Cause, Assessment & Management of Flood Hazards associated with Landfalling Tropical Cyclones & Heavy Rain

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Outlines

Part 1 –

Cause & Impact of Landfalling Tropical Cyclones

Part 2 –

Case Assessment of the Failure of 'New Orleans Flood Protection System' from Hurricane Katrina

Part 3 –

Management & Mitigation of Flood Hazards associated with Landfalling Tropical Cyclones

Part 4-

Tutorial- Simulation models for planning, forecast and assessment

Outlines

Part 1 - Cause & Impact of Landfalling Tropical Cyclones

- **Causes**
  - **Formation of tropical cyclones**
  - **Hurricanes, cyclones & typhoons: geographic characteristics:**
  - **Dissipation or breaking of tropical cyclones**
  - **Effect of global warming**
- **Impact**
  - **Coastal flooding: storm surges-wind setup, wave setup & tides; assessment of probability of occurrence**
  - **Inland flooding: storm intensity & pattern, flood magnitude & frequency analysis; impact of urban development & other natural/man-made disturbances**
  - **Estuarine flooding**

Part 1-a

Cause & Impact of Landfalling Tropical Cyclones

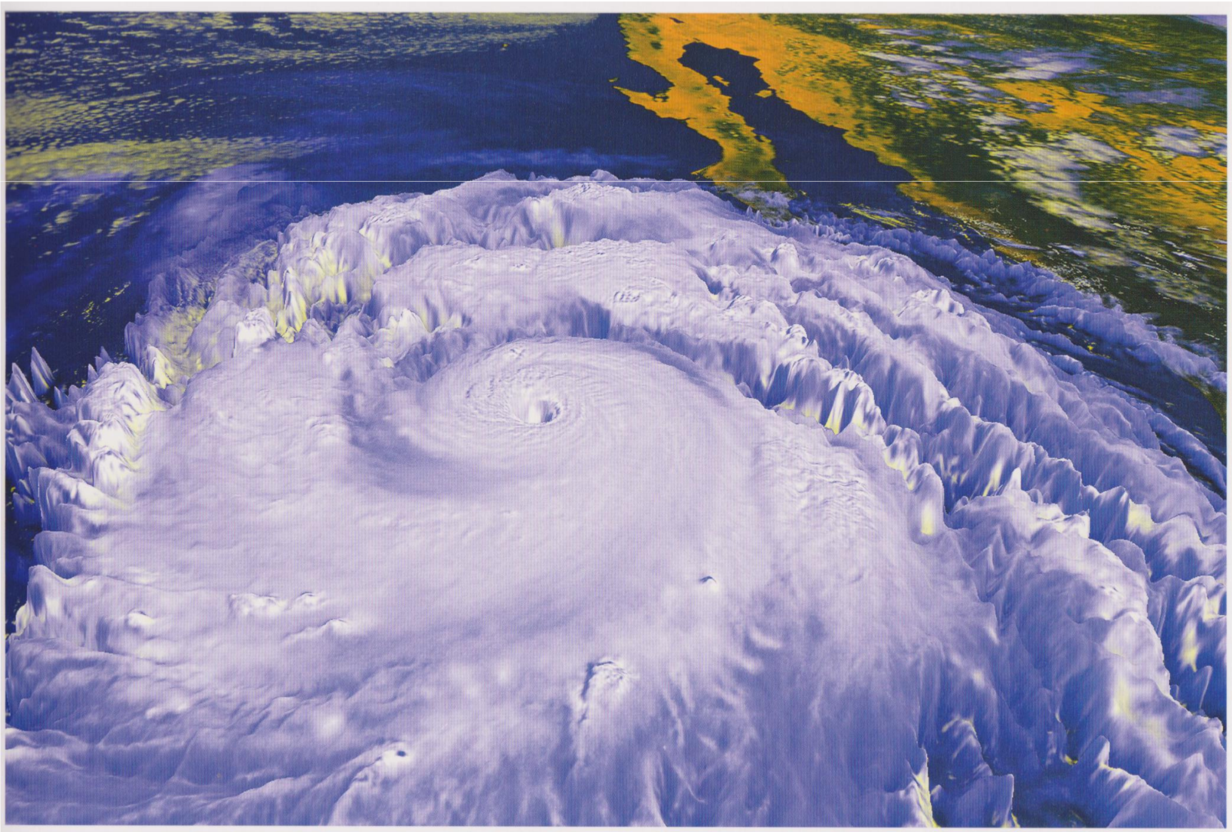
Cause of Land-falling Tropical Cyclones

- Formation of tropical cyclones
- Hurricanes, cyclones & typhoons: geographic characteristics
- Dissipation or breaking of tropical cyclones
- Effect of global warming

