

## Atmospheric Science 101, Spring 2003 Review Sheet for Midterm 2

- **Midterm 2 is in class Thursday May 22. Please bring a scantron for the exam.**

1. **Review Course Notes, Homeworks and Solutions**, as well as **Section Materials**!

2. Match the wind flow to the feature (in the Northern Hemisphere):

- |                                |                                              |
|--------------------------------|----------------------------------------------|
| <u>c</u> Upper-level trough    | a. anticyclonic(clockwise)                   |
| <u>a</u> Upper-level ridge     | b. converging and cyclonic(counterclockwise) |
| <u>b</u> Surface Low Pressure  | c. cyclonic                                  |
| <u>d</u> Surface High Pressure | d. diverging and anticyclonic                |

3. Based on the terms listed below and their definitions answer the following question:

Temperature

Dew Point Temperature

Relative Humidity

Vapor pressure

Saturation vapor pressure

- a. Which of these quantities indicates how much water vapor is in the air

### Dew Point Temperature and Vapor Pressure

The dew point temperature indicates the amount of water vapor in the air, as it is the temperature to which air must be cooled for water vapor to condense. So, higher dew point temperatures indicate more water vapor, and low dew point temperatures reflect little water vapor present. The vapor pressure also gives us insight into the total amount of water vapor in the air, as VP is the pressure exerted by the water vapor molecules in a given volume of air. The higher the vapor pressure, the more water vapor molecules are present in the given volume of air. For each value of vapor pressure, there is one corresponding dew point temperature.

- b. What does it mean for air to be saturated?

For air to be saturated, the given volume of air is holding the maximum amount of water vapor molecules that it can hold. In other words, the vapor pressure (a measure of the amount of water vapor in the volume of air) is equal to the saturation vapor pressure (a measure of how much water vapor that volume of air could possibly hold). When saturated, the temperature equals the dew point temperature and the relative humidity is 100%.

- c. What does the saturation vapor pressure tell us? And what is it dependent on?

The saturation vapor pressure represents the pressure that would be exerted by water vapor molecules in a given volume of air if that volume of air were holding the

maximum amount of water vapor molecules that it can hold at a given temperature. As the temperature increases, the volume of air has the ability to hold more water vapor, thus the saturation vapor pressure increases. If the temperature decreases, the air cannot hold as much water vapor and the saturation vapor pressure decreases.

- d. What can we say about the relative humidity and/or saturation of an air parcel that has reached its dew point temperature?

When an air parcel is cooled to its dew point temperature, condensation will occur and the parcel will be saturated. When this occurs the amount of water vapor in the parcel of air, measured by vapor pressure, will equal the maximum amount of water vapor that air at that temperature has the ability to hold (i.e. saturation vapor pressure). Since the amount of water vapor in the air is equal to the maximum amount of water vapor that air parcel can hold, the relative humidity of that parcel equals 100%.

$$\text{Relative Humidity} = \frac{\text{vapor pressure}}{\text{saturation vapor pressure}} * 100$$

- e. If two air parcels at different temperatures have the same actual vapor pressure, what can be said about the dew point temperature of those parcels? What can you say about the relative humidity of those parcels?

Air parcels with the same vapor pressures have exactly the same amount of water vapor molecules within them, thus the dew point temperature will also be the same. The relative humidity of each parcel will not be the same. Since relative humidity is a measure of the ratio of the amount of water vapor in the parcel, compared to the amount of water vapor that parcel can hold, they will be different. In this case, since the two parcels are at different temperatures, the warmer parcel will have the ability to hold more water vapor than the cooler one (i.e. the warmer parcel will have a higher saturation vapor pressure), this results in the relative humidity being lower for the warmer parcel.

- f. Name two ways you can change the relative humidity of an air parcel.

The relative humidity depends on both the amount of water vapor in the air, and the amount of water vapor that air can hold.

