TOPIC: -

TEMPERATE CYCLONES: DEVELOPMENT, WEATHER CONDITIONS AND DISTRIBUTION.

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INTRODUCTION: -

We all experience different kinds of temperature, humidity, cloud cast sky related to weather phenomena every day. Have you ever noticed that there are changes in pattern of weather events in an annual cycle? Depending on where you live, there could be different reasons for that. You have already studied about the planetary wind patterns and shifting of wind belts. You are also well aware about the air masses and front formations. These atmospheric phenomena in the mid latitudes create conditions for the developments of cyclonic conditions. Whenever they develop, numerous changes are observed in a shorter span of time, say few days or a week. They are termed as temperate cyclone or frontal cyclones. This module discusses about the development of this cyclone, the associated weather and their distribution over the globe.

TEMPERATE CYCLONES: -

A temperate cyclone is referred as mid-latitude depressions, extra-tropical cyclones, frontal depressions and wave cyclones. Temperate cyclones are active above mid-latitudinal region between 35º to 65º latitudes in both hemispheres. The direction of movement is blow from west to east and more pronounced in the winter seasons. It is in these latitude zones the polar and tropical air masses meet and form fronts.

Most of these cyclones form at wavelike twist or perturbation on these fronts. On weather map, cyclones are shown as a low pressure area enclosed by a number of isobars circular or elliptical

in shape. It is also referred as cyclone or depression. When these isobars take an elongated shape, the pressure system is called as trough. These cyclones are mainly observed in Atlantic Ocean and northwest Europe. These cyclones have characteristics to develop over both oceanic and land surface. Much of the highly variable and cloudy weather come across in the temperate zone. Since mid-latitude is an area of convergence of different air masses, it leads to the formation of fronts as well as the cyclonic conditions are bound to happen.

FRONTS: -

Air masses have been dealt in Module 21 and you know it very well that the air masses develop in specific regions over uniform physical properties (temperature, air pressure, humidity etc.). They have similarity in terms of air pressure, horizontal temperature and moisture distribution. Based on temperature characteristics, air masses are of two types – warm and cold. Both of the air masses march forward and both of them converge. The convergence is known as fronts.

Chritchfield defined front as "sloping boundary surface between contrasting air masses". Strahler and Strahler have defined the front as "sharply defined boundary between itself and a neighbouring air mass". According to Oliver and Hidor front is "identified as a zone of transition between airs of different properties". In a very simple term, front is a narrow zone between two air masses like a frontier when the armies of two countries come to fight each other.

As mentioned before, air masses are of two types – warm and cold, two types of fronts with distinct characteristics are formed in the process of marching forward and getting interacted with each other. Latter on the intermingling of the two gives birth to another one known as – occluded front.

WARM FRONT: In the northern hemisphere, the warm front (Figure 4) develops to the southeast; to the right side of the moving direction of warm air mass. In southern hemisphere, it develops to the southeast; to the left side of the moving direction of warm air mass. The warm front development is caused and modified due to the interaction of the air masses. On the warm front, the effect of warm air mass is pronounced, and hence, it is named so.

COLD FRONT: In the northern hemisphere, the cold front (Figure 4) develops to the northwest; to the right side of the moving direction of cold air mass. In southern hemisphere, it develops to the southwest; to the left side of the moving direction of cold air mass. The development is caused and modified due to the interaction of the air masses. On the cold front, the effect of cold air mass is marked, and hence, it is named as cold front.

OCCLUDED FRONT: Occlusion means the blocking or sealing the existence and with respect to fronts. It signifies the removal of the fronts from the ground. Occlusion of the fronts occurs when the cold air mass occupies the ground space surrounding the hairpin turned clubbed warm and cold

fronts. This type of fronts does exist but for short time. They remain on suspension in the sky. It is termed as occluded front.

ORIGIN AND DEVELOPMENT OF TEMPERATE CYCLONE: -

The most significant and lasting contribution to synoptic meteorology towards the end of World War I was made by Norwegian meteorologists associated with 'Bergen School of Meteorologist' VilhelmBjerknes, his son J. Bjerknes and associates. They brought about major advances in understanding the temperate cyclones. They focused on careful, systematic analysis of synoptic weather maps and time cross-sections of weather systems. They identified and developed first model for the life cycle of mid-latitude cyclones. Being associated with the development of an occluded front, wherein the mid-latitude cyclone's cold front overtakes its warm front. Their investigations and researches resulted in explanation of Polar Front Theory of cyclones or simply as Wave Theory.

The origin and development temperate cyclone is best explained by the Norwegian model. It is very popularly known as polar front theory.

POLAR FRONT THEORY: -

According to this theory, the warm-humid air masses from the tropics meet the dry-cold air masses from the poles and thus a polar front is formed. It creates a surface of discontinuity between two air masses. Such conditions occur between sub-tropical highs and sub-polar lows. The cold air is denser and heavier as the intermolecular space of the cold air is smaller. It always occupies the lower ground space. Due to this reason, warm sub-tropical air is pushed up. There is interaction between the two air masses depending upon their nature in terms of temperature and moisture conditions. This interaction of cold and warm air masses creates instability and a low pressure is created at the junction particularly in the center of interactions. The center of interaction is that zone where the warm and cold fronts are differentiated. Latter on this point develops as the eye of cyclone.