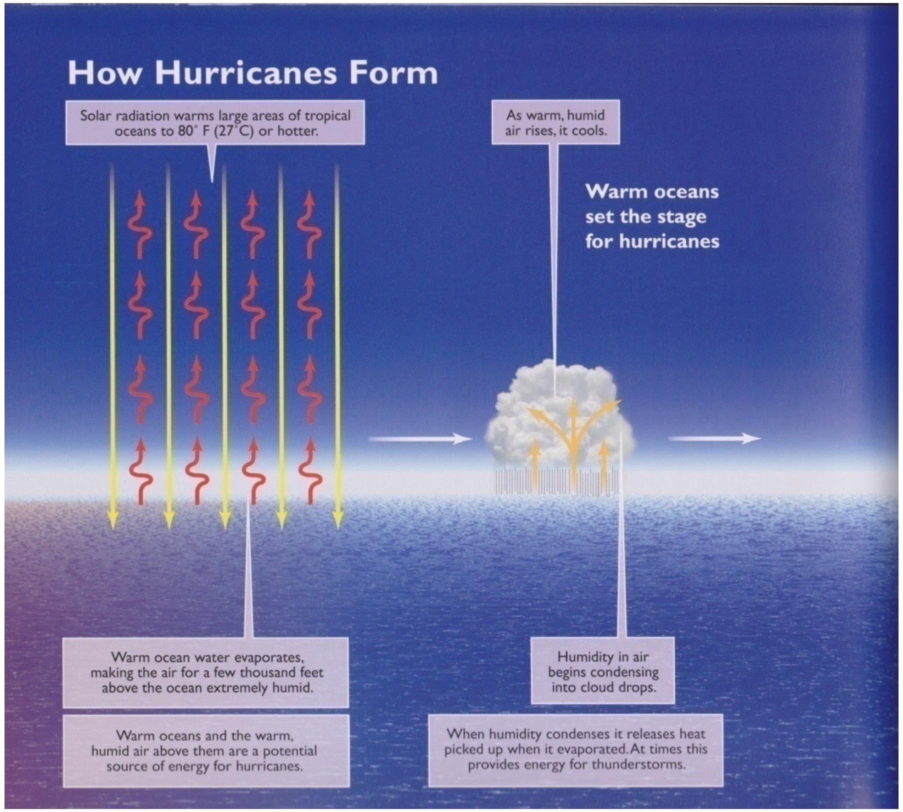
Formation of tropical cyclones

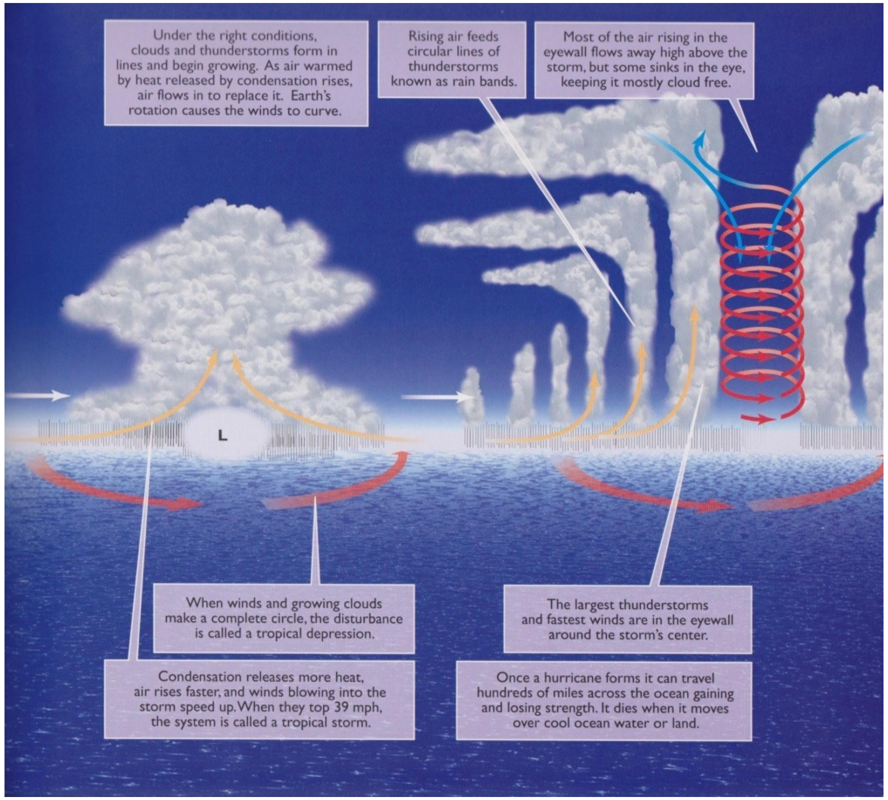
Tropical cyclone

is the general term for all cyclonic circulations originating over tropical oceans.

