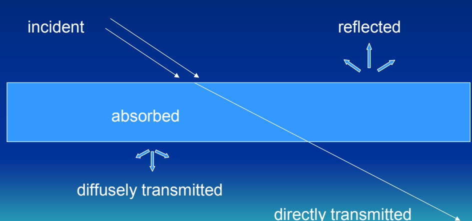
Lecture #7
20 June 2006

Scattered and reflected solar energy

- Solar energy entering the atmosphere interacts with molecules and particles
- Energy may be *absorbed* or *scattered*, i.e. redirected without being absorbed
- When scattering takes place from a surface such as the land or ocean or the top of a cloud layer, this is a process of reflection and the fraction of solar energy reflected is called the ALBEDO
- Energy that is neither absorbed nor reflected is *directly transmitted* along the direction of propagation
- Energy that is scattered (i.e. redirected) but continues in the downward direction is called *diffuse transmission*

- Energy conservation requires that

incident energy = absorbed energy + reflected energy + directly transmitted energy + diffusely transmitted energy



ALBEDO

TABLE 2.2
Typical Albedo of Various Surfaces

SURFACE	ALBEDO (PERCENT)
Fresh snow	75 to 95
Clouds (thick)	60 to 90
Clouds (thin)	30 to 50
Venus	78
Ice	30 to 40
Sand	15 to 45
Earth and atmosphere	30
Mars	17
Grassy field	10 to 30
Dry, plowed field	5 to 20
Water	10*
Forest	3 to 10
Moon	7

*Daily average. (albedo depends on the solar zenith angle)

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Table 2.2 p. 40

Interaction of Solar Radiation with Clouds

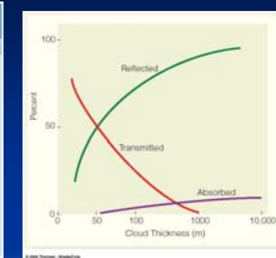

Fig. 15.2 p. 405

The values above represent the total reflection (or transmission, absorption) summed over the solar spectrum

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Disposition of Solar Radiation

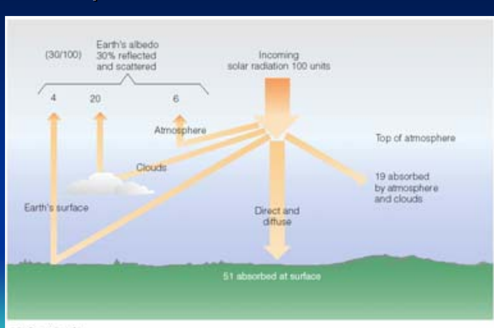


Fig. 2.13 p.41

Scattering by Atmospheric Constituents

- Molecules, aerosols and cloud particles absorb and scatter solar energy
- The scattering process depends very strongly on the size of the particles, *a*, relative to the wavelength of electromagnetic radiation, λ

• a << λ	Rayleigh	molecules and visible light; cloud drops and radar; aerosols and infrared

scattering efficiency $\propto 1/\lambda^4$

• a ≈ λ	Mie	aerosols and visible light
• a >> λ	Geometric Optics	cloud drops and visible light

scattering efficiency is the same for all λ

Colors of the Sky

- Since blue light (λ=0.47μm) has a shorter wavelength than red light (λ=0.64μm), it is scattered more effectively by molecules
- The human eye is more sensitive to blue than to violet, which has a shorter wavelength
- Clear skies are therefore BLUE
- When there are small particles in the air, the scattering regime shifts from Rayleigh to Mie and longer wavelengths are scattered almost as efficiently as shorter wavelengths
- Polluted skies are therefore MILKY or HAZY
- Chemical properties of particles (e.g. dust) can give the sky some color, such as BROWN

Cloudy Skies

- Cloud drops are in the *geometric optics* limit for visible light and all colors are scattered efficiently
- Cloudy skies are therefore WHITE as long as solar radiation is being transmitted
- The base of thick clouds appears dark because *transmission* is nearly zero
- The tops of these same thick clouds will appear bright WHITE when viewed from above

