

Atmospheric Science 101, Spring 2003 Solutions for Review Sheet for Midterm 1

1. What is the atmosphere mainly composed of? Which of its constituents absorb infrared radiation and which absorb ultraviolet? What is the greenhouse effect, and how does it work?

The atmosphere is mainly composed of nitrogen (N_2), which makes up 78% of dry air, and oxygen (O_2), which makes up 21%. A little less than 1% of dry air is argon (Ar). Water vapor (H_2O) can account for anywhere from 0 to 4% of air, depending on its temperature and relative humidity.

Water vapor and carbon dioxide (CO_2) are the two atmospheric gases that are most effective at absorbing infrared radiation. Ozone (O_3), methane (natural gas, CH_4), and nitrous oxide (laughing gas, N_2O) also absorb infrared radiation. Finally, while they are not a gas, clouds (small particles of liquid or solid water) are another part of the atmosphere that is a very effective absorber of infrared radiation. Ozone also absorbs ultraviolet radiation, especially in the stratosphere, where its UV absorption causes the air temperature to warm with height. (In the upper-most levels of the atmosphere (the thermosphere), molecular oxygen (O_2) and nitrogen (N_2) absorb the shortest, most energetic ultraviolet waves from sunlight.)

The greenhouse effect is due to the fact that greenhouse gases (those listed above as absorbing IR radiation) allow sunlight to reach and warm the surface, but absorb the IR radiation emitted by the surface before it reaches space. This absorption causes the atmosphere to warm up, and emit more radiation (IR) back to the surface, which warms the surface. On average, this process keeps the surface of the Earth about $33^\circ C$ ($59^\circ F$) warmer than it would be without the greenhouse effect. In Figure 2.14 of EOM, the 111 units of IR absorbed by the atmosphere (just left of incoming sunlight) and the 96 units of IR reaching the surface (on the right) are the components of the greenhouse effect.

2. Why does pressure always decrease with height?

The pressure at any height is determined by the weight of air above that point. As you move straight up, you are constantly moving above more and more air, leaving less of it above you. Therefore, as you move up, the weight of air above you always decreases, so the pressure also always decreases.

Near sea level, the weight of air above us is 14.7 pounds per square inch (over one ton per square foot). This is equivalent to having a car parked on every square foot of the roof of a building. Why don't buildings have to be built to support this weight?

At any point, air pressure acts equally in all directions. The pressure pushing down on the roof is balanced by the equal amount of pressure from the inside pushing up. Likewise, the air outside a building presses in on the walls, but this pressure is balanced by the air inside pushing out on the walls.

3. Why does temperature generally decrease with height in the troposphere and increase with height in the stratosphere? Be able to draw a temperature profile and to determine wind speed and direction from a wind barb.

The troposphere is warmed mainly by hot air rising from the surface. As this air rises, it expands and cools, resulting in a temperature profile that cools with height. The stratosphere is warmed by absorption of ultraviolet light from the sun by ozone. As you move up from the tropopause the amount of ozone and the amount of available ultraviolet light both increase until you reach the stratopause, meaning that the temperature also increases with height through the stratosphere. Above the stratopause, the ozone goes away and the temperature again decreases with height.

4. What is an inversion?

An inversion is a layer of the atmosphere where the temperature increases as you move up, where there is warm air above cold air.

5. Understand the roles of radiation, conduction, convection, and latent heat absorption and release in the transfer of heat in the atmosphere. See Demo 1. How effective is each process?

Radiation is the Earth's only way of exchanging energy with the vacuum of space. We receive energy from the sun mostly in the form of UV, visible, and near infrared radiation. All parts of the Earth's surface and atmosphere are emitting (far) infrared radiation at all times. Some of this emission accounts for the greenhouse effect (radiation emitted by the surface and absorbed by the atmosphere, and radiation emitted by the atmosphere and absorbed by the surface). Some of the emitted infrared radiation escapes to space, allowing the Earth to lose as much energy as it gains from the sun. It is the only form of heat transfer that is always happening at every point of the Earth-Atmosphere system. Radiation is very effective at transporting energy through a vacuum (it's the only way possible). It is only moderately effective at transporting heat in the atmosphere since some of it is absorbed, but some will simply pass through the atmosphere and escape to space.

