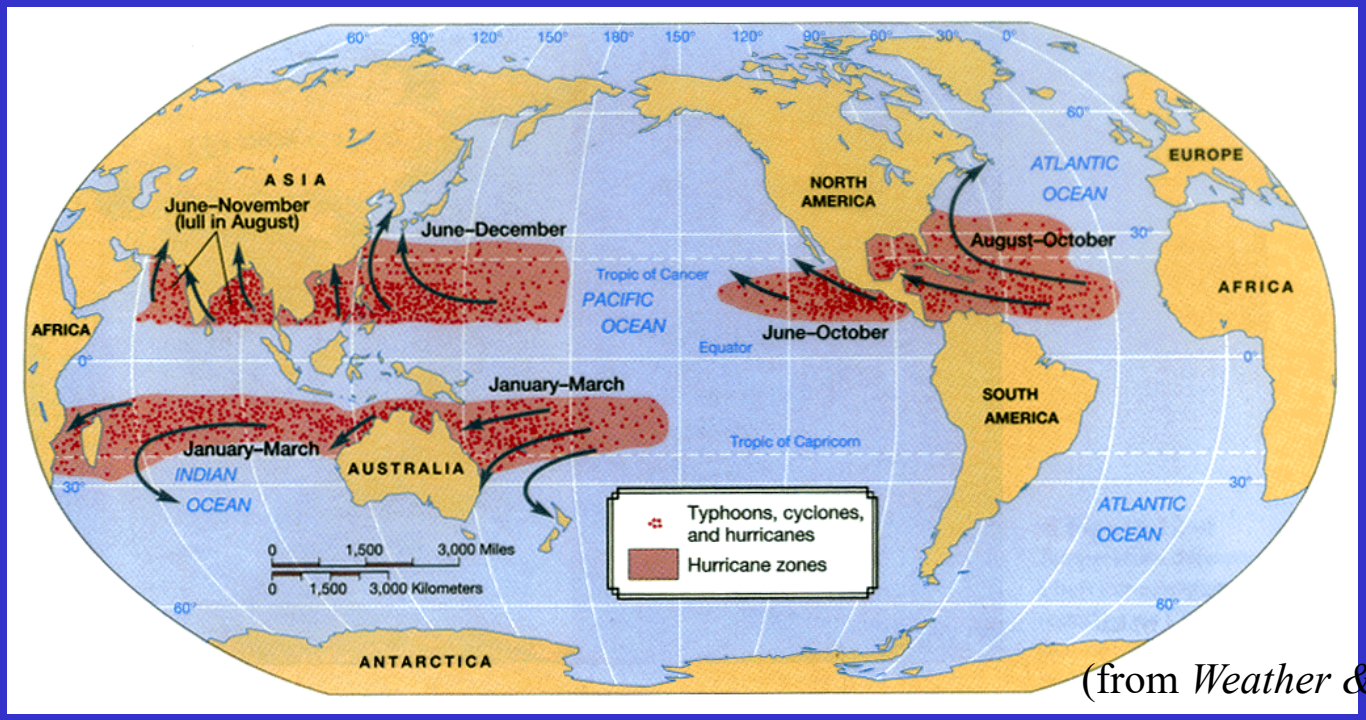
Lecture 9: Tropical Storms and Hurricanes

- Hurricane Characteristics
- Hurricane Formation, Movement and Dissipation
- Hurricane Destruction and Warming

