Government of India
Ministry of Earth Sciences
India Meteorological Department
Meteorological Training Institute

# Lecture notes On Climate Science For E-learning phase of Forecaster's Training Course

Prepared
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Scientist D

# Extra-Tropical

## 1. Air Masses

Air mass concept, developed by Vilhelm and Jacob Bjerkness is known as Air mass analysis. This helps to understand the weather of middle latitudes which is mainly characterized by cyclones and anticyclones and many other day to day weather changes. Credit goes to Tor Bergeron, J. Bjerkness and Solberg for introducing the air mass concept to field of meteorology and for forecasting the weather on the 24 to 36 hours. Air mass analysis technique enables the meteorologists to understand various weather phenomena more clearly.

When air mass remains in contact with a large and uniform surface for a couple of days, its temperature and moisture attain equilibrium with the surface. For example, if underlying surface is warm, the overlying air will be warmed by gradual heating by conduction. If surface is cold, the overlying air will be cooled and heat will be removed from the lower part of the air. Similarly, the moist surface will impart its moisture to air above it whereas the overlying air will lose moisture to the underlying dry surface. The time taken to reach equilibrium may vary from 2 to 3 days to a week or two. Once the equilibrium is reached, it will change only slowly with time. Such an extensive portion of atmosphere that has acquired some sort of equilibrium with the surface into its contact over a large area is designated as an **air mass**. Such a large uniform surface is called an air mass source region.

Air masses retain their identity by conserving their original physical properties only in the upper parts even after they move far away from their source of region. Air masses control the weather associated with it through a) the vertical distribution of temperature in an air mass (indicative of stability of air besides its warmness or coldness); b) the moisture content of air determining the presence or absence of condensation forms. Air masses play an important role in removing the latitudinal imbalances in heat (i.e heat transfer from the tropical to polar region).

Primary source region of air masses are the tropical seas and hot desserts during much of the year and over the Arctic region, particularly in winter. Secondary source regions are regions over which air flow is generally not stagnant and if the air masses pass over such region can be transferred rapidly and may acquire unique characteristics. It is noteworthy that no major source regions are found in the middle latitudes. They are generally confined to tropical or polar locations. Examples of the primary source regions are the following: the tropical Atlantic Ocean around Bermuda, the tropical Pacific Ocean around Hawaii, the Sahara Desert region and the interior of Siberia. Some of the secondary source regions are: the North Pacific Ocean between Siberia and Canada, North Atlantic Ocean between Canada and Northern Europe, and the arid south-west of the United States.

## 2. Classification of the Air masses.

The principal source regions of the earth may be classified according to the nature of the surface (land or water) and latitude of the region. Thus the source regions are classified as under:

**I) <u>Surface</u>**

a)Continental

b)Maritime

**II) <u>Latitude</u>**

a)Arctic (located in the high latitudes)

b)Polar (between Arctic source regions and subtropical highs)

c)Tropical (occupy subtropical high pressure belts)

d)Equatorial (located around the equator between the trade winds of the northern and southern hemispheres)

The air masses may be classified as under:

**I)Polar**

a) continental Polar airmass (winter time) cPK
Source regions: Central Canada and Siberia.
Extremely cold, dry, stable airmass
(coldest wintertime airmasses)
Produce intense cold waves
No clouds in these air masses.

b)continental Polar airmass (summer time) cPW
Source regions: Central parts of high latitude continents. Example Central Canada
Cool and dry airmasses
Steep lapserates.
When cPK moves out to oceanic surface, it is modified into cPW air mass with haze, fog and low stratus clouds.

c) maritime Polar airmass (winter time) mPK
forms over open areas in the higher latitudes
cool and moist
few clouds in their source regions
Extensive precipitation is produced when forced to ascend mountain barriers
Lower layers moist and unstable and dry and cool in upper parts.
Produce squally weather.

d)maritime Polar airmass (summer time) mPW

cool and moist in the lower parts, but dry aloft

Temperature inversion is produced with moisture discontinuity

Temperature slightly higher

**II) Continental**

a)**continental Tropical air mass**

Source regions: Subtropical high pressure land areas

High temperature and low moisture content.

In United States, these air masses are only important in summer.

They are both dry in winter and summer.

In summer they are very hot

Subsidence and stability found in the upper parts of these air masses in their source regions.

If cT air mass is aloft over warm moist air at the surface, atmosphere becomes convectively unstable and violent thunderstorms and tornadoes are produced.

b)**Maritime Tropical air mass mT**

Warm and moist and highly unstable having convective unstability.

