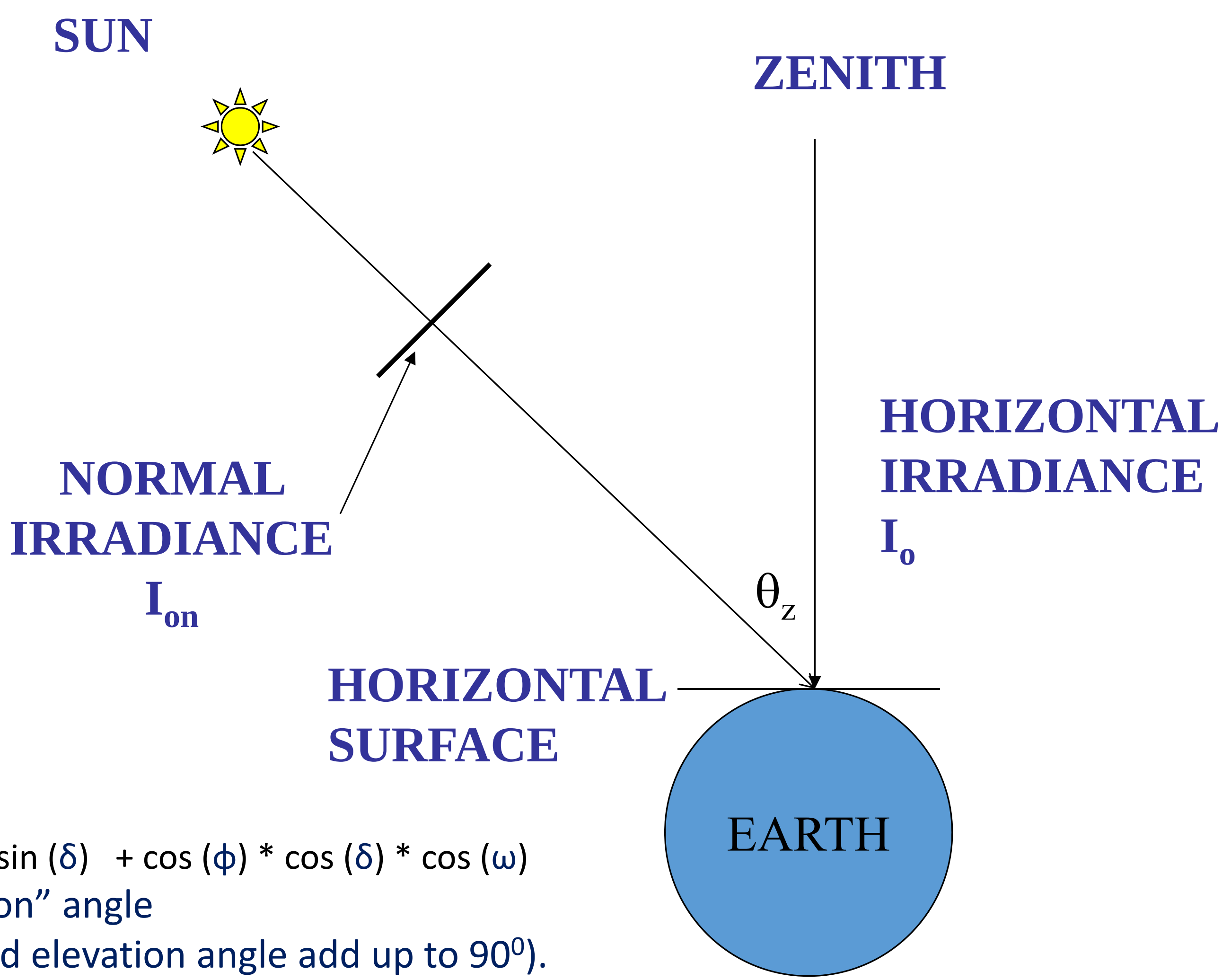
Joint Base Andrews Air Show on Saturday Sept 19, 2015 in Price George's County, MD.

Example on integrating information from class.

How to determine the length of a day?

First refresher on the concept of solar zenith angle and its determination.

How to determine sun elevation θ?



$\sin(h) = \sin(\phi) * \sin(\delta) + \cos(\phi) * \cos(\delta) * \cos(\omega)$

h is the “elevation” angle

(zenith angle and elevation angle add up to 90^0).

How to compute the solar zenith angle

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

- $\cos\theta_z = \sin(\delta)\sin(\phi) + \cos(\delta)\cos(\phi)\cos(\omega)$
- 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

Example:

Compute length of day for June 21, at lat of 48^0

June 21, δ =23.5° (from table next page or from formulas provided)

φ =48°

Substitute in:

$\cos\theta_z = \sin(\delta)\sin(\varphi) + \cos(\delta)\cos(\varphi)\cos(\omega)$

we get ω = 118.9°

corresponding to 7.93 hours (since ω =360° corresponds to 24 hours), one can determine to how many hours ω = 118.9° corresponds.

The Sun rises 7.93 hours before solar noon and sets 7.93 hours after, length of solar day is about 15.85 hours.

The equation for computing the solar zenith angle, for the case at hand, can be simplified as follows:

$$\cos\omega_\circ = -\tan\phi \times \tan\delta$$

where:

- $\omega_\circ$ is the hour angle at either sunrise (when *negative* value is taken) or sunset (when *positive* value is taken);
- ϕ is the latitude of the observer
- δ is the sun declination.

