



# Introduction to Meteorology

**19** Scales of atmospheric motion

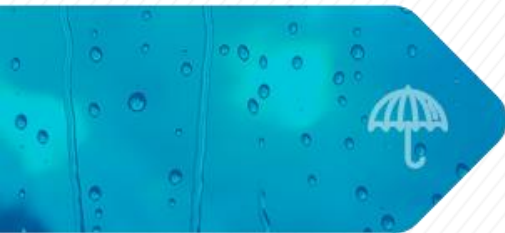
## Introduction



Atmospheric motions occur on a variety of temporal and spatial scales. For example, the horizontal size of cumulus cloud is about 100m~1km, large thunderstorm is about 10 km, the radius of Typhoon is several hundred kilometers, and extratropical cyclone is thousands of kilometers.

For the temporal scale, lifetime of cumulonimbus cloud is about 30 minutes, a giant thunderstorm is usually about a few hours, Typhoon is about one week. Weather system varies rapidly, the cyclones pass an area in 2~3 days. Seasonal wind changes after about six months. Therefore, understanding the temporal and spatial scale of atmospheric motion is crucial.

## Contents



1. Global scale
2. Mesoscale scale
3. Microscale
4. Eddies

## Learning objectives



1. Describe the atmospheric motion by each scale.

## Learning Activities

### 1. Global scale

The most fundamental motion is on the global scale. The global scale includes waves of 1,000km wavelength and longer. Most of the kinetic energy of atmospheric motion is related to the motion in this scale. Global scale motion can be further classified into planetary and synoptic scales.

## Learning Activities

### 1. Global scale

#### 1) Planetary scale motion

Planetary scale is a very large atmospheric motion which is comparable to the radius of a planet. Climatologically, the area of the maximum westerly wind is called Jet stream. It also refers to the strong winds that are locally superimposed on upper level trough. Strong easterly wind region is called the easterly Jet.

A strong wind at 850 hPa with heavy rain is called the lower jet. The jet stream is associated with the atmospheric large-scale circulation. The cold front jet stream exists where there is strong meridional temperature gradient in accordance with the thermal wind balance. Subtropical jet stream exists as a convergence zone of angular momentum transportation.

The jet stream's existence was confirmed by the invention of radiosonde. Horizontal pattern of the jet was observed after World War II by Carl-Gustaf Rossby, University of Chicago.

Compared to the subtropical jet which has a wavy west-to-east pattern, polar jet has a large wavy meridional pattern and is hard to be identified in long-term climate patterns.

## Learning Activities

### 1. Global scale

Ultra-long wave is the longest wave in the upper atmosphere with a wavelength of 10,000 km, wavenumber 1–4, and period longer than a week, and can be observed in weather maps or monthly mean maps. It can be detected by spectral analysis.

Ultra-long wave determines the weather longer than a week. Clouds and precipitation are likely to persist on the trough and clear sky on the ridge, when an ultra-long wave is at rest. Blocking is associated with ultra-long waves. Also, in the equator, a quasi-biennial oscillation (QBO) is related to ultra-long wave. The ultra-long wave does not directly change the weather, but modulates the large-scale atmospheric condition which can alter the weather.

Long wave is a wave in the upper atmosphere with a wavelength of about 5,000~6,000 km, wavenumbers 5–9, and period of 2~3 days. It can be seen in daily upper-level weather chart, and in wave analysis such as atmospheric pressure (height) and wind field.

A baroclinic wave which is related to mid and high-latitude weather is a long wave. Baroclinic wave is superimposed on the ultra-long wave and makes the wave to propagate eastward. Weather changes and frontal system moves with this wave.

## Learning Activities

### 1. Global scale

#### 2) Synoptic scale

The Synoptic scale generally refers to an atmospheric motion with horizontal scale of thousands of km, 10 km in vertical scale, and period of 2-3 day. Low and High pressure systems seen in the surface weather chart and troughs and ridges in upper-level chart are synoptic in scale. The scale ranges between planetary scale and mesoscale.

Synoptic scale includes air mass, frontal system, highs and lows, easterlies, stationary highs. First, the air mass is an air with similar temperature and humidity that are distributed over a wide range in a horizontal direction from hundreds to thousands of kilometers.