Conduction is the transfer of energy by molecular motions, and can take place in solids, liquids, or gases. The hotter something is, the faster its molecules are moving. If something hot is next to something cold, the faster moving molecules in the hot area bump into the slower moving molecules in

the cold area, slowing down the fast molecules and warming up the slow molecules, or cooling the hot area and warming the cold area. Conduction is very effective at transporting heat in solids, where molecules are packed tightly together. It is far less effective in a gas, like the atmosphere, where molecules are farther apart, and bump into each other less frequently.

Convection is the transport of heat through bulk (much larger than molecular scale) movements in a fluid (liquid or gas). Convection transports heat when hot air moves to a cold region, or cold air moves to a hot region. Convection is the most effective form of heat transfer in the atmosphere, carrying warm air from the surface to the upper troposphere.

Heat can be transferred from one place to another by moving water, because of the latent heat of evaporation and condensation. Evaporation from the surface will cool that surface. If that evaporated water vapor then moves to a different location, say 5 km up, and then condenses, it releases latent heat, and warms the area in which it is condensing. So, by evaporating water from the ocean and forming a cloud aloft, heat is being moved from the surface to upper levels. Latent heat is an effective way to transport heat in the atmosphere where it operates. It can only operate in regions where there is plenty of water though. This limitation makes it only moderately effective at transporting heat in the atmosphere.

6. Which is hotter, a red star or a blue star? How do you know?
Assuming both stars are the same size, which one emits the most intense radiation?

The blue star is hotter. Hotter objects emit shorter wavelength radiation (sun emits visible, earth emits far IR). The blue star is also emitting the most intense radiation. Objects with a high temperature emit radiation at a greater intensity than objects with a lower temperature. [p. 32 EOM]

7. The sun primarily emits radiation in the ultraviolet, visible and near-infrared. What type of radiation is emitted by the Earth, and how does it differ from the radiation emitted by the sun?

The Earth primarily emits far infrared radiation (5-25 μ m). It differs from sunlight in that it has a longer wavelength.

8. How does surface albedo affect the amount of sunlight absorbed at the surface? How does it affect the surface absorption of infrared radiation emitted by the atmosphere? How does it affect the emission of infrared radiation by the surface? See Demo 2.

The higher the surface albedo, the more sunlight is reflected away from the surface without being absorbed. So a surface with high surface albedo absorbs less sunlight than a surface with low surface albedo. Since the albedo is defined based only on the objects ability to reflect sunlight (or often just visible light), it has no effect on infrared emission or absorption. A white object (very high albedo) will very often absorb just as much far infrared

light as a black object (very low albedo). Since we can't see far infrared light, the only way to tell how much is reflected by an object is to measure it with an instrument designed to see far infrared light.

9. Describe the processes involved in transferring heat between the earth's surface and the atmosphere in relation to the overall earth-atmosphere radiative balance (i.e. the development of thermals, the role of evaporation/condensation, and the influence of clouds and greenhouse gases).

The Earth's surface is warmed by absorption of sunlight and infrared light emitted by the greenhouse gases and clouds in the atmosphere. Some of the radiation absorbed at the surface warms it. The warm surface then warms the lowest few centimeters of air through conduction. This warm air near the surface then becomes less dense than the air above it and rises, mixing with the cooler air aloft, warming the atmosphere through convection.

Some of the radiation absorbed at the surface provides the latent heat to evaporate water. This water is then carried somewhere else (as water vapor, a gas), where it eventually condenses to form a cloud (or dew or frost). In the process of condensing it releases latent heat, and warms its new location.

