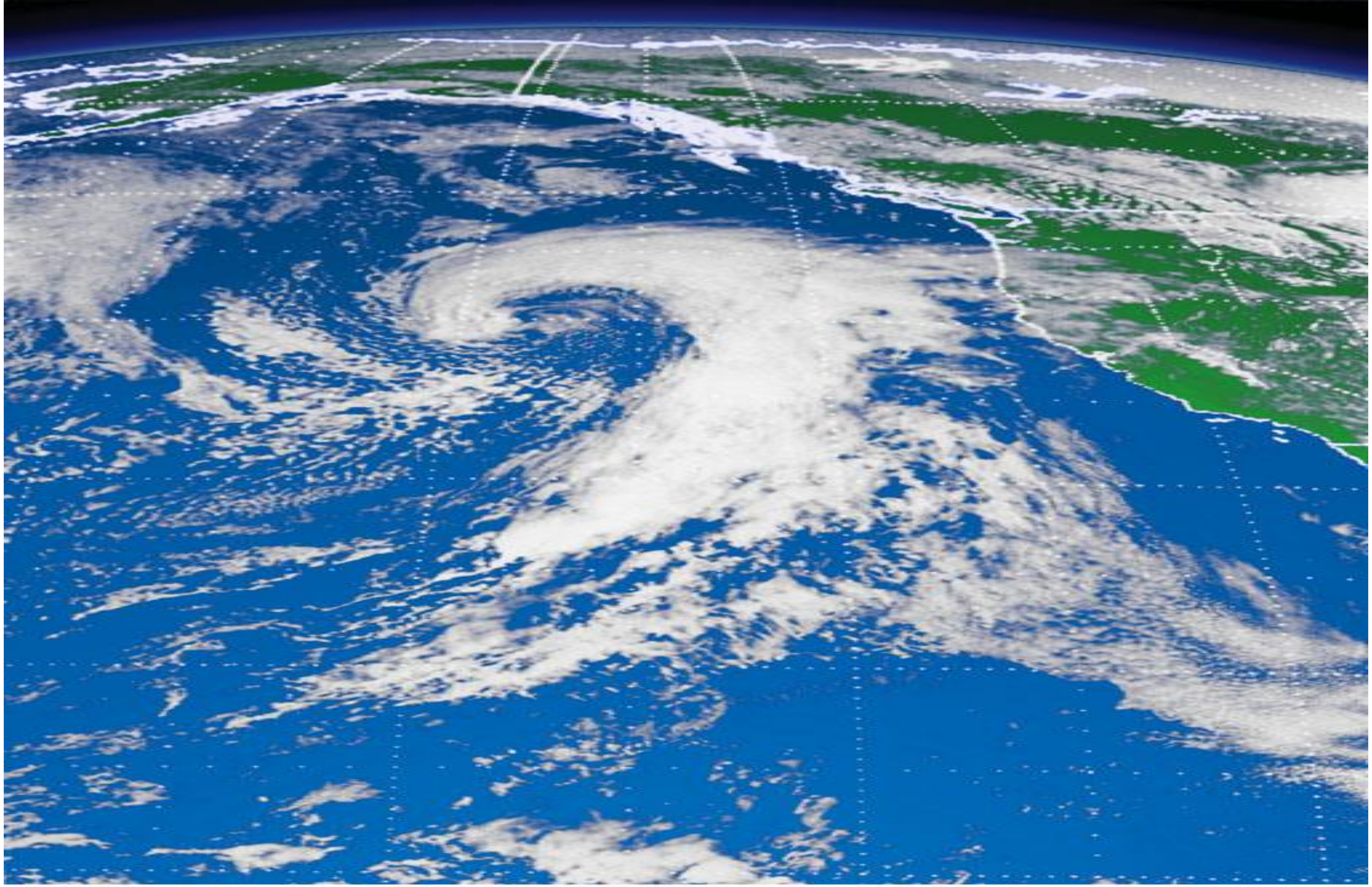
Polar-orbiting satellites scan from north to south, and on each successive orbit the satellite scans an area farther to the west.

Infra-red imagery

Responds to window at a wavelength of 10.7 µm, in which radiation emitted from the Earth's surface and cloud tops penetrates through cloud-free air with little absorption. Intensities in this channel are indicative of the temperatures of the surfaces from which the radiation is emitted as inferred from the Planck function.

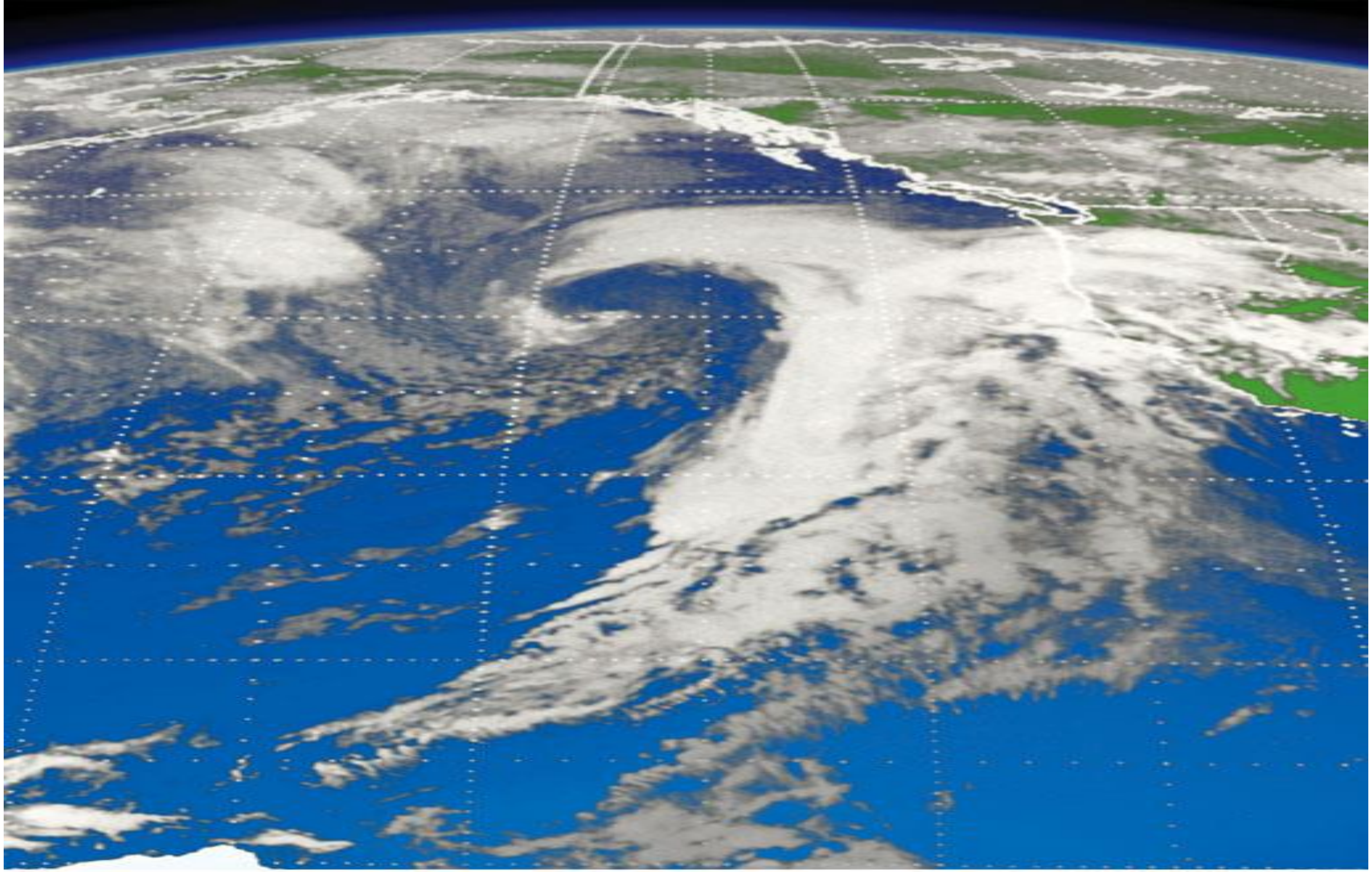
In contrast to visible imagery, high clouds are usually clearly distinguishable from low clouds in infrared imagery by virtue of their lower temperatures.

