Weather Systems & Severe Weather Events and Meteorological Hazards, and Climate-Related Disasters

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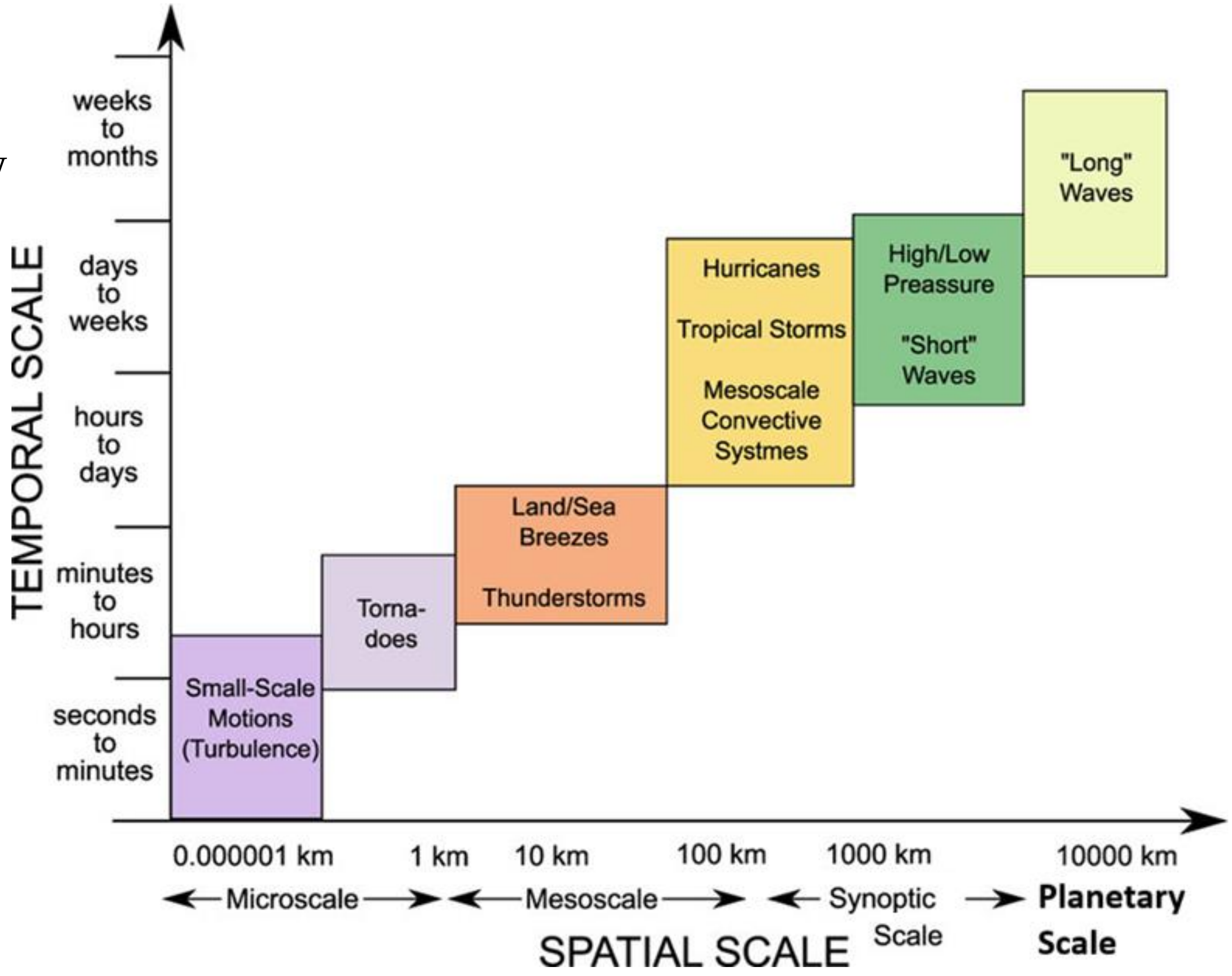
Scales of atmospheric Motions

Scale of the weather systems, vary widely in space and time for e.g. formation of dew in plant leaf, millimetres of dimension & period of few minutes.

- The variation is from less than 1 km. to > 1000 km in horizontal, in vertical the variation can be from less than one meter up to the > 10 kms.
- The life period of the systems can vary from few minutes to large number of days.
- Depending upon these variations the Synoptic systems can be divided in to the following categories:
  - *1) Microscale*
  - *2) Mesoscale*
  - *3) Synoptic scale*
  - *4) Planetary Scale*



Microscale systems

- Horizontal extension is less than one km and time period is few minutes while vertical extension, upto 10 meters.
- These systems include formation of dew or small air eddy currents which are there in very lower levels of the atmosphere.
- Similarly smokes generated by industries are also the examples of this scale.
- To study these microscale systems we should have observations at every few meters and at the intervals of few minutes or the continuous observations. Forecast- short range- very short.

Mesoscale systems

- Horizontal extension is from 1 km to 100 km.
- time is about 1 day or little more.
- Examples are Thunderstorms (Group of convective clouds, tornado, dust storm, squall lines, fog, Land and see breeze.
- To study this weather phenomenon the observations should be available at every 10 kms and at the interval of every half an hour. Forecast- short range-very short.
- Most of the meteorological services do not study these Micro and Mesoscale Phenomenon as a routine basis.
- As this much close network of observatories is not available. These systems may studied in detail form of special project.

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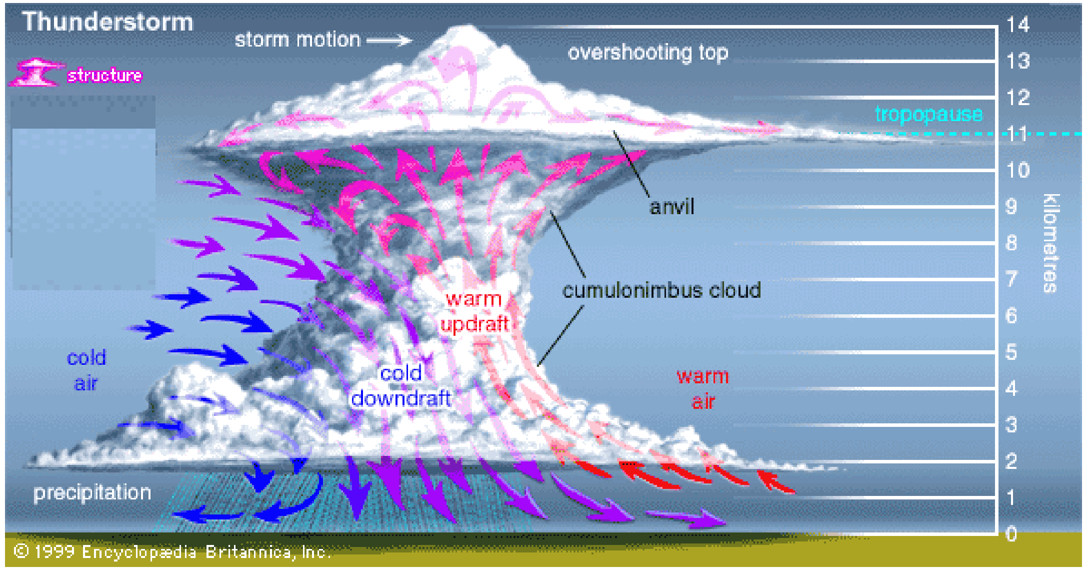
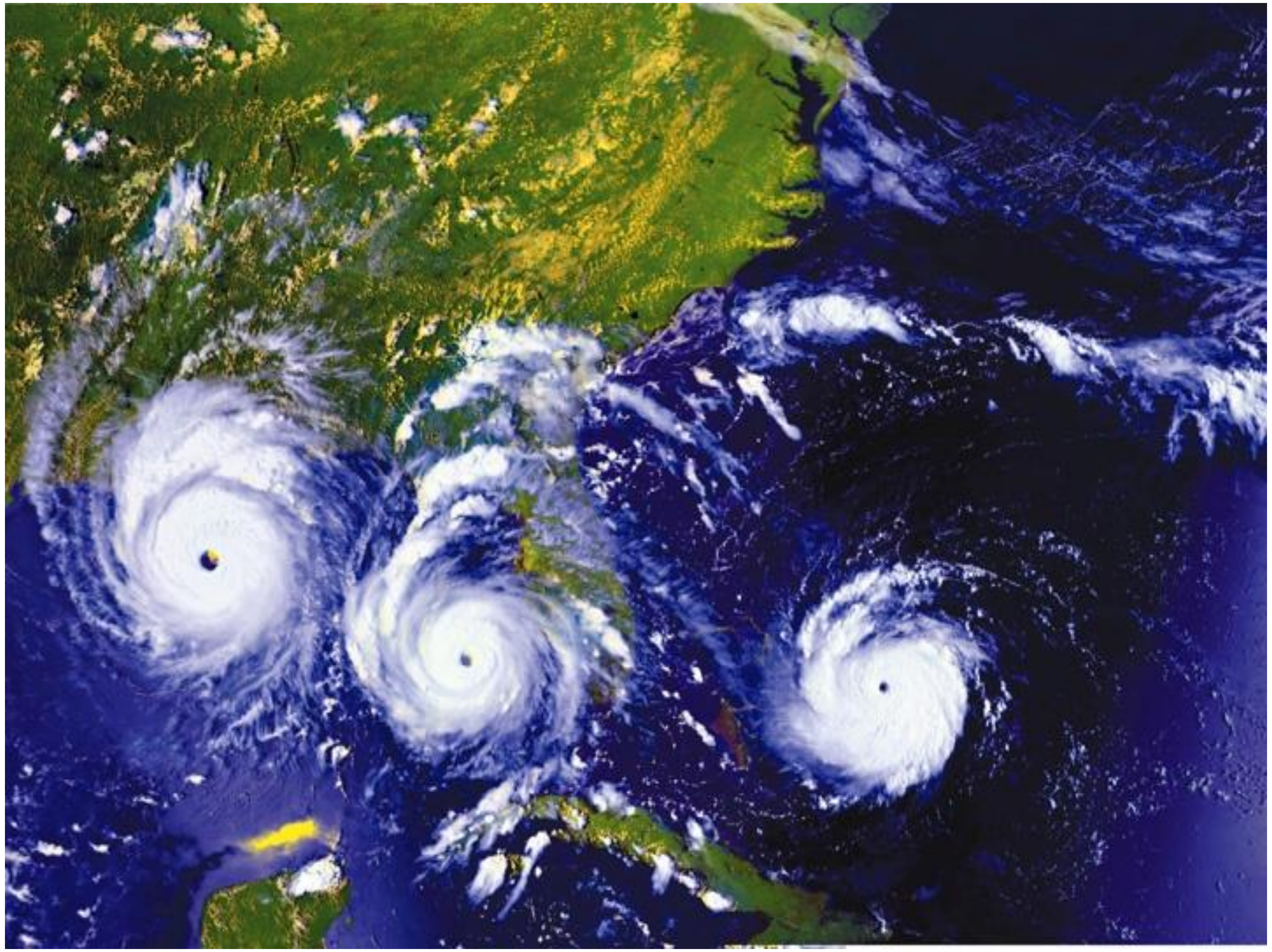


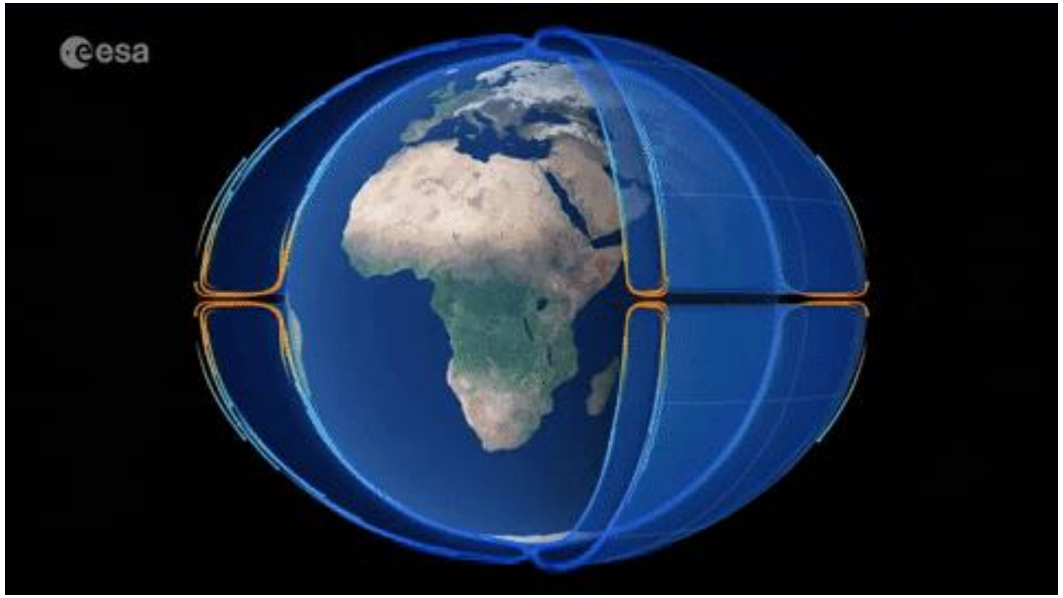
Synoptic Scale :

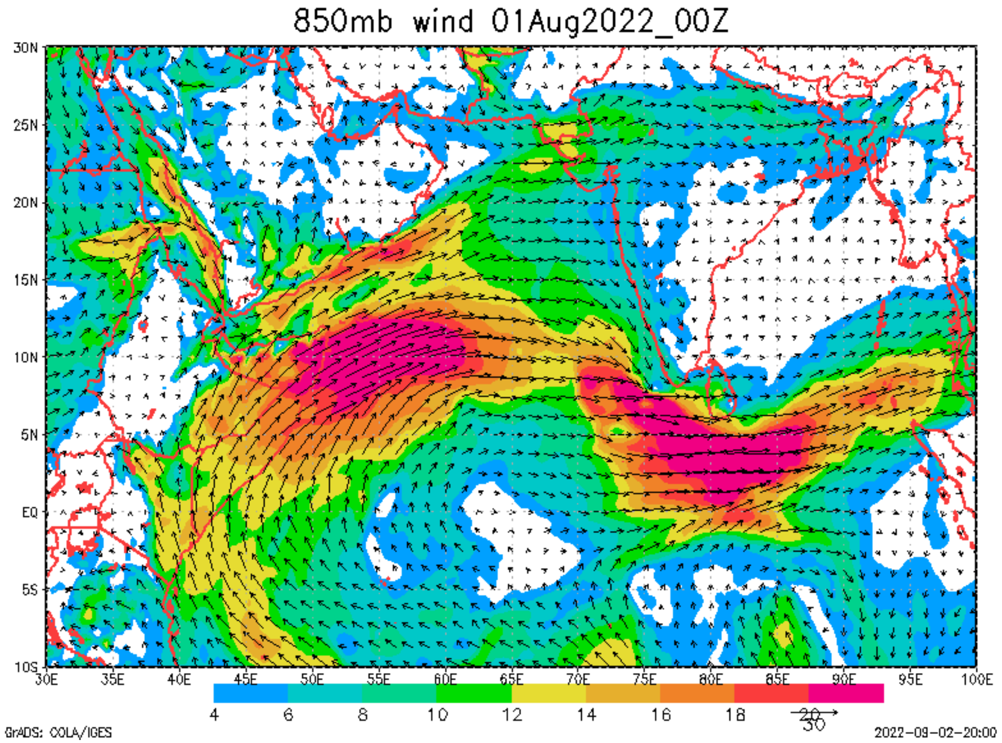
- Horizontal extension i.e. diameter of this scale systems is about 100 to 1000 kms and vertical extension is about 10 km.
- Time scale is few days examples for this scale of systems are low pressure areas, High pressure areas, Depressions, Cyclonic storms, troughs and ridges etc.
- To study Synoptic scale motions we should have surface observations at every 150 kms and upper air observations at every 300 kms.
- Interval for surface observations is every 3 hrs., and for upper air observations is every 12 hrs. Forecast- (Short range, Medium range.)



Planetary scale:

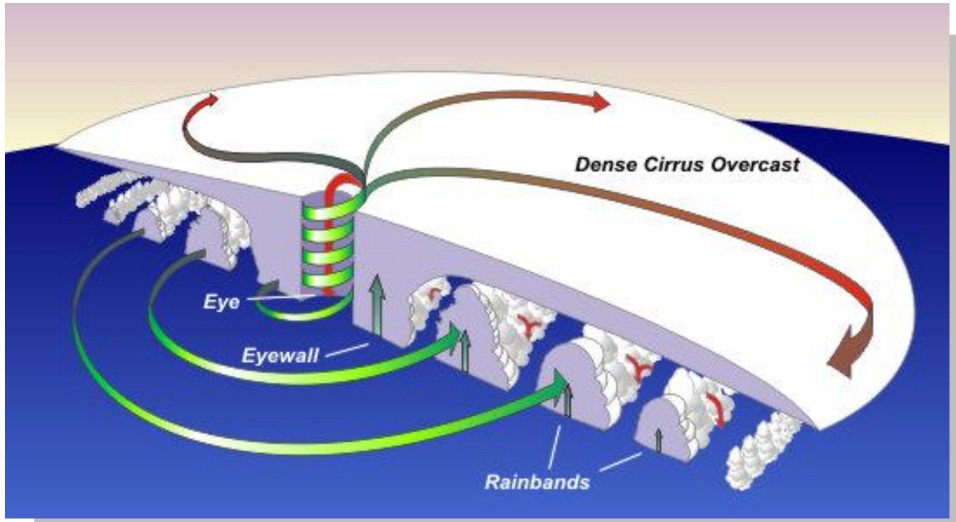
- This scale is also known as Macro scale. Horizontal scale is > 1000 kms and vertical scale is > 10 kms.
- Time scale is large number of days.
- These types of systems give rise to abnormalities in precipitation and in temperatures over a large region.
- Example for this scale is Global circulation, Blocking highs, I.T.C.Z., Monsoon trough. To study this phenomenon Synoptic scale network is sufficient.



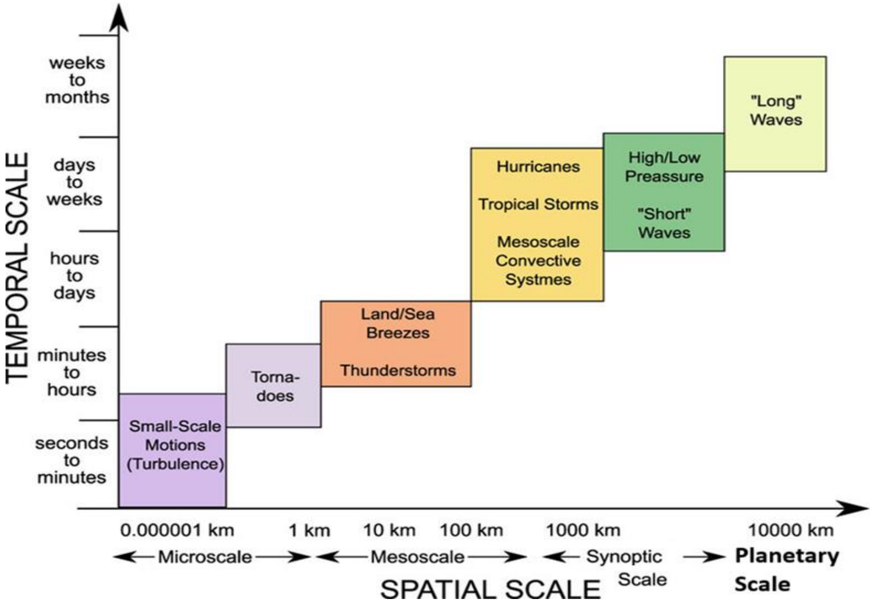


TROPICAL CYCLONES

TROPICAL CYCLONE DEFINED!

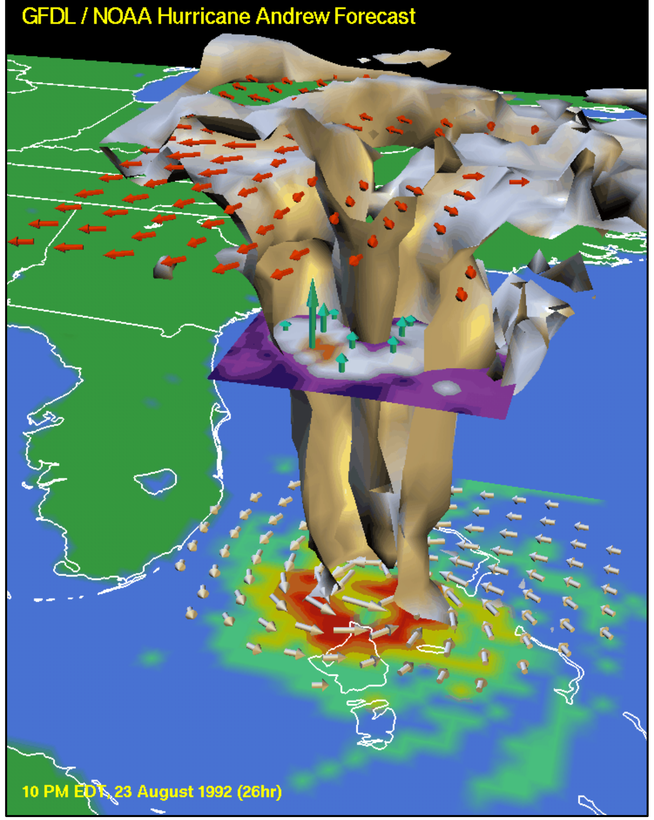


A warm core, non-frontal, synoptic scale system with cyclonically rotating winds characterized by a rapid decrease in pressure and increase in winds toward the center of the storm. Cyclones develop over tropical or subtropical waters and have a definite organized circulation .



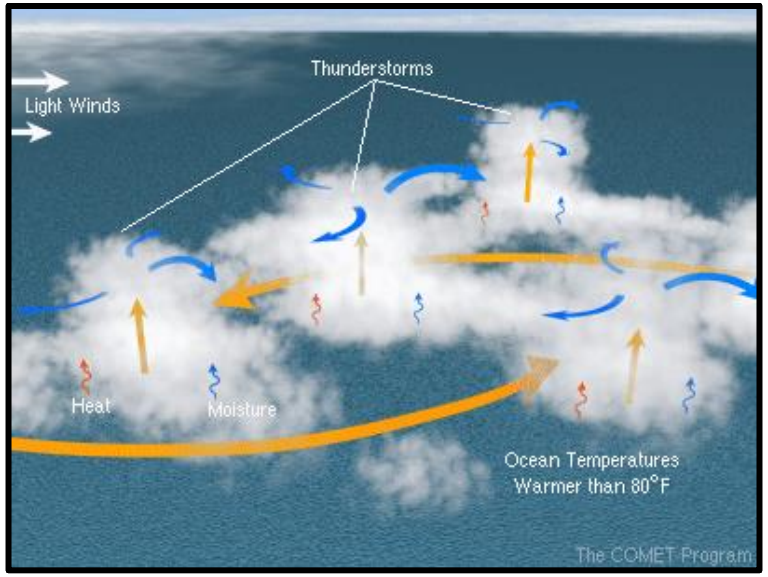
Warm core: The center of the cyclone is warmer than its surroundings, which is a key characteristic of tropical cyclones. Non-frontal: The system is not associated with weather fronts (boundaries between different air masses).

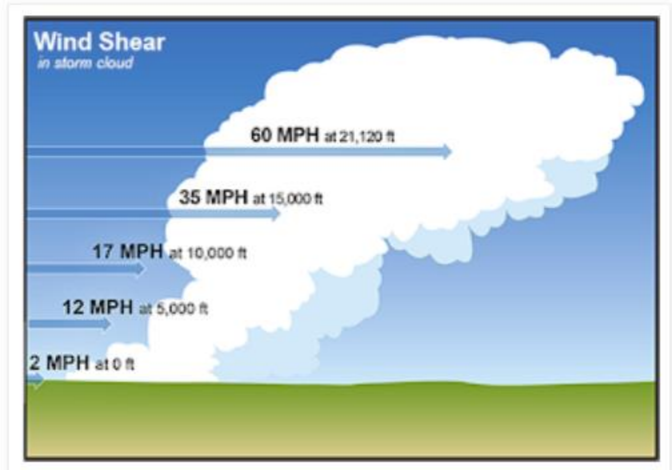
How do they develop?



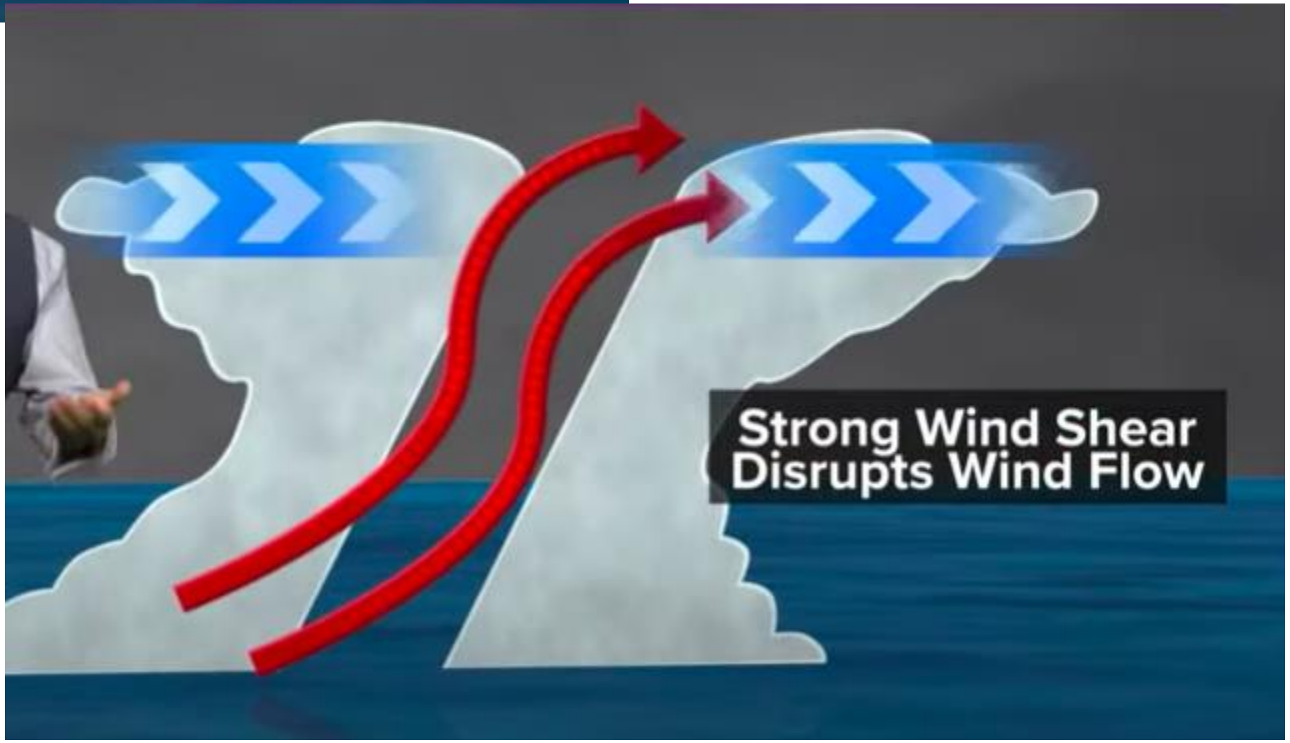
Favorable environmental conditions that must be in place before a tropical cyclone can form:

- Warm ocean waters (at least 27°C) throughout a depth of about (50 m).
- An atmosphere which cools fast with height (potentially unstable).
- Moist air near the mid-level of the troposphere (4,900 m).
- Generally a minimum distance of at least 480 km from the equator.
- A pre-existing near-surface disturbance.
- Little vertical wind shear between the surface and the upper troposphere. *(Vertical wind shear is the change in wind speed with height.)*
- Outflow aloft/exhaust





Vertical wind shear is the change in wind speed with height

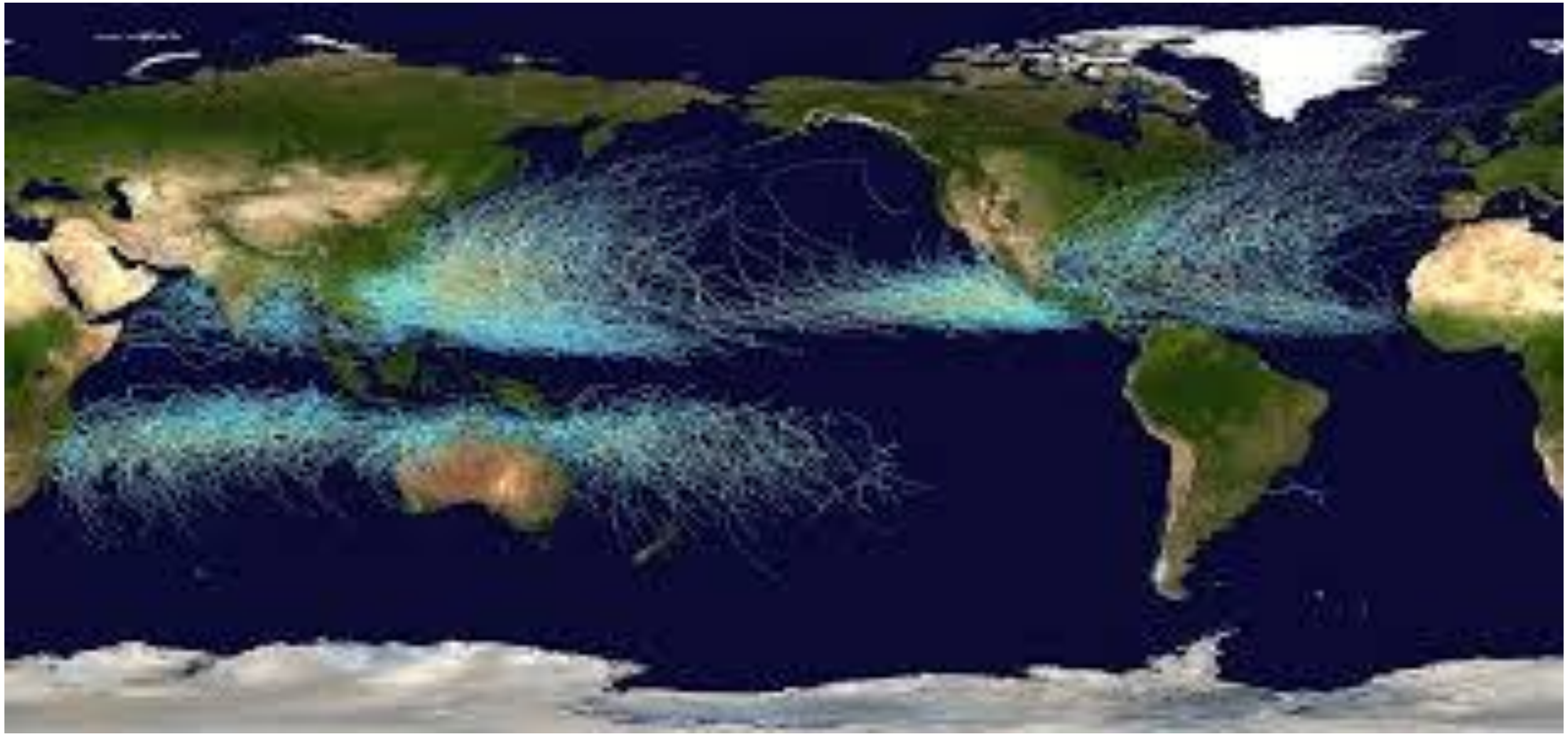


STAGES OF DEVELOPMENT

- **Tropical Depression(TD):** A tropical cyclone with wind speeds up to **17-and 33kts** knots.
- **Tropical Storm (TS):** A tropical cyclone with wind speeds **34 to 47 kt** knots.
- **Tropical Cyclone:** A tropical cyclone with wind speeds greater than **63** knots.

TROPICAL CYCLONE FORMATION, LOCATION

- The map below shows where the seven basins noted for TC development are located and typical tracks for each. It also has the average number of tropical storms, and Tropical Cyclones, created in each basin.