TABLE 2.4 Summary Solar Ephemeris[a]

		Declination		Equation of time				Declination		Equation of time	
Date		Deg	Min	Min	Sec	Date		Deg	Min	Min	Sec
Jan.	1	−23	4	− 3	14	Feb.	1	−17	19	−13	34
	5	22	42	5	6		5	16	10	14	2
	9	22	13	6	50		9	14	55	14	17
	13	21	37	8	27		13	13	37	14	20
	17	20	54	9	54		17	12	15	14	10
	21	20	5	11	10		21	10	50	13	50
	25	19	9	12	14		25	9	23	13	19
	29	18	8	13	5						
Mar.	1	− 7	53	−12	38	Apr.	1	+ 4	14	− 4	12
	5	6	21	11	48		5	5	46	3	1
	9	4	48	10	51		9	7	17	1	52
	13	3	14	9	49		13	8	46	− 0	47
	17	1	39	8	42		17	10	12	+ 0	13
	21	− 0	5	7	32		21	11	35	1	6
	25	+ 1	30	6	20		25	12	56	1	53
	29	3	4	5	7		29	14	13	2	33
May	1	+14	50	+ 2	50	June	1	+21	57	+ 2	27
	5	16	2	3	17		5	22	28	1	49
	9	17	9	3	35		9	22	52	1	6
	13	18	11	3	44		13	23	10	+ 0	18
	17	19	9	3	44		17	23	22	− 0	33
	21	20	2	3	34		21	23	27	1	25
	25	20	49	3	16		25	23	25	2	17
	29	21	30	2	51		29	23	17	3	7
July	1	+23	10	− 3	31	Aug.	1	+18	14	− 6	17
	5	22	52	4	16		5	17	12	5	59
	9	22	28	4	56		9	16	6	5	33
	13	21	57	5	30		13	14	55	4	57
	17	21	21	5	57		17	13	41	4	12
	21	20	38	6	15		21	12	23	3	19
	25	19	50	6	24		25	11	2	2	18
	29	18	57	6	23		29	9	39	1	10
Sep.	1	+ 8	35	− 0	15	Oct.	1	− 2	53	+10	1
	5	7	7	+ 1	2		5	4	26	11	17
	9	5	37	2	22		9	5	58	12	27
	13	4	6	3	45		13	7	29	13	30
	17	2	34	5	10		17	8	58	14	25
	21	+ 1	1	6	35		21	10	25	15	10
	25	− 0	32	8	0		25	11	50	15	46
	29	2	6	9	22		29	13	12	16	10
Nov.	1	−14	11	+16	21	Dec.	1	−21	41	+11	16
	5	15	27	16	23		5	22	16	9	43
	9	16	38	16	12		9	22	45	8	1
	13	17	45	15	47		13	23	6	6	12
	17	18	48	15	10		17	23	20	4	17
	21	19	45	14	18		21	23	26	2	19
	25	20	36	13	15		25	23	25	+ 0	20
	29	21	21	11	59		29	23	17	− 1	39

[a]Since each year is 365.25 days long, the precise value of declination varies from year to year. *The American Ephemeris and Nautical Almanac* published each year by the U.S. Government Printing Office contains precise values for each day of each year.

Solar Calculators

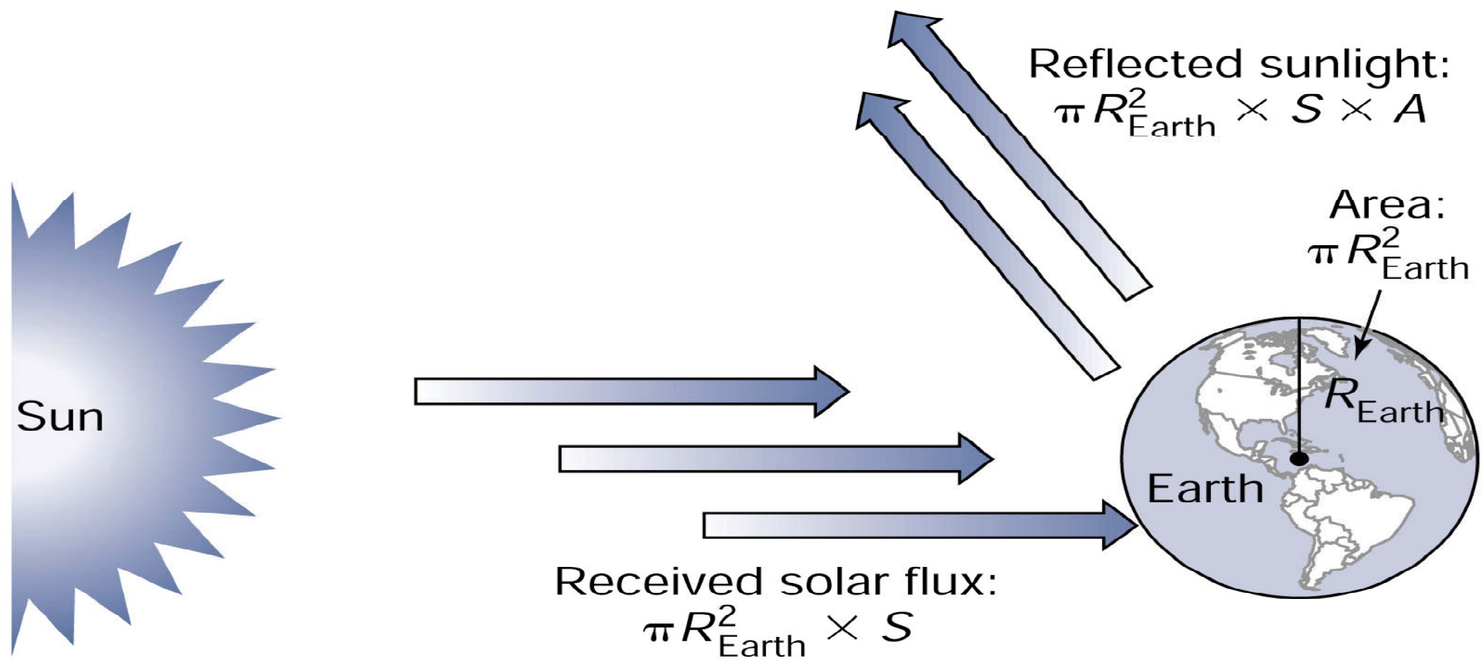
You can check results against the provided calculator.