Clear and Cloudy Skies

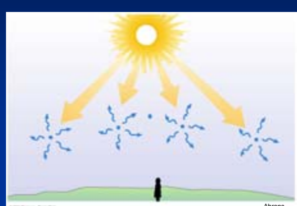


Fig. 15.3 p. 406

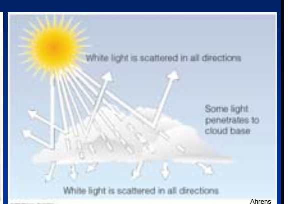


Fig. 15.1 p. 405

Halos from Cirrus Clouds

Fig. 15.17 p. 414

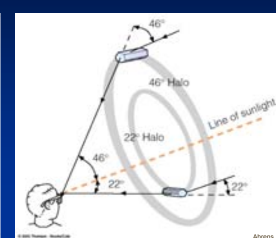


Fig. 15.18 p. 415

Halos around the Sun or the Moon (easier to see) indicate the presence of high thin cirrus clouds, which could be part of an approaching weather front and precipitation

Rainbows from Water Clouds

Fig. 15.25 p. 418

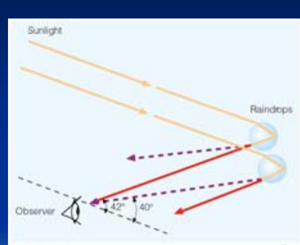


Fig. 15.26 p. 419

Rainbows and Weather Systems

Rainbows at sunset indicate clearing weather moving in from the west

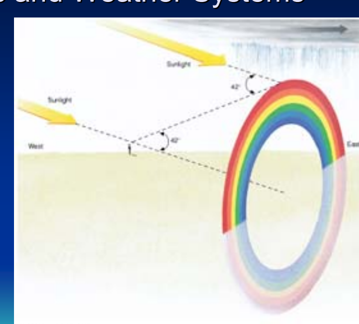


Fig. 15.24 p. 418

A Good Book on the Subject

Rainbows, Halos, and Glories
Author : Robert Greenler
Published by : Cambridge University Press, 1994
ISBN 1-56458-349-x

An Interesting Web Site

Alistair B. Fraser, Emeritus Professor, Penn State

Has written about colors, rainbows, optical phenomena

http://www.ems.psu.edu/~fraser/cv/

Terrestrial Radiation

- All natural bodies on the Earth and in the atmosphere emit electromagnetic radiation primarily at wavelengths longer than 4 μm
- This radiation is called LONGWAVE or TERRESTRIAL radiation
- Most surfaces and the gaseous constituents of the atmosphere have different radiative properties in the *shortwave (λ < 4 μm)* and *longwave (λ > 4 μm)*

Selective Absorption

- The property of gases absorbing radiation at some particular wavelengths and not at others is called SELECTIVE ABSORPTION
- Gases that absorb longwave radiation and are transparent to visible radiation are called GREENHOUSE gases because this property is quite similar to the radiative property of glass
- Selective absorption plays a fundamental role in controlling the mean surface temperature of the Earth and other planets (such as Venus) that have atmospheres composed of greenhouse gases

Absorption by gases in the atmosphere

- Water vapor and carbon dioxide are the strongest absorbers of infrared radiation
- Ozone is a very strong absorber of ultraviolet radiation
- Water vapor is a significant absorber of solar infrared radiation (also called near-infrared)
- There is an atmospheric window at visible wavelengths
- With the exception of a strong absorption feature of ozone, there is an atmospheric window between 8 – 11 μm

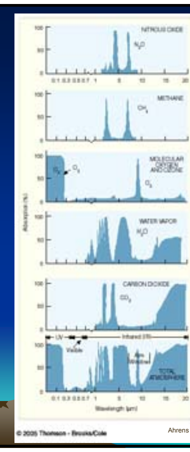


Fig. 2.9 p. 36

- *Black body emission* is also the upper limit of radiation that can be emitted by a *real body* at a particular *temperature* and *wavelength*
- Kirchhoff's Law: good absorbers are good emitters at a particular wavelength and poor absorbers are poor emitters at the same wavelength

Conservation of Radiant Energy and Radiative Equilibrium

- Although electromagnetic energy does not need a medium to propagate, when it interacts with matter, energy is conserved
- Incident energy = reflected energy + absorbed energy + transmitted energy
- Matter that has absorbed radiant energy will also emit energy, perhaps at different wavelengths, depending on its temperature and properties
- When radiation is the only mechanism for energy transfer and the total absorbed energy is equal to the total emitted energy, the system is said to be in a state of *radiative equilibrium*

