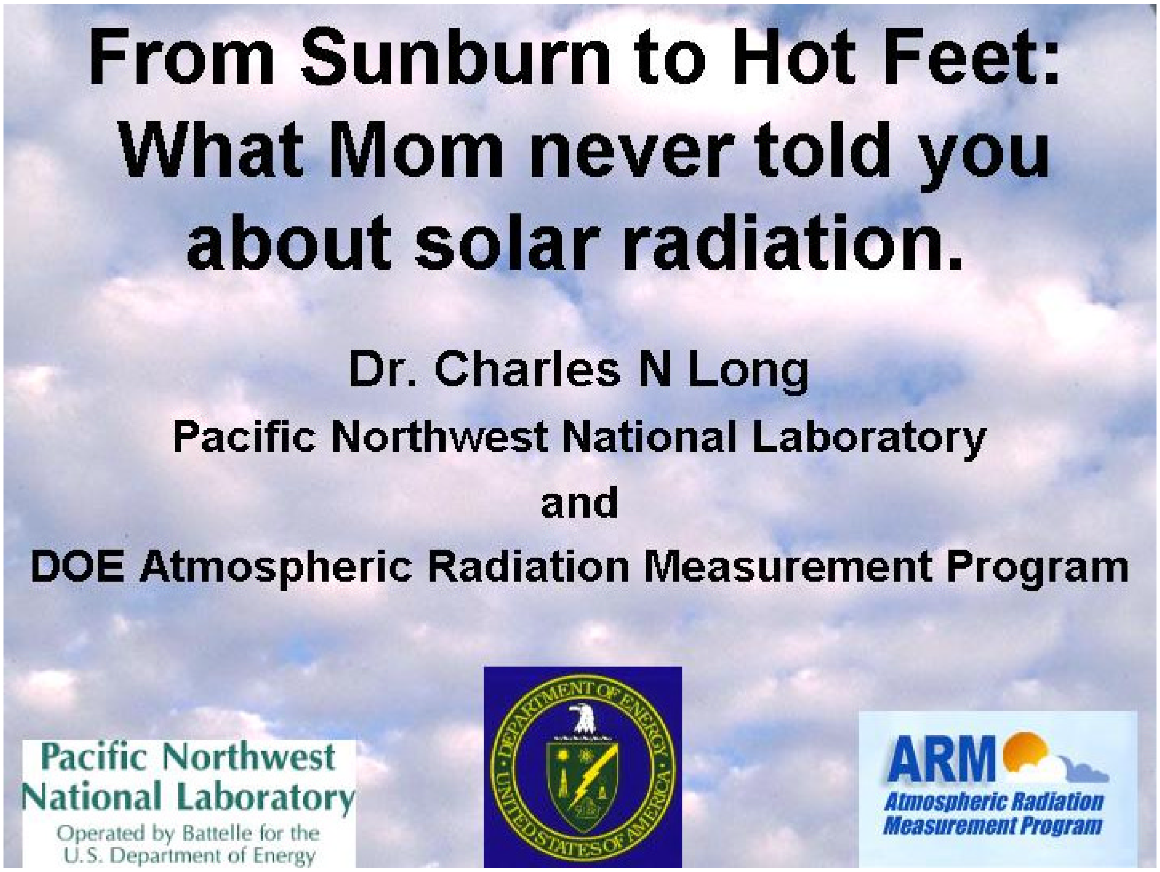
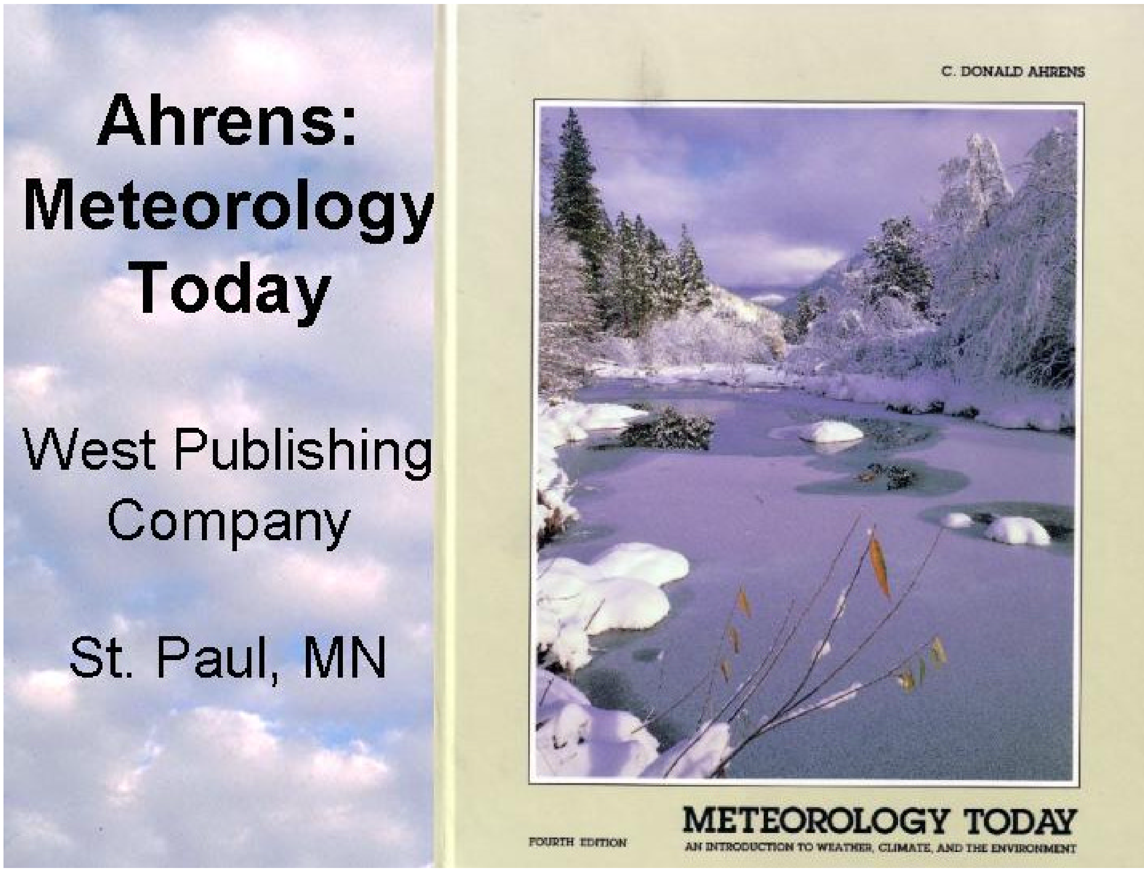
Slide 1



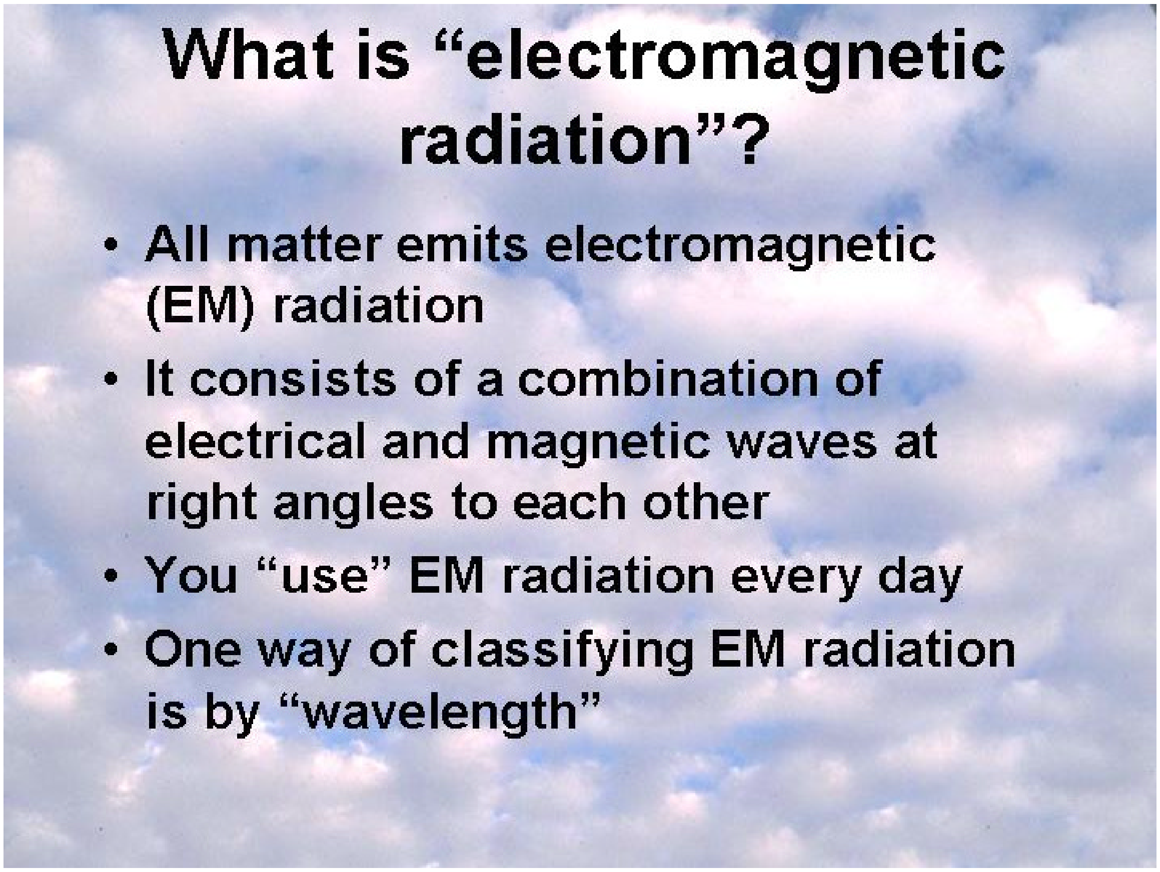
This presentation given on the Explorer of the Seas Feb. 1, 2002 by Dr. Charles N. Long.

Slide 2



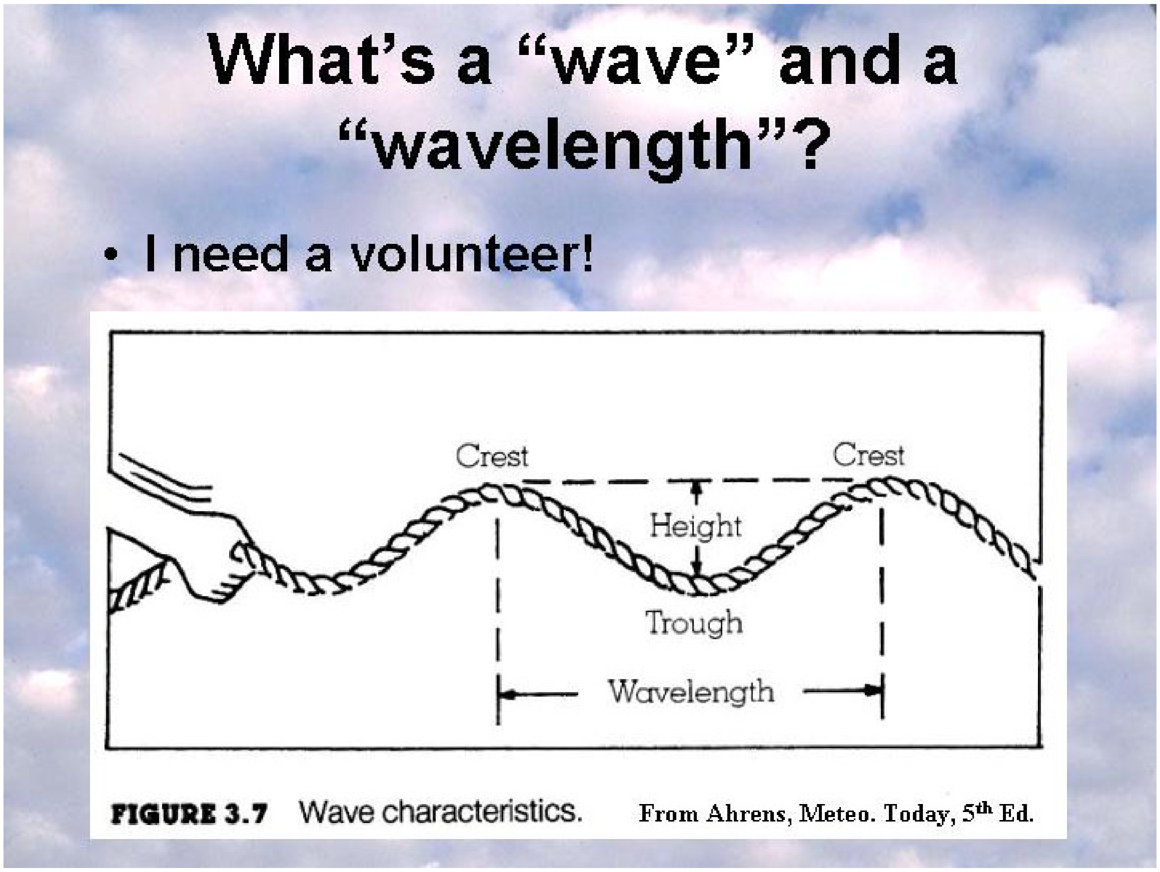
A recommended text for further information about weather, climate, and the topics covered in this talk. Many of the figures and illustrations used in this talk are from this text.