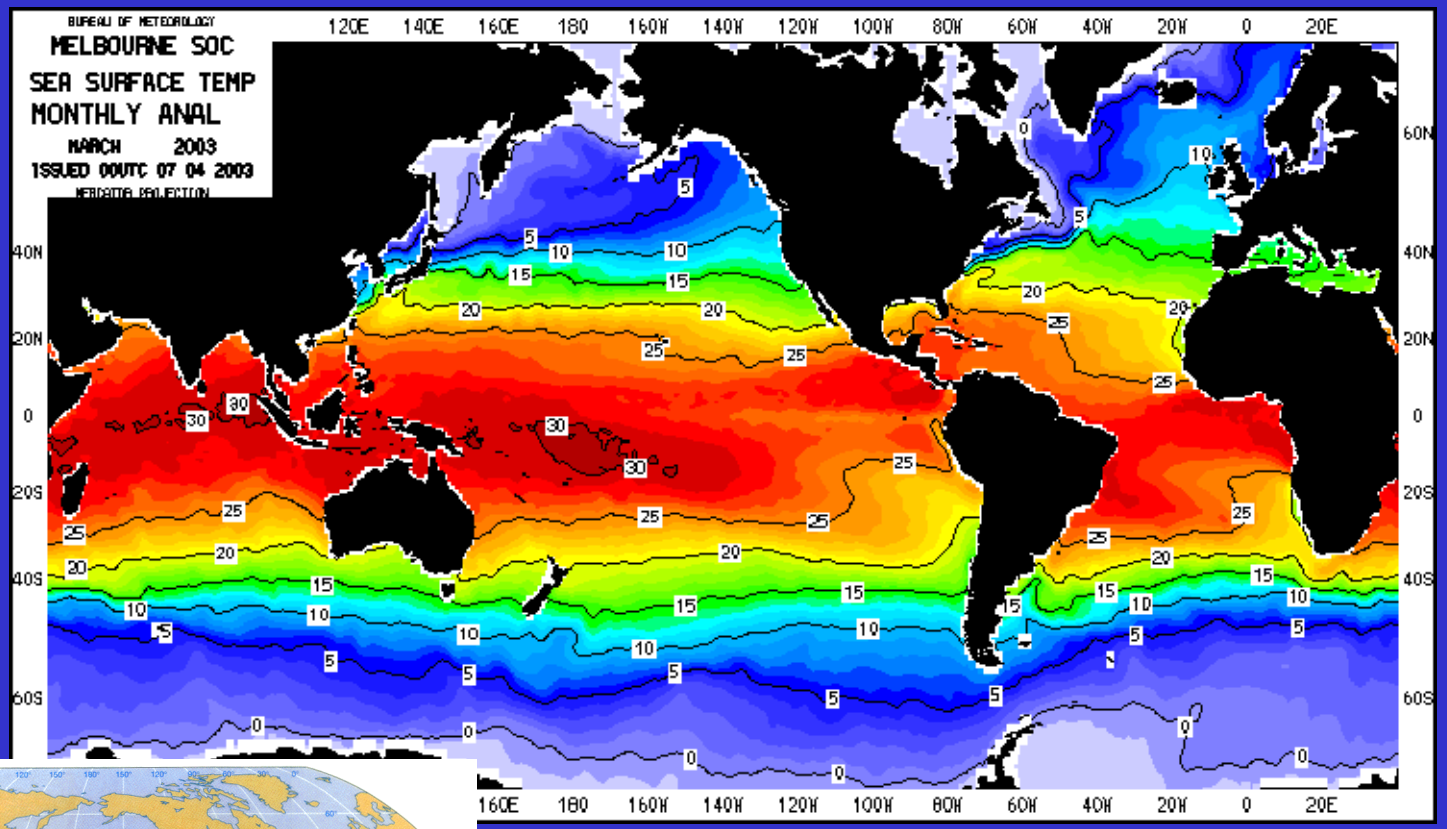
Naming Convention

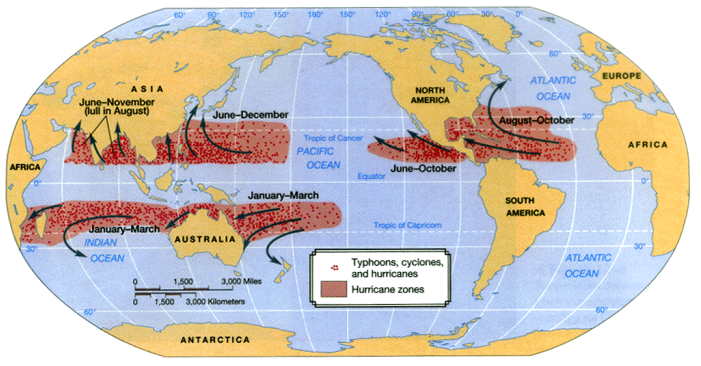


(from *Weather & Climate*)

- ***Hurricanes:*** extreme tropical storms over Atlantic and eastern Pacific Oceans.
- ***Typhoons:*** extreme tropical storms over western Pacific Ocean.
- ***Cyclones:*** extreme tropical storms over Indian Ocean and Australia.

Ocean Temperature And Hurricane





pend on a large pool of warm water.

ESS5
Prof. Jin-Yi Yu

Annual Hurricane Frequency

Table 12–1 Maximum, Minimum, and Average Number of Hurricanes (and Their Counterparts) per Year over Various Parts of the World's Oceans, 1968 to 1989 (1968 to 1990 for the Southern Hemisphere)

Basin	Maximum	Minimum	Average
Atlantic	12	2	5.4
Eastern Pacific	14	4	8.9
Western Pacific	24	11	16.0
Northern Indian Ocean	6	0	2.5
Southwestern Indian Ocean	10	0	4.4
Southeastern Indian Ocean/Australia	7	0	3.4
Australia/Southwestern Pacific	11	2	4.3
Global	65	34	44.9

Source: Colorado State University

- No hurricane in the Southern Atlantic Ocean.
- Western Pacific hurricanes are the strongest.

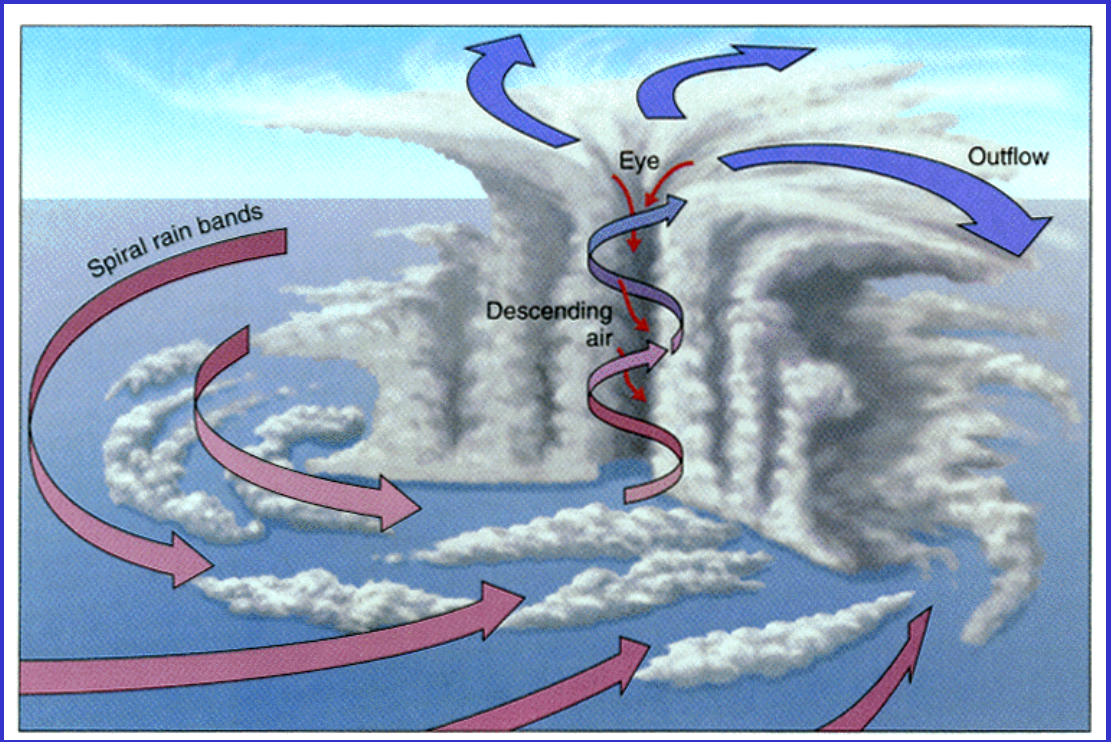
Hurricane Characteristics

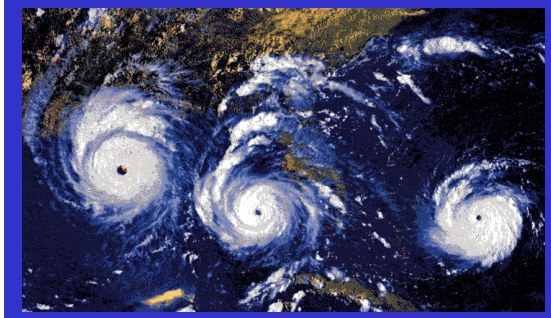
- Definition: Hurricanes have sustained winds of 120 km/hr (74 mph) or greater.
- Size: Average diameters are approximately 600 km (350 mi). (one third the size of mid-latitude cyclone)
- Duration: days to a week or more.
- Strength: Central pressure averages about 950 mb but may be as low as 870 mb.
- Power: The energy released by a single hurricane can exceed the annual electricity consumption of the US and Canada.