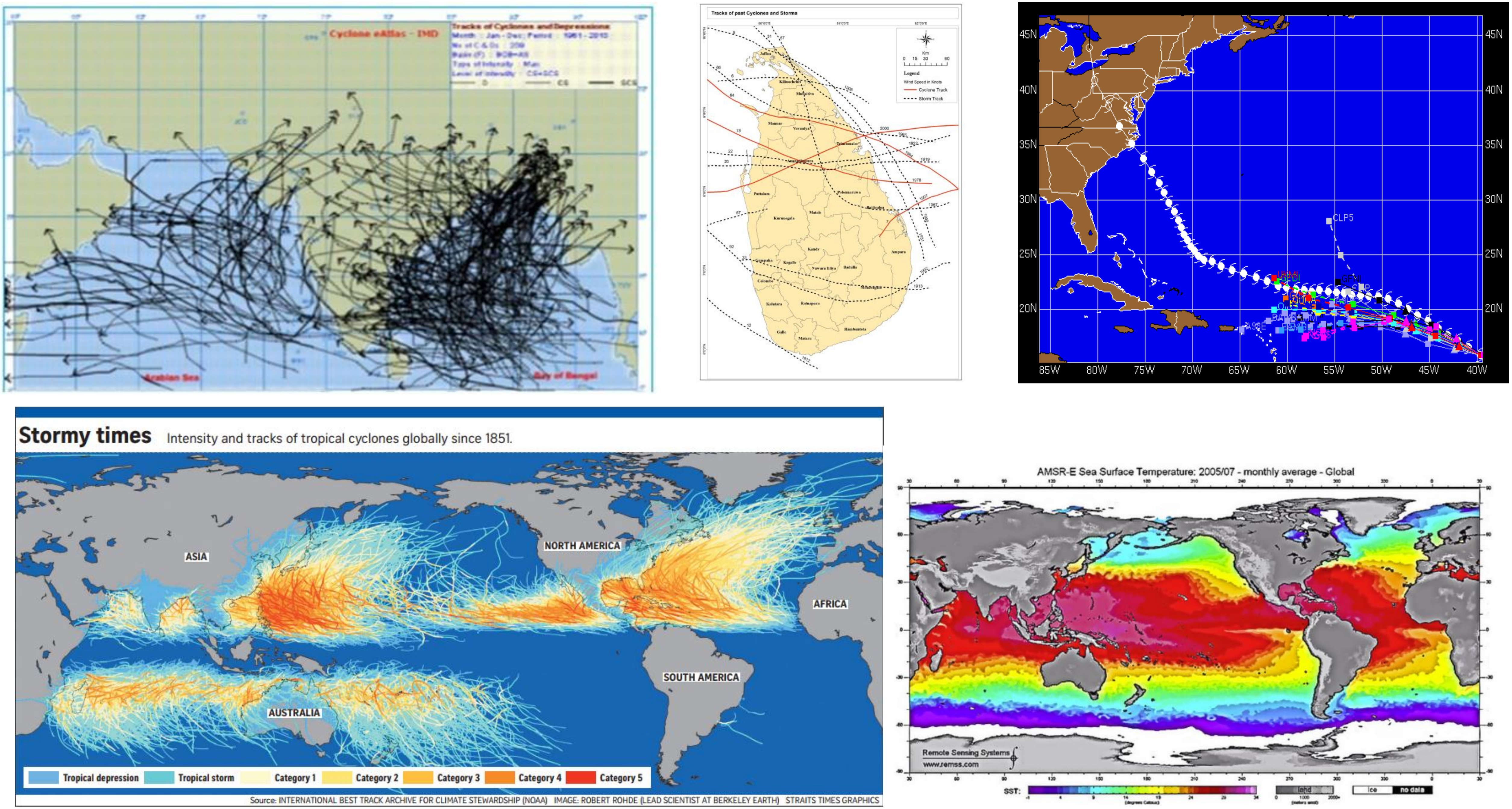


Figure: Climatology of the intensity and tracks of tropical cyclones globally since 1851 (Source: International Best track Archive for Climate Stewardship, NOAA)

knot	km/h	Beaufort	South West Indian Ocean*	Arabian Sea and Bay of Bengal**	North West Pacific**	North Atlantic and North East Pacific***	South West Pacific and South East Indian Ocean*
Average wind speed			knot km/h	knot km/h		Knot km/h mi/h	knot km/h
			Zone of disturbed weather	Low pressure area			Tropical disturbance
17 27	31 50	6	Tropical disturbance	Depression	Tropical depression	Tropical depression	Tropical low/depression
28 33	51 62	7	Tropical depression	Deep depression			
34 40 47	63 88	8 9	Moderate tropical storm	Cyclonic storm	Tropical storm	34 39 Tropical storm	Tropical cyclone (gale) / Category 1
48 52 63	89 117	10 11	Severe tropical storm	Severe cyclonic storm	Severe tropical storm	73	Tropical cyclone (storm) / Category 2
64	118	12	64 Tropical cyclone	64 Very Severe Cyclonic Storm	Typhoon	64 Hurricane CAT 1 82 153 95	64 Severe tropical cyclone (hurricane) / Category 3
						83 154 96 Hurricane CAT 2 95 177 110	
			89 165	89 166		96 178 111 Hurricane CAT 3 112 208 129	85 159
			90 166 Intense tropical cyclone 115 212	90 167 Extremely Severe Cyclonic Storm 119 221		113 209 130 Hurricane CAT 4 136 251 156	86 160 Tropical cyclone / Category 4 107 199
			116 213 Very intense tropical cyclone	120 222 Super cyclonic storm		137 252 157 Hurricane CAT 5	>107 >200 Tropical Cyclone / Category 5

Weather system	Maximum wind speed
Low pressure area	Wind speed less than 17 kt (31 km/h)
Depression	Wind speed between 17 and 27 kt (31 and 49 km/h)
Deep Depression	Wind speed between 28 and 33 kt (50 and 61 km/h)
Cyclonic storm	Wind speed between 34 and 47 kt (62 and 88 km/h)
Severe cyclonic storm	Wind speed between 48 and 63 kt (89 and 117 km/h)
Very severe cyclonic storm	Wind speed between 64 and 89 kt (118 and 166 km/h)
Extremely severe cyclonic storm	Wind speed between 90 and 119 kt (167 and 221 km/h)
Super cyclonic storm	Wind speed 120 kt (222 km/h) and above

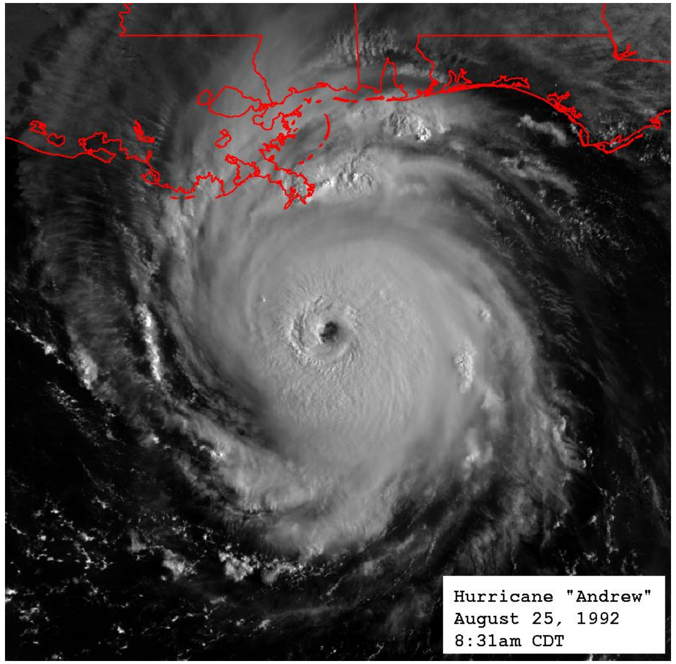
HURRICANE / TYPHOON / WILLY-WILLY/VERY SEVERE CYCLONIC STORM/EXTREMELY SEVERE CYCLONIC STORM/SUPER CYCLONIC STORM (MATURE STAGE)

Winds > 63 kts

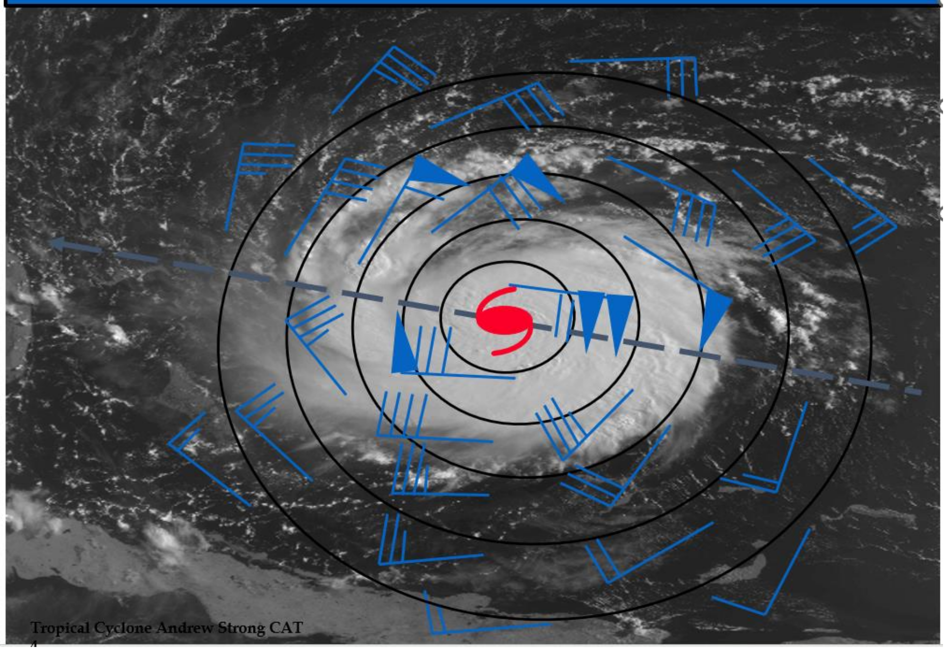
DANGEROUSLY HIGH SEAS navigation severely impaired

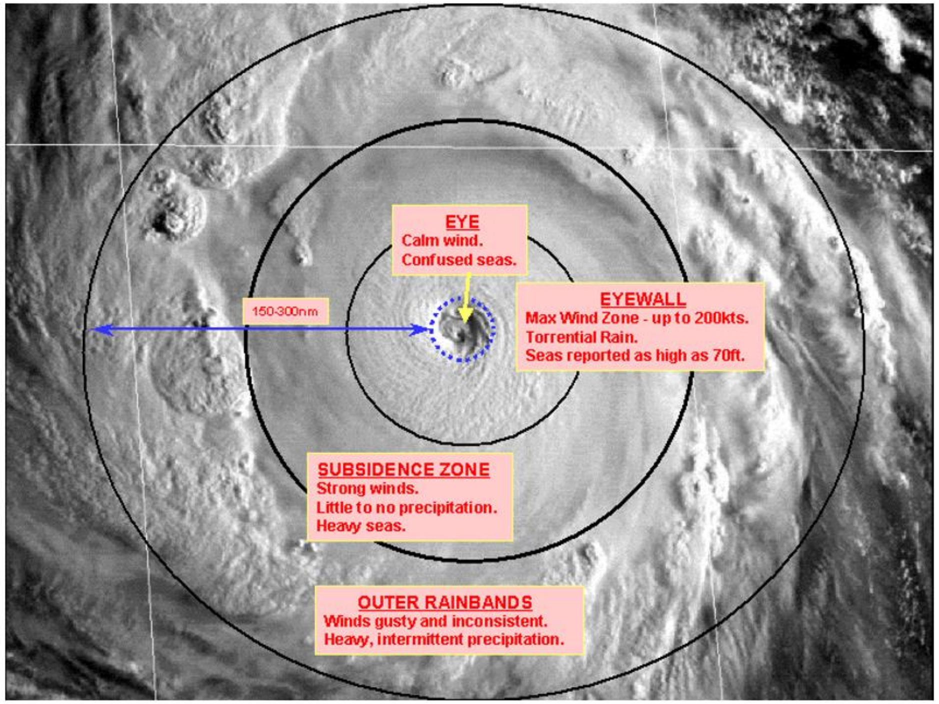
Radius of strong winds may exceed 350 NM

Gale Force Winds extend out further in right front quadrant (typically 120 NM)



Distribution of Surface Winds

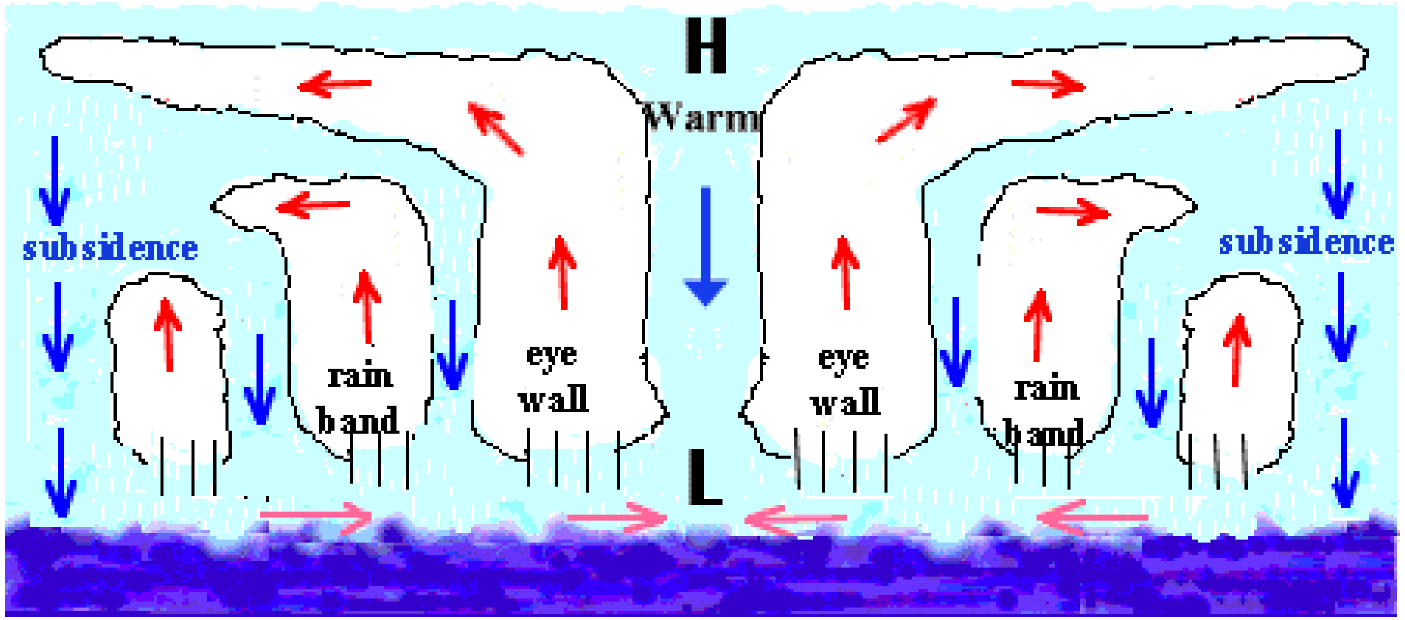




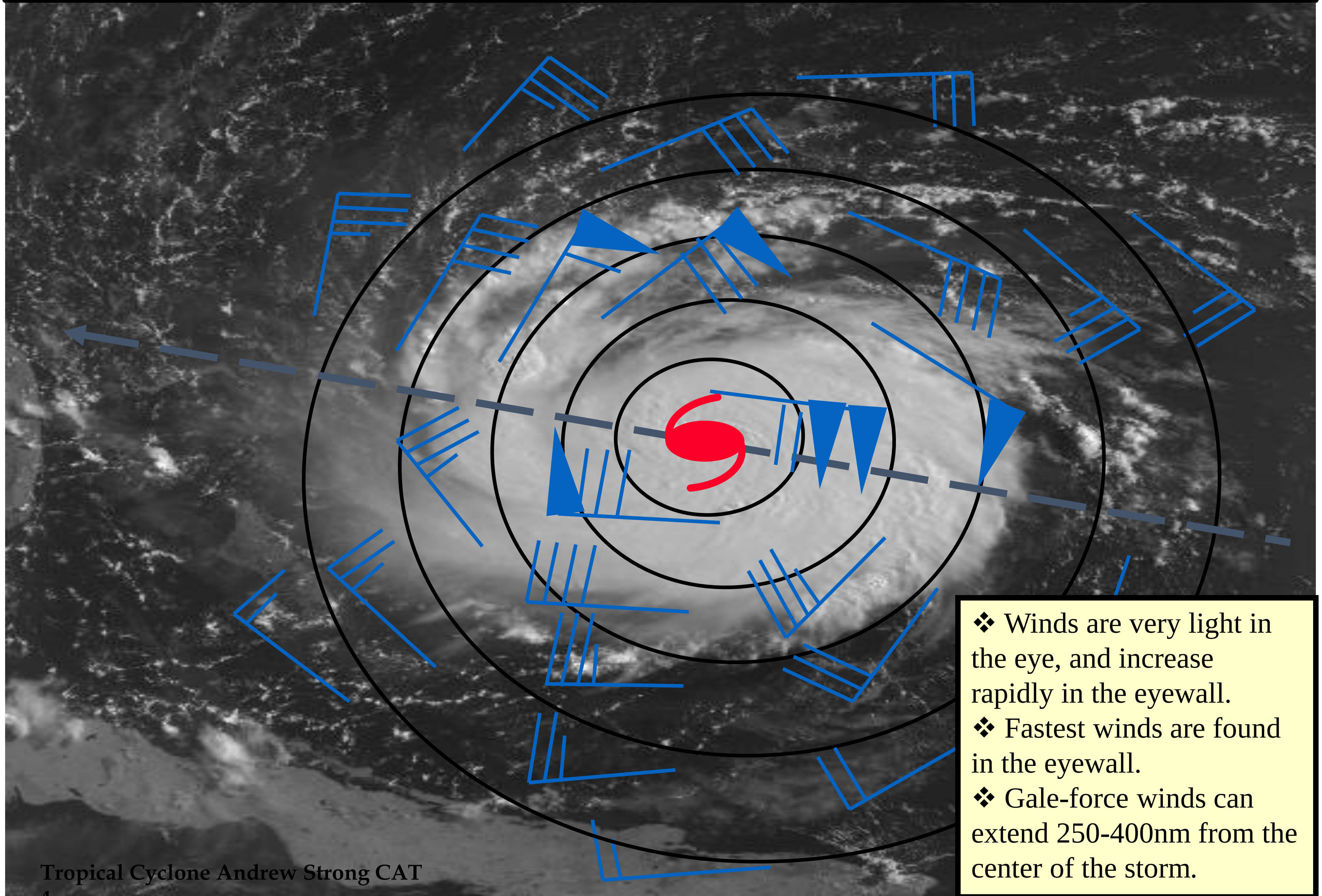
TROPICAL CYCLONE CHARACTERISTICS

- ❖ Winds are very light in the eye, and increase rapidly in the eyewall.
- ❖ Fastest winds are found in the eyewall.
- ❖ Gale-force winds can extend 250-400nm from the center of the storm.

Feeder Bands (curved lines of convection) spiral inward to the Eye Wall. Some of the most violent weather (tornadoes/severe thunderstorms) occur in these areas



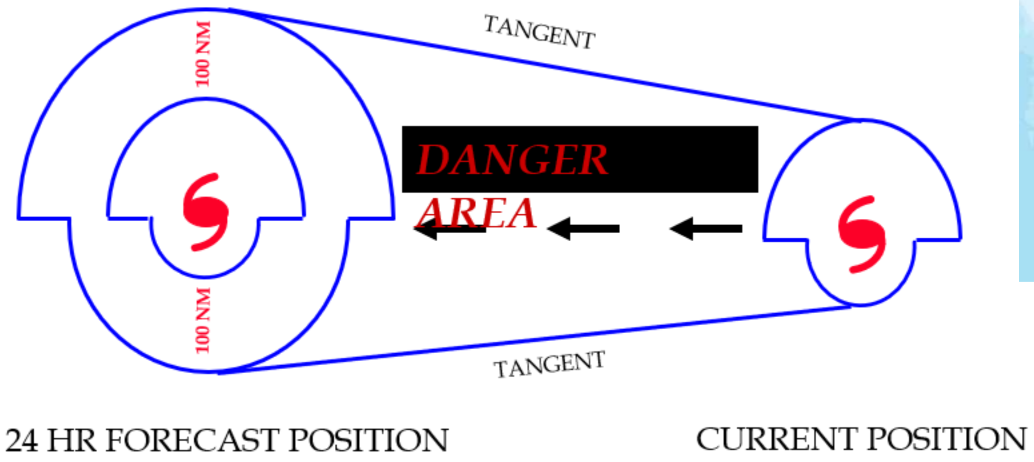
Distribution of Surface Winds

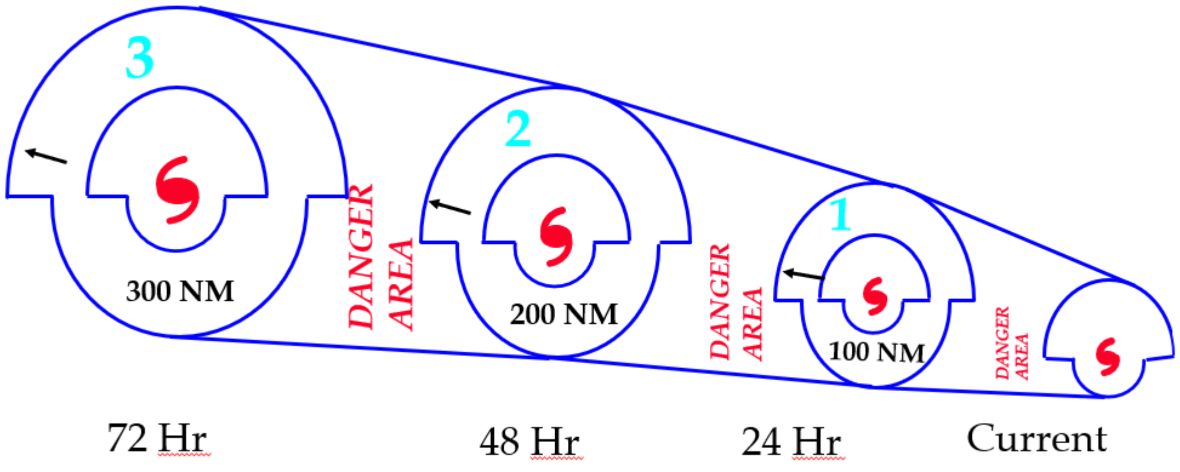


Tropical Cyclone Andrew Strong CAT 4

- ❖ Winds are very light in the eye, and increase rapidly in the eyewall.
- ❖ Fastest winds are found in the eyewall.
- ❖ Gale-force winds can extend 250-400nm from the center of the storm.

WARNING'S

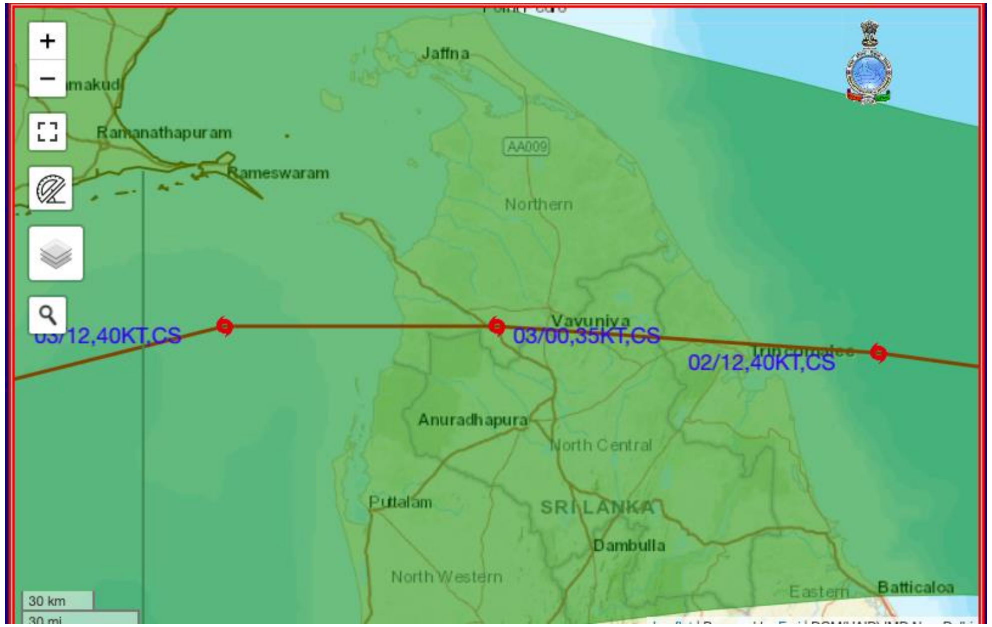




Cone of uncertainty

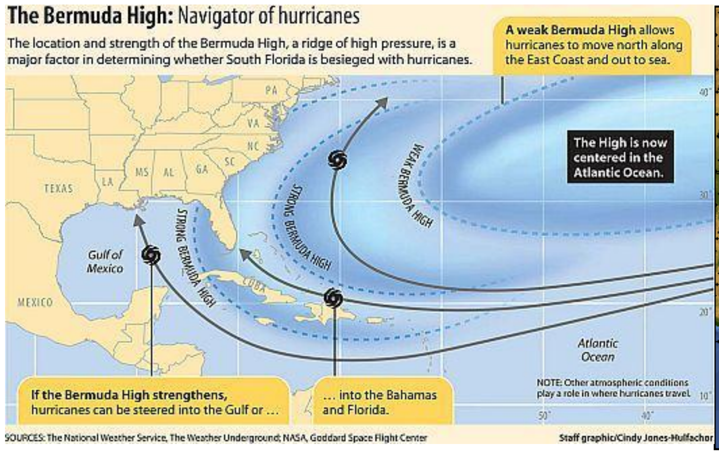
Draw tangents relative to the direction of the storm from the 35 kt radius (current position) to the outermost radius at the 24 hr forecast position. Avoid the **DANGER AREA**

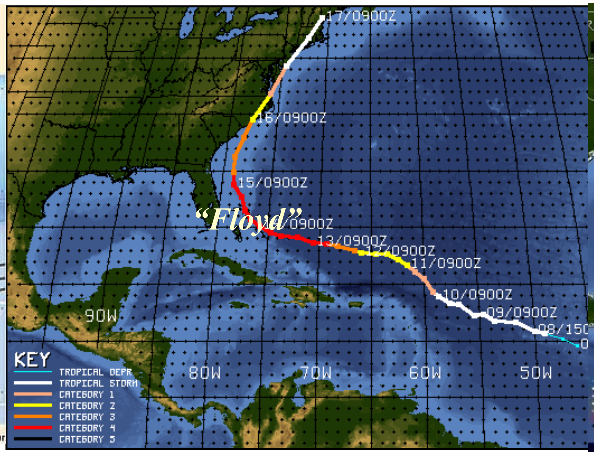
Use the same procedure for the 48 and 72 hr forecast positions, however, use 200 and 300 NM radii/respectively. Avoid the **DANGER AREA**.

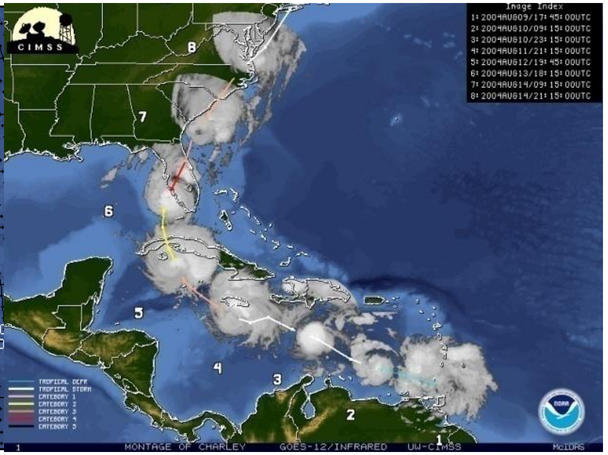


- The **cone of uncertainty** is a graphical representation used in tropical cyclone forecasting to show the probable path of the storm's center. Here are the key points:
- **Probable Track**: The cone represents the likely path of the storm's center based on historical forecast errors.
- **Increasing Uncertainty**: The cone widens over time, indicating increasing uncertainty in the storm's future position.

TROPICAL CYCLONE RECURVATURE & DISSIPATION





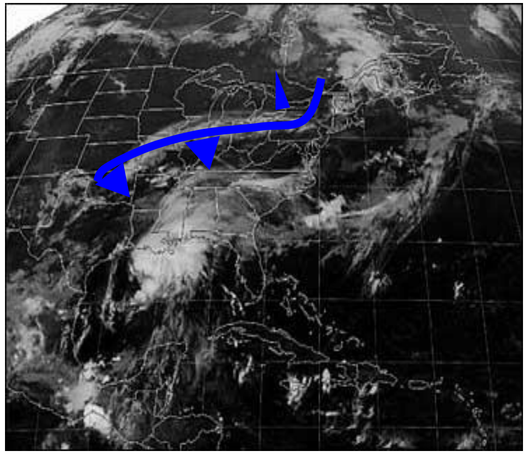


"Charley"

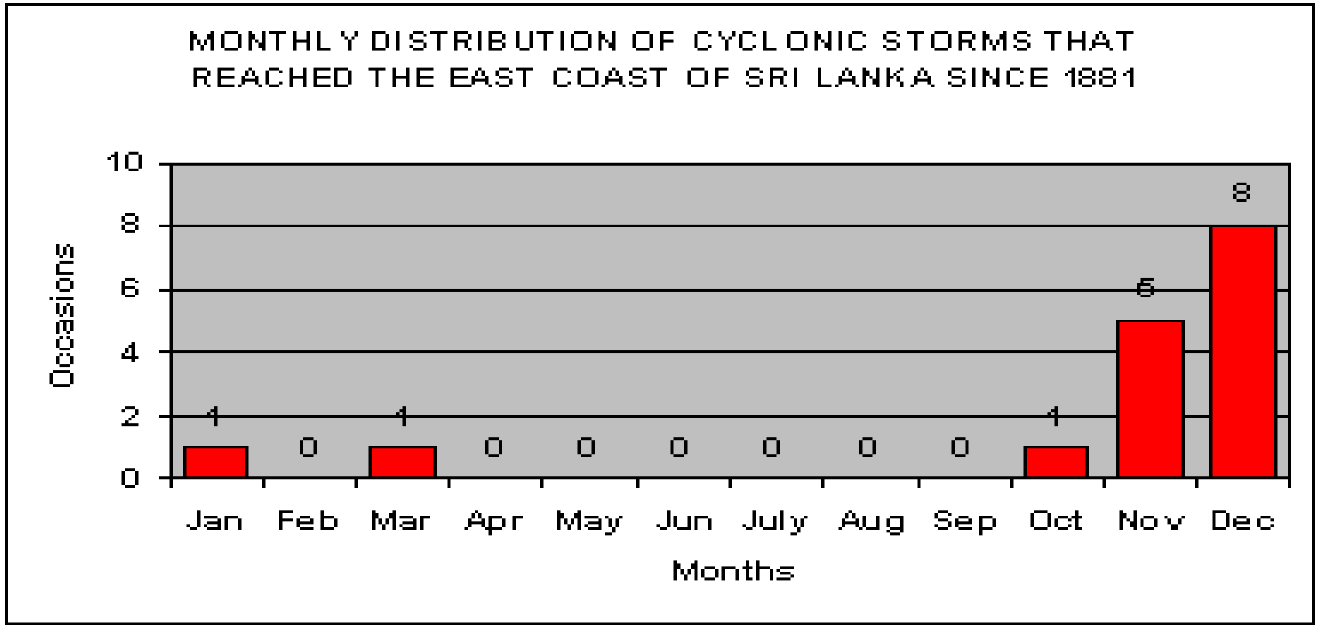
Recurvature:
Tropical storm curves towards the NNE-E. Usually accelerating and decreasing in strength, often increasing in size. Speed is difficult to forecast.

Frictional forces of land:
Often becoming extra-tropical as storm merges with frontal zone.

Unfavorable atmospheric/oceanographic influences:
Includes, but not limited to, upper level shearing, dry air intrusion in mid levels, cooler sea surface temperatures, upwelling behind other tropical systems, etc…



Monthly Distribution of Cyclones That Reached The East Coast of Sri-Lanka Since 1881



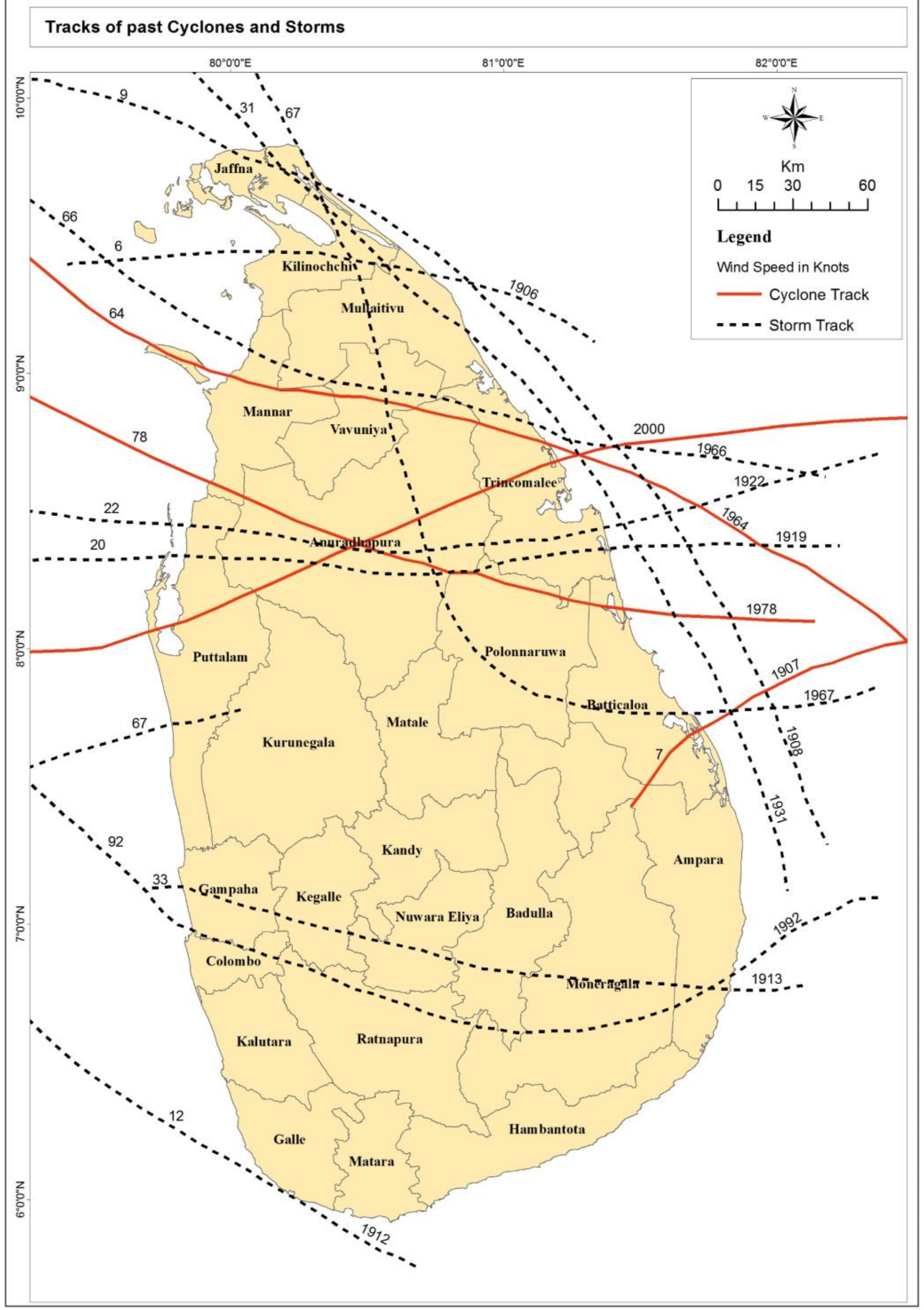
JANUARY - 1906

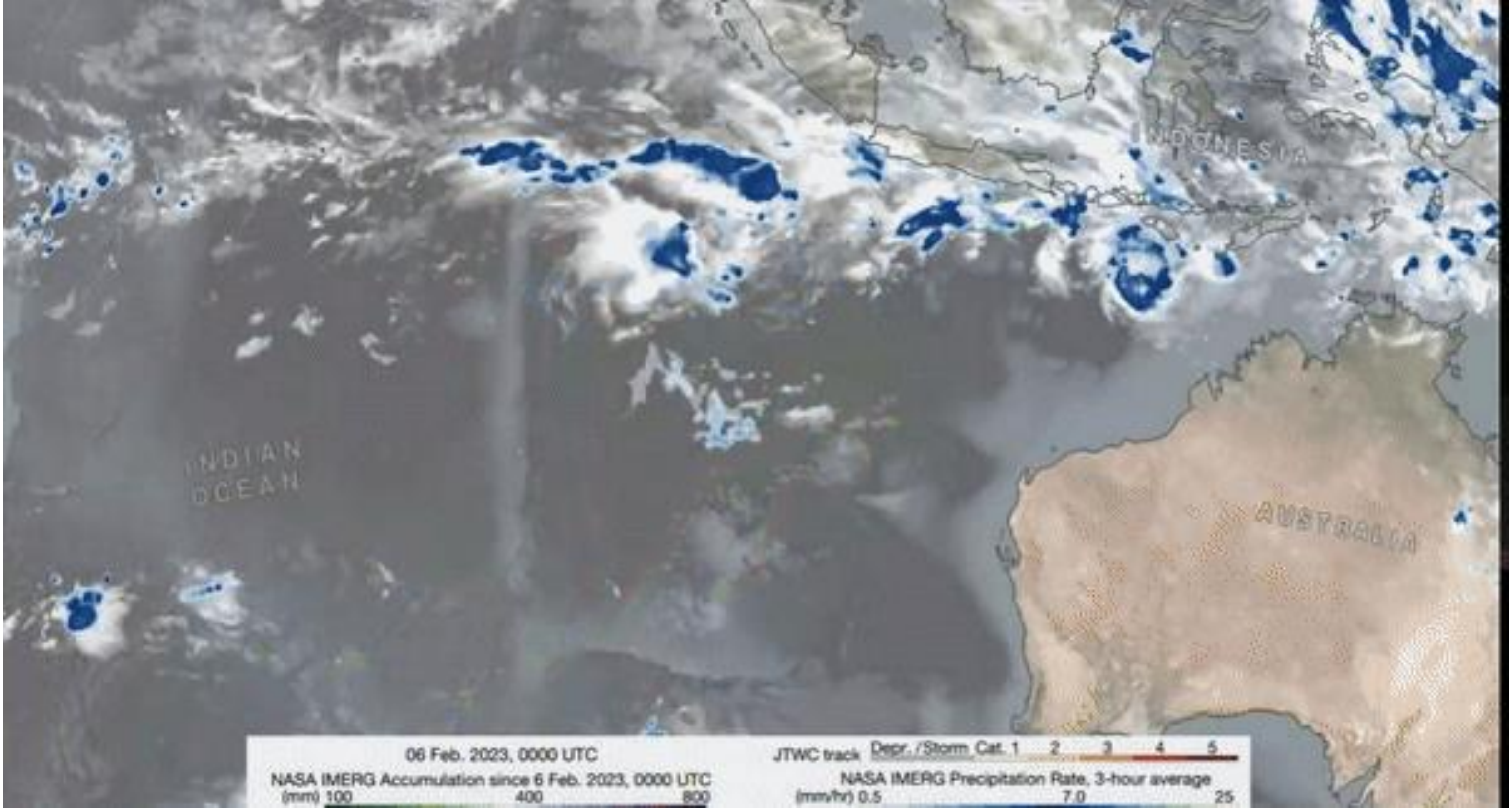
MARCH - 1907

OCTOBER - 1967

NOVEMBER - 1912, 1922, 1966, 1978, 1992

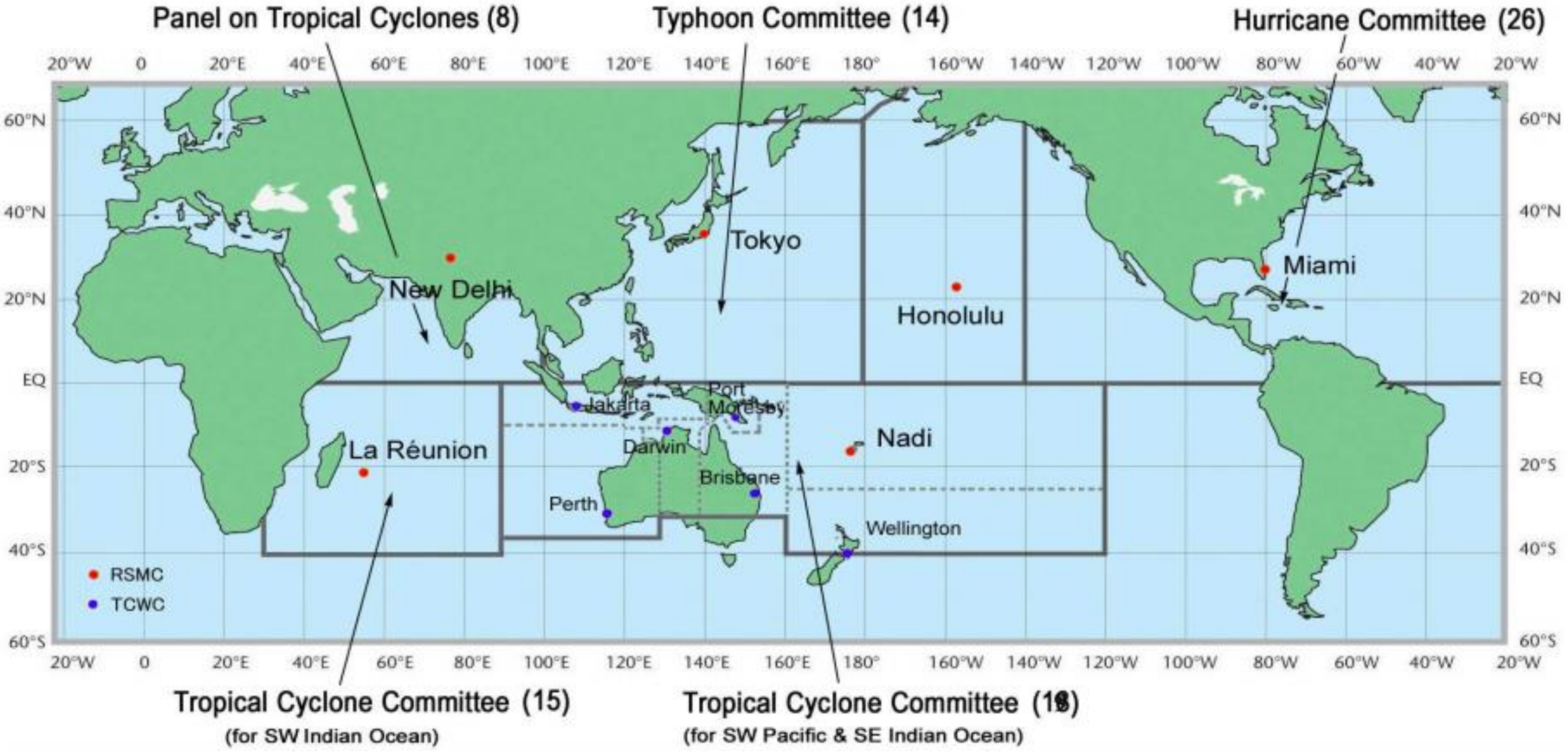
DECEMBER - 1908, 1912, 1913, 1919, 1931, 1964, 1967, 2000





Cyclone Freddy (2023) lasted 36 days, made it the longest-lasting tropical cyclone worldwide, in terms of the number of days maintaining tropical storm status or higher, beating the previous record set by Hurricane John in 1994.

