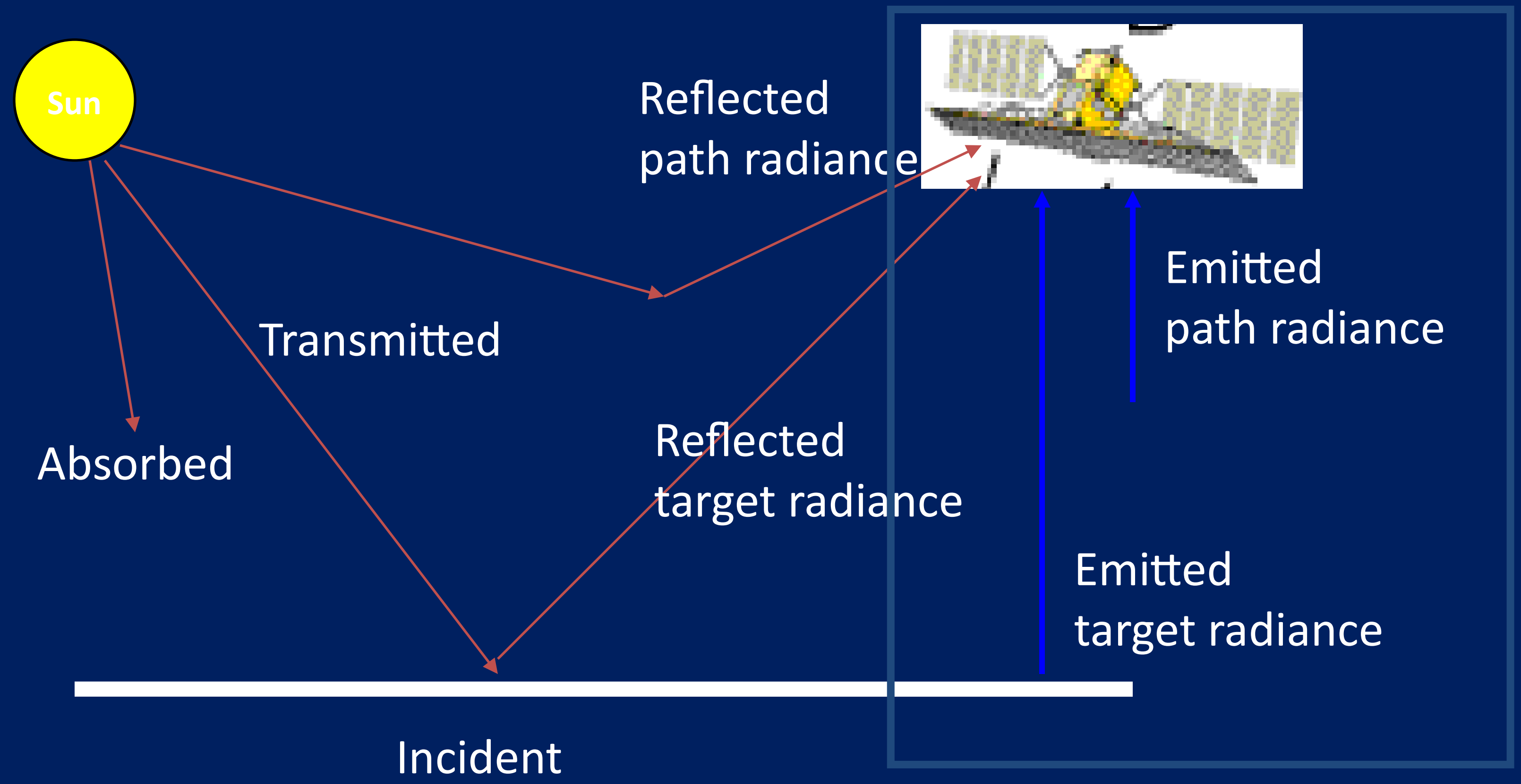
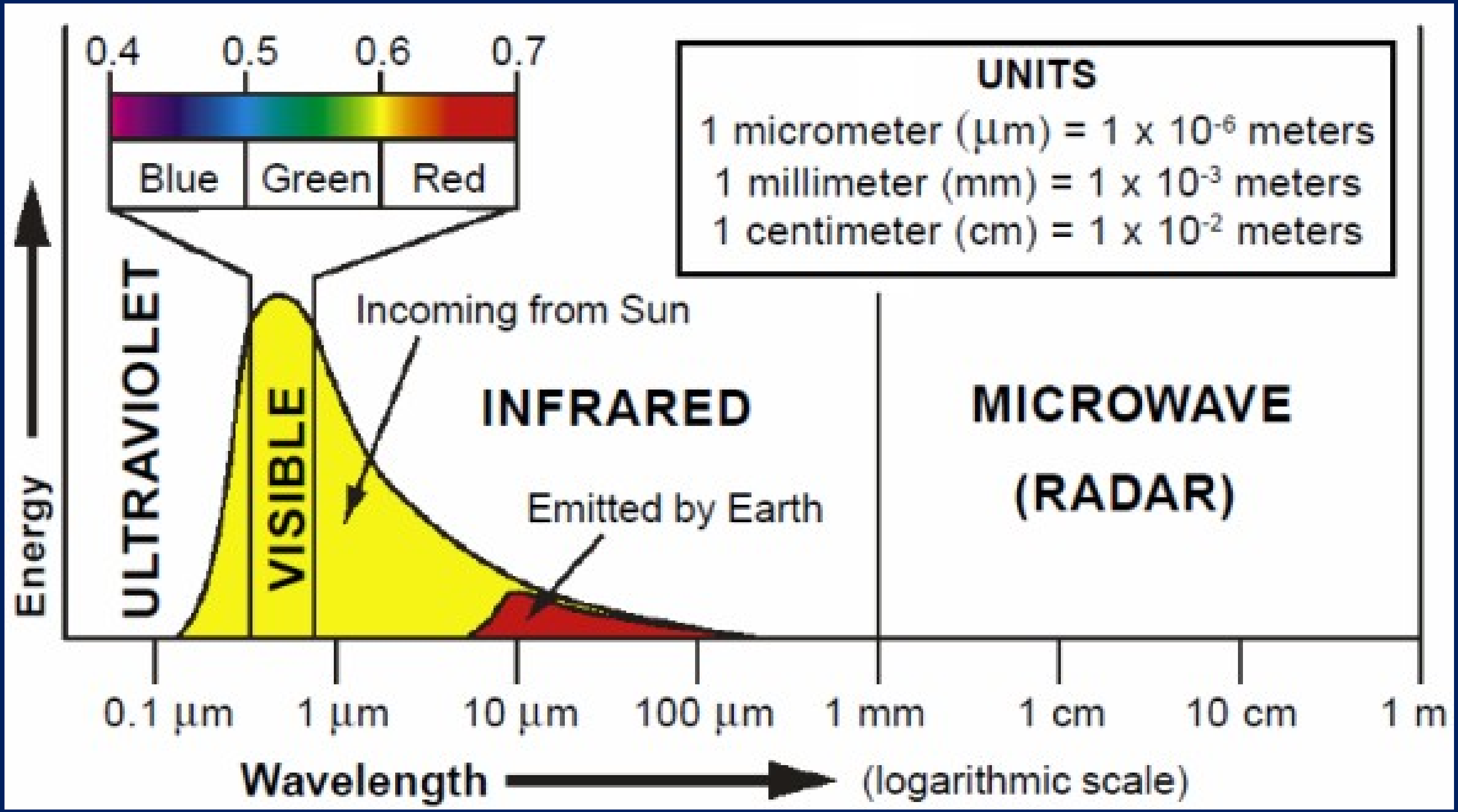
Thermal Remote Sensing:

- Thermal remote sensing is the branch of remote sensing that deals with the acquisition, processing and interpretation of data acquired primarily in the thermal infrared (TIR) region of the electromagnetic (EM) spectrum. or
- Sensing of terrestrial objects under the IR ranges on the basis of their temperature emittance variations is called thermal remote sensing.
- In thermal Remote Sensing we measure the radiations 'emitted' from the surface of the target, as opposed to optical remote sensing where we measure the radiations 'reflected' by the target.


Sun
Reflected
path radiance
Emitted
path radiance
Transmitted
Absorbed
Reflected
target radiance
Emitted
target radiance
Incident



0.4
0.5
0.6
0.7
Blue
Green
Red
UNITS
1 micrometer (μm) = 1 x 10-6 meters
1 millimeter (mm) = 1 x 10-3 meters
1 centimeter (cm) = 1 x 10-2 meters
ULTRAVIOLET
VISIBLE
Incoming from Sun
INFRARED
MICROWAVE
(RADAR)
Emitted by Earth
Energy
0.1 μm
1 μm
10 μm
100 μm
1 mm
1 cm
10 cm
1 m
Wavelength
(logarithmic scale)

Spectral Range of Thermal regions

- O.7-1.3 NIR for both absorption and reflection
- 1.6.to3 MIR reflection and emission
- 8 to 14 TIR only emission

