都市基盤工学 （リモートセンシングとGIS入門）

Introduction to Remote Sensing and GIS

第2回
2018. 4.18

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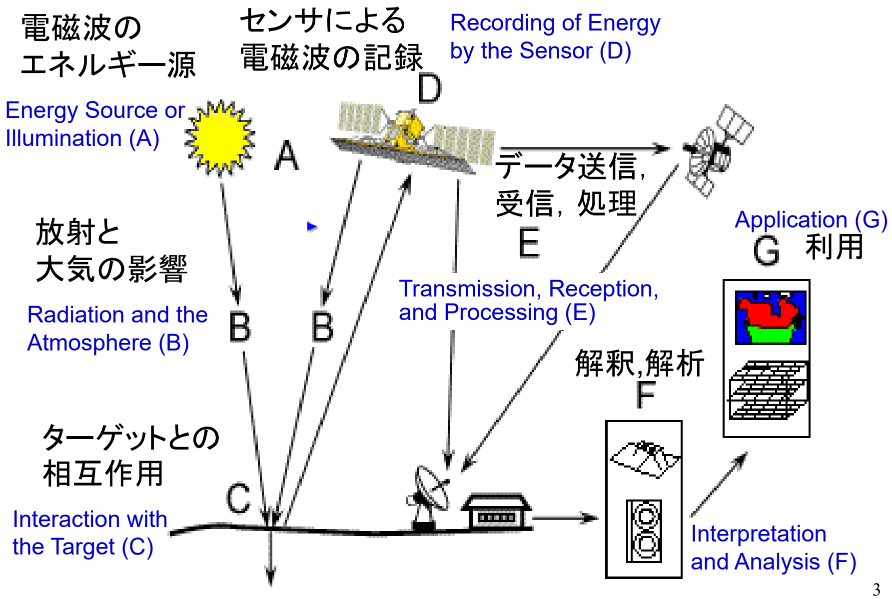
講義予定 Lecture Schedule

(1) 2018年 4月11日（水）イントロダクション　Introduction
(2) 2018年 4月18日（水）リモセンの基礎原理1 Fundamentals of RS #1
(3) 2018年 4月25日（水）リモセンの基礎原理2 Fundamentals of RS #2
(4) 2018年 5月 9日（水）衛星とセンサ1 Satellites and sensors #1 *Liu*
(5) 2018年 5月16日（水）衛星とセンサ2 Satellites and sensors #2
(6) 2018年 5月23日（水）衛星とセンサ3 Satellites and sensors #3
(7) 2018年 5月30日（水）画像解析1 Image Analysis #1 *Liu*
(7) 2018年 6月 6日（水）画像解析2 Image Analysis #2 *Liu*
(9) 2018年 6月13日（水） GISの基礎1 Basics of GIS #1 *Maruyama*
(10) 2018年 6月20日（水）GISの基礎2 Basics of GIS #1 *Maruyama*
(11) 2018年 6月27日（水）マイクロ波リモセン#1 Microwave RS #1 *Liu*
(12) 2018年 7月 4日（水）GISの基礎3 Basics of GIS #3 *Maruyama*
(13) 2018年 7月11日（水）課題発表1 Presentation by Students #1
(14) 2018年 7月18日（水）課題発表2 Presentation by Students #2
(15) 2018年 7月25日（水）課題発表3 Presentation by Students #3

リモートセンシングの手順 Process of RS



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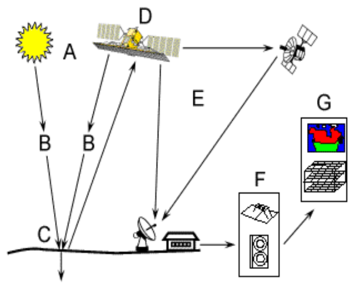


1. Fundamentals

リモートセンシングの基礎原理

Process of Remote Sensing (1)

Energy Source or Illumination (A) - the first requirement for remote sensing is to have an **energy source** which illuminates or provides electromagnetic energy to the target of interest.

Radiation and the Atmosphere (B) - as the energy travels from its source to the target, it will come in contact with and **interact with the atmosphere** it passes through. This interaction may take place a second time as the energy travels from the target to the sensor.

Interaction with the Target (C) - once the energy makes its way to the target through the atmosphere, it **interacts with the target** depending on the properties of both the target and the radiation.