- http://www.srrb.noaa.gov/surfrad/
- http://www.srrb.noaa.gov/highlights/sunrise/sunrise.html

AOSC400-2015
September 22, Lecture # 6

- Example how to compute length of day
- Reflection/albedo
- Refraction
- Relative optical path length
- Empirical expression for air mass
- Instruments to measure components of radiative fluxes
- Film clips on albedo issues

The Energy Source for Weather and Climate is Solar Radiation from the Sun



Of interest: what fraction of received goes back

The ratio between the r*eflected* part and the *incoming* part is called albedo (A)

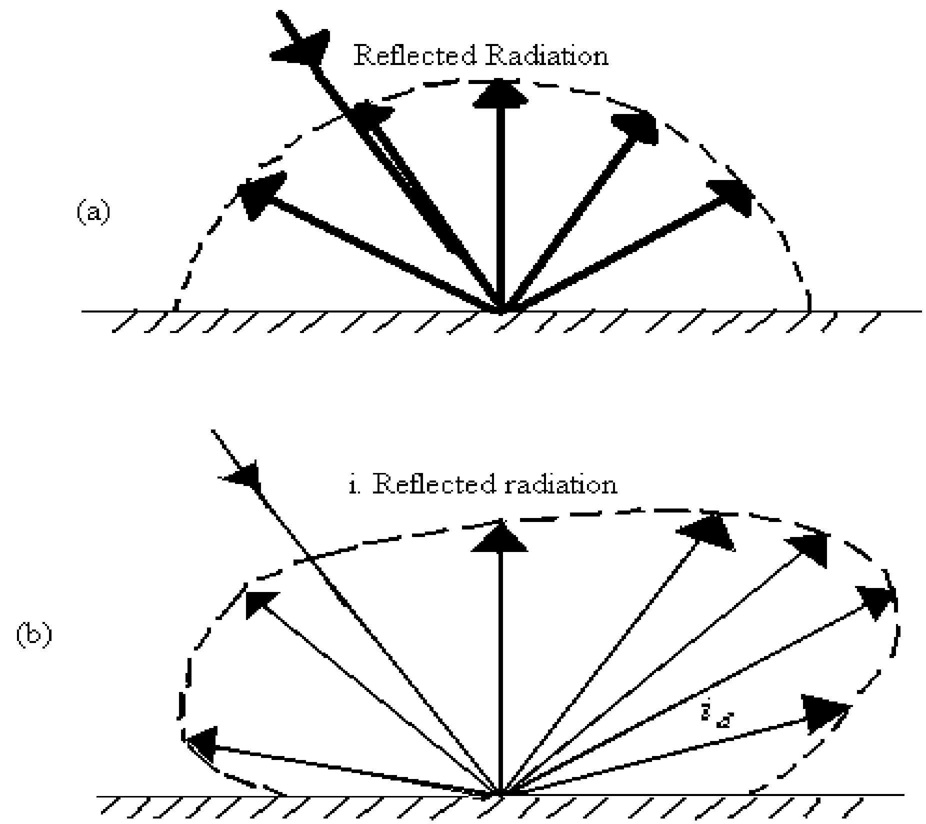
Earth's albedo that includes clouds can be estimated from satellites

The various elements that affect the Earth's albedo cover a large range of values:
Water: 10%
Snow: 80-90%
Desert sand: 40%