**Maritime Tropical air mass (winter time)**

Source regions: Warm oceans in both the hemisphere

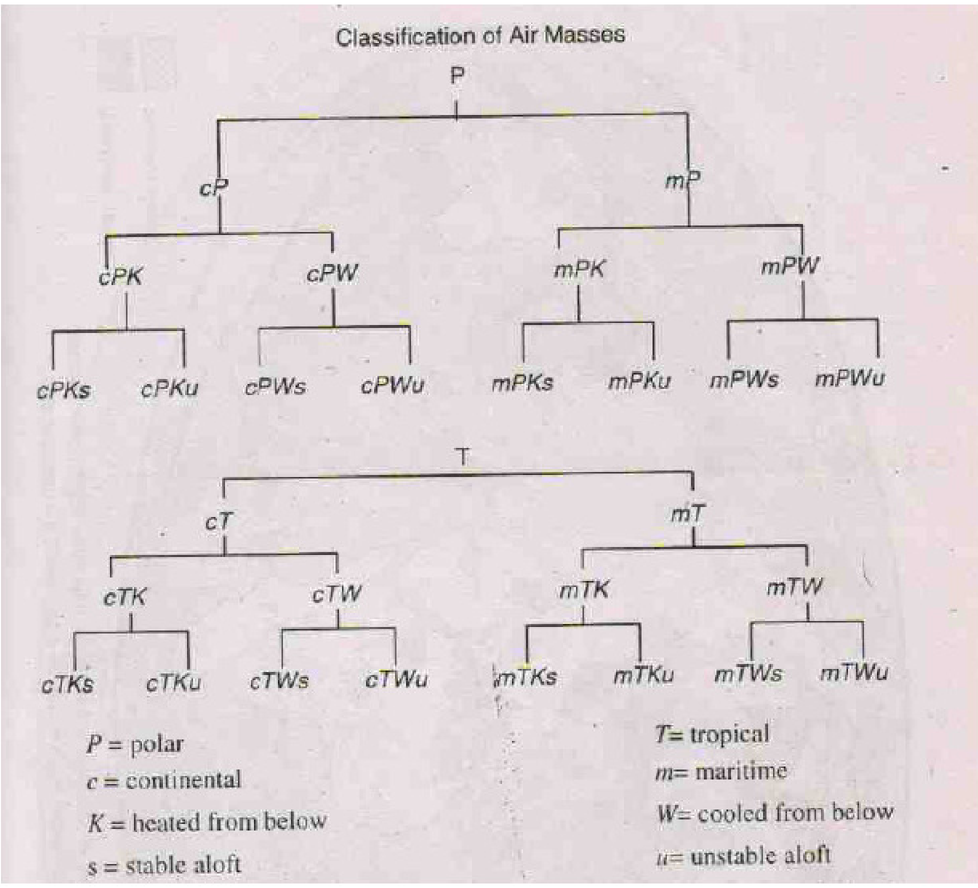
Warm moist and unstable air masses

Steep lapse rate up to tropopause and moisture well distributed up to high levels.

When these air masses are lifted over fronts or high mountains, they produce heavy Precipitation

**Maritime Tropical air mass (summer time)**

Source regions located in the belt of great semi permanent highs of the tropical oceans including the Caribbean Sea.




**3. Geographical distribution of Fronts and Frontal zones.**

If Two Air masses with sharp contrasts in their physical characteristics (Temperature, humidity, pressure,density) are brought together by converging movements in the general atmospheric circulation, they do not mix readily. They come in contact with one another along sloping boundaries which are actually a transition zone across which a sharp transition in weather condition occurs. The term "front" is defined as an interface or transition zone between two air masses of different density. Since air masses are three dimensional i.e. having vertical as well as horizontal extent, the surface separating adjacent air masses in vertical plane is known as the frontal zone i.e. zones of discontinuities in the air mass properties. Weather charts and maps depict the air masses and fronts as two dimensional. On occasions, in a narrow frontal zone a temperature change of 10˚ to 20˚ Celsius may be observed over a short distance of 3 Km. In the air mass the changes in the different climatic elements is only gradual but the boundary lines of air masses are distinguished by rapid changes in the weather elements.

Fronts usually develop in those areas of the world where air masses have strong temperature contrasts. The major zones of frontogenesis i.e. creation of new fronts or regeneration of decaying fronts already in existence.