TC Regional Bodies and TC Regional Warning Centres (full coverage)



Panel on Tropical Cyclones - Bay of Bengal and the Arabian Sea

- The **1970 Bhola cyclone** landfall over Bagladesh consired as the deadliest tropical cyclone ever recorded and at least 500,000 people lost their lives in the storm, due to storm surge .
- Recognizing importance of an efficient cyclone warning service in this region, the World Meteorological Organization (WMO) and the Economic and Social Commission for Asia and the Pacific (ESCAP) jointly established the Panel on Tropical Cyclones in 1972 as an intergovernmental body.
- Its membership comprises countries affected by tropical cyclones in the Bay of Bengal and the Arabian Sea.
- Originally its member countries were Bangladesh, India, Myanmar, Pakistan, Sri Lanka and Thailand. Later Maldives joined this Panel in 1982 followed by Sultanate of Oman in 1997, Yemen joined in 2016 and Iran, Qatar, Saudi Arabia & United Arab Emirates joined in 2018.

Tropical cyclone warnings

Tropical cyclone advisories/ alerts/ warnings are issued under two criteria, viz., Distance from the Coast and Intensity of the System, each criterion having key stages.

(a). Distance Criterion

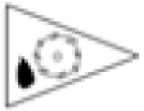
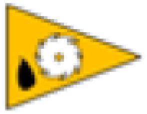
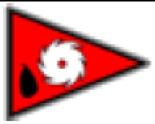
(i) When a depression or a cyclonic storm is about 550 km off the coast. In addition to distance of storm centre from coast, this bulletin indicates forecast conditions on the (a) speed and direction of movement and (b) maximum surface wind speed likely. This bulletin is issued every twelve (12) hours and wherever imperative.

(ii) When the cyclonic storm is 300 km off the coast.

In addition to above contents, information on areas likely to be affected are provided. This bulletin is issued every six (6) hours and wherever imperative. And

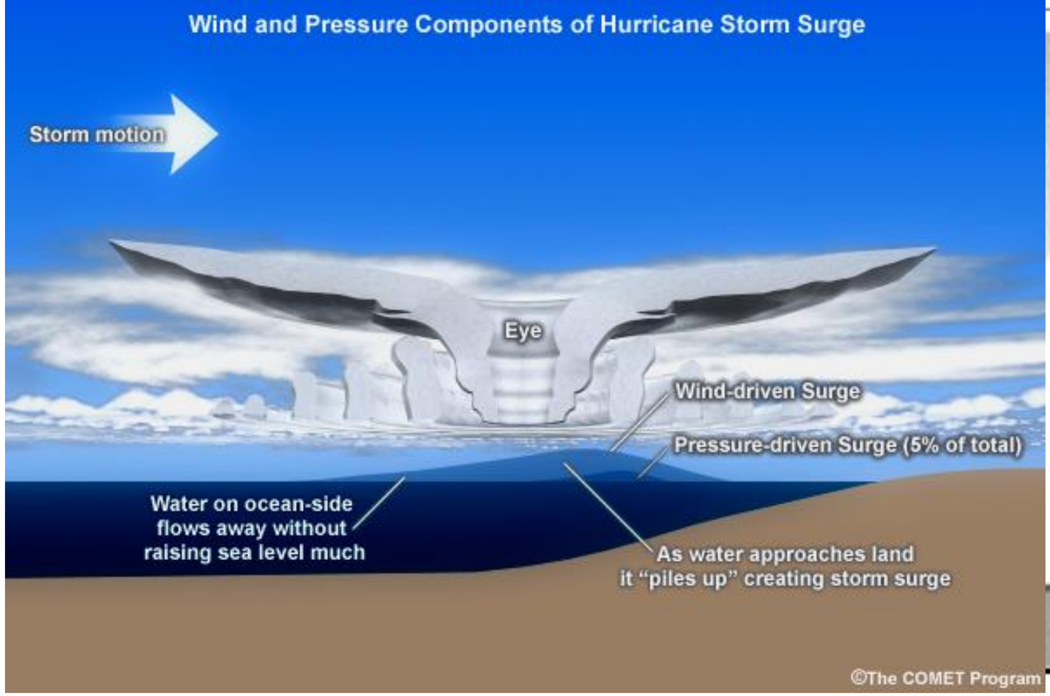
(iii) When the cyclonic storm is 200 km off the coast.

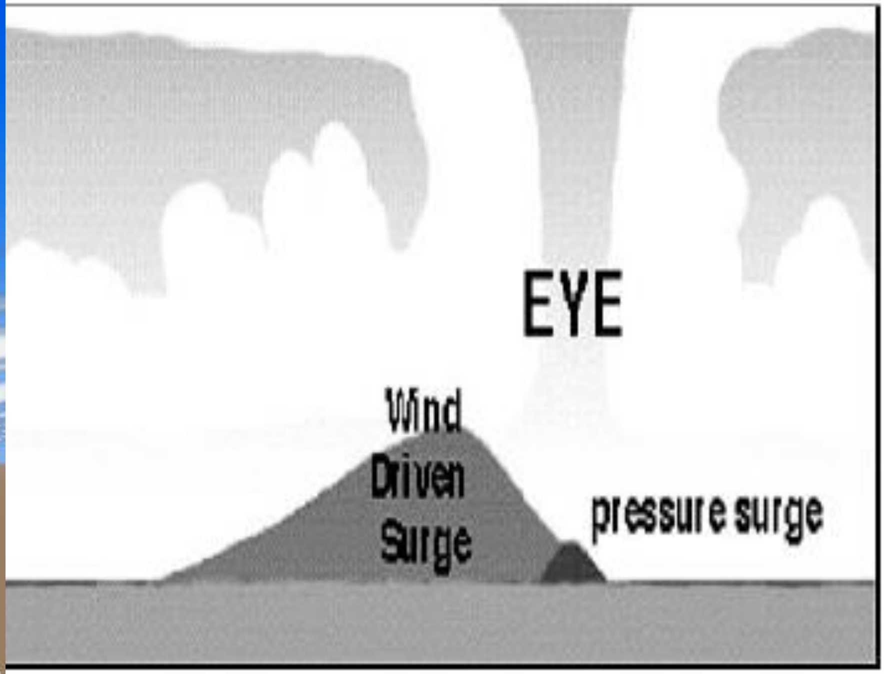
If landfall is indicated, a bulletin is issued every three (3) hour and wherever imperative. This bulletin includes additional information on point of landfall, storm surges and areas likely to be inundated.

Signal No	Colours	Description	Action Required
1	white 	Potential area of possibility to development of vortex /disturbance /	Information only, Vessels at sea to be vigilant and avoid the area, Listen to media
2	Yellow 	Cyclone has formed in the vicinity, heavy rain with strong winds, rough seas (30-40 kts, 55-75kmph)	Stay away from beach/sea, vessels in danger/be inside building/ Be ready to leave weak buildings and low lying areas (flood prone areas), secure your home valuables
3	Red 	Cyclone is expected to cross land, Very heavy rain/very strong winds (v>50kts,100kmph)	Evacuate to predesignated areas
4	Green 	Cyclone warning cancellation/withdrawal bulletin	

storm surge

- Globally, storm surge is the most deadly direct TC hazard.
- The storm surge is created by wind-driven waves with a very small component due to the low-pressure at the center of the cyclone.
- The surge is strongest where the winds are enhanced by the motion of the cyclone, therefore, the right forward quadrant of cyclones in the NH are the most dangerous for storm surge;
- Storm surges are aggravated by high tide.
- Forecast of storm surge height is important because it will provide useful information for early warnings and evacuation preparations for the coastal communities to reduce the hazards.





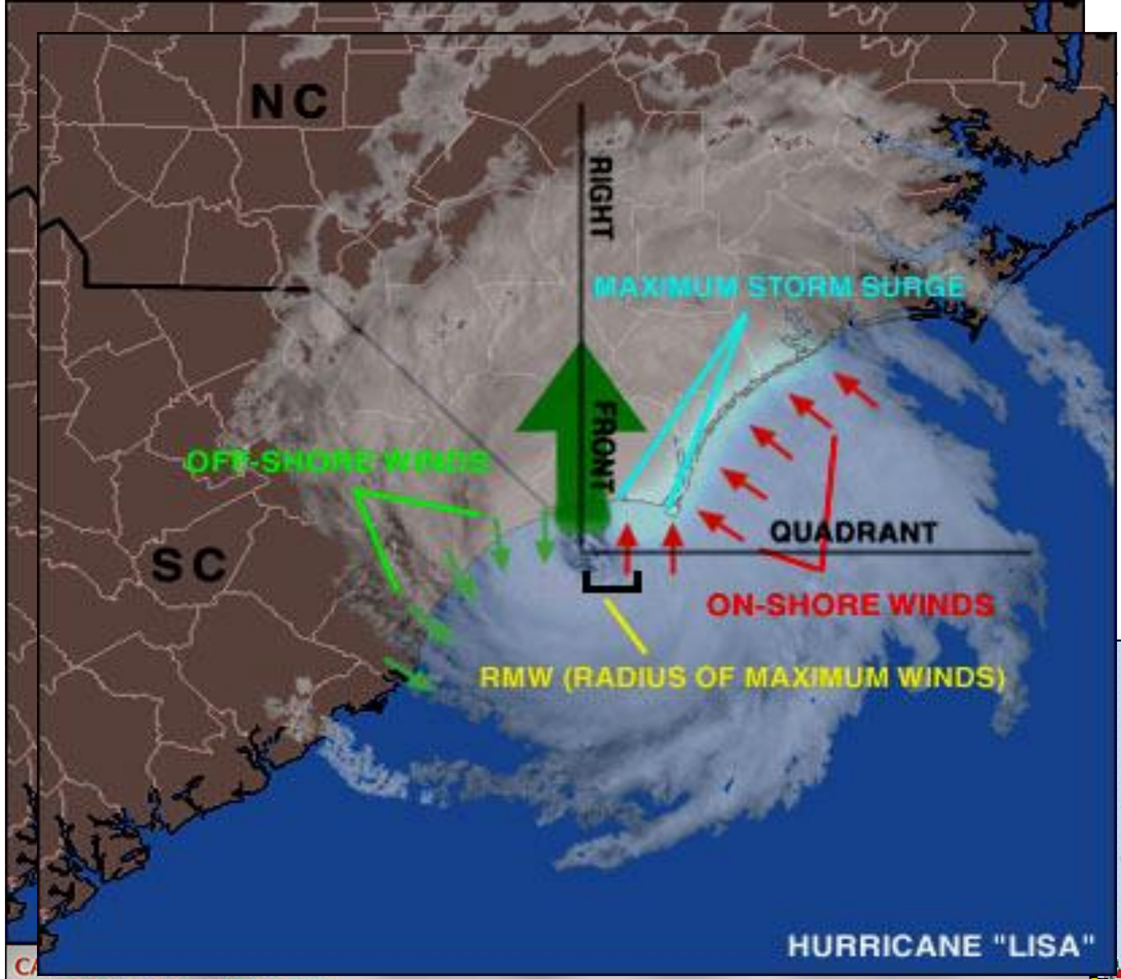
There are two basic mechanisms for storm surge generation at or near the shoreline:

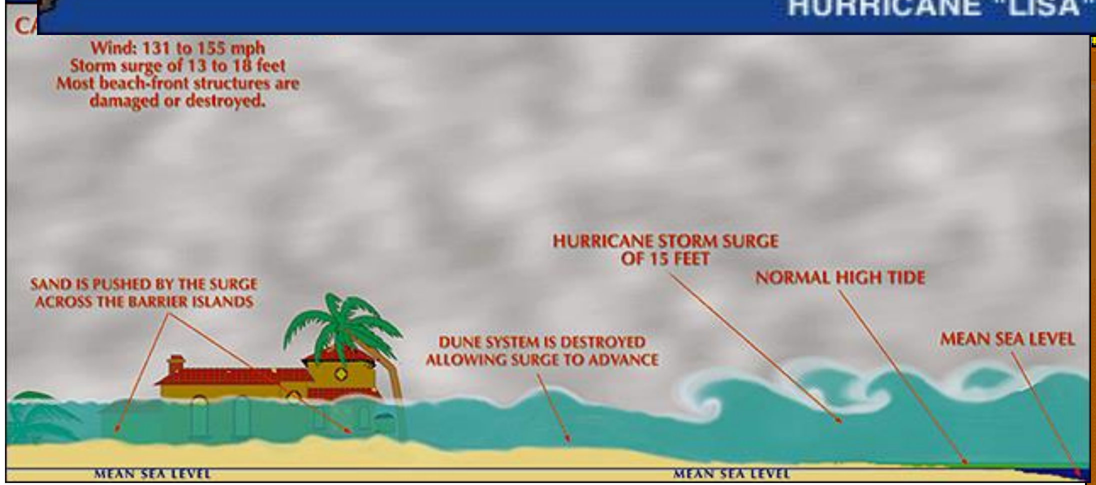
1) wind-driven surge caused by strong onshore winds
2) inverted barometric effect (pressure surge),

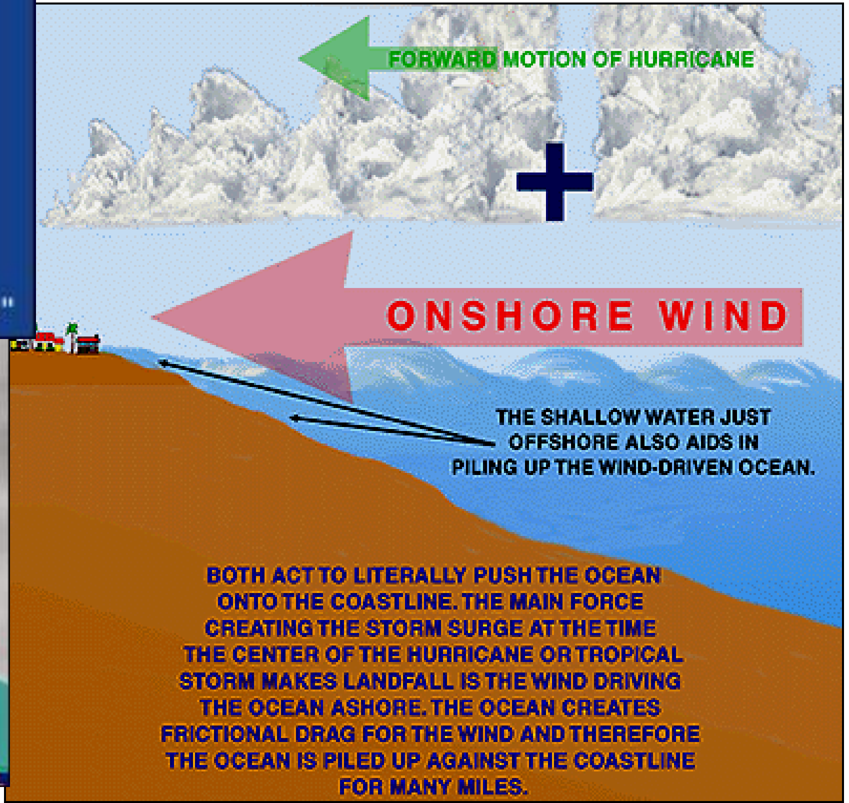
pressure surge (*inverted barometer effect where the ocean level is slightly higher in the center of the cyclone due to the lowered atmospheric pressure*) is small compared with the surface wind stress.

•**Pressure surge** : **fall of pressure of 1 hPa will lead to rise of about 1cm in the sea level.**

The **right-front quadrant** of a cyclone typically contains the strongest winds and thus, the highest storm surge.

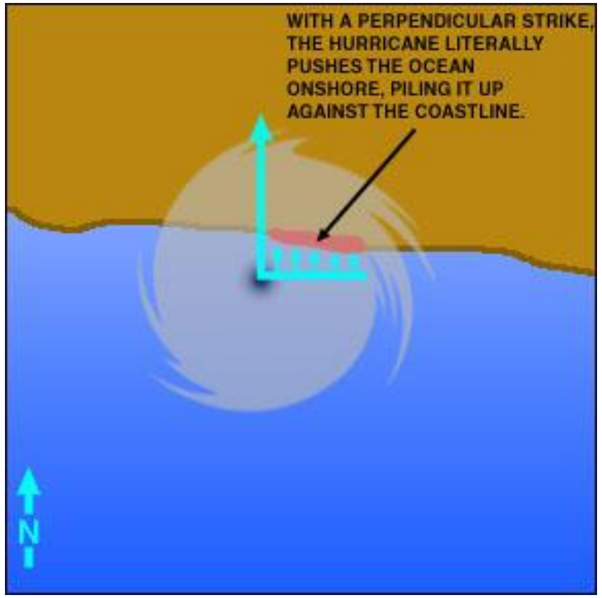






factors influencing Storm Surge

- Storm surge phenomenon is known to be highly dependent on off shore coastal bathymetry.
- The shallowness of the water in coastal regions may considerably modify the surge heights in the region.
- A Tropical Cyclone striking the coast perpendicular, will do the most damage as far as storm surge is concerned.
- 10 hPa pressure drops may lead to to 12-13% in the surge amplitude
- Increase of 10 Km of radius of maximum sustained wind may lead to 25-30% in estimating the surge amplitude



Storm surge and coastal flooding depend on a number of factors. There are several other effects that can influence the size and destructiveness of a storm surge.

High rainfall amounts can lead to fresh water flooding, which can exacerbate the storm surge problem.

If a cyclone makes landfall in a location where several rivers empty into the ocean, the runoff from the rivers can increase flooding. An example of this is Bangladesh, which is located in a low lying flood plain where several rivers empty into the Indian Ocean.

The shape of the coastline also has a strong effect on the size of a storm surge. A concave coastline is favored for greater storm surge, as water can be funneled toward the center of the coastline.

IIT storm surge model is simulated to see the possibility of occurrence of surge as indirect effect of a cyclone moving close to Sri Lanka. The onshore wind component of the cyclone produce surge with 0.5m height between Mannar, Veravil and Poonerin in North-northwest coast where bathymetry is very shallow.

Burevi Cyclone : Nov 30 –Dec 03 2020

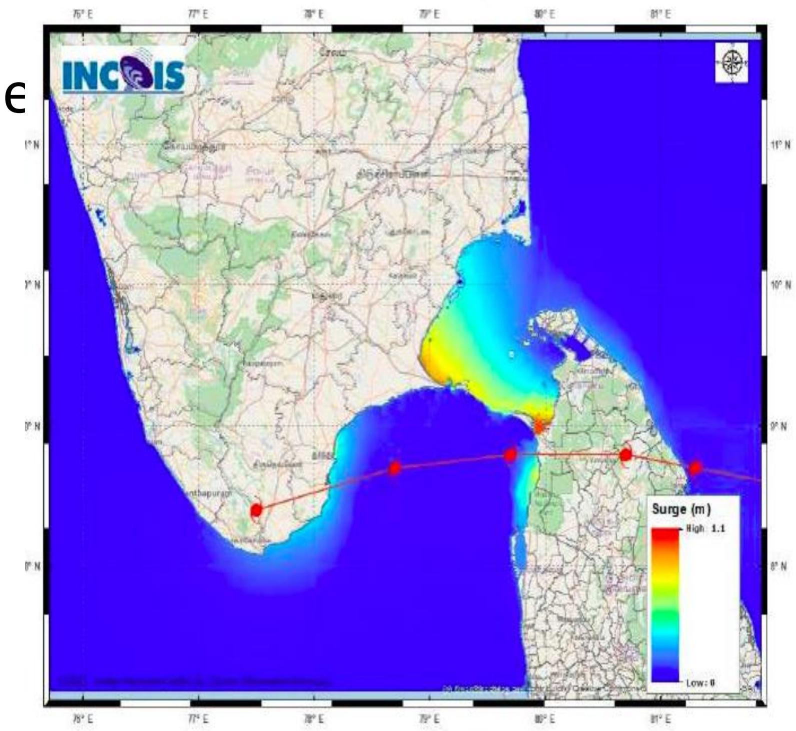
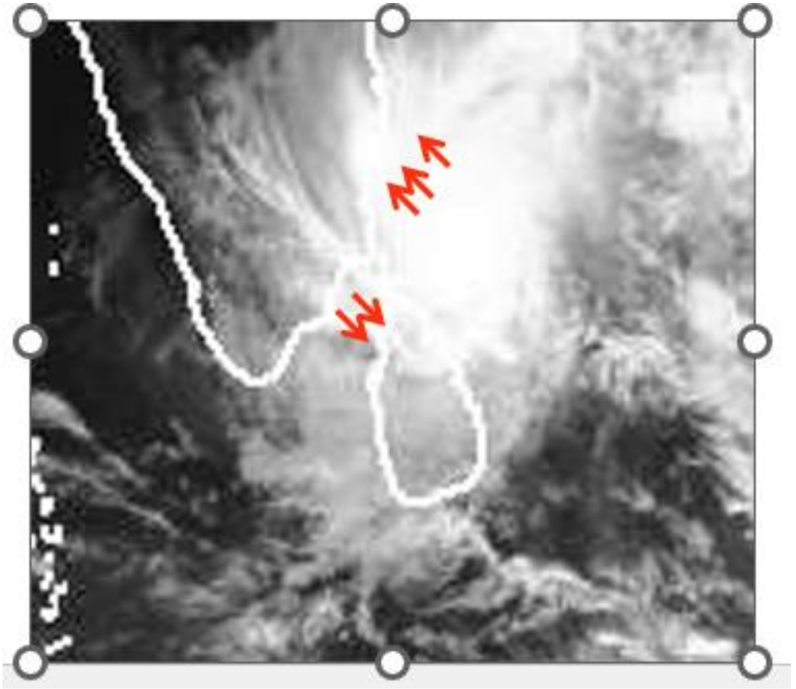
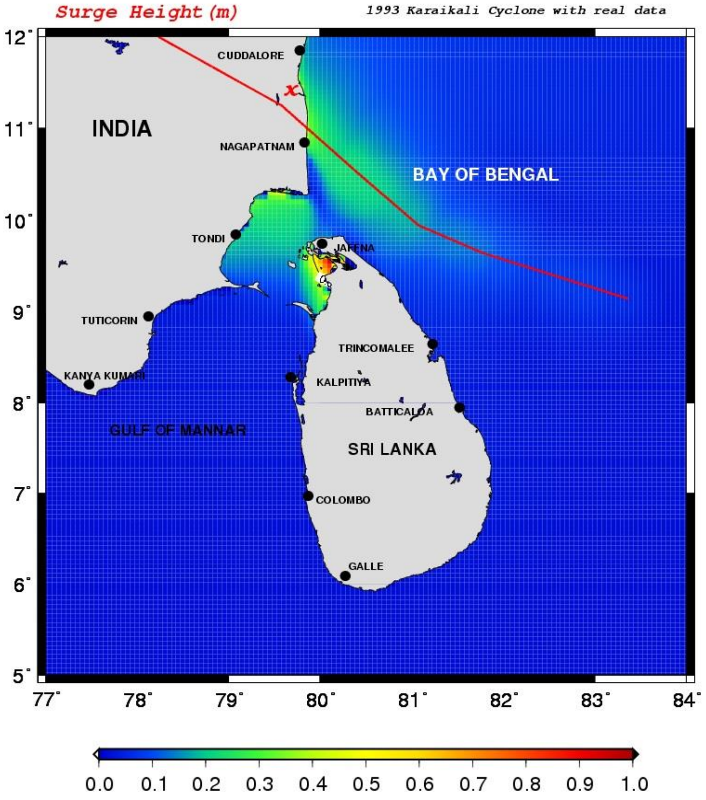


Figure:Storm Surge Map

Storm Surge Forecast by INCOIS Model

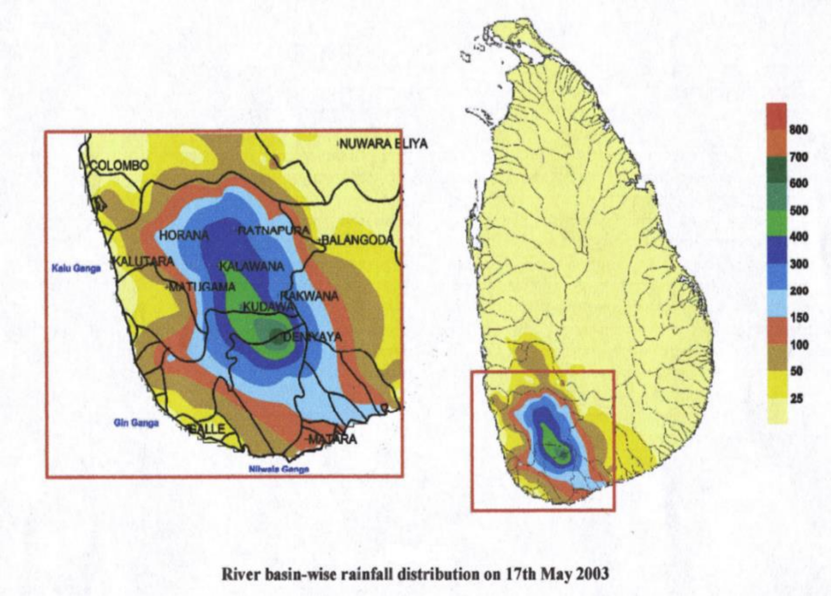
1993 Cyclone : Nov 27 –Dec 05):



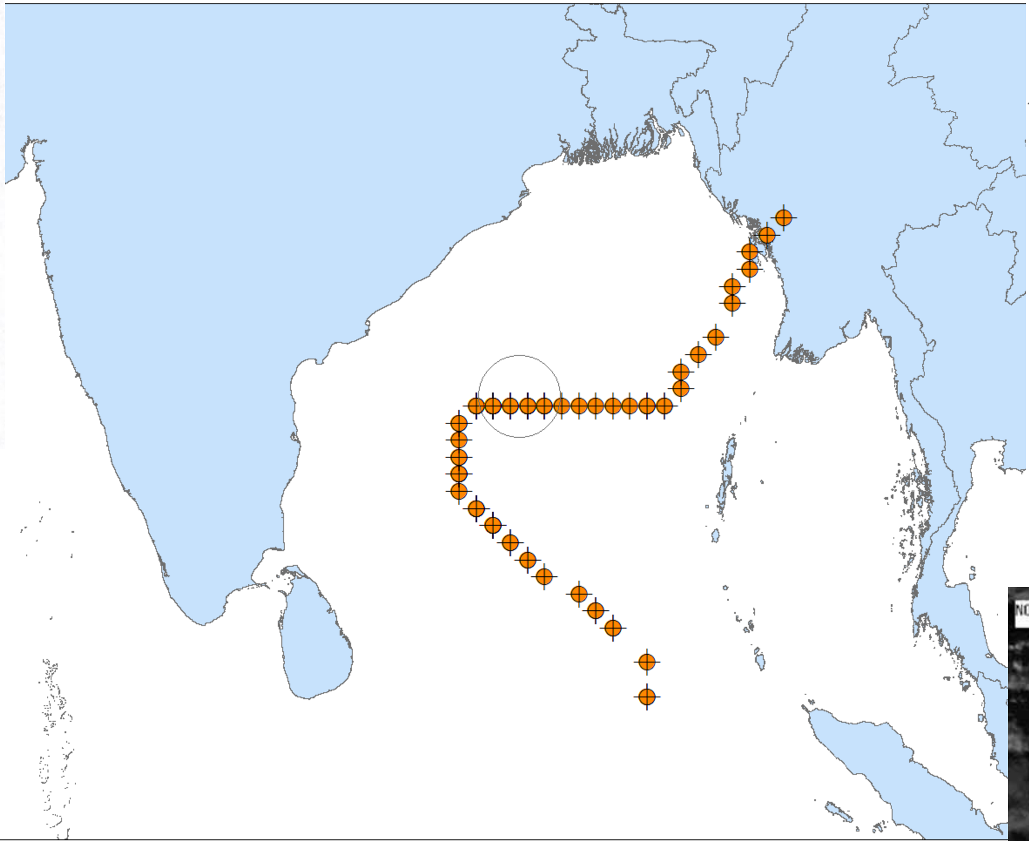


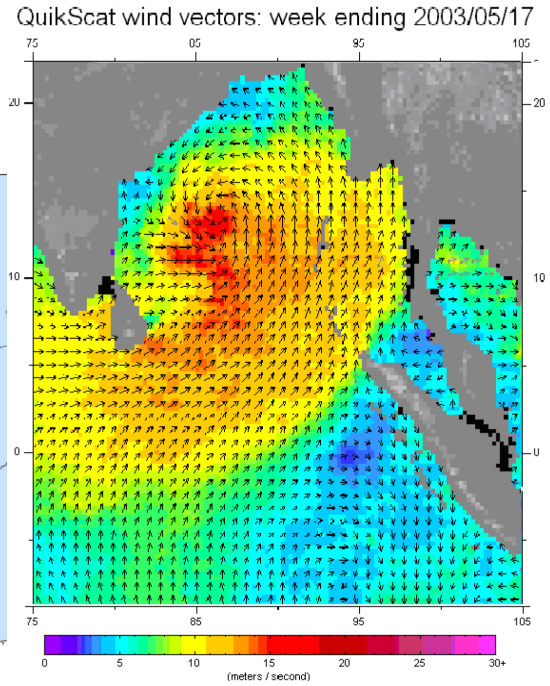
STORM SURGE GUIDNACE FOR SRILANKA COAST: STORM SURGE OF ABOUT 1 METER HEIGHT ABOVE THE ASTRONOMICAL TIDE IS LIKELY TO INUNDATE LOW LYING AREAS OF EAST SRILANKA COAST DURING LANDFALL.