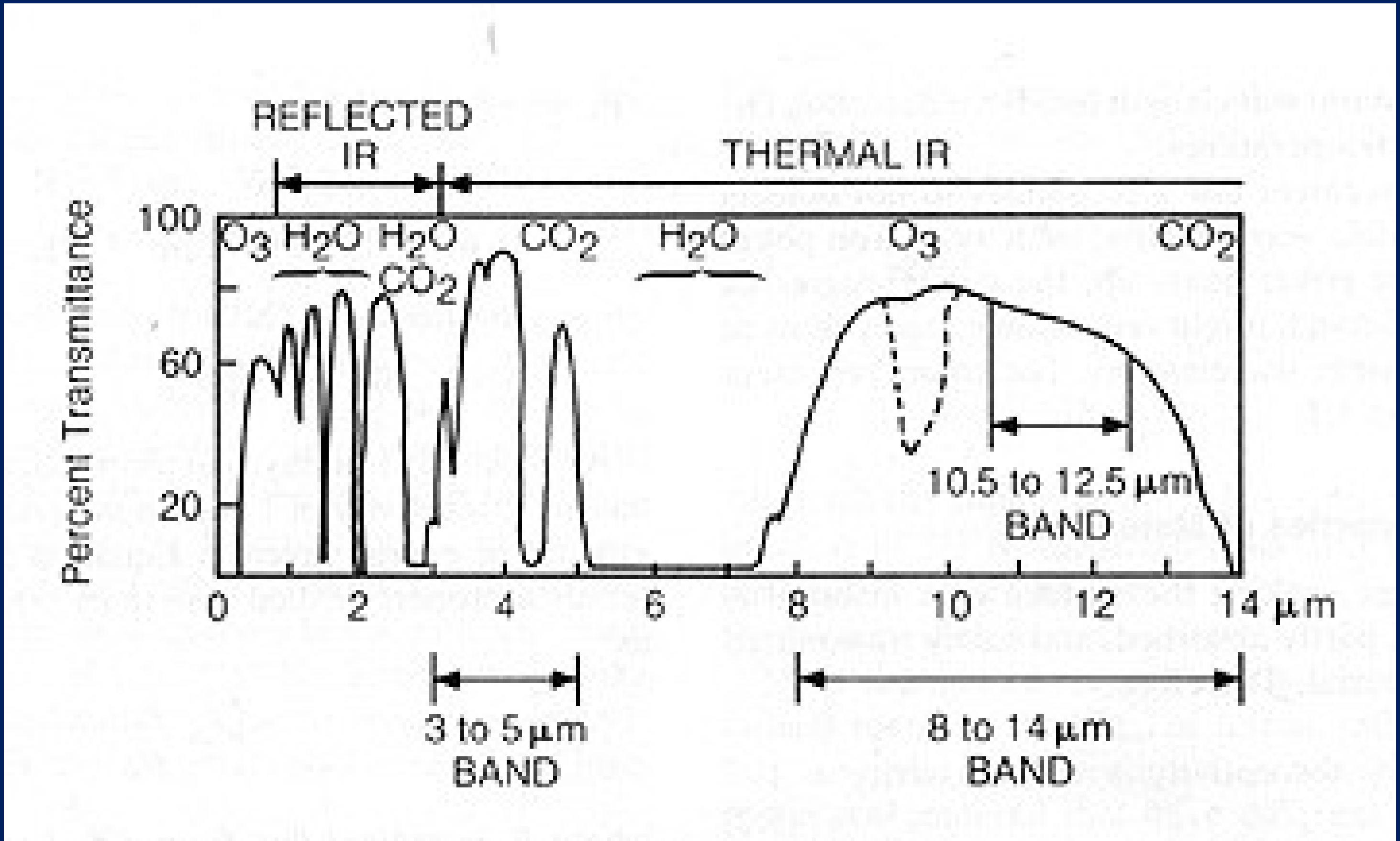


Figure: IR region of EM Spectrum

Principles of TIR:

Temperature of the object is controlled by physical, chemical and biological environment of the object.

Kinetic temperature:

It is actually measured temperature of the object by physically touching it. Such kinetic temperature will give the internal manifestation of energy of the molecules.

The internal or kinetic heat energy of matter is then converted in to radiant energy

Kinetic temperature is the surface temperature of a body/ground and is a measure of the amount of heat energy contained in it.

It is measured in different units, such as in Kelvin (K); degrees Centigrade (°C); degrees Fahrenheit (°F).

The Kelvin scale is called absolute temperature and the Kelvin is the SI unit for temperature

Radiant Temperature

- The heat is radiated by the terrestrial object is called Radiant Temperature
- How much energy is radiated, and at which wavelengths, depends on the emissivity of the surface and on its kinetic temperature.
- Thermal remote sensing exploits the fact that everything above absolute zero (0 K or -273.15°C or –459°F) emits radiation in the infrared range of the electromagnetic spectrum

Emissivity is the emitting ability of a real material compared to that of a black body, and is a spectral property that varies with **composition of material** and **geometric configuration of the surface**.

Emissivity denoted by epsilon (ε) is a ratio and varies between 0 and 1. For most natural materials, it ranges between 0.7 and 0.95.

Black body is one which totally absorb and reemits all energy incident upon it.

Heat transfer

Heat energy is transferred one place to another place by three ways, Conduction, 2. Convection and 3.Radiation

Conduction: It transfer the heat through a material by molecular contact.

Convection. It transfer the heat the physical movement of heated matter

Radiation transfer the heat in the form of EM waves. Heat from the sun reaches the earth by radiation. Radiation can transfer the heat through the vacuum

Atmospheric Transmission:

- The atmosphere does not transmit all W.L of TIR radiation uniformly. CO_2, O_3 and H_2O absorb the energy in certain W.L regions called absorption bands.
- The atmosphere transmit the W.L of 3 to 5 and 8 to 14 um. These bands are called atmospheric windows.
- The windows normally used for aircraft platforms are in the 3-5 micron and 8-14 micron wavelength regions
- 10.5 to 12.5 is suitable for satellite images because band 9 to 10 is affected by the ozone layer at the top of the earth's atmosphere.

Planck Radiation (Blackbody) Law

$$E(\lambda, T) = \frac{2\pi hc^2}{\lambda^5 (e^{hc/\lambda kT} - 1)}$$

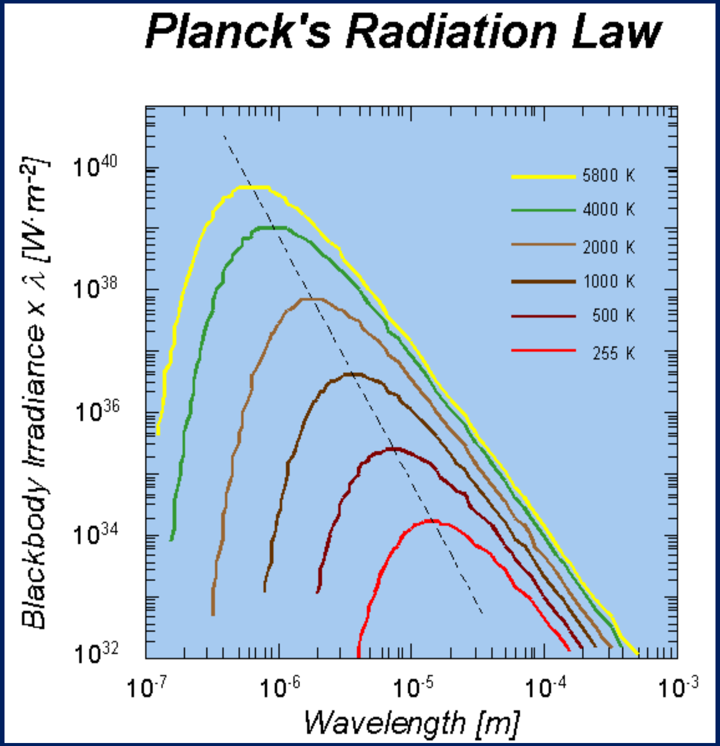
E= Energy or total radiant exitance, W m-2
h = Placnk's constant
k = Boltzmann constant
c = speed of light
(constant)
T = temperature (in K)
λ = Wavelength

Plank's Radiation Law for blackbodies gives the position of the peak and total spectral radiance (area under the curve) of an object as a function of its temperature

Principles of Emitted Radiation

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

- internal temperature; and
- emissivity



Wien's Displacement Law

As the temperature of an object increases, the total amount of radiant energy (area under the curve, in W/m2) increases and the wavelengths at which the objects emits the most energy decreases.

To determine this peak wavelength (λmax) for a blackbody:

$$\lambda max = A/T$$

where A is a constant (2898 μm K) and T is the temperature in Kelvins.

- The 300 K Earth's peak emmitance wavelength is: 2898 / 300 = 9.7 μm, in the thermal IR
- What wavelength is the Sun's radiant energy peak (6000 K)?

Thermal Energy Interaction with Atmosphere

Atmospheric Scattering

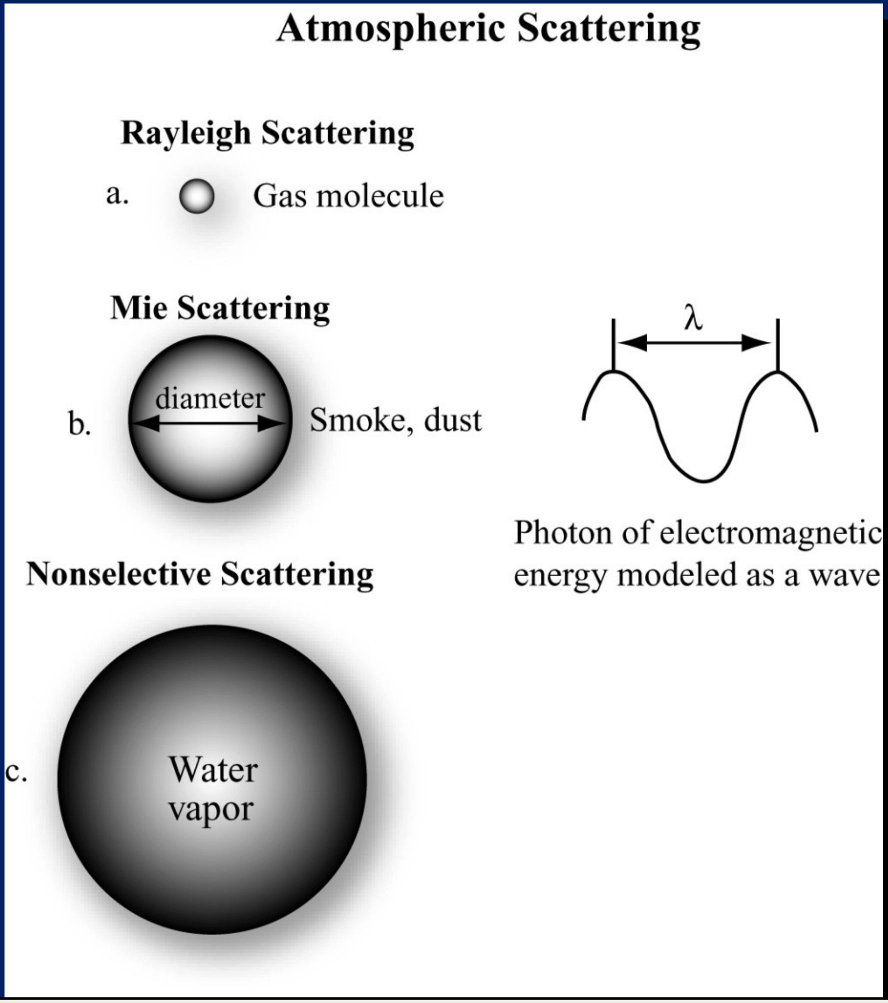
Once electromagnetic radiation is generated, it is propagated through the earth's atmosphere almost at the speed of light in a vacuum.