1) Atlantic Polar Front

This front develops in winter. cP and mT air masses come together in close proximity to create the polar front. This front extends up to Europe in the east, the West Indies and Portugal form the southern limit whereas great lakes and Iceland define the northern limit. Cyclones which are produced along this front account for widespread precipitation over a large area extending from eastern part of North America, through the North Atlantic to the north-western part of the Europe. During summer this front is less developed than in winter.

2) Atlantic Arctic Front

The formation of this front takes place along the boundaries of the Arctic source region and the maritime polar air masses. During winter all storms produced on this front move out from Iceland to Barent's Sea via Northern Norway. The Arctic Front changes its location according to the season. In summer this frontal zone develops along the Arctic coasts of Siberia and North America. In Winter over North America it develops on the border between cP air and Pacific maritime air.

3) Mediterran Front

This front is located over Mediterran-Caspian Sea region in winter. The Winter storms that develop here move towards east and northeast; some move towards southern Russia, while others travel towards the north east giving winter precipitation over arid regions. Sometimes Frontal weather disturbances developing over the Mediterran basin travel up to Pakistan and North West India.

4) Pacific Arctic Front

This front extends from the Rocky mountains to the great Lakes region in the United States. In winter there is a general equatorward shift of this front. Winter disturbances that develop along this front move out to Texas and northern Mexico. Cold wave sweeps in the rear of such storms across the entire region of Southern United States.

Two pacific fronts one near the coast of Asia and other near the coast of North America are seen in winter and frontal storms from this fronts control the weather of the entire region extending from the gulf of Alaska to southern California and Western Mexico.

During summer the air mass contrasts are weaker so that permanent fronts are only present around the Arctic region. On the Atlantic side, cold Arctic air mass sometimes travels far southward. On Pacific side of North America, powerful subtropical high pressure cell does not allow the formation of polar fronts in summer. The summer polar fronts develop over Eurasia and middle North America.

In southern Hemisphere, the average position of the polar front is about 45˚S in January. In July there are two Polar fronts – one originating over South America and other at 170˚W.