The formation of wave is indicative of thermal contrast. The two air masses start encroaching the domain of each other. In northern hemisphere the warm air mass moves northward, as westerlies. The cold air mass moves southward as easterlies. Since it is the case of northern hemisphere, winds are bending to the right direction as per the Ferrel's law. In this process, both westerlies and easterlies are deflected to the right from their designated direction. Therefore, along the front creation in the northern hemisphere, eastern part of the front is dominated by the warm air mass. On the contrary, to the western side, the dominance of the cold air mass is prominent. The reverse is the case if we take the example of southern hemisphere. The successive development of the mid-latitude cyclone may be explained through following stages:

- Stage I: Stationary/ Beginning
- Stage II: Beginning of Young Adult

- Stage III: Mature
- Stage IV: Occlusion
- Stage V: Dissipation

STAGE I: STATIONARY/ BEGINNING: -

The cold air mass and warm air mass tend to converge along an axis as shown in Figure 1. The sequential development of temperate cyclone can be seen from Figure 2A to 2E on a three dimensional configuration. In this situation, both of the air masses are almost stable and are in contact with each other. It is also known as the stationary stage of front formation. Though the difference in temperature, moisture and pressure remains marked between two air masses, still it is not that great to create instability at a bigger scale. With passage of time, and with interaction between them particularly in the fringe margin of the contact zone, there starts some push by warm air mass to the eastern side and to the western side, the impacts of cold air mass is distinctly visible. At the latter phase of stage, the straight and flat formed front (Figure 1) is turned by the advancing air masses of their influence (Figure 2B and clearly visible in Figure 3). After this the second stage of the beginning of young adult starts.

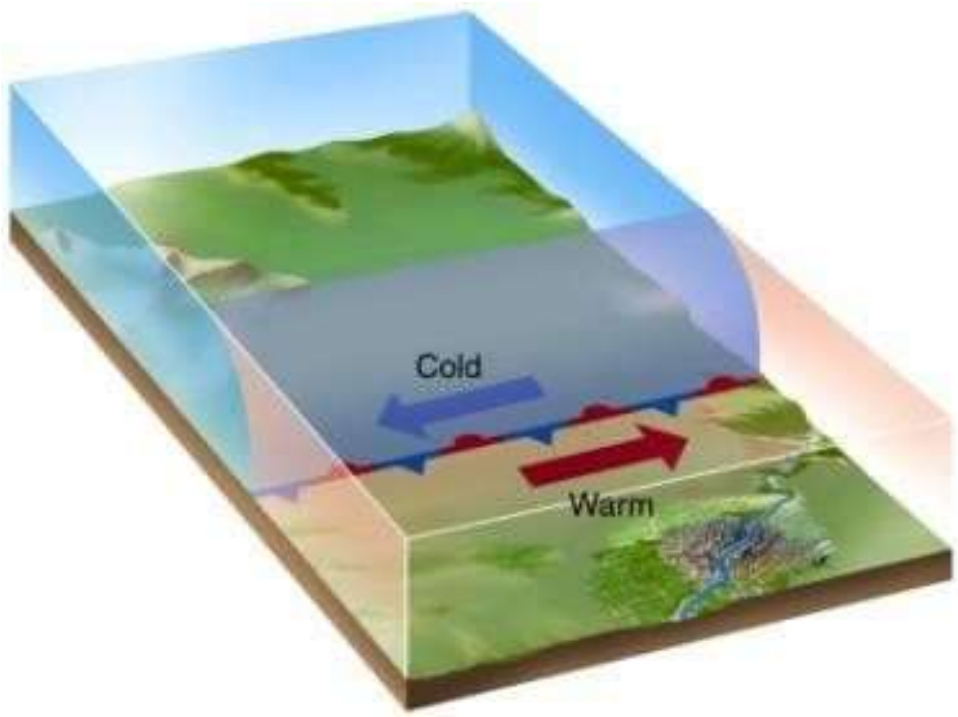


Fig. 1: Convergence of Warm and Cold Air Masses

STAGE II: BEGINNING OF YOUNG ADULT: -

By the end of first stage, the frontiers of two air masses are conspicuously different. First, where the greater impact of warm air is observed, it is warm front and it lays to the eastern part in northern hemisphere. The impact of cold air mass is very significantly seen in the western part in the northern hemisphere. To the north and north-west, the area occupied by cold air mass is known as cold sector (Figure 2B and clearly visible in Figure 3). Opposite to it, i.e. south and south-east, the area is dominated by warm air mass and hence, it is known as warm sector. It is all happening under the general principles of the winds associated with Coriolis Effect and Ferrel's law. A mirror image situation is applicable in the case of southern hemisphere.

