AOSC400-2015
September 10, Lecture # 4

Heat transfer in the atmosphere

Solar radiation - *sun source of energy*

Refresher on:

- ❑ Electromagnetic spectrum
- ❑ Inverse-Square; Sun Angle

Seasons

- ➢ Solar zenith angle and how to compute it
- ➢ Solar time-equation of time
- ➢ Declination

How much energy received on a horizontal surface

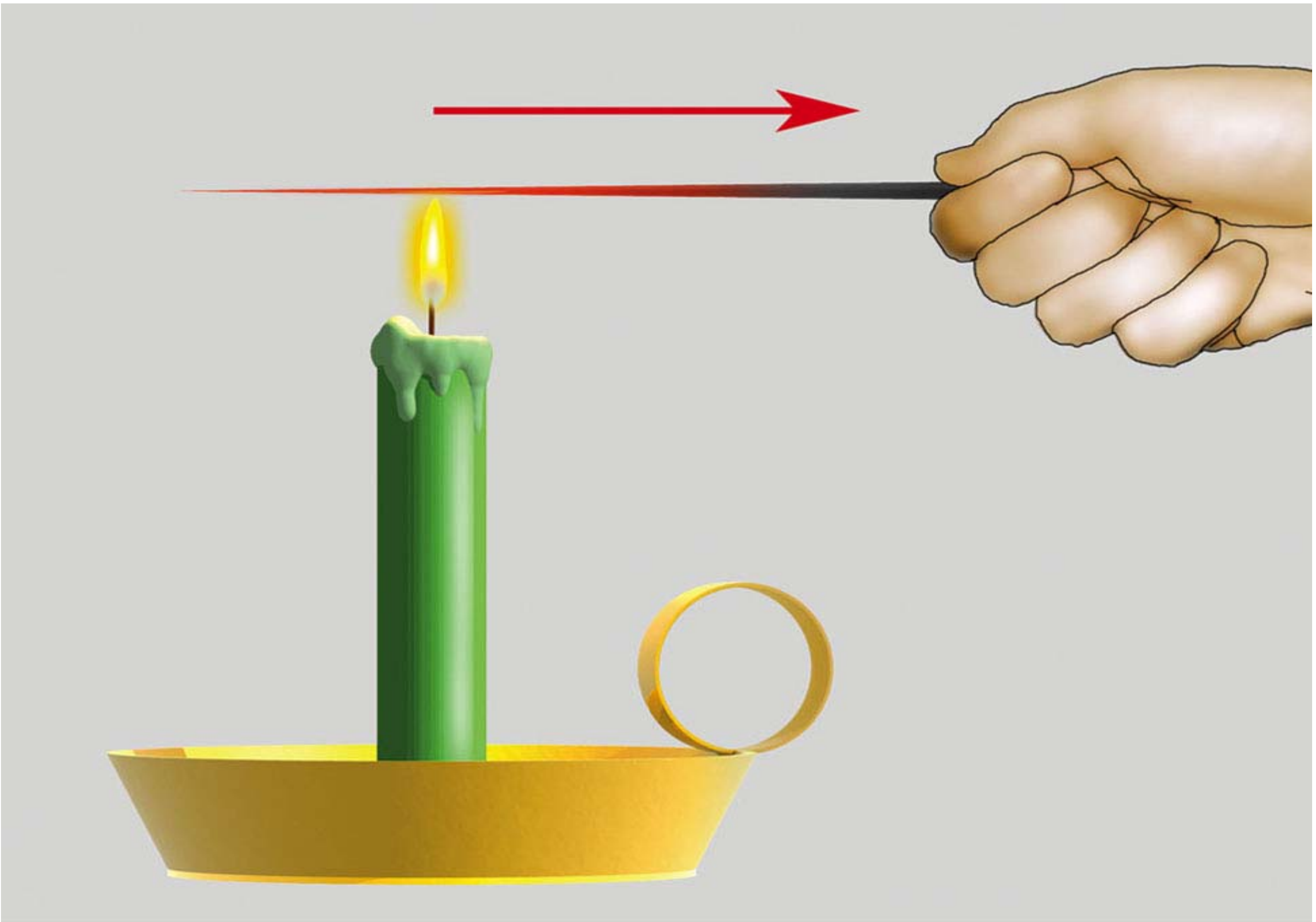
Heat transfer in the atmosphere

conduction, convection, advection, latent heat, and *radiation*

- conduction - heat is conducted by *molecular motion.* Air is a *poor conductor*, heated by conduction only within few cm of heat source.
- eddy heat conduction - transfer of heat by eddies in turbulent flow.
- convection - mass motion in a fluid as a result of *transport and mixing of fluid*.
- advection - transport of atmospheric property by mass movement.
- Latent heat

Example: Conduction

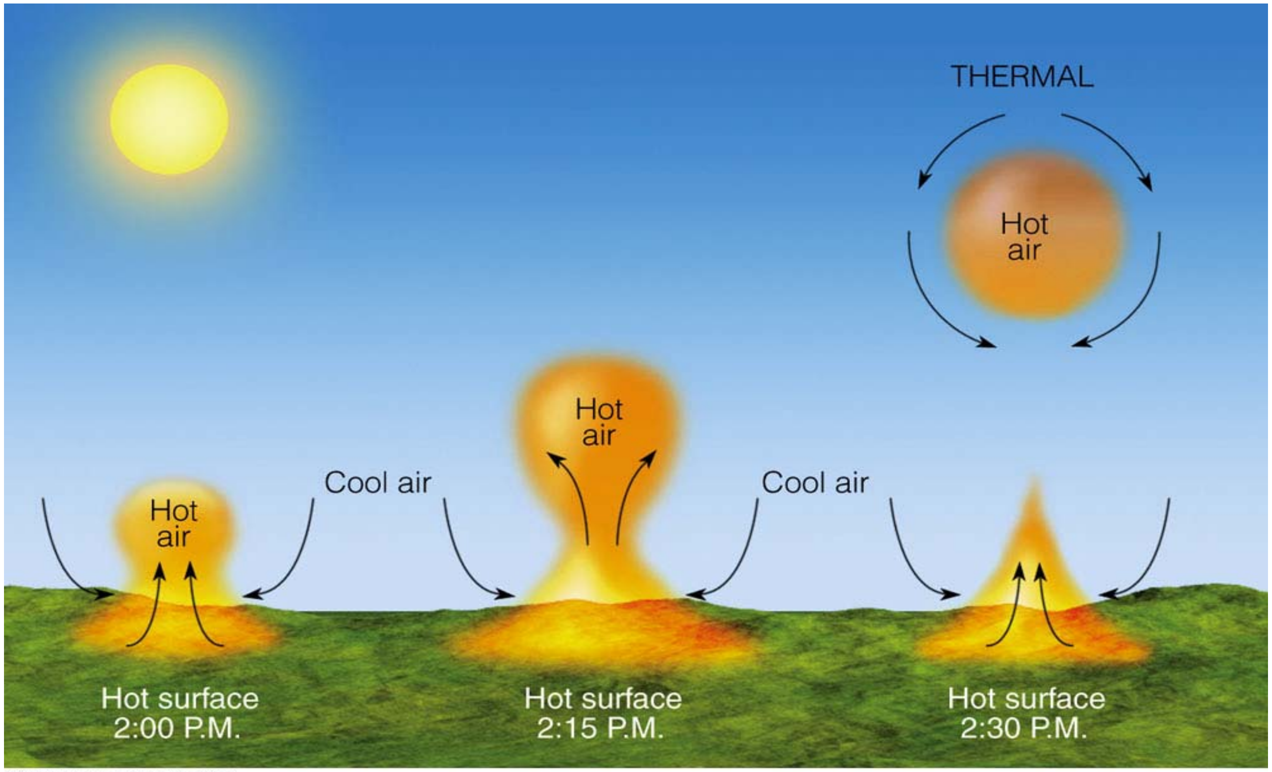
- conduction and heat transfer
- good conductors and poor conductors



Example: Convection

- convection and heat transfer
- thermals

Soaring birds, like hawks and falcons, are highly skilled at finding thermals.



