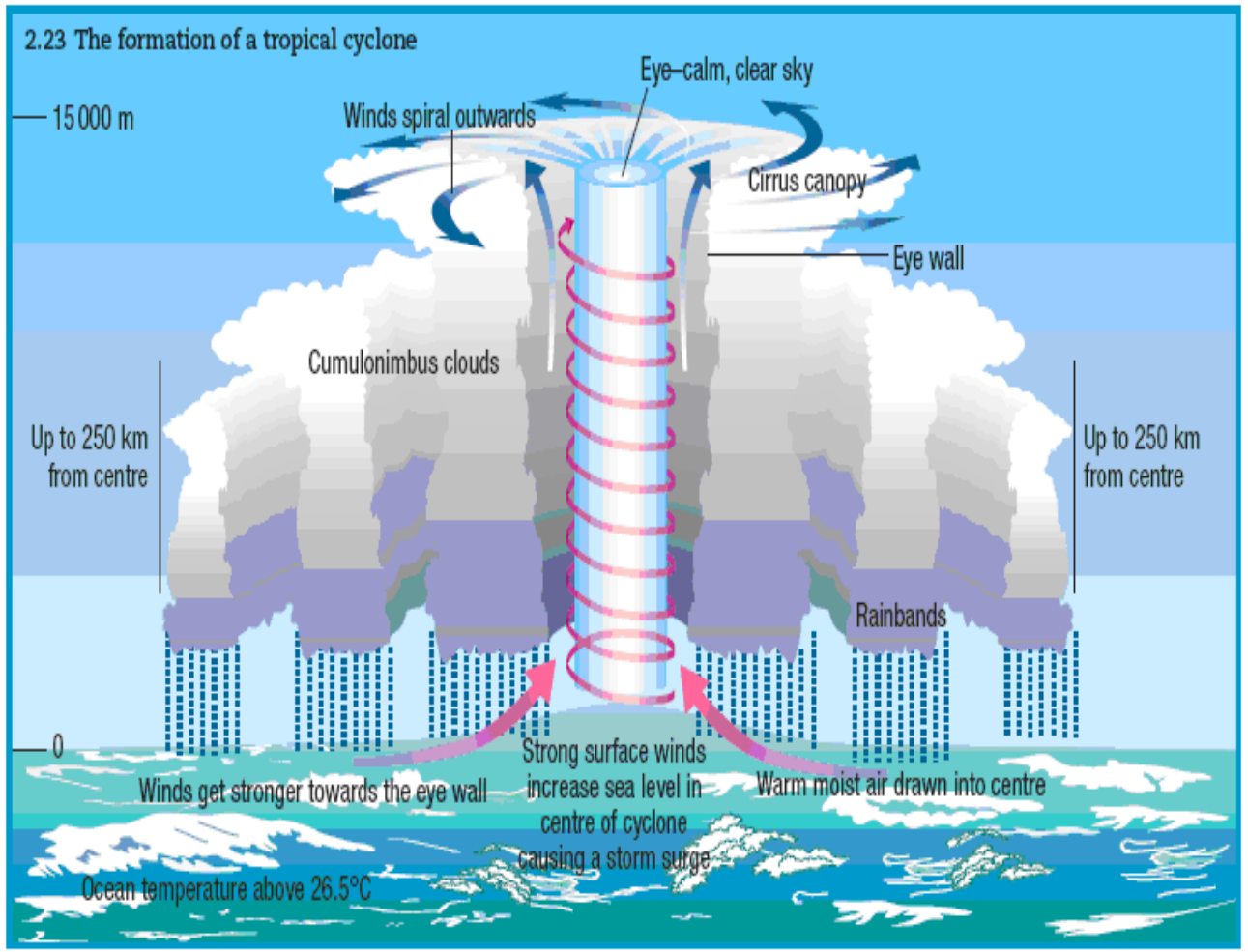
- FACULTY NAME:
  - KANHAIYA JHA
- SUBJECT:
  - GEOGRAPHY
- TOPIC NAME:
  - CYCLONE
  - AIR MASS
  - FRONT
  - TWISTER

CYCLONES



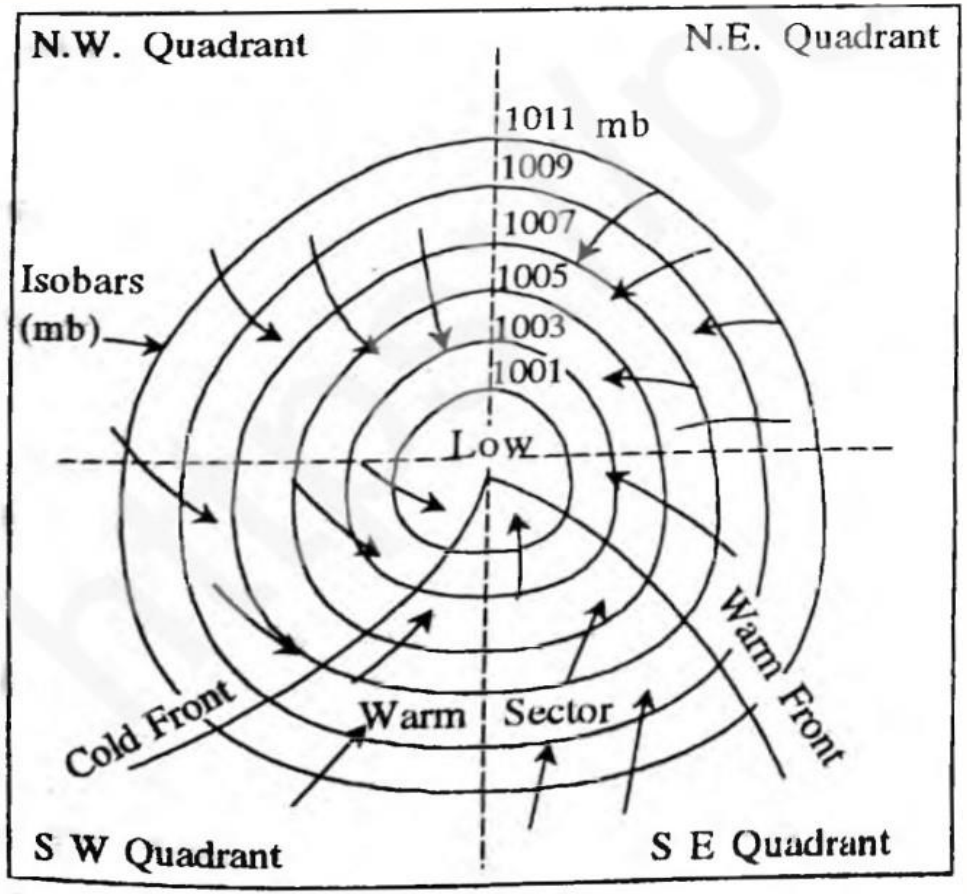
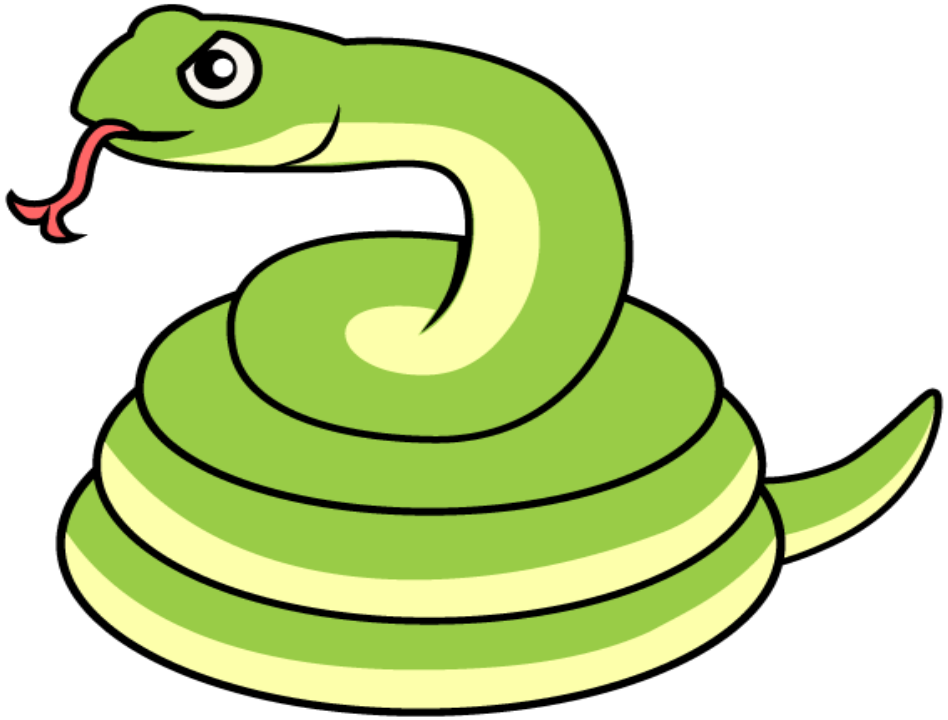


Fig. 11.5 : An average temperate cyclone in northern hemisphere.

- Cyclones are *centers of low pressure*. It is surrounded by closed isobars having increasing pressure outward and closed air circulation from outside towards the central low pressure.
- Generally *air blows inward in anticlockwise* direction in the northern hemisphere and *clockwise in the southern hemisphere.*
- Cyclones are also termed as atmospheric disturbances.
- They range in shape from circular, elliptical to 'V' shape.

- The **word Cyclone** is derived from the **Greek word Cyclos meaning the coils of a snake**.
- It was coined by **Henry Peddington** because the tropical storms in the Bay of Bengal and the Arabian Sea appear like coiled serpents of the sea.



Classification of cyclone

- From the locational point of view cyclones are classified in to two principal type-
  - (i) **extratropical cyclones/** temperate cyclones/ wave cyclones
  - (ii) **tropical cyclones.**

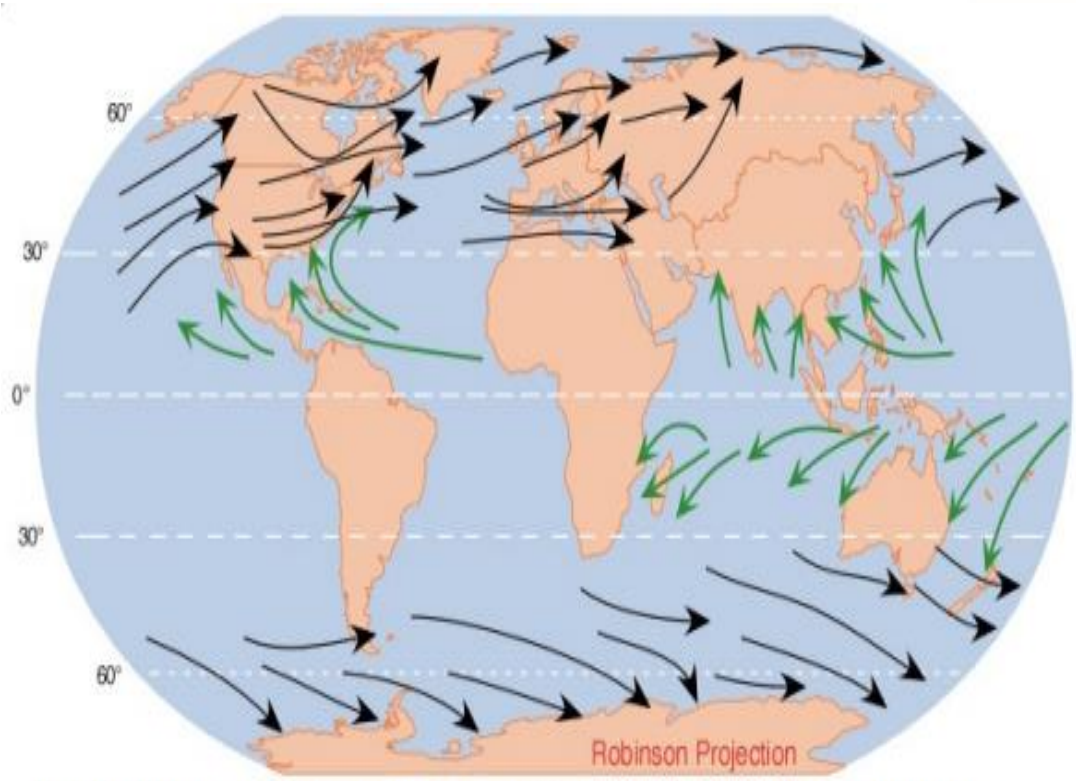
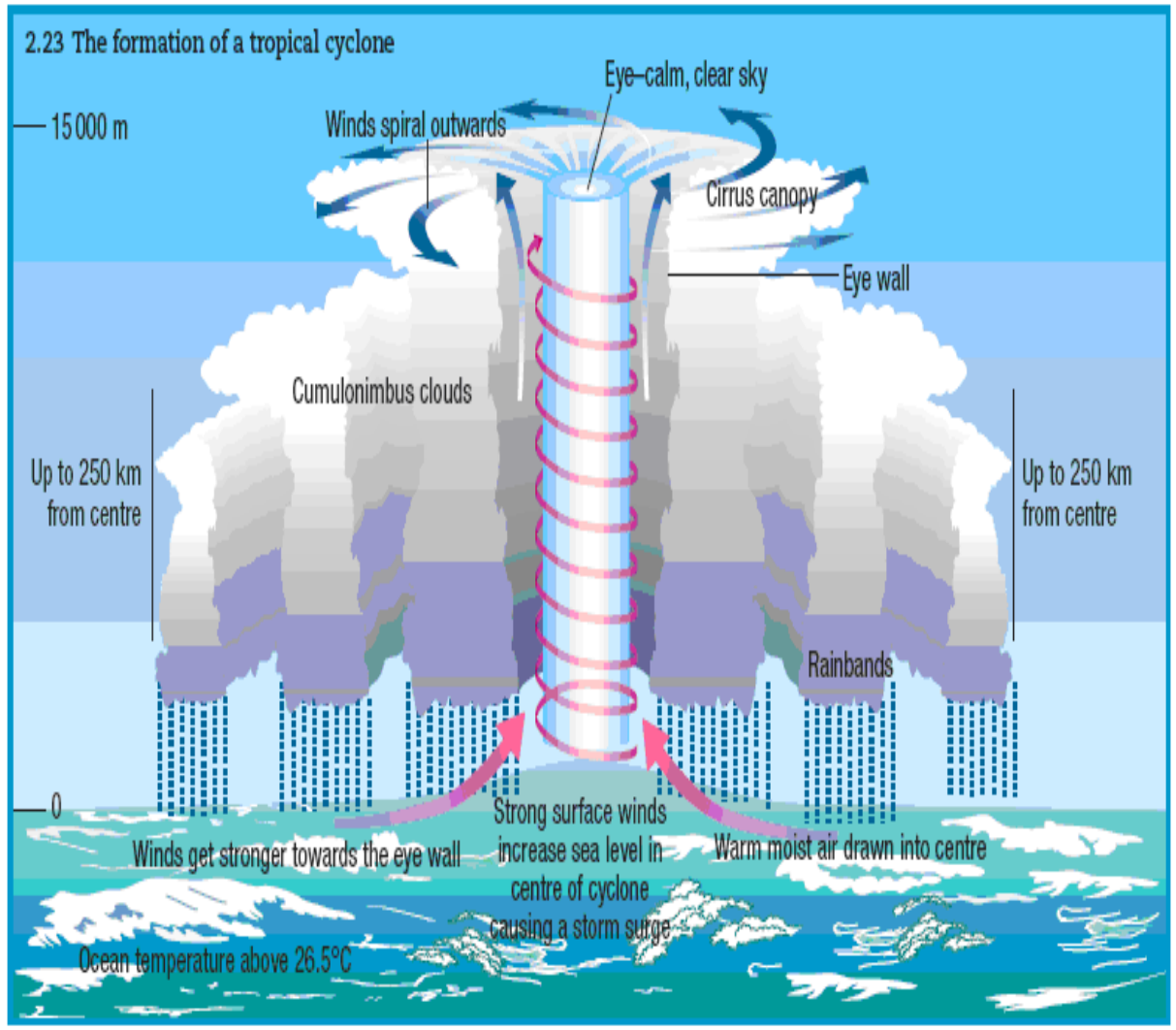
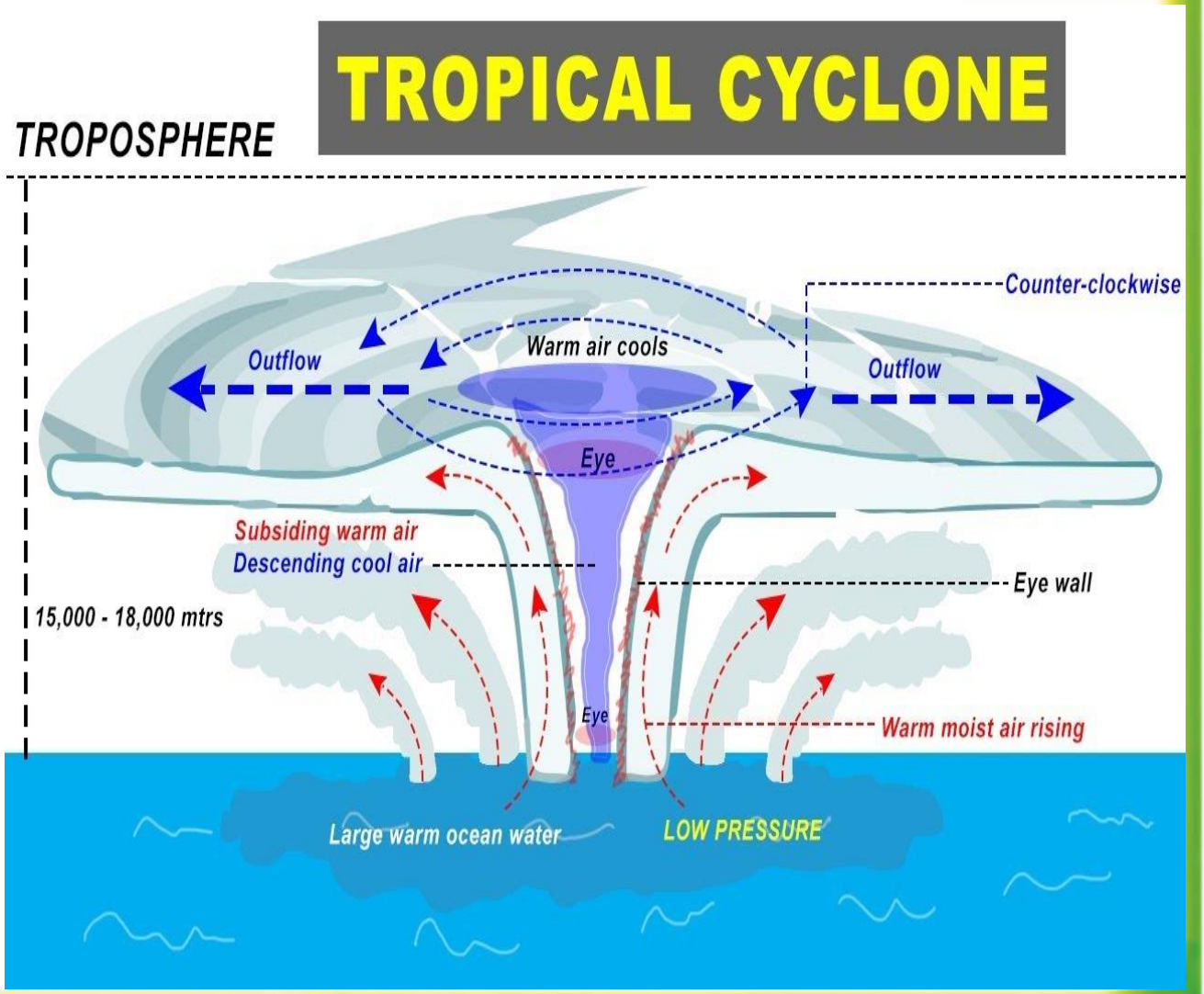


Fig: Principle areas of Temperate cyclones (Black arrow lines) and Tropical cyclones (Green arrow lines)

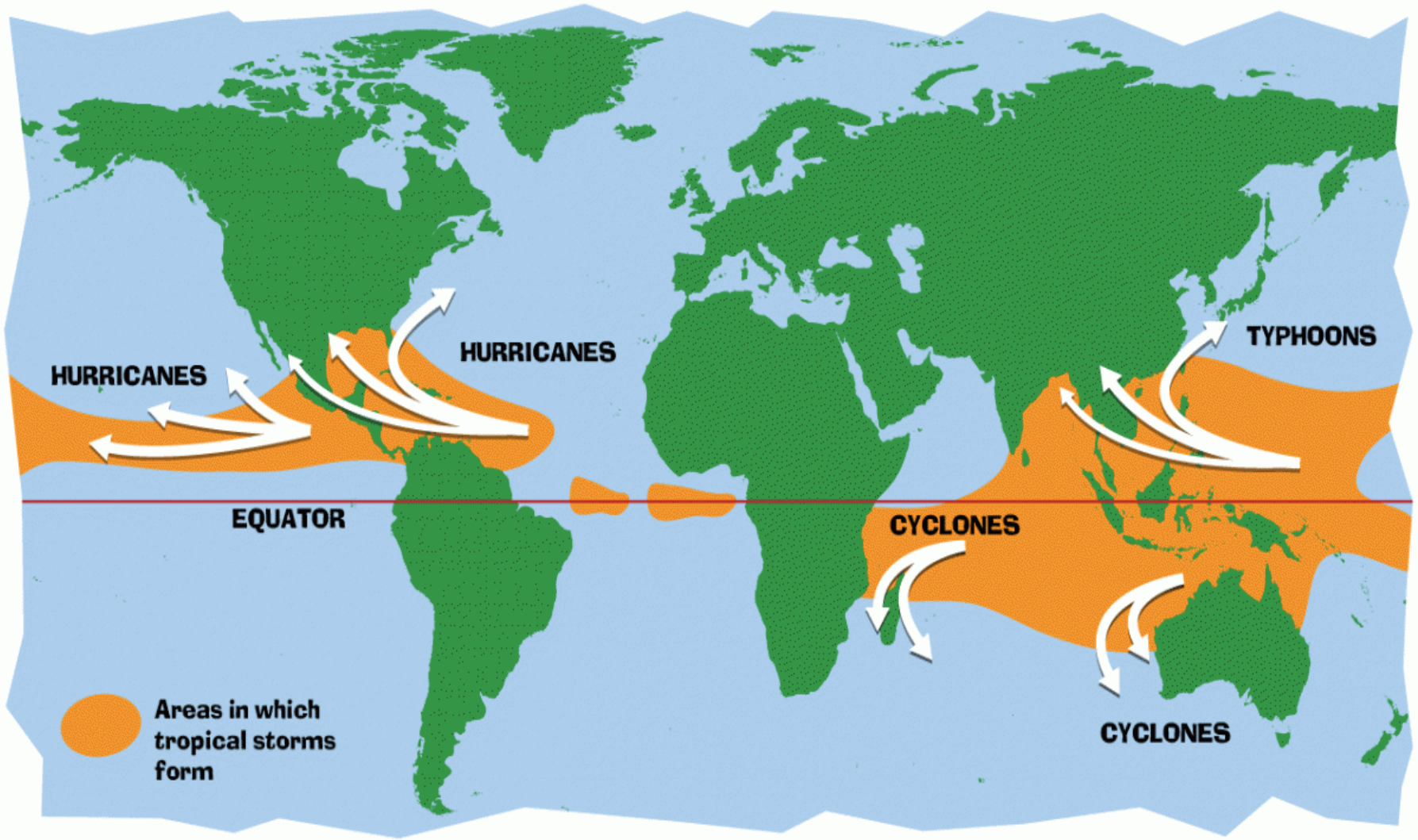
Tropical Cyclones

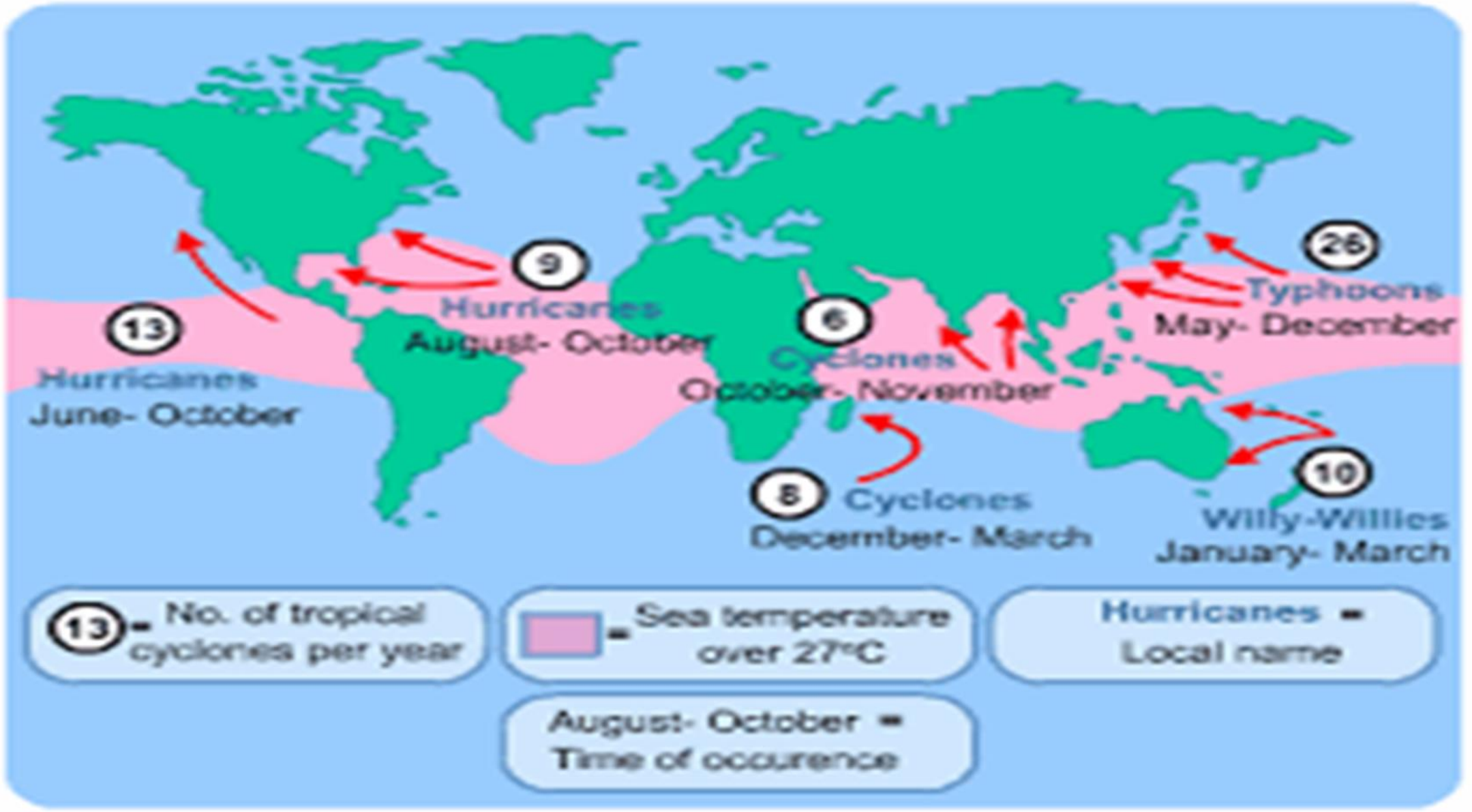




- The system of rotating wind around an acute low pressure between 10-20 N/S LAT, that creates devastating impact on coastal region of tropical regions is called tropical cyclone.
- It is dubbed by different name-
  - Indian ocean - Cyclones
  - Atlantic ocean - Hurricanes
  - Western Pacific and South China Sea - Typhoons
  - Western Australia - Willy-willie

Regional names for Tropical Cyclones

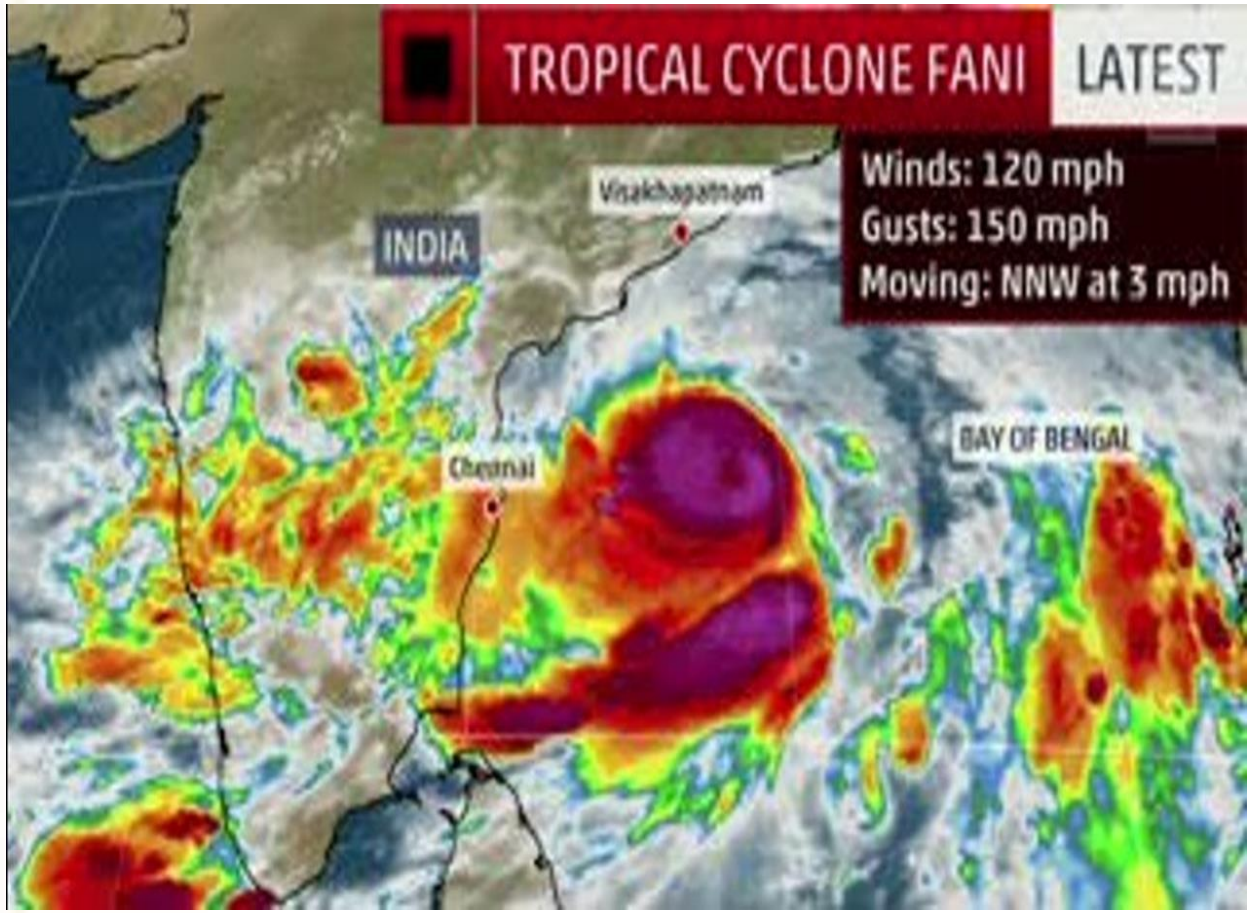


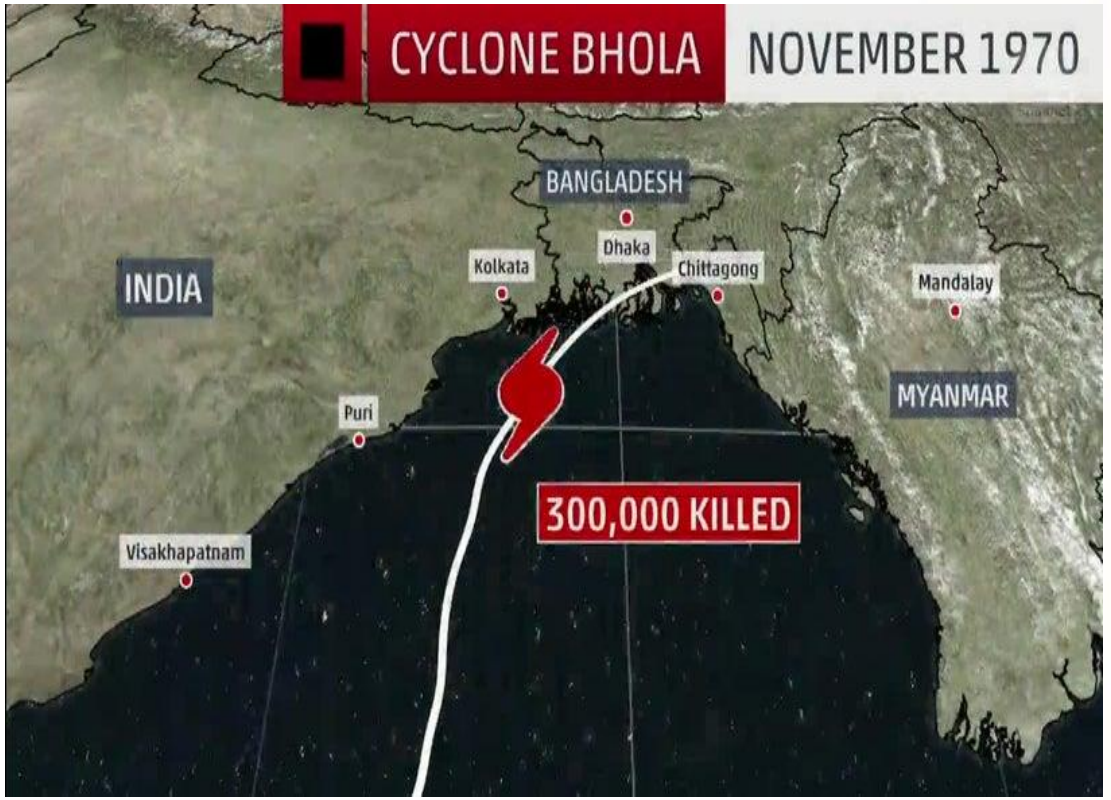

9
Hurricanes
August- October
13
Hurricanes
June- October
6
Cyclones
October- November
26
Typhoons
May- December
8
Cyclones
December- March
10
Willy-Willies
January- March
13 - No. of tropical cyclones per year
- Sea temperature over 27°C
Hurricanes - Local name
August- October - Time of occurence

Characteristics of Tropical Cyclones

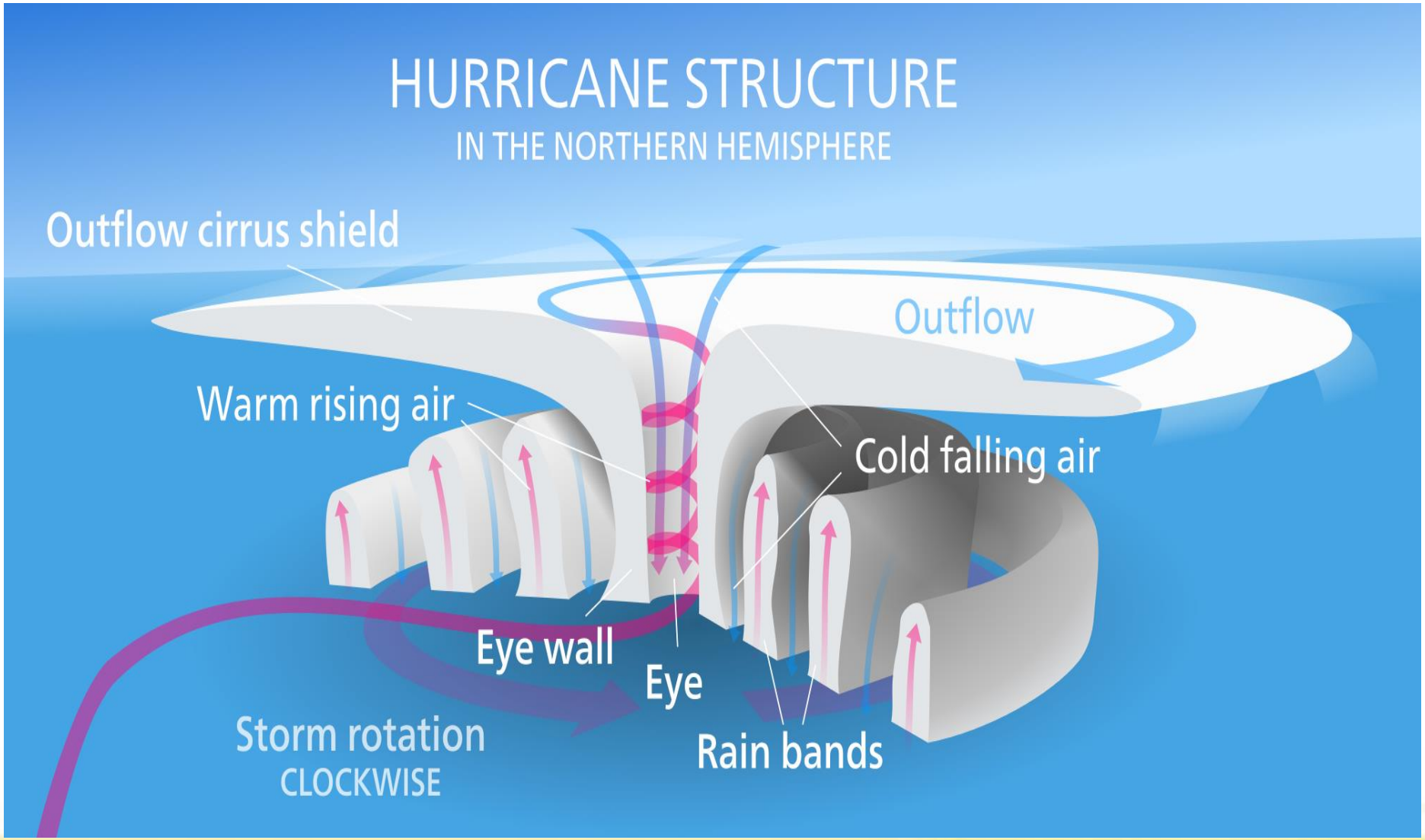
Symmetrical Elliptical Shapes:	• Tropical cyclones exhibit symmetrical elliptical shapes with a length-to-breadth ratio of 2:3, featuring steep pressure gradients.
Funnel-shaped Wind System:	• Vertically, tropical cyclones form funnel-shaped wind systems.
Compact Size:	• Typically, tropical cyclones maintain a compact size, with a diameter near the center ranging from 80 km, which may expand to sizes between 300 km to 1500 km.
Wide Range of Wind Velocity:	• The wind velocity within a tropical cyclone varies significantly, spanning from calm conditions to speeds reaching up to 1200 km per hour.

