Bernd Richter Marine Meteorology

2022/23 Klausur/Test (H) 90 Min 08.03.2023 13:00 – 14:30 Hörsaal 200

Questions and examples of answers **sufficient for full score**

1. 8 Points: Which physical variables describe the humidity of air?

   a. Give examples of humidity parameters (4 P)

Here are some examples of humidity parameters:

2. Relative humidity (RH): This is a measure of the amount of moisture in the air compared to the maximum amount of moisture the air can hold at a given temperature. It is usually expressed as a percentage.
3. Dew point: This is the temperature at which the air would become saturated with water vapor, leading to the formation of dew. It is a good indicator of how much moisture is in the air.
4. Absolute humidity: This is the measure of the actual amount of moisture in the air, expressed in grams of water vapor per cubic meter of air.
5. Mixing ratio: This is the ratio of the mass of water vapor to the mass of dry air in a given volume of air. It is often used in meteorology to describe the amount of moisture in the atmosphere.
6. Specific humidity: This is the ratio of the mass of water vapor to the total mass of the air in a given volume of air. It is often used in atmospheric science to
7. describe the moisture content of the air.

Give a typical humidity problem with the best suited parameter (4 P)

A typical humidity problem could be: "How can we determine if the air is too humid for comfort in a room with a temperature of 25°C?"

In this case, the best parameter to use would be relative humidity (RH), as it provides a measure of the amount of moisture in the air compared to the maximum amount of moisture the air can hold at a given temperature.

To solve the problem, we would need to measure the absolute humidity of the air in the room, and then use the temperature to calculate the maximum amount of moisture the air can hold (also known as the saturation point). We could then calculate the relative humidity using the formula:

RH = (Absolute humidity / Saturation point) x 100%

If the relative humidity is above a certain threshold, such as 60%, it may indicate that the air is too humid for comfort, which could lead to problems such as mold growth, musty smells, and respiratory issues. In this case, it may be necessary to take steps to reduce the humidity, such as using a dehumidifier or improving ventilation.

8. 6 Points: Which types of fog do you know? Describe the typical process of forming. (6 P)

There are several types of fog that can occur, each with its own unique characteristics. Here are some of the most common types of fog:

1. Radiation fog: This type of fog forms on clear, calm nights when the ground cools rapidly, causing the air near the ground to cool and condense. It is most common in autumn and winter, and can last for several hours after sunrise.
2. Advection fog: This type of fog forms when warm, moist air moves over a colder surface, causing the air to cool and condense. It is common in coastal areas, and can last for several days.
3. Upslope fog: This type of fog forms when moist air is forced up a slope or mountain, causing it to cool and condense. It is most common in hilly or mountainous regions, and can last for several days.
4. Evaporation fog: This type of fog forms when cold air moves over a warm, moist surface, causing the moisture to evaporate and condense into fog. It is most common in the winter when cold air moves over a warm body of water.
5. Steam fog: This type of fog forms when cold air moves over a warm body of water or moist ground, causing the moisture to evaporate and condense into fog. It is most common in the winter when cold air moves over a warm body of water or moist ground.
6. Freezing fog: This type of fog forms when the temperature is below freezing, and the fog droplets freeze upon contact with surfaces, creating a layer of ice. It can be hazardous for transportation and can cause icy roadways and other surfaces.

Describe the typical process of forming.

Fog forms when the air is cooled to the point where it can no longer hold all of the moisture it contains in the form of water vapor. The cooling causes the water vapor to condense into tiny droplets, which become suspended in the air, creating a visible cloud near the ground. The process of fog formation can occur through several mechanisms:

1. Radiation cooling: On clear, calm nights, the ground can radiate heat back into the atmosphere, causing the air near the surface to cool. If the temperature drops to the dew point, the moisture in the air can condense into fog.
2. Advection cooling: When warm, moist air moves over a cold surface, such as a body of water or cold landmass, it can cool and condense into fog.
3. Upslope cooling: As moist air is forced up a slope or mountain, it can cool and condense into fog.
4. Frontal lifting: When warm air meets cold air, it can be forced to rise and cool, leading to the formation of fog.

Once the air is cooled to the dew point and the moisture condenses into droplets, the fog can persist as long as the air remains cool and humid. In some cases, the fog can become thick and reduce visibility, creating hazardous conditions for transportation and outdoor activities. As the air warms or the humidity decreases, the fog will gradually dissipate, and the droplets will evaporate back into the air.

9. 2 Points: How can you define the meteorological visibility? (2 P)

Meteorological visibility refers to the distance an observer can see and identify prominent objects or landmarks in the atmosphere, such as mountains, buildings, or other features. It is a measure of how far light can travel through the atmosphere before being scattered or absorbed by particles such as water droplets, dust, or pollutants. Meteorological visibility is influenced by various factors, including the amount of moisture in the air, the concentration of particles in the atmosphere, and the angle and intensity of sunlight. It is typically measured in units of distance, such as meters or kilometers, and can be reported in various ways, including prevailing visibility, minimum visibility, and runway visibility. The World Meteorological Organization defines visibility as the greatest distance at which a black object of suitable dimensions can be seen and recognized when observed against a bright background. Meteorological visibility is important for various applications, including aviation, maritime operations, and transportation safety.

10. 10 Points: What determines the layer thickness 500 over 1000 hPa (rel. topography)? (2 P)

The thickness of the layer between 500 hPa and 1000 hPa is determined by the average temperature of the layer. This thickness is often used as a measure of the depth of the layer, which can provide useful information about the atmospheric conditions.

The thickness of the layer is related to the average temperature because temperature generally decreases with altitude in the troposphere, which is the lowest layer of the Earth's atmosphere where weather occurs. The thickness between two pressure levels is inversely proportional to the average temperature of that layer. This relationship is described by the hypsometric equation, which relates the thickness of a layer to the average temperature, pressure, and gravitational acceleration.