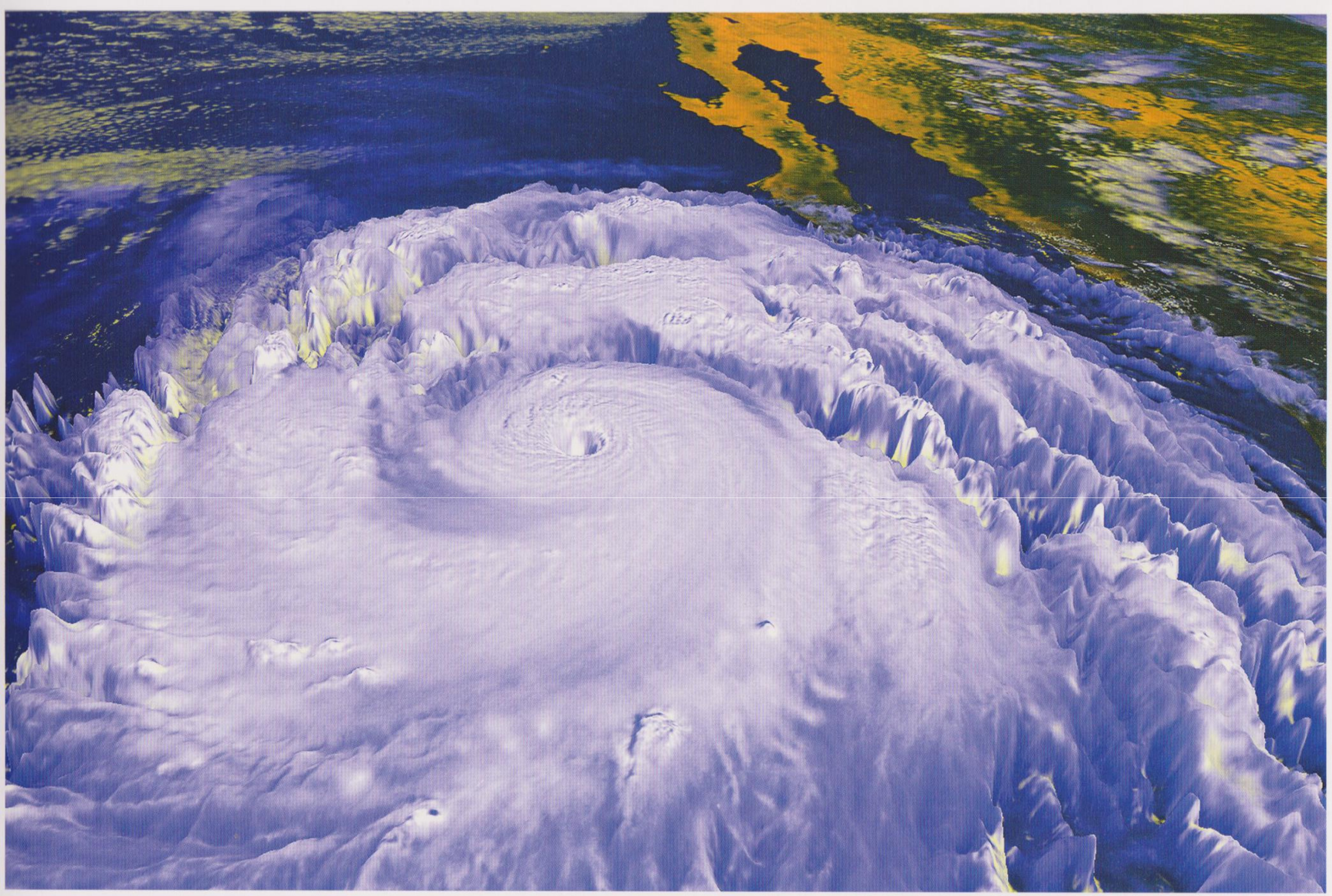


- As warm, moist air rises, it lowers air pressure at sea level and draws surrounding air inward & upward in a rotating pattern-counter clockwise in northern hemisphere.
- As water vapor-laden air spiral in and rises to higher altitudes, it cools & releases heat as it condenses to rain.
- This cycle of evaporation & condensation brings the ocean’s heat energy into the vortex, powering the storm.
- It’s a ‘warm core’ cyclonic system with its central core area warmer than its surroundings.