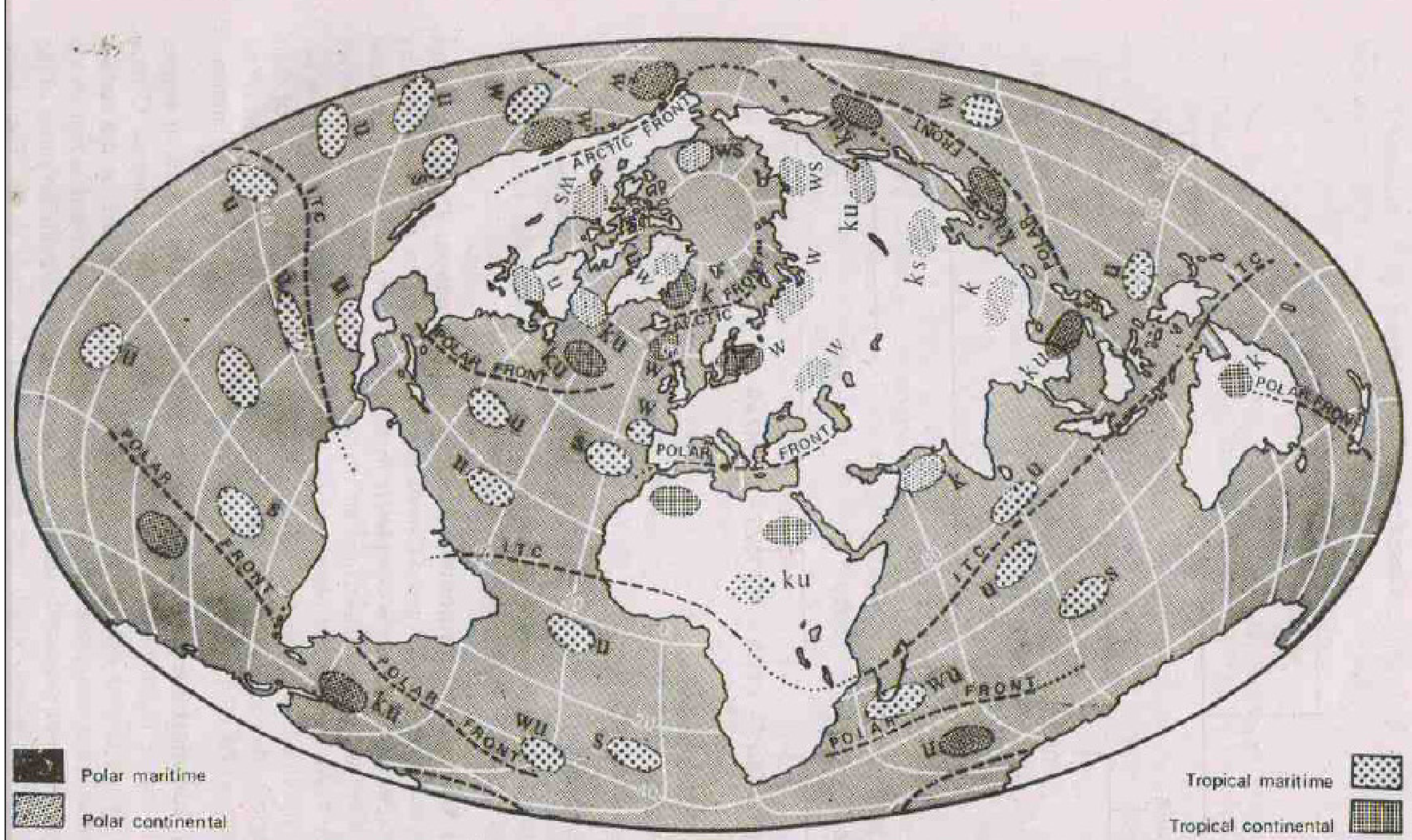



**Fig.14.2** World distribution of principal air masses and fronts in July (After Willet). *w* = warmer than underlying surface; *k*= colder than underlying surface; *s*= stable aloft; *u* = unstable aloft.