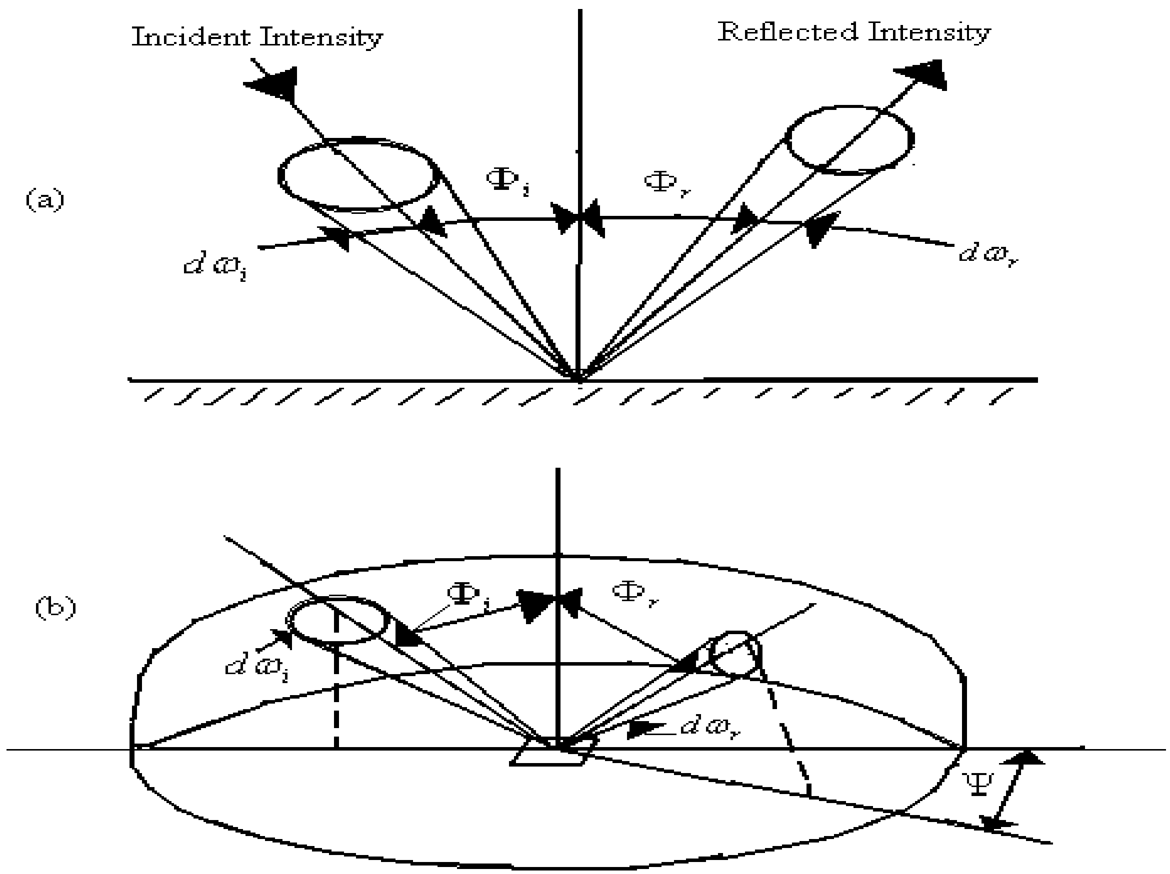
Earth average: 31%

Reflection is the change of direction of wave.

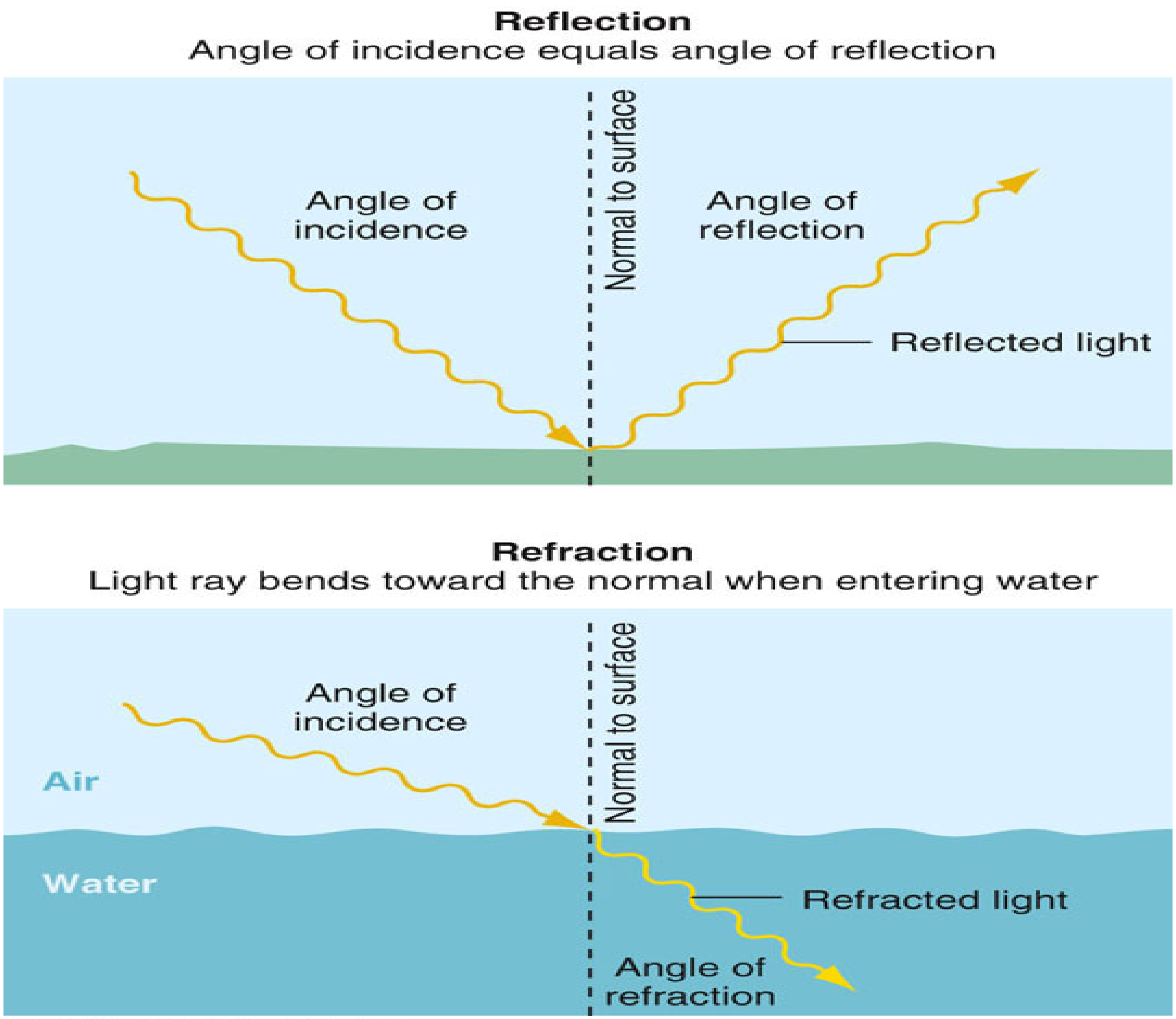
- It can be categorized as the specular reflection, bi-directionally specular reflection and diffuse reflection. It is one of the ways to lose information. It can be specified for a particular wavelength.
- Surface albedo generally refers to the total solar spectrum integrated over all angles.
- Albedo is used in climate to form surface energy budgets. For this purpose, the integrated albedo is needed.
- We have already discussed the concept of "planetary albedo", namely, from the earth-atmosphere system (next 2 slides).