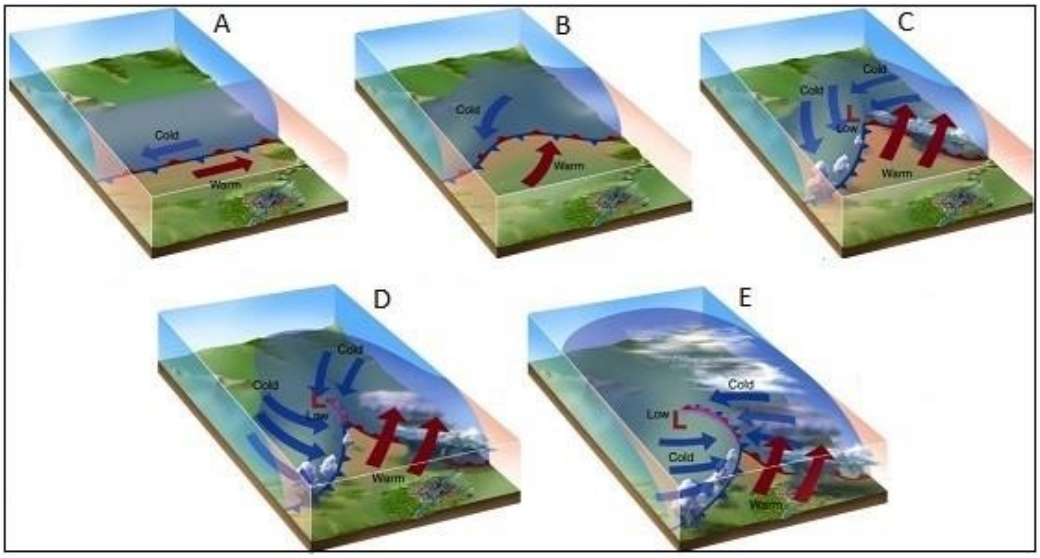


Fig. 2: Different Stages of the Development of Temperate Cyclone

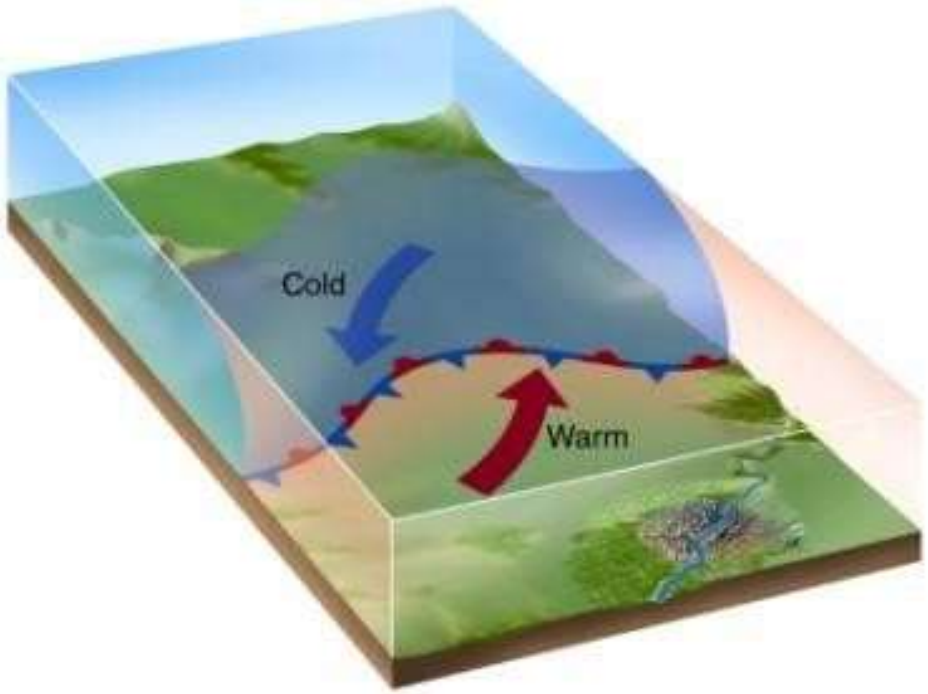


Fig. 3: Initial Stage Low formation at the Warm-Cold Front Junction

The warm front has more instability because impact of more moisture found with it. Contrary to this, along the cold front, the stability is relative greater as cold air mass has less moisture. Previously, you have already read about the instability in the air. You also know that addition or availability of more and more moisture causes the air to be more and more unstable. At the junction of the two fronts – warm and cold, the instability is greater. The cold air mass tries to push the warm air mass and in this process the junction becomes more and more sharp. The warm sector starts shrinking and the turn of the bend become more sharp (Figure 4). Since the warm air mass is lighter in density and therefore is pushed up on the cold air mass. Rising warm air, with moisture, cools down under the influence of cold air as well as increasing height. The condensation is evident. After the precipitation, latent heat is released and further low pressure is created over the junction of the two fronts. It is the beginning situation of the tropical cyclone formation. Since the cyclonic condition is already initiated by the end of this stage, that is why this stage is known as beginning of young stage of temperate cyclone.