* Source: Hurricanes-causes, effects & future by Leatherman & Williams
Voyageur Press, 2008



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Voyageur Press, 2008

Formation of tropical cyclones

Pre-requisite conditions:

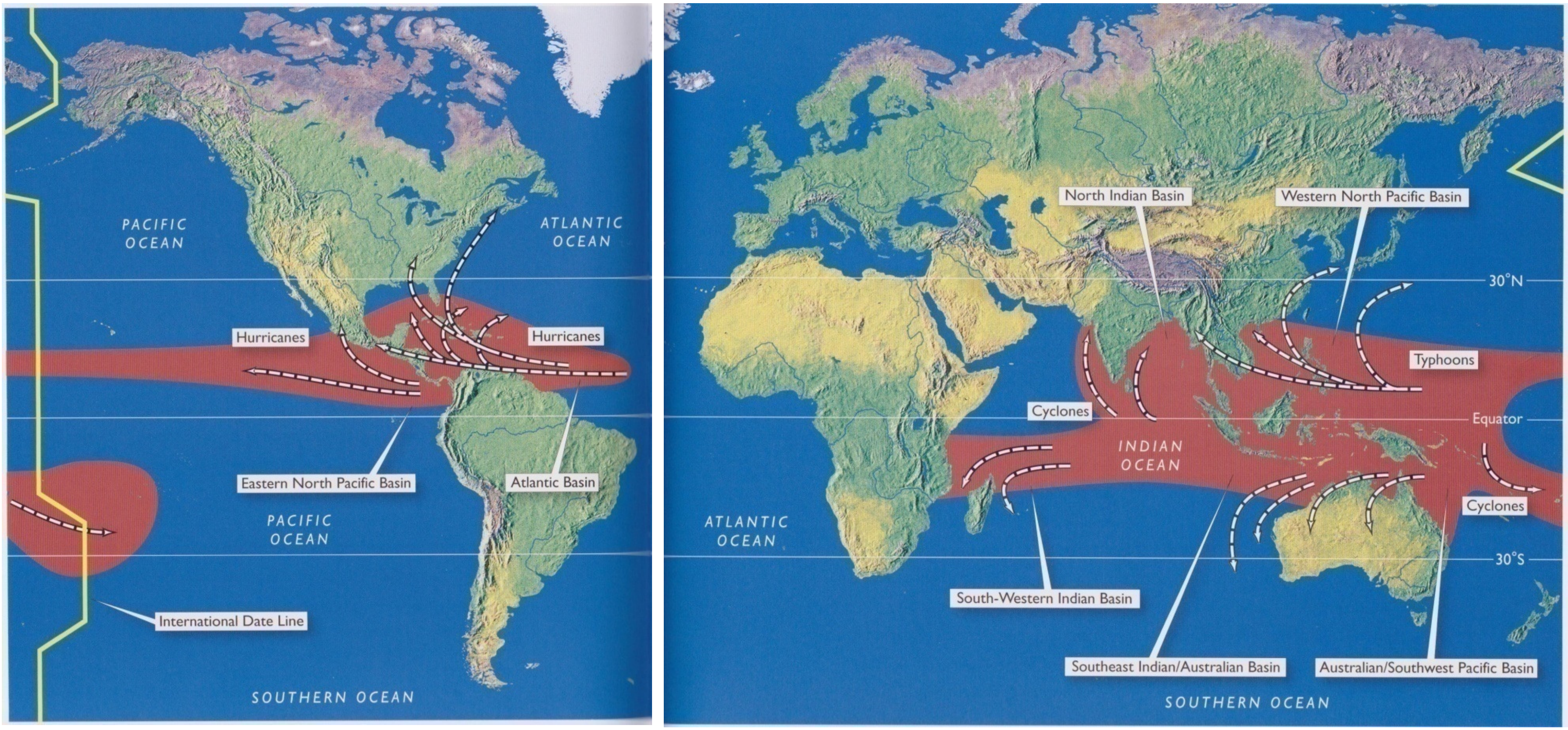
- Warm ocean temperature (surface ocean water temp (down to 60m depth) >26°C or 79°F
- High humidity or abundant vapor moisture
- Low vertical wind shears (no strong change in wind speed or direction between two diff altitudes)
- Sufficient Coriolis force to initiate rotation