Slide 3



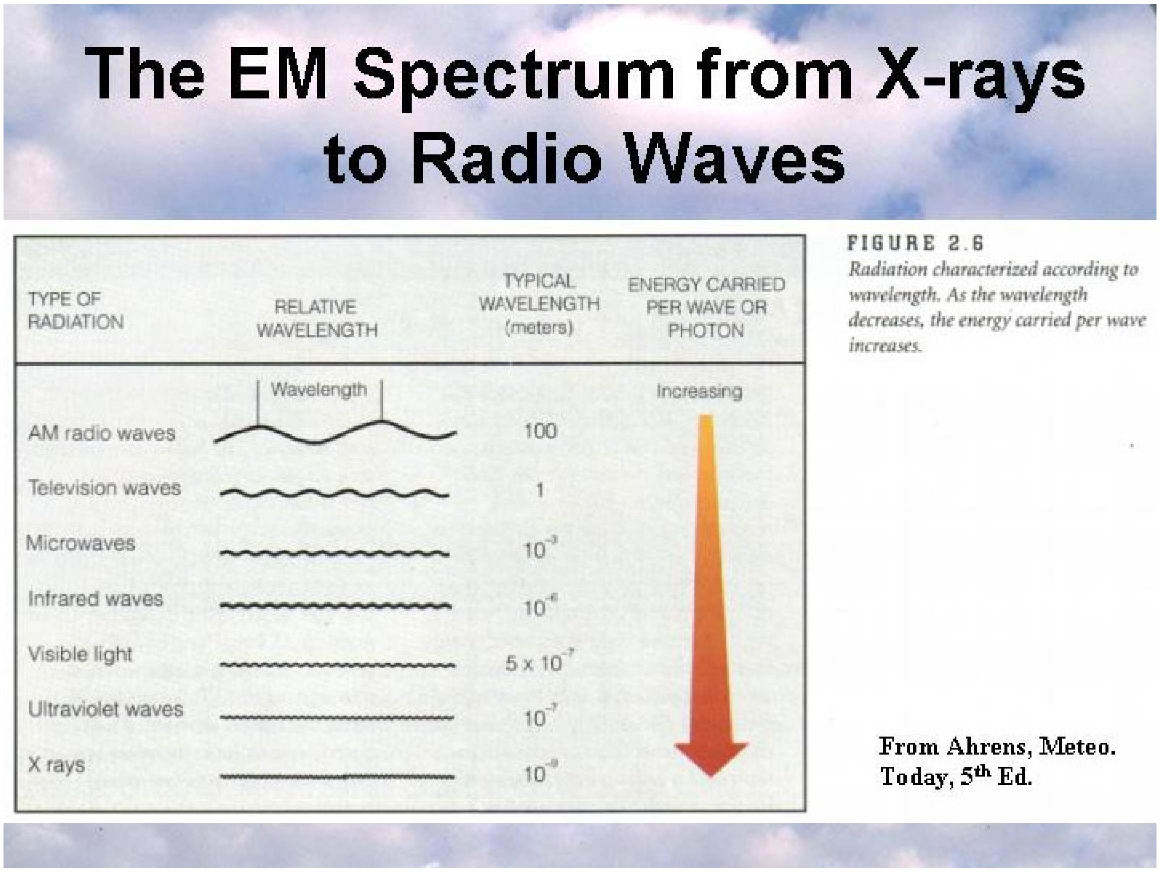
Electromagnetic (EM) radiation surrounds us every day. Visible and infrared light, microwaves, radio waves; these are all EM radiation. The only difference is in the wavelength.

Slide 4



The volunteer and presenter take a length of rope (clothesline), stretch it between them, and one shakes the rope up and down to produce waves that travel down the length of the rope as a demonstration. Then the above figure is presented to show what defines a wavelength.

Slide 5



The EM radiation spectrum, showing the common names of wavelength ranges, and that the shorter the wavelength, the more energy per photon. UV radiation contains enough energy to cause skin damage (sunburn and cell damage), whereas visible light does not.

Slide 6

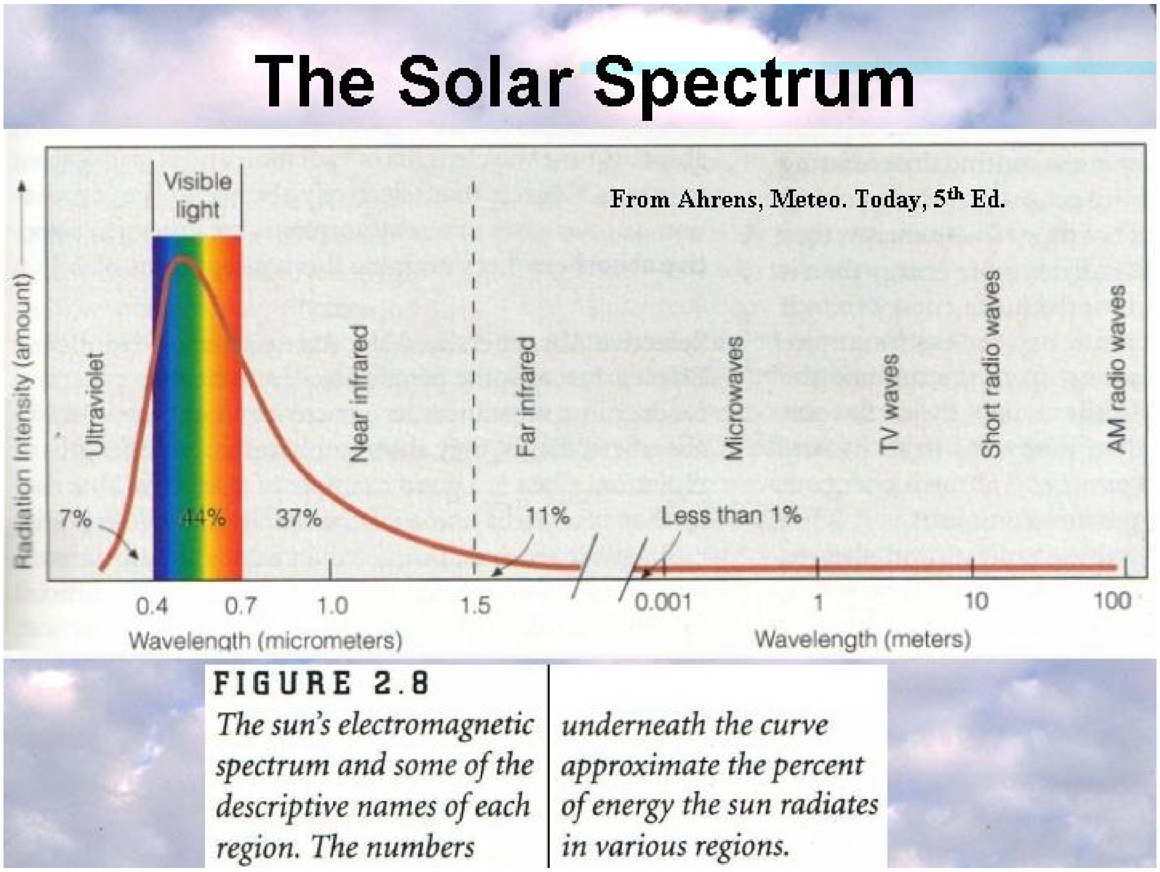
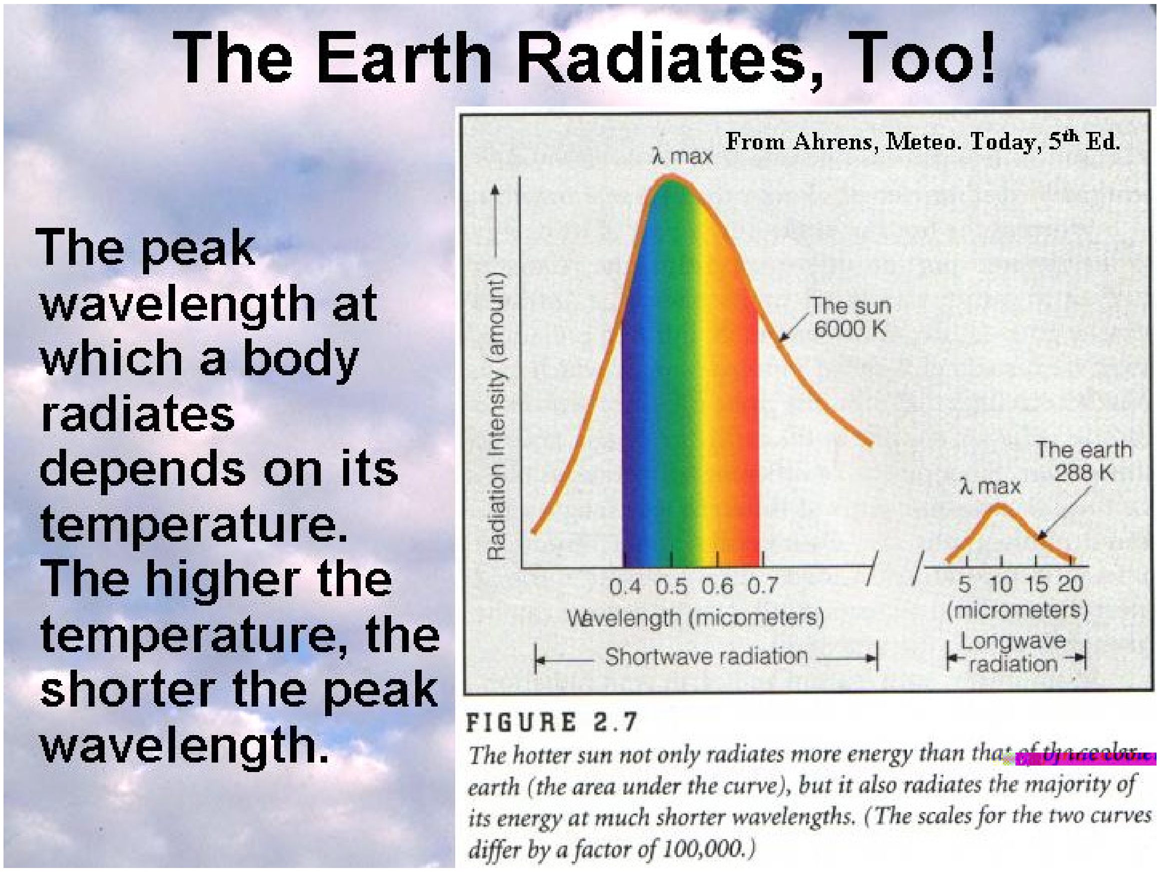


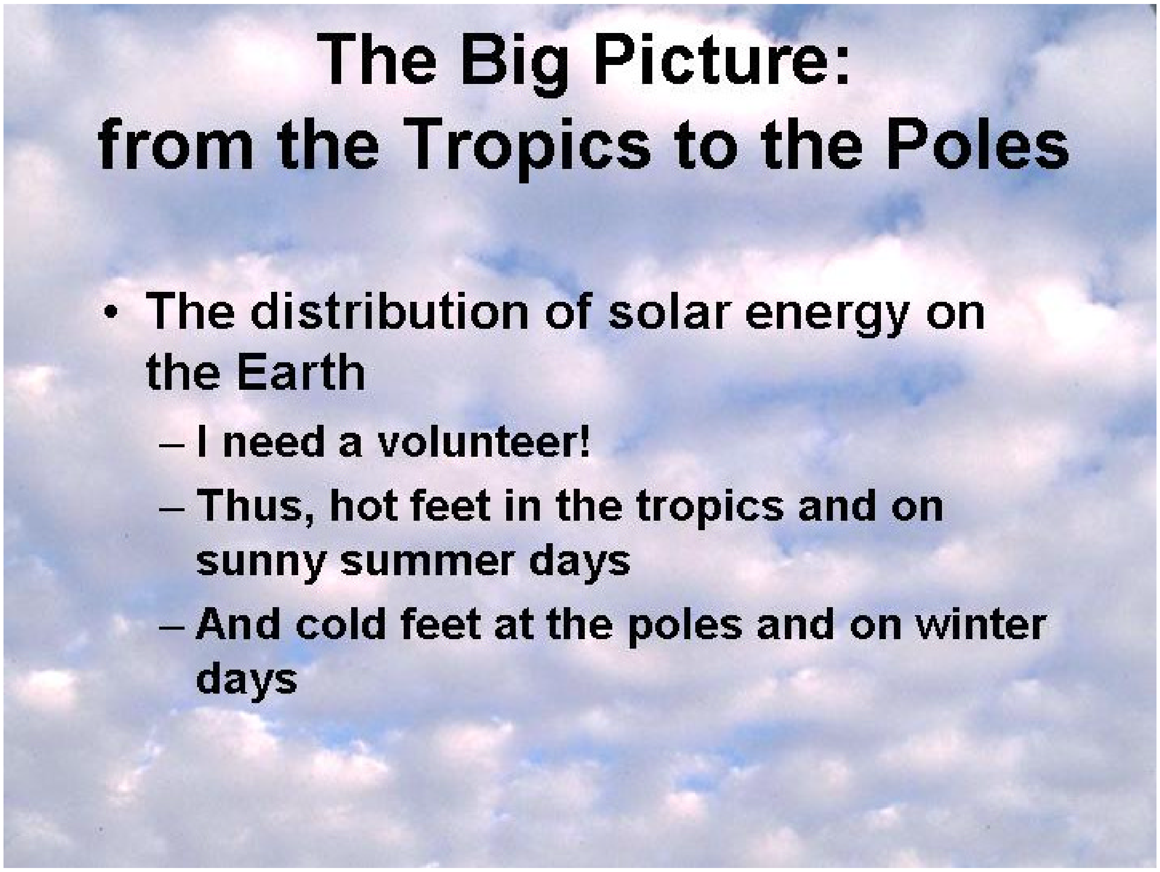
Illustration showing the relative amount of energy across the EM spectrum that the Sun emits. Isn't it curious that the range that we use to see by (visible) just happens to be the range at which the Sun gives off the most energy? (Adaptive evolution)

Slide 7



The Earth gets energy from the Sun. The Earth also radiates energy to space, but at longer wavelengths than the Sun emits because the Earth's temperature is lower. If the Earth did not radiate away energy, then the temperature would continue to climb. The Earth's temperature is determined by how much longwave radiation emission is needed to strike a balance with the average amount of incoming solar energy.