Transfer of Electromagnetic Energy
電磁波エネルギーの伝播

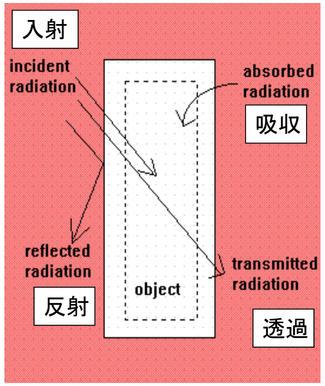
Energy must be **transferred** from one body/place to another by **conduction**, **convection** and **radiation**.

Conduction （伝導): Atomic or molecular collisions.

Convection （対流): The physical movement of bodies of energetic material.

Radiation (放射): Transmission of **electromagnetic energy** through a medium or vacuum.

Observed by Remote Sensing



Energy Sources エネルギー源

- 可視光
  Visible Light is only **one form** of electromagnetic energy.
- Radio waves, heat, ultra-violet rays and X-rays are other familiar forms.
- All of this energy is inherently similar, and radiates in accordance with **basic wave theory**.
  波動理論

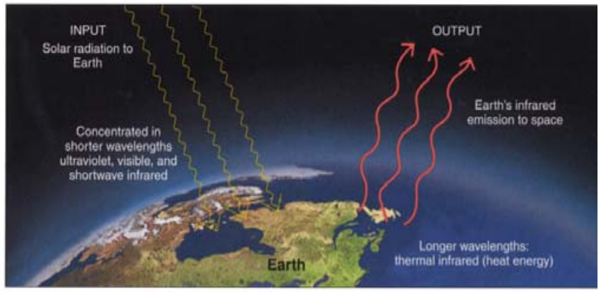
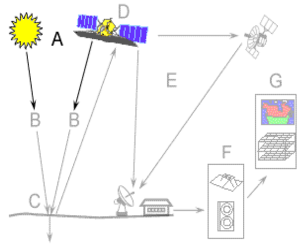


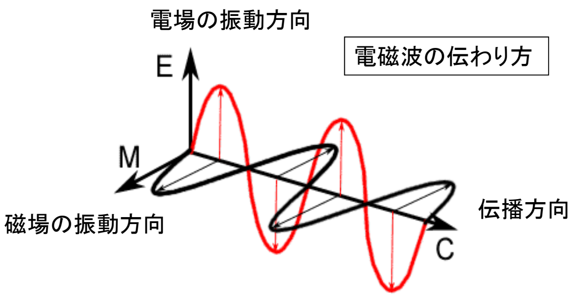
Figure 2-7 Earth's energy budget simplified.
Solar radiation is concentrated in shorter wavelengths. Earth emits longer wavelengths of infrared to the atmosphere and eventually to space.



Electromagnetic Wave 電磁波の波動的性質

Electromagnetic radiation consists of **an electrical field (E)** which varies in magnitude in a direction perpendicular to the direction in which the radiation is travelling, and **a magnetic field (M)** oriented at right angles to the electrical field.

Both these fields **travel** at **the speed of light (c)** 光速



Wavelength and Frequency
波長と振動数

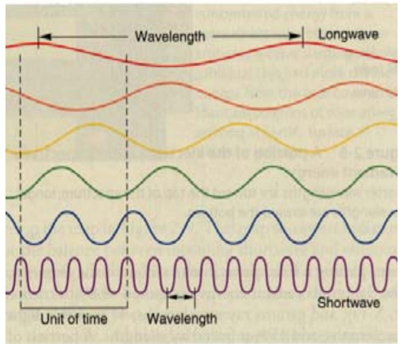


Figure 2-5 Wavelength and frequency.

Wavelength is measured in metres (m) or some factor of metres such as:

- nanometers (nm, 10^{-9} metres),
- micrometers (µm, 10^{-6} metres),
- centimetres (cm, 10^{-2} metres).

Frequency refers to **the number of cycles** of a wave passing a fixed point **per unit of time**.
Frequency is normally measured in **hertz** (Hz), equivalent to one cycle per second, and various multiples of hertz.