(a) Ground reflection is even in all directions (isotropic); (b) can prefer certain directions (anisotropic)



Reflection can be only in one direction-specular; (a) perfectly specular (b) bidirectionally specular


Reflection
Angle of incidence equals angle of reflection
Angle of incidence
Normal to surface
Angle of reflection
Reflected light
Refraction
Light ray bends toward the normal when entering water
Angle of incidence
Normal to surface
Air
Water
Refracted light
Angle of refraction

Refraction

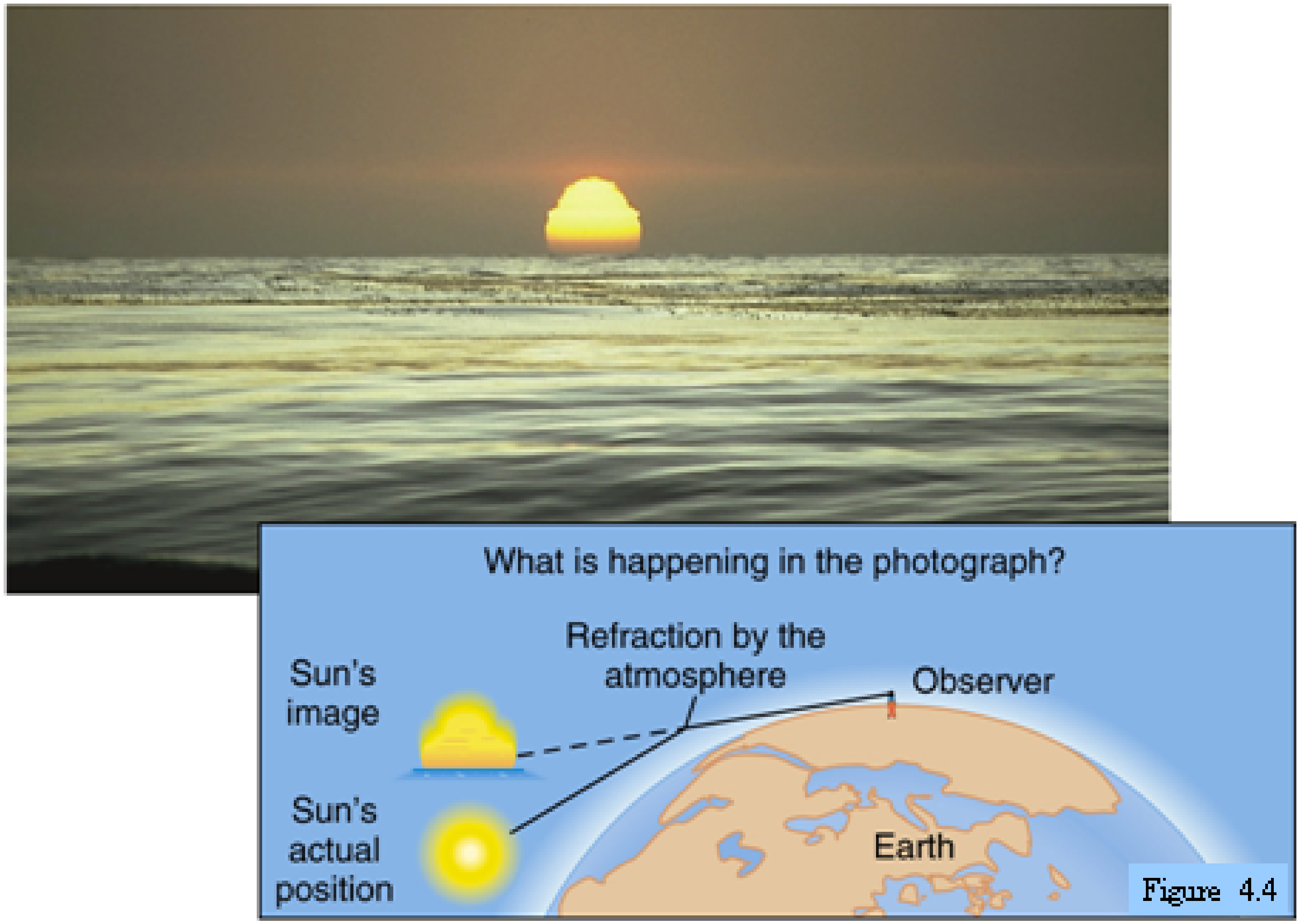
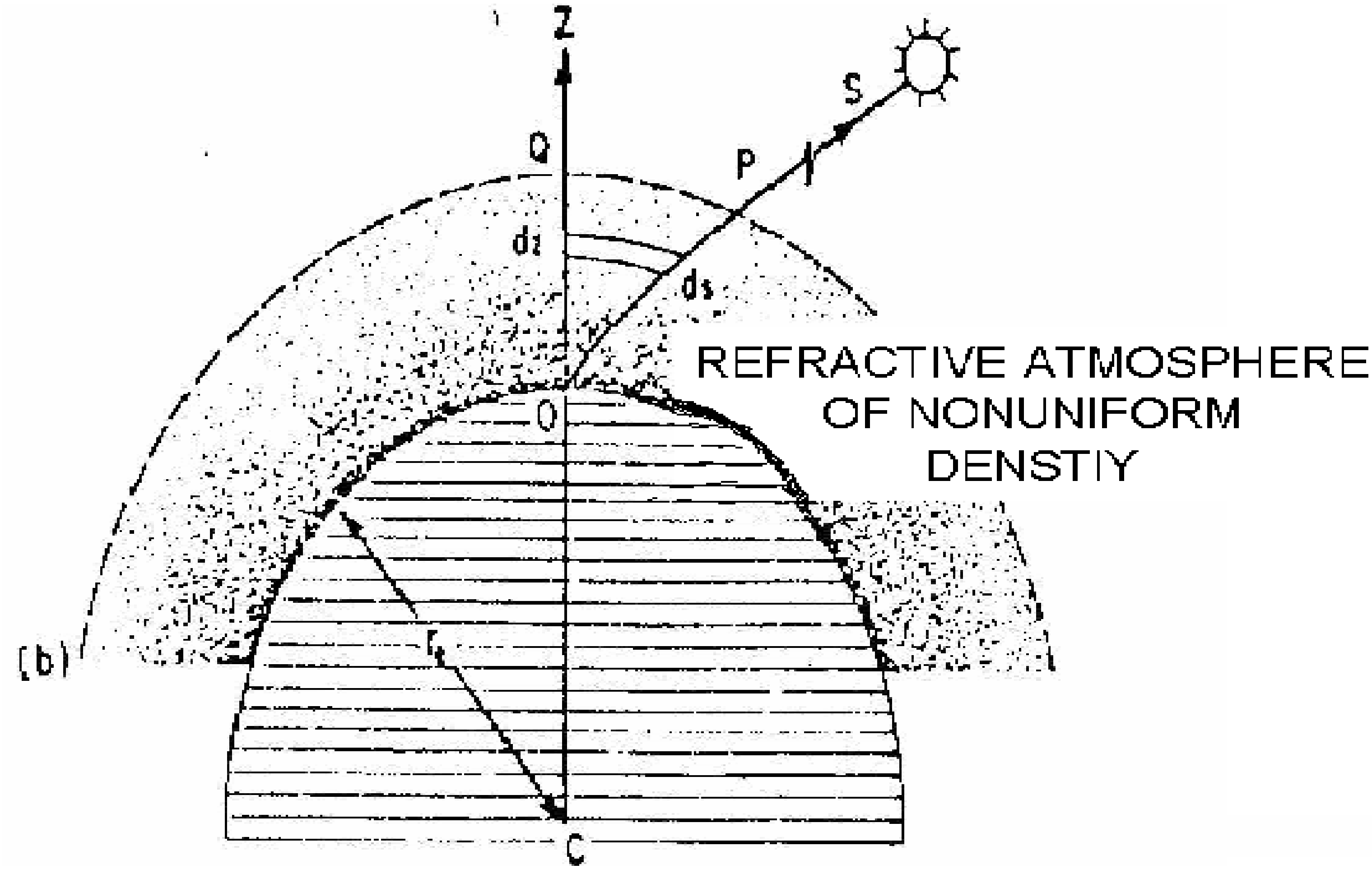