In a high latitude or low latitude, over a wide area of land or ocean where the surface property is homogeneous or around a calm stationary high, the temperature and humidity become equilibrium between the surface and its above if the air is stationary over a long period of time. In the mid-latitude, strong low or high pressure moves continuously, making it difficult for air mass to form.

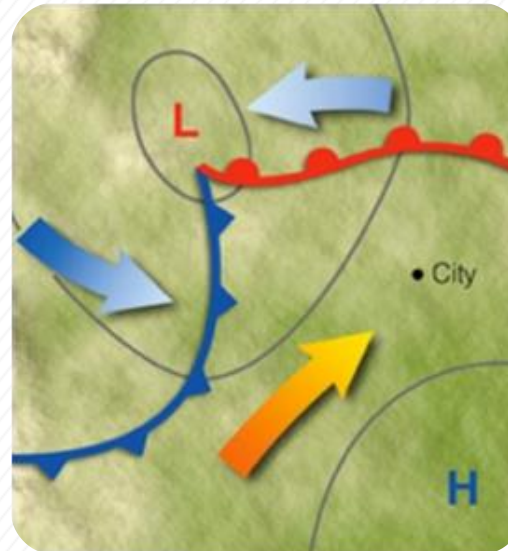
Next is the frontal system. Front is the interface or transition zone between two air masses of different density. The interface, the surface of discontinuity, is called the frontal surface. The line of discontinuity where the frontal surface encounters with the ground is called the front.

## Learning Activities

### 1. Global scale

Low pressure (depression, low pressure, cyclone) is a low-pressure region characterized by a closed isobars, cyclonic circulation converging toward the center. The term 'depression' is commonly used to refer to disturbance systems outside the tropics, often associated with different air masses, fronts and warm lows.

Diameter of low is 2,000 ~ 4,000km at most. Overall, the low pressure system tends to move from west to east with a speed up to 90 m/s (50 knots). There are also lows that move in various directions. Large lows sometimes do not move for several days.



※ Source: Meteorology Today 10<sup>th</sup> edition, Figure 9.1

## Learning Activities

### 1. Global scale

High pressure (anticyclone, high) is a relatively high atmospheric pressure area and appears as a series of closed, nearly circular or elliptical isobars. Air descends from the top of the troposphere to its center and moves outward from the center in low levels. The highs move slower than lows (cyclones, depressions, lows) and usually change weather slowly.

Easterly refers to the wind blowing from east to west. It is a wind blowing in the equator within approximately 30 degrees north and south, from subtropical high-pressure zone to equator. It is called the trade wind and is due to the rotation of the Earth. Weak easterlies can be found in the lower troposphere of the polar region.

Tropical easterly wave is known as a precursor to tropical cyclones genesis. It is found over the tropical western Pacific, Caribbean, tropical Central Pacific, West Africa, tropical Atlantic, and Bay of Bengal. The period is about 3~6 days, wavelength is about 2,500 to 4,000 km, and maximum amplitude of meridional wind is near at 700hPa. The opposite phase of low-level wind is around 200 hPa. Easterly waves are located near the ITCZ (Intertropical Convergence Zone) or low pressure area, and develop to typhoons or hurricanes.

