MET 4410 Remote Sensing: Radar and Satellite Meteorology
MET 5412 Remote Sensing in Meteorology

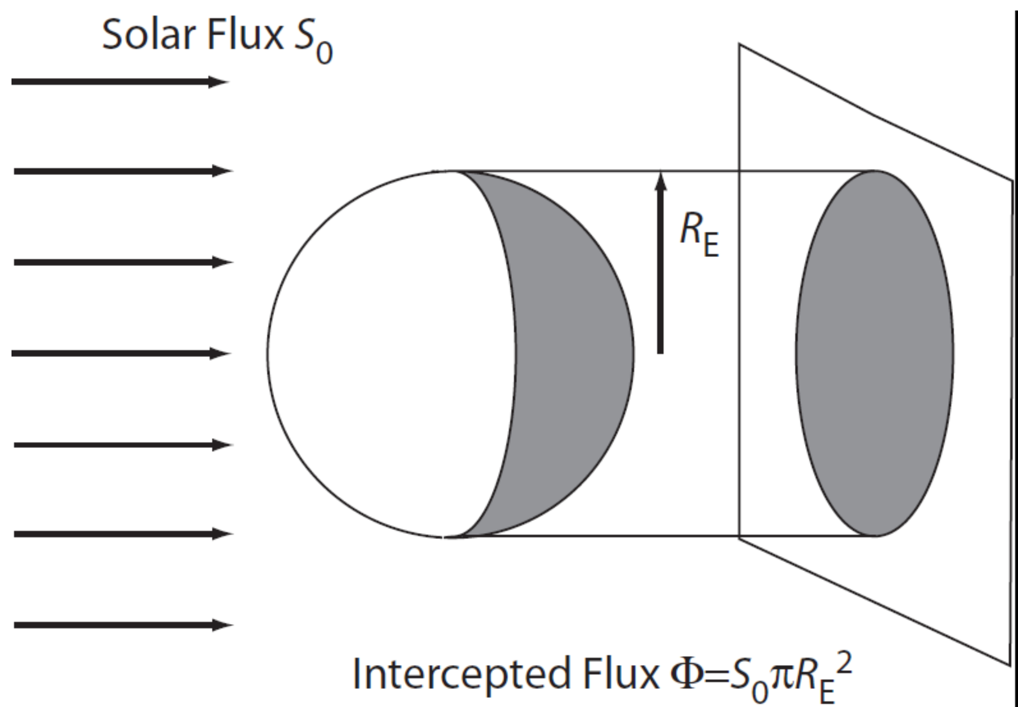
Lecture 4: Global Insolation & EM Spectrum

Energy Input from the Sun

- Of fundamental importance to the global climate is the input of energy from the sun and its spatial and temporal distribution. This input is a function of two variables:
  - ***1) the flux of solar radiation incident on the top of the atmosphere***, and
  - 2) the fraction of that flux that is absorbed by either the surface or the atmosphere at each point in the earth-atmosphere system.
- The second depends in a complex way on distributions of clouds and absorbing gases in the atmosphere, as well as on the absorbing properties of the surface.

Global Insolation

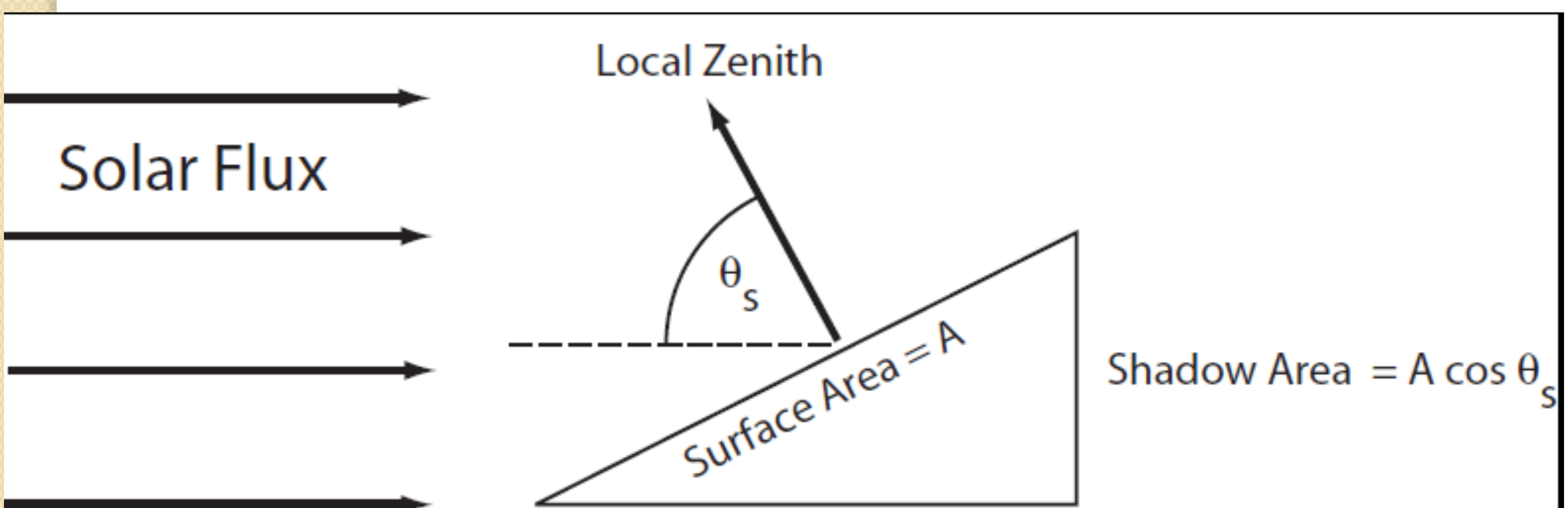
- How much total solar radiation is incident on the earth's atmosphere, on average?
- The sun's incident flux (flux density) at Earth's mean distance from the Sun is $S_0 = 1370\ W\ m^{-2}$
- Thus, the total flux of solar radiation intercepted by the earth is $\boldsymbol{\Phi} = S_0 \pi R_E^2 = 1.74 \times 10^{17}\ W$



Regional Dependence of Insolation

- The flux (density) of solar radiation measured on a unit horizontal area at the top of the atmosphere depends on the angle of incidence of the sun (solar zenith angle):