Major mechanism of heat transfer in the atmosphere

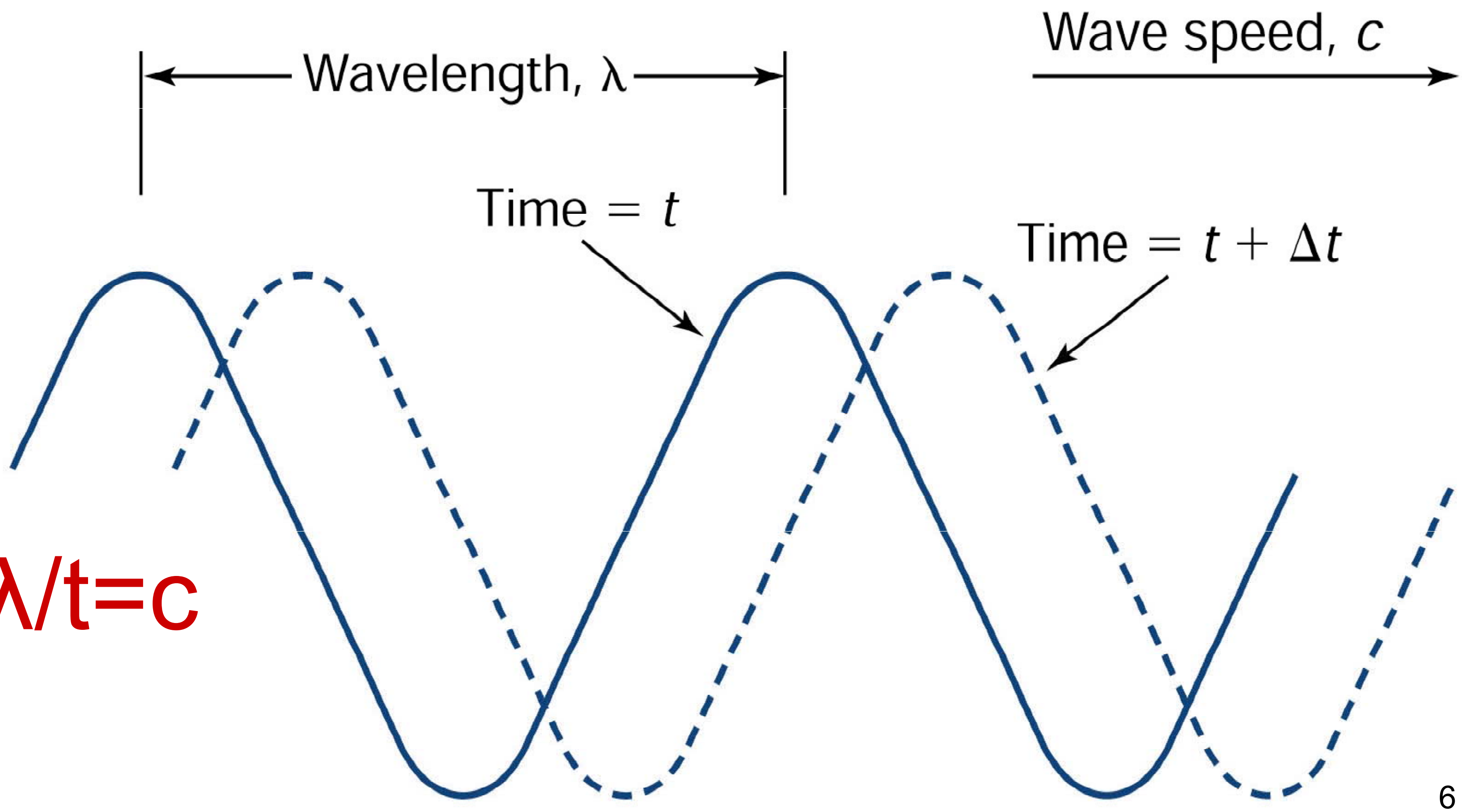
Radiation

Radiation from the sun is an electromagnetic wave

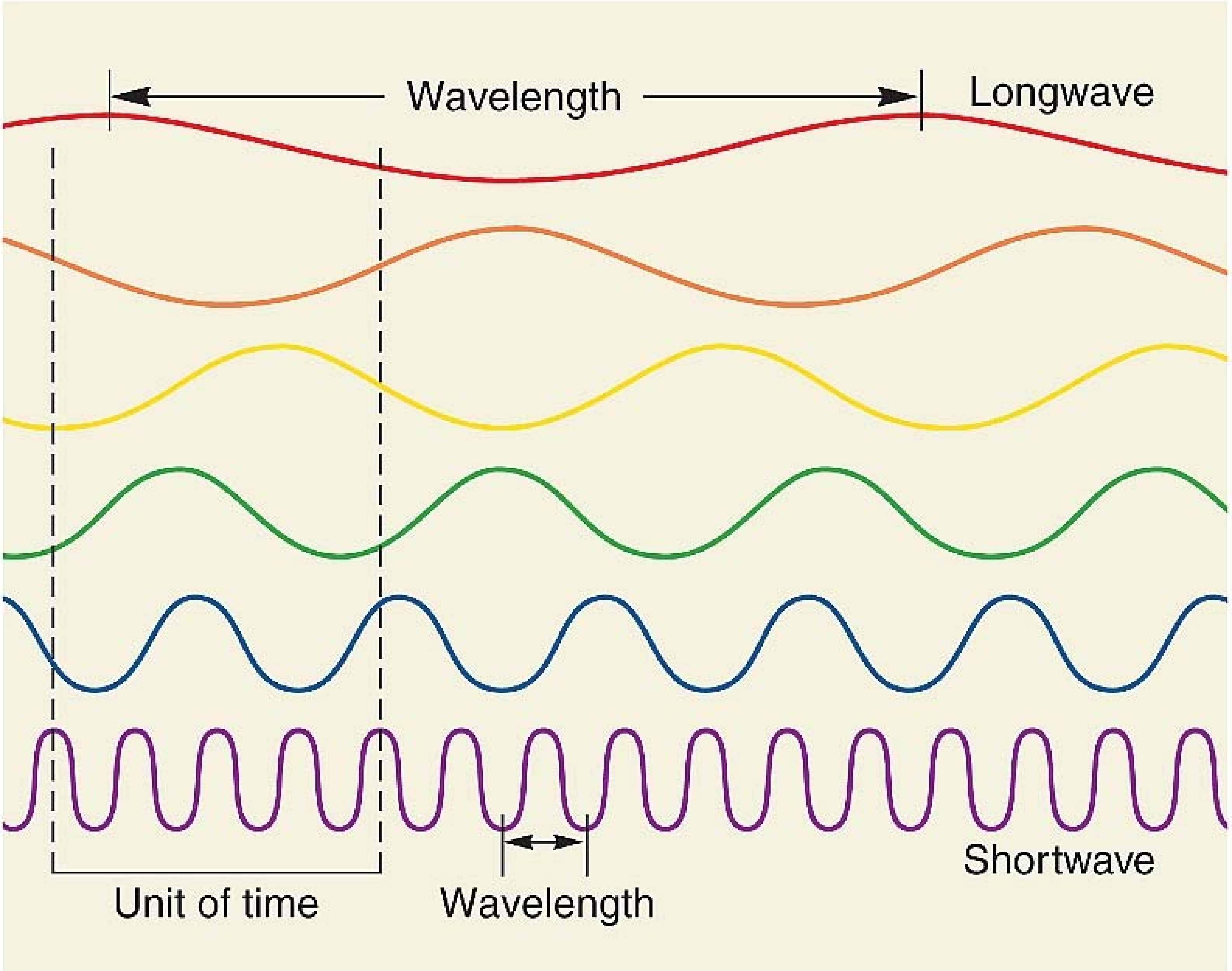
Solid curve - position of the wave at time t

Dashed curve – position of wave at a later time

Wavelength – distance from crest to crest



$\lambda/t=c$



Wavelength (μm)

Electromagnetic waves can be described by their wavelengths, energy, and frequency. All three describe a different property of light, yet they are related to each other mathematically. The two equations below show the relationships:

- Equation 1

$\lambda/t = c$ or $\lambda * f = c$

f = frequency = ν

λ = wavelength

c = speed of light (3×10^8 m/sec)

t=time; $f=1/t$

$\tilde{\nu} = 1/\lambda$ = wave-number

1 micrometers (µm)=10^{-6} m

1 µm=1000 nm

1 nm= 10 A^0 (Angstrom)

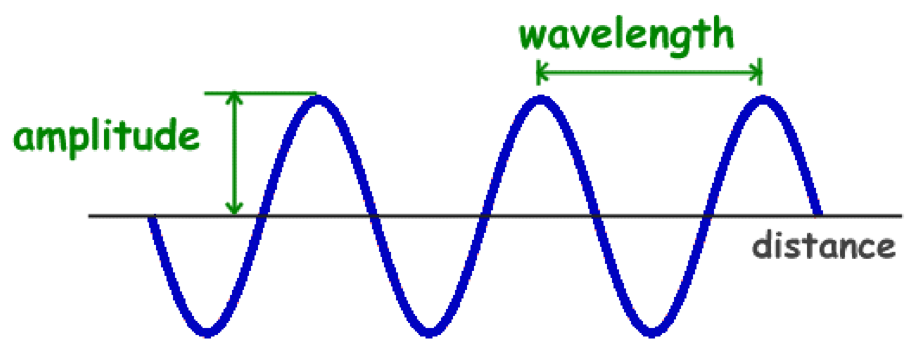
- Equation 2

$E = h * f$

where E = energy

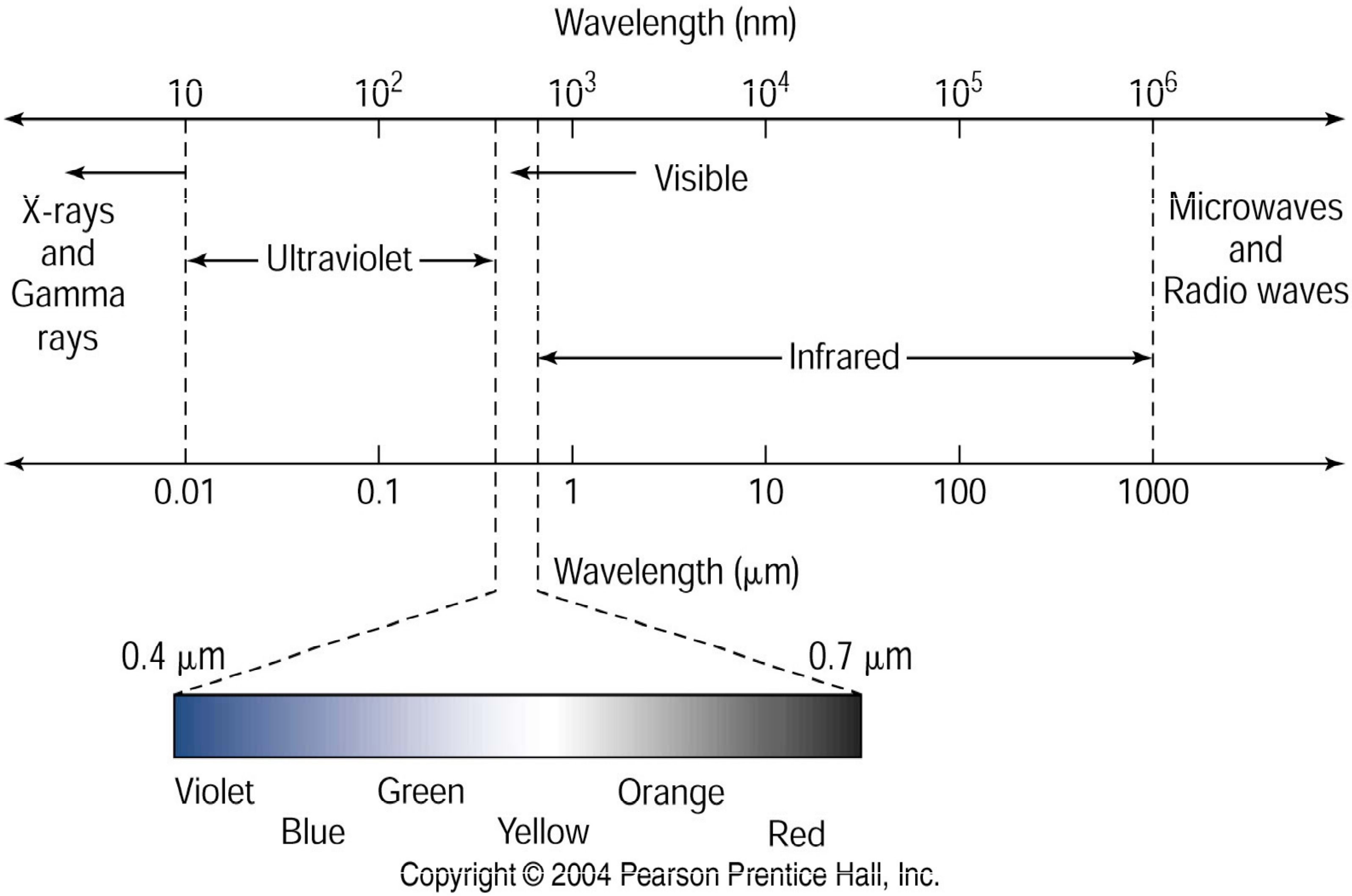
h = Plank's constant

f = frequency



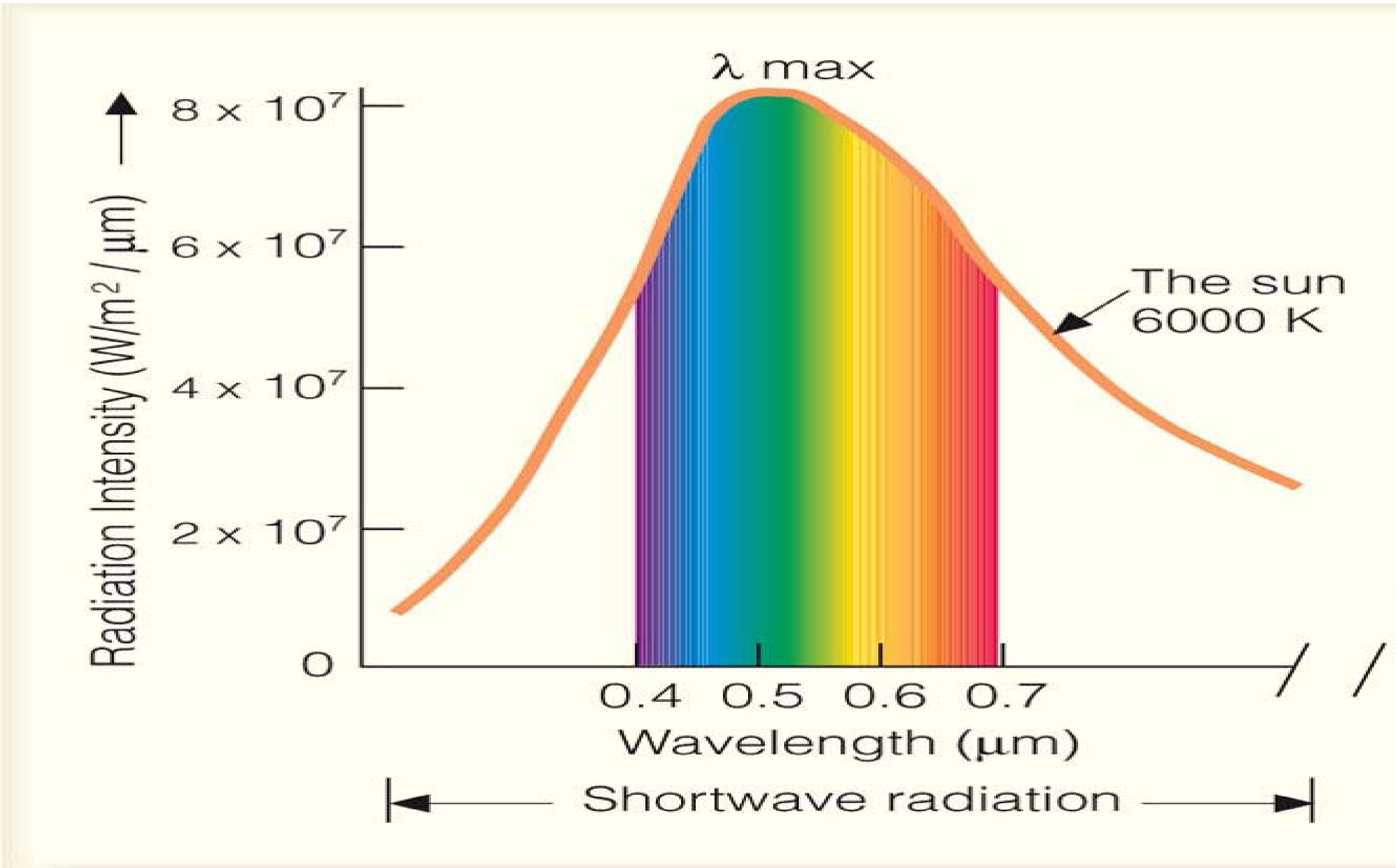
Other property used to describe a wave is the wave amplitude which is one half the height from the peak of a crest to the lowest point of the wave.