- Unlike a vacuum in which nothing happens, however, the atmosphere may affect not only the speed of radiation but also its wavelength, intensity, spectral distribution, and/or direction.

Scatter differs from *reflection* in that the direction associated with scattering is ***un***predictable, whereas the direction of reflection is predictable. There are essentially three types of scattering:

- Rayleigh,
- Mie, and
- Non-selective.

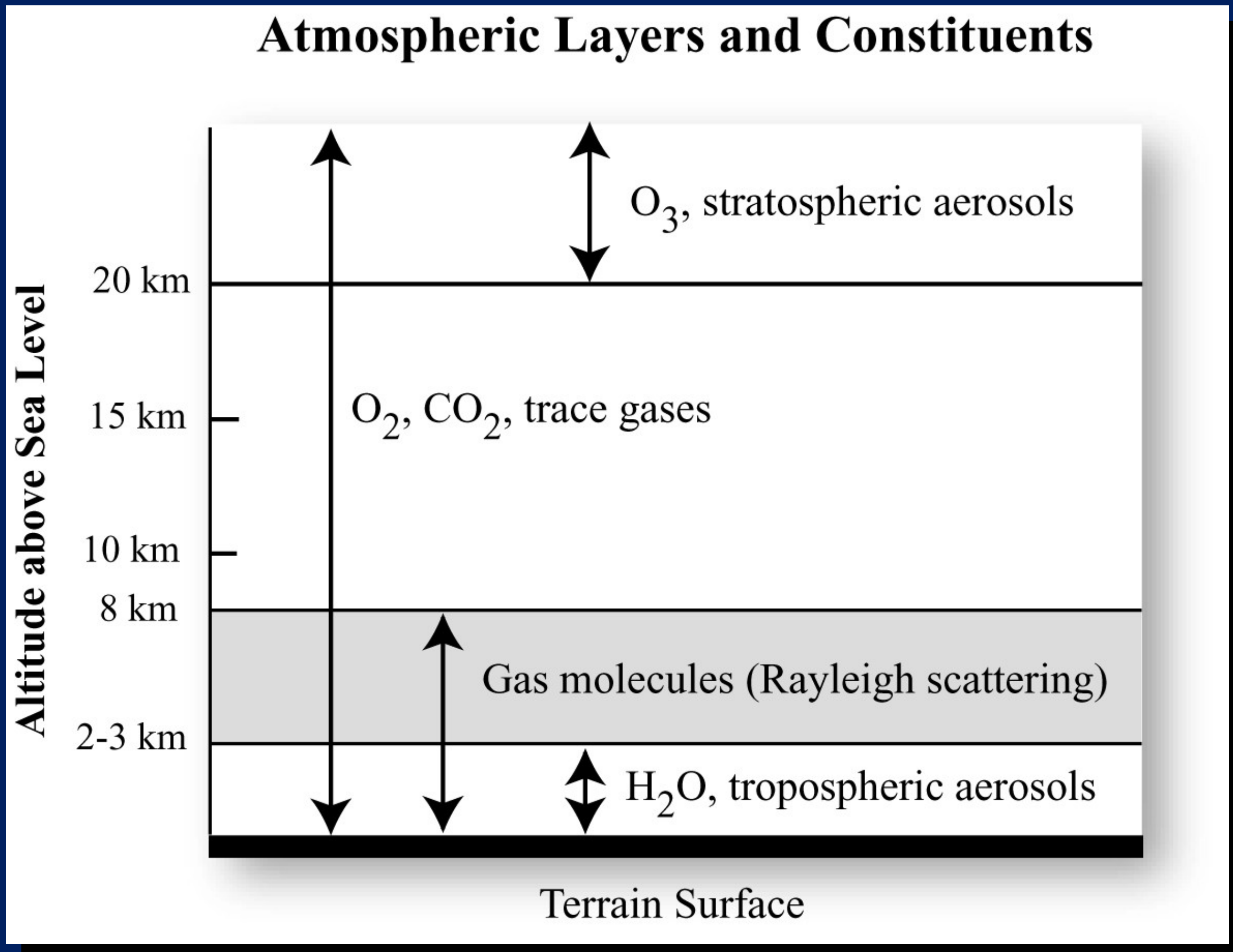
Atmospheric Scattering



Type of scattering is a function of:

1) the wavelength of the incident radiant energy, and

2) the size of the gas molecule, dust particle, and/or water vapor droplet encountered.



Major subdivisions of the atmosphere and the types of molecules and aerosols found in each layer.

Rayleigh Scattering

Rayleigh scattering occurs when the diameter of the matter (usually air molecules) are *many times smaller than the wavelength of the incident electromagnetic radiation*.

The energy required to excite an atom is associated with short-wavelength, high frequency radiation. *The amount of scattering is inversely related to the fourth power of the radiation's wavelength*. For example, blue light (0.4 μm) is scattered 16 times more than near-infrared light (0.8 μm).

- *Rayleigh scattering* is responsible for the *blue sky*. The short violet and blue wavelengths are more efficiently scattered than the longer orange and red wavelengths. When we look up on cloudless day and admire the blue sky, we witness the preferential scattering of the short wavelength sunlight.

The approximate amount of Rayleigh scattering in the atmosphere in optical wavelengths (0.4 – 0.7 mm) may be computed using the *Rayleigh scattering cross-section* (t_m) algorithm:

$$\tau_m = \frac{8\pi^3\left(n^2-1\right)^2}{\left(3N^2\lambda^4\right)}$$

where n = refractive index, N = number of air molecules per unit volume, and l = wavelength. The amount of scattering is inversely related to the fourth power of the radiation's wavelength.

Mie Scattering

- *Mie scattering* takes place when there are essentially *spherical* particles present in the atmosphere *with diameters approximately equal to the wavelength of radiation being considered*. For visible light, water vapor, dust, and other particles ranging from a few tenths of a micrometer to several micrometers in diameter are the main scattering agents. The amount of scatter is greater than Rayleigh scatter and the wavelengths scattered are longer.

- *Pollution* also contributes to beautiful *sunsets* and *sunrises*. The greater the amount of smoke and dust particles in the atmospheric column, the more violet and blue light will be scattered away and only the longer *orange* and *red* wavelength light will reach our eyes.

Non-selective Scattering

- *Non-selective scattering* is produced when there are particles in the atmosphere *several times larger than the he diameter of the radiation being transmitted*. This type of scattering is non-selective, i.e. all wavelengths of light are scattered, not just blue, green, or red. Thus, water droplets, which make up clouds and fog banks, scatter all wavelengths of visible light equally well, causing the cloud to appear white (a mixture of all colors of light in approximately equal quantities produces white).

Absorption

- *Absorption* is the process by which radiant energy is absorbed and converted into other forms of energy. An *absorption band* is a range of wavelengths (or frequencies) in the electromagnetic spectrum within which radiant energy is absorbed by substances such as water (H_2O), carbon dioxide (CO_2), oxygen (O_2), ozone (O_3), and nitrous oxide (N_2O).

- The cumulative effect of the absorption by the various constituents can cause the atmosphere to *close down* in certain regions of the spectrum. This is bad for remote sensing because no energy is available to be sensed.