  $F=S_0\cos\Theta_s$



Total Insolation of a Single Location

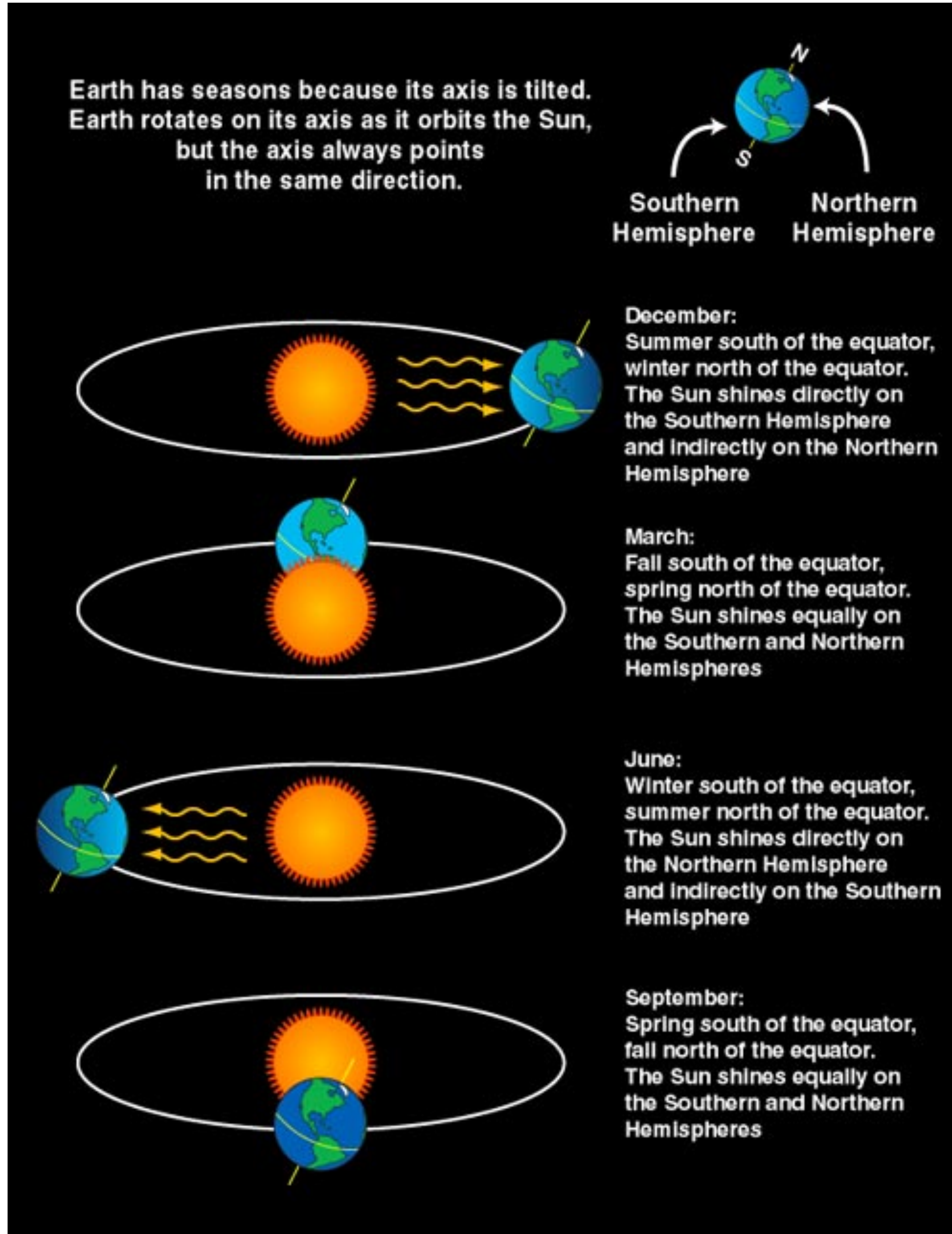
- Total insolation [energy per unit area] at the top of the atmosphere at a single location over the course of a 24-hour period. This insolation is given by

$$W = \int_{t_{\text{sunrise}}}^{t_{\text{sunset}}} S_0 \cos \theta_s(t)\, dt.$$

- W depends on two readily identifiable factors: (1) the length of the day $t_{sunset} - t_{sunrise}$, and (2) the average value of cos θs(t) during the time the sun is up.

What causes Earth's Seasons

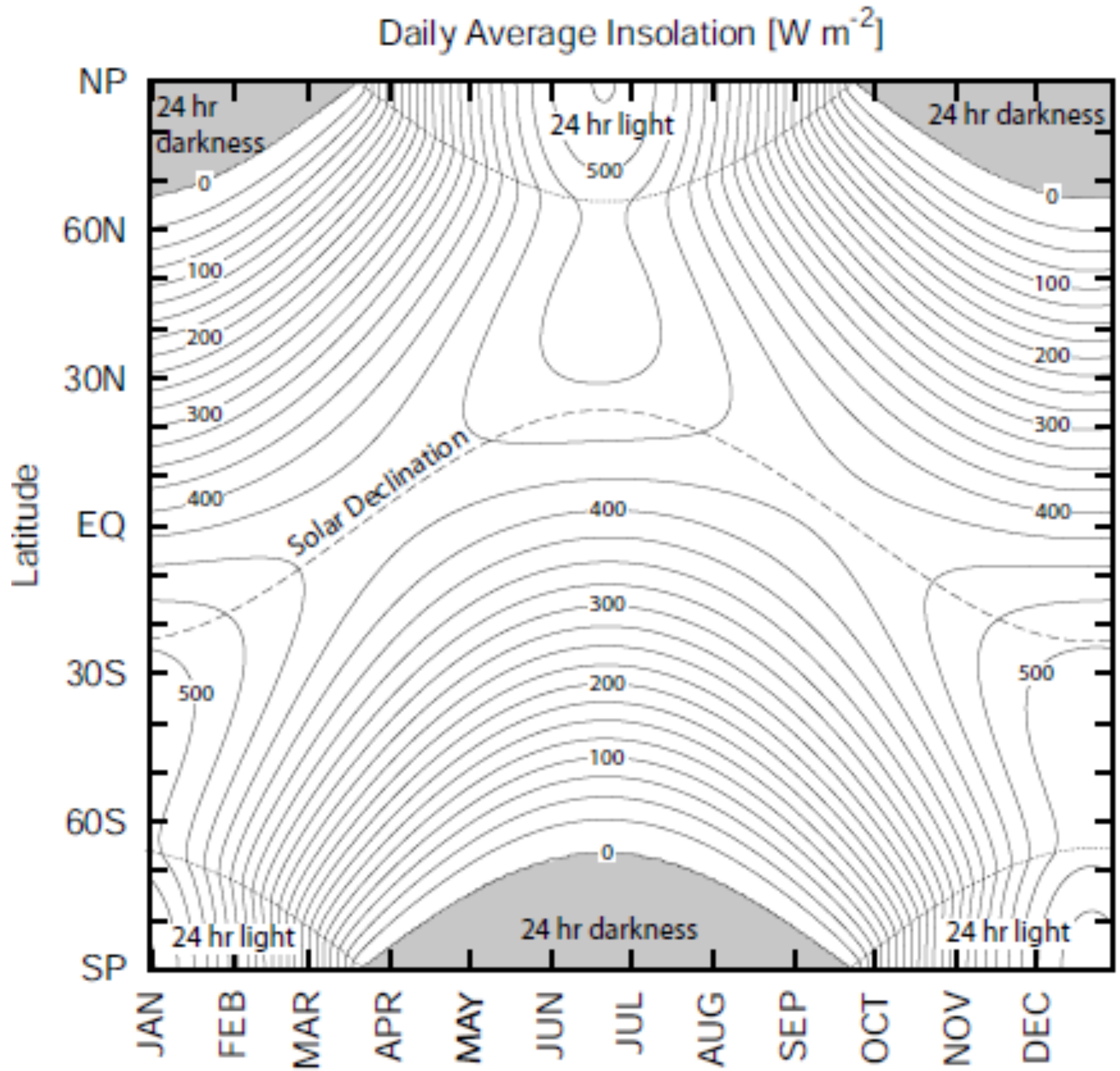
The changing season is due to the tilt of Earth's spin axis