Classification by intensity & geographic location

- Tropical cyclones are low pressure systems and have a closed wind circulation with sustained winds of at least 63 km/h (39 mph)
- When wind speed exceeds 119 km/h (74 mph), or generated over an area of about 160 km in diameter, the storm is classified according to its geographical location:

Geographic characteristics

Hurricanes: Atlantic, NE & S Pacific
Cyclones: Indian Ocean, SW Pacific, Australia
Typhoons: NW Pacific



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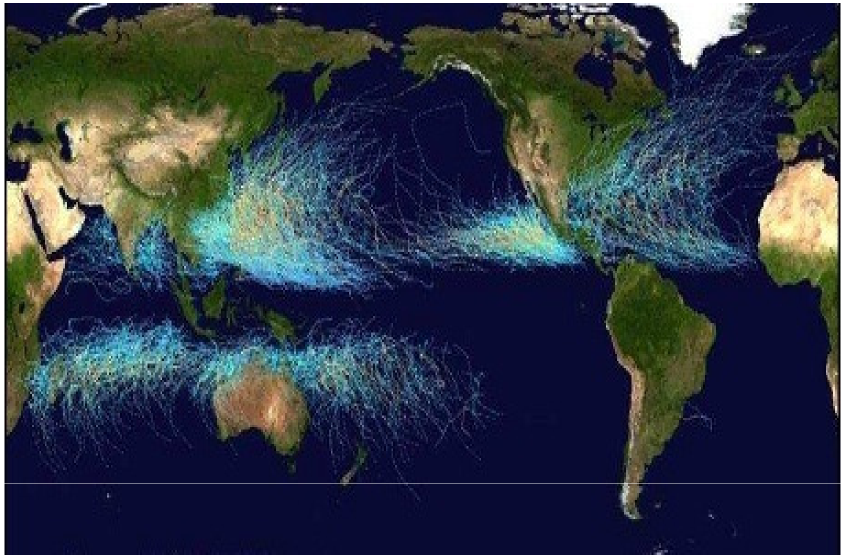
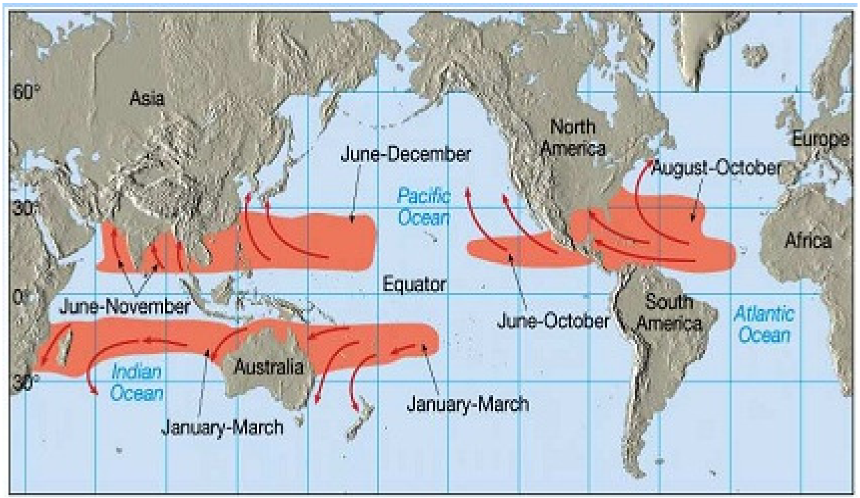
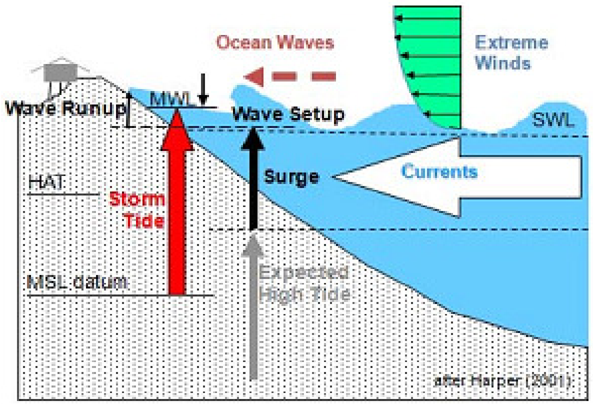
Typhoon/ Hurricane/ Cyclone