Hurricane Seasons

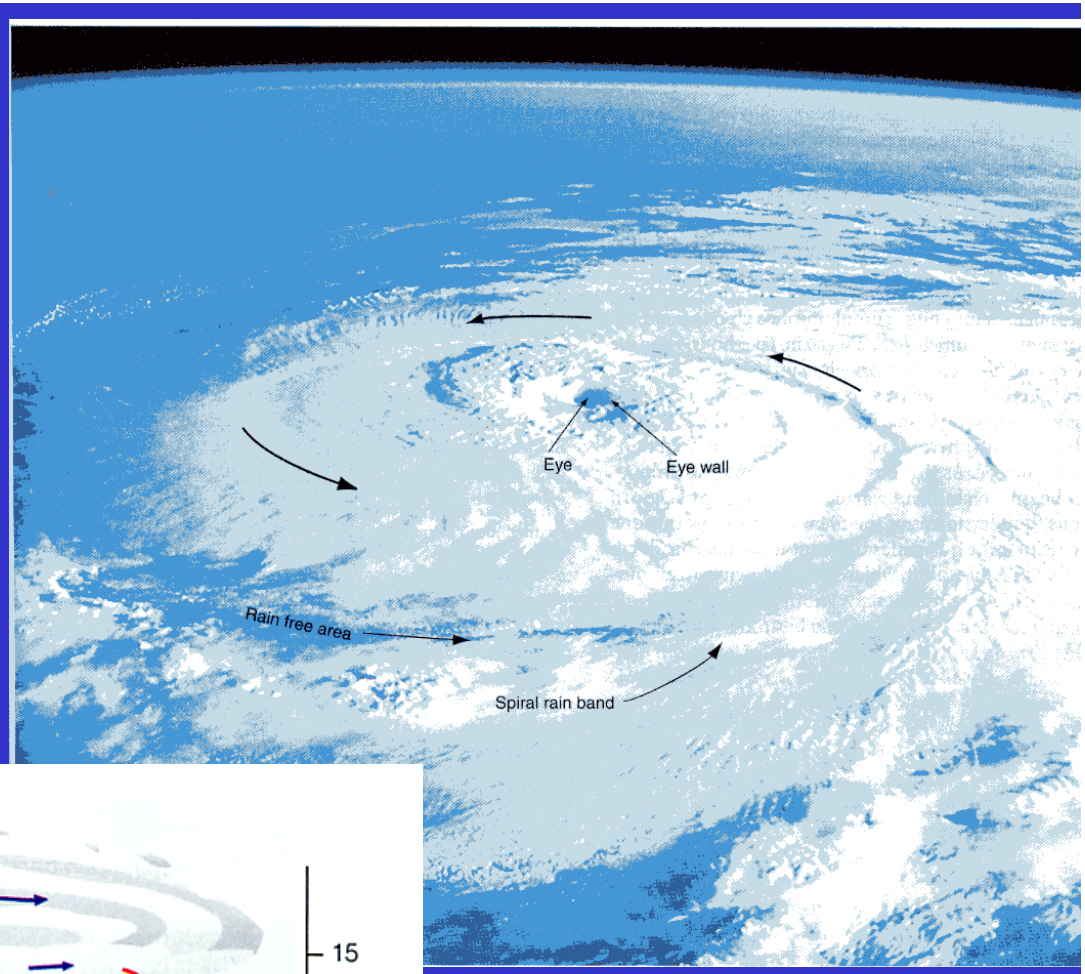
- Hurricanes obtain their energy from latent heat release in the cloud formation process.
- Hurricanes occur where a deep layer of warm waters exists and during the times of highest SSTs.
- For the N.H., August and September are the most active months.
- For the S.H., the hurricane season is January-March.

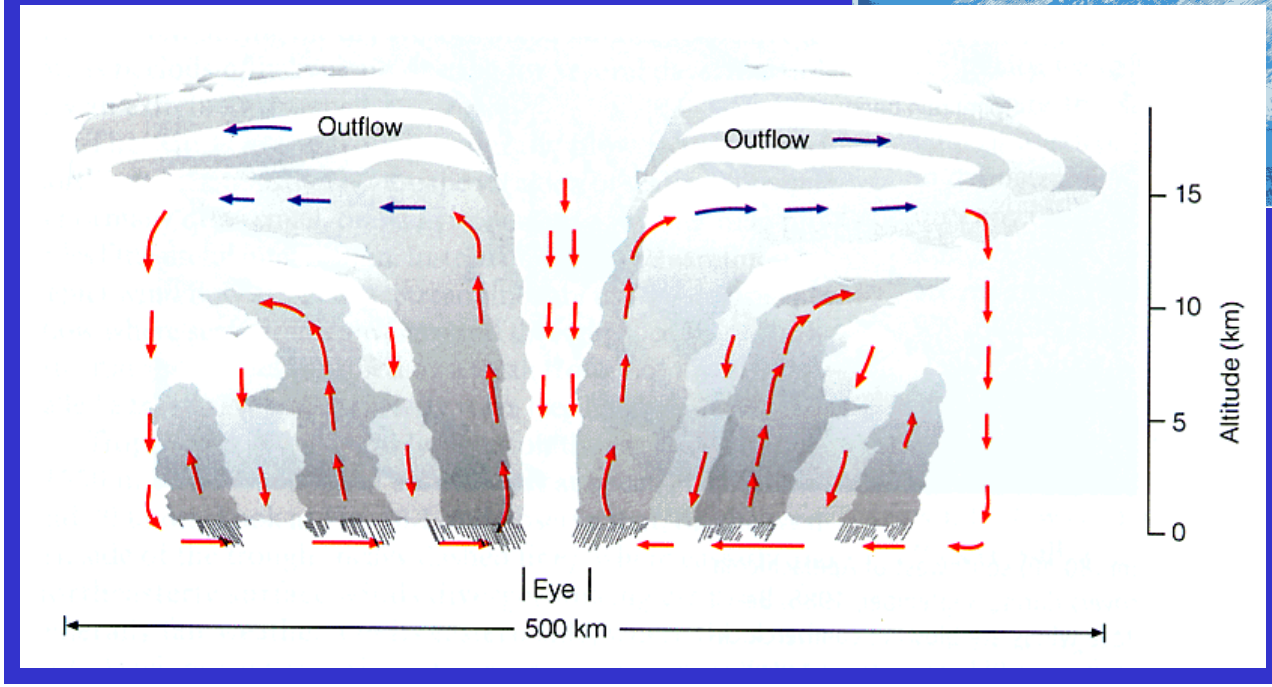
Hurricane Structure





- A ***central eye*** surrounded by large cumulonimbus thunderstorms occupying the adjacent ***eye wall***.
- Weak uplift and low precipitation regions separate individual ***cloud bands***.