Guided by Trade Winds:	• Tropical cyclones are primarily guided by trade winds and tend to move from west to east.
Parabolic Path:	• They follow a parabolic path, with their axis running parallel to the isobars.
Direction of Wind Movements:	• In the northern hemisphere, cyclonic wind movements occur anticlockwise, while in the southern hemisphere, they move clockwise, attributed to the Coriolis force.


TROPICAL CYCLONE FANI
LATEST
Winds: 120 mph
Gusts: 150 mph
Moving: NNW at 3 mph
Visakhapatnam
INDIA
Chennai
BAY OF BENGAL


CYCLONE BHOLA
NOVEMBER 1970
BANGLADESH
Dhaka
Kolkata
Chittagong
Mandalay
INDIA
MYANMAR
Puri
300,000 KILLED
Visakhapatnam

STRUCTURE OF A TROPICAL CYCLONE

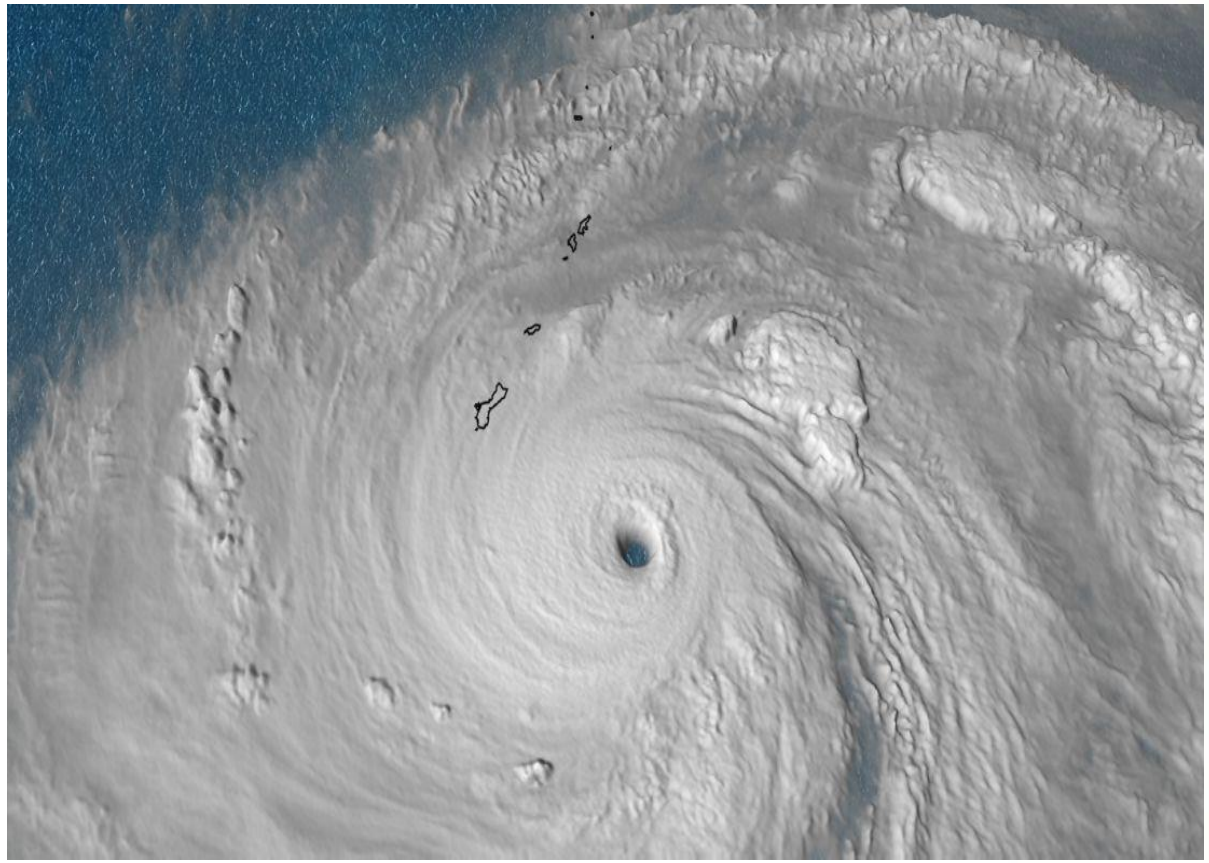


Eye

- The "eye" is a roughly circular area of comparatively light winds with fair weather..
- There is little or no precipitation and sometimes blue sky or stars can be seen.
- The eye is the region of **lowest surface pressure and warmest temperatures** .
- Eyes range in size from 8 km to over 200 km across, but most are approximately 30-60 km in diameter.

Eye wall

- The most **dangerous and destructive part** of a tropical cyclone is the eyewall
- The eye is surrounded by **the "eye wall"**, the roughly circular ring of deep convection, which is the area of highest surface winds in the tropical cyclone.
- Eye Wall region also sees the maximum sustained winds i.e. fastest winds in a cyclone occur along the eye wall region.



Spiral / Rain bands

- Curved bands of clouds and thunderstorms that trail away from the eye wall in a spiral fashion.
- These bands are capable of producing heavy bursts of rain and wind, as well as tornadoes.
- There are sometimes gaps in between spiral rain bands where no rain or wind is found

Vertical Structure of a Tropical Cyclone

Lower layer (0-3 km)

- It extends up to 3 km and known as the **inflow layer**, is responsible for driving the storm.

Middle layer (3-7 km)

- It extends from 3 km to 7 km, where the **main cyclonic storm** takes place.

Upper layer (7-12 km)

- The **outflow layer** lies above 7 km. The maximum outflow is found at 12 km and above. The movement of air is anticyclonic in nature.

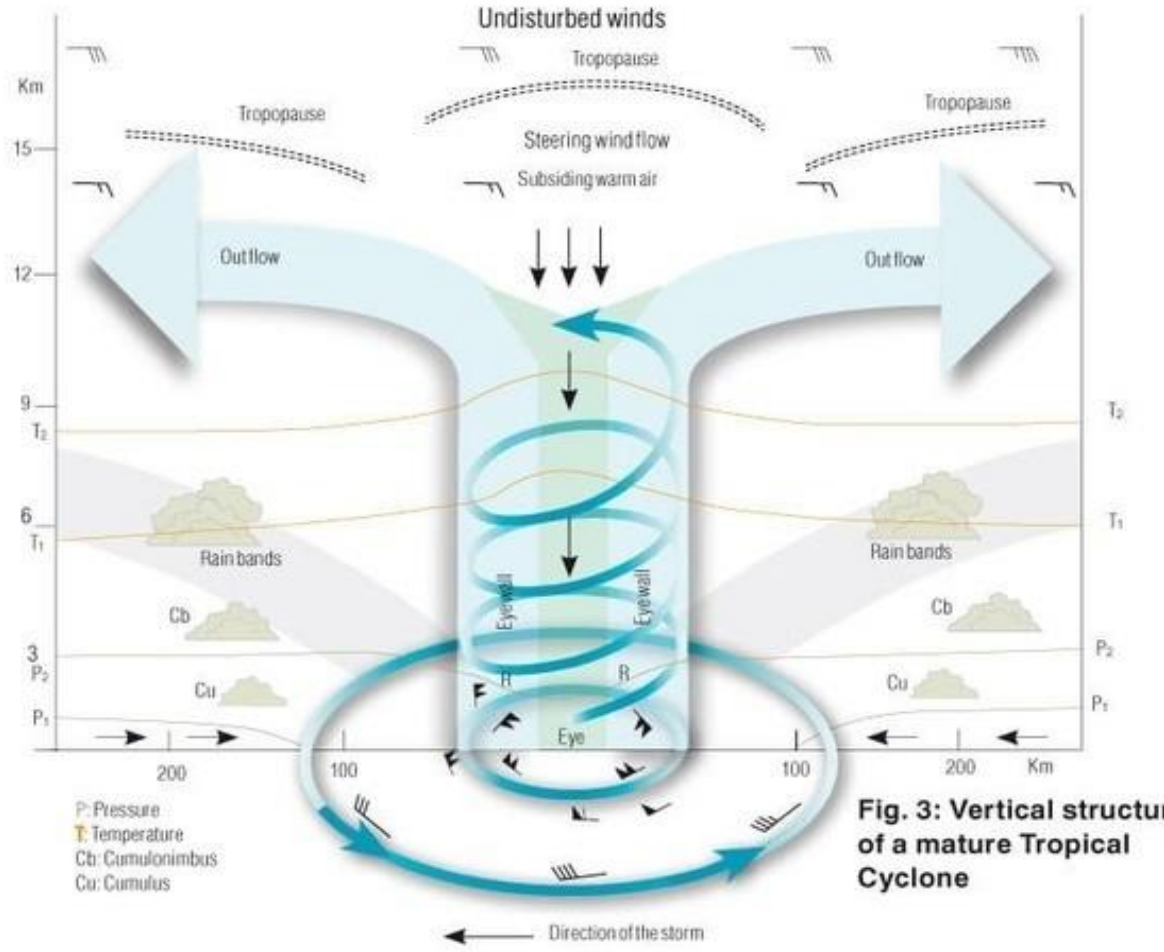
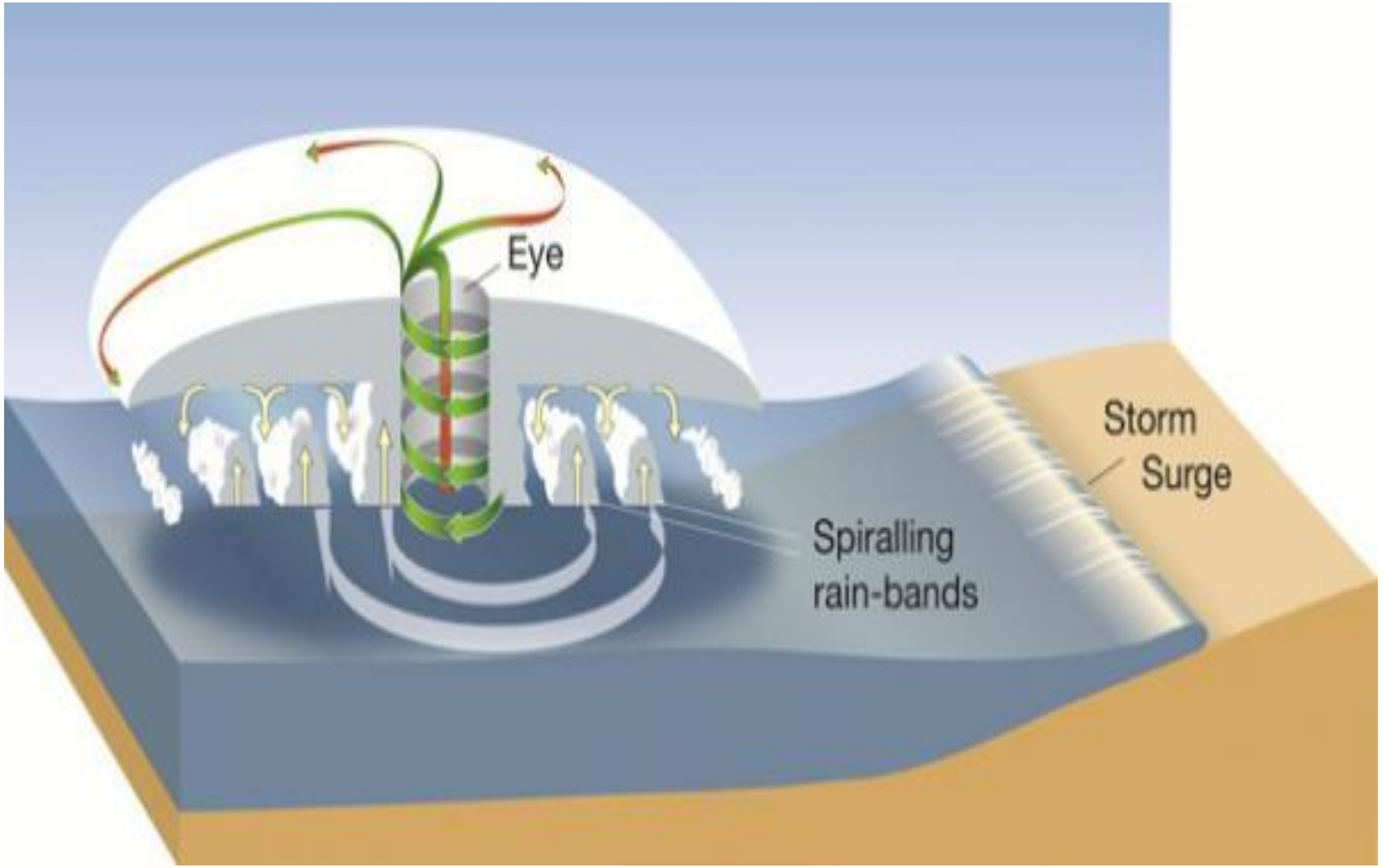
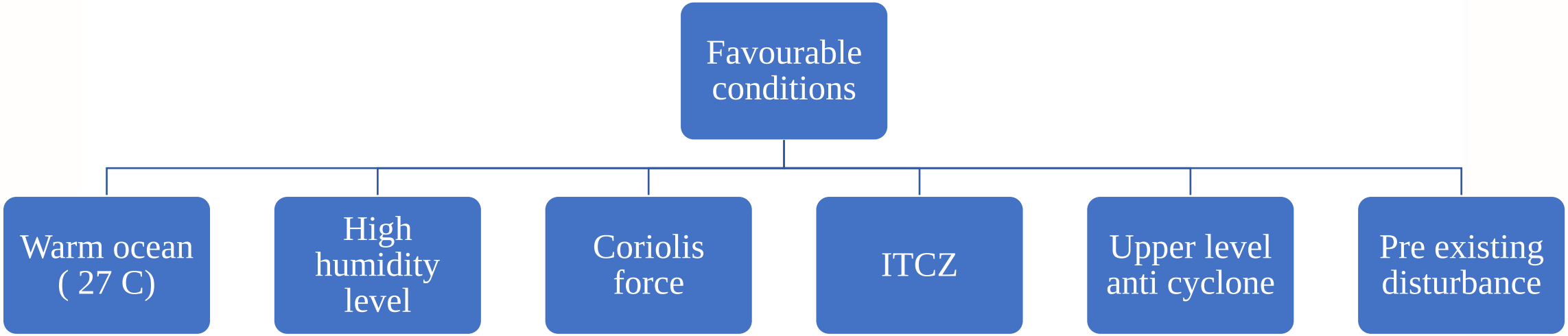


Fig. 3: Vertical structure of a mature Tropical Cyclone

Origin of Tropical Cyclone



- As a complex weather phenomenon, the origin of tropical cyclone is not same as the temperate cyclone. Temperate cyclone are produced by contrasting air masses but no such air masses found in tropical regions.
- The tropical cyclones have a thermal origin, and they develop over tropical seas during early/late summers.
- At these locations, the strong local convectional currents acquire a whirling motion because of the Coriolis force.
- Meteorologist explains that the formation of tropical cyclone depends upon favourable conditions, if such condition is there it forms.


Favourable conditions
Warm ocean (27 C)
High humidity level
Coriolis force
ITCZ
Upper level anti cyclone
Pre existing disturbance

- **Warm ocean with temperature higher than 27° C**

➢Ocean waters having temperatures of 27° C or more is prerequisite for tropical cyclone.

➢The depth of warm water (26-27°C) should extend for 60-70 m from surface of the ocean/sea.

➢It creates a acute low pressure toward which surrounding air rushes hurriedly.

➢Before reaching at center the advancing air gradually warms up and rises upward.

➢Notably, summer season heat and warm ocean current causes heating of ocean mainly.

DISTANCE SUNLIGHT TRAVELS IN THE OCEAN

sea level

TUNA

euphotic(sunlight) zone
Sunlight rarely penetrates beyond this zone.

200 meters

SHRIMP

SWORDFISH

HATCHET FISH

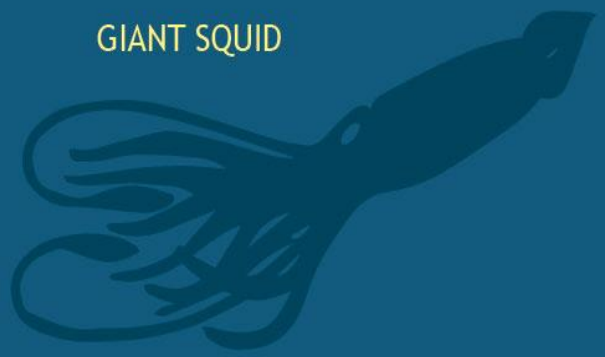
dysphotic (twilight) zone
Sunlight decreases rapidly with depth.
Photosynthesis is not possible here.

1000 meters and deeper

The aphotic zone includes:
- The **bathypelagic** (midnight) zone between 1000-4000 meters.
- The **abyssopelagic** (abyss) zone between 4000-6000 meters.
- The **hadopelagic** (hadal) zone is 6000 meters and deeper.

ANGLER FISH

GIANT SQUID



aphotic zone
Sunlight does not penetrate.
This zone is bathed in darkness.

oceanservice.noaa.gov

- **High Humidity**

➢ High humidity (around 50 to 60 per cent) is required for tropical cyclone formation.

➢ The fairly warm ocean produces enough water vapour during summer.

➢ The latent heat of water vapour triggers the vertical movement of air and creates low pressure.

➢ Furthermore, in presence of moist air leads to the formation of cumulonimbus cloud.

- **Coriolis Force**

➢ The deflectional coriolis force found zero at the equator (no cyclones at equator because of zero Coriolis Force) but it increases with latitude.

➢ Coriolis force at 5° latitude is significant enough to create a storm [cyclonic vortex].

➢ About 65 per cent of cyclonic activity occurs between 10° and 20° latitude.

➢ The developing system must be at least 500 km (300 miles) away from the Equator.

- **Pre existing Disturbances**

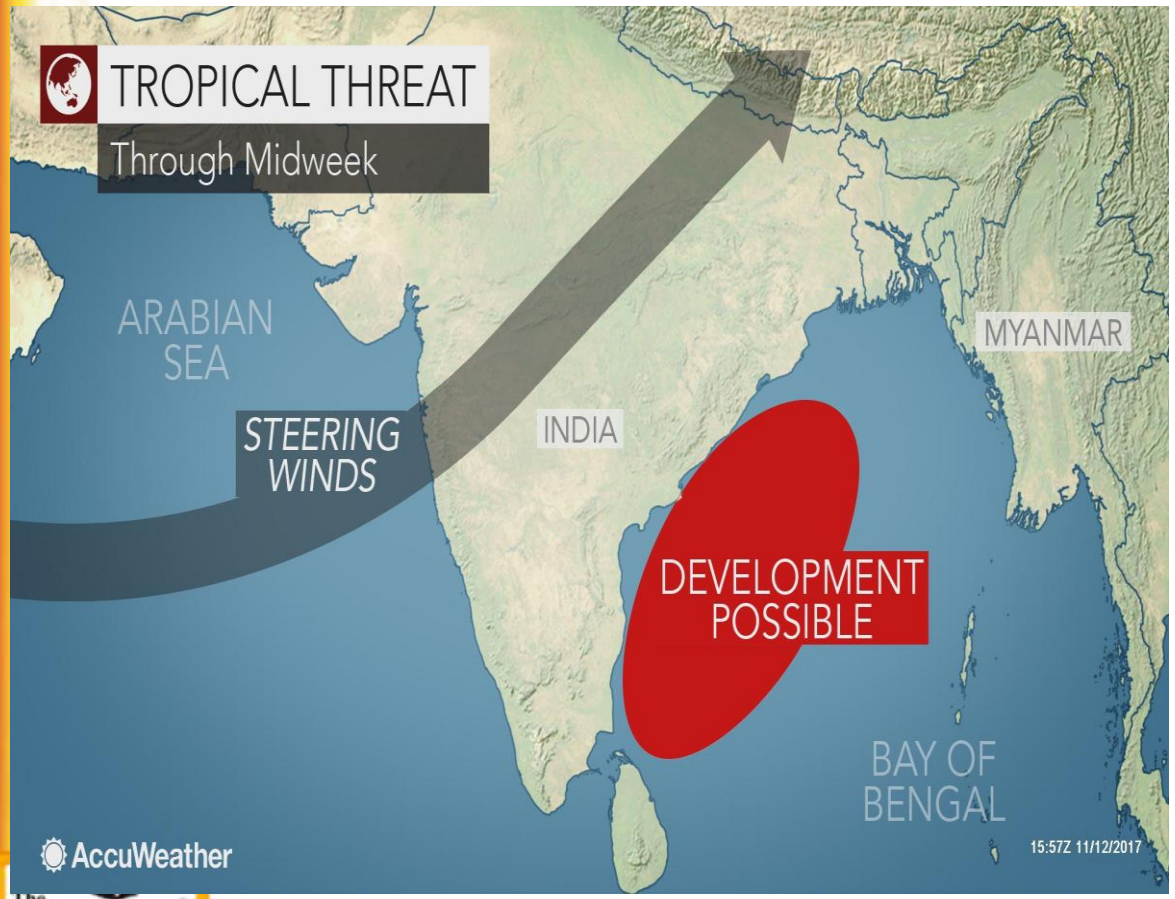
➢ A preexisting atmospheric circulation must be located near the surface warm layer.

➢ Low-level disturbance or thunderstorms are the seeds of cyclones.

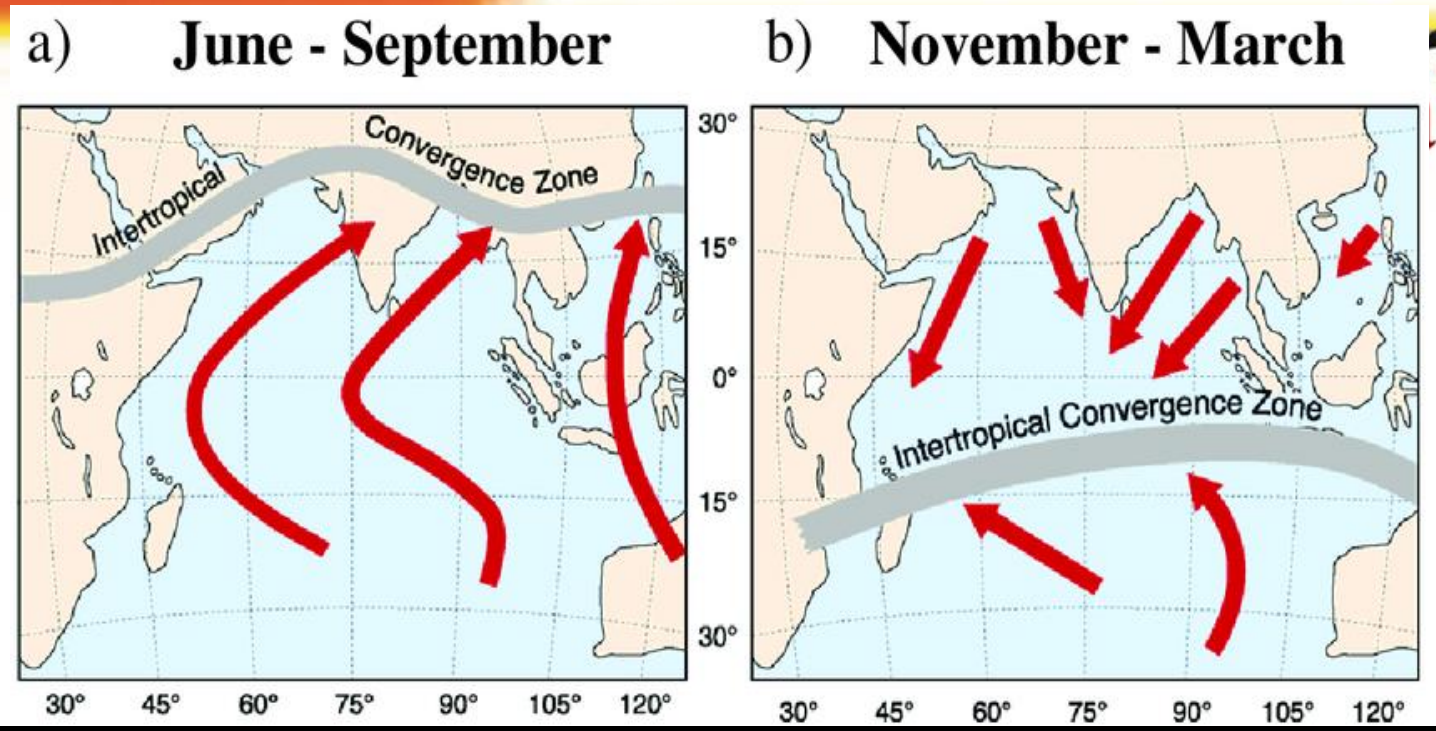
➢ Small local differences in the temperature of water and of air produce various low pressure centers of small size. A weak cyclonic circulation develops around these areas.

➢ Because of the rising warm humid air, a true cyclonic vortex may develop very rapidly.

➢ However, only a few of these disturbances develop into cyclones.

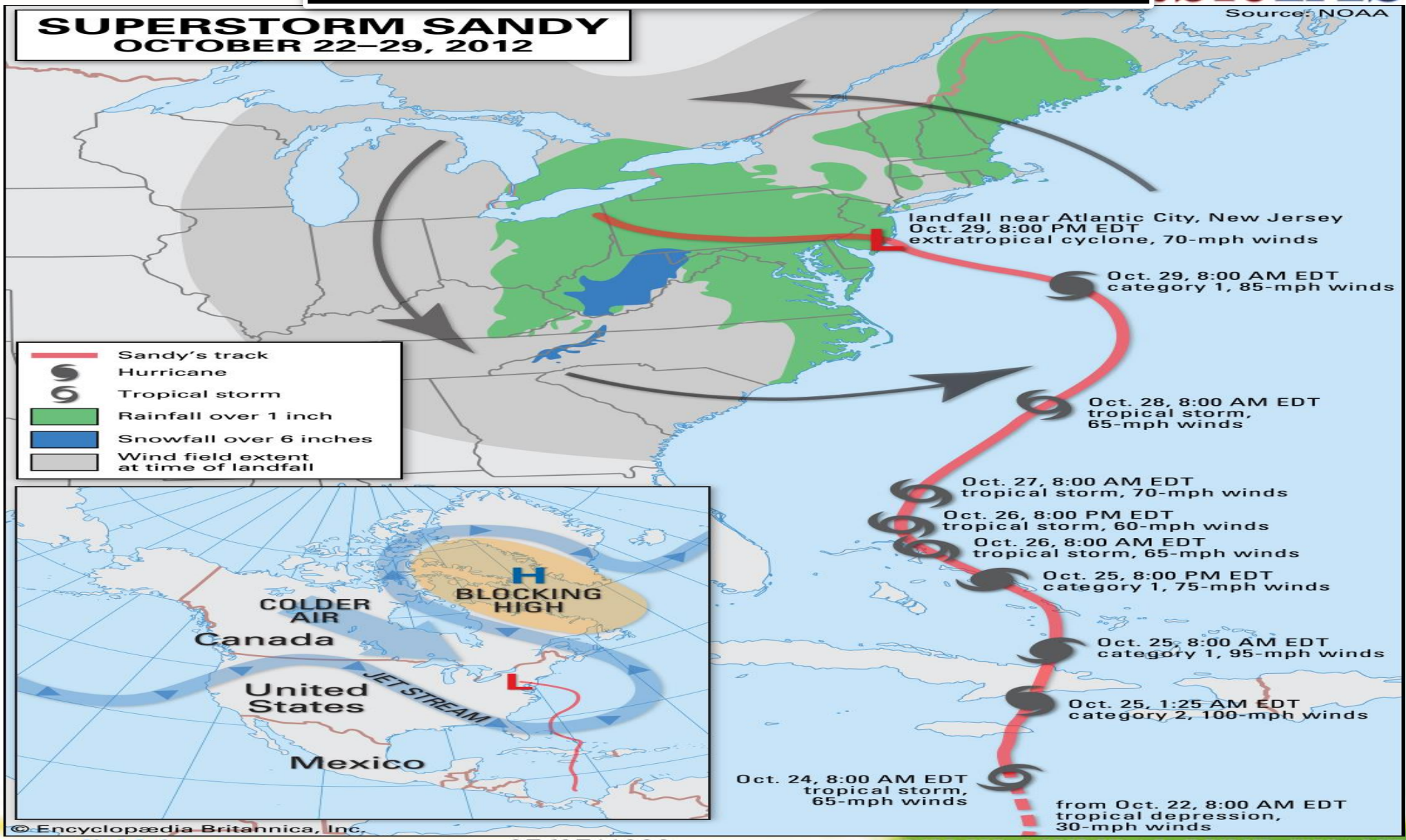


- **Upper Air anti cyclone**
- The upper air anti cyclonic condition intensify the lower cyclone as it sucks the rising air and pumped out.
- Therefore cyclone continue to be and a low pressure maintained at the center.
- Sometimes jet stream creates such condition.



- Role of ITCZ
- As being a low-pressure it initiate the wind movement.
- Immense amount of wind heads towards convergence zone. Hence favourable condition exist.
- It also produces small **atmospheric vortices** in vicinity to its margin.

Life cycle of Tropical Cyclones



➢ The tropical cyclone passes through following successive stages-

Early / Formation stage → Intensification → Dissipation/ landfall

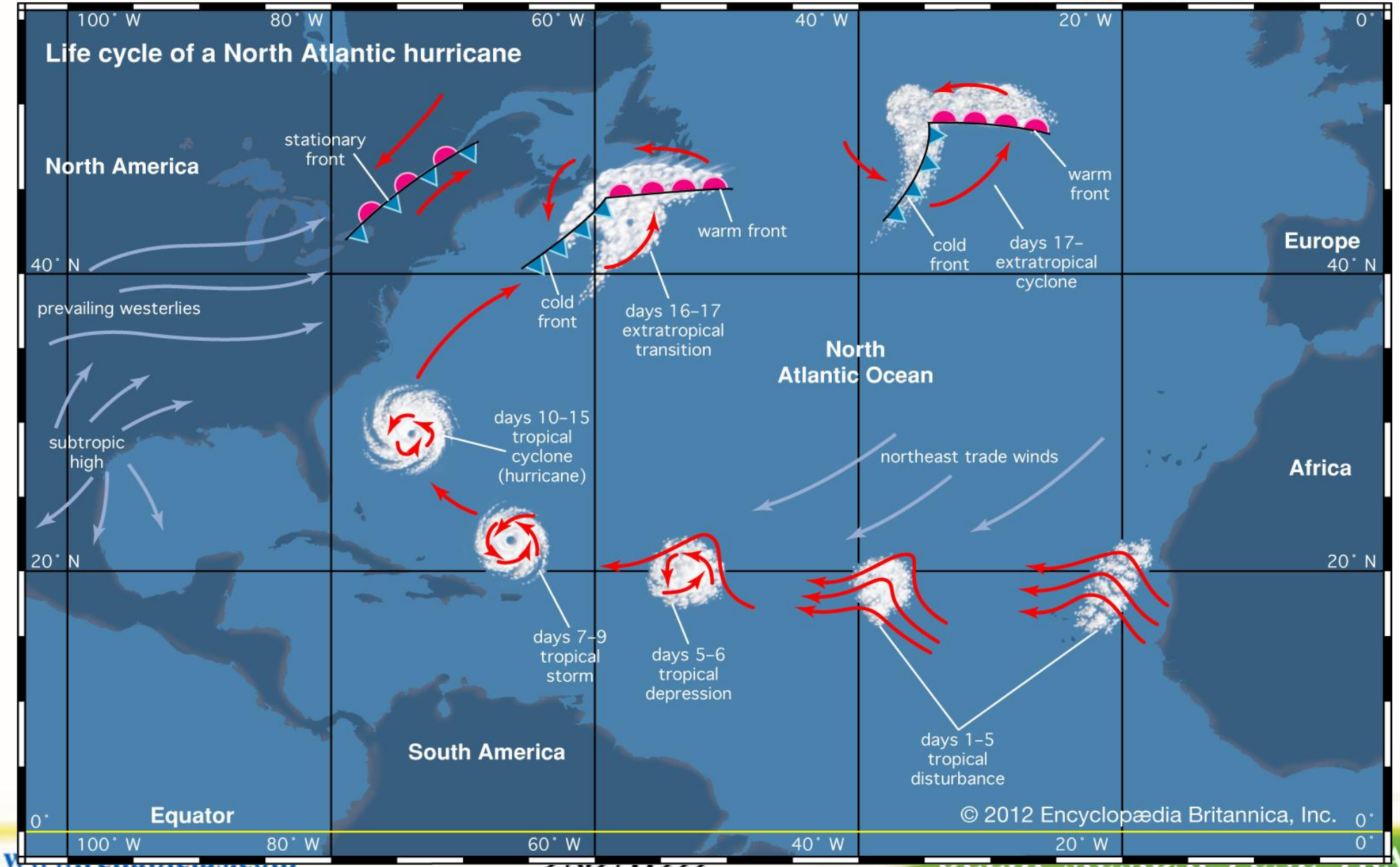
- **Early / Formation stage**
- The formation of tropical cyclone takes places during summer over warm ocean.
- In presence of favourable condition rising convective current with moisture create a acute low pressure.
- The air from surroundings rushes in and undergoes deflection due to Coriolis force creating a cyclonic vortex.

- **Intensification**
- Intensification of cyclone depends on following conditions-
  - For intensification , **it is necessary that the temperature of the atmosphere drop sufficiently and rapidly with height**.
  - The warm, saturated air rising in the centre of the circulation tends to keep rising as long as the surrounding air is cooler and heavier.
  - This vertical movement allows deep convective clouds to develop.
- The rising air in the core also draws in some air from the surrounding atmosphere at altitudes of around 5,000 metres (16,000 feet). If this **external air is relatively humid**, the circulation will continue to intensify. If it is sufficiently dry, then it may evaporate some of the water drops in the rising column, causing the air to become cooler than the surrounding air.
- This cooling will result in the formation of strong downdrafts that will disrupt the rising motion and inhibit development.

- For the intensification of tropical cyclones is that there must be **little change in the wind speed** with height above the surface.
- If the **winds increase too much with altitude**, the core of the system will no longer be vertically aligned over the warm surface that provides its energy. The area being warmed and the surface low-pressure centre will move apart, and the positive feedback mechanism described above will be suppressed.
- Conditions in the tropics that encourage the development of tropical cyclones include a **typically minor north-to-south variation in temperature.** This relative lack of a temperature gradient causes wind speed to remain relatively constant with height.

- **Dissipation**
- Tropical cyclones dissipate when they can no longer extract sufficient energy from warm ocean water.
- Dissipation takes places when a tropical cyclone
  - Moves toward deeper and cooler oceans
  - Moves over land
- The arrival of cyclone on coastal region is called land fall of cyclone. When it reaches to the coastal region havoc and destruction happens.
- However due to lack of moist air and latent heat it loses intensity and disappear gradually.

Category / Type of a cyclone



On the basis of wind speed the tropical cyclone are classified into following group-

- Tropical disturbance (up to 36 km)
- Tropical depression (36-63 km)
- Tropical storm (63-119 km)
- Full-fledged tropical cyclone. (above 120 km)

Modified Saffir Simpson Hurricane Wind Scale

Category	Wind km/h	Wind knots	Wind mph
Tropical Depression	31-50	17-27	19-31
Deep Tropical Depression	51-62	28-33	32-39
Tropical Storm	63-88	34-47	40-55
Severe Tropical Storm	64-119	48-64	56-74
Category 1 Hurricane/Typhoon	120-152	65-82	75-94
Category 2 Moderate Hurricane/Typhoon	153-176	83-95	95-107
Category 3 Significant Hurricane/Typhoon	177-225	96-112	108-140
Category 4 Very Significant Hurricane/Typhoon	226-246	113-133	141-152
Category 5 Extremely Significant Hurricane/Typhoon	≥247	≥134	≥153

- **Indian Meteorological Department**
- The criteria below has been formulated by the Indian Meteorological Department (IMD), which classifies the low pressure systems in the Bay of Bengal and the Arabian Sea on the basis of capacity to damage, which is adopted by the WMO.

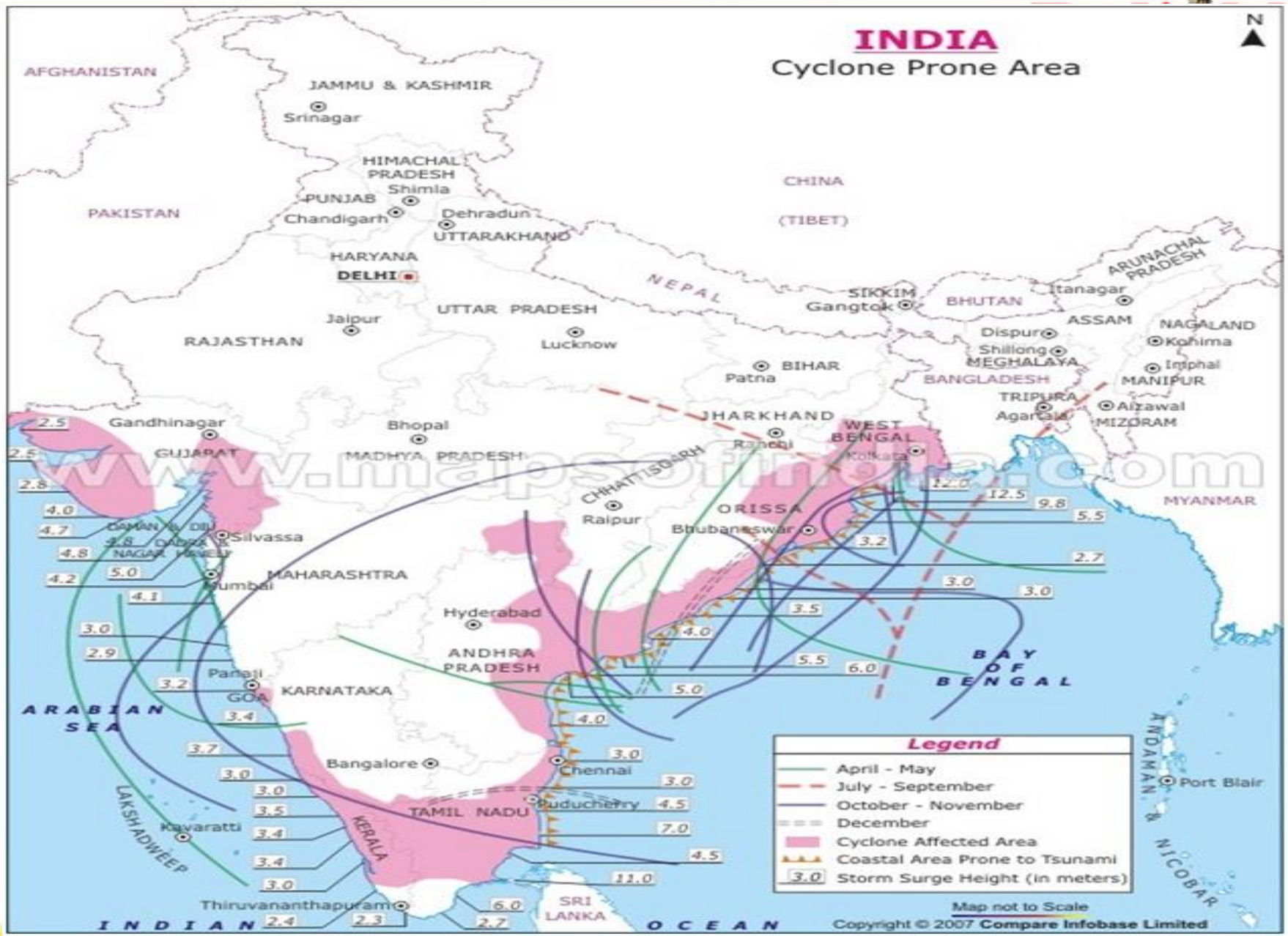
Type of Disturbances	Wind Speed in Km/h	Wind Speed in Knots
Low Pressure	Less than 31	Less than 17
Depression	31-49	17-27
Deep Depression	49-61	27-33
Cyclonic Storm	61-88	33-47
Severe Cyclonic Storm	88-117	47-63
Super Cyclone	More than 221	More than 120

- They are further divided into the following categories according to their capacity to **cause damage**:-

Cyclone Category	Wind Speed in Km/h	Damage Capacity
01	120-150	Minimal
02	150-180	Moderate
03	180-210	Extensive
04	210-250	Extreme
05	250 and above	Catastrophic

Topical cyclone in India

- The Indian subcontinent **is one of the worst affected regions in the world**. The subcontinent with a long **coastline of 8041** kilometres is **exposed to nearly 10 per cent of the world's tropical cyclones.**
- Of these, **the majority of them have their initial genesis over the Bay of Bengal and strike the East coast of India.**
- On an average, **five to six tropical cyclones form every year, of which two or three could be severe.**
- More cyclones occur in the Bay of Bengal than the Arabian Sea and the ratio is approximately **4:1.**
- An analysis of the frequency of cyclones on the East and West coasts of India between 1891 and 1990 shows that nearly 262 cyclones occurred (92 of these severe) in a 50 km wide strip above the East coast.
- Less severe cyclonic activity has been noticed on the West coast, where 33 cyclones occurred the same period, out of which 19 of were severe.