Wave Theory　波動理論

Wavelength and frequency are related by the following formula:
波長と振動数，光速の関係

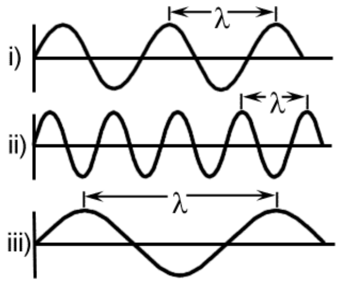
$$c = \lambda \nu$$

where

λ = **wavelength (m)**　波長

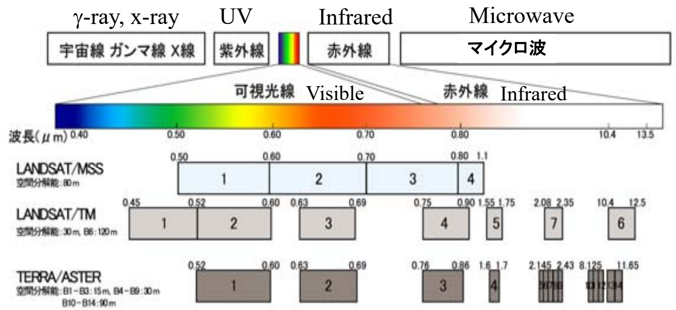
ν = **frequency (Hz)**　振動数，周波数

c = **speed of light (3×10^8 m/sec)**　光速



Since **c** is essentially a **constant**, **frequency ν** and **wavelength λ** for any given wave are **related inversely**, and either term can be used to characterise a wave into a particular form.

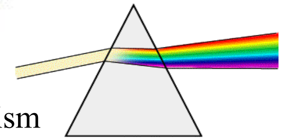
Electromagnetic Spectrum 電磁波の分類と名称



Visible Spectrum　可視領域

The visible portion is very small relative to the rest of the spectrum.
It is important to note that this is the only portion of the EM spectrum we can associate with **the concept of colours**.

色彩は可視光のみ



Violet: 0.400 - 0.446 μm
Blue: 0.446 - 0.500 μm
Green: 0.500 - 0.578 μm
Yellow: 0.578 - 0.592 μm
Orange: 0.592 - 0.620 μm
Red: 0.620 - 0.700 μm

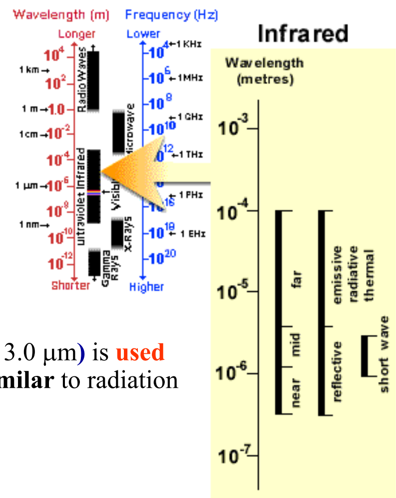
Infrared Region
赤外領域

■**The IR Region** covers the wavelength range from approximately **0.7 - 100 μm**.

■**The IR region** can be divided into **two** categories based on their radiation properties - the **reflected IR**（反射赤外）, and the **emitted** or **thermal IR**（放射赤外，熱赤外）.

■Radiation in **the reflected IR region** (0.7 – 3.0 μm) is **used for remote sensing** purposes in ways **very similar** to radiation in the visible portion.

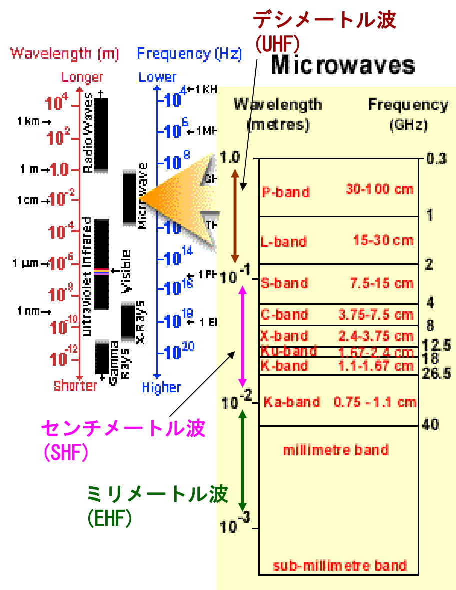
near IR (近赤外) : 0.7 -1.3 μm
short wave IR (短波長赤外) : 1.3 -3 μm



■**The thermal IR region** (3.0 – 100 μm) is quite **different** than the visible and reflected IR portions, as this energy is essentially the **radiation that is emitted from the Earth's surface in the form of heat**.

mid IR (中間赤外) : 3 -8 μm ,　thermal IR (熱赤外) : 8 -14 μm
far IR (遠赤外) : 14 -100 μm

Microwave Region　マイクロ波のバンド名称



➤**Ka, K,** and **Ku bands**: very short wavelengths used in early airborne radar systems but uncommon today.