Figure 4.4



The trajectory of a solar ray through the earth's atmosphere in a refractive spherical atmosphere of variable density.

5.6 Relative Optical Path Length,[1] Relative Optical Mass m

When monochromatic radiation traverses a medium, each molecule (or particle, in the case of aerosols) attenuates energy. Attenuation is a function of the type and the number of molecules in the path of a solar ray. The number of molecules a solar ray strikes before reaching the ground is related to the distance traversed by the ray. Calculation of this distance, called the path length or slant path, is the subject of this section.

The density multiplied by the path length represents the mass of a substance in a column of unit cross section; this is also called the optical mass. The actual optical mass can be written

$$m_{act} = \int_0^\infty \rho \, ds, \qquad (5.6.1)$$

where ds is the geometrical path length of the light ray from the sun and ρ is the density of the substance at ds. The integration is along a path s (called the slant path) traversed by the beam of radiation from the upper limits of the atmosphere to the ground (or to a surface at a certain height). Since refraction is wavelength dependent, the slant path varies with wavelength, and consequently Eq. (5.6.1) applies to monochromatic radiation. When the sun is at its zenith, the light path goes straight downward and ds equals the height of an element dz, where z is the distance along the vertical direction. Thus the actual optical mass in the vertical direction is as follows:

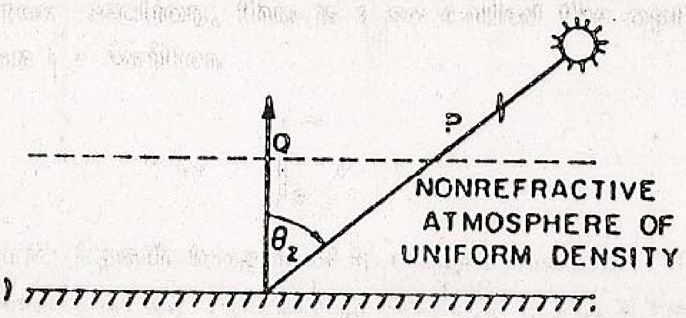
$$m_{act,v} = \int_0^\infty \rho \, dz. \tag{5.6.2}$$

This is the mass of a substance in a vertical column of unit cross section.

The relative optical mass m_r is defined as the ratio of the optical path along the oblique trajectory to the vertical path in the zenith direction. Thus

$$m_r = \int_0^\infty \rho \, ds \Big/ \int_0^\infty \rho \, dz. \tag{5.6.3}$$

In the foregoing, the word "air" has been deliberately avoided since attenuation of a solar beam takes place not only by dry air molecules, but also by water vapor and aerosols, etc. Therefore, Eq. (5.6.3) should be solved separately for each one of the attenuating components of the atmosphere. Optical masses for the various components are discussed below.