INDIA
Cyclone Prone Area
N
AFGHANISTAN
JAMMU & KASHMIR
Srinagar
HIMACHAL PRADESH
Shimla
PUNJAB
Chandigarh
Dehradun
UTTARAKHAND
PAKISTAN
CHINA
(TIBET)
HARYANA
DELHI
NEPAL
SIKKIM
Gangtok
BHUTAN
ARUNACHAL PRADESH
Itanagar
ASSAM
NAGALAND
Kohima
Dispur
Shillong
MEGHALAYA
Imphal
MANIPUR
BANGLADESH
TRIPURA
Agartala
Aizawal
MIZORAM
UTTAR PRADESH
Jaipur
Lucknow
RAJASTHAN
BIHAR
Patna
JHARKHAND
Ranchi
WEST BENGAL
Kolkata
Gandhinagar
Bhopal
GUJARAT
MADHYA PRADESH
CHHATTISGARH
Raipur
ORISSA
Bhubaneswar
MYANMAR
Silvassa
MAHARASHTRA
Mumbai
Hyderabad
ANDHRA PRADESH
Panaji
GOA
KARNATAKA
ARABIAN SEA
BAY OF BENGAL
Bangalore
Chennai
Puducherry
TAMIL NADU
KERALA
LAKSHADWEEP
Kavaratti
Thiruvananthapuram
SRI LANKA
INDIAN OCEAN
ANDAMAN & NICOBAR
Port Blair
Legend
April - May
July - September
October - November
December
Cyclone Affected Area
Coastal Area Prone to Tsunami
Storm Surge Height (in meters)
Map not to Scale
Copyright © 2007 Compare Infobase Limited


NORTH INDIAN OCEAN CYCLONES
1999-2018
1
1
1
4
16
4
1
0
5
21
17
9
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Why do maximum tropical cyclones come in bay of Bengal than Arabian sea?

Warmer Sea Surface Temperatures:

- The Bay of Bengal generally has warmer sea surface temperatures compared to the Arabian Sea. Warmer waters provide the energy needed for tropical cyclones to develop and intensify.

Greater Moisture Content:

- The Bay of Bengal typically has higher moisture content in the atmosphere, which is conducive to the formation and sustenance of tropical cyclones. This moisture provides additional fuel for the storms to grow.

Geographical Features:

- The geographical features surrounding the Bay of Bengal, such as the Indian subcontinent and the Indo-China peninsula, can enhance cyclone formation. These landmasses can influence wind patterns and contribute to the development of favorable atmospheric conditions for cyclone formation.

Oceanic Currents:

- The ocean currents in the Bay of Bengal, such as the warm and nutrient-rich waters of the Indian Ocean, can support the development of tropical cyclones by providing favorable conditions for the transfer of heat and moisture from the ocean surface to the atmosphere.

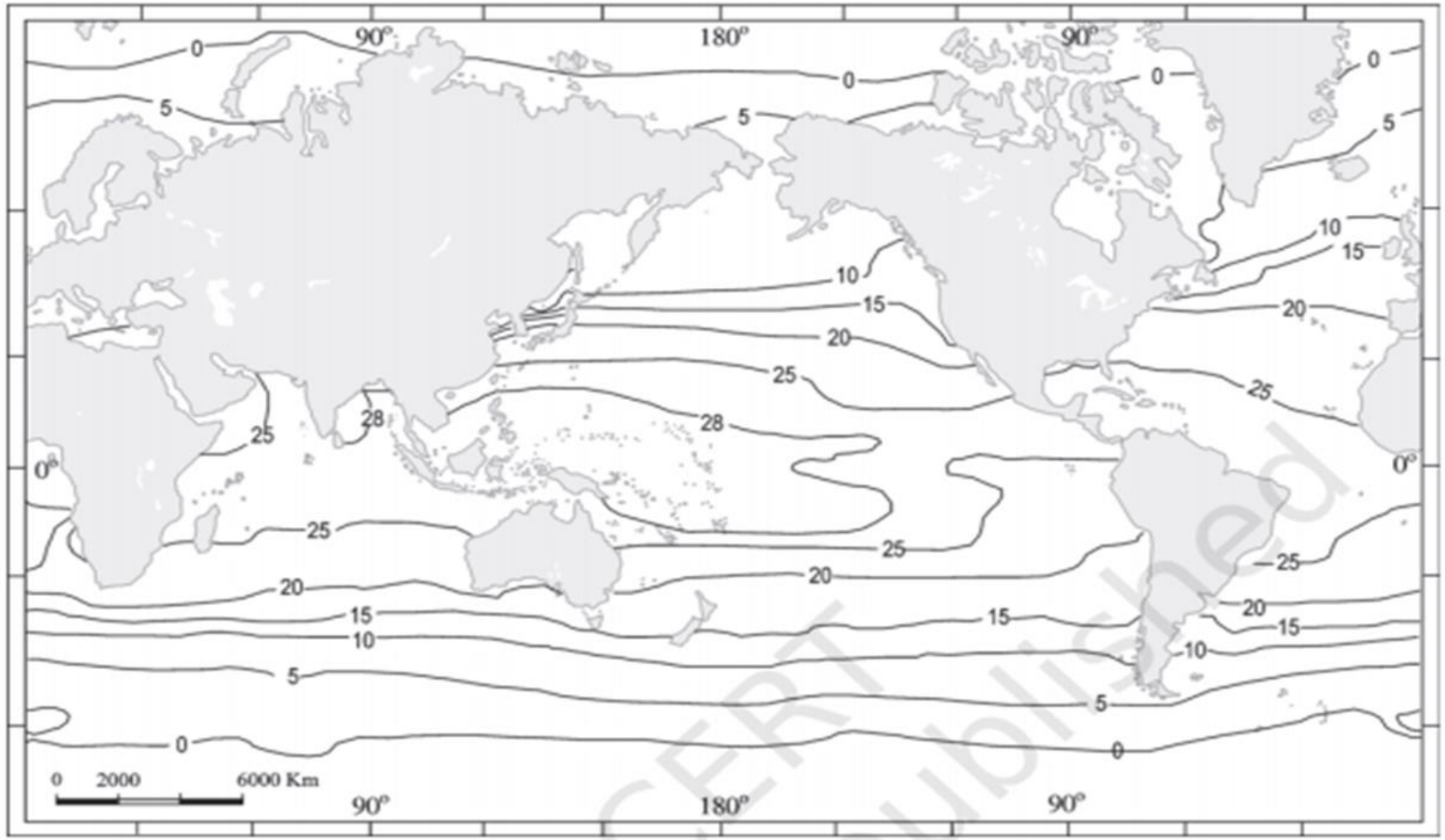
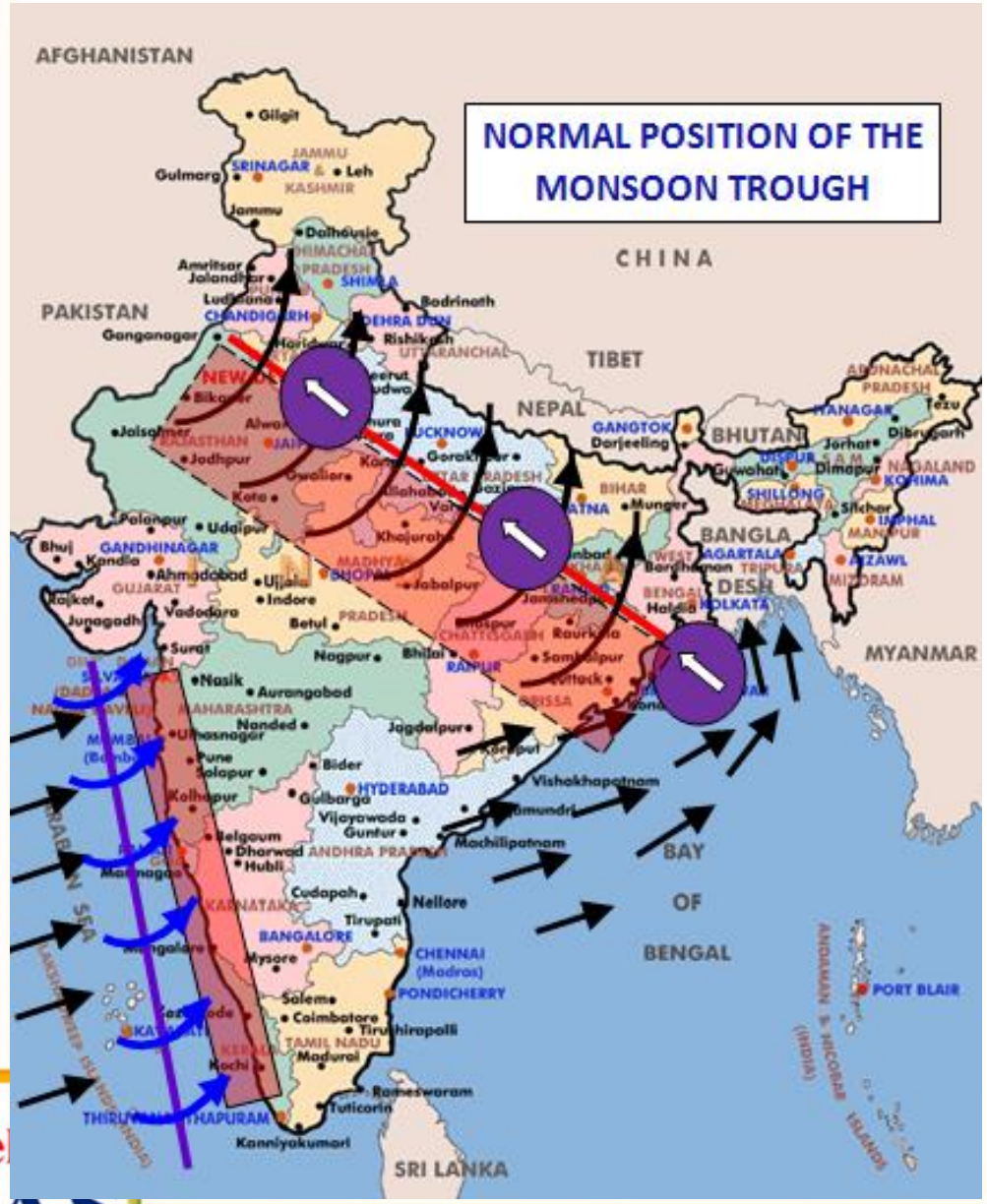


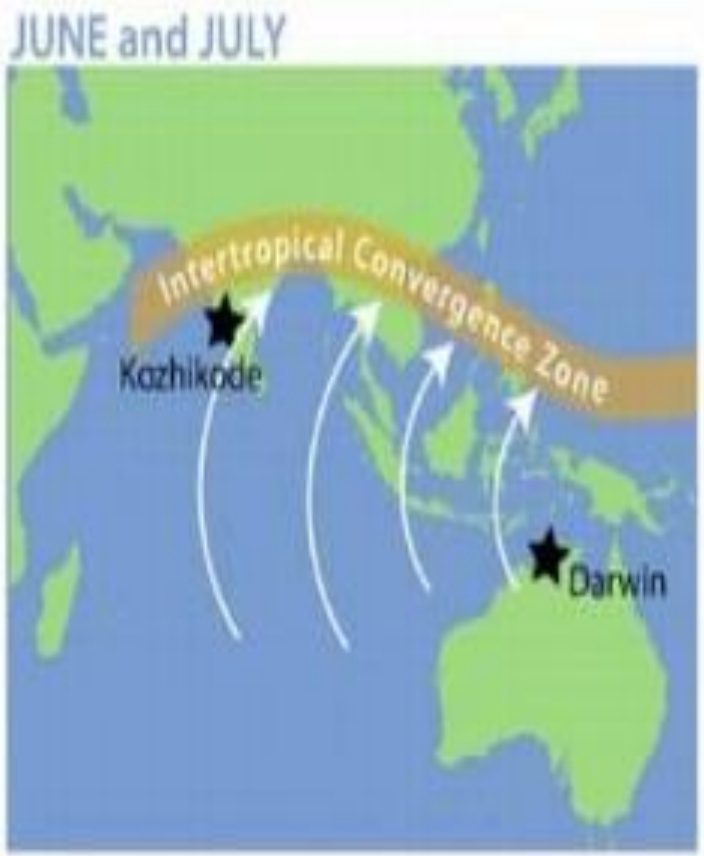
Figure 13.4 : Spatial pattern of surface temperature (°C) of the oceans

Why do maximum tropical in India comes during may and October?

Pre-Monsoon and Post-Monsoon Seasons:	• May is part of the pre-monsoon season, and October falls in the post-monsoon season. These transitional periods are characterized by changes in wind patterns and sea surface temperatures, which are conducive to cyclone formation.
Sea Surface Temperatures:	• The sea surface temperatures (SSTs) are typically higher during these months, especially in the Bay of Bengal, providing the necessary energy for cyclone development.
Wind Shear:	• Low wind shear, which is a difference in wind speed and direction over a short distance in the atmosphere, is also a contributing factor. During May and October, the wind shear is low, allowing cyclones to form and intensify.
Monsoon Trough:	• The monsoon trough, which is an area of low pressure, shifts its position during these months, creating favorable conditions for the genesis of cyclones.
Atmospheric Conditions:	• The atmospheric conditions during these months are often unstable, which can lead to the formation of deep convection currents necessary for cyclone development.

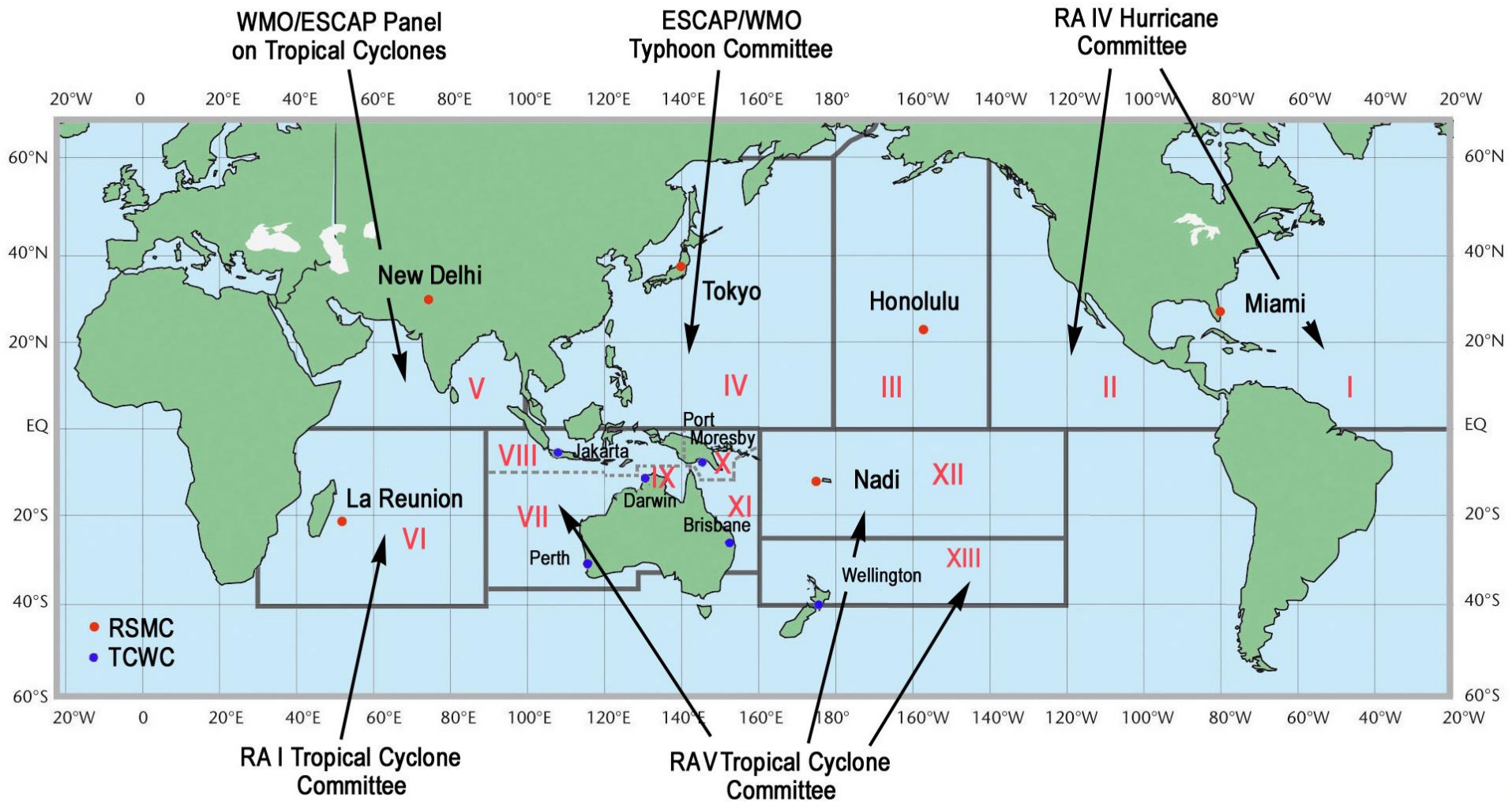

NORMAL POSITION OF THE MONSOON TROUGH
AFGHANISTAN
PAKISTAN
CHINA
TIBET
NEPAL
BHUTAN
BANGLADESH
MYANMAR
SRI LANKA
BAY OF BENGAL
ARABIAN SEA
Gilgit
SRINAGAR
Leh
Gulmarg
Jammu
Dalhousie
Amritsar
Jalandhar
SHIMLA
Ludhiana
CHANDIGARH
Badrinath
Ganganagar
DEHRA DUN
Rishikesh
NEWDELHI
Bikaner
Jaisalmer
Jodhpur
Alwar
LUCKNOW
Gorakhpur
Gwalior
Kota
Khajuraho
PATNA
Munger
GANGTOK
Darjeeling
Jorhat
Dibrugarh
Guwahati
Dimapur
SHILLONG
Silchar
IMPHAL
AIZAWL
Polanpur
Udaipur
Bhuj
GANDHINAGAR
Kandla
Ahmadabad
Rajkot
Vadodara
Junagadh
Ujjain
Indore
Bhopal
Jabalpur
Betul
Surat
Nagpur
Bhilai
RAIPUR
Raurkela
Sambalpur
Cuttack
KOLKATA
Nasik
Aurangabad
Nanded
Ulhasnagar
Pune
Solapur
Bider
Kolhapur
HYDERABAD
Gulbarga
Vijayawada
Guntur
Vishakhapatnam
Rajmundry
Machilipatnam
Belgaum
Dharwad
Hubli
Cudapah
Nellore
Tirupati
BANGALORE
Mysore
CHENNAI (Madras)
PONDICHERRY
Salem
Coimbatore
Tiruchirapalli
Madurai
Kochi
Rameswaram
Tuticorin
Kanniyakumari
PORT BLAIR


DECEMBER and JANUARY
Kozhikode
Intertropical Convergence Zone
Darwin


JUNE and JULY
Intertropical Convergence Zone
Kozhikode
Darwin

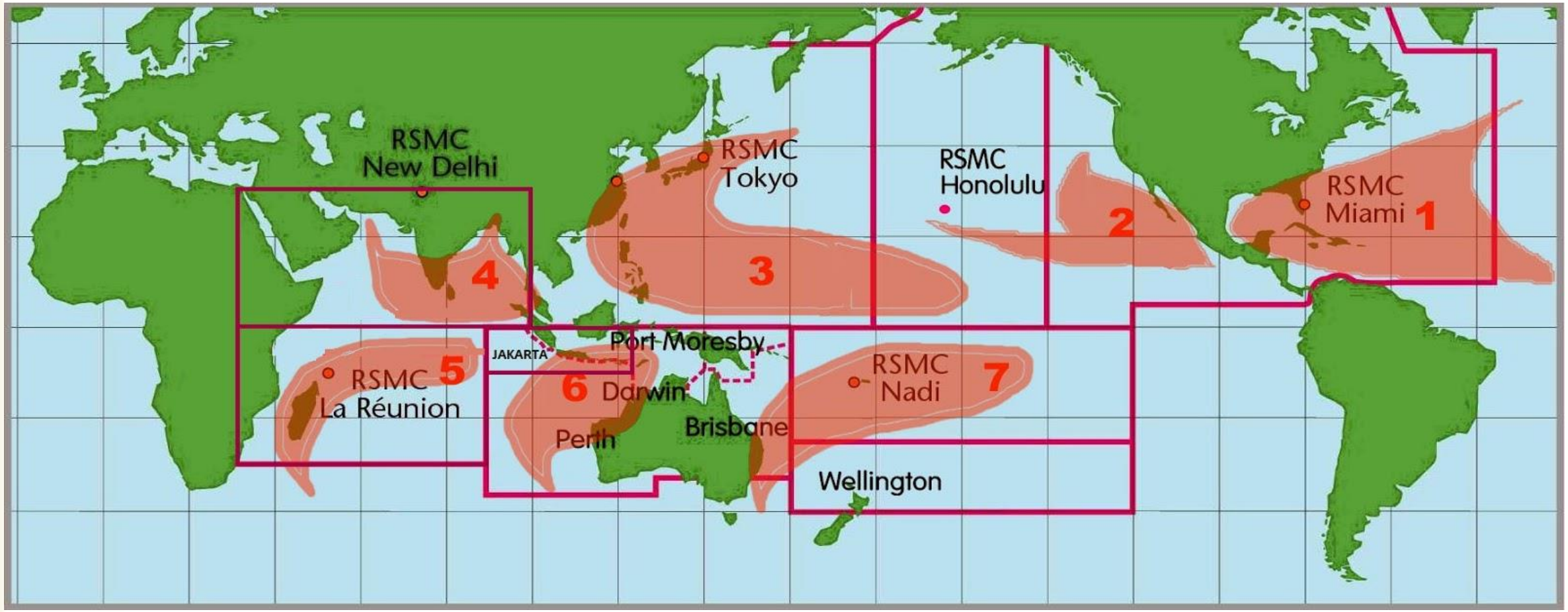
NAMING OF TRPICAL CYCLONE

- Tropical cyclones and subtropical cyclones are named by **various warning centers** to simplify communication between forecasters and the general public regarding forecasts, watches, and warnings. The names are intended to reduce confusion in the event of concurrent storms in the same basin.
- Before the formal start of naming, tropical cyclones were named after places, objects, or saints' feast days on which they occurred.
- The credit for the first usage of personal names for weather systems is generally given to the **Queensland Government Meteorologist Clement Wragge, who named systems between 1887 and 1907.**


WMO/ESCAP Panel on Tropical Cyclones
ESCAP/WMO Typhoon Committee
RA IV Hurricane Committee
New Delhi
Tokyo
Honolulu
Miami
La Reunion
Nadi
Jakarta
Port Moresby
Darwin
Brisbane
Perth
Wellington
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII
RSMC
TCWC
RA I Tropical Cyclone Committee
RA V Tropical Cyclone Committee

- Cyclones that **form in every ocean basin** across the world are named by the
  - Regional specialised meteorological centres (RSMCs) and
  - Tropical Cyclone Warning Centres (TCWCs).
- There are six RSMCs in the world, including the India Meteorological Department (IMD), and five TCWCs.

No.	RSMC	Location
1	NHC/RSMC Miami	United States
2	CPHC/RSMC Honolulu	United States
3	JMA/RSMC Tokyo	Japan
4	IMD/RSMC New Delhi	India
5	MFR/RSMC La Réunion	Réunion
6	FMS/RSMC Nadi	Fiji
7	BMKG/TCWC Jakarta	Indonesia
8	TCWC Port Moresby	Papua New Guinea
9	BOM/TCWC Melbourne	Australia
10	MetService, TCWC Wellington	New Zealand
11	Brazilian Navy Hydrographic Center	Brazil


RSMC
New Delhi
RSMC
Tokyo
RSMC
Honolulu
RSMC
Miami
1
2
3
4
5
6
7
JAKARTA
Port Moresby
RSMC
La Réunion
Darwin
RSMC
Nadi
Perth
Brisbane
Wellington

- The WMO/ESCAP Panel on Tropical Cyclones **held in 2000** in Muscat, Oman agreed **in principle to assign names to the tropical cyclones in the Bay of Bengal and Arabian Sea**.
- After long deliberations among the member countries, the naming of the tropical cyclones over north Indian Ocean **commenced from September 2004**.

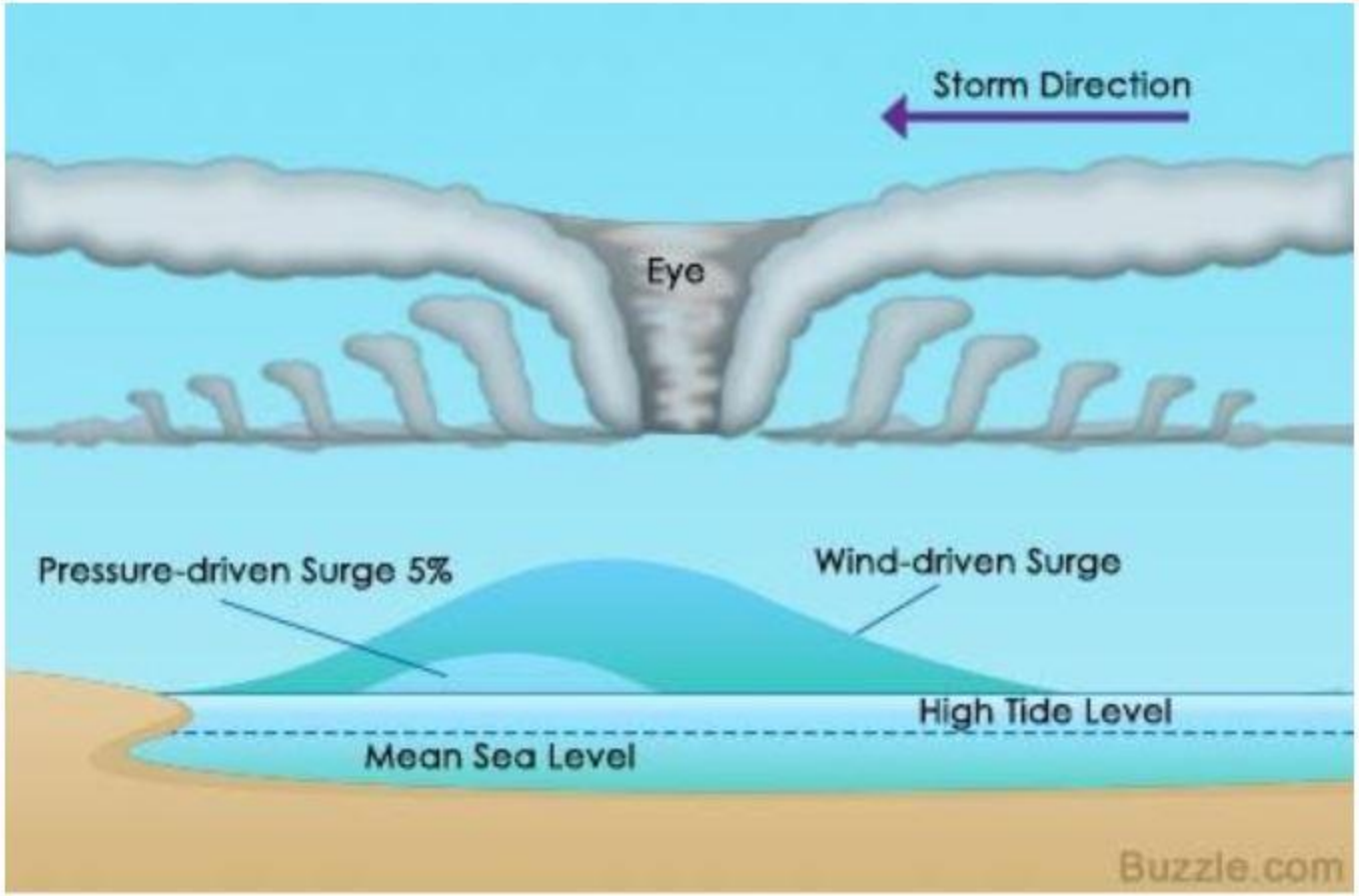
- **India Meteorological Department is one of the six RSMCs** to provide tropical cyclone and storm surge advisories to 13 member countries under WMO/ESCAP Panel including Bangladesh, India, Iran, Maldives, Myanmar, Oman, Pakistan, Qatar, Saudi Arabia, Sri Lanka, Thailand, United Arab Emirates and Yemen.
- RSMC, New Delhi is also mandated to name the Tropical Cyclones developing over the **north Indian Ocean (NIO) including the Bay of Bengal (BoB) and the Arabian Sea (AS).**

For naming -

- The Panel member’s names are listed alphabetically country wise.
- The name will be used sequentially column wise.
- The first name will start from the first row of column one and continue sequentially to the last row in column eight. Example, this will be as Onil, Hibaru, Pyarr, Baaz …… Amphan
- The names which have been already used from the list are highlighted

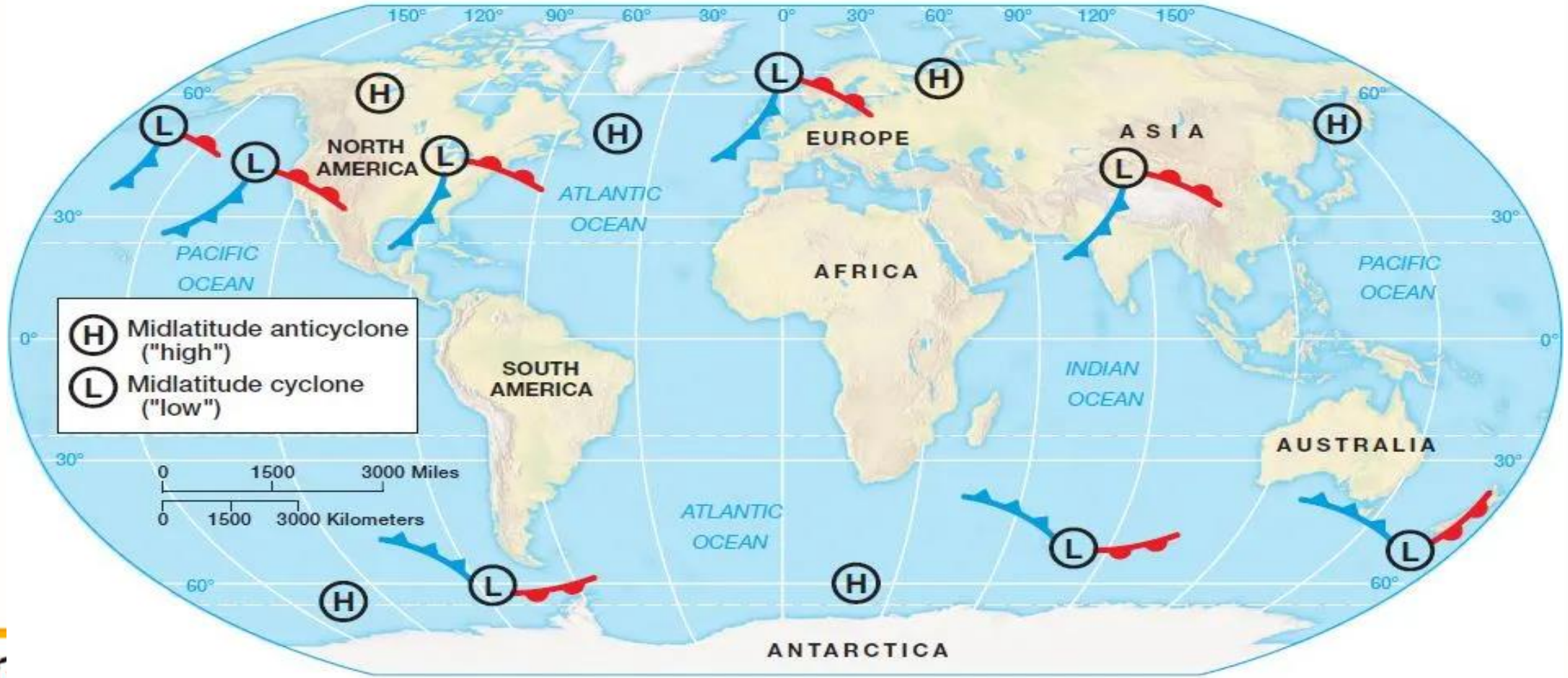
- Following criteria for name selection have decided-
  - proposed name should be neutral to
    - politics and political figures
    - religious believes,
    - cultures and
    - gender
  - Name should be chosen in such a way that it does not hurt the sentiments of any group of population over the globe.
  - It should not be very rude and cruel in nature
  - It should be short, easy to pronounce and should not be offensive to any member
  - The maximum length of the name will be eight letters.
  - The proposed name should be provided along with its pronunciation and voice over

Storm surges (tidal waves)

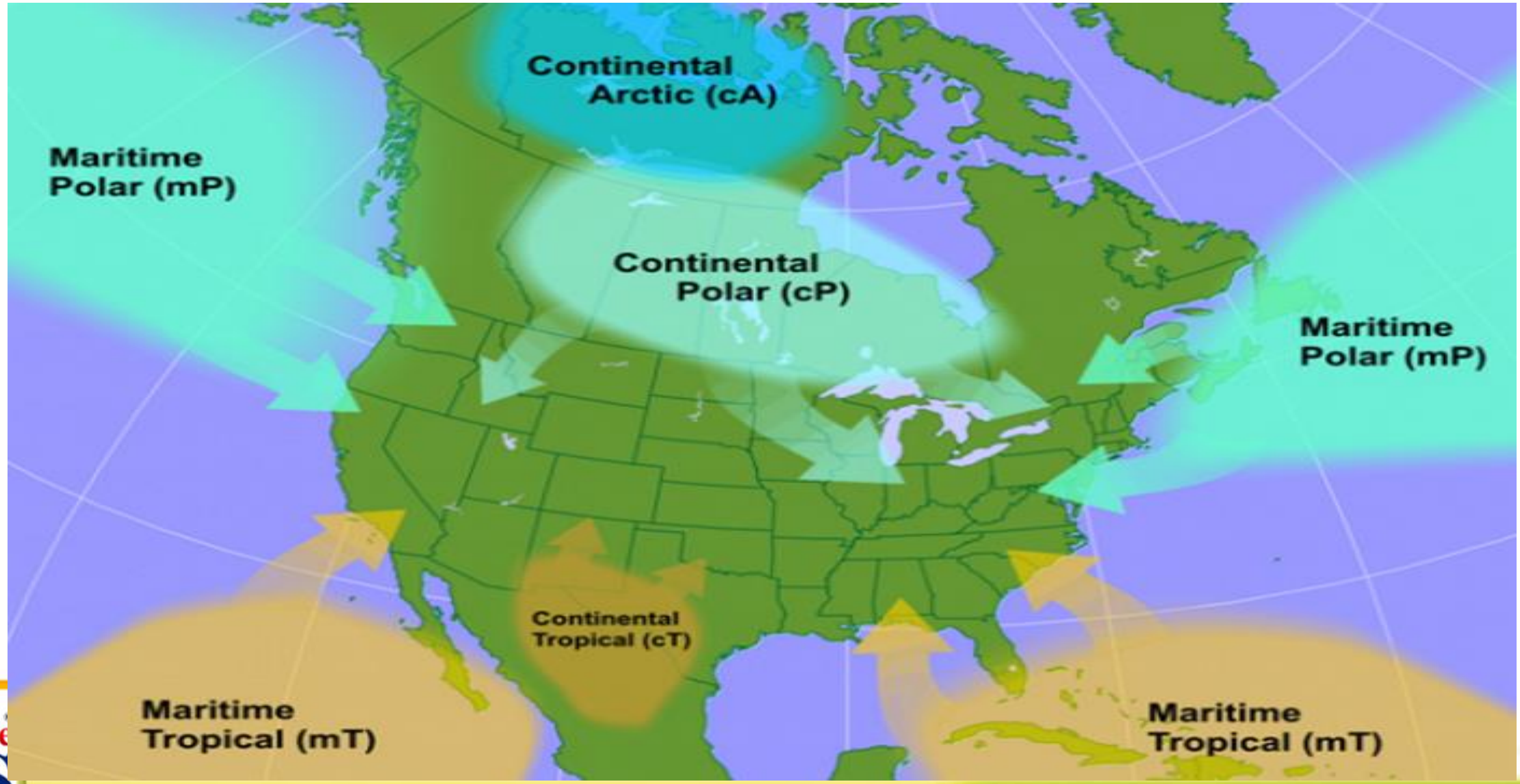


- **Storm surges (tidal waves)** are defined as the rise in sea level above the normally predicted astronomical tide.
- Major factors include:
  - A fall in the atmospheric pressure over the sea surface
  - Effect of the wind
  - Influence of the sea bed
  - A funnelling effect
  - The angle and speed at which the storm approaches the coast
  - The tides