Figure (a)

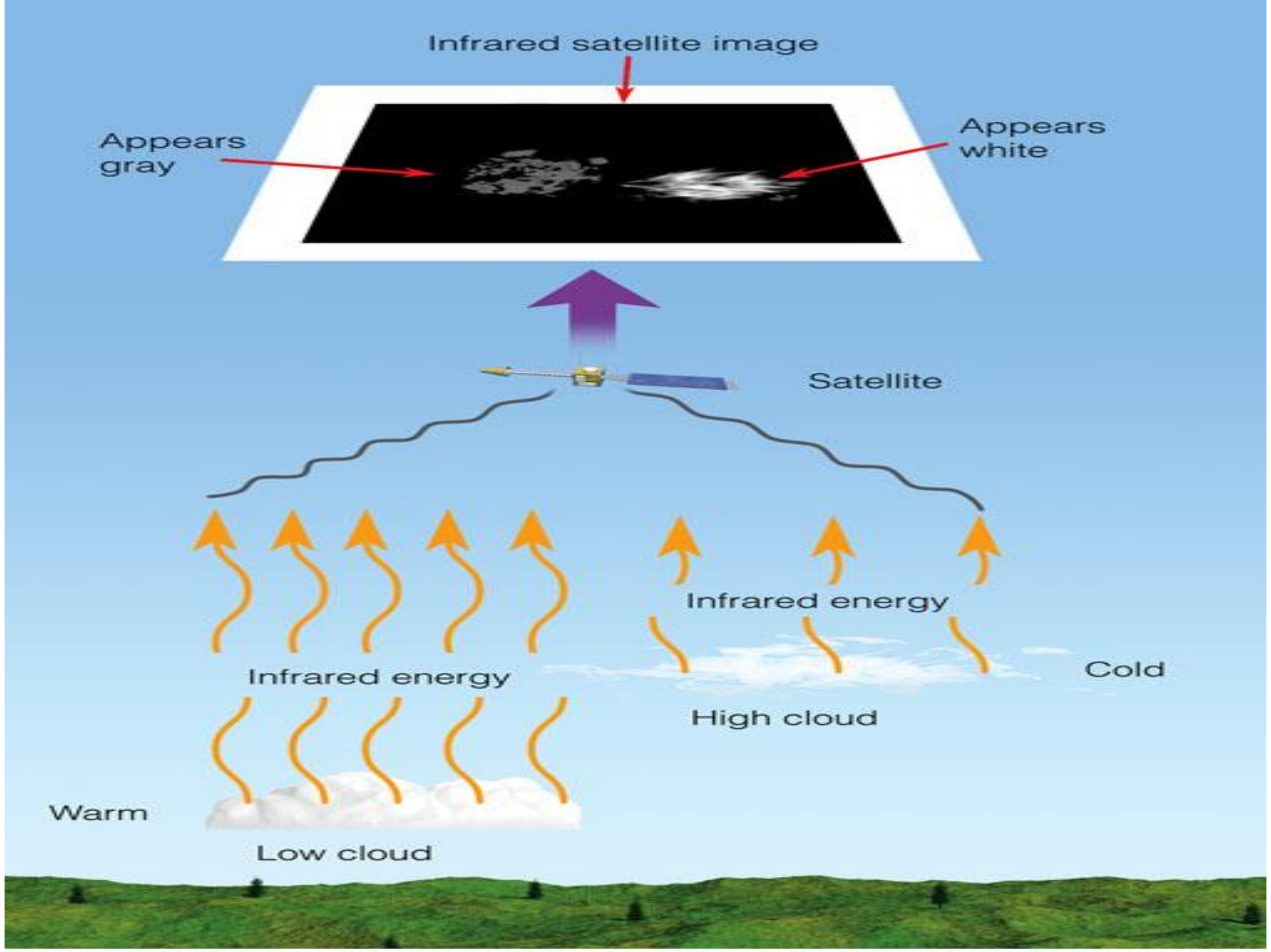


A visible image of the eastern Pacific taken at just about the same time on the same day as the image in Fig. (b). Notice that the clouds in the visible image appear white

Figure (b)



Infrared image of the eastern Pacific taken at just about the same time on the same day as the image in Fig. (a). Notice that the low clouds in the infrared image appear in various shades of gray.



Generally, the lower the cloud, the warmer its top. Warm objects emit more infrared energy than do cold objects. Thus, an infrared satellite picture can distinguish warm, low (gray) clouds from cold, high (white) clouds.

Example of a long existing satellite prototype sensor

Advanced Very High Resolution Radiometer - AVHRR

The AVHRR is a radiation-detection imager that can be used for remotely determining cloud cover and the surface temperature.

Note that the term *surface* can mean the surface of the Earth, the upper surfaces of clouds, or the surface of a body of water.

This scanning radiometer uses 6 detectors that collect different bands of radiation wavelengths (see next slide).

The first AVHRR was a 4-channel radiometer, first carried on TIROS-N (launched October 1978). This was subsequently improved to a 5-channel instrument (AVHRR/2) that was initially carried on NOAA-7 (launched June 1981). Later instrument version is AVHRR/3, with 6 channels, first carried on NOAA-15 launched in May 1998.

http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html

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

Active Remote Sensing

Active instruments provide their own energy to illuminate the scene they observe. They send a pulse of energy from the sensor to the object and then receive the radiation that is reflected or backscattered from that object. Scientists use many different types of active remote sensors.

Examples of passive remote sensors:

Radar (Radio Detection and Ranging)

A radar uses a transmitter operating at either radio or microwave frequencies to emit electromagnetic radiation and a directional antenna or receiver to measure the time of arrival of reflected or backscattred pulses of radiation from distant objects. Distance to the object can be determined since electromagnetic radiation propagates at the speed of light.