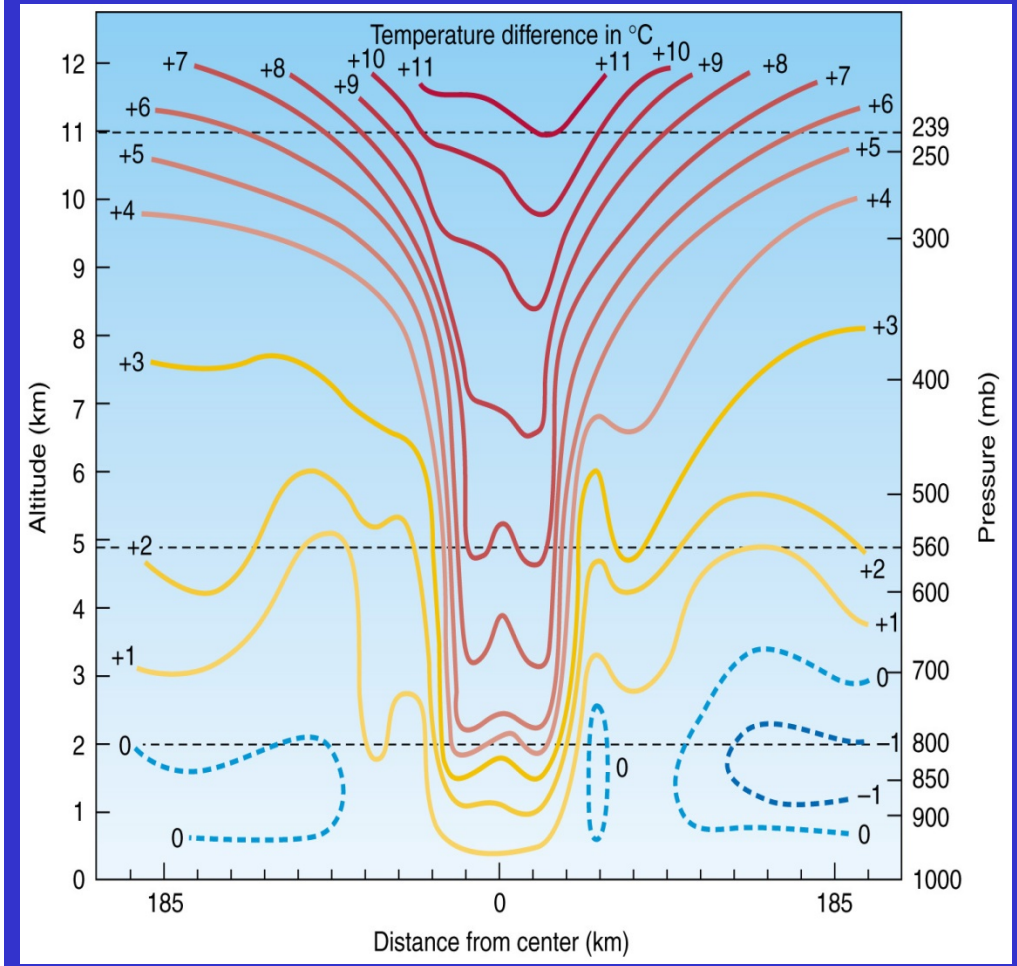




(from Meteorology Today)

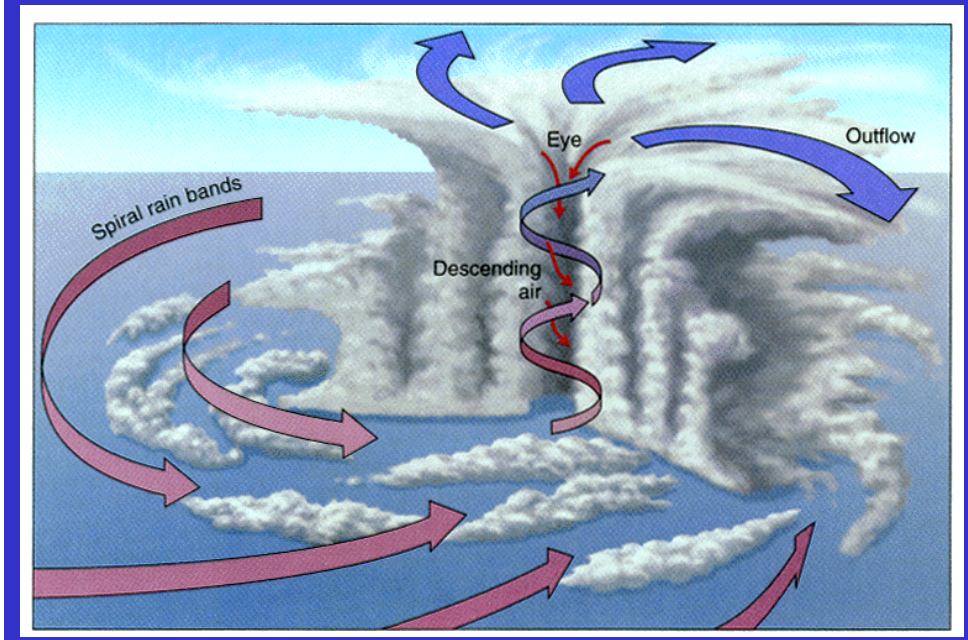
ESS5
Prof. Jin-Yi Yu

Temperature Structure



- Hurricane is characterized by a strong thermally direct circulation with the rising of warm air near the center of the storm and the sinking of cooler air outside.
- The warm core of the hurricane serves as a reservoir of potential energy, which is continuously being converted into kinetic energy by the thermally direct circulation.