Slide 8



The volunteer holds up a basketball or beach ball. The presenter shines a flashlight on the ball (at the same relative height, from the side) to show that the flashlight's bright spot is smaller at the "equator" than near the edge of the ball (at the poles, and sunrise/sunset). This demonstrates that the same amount of solar energy (flashlight beam) is spread out over a larger surface area at glancing incidence than it is when striking straight on. Thus, at the Equator and at solar noon, there is more energy per unit area deposited than at the poles and sunrise/sunset. The point: the tropics get much more solar radiative energy coming in than do the poles.

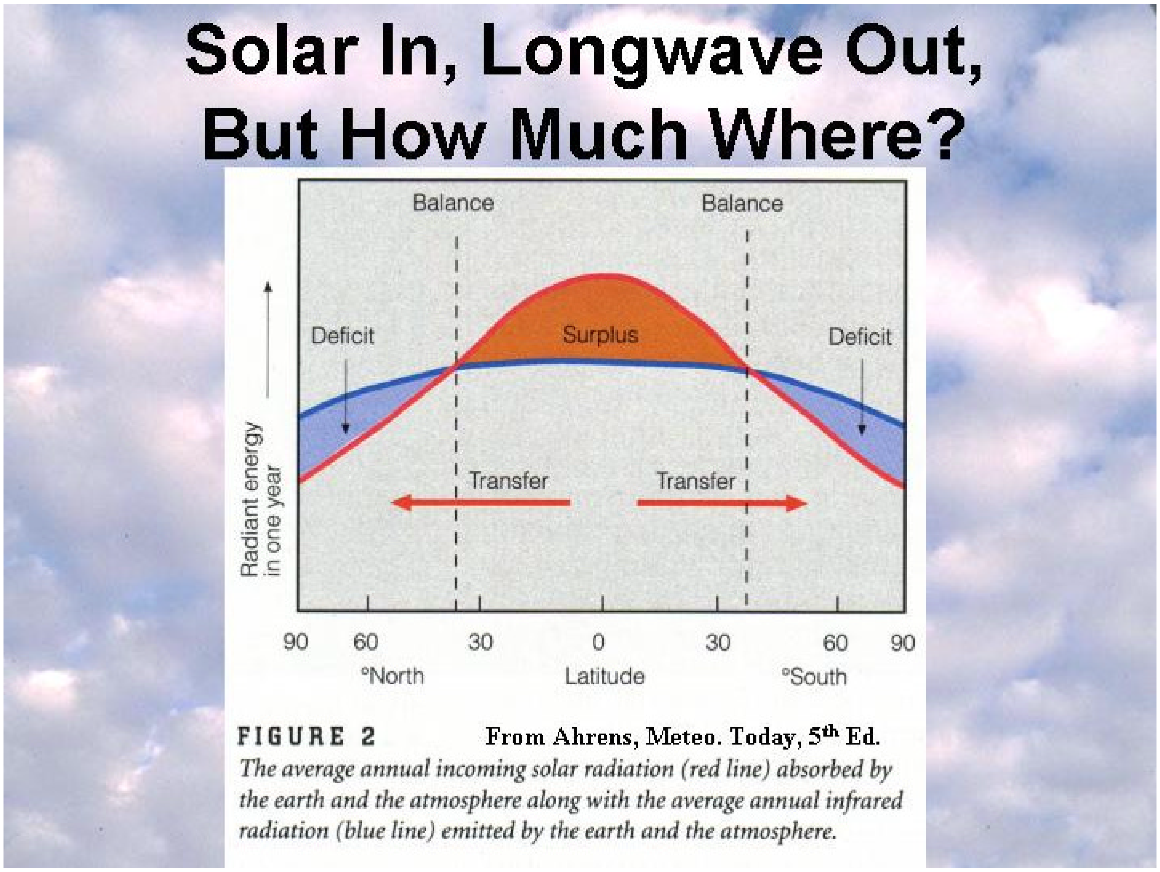
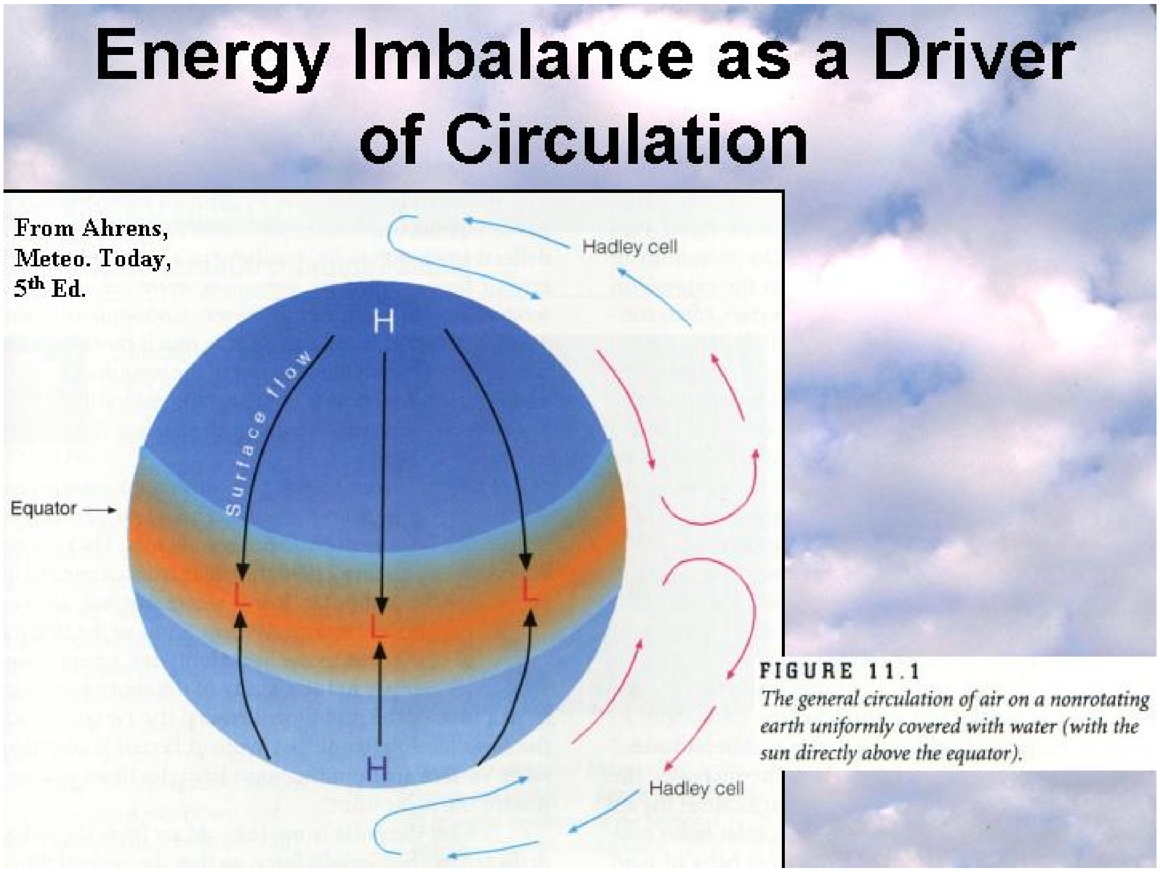


FIGURE 2 From Ahrens, Meteo. Today, 5th Ed.
The average annual incoming solar radiation (red line) absorbed by the earth and the atmosphere along with the average annual infrared radiation (blue line) emitted by the earth and the atmosphere.

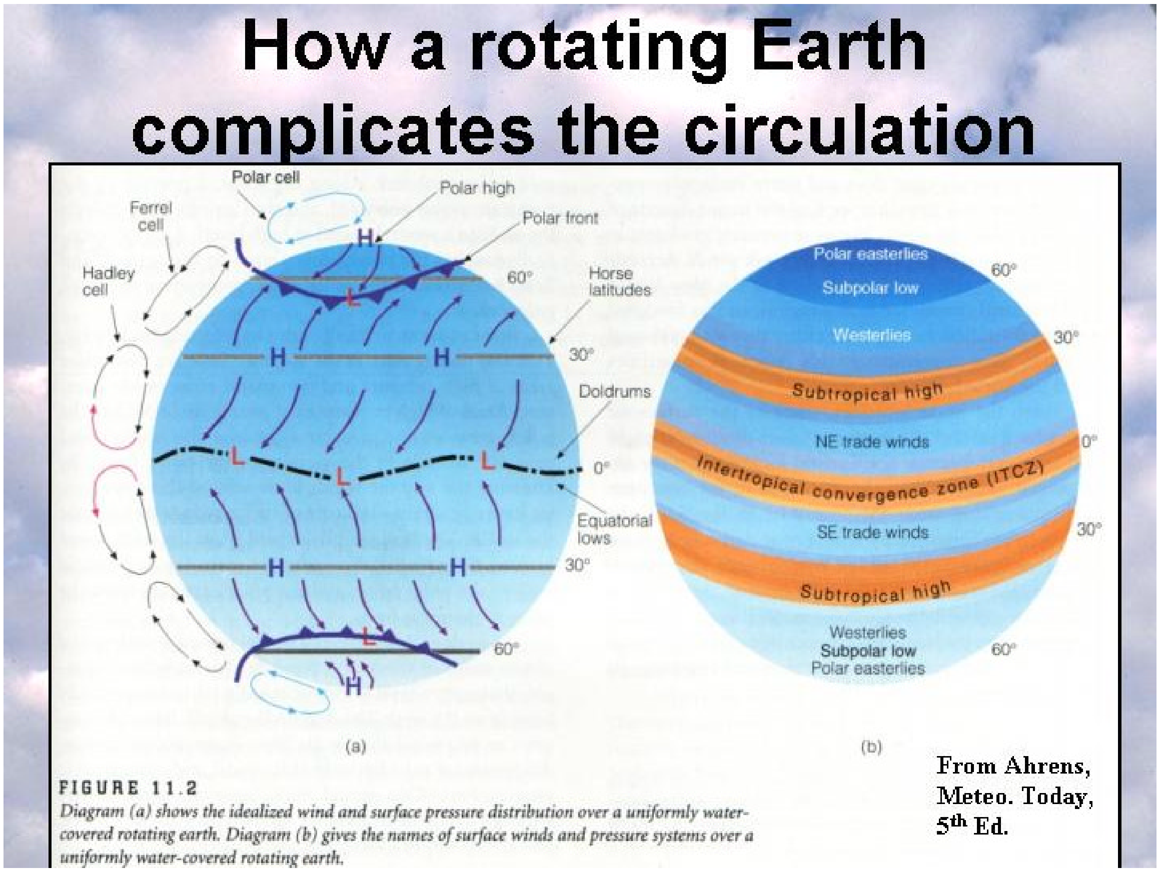
Illustration showing that the lower latitudes have a surplus of radiative energy, i.e. more solar energy coming in (red line) than longwave energy going out to space (blue line). In contrast, the higher latitudes suffer a radiative energy deficit. It is the surplus of energy at low latitudes and deficit of energy at higher latitudes that is the cause of the Earth's atmospheric circulation, the means by which the Earth system redistributes the excess energy to where there is a deficit. It should be noted that the same is true for ocean circulation, another major means of moving the energy toward higher latitudes.