One way to change the RH would be to keep the temperature of the parcel constant (this would mean that the saturation vapor pressure, or the maximum amount of vapor that air can hold would not change) and change the amount of water vapor in the parcel (i.e. change the parcel's vapor pressure).

Another way to change the RH would be to change the temperature of the parcel, while keeping the amount of water vapor within the parcel constant. Since by changing the temperature we can increase/decrease the amount of water vapor that parcel can hold by warming/cooling its temperature, this would also change the RH. For example, cooling the parcel would decrease the amount of water vapor that

**parcel could then hold, which reduces the parcel's saturation vapor pressure. Since the vapor pressure was unchanged, the relative humidity will increase.**

4. A saturated air parcel cools at the moist adiabatic lapse rate which is 6 °C/km. An unsaturated air parcel cools at the dry adiabatic lapse rate which is 10 °C/km.

Describe why these lapse rates are different.

**When a saturated parcel is lifted, it cools at the moist adiabatic lapse rate of 6 °C/km, which is cooling less quickly than the dry adiabatic lapse rate of 10 °C/km due to the release of latent heat associated with the process of condensation (phase transition of water vapor to liquid water).**

5. Define and give an example of each fog type:
- Steam fog – forms when warm, moist air mixes with cold air. Ex: fog seen atop pavement following a rain shower, as a result of the sunlight heating the asphalt which quickly evaporate the water along the pavement. The added vapor mixes with the air above it, producing steam fog.**
  - Radiation fog – produced as a result of the earth's radiational cooling which sets up a shallow layer of cold air near the ground, overlain by warmer air. The cold air is cooled to its dew point temperature, causing condensation. Ex: fog nestled in the relatively cool valley (EOM p.88 Fig. 4.14)**
  - Upslope fog – forms as a result of air flowing up along an elevated plain, hill, or mountain. As it rises, it cools adiabatically, eventually reaching its dew point temperature. Ex: fog forming on the eastern slopes of the Rockies.**
  - Advection fog – the result of warm moist air moving over a sufficiently colder surface, allowing the moist air to cool to its saturation point. Ex: fog rolling past the Golden Gate Bridge in San Francisco (EOM p. 89 Fig 4.15)**
6. Describe what happens to a storm system as it progresses across a mountain range such as the Rockies. Does the cyclonic circulation in the storm strengthen/weaken as it moves over the mountains? Does the cyclonic circulation in the storm strengthen/weaken as it moves into the lee of the mountains? What is responsible for the changes in storm intensity?

**As the storm system, which can be thought of as a vertical column of spinning air, moves over the Rockies, the bottom of the storm is pushed upward by the rising terrain while the bottom of the stratosphere acts as a lid on its top. The storm has then become a short, fat column of air once over the mountain peaks. This squashing of the spinning air column reduces the relative vorticity (vorticity = 'spin' of air about the vertical axis) resulting in a weakened cyclonic circulation (this is**

analogous to an ice-skater extending his/her arms resulting in decreased spin). When the short, squashed storm then moves into the lee of the mountain range, the bottom of the column of air descends along the terrain, causing the entire column of spinning air to stretch out. This stretching of the air column increases the relative vorticity within the storm, meaning that the cyclonic circulation increases (this is analogous to an ice-skater pulling his/her arms inward resulting in increased spin). In each of these cases, the squashing and stretching of the air column, which results in relative vorticity changes is responsible for the changes in the intensity of circulation within the storm.

7. What are cloud condensation nuclei, and what is their role in the formation of clouds? What served as CCN in the 'cloud in the bottle' demonstration done in section? Give two examples of naturally occurring CCN.

Cloud condensation nuclei are tiny particles upon whose surfaces condensation of water vapor begins in the atmosphere. For the 'cloud in the bottle' demo performed in section, the smoke from an extinguished match served as the tiny particles upon which water condensed to form the 'cloud'. A few naturally occurring CCN include: salt from ocean spray, fine dust particles, and smoke from fires.

