Introduction to Meteorology

21 Westerlies and Jets

Introduction

Atmospheric motions are occurring on a variety of temporal and spatial scales. Above all, westerlies and jet are vast planetary-scale disturbance and characterize the mid-latitude weather and climate system including East Asia.
The jet refers to a strong horizontal wind that concentrates on a narrow zone. Depending on its location, it can be classified as tropospheric jets, middle-atmosphere jets, and low-level jets. These form an axis of thousands of kilometers with the strong east-west wind in a narrow meridional zone. The difference between horizontal and vertical wind speed is large.
The jets are climatologically strong on the eastern side of the continent. It does not appear consecutively across the latitude and is disconnected at specific longitude zones. The pattern of jet shows more complex characteristics in daily weather maps. Strong westerlies in the upper levels are due to the thermal wind balance caused by the meridional temperature gradient.

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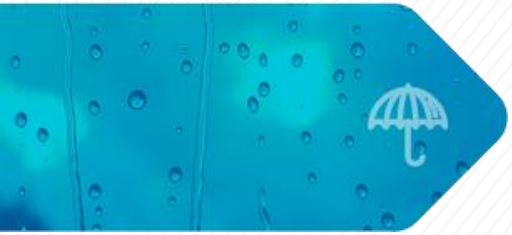


Learning objectives

1. Describe the types and characteristics of the jet stream.
2. Describe the causes of jet formation.
3. Explain the effects of the jet stream.

Learning Activities

1. Jet stream

1) Definition of jet stream

The jet stream is a strong horizontal flow that concentrates in a narrow zone forming a long axis. Depending on its location, the jet can be classified as tropospheric jets, middle-atmosphere jets, and low-level jets. The jet stream in the troposphere and stratosphere expands thousands of kilometers zonally and hundreds of kilometers meridionally.

As the jet stream is confined in a narrow range, the horizontal and vertical wind shears are very strong. There are polar and subtropical jets. Polar jet shows north-south meandering movement compared to the subtropical jet. Due to its movement, it can be hardly seen in climatology maps.

Climatologically, the area of strong westerly wind is called jet stream. Sometimes it refers to a strong wind that is accompanied locally by the upper-level trough. The existence of strong winds in the easterly zone was also confirmed and is called "easterly jet".

Learning Activities

1. Jet stream

2) Discovery

Until World War II, there was little knowledge about the structure of the wind field above 6 km. After World War II, it was necessary to forecast the upper-level wind field near at 9 km. Wind data above 6 km have been estimated on the basis of theories and empirical methods. In 1956 TIME magazine, C. G. Rossby, the famous atmospheric scientist, named the strong wind as “jet stream”. The German meteorologist, Seilkopf, used ‘Strahlstomung’, which means jet stream in German, before Rossby.

At the same time, European Union pilots recognized the presence of strong upper-level winds over Europe. However, differing from the US Air Force, they depended only on empirical methods due to the lack of observations and data analysis.