Atmospheric Greenhouse Effect

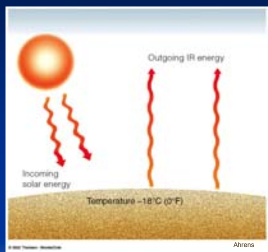
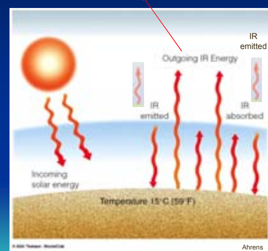


Fig. 2.10 p. 37

Radiative Equilibrium without an atmosphere

Escapes through the atmospheric window between 8 -11 μm



Radiative Equilibrium with an atmosphere

CO_2 measurements at Mauna Loa

Pre-industrial level

280 ppmv

Current rate of increase

1.5 ppmv/year

Expected level in 2100

500 ppmv

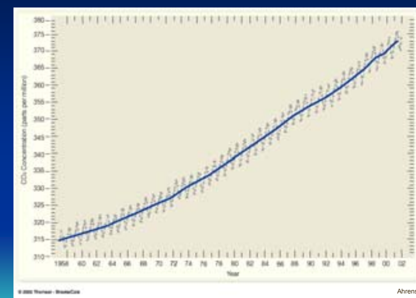


Fig. 1.3 p. 5

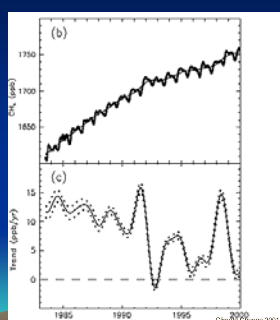
Increase in the concentration of atmospheric methane (CH_4) since 1983

Pre-industrial level

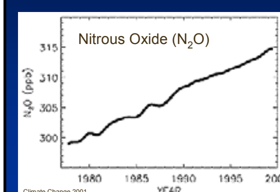
750 ppb

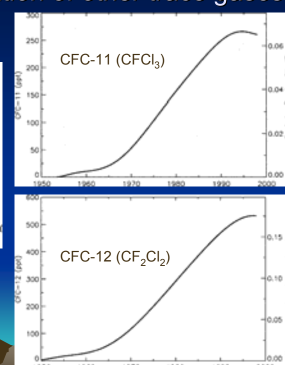
Average increase from 1992-1998

4.9 ppb/yr



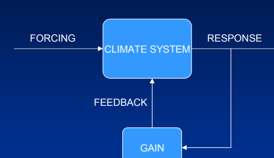
Increase in concentration of other trace gases





- Increasing concentrations of greenhouse gases block the atmospheric window thereby increasing the greenhouse effect
- Molecules such as CFC-12 have a far greater effect on a per molecule basis than CO_2 molecules
- When the atmosphere warms due to increased greenhouse gas concentrations, the *concentration of water vapor* in the atmosphere increases accentuating the greenhouse effect because H_2O is a strong absorber of LW radiation

Forcing and Feedback



Positive feedback: when the initial response is enhanced, e.g. ice/snow albedo feedback, high-level cirrus cloud cover feedback, water vapor feedback

Negative feedback: when the initial response is moderated, e.g. temperature-infrared feedback, low-level cloud cover feedback, cloud optical depth feedback

- This enhancement of water vapor concentration is a POSITIVE FEEDBACK
- Warmer atmospheres may (or may not) have more (and thicker clouds) clouds. Since clouds reflect SW but absorb LW radiation the feedback effect of changing cloud cover is uncertain. It may be NEGATIVE or POSITIVE
- Current global models are unable to provide a definitive answer

Clouds interact selectively with electromagnetic radiation

- CLOUDS *reflect* (consequence of scattering by water drops and ice crystals) SHORTWAVE RADIATION significantly and *absorb* it very weakly (water substance is a weak absorber of shortwave radiation)
- CLOUDS *absorb* and hence, *emit* (Kirchhoff's Law) LONGWAVE RADIATION very strongly