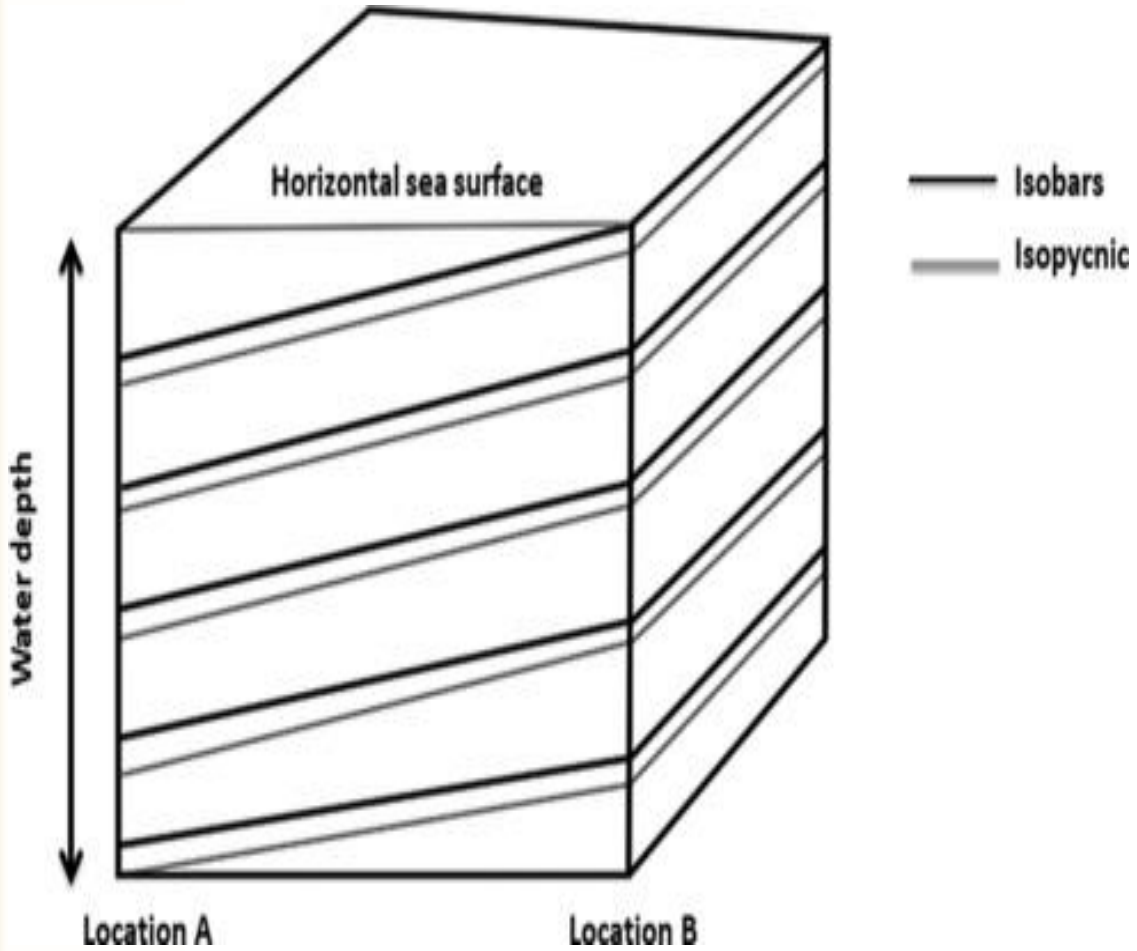
TEMPERATE CYCLONES



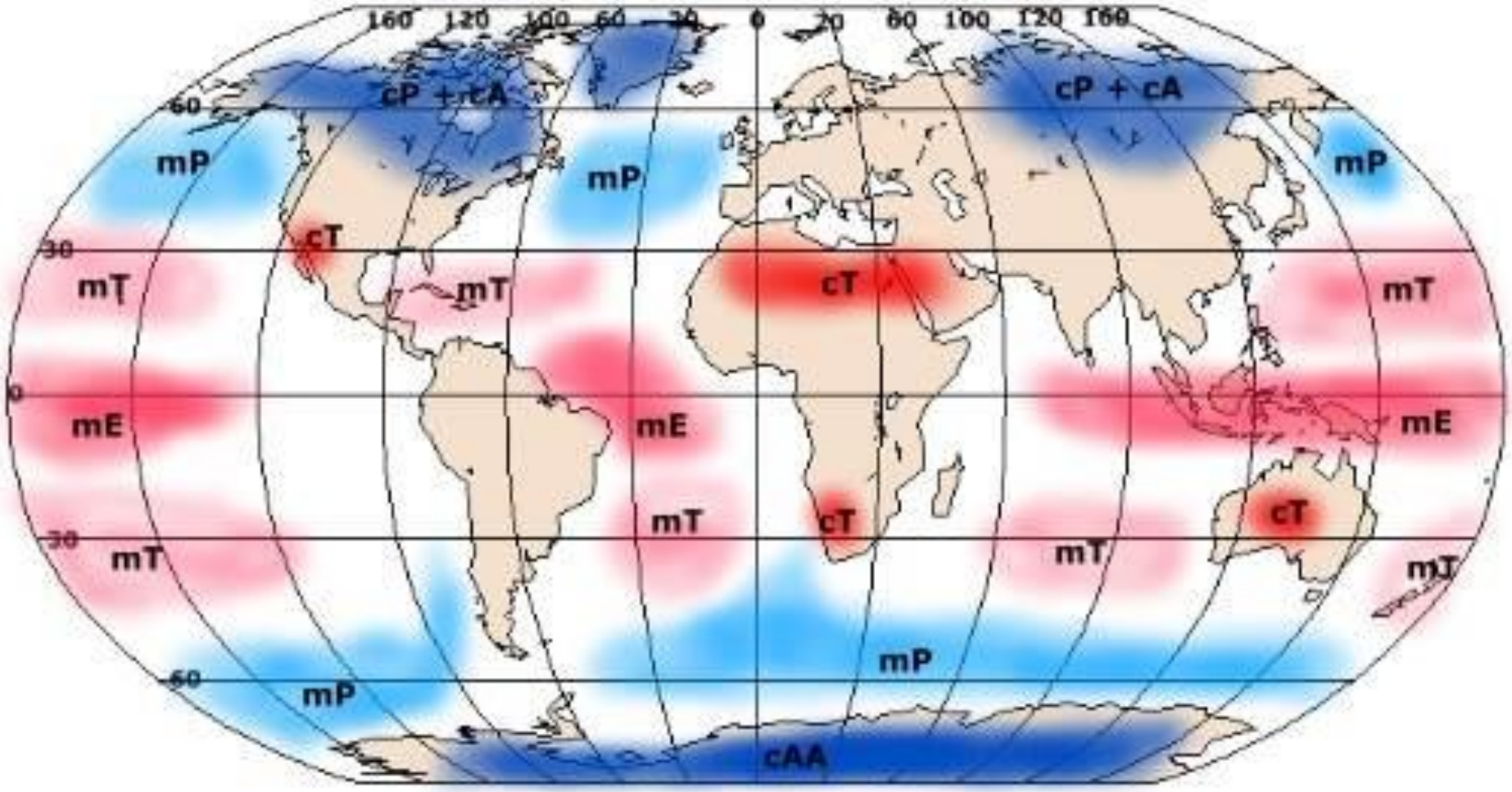
Air Masses


Continental
Arctic (cA)
Maritime
Polar (mP)
Continental
Polar (cP)
Maritime
Polar (mP)
Continental
Tropical (cT)
Maritime
Tropical (mT)
Maritime
Tropical (mT)

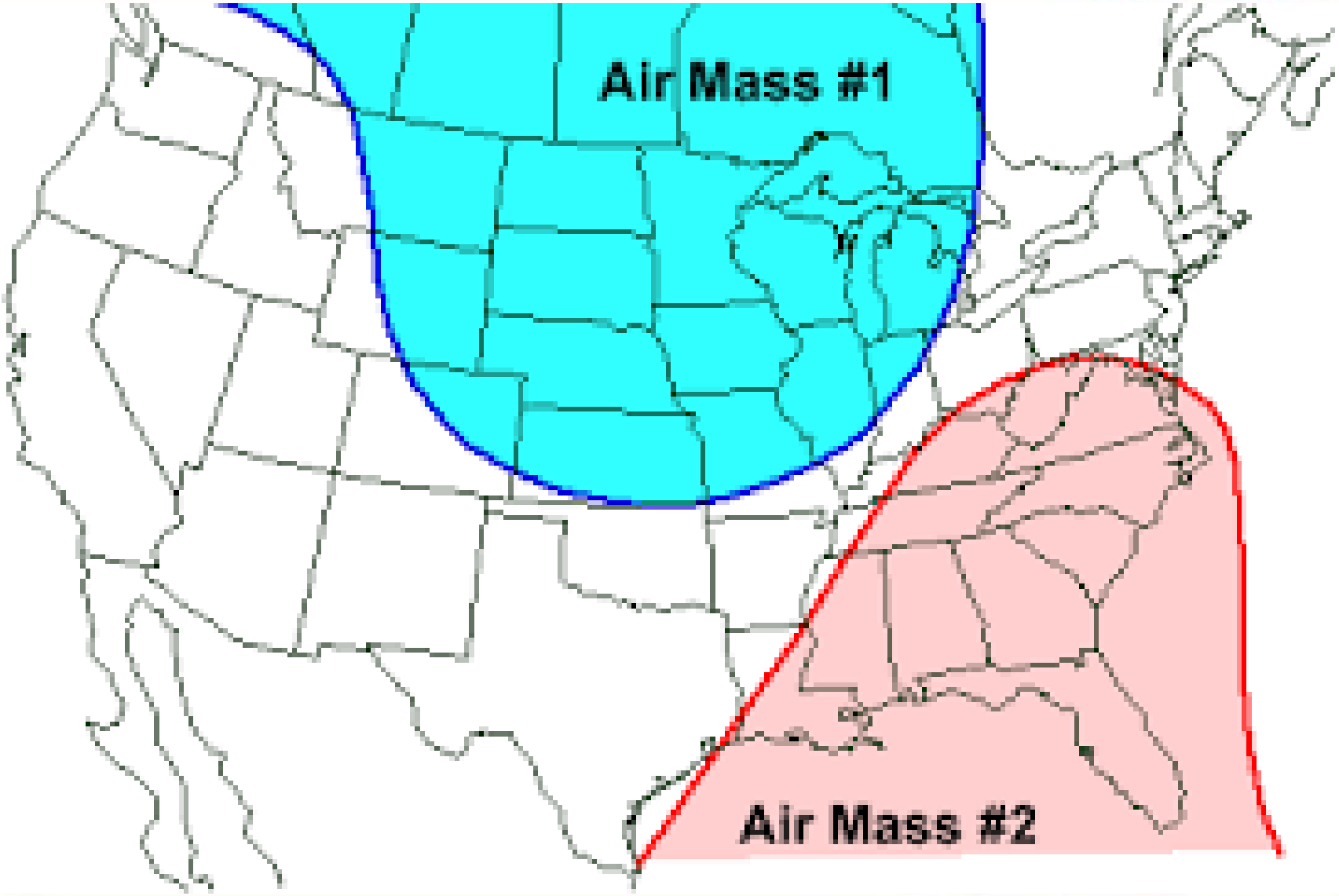
- Air mass is the larger body of air having uniform horizontal temperature and pressure condition.
- It is associated with **barotropic condition** in which temperature and pressure surfaces are coincident, i.e., temperature is uniform (no temperature gradient) on a constant pressure surface.
- Barotropic systems are characterized by a lack of wind shear, and thus are generally unfavorable areas for severe thunderstorm development.
- Air mass affects weather and temperature condition at large and can control the weather for a relatively long time period, from a period of days, to months.


Horizontal sea surface
Water depth
Location A
Location B
Isobars
Isopycnic

Source regions



- The homogenous surfaces, over which air masses form, are called the **source regions**.
- There are five major source regions identified possess ideal conditions. These are:
  - i. Warm tropical and subtropical oceans
  - ii. The subtropical hot deserts
  - iii. The relatively cold high latitude oceans
  - iv. The very cold snow covered continents in high latitudes
  - v. Permanently ice covered continents in the Arctic and Antarctica

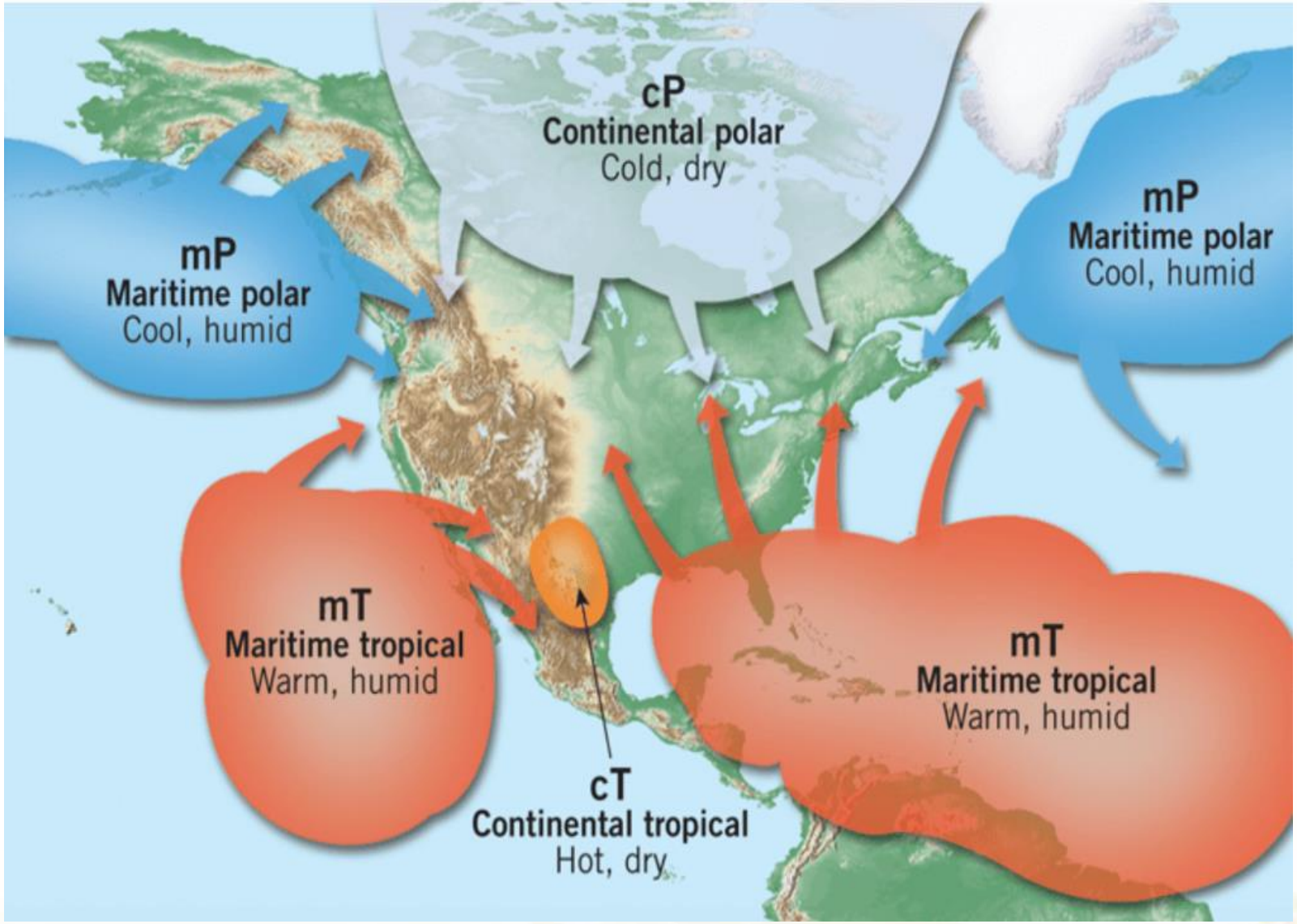

Air Mass #1
Air Mass #2

Formation of Air- mass

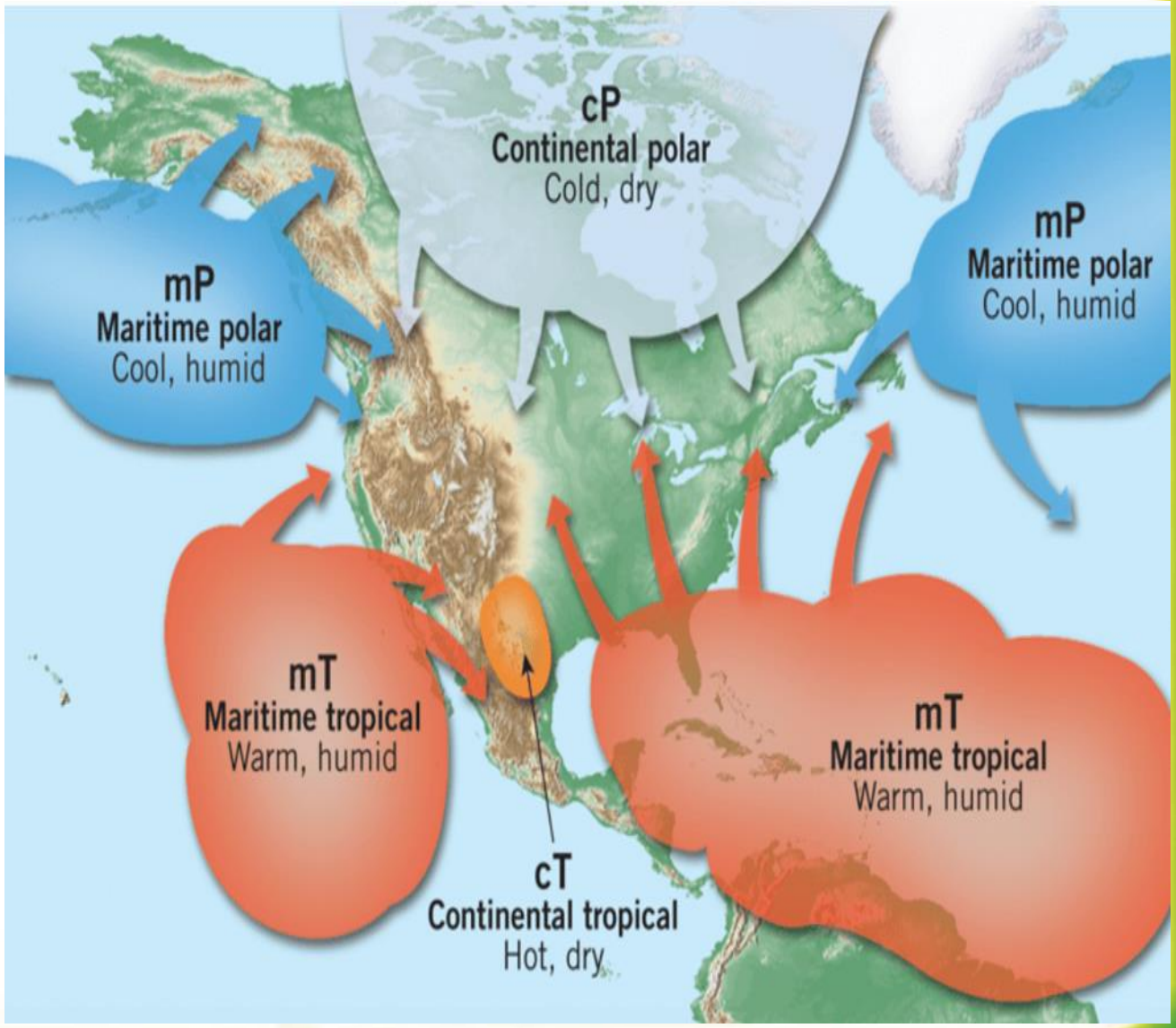
- The formation of air masses takes places at source region in presence of following conducive conditions-

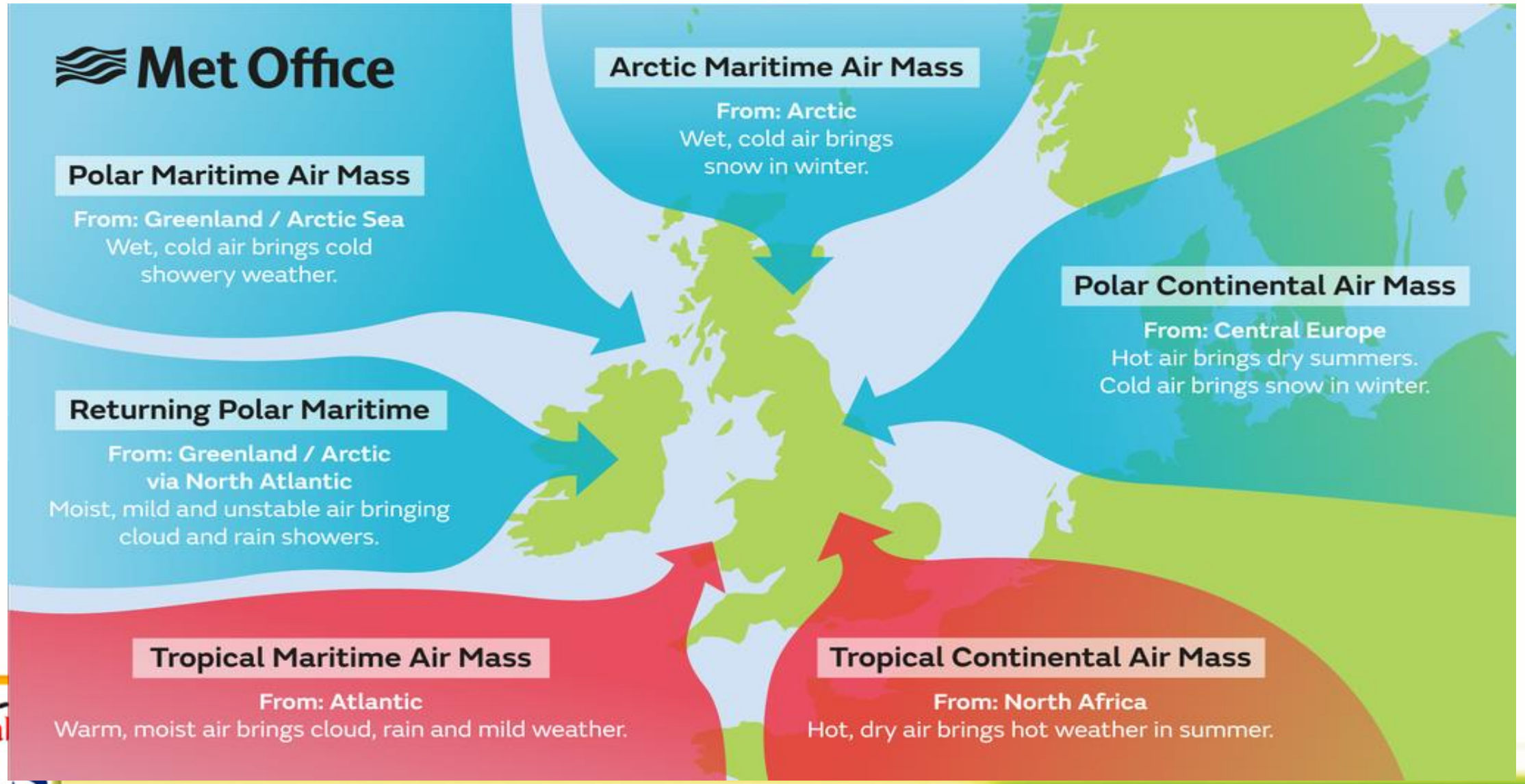
Classification of Air-mass

- The air masses are classified according to the source regions.
- Air masses originated from tropical region are warm while those originated from polar region are cold.
- **Air masses originated from these regions are called primary air masses.**



- On the basis of geographical properties (latitude and region) the airmasses are classified into following major group-
  - Maritime tropical(mT) –
    - warm, moist, usually unstable
  - Continental tropical (cT) –
    - hot, dry, unstable surface air
  - Maritime polar (mP)-
    - cool, moist, unstable
  - Continental polar (cP)-
    - cold, dry, stable
  - Continental arctic (cA)-
    - very cold, very dry, stable

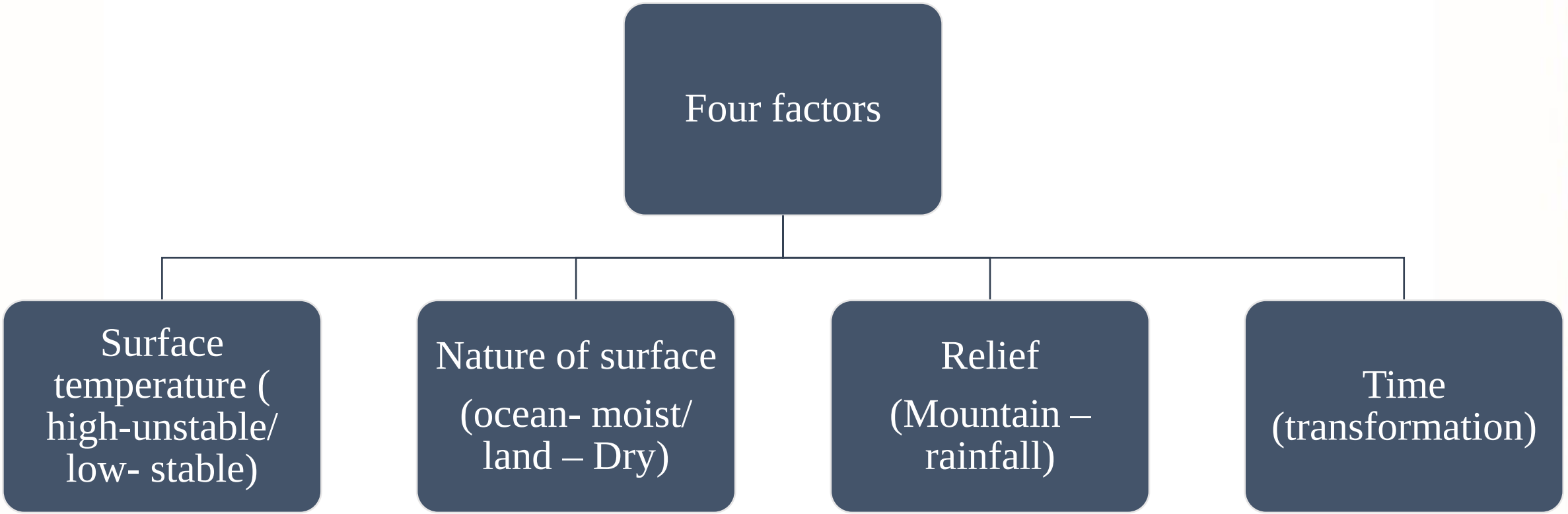


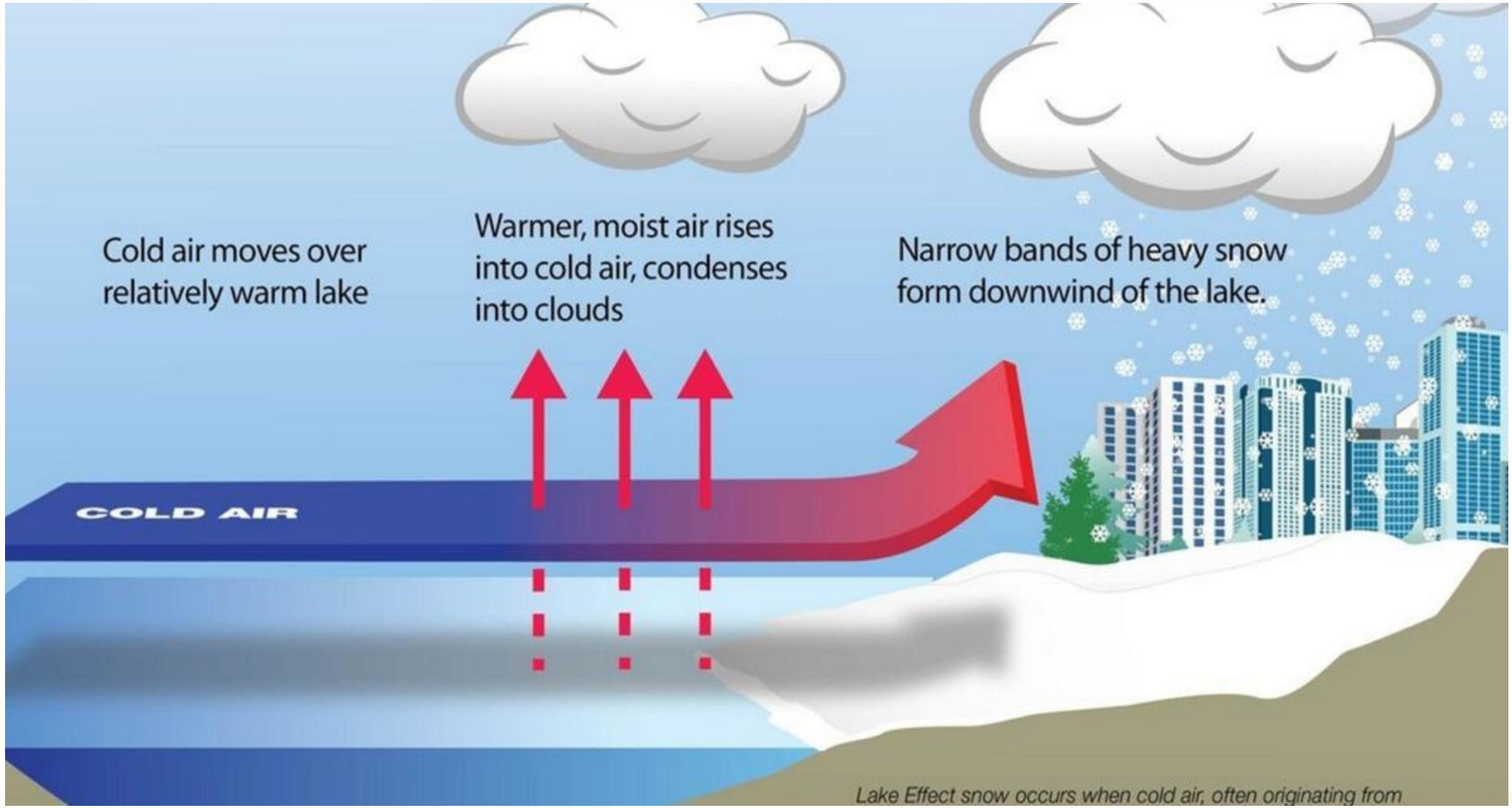

Met Office
Arctic Maritime Air Mass
From: Arctic
Wet, cold air brings snow in winter.
Polar Maritime Air Mass
From: Greenland / Arctic Sea
Wet, cold air brings cold showery weather.
Polar Continental Air Mass
From: Central Europe
Hot air brings dry summers.
Cold air brings snow in winter.
Returning Polar Maritime
From: Greenland / Arctic via North Atlantic
Moist, mild and unstable air bringing cloud and rain showers.
Tropical Maritime Air Mass
From: Atlantic
Warm, moist air brings cloud, rain and mild weather.
Tropical Continental Air Mass
From: North Africa
Hot, dry air brings hot weather in summer.

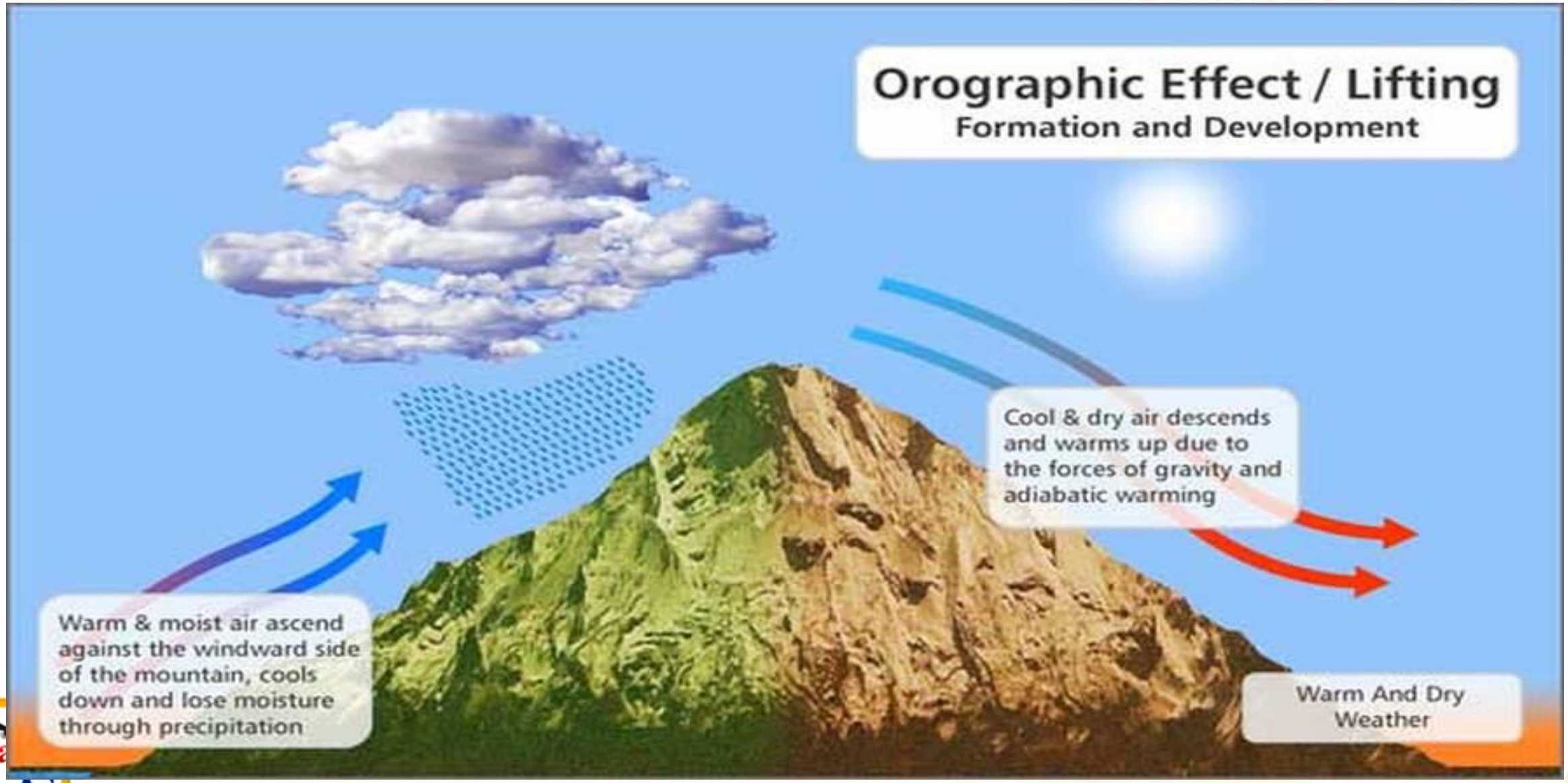
Stability of air masses

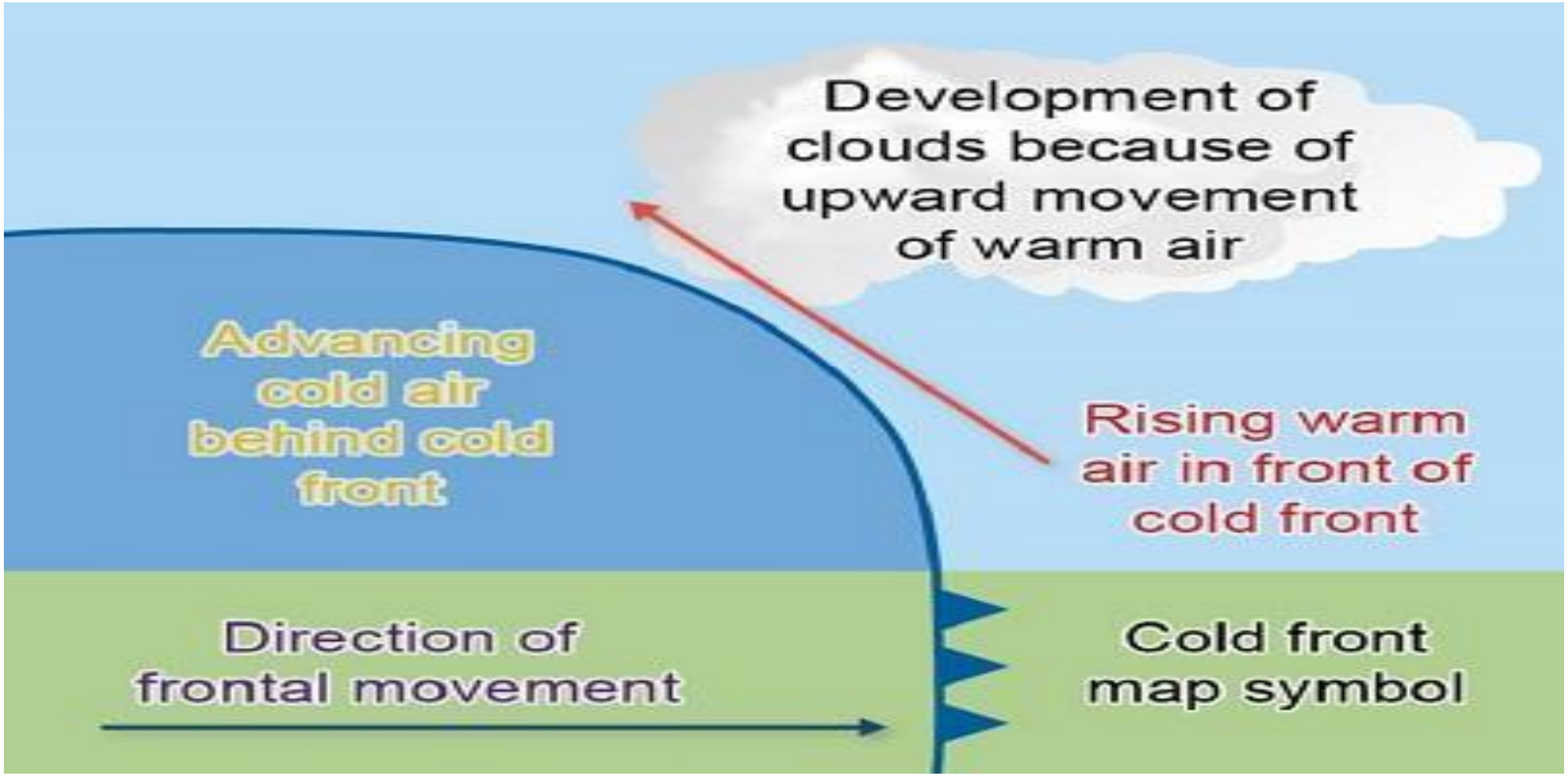
- Stability of air mass depends upon **temperature and moisture**. If cold air mass come into contact with warm ocean it becomes unstable.
- Moist air, by nature, is lighter and less dense than dry air at the same temperature. Moist air rises more readily.
- Higher rate of evaporation and convection aggravate the airmass in the atmosphere.
- Dry air consist of mainly Nitrogen, Oxygen and Argon but Moist air comprises all this plus water vapour (H2O). The latent heat of Maoist air lift this upward.