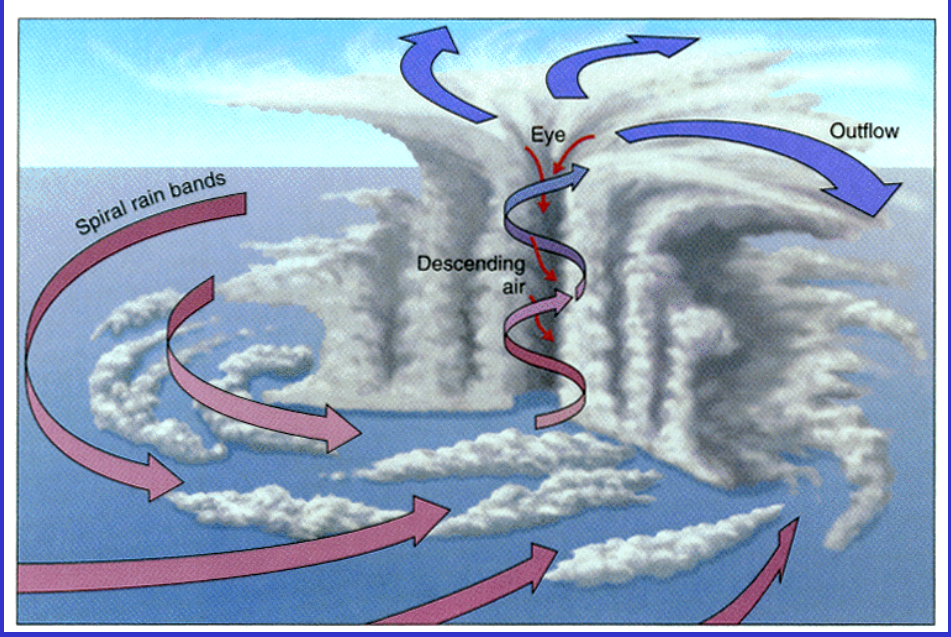
Pressure Structure



- The horizontal pressure gradient with altitude decreases slowly.
- At about 400 mb, pressures within the storm are approximate to that outside.
- Surface-400mb: Cyclonic circulation.
- 400mb-tropopause: anticyclonic circulation.

- The upper portions of the storm are blanketed by a cirrus cloud cap due to overall low temperatures.

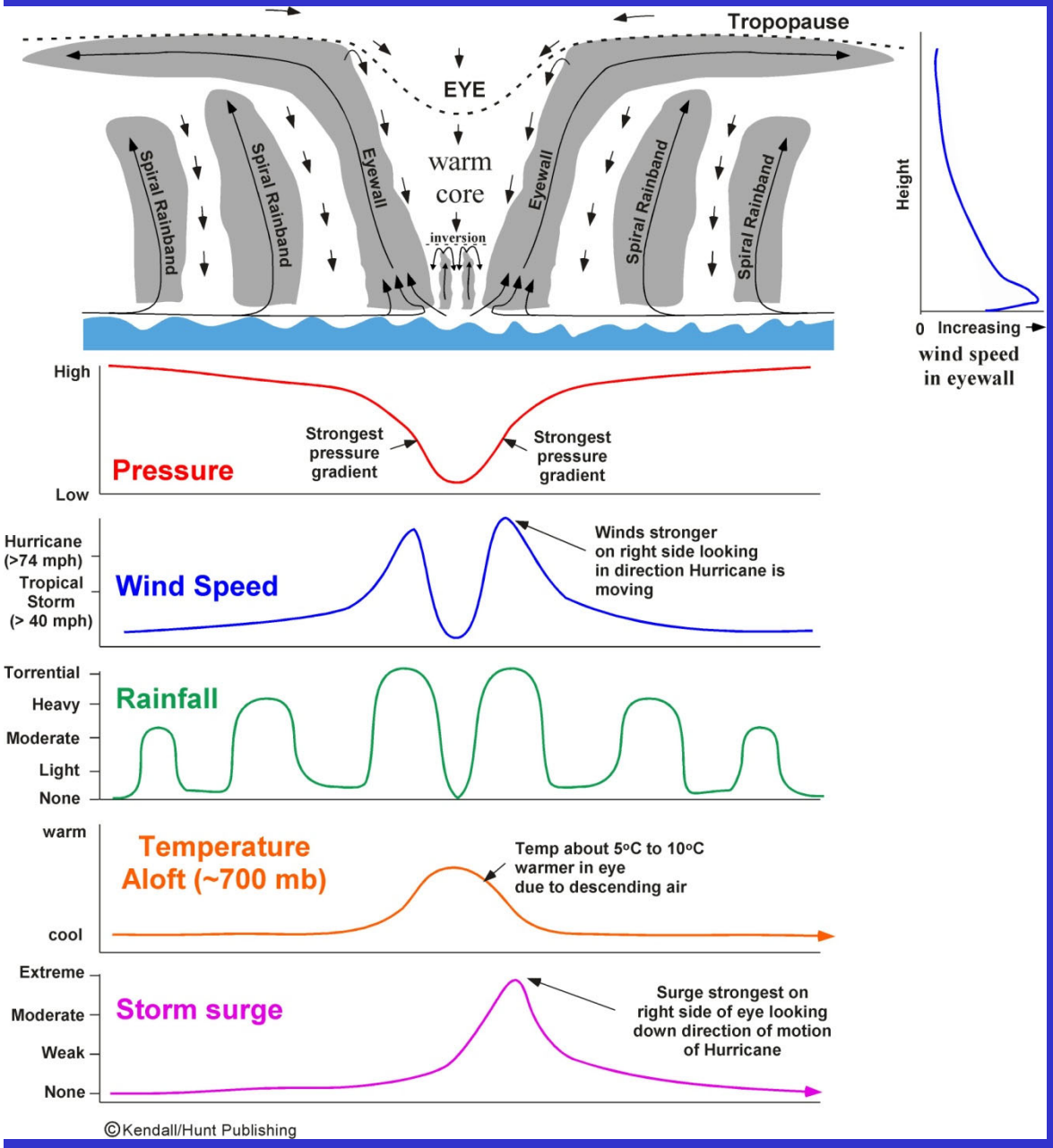
Hurricane Eye and Eye Wall



- The eye is an area of descending air, relatively clear sky, and light winds which is about 25 km (15 mi) in diameter on average.
- A shrinking eye indicates storm intensification.
- The eye wall is comprised of the strongest winds, the largest clouds, and the heaviest precipitation with rainfall rates as high as 2500 mm/day (100 in.).

- The eye moves at a speed of 20 km/hr ➔ The calm weather associated with the eye will last less than an hour.