(a)

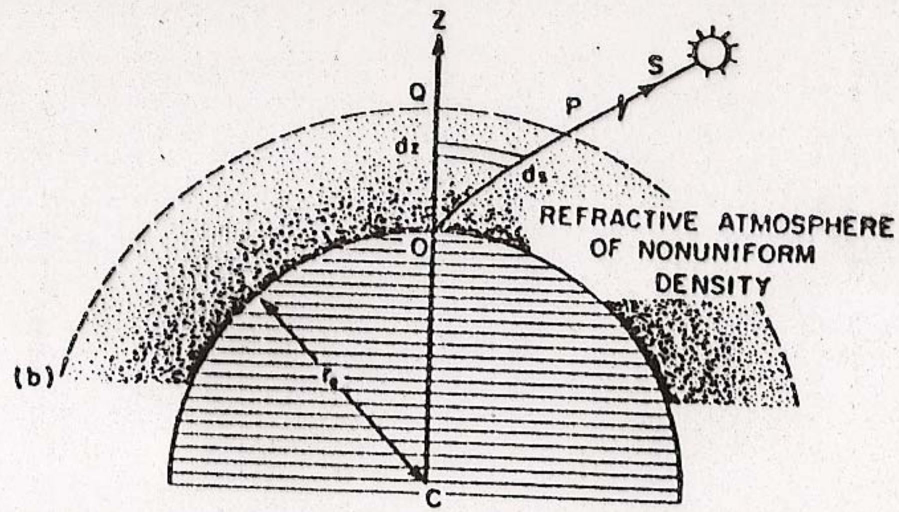


Figure 5.6.1 The trajectory of a solar ray through the earth's atmosphere. (a) Nonrefractive plane parallel atmosphere of uniform density. (b) Refractive spherical atmosphere of variable density.

Ignoring the earth's curvature and assuming that the atmosphere is nonrefractive and completely homogeneous (Fig. 5.6.1a), it can be seen that the relative optical mass applied to all the atmospheric constituents is

$$m'_r = \sec \theta_z . \tag{5.6.4}$$

The error in this equation, because the earth's curvature and the refraction of the real atmosphere have been neglected, is 0.25% at $\theta_z = 60°$, and increases to 10% at $\theta_z = 85°$.

However, density is actually variable with height. Furthermore, because of the curvature of the earth and refraction of the atmosphere, the slant path of the beam radiation will follow the path OP (Fig. 5.6.1b). Therefore Eq. (5.6.3) has to be evaluated through integration along the slant path and the zenith direction. The relative optical mass is obviously a function of the distribution, with height, of atmospheric density and refractive index: the relative mass from a mountain location will be different from that recorded at sea level.

Among the individual optical masses, we begin with that for clean dry air. Because ozone has a distinct concentration profile different from the rest of the air molecules, its relative optical mass will be treated separately from that of clean dry air.

Comparision of sec Z to Relative Optical Air Mass[27] as a Function of Zenith Angle

Z	sec Z	m
0	1.00	1.00
30	1.15	1.15
60	2.00	2.00
70	2.92	2.90
80	5.76	5.60
85	11.47	10.39
86	14.34	12.44
87	19.10	15.36
88	28.65	19.79
89	57.30	26.96
90	∞	39.70

Empirical expression for air mass suggested by Rosenberg (1966) is:

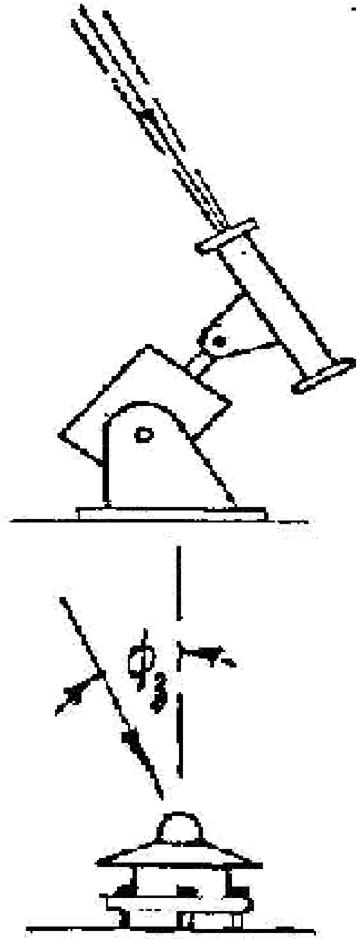
$$m(\theta_0) = (\cos \theta_0 + 0.025\, e^{-11 \cos \theta_0})^{-1}$$

The second term accounts for the curvature of e-a system.

Contributes significantly only for

$$\theta_0 > 80^0$$

Instruments used to measure radiation



- Normal incidence pyrheliometer (NIP) responds to direct and circumsolar components output =

$$I_{DN} + I_{CS}$$

- Pyranometer (horizontal mount) responds to direct + circumsolar + diffuse components output =

$$\left(I_{DN} + I_{CS}\right)\cos\varphi_z + I_{dH} = I$$

Measuring The Solar Radiation

Campbell-Stokes sunshine recorder

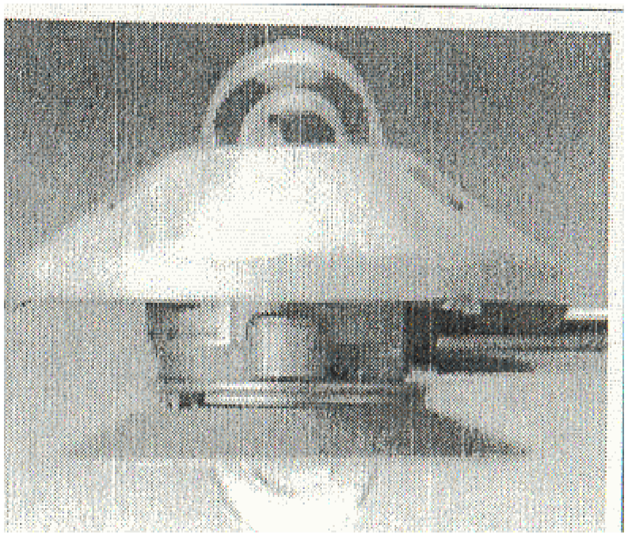
This type of equipment is the most widely found in traditional meteorological stations.

It distinguishes itself for its reliability, but only measures the number of insolation hours. To determine the solar radiation based on the number of hours of insolation, the Angström method is used.

Pyranometer

This is the most widely-used equipment to measure global solar radiation.