➤**X-band**: **used extensively** on **airborne** systems (e.g. PI-SAR) for military reconnaissance and terrain mapping. TerraSAR-X

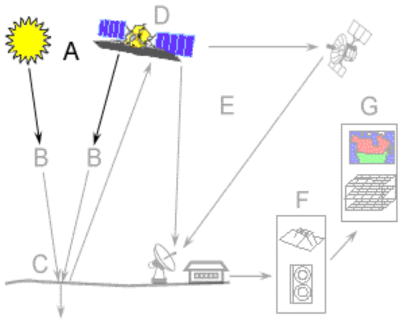
➤**C-band**: **common** on many **airborne** research systems (e.g. NASA AirSAR) and **spaceborne** systems (ERS-1 & 2, RADARSAT, ENVISAT/ASAR).

➤**S-band**: used on board the Russian ALMAZ satellite.

➤**L-band**: used onboard SEASAT and JERS-1, ALOS/PALSAR satellites and airborne systems.

➤**P-band:** longest radar wavelengths, used on NASA experimental airborne research system.

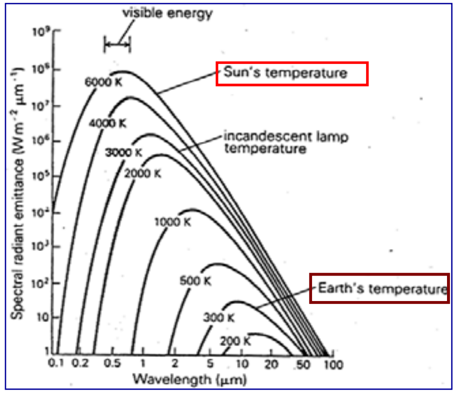
Emission of Radiation from Energy Sources
エネルギー源



- Each energy/radiation source, or **radiator**, emits a characteristic array of radiation waves.
  放射源：　通常は太陽
- A useful concept, widely used by physicists in the study of radiation, is that of a **blackbody,** defined as an object or substance that **absorbs all of the energy** incident upon it, and **emits the maximum amount of radiation** at all wavelengths.
  黒体：　入射する電磁波を完全に吸収し，最大限に放射する．
  反射も透過もしない．
- A **series of laws** relate to the comparison of natural surfaces/radiators to those of a black-body:
  黒体放射の法則

Black body radiation and Planck's law
黒体放射とPlanckの法則

黒体から放射される電磁波エネルギー



Black Body Radiation as a function of Temperature and Wavelength

Planckの法則

Table 1.7.1 Plank's law of radiation

spectral radiance of black body $B\lambda$ is given as follows.

$$B\lambda = \frac{2hc^2}{\lambda^5} \cdot \frac{1}{exp(hc/k\lambda T) - 1}$$

$B\lambda$:	black body spectral radiance ($W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$)		
T :	absolute temperature of Black body (K)		
λ :	wavelength (μm)		
c :	velocity of light	2.998×10^8	($m \cdot s^{-1}$)
h :	plank's constant	6.626×10^{-34}	($J \cdot s$)
k :	Boltzmann's constant	1.380×10^{-23}	($J \cdot K^{-1}$)

黒体の単位表面積から単位時間に放射されるエネルギー（分光放射輝度）は絶対温度と波長の関数

Stefan-Boltzmann Law

All matter at temperatures above absolute zero (-273 ^oC) continually **emit EM radiation**.（全ての物質は絶対0度以上の温度で電磁波を放射）