Learning Activities

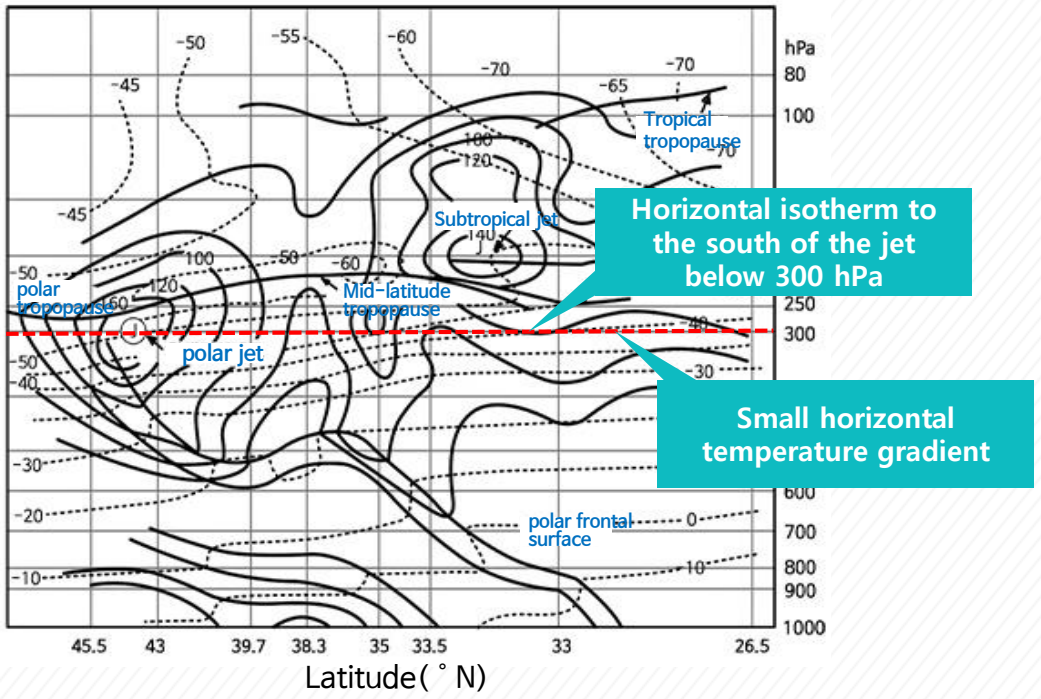
1. Jet stream

3) Jet formation

Warm air from the south and cold air from the north forms together a cold front. Based on the thermal wind relation, we can infer that the westerlies become the strongest near the tropopause, where the horizontal temperature gradient is almost zero. While heat is carried from low to high latitudes, the cold air is transported from high to low latitudes.

Looking at the subtropical jet stream, the isotherm to the south of the Jet below 300 hPa is almost horizontal, and the horizontal temperature gradient is very small. Therefore, the cause of the subtropical jet is not related to the troposphere, unlike the polar jet.

The horizontal temperature gradient above 250 hPa is large. It can be deduced that the temperature gradient has been adjusted to the strong westerly wind. After all, the cause of the subtropical jet stream is attributed to the angular momentum transport. Because the earth's circumference is different at low and high latitudes, low-latitude westerly wind that moves to high latitudes maintains a relatively fast wind speed according to the conservation of angular momentum, which forms a jet stream faster than the existing wind.



〈Latitude-height cross-section〉

※ Source: Introduction to Atmospheric Science (So, Sun-Sup et al. Cheongmoongak)

Learning Activities

1. Jet stream

The jet stream does not exist only in certain areas, but it is zonally distributed. However, it does not have uniform distributions due to instabilities and atmospheric conditions.

The tropospheric jet stream is observed in the latitudes of 30~50˚. Its maximum wind speed is observed around 200 hPa in both hemispheres. In the northern hemisphere winter, the maximum wind speed reaches up to 40ms^{-1}.

The intensity of the wind varies throughout the year, but the direction remains constant as a westerly. The strength of the jet stream is greater in winter than in summer, because of the stronger meridional temperature gradient in winter. The southern hemisphere has weaker jet than the northern hemisphere, because of the smaller portion of the land area.

The strong jet in the middle atmosphere (around 60 km) is called the mesospheric jet. Its speed is 80ms^{-1} on average and easily exceeds 100ms^{-1}.

Unlike the troposphere, the mesospheric jet direction reverses from a westerly wind (winter) to an easterly wind (summer), which denotes that the mechanism of jet formation in the troposphere and the middle atmosphere is different. In the winter season of each hemisphere, the jet becomes stronger than in summer.