Finally, some of the energy gained at the surface is lost by emission of infrared radiation by the surface. Most of this emitted infrared energy is absorbed by clouds and greenhouse gases in the atmosphere, warming the atmosphere. The atmosphere also loses energy by emitting infrared energy, some of which reaches the surface (greenhouse effect) and some of which is lost to space, balancing the energy coming in from the sun.

10. Why do clouds at different altitudes look different on an infrared satellite image?

An infrared satellite image is showing how much infrared radiation is being emitted by a surface (the Earth's surface, or a cloud above it). In the image, areas that are emitting very little IR radiation are white, and areas emitting a lot of IR are black. Colder objects emit less IR radiation, and therefore show up on the image as brighter areas. So, a cloud which is cold (high) will look brighter than a nearby cloud which is warm (low).

11. Why do you feel cool after you run under a sprinkler, even if the water temperature is the same as the air temperature?

The water on your body is evaporating, and it is taking the latent heat required to evaporate it from your skin, cooling you off.

12. If the Earth's rotation slowed such that a day lasted 48 hours instead of 24 hours, how would the daily cycle of temperature change? How would the Coriolis force change? What other factors can influence the diurnal temperature range.

During the day, the sun would be warming the surface for 24 hours instead of 12, so the daily high temperatures would increase. Likewise, the surface

could cool at night for 24 hours instead of 12, so nighttime low temperatures would decrease. The average temperature (average of high and low) would remain the same since we would still receive sunlight for half of the time. The Coriolis force would decrease since the rotation rate would have decreased.

Other factor that can increase diurnal temperature range:

Clear skies instead of clouds

Calm instead of windy

Inland instead of near a coast (water temperature remains relatively constant over a day, so places near the water have smaller diurnal temperature ranges)

13. On a winter night, would frost be more likely to form on a car:

If it is clear or if it is cloudy? **Clear**

If it is windy or if it is calm? **Calm**

A clear night allows more surface cooling by reducing the amount of infrared radiation reaching the surface from the atmosphere (clouds are very good at emitting and absorbing IR). A calm night allows more surface cooling by reducing the amount of warm air mixed down to the surface from higher up.

14. Which would be more likely to keep the nighttime temperature warmer, low clouds or high clouds?

Low clouds are generally warmer than high clouds, so they will emit more radiation to keep the surface warm at night.

15. Why is precipitation typically associated with low-pressure systems?

Near the surface, air typically spirals in towards the center of a low-pressure system. As air converges into the region from all directions; since it cannot go into the ground, it must go up. As it rises it cools and eventually forms clouds and precipitation.

16. Why is the annual range of temperature typically smaller in Southern Hemisphere mid-latitudes than in Northern Hemisphere mid-latitudes?

The mid-latitudes of the Southern Hemisphere are dominated by ocean, with very little, if any land at many latitudes. Since water has a higher heat capacity (it requires more energy to warm or cool water) than land, oceans tend to warm less in the summer and cool less in the winter than land, reducing the annual range of temperature over oceans.

17. How do we normally measure the environmental lapse rate? If an air parcel is lifted 1000 meters and cools at the dry-adiabatic lapse rate, where the environmental lapse rate is 8°C per kilometer, will it continue rising, or return to its original height?

We normally measure the environmental lapse rate by launching a balloon carrying a radiosonde, which radios the temperature at different heights in the atmosphere back to the observer. The environmental lapse rate is then determined by seeing how much the temperature decreases with each kilometer of height increase.

If an air parcel is lifted dry-adiabatically 1000 m (1 km) it will cool by 10°C . If the environmental lapse rate is only 8°C per km, then the air around the parcel will be only 8°C cooler than where the air parcel originated. This means that after being lifted 1000 m, the air parcel is 2°C colder than the air around it, and is therefore denser than the surrounding air. Since it is denser, it will sink until it reaches its original height, where it will again be the same temperature as the surrounding air.

18. If there is low pressure to the west and high pressure to the east, which direction does the pressure gradient force act on an air parcel?

The pressure gradient force always acts to move air from high to low pressure, so it will act to move the parcel to the west in this case.