The thickness between 500 hPa and 1000 hPa is often used as a measure of the depth of the layer because this range is near the middle of the troposphere and is an important region for many atmospheric processes. For example, the thickness between these two levels is often used to estimate the stability of the atmosphere and to identify areas of potential weather disturbances, such as troughs or ridges in the upper-level flow.

a. What is the consequence for the thickness of this layer extending over an area of different vertical average temperature? (4 P)

f the thickness of the layer between 500 hPa and 1000 hPa extends over an area with different vertical average temperatures, the thickness of the layer will vary across that area. This is because the thickness of the layer is determined by the average temperature of the layer, which is related to the vertical temperature profile of the atmosphere.

For example, if a warm air mass with a higher average temperature is situated over an area, the thickness of the layer between 500 hPa and 1000 hPa will be greater than over a nearby area with a colder air mass with a lower average temperature. This is because the warmer air mass will have a lower lapse rate (rate of temperature decrease with height) and therefore a higher average temperature over the layer, resulting in a thicker layer between the two pressure levels.

Conversely, if a cold air mass with a lower average temperature is situated over an area, the thickness of the layer between 500 hPa and 1000 hPa will be smaller than over a nearby area with a warmer air mass with a higher average temperature. This is because the colder air mass will have a higher lapse rate and therefore a lower average temperature over the layer, resulting in a thinner layer between the two pressure levels.

The variation in thickness of the layer between 500 hPa and 1000 hPa across an area with different vertical average temperatures can have important implications for atmospheric stability, moisture transport, and the formation and evolution of weather systems.

b. What results for the 500 hPa layer height (absolute topography) over an area of varying vertical average temperature if the MSL pressure is constant?? (4 P)

If the mean sea level (MSL) pressure is constant, the height of the 500 hPa pressure level (known as the geopotential height or absolute topography) will vary over an area with different vertical average temperatures. This is because the geopotential height is determined by the temperature and pressure profile of the atmosphere, which can vary across an area.

The geopotential height is a measure of the height above mean sea level that a pressure level (in this case, the 500 hPa pressure level) would be located at in a hypothetical atmosphere with a uniform temperature and constant gravity. The actual height of the 500 hPa pressure level will vary from this hypothetical height due to variations in temperature and pressure across an area.

If the MSL pressure is constant, the pressure gradient force (the force that causes air to move from high pressure to low pressure) is also constant.

Therefore, if the temperature decreases with height (as is typical in the troposphere), the pressure level surfaces will be closer together, resulting in a lower geopotential height for the 500 hPa pressure level. Conversely, if the temperature increases with height, the pressure level surfaces will be farther apart, resulting in a higher geopotential height for the 500 hPa pressure level.

Therefore, over an area with varying vertical average temperatures and constant MSL pressure, the geopotential height of the 500 hPa pressure level will vary depending on the temperature profile of the atmosphere. This variation in geopotential height can have important implications for atmospheric dynamics, weather patterns, and the formation and evolution of weather systems.

11. 15 Points: The dynamic consequence of an air pressure field with areas of higher and lower pressure (pressure gradient) is wind. Answer the following questions

a. Which forces change a pressure field with a pressure difference on the rotating Earth? (3 P)

On a rotating Earth, there are three primary forces that affect the pressure field and cause pressure differences:

1. Pressure gradient force: This force arises due to pressure differences across an area. Air naturally flows from areas of high pressure to areas of low pressure, which results in a pressure gradient force that acts to equalize pressure differences. The strength of this force is determined by the magnitude of the pressure difference and the distance over which it changes.
2. Coriolis force: This force arises due to the rotation of the Earth. As air moves horizontally, it experiences an apparent force that is perpendicular to its direction of motion, known as the Coriolis force. This force is strongest at the poles and weakest at the equator and causes air to deflect to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.
3. Frictional force: This force arises due to interactions between the air and the Earth's surface. As air moves over the surface, it experiences frictional drag, which slows its motion and reduces the effect of the pressure gradient force and Coriolis force. The strength of the frictional force is influenced by the roughness of the surface and the speed of the air flow.

Together, these three forces influence the movement and behavior of air in the atmosphere, causing pressure differences to change and resulting in the formation of weather patterns and other atmospheric phenomena.

How does the curvature of isobars affect the windspeed? (3 P)

The curvature of isobars, which are lines connecting points of equal pressure on a weather map, can have a significant impact on the speed of winds in the atmosphere. The curvature of isobars is related to the magnitude of the pressure gradient force, which acts to accelerate air from areas of high pressure to areas of low pressure.

If the isobars are straight and evenly spaced, it indicates that the pressure gradient force is constant across the area, and the resulting winds are generally steady and uniform in speed. However, if the isobars are curved, it indicates that the pressure gradient force is changing across the area, resulting in changes in wind speed and direction.

When the isobars are closely spaced and curved, such as in a cyclone or low-pressure system, the pressure gradient force is relatively strong and causes the winds to increase in speed. This is because the air is being forced to accelerate around the low-pressure center, resulting in faster wind speeds.

Conversely, when the isobars are widely spaced and relatively straight, such as in a high-pressure system, the pressure gradient force is relatively weak, and the resulting winds are generally slower and weaker. This is because the air is not being forced to accelerate as strongly, and there is less of a pressure difference to drive the air flow.

Therefore, the curvature of isobars is an important factor in determining wind speed, as it reflects the strength and direction of the pressure gradient force acting on the atmosphere.

How does friction affect the windspeed and -direction? (3 P)

Friction between the atmosphere and the Earth's surface can have a significant impact on the speed and direction of wind in the lowest layer of the atmosphere, known as the boundary layer. This is because friction acts to slow down the horizontal movement of air near the surface, reducing the effect of the pressure gradient force and altering the direction of air flow.