Determinants of Air - Mass

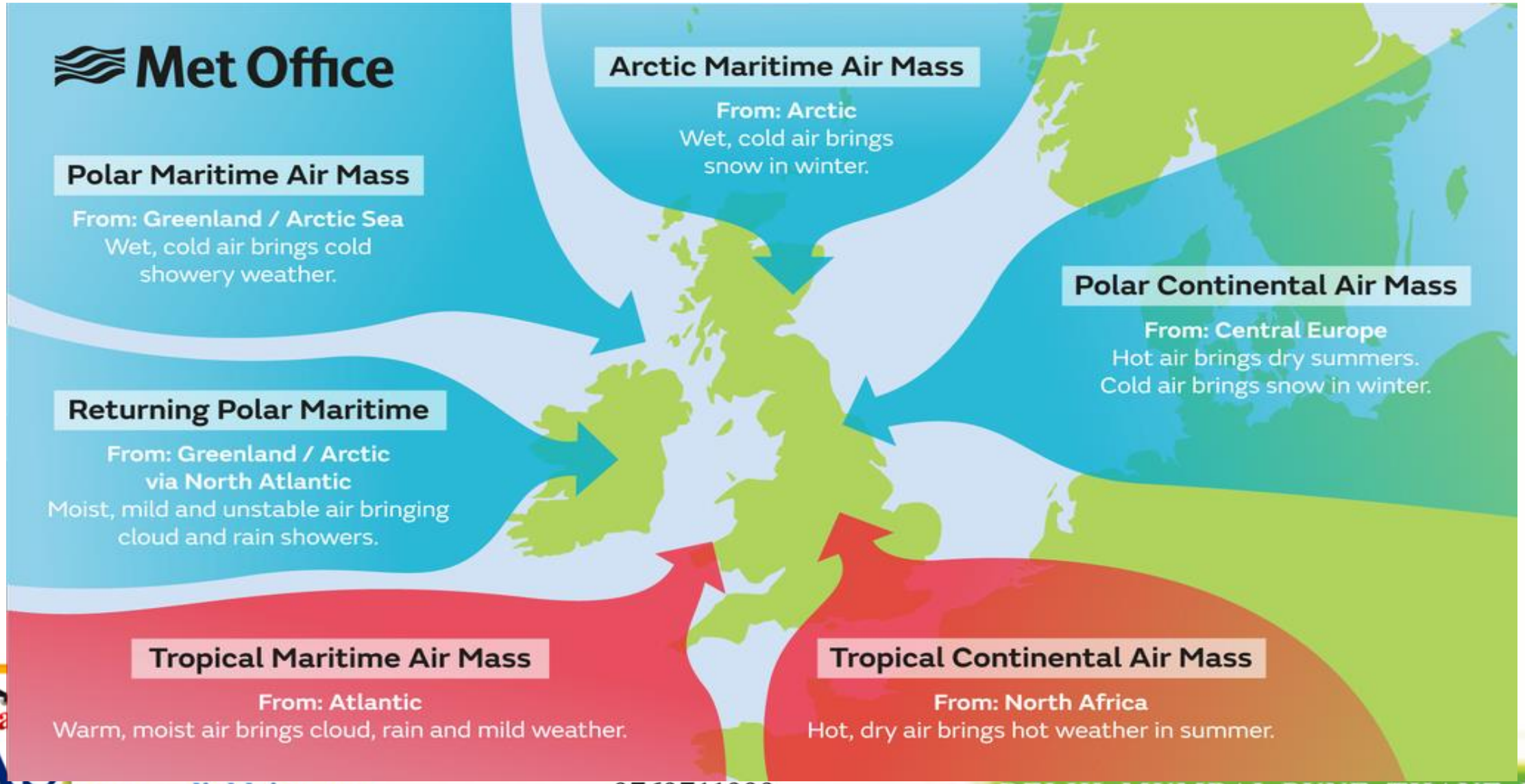



Cold air moves over relatively warm lake
Warmer, moist air rises into cold air, condenses into clouds
Narrow bands of heavy snow form downwind of the lake.
COLD AIR
Lake Effect snow occurs when cold air, often originating from

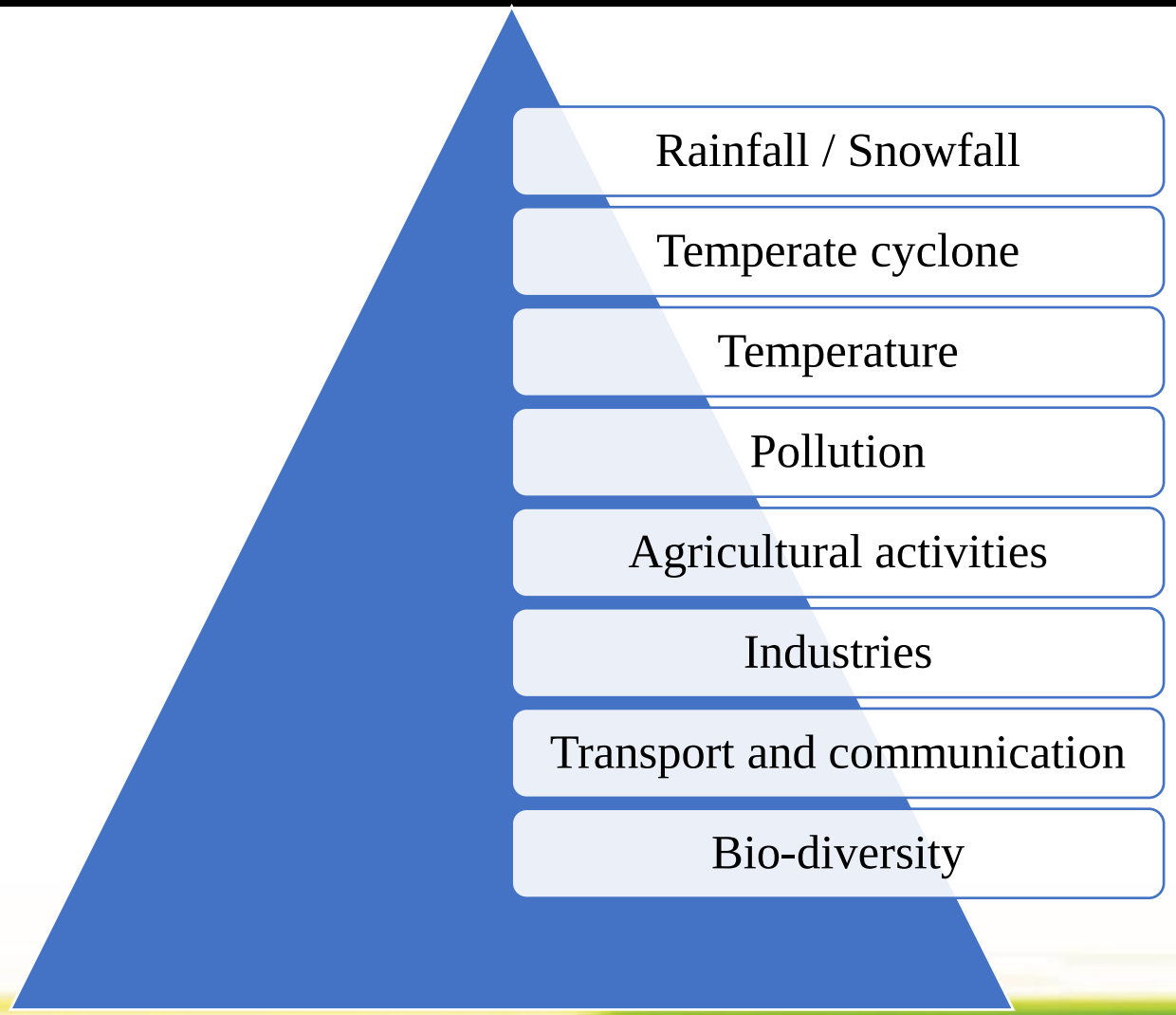

Orographic Effect / Lifting
Formation and Development
Cool & dry air descends and warms up due to the forces of gravity and adiabatic warming
Warm & moist air ascend against the windward side of the mountain, cools down and lose moisture through precipitation
Warm And Dry Weather

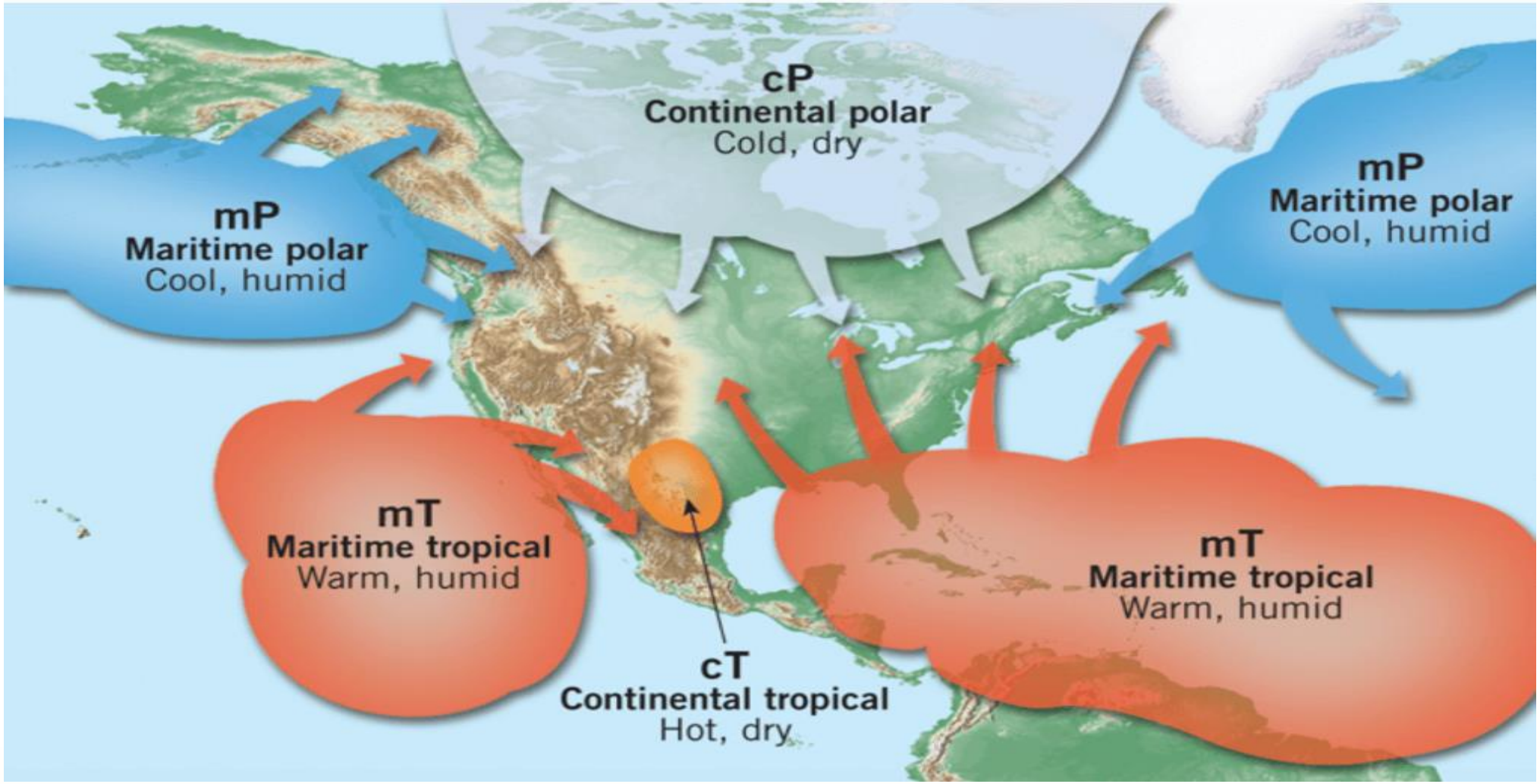

Development of clouds because of upward movement of warm air
Advancing cold air behind cold front
Rising warm air in front of cold front
Direction of frontal movement
Cold front map symbol

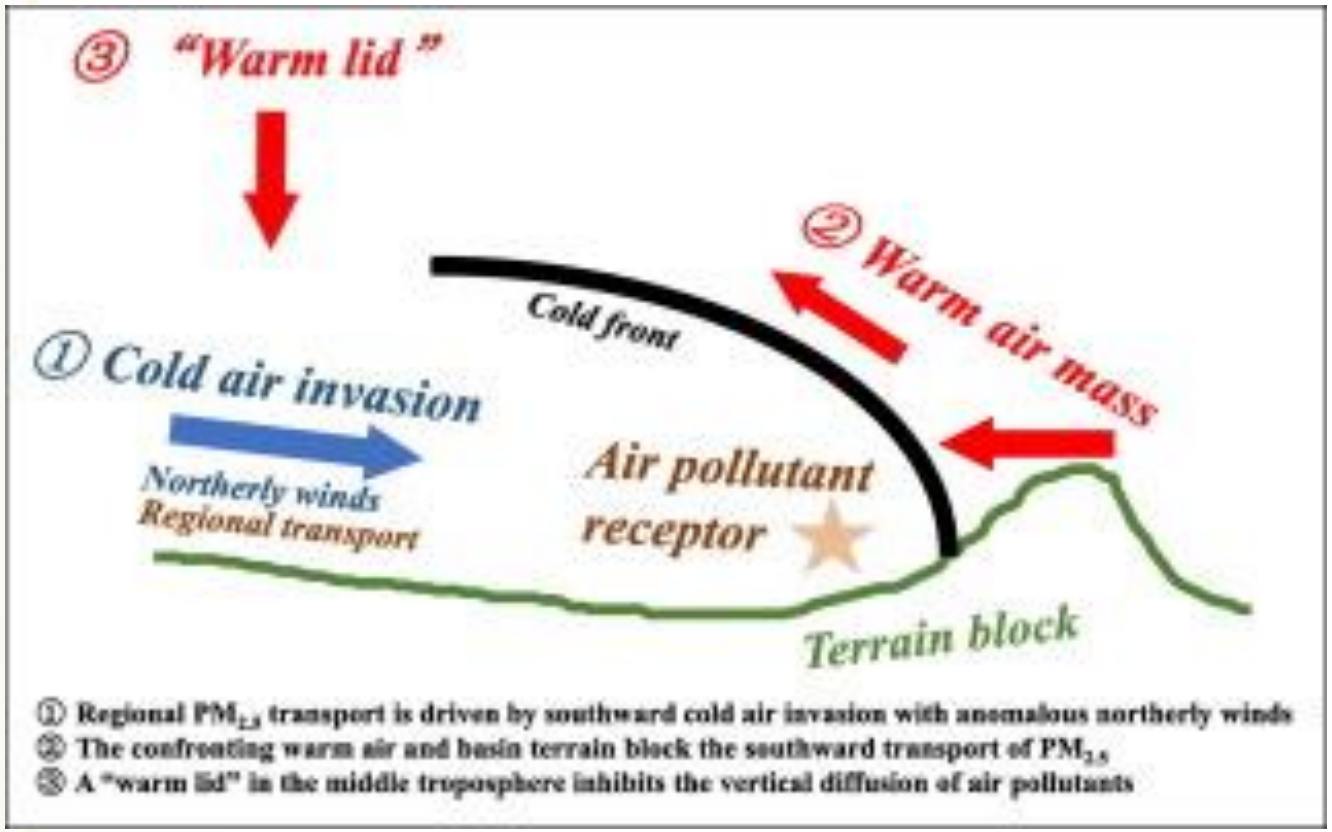
Impact of Air - Mass



- Air mass largely controls the weather condition of affected regions.




cP
Continental polar
Cold, dry
mP
Maritime polar
Cool, humid
mP
Maritime polar
Cool, humid
mT
Maritime tropical
Warm, humid
mT
Maritime tropical
Warm, humid
cT
Continental tropical
Hot, dry

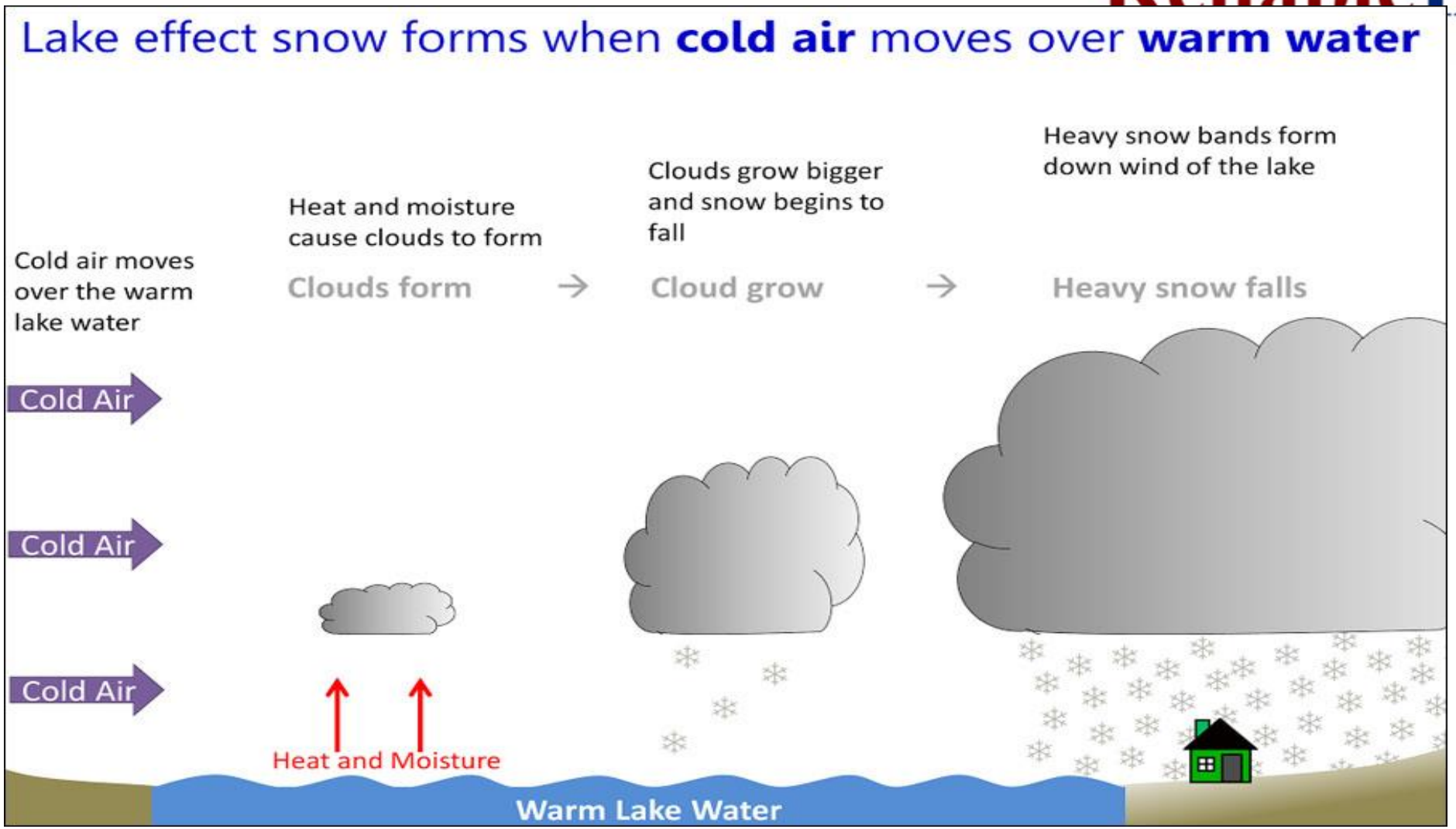


① Regional $PM_{2.5}$ transport is driven by southward cold air invasion with anomalous northerly winds
② The confronting warm air and basin terrain block the southward transport of $PM_{2.5}$
③ A "warm lid" in the middle troposphere inhibits the vertical diffusion of air pollutants

Lake-Effect Snow

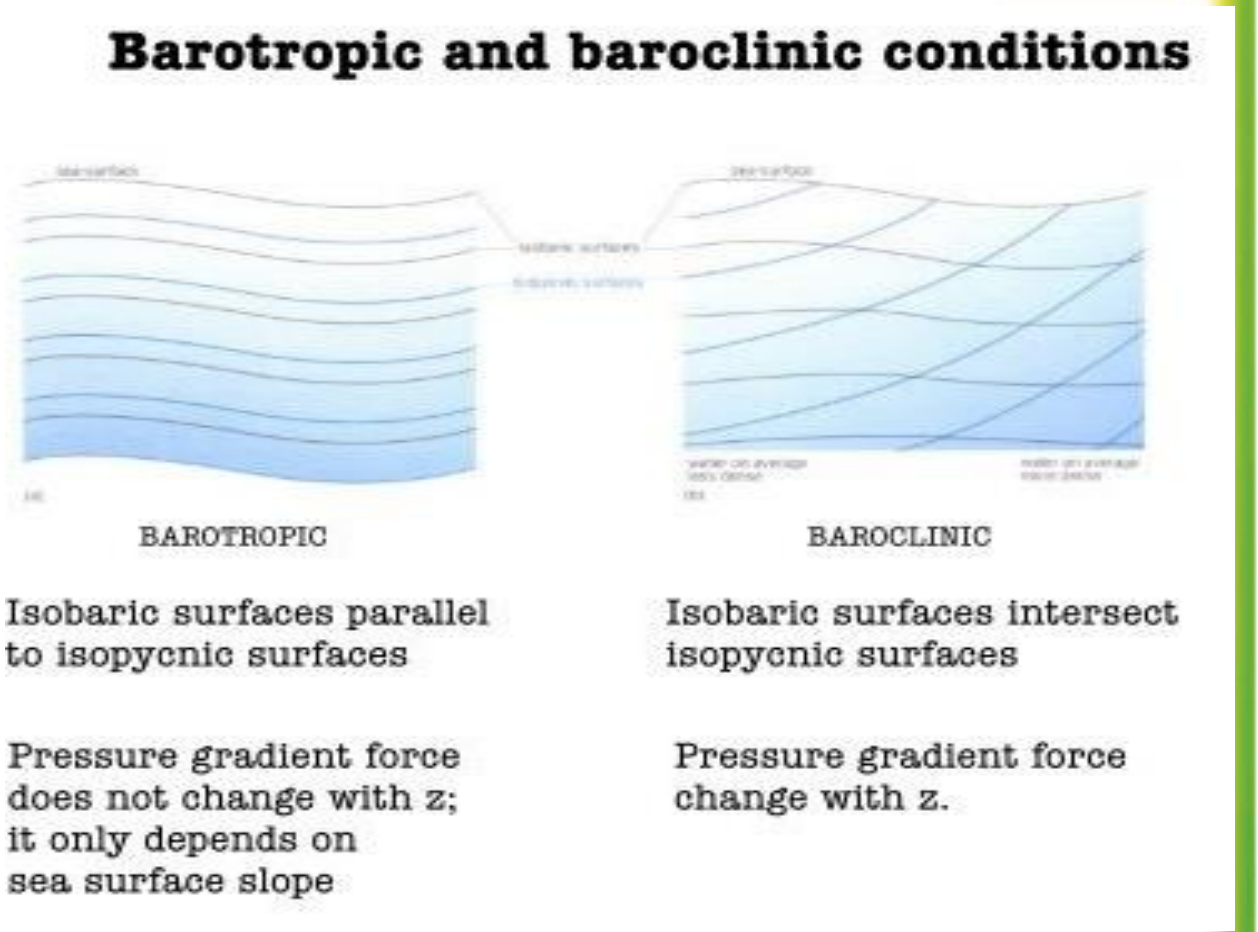
- It is a local phenomena refers to increased snow showers on the downwind side of large unfrozen lakes.
- It takes place when the water is warmer than the ground (the first half of the winter) in higher latitude region and Cold dry air is moving over the lake.
- The cold dry air is warmed up at the surface and picks up moisture. The boundary layer becomes unstable.
- Warm and moist air rises and forms cold cumulous clouds. There is a continuous supply of moisture from the lake.
- On the downwind side the air is additionally cooled and/or lifted up by topography and precipitation occurs.

Lake effect snow forms when **cold air** moves over **warm water**



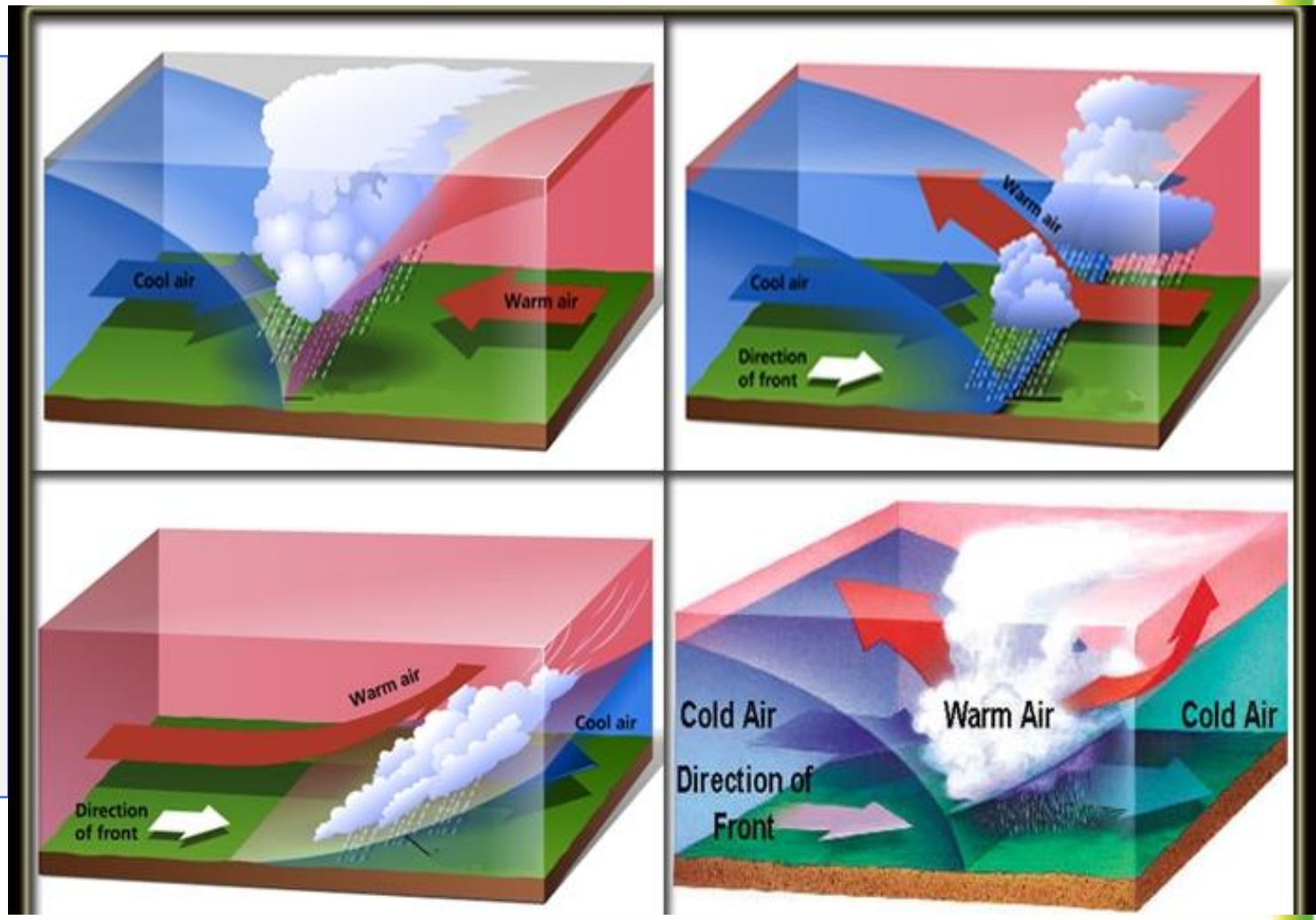
BAROCLINIC CONDITION
(unstable atmospheric condition)

- Baroclinic conditions refer to a state in the atmosphere where surfaces of constant pressure (isobars) and surfaces of constant density (isopycnals) intersect rather than being parallel.
- This misalignment creates conditions where there is a horizontal temperature gradient, which can lead to dynamic processes like the generation of vorticity and weather phenomena.
- It appears when distinct air mass in a regions exist and fronts separate warmer from colder air.



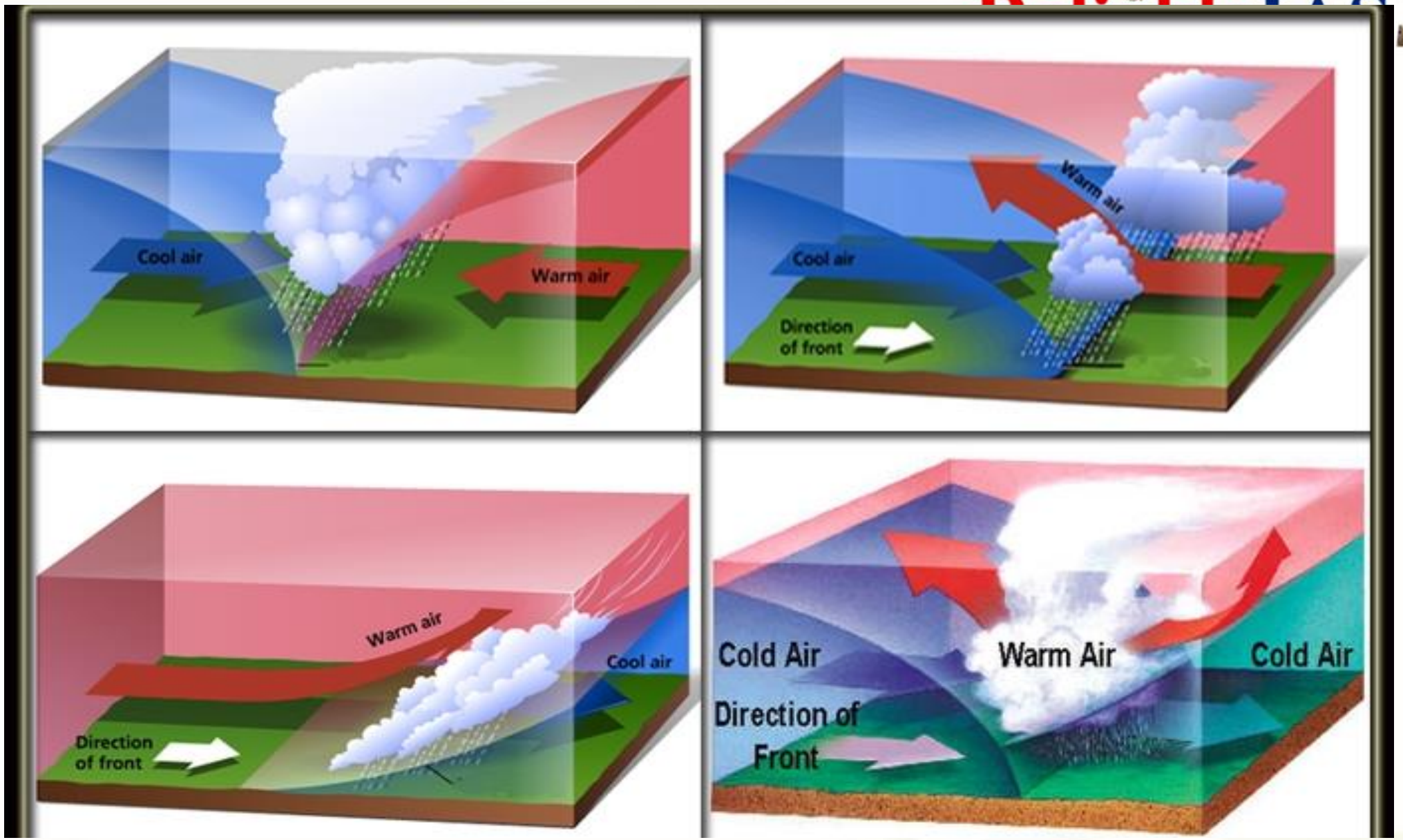
Fronts

- Front is the typical features of midlatitudes weather (temperate region – 30° - 65° N and S).
- **It is a three dimensional boundary forms between two contrasting air masses with different physical properties.**

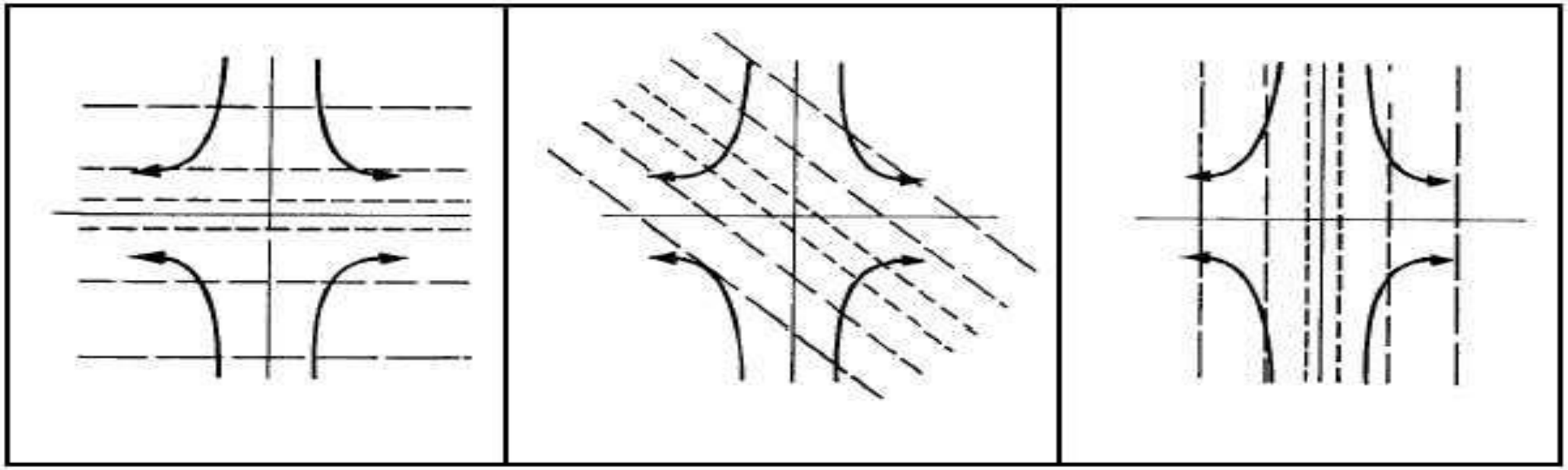


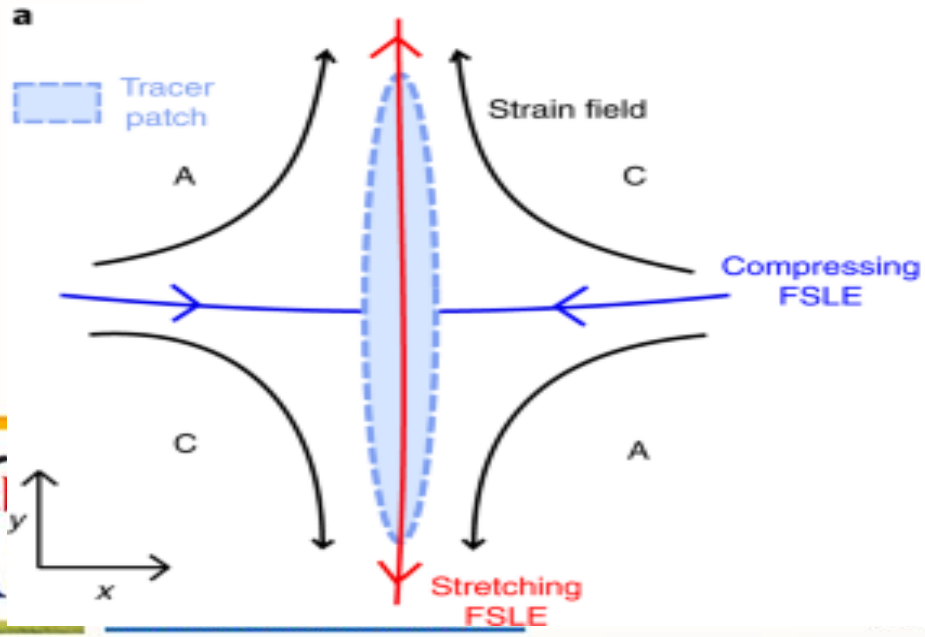
Characteristics of Fronts

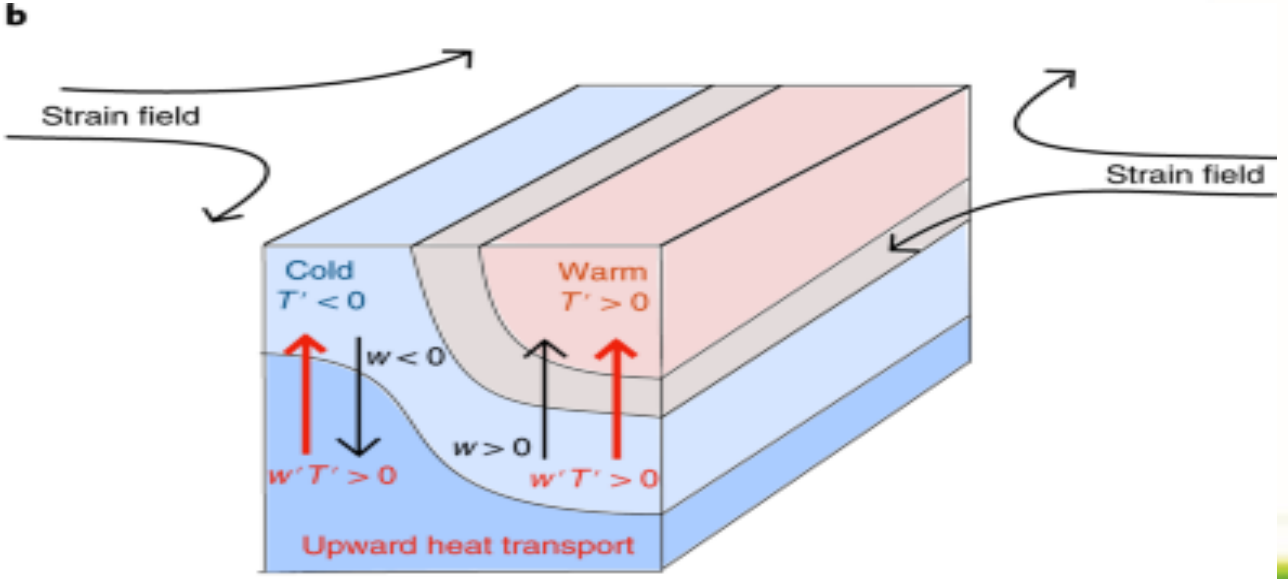
- Contrast temperature and pressure is found to both side of front.
- It is few meter thick but 12-14 km of height. Often it reaches up to tropopause.
- Front are not vertical but some short of slant toward earth slope.
- Frontal area is marked with cloudiness and calm but adjacent area witness weather difference.
- Instead of stationary front travels steadily.