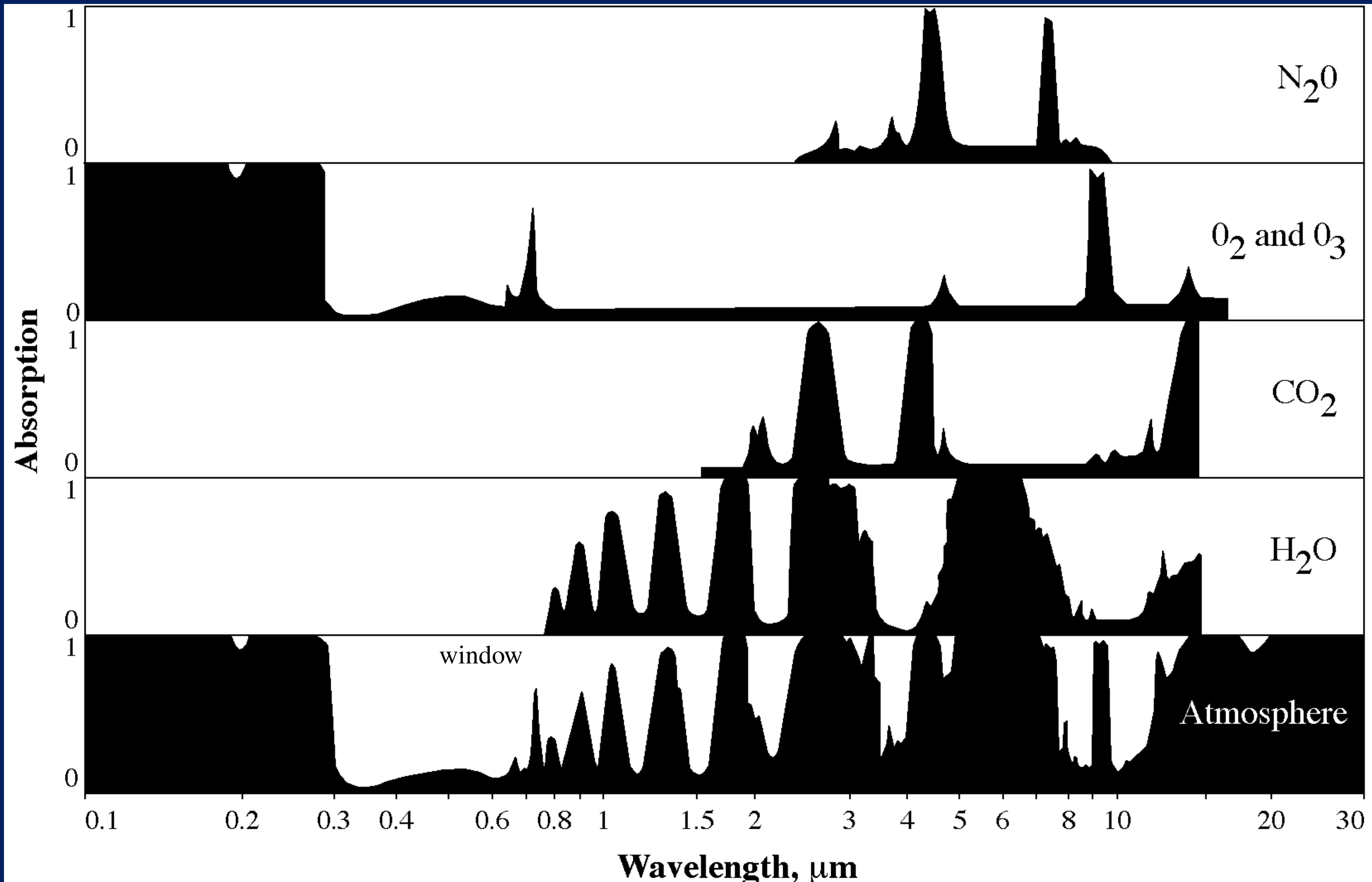
Absorption

• In certain parts of the spectrum such as the visible region (0.4 - 0.7 μm), the atmosphere does not absorb all of the incident energy but transmits it effectively. Parts of the spectrum that transmit energy effectively are called "atmospheric windows".

• *Absorption* occurs when energy of the same frequency as the resonant frequency of an atom or molecule is absorbed, producing an *excited state*. If, instead of re-radiating a photon of the same wavelength, the energy is transformed into heat motion and is reradiated at a longer wavelength, absorption occurs. When dealing with a medium like air, absorption and scattering are frequently combined into an *extinction coefficient*.

• *Transmission* is inversely related to the extinction coefficient times the thickness of the layer. Certain wavelengths of radiation are affected far more by absorption than by scattering. This is particularly true of infrared and wavelengths shorter than visible light.

Absorption of the Sun's Incident Electromagnetic Energy in the Region from 0.1 to 30 μm by Various Atmospheric Gases



a) The *absorption* of the Sun's incident electromagnetic energy in the region from 0.1 to 30 mm by various atmospheric gases. The first four graphs depict the absorption characteristics of N_2O, O_2 and O_3, CO_2, and H_2O, while the final graphic depicts the cumulative result of all these constituents being in the atmosphere at one time. The atmosphere essentially "closes down" in certain portions of the spectrum while "atmospheric windows" exist in other regions that transmit incident energy effectively to the ground. It is within these windows that remote sensing systems must function.

b) The combined effects of atmospheric absorption, scattering, and reflectance reduce the amount of solar irradiance reaching the Earth's surface at sea level.

Interaction of Thermal Radiation with Terrain Elements

The energy radiated from an object usually is the result of energy incident on the feature

$$E_I = E_A + E_R + E_T$$

The energy incident on the surface of the terrain element

$$\frac{E_I}{E_I} = \frac{E_A}{E_I} + \frac{E_R}{E_I} + \frac{E_T}{E_I} = 1$$

Alfa, Rho & Tau

$$\alpha(\lambda) = \frac{E_A}{E_I}, \rho(\lambda) = \frac{E_R}{E_I}, \tau(\lambda) = \frac{E_T}{E_I}$$

Absorptance of the terrain element

Reflectance of the terrain element

Transmittance of the terrain element

Interaction of Thermal Radiation with Terrain Elements

$$\varepsilon(\lambda) = \alpha(\lambda)$$

Kirchhoff radiation law states that the spectral emissivity of an object equals to its spectral absorbance (Good absorbers are good emitters):

So: $$\varepsilon(\lambda) + \rho(\lambda) + \tau(\lambda) = 1$$

Assuming opaque objects: $$\varepsilon(\lambda) + \rho(\lambda) = 1$$

Emissivity—objects are not blackbodies

- Kirchhof's Law: emissivity = absorptance
  - Probability of emission of a photon at a given frequency and angle is same as probability of absorption at same frequency and angle
- Emissivity + Reflectance + Transmittance = 1
  - (all functions of wavelength and angle)

Basic Thermal Radiation Principles

- Kinetic temperature: Internal temperature of an object determined by random molecular motion

- Thermal scanning detects energy which is function of temperature (radiant temperature); Radiant flux emitted by a body at a given temperature.

Interaction of Thermal Radiation with Terrain Elements

The kinetic temperature of an object is related to its radiant temperature by:

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

Thermal sensors detect radiation from the surface of ground objects (approximately the first 50 μm)

Emissivity

- ERM is emmitted by all objects above absolute zero (0k, or -273 c), and the magnitude and spectral range of the emitted ERM is governed by the temperature and emissivity of the material
  - Kelvin = Celsius + 273
- There are no blackbodies is nature.
- Blackbody is a hypothetical, ideal radiator that perfectly absorbs and reemits all energy that is incident upon it.
- All natural objects are graybodies, they emit a fraction of their maximum possible blackbody radiation at a given temperature.

Basic Thermal Radiation Principles

- Emissivity (ε) describes the absorption and emission properties of real objects. It is the ratio of the emittance (radiant flux) from an object at a given temperature to that of a blackbody

$\varepsilon(\lambda)$= radiant flux of an object at given temperature/ radiant flux of a blackbody at same temperature

ε varies with wavelength and somewhat with temperature

If the emissivity of an object varies with wavelength, the object is said to be a selective radiant

Basic Thermal Radiation Principles

- Many materials radiate like blackbodies over certain wavelength intervals.
- Most thermal sensing is performed in the 8-14 μm region of the spectrum not only because it includes an atmospheric window, but because it contains the peak energy emissions for most surface features.

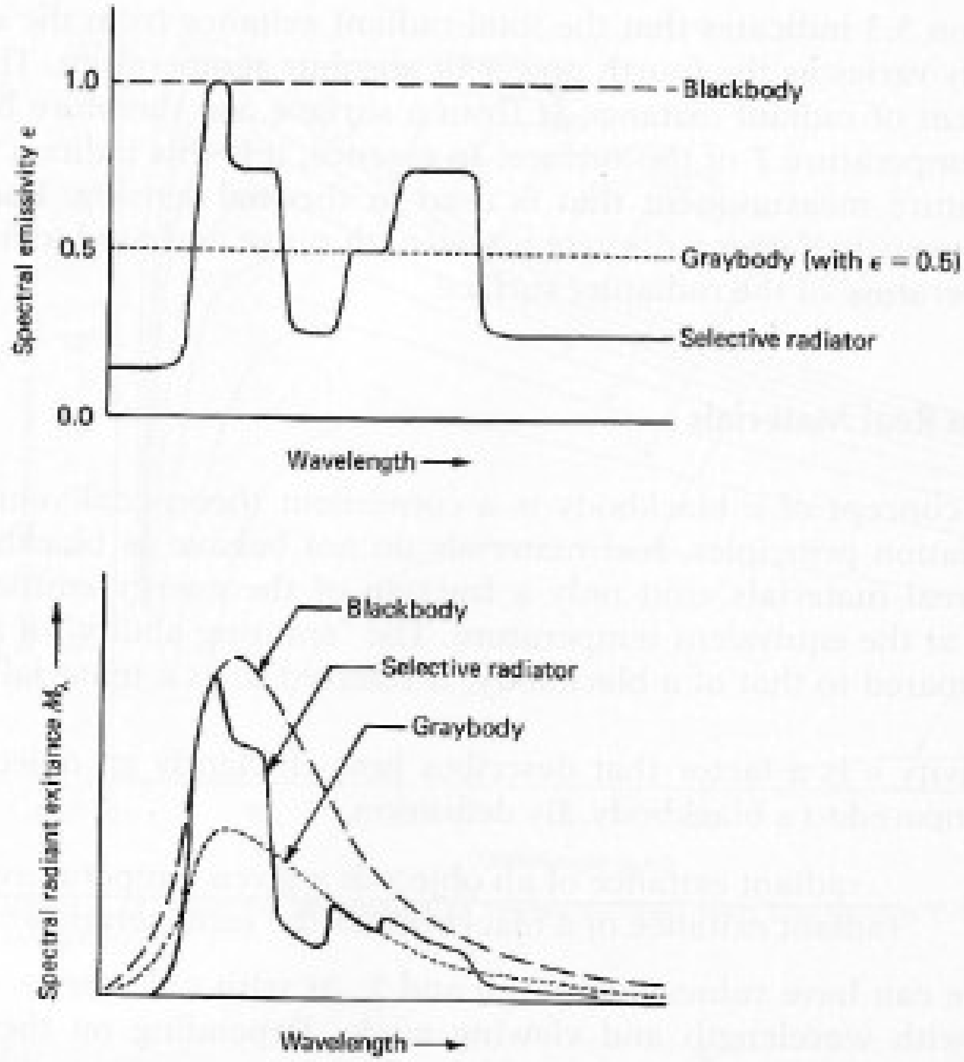


Figure 5.12 Spectral emissivities and radiant exitances for a blackbody, a graybody, and a selective radiator. (Adapted from Hudson, 1969.)