When there is little or no friction, such as in the free atmosphere above the boundary layer, wind speeds are generally faster and more closely aligned with the direction of the pressure gradient force. However, as air moves closer to the Earth's surface, it encounters increasing amounts of friction, which slows down the wind speed and causes the direction of air flow to deflect towards the right in the Northern Hemisphere and towards the left in the Southern Hemisphere due to the Coriolis effect.

In the boundary layer, friction also results in the formation of turbulent eddies and vertical mixing of air, which can further alter the speed and direction of wind. For example, when wind flows over a rough surface, such as a forest or urban area, the turbulent eddies and mixing can cause the wind to be deflected and slowed down, resulting in lower wind speeds and altered wind direction compared to areas with smooth surfaces.

In addition, the strength of the frictional force is influenced by the roughness of the Earth's surface, with rough surfaces causing greater amounts of friction and smoother surfaces causing less. This means that wind speeds and directions can vary significantly depending on the nature of the Earth's surface over which the wind is flowing.

Therefore, friction plays an important role in determining wind speed and direction in the boundary layer, where surface effects are most pronounced, and can result in significant differences in wind behavior compared to the free atmosphere.

What are the synoptic consequences of friction in a low pressure area? (3 P)

Friction can have important synoptic consequences in a low-pressure area, particularly in the boundary layer where surface effects are most pronounced. In a low-pressure area, air flows from areas of high pressure towards the center of the low-pressure system, resulting in converging airflows near the surface.

As this air converges towards the low-pressure center, friction between the air and the Earth's surface causes the air to slow down, reducing wind speeds and altering the direction of air flow. This causes the formation of a zone of low-level convergence near the surface, where air is converging towards the center of the low-pressure system.

This low-level convergence can result in the formation of clouds and precipitation in the low-pressure area, as rising air cools and condenses, leading to the development of weather systems such as storms or cyclones. The strength and location of this convergence zone can also have important synoptic consequences, influencing the development and movement of weather systems and their associated fronts.

In addition, friction can cause the low-pressure system to be displaced from its ideal location, particularly if it is situated over a rough or complex surface such as a mountain range or coastline. This can cause the low-pressure center to become displaced, leading to changes in the location of the associated weather systems and fronts.

Therefore, friction plays an important role in the synoptic behavior of low-pressure systems, particularly in the boundary layer where surface effects are most pronounced, and can have important consequences for weather patterns and the development of weather systems.

What is super-geostrophic wind? (3 P)

Super-geostrophic wind refers to wind speeds that are greater than the theoretical speed predicted by the geostrophic wind equation. The geostrophic wind equation describes the balance between the Coriolis force and the pressure gradient force, which determines the direction and magnitude of wind at upper levels in the atmosphere.

Under certain conditions, such as when there is a strong gradient in the height of the pressure surfaces, wind speeds can exceed the predicted geostrophic speed, resulting in super-geostrophic winds. This occurs because the pressure gradient force is not the only force acting on the air, and other factors such as the centrifugal force and the curvature of the pressure surfaces can also play a role in determining the wind speed and direction.

Super-geostrophic winds are typically found in the lower atmosphere, where the effects of friction and other factors not accounted for in the geostrophic wind equation become more important. These winds can have important implications for aviation and other activities that rely on accurate wind speed and direction information.

It is important to note that super-geostrophic wind is a relatively rare phenomenon and is typically associated with certain types of weather systems, such as cyclones or thunderstorms, where the conditions required for the phenomenon to occur are present.

12. 26 Points: The temperature T normally decreases with height (vertical T-gradient)

    a. Give a typical value for the vertical T-gradient in the dry atmosphere? (2P)

In the dry atmosphere, the typical value for the vertical temperature gradient is known as the dry adiabatic lapse rate, which is approximately 9.8°C per kilometer (or 5.4°F per 1000 feet) of altitude. This value describes the rate at which temperature decreases with increasing altitude in a dry environment where no condensation or precipitation is occurring.

However, it is important to note that the actual temperature gradient in the atmosphere can vary significantly depending on a variety of factors, including moisture content, solar radiation, atmospheric pressure, and local geography. In addition, atmospheric conditions such as inversions, fronts, and other weather patterns can also cause the temperature gradient to deviate from the dry adiabatic lapse rate, leading to significant variations in temperature with altitude.

b. How does the vertical T-gradient change for moist air and condensation? (2P)

The vertical temperature gradient for moist air and during condensation is different from the dry adiabatic lapse rate of approximately 9.8°C per kilometer. In the presence of moisture, the rate at which temperature changes with height is slower than the dry adiabatic lapse rate due to the release of latent heat during the process of condensation.

As air rises, it cools and eventually reaches its dew point temperature, which is the temperature at which water vapor in the air begins to condense into liquid water droplets. During the process of condensation, the heat released due to the phase change of water vapor to liquid water is released into the surrounding air, which slows the rate of cooling of the rising air mass.

This slower rate of cooling is known as the saturated adiabatic lapse rate, which is typically around 5-6°C per kilometer (or 2.7-3.3°F per 1000 feet). The exact value of the saturated adiabatic lapse rate depends on factors such as the moisture content of the air and the rate of condensation.

If the air continues to rise and cool, the water droplets may grow and eventually fall as precipitation, further releasing heat into the surrounding air and slowing the rate of cooling. As a result, the temperature gradient for saturated air is typically much less steep than for dry air, as the release of latent heat during condensation acts to slow the rate of cooling of rising air masses.

c. How does the vertical T-gradient change for different stability conditions. (3 P)

The vertical temperature gradient in the atmosphere can vary depending on the stability conditions of the air. Stability refers to the tendency of the air to resist vertical motion, and is determined by the relationship between the temperature of the air and the temperature of the surrounding environment.