The **amount of energy** that an object radiates can be expressed by:
（Planckの式を全波長域で積分）

$$M = \varepsilon \sigma T^4$$ Stefan-Boltzmannの法則

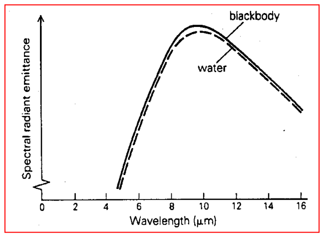
M = total radiant exitance from the surface of a material ($W\ m^{-2}$)
σ = Stefan-Boltzmann constant, ($5.6697 \times 10^{-8}\ W\ m^{-2}\ K^{-4}$)
T = absolute temperature (K) of the emitting material
ε = spectral emissivity 分光放射率

$$\varepsilon = M / M_b$$

black-body ε= 1, and white-body ε= 0

M_b = the radiant exitance from black body

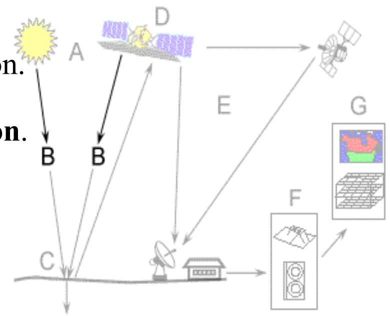
Water is a good approximation of a black body (grey body) 水は黒体に近い

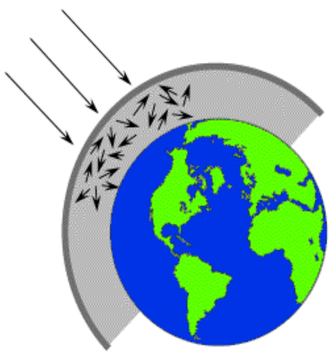


Radiation of Blackbody and water

Energy Interactions with the Atmosphere
大気との相互作用

Particles and gases in the atmosphere can affect the incoming light and radiation. These effects are caused by the mechanisms of **scattering** and **absorption**.
大気中の粒子やガスが，散乱や吸収を起こす．





Scattering occurs when particles or large gas molecules interact with and cause the **EM radiation to be redirected** from its original path.

散乱：電磁波の放射が，方向を変えること

Atmospheric Scattering　大気による散乱

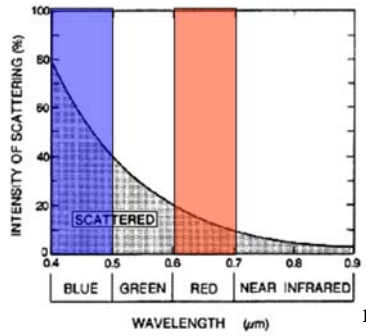
- The effect of **the atmosphere** varies with:
  - ■ Differences in path length　大気の通過距離
  - ■ the wavelength of the radiation (λ)　電磁波の波長
  - ■ the diameter of scattering particle (**a**)　散乱体となる粒子の大きさ
  - ■ the abundance of particles or gases,　散乱体の量
- **Three (3) types of scattering** can be distinguished, depending on the relationship between **a** and λ.
  散乱体粒子の大きさと電磁波波長による3種の散乱
  - ■ Rayleigh scattering　レイリー散乱　$a < \lambda$
  - ■ Mie scattering　Mie散乱　$a \approx \lambda$
  - ■ Non-selective scattering　無差別散乱　$a > \lambda$

Rayleigh Scattering レイリー散乱　$a < \lambda$

■ **Rayleigh** scatter is common when radiation interacts with atmospheric molecules and other tiny particles (aerosols) that are much smaller in diameter than the wavelength of the incoming light.
光の波長よりずっと小さいO_2, NO_2などの粒子による散乱

■ The effect of **Rayleigh** scatter is **inversely proportional** to the **wavelength**: short wavelengths are more likely to be scattered than long wavelengths.　短波長成分がより散乱される

■ **Rayleigh** scattering is the dominant scattering mechanism in the **upper atmosphere**.
大気圏上層で支配的な散乱の形態



Colors of sky due to Rayleigh scattering 空はなぜ青い

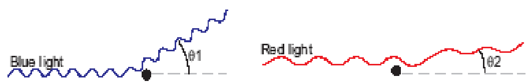


Figure 2.9: Rayleigh scattering is caused by particles smaller than the wavelength and is maximal for small wavelengths.