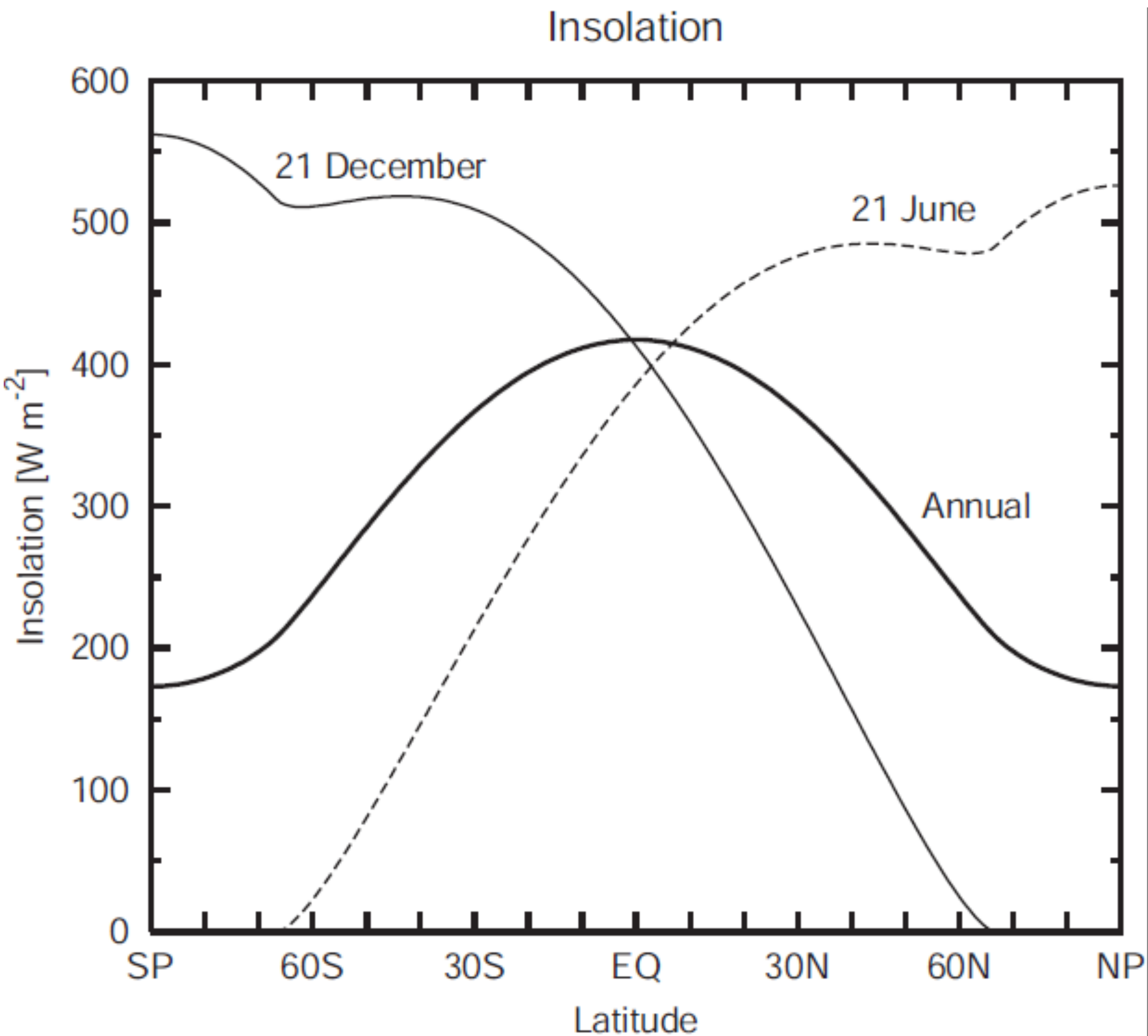
Seasonal Variation of Total Insolation

- At equator, the length of a day is 12 hours year-round, but the maximum elevation (zenith angle) the sun reaches in the course of the day varies with the time of year. Twice a year, at the time of the vernal and autumnal equinox (approximately March 21 and September 21, respectively), the sun passes directly overhead at noon (zenith angle =0). At other times of year, the minimum zenith angle achieved in the course of the day is equal to the angle of tilt of the earth's axis toward or away from the sun, up to a maximum of 23◦ at the time of the summer and winter solstices (June 21 and December 21, respectively).
- At At latitudes poleward of 23◦, the sun is never directly overhead, and the minimum zenith angle is always greater than zero. Dur-ing the summer season, the sun can reach a point fairly high in the sky, whereas in the winter season, the maximum elevation angle is much lower. Moreover, the days are longer in the summer hemi-sphere than in the winter hemisphere.

Daily average solar flux at TOP as a function of latitude and time of year



Daily average solar flux at TOP as a function of latitude for the two solstice dates and averaged over a year



The Electromagnetic Spectrum

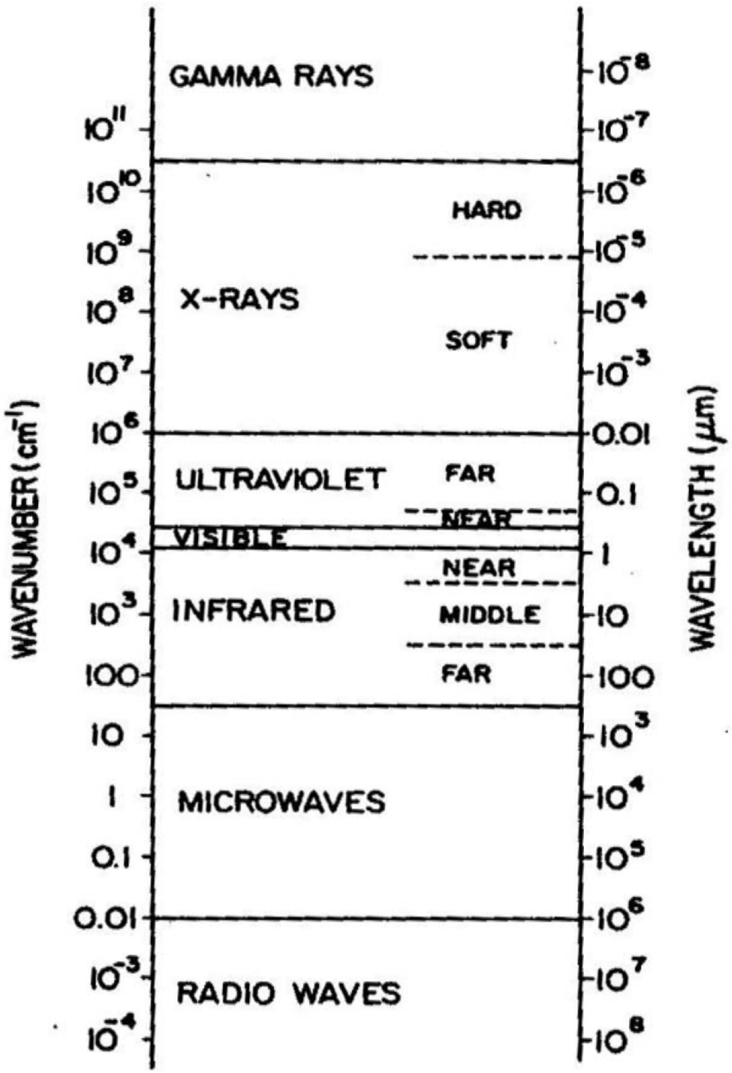


FIGURE 3.2. The electromagnetic spectrum.

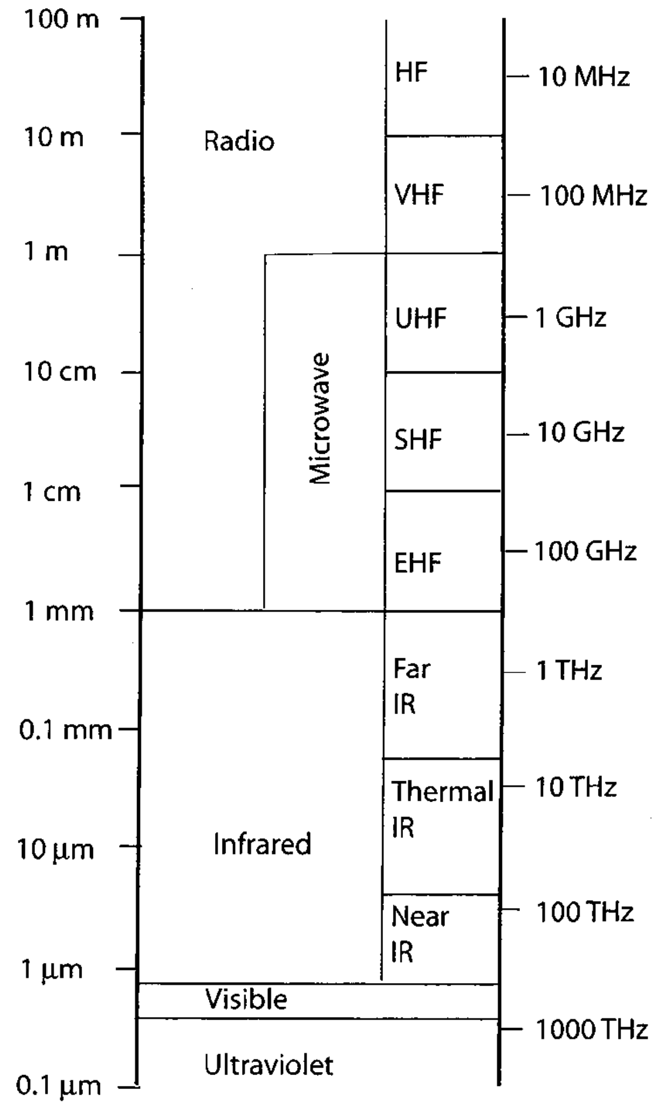


Fig. 3.1: The electromagnetic spectrum.

Why is a specific spectral band interesting to atmospheric scientists ?

- **Diabatic heating/cooling:** heat exchange between earth and the rest of the universe.
- **Photochemistry:** chemical reactions in the atmosphere are driven by sunlight..
- **Remote sensing**: Any frequency of radiation that is absorbed, scattered or emitted by the atmosphere can potentially be exploited for satellite- or ground-based measurements of atmosphere properties.