Vertical Cross Section of Hurricane

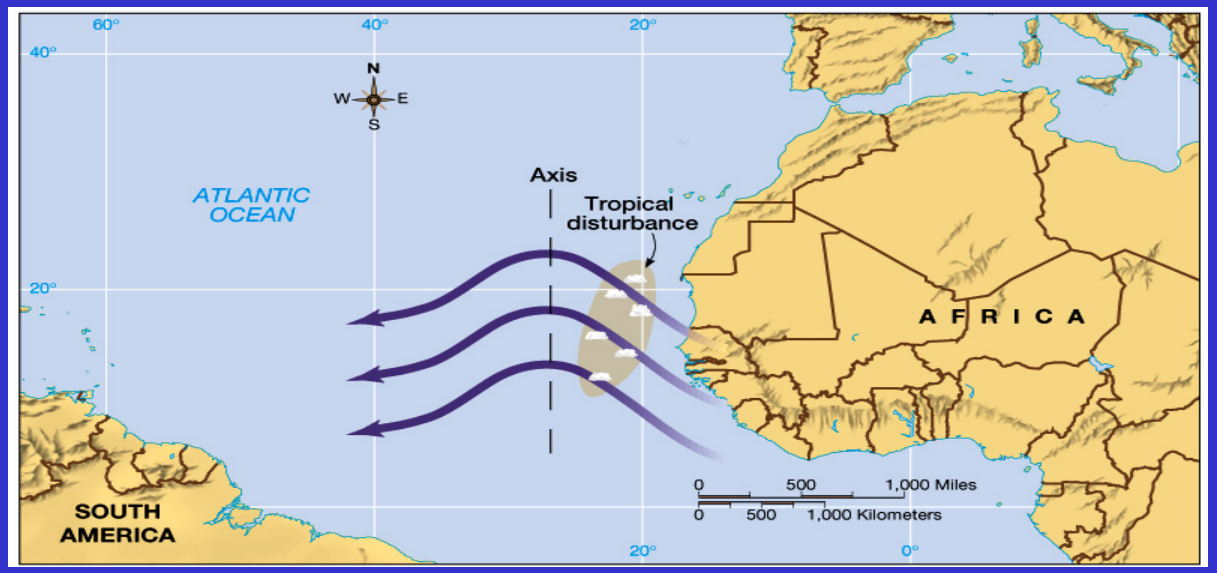


- Most of the air in the eye descends very slowly, taking days to traverse the eye's depth.
- Air sinks in the eye warms adiabatically and make the eye much warmer than other regions of the hurricane.
- In the eye wall air ascends from the surface to the tropopause.
- Pressure gradient is the strongest near the eye wall, where the most violent winds are produced.
- Strongest rainfall is also produced near the eye wall.
- Strongest storm surge occurs to the right of the hurricane.

Hurricane Formation

- ***Tropical Disturbance***: Clusters of small thunderstorms.
- ***Tropical Depression***: When at least one closed isobar is present, the disturbance is classified as a ***tropical depression.***
- ***Tropical Storm:*** Further intensification, to wind speeds of 60 km/hr (37 mph), place the storm in the category of ***tropical storm.*** At this point, the system is named.
- ***Hurricane***: Hurricane status is gained when winds reach or exceed 120 km/hr (74 mph).

Tropical Disturbances and Easterly Waves

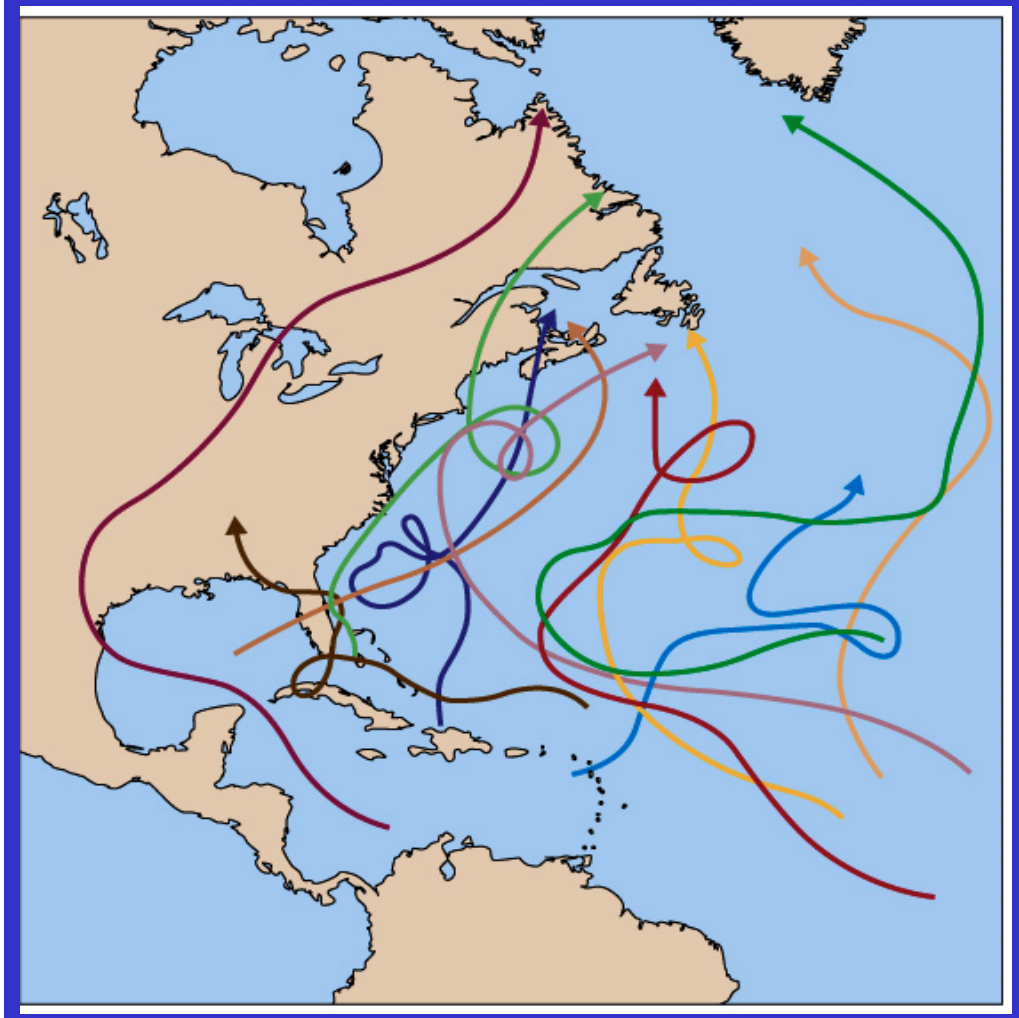


- Some tropical disturbances form in association with mid-latitude troughs migrating toward lower latitudes, some form from ITCZ-related convection, but most develop from easterly waves.
- ***Easterly waves***, or undulations in the trade wind pattern, spawn hurricanes in the Atlantic (typically 2–3000 km).
- Only about 10% tropical disturbances intensify into more organized, rotating storms.