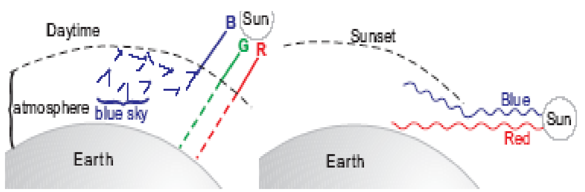
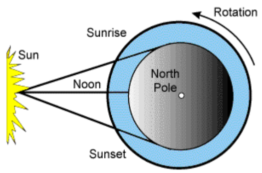


Figure 2.10: Rayleigh causes us to perceive a blue sky during daytime and a red sky at sunset.

青が最も散乱され空に広がる

距離が長くなり，青は散乱し赤のみ届く



Mie Scattering
Mie散乱

■ **Mie** scattering occurs when **the particles** are just **about the same size as the wavelength of the radiation**.
散乱体粒子の大きさと電磁波波長がほぼ等しいとき　$a \approx \lambda$

■ Aerosols (a mixture of gases, water vapour and dust) are common causes of **Mie** scattering which tends to affect longer wavelengths than those affected by Rayleigh scattering.
エアゾルが最も大きな原因

■ **Mie** scattering occurs mostly in **the lower portions of the atmosphere** where larger particles are more abundant, and dominates when **cloud** conditions are **overcast.**
大気圏下層で起きる．曇りの時

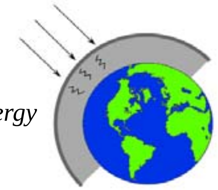
Non-selective scattering　無差別散乱

- **Non-selective** scattering occurs when **the particles** (e.g., water droplets and large dust particles) **are much larger than the wavelength of the radiation**.
  散乱体粒子の大きさが電磁波波長より大きいとき　$a > \lambda$
- **Non-selective** scattering gets its name from the fact that all wavelengths are scattered about **equally**.
  波長によらず同様に散乱するのでこの名前がついた
- This type of scattering **causes fog and clouds** to appear **white** to our eyes because blue, green, and red light are all scattered in approximately equal quantities.
  青，緑，赤が同様に散乱するので雲や霧は白く見える

Non-Selective scatter of EM radiation by a cloud

Atmospheric absorption
大気による吸収

Absorption of EM energy by the atmosphere



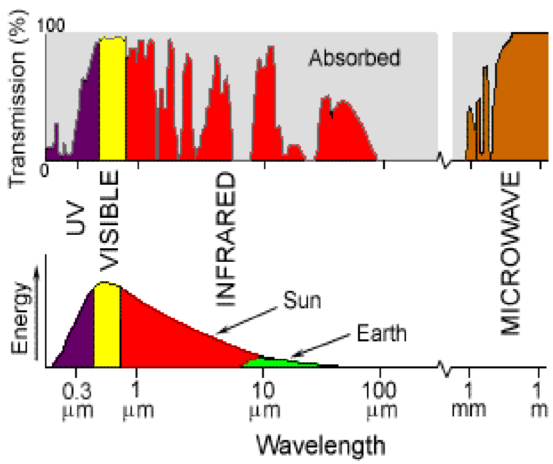
- In contrast to scattering, **atmospheric absorption** results in the **effective loss of energy** to atmospheric constituents.
- Normally absorb energy **at a given wavelength**
  特定の波長を吸収
- The most efficient absorbers of solar radiation in this regard are:
  - **Ozone:** the (harmful) **ultraviolet** radiation
    オゾンは紫外線を吸収
  - **Carbon Dioxide:**
    the **far infrared** spectrum　(trap heat ➔ greenhouse effect)
    CO_2は遠赤外を吸収し，温室効果を起こす
  - **Water Vapour:** the IR and microwave radiation
    水蒸気は赤外とマイクロ波を吸収

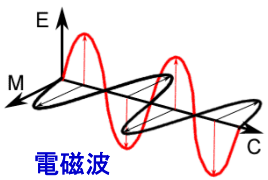
Atmospheric Windows and Energy level of the Sun and the Earth
大気の窓，太陽と地球の電磁波エネルギー