19. Answer the questions based on the wind barb pictured below:



What direction is the wind? **North** (This wind is blowing from north to south, wind direction is always given as the direction from which the wind is blowing.)

What is the wind speed? **25 knots** (50 kts per triangle, 10 kts per long barb, 5 kts per short barb)

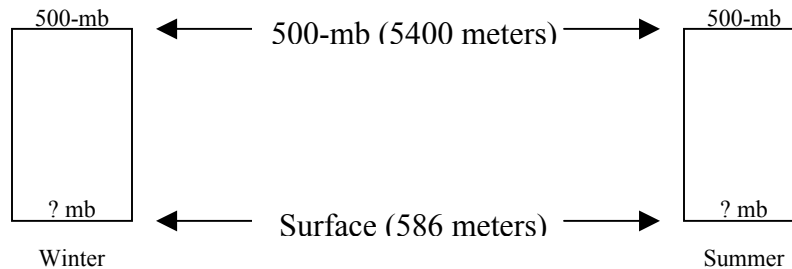
20. What do the values on a 500-millibar map show (i.e., what do the numbers on the chart represent)? **They show the height of the 500-millibar pressure surface above sea level in meters (sometimes in 10's of meters).**

On some random day a 500-mb map shows heights of 5100 meters over Helsinki, Finland and 5320 meters over Athens, Greece. Is the pressure at a height of 5200 meters greater over Helsinki or over Athens?

The pressure at 5200 meters is greater over Athens. In Athens, 5200 meters lies 120 meters below the 500 millibar level, meaning the pressure is *greater than* 500

millibars (pressure decreases with height, increases as you go down). In Helsinki, 5200 meters is 100 meters above 500 millibars, so the pressure must be *less than* 500 millibars. If the pressure at 5200 meters is greater than 500 mb over Athens and less than 500 mb over Helsinki, then the pressure at 5200 meters is obviously higher over Athens than Helsinki.

21. Suppose that on two days, one a cold winter day in January and the other a hot summer day in July, the values on 500-mb maps over Spokane are both 5400m.



Would the surface pressure be greater on the winter day or on the summer day? Why?

The surface pressure would be greater on the winter day.

The heights (and thus volumes) of the two columns are the same, and the cold column is denser, so it contains more mass, resulting in a greater pressure at the surface.

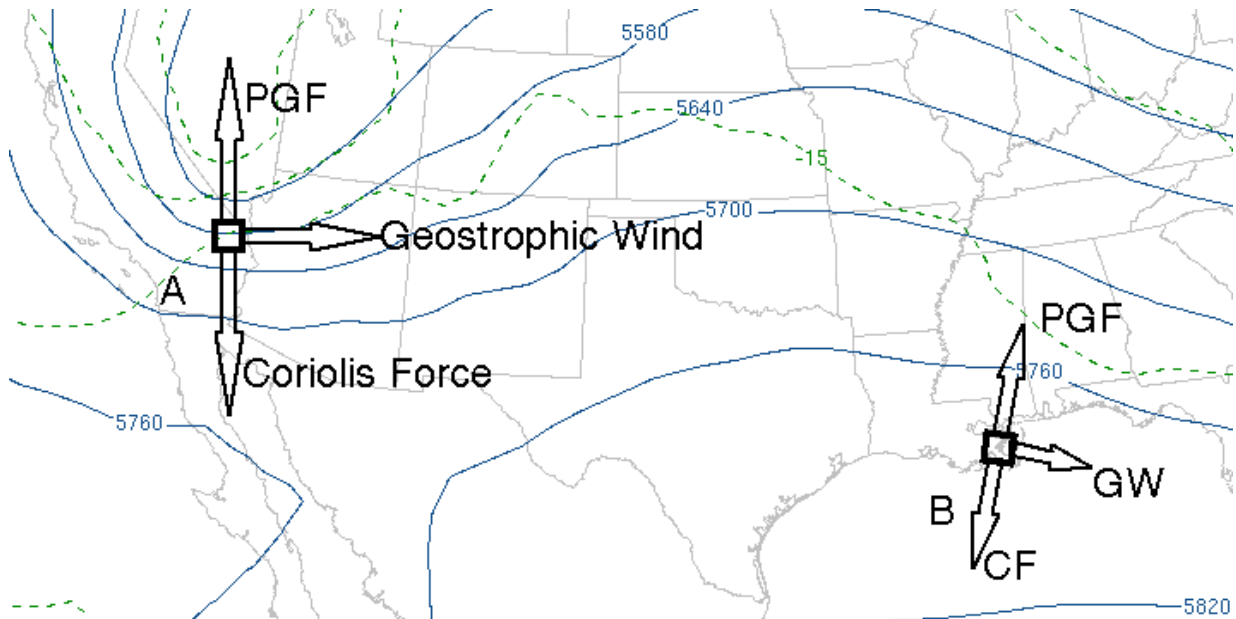
Put another way, because colder air is more dense, pressure changes more rapidly in cold air than warm air when moving vertically, so the total difference in pressure through the cold column between top and bottom must be greater, thus since both have the same pressure at the top the cold column must have a greater surface pressure.