Scatterometer

A scatterometer is a high frequency microwave radar designed specifically to measure backscattered radiation. Over ocean surfaces, measurements of backscattered radiation in the microwave spectral region can be used to derive maps of surface wind speed and direction

Lidar

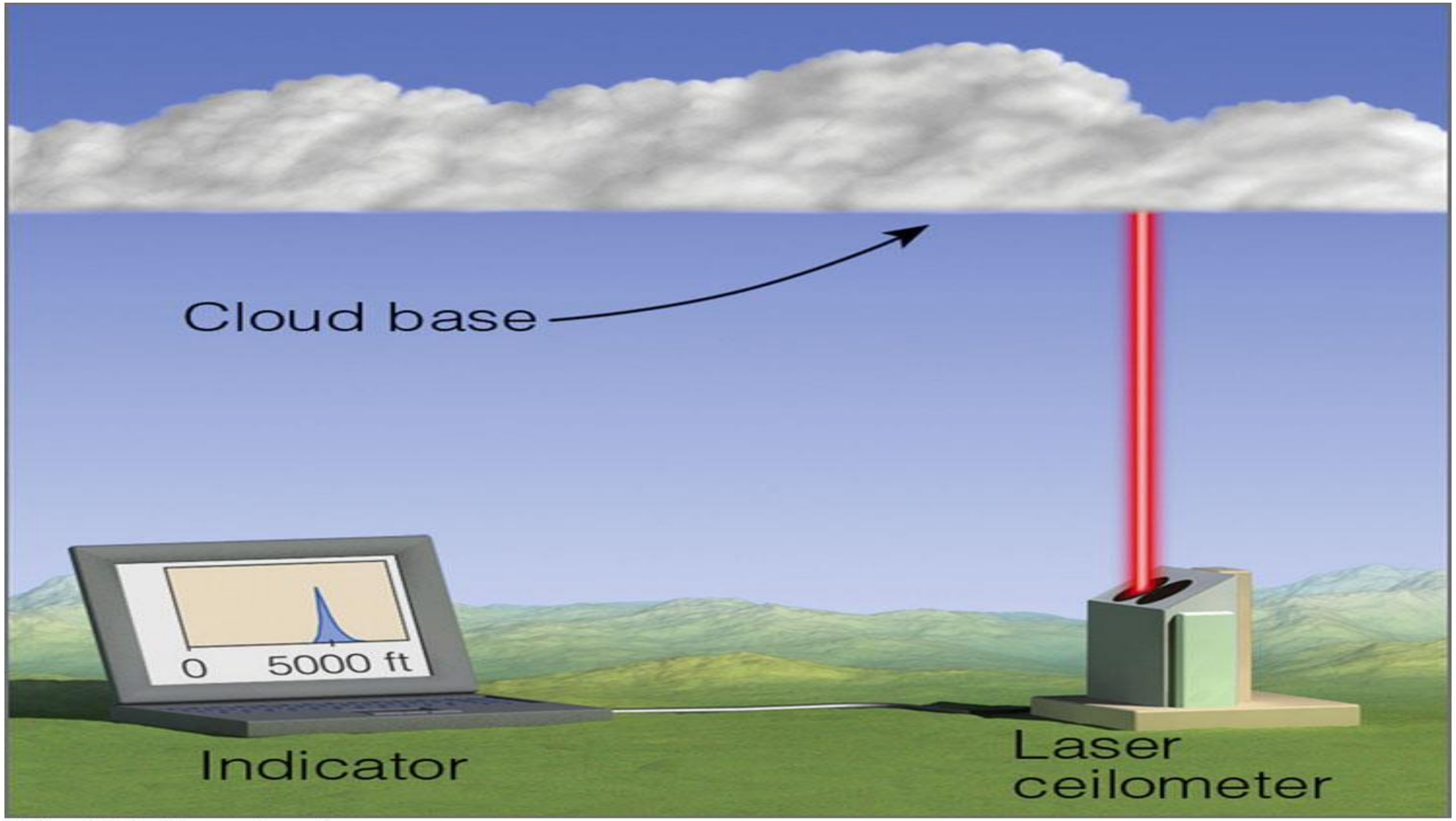
A lidar uses a laser to transmit a light pulse and a receiver with sensitive detectors to measure the backscattered or reflected light.

Distance to the object is determined by recording the time between the transmitted and backscattered pulses and using the speed of light to calculate the distance traveled.

Lidars can determine atmospheric profiles of aerosols, clouds, and other constituents of the atmosphere.

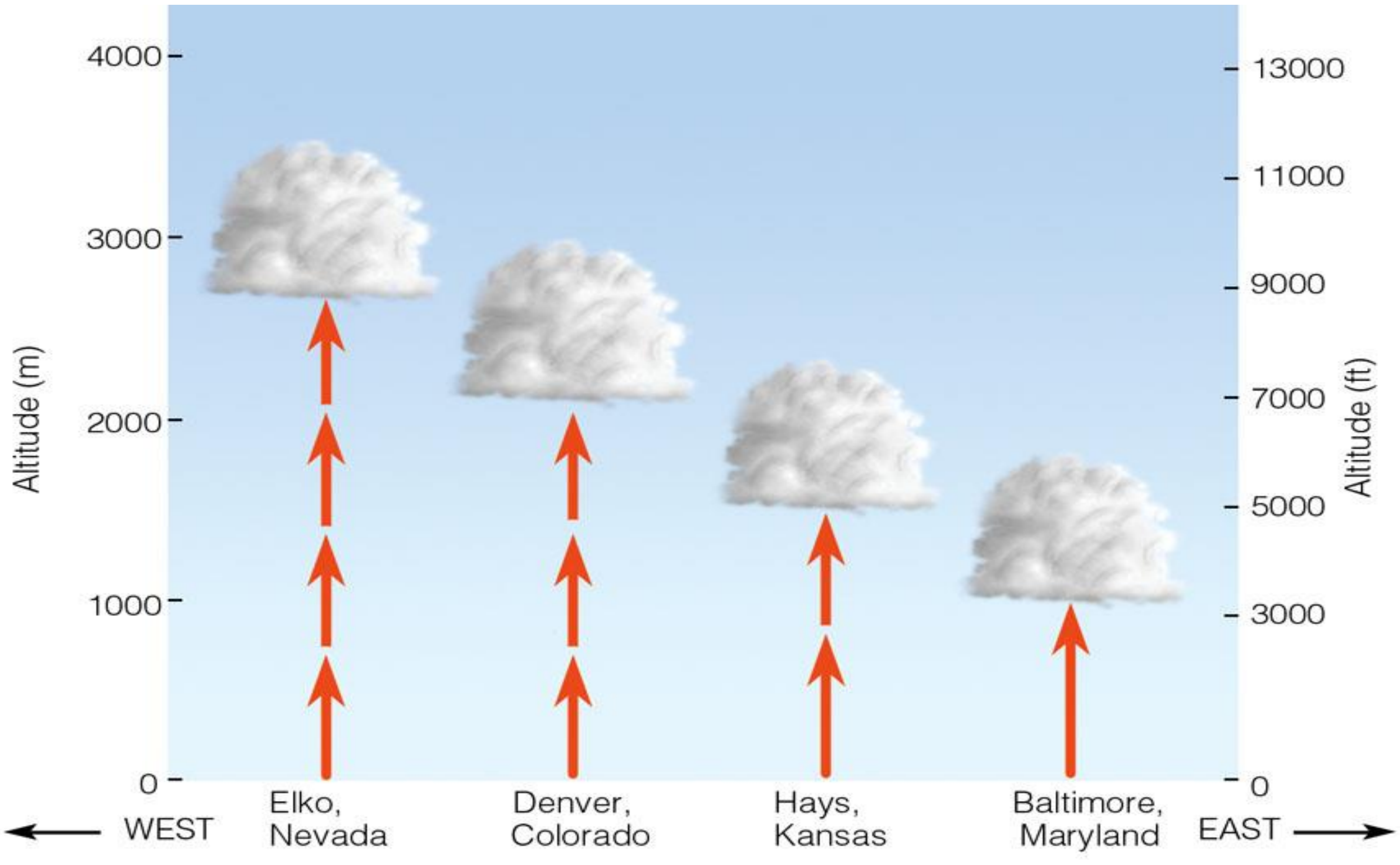
Laser Altimeter

A laser altimeter uses a lidar to measure the height of the instrument platform above the surface. By independently knowing the height of the platform with respect to the mean Earth's surface, the topography of the underlying surface can be determined.