大気の窓の透過率

人工衛星のセンサの設計に考慮

太陽と地球の電磁波エネルギー





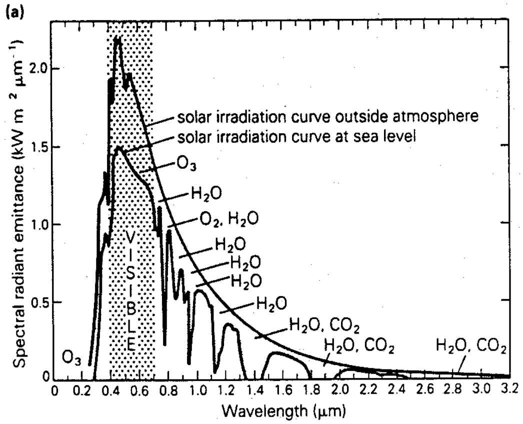
電磁波

Atmospheric Windows　大気の窓の特性

- The **visible portion** of the spectrum, to which our eyes are most sensitive, **corresponds to** both an **atmospheric window** and the **peak energy level of the sun**.
  可視光はエネルギーも大きく大気の窓に対応
- **Heat energy emitted by the Earth** corresponds to a window around 10 µm in **the thermal IR** portion of the spectrum.
  地球から放散される熱エネルギーは熱赤外
- **Some sensors**, especially those on meteorological satellites, seek to directly **measure absorption phenomena** such as those associated with CO_2 and other gaseous molecules.
  気象衛星などは吸収現象も観測
- **The atmosphere is nearly opaque** to EM radiation in **the mid and far IR**.　大気は中間赤外，熱赤外をあまり通さない
- **In the microwave region**, most of the EM radiation **moves through unimpeded** - so that radar at commonly used wavelengths will nearly all reach the Earth surface unimpeded.
  マイクロ波はよく通す

View through atmospheric "windows"

大気の窓と吸収体



Relative atmospheric radiation transmission of different wavelengths

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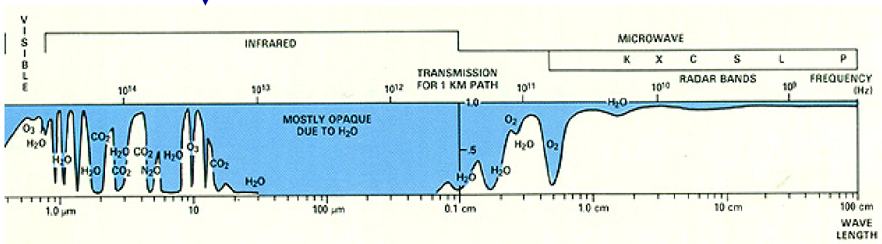


Effects of clouds in optical remote sensing

光学センサにおける雲の影響

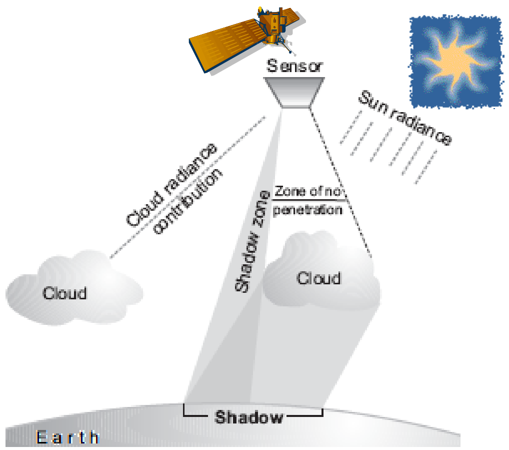


Figure 2.11: Direct and indirect effects of clouds in optical remote sensing

"Principles of Remote Sensing", ITC Educational Textbook Series, 2001.

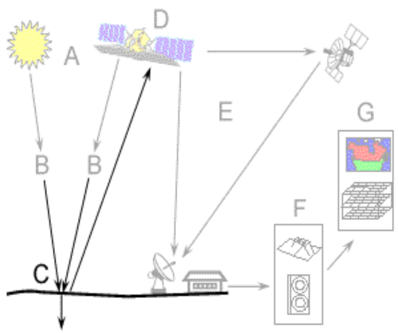
Energy Interactions with the Earth Surface