Conditions Necessary for Hurricane Formation

- Hurricanes form only over deep (several tens of meters) water layers with surface temperatures in excess of ***27 ^{o}C.***
- Poleward of about 20^{o}, water temperatures are usually below this threshold
- Hurricanes are most frequent in late summer and early autumn during high SST times
- ***Coriolis force*** is an important contributor, and as such, hurricanes do not form equatorward of 5^{o}.
- Need an unstable atmosphere: available in the western tropical ocean but not in the eastern parts of the ocean.
- Strong vertical shear must be absent for hurricane formation.

Hurricane Movement



- Tropical disturbances and depressions are largely regulated by trade wind flow and simply move westward.
- For tropical storms and hurricanes, upper-level winds and ocean temperatures gain importance .
- Fully developed hurricanes move poleward.

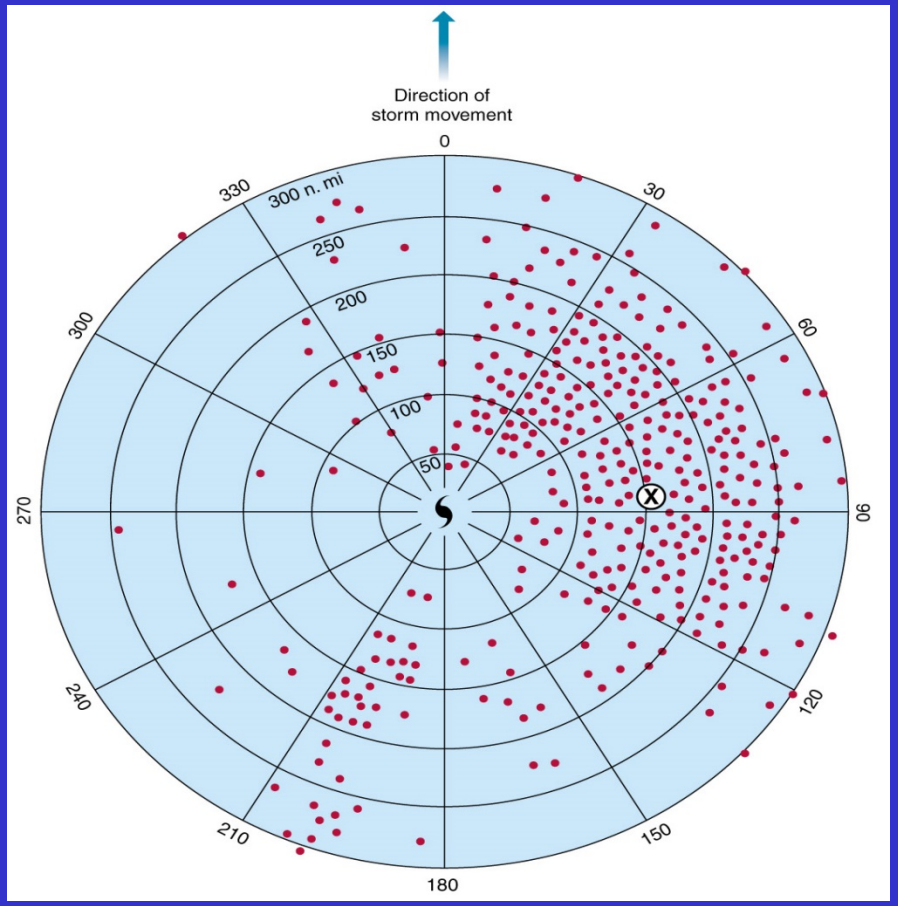
Hurricane Dissipation

- After making landfall, a tropical storm may die out completely within a few days.
- Even as the storm weakens, it can still bring in huge amount of water vapor and rainfall hundreds of kilometers inland.

Hurricane Damages

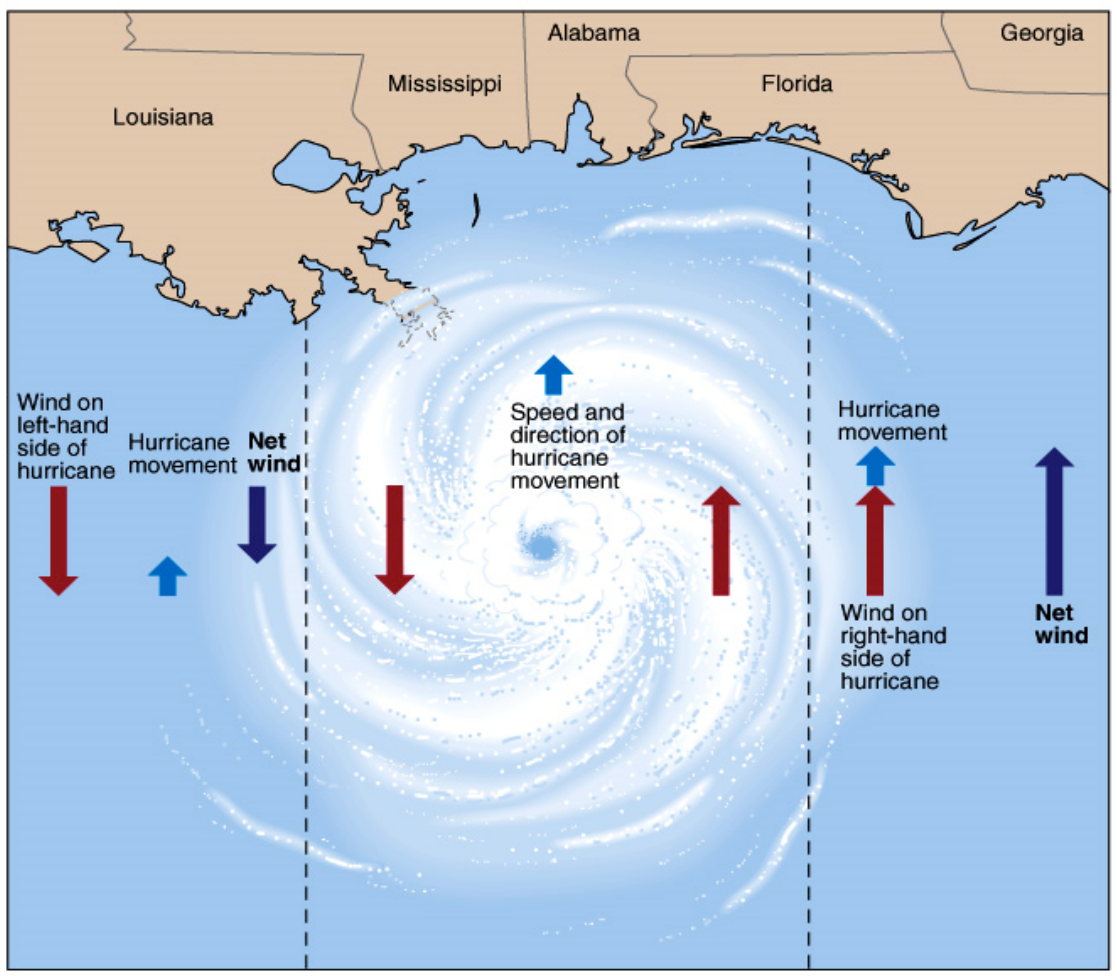
- Heavy rainfalls
- Strong winds
- Tornadoes
- Storm Surges: A rise in water level induced by the hurricane.

