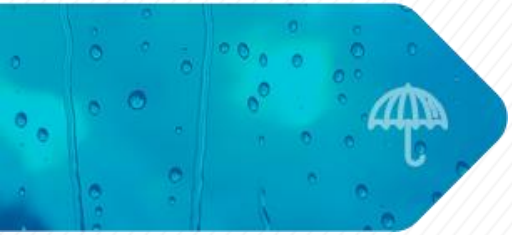
Introduction to Meteorology

22 General circulation (1)

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. Definition and history of atmospheric general circulation

Learning objectives

1. Describe the definition and history of atmospheric general circulation

Learning Activities

1. Definition and history of atmospheric general circulation

Atmospheric general circulation means the large-scale atmospheric motion which is taking place in the atmosphere, including large-scale horizontal and long-term (low-frequency) circulations.

Hadley proposed the first theory of large-scale atmospheric circulation. The trade winds are linked to the polar regions in addition to the equatorial regions. The heated air in the equatorial region rises and moves to the polar region and the circulations are symmetric around the equator.

Ferrel, after about 100 years Hadley's theory published, argued that the global general circulation is not a single-cell model (as described by Hadley), but a three-cell model, based on more accurate observational data. He explained that the poleward wind near the surface results in westerlies, and the equatorward wind results in easterlies due to the Earth's rotation.

Bergeron and Bjerknes more clearly described the three-cell model. They found that circulations are not regular flows around horizontal axes (as in the three-cell model) but rather closely linked to frontal systems. They proposed a polar front theory.

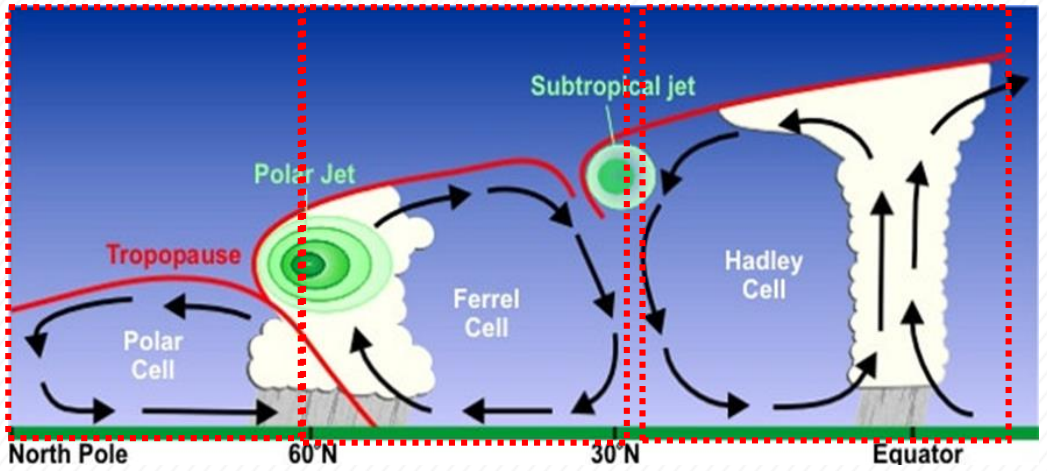
Learning Activities

1. Definition and history of atmospheric general circulation

1) Mean meridional circulation

Because the southern and the northern hemispheres have different conditions, the average meridional circulation has an asymmetric structure even though the incoming solar energy is symmetric about the equator. The average meridional circulation is composed of two direct cells and one indirect cell. Thermally induced, the direct cells have ascending motion at latitudes with higher temperature and descending motion at lower temperature latitudes.

The Hadley cell in the lower latitude is maintained by the latent heat generated by condensation of water vapor, while the polar cell is maintained by negative buoyancy caused by the differential radiative cooling of the surface. The indirect cell (Ferrel cell) in the mid-latitude is supported by baroclinic instability and is weaker than the Hadley circulation. Without the baroclinic instability, the circulation would have become a single-cell as proposed by Hadley



〈Atmospheric circulation cells〉

※ Source: Wikipedia (url: wikipedia.org)