Cool air
Warm air
Warm air
Cool air
Direction of front
Warm air
Cool air
Direction of front
Cold Air
Warm Air
Cold Air
Direction of Front

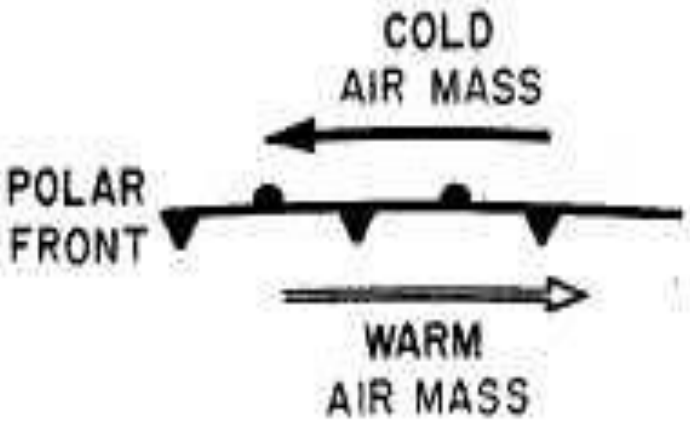
Frontogenesis & Frontolysis



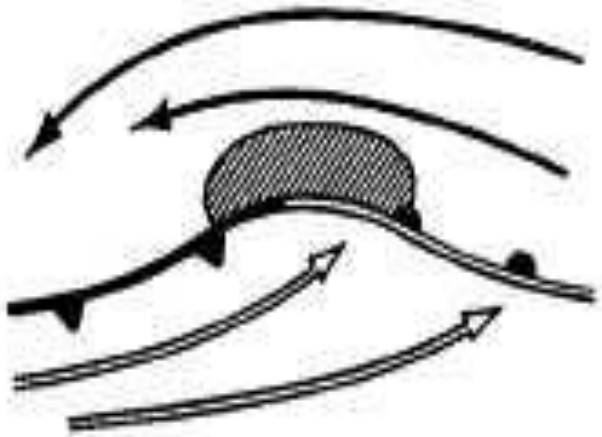




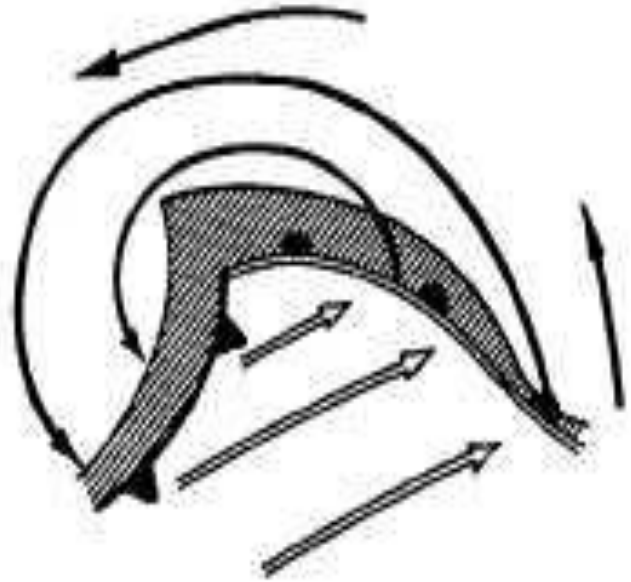
- The process of formation of a front is known as **Frontogenesis** and dissipation of a front is known as **Frontolysis.**
- **Two condition –**
  - **convergence of two distinct** air masses from different direction(**Deformatry circulation of wind)**
  - Air mass with d**istinct physical properties** i.e. - temperature, humidity, density etc.
- **Frontolysis** involves overriding of one of the air mass by another.



A. Cold and warm air flow



B. Formation

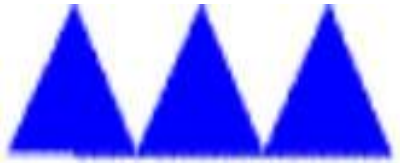


C. Typical wave

- In northern hemisphere Frontogenesis (convergence of air masses) happens in anti-clockwise direction and in southern hemisphere, clockwise direction. This is due to Coriolis effect.
- Mid-latitude cyclones or temperate cyclones or extra-tropical cyclones occur due to frontogenesis.

Classification of Fronts

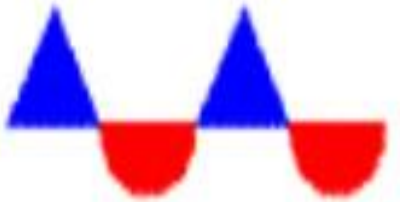
FRONT	CHART SYMBOL	DEFINITION
Cold Front		A front that moves in such a way that colder air replaces warmer air.
Warm Front		A front that moves in such a way that warmer air replaces colder air.
Stationary Front		A front which is stationary or nearly so.
Occluded Front		A composite of two fronts as a cold front overtakes a warm front or stationary front.



Cold Front

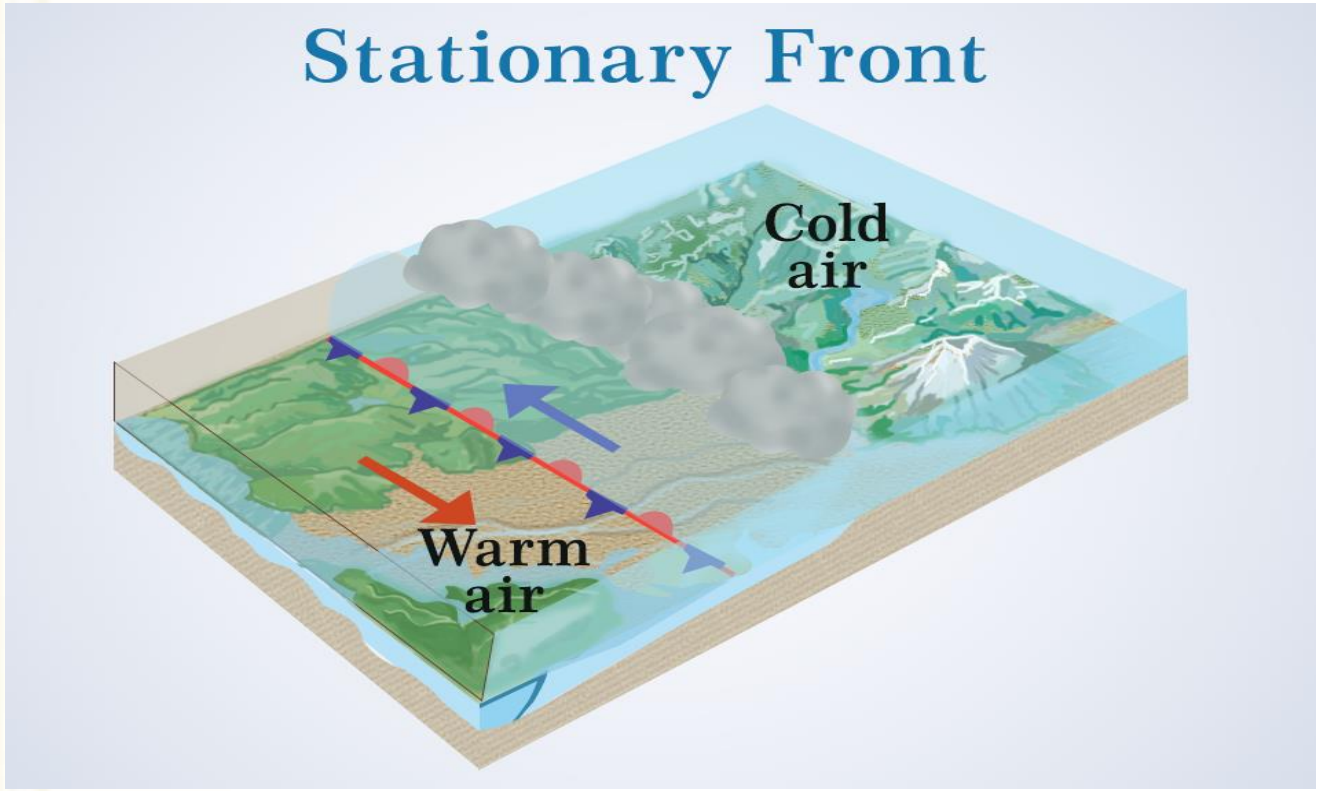
Warm Front

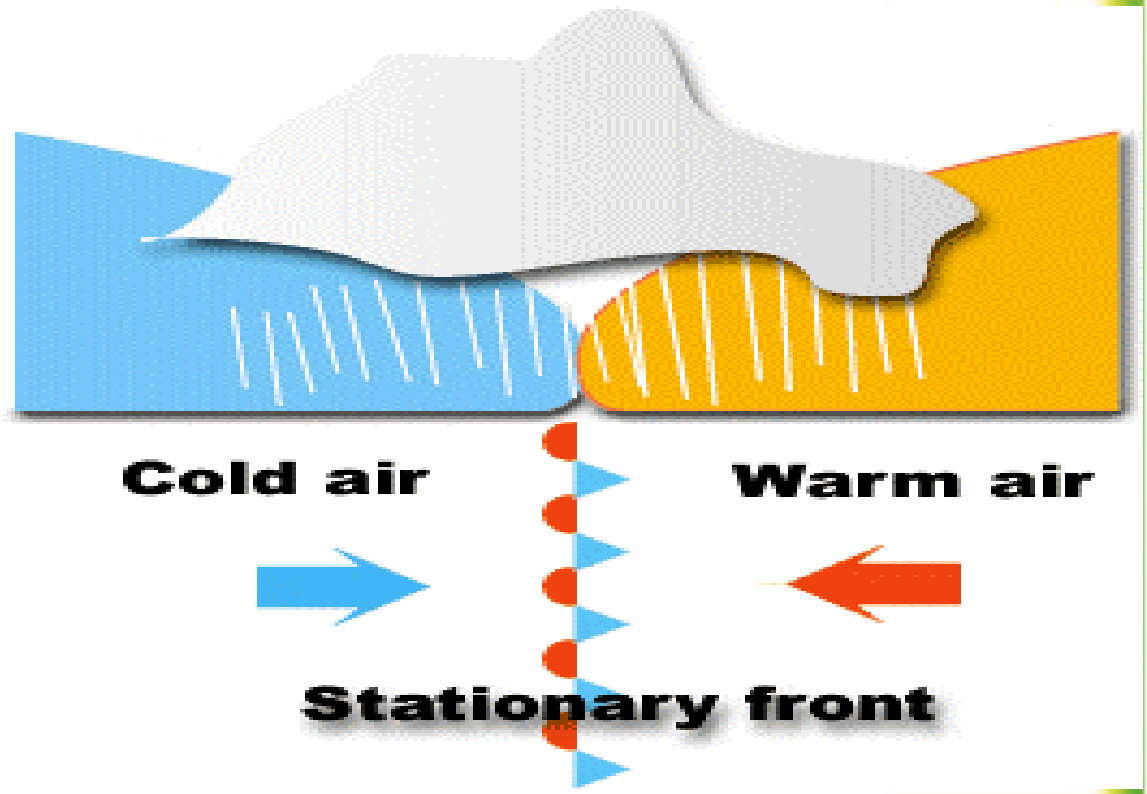
Occluded Front



Stationary Fron

1. Stationary Front

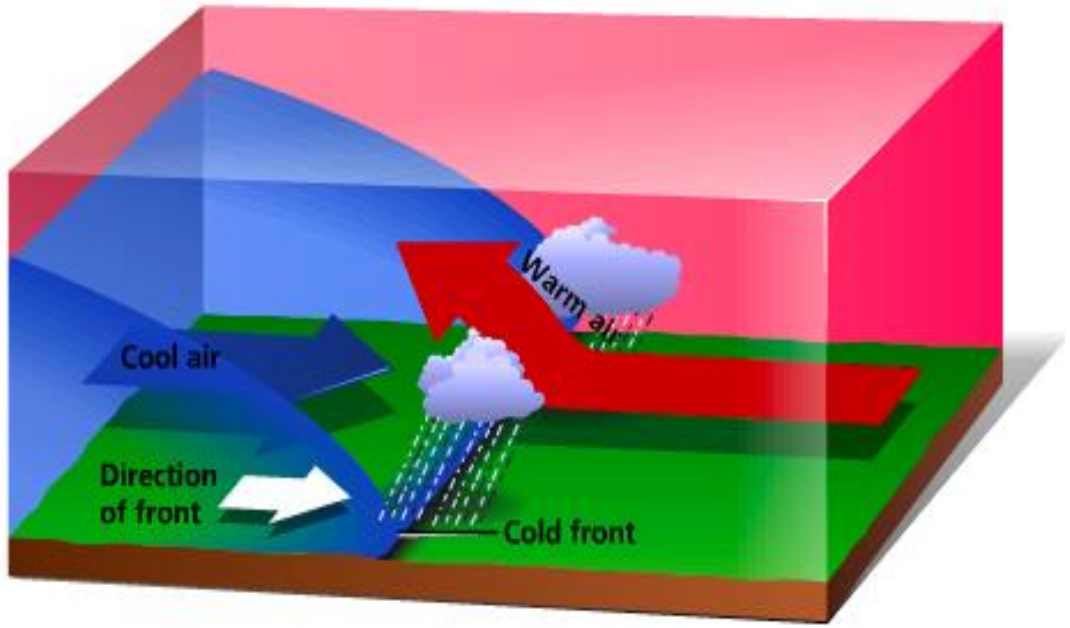


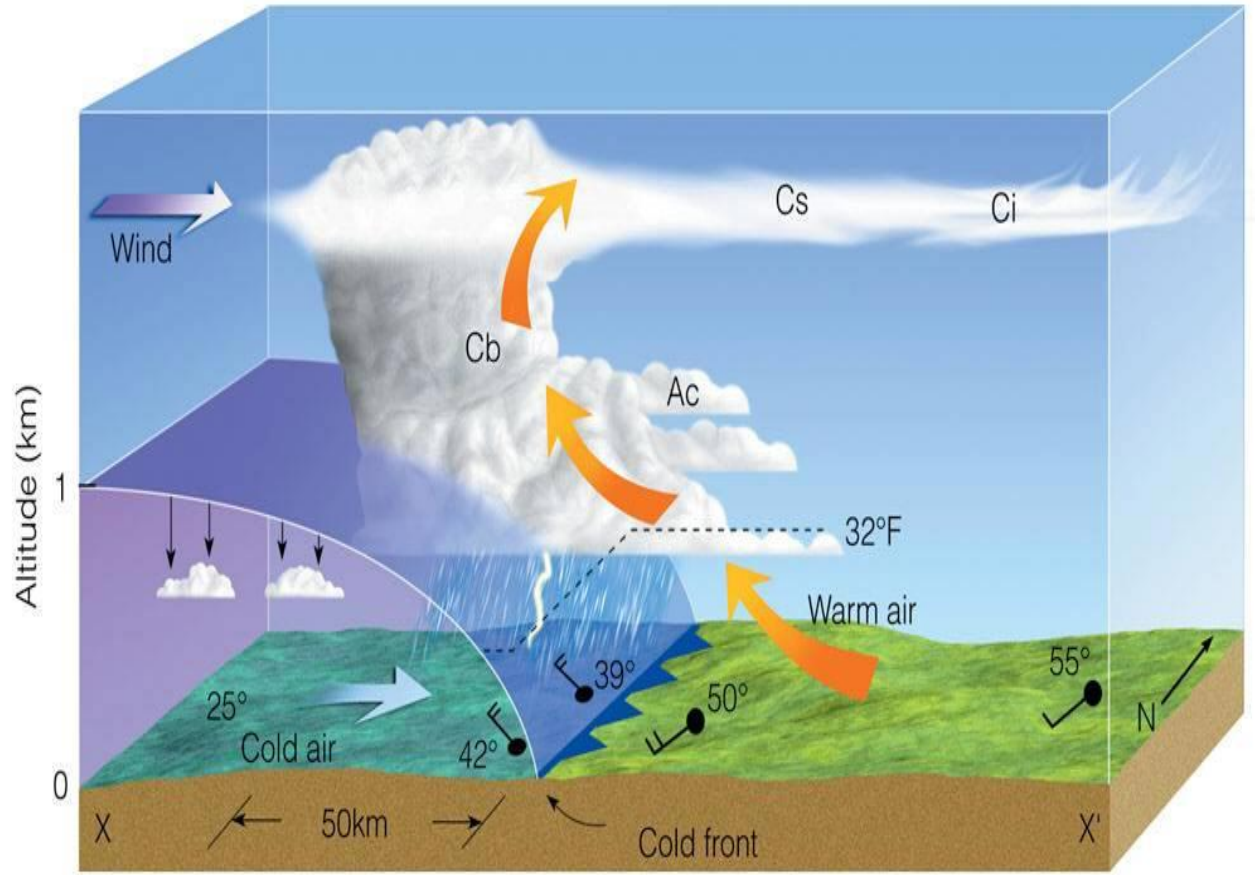


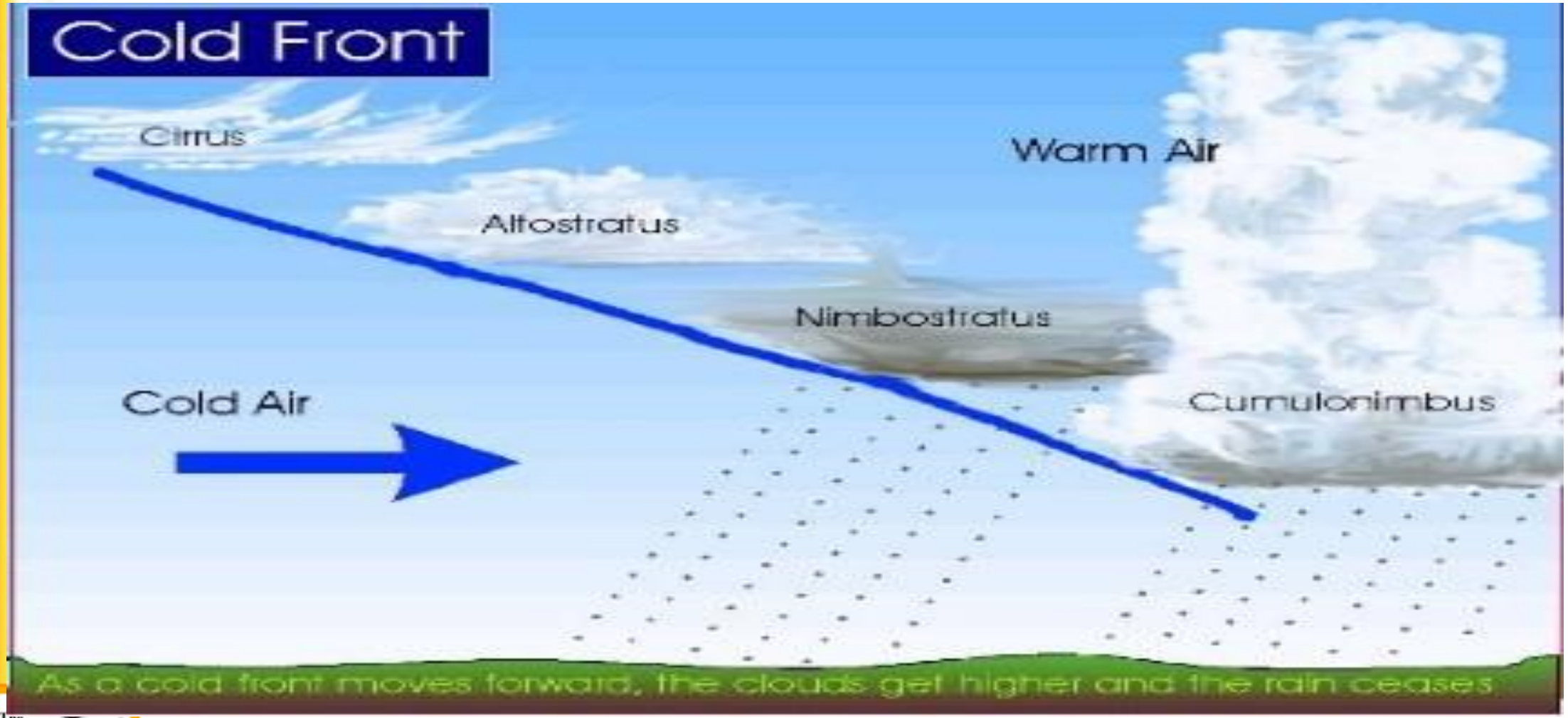
- Initially, when two contrasting air masses approaches head on direction the vertical but calm transition zone evolves, called stationary front.
- Two air masses are unable to push against each other during this condition.
- The wind moves parallel to front on both sides.
- It does not affects weather at large.

2. Cold Front

- When a cold air mass become aggressive and violent, replaces a warm air mass cold front takes places.
- The area of warm air mass during it being invaded by cold air masses.
- Vigorous cold wind causes steep slope of front.
- Warm air mass is uplifted by the cold air mass.
- With it **cirrus clouds, alto-cumulous,** altostratus and **cumulonimbus** clouds appears.
- That yields heavy downpours with thunder and lightings.
- Notably, heavy precipitation occurs within short span of time.

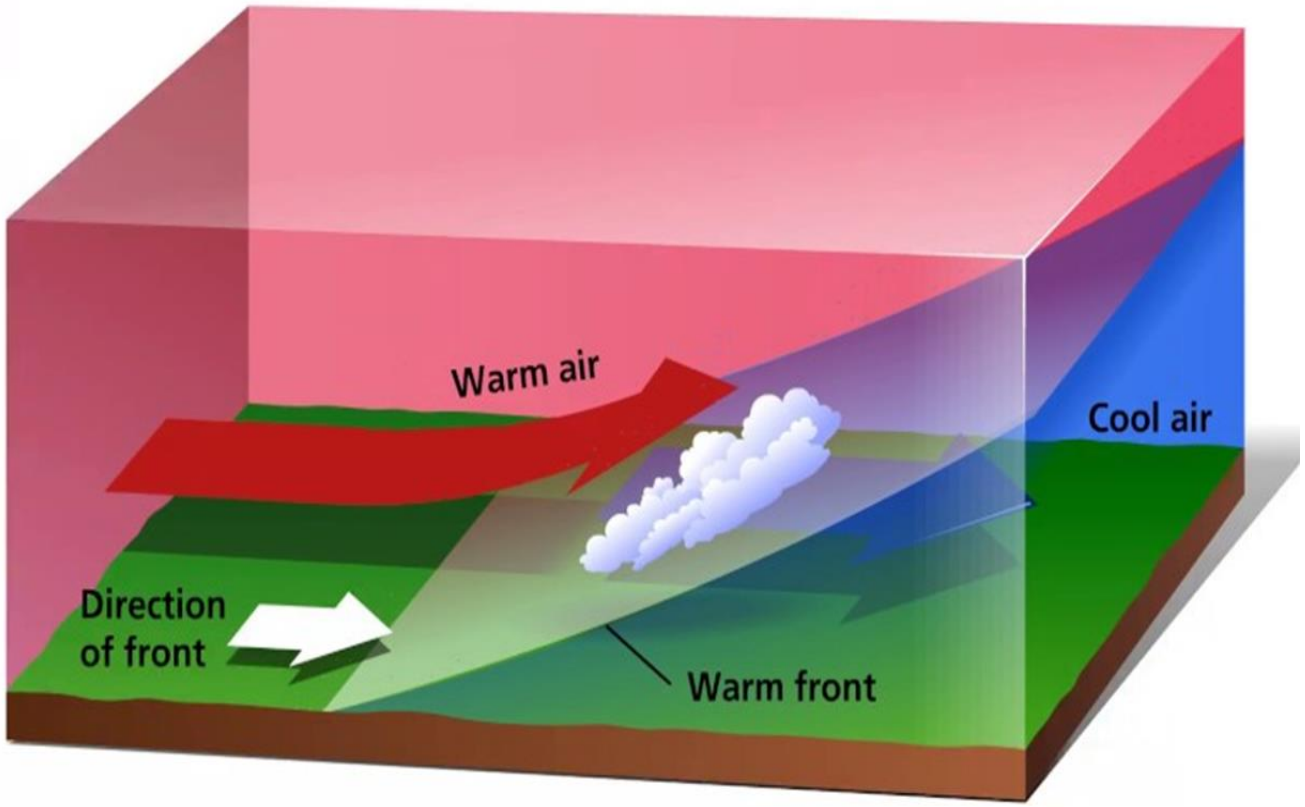


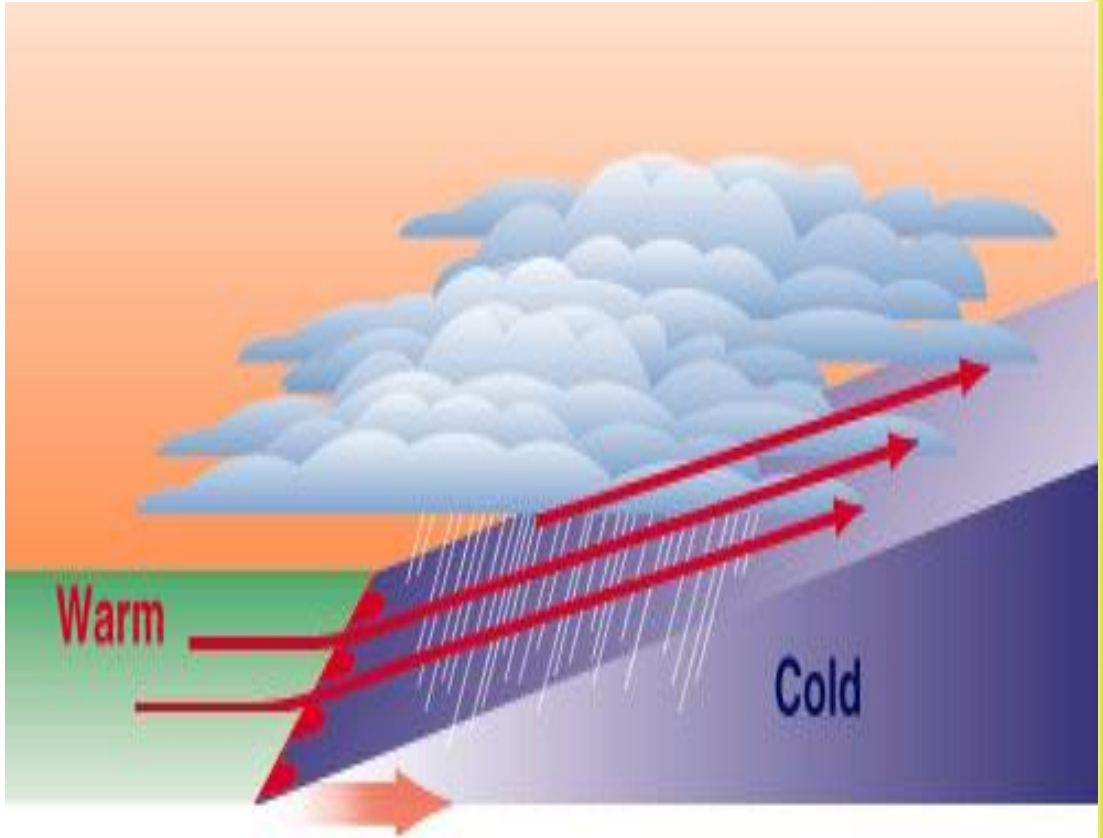


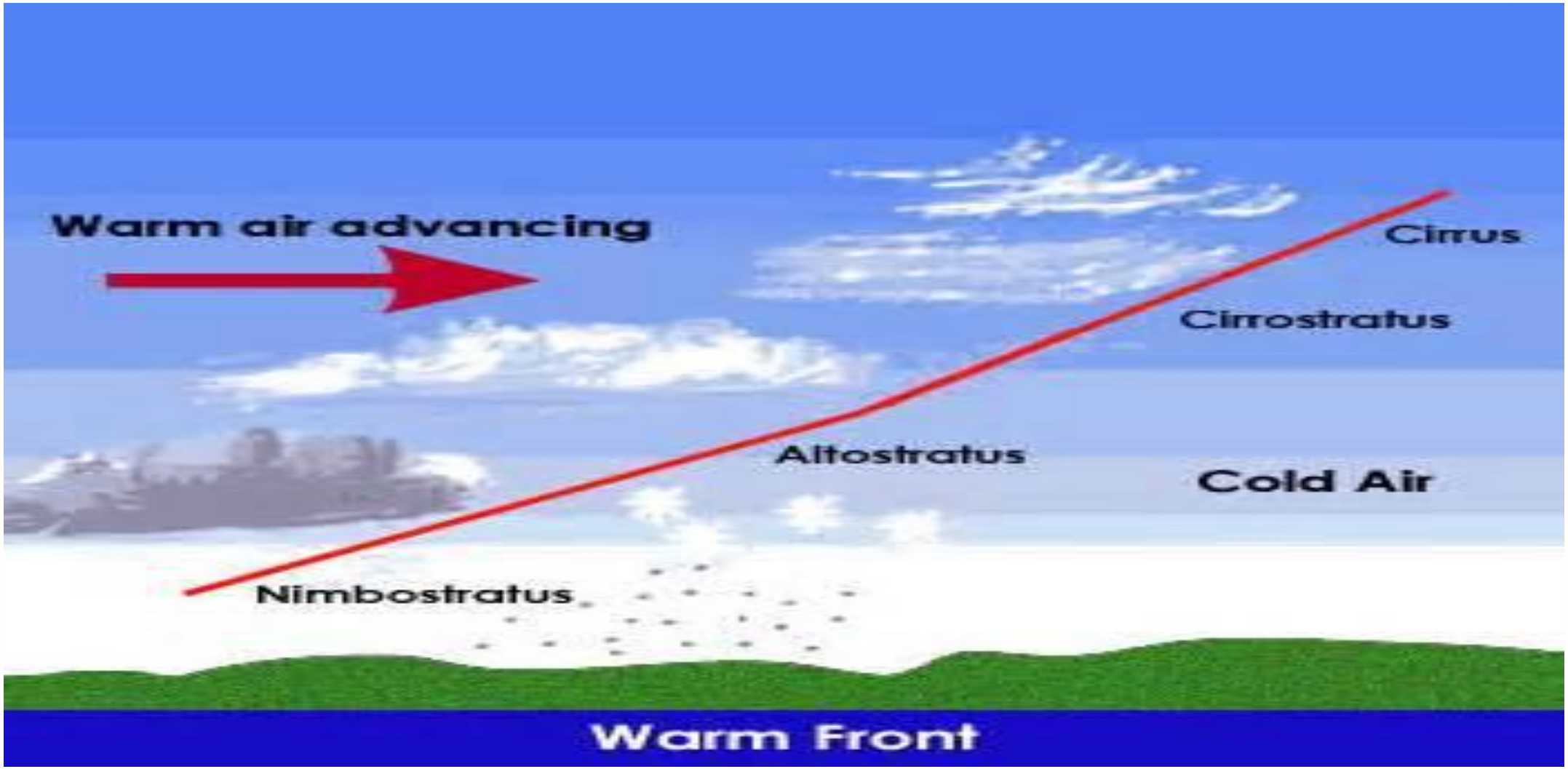

Cold Front
Cirrus
Warm Air
Altostratus
Nimbostratus
Cumulonimbus
Cold Air
As a cold front moves forward, the clouds get higher and the rain ceases

Warm Front

- When warm air mass become aggressive and dominant replaces cold air mass and gives birth to warm front.
- It forms into eastern part of temperate cyclone in northern hemisphere where westerlies wind remains vigorous.
- It marked with gentle slope.
- With the approach, the hierarchy of clouds is—-cirrus, stratus and nimbus.
- **No cumulonimbus clouds** as the gradient is gentle.
- Such fronts cause **moderate to gentle precipitation over a large area**, over several hours.


Warm air
Cool air
Direction of front
Warm front

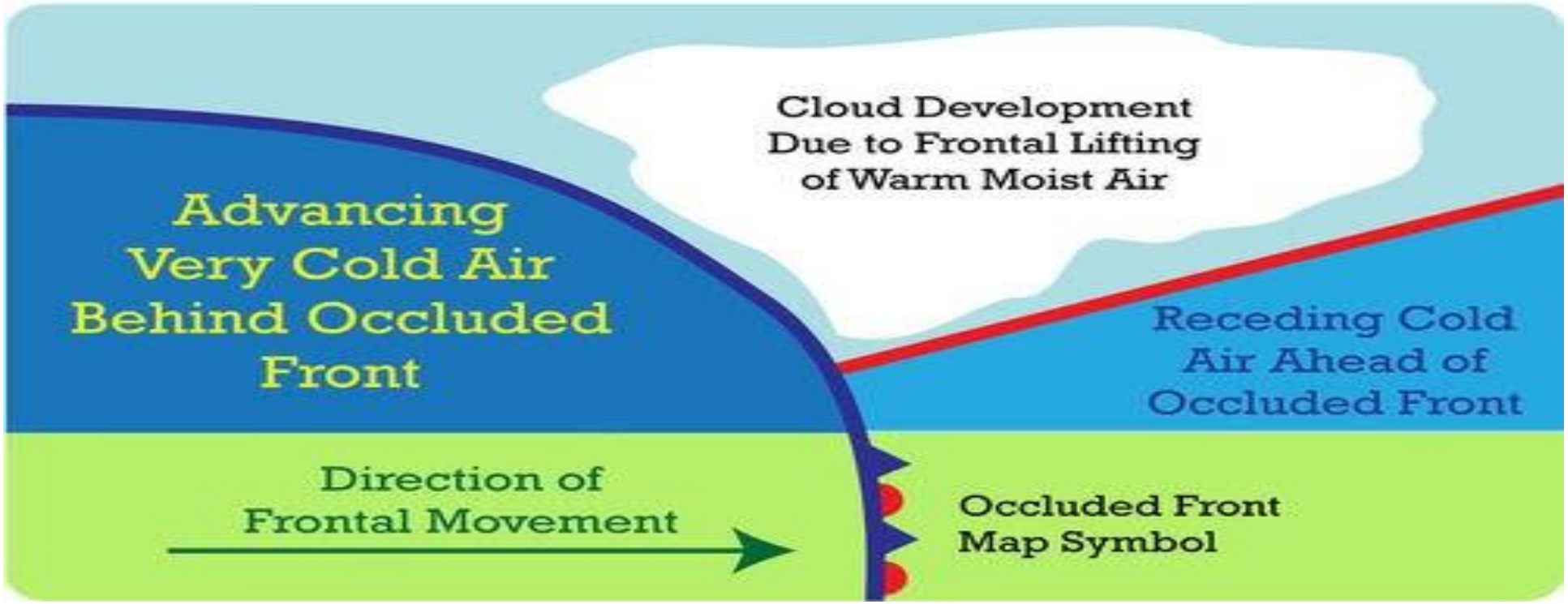

Warm
Cold

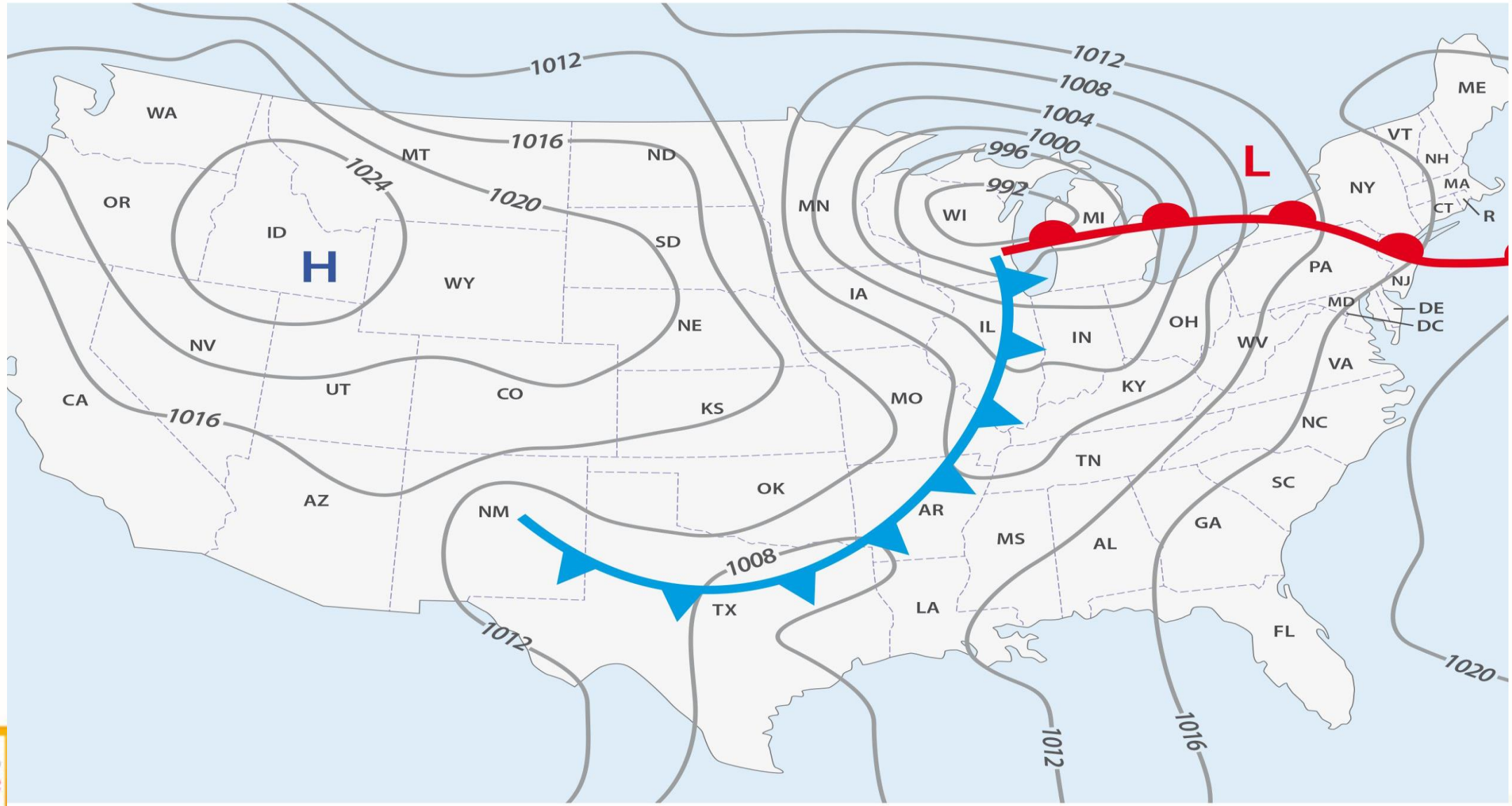

Warm air advancing
Cirrus
Cirrostratus
Altostratus
Cold Air
Nimbostratus
Warm Front

Occluded Front

- When aggressive cold airmass invades the area occupied by warm airmass and warm air mass detached from the ground surface it forms.
- Along an occluded front is complex—a mixture of cold front type and warm front type weather appears.
- Clouds of each warm and cold front is figure out during it.
- It is the indication of dissipation of temperate cyclone.