Approx north of 15°N & south of 15°S) . There are exceptions, such as Typhoon Vamei near equatorial East Malaysia in Dec. 2001.

- Intense rainfall
- Storm surge
- High waves
- Gusty winds (> 120 km/hr)
- Debris flood
- Tornadoes







Tropical cyclone is the general term for all cyclonic circulations originating over tropical oceans, classified by form & intensity (max sustained wind speed) as follows:

- **Tropical disturbance**
- **Tropical depression**: U<39 mph(61kmh)

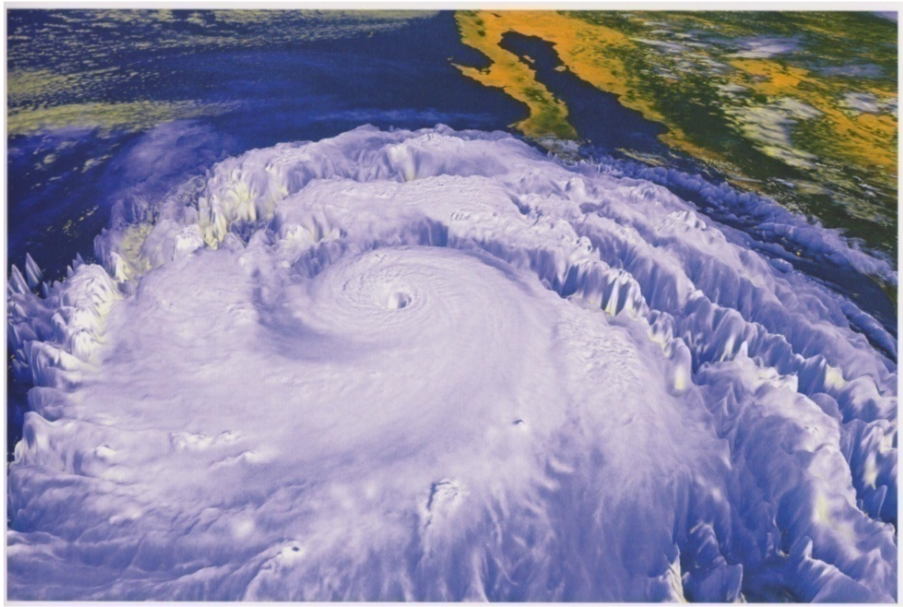
  has no eyes, nor spiral shape
- **Tropical storm**: 39<U<73 mph (117 kmh)

  no eye formed yet
- **Hurricane/Typhoon**: **U>74** mph (119 km/h) or 33 m/s. the ‘eyewall’ ranges from 16 to 80 km wide