Slide 10



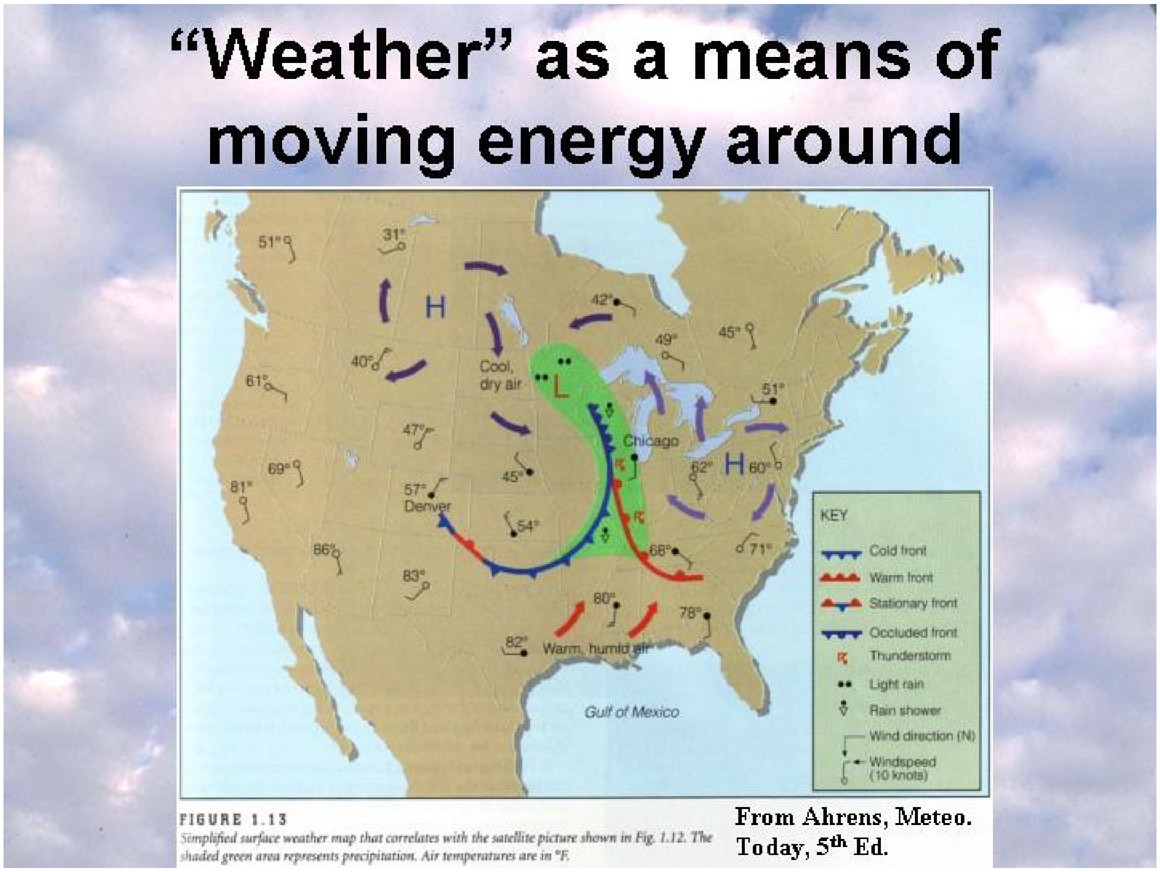
Solar energy heats the surface, which in turn heats the air. This causes a rising motion. Climatically, air rises at lower latitudes, travels toward the poles where it cools and sinks, then this colder air flows toward lower latitudes. If the earth did not rotate, this would be a direct circulation, producing two large circulation (Hadley) cells from the equator to each pole.

Slide 11



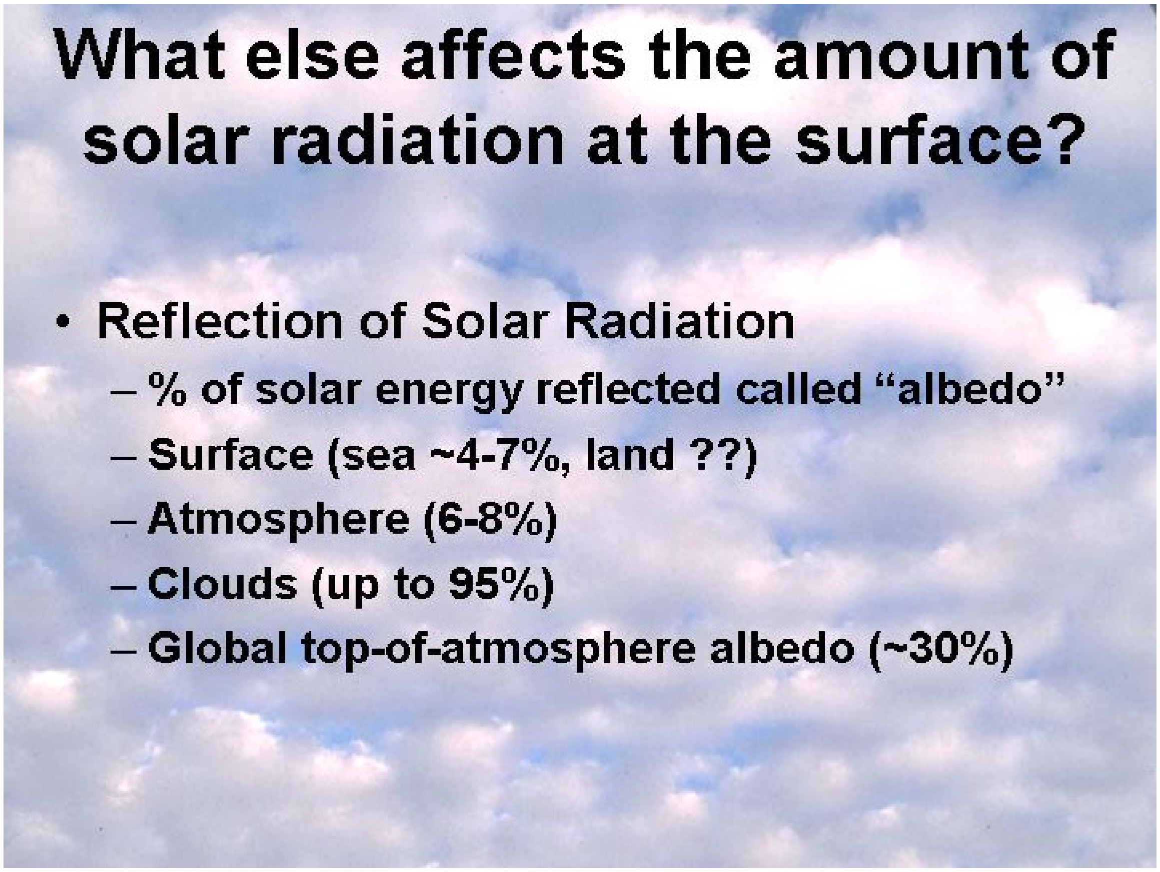
The rotation of the Earth causes an "apparent" force to act on moving air called the Coriolis force. The interaction of poleward flowing air and the Coriolis force prevents the formation of one large circulation cell in each hemisphere, and instead produces three cells in each. Note that the mid-latitude cell, the Ferrel cell, works opposite what we need for moving energy toward the poles!

Slide 12



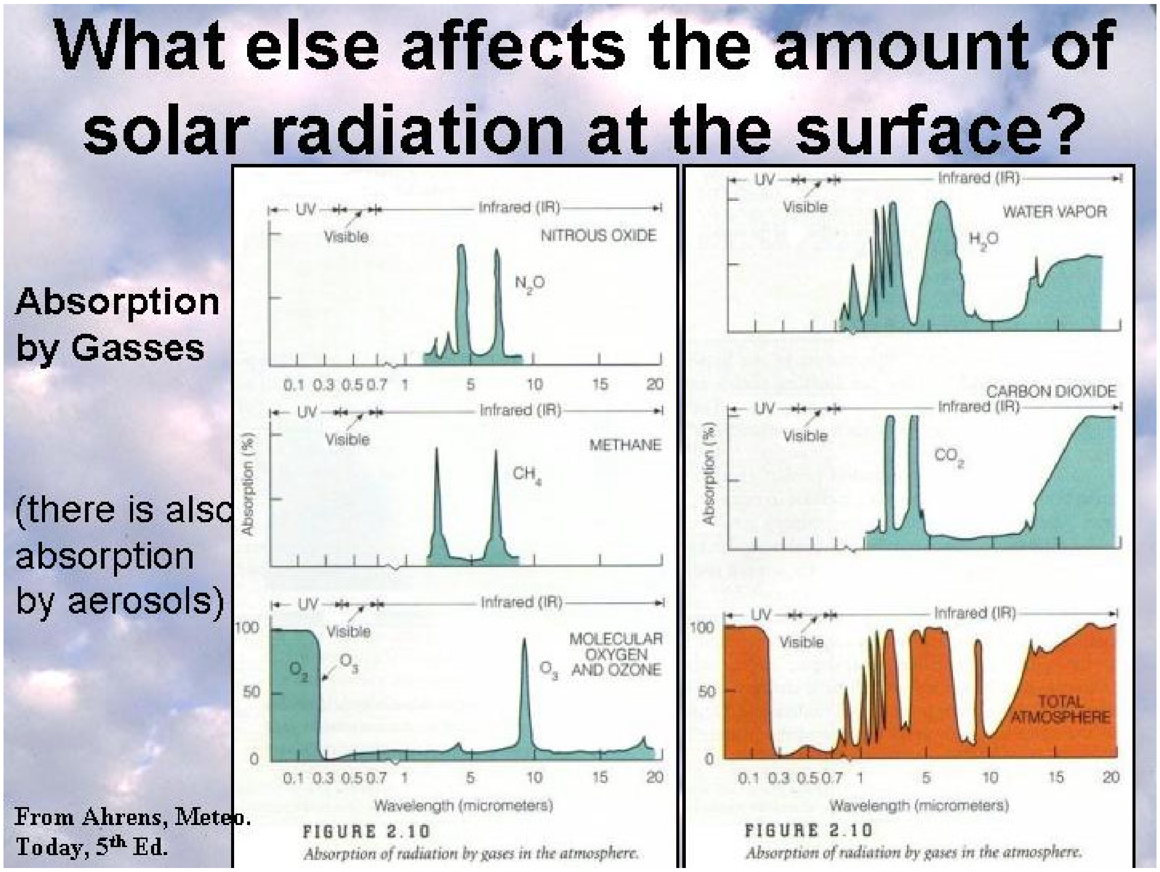
In the mid-latitudes, low and high pressure systems (cyclones and anti-cyclones) help move the excess energy toward the poles, countering the tendency of the Ferrel cell. Air moves counter clockwise around lows, and vice versa for highs. The most active systems are the mid-latitude cyclones, which often produce precipitation. Note the cold air moving south to the west of the low pressure center, while warmer air is moving toward the north to the east of the low.

Slide 13



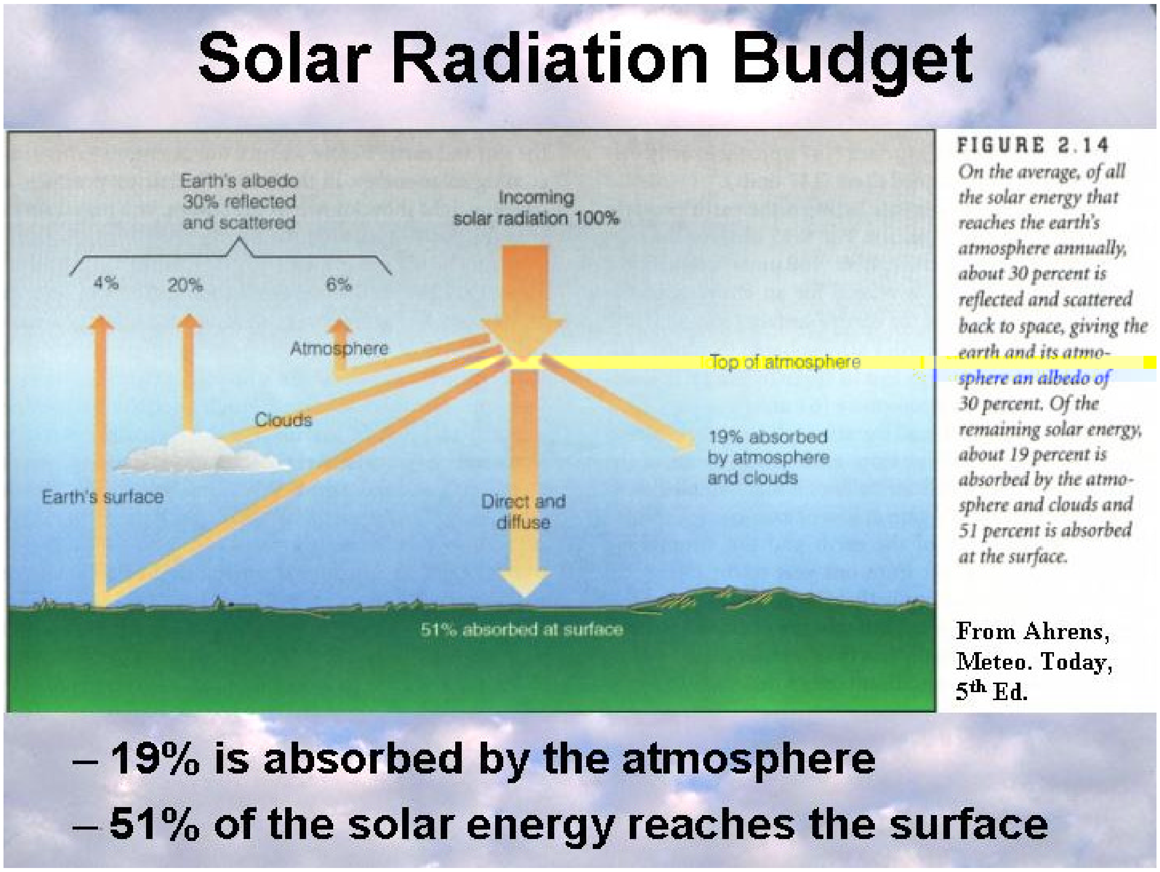
We are able to see objects because they scatter visible light, which our eyes can then sense. This is evidence that some solar radiation is reflected. The percentage of solar radiation that is reflected from a surface is called the albedo. The ocean has a low albedo, only a few percent. Clouds and snow, however, are highly reflective. Even the clear atmosphere itself reflects (scatters) solar radiation back to space. On average, about 30% of the solar radiation striking the Earth is reflected away without adding it's energy to the system.