Emissivity of Common Materials

Clear water	0.98-0.99	Dry mineral soil	0.92-0.94
Wet snow	0.98-0.99	paint	0.90-0.96
Human skin	0.97-0.99	Dry vegetation	0.88-0.94
Rough ice	0.97-0.98	Dry snow	0.85-0.90
Vegetation	0.96-0.99	Granite rock	0.83-0.87
Wet soil	0.95-0.98	Glass	0.77-0.81
Asphalt concrete	0.94-0.97	Sheet iron (rusted)	0.63-0.70
Brick	0.93-0.94	Polished metals	0.16-0.21
Wood	0.93-0.94	Aluminum foil	0.03-0.07
Basalt rock	0.92-0.96	Highly polished gold	0.02-0.03

Emissivity

The emissivity of an object may be influenced by a number factors, including:

• **color** -- darker colored objects are usually better absorbers and emitters (i.e. they have a higher emissivity) than lighter colored objects which tend to reflect more of the incident energy.

• **surface roughness** -- the greater the surface roughness of an object relative to the size of the incident wavelength, the greater the surface area of the object and potential for absorption and re-emission of energy.

• **moisture content** -- the more moisture an object contains, the greater its ability to absorb energy and become a good emitter. Wet soil particles have a high emissivity similar to water.

• **compaction** -- the degree of soil compaction can effect emissivity.

• **field-of-view** -- the emissivity of a single leaf measured with a very high resolution thermal radiometer will have a different emissivity than an entire tree crown viewed using a coarse spatial resolution radiometer.

• **wavelength** -- the emissivity of an object is generally considered to be wavelength dependent. For example, while the emissivity of an object is often considered to be constant throughout the 8 - 14 mm region, its emissivity in the 3 -5 mm region may be different.

Wien's Displacement Law

- As the temperature of an object increases, the total amount of radiant energy (area under the curve, in W/m^2) increases and the wavelengths at which the objects emits the most energy decreases.
- To determine this peak wavelength (λmax) for a blackbody:

$$\lambda max = A/T$$

where A is a constant (2898 μm K) and T is the temperature in Kelvins.

- The 300 K Earth's peak emmitance wavelength is: 2898 / 300 = 9.7 μm, in the thermal IR
- What wavelength is the Sun's radiant energy peak (6000 K)?

Developments from Planck's Law
Stefan-Boltzmann Law

The Stefan-Boltzmann law is derived by integrating the Planck function with respect to wavelength:

$$E = \sigma T^4$$

σ is called the Stefan-Boltzmann constant.
$\sigma = 5.667 \times 10^{-8}$

Energy or the radiant flux (rate of flow of EM energy)

Stefan-Boltzmann Law: the amount of energy emitted from an object is primarily a function of its temperature.

Thermal Properties of Materials

Thermal conductivity K ($cal.cm^{-1} \odot sec^{-1} \odot {}^oC^{-1}$)
is a measure of the rate at which heat passes through a material

- heat passes through metals much faster than through rocks
- Water has a higher K value than many other materials
- It takes a longer time for water to transfer heat over a given distance than many other materials

Thermal Properties of Materials

Thermal capacity C (cal/g^{-1}°C^{-1}) determines how well a material stores heat.

- Water has a high thermal capacity compared to other material types
- It takes more energy for water to warm up to the same temperature than many other materials do
- Rank of heat capacity

  Water > forest > grass > land
- In other words, for a given amount of energy, water warms up slower than many other materials

Thermal Properties of Materials

- Thermal Inertia (P) -- Resistance of a material to temperature change.
- It increases with an increase in material conductivity, capacity, and density
- In general, materials with high thermal inertia have more uniform surface temperatures throughout the day and night than materials of low thermal inertia

Important Thermal IR Sensors

- TIROS (Television IR Operational Satellite), launched in 1960
- GOES (Geostationary Operational Environmental Satellite), TIR at 8 km spatial resolution, full-disk of Earth day and night
- HCMM (Heat Capacity Mapping Mission), launched in 1978- 600 m spatial resolution, 10.5 – 12.6 micron range
- CZCS (Coastal Zone Color Scanner) on Nimbus 7, launched in 1978, for SST
- AVHRR (Advanced Very High Resolution Radiometer), 1.1 and 4 km
- TIR bands TIMS (Thermal Infrared Multispectral Scanner), Airborne, 6 bands
- ATLAS (Airborne Terrestrial Applications Sensor)
- Landsat ETM+ Band 6- 10.4 – 12.5 micron range
- ASTER (Advanced Spaceborne Thermal Emmission and Reflection Radiometer) on Terra, 5 bands :8.125-11.65 micron range

Infrared spectral regions

	attributes	disadvantages
3.5–4.5 μm (Mid IR)	Clearest atmospheric window and finest spatial resolution for measuring temperature.	Cloud cover. Less energy than 8–12 μm. Mixed with solar radiation in daytime.
8–12 μm (Thermal IR)	Atmospheric window. Peak of energy emitted from Earth. Most accurate temperatures.	Cloud cover. Coarser spatial resolution than MWIR.

Geometry of Thermal Images

- Tangential scale distortion
  - caused by varied viewing distance
- Aircraft instability
  - roll: side by side motion
  - crab (yaw): by compensating drift
  - pitch: head/tail motion

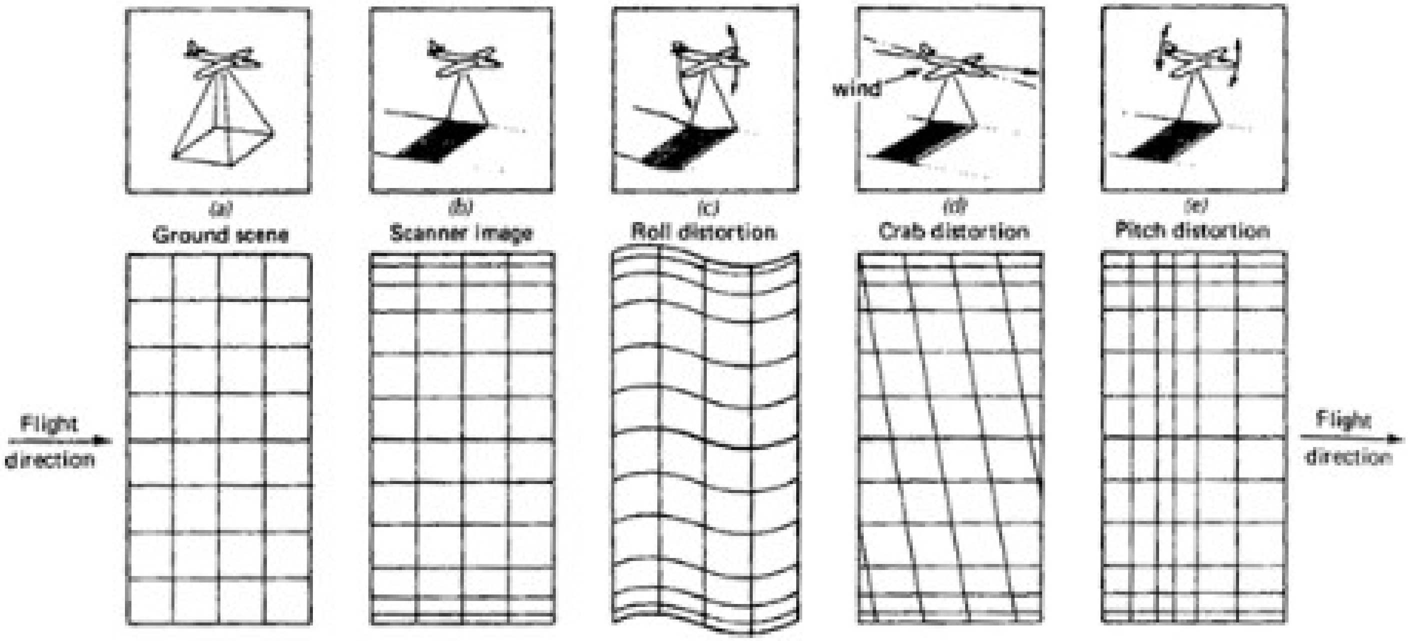


Figure 5.31 Across-track scanner imagery distortions induced by aircraft attitude deviations: (*a*) ground scene; (*b*) scanner image; (*c*) roll distortion; (*d*) crab distortion; (*e*) pitch distortion.