Cloud ceilings

- Ceilometer used at airports to determine height from clouds by light or laser striking clouds and then reflected to a recorder. The interval of time between pulse transmission and return is a measure of cloud height, as displayed on the indicator screen.



	Elko, Nevada	Denver, Colorado	Hays, Kansas	Baltimore, Maryland
Surface temperature (T)	32°C (90°F)	32°C (90°F)	32°C (90°F)	32°C (90°F)
Dew point (T_d)	10°C (50°F)	15°C (59°F)	20°C (68°F)	24°C (75°F)

During the summer, cumulus cloud bases typically increase in elevation above the ground as one moves westward into the drier air of the Central Plains.

Absorption spectrum in microwave

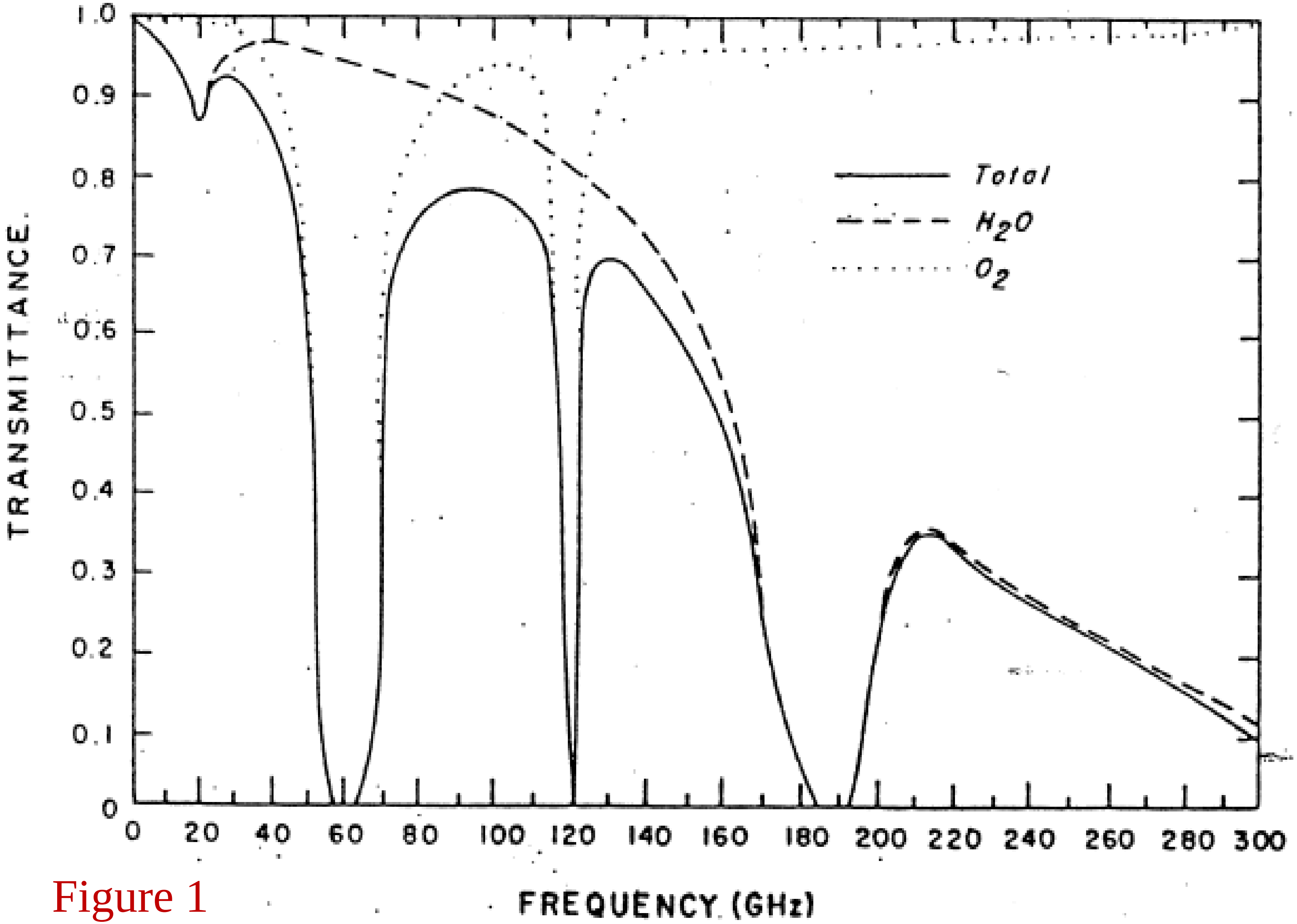


Figure 1

Water vapor and molecular oxygen exhibit absorption lines in the microwave region.

- Below 40 GHz (1 GHz = 10^9 cycles/sec; note 1 cm = 30 GHz) only the weakly absorbing pressure broadened 22.235 GHz water vapor line is dominant.
- At about 31.4 GHz, air is relatively transparent.
- For frequencies greater than 120 GHz. water vapor absorption again becomes dominant due to the strongly absorbing line at 183 GHz. *Figure 1* show the vertical atmospheric transmittance as a function of frequency for a standard atmosphere.

Special problem in the use of microwave from a satellite platform is the emissivity of the earth surface.

In the microwave region of the spectrum, emissivity values of the earth surface range from 0.4 to 1.0. The emissivity of the sea surface typically ranges between 0.4 and 0.5, depending upon such variables as salinity, sea ice, surface roughness and sea foam. This complicates interpretation of terrestrial and atmospheric radiation with earth surface reflections.

In addition, there is a frequency dependence with higher frequencies displaying higher emissivity values. Over land, the emissivity depends on the moisture content of the soil. Wetting of a soil surface results in a rapid decrease in emissivity. The emissivity of dry soil is on the order of 0.95 to 0.97, while for wet bare soil it is about 0.80 to 0.90, depending on the frequency. The surface emissivity appearing in the first term has a significant effect on the brightness temperature value.

Principles of MW radiometry

Radiometers are passive instruments, so they detect radiation emitted by Earth’s atmosphere or surface. The ocean is a weak emitter with emissivity of the order of 50%, so its black body temperature in most MW wavelengths is low.

