



Introduction to Meteorology

23 General circulation (2)

Introduction



Atmospheric circulation is modulated by pressure gradient force, centrifugal force, friction, heating and cooling, and instability. The scale of the atmospheric circulation depends on the balanced forces and the characteristics of the atmosphere: from a turbulence to a planetary scale. The atmospheric general circulation is a global scale and is primarily a response to the solar radiation. General circulation includes meridional circulation, and circulation on constant pressure or height, as well as low-frequency (or long term) variation. Long-term oscillation generally refers to a variation whose period is longer than a week. This includes various phenomena such as blocking, fluctuation in planetary waves, intraseasonal oscillation, and monsoon circulation. To identify the characteristics of the large-scale low-frequency circulation, appropriate statistical analysis is required to filter out higher spatial-temporal variations. Atmospheric motion has strong nonlinearity. There are interactions among various spatial and temporal scales of motions. Motions at small scale and high-frequency influence the large-scale motions. Therefore, to understand the general circulation, a better understanding of the characteristics of high-frequency variability is necessary.

Contents



1. Baroclinic waves
2. Atmospheric waves

Learning objectives



1. Explain the types of blocking and the definition and structure of the baroclinic instability waves.
2. Describe various wave phenomena in the atmosphere.

Learning Activities

1. Baroclinic instability waves

1) Definition of baroclinic waves

The baroclinic instability wave is a wave that occurs when the atmosphere is unstable, when the available potential energy is converted to kinetic energy, and when warm air ascends as it moves poleward, or when cold air descends as it moves equatorward.

The baroclinic instability wave is significant for atmospheric circulation. It acts as a source of energy for atmospheric circulation, especially in the mid-latitude. This wave is commonly seen in atmospheres of rotating planets.

Charney and Eady proposed theories about the genesis and development of the baroclinic wave and explained the basic characteristics of the atmospheric disturbances observed in mid-latitudes. Charney proposed a theory that takes into account the beta-effect and the effect of the earth's curvature. Although the curvature effect was not considered in Eady's model, the important features of observed cyclones were well explained. The theoretical models of baroclinic instability have similar features (growth rate, energy conversion, a vertical structure) to the observed life-cycle of cyclones.

The recent studies on the baroclinic instability are dealing with problems considering the physical processes which haven't been considered in the previous theoretical model

Learning Activities

1. Baroclinic instability waves

2) Structure of baroclinic waves and sphericity effect

The existence of the beta-effect, which is one of the significant differences between Eady's and Charney's models, is essential in instability theory. The horizontal shear of the basic flow was neglected in Eady's model which results in zero momentum transport. Also, both in Eady and Charney model, the effect of sphericity was only partly considered. Therefore, the instability wave from their model is far from the reality.