Electromagnetic Spectrum



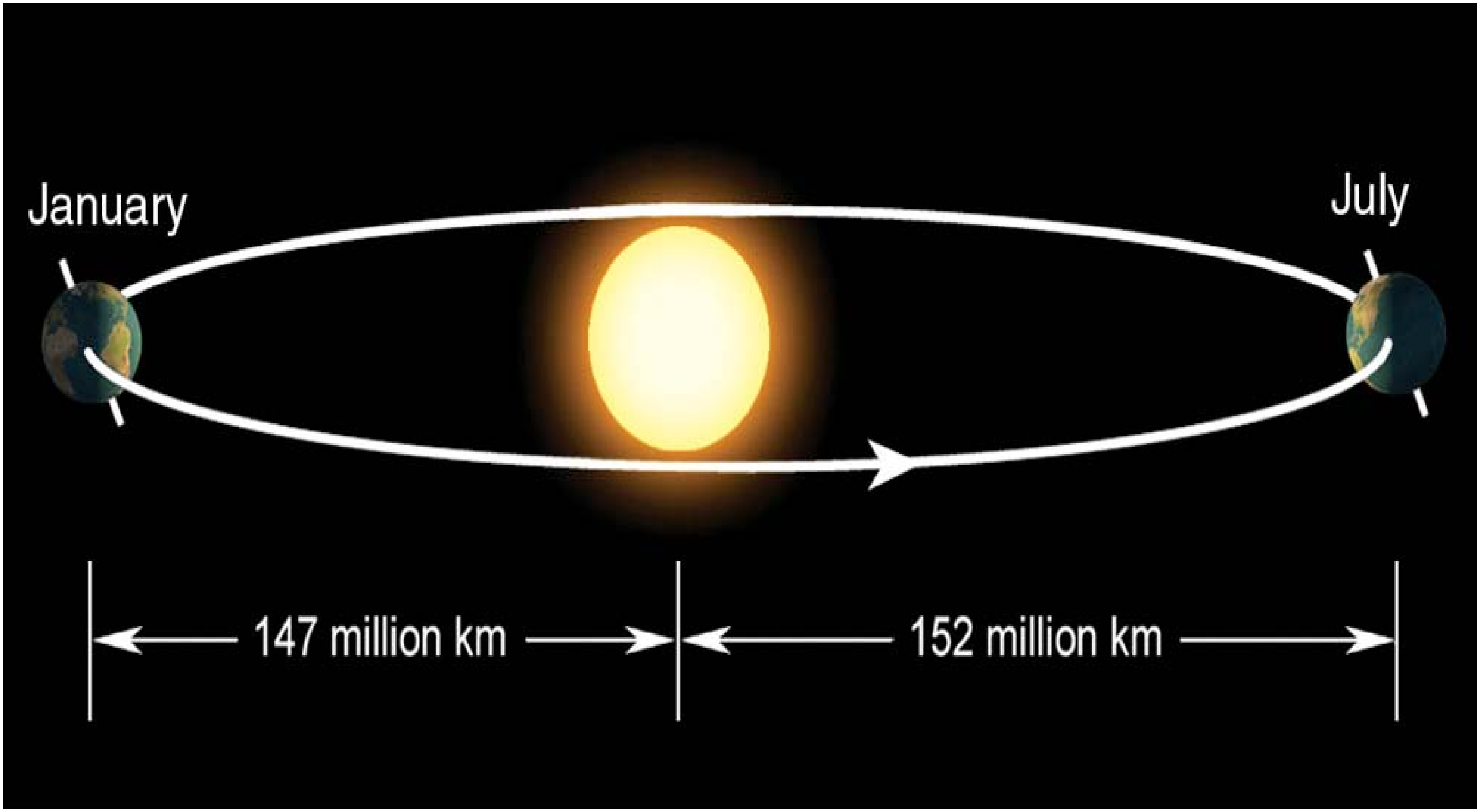
The wavelengths range from ultra-long radio waves to high-energy gamma rays. The amount of energy in the wave increases as wavelengths get smaller

The visible spectrum

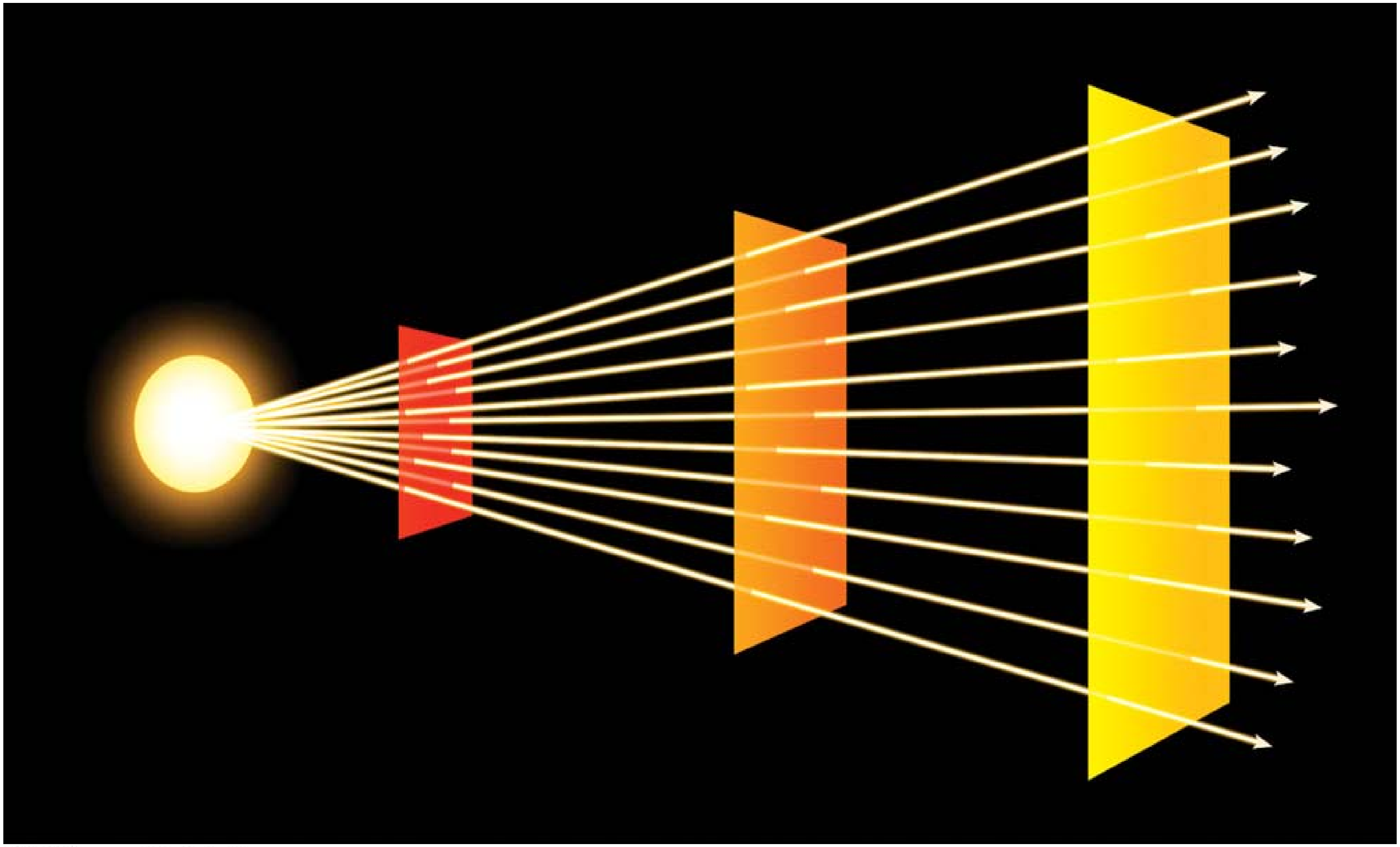


Sir Isaac Newton used a prism to split sunlight into its fundamental colors of the rainbow.

Earth-sun distance factor



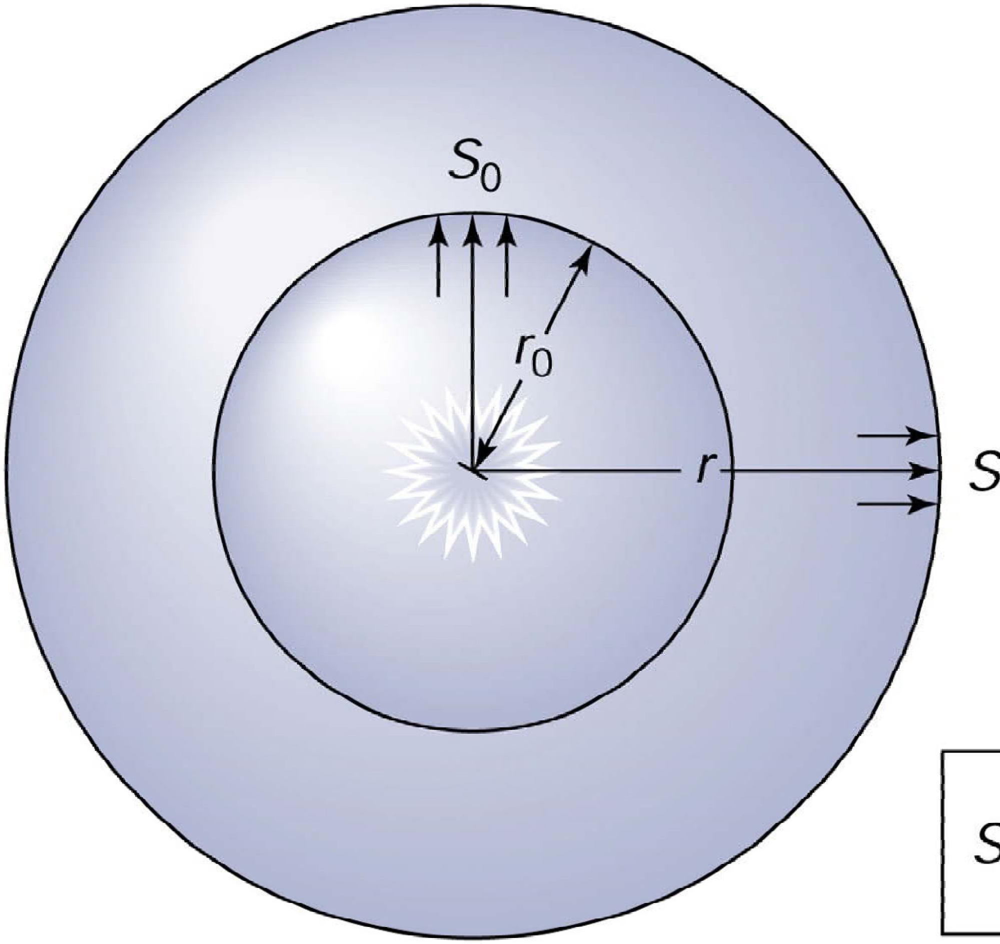
Laws that apply to solar radiation:
The Inverse Square Law



As you go away from the sun, the same energy is distributed over a larger area resulting in less energy per unit area.

Basic laws affecting the amount of radiation received from the sun:

The Inverse Square Law



$$S = S_0\left(\frac{r_0}{r}\right)^2$$

More detail on the Inverse square law:

Energy received from sun at a distance of r_0

Is inversely proportional to distance square:

$$S_0 \sim 1/r_0^2$$

Energy received from sun at a distance of r

Is inversely proportional to distance square:

$$S \sim 1/r^2$$

Divide the two by each other:

$$S/S_0 = 1/r^2/1/r_0^2 = r_0^2/r^2 = (r_0/r)^2$$

or (like on previous slide):

$$S = S_0 (r_0/r)^2$$

The ratio $(r_0/r)^2$ is denoted by ε_0

and can be computed as follows:

A simple way to determine the Earth – Sun distance Factor , ε_0

$$\varepsilon_0 = (r_0/r)^2 = 1.000110+0.034221\cos\Gamma+ 0.001280\sin\Gamma+0.000719\cos2\Gamma+ 0.000077\sin2\Gamma$$

Here Γ is in radians and known as the day angle and equals:

$$\Gamma = 2\pi\ (d_n-1)/365$$

d_n is the day number of the year ranging from 1 on January 1 to 365 on December 31.