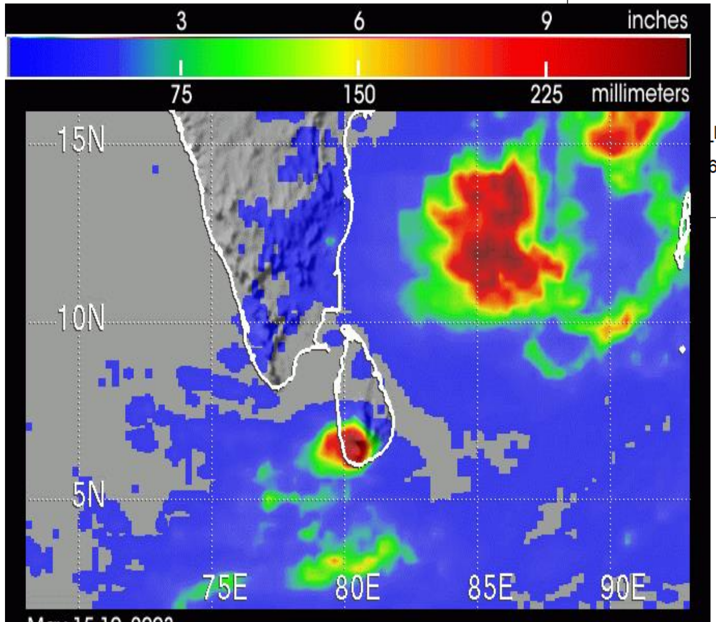
May 2003

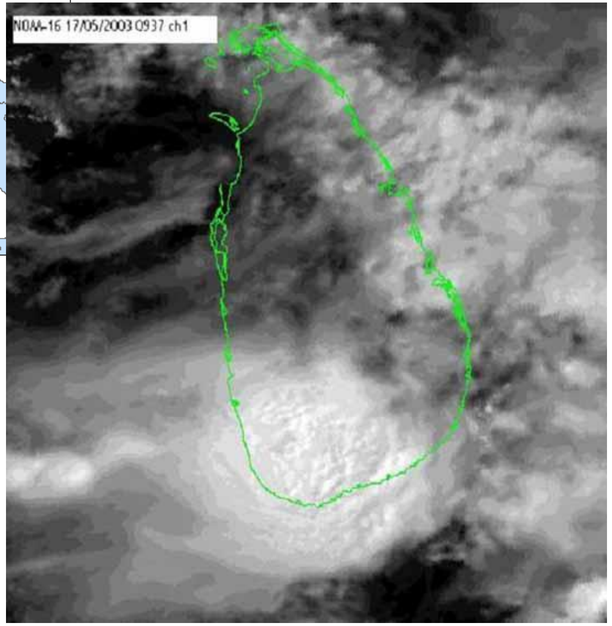


: Rainfall distribution 17 May 2003 (Chandrapala 2003)



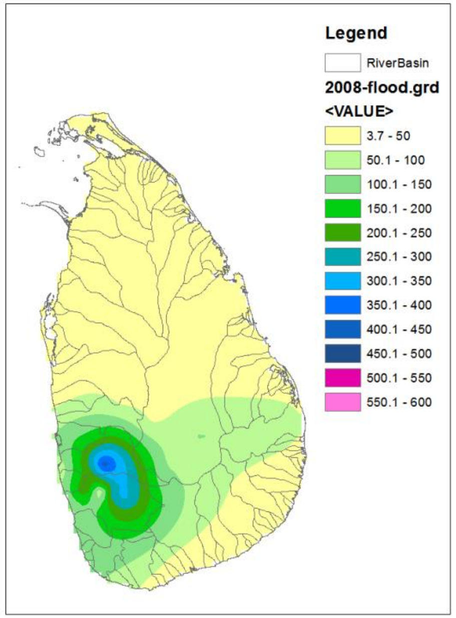


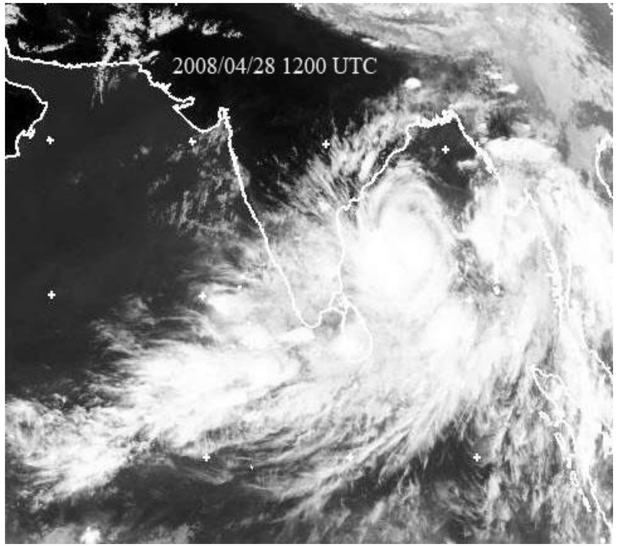


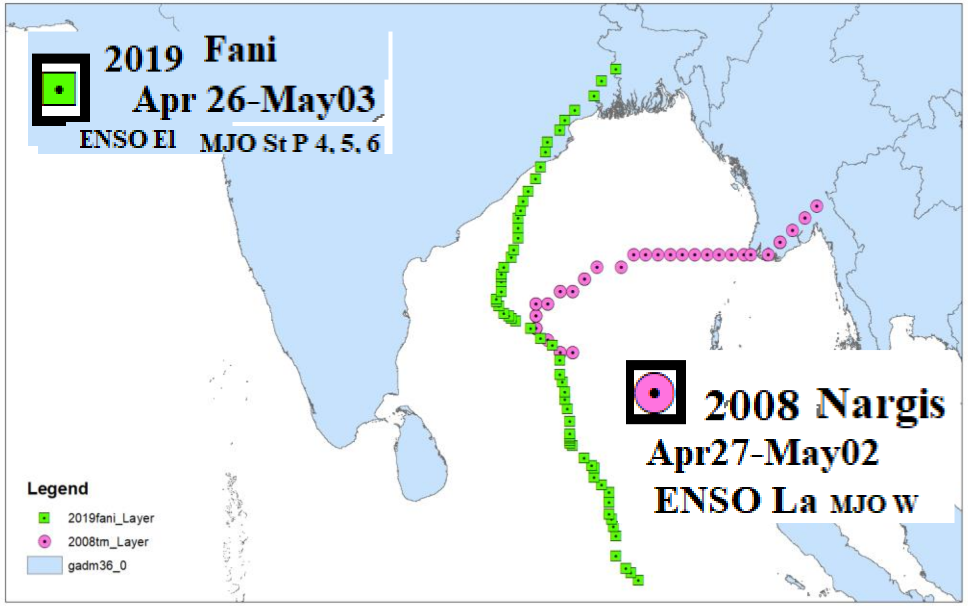


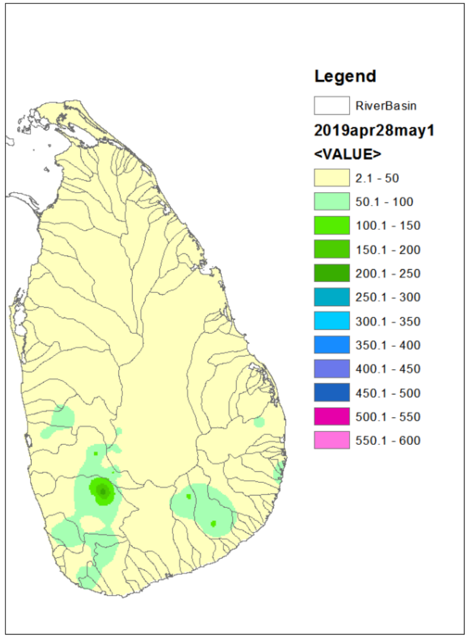
Number of Deaths	236
Number of missing	19
Houses totally destroyed	9,136
Houses partly damaged	30,385
Families affected by Floods & Land Slides	137,221

2008 April 28-May 01 event

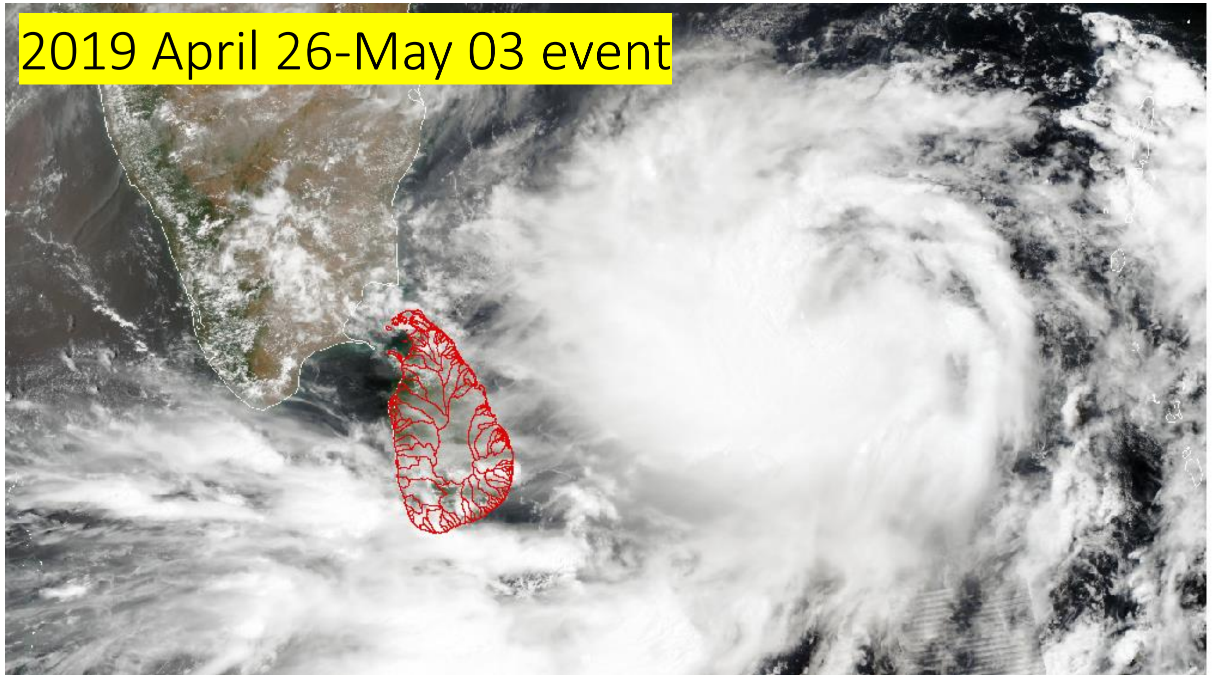




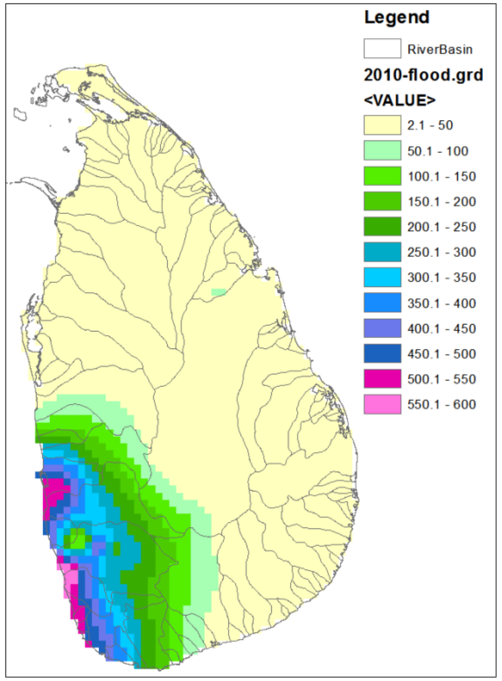


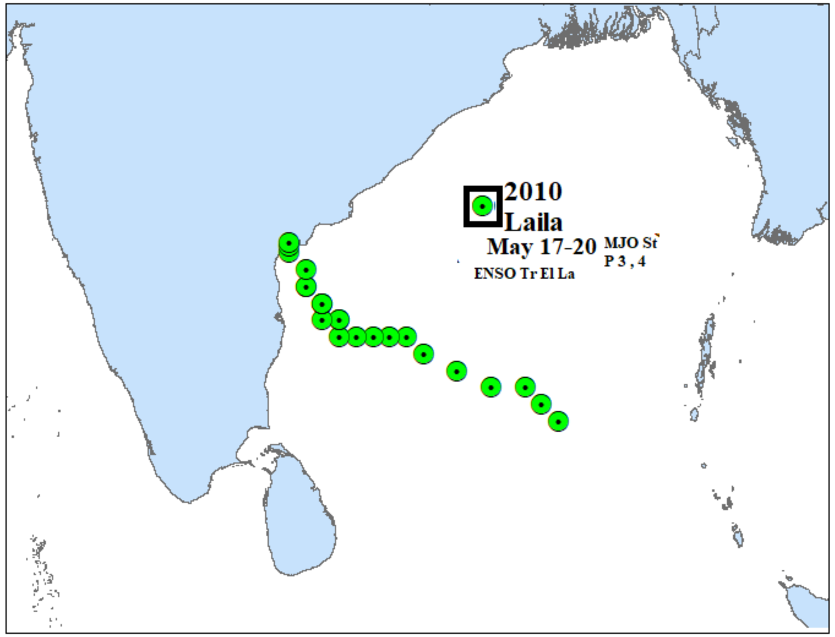


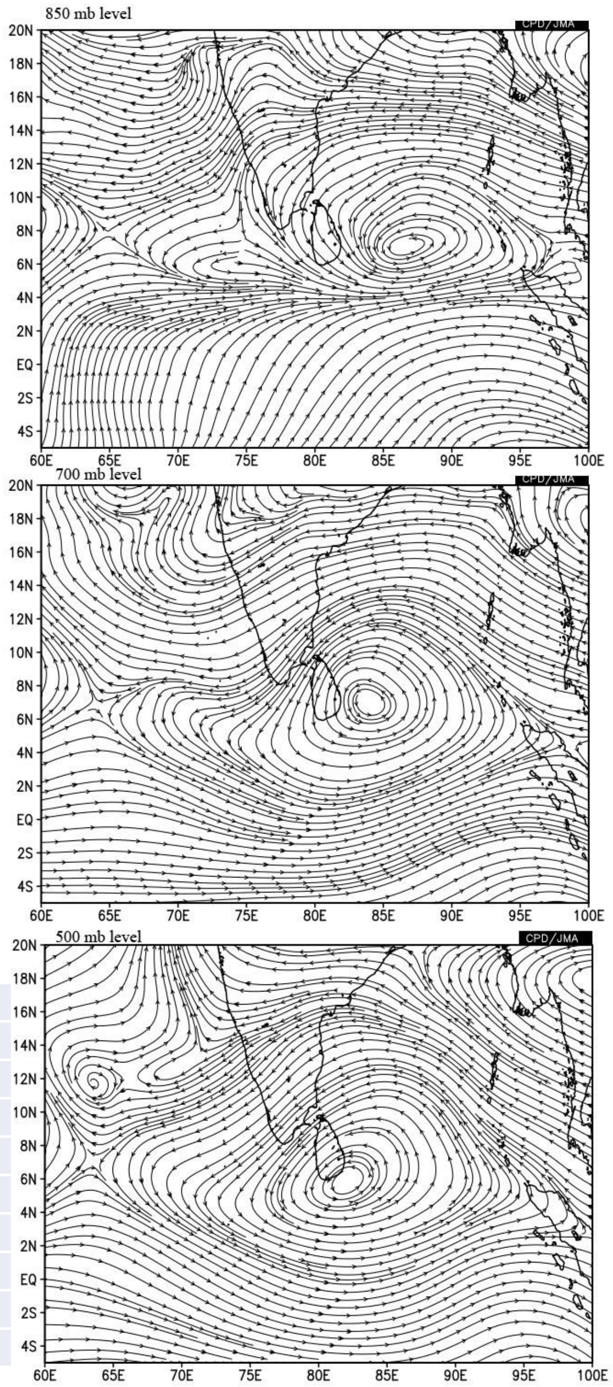
2019 April 26-May 03 event

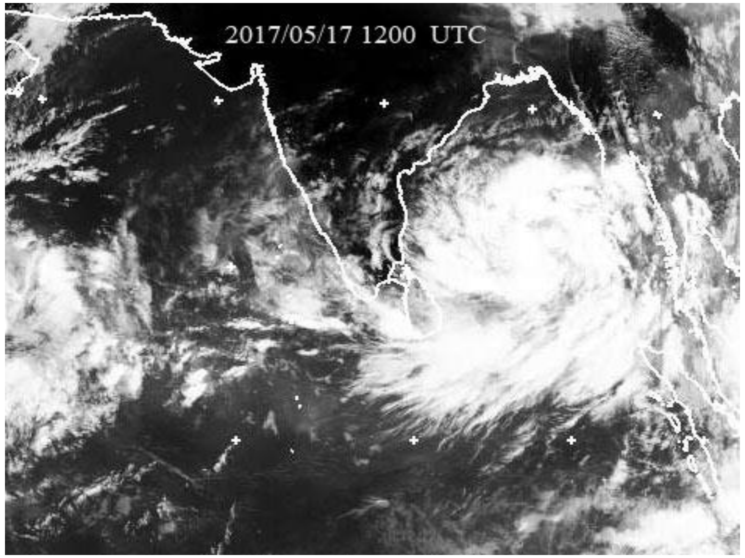


2010 event (May 14-18)









RF on May 17

Elston	313.0
Gampaha	283.0
Kalatuwawa	219.5
Labugama	216.4
Hanwella	210.0
Kukuleganga	188.0
Bandaragama	174.0
Dehiwala(Zoo)	168.0
Avissawella	157.0

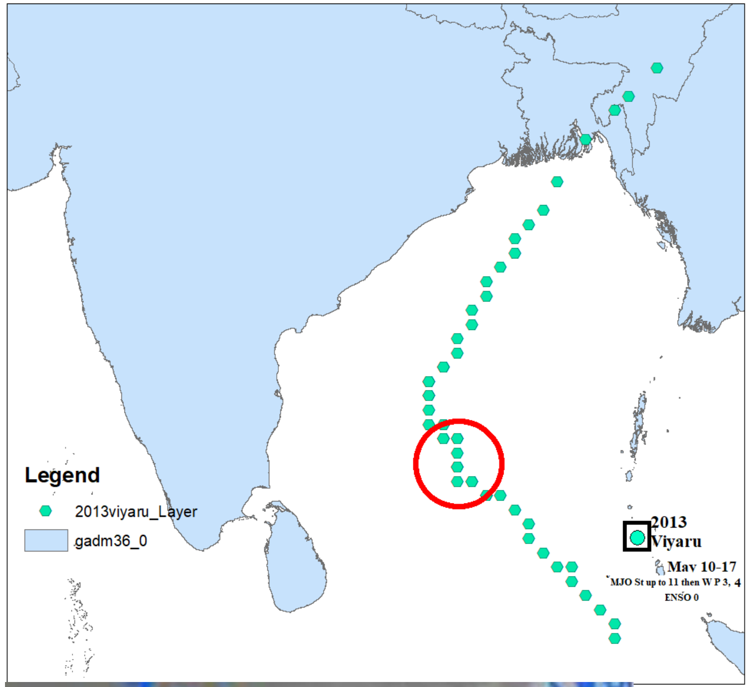
RF on May 18

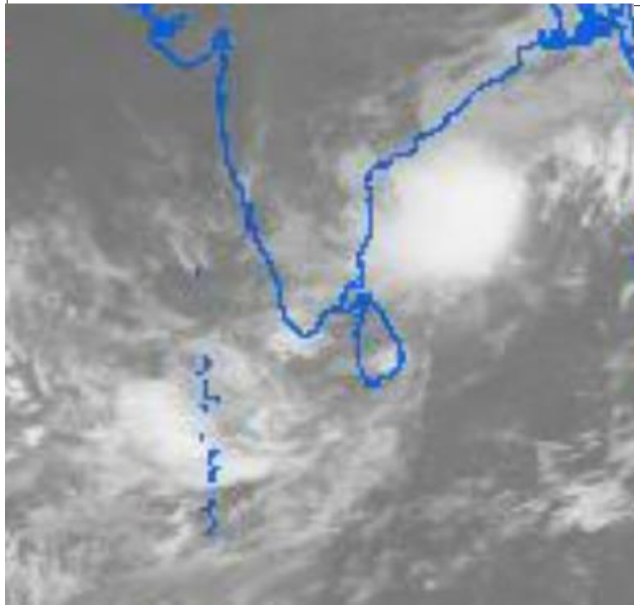
Galle	283.8
Kalutara	278.6
Mathugama	184.9
Ratmalana	177.1
Neboda	172.3
Colombo Fort	147.3
Kukuleganga	135.0
Colombo	133.1
Hiniduma	123.7
Maliboda	106.8

Cyclonic Storm Viyaru May 10-17, 2013

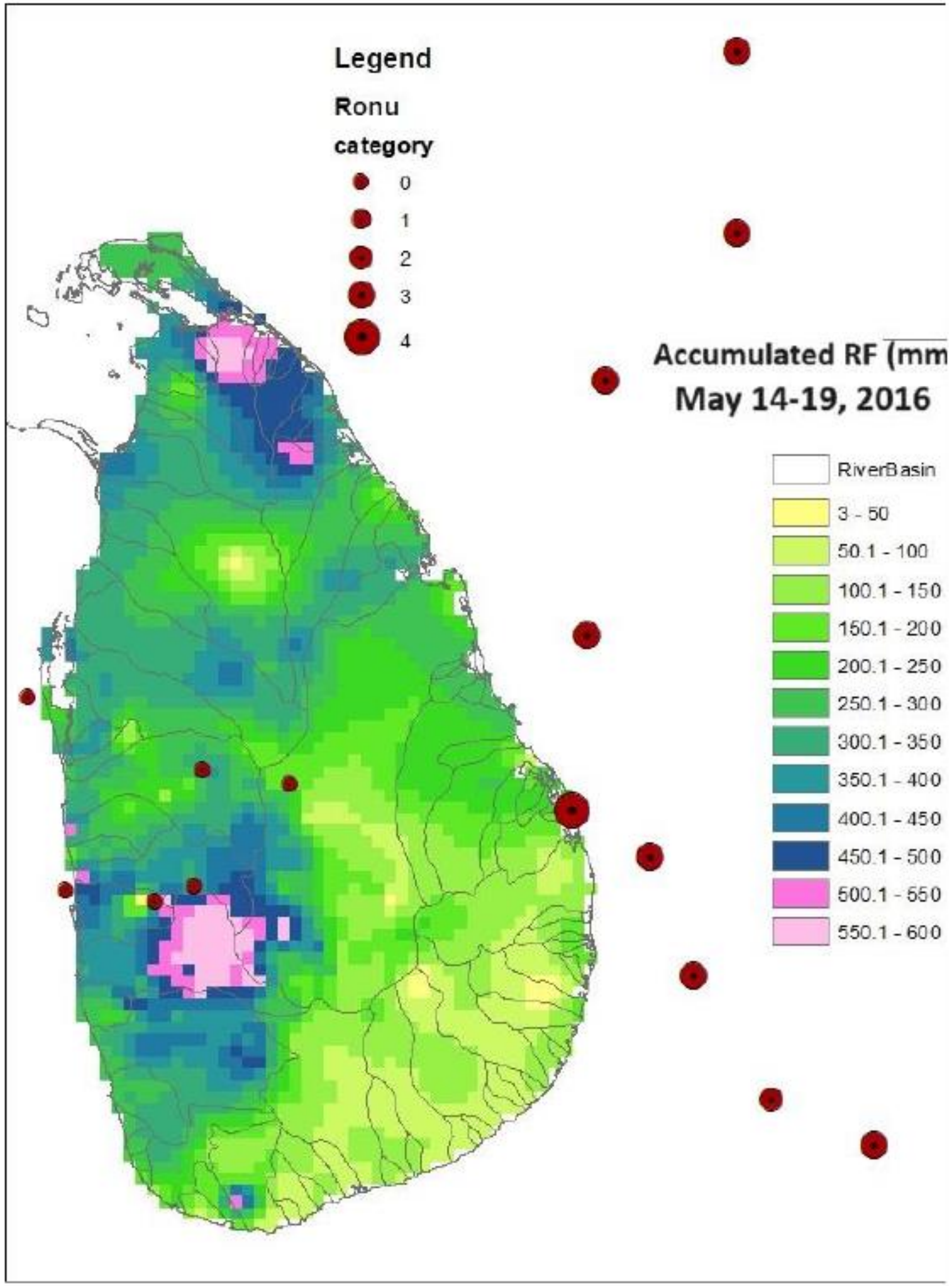
2013 May 13 Rainfall (mm)

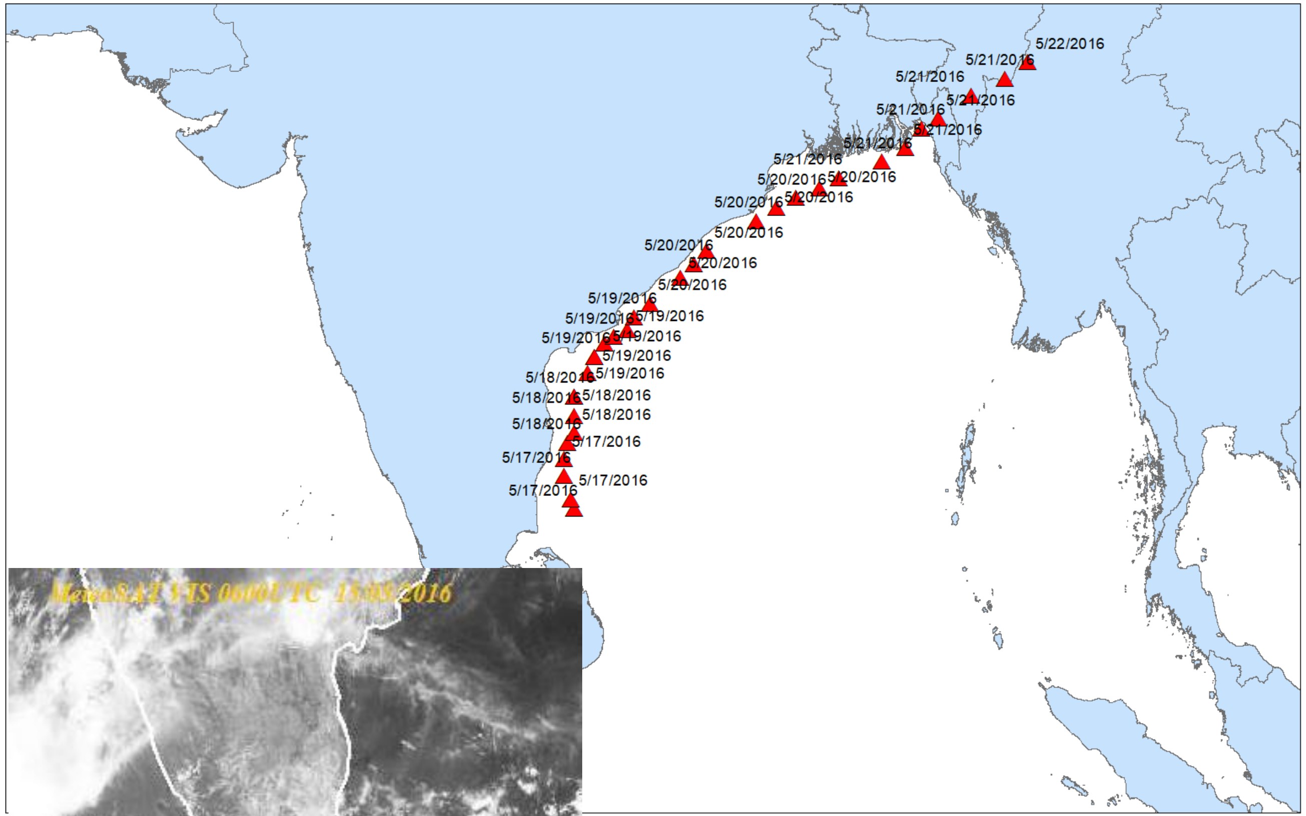
Canyon	409.1
Castlereigh	393.7
Norton	373.4
Maussakele	354.1
Kotagala Rosita	318.4
Laksapana	272.5
Upper kotmalee	241
Kotmale	191
Wellawa	177.4
Maskeliya	162
Yatiyanthota	154.6
Detanagalla	151.4
Helboda North	148
Balangoda	146
Batalagoda	146
Undugoda	145.6
Weweltalawa	144.2
Dodangaslanda	141.4
Udaradella	138
Bogawanthalawa	135.5
Embilipitiya	127.6

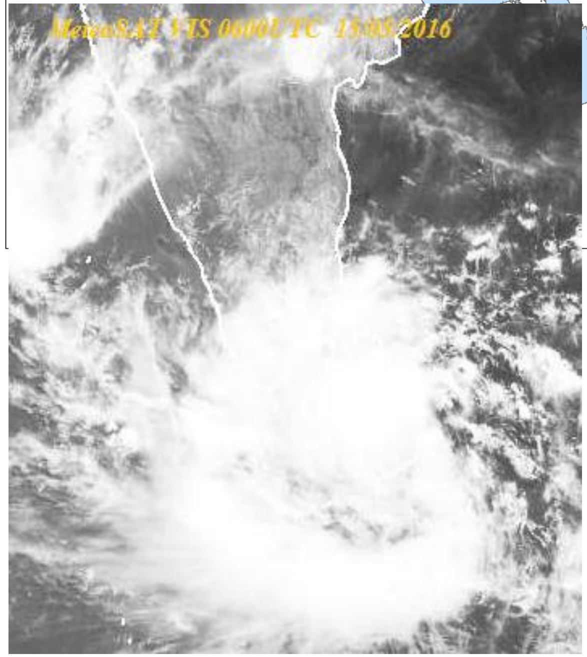




2016 May event

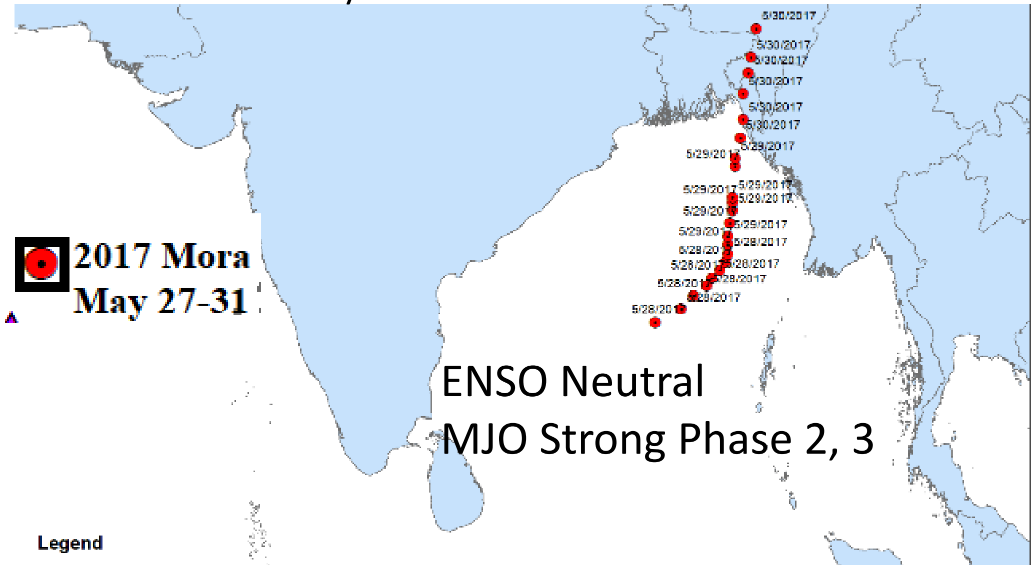


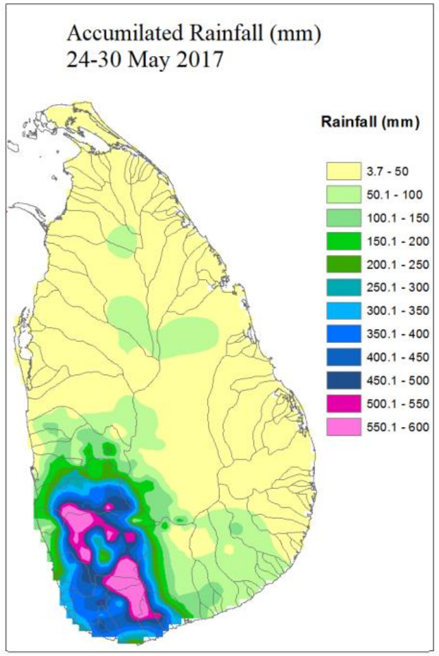


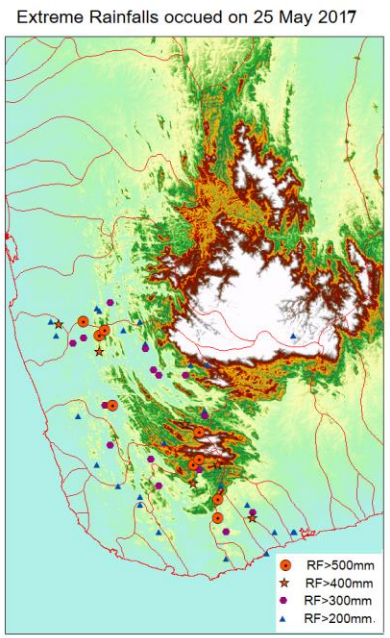


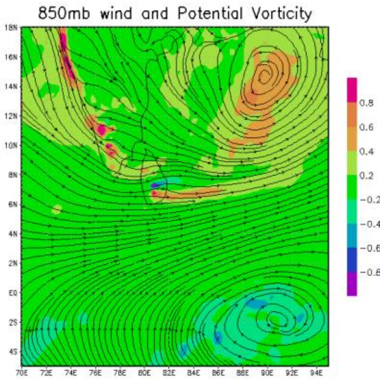
Cyclone Ronu - May 17-22, 2016
ENSO Transition from El Nino to Neutral
MJO Strong Phase 2, 3, 4

May 2017

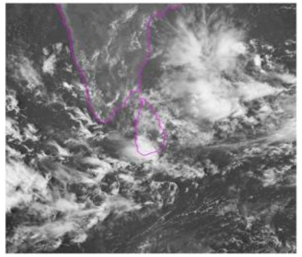






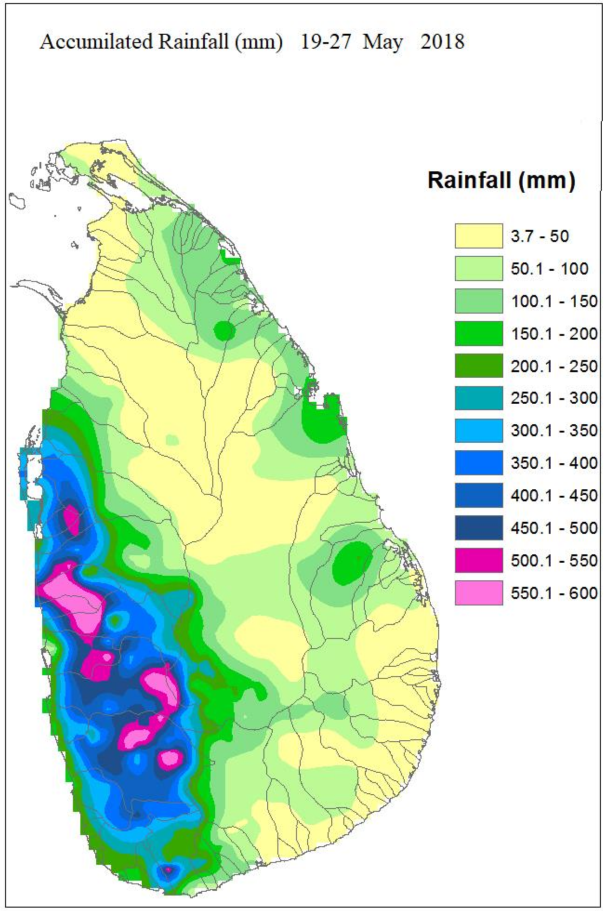


VIS Image 25/05/2017 0630Z

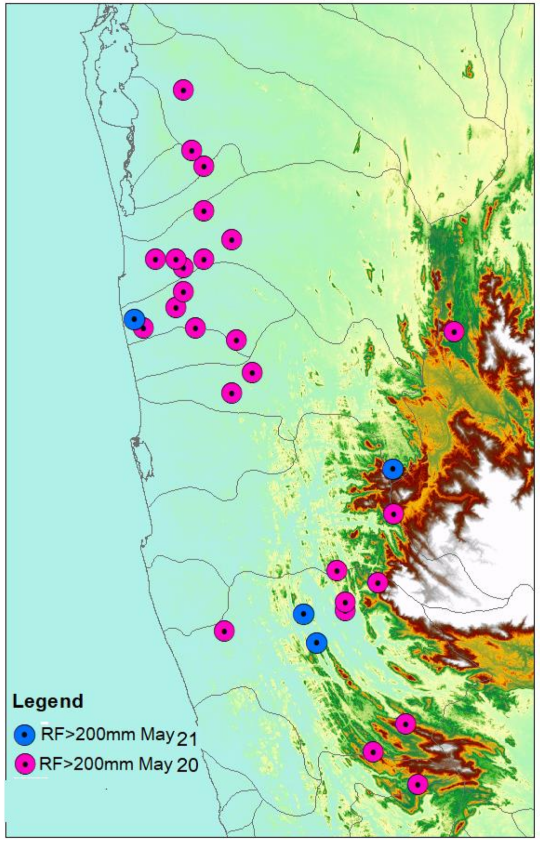


station_name	May25
LABUGAMA TANK	643.5
PALLEGAMA	607.8
Beverly Estate	586
KEKIRIOBOCLA TANK	567
KALATUWAWA	548.3
THALAPATHKANDA	540.5
DEPEDENA GROUP	540
HANWELLA GROUP	520
USK VALLEY S.P.	512
WEERAKETIYA IRRIGATION	497.5
Delwala	490
KOTAPOLA	460
RAYIGAMA	450
ANNINGKANDA ESTATE	446
Meegoda-Nawalamulla	418.3
MUTWAGALLA ESTATE	398
MEDAMULANA	396.7
BATUWANGALA	395.6
MILLEWA ESTATE	395
PELAWATTE	390.5
PADUKKA ESTATE	387.2
LELLOPITIYA ESTATE	380
DENIYAYA WILLIE GROUP	372
RATNAPURA	348.5
OPATHA	344.2
DELKETH EST(BADURALIYA)	340.2
WELLANDURA ESTATE	338.5
DENAGAMA	325
AVISSAWELLA HOSPITAL	314.2
KERAGALA	311.5