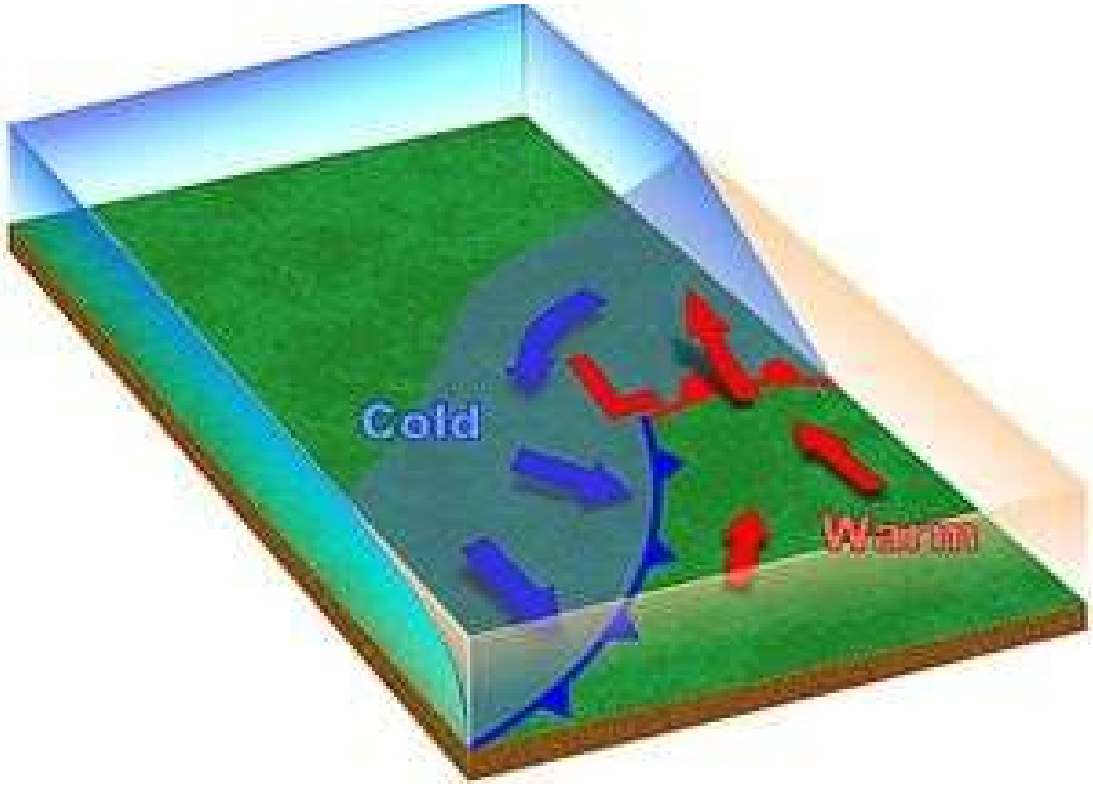


Fig. 4: Increasing Impact of Cold Air Mass and Shrinking Cold Sector

STAGE III: MATURE: -

By the end of second stage, the low air pressure has already initiated at the junction of the two fronts particularly due to condensation. That low pressure attracts air from the surrounding region and a vertical updraft of the air is observed very significantly. In the third stage, the intensification of the second stage is resulted. Due to intensification, the isobars become closer. The pressure gradient becomes very sharp. Swiftly updraft of the air moves in a whirling manner. The invasion of the cold air mass is greater. Warm sector becomes still smaller and shrinks. More and more sharp turns of the two fronts are seen. That creates the real and advance stage of temperate cyclone. Since the general patterns of the winds are westerlies, the temperate cyclones are in a tendency to march towards eastern side. Therefore, wherever it strikes, it brings changing weather conditions. By the end of this stage, the combinedfrontstarts lifted above and it is the beginning of the diminishing strength of cyclone.