For engineering application:

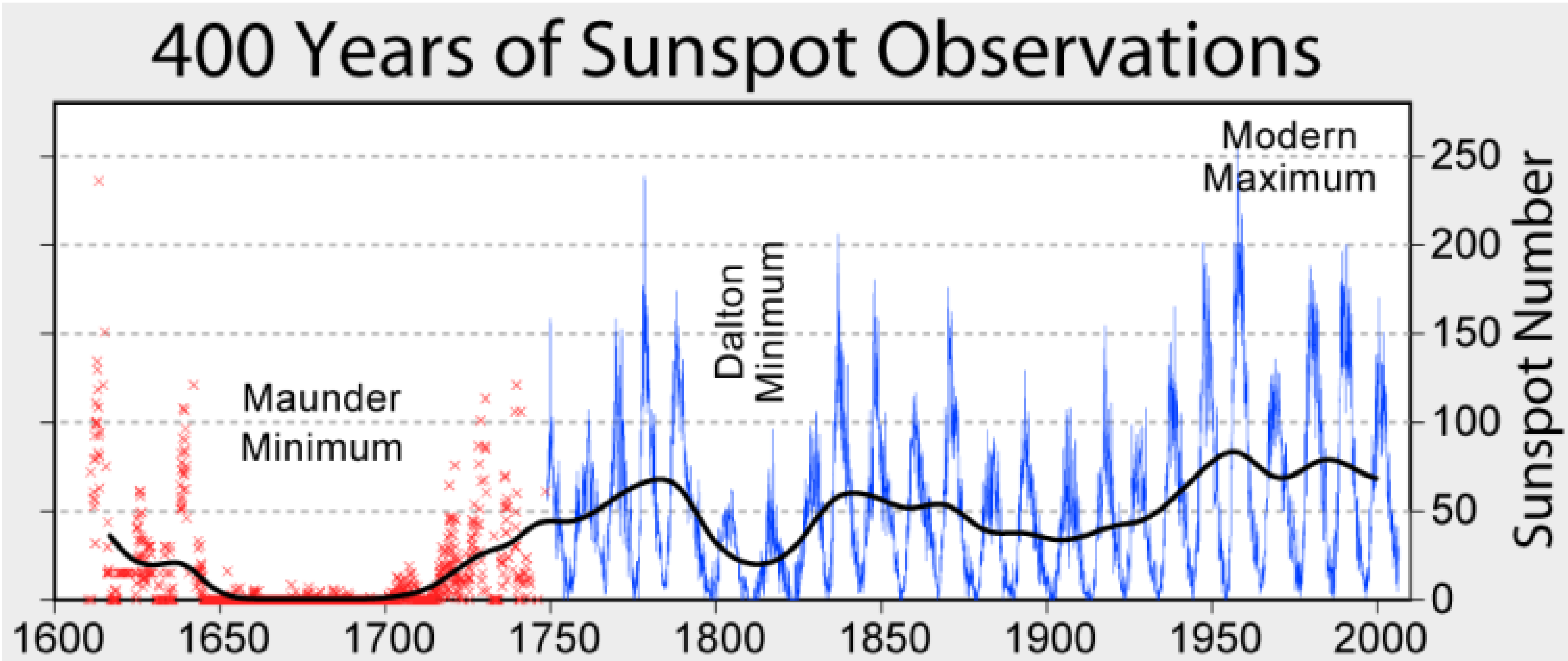
$$\varepsilon_0 = (r_0/r)2 = 1+0.033\cos[(2\Pi d_n/365)]$$

Reference Unit of Energy from the Sun

Solar Constant – S_0 is the irradiance of solar energy received on a surface exposed normal to sun's rays (the I_{0n} in previous slide) when the distance represents a mean value of the Earth-Sun distance and in absence of atmosphere

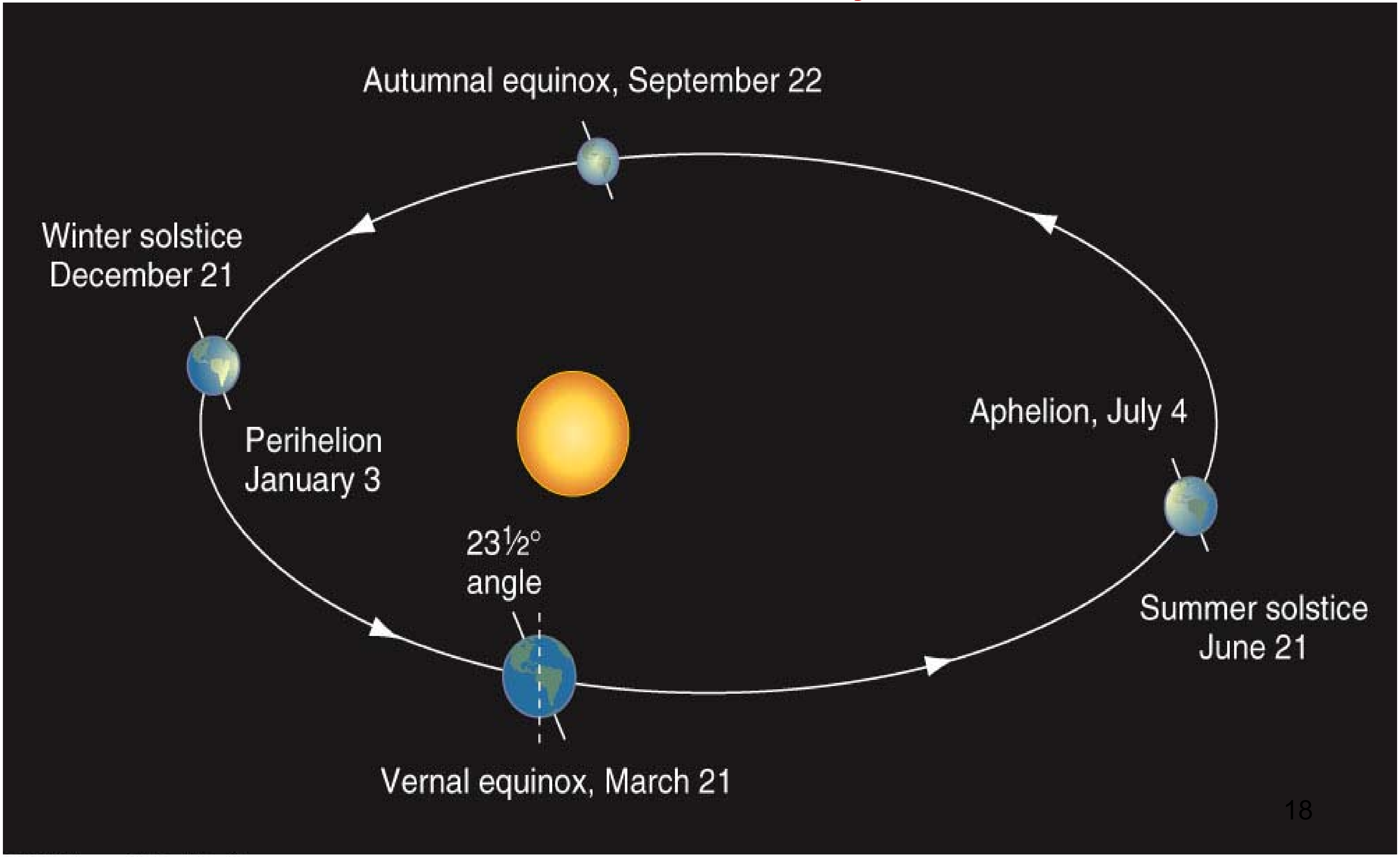
- S_0 = 1372 W/m^2
- Watts per square meter

Note: Read the posted paper on: Living with a variable sun.

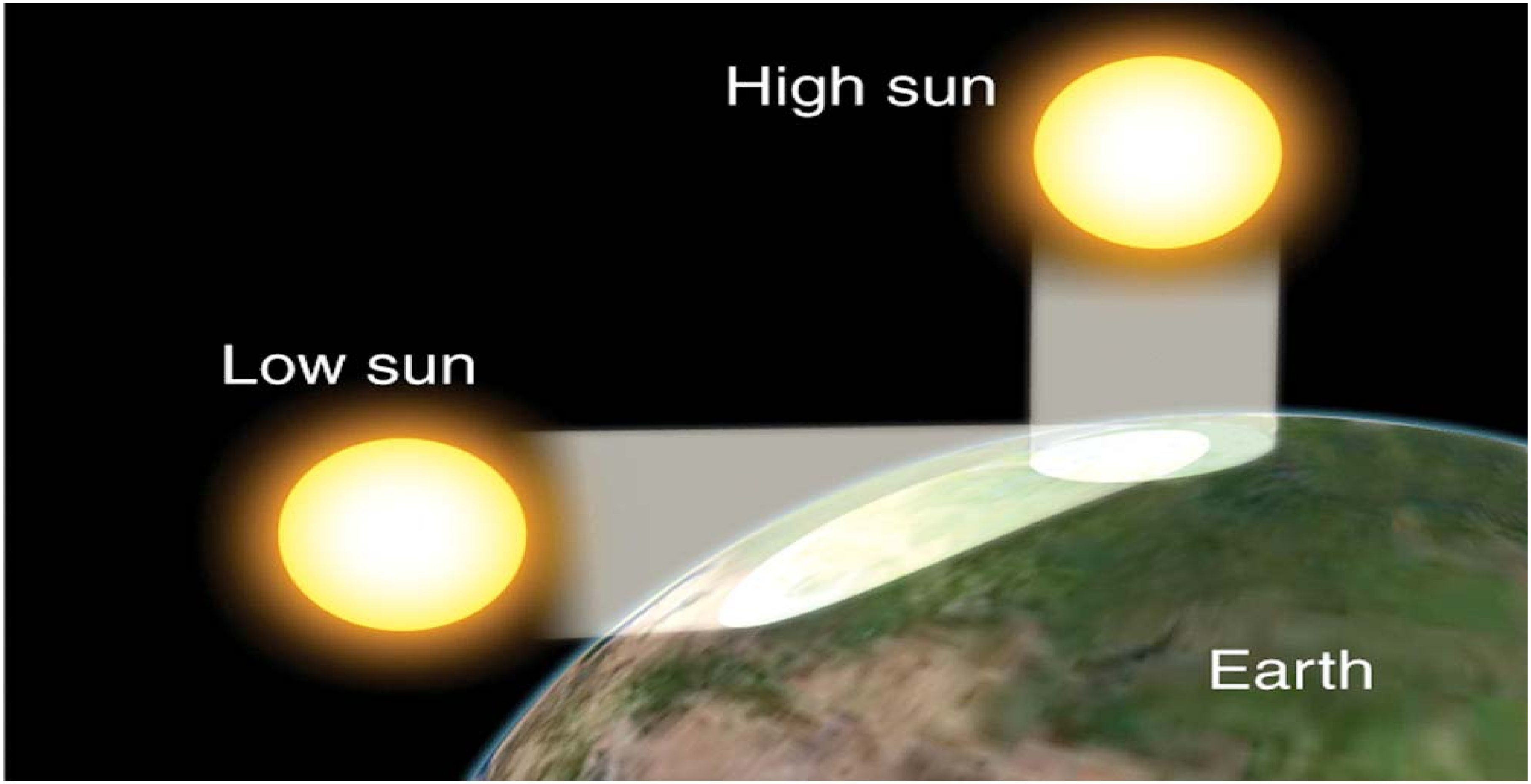


Information on sun spots and climate can be found in the classical paper::
The Maunder Minimum
John A. Eddy
Science 18 June 1976: 1189-1202

Earth closer to sun in winter; yet, more energy received in summer. Why?

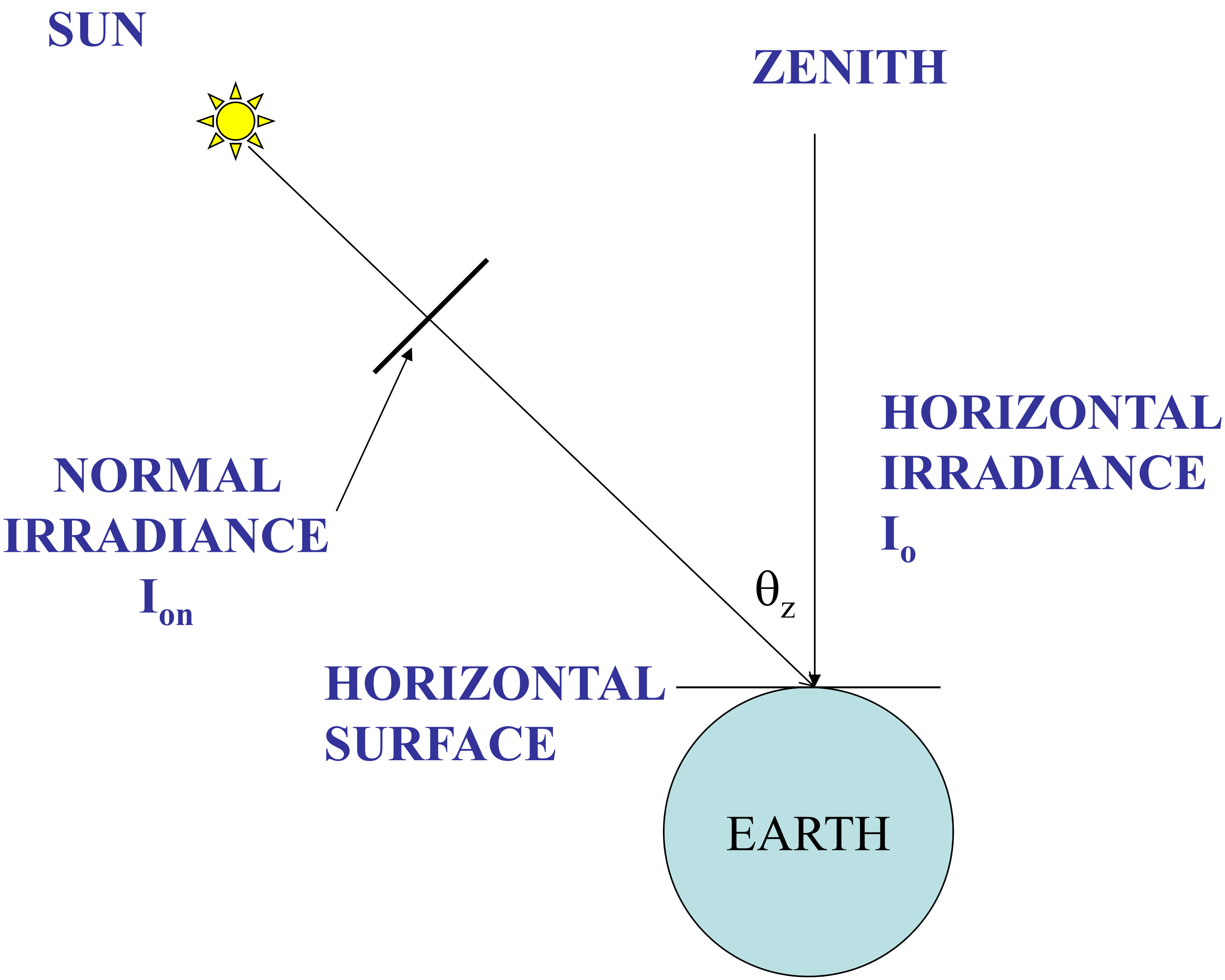


The Sun Elevation Law



When sun high in the sky, perpendicular to earth, energy distributed over smaller area. If sun low in the sky, same energy distributed over larger area.