Geometry of Thermal Images

- Relief displacement
  - differs from that of aerial photography
  - vertical features on thermal images displaced from the nadir for each scan
  - vertical features on air photo displaced radially from the principal point

Interpreting Thermal Scanner Imagery

- Landscape factors
  - surface material: land vs. water
  - topography: sunlit vs. shadowed
  - vegetation cover: land, grass, forest, water
  - moisture
- Quantitative data analysis
  - e.g. water temperatures
- Times of day (diurnal temperature variations)
  - Thermal images will vary in appearance depending on whether they are acquired during the warm part of the day or after a night of absence of the sun and resultant cooling of the atmosphere as well as heat loss from the surface and shallow depths beneath
- Temperature extremes, heating & cooling rates

Interpreting Thermal Scanner Imagery

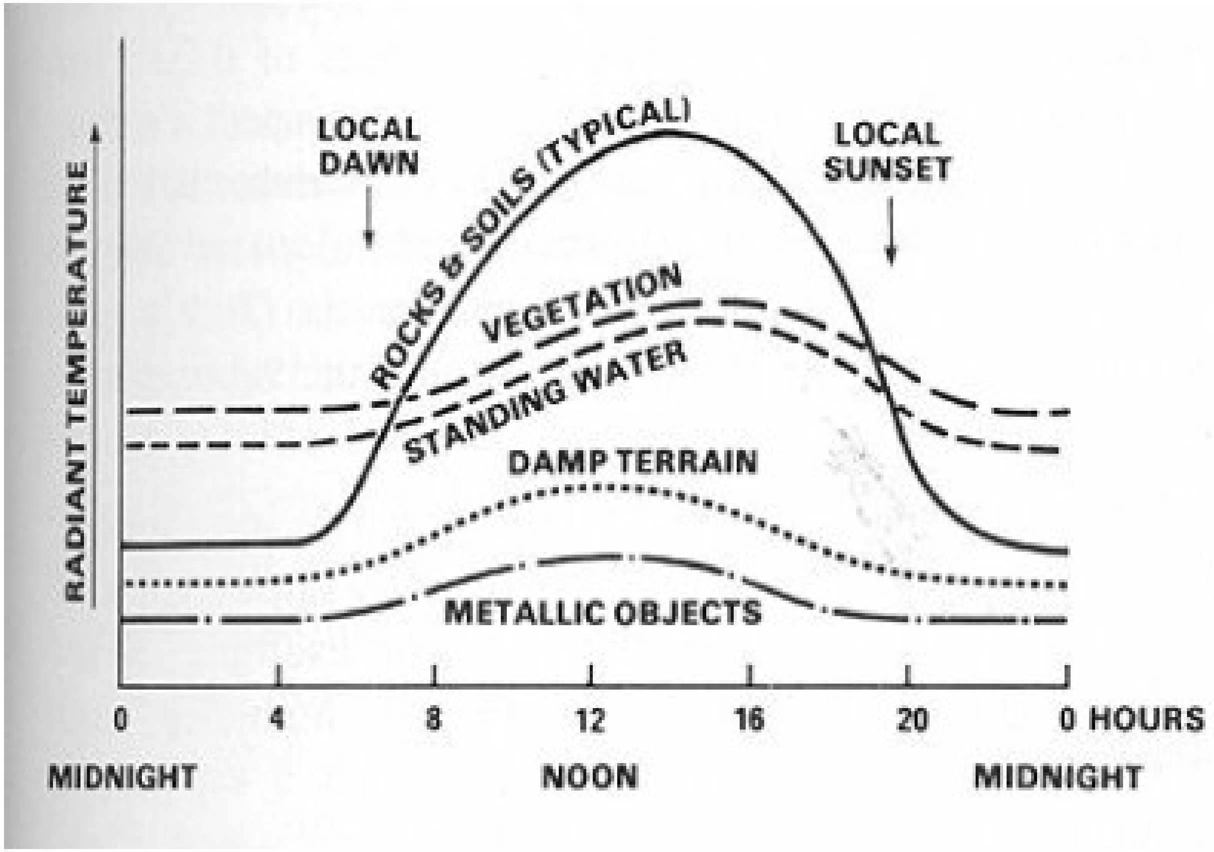
- Direct sunlight heats objects according to their thermal characteristics and sunlight absorption

- Predawn imagery: stable temperatures

- Darker tones: cooler temperatures

- BUT, Limitations
  - thermal images contain noise and errors
  - differences in emitted energy is not directly related to differences in temperature, must know emissivity of each material
  - sensors only record the radiance at the surface

Changes in radiant temperatures of five surface-cover types during a 24-hour thermal cycle



Day versus Night Image

Day

Night

Day image: Contrasts between heated buildings and streets and areas in shadow create a scene that resembles an aerial photo

Night image: Many streets are evident because, being asphalt paved, they absorp more heat and remain warmer through the night

THERMAL SENSORS

- **AVHRR** (Advanced Very High Resolution Radiometer), 1.1 and 4 km TIR bands.

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

- **<u>TIMS</u>** (Thermal Infrared Multispectral Scanner), Airborne, 6 bands.

1. Six discrete channels in the 8.2 to 12.2 micron region
2. Used to detect mineral signatures that permit the discrimination of silicate and carbonate.
3. Extensively used in volcanology research in the western United States, Hawaiian islands and Europe.

Channel	Wavelength, micrometers
1	8.2 - 8.6
2	8.6 - 9.0
3	9.0 - 9.4
4	9.4 - 10.2
5	10.2 - 11.2
6	11.2 - 12.2

- **ASTER** (Advanced Spaceborne Thermal Emission and Reflection Radiometer) on Terra, 5 bands 8.125-11.65 micron range (14 total)

Subsystem	Band No.	Spectral Range (μm)	Spatial Resolution, m	Quantization Levels
VNIR	1	0.52-0.60	15	8 bits
	2	0.63-0.69		
	3N	0.78-0.86		
	3B	0.78-0.86		
SWIR	4	1.60-1.70	30	8 bits
	5	2.145-2.185		
	6	2.185-2.225		
	7	2.235-2.285		
	8	2.295-2.365		
	9	2.360-2.430		
TIR	10	8.125-8.475	90	12 bits
	11	8.475-8.825		
	12	8.925-9.275		
	13	10.25-10.95		
	14	10.95-11.65		

➢ LANDSAT

✓ Landsat 4 & 5	;	Band 6 10.4 – 12.5 µm 120 m
✓ Landsat 7	;	Band 6 10.4 – 12.5 µm 60 m
✓ Landsat 8	;	Band 10 (TIRS – 1) 10.6 – 11.19 µm 100m
	;	Band 11 (TIRS – 2) 11.50 m – 12.51 µm 100m

- Thermal imagers are typically across-track scanners that detect emitted radiation in only the thermal portion of the spectrum.
- The data are generally recorded on film and/or magnetic tape and the temperature of current sensors can reach 0.1 °C.
- For analysis, an image of relative radiant temperatures is depicted in grey levels, with warmer temperatures shown in light tones, and cooler temperatures in dark tones.
- Absolute temperature may be calculated but require accurate calibration, measurement of the temperature references and detailed knowledge of the thermal properties of the target.

- Thermal sensors generally have large IFOVs to ensure that enough energy reaches the detector in order to make a reliable measurement.

- Therefore the spatial resolution of thermal sensors is usually fairly coarse, relative to the spatial resolution possible in the visible and reflected infrared.

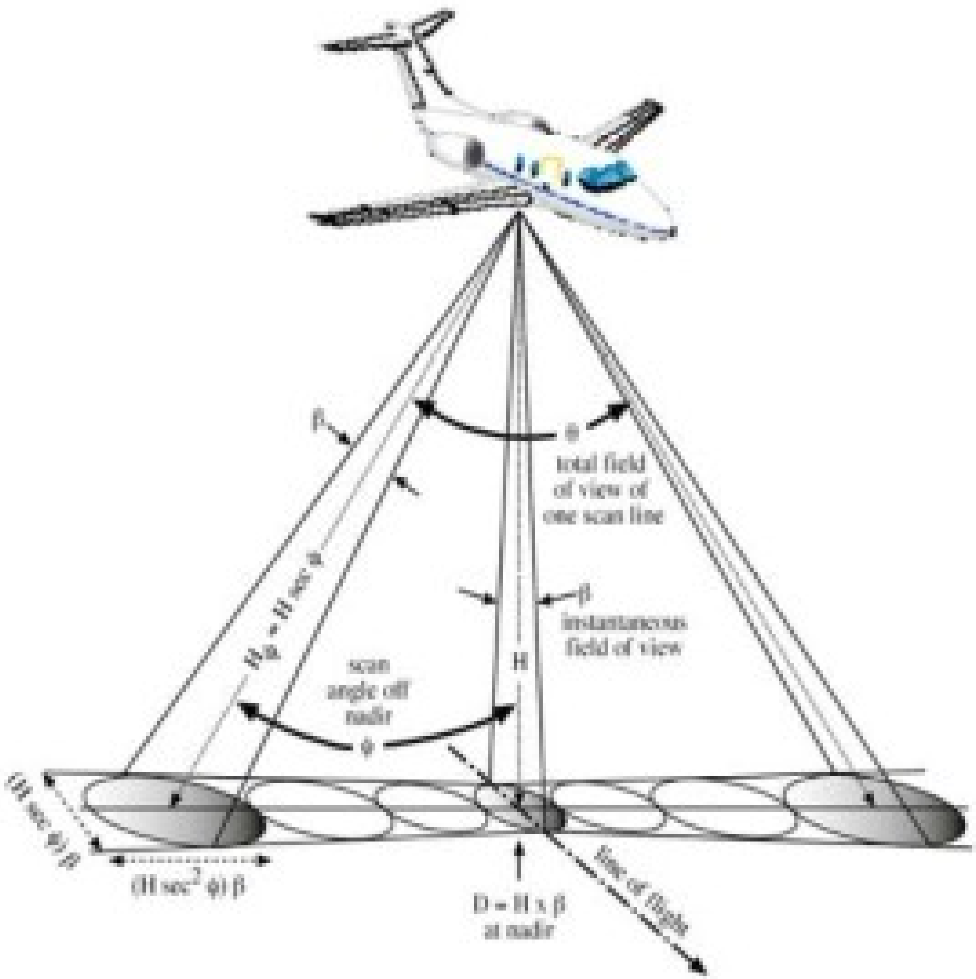
- Thermal imagery can be acquired during the day or night and is used for a variety of applications such as military reconnaissance, disaster management (forest fire mapping), and heat loss monitoring.

Thermal Infrared Data Collection

Thermal infrared remote sensor data may be collected by:

- across-track thermal scanners, and
- push-broom linear and area array charge-coupled device (CCD) detectors.

Ground Resolution Cell Size Along a Single Across-Track Scan



Thermal Infrared Detectors

Thermal infrared detectors are usually composed of:

- In:Sb (indium antimonide) with a peak sensitivity near 5μm;
- Gd:Hg (mercury-doped germanium) with a peak sensitivity near 10 μm, or
- Hg:Cd:Te (mercury-cadmium-telluride) sensitive over the range from 8 - 14 μm.