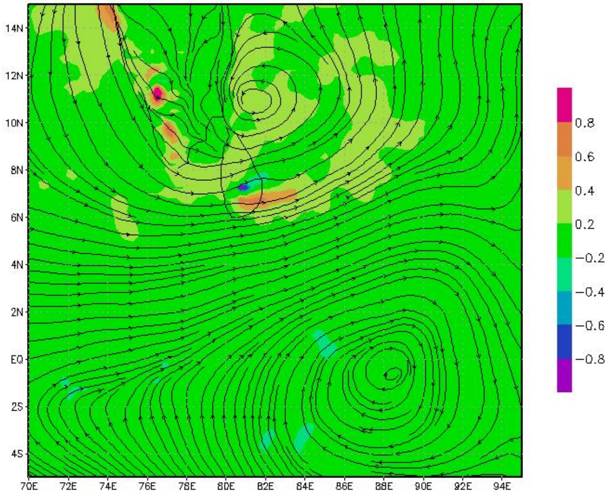
2018 May 19-27



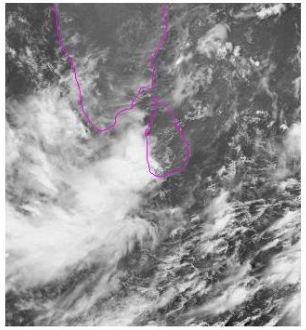
Rainfall Extremes > 200mm on
20th and 21st May 2018



850mb wind and Potential Vorticity



VIS Image 2018/05/20
0630Z



VIS Image 2018/05/25
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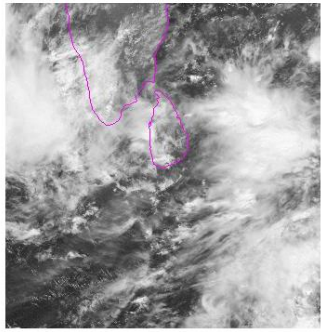
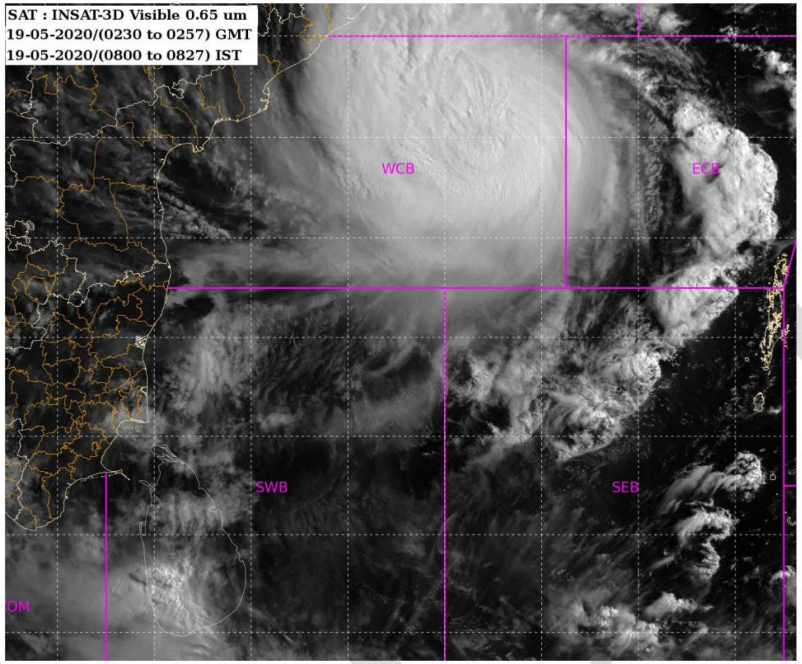
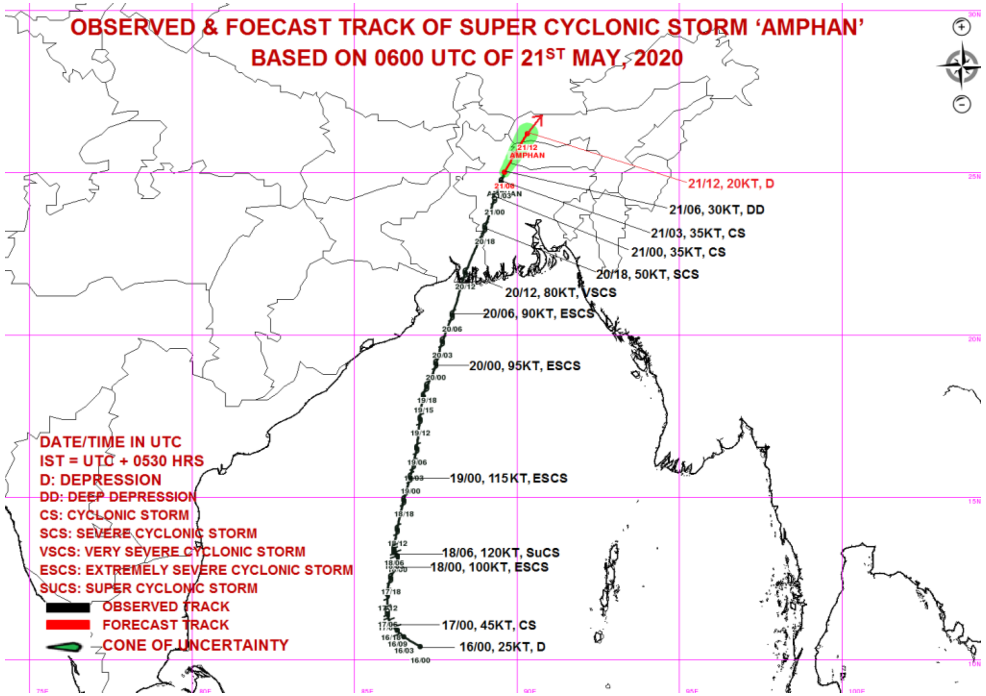


ENSO Transition from La Nina to Neutral
MJO Strong Phase 2, 3

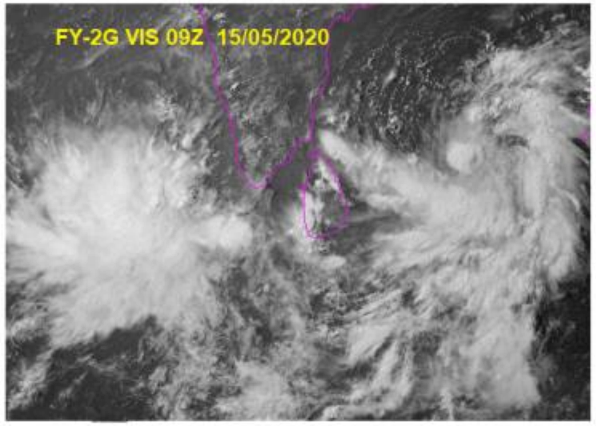


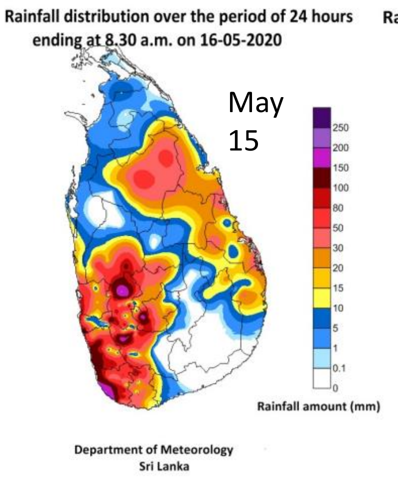


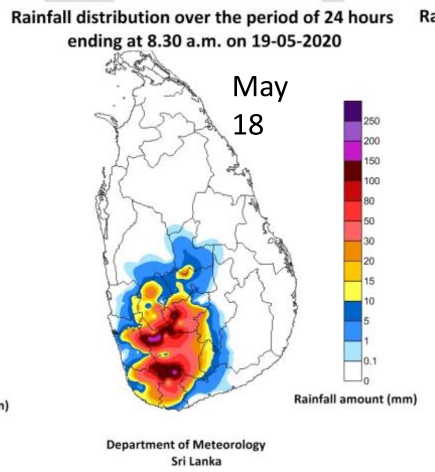
2020 May 15-19

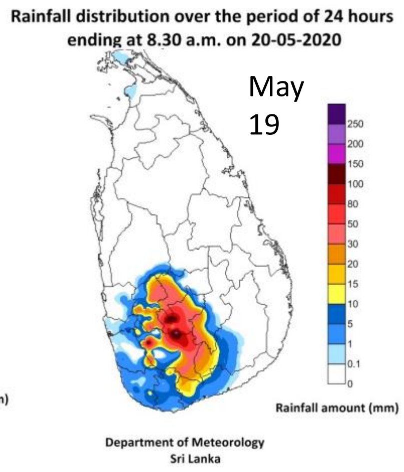
ENSO Neutral

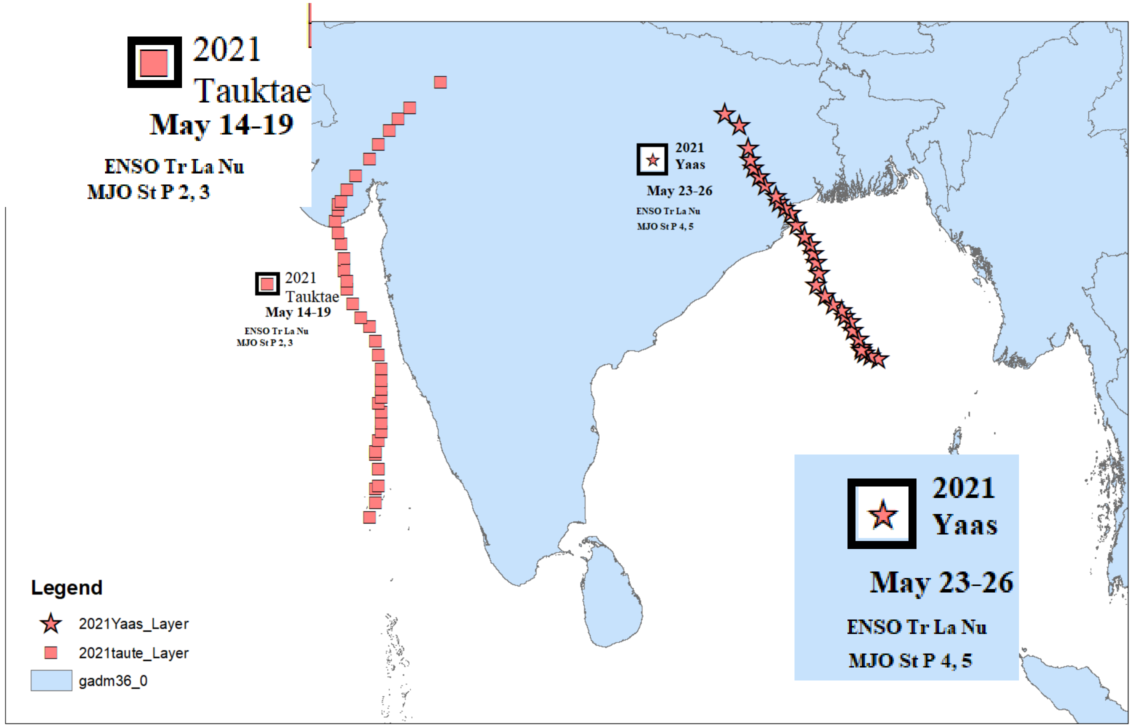
MJO Strong Phase 2

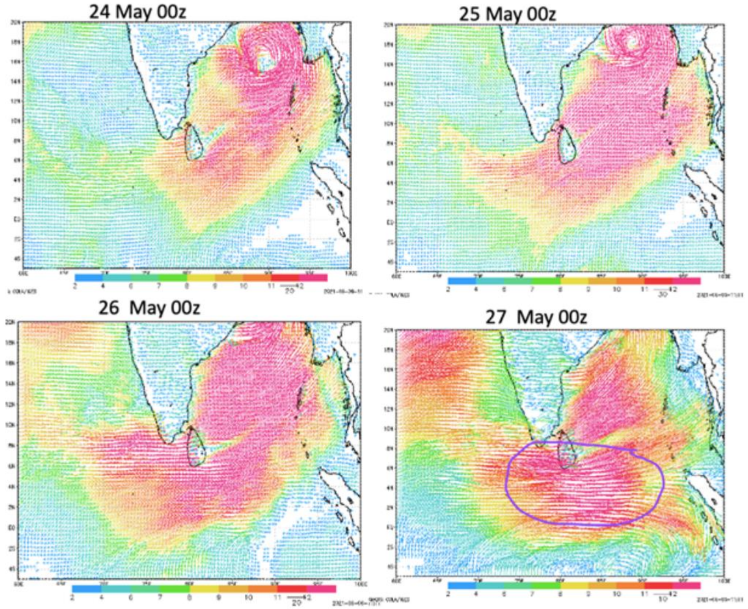


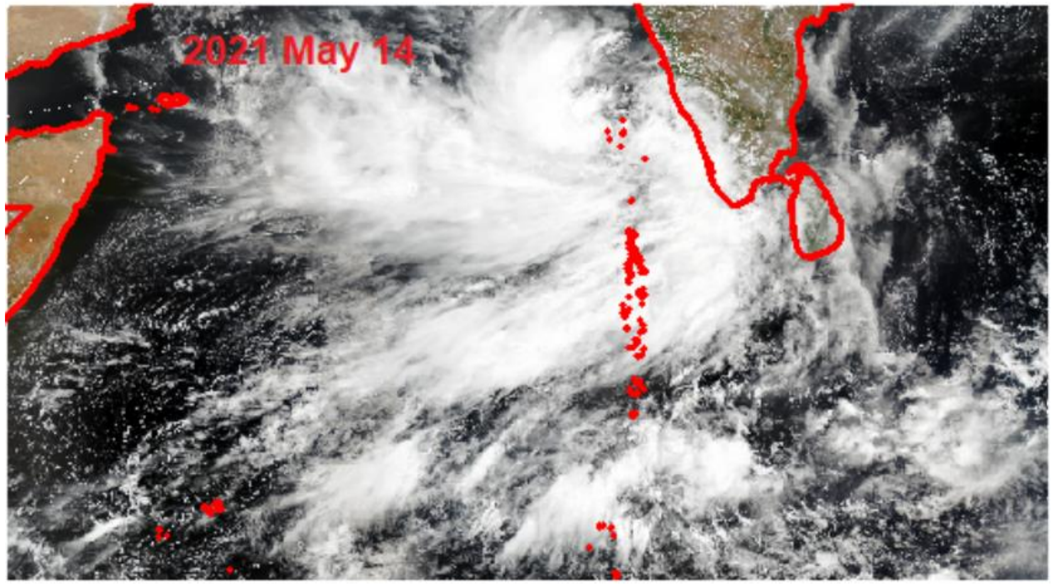


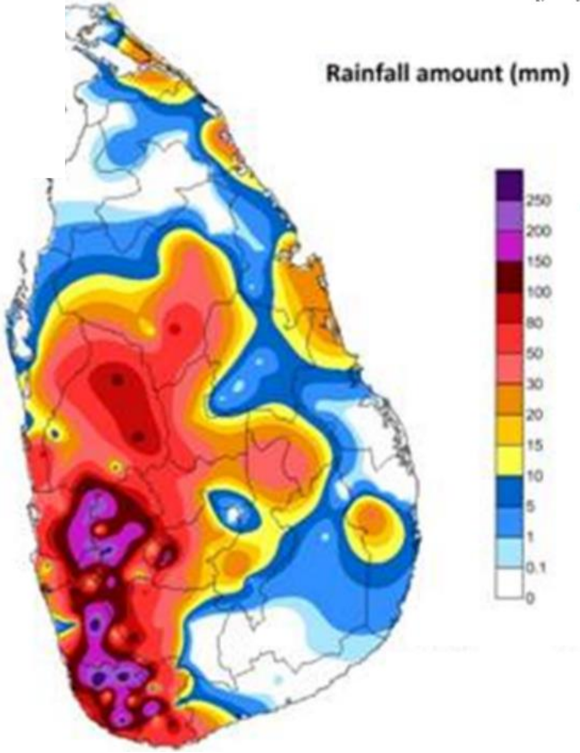


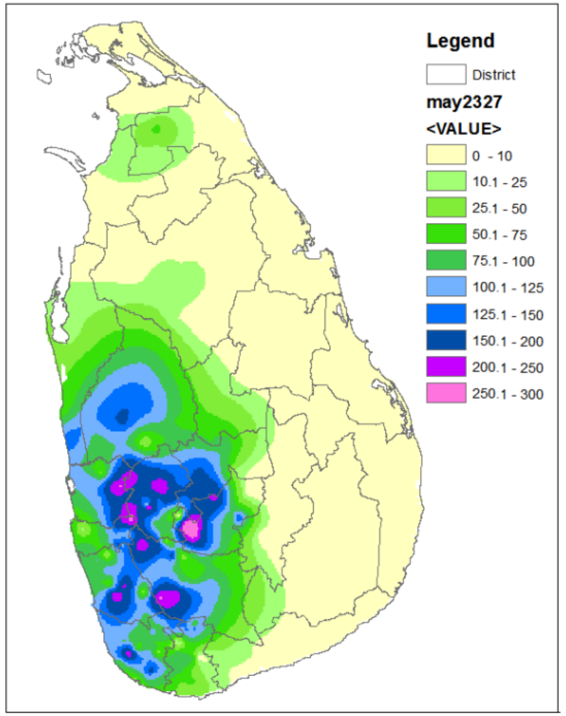



2021
Tauktae
May 14-19
ENSO Tr La Nu
MJO St P 2, 3
2021
Yaas
May 23-26
ENSO Tr La Nu
MJO St P 4, 5
2021
Tauktae
May 14-19
2021
Yaas
May 23-26
ENSO Tr La Nu
MJO St P 4, 5
Legend
2021Yaas_Layer
2021taute_Layer
gadm36_0


24 May 00z
25 May 00z
26 May 00z
27 May 00z


2021 May 14


Rainfall amount (mm)
250
200
150
100
80
50
30
20
15
10
5
1
0.1
0


Legend
District
may2327
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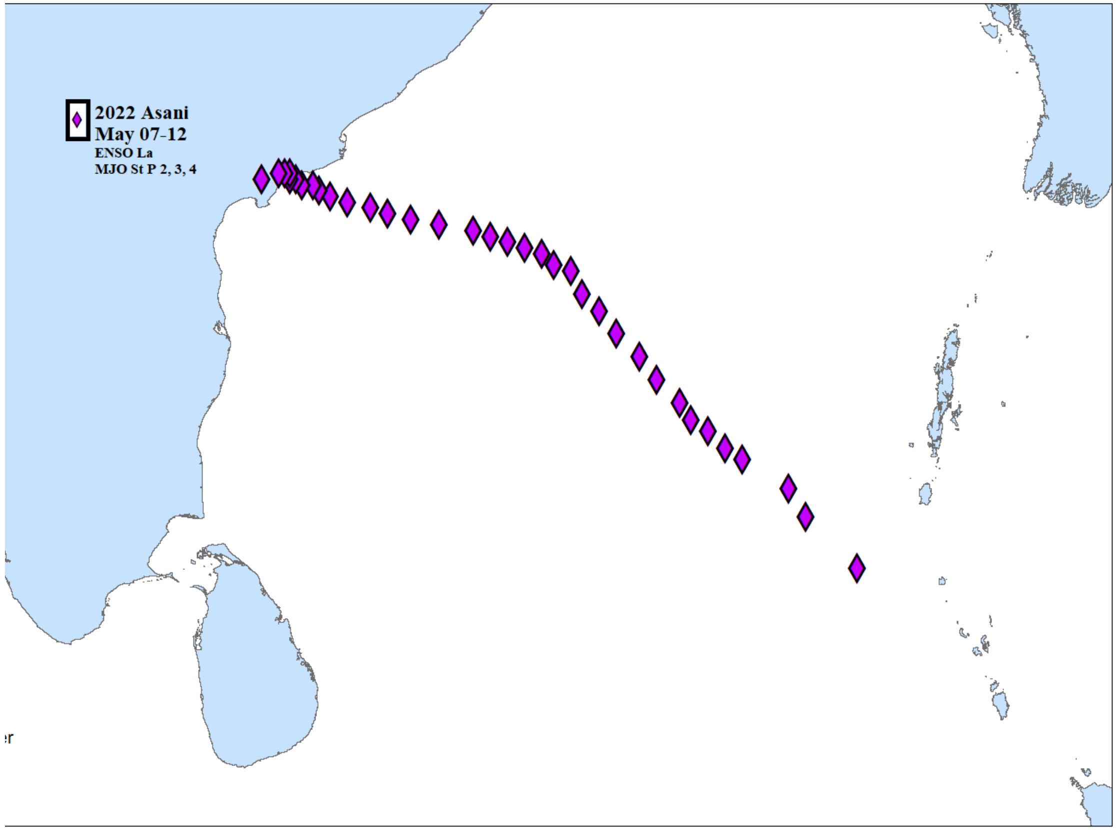
0 - 10
10.1 - 25
25.1 - 50
50.1 - 75
75.1 - 100
100.1 - 125
125.1 - 150
150.1 - 200
200.1 - 250
250.1 - 300

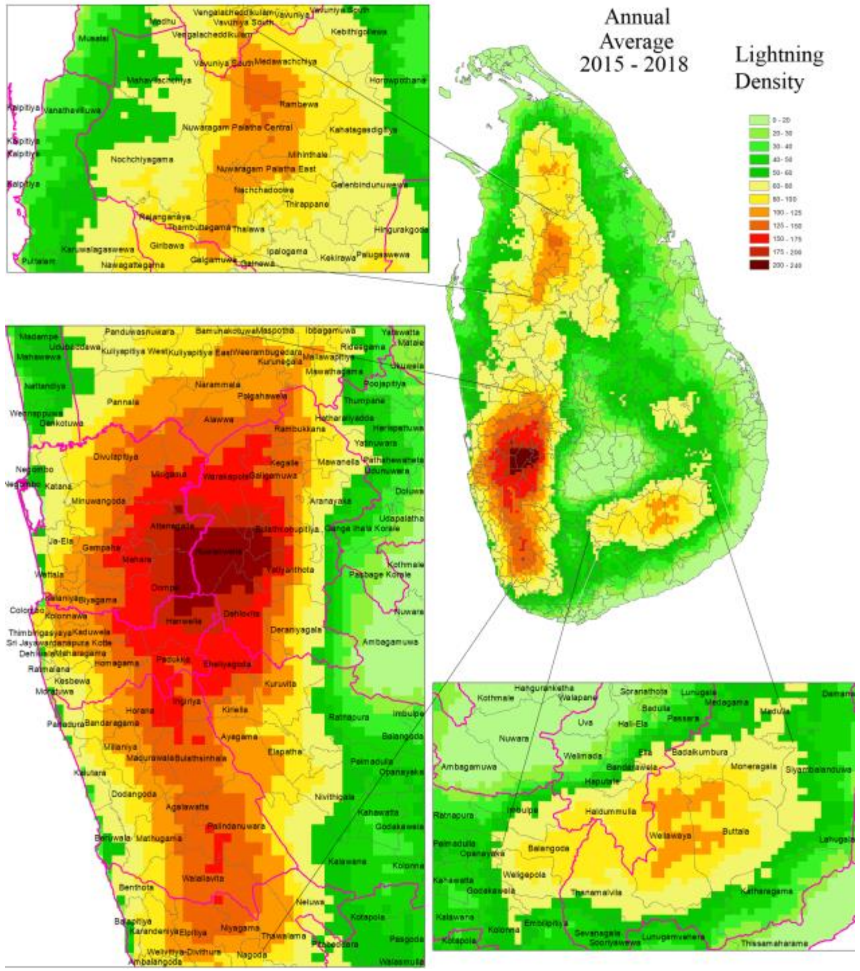
2022 May 07-12 Asani

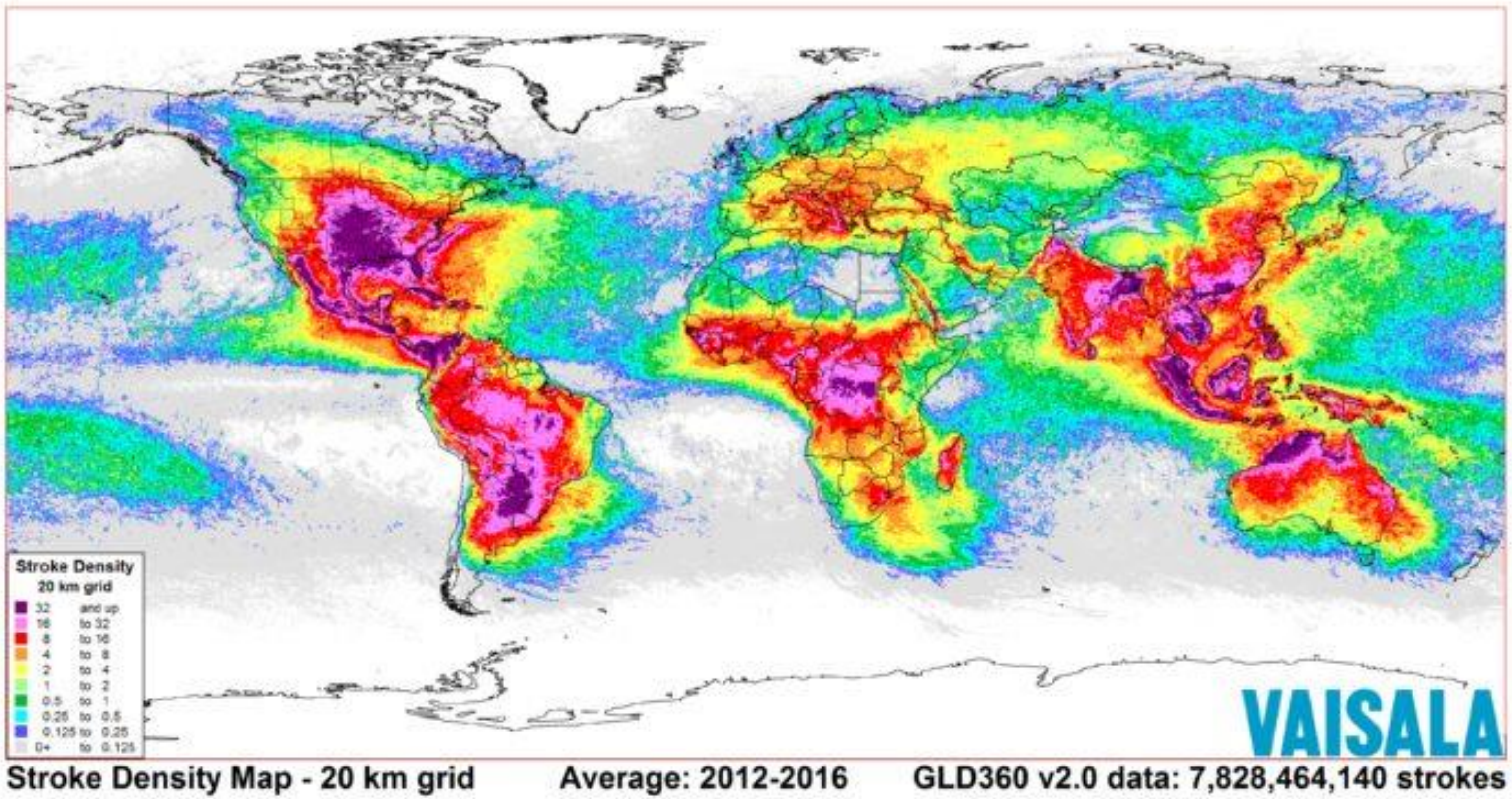
10 May 2022		
10 May 2022	**Norton**	**233.5**
10 May 2022	**Laksapana**	**190.7**
10 May 2022	**Castlereigh**	**180.5**
10 May 2022	Detanagalla	**178.6**
10 May 2022	Watawala	**173.2**
10 May 2022	Weweltalawa	**170.0**
10 May 2022	**Canyon**	**160.7**
10 May 2022	**Maussakele**	**153.0**
10 May 2022	**Maskeliya**	**127.0**
10 May 2022	**Kotmalee**	**113.5**
10 May 2022	**Upper kotmalee**	**113.0**
11 May 2022		
11 May 2022	Weweltalawa	**190.0**
12 May 2022		
12 May 2022	Weweltalawa	**180.1**
12 May 2022	Maradankadawala	**167.0**
12 May 2022	Undugoda	**118.1**
12 May 2022	**Kukuleganga**	**115.0**



THUNDERSTORMS

THUNDERSTORMS



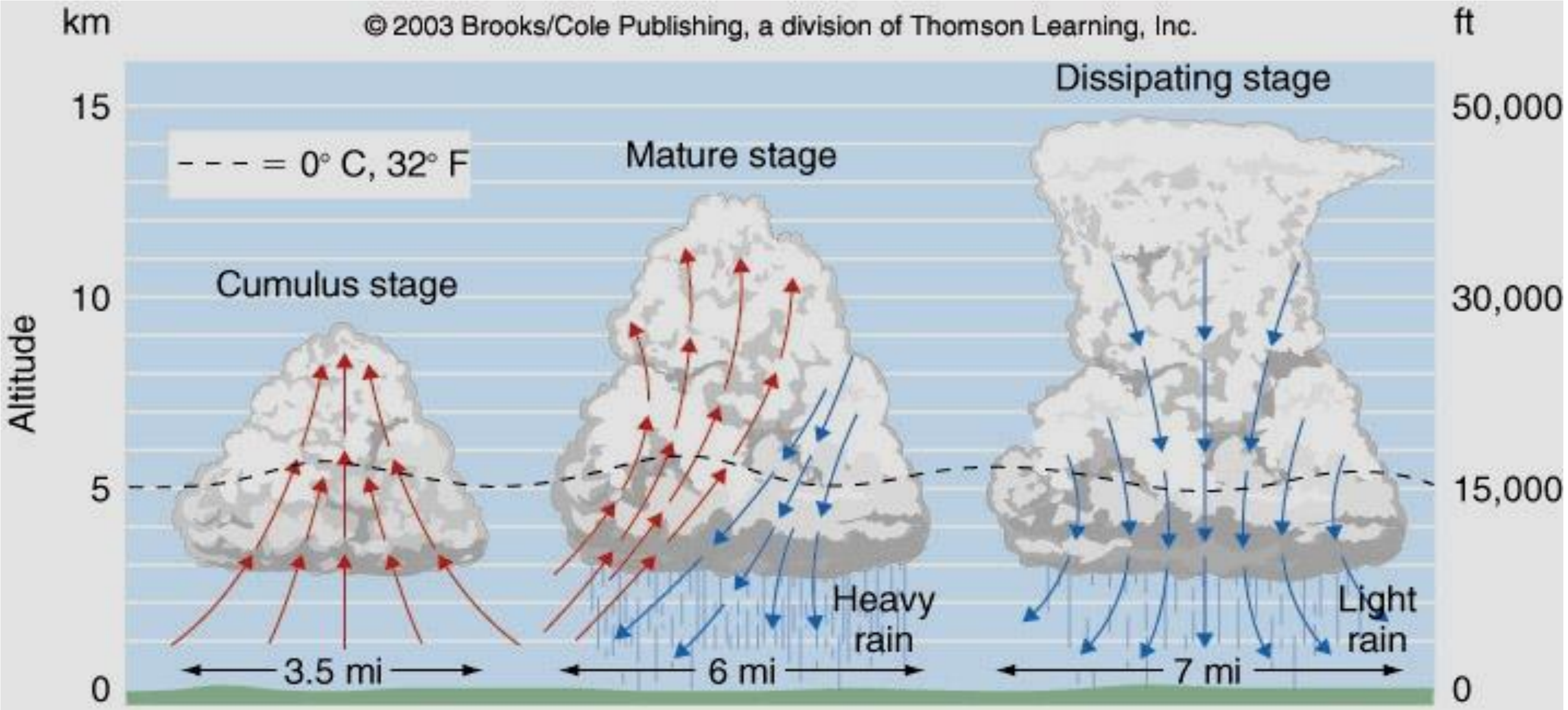


- Thunderstorm is a cloud or cluster of clouds that produces thunder, lightning, heavy rain, and sometimes hail and tornados
- can divide thunderstorms into two main types
  - isolated thunderstorms produced within a warm humid air
  - severe thunderstorms produced by forceful lifting
- at any given time ~ 2000 thunderstorms are in progress globally

Thunderstorm

- A thunderstorm is a storm accompanied by lightning and thunder.
- It affects a relatively small area and is short-lived.
- A thunderstorm is the product of vigorous convection that extends high into the troposphere, sometimes reaching the tropopause or even higher.
- Upward surging air currents are made visible by cauliflower-shaped cumuliform clouds.

Life cycle of an ordinary thunderstorm cell

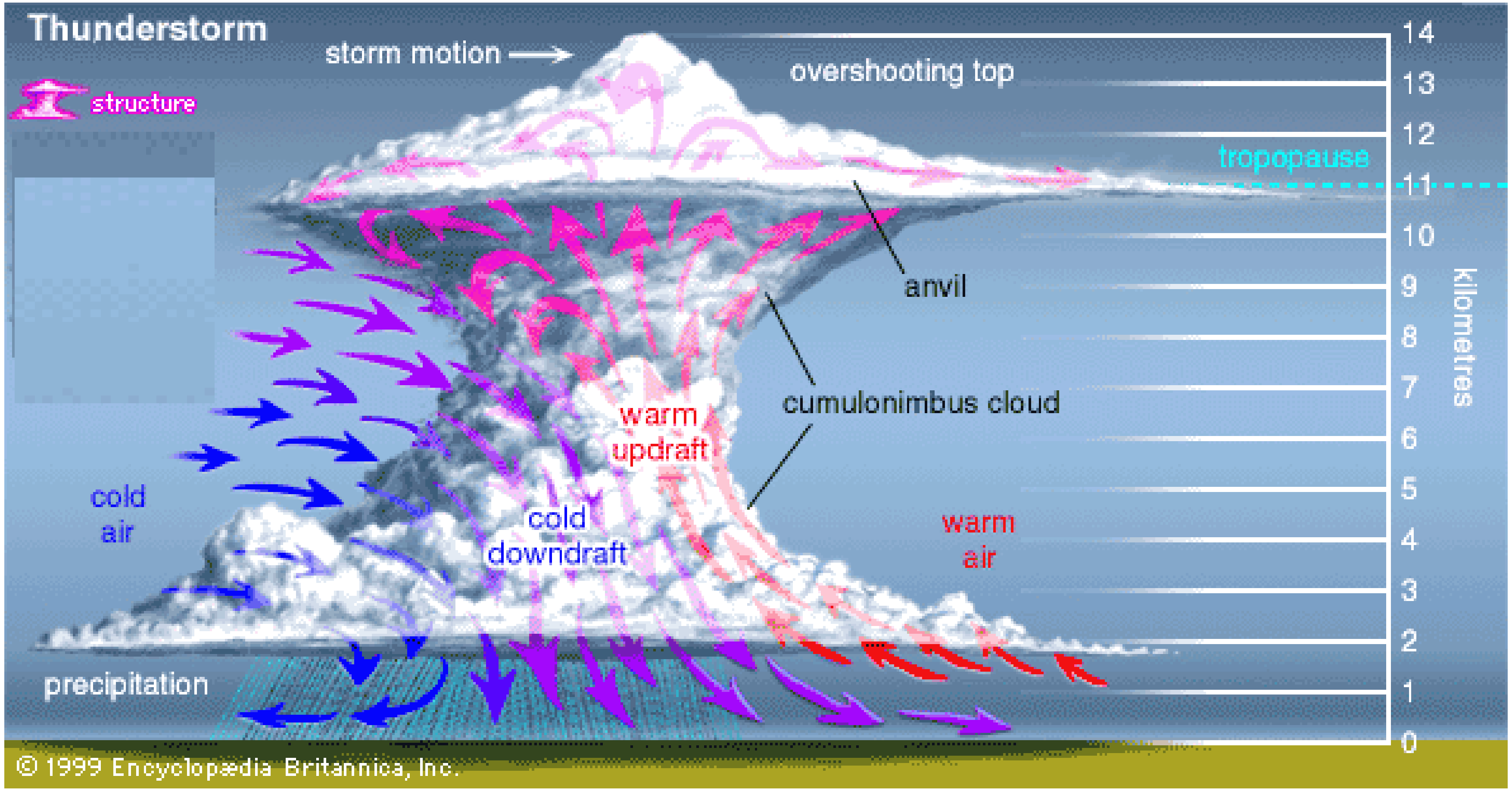


Thunderstorm Life Cycle

A thunderstorm consists of one or more convection cells, each of which progresses through a life cycle that is divided into three stages: towering cumulus, mature, and dissipating

The Structure of a Thunderstorm

- A thunderstorm cell attains maximum intensity during its mature stage. Rain is heaviest, lightning is most frequent, and hail, strong surface winds, and even tornadoes may develop.
- Cloud tops can build to altitudes in excess of 18km.
- Strong winds at such great altitudes distort the cloud top into an anvil shape
- The flat top of the anvil indicates that convection currents have reached the extremely stable air of the tropopause.
- thunderstorms overshoot tops.