Direct normal (I_{on}) and horizontal (I_o) irradiance



Combination of the two factors:

Simple statement

The irradiance over an area A depends on the angle between the overhead direction and the central ray to the sun and inversely to the distance from the sun

Mathematical statement

The irradiance over an area A is proportional to the cosine of the angle between the surface normal and the central ray and inversely to the distance from the sun

$$E = I_{on} \cos\theta / r^2$$

How to derive θ?

Why the Earth has seasons

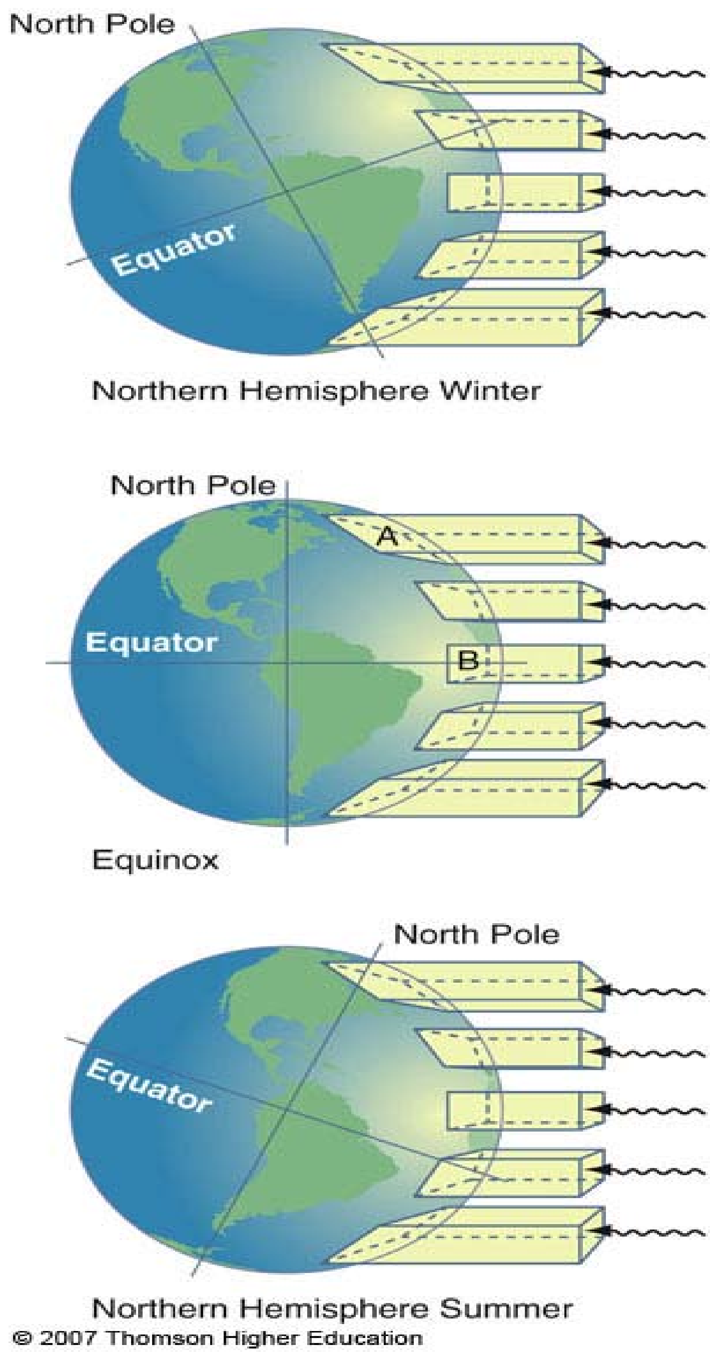
Some facts:

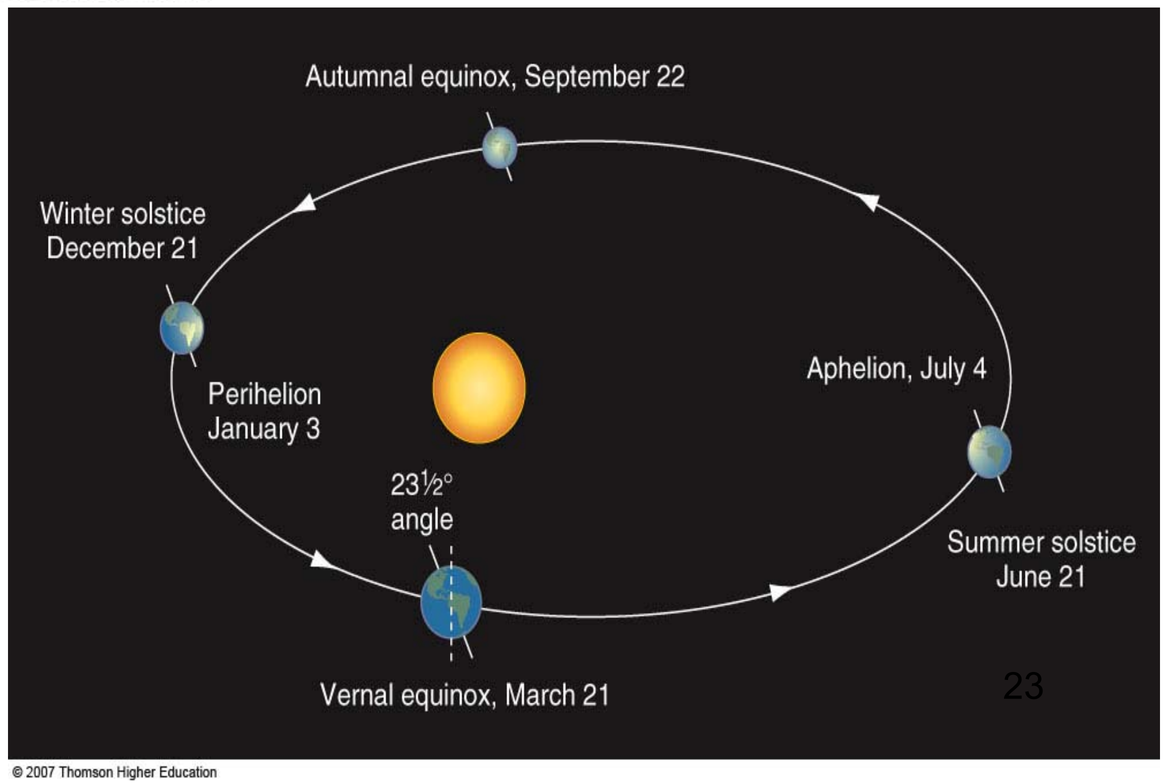
- Earth revolves in elliptical path around sun every 365 days.
- Earth rotates counterclockwise or eastward every 24 hours.
- Earth closest to Sun (147 million km) in January, farthest from Sun (152 million km) in July.

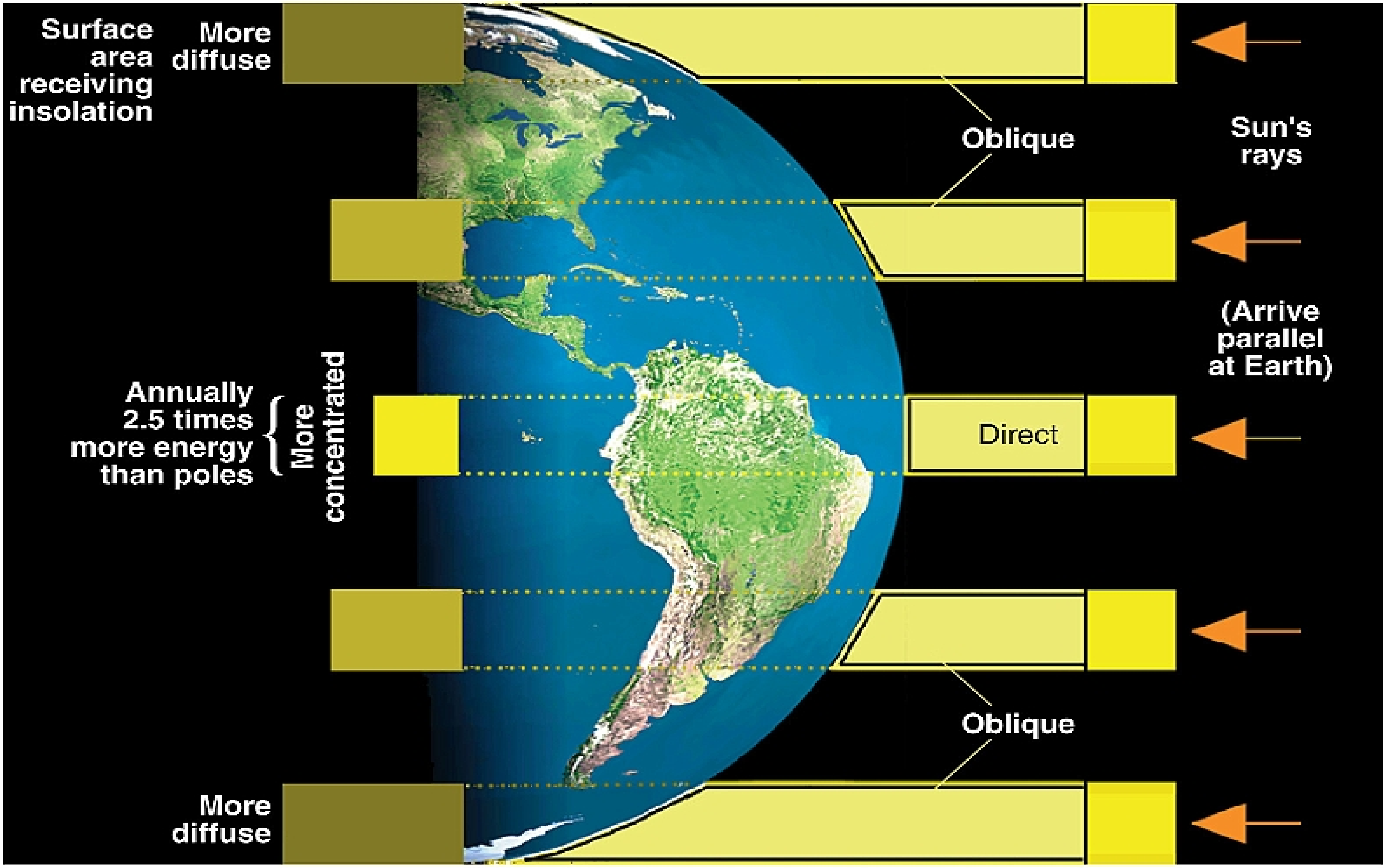
Factors that impacts seasons:

- ❑ Distance from sun
- ❑ Orientation

Seasons


North Pole
Equator
Northern Hemisphere Winter
North Pole
A
Equator
B
Equinox
The same amount of
light is distributed
over a larger area
in A than in B
North Pole
Equator
Northern Hemisphere Summer
© 2007 Thomson Higher Education


Autumnal equinox, September 22
Winter solstice
December 21
Perihelion
January 3
Aphelion, July 4
23½°
angle
Summer solstice
June 21
Vernal equinox, March 21
© 2007 Thomson Higher Education