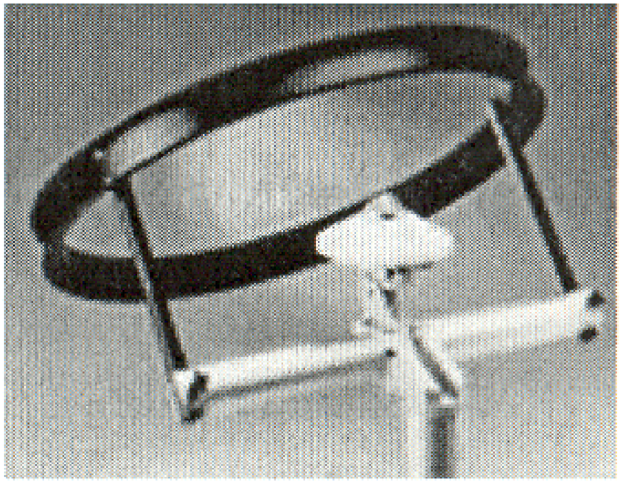
- There are different types of pyranometers ; the most common those with sensors composed of thermopiles or photovoltaic cells.
- The photovoltaic sensors are in general much less precise than the thermopiles due to the fact that the spectral response is not the same in the entire solar radiation spectrum.



Shaded pyranometer

Used to measure diffuse solar radiation.

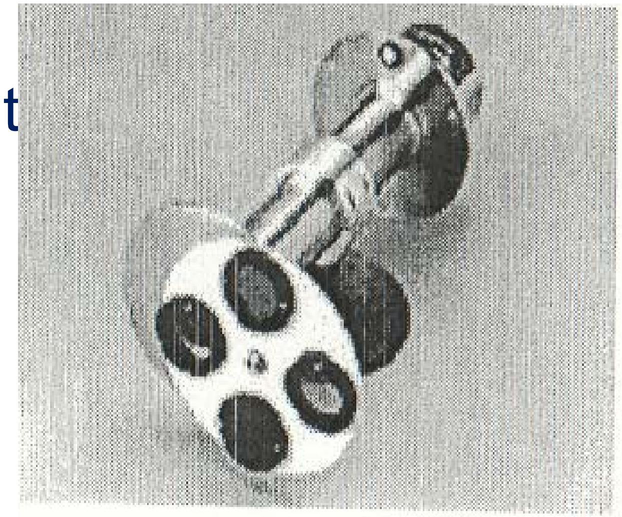
It needs a shading device so that the sensor cannot "see" the sun, thus allowing, in this way, that the radiation which comes directly from the sun not be measured.



Pyranometer With Shading Disc

- More expensive solution for diffuse solar radiation measurement.
- Measured data do not require correction, because the disc obstructs only the path of direct radiation.
- On the other hand, requires a sun-tracking device, which can be one or two axis.

Pyrheliometer



This equipment is used to measure direct solar radiation. It works in a similar way as to the pyranometer, but a tube only allows that the direct solar radiation reaches the sensor.

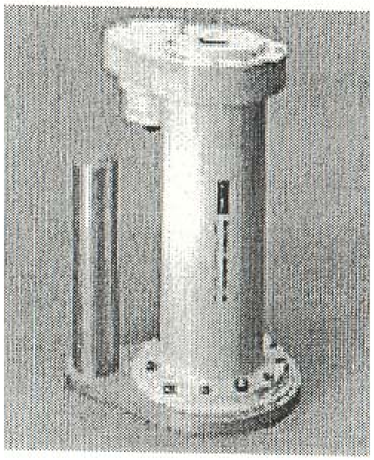
Since the position of the sun changes during the day, it is necessary to have a device, which does the sun-tracking, that is, it always needs to be aligned with the sun.

The pyrheliometer is also utilized as a calibration reference of solar radiation sensors.

Angström Compensation Pyrheliometer

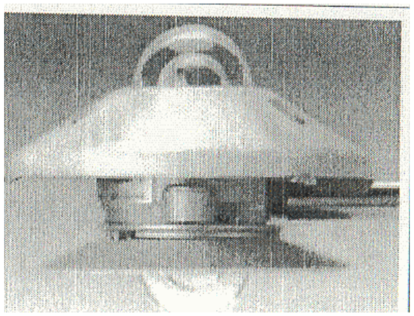
First instrument for precise direct solar radiation measurements

(end of XIX century).



Pyrgeometer

- Pyrgeometer is used to measure long-wave radiation.
- It is utilized with or without shading to block the direct solar radiation.
- The protecting dome has filters to avoid the entrance of radiation of other wavelengths.



Components of radiation

Terms		Descriptions
Short-wave radiation (solar radiation)		radiation of wavelength <0.2-5μm
Long-wave radiation (terrestrial radiation)		radiation of wavelength >2.5μm
Direct solar radiation		Solar radiation coming from the solid angle of the sun’s disc on a surface perpendicular the axis of the solid angle.
Diffuse solar radiation (sky radiation)		downward solar radiation as received on a horizontal surface from a solid angle of 2π with the exception of the solid angle subtended by the sun’s disc

(Continued)

Global solar radiation		downward direct and diffuse radiation as received on a horizontal surface from a solid angle 2π
Vertical component of direct solar radiation		direct radiation as received by horizontal surface
Atmospheric radiation		radiation emitted by the atmosphere, and upward terrestrial radiation which includes both atmosphere and surface radiation
Net radiation		net of the upward and downward components of both short and long wave radiation

Albedometer

- Albedo is the measurement which quantifies how much the medium (vegetation, buildings, mountains, soil, snow, etc.) reflects solar radiation that falls on it.
- A value is calculated by dividing the total solar radiation reflected by the medium by the global solar radiation incident at the location.
- To assure a more precise measurement, it is generally installed several meters above the surface.
- http://www.youtube.com/watch?v=9UJKVa2ClCU
- https://www.youtube.com/watch?v=QgzggbEQ2MY