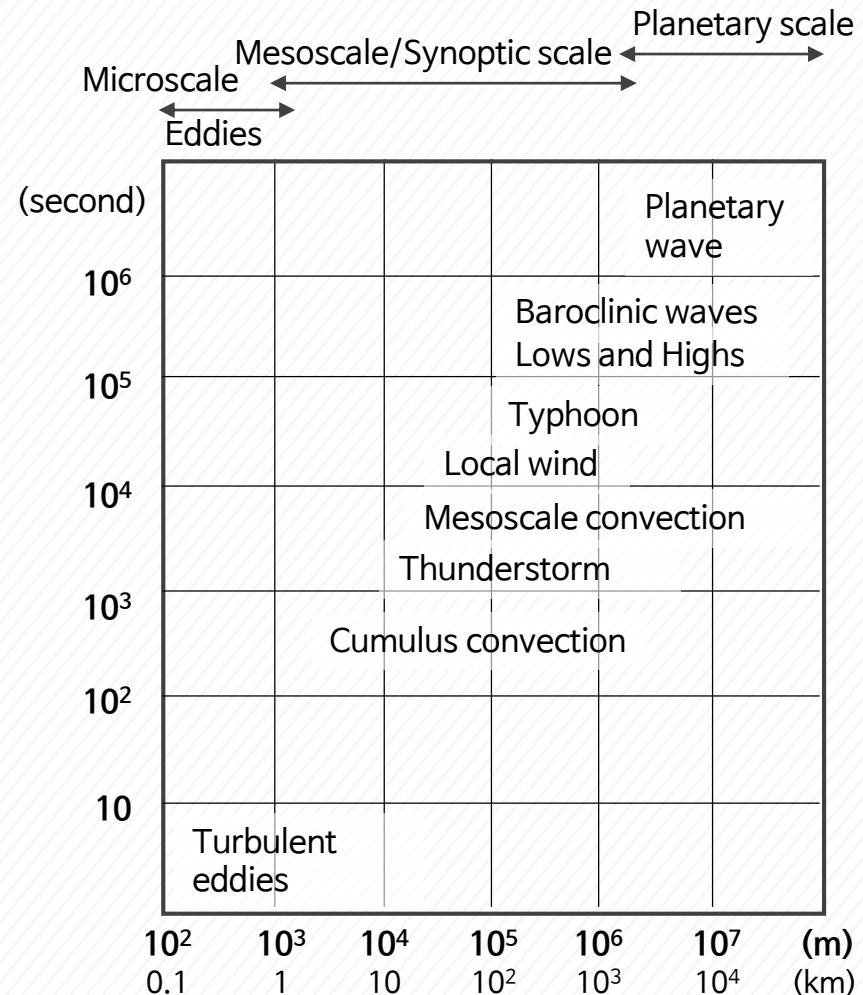
Blocking is a large scale pattern of the obstructing normal west-to-east progress of migratory cyclones and anticyclones. Blocking high (anticyclone) is a high (or anticyclone) that remains nearly stationary or moves slowly compared to the west-to-east motion "upstream" from its location, so that it effectively "blocks" the movement of migratory cyclones across its latitude.

## Learning Activities

### 2. Mesoscale

Mesoscale motion has horizontal scale about 1~2,000km which is between large (>2,000) and small (<1 km) scales. It is smaller than warm lows and migratory highs. Convective systems, thunderstorms, mountain & lake disturbances are mesoscale systems.

The maximum amplitude of mesoscale motion is in the lower troposphere, and the life cycle is shorter than one day. It can be developed into frontal system when it is combined with the upper-level waves.



## Learning Activities

### 2. Mesoscale

#### 1) Heavy rain

Large amount rainfall in a short time is called heavy rain. Weather conditions that are subject to heavy rains are: large amount of water vapor in the atmosphere, convergence of water vapor, and ascending motion that causes condensation.

Uplift by orography, disturbances associated with tropical cyclones, lows, fronts, and convection causes heavy rain.

## Learning Activities

### 2. Mesoscale

#### 2) Local wind system

A unique wind caused by orography or land-sea distribution is called local wind. The local wind system interacts with large-scale circulation system. Land-sea breeze and mountain-valley breeze are local wind system.



Land-sea breeze



Mountain-valley breeze

Sea breeze is the wind caused by pressure gradient force due to thermal difference between the land and sea (water). During daytime, the air over the land is heated quickly and becomes less dense than over the adjacent water, and the heating of the air above produces a shallow thermal low. The pressure gradient results in a breeze that blows at the surface from the sea toward the land during daytime (sea breeze), and the opposite direction (from land to sea) during nighttime (land breeze).

Mountain-valley is a local wind developing along mountain slope. During daytime, sunlight warms the valley walls, which in turn heats up the air in contact with them. The heated air, becoming less dense than the air at the same altitude, rises as a gentle upslope wind known as a valley breeze. Mountain breeze is the wind that glides downslope into the valley during night time. Mountain-valley breeze is most frequent in clear summertime when prevailing winds are light.