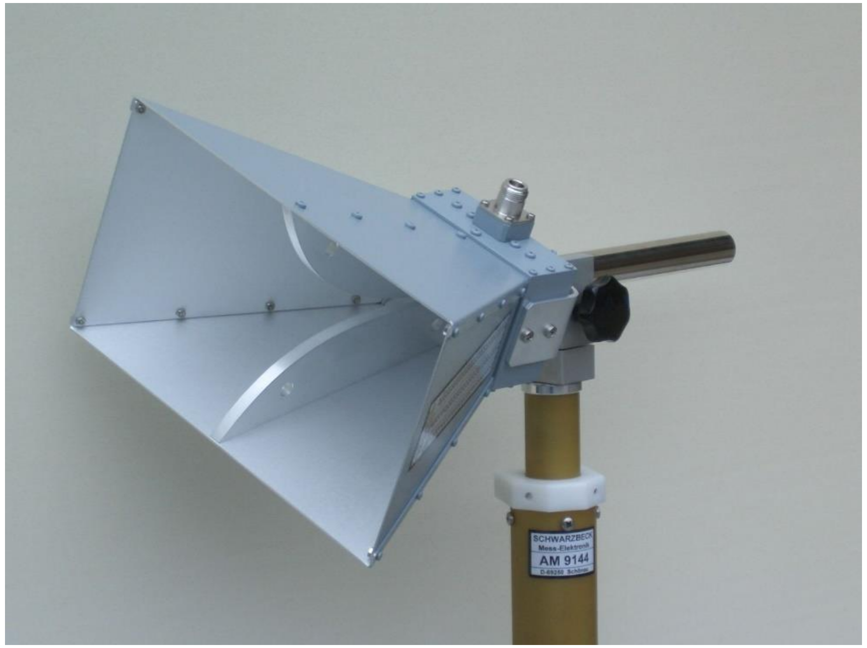
The atmosphere has a strong emission line around 22GHz, so that frequency is used to measure the total column of water vapor.

19 GHz and 37 GHz are sensitive to the “Mie scattering” by cloud droplets, so these frequencies are used for total liquid water content, and 85 GHz receives scattering from ice particles at the top of clouds, indication of possible rain.

The solid Earth is a strong emitter, so atmospheric signals cannot be separated out over land

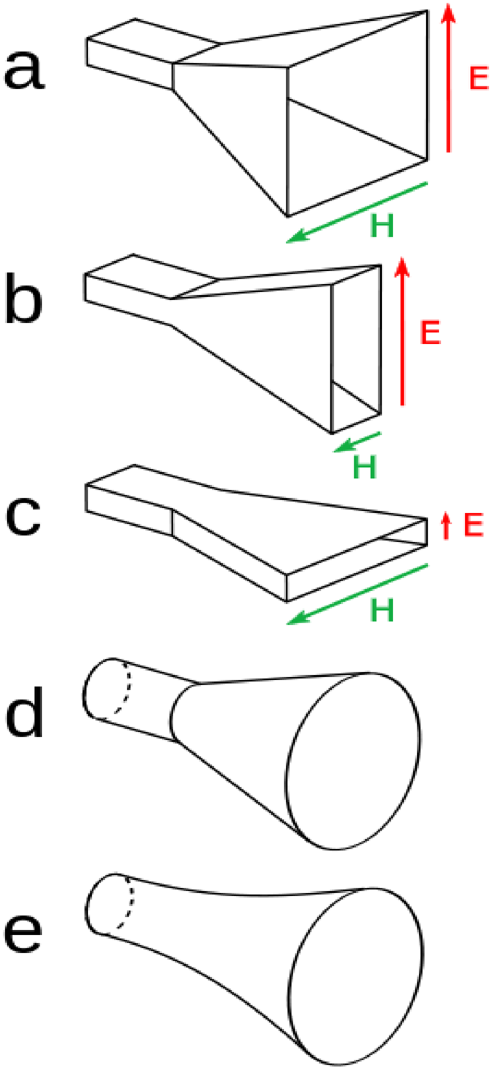
Detection of MW radiation

Signals are received in so called “horns”, which have rectangular openings. The electro-magnetic radiation is received in horizontal or vertical planes, which means that the radiation is either horizontally or vertically polarized. The same is true for radiation sent out by a MW emitter that also can receive – a radar.