Table 3.1: Regions of the electromagnetic spectrum

Region	Spectral range	Fraction of solar output	Remarks
X rays	$\lambda < 0.01\ \mu m$		Photoionizes all species; absorbed in upper atmosphere
Extreme UV	$0.01 < \lambda < 0.1\ \mu m$	3×10^{-6}	Photoionizes O_2 and N_2; absorbed above 90 km
Far UV	$0.1 < \lambda < 0.2\ \mu m$	0.01%	Photodissociates O_2; absorbed above 50 km
UV-C	$0.2 < \lambda < 0.28\ \mu m$	0.5%	Photodissociates O_2 and O_3; absorbed between 30 and 60 km
UV-B	$0.28 < \lambda < 0.32\ \mu m$	1.3%	Mostly absorbed by O_3 in stratosphere; responsible for sunburn
UV-A	$0.32 < \lambda < 0.4\ \mu m$	6.2%	Reaches surface
Visible	$0.4 < \lambda < 0.7\ \mu m$	39%	Atmosphere mostly transparent
Near IR	$0.7 < \lambda < 4\ \mu m$	52%	Partially absorbed, mainly by water vapor
Thermal IR	$4 < \lambda < 50\ \mu m$	0.9%	Absorbed and emitted by water vapor, carbon dioxide, ozone, and other trace gases
Far IR	$0.05 < \lambda < 1$ mm		Absorbed by water vapor
Microwave	$\lambda > 1$ mm		Clouds semi-transparent

Gamma Rays and X-Rays

- $\boldsymbol{\lambda} < 0.01\mu m$, so-called cosmic rays;
- Very energetic, can ionize atoms and decompose chemical compounds, harmful to life.
- Intensity is reduced rapidly through the atmosphere. Very little of this radiation makes it to the lowest levels
- Airline passengers are exposed to nonnegligible levels of cosmic radiation.
- No major significance for any of the three processed identified above.

Ultraviolet (UV) Band

- 0.01µm<λ < 0.4µm
- The sun is the sole significant source of natural UV radiation in the atmosphere.
- Only a few percent of total Sun's power output falls in this band.
- Satellite remote sensing of ozone and other stratosphere constituents is possible in UV band.
- UV is a major player of atmospheric photochemistry.
- Sun-bands:
  - UV-A: 0.32µm< λ < 0.4µm; comprising 99% of the total solar radiation that reaches seas level. No harm to living organisms. The atmosphere is transparent to UV-A.
  - UV-B: 0.28µm< λ < 0.32µm; more energetic, can initiate photochemical reactions such as sun-burn, skin cancer. Most of UV-B is absorbed by the ozone layer in the stratosphere.
  - UV-C: 0.1µm< λ < 0.28µm; All UV-C radiation is absorbed in the mesosphere & uppermost stratosphere.

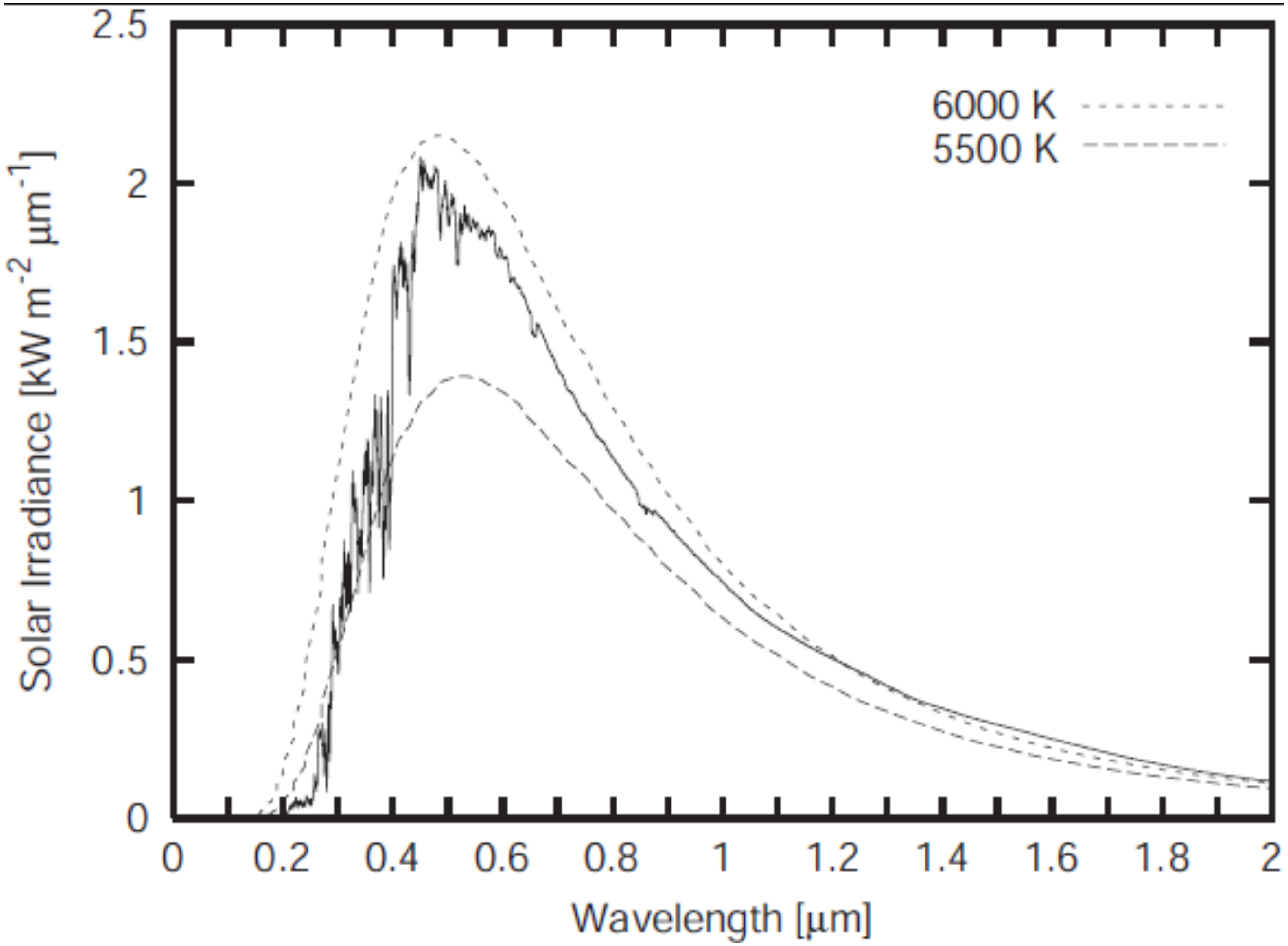
Visible Band

- $0.4\mu m < \lambda < 0.7\mu m$
- Visible band is very important because:
  - The visible band includes the wavelength of maximum emission of radiation by the sun.
  - The cloud-free atmosphere is remarkably transparent to all visible wavelengths. → This means that the absorption of visible solar radiation occurs primarily at the surface of the earth. The atmosphere is heated from below.
  - Clouds are remarkably reflective in visible band. The global distribution of cloud cover has a huge influence on the earth-atmosphere's radiation budget.
- Therefore, satellite remote sensing in the visible band is important – detect cloud cover, map surface features such as vegetation types, ocean color, etc.