In an unstable atmosphere, the temperature of the air decreases rapidly with height, leading to a steep vertical temperature gradient. This occurs when the air near the surface is warmer than the air at higher altitudes, leading to buoyancy forces that encourage vertical motion. In an unstable atmosphere, rising air will continue to rise until it reaches an altitude where the temperature of the air is equal to or colder than the temperature of the surrounding environment. The vertical temperature gradient in an unstable atmosphere can be much steeper than the dry or saturated adiabatic lapse rates.

In a stable atmosphere, the temperature of the air is colder near the surface than at higher altitudes, leading to a shallow vertical temperature gradient. This occurs when the surface is cooler than the surrounding air, leading to a suppression of vertical motion. In a stable atmosphere, rising air will tend to cool and eventually sink back down to the surface, creating a stable stratification. The vertical temperature gradient in a stable atmosphere can be much shallower than the dry or saturated adiabatic lapse rates.

In a neutral atmosphere, the temperature of the air does not change significantly with height, leading to a more gradual vertical temperature gradient. This occurs when the temperature of the air near the surface is similar to the temperature of the surrounding environment. In a neutral atmosphere, rising air will tend to cool at the dry adiabatic lapse rate until it reaches an altitude where it is in thermal equilibrium with the surrounding environment. The vertical temperature gradient in a neutral atmosphere is typically intermediate between the steep gradient of an unstable atmosphere and the shallow gradient of a stable atmosphere.

d. Name the cloud types that result from different vertical T-gradients? (3 P)

Clouds are classified based on their height and vertical structure, as well as the temperature and moisture content of the air. The types of clouds that result from different vertical temperature gradients include:

Cumulus clouds: These are low-level clouds that form in unstable air with a steep vertical temperature gradient. They are puffy, white clouds that often resemble cotton balls, and are associated with fair weather or the early stages of a thunderstorm.
Stratus clouds: These are low-level clouds that form in stable air with a shallow vertical temperature gradient. They are flat, featureless clouds that can cover the entire sky, and are often associated with drizzle or light rain.
Altocumulus clouds: These are mid-level clouds that form in stable or slightly unstable air with a moderate vertical temperature gradient. They are white or gray clouds that often have a wavy or banded appearance, and are usually associated with fair weather.
Altostratus clouds: These are mid-level clouds that form in stable or slightly unstable air with a shallow to moderate vertical temperature gradient. They are gray or blue-gray clouds that often cover the entire sky, and are usually associated with light precipitation.
Cirrus clouds: These are high-level clouds that form in very stable air with a very shallow vertical temperature gradient. They are thin, wispy clouds that are composed of ice crystals, and are usually associated with fair weather.
Cumulonimbus clouds: These are tall, vertical clouds that form in very unstable air with a steep vertical temperature gradient. They are associated with thunderstorms and can produce lightning, thunder, and heavy precipitation.

e. Which consequences result for the character of the wind? (2 P)

The stability conditions of the atmosphere can have a significant impact on the character of the wind. Wind is the movement of air in response to differences in pressure, and the stability of the atmosphere affects the distribution of pressure and the resulting wind patterns.

In an unstable atmosphere, the wind tends to be turbulent and gusty. This is because buoyancy forces promote vertical motion, which can lead to the development of eddies and turbulent flow patterns. In addition, rising air can lead to the formation of convection cells, which can produce localized areas of strong updrafts and downdrafts.

In a stable atmosphere, the wind tends to be more uniform and laminar. This is because stability suppresses vertical motion, which can lead to a more organized flow pattern. However, stable conditions can also lead to the development of low-level inversions, which can trap pollutants near the surface and lead to poor air quality.

In a neutral atmosphere, the wind tends to be more variable and influenced by other factors such as surface roughness and topography. The wind can exhibit both turbulent and laminar characteristics, depending on the local conditions.

Overall, the stability conditions of the atmosphere can have a significant impact on the character of the wind, and can influence many aspects of atmospheric processes, including weather patterns, air pollution, and atmospheric transport.

f. Give basic types of clouds and their typical vertical extent. (6 P)
   - (Alto-, Cirro-)-Stratus, (Alto-, Cirro-)-Cumulus, Stratocumulus, Cumulonimbus
     Answer above **sufficient for full score**

   - 0 – 3 km Stratus, Cumulus, Stratocumumlus
   - 3 – 5 km Altostratus, Altocumulus
   - 5 – Tropopause Cirrus, Cirrostratus, Cirrocumulus
   - 0 – Tropopause Cumulonimbus, Nimbostratus

g. Give examples for abnormal vertical temperature profiles. (2 P)
   - Inversions

h. Describe three different types of inversion and the physical process behind (6 P)

In meteorology, an inversion refers to a deviation from the normal decrease of air temperature with increasing height in the atmosphere. Instead, the temperature increases with altitude, creating a layer of warm air above a layer of colder air. There are several types of inversions, including:

1. Radiation inversion: This occurs on clear, calm nights when the ground cools rapidly by radiating its heat into space. The cool air near the ground is denser than the warmer air above it, so it becomes trapped beneath the warmer air. This creates a stable layer of air near the surface, which can cause fog to form.
2. Advection inversion: This occurs when a layer of warmer air moves over a layer of cooler air. The warm air is less dense than the cool air, so it rises and becomes trapped beneath an inversion layer. This type of inversion is common in coastal areas where sea breezes can bring in cooler air from the ocean.
3. Subsidence inversion: This occurs when a large area of sinking air creates a layer of warm air aloft. As the air sinks, it compresses and warms up, creating a layer of stable air above it. This type of inversion is common in high-pressure systems and can trap pollutants near the surface, leading to poor air quality.

Inversions can have important effects on weather and air quality, as they can trap pollutants near the surface and prevent mixing of the atmosphere, leading to stagnant air masses.

13. 7 Points: What is the height of the tropopause?