Occluded Front




1012
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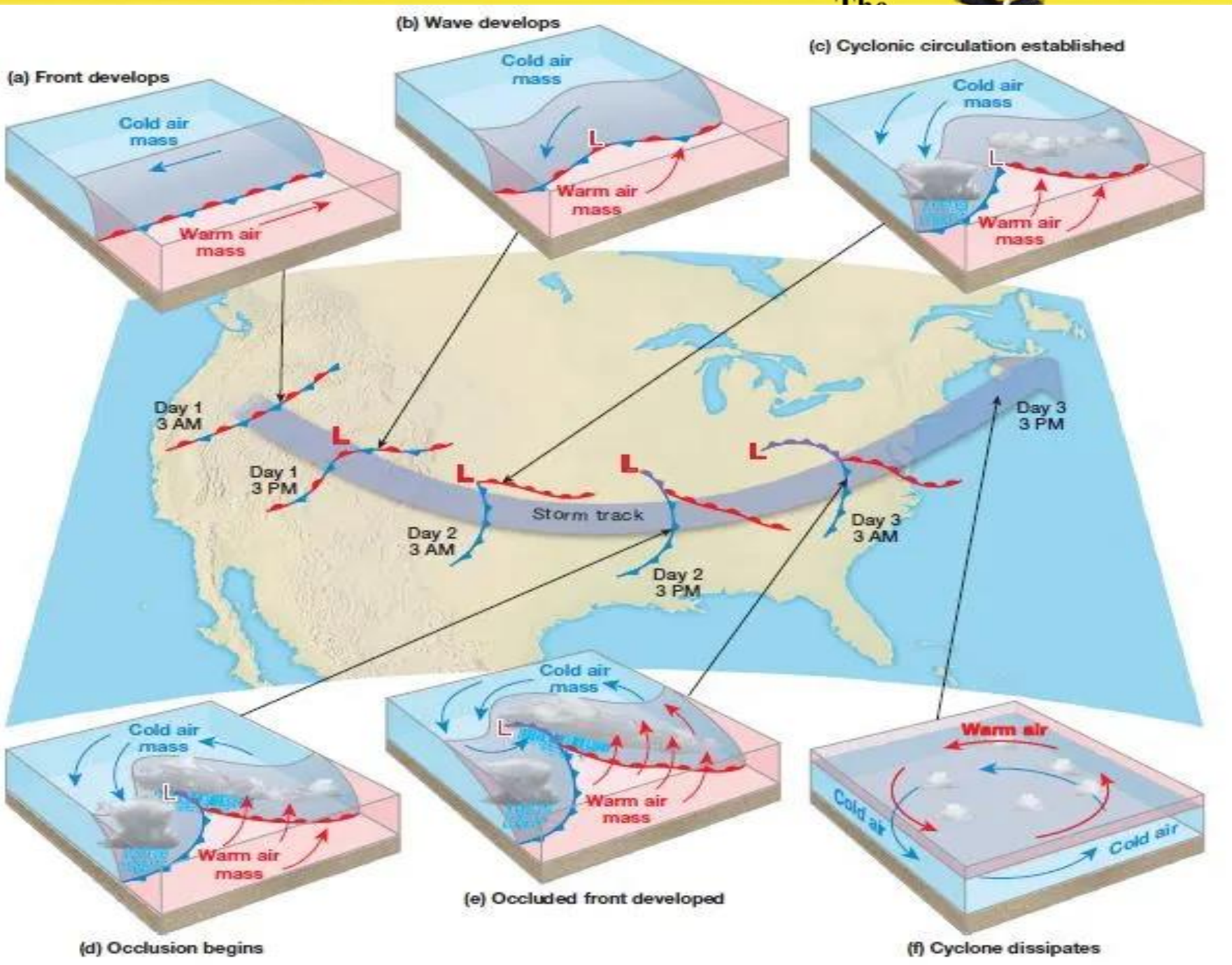
OH
WV
GA
FL
SC
NC
VA
PA
NY
MD
DE
DC
NJ
CT
R
MA
NH
VT
ME

TEMPERATE CYCLONES

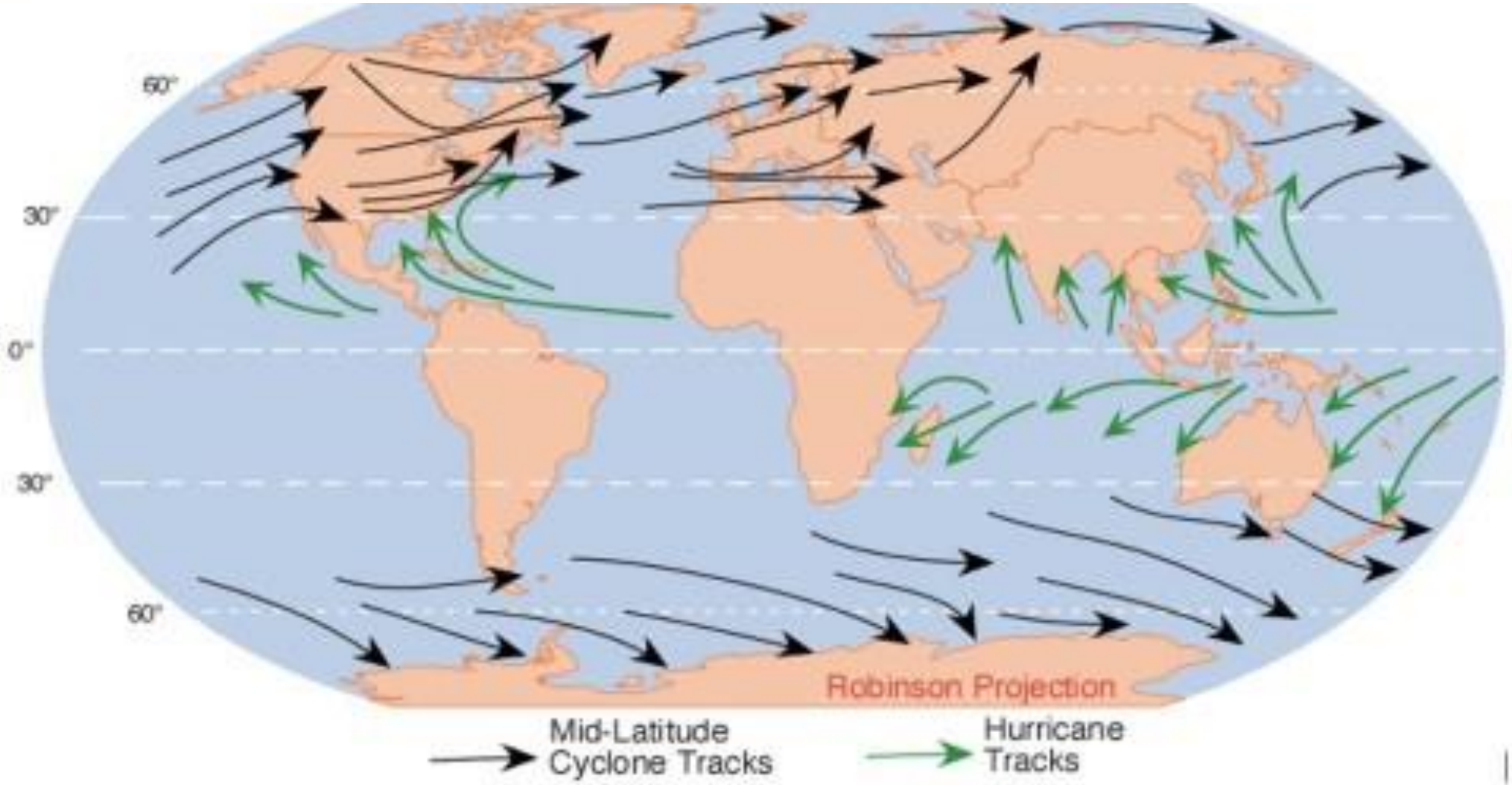
- Temperate cyclones, also called as **extratropical cyclones or wave cyclones or simply depressions**, are atmospheric disturbances having low pressure in the center and increasing pressure outward.
- They are formed in the regions extending between **35^0-65^0 latitudes in both the hemispheres due to convergence of two contrasting air masses** (warm, moist and light tropical air masses (westerly winds) and cold, and dense polar air masses.).

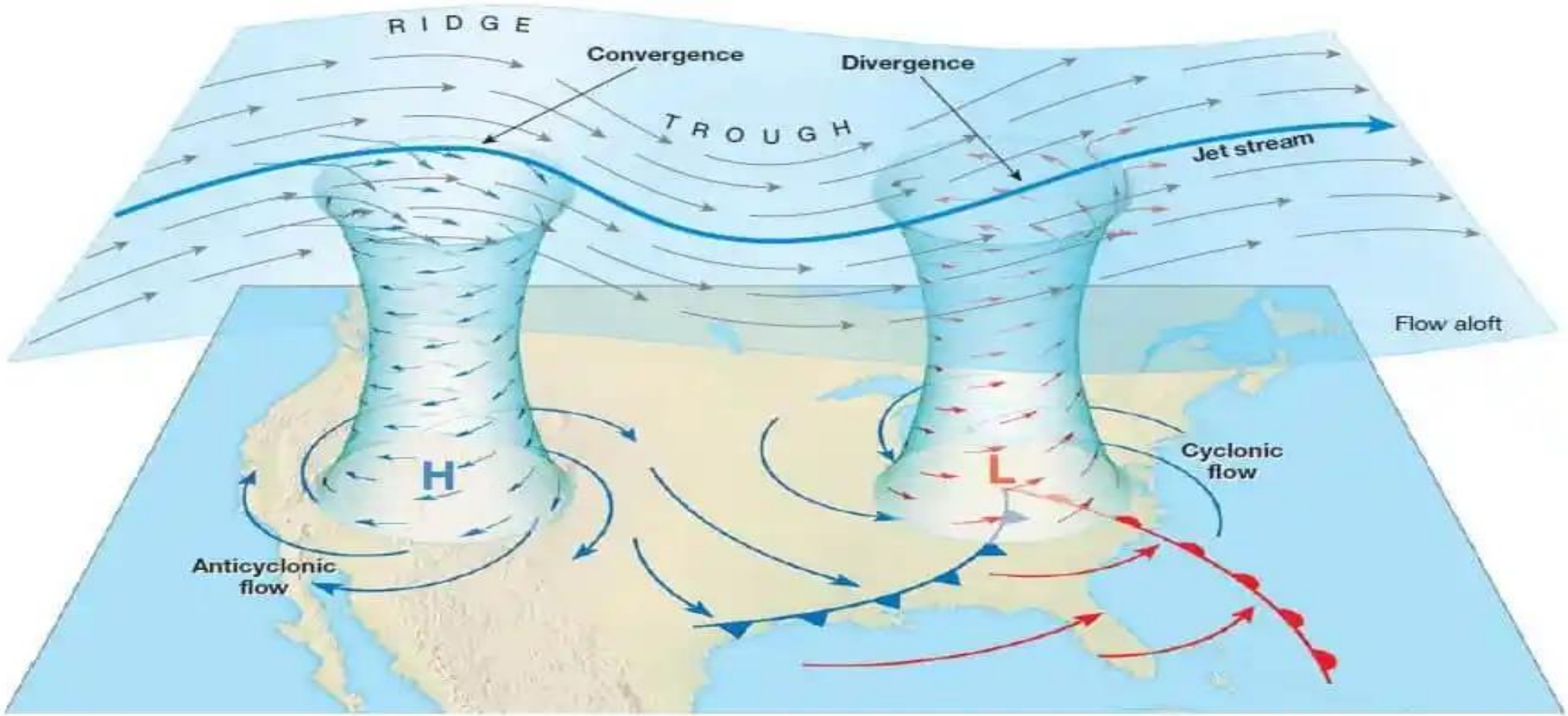
Characteristic of Temp. Cyclones

Shapes:	Temperate cyclones can assume various shapes, including circular, semi-circular, elliptical, elongated, or 'V' shaped.
Pressure difference:	Typically, the pressure disparity between the center and periphery of these cyclones ranges from 10 to 20 mb, occasionally increasing to 35 mb.
Size and coverage:	Temperate cyclones exhibit significant diversity in size, with an average large diameter of approximately 1900 km and a short diameter of 1000 km. Some can expand to cover over 1,000,000 square km.
Vertical extent:	The vertical span of these cyclones ranges from 10 to 12 km.
Movement:	Driven by westerly winds, temperate cyclones move eastward, with velocities averaging 32 km per hour in summers and 48 km per hour in winters.

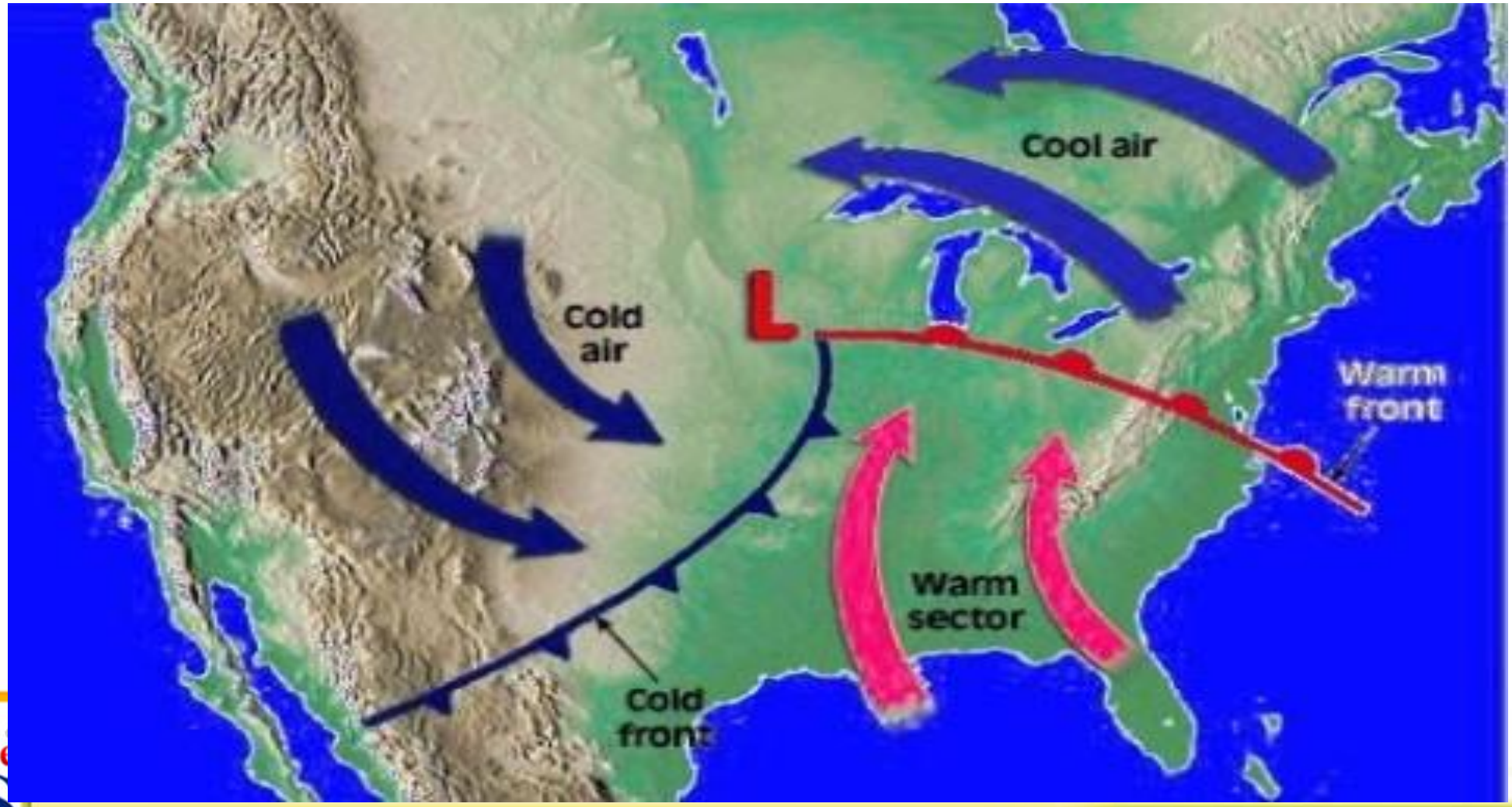


Trajectories:	The paths followed by temperate cyclones are known as 'storm tracks'.
Wind direction:	In the northern hemisphere, wind direction within these cyclones is anticlockwise, while in the southern hemisphere, it is clockwise.
Temperature variations:	Different temperature zones exist within temperate cyclones due to the convergence of warm and cold air masses. The southern region tends to be warmer, while the northern and western regions experience lower temperatures.
Influence of jet streams:	Jet streams also affect the trajectory of temperate cyclones. Since these cyclones move with the westerlies (Jet Streams), they are oriented east-west.
Wind shift line:	Significant changes in wind direction occur along the warm and cold fronts, marked by the wind shift line.


60°
30°
0°
30°
60°
Robinson Projection
Mid-Latitude Cyclone Tracks
Hurricane Tracks


RIDGE
Convergence
Divergence
TROUGH
Jet stream
Flow aloft
H
L
Cyclonic flow
Anticyclonic flow

Weather Conditions Associated With Temperate Cyclones

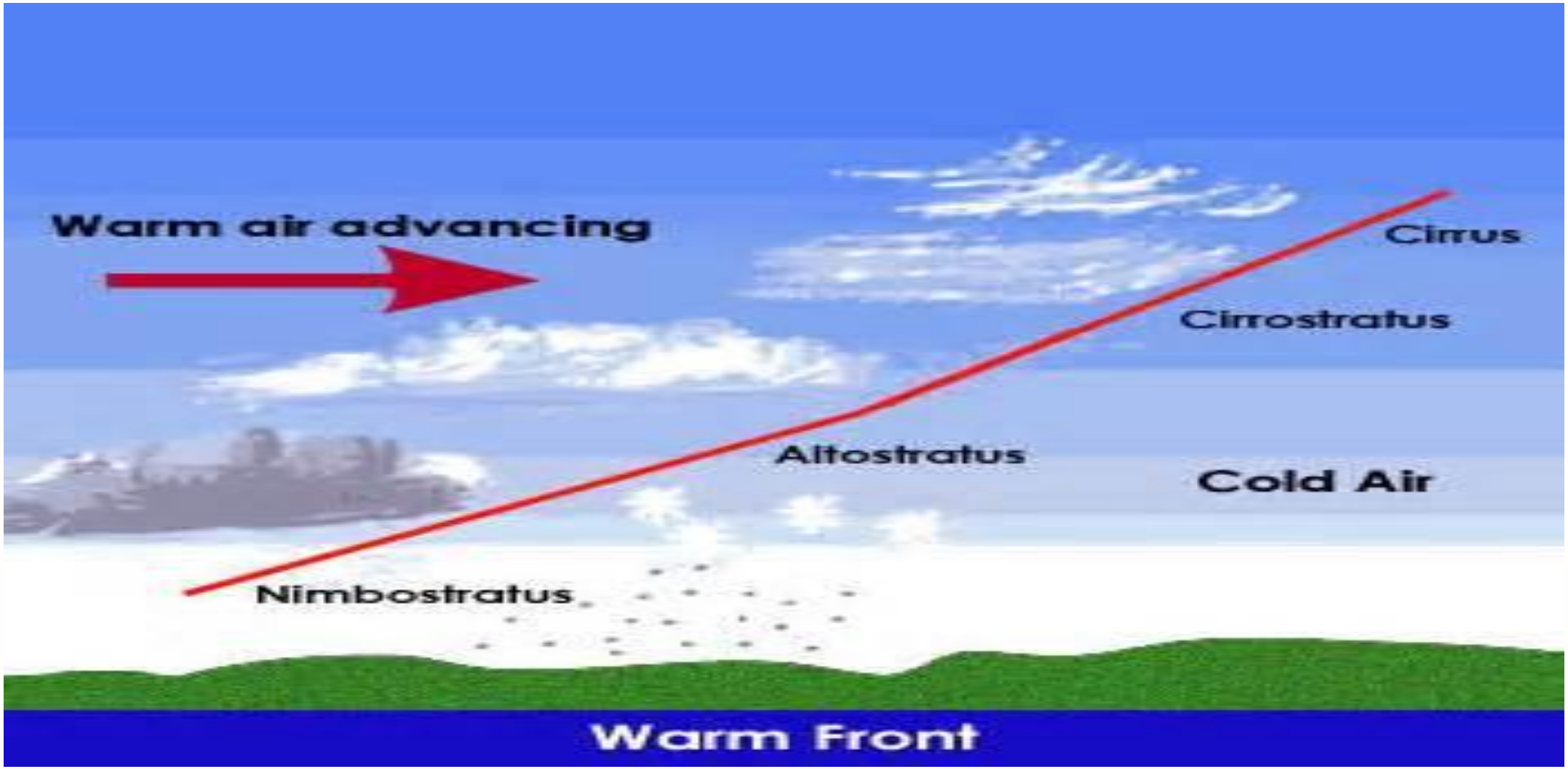


1. Arrival of cyclone :

- When the cyclone coming from the western direction wind velocity slows down considerably and air pressure decreases .
- The sun and the moon are encircled by halo due to cirrostratus clouds.
- Temperature suddenly increases when the cyclone comes very close to the observation point.
- Wind direction, also Changes from easterly to south-easterly,.
- With approaching cyclone the cloud gets thicker and the sky becomes overcast With dark, thick and low clouds, mainly **nimbostratus clouds**.

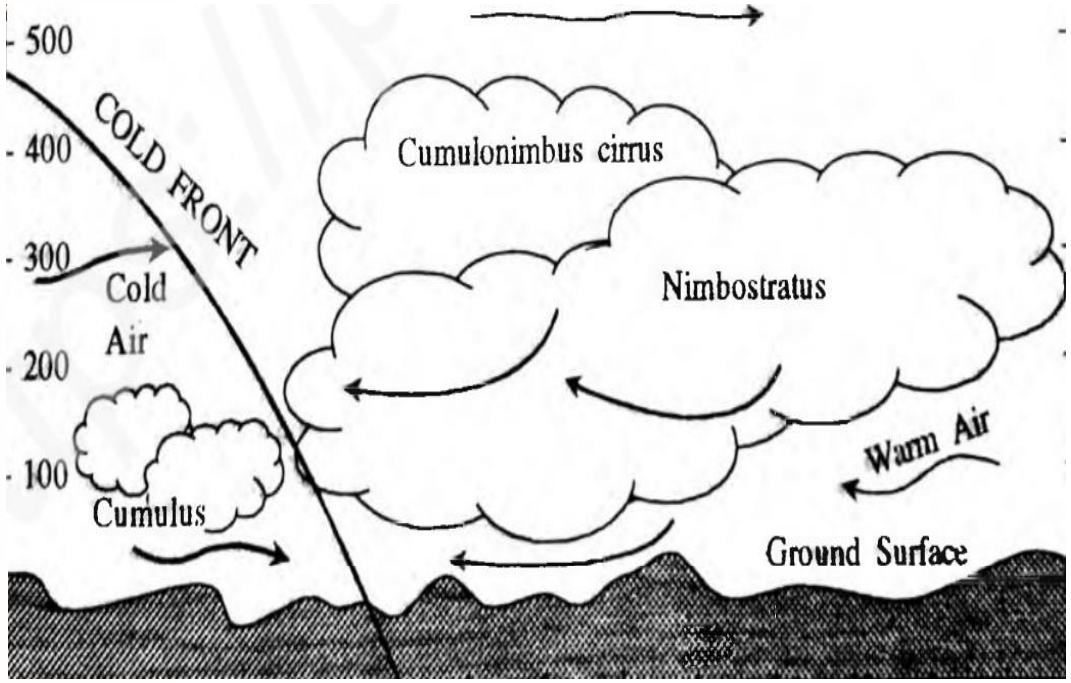
(2) Warm Frontal Precipitation :

- Clouds become very thick and dark with the arrival of warm front of the cyclone and heavy shower begins with nimbostratus clouds.
- Since the warm air rises slowly along the front, and hence the precipitation is slow, gradual but of long duration.
- The warm frontal precipitation largely depends on the amount of moisture and instability of the rising warm air.


Warm air advancing
Cirrus
Cirrostratus
Altostratus
Cold Air
Nimbostratus
Warm Front

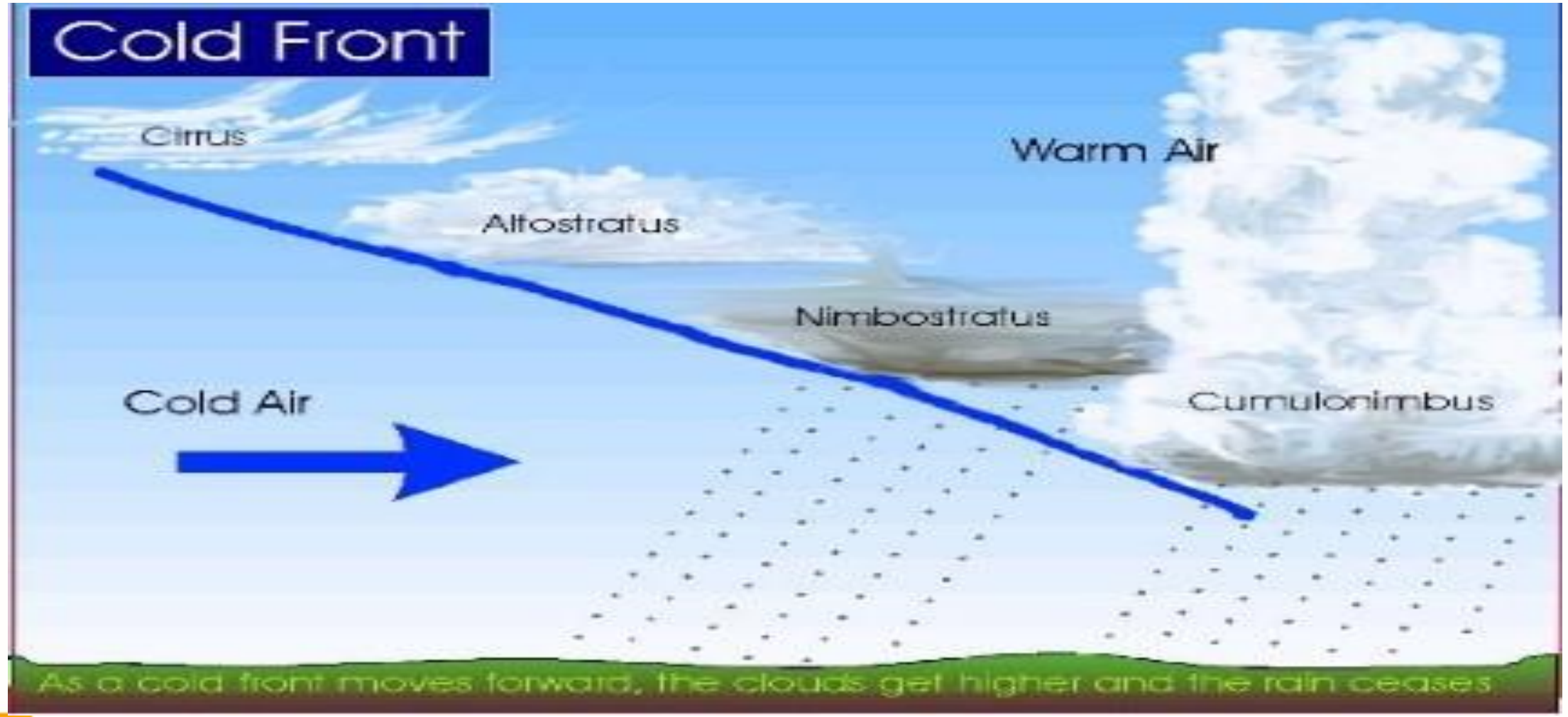
(3) Warm Sector :

- The warm sector comes over the observation point after the passage of warm front, and there is sudden change in the preexisting weather condition.
- The wind direction southerly and southwesterly.
- The sky becomes cloudless and clear.



(iv)Cold front :

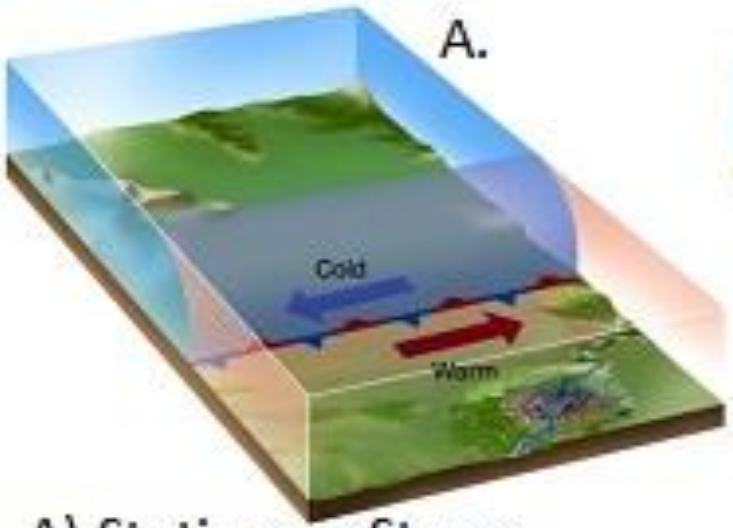
- Temperature registers marked decrease with the arrival of cold from thus Cold increases considerably.
- The cold air pushes the warm air upward and there is change in wind direction from southerly to south-westerly and westerly.
- Sky is again covered with clouds which soon start precipitation.
- Sky becomes overcast with **cumulonimbus clouds** yield heavy showers.
- Since the warm air is forcibly lifted upward hurriedly, the cold frontal precipitation is in the form of heavy downpour with thunder and lightning but the precipitation is of short and less widespread sector is very close.


Cold Front
Cirrus
Warm Air
Altostratus
Nimbostratus
Cumulonimbus
Cold Air
As a cold front moves forward, the clouds get higher and the rain ceases

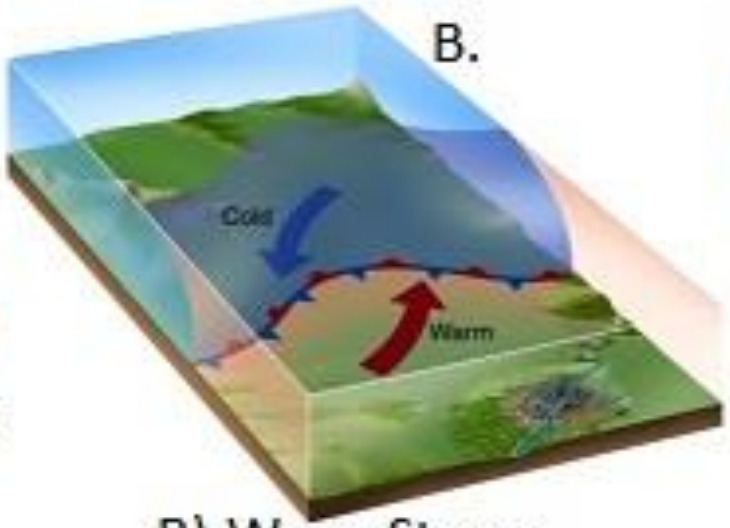
(V) Cold Sector :

- Weather again changes remarkably with the passage of cold front and arrival of cold sector.
- Sky becomes cloudless and hence clear. There is sharp fall in air temperature and considerable rise in air pressure but decrease in specific humidity.

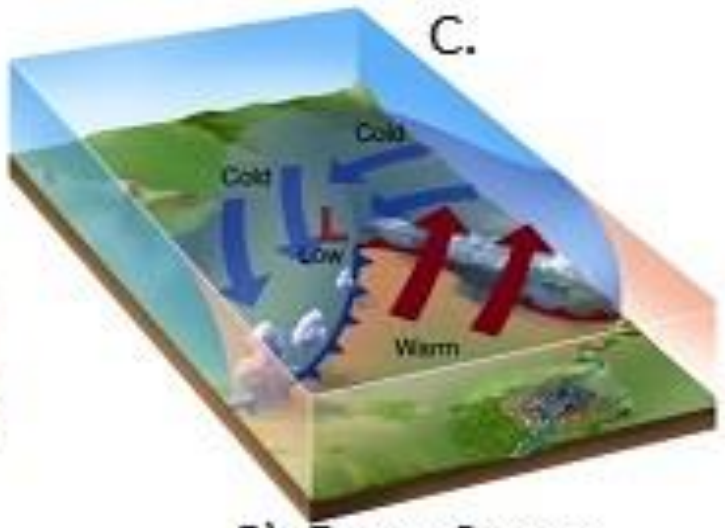
Origin of Temperate Cyclones



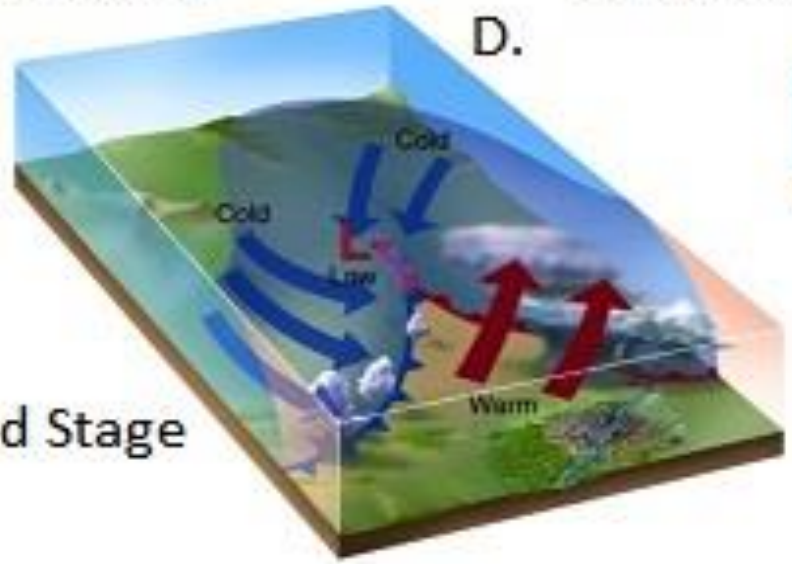
A) Stationary Stage



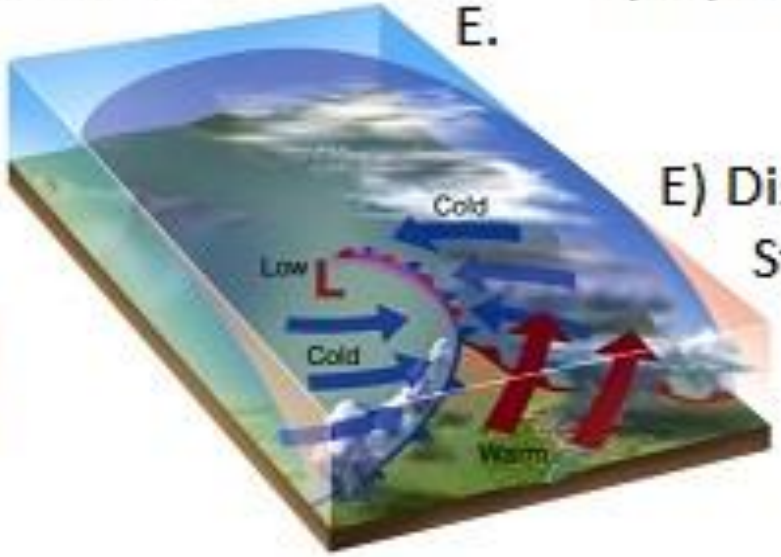
B) Wave Stage



C) Open Stage



D) Occluded Stage



E) Dissipation Stage

- **Polar front theory / 'frontal theory' / 'wave theory' / Bergen theory : - propounded by V. Bjerknes and J. Bjerknes in 1918**

1. First stage (Stationary stage)

- It involves the convergence of two air masses of contrasting physical properties and directions.
- The air masses (warm and cold) move parallel to each other and a **stationary front** is formed. The stable front remains in equilibrium state.

2. Second stage (wave stage)

- During which the warm and cold air masses penetrate into the territories of each other.
- Thus a wave-like front is formed. This is unstable front.

3. **Third stage (mature stage)**

- when the cyclone is fully developed and isobars become almost circular.
- Warm and cold fronts are fully developed

4. Forth stage(occlusion stage)

- It starts with the occlusion of cyclone.
- when the advancing cold front finally overtakes the warm front and occluded front is formed.

5.Fifth stage (Dissipation stage)

- warm sector completely disappears, occluded front is eliminated and ultimately cyclone dies out.