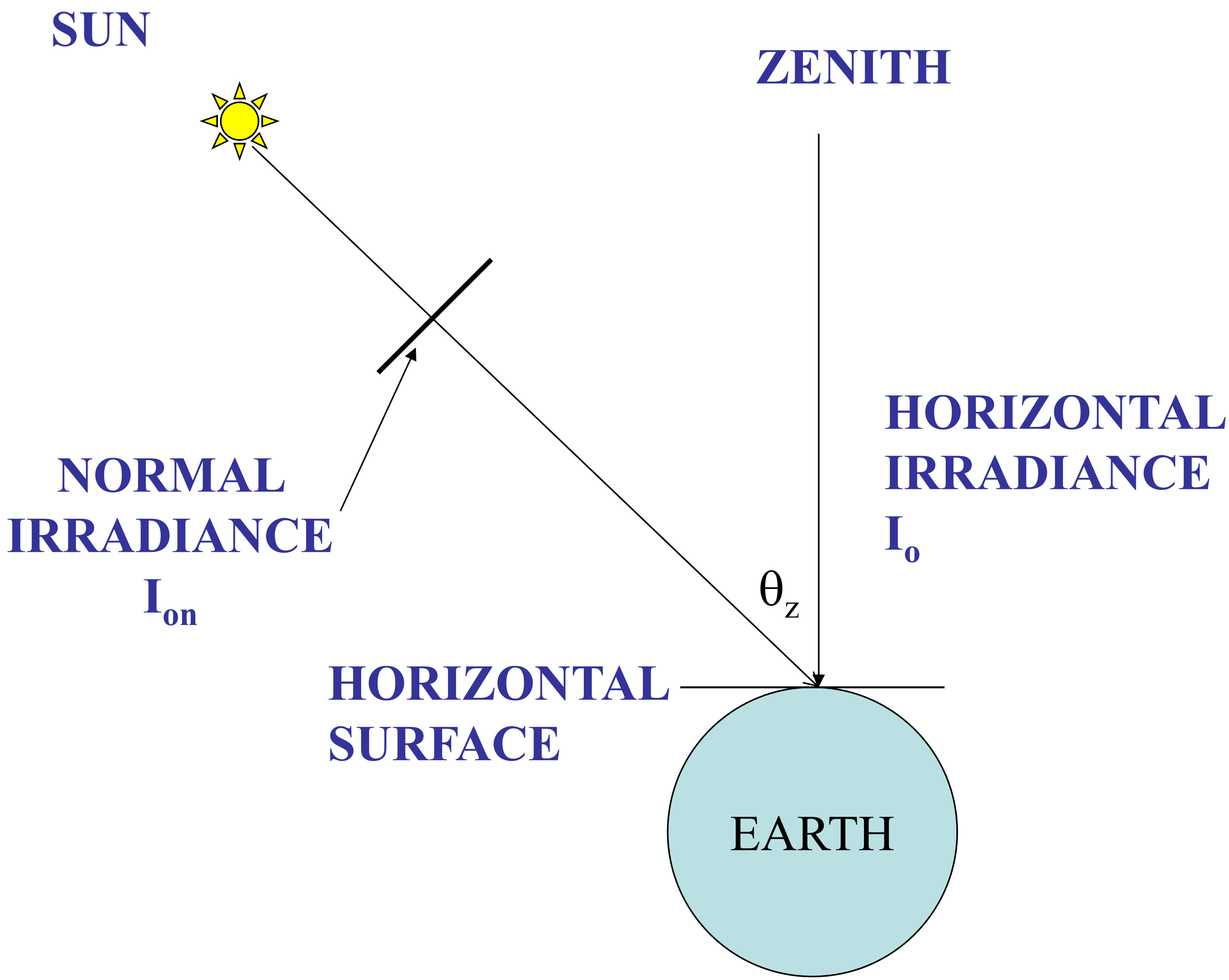
Direct radiation: no obstacles along the way; *Diffuse radiation*: after interaction with obstacles. Proportion of diffuse increases when sun’s ray traverses longer distance.

Dates for season changes

Seasons in the Northern Hemisphere

- Summer solstice: June 21, Sun directly above Tropic of Cancer, Northern Hemisphere days greater than 12 hours
- Winter solstice: December 21, Sun directly above Tropic of Capricorn, Northern Hemisphere days less than 12 hours
- Autumnal and Spring Equinox: September 22, March 20, Sun directly above Equator, all locations have a 12 hour day

How to determine sun elevation θ?



The solar zenith angle - θ_z

- Intuitively, this angle depends on where on earth we are (latitude), what is the time of the day (measured in hour angles) and the season of the year (declination). Namely, the following parameters:
- φ – latitude
- ω hour angle
- δ - declination

- Each will be discussed in detail.

How to compute the solar zenith angle

Based on spherical geometry, the following relationship between the relevant angles is derived:

- $\cos\theta_z = \sin(\delta)\sin(\varphi) + \cos(\delta)\cos(\varphi)\cos(\omega)$
- φ – latitude
- δ - declination
- ω hour angle
- Hour angle ω is the distance in angle units from the solar noon (one hour is 15 deg). So first we need to derive the solar time for the location under consideration.
- Solar time = standard time + E + 4 ($L_{st} - L_{loc}$)

- E - equation in time in minutes
- L_{st} - standard meridian for local time zone
- L_{loc} - longitude of location in degrees west

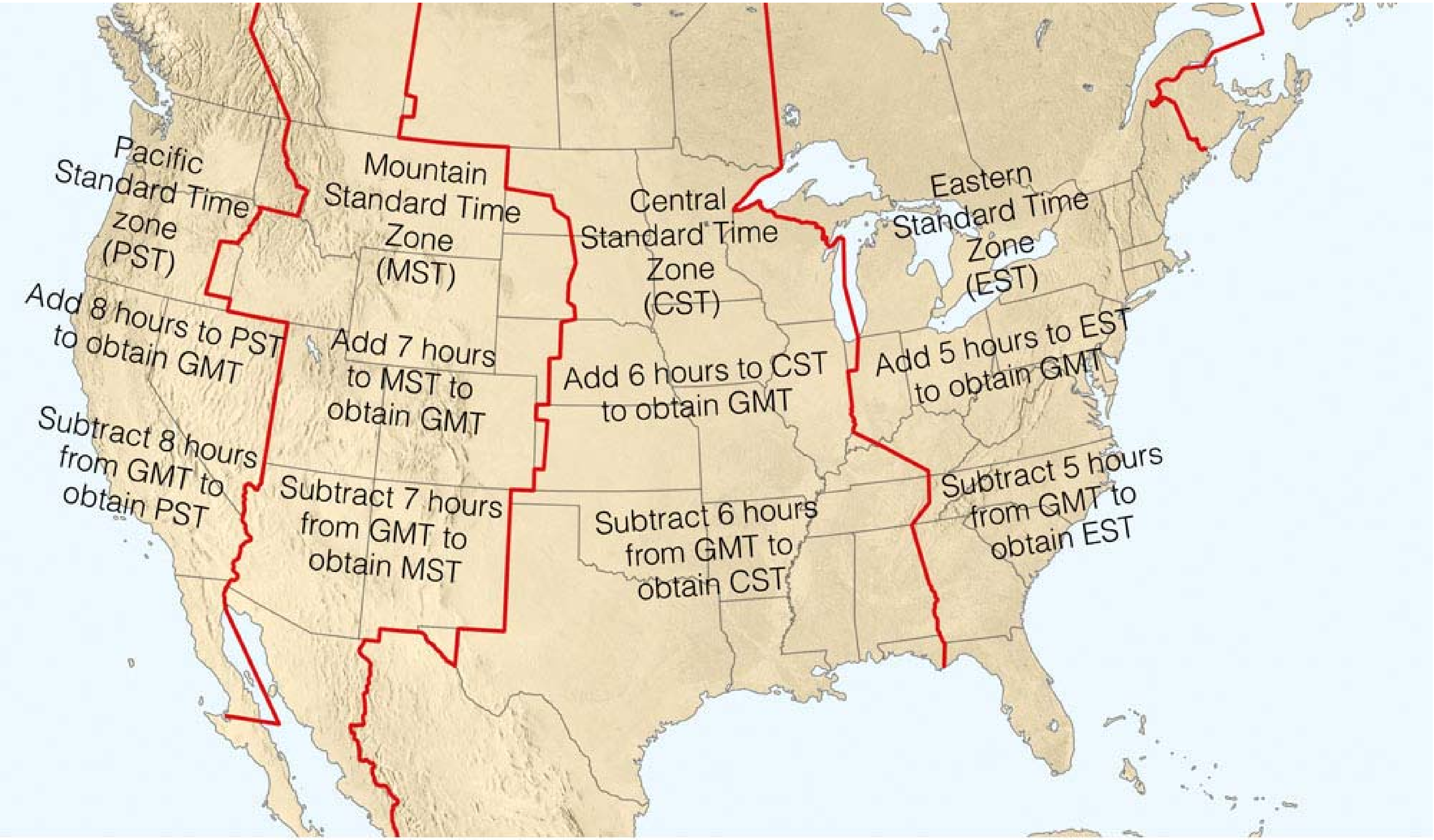
Solar Time

Time based on the *apparent angular motion of the sun across the sky*, with solar noon the time the sun crosses the meridian of the observer.

It is necessary to *convert* standard time to solar time by applying two corrections:

First-a constant correction for the difference in longitude between the observer's meridian and the meridian on which the local standard time is based. The sun takes 4 minutes to transverse 1^0 longitude.

Time zones



A **time zone** is a region on Earth that has a uniform standard time for legal, commercial, and social purposes.

- **Second** - *equation of time.* Takes into account the perturbation in the earth rate of rotation which affect the time the sun crosses the observer's meridian. Solar time is:
- Solar time = standard time + $4(L_{st} – L_{loc})$ + E
- L_{st} is the standard meridian for local time zone
- L_{loc} is the longitude of the location in degrees west
- $E = (0.000075+0.001868\cos\Gamma-0.032077\sin\Gamma-0.014615\cos 2\Gamma-0.04089\sin 2\Gamma)\ (229.18)$
- The number 229.18 converts radians into minutes. $\Gamma = 2\pi(d_n-1)/365$

Appendix

The following three slides are for the benefit of those not familiar with the concept of Greenwich Mean Time (GMT)

Greenwich Mean Time (GMT) was established in 1675 when the Royal Observatory was built as an aid to (English) mariners to determine longitude at sea, providing a standard reference time when each city in England kept a different local time.

Before 1972, all time zones were specified as an offset from Greenwich Mean Time (GMT), which was the mean solar time at the meridian passing through the Royal Observatory in Greenwich, London. Since 1972 all official time services have broadcast radio time signals synchronized to UTC, a form of atomic time that includes leap seconds to keep it within 0.9 seconds of this former GMT.

In the US the Standard Zone time was formally adopted by the U.S. Congress in the Standard Time Act of March 19, 1918.

Many countries now legally define their standard time relative to UTC, although some still legally refer to GMT, including the United Kingdom itself. UTC, also called Zulu time, is used everywhere on Earth by astronomers and others who need to state the time of an event unambiguously.

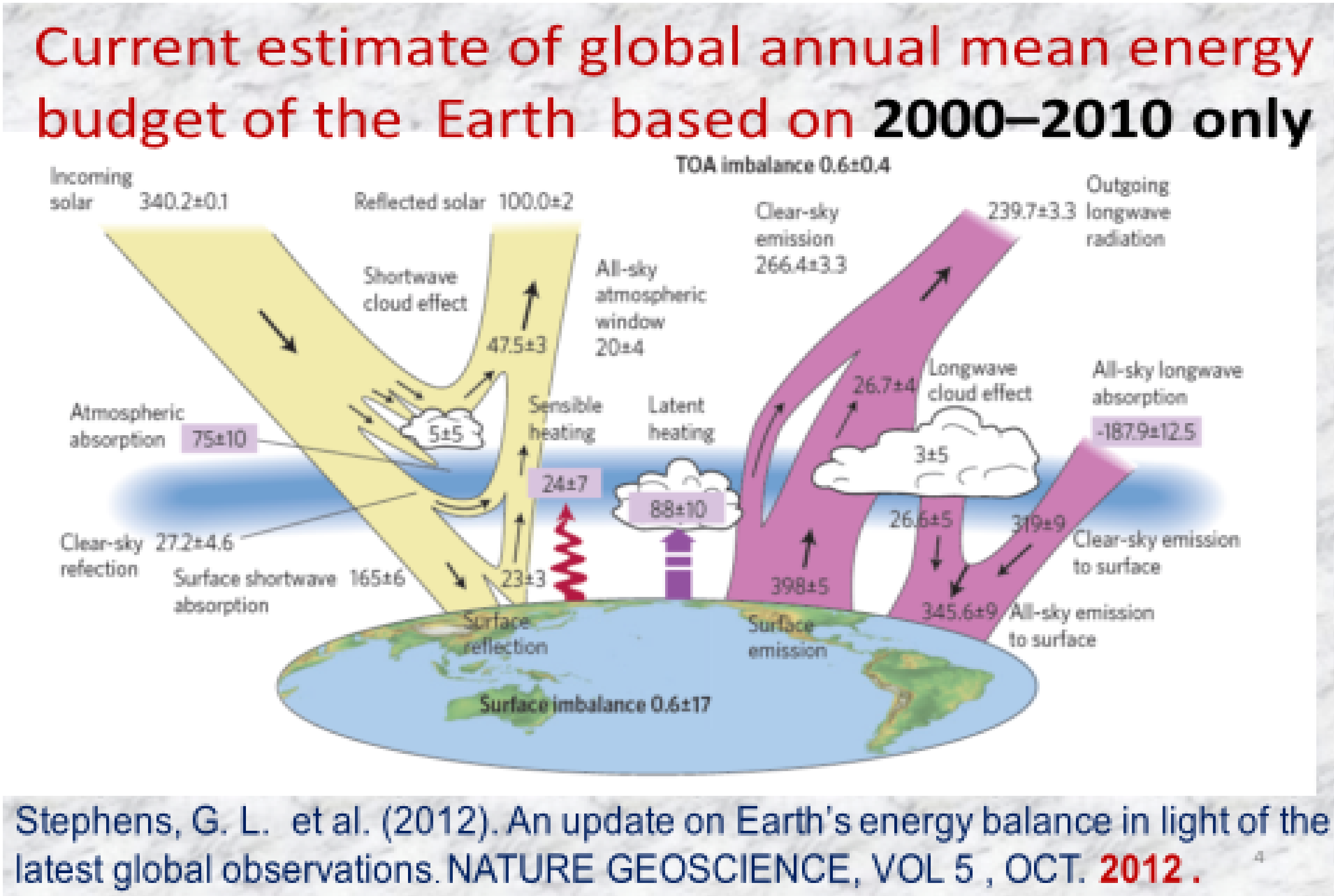
The Arizona time zone is the Mountain Standard Time (MST) zone. Other states included in this time zone are Utah, Colorado, New Mexico, Wyoming, Idaho and Montana.