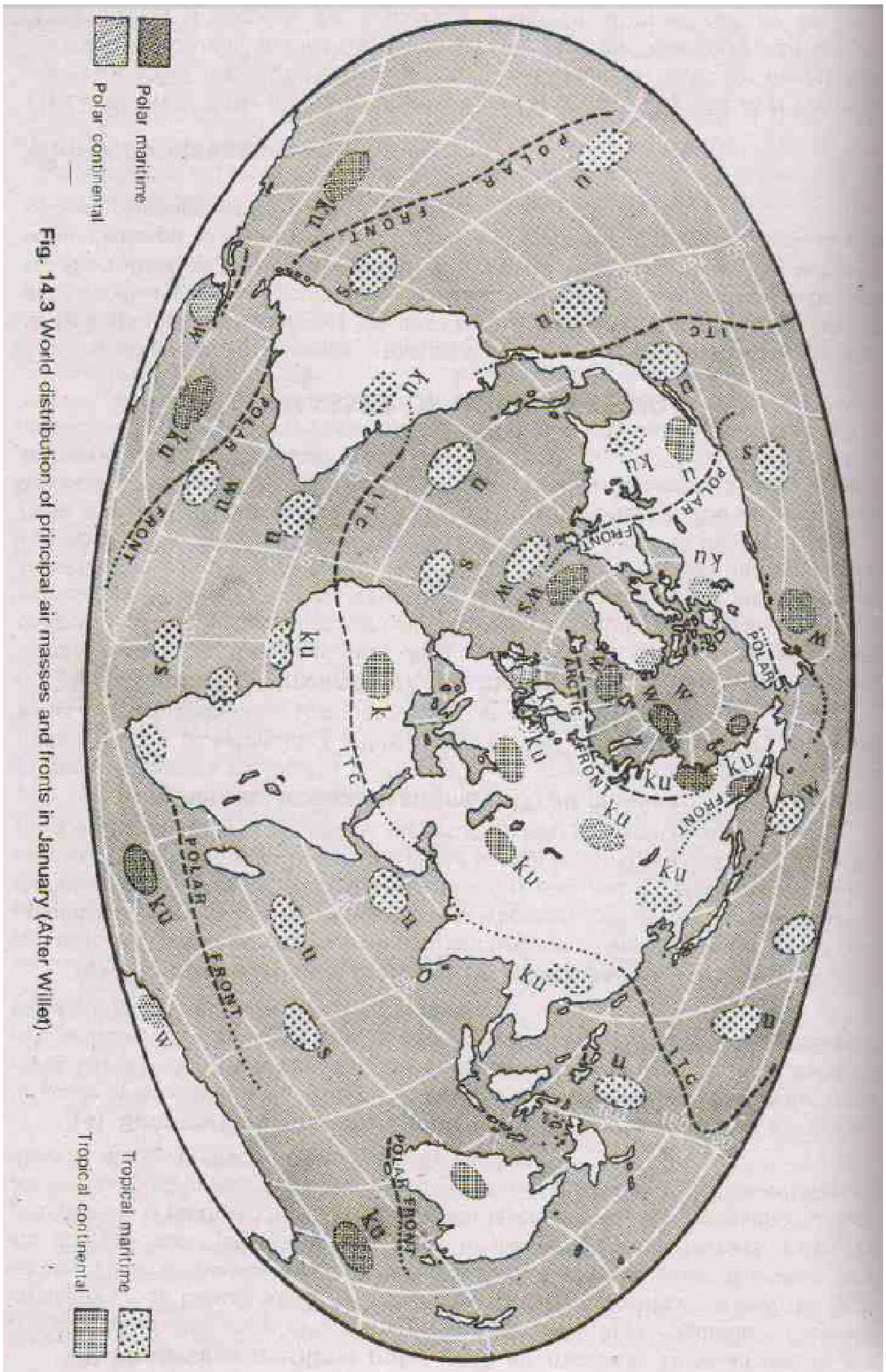


Fig. 14.3 World distribution of principal air masses and fronts in January (After Willet).

## 4. Extra-Tropical cyclones.

There are four stages in the life cycle of an extra-Tropical cyclone viz. the initial stage, the incipient stage, the mature stage and the occlusion stage.

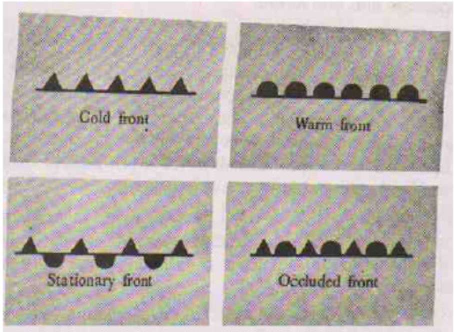


Fig 15.1 Frontal symbols used on weather maps.

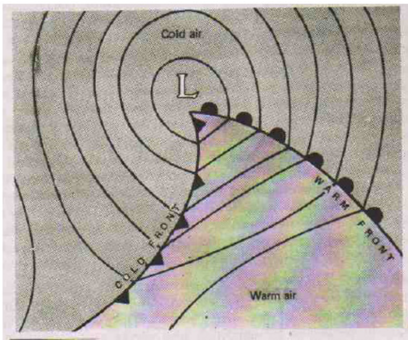


Fig. 16.1. A cold front and a warm front in an extratropical cyclone as depicted on a surface weather chart.

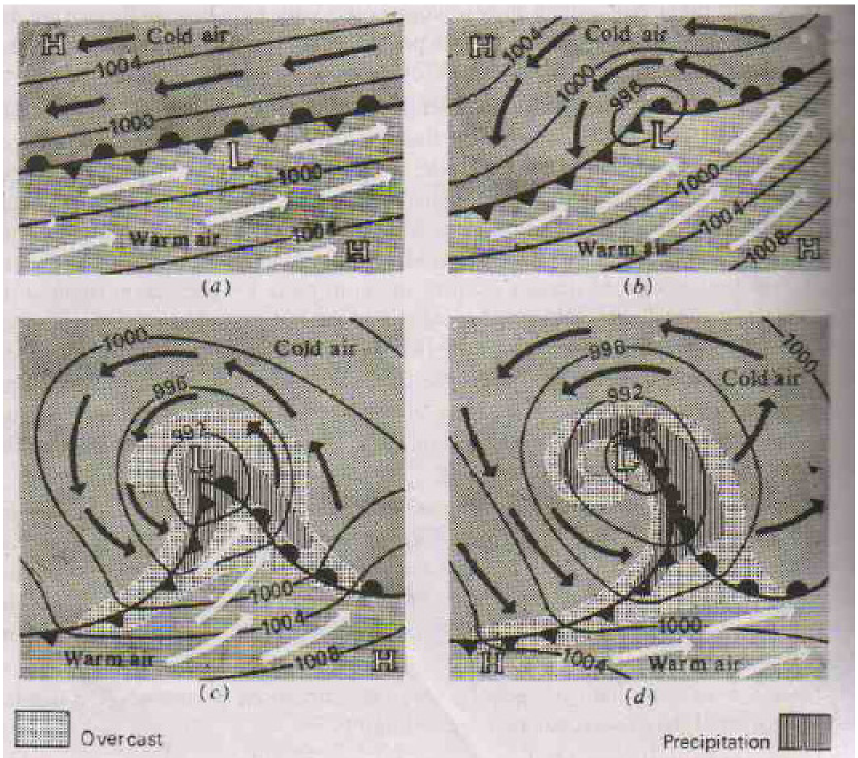


Fig.16.4 Stages in the life cycle of an extratropical cyclone (a) Initial stage (b) Incipient stage (c) Mature stage (d) Occlusion.