8. Describe how the separation of charge within a thunderstorm develops.

While still not completely understood, scientists believe that the separation of charge develops within thunderstorms as a result of collisions between large and small ice particles, as well as collisions between ice crystals and supercooled water droplets within the cloud. Following collisions, the smaller particles become positively charged, while the larger precipitation particles become negatively charged. Updrafts within the thunderstorm are then able to transport the small, lighter, particles that have the positive charge into the upper levels of the storm cloud, while the heavier particles, which are negatively charged settle towards the bottom of the cloud, setting up a separation of charge between the top and bottom of the cloud. This separation of charge sets the environment for lightning to occur.

9. Describe the growth of precipitation in warm clouds and cold clouds (i.e. the processes of Collision-Coalescence in warm clouds, and the Bergeron process in cold clouds).

Precipitation sized water droplets form in warm clouds (clouds that have above-freezing temperatures at all levels which can occur within clouds in the tropics) by a process called collision-coalescence. The collisions between droplets of varying sizes occurs due to the fact that the droplets, since their size varies, fall at differing speeds. As a result, larger droplets fall through the cloud more quickly than smaller droplets, thus allowing for the large droplets to collect small droplets as they fall into (collide with) them. This results in the large droplets growing even larger before falling out of the cloud.

The process of precipitation growth is different in cold clouds (clouds that exist having some of its levels at temperature below freezing which is typical of clouds at

middle and high latitudes). The ice-crystal process, or Bergeron process, occurs in these clouds when both supercooled water droplets and ice crystals co-exist. The ice crystals in this type of environment can grow at the expense of the supercooled droplets, because as vapor is deposited onto ice crystals, the vapor pressure of the air is lowered, making room for the supercooled droplets to evaporate. This occurs because the saturation vapor pressure just above the water surface is greater than the saturation vapor pressure above the ice surface. As the supercooled water droplets evaporate, they supply the vapor that is then added (by deposition) to the ice crystals, causing them to grow in size.

10. How is the stability of a layer of the atmosphere determined? What is the difference between absolutely stable, absolutely unstable, and conditionally unstable?

The stability of a layer can be determined by computing the environmental lapse rate (i.e. the amount of cooling with height) and use it to compare the environmental lapse rate to the moist and dry adiabatic lapse rate. The moist and dry adiabatic lapse rates represent the rate of cooling an air parcel would experience if lifted, whereas the environmental lapse rate is the actual temperature profile at that location as measured by a radiosonde.

An absolutely stable environment means that as an air parcel is taken from the environment and lifted, the parcel will sink at any level (as it will be cooler than the environmental air at any level). To ensure that the parcel will be stable whether it is lifted as a saturated parcel (i.e. following the moist adiabatic lapse rate) or it is lifted as an unsaturated parcel (i.e. following the dry adiabatic lapse rate), the environmental lapse rate must be less than  $6^{\circ}\text{C}/\text{km}$ .

An absolutely unstable environment means that if we lift an air parcel following either the moist or dry adiabatic lapse rate, that parcel will always be warmer than the environmental air at a given level and will always be positively buoyant and continue to rise. For this case to be satisfied, the environmental lapse rate must be greater than  $10^{\circ}\text{C}/\text{km}$ .

A conditionally unstable environment is one in which the environmental lapse rate is greater than  $6^{\circ}\text{C}/\text{km}$  but less than  $10^{\circ}\text{C}/\text{km}$ . In a conditionally unstable environment, a parcel that is saturated, and therefore being lifted at the moist adiabatic lapse rate will cool more slowly than the surrounding environmental air, and thus will be buoyant and continue to rise at a given level. However, an unsaturated air parcel which is lifted and cooled at the dry adiabatic lapse rate of  $10^{\circ}\text{C}/\text{km}$  will be cooling at a rate faster than the environmental lapse rate, therefore the parcel will be colder than the surrounding environmental air at a given level and would want to sink.