The detectors are cooled to low temperatures (-196 ˚C; -243 ˚C; 73 ˚K) using liquid helium or liquid nitrogen. Cooling the detectors insures that the radiant energy (photons) recorded by the detectors comes from the terrain and not from the ambient temperature of objects within the scanner itself.

Geometric Correction of Across-Track Thermal Infrared Scanner Data

Thermal infrared scanning systems (actually all scanning systems) introduce numerous types of *geometric error* that must be understood because they impact a) the quality of the imagery for visual or digital image processing and analysis, and b) the creation of planimetric maps from the thermal infrared data. The most important considerations are:

- ground swath width;
- spatial resolution cell size;
- tangential scale distortion, and
- one-dimensional relief displacement.

Radiometric Calibration of Thermal Scanner Data

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

• internal blackbody source referencing, or

• external empirical referencing based on *in situ* data collection.

Push-broom Linear and Area Array Charge-coupled device (CCD) Detectors

It is possible to make both linear and area arrays that are sensitive to mid- and thermal infrared radiation. Linear and area arrays allow improved thermal infrared remote sensing to take place because:

• the solid-state microelectronic detectors are smaller in size (e.g. 20 x 20 mm) and weight, require less power to operate, have fewer moving parts, and are more reliable;

• each detector in the array can view the ground resolution element for a longer time (i.e. it is as longer dwell time), allowing more photons of energy from within the IFOV to be recorded by the individual detector resulting in improved radiometric resolution (the ability to resolve smaller temperature differences);

• each detector element in the linear or area array is fixed relative to all other elements therefore the geometry of the thermal infrared image is much improved relative to that produced by an across-track scanning system; and
• some linear and area thermal detectors do not even require the cooling apparatus.

Forward-Looking Infrared (FLIR) Systems

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

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

Radiometric resolution

The radiometric resolution specifies how well the differences in brightness in an image can be perceived; this is measured through the number of the grey value levels. The maximum number of values is defined by the number of bits (binary numbers). An 8 bit representation has 256 grey values, a 16 bit (ERS satellites) representation 65.536 grey values.

The finer or the higher the radiometric resolution is, the better small differences in reflected or emitted radiation can be measured, and the larger the volume of measured data will be (compare with the image on the right).

The advantage of a higher radiometric resolution is rather small - when comparing LANDSAT-MSS (6 bits) and TM (8 bits) the improvement is in the order of 2-3%.

Radiometric resolution depends on the wavelengths and the type of the spectrometer:

1. LANDSAT-MSS (from LANDSAT 1-3): 6 bits (64 grey values)
2. IRS-LISS I-III: 7 bits (128 grey values)
3. LANDSAT-TM (from LANDSAT 4-5) & SPOT-HRV: 8 bits (256 grey values)
4. LANDSAT-ETM & ETM+ (from LANDSAT 6-7): 9 bits (only 8 bits are transmitted)
5. IRS-LISS IV: 10 bits (only 7 bits are transmitted)
6. IKONOS & QuickBird: 11 bits.

Landsat 8 Instruments

Thermal Infrared Sensor (TIRS) provides two thermal bands. These sensors both provide improved signal-to-noise (SNR) radiometric performance quantized over a 12-bit dynamic range. (This translates into 4096 potential grey levels in an image compared with only 256 grey levels in previous 8-bit instruments.)

Improved signal to noise performance enable better characterization of land cover state and condition. Products are delivered as 16-bit images (scaled to 55,000 grey levels)

Thermal Radiometer

Infrared Radiometers (IRRs) measure surface temperature by converting thermal energy radiated from any surface in its field-of-view (FOV) to an electrical signal with a response time of 0.6 seconds.

Infrared radiometers, also referred to as infrared thermometers, provide a non-contact method of measuring the thermal energy emitted by any object

The resilient 8-14 μm germanium window corresponds to the atmospheric window in order to minimize the effects of water bands below 8 μm and above 14 μm.

Radiation from Real materials:

The terrestrial objects do not behave like black body. They emits only a part of energy received from the sun, which is called emissivity.

That is....

$$E(\lambda) = \frac{\text{radiant existence of an object at a given temperature}}{\text{radiant existence of a black body at the same temperature}}$$

or

$$E(\lambda) = \frac{\text{radiant existence from an object}}{\text{Kinetic temperature of the same object}}$$

Interaction of thermal radiation with terrain elements

When a sun is incident on a terrestrial objects the energy is

1. **Absorbed (E_A)**
2. **Reflected ($E_{R)}$)**
3. **Transmissivity (E_T)**

So, we can get the relationship between incident and disposition upon interaction with the terrain elements as

$E_I = E_A + E_R + E_T$ ----------------1

Where E_I=Energy incident on the surface of the terrain

E_A= component of Incident energy absorbed by the terrain element

E_F= component of Reflected energy absorbed by the terrain element

E_T= component of Transmitted energy absorbed by the terrain element

We obtain the relationship by dividing the equation no. 1 by E_I

$$\overline{E_I} = \overline{E_A} + \overline{E_F} + \overline{E_T}$$, further we define-----------2

$$E_I \quad E_A + E_F + E_T$$

Thermal capacity:

Thermal conductivity:

$$\frac{E_I}{E_I} = \frac{E_A}{E_A} + \frac{E_F}{E_F} + \frac{E_T}{E_T}$$

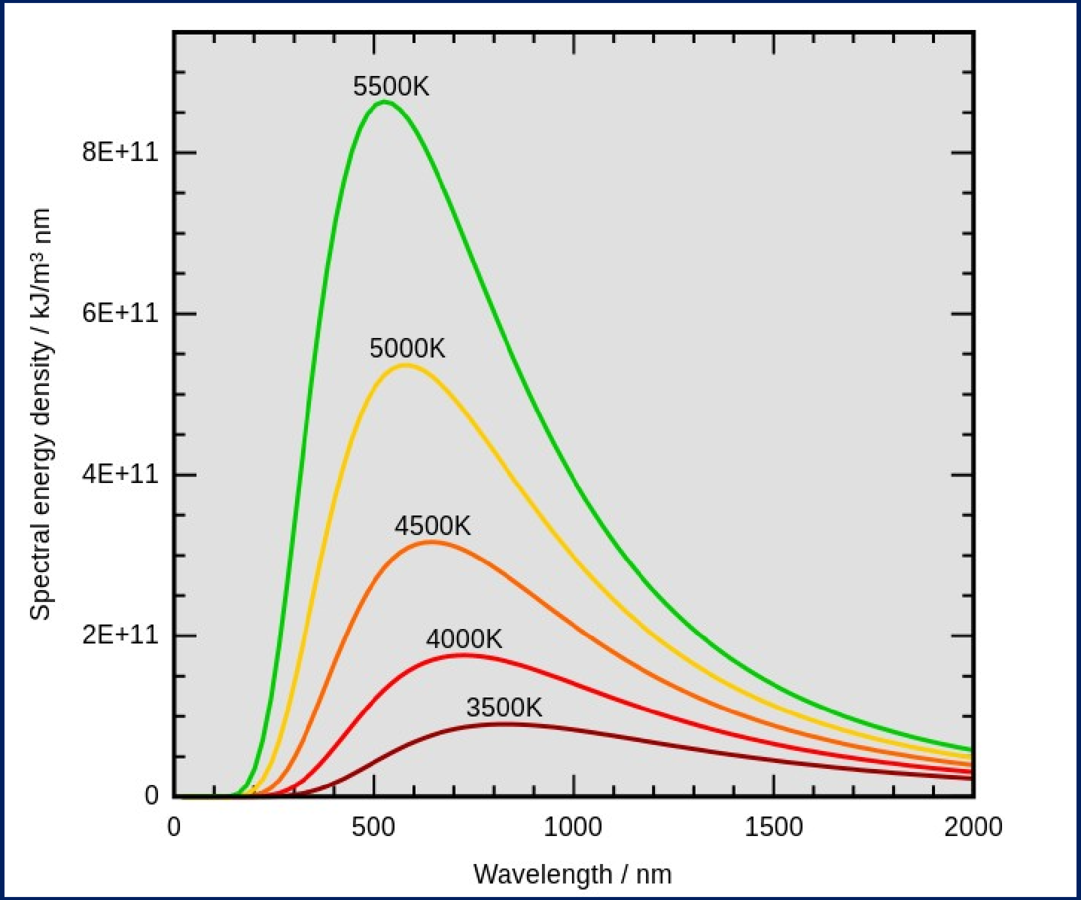
Weins Law

When the black body is getting heated from 200k to 6000k, its emittances is gradually increasing that too it is gradually shifted to lower wavelength. This is called weins displacement law. $\lambda m = b/T$

λm = W.L of maximum spectral radiance existence μm

b= $2.8977721(26)\times10^{-3}$ m K. (weins displacement constant)