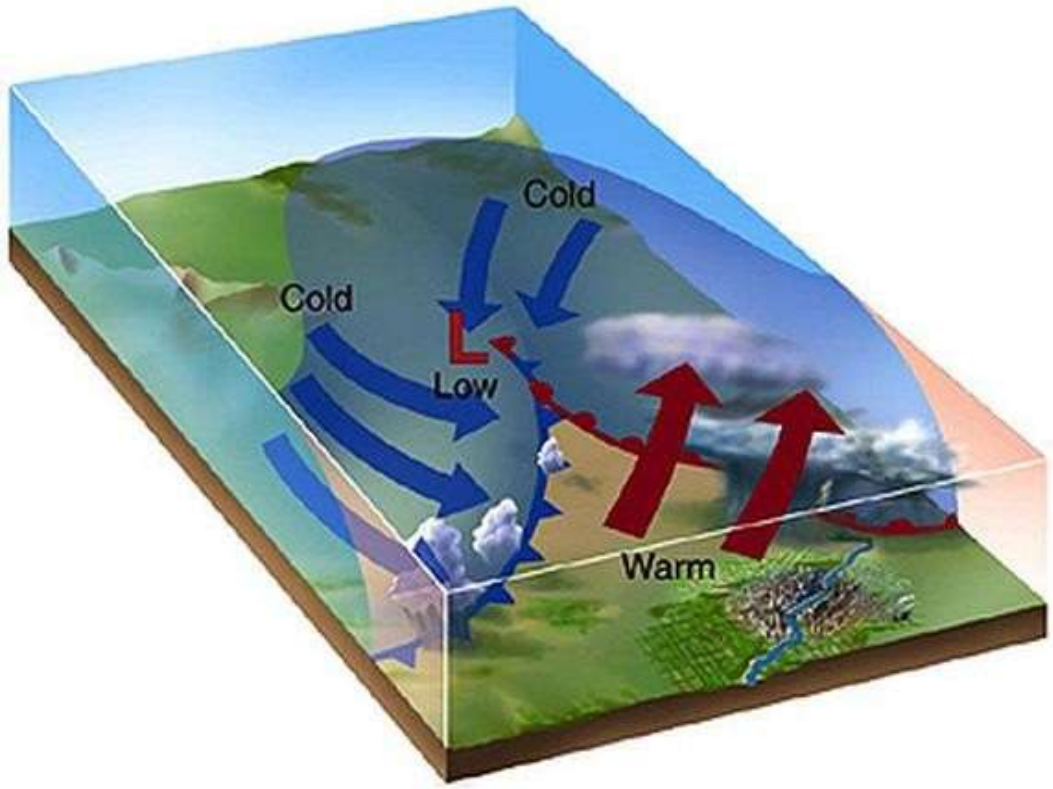


Fig. 5: Initial Stage of Occlusion

STAGE IV: BEGINNING OF OCCLUSION: -

The literal meaning of occlusion is constriction or compression. The two distinctly formed fronts are getting compressed because of their diffusion. By the end of third stage, both fronts were coming closer and finally they culminate into merging together which we call the occluded front. In occlusion stage, the cyclone starts declining as the low pressure gets weakened. The intensity is lowered and the wind velocity is on decline. The convergence of the two fronts gets detached from the ground and are still suspended in the sky (Figure 6). Ground level, in the beginning, was occupied by the two different air masses but now after occlusion, it is the occupation of cold air all through on the ground. Clubbed fronts are still hanging in the sky. Warm sector has been shifted above the ground. Discontinuity is still there but in the sky and not on the ground.

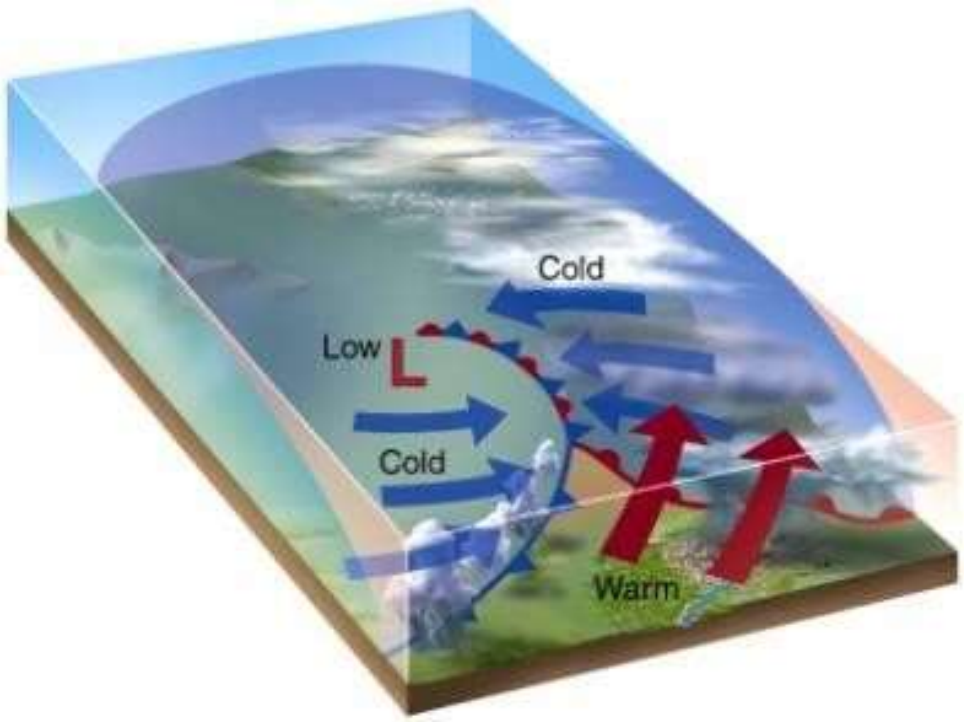


Fig. 6: Advance Stage of Occlusion

STAGE V: LATE OCCLUSION OR DISSIPATION: -

In the beginning stage of the occlusion, the temperate cyclone was still very dynamic and strong, but by the end phase of occlusion it is substantially weakened. In the last stage of cyclone, more and more areas are occupied by cold air mass. It happens so, because it is much dense/ heavy in comparison to warm air. Warm air areas are completely governed by cold air. The pushed up warm air cools down under the impact of cold air as well as by adiabatic cooling. By the end of this stage, the low pressure is completely eliminated and the normal condition is reached. Even the occluded front pushed up is completely removed. All these conditions are the characteristics of the dissipation stage.

SUMMING UP OF DIFFERENT STAGES: -

All the stages discussed above develop in a sequential order – one after the other. Starting from the simple convergence of two air masses to the modification depending upon the temperature, moisture and air pressure conditions. The typical development of temperate cyclone over North America is very clearly shown in Figure 7A and 7B. It is showing the direction of winds, front formation, front modification in different stages, cyclone's isobaric pressure variations. From the development to dissipation stages, changes over a period of eight days, is quite clear and vivid from the two figures.