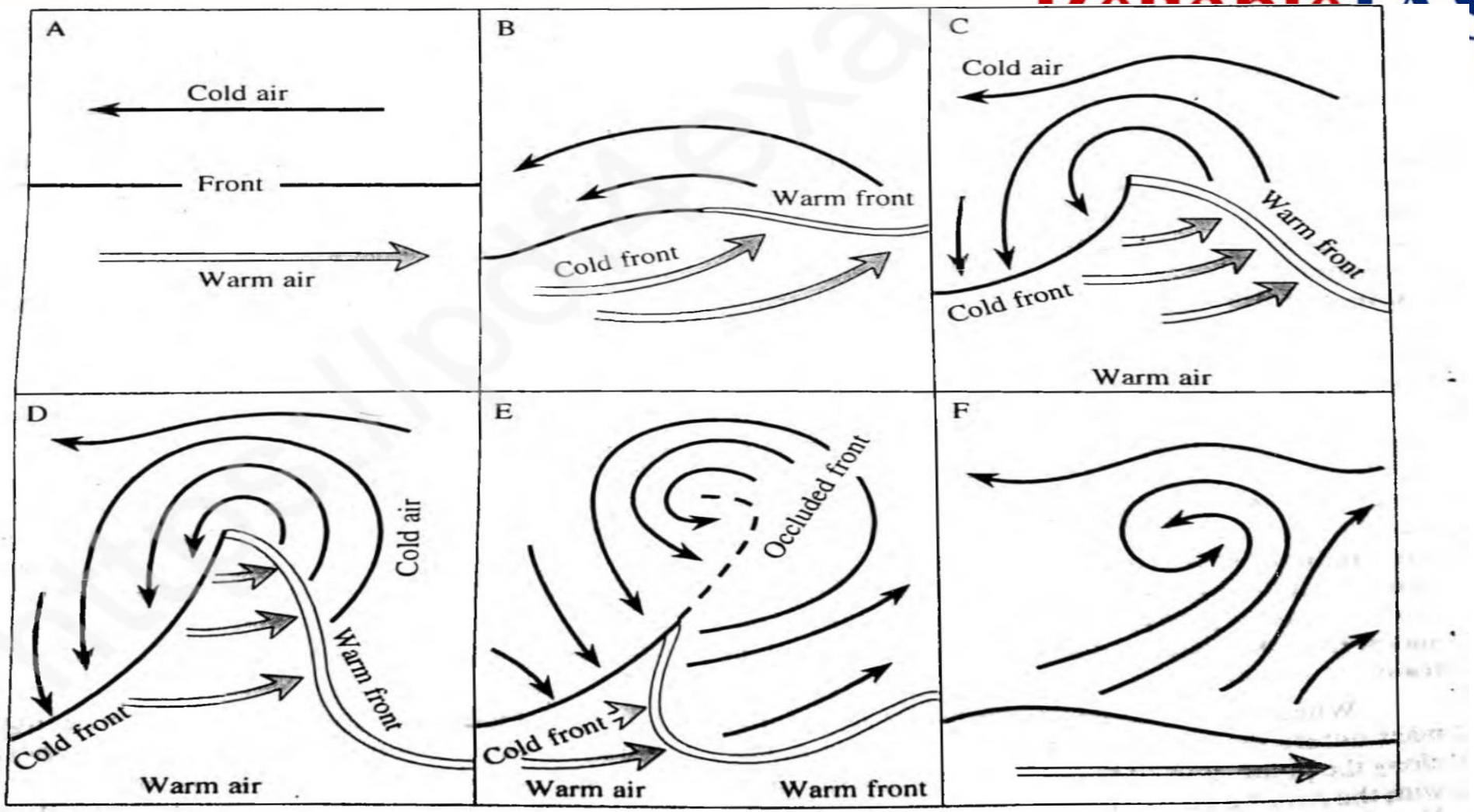


Fig. 11.12 : Stages of life-cycle of a cyclone.

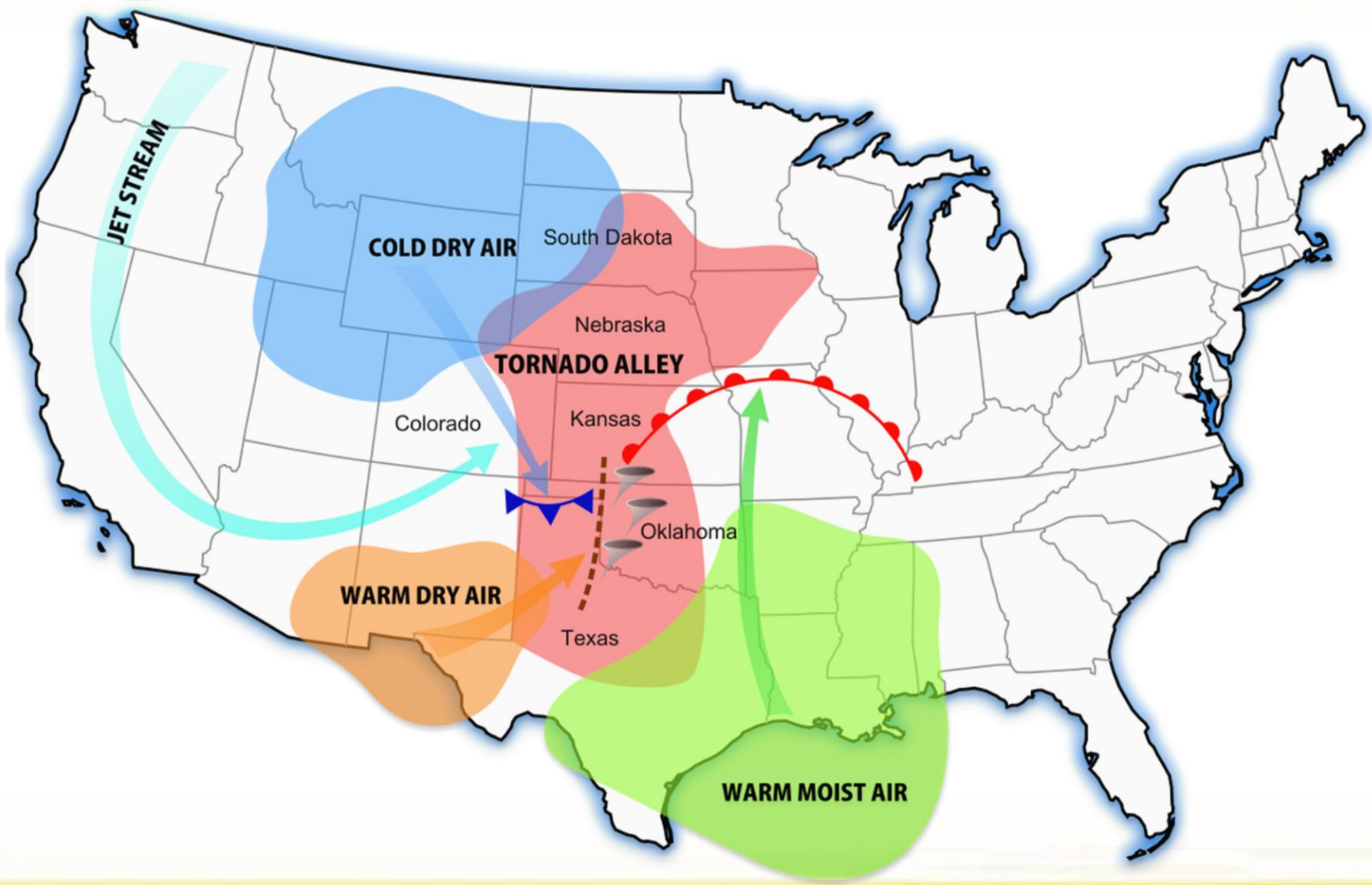
TORNADO

- Tornadoes are **funnel shaped storms** often touches the ground surface.
- Tornadoes are **smallest but most violent and disastrous atmospheric storms.**
- Tornadoes are **violently rotating columns of air** having upper portion of funnel shape of cumulonimbus clouds which are attached to the ground by very narrow column of air.

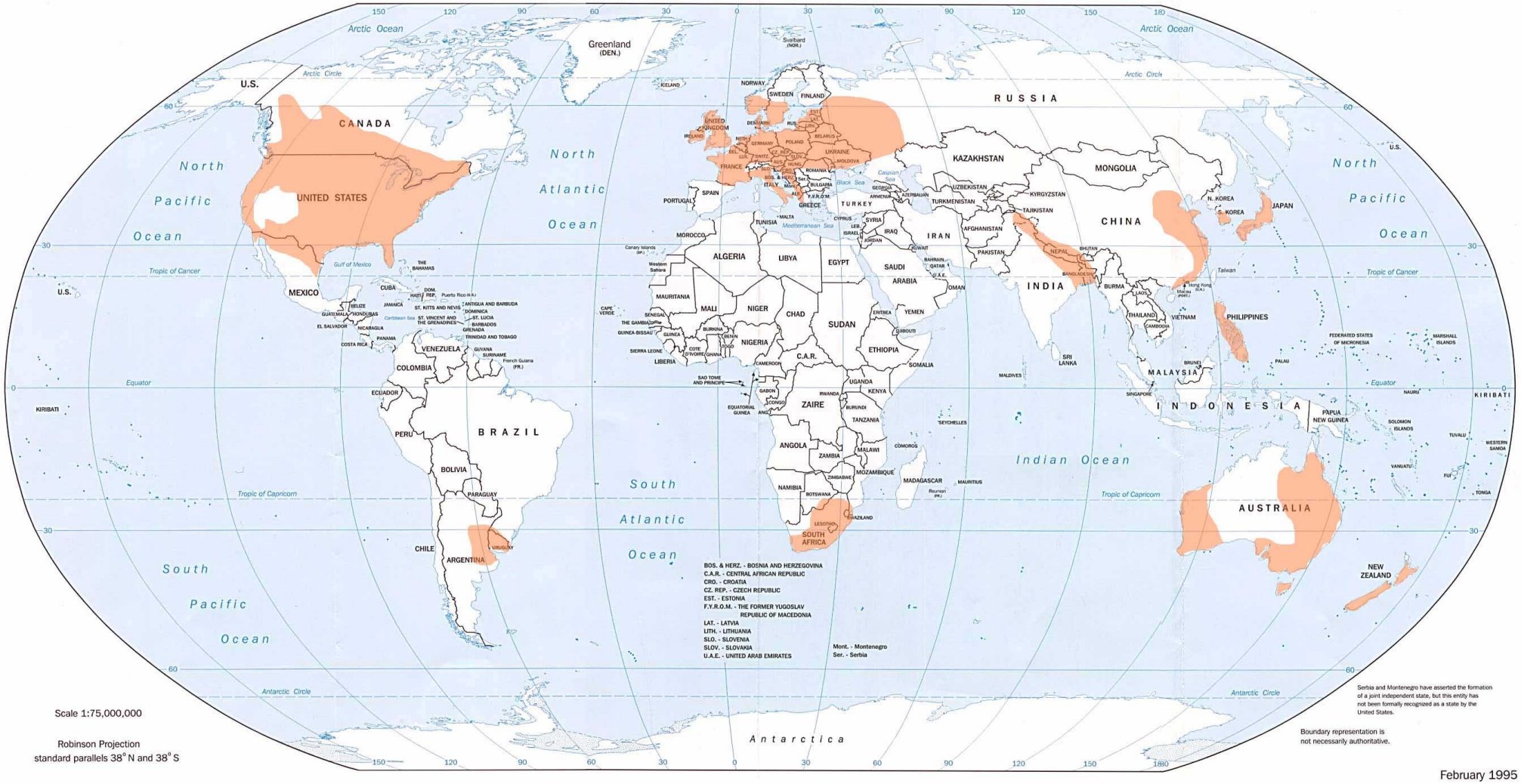
- Tornadoes are known by different names in various parts of the world, depending on regional terminology and characteristics. Some of these include:
  - **Twister**: A colloquial term commonly used in the United States.
  - **Cyclone**: In Australia, though this term often refers to tropical cyclones, it can also denote tornadoes.
  - **Waterspout**: When a tornado occurs over a body of water.
  - **Dust Devil**: A weaker phenomenon resembling a tornado, occurring in arid regions.
  - **Landspout**: A type of tornado that forms without a significant thunderstorm.
  - **Tromba (or Tromba d'Aria)**: Italian term for tornado.
  - **Cyclonic Storm**: In South Asia, "cyclonic storm" sometimes generically describes rotating systems, including tornadoes.
  - **Cordonazo**: Used in parts of Latin America for localized intense winds, occasionally associated with tornadoes.

Distribution of Tornadoes

- Though tornadoes can develop in any part of the world except extreme cold regions but the **United States of America** is most important breeding region of tornadoes.
  - The region to the south of 45°N latitudes and to the east of the Rocky mountains is frequented by tornado outbreak from April to September.
  - The **Great Plains present** most ideal conditions for the formation of tonadoes where these are associated with frontal activity (cold fronts).
  - The **Great Plains are also called Tornado Alley** because of maximum frequency of their occurrences.
  - The most adversely affected states are Texas, Mississippi, Alabama, Missouri, Oklahoma, Arkansas, Kansas and Iowa.


JET STREAM
COLD DRY AIR
South Dakota
Nebraska
TORNADO ALLEY
Colorado
Kansas
Oklahoma
WARM DRY AIR
Texas
WARM MOIST AIR

- The occurrence of thunderstorms and tornadoes in the USA are synchronous (*Le*. they occur at the same time-April to September, during daylight).
- The occurrence of tornadoes in groups involving large numbers on a specific day are called in the USA tornado outbreak. One such tornado outbreak occurred on Feb. 19, 1884 when 60 tornadoes struck the states of Virginia, North Carolina, South Carolina, Georgia, Alabama, Mississippi, Tennessee and Kentucky between 10 A.M. and 12 midnight wherein the most terrible devastation was caused by terrific wind storms ever experienced in the USA before this date.
- **Besides the USA, tornadoes also occur in France, United Kingdom, China, Australia, eastern India etc**.



BOS. & HERZ. - BOSNIA AND HERZEGOVINA
C.A.R. - CENTRAL AFRICAN REPUBLIC
CRO. - CROATIA
CZ. REP. - CZECH REPUBLIC
EST. - ESTONIA
F.Y.R.O.M. - THE FORMER YUGOSLAV REPUBLIC OF MACEDONIA
LAT. - LATVIA
LITH. - LITHUANIA
SLO. - SLOVENIA
SLOV. - SLOVAKIA
U.A.E. - UNITED ARAB EMIRATES
Mont. - Montenegro
Ser. - Serbia

Scale 1:75,000,000

Robinson Projection
standard parallels 38° N and 38° S

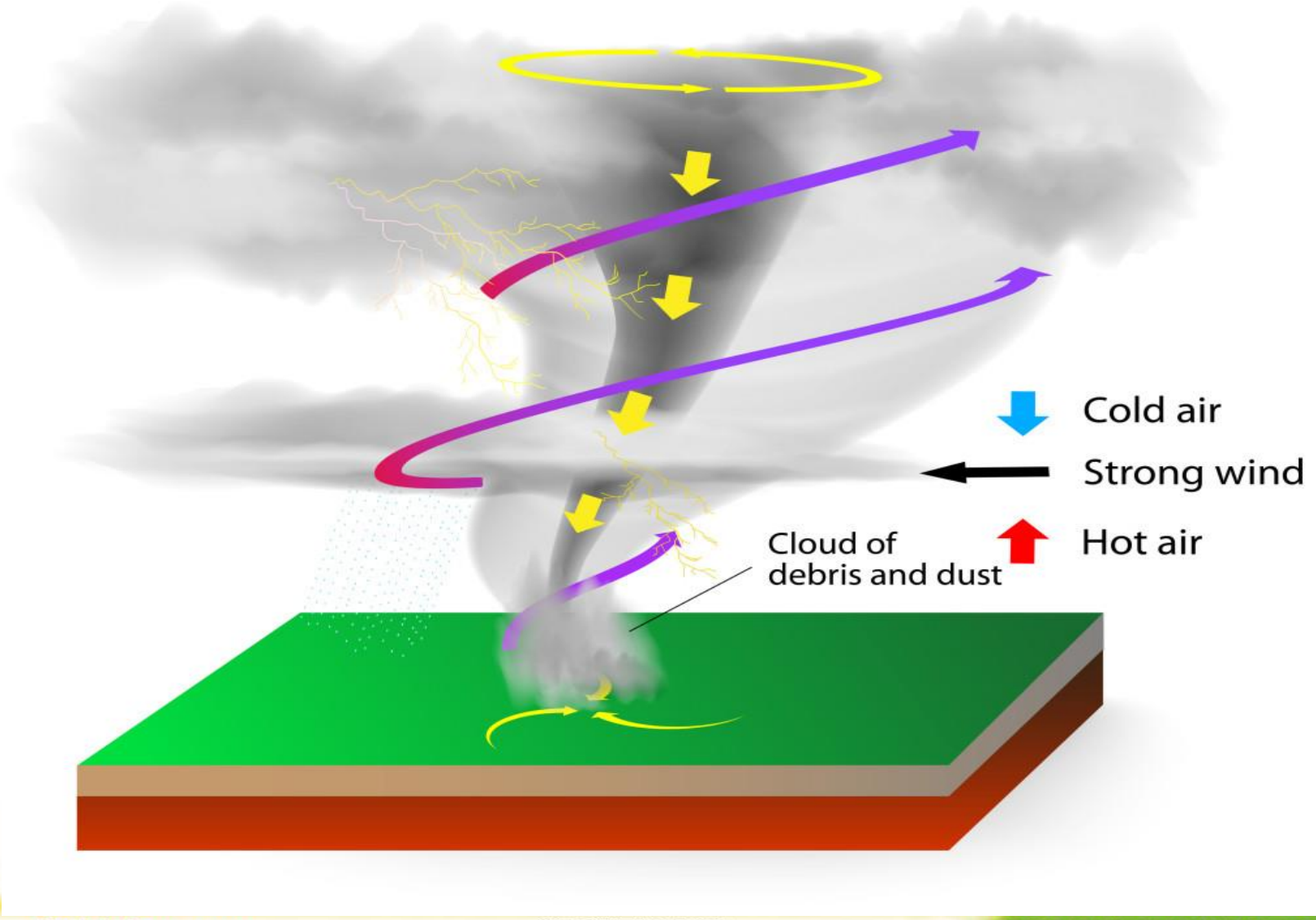
Serbia and Montenegro have asserted the formation of a joint independent state, but this entity has not been formally recognized as a state by the United States.

Boundary representation is not necessarily authoritative.

February 1995

802353 (R00350) 2-95

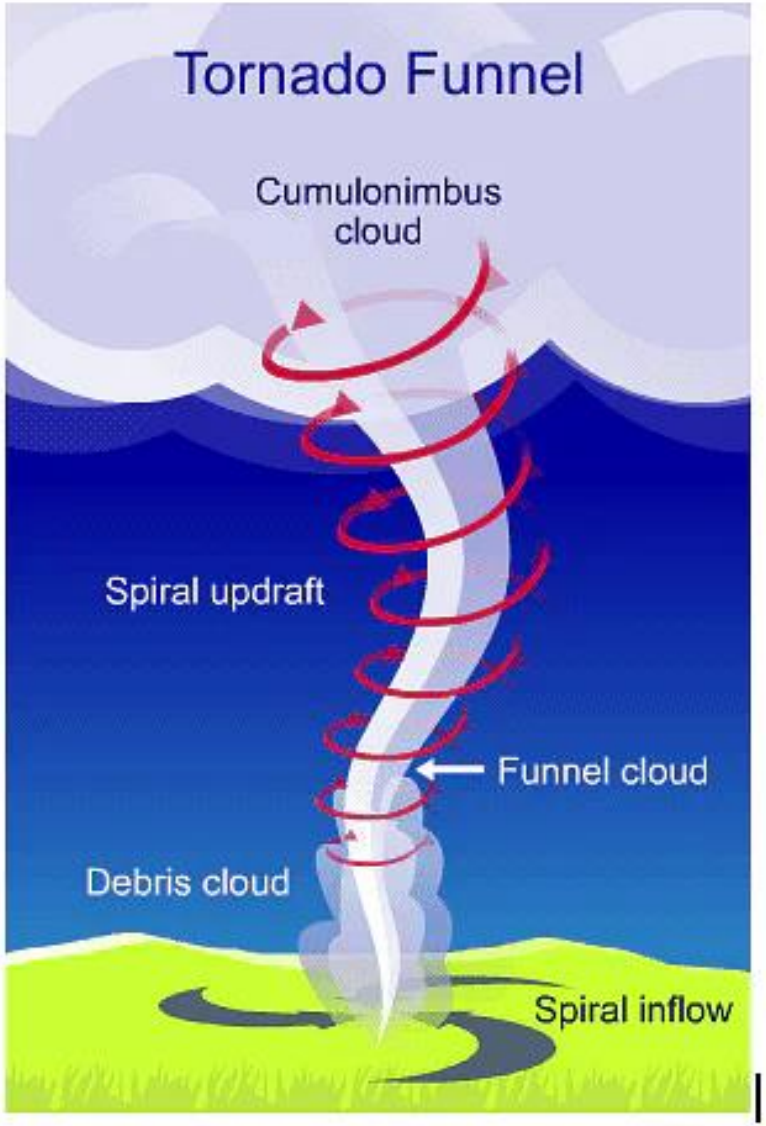
Characteristics of tornadoes



- The tornadoes are characterized by the following salient features.
  - Tornadoes are very **violent rotating systems** of air wherein the air from the ground surface having lowest pressure is sucked by the upper air and is suddenly uplifted causing convective instability.
  - The pressure in the center of tornado, though not precisely measured as the instruments meant for measuring wind speed and air pressure are destroyed by gusty wind, is extremely low.
  - The recorded lowest pressure (in 1904) of a tornado in the state of Minnesota of the USA was **813 mb.**
  - On an average, the center of a tornado is characterized by **extremely low pressure, say 100** mb less than the outside environments.
  - The diameter of the upper funnel increases from 90m in the lower portion say at the base at the ground to 460 m in the upper portion, say at the top.

- Because of **steep pressure gradient** winds rush up with great force towards the center having furious velocity ranging between **400 km to 800 km per** hour depending upon the magnitude of pressure gradient. Thus, the swiftly inward rushing air is caught into a vortex of the storm and is rapidly lifted upward and cools adiabatically and forms thunderstorms. This is why tornadoes are always associated with **violent thunderstorms**.
- The **movement of tornadoes is not in well defined** route and direction. Some times they become stationary at a place.
- Generally, they **move with average speed of 40-60km** per hour, though the speed of movement becomes zero for stationary tornadoes while it in exceptional cases may exceed 100 km per hour.

- Tornadoes **follow very narrow paths**, the width of which ranges between a few meters to more than 2000 meters, while the average length of path followed by a tornado is about40-50 km. The recorded long distance covered by a tornado in the states of Illinois and Indiana (USA) in May 1977 was 570 km.
- The **average duration of existence of a tornado ranges between 15 -20 minutes** but occasionally they may be in existence for a few hours.
- Tornadoes look very dark in colour because of the of dusts, sands, debris and condensed moisture.



- The arrival of tornado is heralded by **dark and thick clouds** in the sky resulting into complete darkness, minimum visibility and low pressure.
- Tornadoes move as **a single unit or in a group consisting of an average 7-8 in number.** The cluster or group of tornadoes is called **tornado family** while occurrence of several tornadoes in succession as a group or cluster is called tornado outbreak.

Categories of tornado

Fujita Scale		Enhanced Fujita Scale* * In use since 2007	
F–0	40–72 mph winds	EF–0	65–85 mph winds
F–1	73–112 mph	EF–1	86–110 mph
F–2	113–157 mph	EF–2	111–135 mph
F–3	158–206 mph	EF–3	136–165 mph
F–4	207–260 mph	EF–4	166–200 mph
F–5	261–318 mph	EF–5	>200 mph

UNDERSTANDING THE ENHANCED FUJITA SCALE

SCALE OF DAMAGE CAUSED BY TORNADOES

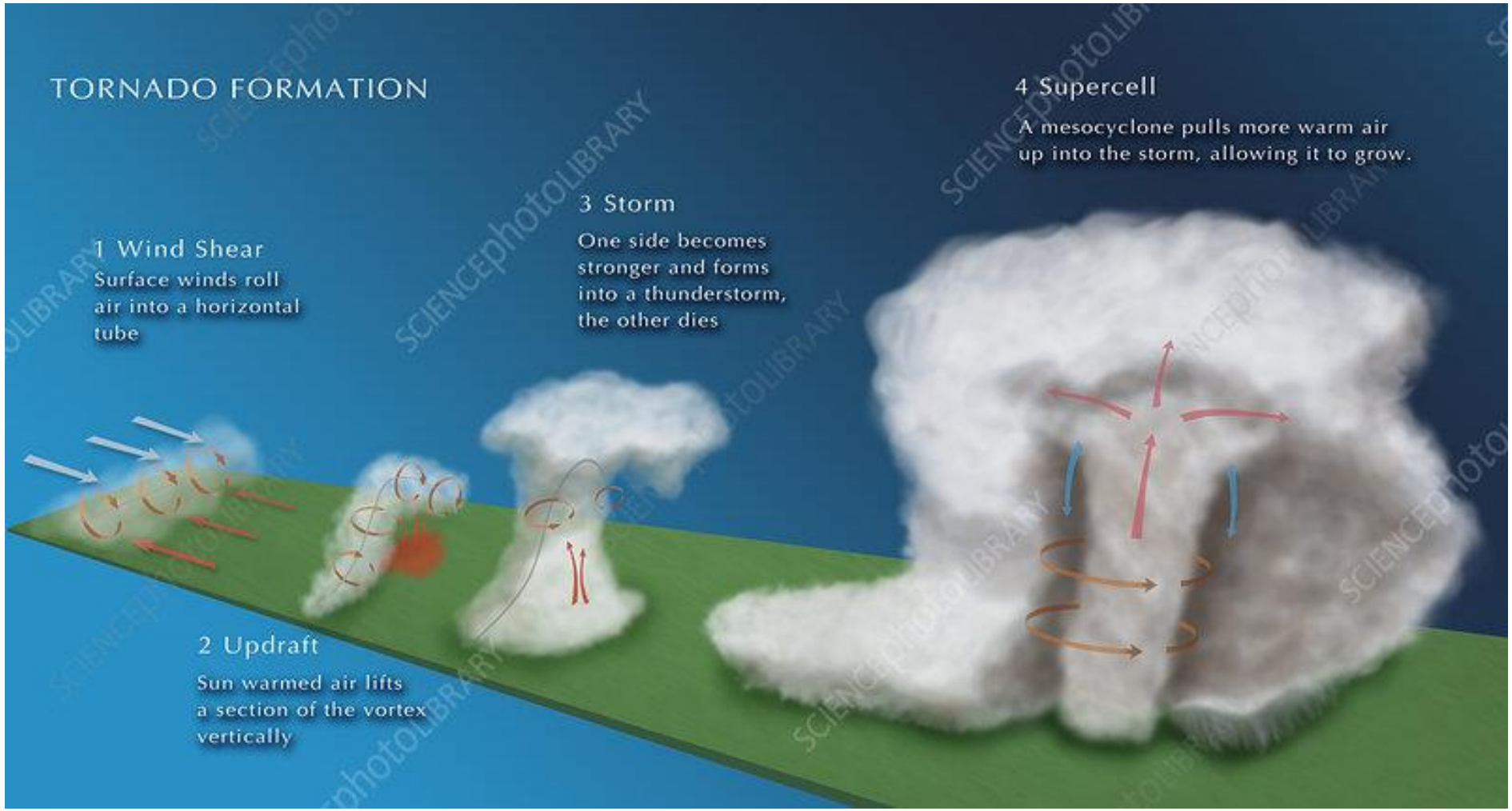
- **Fujita Scale tornadoes are** divided into **three major categories** as follows:

- **Weak tornadoes** are characterized by wind speed ranging between 64 km/hr to 179km/ hr. These tornadoes are further divided into two subcategories on the basis of expected damage *e.g.*
  - **category O** : light damage, branches of trees are broken, sign boards are damaged etc., wind speed from 64 km/hr to 115km/hr;
  - **category l :** wind speed ranging between 116km/ hr and 179km/hr, moderate damage, trees are broken, windows of houses broken, broken parts whisked away.

- **Strong tornadoes** are characterized by wind speed ranging between 180km/hr to 329km/ hr, these are further divided into two subcategories *e.g.*
  - ***category* 2 :** wind speed between 180km/hr and 187km/hr, considerable damage, large trees are broken and uprooted, moving houses flown, weakly fixed building structures are damaged and rem oved;
  - **category 3**: wind speed between 188km/hr and 329km/hr, severe damage, uprooted trees are carried away as tornado m ssiles, four wheeler and three wheeler autom obiles are overturned and uplifted, roofs and walls of buildings are damaged and removed.

- **Violent tornadoes** are characterized by very high wind speed ranging between 330km/hr and 509km/hr. These are further subdivided into 2 categories on the basis of wind speed and expected damage *e.g.*
  - **category 4:** wind speed ranging from 330km/hr to 416km/hr, devastating damage, houses are destroyed, roofs, trees and automobiles are carried as tornado missiles',
  - **category 5 :** wind speed ranging between 417km /hr and 509km/hr, incredible damage

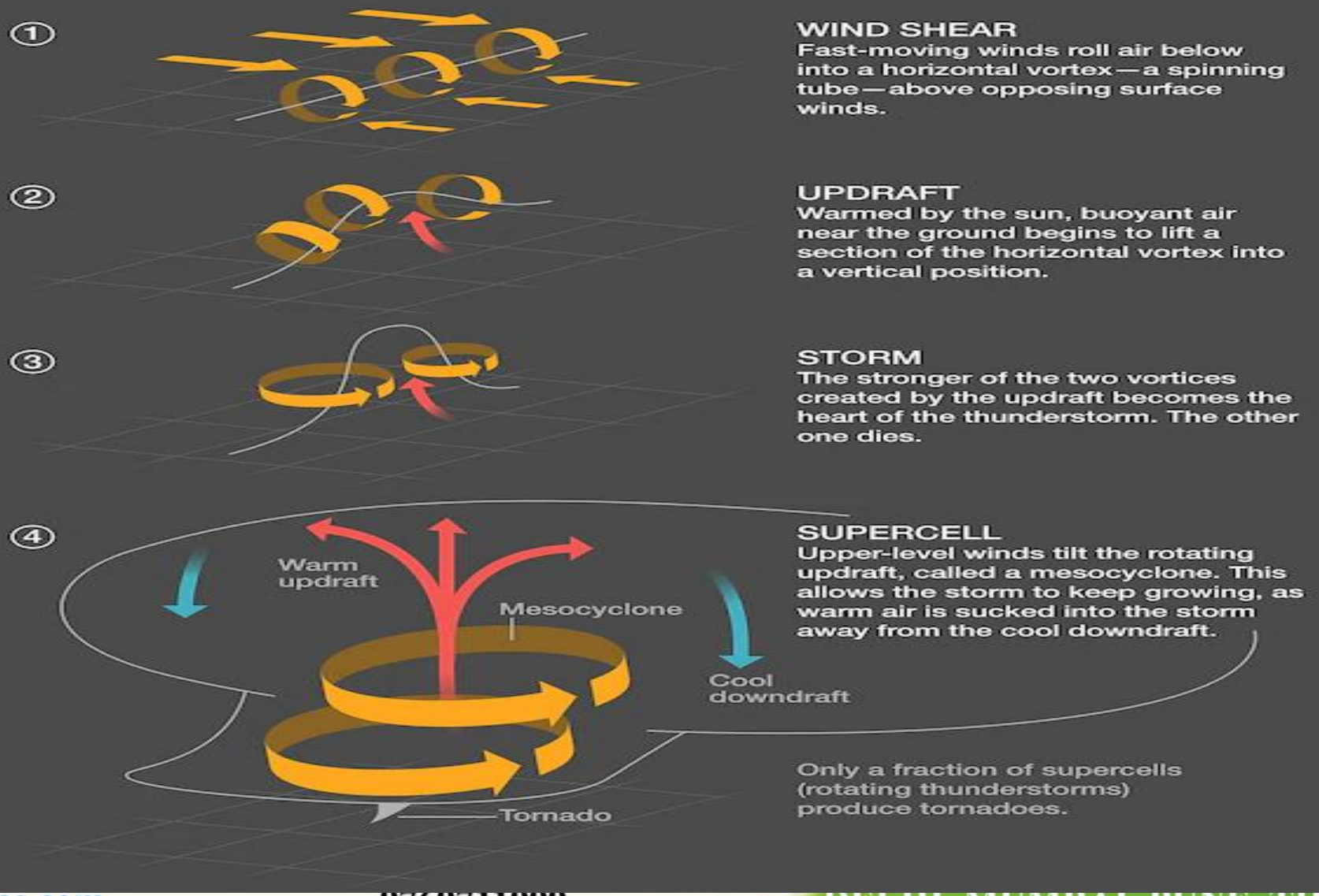
Formation of Tornadoes



- It may be mentioned at the very outset that exact mode of **formation and development of tornadoes is not properly understood by the storm experts** and meteorologists because the measurement of wind speed, temperature, humidity, and pressure at the time of their occurrence becomes practically difficult as the instruments are also lifted up and destroyed by the furocity of the storms.
- However majority of the meteorologists are of the opinion that **the primary cause of the origin of tornadoes is violent convection of conditionally or convectively unstable column of warm and moist ascending air.**

How a Tornado Forms

While tornadoes can differ in size, strength, and location, they all share certain characteristics. They are spawned from a type of rotating storm called a supercell thunderstorm.



WIND SHEAR
Fast-moving winds roll air below into a horizontal vortex—a spinning tube—above opposing surface winds.

UPDRAFT
Warmed by the sun, buoyant air near the ground begins to lift a section of the horizontal vortex into a vertical position.

STORM
The stronger of the two vortices created by the updraft becomes the heart of the thunderstorm. The other one dies.

SUPERCELL
Upper-level winds tilt the rotating updraft, called a mesocyclone. This allows the storm to keep growing, as warm air is sucked into the storm away from the cool downdraft.

Only a fraction of supercells (rotating thunderstorms) produce tornadoes.

- The following are the **prerequisite conditions** for the formation of tornadoes:
  - (1) mass convergence of air near the ground surface,
  - (2) mass divergence aloft,
  - (3) buoyant air mass,
  - (4) wind shear in the vertical,
  - (5) moist air mass in the lower layers,
  - (6) a trigger mechanism,
  - (7) unstable vertical temperature structure,
  - (8) some preexisting mechanism for rotating the winds
  - (9) surface cyclogenesis

- The origin of **tornadoes has also been related to fronts**. The up thrusting of warm and moist tropical and subtropical air mass by cold polar air mass along the cold front presents ideal condition for tornado development.
- Some times **intense local heating of the ground** surface causes strong convection which induces ideal conditions for the formation of tornadoes.
- According to Californian scientist V. J. Rossaw tornadoes develop because of **attraction of two cloud masses.**
- Though tornadoes may develop at any time but they are more *common during spring and summer seasons.*
- In the **regions of polar frontogenesis** tornadoes are formed due to **strong collision of warm and moist air mass from tropical** and subtropical regions with cold and dry air m ass from polar regions.
- Due to such strong collision strong turbulence develops along the air mass collision boundary, this strong turbulence causes the development of several eddies which develop into powerful wind whirls having rotating winds, these whirls allow the warm, moist and unstable warm air to escape upward like smokes in a factory chimney.

- The trigger mechanism which causes violent exchange of air of contrasting properties requires some sort of disturbance which may be heat at the ground.
- The intensely heated ground radiates heat upward which provides energy to the ascending warm air. This causes extremely low pressure at the ground and strong convective mechanism above the ground surface i.e. intense insolational heating of the ground.
- Extremely low central pressure draws air from all directions. Thus, a rising column of rotating warm air is developed and a tornado storm is formed.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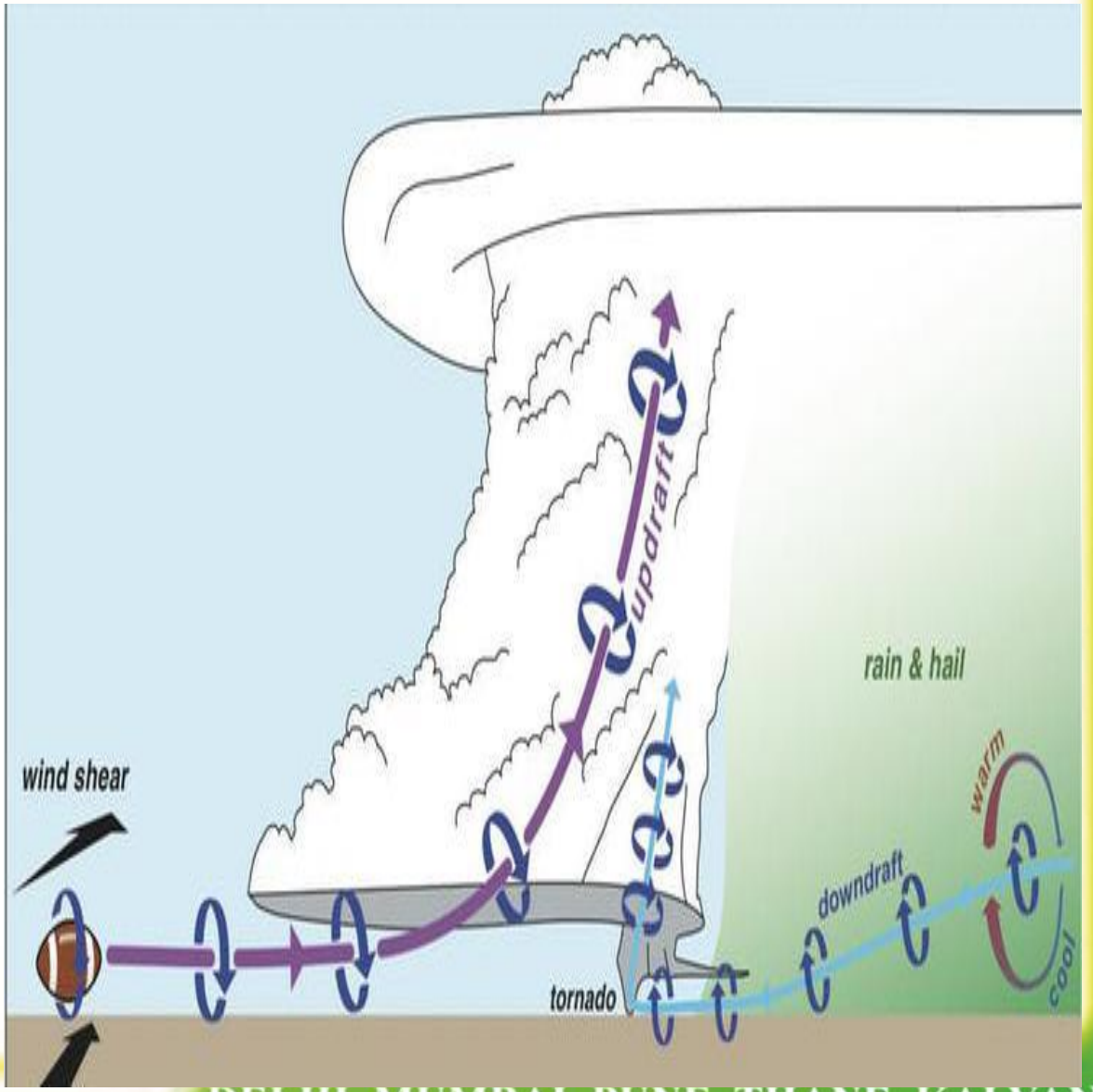
updraft
rain & hail
wind shear
warm
downdraft
cool
tornado

- Such violent storm is comprised of several supercells. Further violent strong upward movement of warm and moist air results in the formation.
- It may be mentioned that wind shear (change of **enormous thunderstorm having numerous supercells which yield copious rainfall and hail s**peed and direction of wind) acts as a mechanism to rotate the winds rushing towards the central lowest pressure.
- As the storm develops into thunderstorm characterized by strong turbulence and up draughts, **mamantus clouds are formed** at lowest level of clouds *i.e.* near the ground surface while funnel clouds develop at the top of thunderstorm. All these are indicators of the formation of a tornado. The funnel clouds drop down and the tornado develops from the cloud wall.