T= Temperature k

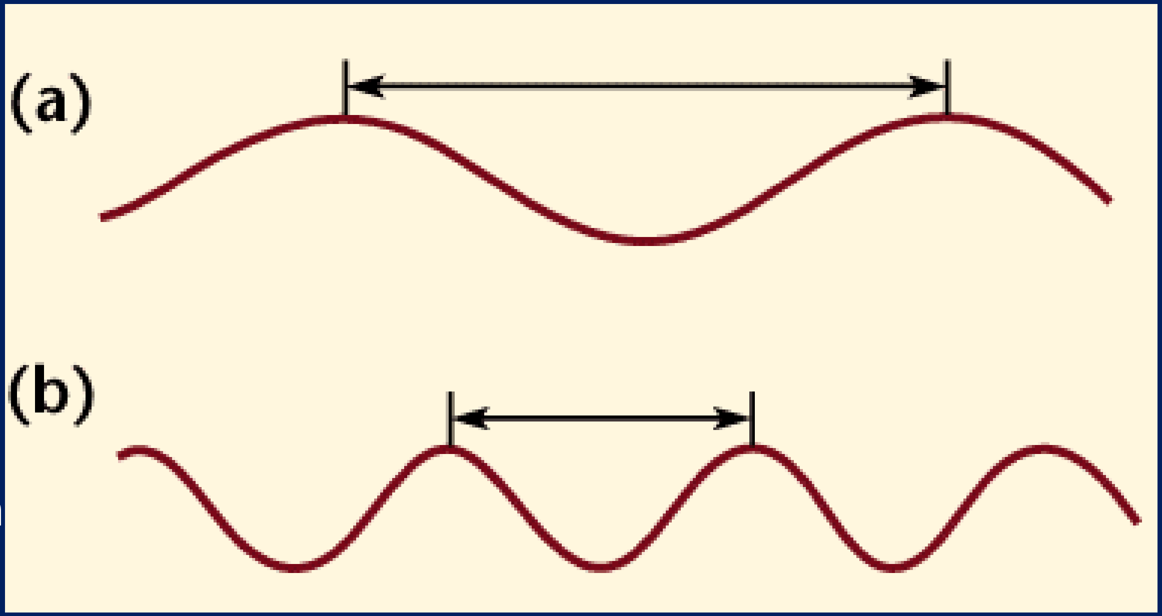


Black body radiation as a function of wavelength for various absolute temperatures. Each curve is seen to peak at a somewhat different wavelength; Wien's law describes the shift of that peak in terms of temperature

Wavelength/Frequency

Long wavelength

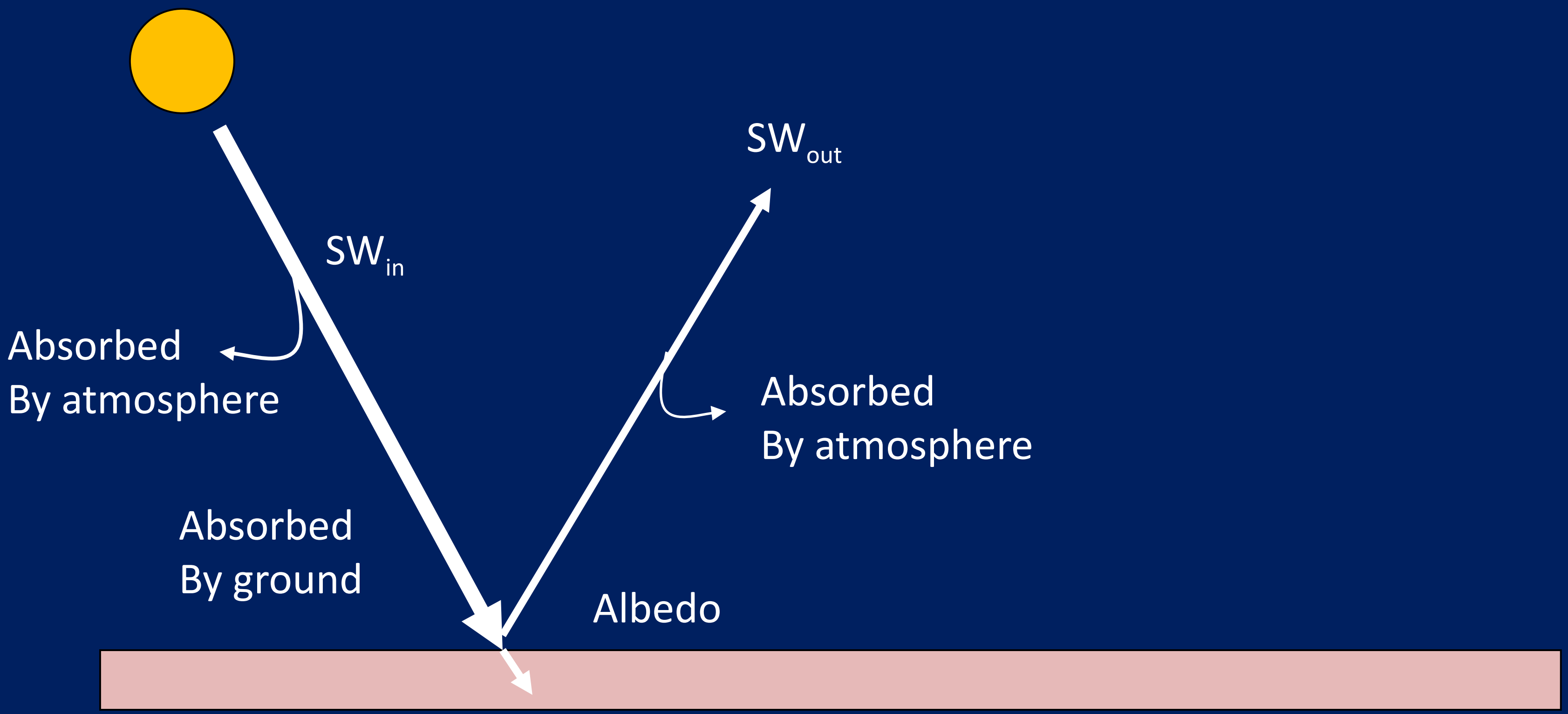
Short wavelength



Low frequency

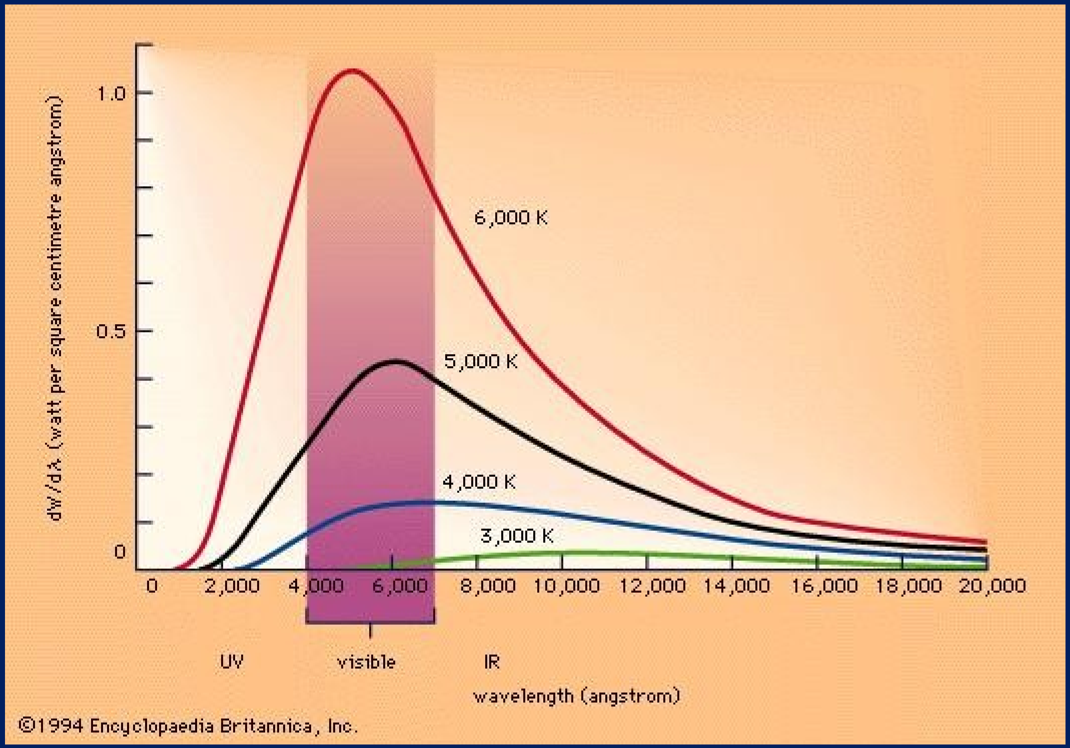
High frequency

Radiation in the Atmosphere



Wiens Displacement Law:

A law which states that for a blackbody, the wavelength of maximum radiation is inversely proportional to its absolute temperature. Also called Wien's law.



Wien’s law, also called Wien’s displacement law, relationship between the temperature of a blackbody (an ideal substance that emits and absorbs all frequencies of light) and the wavelength at which it emits the most light. It is named after German physicist Wilhelm Wien, who received the Nobel Prize for Physics in 1911 for discovering the law.

Emissivity of Common Materials

Clear water	0.98-0.99	Dry mineral soil	0.92-0.94
Wet snow	0.98-0.99	paint	0.90-0.96
Human skin	0.97-0.99	Dry vegetation	0.88-0.94
Rough ice	0.97-0.98	Dry snow	0.85-0.90
Vegetation	0.96-0.99	Granite rock	0.83-0.87
Wet soil	0.95-0.98	Glass	0.77-0.81
Asphalt concrete	0.94-0.97	Sheet iron (rusted)	0.63-0.70
Brick	0.93-0.94	Polished metals	0.16-0.21
Wood	0.93-0.94	Aluminum foil	0.03-0.07
Basalt rock	0.92-0.96	Highly polished gold	0.02-0.03

APPLICATIONS

Thermal property of a material is representative of upper several centimetres of the surface. As in thermal remote sensing we measure the emitted radiations, it proves to be complementary to other remote sensing data and even unique in helping to identify surface materials and features such as rock types, soil moisture, geothermal anomalies etc. The ability to record variations in infrared radiation has advantage in extending our observation of many types of phenomena in which minor temperature variations may be significant in understanding our environment. Thermal remote sensing reserves immense potential for various applications. The following is a list of some of the areas in which thermal data is put to use

- Identification of geological units and structures
- Soil moisture studies
- Hydrology
- Coastal zones
- Volcanology
- Forest fires
- Coal fires
- Seismology
- Environmental modelling
- Meteorology
- Medical sciences
- Vetenary sciences
- Intelligence / military applications
- Heat loss from building

For example, when you stand in the sun on a cold winter day you feel radiant heat gain from the sun even though the air temperature is cold. On the other hand, when you open the freezer door on a hot summer day you feel radiant heat loss to the interior of the freezer.

In both cases your thermal comfort is being largely affected by difference in radiant heat gain or loss, not air temperature