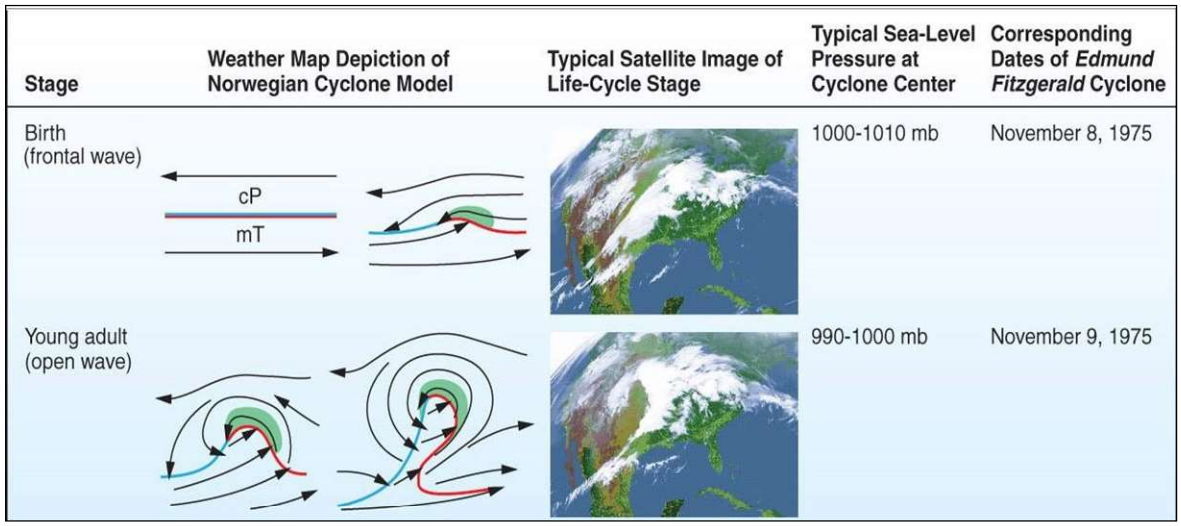


Fig. 7A: Idealized View of the Successive Stages of Temperate Cyclone

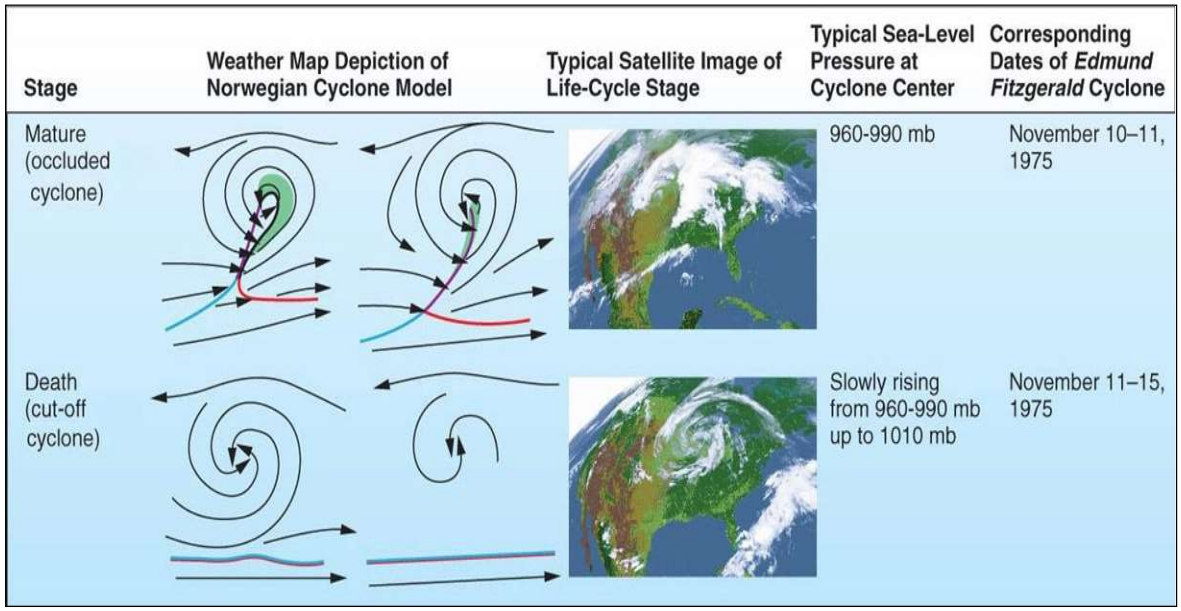


Fig. 7B: Idealized View of the Successive Stage of Temperature Cyclone.

CHARACTERISTICS OF TEMPERATE CYCLONES: -

LOCATION: Temperate cyclones exhibits wide variety of characteristics. They are formed between to 35˚ to 65˚ north and south latitudes in the sub-polar frontal zone and this is a result of interaction between cold polar mass and warm tropical air masses in the westerly wind belt. This type of cyclone is more pronounced in northern hemisphere due to greater temperature contrast created by land-water distribution. Climatologist suggest that, globally, mid-latitude cyclones

predominantly form in one of two locations: downwind of major mountain ranges and near the eastern coastlines of continents.

FORMATION: The formation of temperate cyclone is predominantly controlled and dominated by the formation of the fronts after coming into the contacts of two different air masses warm and cold. Thermal contrast of the two types of air masses is the genesis for the development of low pressure center and finally the creation of temperate/ extra-tropical cyclone. Their occurrence is possible over large arrears characterized by land or water or at the joining places of the two.

VELOCITY: The temperate cyclones are formed over a very large area. The development of low pressure is not very intense. The isobars are relatively wide apart and therefore, the pressure gradient is smaller and hence, the velocity is moderate around 30 to 40 km per hour.

FREQUENCY: Since the temperate cyclones are formed due to front formation, they are occurring throughout the year. Therefore, they are not confined to any particular season but are slightly their frequency is less during summer in comparison to winter.

AREAL COVERAGE: The temperate cyclones develop over a very large areas occupying more than 1500 or even sometime more than 2000 km in diameter. Its vertical dimension's reach up to tropopause limit.

AIR PRESSURE: As mentioned before, the pressure gradient in temperate cyclone is gentle as the isobars are widespread. Hence, the intensity of the winds in this type of cyclones are moderate. Generally, the isobaric difference varies between 10 to 15 mb.