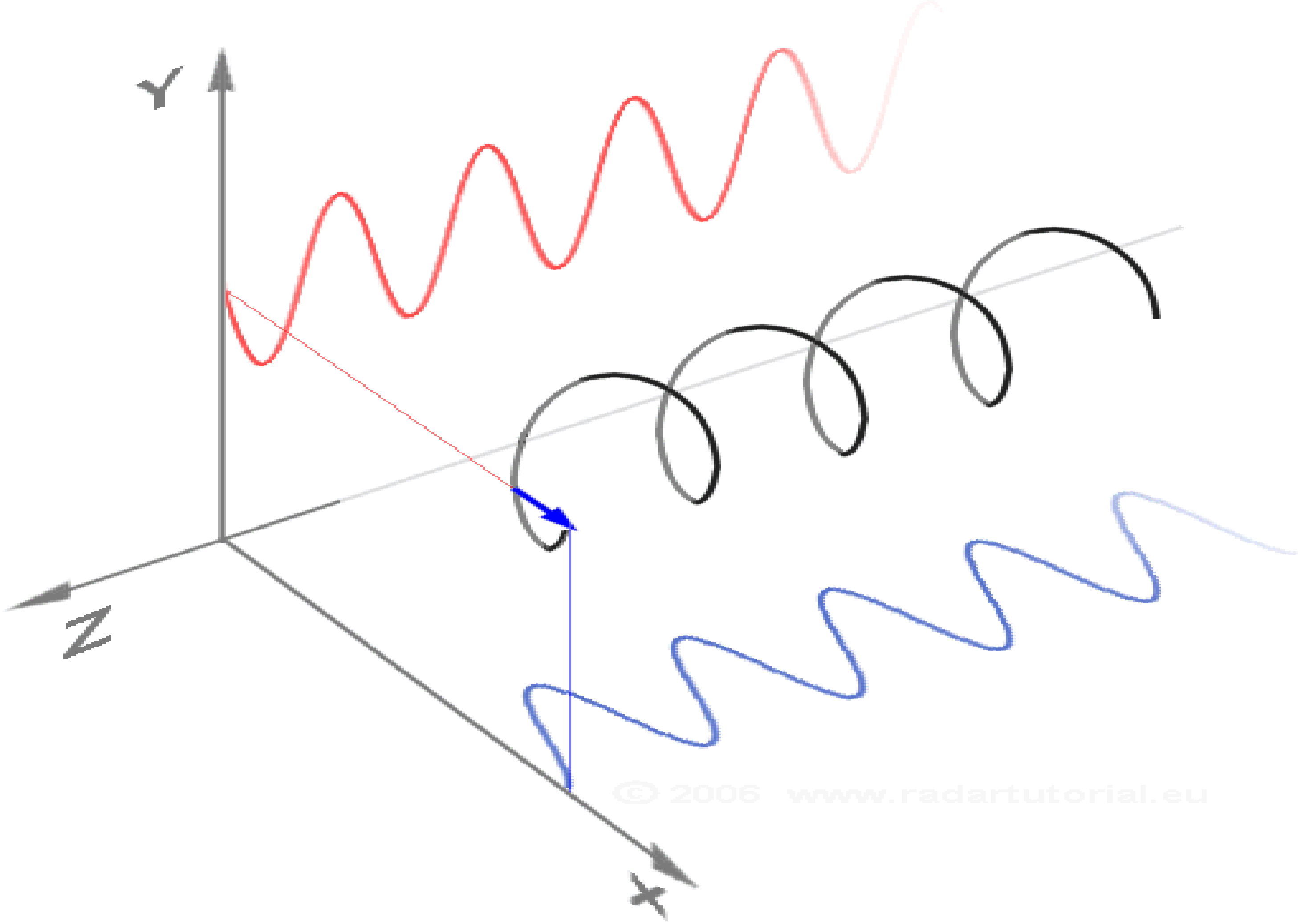


Pyramidal microwave horn antenna, with a bandwidth of 0.8 to 18 GHz

Pyramidal horn antennas for a variety of frequencies



Horn antenna types

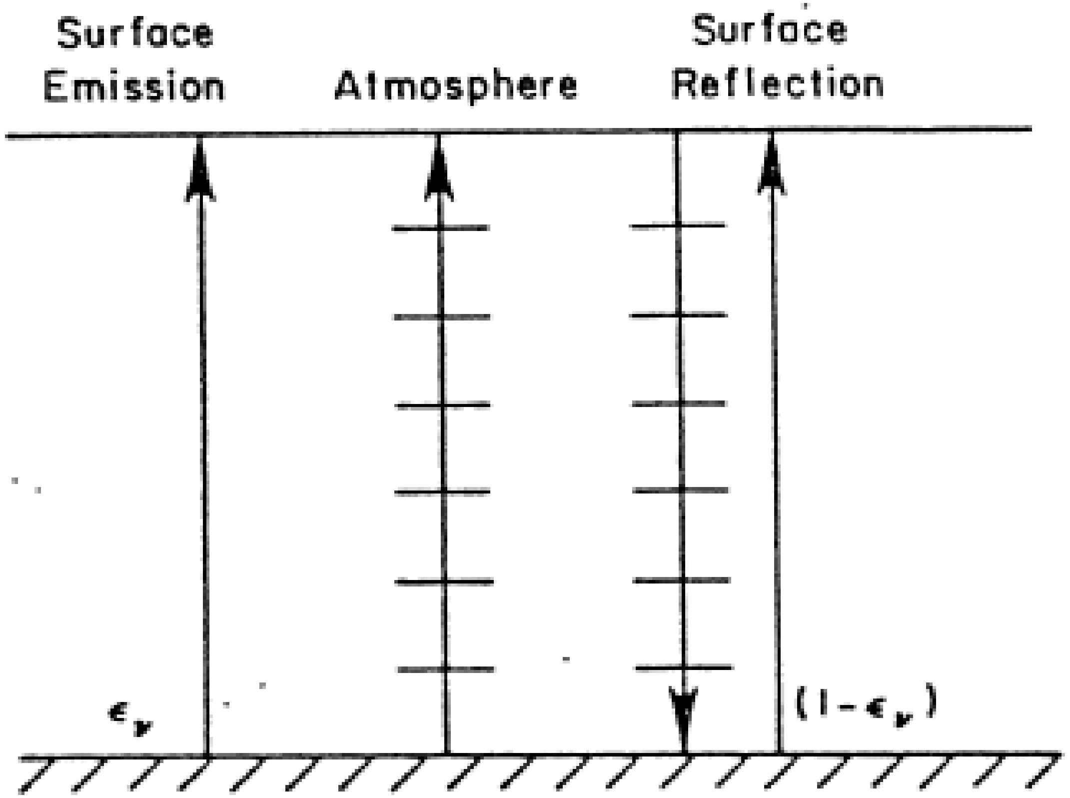


Vertically, horizontally and a circularly polarized wave as a sum of the two components

Microwave Instruments of focus

- Passive = radiometers
- Scanning Multichannel Microwave Radiometer, Special Sensor Microwave Imager, Sounder
- SMMR, SSM/I, SSMIS, TMI, AMSU-A, B-true workhorses
- Active = radar types
- Scatterometers, SEASAT, ERS 1, 2, QuikSCAT; also workhorses—Currently Metop' s ASCAT
- Altimeters, TOPEX, Poseidon, Jason 1, 2, others.
- Synthetic Aperture Radars, SARs RADARSAT 1, 2 , ENVISAT/ASAR , Tetra-SAR X
- Precipitation /Cloud Radars, TRMM, CloudSat

Since the emissivity in microwave is less than 1, there is a reflection contribution from the surface.



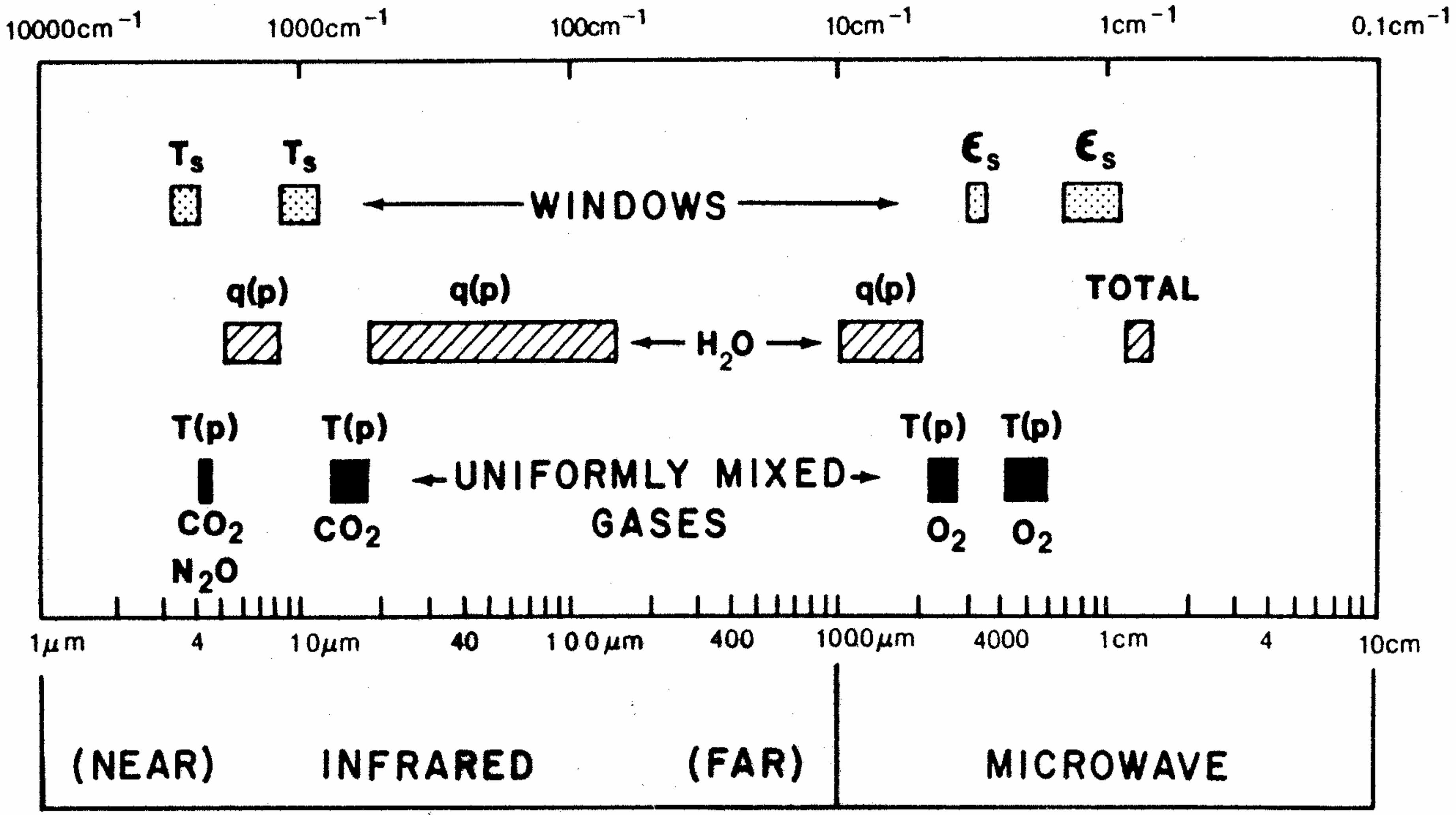
Contribution of each term to the brightness temperature at the top or the atmosphere