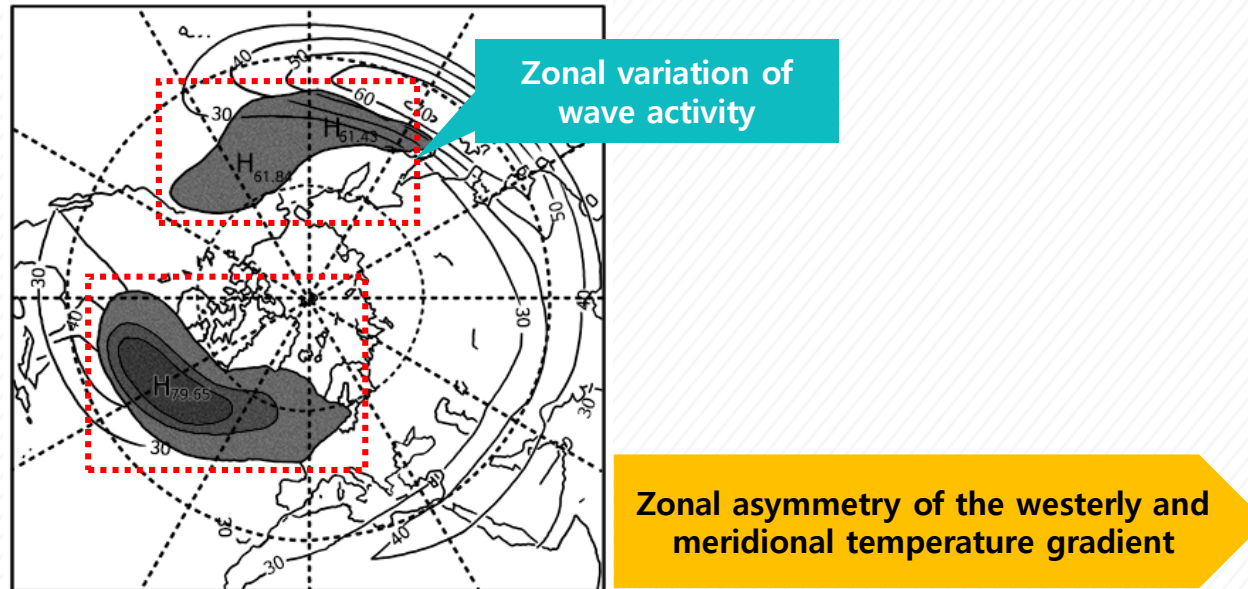
Later, Simmons and Hoskins use a 3D numerical model that takes full account of the spherical effects to reveal the structure of the baroclinic wave. Based on these studies, recent numerical models simulate the life cycle of the mid-latitude baroclinic waves as observed in the real atmosphere.

Learning Activities

1. Baroclinic instability waves

3) Baroclinic wave activity

The distribution of baroclinic wave activity shows strong zonal variation because of the zonal asymmetry of the westerly and meridional temperature gradient, which are the key factors that generate the baroclinic waves. The two regions where the maximum value of the westerlies appear are the Pacific and Atlantic storm tracks.



〈Observed pattern in January〉

※ Source: Introduction to Atmospheric Science

Learning Activities

2. Atmospheric waves

The atmosphere is likely to maintain its equilibrium state. If any forcing breaks the balance, the atmosphere tends to return to its initial equilibrium state by several processes.

The waves are induced by the restoring force acting on the fluid that deviates from its equilibrium state. The restoring forces include compression, gravity, buoyancy, Coriolis force, and so forth. They cause sound waves, gravity waves, inertia waves, and Rossby waves. The energy is transmitted through wave propagation and dispersion, but the air itself does not move.

The large-scale waves that dominate the atmospheric circulation can be classified as stationary waves and transient waves. The term stationary waves refer to the zonally asymmetric features of the time-averaged atmospheric circulation. Stationary waves have a strong effect on the season and climate. Transient waves are the instantaneous departures of the flow from its climatological state and are superimposed on stationary waves. Transient eddies are closely linked to the weather.

Learning Activities

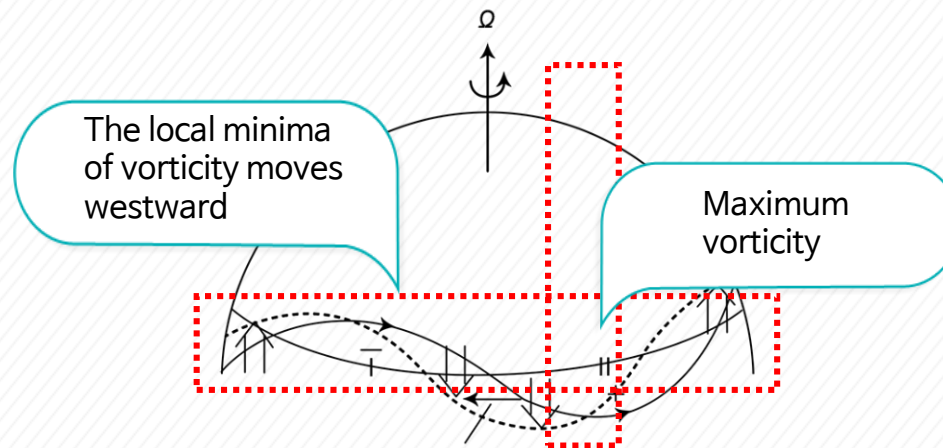
2. Atmospheric waves

1) Rossby wave propagation mechanism

The Rossby wave, the most critical wave in large-scale circulation, has a dominant influence on the mid-latitude climate.