Table 3.2: Relationship between color and wavelength

Wavelength interval (μm)	Color
0.39–0.46	Violet
0.46–0.49	Dark Blue
0.49–0.51	Light Blue
0.51–0.55	Green
0.55–0.58	Yellow-Green
0.58–0.59	Yellow
0.59–0.62	Orange
0.62–0.76	Red

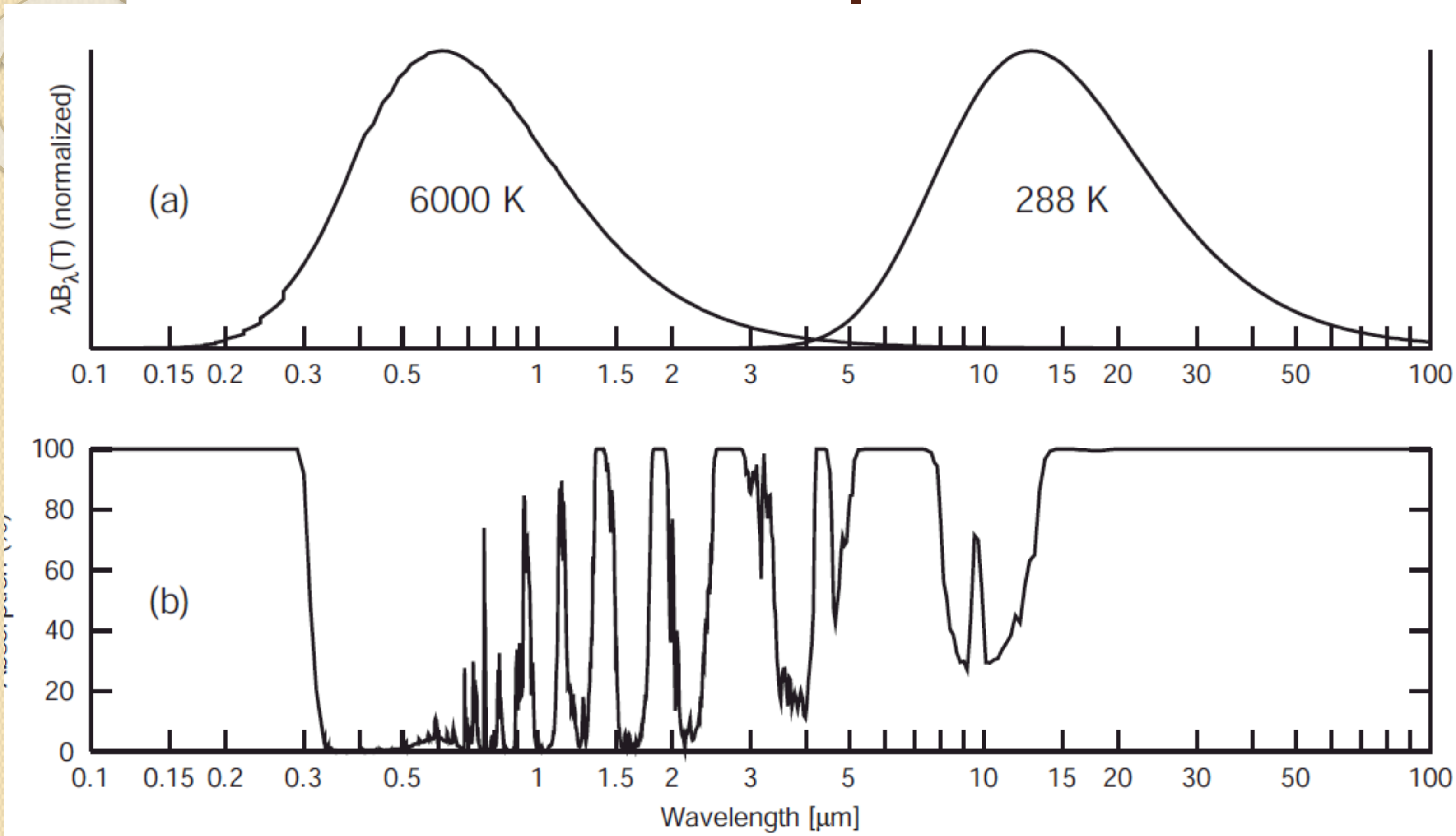
Solar Radiation at TOP



Infrared (IR) Band

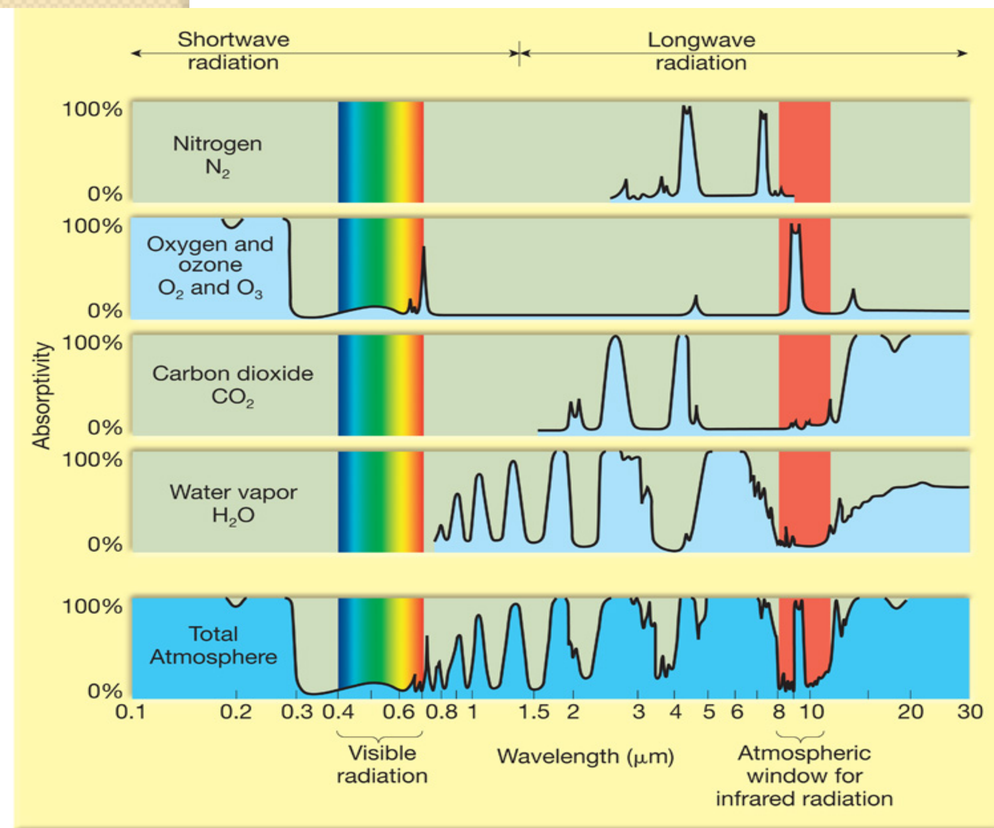
- 0.7 µm < **λ**<1000 µm (1 mm)
- IR band is very important to both diabatic heating/cooling & remote sensing because:
  - Energy exchange through IR band between lower and upper levels of the atmosphere and between earth-atmosphere system and outer space.
  - Major and minor gas species of the atmosphere have distinctive absorption features in the IR band, which allow us to exploit this band for remote sensing of temperature, water vapor, and trace gases.
  - Green house gases: IR absorbing trace gases.
- Sub-bands:
  - Near IR: 0.7 µm < **λ**<4 µm, 52% of solar output is in this band. Atmosphere is not uniformly transparent. There are several absorption lines. For example, **λ**=1.3 µm.
  - Thermal IR: 4 µm < **λ**<50 µm, 0.99% of total solar output. Very important for energy exchange and atmospheric absorption.
  - Far IR: 50 µm < **λ**<1000 µm, energy transfer is insignificant. Potential applications to remote sensing of cirrus clouds.