DIRECTION OF MOVEMENT: Since, the temperate cyclones are developed in the mid-latitudes areas where the westerlies are prominently blowing, the direction is, in general, from west to east. Due to Coriolis effects, the direction is not straight from west to east but follow the path from southwest to northeast in northern hemisphere. In southern hemisphere, it is from northwest to southeast direction. Therefore, they move from mid-latitude areas to high latitude areas. The direction of the tracks of this type of cyclone is governed by the surface roughness and the characteristics of the areas from where they pass. In general, it is curvilinear direction that they follow. With the passage of the cyclonic tracks, they get reduced, fronts weakened and finally they dissipate.

WEATHER CONDITIONS IN A TEMPERATE CYCLONE: -

WEATHER WITH WARM FRONT: March forward of temperate cyclone is marked by arrival of warm front first towards the cold prevailing areas. Increase in temperature is observed very clearly. Since the warm air, in general, has greater amount of water vapour, the condensation is evident and more rainfall/ snowfall is recorded. The temperate cyclone is slow in its velocity, therefore,

prolonged moderate precipitation is the prime characteristics. As long as the warm sector prevails over the areas, the warmth continues.

WEATHER WITH COLD FRONT: With the passage of the warm sector eastward further is marked by arrival of cold front. Cold front arrival is associated with lowering of the temperature because of the prominence of cold air mass. Since this front is again the combination of the two air masses, here the warm air effect is less and that leads to less amount of water vapour concentration. Cooling is of warm air also causes the condensation. Therefore, the precipitation is less in comparison to the warm front passage. Generally, cirrostratus, altostratus, nimbostratus and stratus clouds are seen. Therefore, hallow around the sun and moon becomes a very distinct feature in temperate cyclone. The central part of is known as the eye of cyclone. It is relatively cool and calm. The sky is clear and up-draft of the air is observed.

PRECIPITATION: The precipitation is dependent upon the availability of water vapour and prevailing temperature conditions. Therefore, the type of precipitation varies from rainfall to hailstorms. Though the hailstorms are not a very regular feature and sometimes associated with thunderstorms. It occurs less frequently but the rainfall, sleet and snowfall is very common. As mentioned before, the temperate cyclone is huge in size in terms of areal expanses, its passage also takes longer duration, the precipitation occurs for a longer duration. The weather associated with both fronts and their movements have been summarized very briefly in Table 1.

Table 1: Weather Associated with the Passage of both Fronts

Elements	In Advance	At the time of Passage	In the Rear
WARM FRONT			
Pressure	Steady fall	Fall arrested	Little change or slow fall
Wind	Backing and increasing	Veer and decrease	Steady direction
Temperature	Steady or slow rise	Rise	Little change
Dew point	Rise in precipitation	Rise	Steady
Relative humidity	Rise in precipitation	May rise further if already not saturated	Little change, may be saturated
Cloud	Cirrus, nimbostratus, cirrostratus in succession; stratus and cumulus below altocumulus and nimbostratus	Low nimbostratus and stratus	Stratus or stratocumulus persist, sometimes cirrus
Weather	Continuous rain or snow	Precipitation almost stops	Dry or intermittent slight precipitation
Visibility	Good except in rain or snow	Poor, often mist or fog	Usually moderate or poor, mist or fog may persist
COLD FRONT			
Pressure	Fall	Sudden rise	Rise continues more slowly
Wind	Backing, increasing	Sudden veer, perhaps squall	Fairly steady
Temperature	Steady but fall in pre- frontal	Sudden fall	Little change, variable in

	precipitation		showers
Dew point	Little change	Sudden fall	Little change, variable in showers
Relative humidity	May rise in pre-frontal precipitation	Remains high in precipitation	Rapid fall in rain or snow, ceases
Cloud	Stratus, altocumulus, stratocumulus	Cumulonimbus, stratus, cumulus	Stratocumulus, altocumulus, cumulus
Weather	Some rain, perhaps with thunder	Heavy rain or snow, perhaps with thunder	Heavy rain or snow for short time followed by shower
Visibility	Moderate to poor, perhaps fog	Temporarily low, latter improves	Very good

Source: K Siddhartha: Physical Geography (2016), p571-572.

After the occupation of warm sector by the cold air masses, the normal condition prevails. It shows clear sky, less air temperature. At this stage, a uniform condition is applicable to the air mass. This uniformity is found in terms of temperature of the air and its pressure. Finally, it becomes an air mass with distinctly uniform temperature, pressure and humidity. This is just like the initial stage of the development of the temperate cyclone.

WORLD DISTRIBUTION PATTERN OF TEMPERATE CYCLONE: -

As discussed before that the temperate cyclones develop in the mid-latitude areas of the world. This area is also known as extra-tropical (beyond tropical), therefore, extra-tropical cyclone or temperate cyclone both represents the same thing. Temperate type of cyclones is primarily found between 35^0 to 65^0 north and south latitudes. Their tracks are found to be even beyond 65^0 of latitudes in both the hemispheres. The tracks of the temperate cyclones are shown in the Figure 8 by black arrows. From this figure, it is obvious that the direction of the cyclone and their tracks follow the easterly direction which has already been mentioned before. In northern hemisphere, it is from southwest to northeast direction whereas, in southern hemisphere, it is northwest to southeast direction.