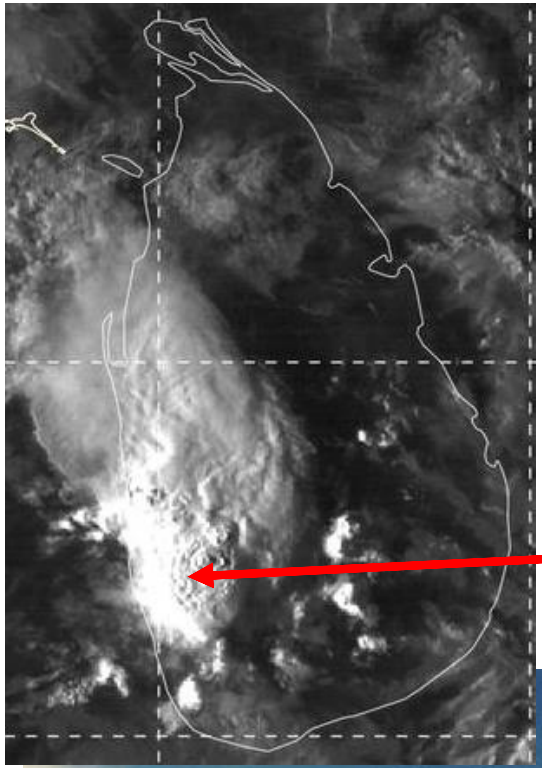


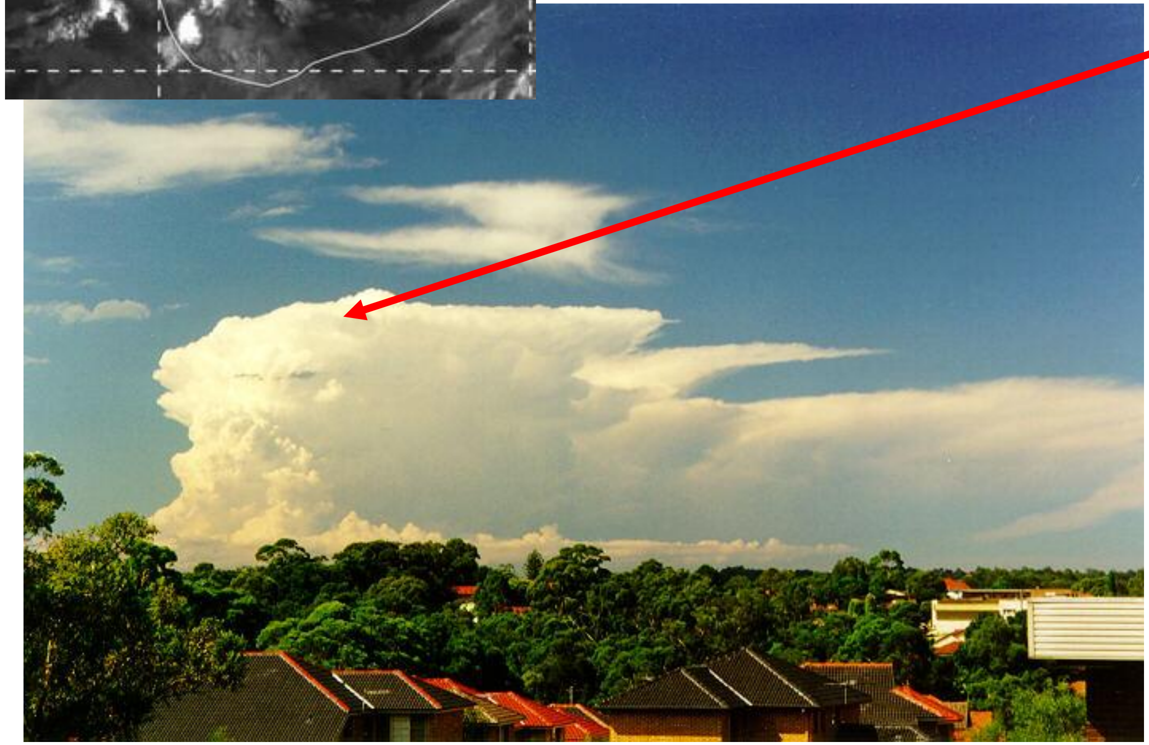
anvil-shaped top at the tropopause, over shooting top, warm updrafts, cold downdrafts. Cumulonimbus clouds typically produce large amounts of precipitation.

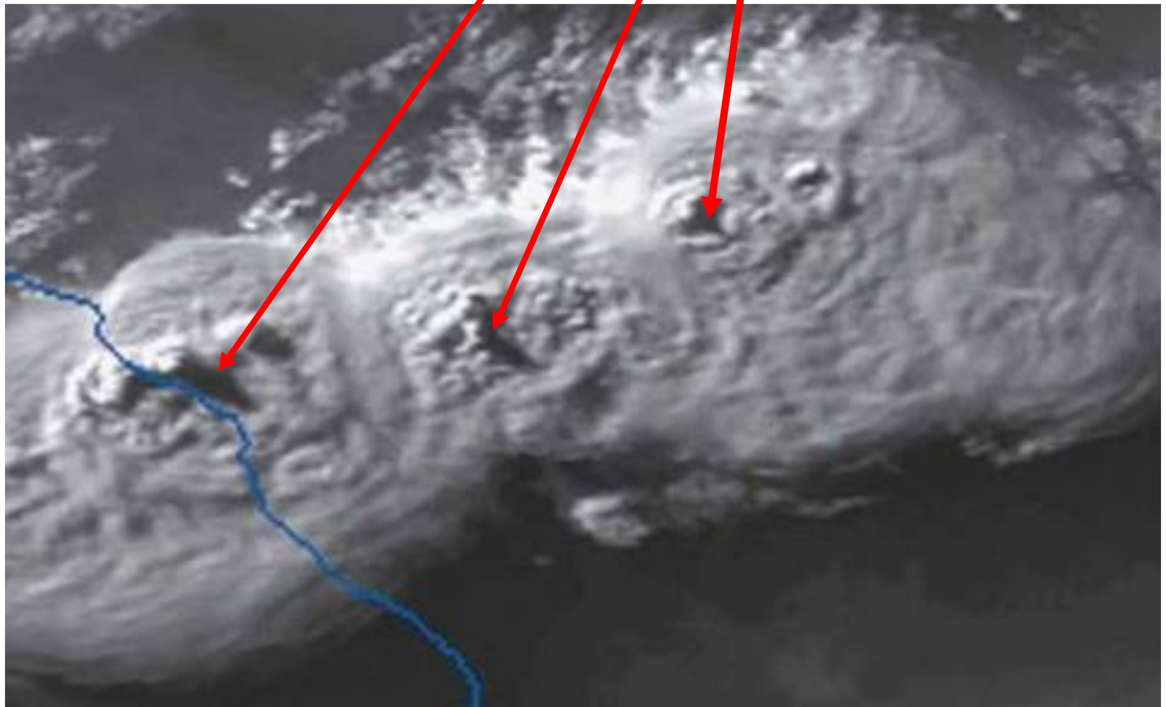
Overshooting Top

- Overshooting top - characteristic of a strong updraft
- The updraft goes higher than the rest of the clouds near it (in the anvil)
- Overshoots the tropopause

Overshooting Top

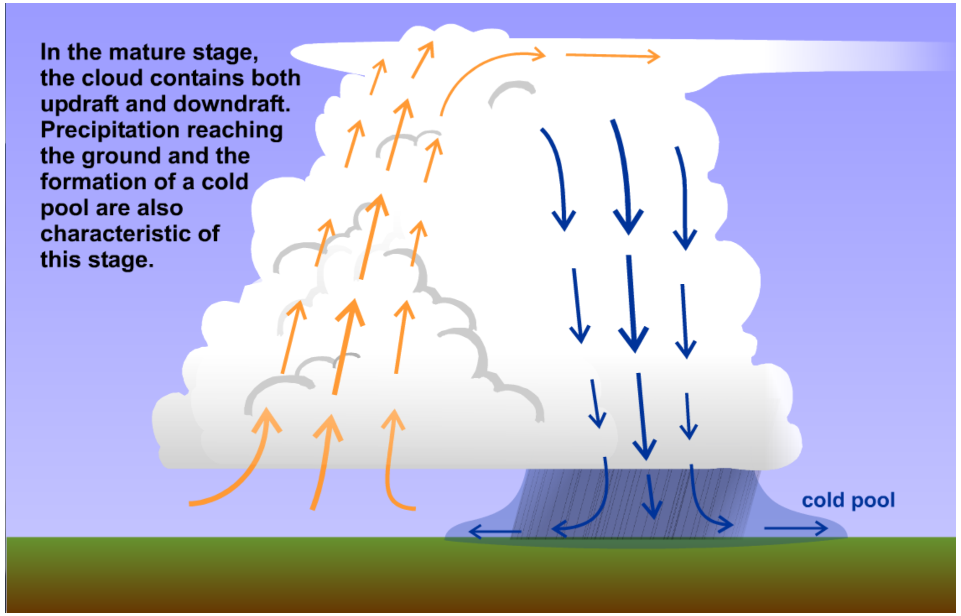


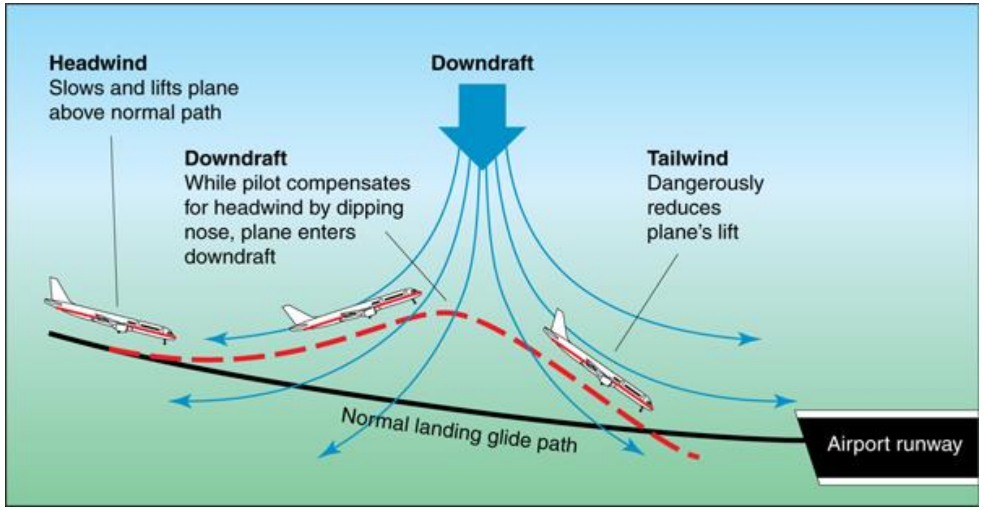


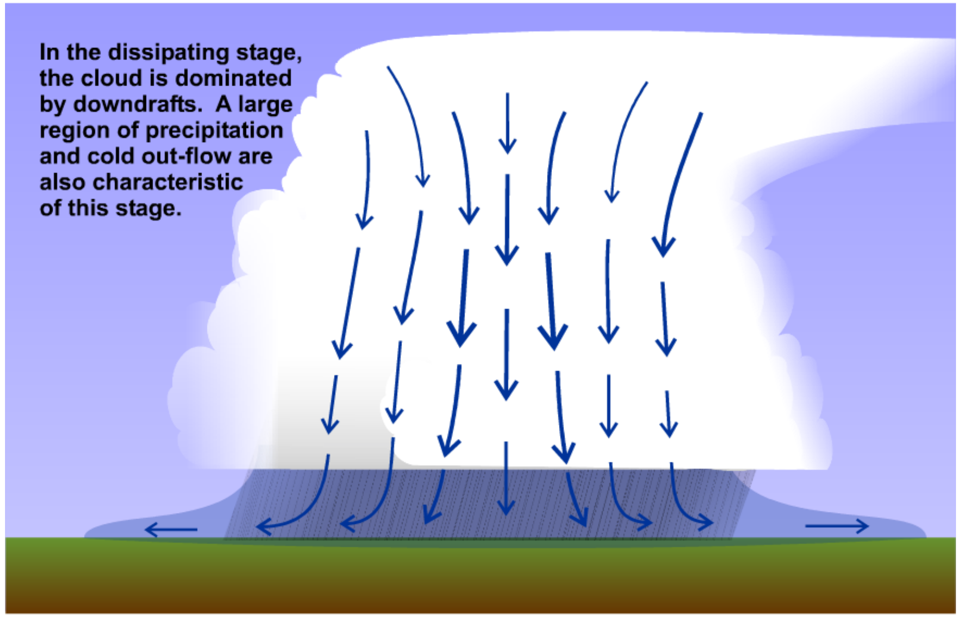


Downdraft

- Initiate by falling precipitation
- Entrainment : influx of cool dry air -Intensify the downdraft – evaporating precipitation – gaining energy from surrounding
- they are kept cool even as they sink to warmer levels by the evaporation of water and melting of ice particles.





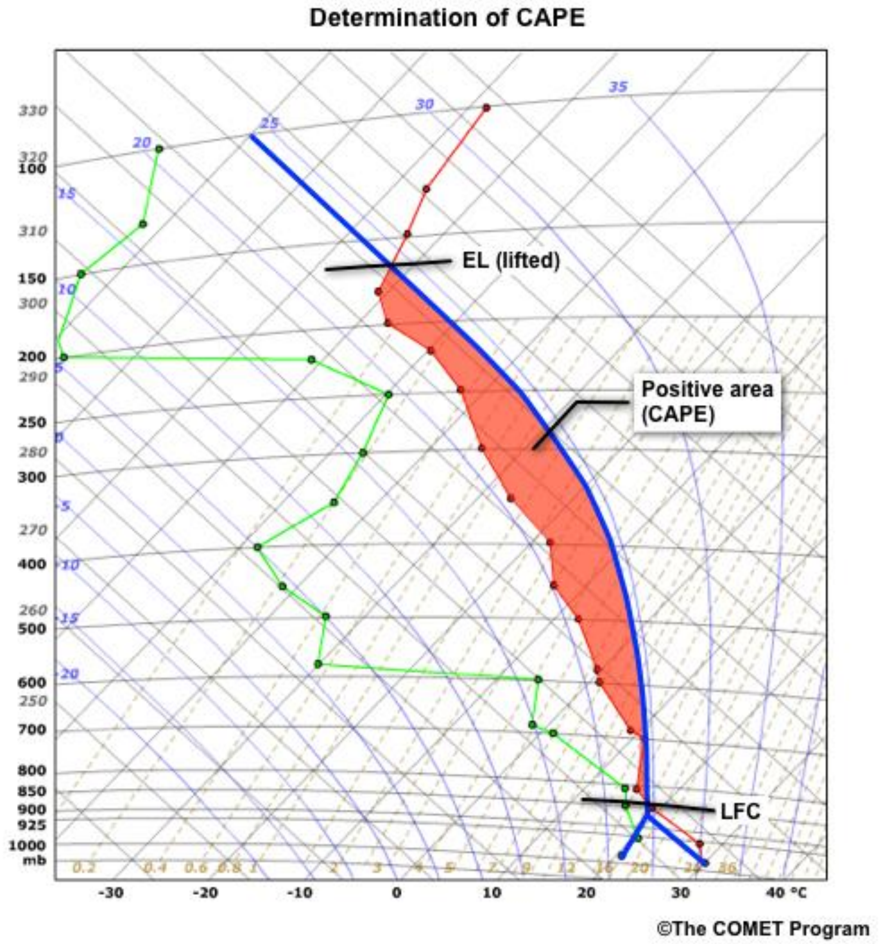


Not only is the sinking air more dense than its surroundings, but it carries a horizontal momentum that is different from the surrounding air.

THUNDERSTORM GROWTH AND DEVELOPMENT

- For thunderstorms, a checklist of three ingredients:
  - Moisture
  - Instability
  - Lift (often referred to as a trigger)

- For severe weather, a fourth ingredient is needed:
  - Vertical wind shear



Moisture and Instability

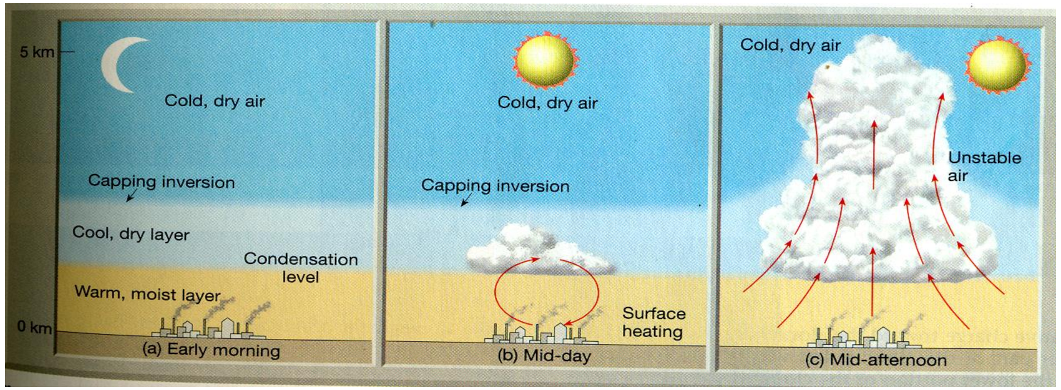
- Contribute to CAPE (Convectively Available Potential Energy)
- Provide positive buoyant energy that can energize updrafts
- Reflected at the surface (e.g. dewpoint) as well as in upper-level temperatures and lapse rates

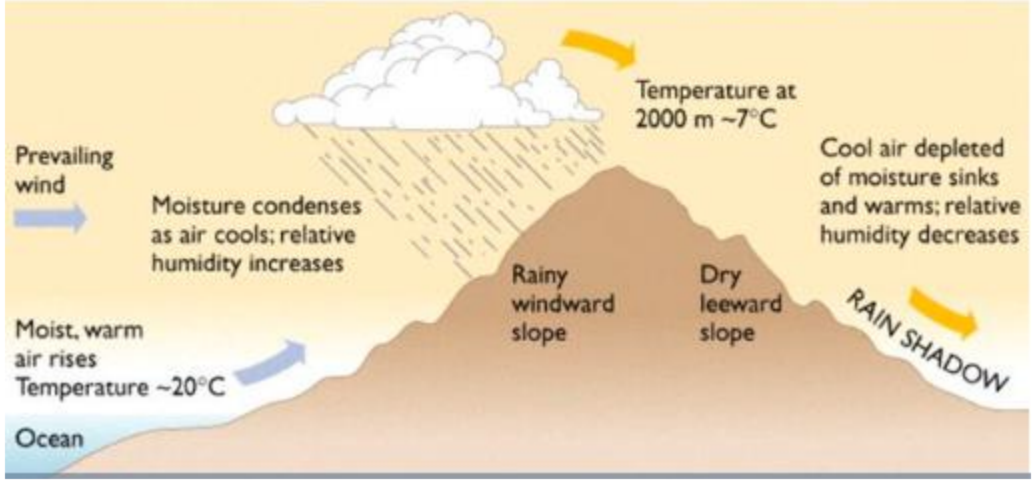
CAPE represents the theoretical amount of energy available for convection. It is directly related to the potential **updraft strength** in convective clouds.

LIFTING CAN BE BY :

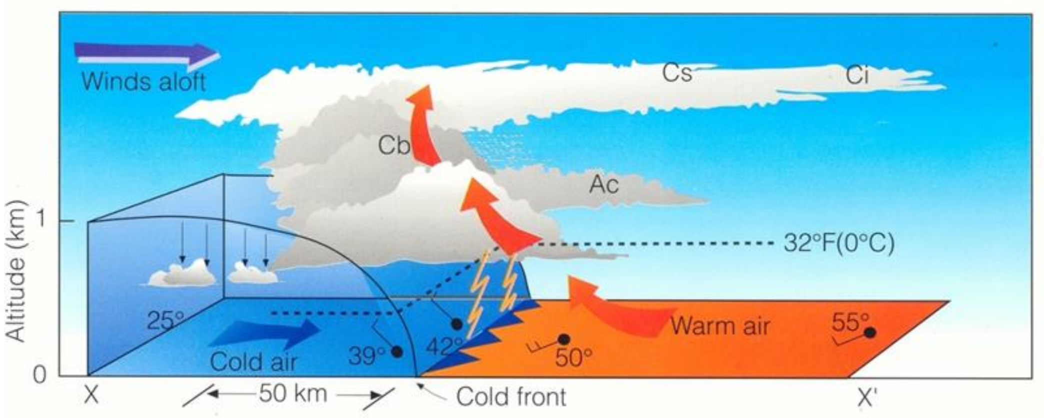
- ➢ Unequal warming of the surface of the Earth.
- Orographic lifting due to topographic obstruction of air flow. Mountains, too, can trigger upward atmospheric motion by acting as topographic barriers that force winds to rise.

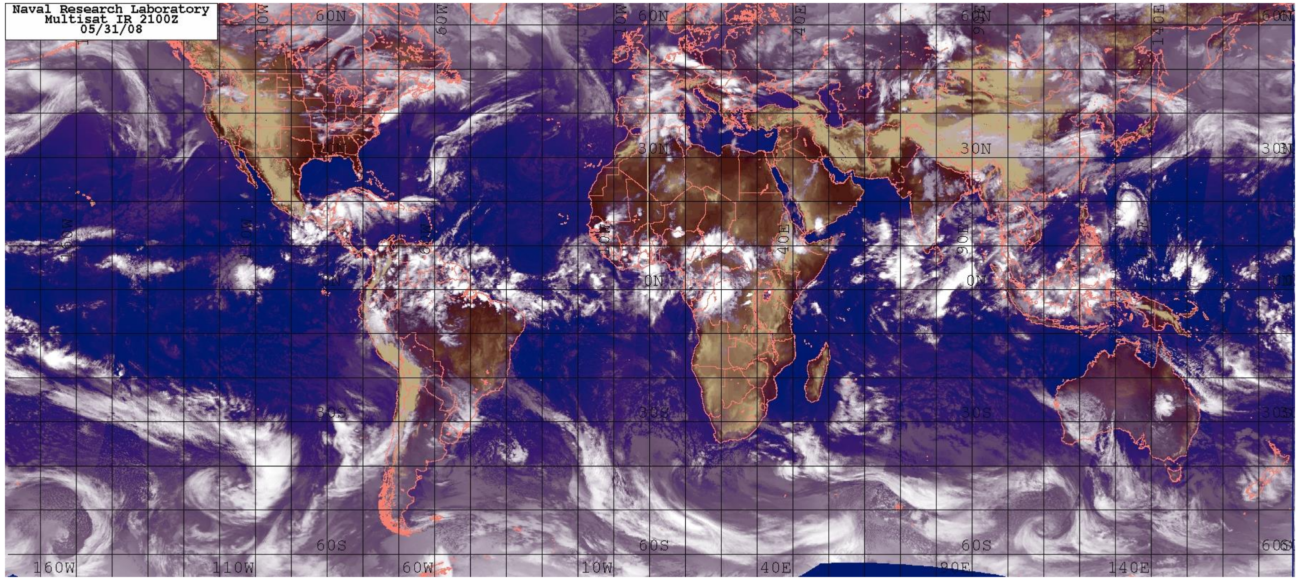
- ➢ Dynamic lifting because of the presence of a low pressure area, depression, tropical cyclone, ITCZ, frontal system





Vertical View of a Cold Front

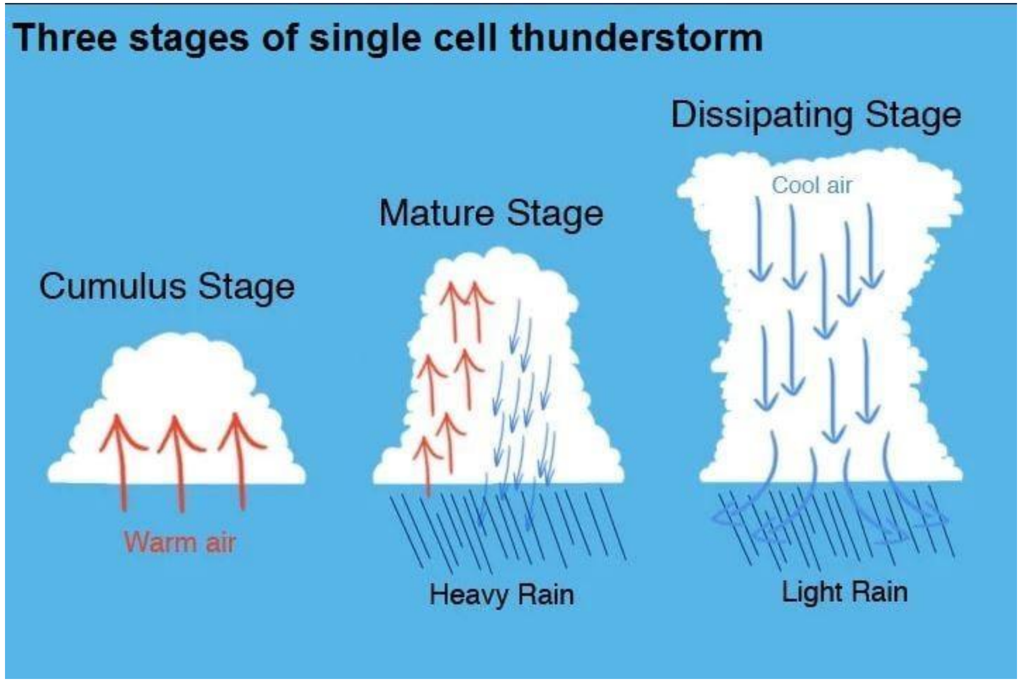


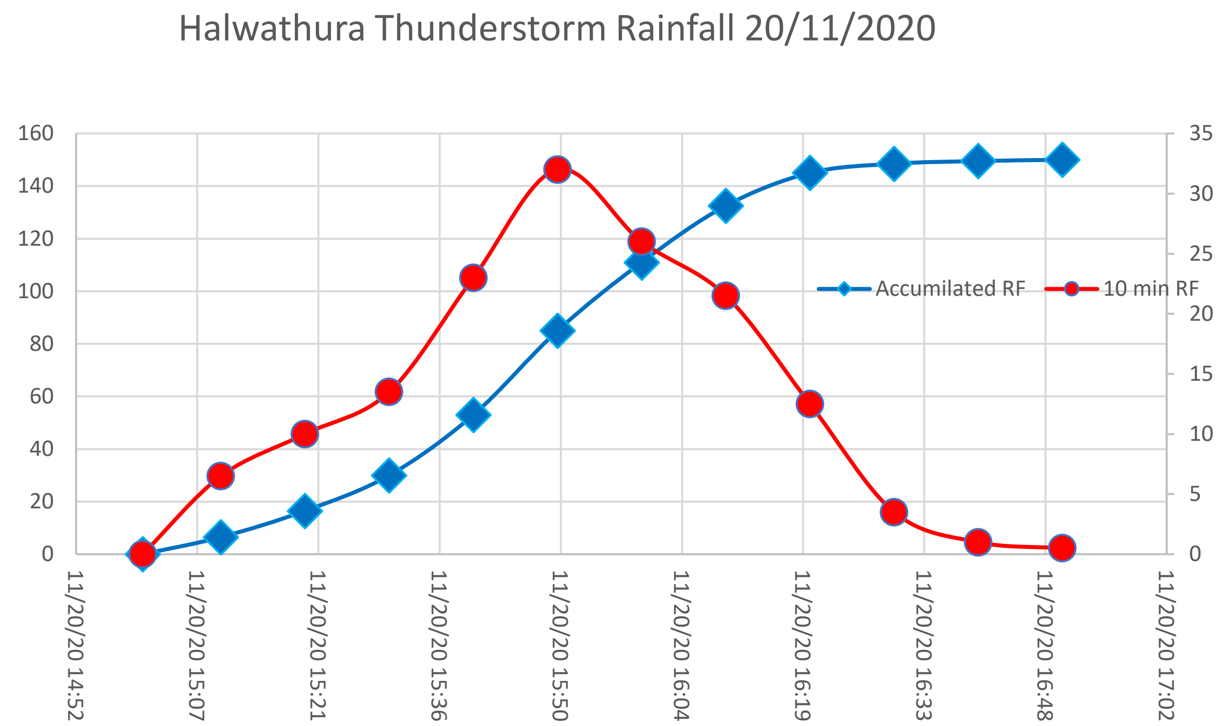


TYPE OF THUNDERSTORM

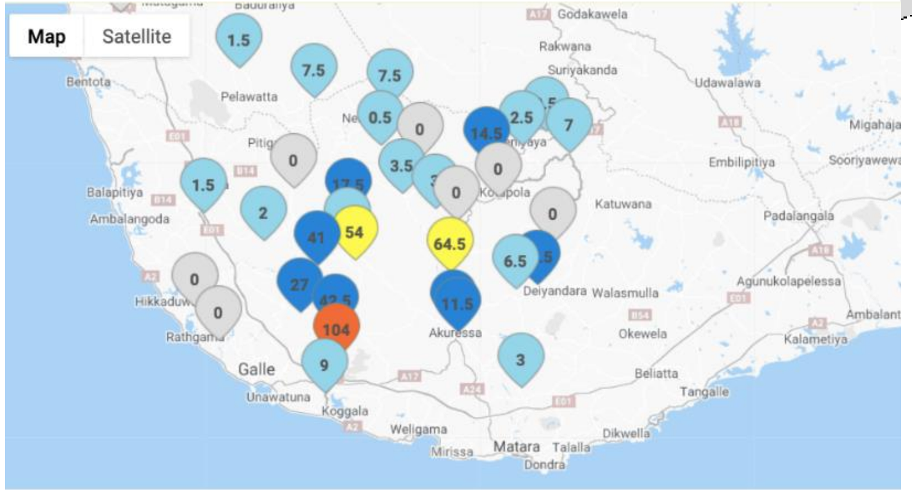
- **ISOLATE THUNDERSTORM**
- **MULTICELL THUNDERSTORM**
- **MESOSCALE CONVECTIVE COMPLEX**
- **SUPERCELL THUNDERSTORM**

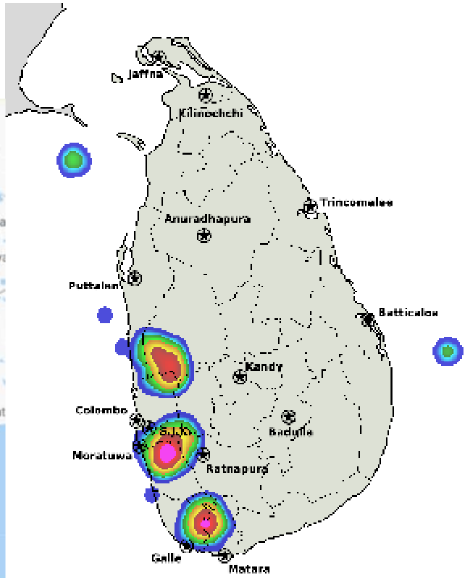
Single cell thunderstorm





- **single-cell thunderstorms** are small, brief, weak storms that grow and die within an hour or so.
- They are typically driven by heating on a summer afternoon.
- Single-cell storms may produce brief heavy rain and lightning.
- In single-cell thunderstorms, the cool downdraft, ultimately leads to the storm's demise by cutting off the supply of warm, moist air that fuels the updraft.





SEVERE THUNDERSTORMS

TYPES:

1) **SQUALL LINE THUNDERSTORMS**

2) **MESOSCALE CONVECTIVE COMPLEX (MCC)**

3) **SUPERCELL THUNDERSTORMS**

All three types last much longer than ordinary thunderstorms.
All three types need warm air and other factors in order to form, especially wind shear.

Vertical Wind Shear

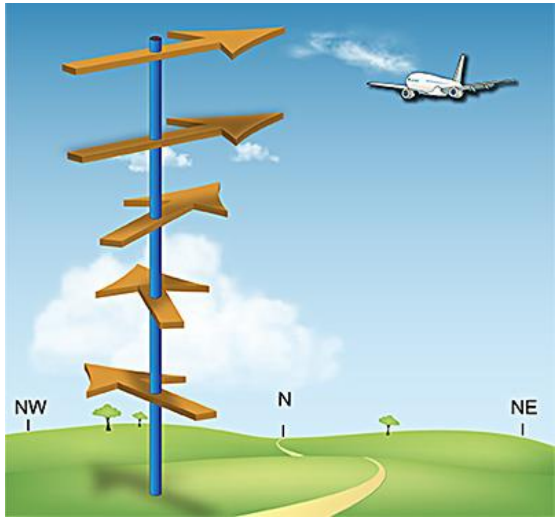
- Allows for the organization of Multiple TS
- Allows for the organization of thunderstorms into cellular structures
  multicell structures

- Allows for the development of rotation within the storm
  - Mesocyclones
  - Rotating updrafts, etc.