a)**The initial stage:**

In this stage, polar and tropical air currents on t he opposite sides of the polar front blow parallel to the isobars and the front. To the north of the polar front, cold air mass is present and flows from east to west. To the south of the polar front, warm air mass is present and flows from west to east. As a result the wave disturbance is produced and front is quasi-stationary and is in perfect equilibrium. The wedge of cold air mass lies under the warm air mass. There is complete absence of wind shift. The weather is fine. Wind shear exists along the slanting surface of discontinuity.

b)**The incipient stage:**

In this stage, a wave is formed on the front. Cold air is turned in a southerly direction and warm air in northerly direction. There is an encroachment of each air mass in to the domain of the other resulting in readjustment of pressure field and isobars are circular in shape.

A cyclonic circulation in initiated around a low centre at the apex of wave and whole cyclonic vortex is carried along with the winds prevailing in the warm air region. The new depression developing in the crest of wave is called nascent cyclone. This stage is commonly known as cyclogenesis i.e., birth of a new cyclone.

c)**The mature stage:**

In this stage, the intensity of the cyclone increases. The curvature and amplitude of the wave also undergoes a marked increase. The warm sector starts flowing from southwest towards colder air flowing from southeast. Now cyclone is fully developed. There are well marked warm and cold sectors.

Warm air moves faster than cold air. The direction of movement is perpendicular to warm front. Warm air is moving in to a region previously occupied by cold air. In the rear of cyclone cold polar air is under-running the air of the warm sector, thus a cold front is generated there. Each of these fronts is convex in the direction of the movement. Ascending air is present along the entire surface of discontinuity. If rising air is moist, cloudiness and precipitation along the warm as well as cold fronts. Precipitation released at warm front is confined to a narrow zone. As position of cold front advances faster than warm front, warm sector becomes progressively narrower. This is beginning of occlusion and marks the maturity of the cyclone and period of maximum intensity.

d)**The occlusion stage:**

In this final stage, the advancing cold front ultimately overtakes the cold front resulting in the formation of an occluded front. Occlusion starts near apex of the wave where warm front is closest to cold front. The warm sector is slowly pinched off and finally the two cold air masses mix across the front. This eliminates the occluded front and now cyclone dies out. Life span of a single frontal cyclone is about five to seven days.

It is observed that the extra tropical disturbances are rarely appearing alone. They will mostly appear in series which is extending from NE to SW direction. The first cyclone in this series is the oldest one and it is fully occluded cyclone. To the SW of this somewhat younger one is noticed and it is partly occluded cyclone. Still to the SW we get the young cyclone and the last is a wave depression. This is called the cyclone family and it consists of 3 to 5 members. Thus 3 to 5 cyclones in different stages of development are present. The cyclone family takes about 5 to 7 days period to pass over a place. The orientation of cyclone family is in ENE to WSW direction.