The height of the tropopause varies depending on factors such as latitude, season, and weather patterns. On average, the height of the tropopause is about 17 kilometers (11 miles) above the equator, 9-10 kilometers (6-7 miles) above mid-latitude regions, and 5-6 kilometers (3-4 miles) above the poles. However, these are just rough estimates, and the height of the tropopause can vary by several kilometers in different regions and at different times.The tropopause is the boundary between the troposphere and the stratosphere, and it is defined by a change in temperature lapse rate. Above the tropopause, the temperature generally increases with altitude, while in the troposphere below the tropopause, temperature generally decreases with altitude. The specific temperature and height of the tropopause can vary depending on location and time of year, but it is typically located at an altitude of around 10-18 km in the middle latitudes.

The tropopause is also characterized by low humidity, as the water vapor content of the atmosphere decreases sharply with altitude above the tropopause. This is due to several factors, including the fact that cold air can hold less moisture than warm air, and the fact that much of the water vapor in the atmosphere is generated by evaporation from the Earth's surface, which is concentrated in the lower troposphere.

The combination of low temperature and low humidity in the tropopause region creates a relatively stable layer of air, which plays an important role in controlling the behavior of weather systems and atmospheric waves. The tropopause is also an important boundary for atmospheric chemistry, as it marks the transition between the well-mixed troposphere and the more stratified stratosphere, where many important chemical processes occur.

14. 20 Points: The General Global Circulation

a. What drives the Global Circulation? (4P)

The global circulation of the Earth's atmosphere is primarily driven by the uneven heating of the Earth's surface by the sun. Different regions of the Earth receive different amounts of solar radiation depending on factors such as latitude, season, and cloud cover. As a result, some regions are warmer than others, and this temperature difference creates a pressure gradient that drives atmospheric circulation.

The general circulation of the atmosphere consists of three major cells in each hemisphere: the Hadley cell, the Ferrel cell, and the polar cell. These cells are driven by the temperature difference between the equator and the poles, and they operate on a scale of thousands of kilometers.

The Hadley cell is driven by the intense solar radiation at the equator, which heats the surface and creates a region of low pressure. Warm air rises and flows towards the poles, where it cools and sinks back towards the surface, creating a region of high pressure. This flow of air creates the trade winds in the tropics and the prevailing westerlies in the mid-latitudes.

The Ferrel cell is driven by the interaction between the Hadley and polar cells. The rising air in the tropics creates a region of low pressure at the surface, while the sinking air at the poles creates a region of high pressure. Air flows from the high-pressure regions towards the low-pressure regions, creating the prevailing westerlies.

The polar cell is driven by the cold temperatures at the poles, which create a region of high pressure. Cold air sinks and flows towards the equator, where it is warmed and rises, completing the cycle of the cell.

Other factors, such as the rotation of the Earth, ocean currents, and topography, also play a role in shaping the global circulation of the atmosphere.

b. Describe its circulation cells and the resulting wind regimes. (4P)
   - Hadley Cell: Rising air in the tropics, upper level poleward winds, subsidence in subtropical latitudes, surface winds towards equator (Tradewinds)
   - Ferrell Cell: Near-surface SW-winds towards polar frontal zone, cyclogenesis
   - Polar Cell: Near-surface NW-winds towards polar frontal zone, cyclogenesis

c. What is the reason for the forming of a Jetstream? (4P)

The formation of a jet stream is primarily due to the temperature contrast between air masses at high latitudes and those at lower latitudes. Jet streams are narrow, fast-moving currents of air found in the upper troposphere and lower stratosphere, typically at altitudes between 30,000 and 50,000 feet.

In general, the jet stream forms where cold polar air meets warm subtropical air, creating a strong temperature gradient or front. The difference in temperature causes the air to move faster, leading to the formation of a high-speed current of air. The jet stream is driven by the large-scale atmospheric circulation and is often associated with the boundary between polar and subtropical air masses.

The jet stream is strongest in the winter, when the temperature difference between the polar and subtropical regions is greatest. It also tends to be stronger over land masses, where temperature contrasts are more pronounced than over the ocean. The jet stream can have a significant impact on weather patterns, as it influences the movement and intensity of storms and weather systems.

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d. What do the wavenumbers of the Global Circulation describe (500 hPa)? (4 P)

The wavenumbers of the Global Circulation at the 500 hPa level describe the patterns and wavelengths of the major wave disturbances in the mid-latitude westerlies. These wave disturbances are important in driving the general circulation of the atmosphere and influencing the distribution of weather patterns.

The wavenumber refers to the number of wave crests (or troughs) that occur in a given distance, typically in a horizontal direction. In the context of the 500 hPa level, wavenumbers are used to describe the spatial patterns of atmospheric pressure anomalies in the mid-latitude westerlies.

The major wavenumbers associated with the Global Circulation are typically described as follows:

- Wavenumber 0: Refers to a zonal flow with no meridional variation in the wind direction or speed. This is associated with a high-pressure ridge over the central North Pacific and a low-pressure trough over the eastern United States.
- Wavenumber 1: Refers to a single meridional wave disturbance with a trough over the western North Pacific and a ridge over North America.
- Wavenumber 2: Refers to two meridional wave disturbances with troughs over the North Pacific and North Atlantic and a ridge over North America.

- Wavenumber 3: Refers to three meridional wave disturbances with troughs over the North Pacific, North Atlantic, and Eurasia, and ridges over the western North America and eastern Asia.

These wavenumbers can have significant impacts on the weather patterns over different regions of the world, and understanding their characteristics is important for weather forecasting and climate modeling.

e. What is the relation between wavenumber and propagation speed of the wave? (4P)

The relation between wavenumber and propagation speed of the wave depends on the type of wave and the medium through which it is propagating.

For example, in the atmosphere, the propagation speed of a wave is determined by the wind speed and direction at the level at which the wave is propagating. The wavenumber, on the other hand, describes the number of wave crests (or troughs) that occur over a given distance. In general, for a given wind speed, the propagation speed of a wave increases with increasing wavenumber.