Rossby wave is generated when large-scale air column moves meridionally. This is because the Coriolis force changes with latitude. When air parcels move to the north (south), the vorticity decreases (increases) and the fluid gains more anticyclonic (cyclonic) rotation.

As you can see from the figure, the area where the minimum vorticity appears moves from the region (I) to the west. In region (II), the maximum vorticity region, the cyclonic circulation induces advection of air to the south in the west and to the north in the east. Therefore, the wave moves westward.



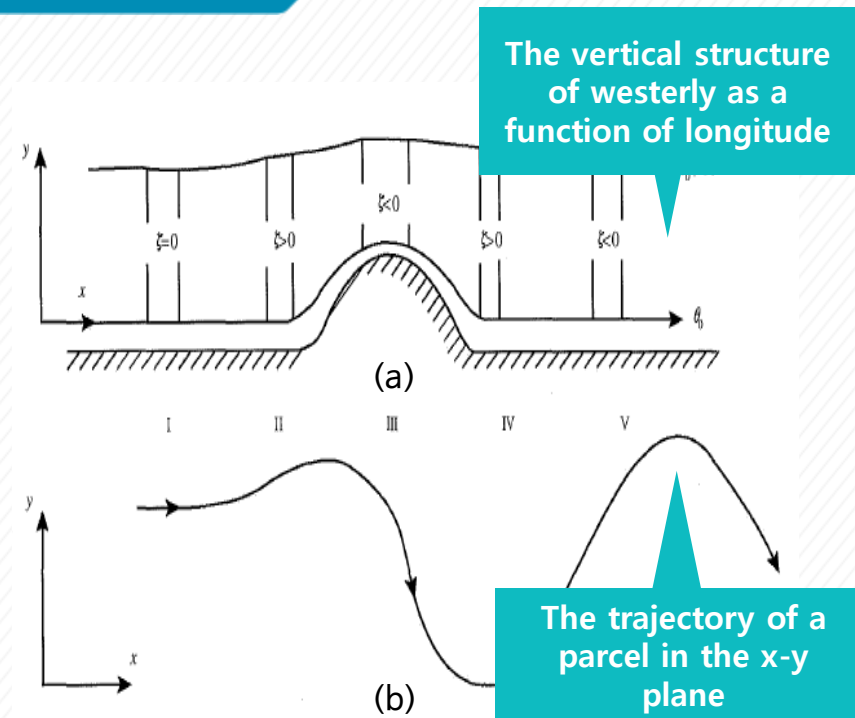
Learning Activities

2. Atmospheric waves

2) Rossby wave generation

Rossby wave can be excited by topographic effect and longitudinally dependent diabatic heating (such as ocean-land thermal contrast). For Rossby wave forced by topography, the vorticity generation by adiabatic compression and expansion is the most important factor when an air parcel flows over a mountain. The air column is adiabatically stretched when it moves over the lee-side. Consistently, the cross-sectional area of the stretched column shrinks and the column spins faster thus increasing cyclonic vorticity.