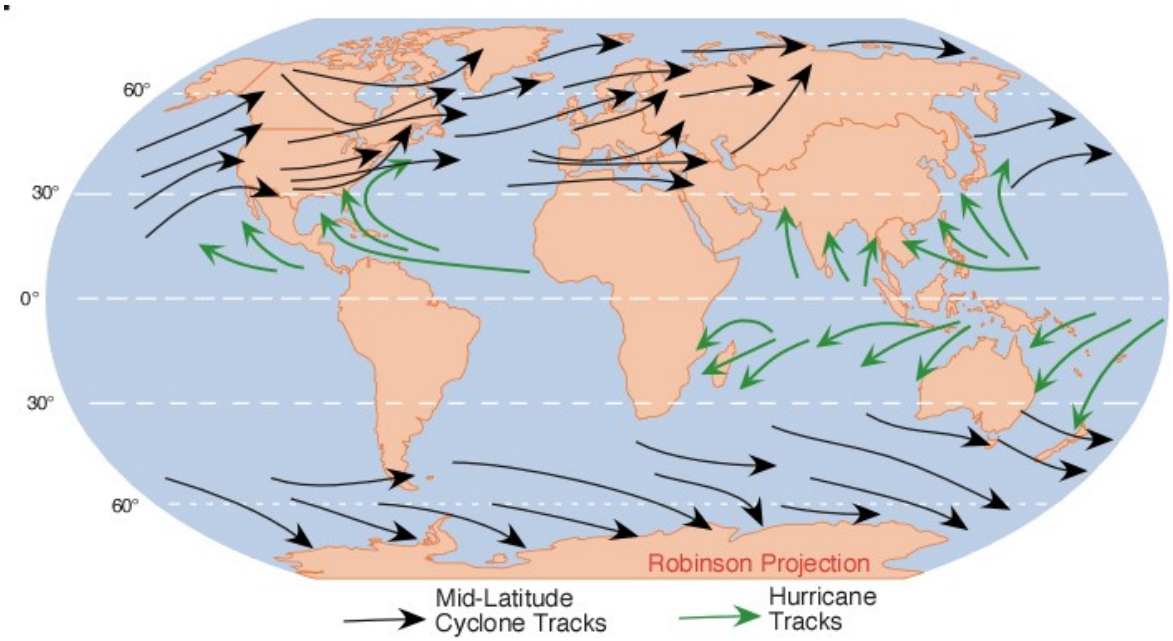
The occurrence and distribution of temperate cyclone show a very well defined zone over the map of the world. Temperate cyclones are found almost all through the year with more or less seasonal variations. But they are more frequent in winter season because greater temperature contrast is seen during this time. Hence, winter is the ideal period for the formation of temperate cyclones and their frequency is also greater at this time. There are three important zones for the development of temperate cyclone in northern hemisphere.

ATLANTIC-ARCTIC FRONT AND CYCLONE: The north Atlantic is much warmer while the Arctic air mass is very cold. When both of them are coming into contact with each other, the strong temperature contrast is created and strong low pressure formation is resulted. It causes to move the cyclone towards northeast direction and reaches to the Western Europe.

NORTH AMERICA-POLAR FRONT AND CYCLONE: The air mass of North America and the north polar air mass convergence cause the cyclone to develop, particularly in the Great Lakes region and move towards northeast direction (Figure 8).

MEDITERRANEAN FRONT AND CYCLONE: The third important area of the development of temperate cyclones in northern hemisphere is the Mediterranean-Caspian front region. Huge expanse of the continental areas to the north of Mediterranean-Caspian parts and relatively warmer air mass over these seas create front. Along this front, the extra-tropical cyclone is generated and moves in the general wind patterns of the region. The light shower in the winter over north-western parts of India is caused by the western disturbances coming from this zone.

EXTRA-TROPICAL CYCLONE IN SOUTHERN HEMISPHERE: The southern hemisphere does not have big landmass for creating temperature contrast, hence, there is no specific regions of the development of extra-tropical cyclone. They are developed with lesser intensity between 35^0 to 65^0 south latitudes and travel in south-easterly direction.



Fig; 8: Principal Areas of Temperate Cyclones

CONCLUSIONS: -

Temperate cyclones develop between 35^0 to 65^0 latitudes in both of the hemispheres. Poleward parts of this limit are very cold while the equatorward limit is much warmer. Both of these regions have different types of air masses. When these air masses come into contact with each other, they form a front, a distinct boundary between the two. The intermingling and interactions between them create disturbances leading to the tropical cyclone. This interaction is through the

fronts – warm and cold. Along the warm front, the prominence of warm air mass is dominated while along the cold front, the prominence is of cold air mass.

The concept of this type of cyclone is explained by polar front theory popularly called Norwegian model of tropical cyclone. The growth and development of this cyclone is explained through successive five stages of beginning, adult, mature, occlusion and dissipation. The main characteristics of temperate cyclones could very well be seen in terms of its location, formation, velocity, frequency, air pressure and direction of its movement. Weather conditions associated with warm fronts, cold fronts and precipitation is quite distinct. Apart from all these, temperature, humidity, dew points, types of clouds and visibility are some of the other parameters of associated weather during temperate cyclone.

The distributional pattern of temperate cyclone is very distinct particularly in northern hemisphere. It happens because of the land water contrast and greater temperature variations. Its frequency is more during winter season than the summer. Southern hemisphere has more water body and the temperature contrast is relatively less and hence the extra-tropical cyclone is not confined to a certain region or pocket. But in northern hemisphere, its major areas of concentration are with Atlantic-Arctic belt, North America Great Lakes belt and Mediterranean-Caspian belt.