地表との相互作用

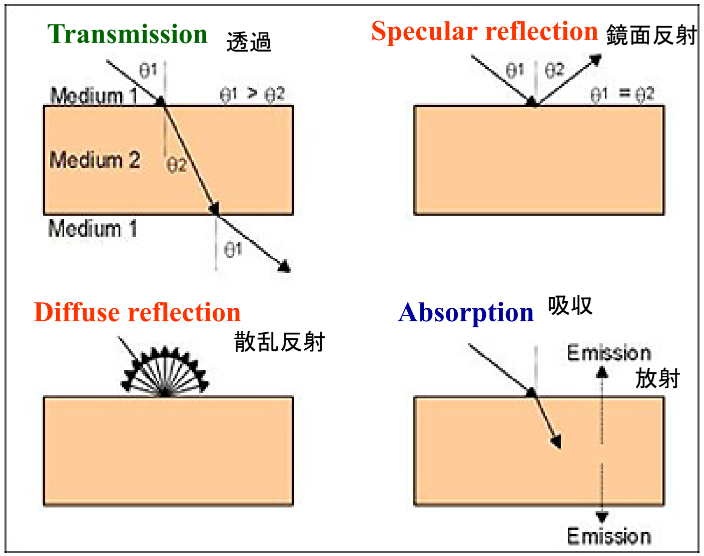
When Electromagnetic energy is **incident** on any given earth surface feature, **three** fundamental energy interactions with the feature are possible:

地表での3つの基本的な相互作用

- **Absorption** 吸収
- **Transmission** 透過
- **Reflection** 反射



Absorption, Transmission and Reflection of Electromagnetic Spectrum



Relationship between the three energy interactions

エネルギー保存則 The law of energy conservation

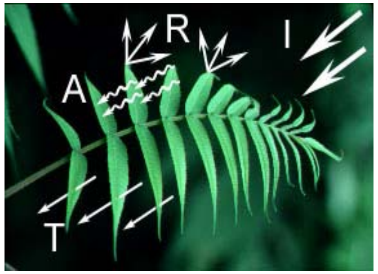
$E_I(\lambda) = E_A(\lambda) + E_T(\lambda) + E_R(\lambda)$

E_I= **Incident energy** 入射

E_A= **Absorbed energy** 吸収

E_T= **Transmitted energy** 透過

E_R= **Reflected energy** 反射



In remote sensing, we are most interested in measuring **the radiation reflected from targets**.

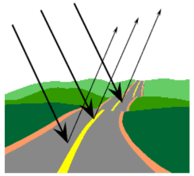
リモートセンシングで測るのは主として対象物からの反射

Reflectance 反射

- The **proportions** of energy reflected, absorbed, and transmitted will depend on the **wavelength of the energy** and **the material and condition of the feature**.
  反射，吸収，透過は波長，物質の材質や状態に依存
- These features permit us to **distinguish different features** on an image.
  物質を見分けるのに利用
- Even with a given feature type, the proportion of reflected, absorbed and transmitted energy will **vary at different wavelengths**.
  同じ物質でも波長により反射率，吸収率，透過率が異なる
- Different features may be distinguished **using more than one spectral range**.
  複数の波長域での特性で物質を見分ける

Reflectance from a surface 表面反射

- The **geometric manner** in which an object reflects energy is also an important consideration. This is primarily a function of **surface roughness**.
  表面粗度が反射に影響
- **Two extreme ends** of the way in which energy is reflected from a target: 2つの極限状態
  - **Specular Reflection**
  - **Diffuse Reflection**



- When a surface is **smooth**, we get **specular** or **mirror-like reflection** where all (or almost all) of the energy is directed away from the surface in **a single direction**

- **Diffuse reflection** occurs when the surface is **rough** and the energy is reflected almost **uniformly in all directions**.

Reflectance of Surfaces 表面反射(2)

- Most earth surface features lie somewhere **between** perfectly **specular** or perfectly **diffuse** reflectors.
  大抵の表面は中間的
- Whether a particular target reflects specularly or diffusely, or somewhere in between, depends on the **surface roughness** of the feature in comparison to the **wavelength** of the incoming radiation. 表面粗度と波長に依存
- **If the wavelengths are much smaller** than the surface variations or the particle sizes, **diffuse reflection** will dominate. 波長が表面粗度より短い時は散乱
- For example, **fine-grained sand** would appear **fairly smooth** to long wavelength **microwaves** but would appear **quite rough** to **the visible wavelengths**.
  砂粒はマイクロ波には平坦だが可視光には粗