The Mountain Standard Time zone is 7 hours behind UTC (Universal Time, Coordinated). Arizona does not observe Daylight Saving Time (mid-March through early November). During Daylight Saving Time (DST) most of Arizona is at the same time as California (Pacific Daylight Time or PDT).

Background information on computer project

1. Objective: provide guidance how to work with meteorological data in computer age.
2. Objective: provide a range of computational examples that will prepare you for conducting research and/or give you ideas what type of skills you need to enhance in the future.
3. Since the students have different computational backgrounds, you will be working in groups of 5-6 with at least one person in each group that has MATLAB experience.
4. Since one of the focus topics of the course is radiation and since information on radiative fluxes is available to us, the examples selected will use such information for illustration.
5. In class on T Sept. 15, 2015 you will be provided with MATLAB programs as well as data and shown what to do. You will be asked to repeat the exercises with independent data.
6. You are to complete the assignment within 2 weeks and submit the results as one report per group.
7. Students that want to do a computer based term project, will receive additional guidance.
8. Students that want to do a term paper, will be allowed to do so and will need to select the topic within the next two weeks. Group effort will be allowed.
9. Each project will also require a short presentation by each group at the end of the semester.

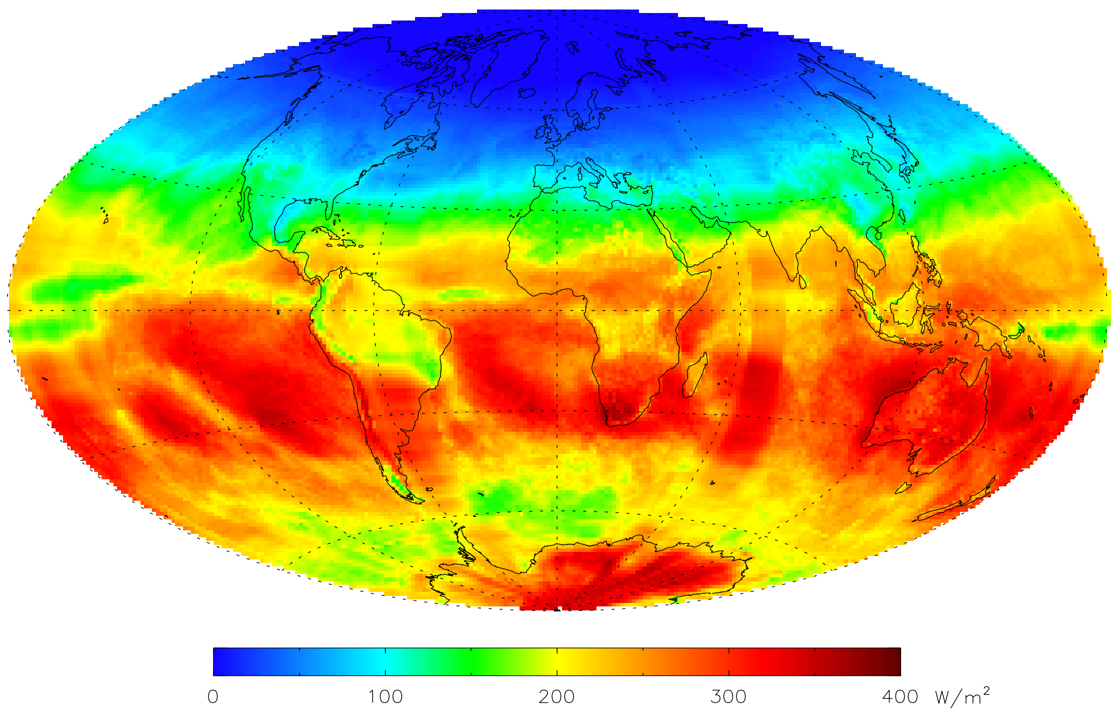
Context of computer training



We will discuss the above figure in class. You will learn how to display distributions of radiative fluxes and how to compute global (or zonal) averages

In our research, we synthesize SW and LW fluxes from satellites for climatic scale time periods. Figure below shows global distribution of shortwave fluxes.

UMD_SW



Relevant reference:

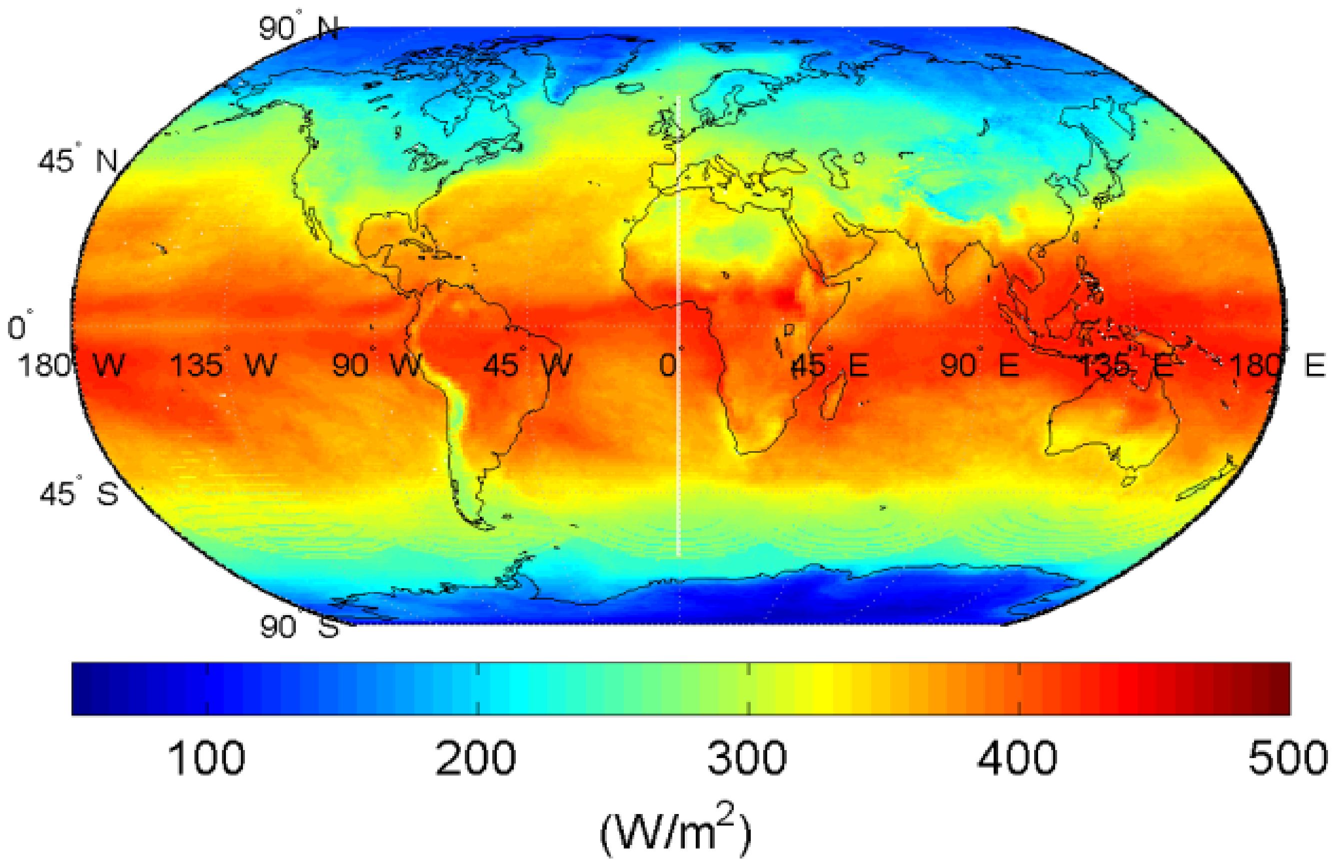
6 MAY 2005 VOL 308 SCIENCE www.sciencemag.org

Do Satellites Detect Trends in Surface Solar Radiation?

R. T. Pinker, B. Zhang, E. G. Dutton

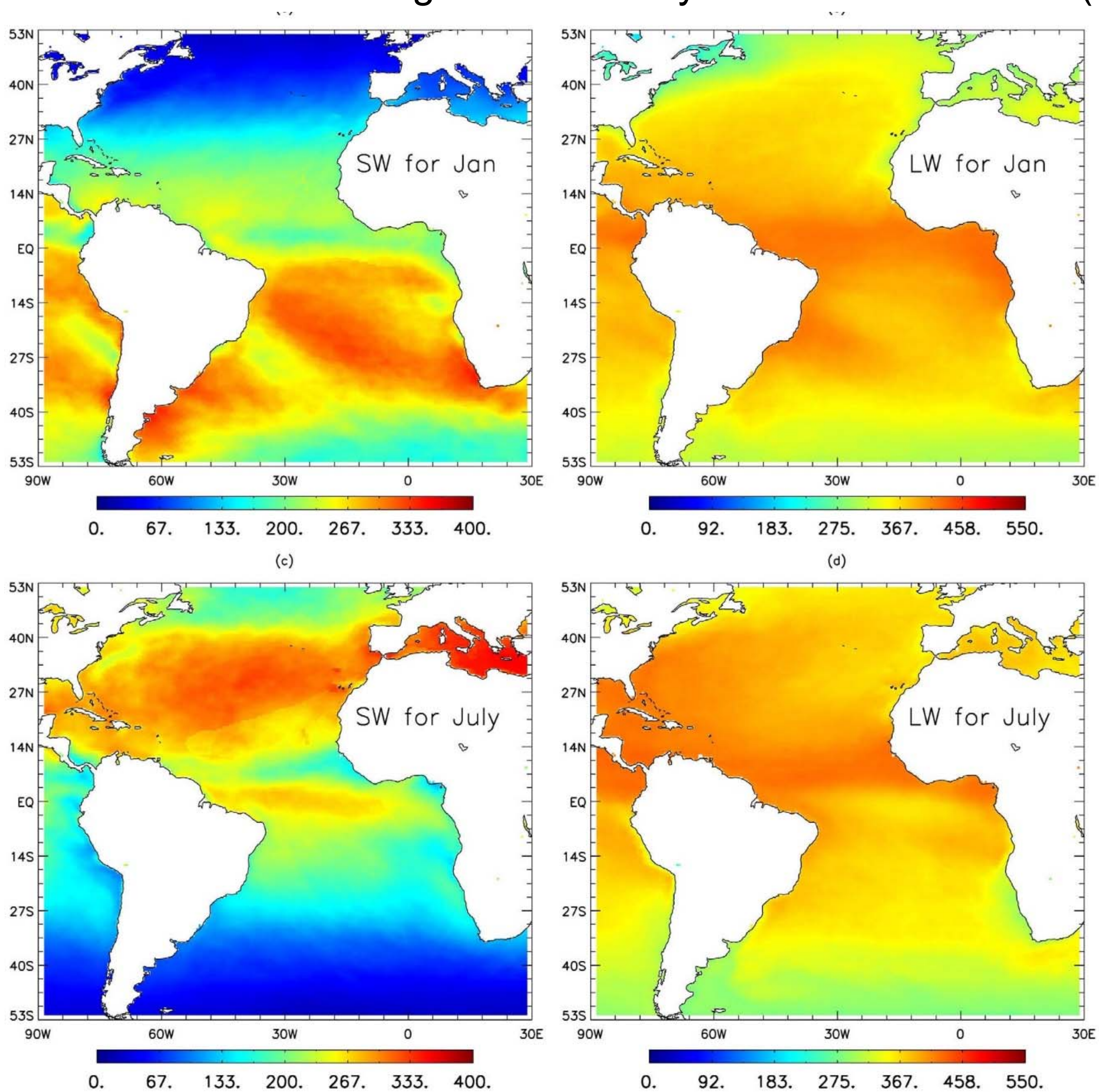
SW-shortwave radiation
LW-longwave radiation