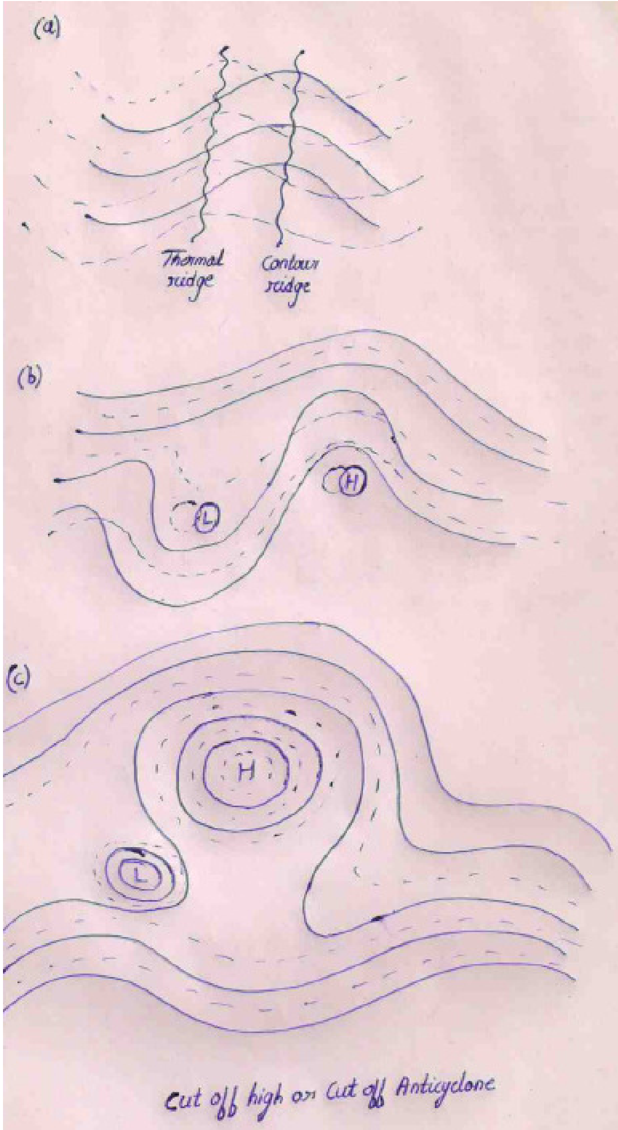
**5. Blocking high**

Irregular quasi-cyclic changes, the period of which may vary from about 3 to 8 weeks is known as zonal circulation index and the changes from one extreme to the other extreme and back to the first is called as index cycle. In case of low index cycle large penetration of polar air occurs behind the trough in long waves and the trough gets amplified. In this case the cold low forms equatorwards of main zonal flow in warm area and a warm high forms poleward of main zonal flow in cold area. These cold lows and warm highs get detached from the main zonal flow and this is called as cut off process which forms mainly in middle and upper tropospheric levels. In this case the deepening of westerly waves takes place and the formed lows and highs area called as cutoff lows or cutoff cyclones and cutoff highs or cutoff anticyclones.

In the early stages (a) the contour ridge is ahead of thermal ridge. Here appreciable amount of warm air advection is found to the wind ward of the ridge aloft. The negative vorticity is generated and the ridge which usually moves very slowly gradually expand northward (intensifies) and after some considerable time stage (b) is reached. The flow around the ridge has been changed from the wave shape to the omega shaped pattern. At this stage the meandering zonal current begins to split. The main current swinging around the ridge and a secondary current begins to penetrate along the base of omega shaped pattern. Under favorable conditions the cut off high acquires appreciable dimensions and intensity. The zonal current develops two distinct branches Sharp troughs and cut off lows develop to the SW or SE as shown in (c). On some occasions the trough may appear as only shear line.

If the cut off high takes the shape of omega Ω shaped blocking and it is known as blocking high. Cut off high normally persists to about 3 to 4 days while the blocking high may persist for 3 to 4 weeks. At surface the pressure and temperature will both be high. It is seen that these anticyclones reach up to great heights and normally dominate the circulation throughout the troposphere and lower parts of stratosphere. Sometimes when cutoff high forms in mid and upper troposphere , the sea level cyclones will have a tendency to be steered around these highs, either to north of cut off high or to south of base of Ω pattern. Such situations associated with this type of blocking generally leads to subnormal rainfall activity over major parts when the flow is located into Ω blocking and the flood will occur to the northernmost and southernmost regions of blocking high.

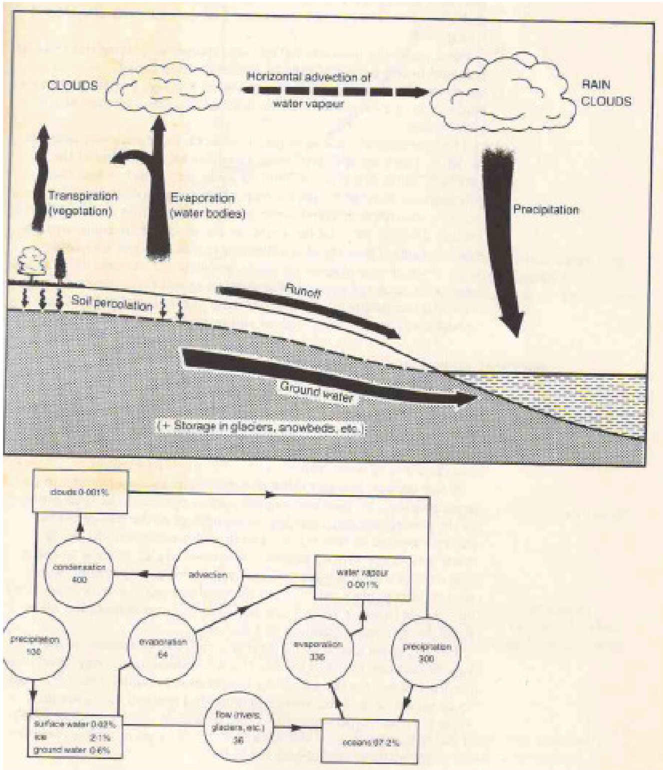
The preferable area for Ω high is east coast of Europe, Australia and America. The cut off highs occur most frequently in high latitudes say between 40 to 65˚N.