However, this relationship can be complicated by other factors such as the vertical structure of the atmosphere and the presence of other waves interacting with the propagating wave.

In other mediums, such as water waves, the relationship between wavenumber and propagation speed can be described by the dispersion relation, which relates the wave frequency, wavelength, and propagation speed. In general, for linear waves in an inviscid, incompressible fluid, the propagation speed increases with increasing wavenumber.

15. 6 Points: Which dynamic and oceanographic conditions are necessary (not sufficient, though) for the development of tropical storms / hurricanes? (6P)

Tropical storms and hurricanes require specific dynamic and oceanographic conditions to develop. These conditions include:

1. Warm water: The ocean temperature needs to be at least 26.5°C (80°F) or warmer throughout a depth of around 50 meters (150 feet). Warm water provides the energy needed to fuel the storm.
2. Moisture: Tropical storms and hurricanes require high levels of moisture and humidity to form and strengthen.
3. Weak vertical wind shear: Vertical wind shear is the difference in wind speed and direction with height. Tropical storms and hurricanes require low vertical wind shear to form, as high vertical wind shear can disrupt the organization of the storm and prevent it from strengthening.

4. Coriolis force: Tropical storms and hurricanes are powered by the Coriolis force, which causes the storm to spin. This force is only significant at a distance of at least 500 km (300 miles) from the equator.
5. Disturbance: A disturbance, such as a tropical wave, is necessary to initiate the development of a tropical storm or hurricane.
6. Atmospheric instability: Tropical storms and hurricanes require an unstable atmosphere to form, which means that warm, moist air needs to be able to rise easily from the surface to high altitudes.

These conditions are necessary but not sufficient for the formation and intensification of tropical storms and hurricanes. Other factors, such as the amount of dry air in the atmosphere, the presence of upper-level wind patterns, and the interaction with land masses, can also impact the development and strength of these storms.

16. 2 Points: What is the main season of tropical storms on the northern hemisphere? (2P)
    - Late summer

17. 6 Points: What is the basic idea behind the 1-2-3 rule for the forecast of hurricanes? (6P)

The 1-2-3 rule is a basic guideline used by the National Hurricane Center (NHC) to help mariners and coastal residents determine when they should make preparations for an approaching hurricane. The rule is based on the idea that hurricanes can be unpredictable in terms of their path and intensity, and it is important to be prepared for the worst-case scenario.

The 1-2-3 rule states that:

- 1 day before the arrival of the storm, the forecast cone of uncertainty will be about 100-150 miles wide. This means that the center of the storm could be anywhere within this cone, and people within this area should be prepared for hurricane conditions.
- 2 days before the arrival of the storm, the forecast cone of uncertainty will be about 200-250 miles wide. This means that people within this area should start monitoring the progress of the storm and be prepared to take action if necessary.
- 3 days before the arrival of the storm, the forecast cone of uncertainty will be about 300-350 miles wide. This means that people within this area should start making preparations for the storm, such as securing their homes and gathering emergency supplies.

It's important to note that the 1-2-3 rule is a general guideline, and the actual size of the cone of uncertainty can vary depending on the size and intensity of the storm.

The NHC encourages people to stay up-to-date with the latest forecast information and to follow the advice of local emergency officials.

18. 6 Points: Describe the qualitative physics and processes behind the Foehn-Effect. (6P)

The Foehn-Effect, also known as a Chinook wind in North America or a Bergwind in South Africa, is a meteorological phenomenon that occurs when a mass of moist air is forced to rise over a mountain range. As the air rises, it cools and expands, which causes water vapor to condense into clouds and precipitation.

On the leeward side of the mountain range, the air begins to descend and warm up as it moves down the slope. This warming is due to the adiabatic heating process, where the air is compressed as it descends and its temperature increases.

The result is a warm and dry wind that can have significant impacts on the weather and climate in the region. The warm and dry air can rapidly melt snow and cause a sudden increase in temperature, which can lead to rapid snowmelt and flooding in some areas. The dry air can also increase the risk of wildfires, as vegetation becomes more susceptible to ignition.

The Foehn-Effect can occur in many mountainous regions around the world, and its effects can be felt over large areas. For example, in Europe, the Foehn-Effect can cause rapid temperature changes and lead to the formation of lenticular clouds, which can look like UFOs hovering over the mountains. In North America, the Chinook winds can cause significant warming in the Great Plains region, and in South Africa, the Bergwind can cause temperatures to rise by as much as 20°C in a matter of hours.

19. 6 Points: How does a sea-breeze develop? (6P)

A sea breeze is a local wind that develops near coastal areas and is caused by differences in temperature and pressure between the land and sea. During the daytime, the land surface heats up faster than the sea surface, causing the air above the land to become warmer and less dense than the air above the sea.

This creates a pressure gradient, where the air over the land rises and the cooler, denser air from the sea moves inland to replace it. As this cooler air moves inland, it is known as a sea breeze. The sea breeze can be felt up to 20-30 km inland, depending on the strength of the wind and the local topography.

The sea breeze usually begins in the late morning or early afternoon, when the temperature difference between the land and sea is at its maximum. It typically reaches its peak strength during the mid to late afternoon and then gradually weakens in the evening as the land begins to cool down.

Sea breezes can have significant impacts on local weather patterns, as they can cause an increase in humidity and cloud cover along the coast, and can also affect the formation of thunderstorms and other convective weather. In some cases, sea breezes can also have a moderating effect on temperatures, helping to cool down areas that would otherwise experience very high temperatures during the summer months.

20. 6 Points: What is the basic idea of Numerical Weather Prediction (NWP)? (6P)

The basic idea behind Numerical Weather Prediction (NWP) is to use mathematical models and computer simulations to forecast the future state of the atmosphere. This involves using complex mathematical equations to represent the physical processes that govern the behavior of the atmosphere, such as the conservation of mass, momentum, and energy.