Slide 14



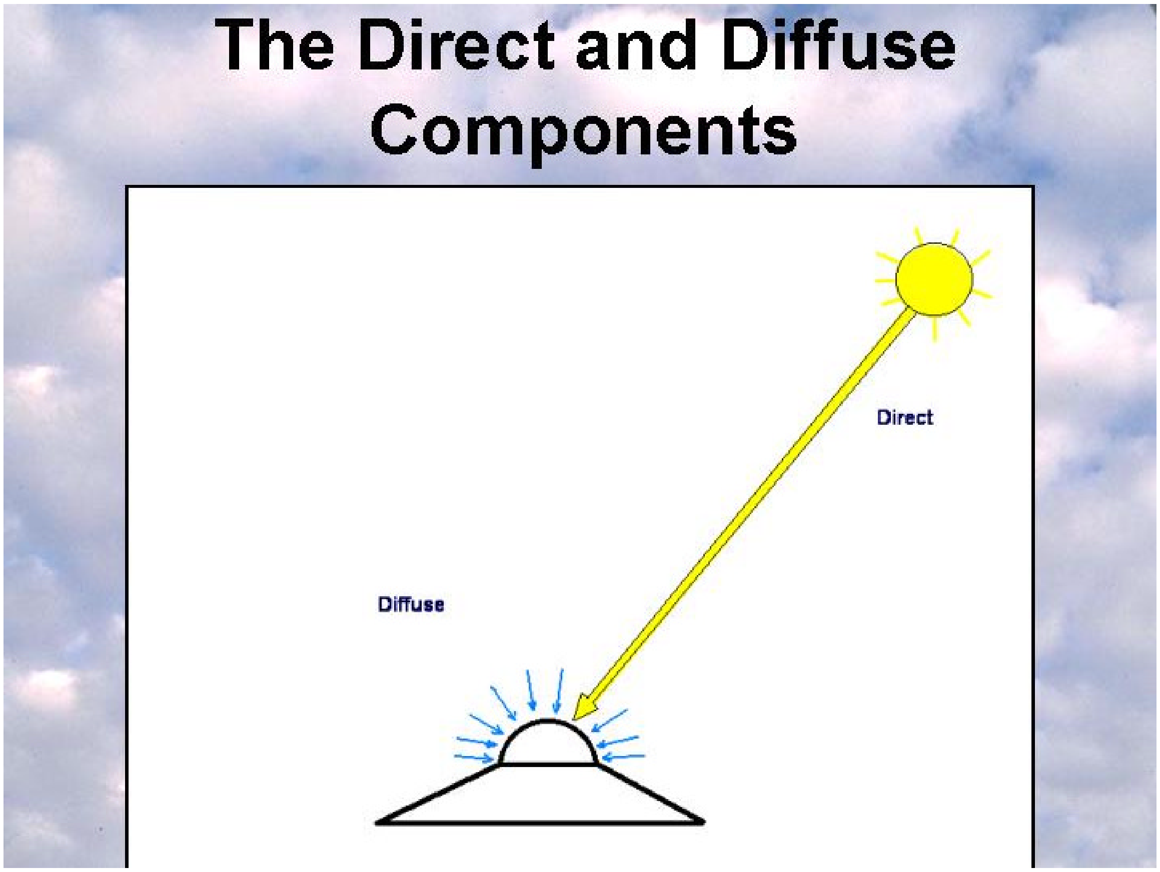
Of the energy that is not reflected away, some is absorbed in the atmosphere. This absorption is accomplished by aerosols, including cloud droplets, and some of the gasses of the atmosphere itself. Much of the UV radiation striking the Earth is absorbed by ozone and molecular oxygen in the stratosphere. This prevents UV from reaching the surface, which would be a health hazard. Of the rest of the solar spectrum, only a little of the energy is absorbed in the atmosphere. For the terrestrial infrared, many gasses absorb longwave energy, most notably carbon dioxide and water vapor. This longwave absorption is what we call the “Greenhouse Effect”.

Slide 15



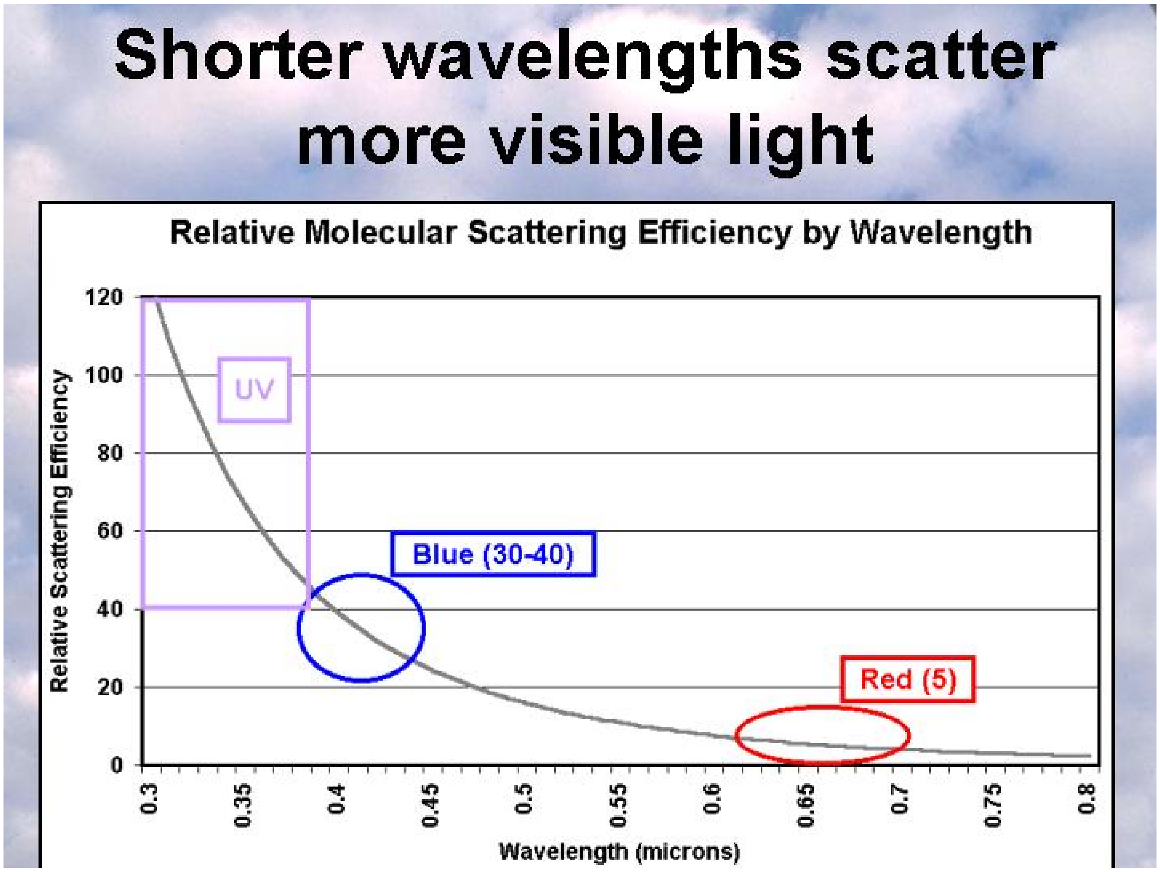
About 19% of the incoming solar energy is absorbed in the atmosphere. Adding this to the 30% that is reflected away, about half of the solar energy striking the Earth/Atmosphere system reaches the Earth's surface.

Slide 16



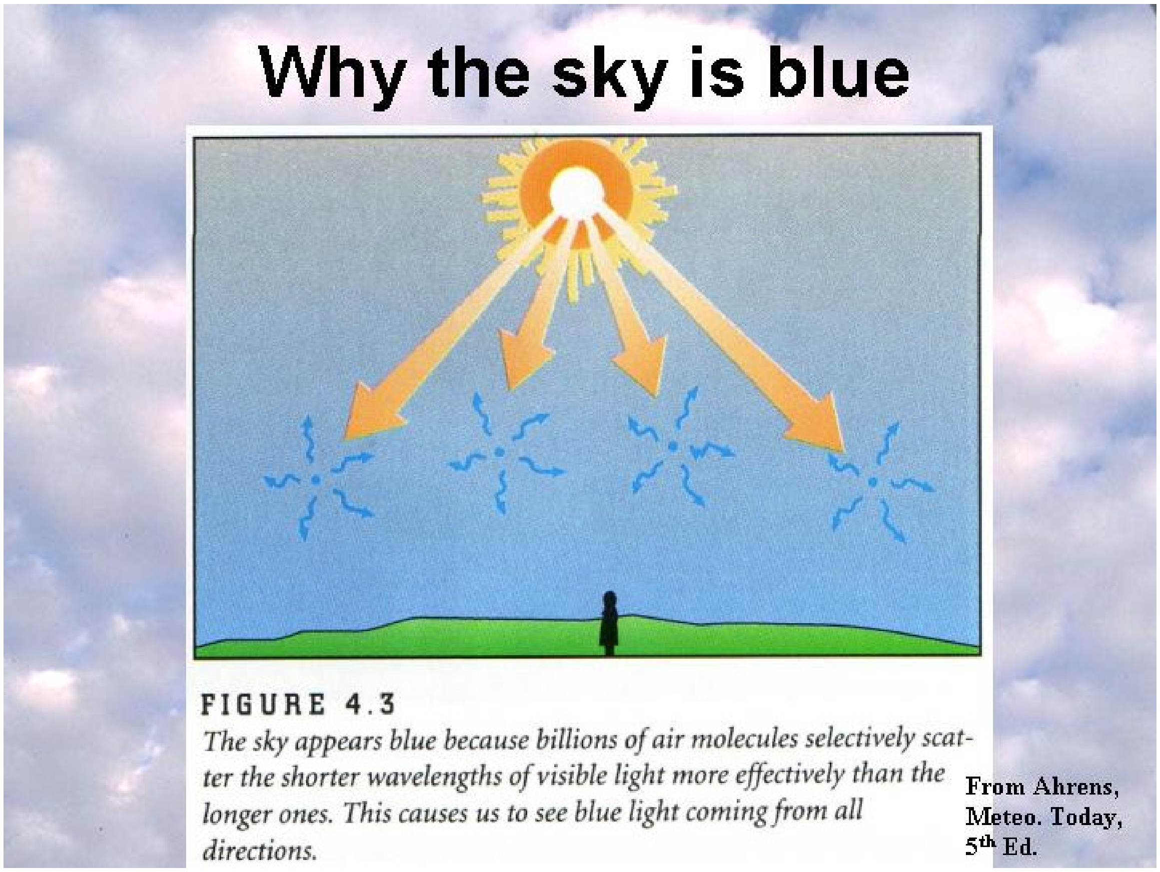
There are two ways that downwelling sunlight can reach the surface. One is the “direct” path, where the beams from the sun make it straight to the ground. The other is by scattering. Even the air molecules in a cloudless sky scatter sunlight, obviously because if they didn’t we would not be able to “see” the sky! We call this “skylight” the diffuse solar radiation. Under clear skies, the direct irradiance is the larger, often making up 80-90% of the total solar irradiance.

Slide 17



The molecular atmosphere scatters shorter wavelengths much more efficiently than longer wavelengths. In fact, the atmosphere scatters blue light about 6-8 times more efficiently than red light.

Slide 18



More blue wavelengths are scattered out of the direct solar beam than red wavelengths. This phenomenon has visible effects. If you glance quickly at the sun high in the sky, it appears white because the light has plenty of all visible wavelengths, and large intensity. But the rest of the cloudless sky appears blue because the amount of shorter wavelengths that have been scattered is large compared to the longer wavelengths. Question: if the shorter wavelengths are scattered more, why isn't the sky violet? (Answer: while violet wavelengths are indeed scattered more efficiently, in panel 6 it is shown that there is much less incoming violet wavelength radiation to scatter. Since the peak output wavelength is dependent on the temperature of the emitting object, if the Sun were hotter, the peak wavelength of emission would be shorter, and we might then have a "violet sky". Conversely, a cooler Sun might give us a "green sky"!)