UMD_LW

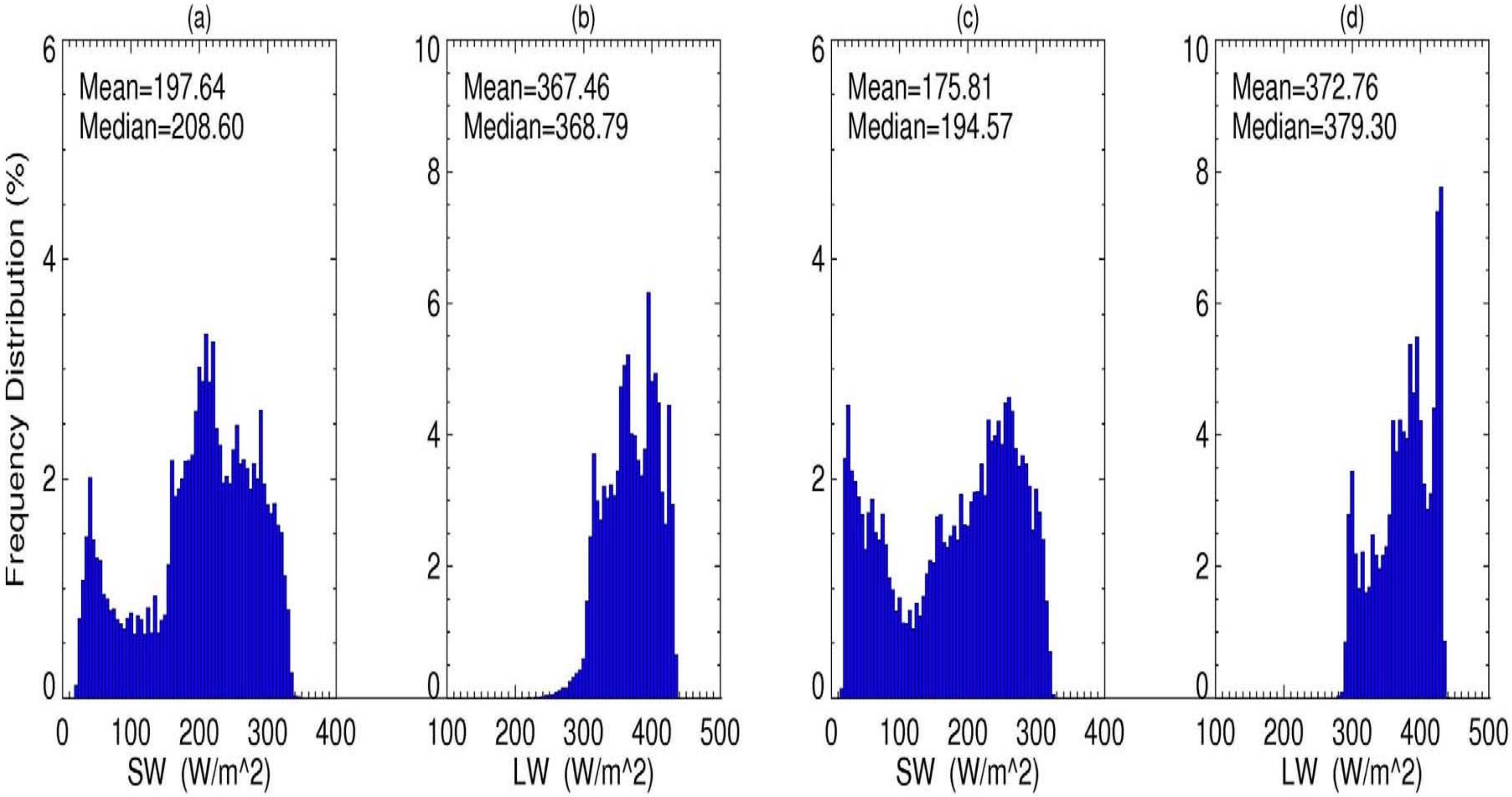


90° N
45° N
0°
45° S
90° S
180° W
135° W
90° W
45° W
0°
45° E
90° E
135° E
180° E
100
200
300
400
500
(W/m^2)

You will learn how to mask out regions in which you are not interested (like land in example below).



Mean surface radiative fluxes as derived from UMD_MODIS_SW and UMD_MO-DIS_LW in W/m^2 (a) downward SW for January, (b) downward LW January, (c) downward SW July, (d) downward LW July for 2003–2005.



Histograms (for previous figure) give the frequency distribution of the various values.

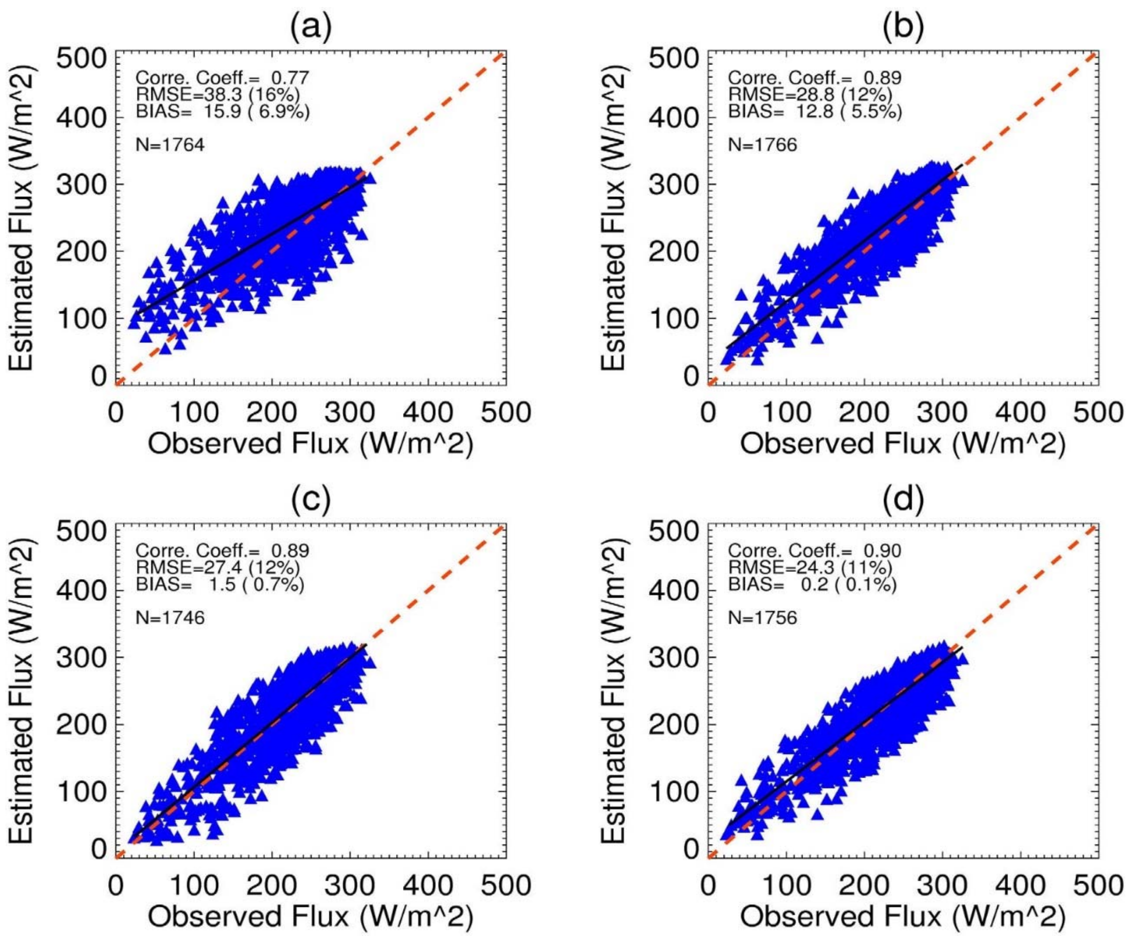
Figures in previous 2 slides come from:

JOURNAL OF GEOPHYSICAL RESEARCH: OCEANS, VOL. 119,
1–18, doi:10.1002/2013JC009386, 2014

Estimates of net heat fluxes over the Atlantic Ocean

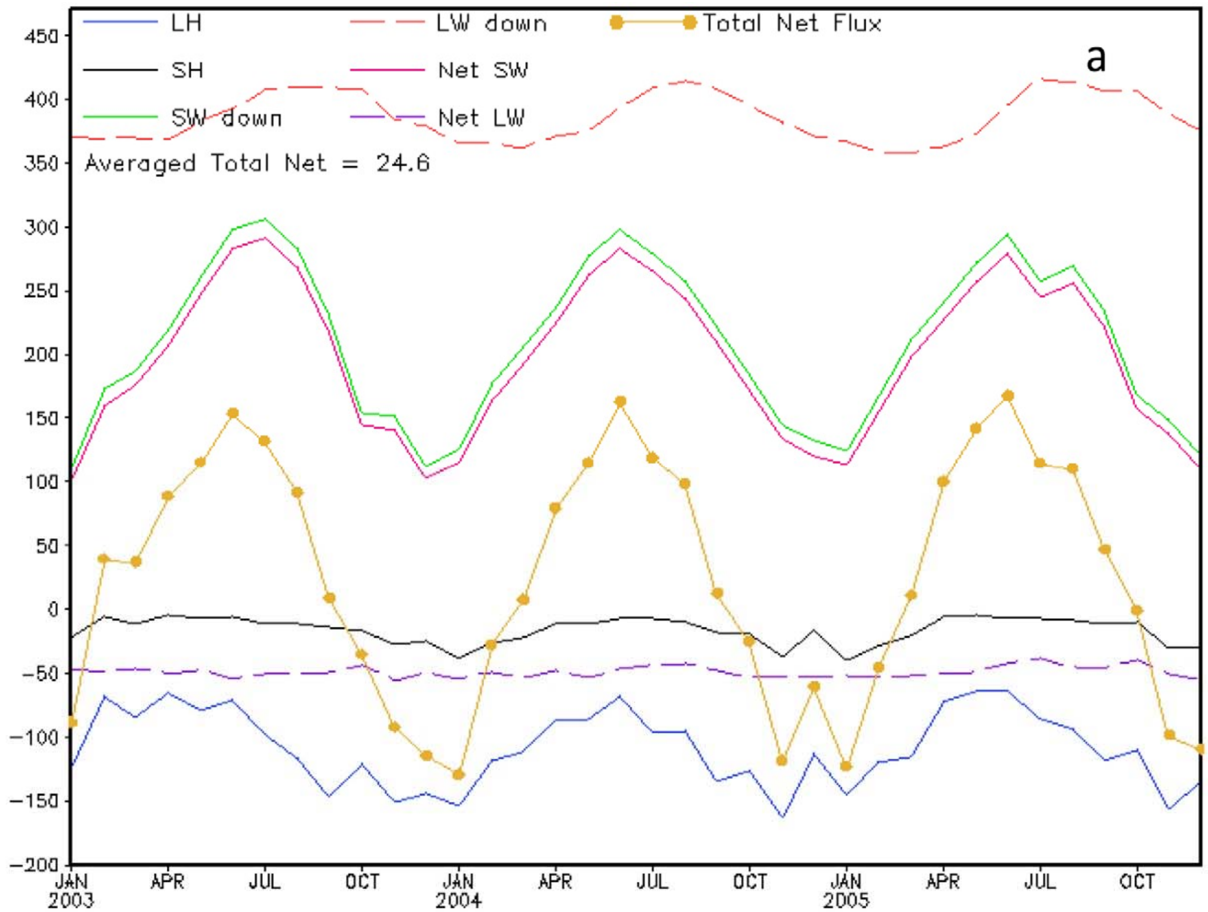
R. T. Pinker, A. Bentamy, K. B. Katsaros, Y. Ma, and C. Li

It is important to know how well estimates of various parameters compare to “ground truth”. You will learn how to plot scatter-plots.



Evaluation of daily surface SW radiative fluxes from satellite estimates against PIRATA buoys for 2004 for estimates from various sources from 1 January 2003 to 31 December 2005 (cases eliminated: 1.1%).

You will learn how to plot time series.



(a) Time series of turbulent flux components (LH and SH), SW# and LW# and net radiative fluxes (K_* and L_*) and total net fluxes (turbulent and radiative, Q_{net}) averaged for 2003–2005 at a: 30$_o$N and 60$_o$W.

Example of an article that can serve as a guideline for a computer based research project.

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE
10.1002/2014JD021730

Evaluation of AERONET precipitable water vapor versus microwave radiometry, GPS, and radiosondes at ARM sites

Daniel Pérez-Ramírez,
David N. Whiteman, Alexander Smirnov, Hassan Lyamani, Brent N. Holben, Rachel Pinker, Marcos Andrade, and Lucas Alados-Arboledas