Learning Activities

1. Definition and history of atmospheric general circulation

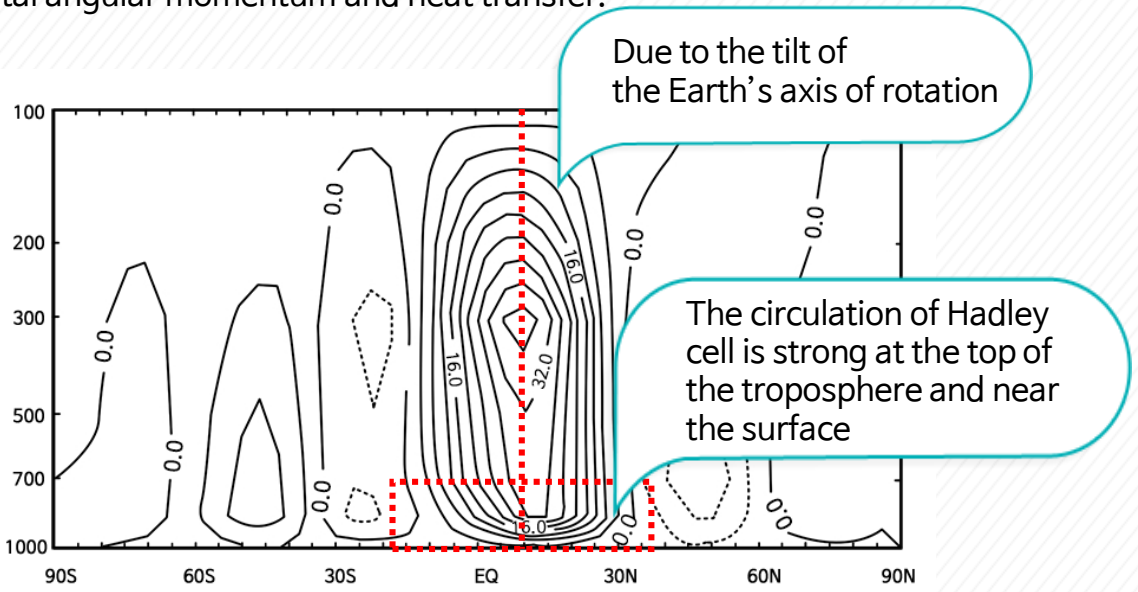
The Hadley circulation is prominent during the Northern Hemisphere winter. It shifts toward the southern hemisphere during boreal winter and the opposite in summer. The southern and northern hemispheres have different surface conditions.

In the long-term average, the mean meridional circulation does not become symmetric around the equator, and the northern hemisphere appears always to be stronger. This asymmetry is due to the distribution of the continents and large-scale ocean-atmospheric interaction.

Learning Activities

1. Definition and history of atmospheric general circulation

This picture shows the averaged meridional circulation during boreal winter from 1980 to 1987. Three cells can be seen in each hemisphere, and it is noticeable that the circulation corresponding to the Hadley cell in the northern hemisphere is remarkably strong. Overall, the cell is biased toward the southern hemisphere due to the tilt of the Earth's axis of rotation, which is reversed in summer. The circulation of Hadley cell is strong at the top of the troposphere and near the surface. The circulation in the horizontal direction is about two orders of magnitude higher than that in the vertical direction and plays a major role in the horizontal angular momentum and heat transfer.



〈Winter (December to February) zonal and time averaged streamfunction (1980 to 1987 average)〉

※ Source: Introduction to Atmospheric Science

Learning Activities

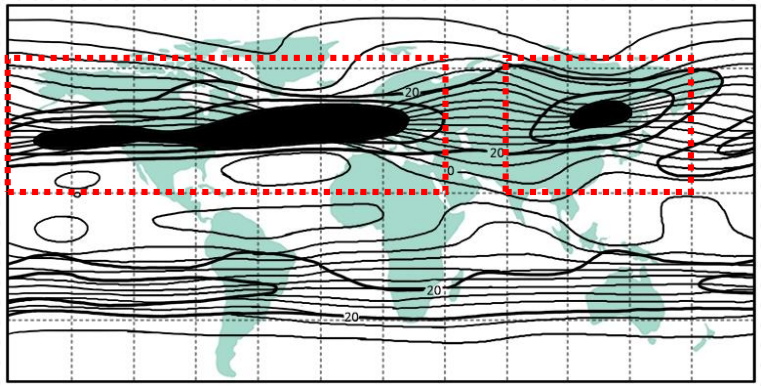
1. Definition and history of atmospheric general circulation

2) Large-scale atmospheric circulation

Let's take a look at the distribution of the streamfunction at 250 hPa during winter. Two large cyclonic circulations can be seen in the northern hemisphere: one on the east coast of the Eurasian and one on the east coast of the North America. They have the characteristics of Rossby wave and are zonally elongated.

Coriolis force induces Rossby wave, so Rossby wave can be generated when large-scale atmospheric motion oscillates in a meridional direction.

The regions of strong cyclonic flows are associated with strong baroclinc instability waves. These storm tracks are called Pacific storm track and Atlantic storm track, respectively. The storm track is the path along which the baroclinic instability waves and extratropical cyclones passes.



〈Winter (December to February) mean streamfunction and zonal wind at 250 hPa〉

※ Source: Introduction to Atmospheric Science

Learning Activities

1. Definition and history of atmospheric general circulation

3) Blocking

The blocking event is one of the phenomena with long-term fluctuation characteristics and was first discovered in the early 1900's. The blocking refers to a phenomenon in which the westerly wind does not flow normally and continues to meander to the north and south for longer than a week. During the blocking period, the quasi-stationary blocking highs (blocking anticyclones) interrupt the westerly and change the paths of highs and lows.

Due to the strong nonlinearity of the atmosphere, it is challenging to predict the occurrence and growth of blocking accurately. Blocking occurs mainly in the upper troposphere over the Pacific and Atlantic during winter and spring and lasts for up to 20 days or longer.

Summary

1. Definition and history of atmospheric general circulation

- Atmospheric general circulation means the large-scale atmospheric motion which is taking place in the atmosphere, including large-scale horizontal and long-term (low-frequency) circulations.
- It was proposed that trade winds are not limited to the equatorial regions but are also linked to the polar regions. The heated air in the equatorial region rises and moves to the polar region and the circulations are symmetric around the equator.

Summary

2. Westerlies

- An important factor for monitoring and forecast of the mid-latitude weather.