NWP models start by gathering observations of the current state of the atmosphere, such as temperature, pressure, humidity, and wind speed and direction, from a variety of sources, such as weather stations, radar, satellites, and other instruments. These observations are then used to initialize the model, which produces a forecast of the future state of the atmosphere.

NWP models take into account a wide range of factors that can influence the weather, including the effects of the sun, the Earth's rotation, topography, and the interactions between the atmosphere, ocean, and land surface. The models are run on powerful supercomputers, which use numerical algorithms to solve the mathematical equations and simulate the behavior of the atmosphere over time.

NWP has revolutionized weather forecasting by allowing meteorologists to make more accurate and detailed predictions of the weather, sometimes up to several days in advance. However, NWP models are still subject to various sources of uncertainty, such as errors in the initial observations, limitations in the accuracy of the models, and the chaotic nature of the atmosphere itself, which means that even small errors can lead to significant changes in the weather over time.

8 Points: How can spot forecasts of the NWP Direct Model Output (DMO) be improved? (4P)

Spot forecasts of the NWP Direct Model Output (DMO) can be improved in several ways, including:

1. Using high-resolution models: Higher resolution models can provide more detailed and accurate forecasts, especially for localized features such as thunderstorms and mountain-valley winds.
2. Incorporating real-time observations: Real-time observations such as surface weather reports, radar and satellite data, and aircraft measurements can be assimilated into the model to improve its initial conditions and reduce errors.
3. Improving the physics parameterizations: NWP models use simplified equations to represent complex atmospheric processes such as cloud formation, precipitation, and turbulence. Improving these parameterizations can lead to more accurate forecasts.
4. Ensemble forecasting: Ensemble forecasting involves running multiple simulations with slight variations in the initial conditions and model parameters to account for the inherent uncertainty in the atmosphere. This can provide a range of possible outcomes and help meteorologists assess the likelihood of different weather scenarios.
5. Machine learning: Machine learning techniques can be used to learn from past forecasts and observations to improve the accuracy of future predictions. This can involve using neural networks or other algorithms to identify patterns and relationships in the data that may be difficult for humans to detect.

Overall, improving spot forecasts of the NWP DMO involves a combination of improving the underlying models, assimilating real-time observations, and using advanced data analysis techniques to extract the most useful information from the available data.

a. Describe the main DMO improvement principles for spot forecasts. (4P)
   - Statistical post-processing combining DMO and …
   - MOS Model Output Statistics: … and past observations
   - PP Perfect Prog: … and past analyses

21. 4 Points: What is the idea behind Ensemble Forecast Technology? (4P)

The idea behind Ensemble Forecast Technology is to use a set of slightly different simulations of the same weather forecast model to generate a range of possible outcomes, instead of relying on a single deterministic forecast. Each simulation, or member, in the ensemble is initialized with a slightly different set of initial conditions or model parameters, reflecting the uncertainty in the atmosphere and the model. By running multiple simulations, meteorologists can assess the range of possible weather scenarios, including the likelihood of extreme events and the uncertainty associated with the forecast.

Ensemble forecasting technology can be used to generate probabilistic forecasts, which provide the likelihood or probability of different weather scenarios. For example, an ensemble forecast for a possible thunderstorm might indicate a 30% chance of thunderstorms in a particular area, compared to a deterministic forecast that simply predicts the occurrence of a thunderstorm.

Ensemble forecasts can also be used to generate forecast maps that show the probability of different weather scenarios in different regions. This can help forecasters to identify areas that are at a higher risk for severe weather and issue more targeted warnings and alerts.

Overall, the idea behind Ensemble Forecast Technology is to provide a more comprehensive and probabilistic assessment of the uncertainty associated with weather forecasts, which can help improve the accuracy and reliability of weather predictions, especially in situations with high uncertainty or potential for extreme weather events.

4 Points: Why and where does the global oceanic conveyor belt start to form? (4P)

The global oceanic conveyor belt, also known as the thermohaline circulation, starts to form in the North Atlantic Ocean. This is because the North Atlantic is the site of the largest surface water cooling and evaporation on the planet, which results in the formation of dense, salty water that sinks to the ocean floor.

Specifically, the conveyor belt starts to form in the Norwegian Sea and the Greenland Sea, where cold, dense water sinks to the bottom and flows southward along the continental slope of the Atlantic Ocean. This deep, dense water is then transported southward through the Atlantic, around the tip of South Africa, and into the Indian and Pacific Oceans, where it eventually resurfaces and returns to the North Atlantic in a process known as upwelling.

The oceanic conveyor belt plays a critical role in regulating the Earth's climate by distributing heat and nutrients around the world's oceans. The warm, salty water that flows northward in the Atlantic transports heat from the equator to the poles, helping to warm Northern Europe and other regions. The conveyor belt also helps to distribute nutrients and oxygen to deep ocean ecosystems, supporting a wide range of marine life.

However, the conveyor belt is vulnerable to disruption due to global warming, as melting ice caps and increased precipitation can reduce the salinity of surface waters in the North Atlantic, reducing the formation of dense, sinking water and slowing the circulation. This could have significant impacts on global climate patterns and marine ecosystems.

22. 4 Points: What is the reason for coastal upwelling / downwelling? (4P)

oastal upwelling occurs when wind blows along the coastline, causing surface water to move offshore. This creates a void that is filled by cold, nutrient-rich water from below, which rises to the surface to replace the water that has moved offshore. Coastal downwelling, on the other hand, occurs when wind blows towards the coast, causing surface water to pile up along the coastline. This causes water to move offshore at depth, drawing warm, nutrient-poor water up from below to replace it. These processes have important effects on the productivity and ecology of coastal marine ecosystems.