  - Essential for the development of supercell TS

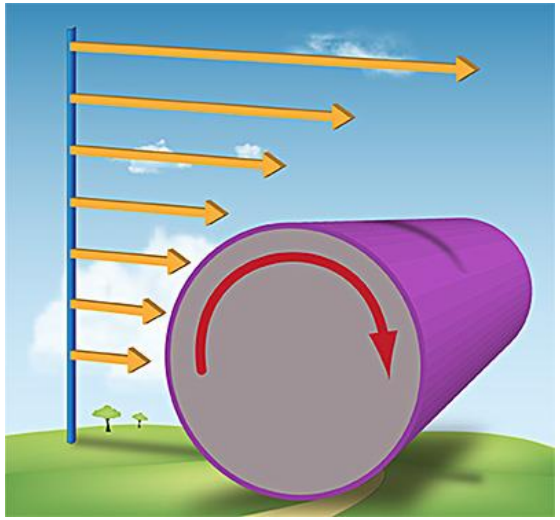
Source : NOAA NWS

Directional Shear

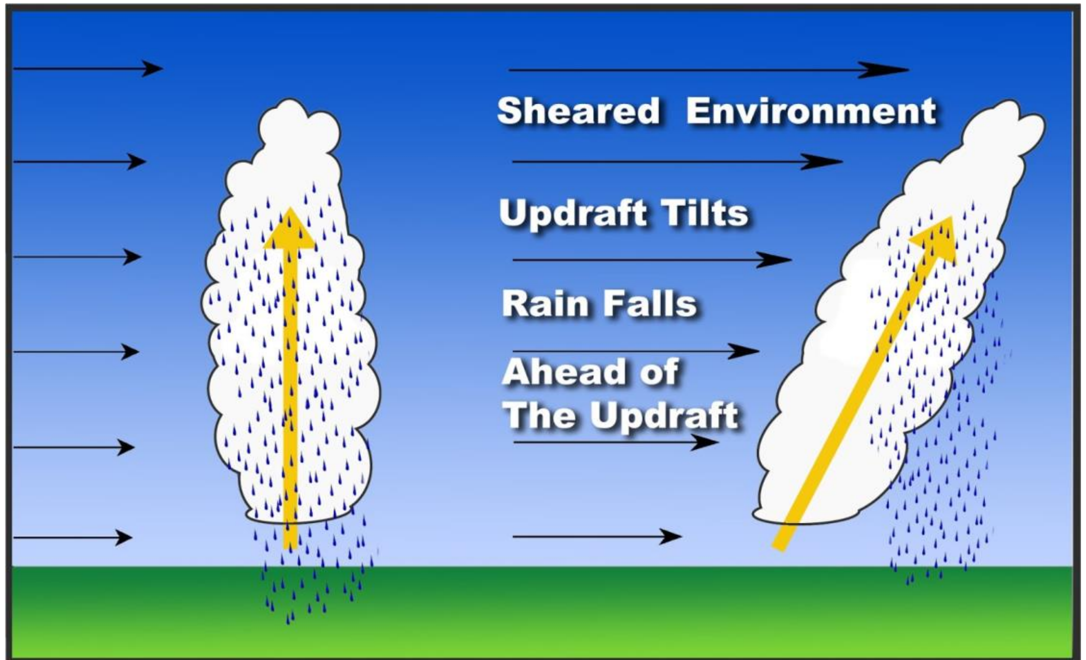


Wind **direction** changes with height

Speed Shear



Wind **speed** changes with height.



Schematic of a multicell thunderstorm. Red arrows represent the warm updraft, blue arrows the cool downdraft

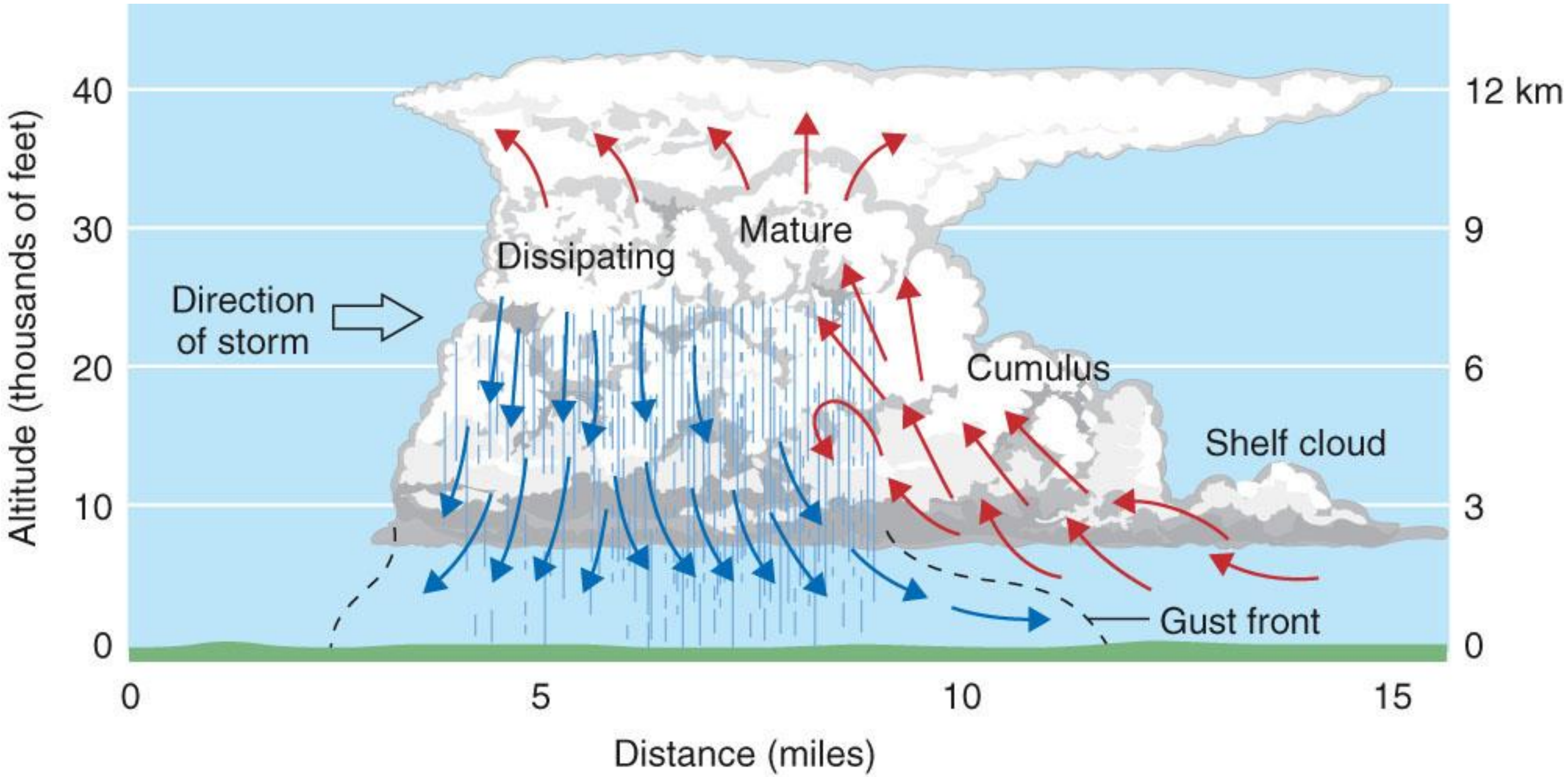
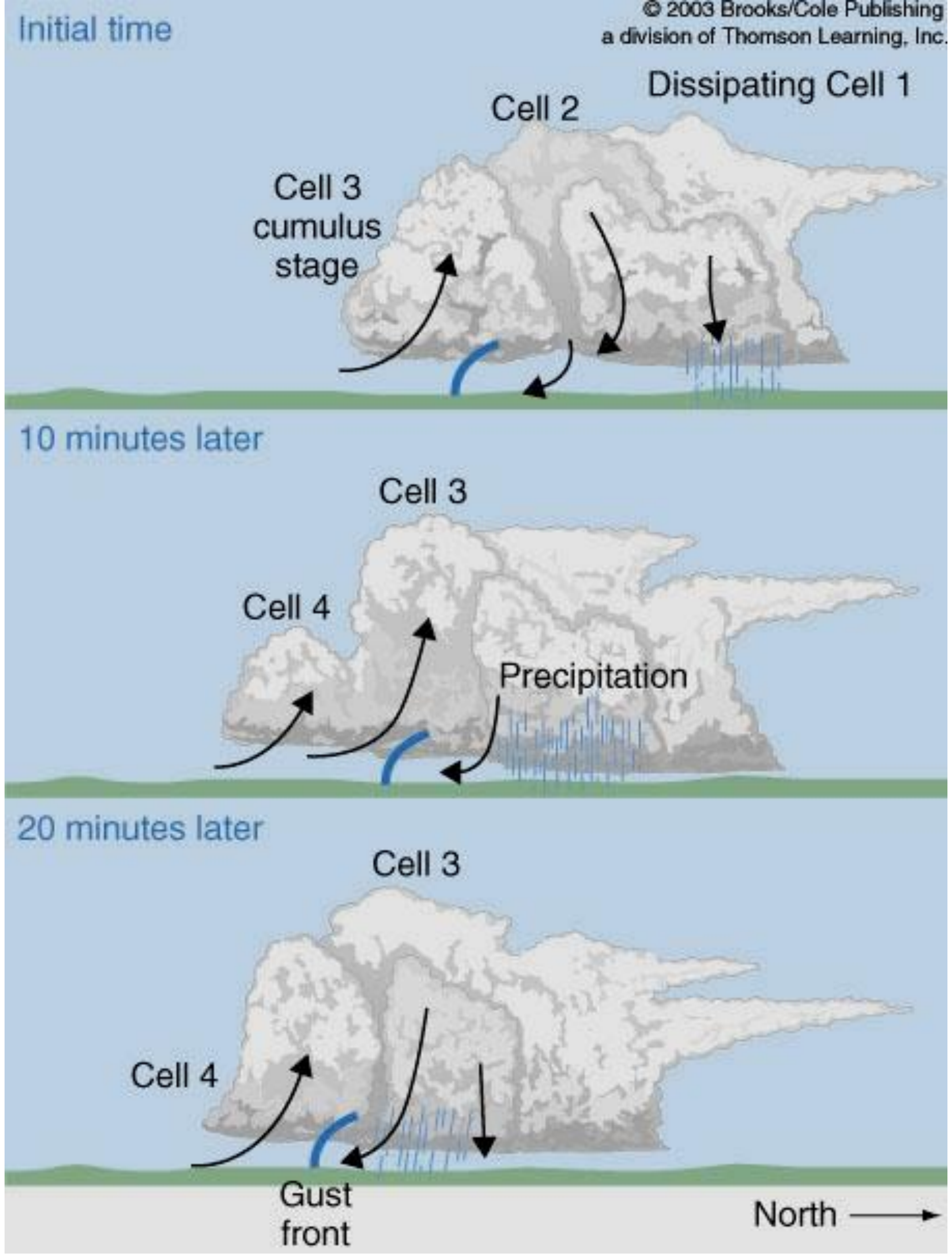
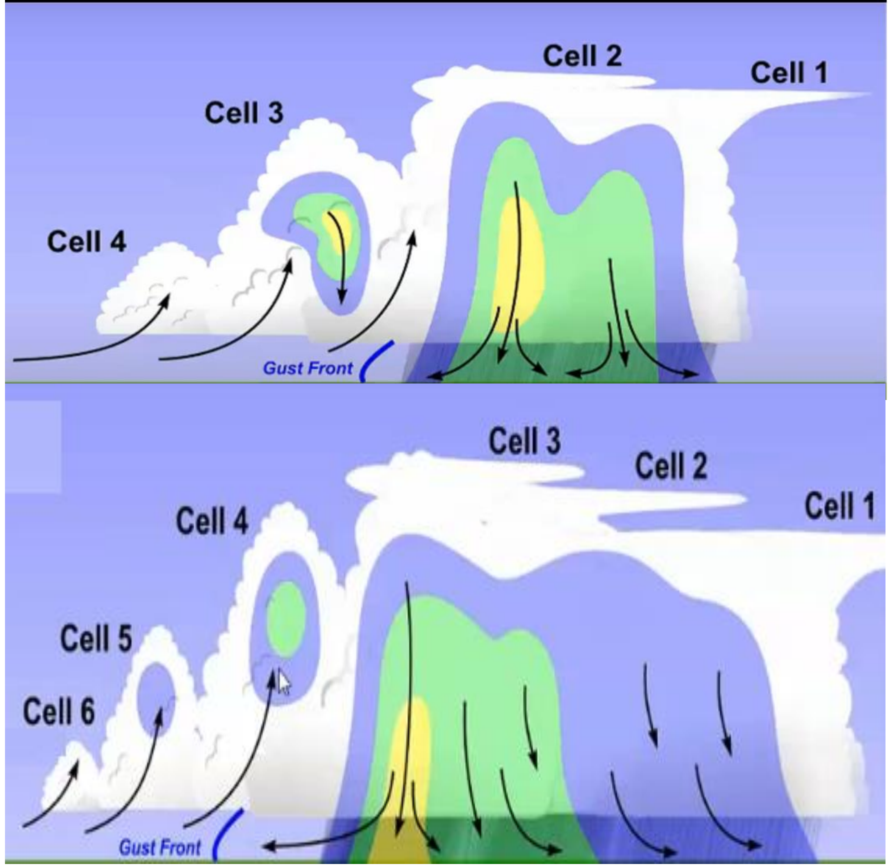


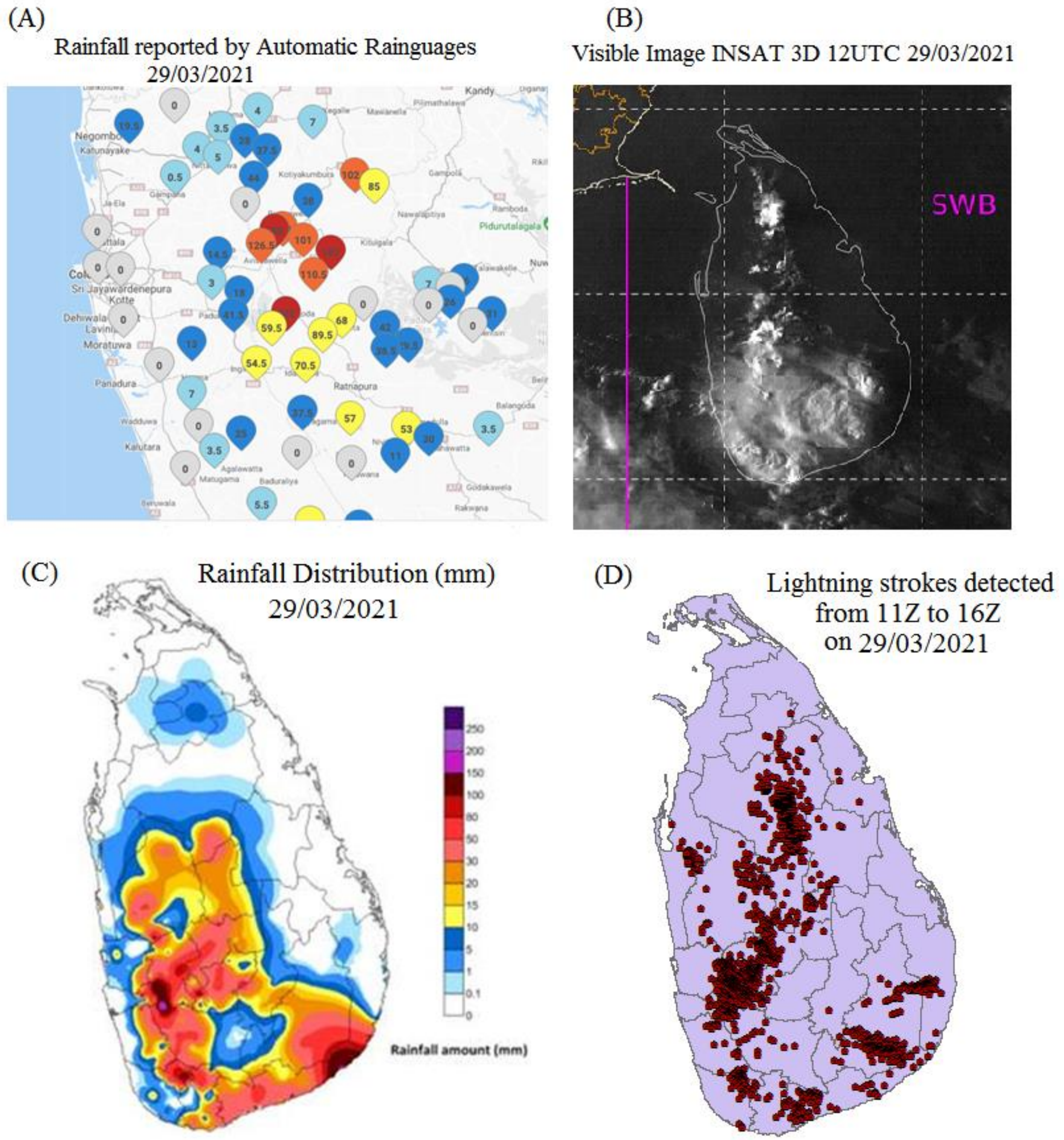
Fig. 11-10, p. 320

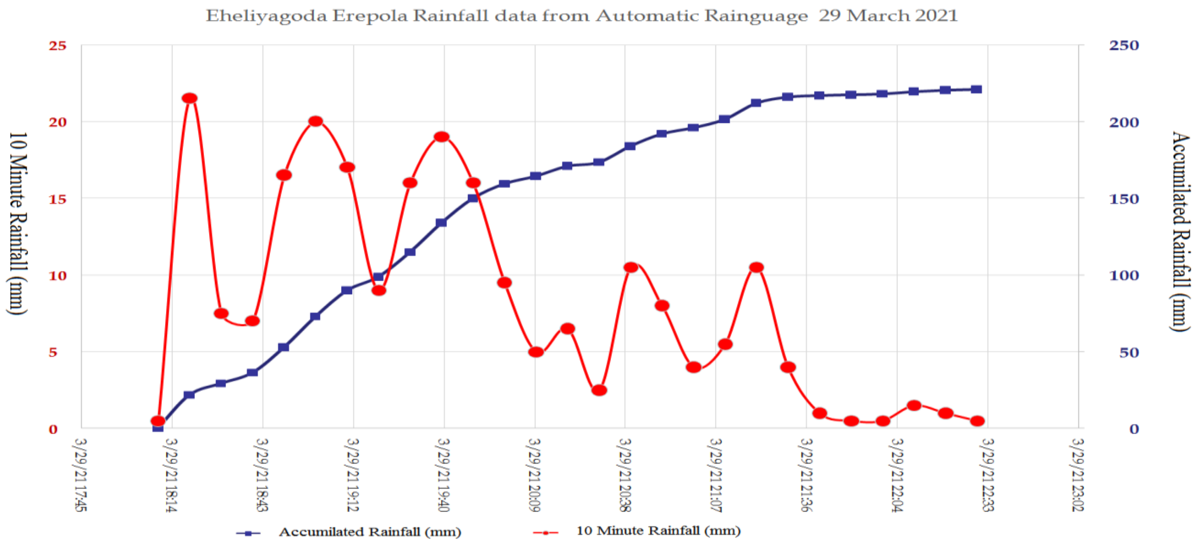




Though each single-cell storm that makes up a multicell thunderstorm has a life cycle on the order of 30 to 60 minutes, multicellular convection can last for hours. What gives multicell thunderstorms (as a group) this increased longevity? New cells continually form along the " gust front, which lifts warm, moist air flowing into the storm.

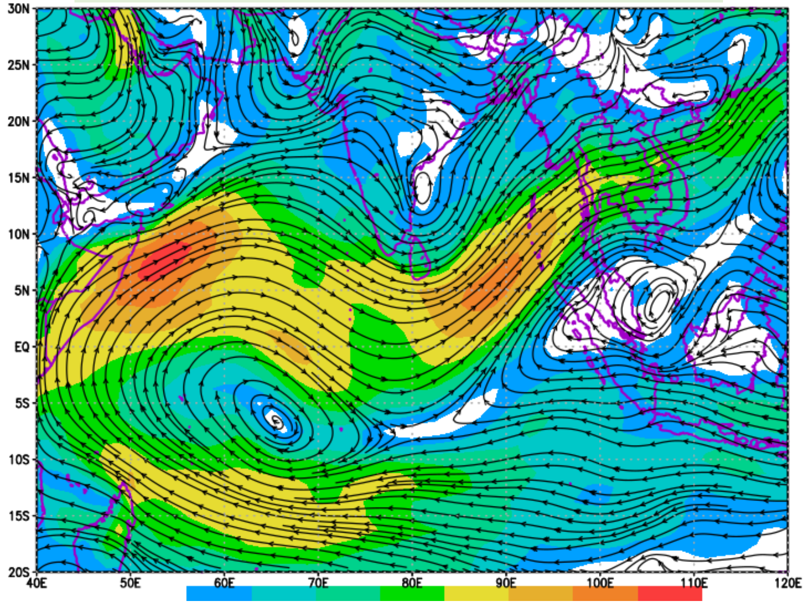
Multicell Thunderstorm developed on 29 March 2021 at Eheliyagoda



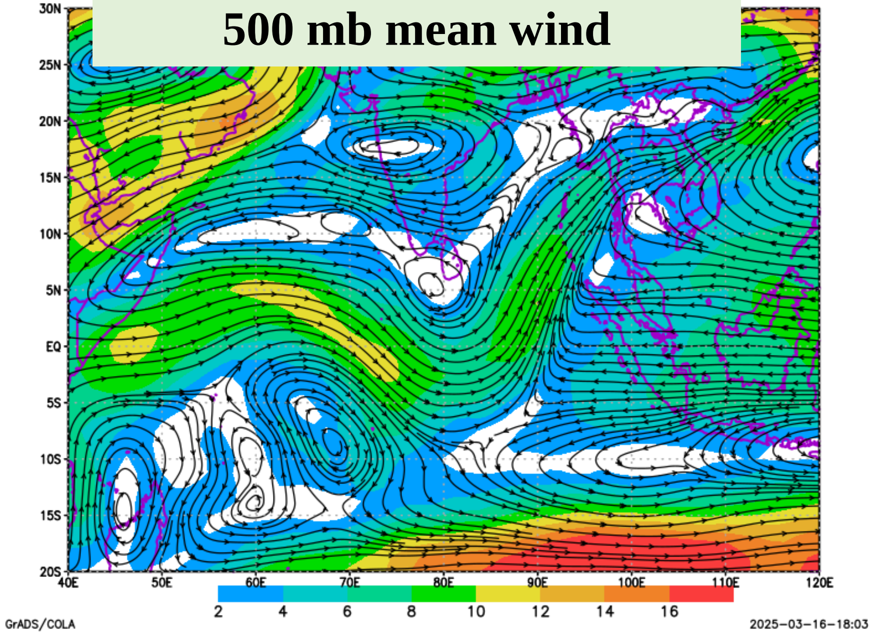


Extreme Rainfall event 01st June to 03rd June 2024

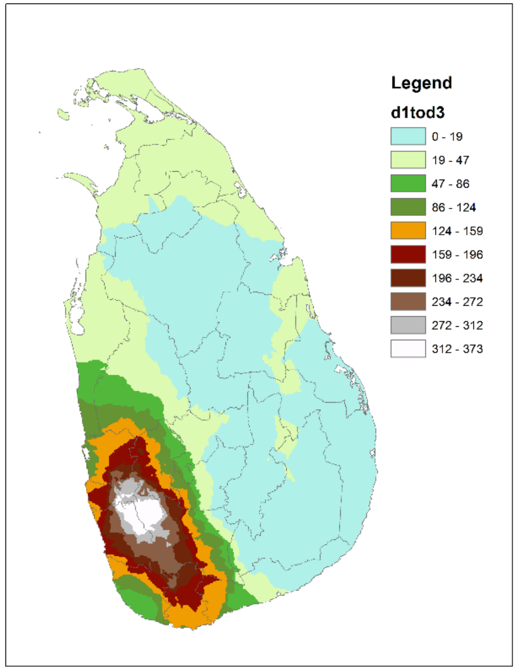
850 mb mean wind

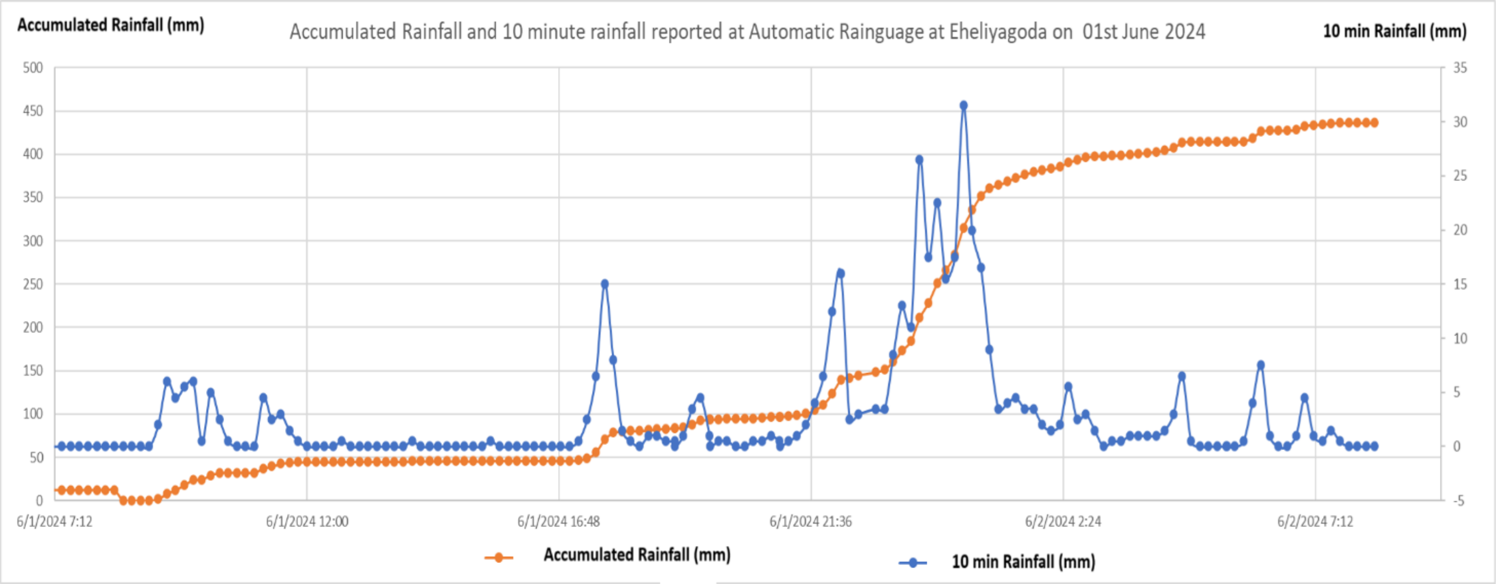


500 mb mean wind

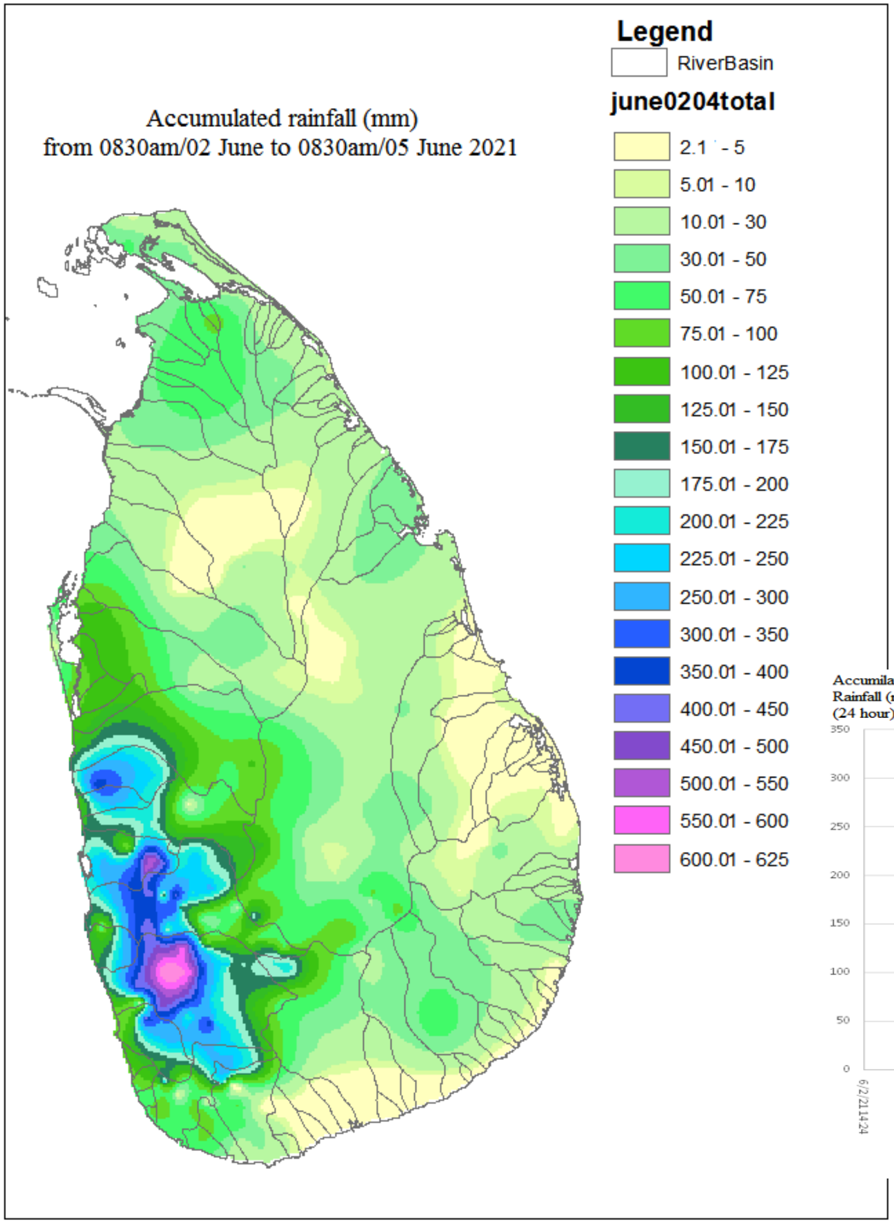


- Cyclonic circulations/Troughs and vertical wind shear (speed and directional) contribute to the formation of extreme rainfall events.
- Current meteorological models fail to accurately predict these extreme events, necessitating improvements in forecasting methods.
- 2024: 25 deaths, 253,581 people impacted by floods and landslides.





Extreme Rainfall event
02nd June to 04th June 2021



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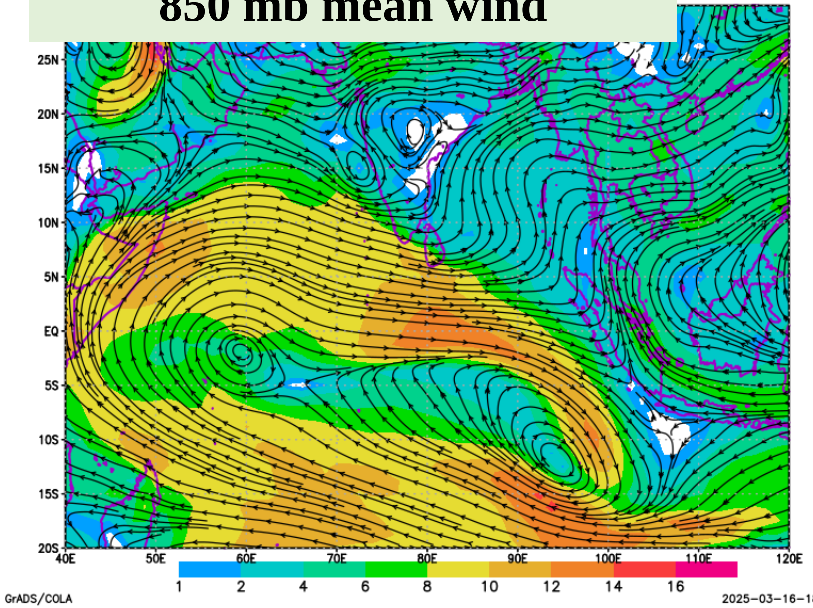
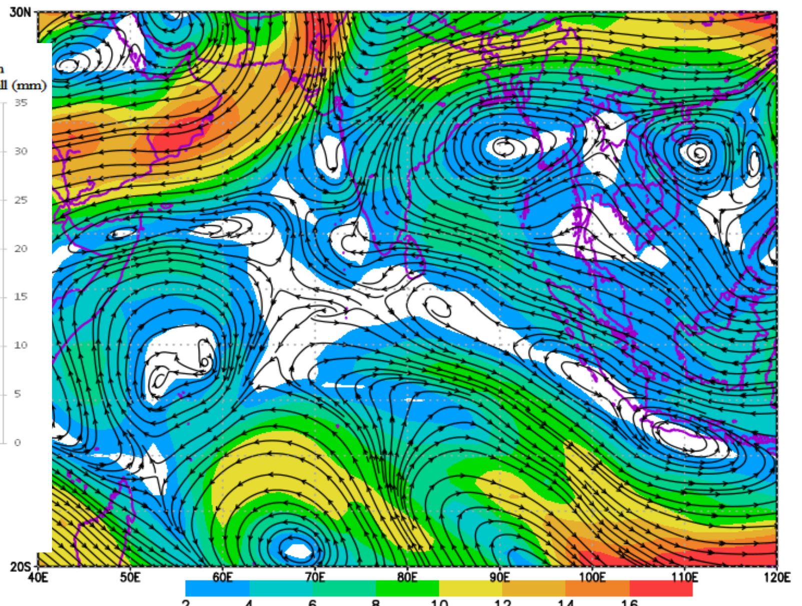
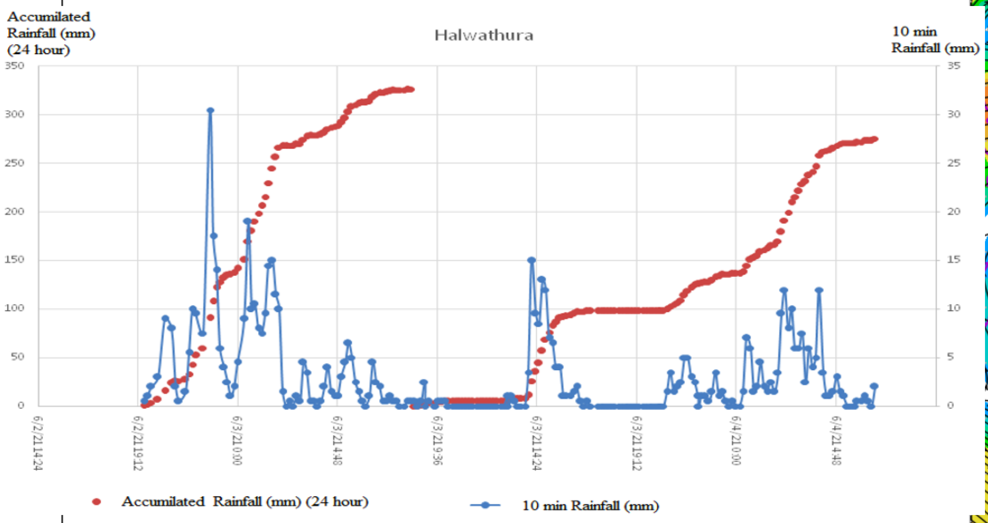
850 mb mean wind



- 2021: 16 deaths, 270,912 people affected across 10 districts.