22. What are the forces that determine the wind direction at the surface and at 500mb? What is different at these levels and why?

At the surface the pressure gradient force, the Coriolis force, and friction balance to determine the wind direction, resulting in wind blowing with low pressure to its left (in Northern Hemisphere) and crossing the isobars at a slight angle towards low pressure.

At 500 mb, you are far enough from the rough surface that there is almost no friction, so the pressure gradient force and the Coriolis force balance to determine wind direction, resulting in wind blowing along the isobars with low pressure to its left (in Northern Hemisphere), called the geostrophic wind.

23. The figure below shows the heights of the 500-mb pressure surface with the solid contours on February 2, 2003 over the US. (The dashed contours show temperatures on the 500-mb surface and may be ignored for this question.) Parcels of air at two locations are noted by squares and labeled. Use the map below to answer the following questions.



Around which air parcel (A or B) is the pressure gradient force the greatest?

A. PGF is greater where pressure changes quickly, or where the isobars are closer together.

Around which air parcel is the Coriolis force the greatest?

A. The geostrophic wind speed will (by definition) adjust so that the Coriolis force is the same strength as the PGF.

Around which air parcel is the geostrophic wind the greatest?

A. A larger pressure gradient (closer isobars) will result in a faster geostrophic wind. The wind speed must be faster to allow the Coriolis force to be large enough to balance the larger PGF. (Latitude also affects the Coriolis force, but these points are close enough in latitude that it won't make much difference. Remember that geostrophic balance does not apply in the tropics, where the low latitude makes the Coriolis force much smaller.)

Sketch in and label the pressure gradient force, Coriolis force and geostrophic wind vectors at points A and B (with the tail ends of the vectors all beginning at the square and the arrowheads pointing outward from the square). Please draw to account for the relative magnitude of the force vectors and wind vectors (denoted by the length of the arrows) between air parcels A and B.