Slide 19

Why sunsets are red

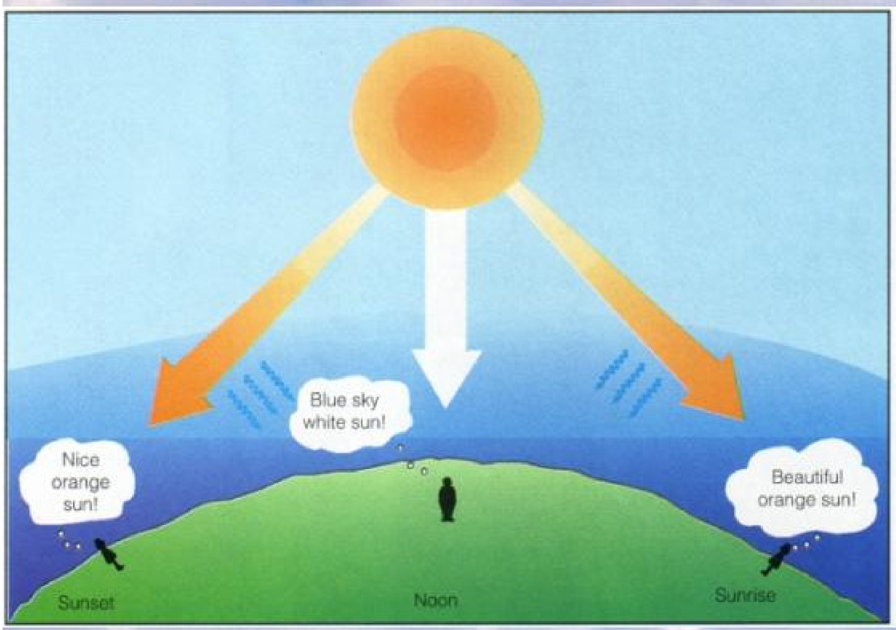
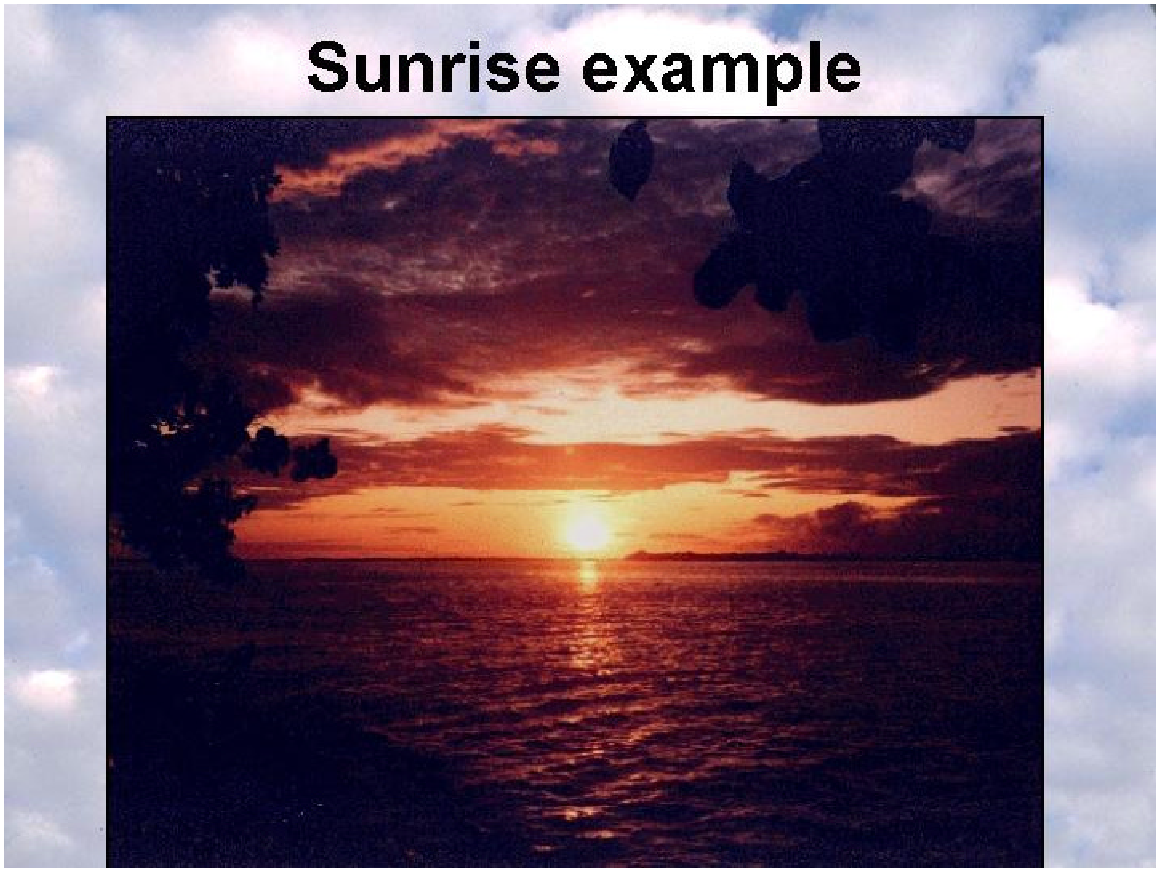


FIGURE 4.7
Because of the selective scattering by a thick section of atmosphere, the sun at sunrise and sunset appears either yellow, orange, or red. At noon, it is usually white.

From Ahrens, Meteo. Today, 5th Ed.

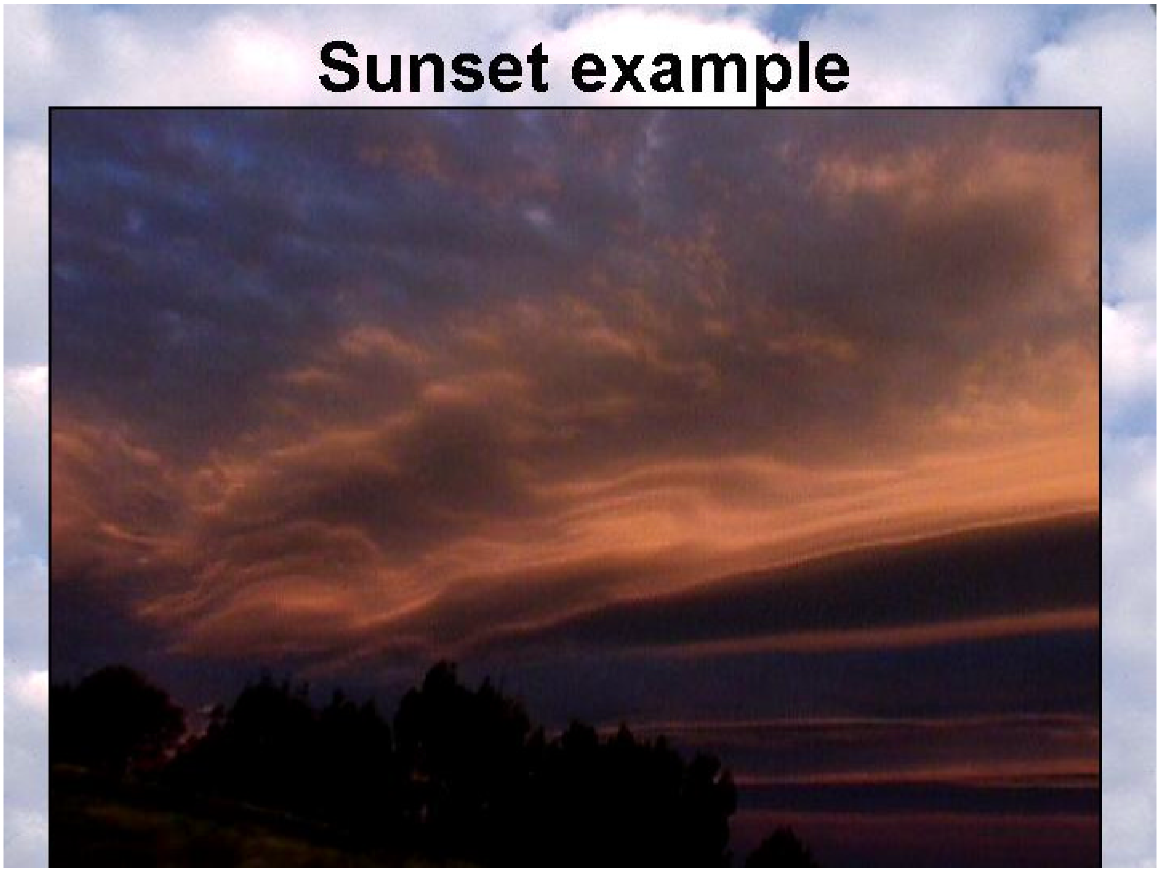
When the sun is low in the sky, the direct beam has had a significant amount of the shorter wavelength radiation scattered out of it because of the long path length of it’s journey through the atmosphere. Thus the sun’s disk is, and the clouds illuminated by the direct sun are, orange or red in color. This makes for some beautiful skies!

Slide 20



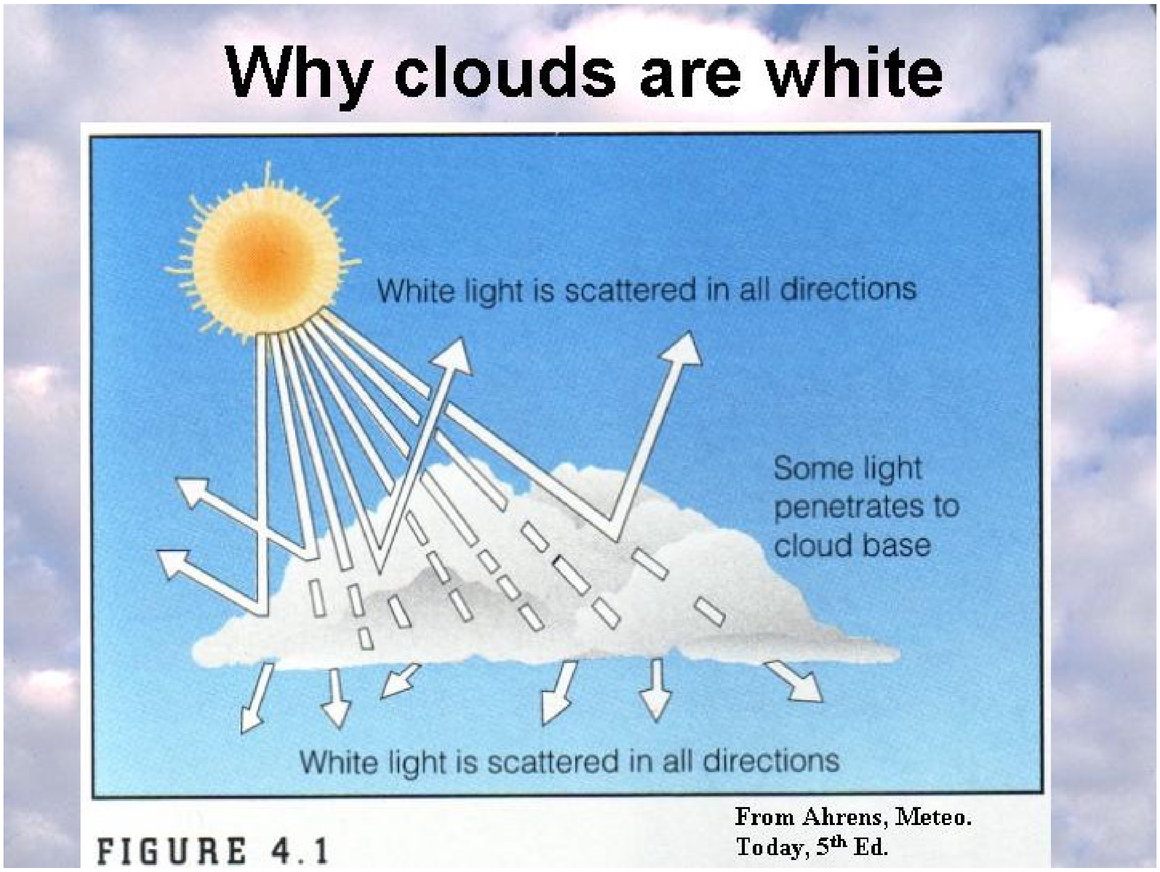
This picture of a sunrise was taken near Kavieng, Papua New Guinea in 1993 by Dr. Long.

Slide 21



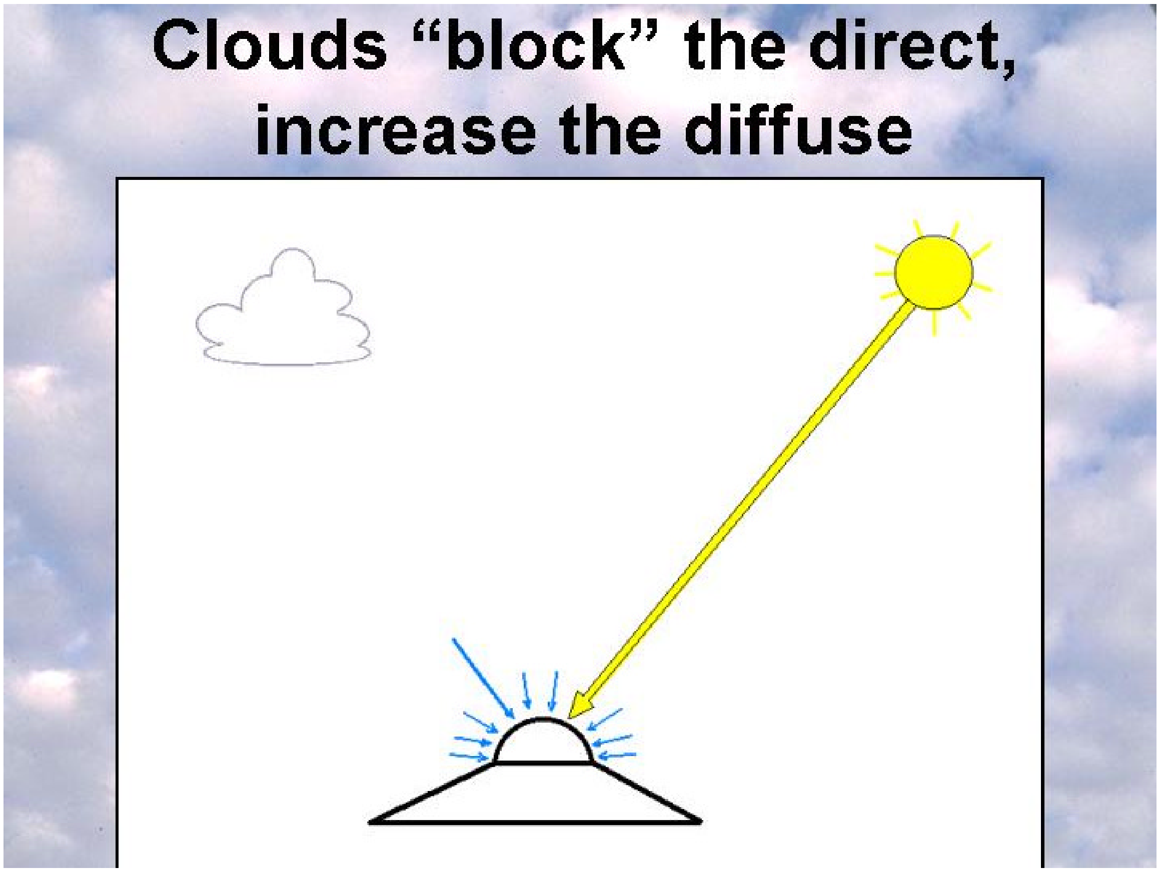
This picture of clouds illuminated at sunset was taken near Lauder, New Zealand in 1998 by Dr. Long.