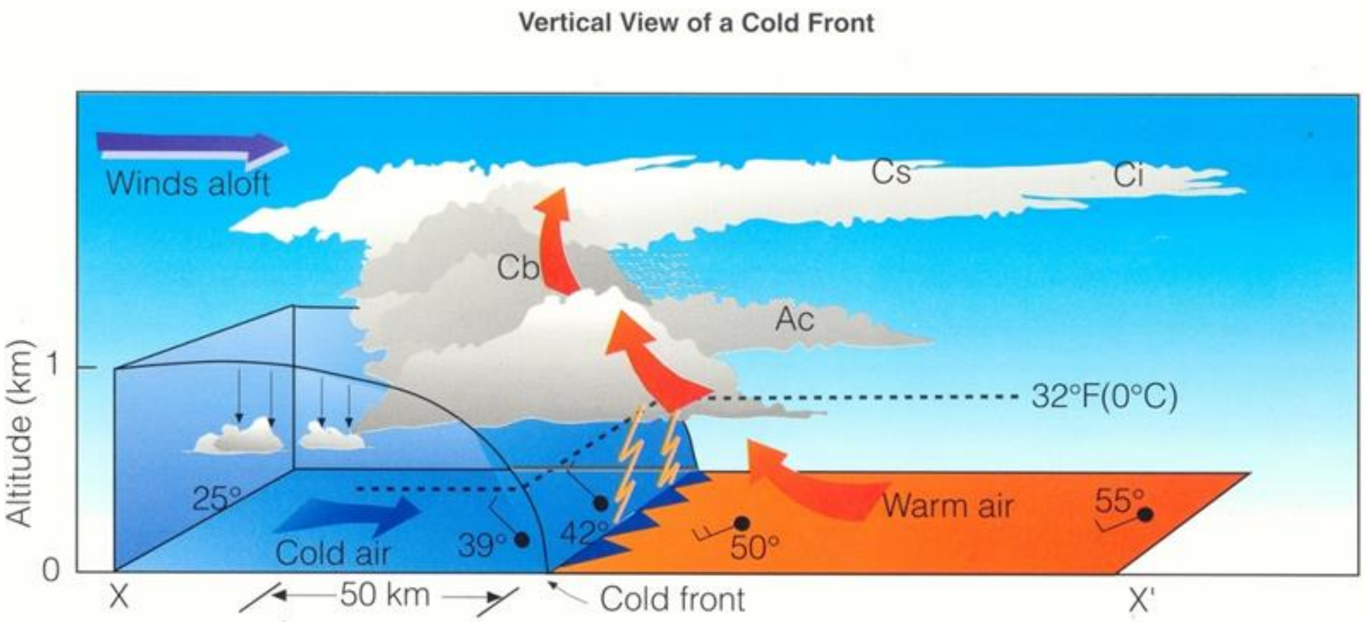
500 mb mean wind

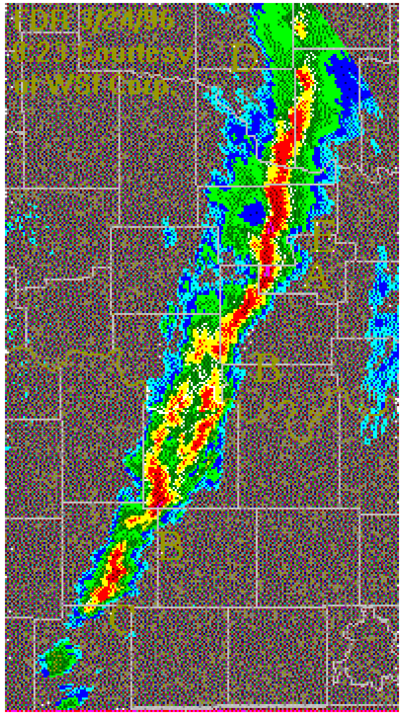


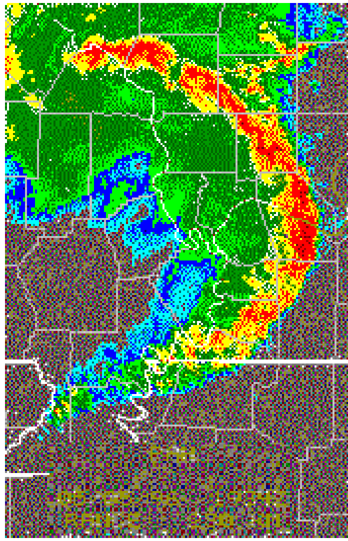


Squall Line

- Is a set of individual intense thunderstorm cells arranged in a line.
- Thy occur along a boundary of unstable air – e.g. a cold front.
- Strong environmental wind shear causes the updraft to be tilted and separated from the downdraft.
- The dense cold air of the downdraft forms a ‘gust front’.





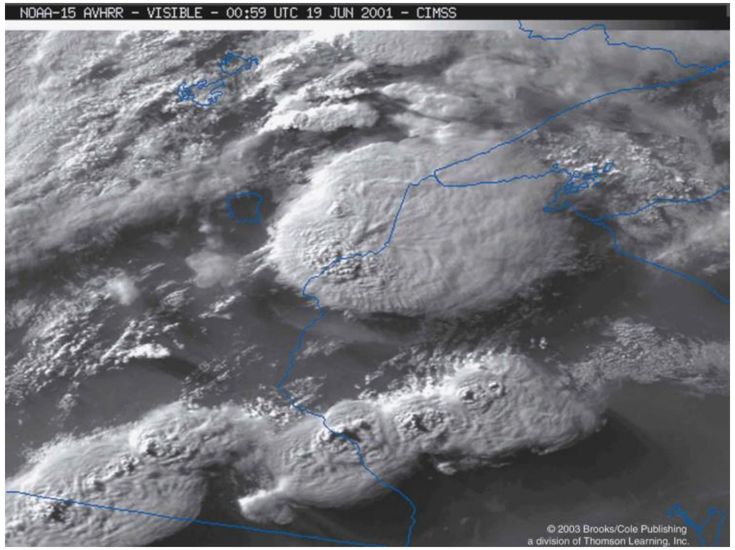


A typical squall line (left) and a seve
bow echo (right). The strongest win
are right at the "point" of the bow
echo.

SUPERCELL THUNDERSTORM

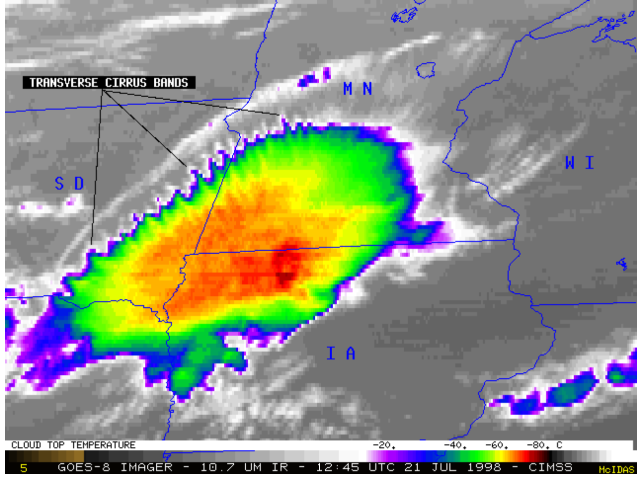
REQUIRES A VERY UNSTABLE ATMOSPHERE AND STRONG VERTICAL WIND SHEAR - BOTH SPEED AND DIRECTION

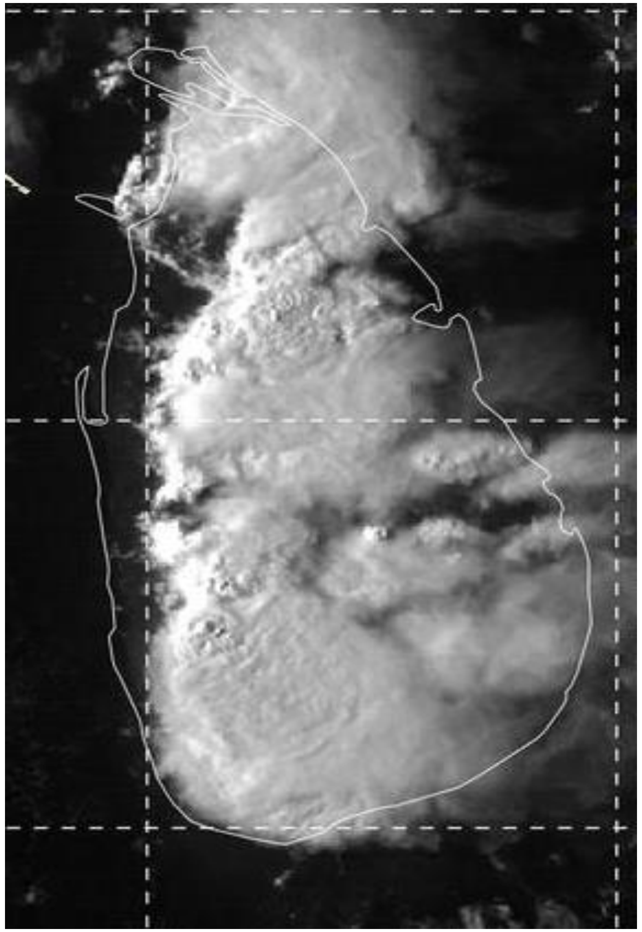
- UNDER THE INFLUENCE OF THE STRONG WIND SHEAR THE ENTIRE THUNDERSTORM ROTATES
- FAVORED REGION IS THE SOUTHERN GREAT PLAINS IN THE SPRING



Mesoscale Convective System (MCS)

- T-Storms merge into **"clusters"**... T-Storm "clusters" merge into a "complex" can last from 6 hours to as long as 16 hours.
- Can develop over a region hundreds of kilometres in diameter
- In order to last a long time, a good supply of moisture is required at low levels in te atmosphere
- Unique to mid-latitudes.
- Stationary MCS can be very dangerous ...
- A single MCS can produce 2 trillion gallons of water!
- Severe multiple-cell thunderstorms and supercell storms are frequently associated with MCSs.

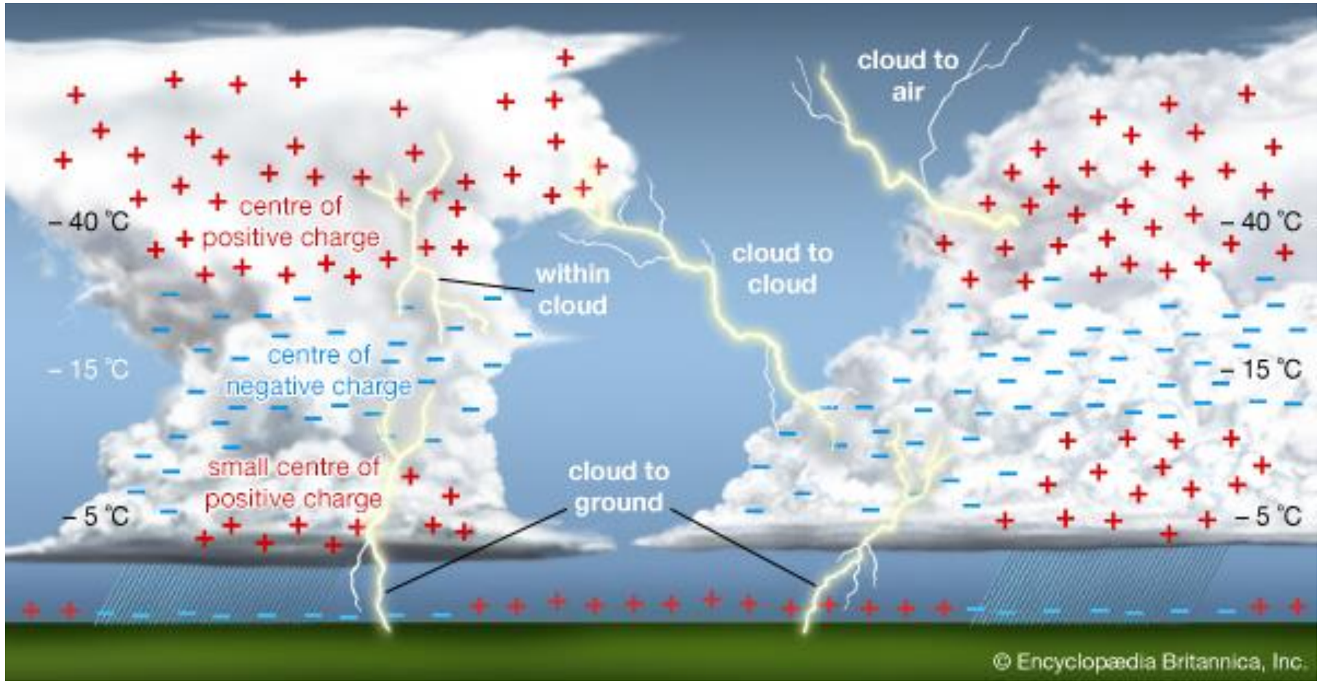




THUNDERSTORM HAZARDS

- Lightning
- Strong winds : Downdrafts
- Microburst
- Tornado
- Hail
- Heavy Rain
- flash floods

LIGHTNING


cloud to
air
centre of
positive charge
within
cloud
cloud to
cloud
centre of
negative charge
small centre of
positive charge
cloud to
ground
– 40 °C
– 15 °C
– 5 °C
– 40 °C
– 15 °C
– 5 °C
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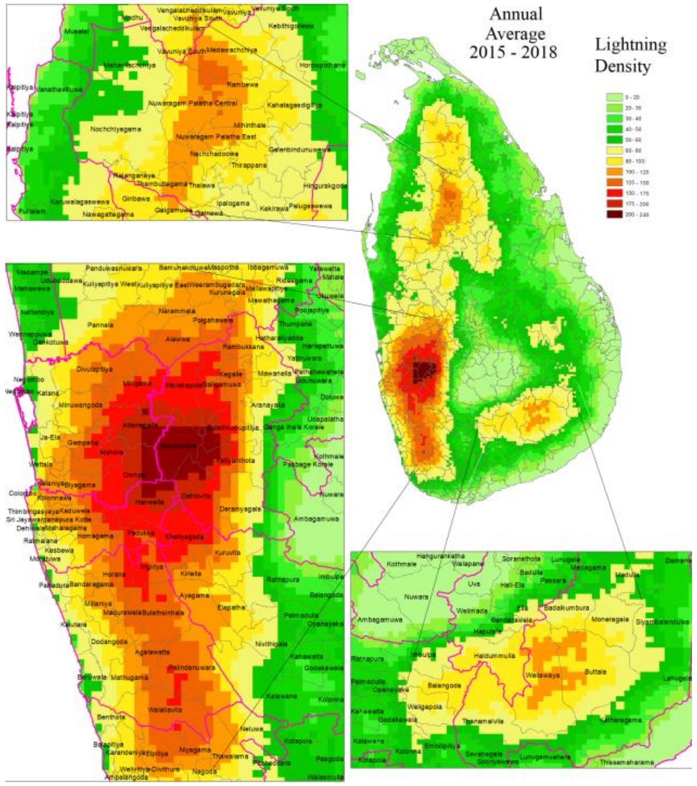
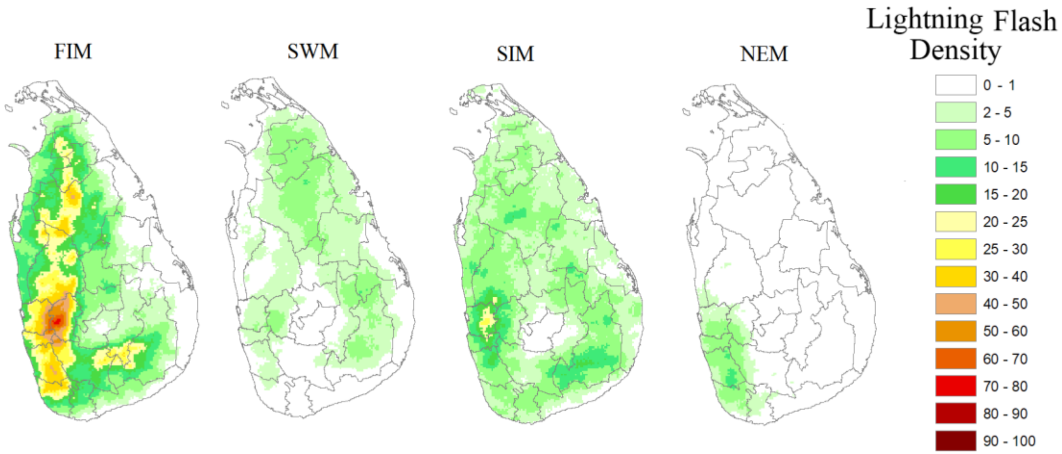
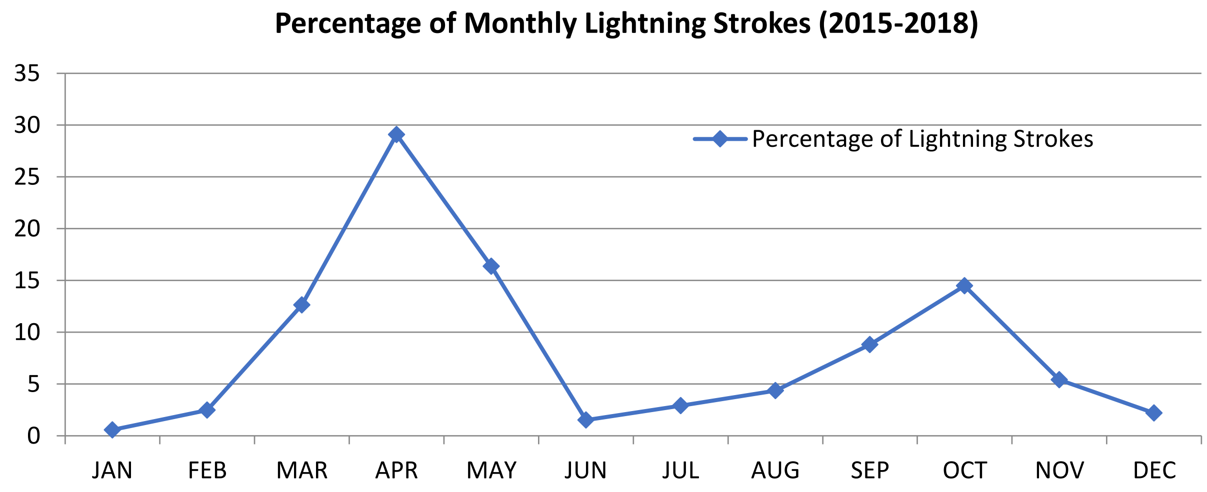
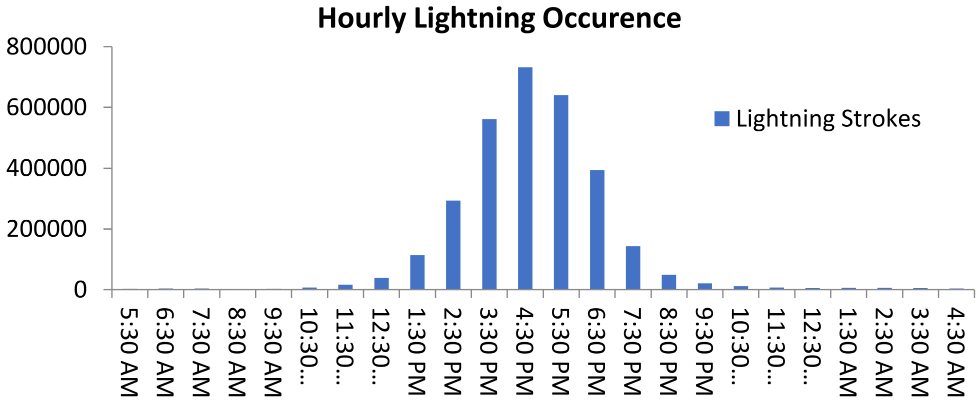
Lightning Occurrence – Sri Lanka









Source : Jayawardena and Mäkelä, 2021

Damaging Winds (non-tornadic)

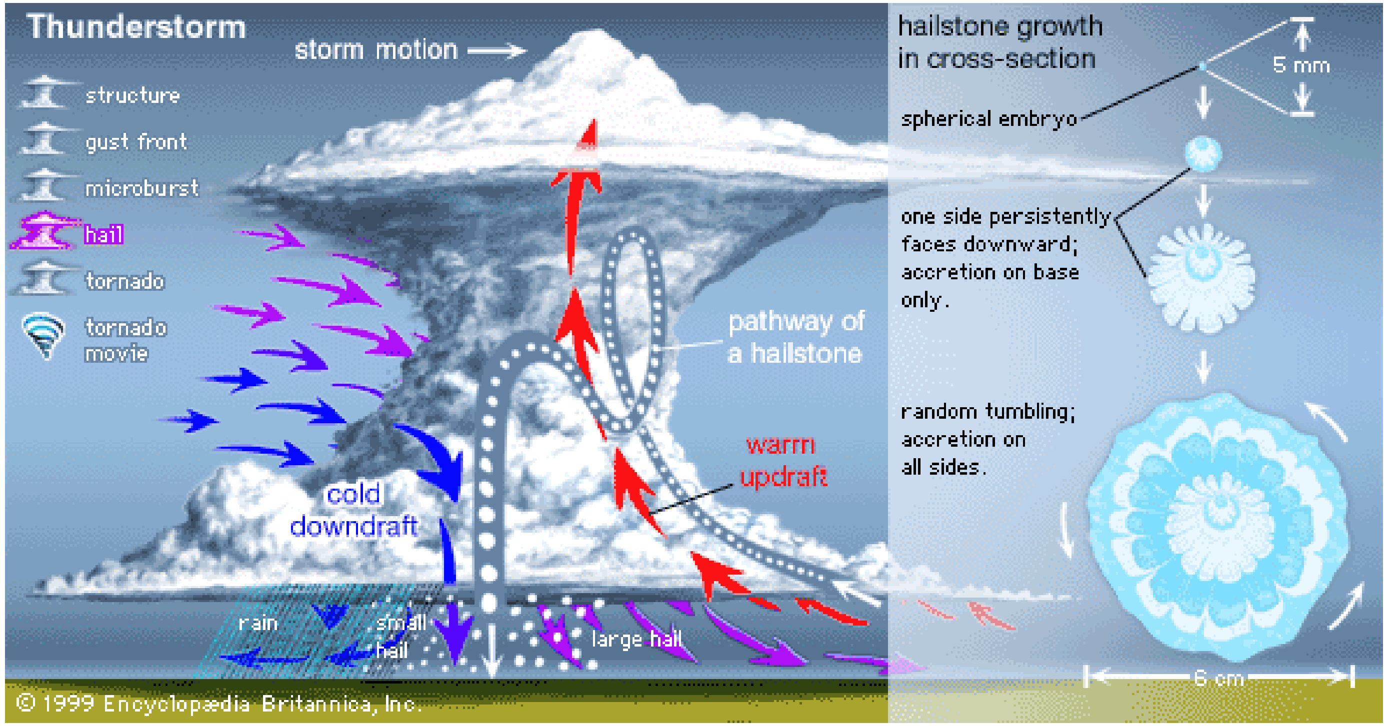
FLASH FLOODS

- A **flash flood** is a short-term, localized, and often unexpected rise in stream level above bankfull, usually because of torrential rain falling over a relatively small geographical area.
- Excessive rainfall may occur when a succession of thunderstorm cells, parts of a squall line or MCC, matures over the same area.
- Alternatively, a stationary or slow-moving intense thunderstorm cell may produce flooding rains.

- A thunderstorm is stationary or slow-moving when the system is embedded in weak steering winds aloft and/or maintained by a persistent flow of humid air up the slopes of a mountain range

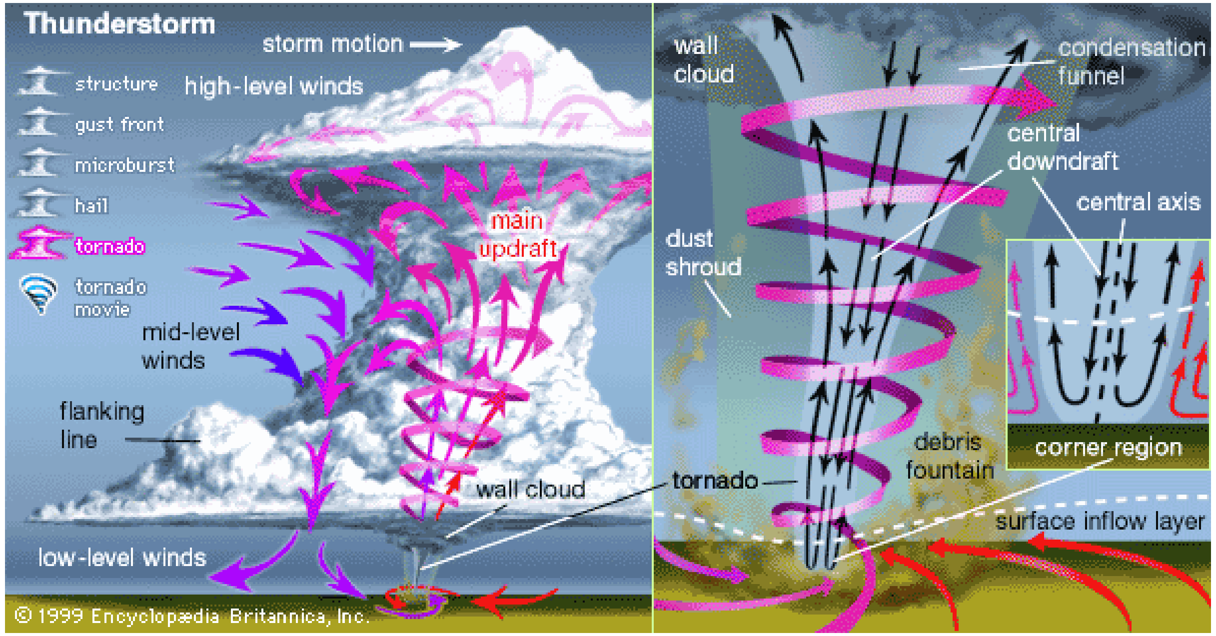
- Because of their design and composition, urban areas are prone to flash floods during intense downpours. Concrete and asphalt surfaces of a city are virtually impervious to water, so elaborate storm sewer systems are required to transport runoff to nearby natural drainage ways.

HAIL



- **Hail** is frozen precipitation in the form of balls or lumps of ice
- **start of as a small ice particle**
- **due to updraft the ice particle does not fall to ground but is recycled into the freezing portion of the thunderstorm,**
- **each time it is taken upward it accumulates more ice**
- **can end up as large as a grapefruit**

Tornados



A rotating column of air

Other Rotating Columns of Air

Figure 11.26

A waterspout in the Florida Keys, as photographed by meteorologist Joe Golden.

Fire whirls or fire devils

Dust-devil

Waterspout

Are we ready to face extreme events in a Warming Climate ?

- Germany, the Netherlands, and Belgium were hit by an extreme rainfall event in July 2021 causing 184 fatalities and estimated damage in the order of EUR 30 billion for Germany alone.

- The flooding in Europe in Mid July 2021 is a sobering demonstration of how even the most developed countries are not prepared for the impacts of climate change

- a monumental failure of the early warning system.
- Early warnings were not taken seriously enough and preparations were inadequate.

- European Flood Awareness System (EFAS) issue an "extreme" flood warning well in advance but did not reached to the people

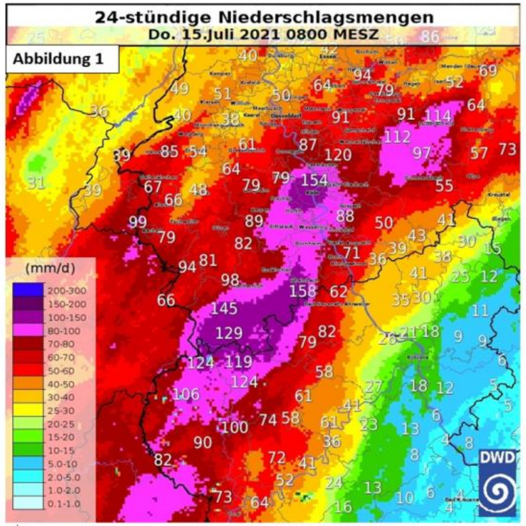
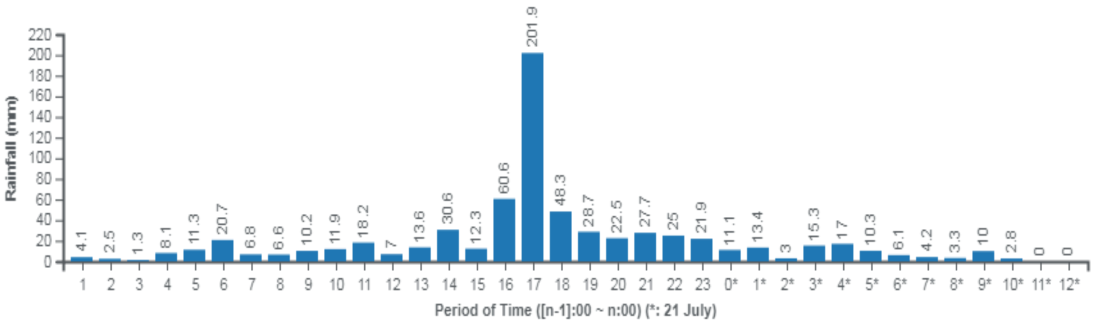


Figure 2: 24-Hour accumulated precipitation values, 15 July 2021, 06 UTC (DWD)

- Massive flooding struck in the city of Zhengzhou and other areas of Henan province, central China, on 20 July 2021
- From July 18 to 21st, Zhengzhou experienced a rare and continuous heavy rainfall process. Zhengzhou recorded 720 mm of rainfall, compared to the annual average of 641. More than half of this deluge fell in the space of six hours,
- Zhengzhou reached 201.9 mm from 16:00 to 17:00 on the 20th, exceeding the extreme hourly rainfall of China's land



- Zhengzhou invested more than 50 billion yuan ($7.7 billion) to build a “sponge city”.
- A sponge city is a new urban construction model for flood management, strengthening ecological infrastructure and drainage systems- stored water in floods and release water in droughts
- This floods put climate-friendly 'sponge cities' to the test.

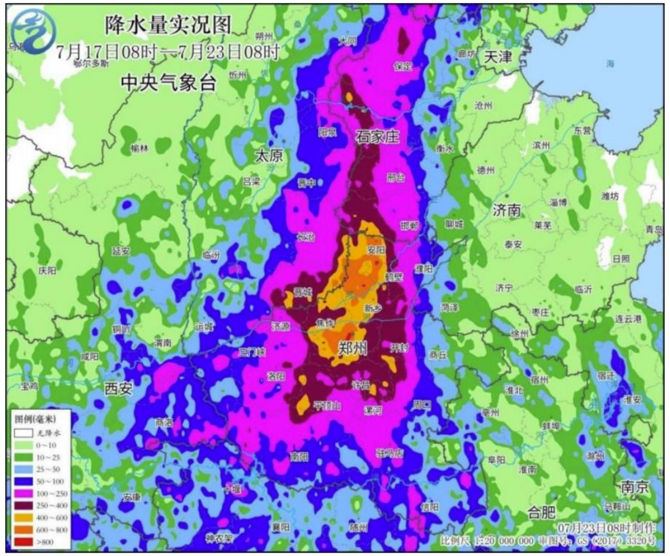


Figure 1. Illustration of the Sponge city concept (updated from Chinese version by authors)

A sponge city is a new urban construction model for flood management, strengthening ecological infrastructure and drainage systems- stored water in floods and release water in droughts

- Sponge is effective on light to medium precipitation - reduced the formation of flood peaks and promoted the sustainable circulation and recovery of rainwater.
- The Sponge City project includes construction of large capacity drainage pipe network, underground storm water storage tanks, water-and-soil conservancy and flood control facilities.
- The aim of the Sponge City project is to protect the city from floods with return periods up to about 1-in-100 year.
- Both the peak rate of precipitation and the total rainfall amount of this event far exceeded the tolerance of the design scope of the Sponge City.
- Estimated direct economic loss is on the order of RMB 88.5 billion (12.5 US$ billion).

Chennaiites need not worry about floods, says CM Stalin

TNN / Updated: Nov 5, 2023, (

One Month Before

Chief Minister M.K. Stalin has reassured residents of Chennai that they do not need to worry about floods during heavy rain. He stated that the city is well-prepared to handle heavy rainfall, thanks to the desilting of stormwater drains and the replacement of old drains. The government is also working on plugging water and sewage pipeline leaks to prevent water contamination. Additionally, long-term solutions include deepening and desilting city lakes to increase their capacity for rainwater storage and groundwater recharge.

Hundreds still stranded, plants closed in India's flood-hit Chennai

By Praveen Paramasivam
December 8, 2023 5:45 PM GMT+5:30 · Updated 15 hours ago

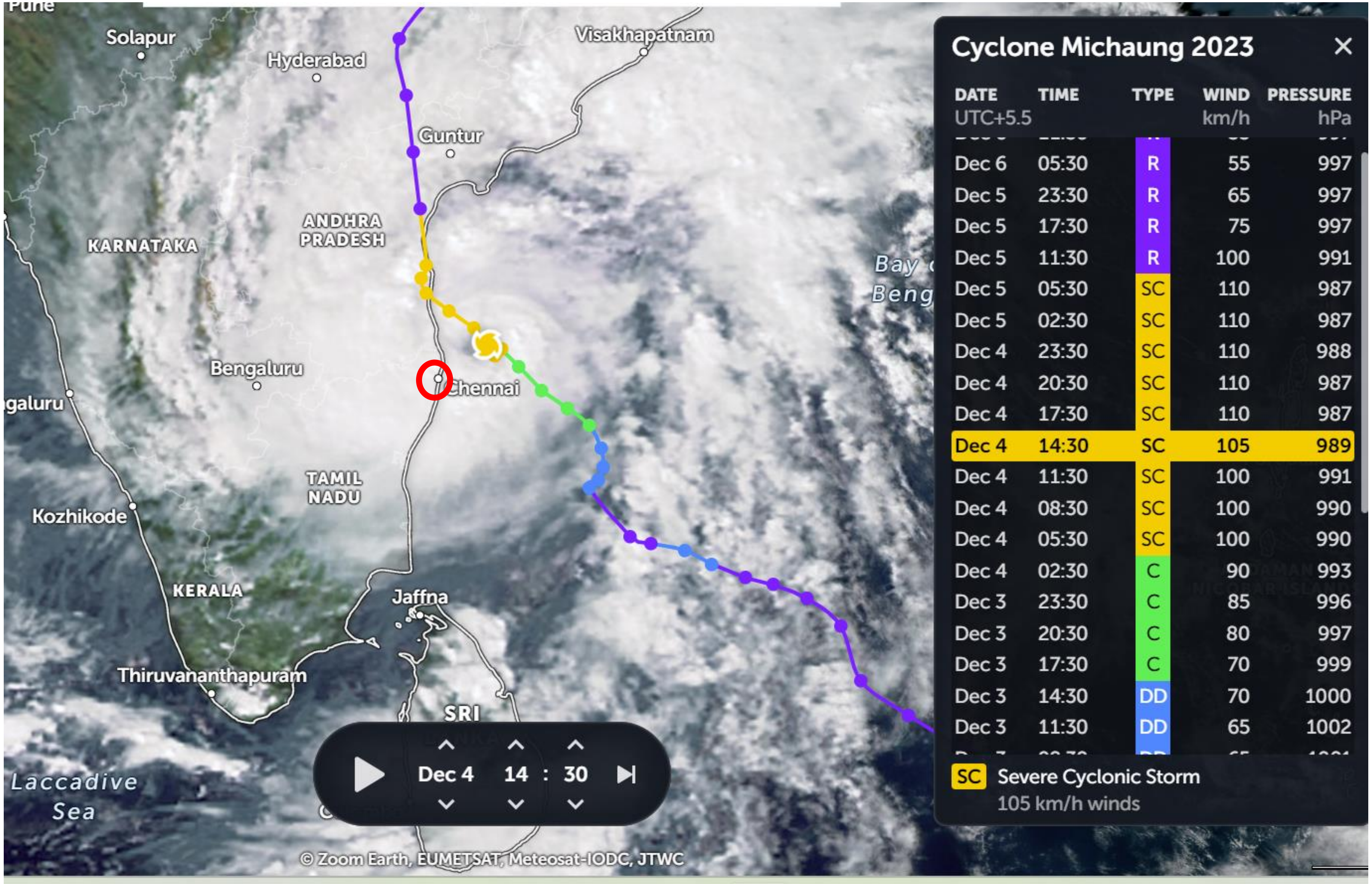
Aa

₹4,000 crore (0.5 Billion US$) storm water drain project implemented in the city

Three days after the rain stopped, about 20,000 roads in Chennai are still under sheets of water, while in suburban areas the flood water mixed with sewage poses the risk of spreading diseases

Deadly floods in 2015 killed more than 200 people in Chennai

Experts say that many Indian cities are [unprepared to deal with extreme weather events] due to unchecked construction and poor urban planning.



urban areas are prone to flash floods during intense downpours. Concrete and asphalt surfaces of a city are virtually impervious to water, so elaborate storm sewer systems are required to transport runoff to nearby natural drainage ways

Thank You