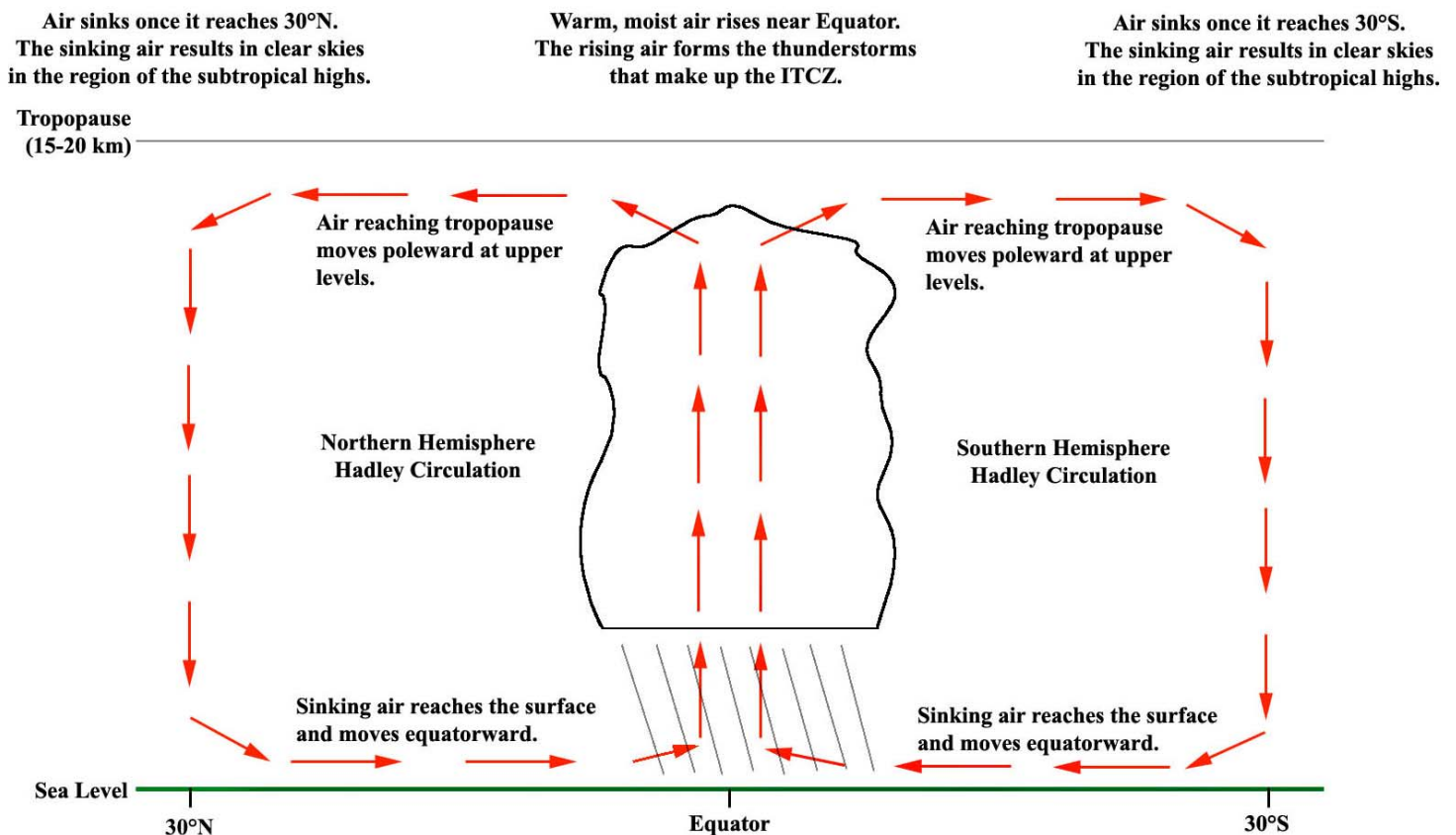
(Answer for last part of 23)

See figure above. Note all arrows are larger for parcel A, consistent with the answers to parts A-C. The arrows represent the forces and the geostrophic wind at the square, but not necessarily the direction of the force or wind at the tip of the arrows.

- Pressure gradient force: points perpendicular to the height contours from high toward low heights (same as from high toward low pressure)
- Geostrophic wind: directed parallel to the height contours with lower heights to the left and higher heights to the right since in the Northern Hemisphere
- Coriolis force: directed 90° to the right of the wind and is equal and opposite to the PGF (since geostrophic wind features a balance between PGF & Coriolis).