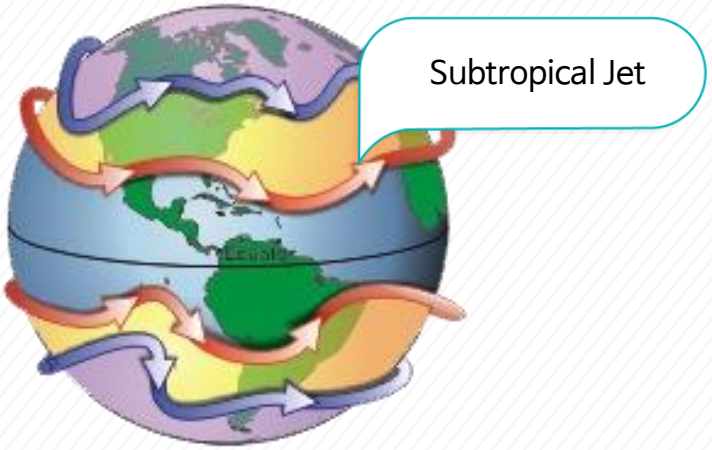
Learning Activities

1. Jet stream

The jet stream can be classified into a subtropical jet stream and polar jet stream. The subtropical jet stream is observed near 30ㅇ but its location and strength vary depending on the day. This has a significant impact in Korea because the high elevations near the Himalayas distrupt the subtropical jet stream.

The subtropical jet normally locates around 30ㅇN, but it can move poleward to about 40ㅇN (but with weaker intensity) during the summer when the direct circulation in the tropics shifts to the north.

The polar jet is associated with the polar front and depends on the lifecycle of the low. Therefore, the variation is greater than the subtropical jet which is not related to frontal systems. The polar jet in the North Pacific covers a broad region from Japan to North America with passing through the Aleutian. When it reaches the eastern coast of North America, it merges with the subtropical jet. Merging and splitting of the polar jet and subtropical jet modulates the daily weather.



〈Jet stream〉
※ Source: Wikipedia

Learning Activities

2. Westerlies

The momentum and vorticity are conserved. In the absence of friction or external forces, the absolute vorticity is the summation of planetary vorticity associated with the Earth rotation and the relative vorticity due to the air motion relative to the Earth. The absolute vorticity is conserved without friction or external force.

As a result, the absolute vorticity does not change even if the air moves to higher latitudes. Therefore, for an air parcel that moves to higher latitudes, as the planetary vorticity increases, the relative vorticity decreases. Therefore, it becomes an anticyclonic circulation flow (a high). On the other hand, the air moving from higher to lower latitudes tends to be a cyclonic flow (a low).

As the vorticity is conserved, air moves in the direction to conserve the vorticity. The northward or southward movement of air with the jet changes to the direction in which the vorticity can be conserved. The movement of air, in turn, looks like a wave moving north and south.

The wave caused by Earth's rotation is called the westerly wave or planetary wave, and moves westward. Synoptic (shorter) waves prefer eastward propagation by relative vorticity advection while planetary (longer) waves prefer westward propagation by planetary vorticity advection.

Learning Activities

2. Westerlies

1) Long wave, barotropic wave, and ultra long wave

The long wave refers to a wave with wavelength of 5,000 to 6,000 km, wave number of 5~9, and a period of 2~3 days. It can be identified in the everyday upper-level weather map. It is detected by wave spectrum analysis of circulation fields (pressure or wind fields). The long wave has the same amplitude as the ultra long wave in the troposphere.

The high and low-pressure systems, which are synoptic scale, are closely connected with long waves. The surface lows and highs are associated with the upper level troughs and ridges. The distribution of the temperature and vertical wind structure influence the baroclinic instability by converting the available potential energy to kinetic energy.

Barotropic waves can be identified in lower latitudes. Eastward propagating baroclinic long waves influence the mid- and high-latitude weather systems.

Warm and cold fronts are also associated with baroclinic waves. When ultra long wave trough remains stationary, a low-pressure system develops, and more severe weather can occur. On the other hand, when a ridge of the long wave becomes stationary, a low-pressure system gets suppressed.

An ultra long wave is the longest wave seen in the upper atmosphere. Its wavelength is more than 9,000 to 10,000 km, wave number ranges from 1 to 4, and its period is about a week. It can be easily depicted in monthly averaged or annually averaged weather maps. The wave is essential to understand how the process in the upper troposphere modulates the weather. It is also crucial for the long-range forecast.

Summary

1. Jet stream

- The jet stream is a strong horizontal flow that concentrates in a narrow zone forming a long axis. Depending on its location, the jet can be classified as tropospheric jet, middle-atmosphere jet.
- Jet stream has been recognized since the Second World War. In 1956, C. G. Rossby defined it as the strong westerly wind in the upper-level.

Summary

2. Westerlies

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