11. Describe the differences between clouds formed in an absolutely stable environment versus those clouds formed in a conditionally unstable environment.

In an absolutely stable environment, clouds cannot develop much in the vertical direction, as a lifted air parcel will not become positively buoyant enough to freely rise throughout large depths of the atmosphere. For this reason, we would most likely expect thin 'sheet-like' or stratus clouds in an absolutely stable environment. In a conditionally unstable environment, however, air parcels that reach saturation cool at a rate of  $6^{\circ}\text{C}/\text{km}$ , which is less than the environmental lapse rate (as a conditionally unstable atmosphere has a lapse rate that is greater than  $6^{\circ}\text{C}/\text{km}$  but less than  $10^{\circ}\text{C}/\text{km}$ ). Since the moist air parcel cools more slowly with height than the surrounding environmental air, the air parcel will be positively buoyant (rises) and can rise very high resulting in towering cloud tops. Clouds such as cumulus and cumulus congestus clouds, which can have large development in the vertical direction, can form in a conditionally unstable environment.

12. Clouds are categorized by their level in the atmosphere, as well as their shape or characteristic weather. List the various types of cloud categories and names associated with each, as well as the height criteria used for naming them.

#### **Cloud Types**

Stratus ('layer') – sheet-like clouds  
Nimbus ('rain') – rain clouds  
Cirrus ('strand of hair') – wispy clouds  
Cumulus ('heap') – puffy clouds  
Lenticular – lens-shaped  
Mammatus – resemble a cow's udder  
Nacreous – mother-of-pearl clouds  
Noctilucent – luminous night clouds

#### **Height Criteria**

High clouds (6 km – tropopause) – ice crystals  
Middle clouds (2-6 km) – 'Alto'  
Low clouds (0-2 km above surface)  
Clouds with vertical development

13. When identifying surface fronts on a surface map, what features would you look for in the case of a warm front, in the case of a cold front, or an occluded front? Draw vertical cross-sections of each case. What are the similarities and differences between a cold and warm front? Why do we see increased clouds cover and precipitation along a frontal boundary?

**Features to look for on a surface map when identifying fronts include: wind shifts, 'kinks' in isobars, strong temperature gradients, and clouds and precipitation.**

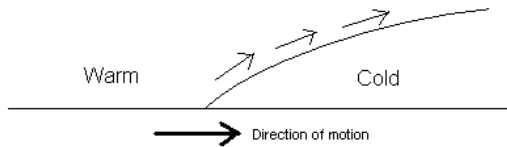
When a cold front is present, typically there exists a wind shift from west or northwest winds on the cold temperature side of the cold front, and southerly winds on the warm side. The front is located at the warm edge of the intense temperature gradient separating the cold air mass, which is moving into the warm air mass. The cold front also typically lies along a trough (or kink) in the surface isobars. Clouds

and precipitation are often time found immediately along the cold front in the region of rising air.

A warm front is a boundary existing in an area in which a warm air mass is pushing into a relatively cooler air mass. Again, the location of the front will lie along the warm edge of a strong temperature gradient, coincide with 'kinks' in the isobars, and will likely have a wind shift from southerly winds on the warmer side of the warm front, to easterly winds on the cooler side. Clouds and precipitation, although often times less intense than in the case of a cold front exist along and ahead of a warm front.

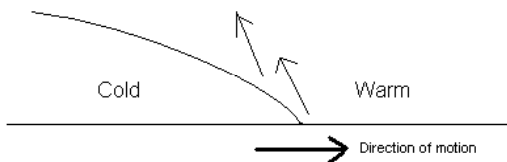
An occluded front exists in an area where the cold front has caught up to the warm front. This causes the warmest air to wedge upward between the coldest air (that is behind the cold front) and the cooler air (that was ahead of the warm front). Since this warm air is wedged upward, clouds and precipitation are also often observed in an area where and occluded front is present.

