

- a) *species of plants that require a relatively cool, moist environment tend to grow on poleward-facing slopes.*

These sides of the slopes will tend to have less average solar insolation, as they are more parallel to the incoming solar radiation than perpendicular to it. Less incoming solar radiation per m^2 means less energy to warm the ground and evaporate surface moisture. Poleward facing slopes are north facing, so that they generally receive less radiation than southward facing slopes.

- b) *on a clear day a snow surface is much brighter when the sun is nearly overhead than when it is just above the horizon*

Directly overhead the sun has its highest solar insolation per m^2 of earth's surface. Snow, with a high albedo, will reflect the short-wave radiation, leading to a brighter surface due to the additional radiation. Snow is almost a Lambertian reflector that turns parallel rays of solar radiation into diffuse reflected radiation. The low sun angle results in less solar irradiance per unit area, and thus less reflected radiation, so the low sun angle is associated with dimmer surfaces.

- c) *light-colored clothing is often worn in hot climates*

It is assumed that the hotter climate has a higher average solar insolation. Lighter colored clothing will have a higher albedo: that is, reflects more of the visible wavelengths and therefore reflects more solar radiation helping to keep the individual cooler.

- d) *the stars twinkle, whereas the planets do not*

Turbulence in the atmosphere will cause small changes in density and velocity of the atmospheric column, changing the speed and amount of visible radiation making it to the surface. Stars, though perhaps as intense in brightness as the planets, are much smaller pinpoints of light hitting the atmosphere when compared to the planets. The planets are much closer and therefore a larger "disk" of light enters the atmosphere. Although, for example, Saturn may have much less brightness than Sirius, the arc of sky covered by light from Saturn is much greater. The beams of light from stars are therefore more affected by the fluctuations in densities and velocities of gas in the atmosphere.

- e) *the radiation emitted by the sun is isotropic, yet solar radiation incident on the earth's atmosphere may be regarded as parallel beam*

The distance is so great, that the only radiation reaching the earth is that which was initially emitted directly towards the earth. Although initially isotropic, the non-direct radiation is “left behind” as it misses the earth due to its angle.

- f) *the colors of the stars are related to their temperatures, whereas the colors of the planets are not*

The stars themselves are emitting radiation, strongly in the visible wavelengths corresponding to their temperatures. The planets, however, do not emit radiation in the visible wavelengths but reflect the visible light coming from the sun. The light reflected is that which is not absorbed by the surface, thus the colors of substances on the surface of the planets are displayed.

- g) *the color temperature of the sun is slightly different from its equivalent blackbody temperature*

The Stephen Boltzmann law relates the temperature of blackbody to its irradiance. The sun is not a true blackbody however and its emission spectrum varies from that predicted for a blackbody by the SB law.

- h) *the equivalent blackbody temperature of venus is lower than that of earth even though venus is closer to the sun.*

Venus has a thick atmosphere with many layers of clouds. Most of the atmosphere is CO₂, which absorbs infrared radiation. According to Kirchoff's law, the absorbtivity of a blackbody equals its emissivity. Thus, the atmosphere absorbs and reemits the radiation from the heated surface, a fraction of which returns to the surface and lower atmospheric layers. The equivalent blackbody temp. is therefore determined by the radiation that escapes from the atmosphere, and therefore from its highest layers that are much colder than the surface. Another factor is that Venus has a high albedo due to its complete cloud cover: therefore, a good fraction of the incoming solar radiation is reflected. The surface of Venus is very hot!!

- i) *the equivalent blackbody temperature of the earth is lower than the global-mean surface temperature by 34°C*

Similar logic as problem 1.h above: the atmosphere contains a good fraction of greenhouse gases like water vapor and CO₂ which absorb terrestrial outgoing infrared radiation. The radiation is reemitted, a fraction back to the surface and a fraction upward. From the moon's perspective we expect a radiation balance between the amount of solar radiation entering the Earth's atmosphere and the amount of IR exiting it.