Hurricane Induced Tornadoes



- Most hurricanes also contain clusters of tornadoes.
- Most of these tornadoes occur in the right front quarter of the hurricane movement.
- It appears the slowing of the wind by friction at landfall contribute to the formation of tornadoes.

Hurricane Wind Structure



- Winds and surge are typically most intense in the ***right front quadrant*** of the storm where wind speeds combine with the speed of the storm's movement to create the area of highest potential impact.

Storm Surges

- Process 1: Hurricane winds drag surface waters forward and pileup the waters near coasts.
- Process 2: Lower atmospheric pressure raises sea level (for every 1 mb pressure decrease, sea level raises 1 cm).
- Storm surges raise costal sea level by a meter or two for most hurricanes, but can be as much as 7 meters.

Trend .vs. Multi-decadal Change

- Middle 1990s-Now: A significant increase in the numbers of hurricanes and intense hurricanes making landfall in the United States.
- 1970s-middle 1990s: lower than normal incidence of Atlantic hurricanes.
- It is still in debate where the recent increase of hurricane and its intensity is a sign of global warming or a part of natural multi-decadal cycle.

Hurricane Forecasts

- The National Hurricane Center is responsible for predicting and tracking Atlantic and east Pacific hurricanes.
- Data are gathered through satellite observations, surface observations, and aircraft using ***dropsondes.***
- Statistical, dynamic, and hybrid computer ***models*** running on supercomputers assist in future track position and storm intensity predictions.
- Future positions are given along six-hour trajectories with accuracy decreasing as lead time increases.

Hurricane Watches and Warnings

- ***Hurricane watch***: if an approaching hurricane is predicted to reach land in more than 24 hours.
- *Hurricane Warning*: if the time frame is less, a ***warning*** is given.

Naming of Hurricanes

- When a tropical disturbance reaches the stage of tropical storm, it will be given a name.
- The name come from a A-W list (A-Z for Pacific) created by World Meteorological Organization (WMO).
- Six lists are created for the Atlantic Ocean, each list is used for one hurricane season.
- The names of the hurricanes that cause devastating damages are removed from the list forever.

Atlantic Hurricane Names by Year

2017	2018	2019	2020	2021	2022
Arlene	Alberto	Andrea	Arthur	Ana	Alex
Bret	Beryl	Barry	Bertha	Bill	Bonnie
Cindy	Chris	Chantal	Cristobal	Claudette	Colin
Don	Debby	Dorian	Dolly	Danny	Danielle
Emily	Ernesto	Erin	Edouard	Elsa	Earl
Franklin	Florence	Fernand	Fay	Fred	Fiona
Gert	Gordon	Gabrielle	Gonzalo	Grace	Gaston
Harvey	Helene	Humberto	Hanna	Henri	Hermine
Irma	Isaac	Imelda	Isaias	Ida	Ian
Jose	Joyce	Jerry	Josephine	Julian	Julia
Katia	Kirk	Karen	Kyle	Kate	Karl
Lee	Leslie	Lorenzo	Laura	Larry	Lisa
Maria	Michael	Melissa	Marco	Mindy	Martin
Nate	Nadine	Nestor	Nana	Nicholas	Nicole
Ophelia	Oscar	Olga	Omar	Odette	Owen
Philippe	Patty	Pablo	Paulette	Peter	Paula
Rina	Rafael	Rebekah	Rene	Rose	Richard
Sean	Sara	Sebastien	Sally	Sam	Shary
Tammy	Tony	Tanya	Teddy	Teresa	Tobias
Vince	Valerie	Van	Vicky	Victor	Virginie
Whitney	William	Wendy	Wilfred	Wanda	Walter

Hurricane Intensity Scale

Table 12–2 The Saffir-Simpson Scale

Category	Pressure mb	Wind Speed km/hr	Wind Speed mph	Storm Surge m	Storm Surge ft	Damage
1	≥ 980	119–154	74–95	1–2	4–5	Minimal
2	965–979	155–178	96–110	2–3	6–8	Moderate
3	945–964	179–210	111–130	3–4	9–12	Extensive
4	920–944	211–250	131–155	4–6	13–18	Extreme
5	< 920	> 250	> 155	> 6	> 18	Catastrophic

- The Saffir-Simpson scale.
- Five categories: larger numbers indicate lower central pressure, greater winds, and stronger storm surges.

Fujita Intensity Scale

Table 11–2 Fujita Intensity Scale

Intensity	Wind Speed (km/hr)	Wind Speed (mph)	Typical Amount of Damage
F0	< 116	< 72	Light: Broken branches, shallow trees uprooted, damaged signs and chimneys.
F1	116–180	72–112	Moderate: Damage to roofs, moving autos swept off road, mobile homes overturned.
F2	181–253	113–157	Considerable: Roofs torn off homes, mobile homes completely destroyed, large trees uprooted.
F3	254–332	158–206	Severe: Trains overturned, roofs and walls torn off well-constructed houses.
F4	333–419	207–260	Devastating: Frame houses completely destroyed, cars picked up and blown downwind.
F5	420–512	261–318	Incredible: Steel-reinforced concrete structures badly damaged.
F6	>513	>319	Inconceivable: Might possibly occur in small part of an F4 or F5 tornado. It would be difficult to identify the damage done specifically by these winds, as it would be indistinguishable from that of the main body of the tornado.

weak

strong

violent