#### Warm Front



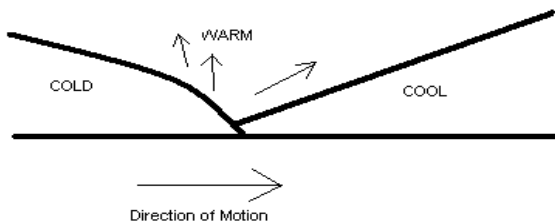
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#### Cold Front



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#### Occluded Front



A warm front and cold front are similar in that in each case warm, less dense air, is forced to rise due to its interaction with a cold, more dense, air mass. Both cold and warm fronts are also characterized by kinks in the surface pressure contours as well as wind shifts across each type of front. The wind shifts, while present in each case, shift from differing directions in each case, but are typically present for both. Another difference between the cold and warm front is the intensity of precipitation along each. The slopes of the leading edge of a cold front is typically more dramatic

than the slope of a warm front, which results in more intense lifting immediately along the cold front than compared to the gradual lifting along the warm front. As a result, the most intense precipitation typically occurs along the cold front.

14. Describe the major characteristics of an El Niño event. How does El-Niño influence the weather in the Pacific Northwest?

During an El Niño event, the surface atmospheric pressure patterns break down, as air pressure rises over the western Pacific and falls over the eastern Pacific. This change in pressure weakens the easterly trade winds along the equator. As a result the depth of the warm surface water in the west Pacific decreases, and the depth of the warm surface water in the eastern Pacific increases. The decrease in the easterly winds as well as the deepening of the thermocline in the eastern Pacific causes upwelling along the west coast of South America to be shut off, resulting in poor fishing in the area. Also, due to the decrease in pressure over the eastern Pacific, increases clouds and precipitation also occur in that area during an El Niño event. For Seattle, El Niño tends to bring a warm and wet late winter and spring. However, only 25% of our winter-to-winter variability is connected to El Niño.

15. Name and describe the three stages of the life of an air-mass thunderstorm.

An air-mass thunderstorm forms in warm air masses away from fronts, where winds are light at all levels, and typically last between 30 and 60 minutes. This type of thunderstorm goes through a three-stage cycle: the cumulus stage, the mature stage, and the dissipating stage.

**Cumulus stage** - The primary characteristic of this stage is the existence of a cloud filled updraft (region of rising air). In this stage, precipitation typically has not yet formed nor has a downdraft developed.

**Mature stage** – The downdraft develops in this stage, as large precipitation particles begin to get too large to remain suspended in the cloud. The falling precipitation drag surrounding air down and create the downdraft (region of sinking air). As the precipitation falls, some evaporates when it encounters the relatively drier air below the cloud, which results in cooling. This makes the downdraft cool and therefore dense causing it to want to continue to descend to the ground. The updraft reaches its maximum height, which corresponds to the top of the conditionally unstable layer during this stage as well.

**Dissipating stage** – In this stage, the downdraft chokes off the low-level updraft that was once feeding into the cumulus cloud. This results in the evaporation of the low-level cumulus cloud leaving only the high anvil as a remnant of the once mature thunderstorm.

16. Describe the differences and/or similarities between the following pairs of terms:

a. freezing rain and sleet

Sleet is a result of the re-freezing of melted snow, or the freezing of rain droplets that fall through a depth of sub-freezing (below 0°C) temperatures at least 500 meters thick above ground level. Freezing rain occurs when the depth of sub-freezing temperature is less than 500 meters thick. Since the layer is too thin to completely freeze the water drops into sleet, the drops instead do not freeze until coming into contact with objects on the ground, this is called freezing rain. Freezing rain can be quite hazardous, as it allows for the accumulation or build-up of layers of ice on anything it comes into contact with at the ground that is below freezing (for example, trees and power lines coated with ice can become very heavy and fall to the ground).