- j) *frost may form on the ground when temperatures just above the ground are above freezing*

The atmosphere is cooled by contact with the surface, which is cooled itself by the emission of infrared radiation to the atmosphere and space. The ground may initially cool to freezing and the atmosphere may be warmer due to the time lag of conduction of heat and due to warming from the greenhouse has absorption of the emitted infrared radiation from the surface. The ground may radiatively cool very effectively, and thereby create a strong temperature inversion. The surface can be cooler than the temperature just above as a consequence.

- k) *at night if air temps are uniform, frost on highways is likely to form first on bridges and hilltops*

The surface emits infrared radiation to the atmosphere and space and is cooled. The reservoir of heat from below the surface conducts upward towards the surface. Bridges do not have a reservoir of heat below them as they are exposed to the air. Hills have less exposure because they are more exposed to the atmosphere and are higher from the base surface. The surface of the hills also have less atmosphere above them to absorb and reemit the infrared back to the surface, when compared to the lower flatlands.

- l) *aerosols in the atmosphere or on windows are more clearly visible when viewed looking toward a light source than away from it*

They may be efficient scatterers of the light due to their size which makes them more visible when the light source is behind them. When away from the source they reflect too little light to differentiate them from the background light so are not as visible. Aerosols and cloud droplets, and ice crystals all tend to strongly scatter light in the forward direction (direction looking at the source). Backscattering (one's back to the source) is much less strong.

- m) *clouds behave as blackbodies in the infrared region of the spectrum, but are relatively transparent in the microwave region*

Water is a good absorber and emitter of a good chunk of the infrared spectrum but is transparent to microwave radiation. This is because the cloud droplets are rather inefficient at scattering wavelengths that are much greater than their average diameter.

- n) *sunlit objects appear reddish around sunrise and sunset on days when the air is relatively free of aerosols*

Aerosols will tend to scatter out the longer wavelengths (red) of visible radiation more readily due to Mie scattering (depends on aerosol size with respect to wavelength. Black carbon aerosol can also absorb radiation with an inverse dependence on wavelength (stronger for blue than for red). Therefore, red wavelengths will tend to reach the surface on days free of aerosols. The shorter (bluer) wavelengths will be scattered out more due to Rayleigh scattering and the deeper path through the atmosphere during sunrise and sunset (versus the shorter path when directly overhead). Thus, red light from the sun is more likely to impact the surface during these periods.

- o) *a given mass of liquid water would produce more scattering if it were distributed among a large number of small cloud droplets than among a smaller number of larger droplets*

This is dependent on the wavelength of radiation used (considering that K is proportional to x^4 ... refer to the radar example where a few large droplets would have a much larger backscatter return than many small droplets). Assuming that the λ chosen puts the small size near the $x=1$ range, much more scattering could occur overall with the higher surface area of the many smaller droplets. The scattering referred to here is probably at visible wavelengths rather than at radar wavelengths, so your interpretation is good.

- p) *the upper layer of the atmosphere in Fig. 4.36 appear blue, whereas the lower layers appear red*

The short-wave radiation is passing through the atmosphere, which is much denser at lower altitudes. Rayleigh scattering will scatter out more and more blue light (shorter wavelengths more efficiently) with a greater optical depth through the thicker atmospheric path. The red radiation comes from looking almost at the source, while the blue radiation is purely scattered radiation (the red preferentially goes in the incident direction compared with the blue).

- q) *smoke particles with a radius of $\sim 0.5\mu\text{m}$ appear bluish when viewed against a dark background but reddish when viewed against a light background (the sky)*

When viewed against a light background, the light is approaching the eye and is scattered by the smoke particle. At $500\mu\text{m}$, it will tend to be more efficient at

scattering the longwave (redder) visible radiation than the shorter (bluer) light. Against a dark background the eye is just seeing light reflecting off of the particles, which appear blue in color because the particles are absorbing the longer (redder) wavelengths, or scatters the red less effectively.