The radiance emitted from the surface is given as:

$$I_{\bar{\nu}}(P_s) = \varepsilon_{\bar{\nu}} B_{\bar{\nu}}(\mathrm{T}_s) T_{\bar{\nu}}(p_s,0) + (1-\varepsilon_{\bar{\nu}}) T_{\bar{\nu}}(p_s,0) \int_0^{P_s} B_{\bar{\nu}}[\mathrm{T}(p)] \frac{\partial T_{\bar{\nu}}(p_s,p)}{\partial p} dp$$

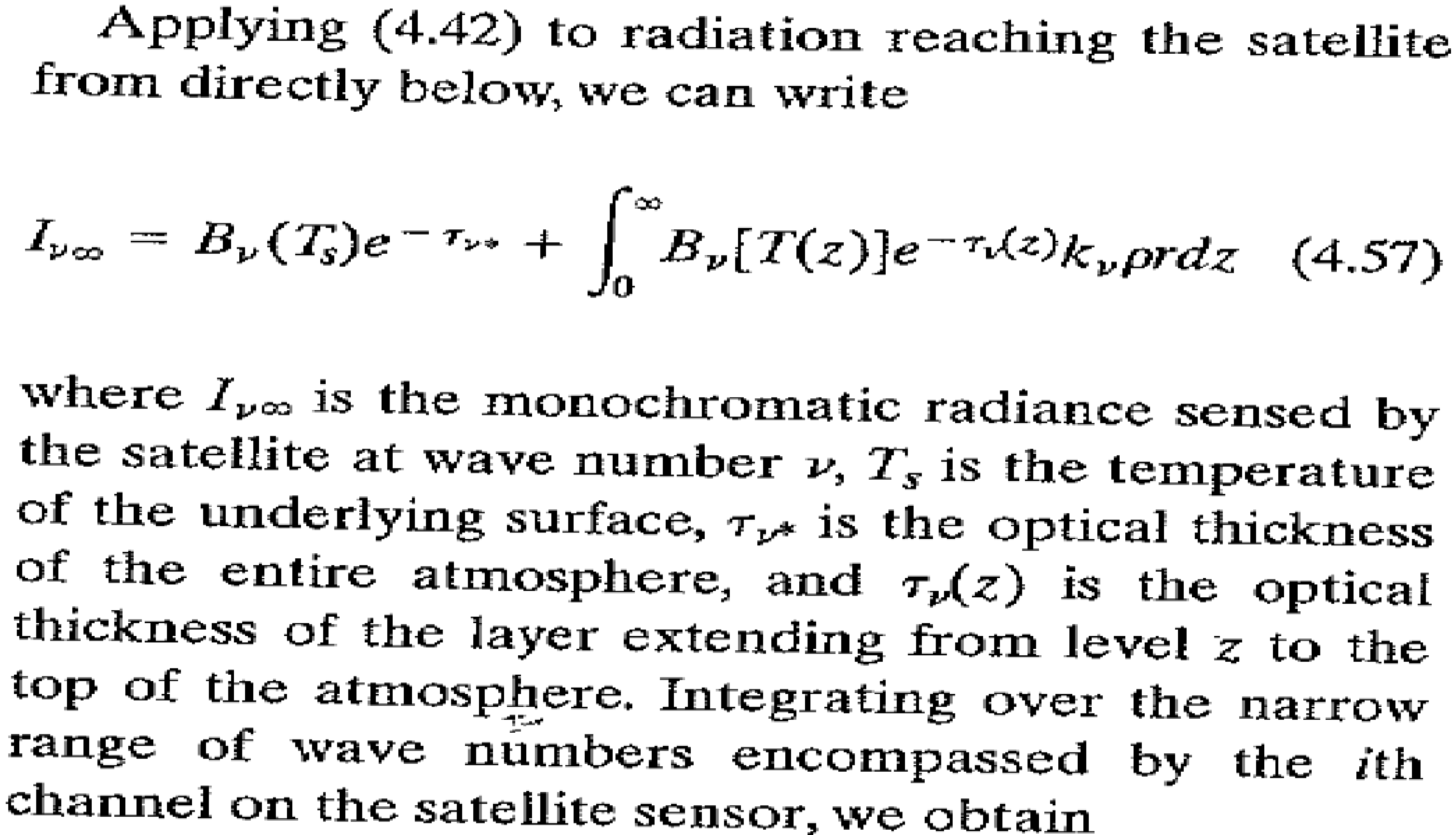
The first term in the right-hand side denotes the surface emission contribution, whereas the second term represents the emission contribution from the entire atmosphere to the surface, which is reflected back to the atmosphere at the same frequency.

Spectral regions used for remote sensing of the earth atmosphere and surface from satellites. ε indicates emissivity, q denotes water vapor, and T represents temperature.



Some comments on what is needed to retrieve atmospheric profiles of parameters (e.g., temperature structure of the atmosphere).

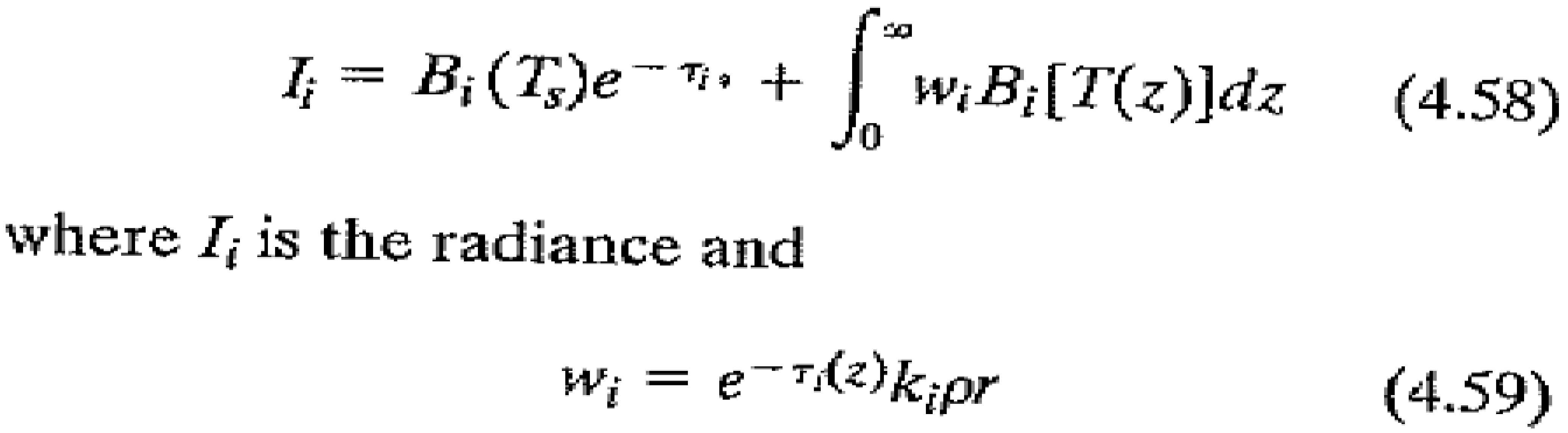
From your textbook (general formula, no special attention to microwave).