b. graupel and hail

Both graupel and hail form in clouds having vigorous updrafts with abundant supercooled drops. Graupel forms as larger, faster-falling ice crystals falling through the cloud accrete droplets (are coated by the supercooled water which then freezes to the outside of the ice crystal). The same process acts in the formation of hail in cumulonimbi with strong updrafts, which can suspend even larger pieces of ice.

c. virga and fall streaks

The process of evaporation is important for both virga and fall streaks. Virga is evaporating streaks of rain falling from a cloud (i.e. liquid precipitation from a cloud that evaporates and cools the air below the cloud before it can reach the ground in liquid form). Fall streaks, sometimes called 'Mare's Tails' due to their appearance, form as a result of evaporating streaks of ice crystals.

17. Precipitation radars can sometimes be used to determine the profile of wind with height, but at other times cannot. Based on how precipitation radars function, what limits their ability to produce wind profiles? During the times when the precipitation radar cannot produce a wind profile, describe an alternative way to obtain wind profile data.

Precipitation radars work by sending pulses of electromagnetic radiation (with wavelengths of 5 cm) out into the atmosphere. These pulses then reflect off water droplets, dust, insects, etc. in the air, and a signal is sent back and received at the radar site. A Doppler radar can also measure the speed of raindrops towards or away from the radar site based on the reflected pulses received. By using the reflected pulses to determine if drops are moving away from or towards the radar, we can then infer the direction the droplets are being blown by the wind, giving us wind data. Since the air is clear (i.e. there are no rain droplets to reflect the pulses sent out by the radar) we cannot determine the wind data. During these times, we can turn to the use of a wind profiler, which emits a longer 60 cm wavelength and is able to detect inhomogeneities in the moisture and temperature of the air instead of relying on raindrops to reflect the pulse back.

18. How would a drought in the Pacific Northwest be reflected in the snow pack atop local mountains? What would be some of the implications of such a change in snow pack?

**A drought (a period of abnormally dry weather) in the Pacific Northwest would result in a diminished depth of snow atop the mountains in the area. This can have several implications including: reduced water necessary for agricultural needs, hydropower, and urban use. The decrease in the snow pack can also cause the land to dry out more quickly leading to increased chances of summer forest fires.**

19. Before entering a forecast in the 101 forecasting competition you may choose to look at a forecast map from an atmospheric model. The first step in producing these types of maps is the acquisition of data. Describe some of the ways that this data is collected; include examples of data collected at the surface and at upper-levels.

**Weather data is collected in a variety of ways at both the surface and in the atmosphere above the surface. A network of weather stations and observers collects surface data where there is land with people/instrumentation taking measurements. Surface data is collected over the oceans via buoys and commercial ships. Weather data for the upper-levels of the atmosphere is collected in a variety of ways including: launching radiosondes, the use of pilot balloons, as well as the use of geostationary and polar orbiting satellites.**

20. How is the accuracy of forecast weather maps determined? How has our ability to forecast weather changed over the last 2 decades?

**The accuracy of a forecast weather map is determined by comparing values on the forecast weather map to the actual analysis of data at the same time that had been forecast. Over the last 2 decades, weather forecasting has shown improvements, as a 10-day forecast in the year 2000 has as much forecast skill as a 7-day forecast made in 1990, and a 4-day forecast made in 1980. Similarly, a 7-day forecast in 2000 has as much skill as a 5-day forecast made in 1990, and a 3.5-day forecast made in 1980. The forecast skill is also the same between a 5-day forecast made in 2000, a 3-day forecast made in 1990, and a 1.5-day forecast in 1980. In conclusion, forecasters in the year 2000 can make forecasts into the future for more days at the same accuracy as those for only a few days 2 decades ago.**

21. List the following atmospheric variables from 1(most predictable) to 4(least predictable).

- |                  |     |
|------------------|-----|
| a. Pressure      | (1) |
| b. Precipitation | (4) |
| c. Temperature   | (3) |
| d. Wind          | (2) |