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r) *the disk of the full moon appears uniformly bright all the way out to the edge*

?The moon is not really a Lambertian reflector. It scatters more light at oblique angles than would a snow surface for example. See <http://www.optics.arizona.edu/palmer/moon/lunacy.htm>

s) *the absorption coefficient of a gas is a function of temperature and pressure*

From Schwarzschild's equation we see that the absorption coefficient α is a function of density. By the ideal gas law we know that density is a function of temperature and pressure.

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t) *the absorptivity of greenhouse gases in the troposphere is enhanced by the presence of high concentrations of N₂ and O₂.*

We can again relate this to the absorptivity coefficient which is dependent on density. The more dense the medium, the greater the coefficient. Actually pressure broadening by N₂ and O₂ increases the linewidth of transitions and therefore increases the amount of radiation absorbed.

u) *low clouds emit more infrared radiation than high clouds of comparable optical thickness*

According to the Stefan-Boltzmann law, the irradiance of a blackbody is proportional to T^4 . Therefore, warmer objects will tend to emit more radiation than colder objects. Low clouds will almost always be warmer than clouds aloft.

v) *the presence of cloud cover tends to favor lower daytime surface temperatures and higher nighttime surface temperatures.*

Clouds have a high albedo (being white), therefore reflecting a large percentage of the incoming solar radiation out to space which results in lower surface temperatures. At night, the cloud layer tends to absorb and reemit I would just call it 'emit' rather than

| 'reemit' infrared radiation acting as an insulator keeping the surface warmer than clear sky conditions.

w) *temperatures inversions tend to form at night immediately above the tops of cloud layers*

This is an area of profound cooling due to the emission of radiation to space from the cloud layer. The top of the cloud also tends to be a region of high evaporation as it marks the mixing region of dry air aloft and saturated air within the cloud.

x) *convection cells are often observed within cloud layers*

This is due to differential radiational heating/cooling. At the top of the cloud, radiational cooling will occur as infrared radiation is emitted to space. The bottom of the cloud will tend to absorb infrared radiation coming from the surface. These processes together will make the temperature gradient within the cloud more unstable to the point that convective cells will form.

y) *at night, when a surface based inversion is present, surface temps tend to rise when a deck of low clouds move overhead*

A surface inversion is usually present due to surface cooling from radiational emission to space and atmosphere. As the cloud deck enters, the radiation is absorbed and reemitted in portion back to the surface. This limits the cooling of the ground. The ground warms from the conduction of heat from lower soil layers.

z) *low clouds are not visible in satellite imagery in the water vapor channel*

Low clouds are much warmer than high clouds in general, closer to the surface temp. The water vapor channel looks at the dense range of absorption lines near 6.7 μm infrared radiation. Deficits in radiation received will be whiter in appearance on the display and represent the amount of radiation absorbed and emitted by water vapor in the column. Clouds near the ground will be emitting a large amount of radiation, similar to the surface, due to their high temperature. The water vapor channel is so strongly absorbing that infrared radiation from the Earth's surface, and near it, is absorbed before it can escape the Earth's atmosphere and be measured by a satellite.

aa) *ground fog is more clearly evident in visible than in infrared satellite imagery*

Ground fog will be near to the same temperature as the ground and will therefore emit infrared radiation at a similar magnitude. The more visible regions will be that with a greater deficit in received infrared radiation at the satellite due to the lower emission at colder temperatures in high clouds.

bb) the fraction of the incoming solar radiation that is backscattered to space by clouds is higher when the sun is low in the sky than when it is overhead

The angle of the incoming radiation is such that the rays have a greater path through the clouds, giving the photons a higher chance of hitting a cloud droplet and scattering. Then angular distribution of light scattered by water droplets is much stronger in the forward direction than at other angles, thereby increasing the amount of radiation scattered and multiply scattered to the surface when the sun is nearly overhead.

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cc) under what conditions can the flux density of solar radiation at the earth's surface locally be greater than that at the top of the atmosphere?

During sunrise or sunset: when the sun is near the horizon. Light can refract in the atmosphere leading to a net positive flux at the surface even when the flux at the top of the atmosphere is zero due to a parallel line of site for incoming solar rays. Actually probably under partly cloudy conditions when the sun light is not obscured by clouds, but is instead strongly scattered by them.