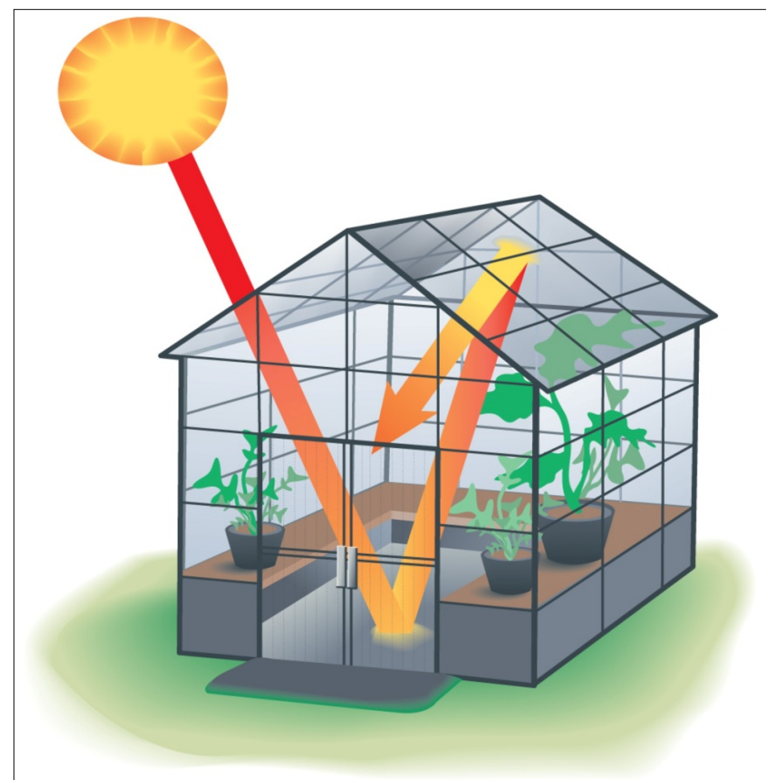
Absorption Spectrum of the Cloud Free Atmosphere



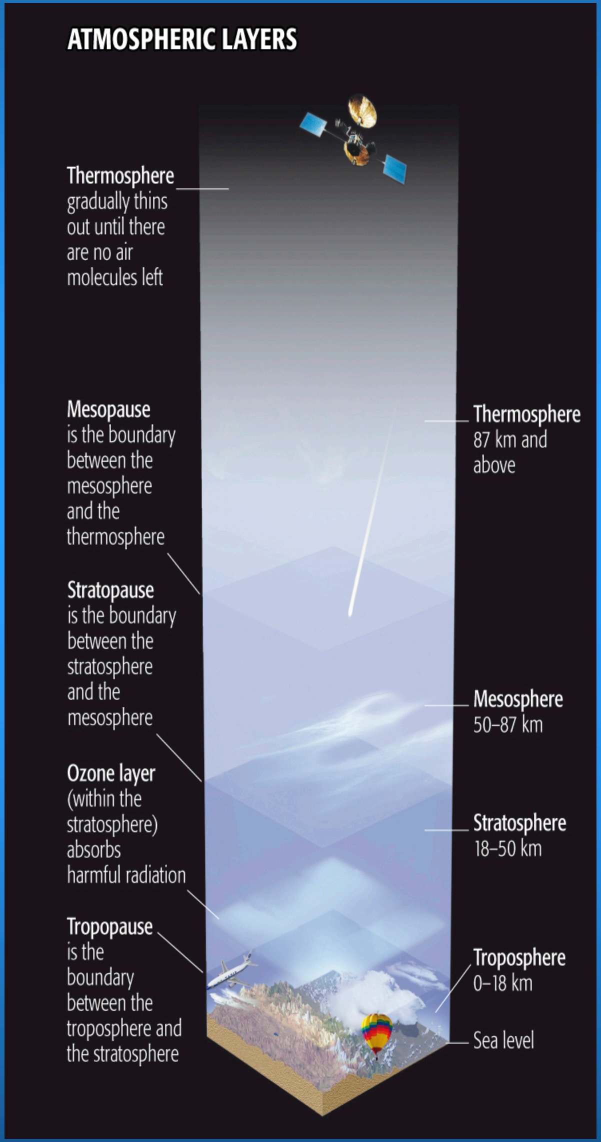
- Solar/shortwave radiation: 0.1 μm < **λ**<4 μm, UV, visible, near IR. 99% of solar output.
- Terristrial/longwave : radiation: 4 μm < **λ**<50 μm, thermal IR. 99% of earth-atmosphere's output radiation.

Greenhouse effect: shortwave solar radiation is nearly transparent to the atmosphere, but longwave terrestrial radiation is trapped by greenhouse gases, causing the increase of surface temperature.

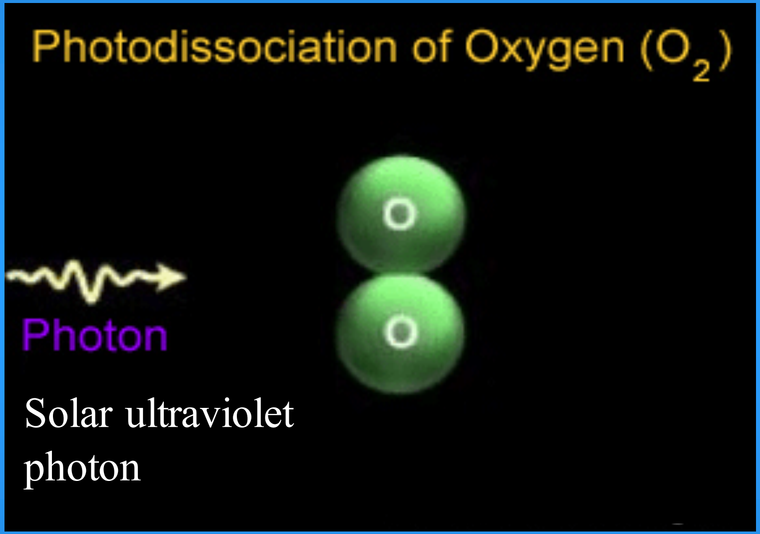


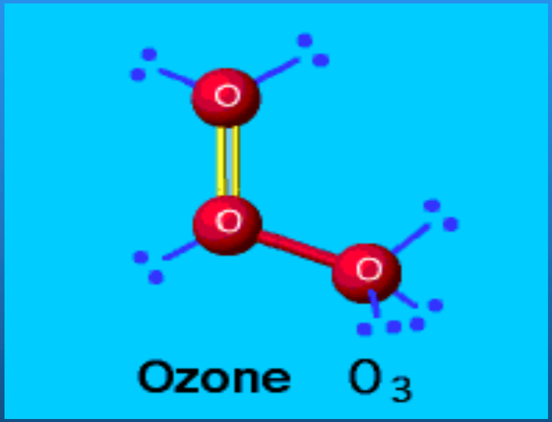


Ozone layer and climate



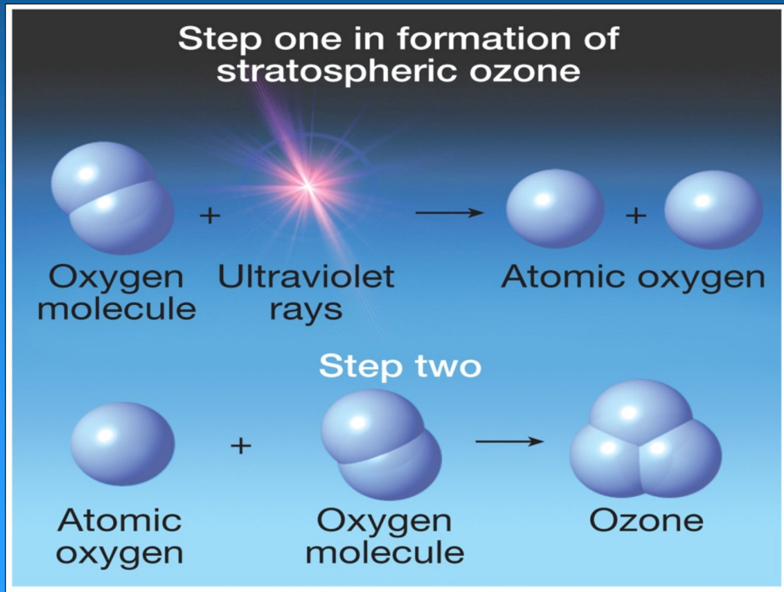
Photodissociation by ultraviolet



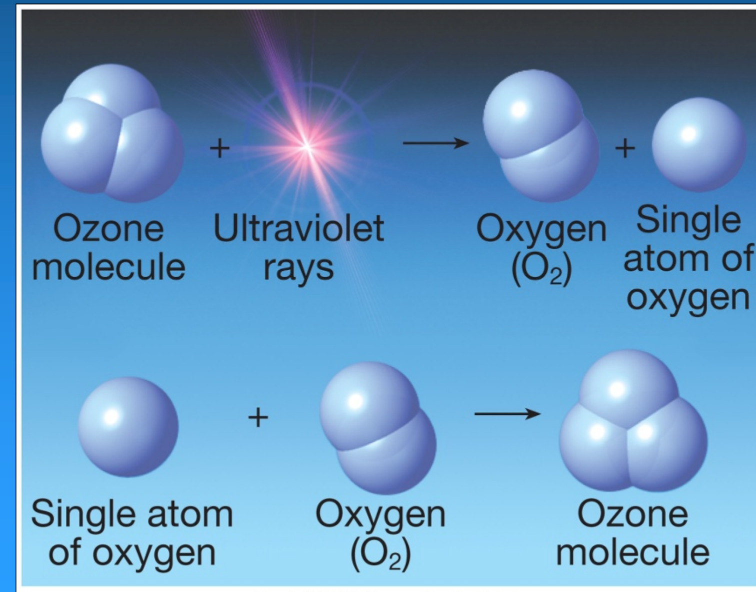


Ozone is a loosely bonded molecule and can be easily dissociated .