## Learning Activities

### 2. Mesoscale

#### 3) Low level jet

The strong winds in a narrow zone in the lower-troposphere are called the low-level jet (LLJ). LLJ are observed in a specific location over the globe or can be observed with thunderstorms. The nocturnal jet in the Great Plains and the Somali jet in the eastern Africa are LLJ.

The nocturnal jet in the Midwest US is seen in the eastern slope of the Rocky Mountains at a height of 500m. It accompanies with a southerly exceeding 20m/s. The LLJ brings moisture from the south to the Midwest, causing a thunderstorm. The development of the boundary layer by the change of the heating and cooling of the slope is essential for the development of LLJ. During the day, the boundary layer is over 2 km high, of which the west has higher temperature. During night, southerly wind prevails and temperature gradient reverses, which induce strong nocturnal jet.

Somali jets occurs near at 850hPa with a wind speed up to 15 m/s. It penetrates into East Africa and traverses the northern parts of the Arabian Sea before reaching India. Indian Monsoon and African highlands are important for Somali Jet.

## Learning Activities

### 3. Microscale

Microscale refers to cumulonimbus, turbulence, and so on. Microscale is defined as a motion less than 2km in US and less than 20 km in Asia.

#### 1) Cumulonimbus

Cumulonimbus is one of 10 basic types of cloud. Cumulonimbus are much larger and more vertically developed than fair weather cumulus. They can exist as individual towers or form a line of towers called a squall line

Fueled by vigorous convective updrafts, the tops of cumulonimbus clouds can easily reach 10,000 km or higher. Lower levels of cumulonimbus clouds consist mostly of water droplets while at higher elevations, where temperatures are well below zero Celsius, ice crystals dominate.



A flat, anvil-like top

Fibrous-edged top  
can be seen

Anvil-topped shape or  
fibrous-edged shape

## Learning Activities

### 3. Microscale

#### 2) Thunderstorm

Thunderstorm is heavy rain in cumulonimbus accompanied by lightning. Thunderstorm can develop by solar radiation gradient in air masses, in frontal systems, and with low pressure such as tropical cyclones. It is triggered in many ways, but all cases are related to developed cumulonimbus.

The thunderstorm is characterized by the length scale and duration. Typically, a single cell storm is about 20 km and lasts about an hour. Multicell cluster storm, a group of storm, is about 30–50 km and lasts a couple of hours.



Thunderstorm by strong solar radiation

Thunderstorm developed in fronts

Thunderstorm accompanied with lows or tropical cyclones

## Learning Activities

### 4. Eddies and turbulences

Eddy and turbulence are atmospheric motions seen in planetary boundary layer.

#### 1) Atmospheric boundary layer

From the perspective of the atmospheric motion, troposphere can be divided into three layers. Near the surface, the speed of air motion becomes slower due to the friction and further slows down the air above. Therefore, surface friction impacts the motion above the surface.

Moreover, the air can be mixed up due to friction, causing turbulence and a mixed layer. Without turbulence, the altitude at which surface friction plays a role will be about 2 m. With turbulence, it will reach several hundred meters to several kilometers. This layer is called the atmospheric boundary layer or planetary boundary layer.

## Learning Activities

### 4. Eddies and turbulences

#### 2) Turbulence

Turbulence is an irregular movement of the fluid, and is not reproducible because of the complexity of its temporal and spatial fluctuations. The atmospheric motion is mostly turbulent, which is especially predominant in the atmospheric boundary layer.

## Summary

### 1. The type of motion and its horizontal scale

Type of motion	Horizontal scale (meter)
Molecular motion	$10^{-3}$
turbulence	$10^{-2} - 10^{-1}$
Eddy	$10^{-1} - 1$
Dust devils	$1 - 10$
Gusts	$10 - 10^2$
Tornado	$10^2$
Thunderclouds	$10^3$
Fronts, squall lines	$10^4 - 10^5$
Typhoon	$10^5$
Synoptic scale	$10^6$
Planetary wave	$10^7$
Atmospheric tides	$10^7$
Large-scale	$10^7$

## Summary

### 2. Horizontal scale of atmospheric motions

- Planetary scale: 10,000km
- Synoptic scale: 1,00 km
- Mesoscale: 1 ~ 1,000km
- Microscale: less than 2km
- Eddies: less than 10m