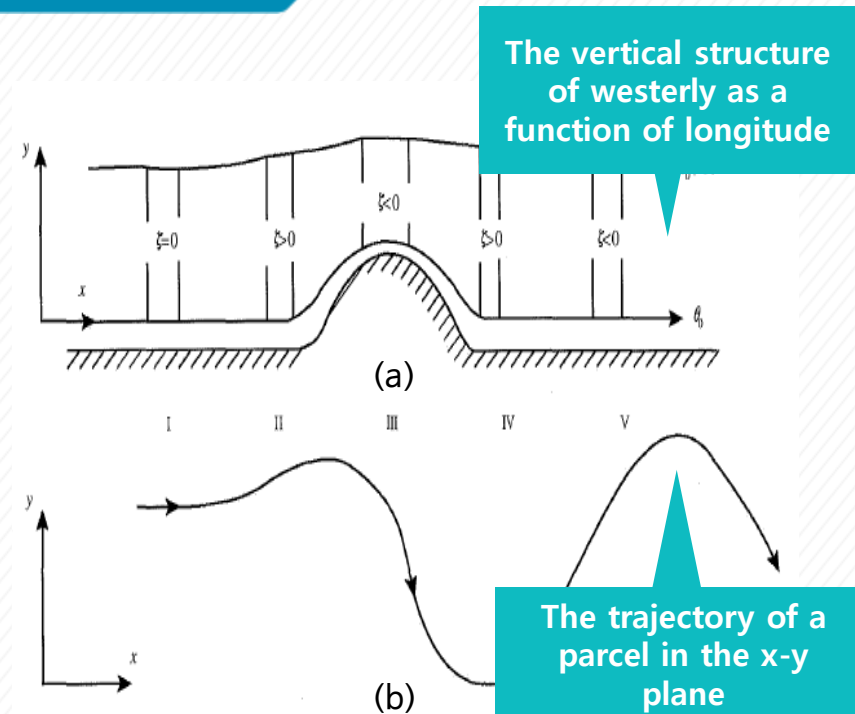
The Rossby wave generation process can be explained by the figure below. Figure (a) is the vertical and (b) is the horizontal structure of the westerly wind that crosses the mountain. We suppose that upstream of the mountain barrier (region I) the flow is a uniform zonal flow with zero vorticity.



Learning Activities

2. Atmospheric waves

In the region II, when the westerlies meet the mountain barrier, the air is expanded adiabatically and positive vorticity is generated. Thus, an air column turns cyclonically as it approaches the barrier. This cyclonic curvature causes a poleward drift so that the planetary vorticity also increases. This, in turn, reduces the relative vorticity to conserve the absolute vorticity. Therefore, the air column will acquire anticyclonic vorticity (region III) and move southward. When the air column moves southward, the planetary vorticity decreases, the relative vorticity increases, so that the air column will acquire cyclonic vorticity. Therefore, steady westerly flow over a large mountain will result in a cyclonic flow pattern to the east of the barrier (lee side trough) followed by series of waves downstream.



Learning Activities

2. Atmospheric waves

The Himalayas and the Rocky Mountains are major mountainous areas in the mid-latitudes of the Northern Hemisphere. During winter, waves propagate equatorward from the Tibetan plateau and east of the Rocky Mountains.

The thermal differences between the ocean and land, such as the heat capacity, moisture content, and albedo, make the atmospheric motion uneven in the longitudinal direction. Monsoon circulation is the zonally asymmetric circulation caused by uneven distribution of land and ocean.

The subtropical Western Pacific region is known as a warm pool region where a large-scale convection occurs. The sea surface temperature is 28 °C which is higher than any other ocean. High temperature is maintained throughout the year. The active convection in the warm pool region induces upper-level divergence and acts as a wave source.

Waves in the atmosphere play a major role in reducing the atmospheric imbalance and maintaining its equilibrium. Momentum and heat transports by the waves are key factors that modulate the large-scale circulation and global temperature.

In general, waves transport the large angular momentum of the equator to the pole, and the relatively small angular momentum in higher latitudes to the equator to conserve the earth's angular momentum. Waves also transport warm air of lower latitude to the pole and cold air to the equator to maintain the Earth's energy equilibrium.

Summary

1. Baroclinic waves

- A wave that generates when the atmosphere is unstable
- Baroclinic waves are generated when the available potential energy is converted to kinetic energy, and when warm air ascends as it moves poleward, or when cold air descends as it moves equatorward.
- The baroclinic instability wave is essential for large-scale atmospheric circulation, especially in the mid-latitude.
- This wave is a commonly seen in atmospheres of rotating planets.

Summary

2. Atmospheric waves

- The atmosphere is likely to maintain its equilibrium state. If any forcing breaks the balance, the atmosphere tends to return to its initial equilibrium state through several processes.
- The waves are generated by the restoring force acting on the fluid that deviates from its equilibrium state.