Slide 22



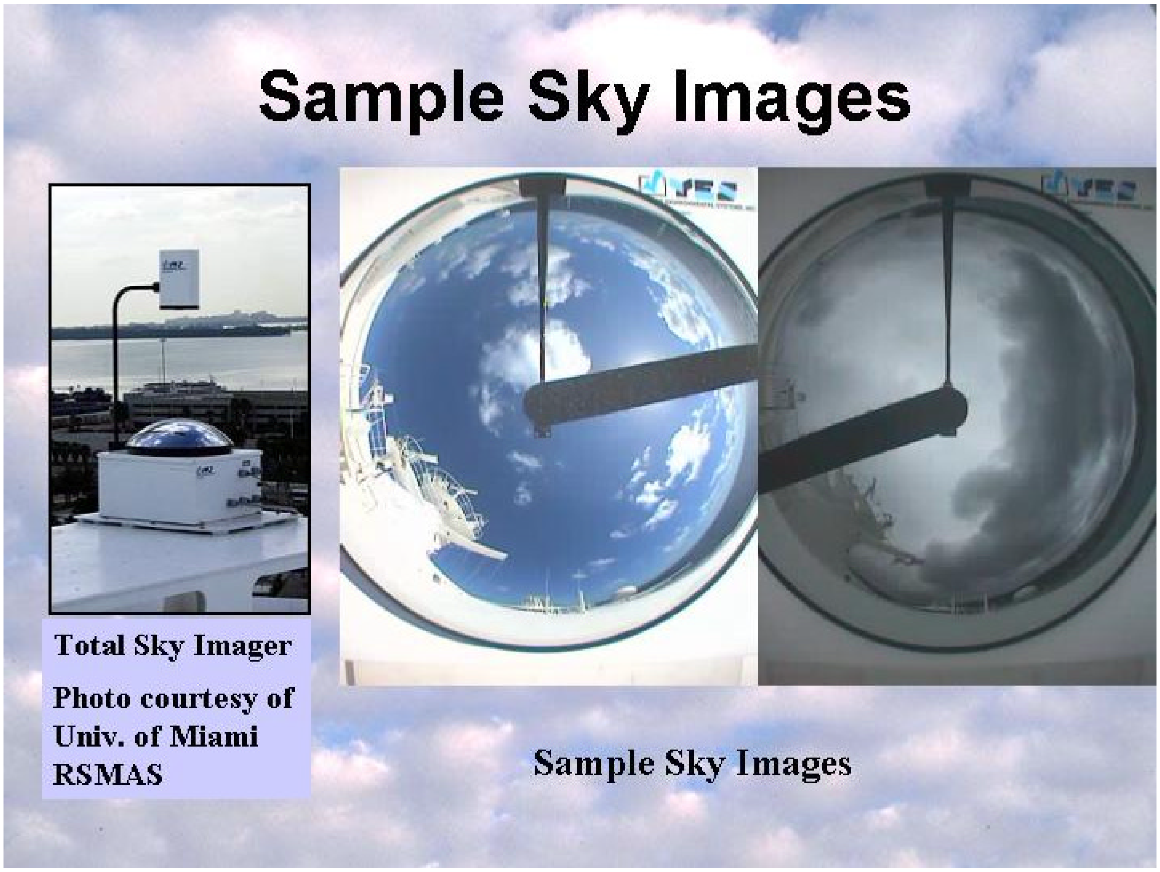
Cloud droplets are much larger than molecules, and scatter light about equally efficiently across the visible spectrum. In addition, the droplets scatter the visible light in all directions, and there are many millions of droplets in a small volume. Thus clouds appear white to our eyes, or gray for thicker clouds (except at sunrise and sunset!). This abundance of scattering is also why clouds reflect so much solar radiation to space.

Slide 23



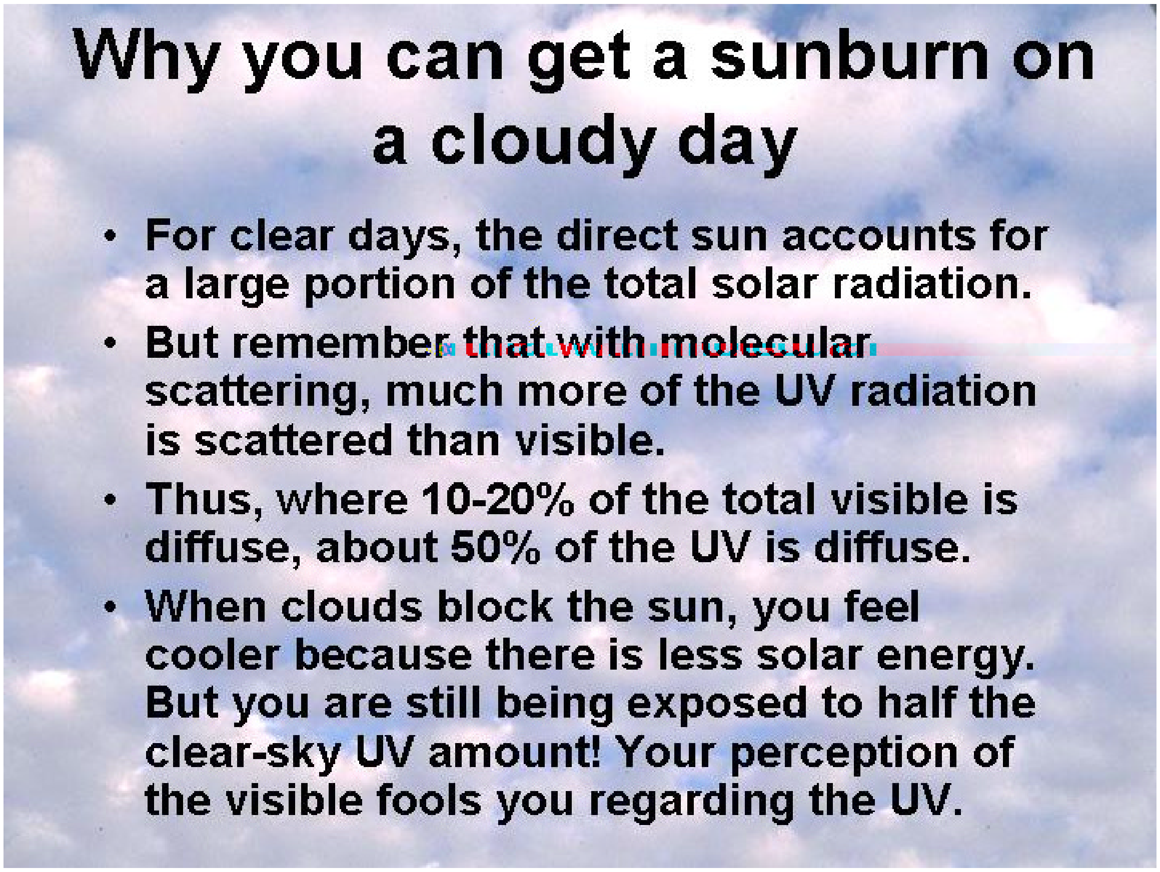
Because clouds reflect solar radiation so well, if a cloud is in front of the sun almost none of the direct beam gets through to the surface. On the other hand, because clouds scatter so well and about equally across the solar spectrum, the presence of clouds tends to increase the diffuse radiation over clear sky amounts.

Slide 24



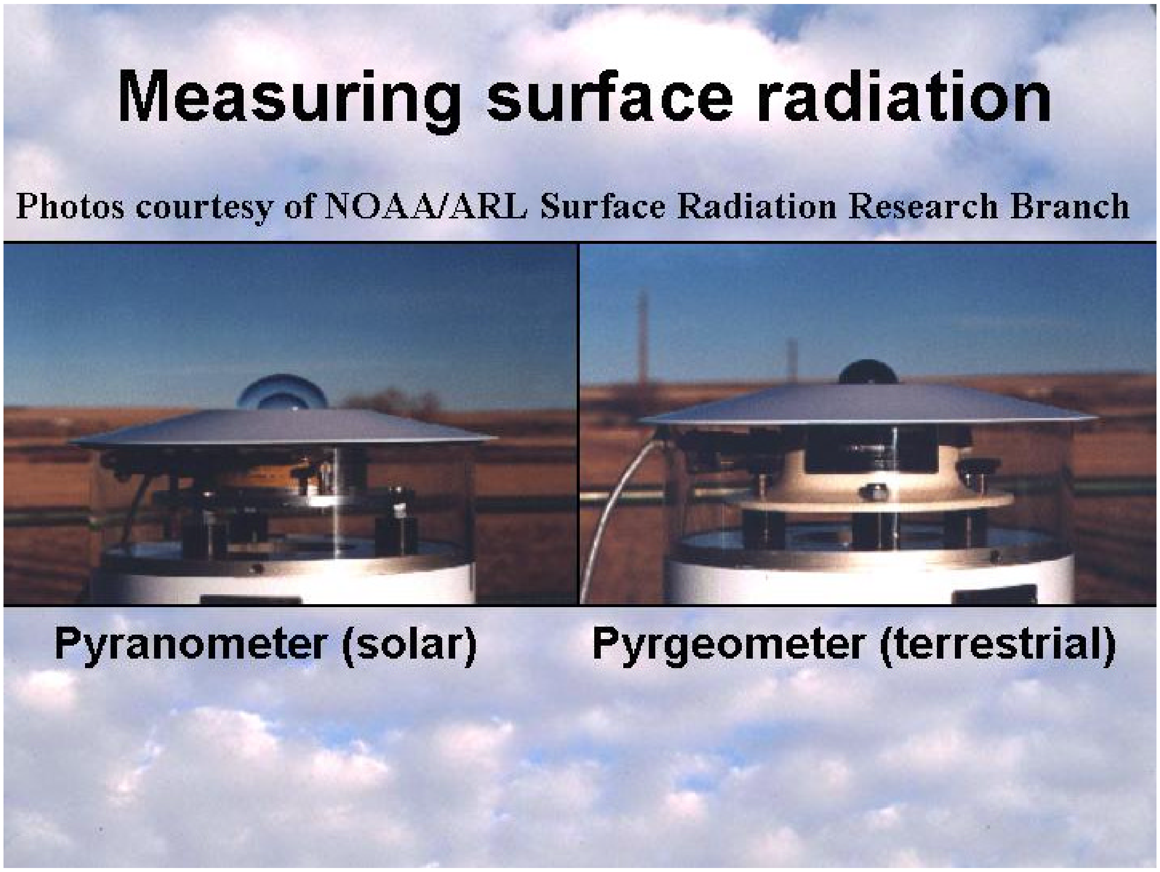
The sample sky image from the Explorer of the Seas TSI on the left shows a partly cloudy sky with clouds brighter than the clear portions of the image. The Explorer sample sky image on the right shows an overcast sky. Even though some of the clouds are thick, and the total solar radiation is less than that for clear sky, the diffuse radiation is actually greater than the clear sky amount even under these overcast conditions!

Slide 25



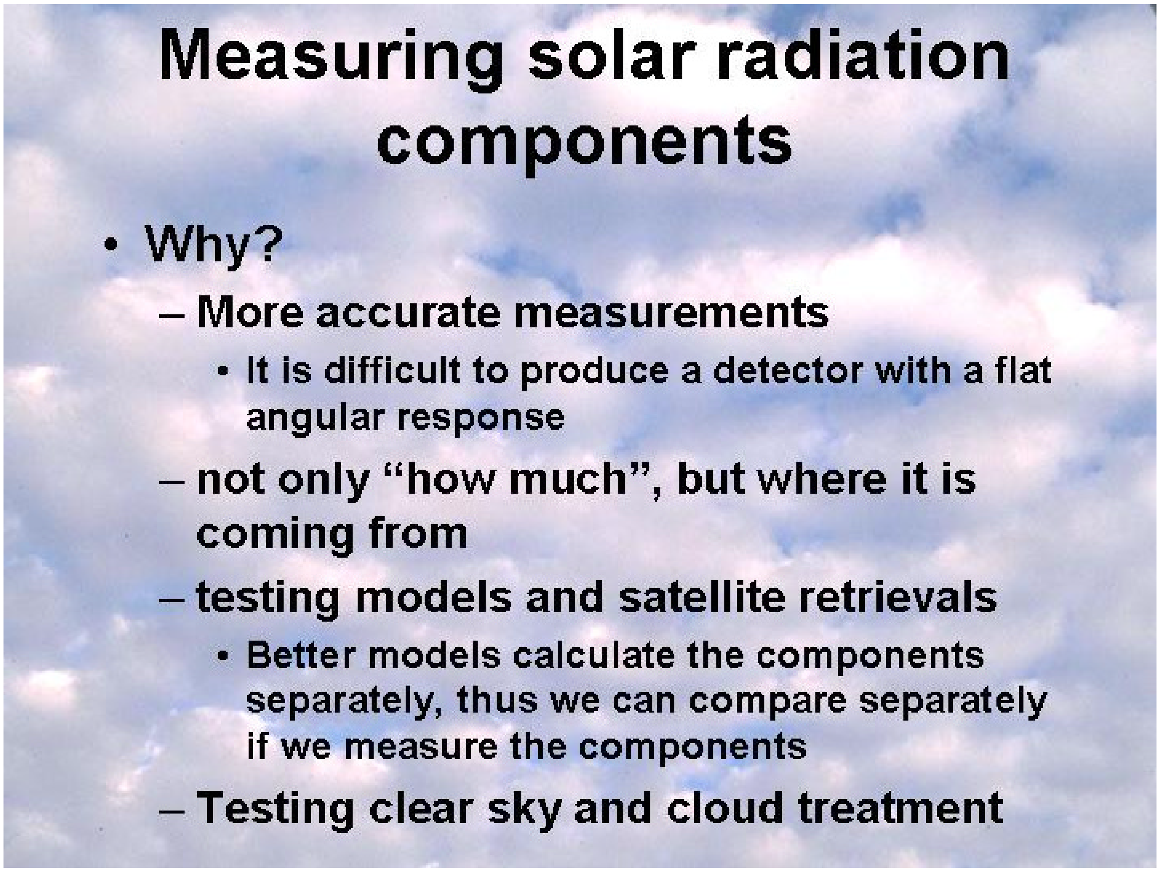
When it is sunny, we feel the heat of solar warming and are reminded of the possibility of sunburn. So we tend to remember not to overexpose ourselves, and to wear sunscreen. Under cloudy skies, we do not experience this "reminder", but we are still being exposed to significant UV radiation.