24. Describe the Hadley Circulation.

The Hadley Circulation rises near the Equator, where the air is very warm and moist. This rising air causes this area, the intertropical convergence zone (ITCZ) to experience many thunderstorms, and is associated with generally low surface pressure. Air moves in near the surface from the north and south to replace the air that is rising near the Equator. This air forms the near-surface, equatorward moving branch of the Hadley Circulation. Near 30° Latitude, air sinks to replace the equatorward flowing air. This sinking air occurs in the subtropical high pressure regions, where there are generally clear skies, and many of the world's deserts are found. In the upper troposphere, the rising air near the Equator spreads out and flows poleward, until it sinks near 30° Latitude.



25. Why do land surfaces heat and cool differently than nearby bodies of water?

The energy of the sun that is absorbed by the land tends to heat up only a very thin layer right at the surface. Solar radiation striking water may penetrate deeper and is thus absorbed throughout a deeper layer. This coupled with the high heat capacity of water relative to the heat capacity of land makes water heat up and cool off more slowly than land.

How do these differences in heating and cooling of land and water cause land/sea breezes?

If the land heats up more quickly than the water during the day then there will be a pressure gradient force at the surface pointing from the near surface atmosphere over the water (cool and more dense) to the near surface atmosphere over the land (warm and less dense) as the warm air over the land rises. This causes a sea breeze.

The opposite (a land breeze) will happen at night as the land cools more quickly than the water. The warmer air over the water will tend to rise and cool air from the land will flow out to sea to replace it.

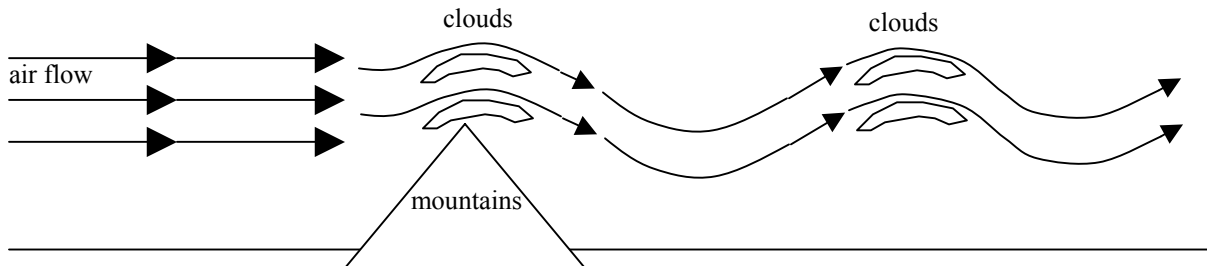
Considering what causes sea breezes, would you expect a stronger sea breeze on an 85°F early summer day in coastal Texas where the sea surface temperatures of the adjacent Gulf of Mexico are 75-80°F or on an 85°F early summer day in coastal central California where the sea surface temperatures of the nearby Pacific Ocean are 55-60°F? Why?

The stronger sea breeze would be over coastal California because the land-sea temperature contrast that drives sea breezes is greater at the Pacific Coast.

Describe how sea breezes influence summertime precipitation over the Florida peninsula.

Sea breezes blow in from the east on the Atlantic side of the state and in from the west on the Gulf side of the state. This movement of air inland, particularly the convergence of the two inland flows from opposite sides of the peninsula, can be the trigger for rain showers to form in the moist, conditionally unstable environment. On a typical summer day there is a short, regular rain shower about 20 km inland from the coast each afternoon that occurs when the land-sea temperature contrast is strong enough to cause a significant sea breeze and the moisture and instability are sufficient.

26. If strong winds are blowing over a mountain peak (or more ideally a line of mountains) waves may form downstream. In such waves, parcels of air that are moving horizontally in the flow also move vertically up and down some distance away from their average height.



Will such waves form in an environment that is stably or unstably stratified?

These waves will form in an environment that is stably stratified (environmental lapse rate is less than the adiabatic lapse rate). If it were unstable, then the parcels forced up as they hit the mountain would be warmer and less dense than the surrounding air, and would keep rising. In a stable atmosphere, the air forced up will cool more quickly than the environmental air does, and end up colder than its environment, causing it to sink back down on the other side of the mountain.