Classification on

Saffir-Simpson damage potential scale, was adopted since 1975 by the NHC of USA

- In terms of wind speed & storm surge
- No hint on rainfall or flood depth
- No indication of potential tornadoes



Saffir-Simpson's damage potential Scale

THE SAFFIR-SIMPSON DAMAGE POTENTIAL SCALE			
CATEGORY	WINDS	STORM SURGE	
1	74-95 mph (119-153 kph)	4-5 feet (1.2-1.5 m)	Little damage to building structures. Most damage to unanchored mobile homes, shrubbery, and trees.
2	96-110 mph (154-177 kph)	6-8 feet (1.8-2.4 m)	Limited damage to roofs, windows, and doors. Some trees blown down. Considerable damage to mobile homes. Flooding of coastal roads and escape routes 2-4 hours before the hurricane arrives.
3	111-130 mph (178-209 kph)	9-12 feet (2.7-3.7 m)	Some structural damage to small houses. Foliage blown off trees and large trees blown down. Mobile homes destroyed. Rising water cuts low-lying escape routes 3-5 hours before the storm arrives.
4	131-155 mph (210-149 kph)	13-18 feet (4-5 m)	Some complete roof failure on small houses. Shrubs, trees, and all signs blown down. Complete destruction of mobile homes. Extensive damage to doors and windows. Low-lying escape roads flooded 3-5 hours before arrival of the hurricane.
5	Greater than 155 mph (249 kph)	More than 18 feet (5 m)	Complete roof failure of houses and industrial buildings. Some complete building failure. Major damage to lower floors of all buildings less than 15 feet above sea level.

Dissipation or braking of tropical cyclones

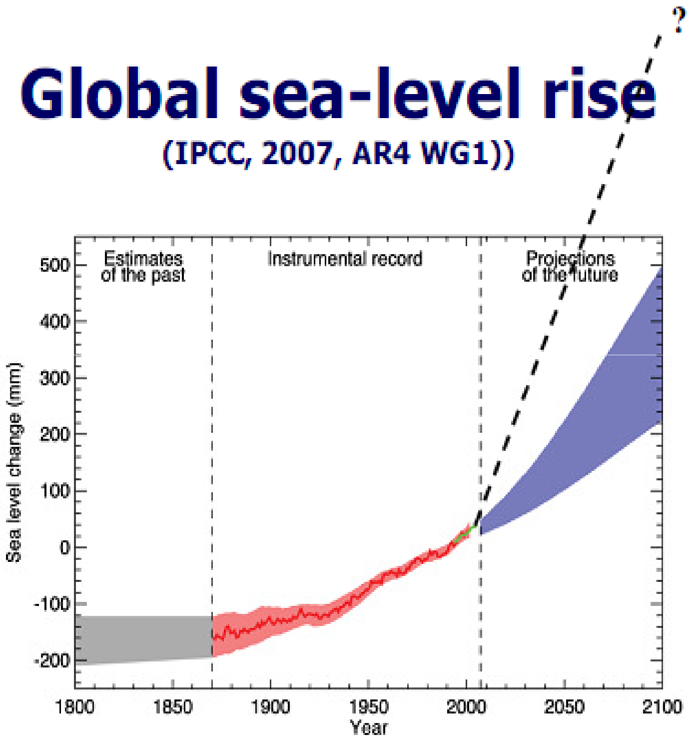
Potential ‘brakes’ on its formation:

- Moving over colder ocean water
- Strong winds that churns up colder ocean water
- High wind shear that diminishes or destroys the vortex
- Dry air migrating to the cyclone
- Land-falling creates high frictional drag that deprives the storm of warm ocean ‘fuel’.