Slide 26



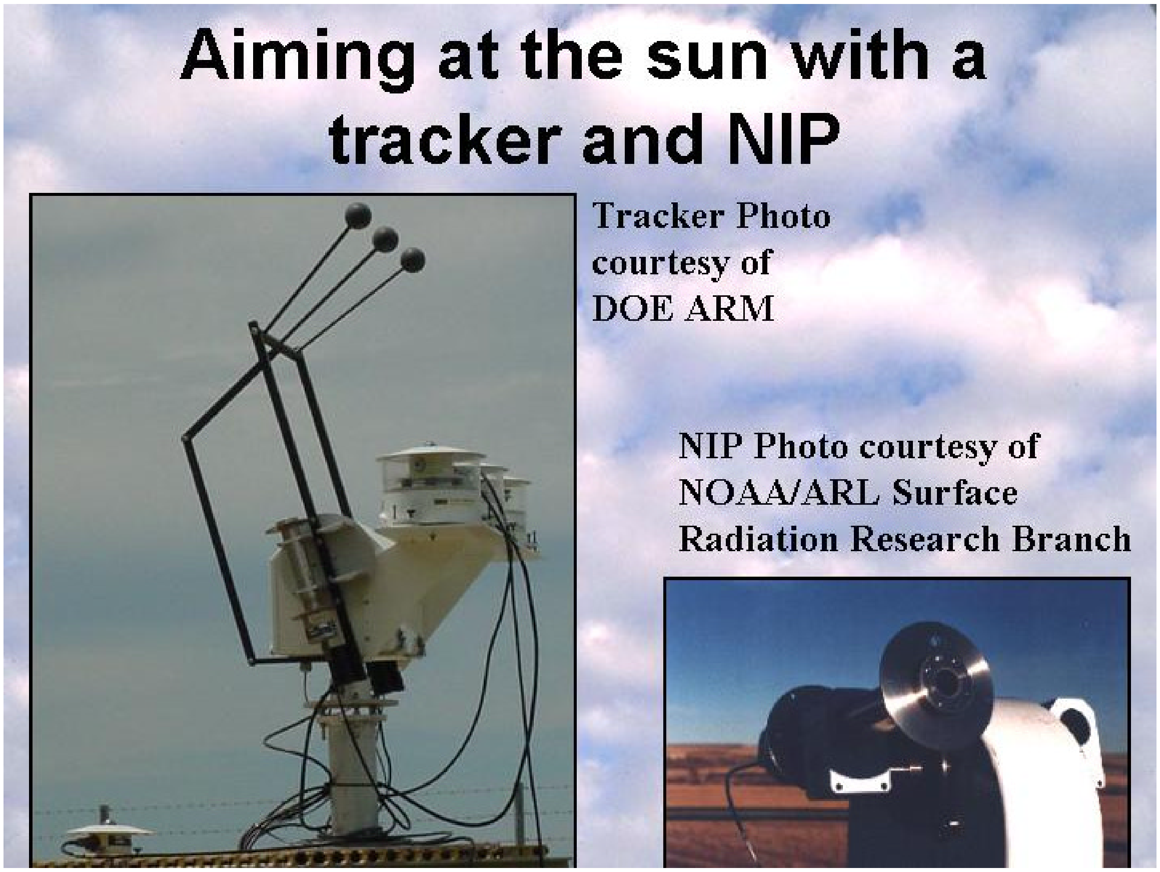
We have seen how important solar radiation is to the Earth/Atmosphere system, thus it is also important that we understand how much solar energy is received where. One way we measure the irradiance at the surface is with hemispheric instruments that use heat transfer. We use a filter to limit the range of wavelengths that can reach the detector, then monitor the amount of heat energy that the detector experiences to infer the amount of energy occurring. Here we show a typical pyranometer (left) for measuring solar radiation, and a pyrgeometer (right) for measuring terrestrial infrared radiation. The primary difference between the two is the filtering characteristics of the domes covering the thermopile detectors (note that you can see through the solar pyranometer filter domes on the left).

Slide 27



We can go a long way toward more accurate measurement of solar radiation by measuring the components, primarily because of the detector angular response errors of the hemispheric instruments. But also, radiative transfer models often calculate the direct and diffuse separately. This is because the scattering out of the direct beam is the source of input of solar radiation into the scattering that produces the diffuse. If we measure the components, then we can compare model component calculations with solar component measurements separately to help develop and refine the models better. In addition, we have seen that molecular and cloud scattering characteristics are quite different. So we can do a better job of testing how the models handle these two different regimes.

Slide 28

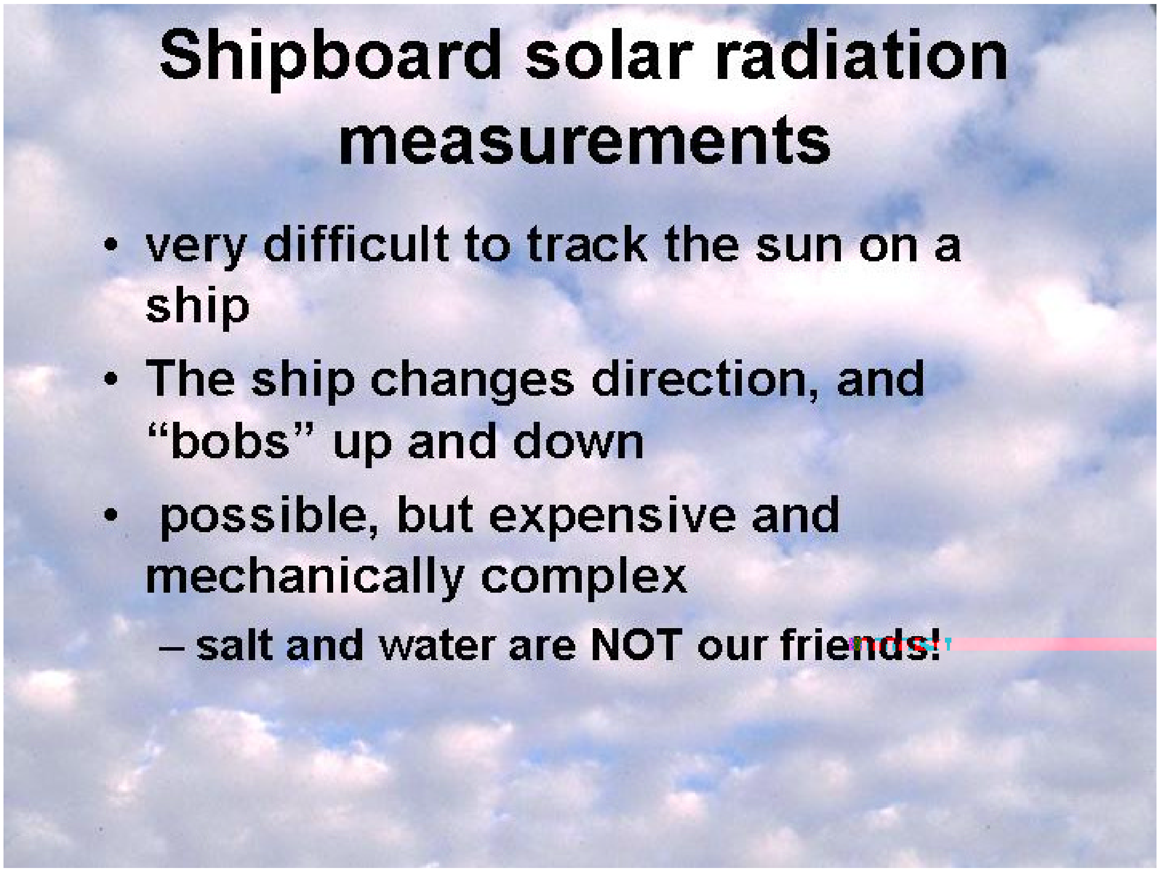


We measure the direct component with a Normal Incidence Perheliometer (NIP). The NIP is mounted on a device that tracks the solar disk across the sky, keeping the NIP precisely aimed at the sun.

Slide 29

We also use a tracker to shade pyranometers from the sun in order to measure the diffuse component.

Slide 30



Tracking mechanisms that could counter the effects of ship direction changes and the movement due to waves are possible. However, these systems tend to be mechanically and electronically complex, both problematic for long-term operations under moist salty conditions.

Slide 31

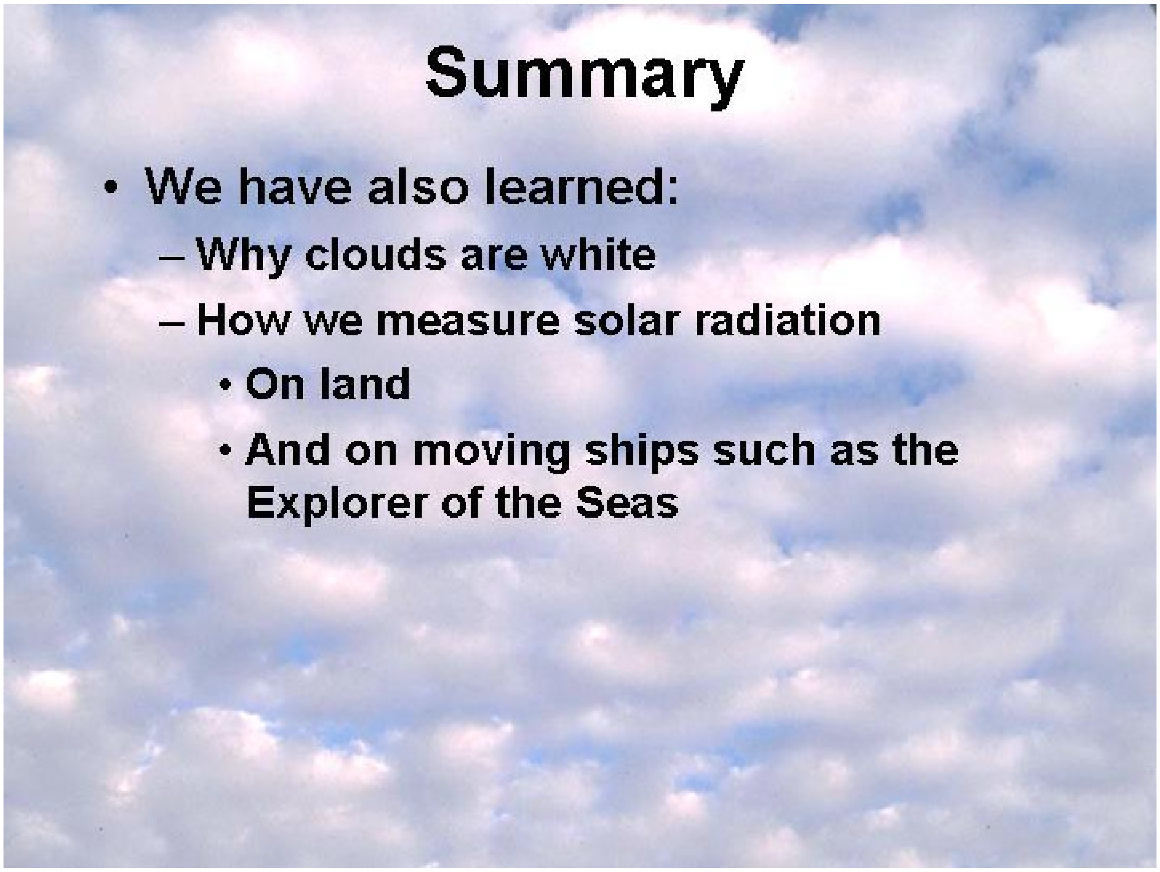
The Portable Radiation Package (PRP) as used on the Explorer of the Seas consists of Eppley PSP (solar) and PIR (longwave) radiometers for measuring total downwelling irradiance. In addition, the PRP includes a Fast Rotating Shadowband Radiometer (FRSR) that measures both broadband solar, and 6 narrow solar spectral channels. The shading band of the FRSR rotates to alternately shade and unshade the detector, thus producing measurements of total and diffuse irradiances. The diffuse is subtracted from the total to estimate the direct components. The 180 degree arc of the FRSR shading band, and a sophisticated diffuse measurement detection process, allow the FRSR to be operated with any ship heading. This unique, reliable design is far simpler than the sophistication needed to measure the direct and diffuse components with ship board tracking devices.

Slide 32

Summary

- In this talk, we have learned:
  - What electromagnetic radiation is
  - What solar and terrestrial radiation are
  - How the global distribution of solar energy determines climate, and causes weather
  - Why the sky is blue, sunsets are red, and you can still get sunburned on partly cloudy days: because of the characteristics of molecular scattering

Slide 33


Summary
• We have also learned:
– Why clouds are white
– How we measure solar radiation
• On land
• And on moving ships such as the Explorer of the Seas