Ozone 10-50 km (stratosphere)



Formation of Ozone



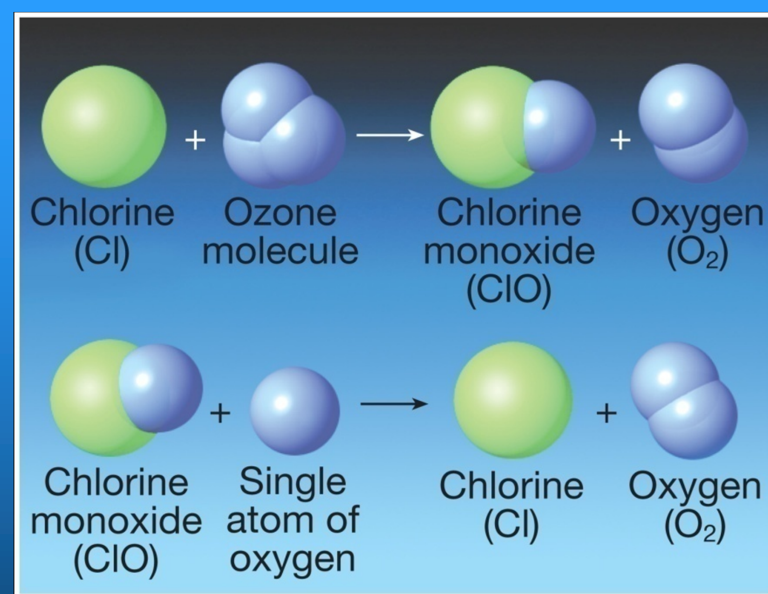
Sustaining Ozone

CFCs such as $CFCl_3$

$CFCl_3 + UV \rightarrow Cl + CFCl_2$

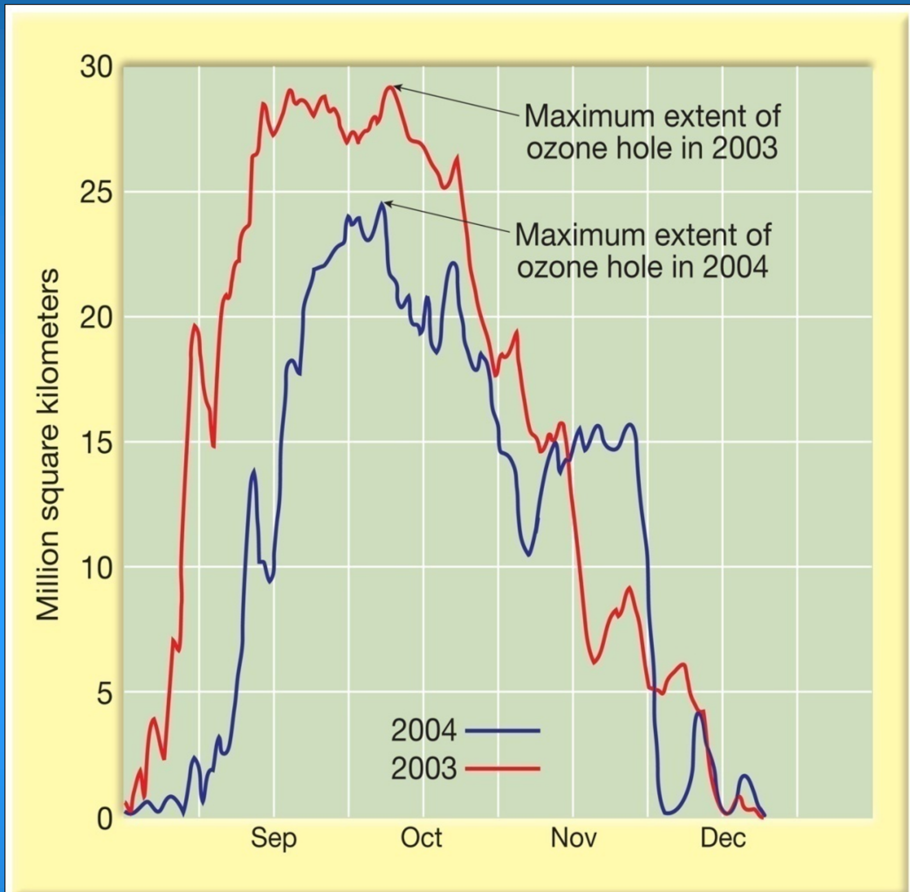
$Cl + O \rightarrow ClO$

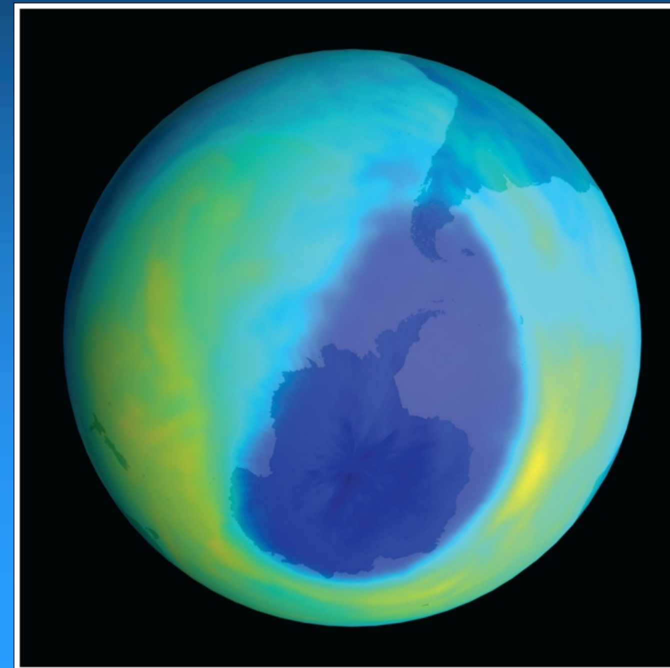
$ClO + O_3 \rightarrow Cl + 2O_2$

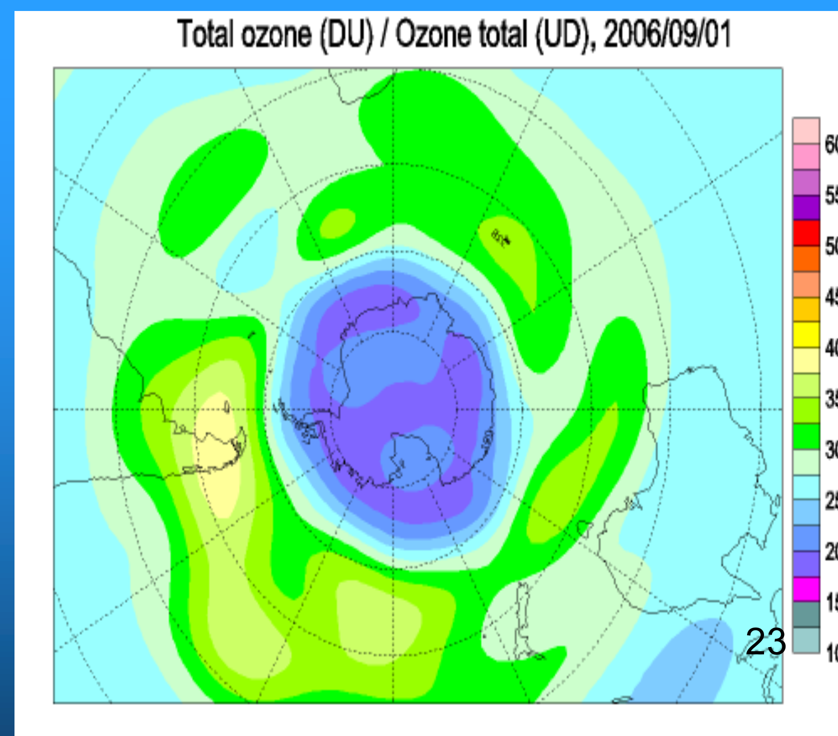


Depletion of Ozone

The Ozone Hole

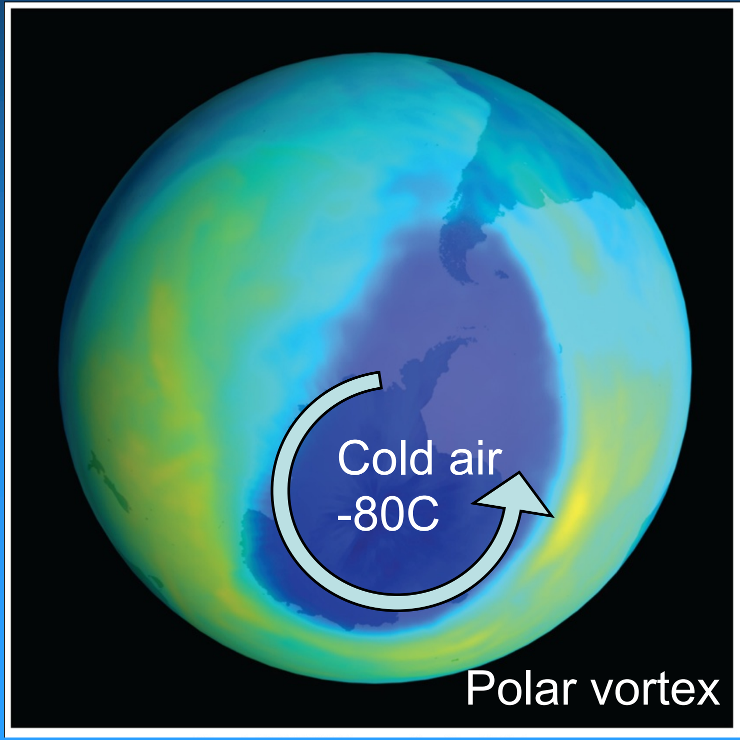






Ozone concentration drops sharply over Antarctica

The Ozone Hole



1. Polar winter leading to the stronger circumpolar wind belt (polar vortex) to isolate the cold air within it.

2. As the cold temperatures persist over the polar, polar stratospheric clouds form.

3. Chlorine reservoir species HCl and ClONO2 become very active on the surface of polar stratospheric clouds.

$$HCl + ClONO_2 \rightarrow NHO_3 + Cl_2$$

$$ClONO_2 + H_2O \rightarrow NHO_3 + HOCl; \quad HOCl + HCl \rightarrow H_2O + Cl_2$$

$$Cl_2 + h\nu \rightarrow Cl + Cl$$

Microwave Band

- 1 mm < λ<10 cm or 3 GHz < f <300 GHz
- No energy transfer in this band in the atmosphere.
- Microwave circuits have a quasi-optical character: waveguides, feedhorns, parabolic reflectors.
- Very useful for radar & passive microwave radiometer.
  - Interactions with precipitation-sized particles (10-85 GHz): monitoring precipitation, convection, and severe weather
  - Relative transparency of clouds when frequency < 100 GHz, allow to detect the properties of surface and of the total atmosphere column under all weather conditions except rainfall.

Radio Band