6. The hydrological cycle

Continual recycling of water between the land, the oceans and the atmosphere is known as the hydrological cycle. Evaporation from water bodies and transpiration from vegetation are continually adding water to the atmosphere. Some of this may condense producing clouds of different types, sizes, and heights and some of these may produce precipitation. Because of horizontal advection of water vapour in the winds, not all clouds give rain and precipitation will not occur in the same location at which evaporation occurred. Some of the precipitation evaporates as it falls through atmosphere and remainder will fall the ground, the water surface or a vegetation surface. Water reaching ground will evaporate; percolate into the surface to water table or runoff over the surface or in confined channels as river flow. Some of soil moisture will be taken up by root system of vegetation and will eventually be transpired. Some water will be stored in soil and lateral flow of soil water occurs into streams and lakes. Evaporation will then occur and the hydrological cycle will repeat itself.

For a particular location, the moisture gain from the precipitation will be balanced over a period of time by the loses from runoff, evapotranspiration and change in soil water storage. For a globe as whole there is a long term balance between total precipitation and total evaporation.




## 7. Angular Momentum cycle

The angular momentum budget of the earth is a beautiful example suggesting that the atmosphere, oceans and solid earth are united through a basic physical conservation law. Angular momentum is the component of angular momentum vector that is parallel to the earth's polar axis.

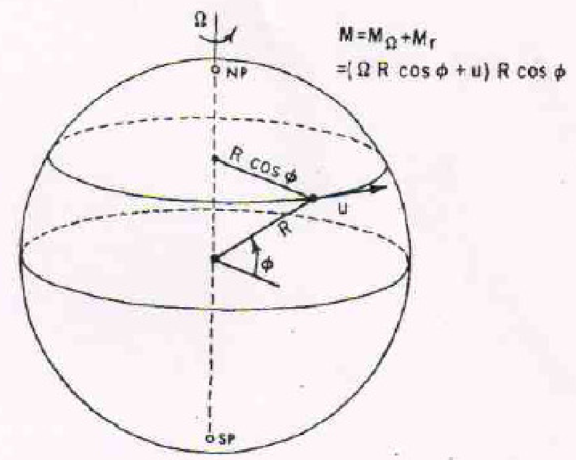



FIG. 2. Schematic diagram of the atmospheric angular momentum around the earth's axis of rotation, $M_{atm} = M_\Omega + M_r$, where $M_\Omega = \Omega R^2 \cos^2\phi$, $M_r = uR\cos\phi$, $\Omega$ = angular velocity of the earth, R = mean radius of the earth, $\phi$ = latitude and u is the eastward (zonal) wind component.

Atmospheric angular momentum around the earth's axis of rotation is expressed as

$M_{atm} = M_\Omega + M_r$

= Angular Momentum of solid earth + zonal component of air flow w.r.t. rotating earth.

Most of the temporal variability is found in relative Angular momentum. Considering the earth as the whole, the angular momentum integrated over all the masses of solid earth, oceans, and atmosphere combined is conserved, assuming external torque (due to the moon and sun) to be negligible at time scale of months to decades. Thus the total angular momentum of the system does not vary with time, and if there would be changes in atmosphere say, there would have to be compensating changes in the other components so that total angular momentum is conserved.

$$\frac{dM}{dt} = 0$$

Where

$M = M_{atm} + M_{ocean} + M_{ice} + M_{crust} + M_{mantle} + M_{core}$

It is well known that substantial changes in the $M_r$ of the global atmosphere are observed to occur at time scale of days, months, years, decades and even longer and there is a close compensation with changes in $M_\Omega$ on time scales of days to years and oceans and snow and ice do not play important role in this. Changes in $M_\Omega$ are observed as changes in the length of day (LOD). Increase in $M_\Omega$ corresponds to decrease in LOD.

**The atmosphere must transport energy from equator to pole to maintain pole-equator temperature gradient. In addition, because of westerlies**

**at the surface in middle latitudes and easterly winds in tropics, angular momentum must be transported from tropics to higher latitudes.**