Applying (4.42) to radiation reaching the satellite from directly below, we can write

$$I_{\nu\infty} = B_\nu(T_s)e^{-\tau_{\nu*}} + \int_0^\infty B_\nu[T(z)]e^{-\tau_\nu(z)}k_\nu\rho r\,dz \qquad (4.57)$$

where $I_{\nu\infty}$ is the monochromatic radiance sensed by the satellite at wave number ν, T_s is the temperature of the underlying surface, $\tau_{\nu*}$ is the optical thickness of the entire atmosphere, and $\tau_\nu(z)$ is the optical thickness of the layer extending from level z to the top of the atmosphere. Integrating over the narrow range of wave numbers encompassed by the *i*th channel on the satellite sensor, we obtain

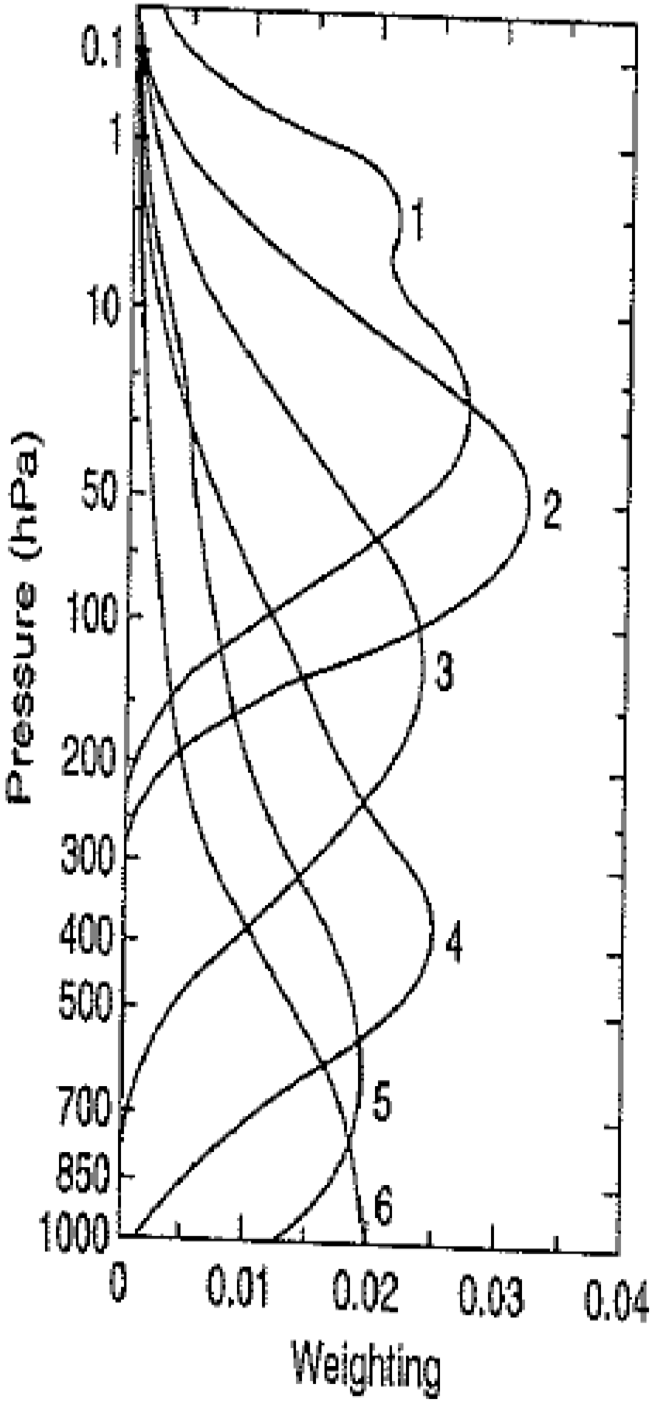


$$I_i = B_i(T_s)e^{-\tau_{i,s}} + \int_0^\infty w_i B_i[T(z)]dz \qquad (4.58)$$

where I_i is the radiance and

$$w_i = e^{-\tau_i(z)} k_i \rho r \qquad (4.59)$$

w_i is called the weighing function, represents the contribution from a layer of unit thickness located at a level z to the radiance sensed by satellites


Pressure (hPa)
0.1
1
10
50
100
200
300
400
500
700
850
1000
0
0.01
0.02
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Weighting
1
2
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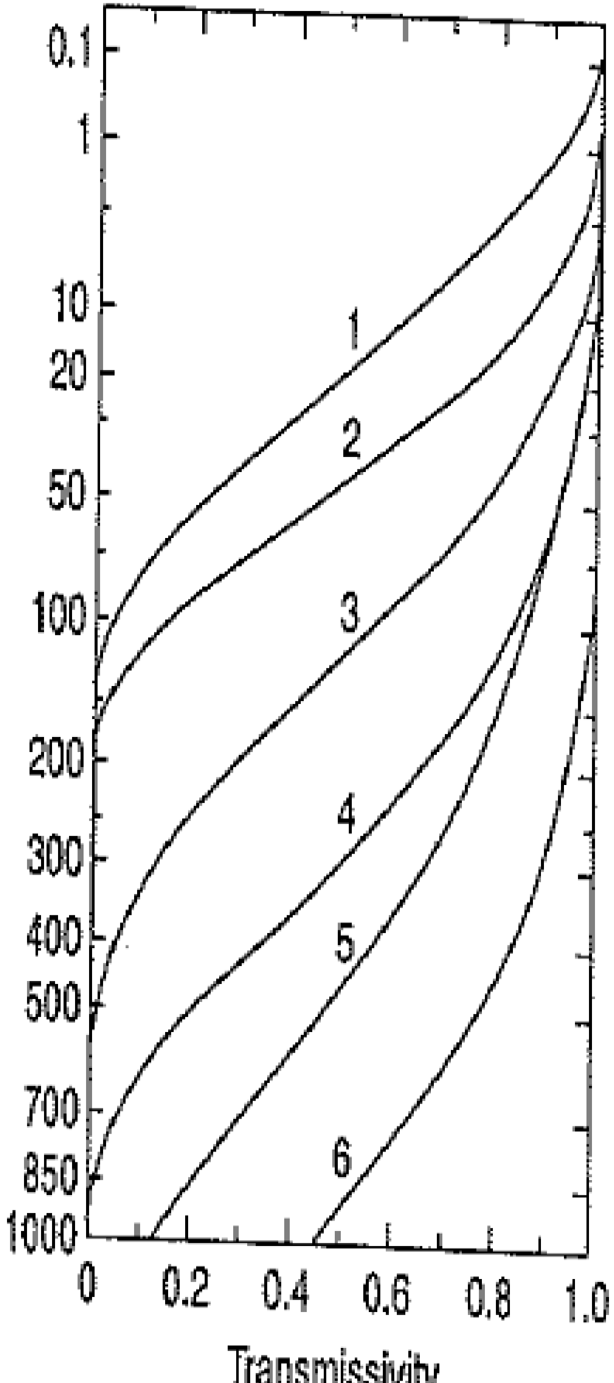
6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0.2
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1.0
Transmissivity
1
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6

Satellite retrieval of temperature

The signal does not come from a well defined/sharp layer