- λ>10 cm or f <3 GHz
- Frequencies are low enough to be amenable to generation, amplification, and detection using traditional electronic components and circuits.
- Radio band radiation tends to interact very weakly with the atmosphere and therefore has only limited applicability to atmosphere remote sensing. Two examples:
  - 915 MHz ground-based Doppler wind profiler. Observing scattering from turbulence-induced fluctuations in atmosphere density and humidity.
  - Lightning detection systems: detect low frequency “static” emitted by lightning discharges.

EM Spectrum for Radar

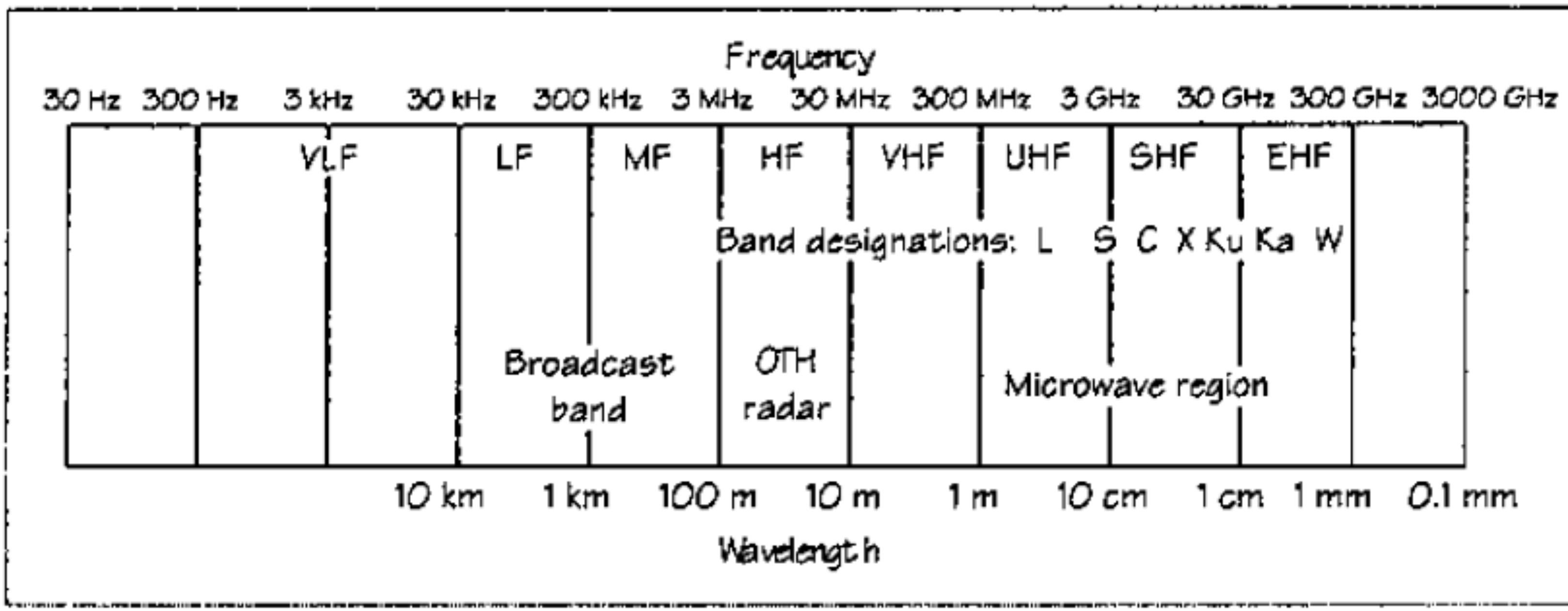


Figure 3.1 Electromagnetic spectrum. After Skolnik, 1980, Introduction to Radar Systems, with permission from McGraw-Hill, Inc.

Table 3.1 Radar bands and the corresponding frequency bands and wavelengths.

Band Designation	Nominal Frequency	Nominal Wavelength
HF	3-30 MHz	100-10 m
VHF	30-300 MHz	10-1 m
UHF	300-1000 MHz	1-0.3 m
L	1-2 GHz	30-15 cm
S	2-4 GHz	15-8 cm
C	4-8 GHz	8-4 cm
X	8-12 GHz	4-2.5 cm
K_u	12-18 GHz	2.5-1.7 cm
K	18-27 GHz	1.7-1.2 cm
K_a	27-40 GHz	1.2-0.75 cm
mm *or* W	40-300 GHz	7.5-1 mm

Summary

- Gamma & X-rays: unimportant.
- UV: important to photochemistry, remote sensing of ozone.
- Visible & IR band: very important to both energy transfer and remote sensing of cloud cover, atmospheric temperature, water vapor, and trace gases, etc.
- Microwave band: remote sensing of precipitation, convection, and severe weather
- Radio band: only a few remote sensing applications (wind profiles, lightning detection, etc.)