23. 4 Which phenomenon is typically associated with up-/downwelling and has global climatological feedback effects? (4P)
Upwelling and downwelling have global climatological feedback effects because they play an important role in the global carbon cycle. In areas of coastal upwelling, cold, nutrient-rich water rises to the surface and stimulates the growth of phytoplankton. Phytoplankton remove carbon dioxide from the atmosphere through photosynthesis and, when they die and sink to the ocean floor, they sequester carbon in the deep ocean. This process helps to regulate the Earth's climate by reducing the amount of carbon dioxide in the atmosphere. In areas of downwelling, on the other hand, carbon-rich water from the surface is transported to the deep ocean, where it can remain sequestered for centuries to millennia. The global distribution of upwelling and downwelling zones thus has a significant impact on the global carbon cycle and on the Earth's climate.

24. 3 Points: Give typical values of salinity for Baltic Sea, other Oceans and for the Dead Sea. (3P)

The salinity of different bodies of water can vary widely. Here are some typical values:

- Baltic Sea: The salinity of the Baltic Sea is relatively low due to its limited connection to the North Sea and the relatively low evaporation rates in the region. The average salinity of the Baltic Sea is around 8-9 parts per thousand (ppt), although this can vary depending on the location and the time of year.
- Other Oceans: The salinity of the world's oceans is generally around 35 ppt, although this can vary depending on the location and the time of year. In areas with high evaporation rates and low rainfall, such as the subtropics, the salinity can be higher, while in areas with high rainfall and low evaporation rates, such as the equator and the poles, the salinity can be lower.
- Dead Sea: The Dead Sea is a highly saline lake located in the Middle East. Its salinity is around 10 times higher than that of the world's oceans, with an average salinity of around 300 ppt. This is due to the fact that the Dead Sea is a closed basin with no outlet, and water can only leave through evaporation, which leaves behind the dissolved salts.

25. 4 Points: How is the characteristic wave height defined? (4P)

The characteristic wave height is defined as the average height of the one-third highest waves in a given wave record. This measure is commonly used in oceanography and meteorology to describe the typical wave conditions in a specific location or during a specific period of time. It provides a useful summary statistic of wave heights that can be used for navigation, coastal engineering, and other applications.

6 Points: Name the main factors to form wave heights specific for the Beaufort Force? (6P)

Wave heights are primarily determined by wind speed, wind duration, and the fetch (distance over water that the wind blows). The Beaufort Scale is a system that relates wind speed to sea state, and provides an estimate of wave height based on the observed wind conditions. The following table provides the wave height estimates for different Beaufort Force values:

Beaufort Force	**Wind speed (knots)**	**Wave height (meters)**
0 (Calm)	0-1	0
1 (Light Air)	1-3	0-0.1
2 (Light Breeze)	4-6	0.1-0.5
3 (Gentle Breeze)	7-10	0.5-1.0
4 (Moderate Breeze)	11-16	1.0-2.0
5 (Fresh Breeze)	17-21	2.0-3.0
6 (Strong Breeze)	22-27	3.0-4.0

Beaufort Force	Wind speed (knots)	Wave height (meters)
7 (Near Gale)	28-33	4.0-5.5
8 (Gale)	34-40	5.5-7.5
9 (Strong Gale)	41-47	7.5-10.0
10 (Storm)	48-55	9.0-12.5
11 (Violent Storm)	56-63	11.5-16.0
12 (Hurricane)	64+	14.0+

So, for a given Beaufort Force, the corresponding wave heights will depend on the wind speed, wind duration, and fetch. The larger the wind speed, the longer the duration of the wind, and the greater the fetch, the larger the wave heights will be.

26. 2 Points: What is the difference between sea and swell? (3P)

Sea and swell are both terms used to describe the state of the ocean surface, but they refer to different things.

Sea refers to the waves that are generated by local wind in the area where they are observed. They are generally shorter in wavelength and have a choppy appearance.

Swell, on the other hand, refers to waves that have been generated by distant winds, sometimes thousands of miles away. Swell waves have longer wavelengths and are more organized than sea waves. They tend to have a smoother appearance, and can travel long distances without losing energy.

In summary, sea waves are generated by local winds, while swell waves are generated by distant winds.

27. 2 Points: Describe typical satellite orbits and their properties. (3P)

There are three main types of satellite orbits:

1. Low Earth Orbit (LEO): These are typically between 160 and 2000 km above the Earth's surface. They are used for earth observation, scientific research, and communication. Satellites in LEO orbit the Earth faster and have a shorter orbital period than those in higher orbits.
2. Medium Earth Orbit (MEO): These are typically between 2000 and 35,786 km above the Earth's surface. They are used for global positioning system (GPS) and navigation. Satellites in MEO have a longer orbital period than those in LEO.
3. Geostationary Earth Orbit (GEO): These are located at an altitude of 35,786 km above the Earth's surface. They are used for communication, weather forecasting, and observation. Satellites in GEO orbit the Earth at the same rate as the Earth's rotation, which means they stay over the same location on the Earth's surface.

Each type of orbit has its own advantages and disadvantages. LEO orbits provide better resolution and data rates but require more frequent revisits. MEO orbits offer better coverage but have longer delays. GEO orbits provide continuous coverage but have higher latency and require more power for communication.

28. 2 Points: What does the IR Greyscale of satellite images represent? (3P)

The IR (Infrared) Greyscale of satellite images represents the temperature of the cloud tops. The image is created by measuring the amount of radiation emitted by the Earth and its atmosphere at different wavelengths in the infrared spectrum. Clouds, which are colder than the Earth's surface, emit less radiation than the surface and appear darker on the image. The temperature information is then converted into a grayscale image, with the coldest temperatures appearing white or light gray, and the warmest temperatures appearing dark gray or black. This type of image is useful for identifying cloud cover, storm systems, and the location and intensity of thunderstorms. 170 Total Points