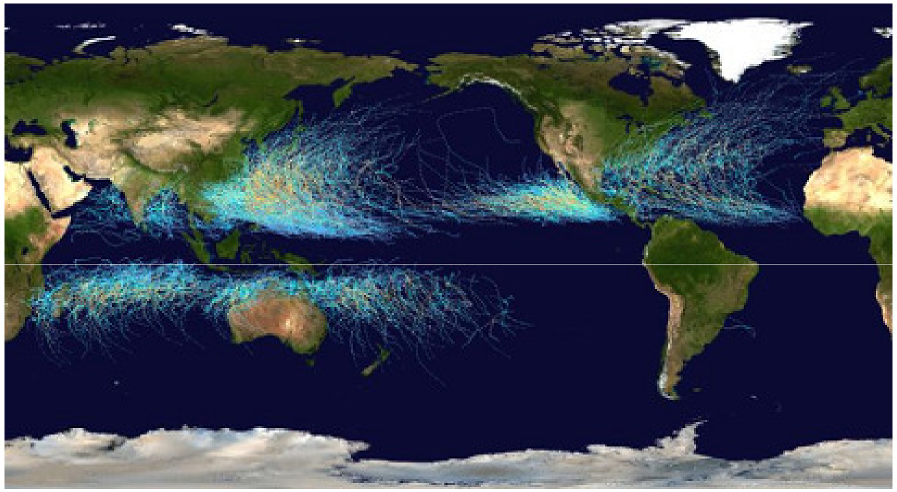
Effects of global warming

- Human activities such as burning of fossil fuels & clearing of forests significantly elevated CO_2 level & other heat-trapping gases in the atmosphere. This in turn contributes to global warming, melting of land ice & potential sea-level rise
- These factors cause the increase of ocean heat content and water vapor which is conducive to the generation of more intense ‘tropical cyclones’

Effects of global warming



Tropical cyclone tracks

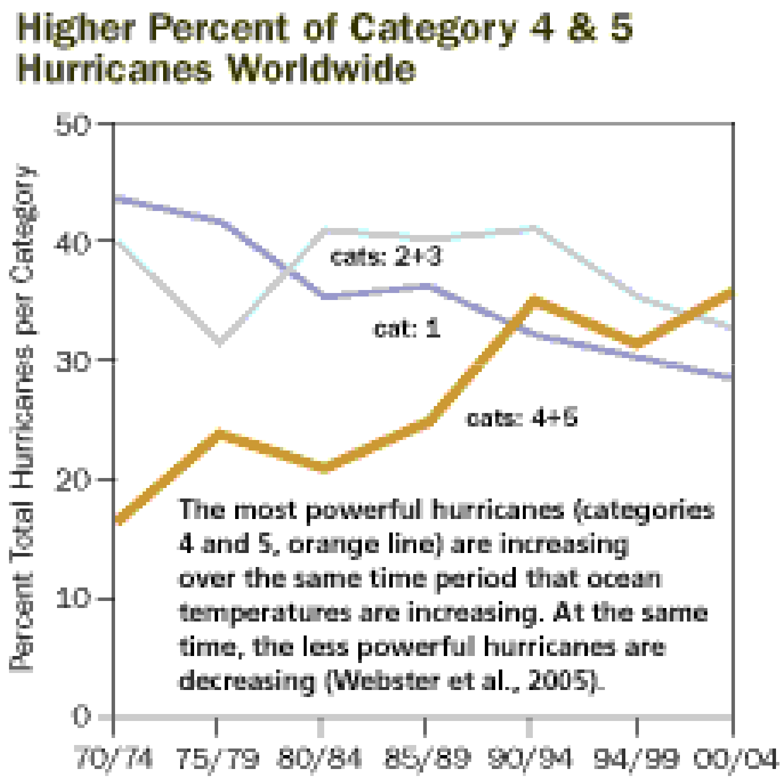


Cumulative tracks of all tropical cyclones during the period 1985–2005.
The Pacific Ocean west of the International Date Line sees more tropical cyclones than any other basin, while there is almost no activity in the Atlantic Ocean south of the Equator.

Source: R.J. Nicholls, The impact of climate change on coastal areas, U. of Southampton, U.K., April 2009

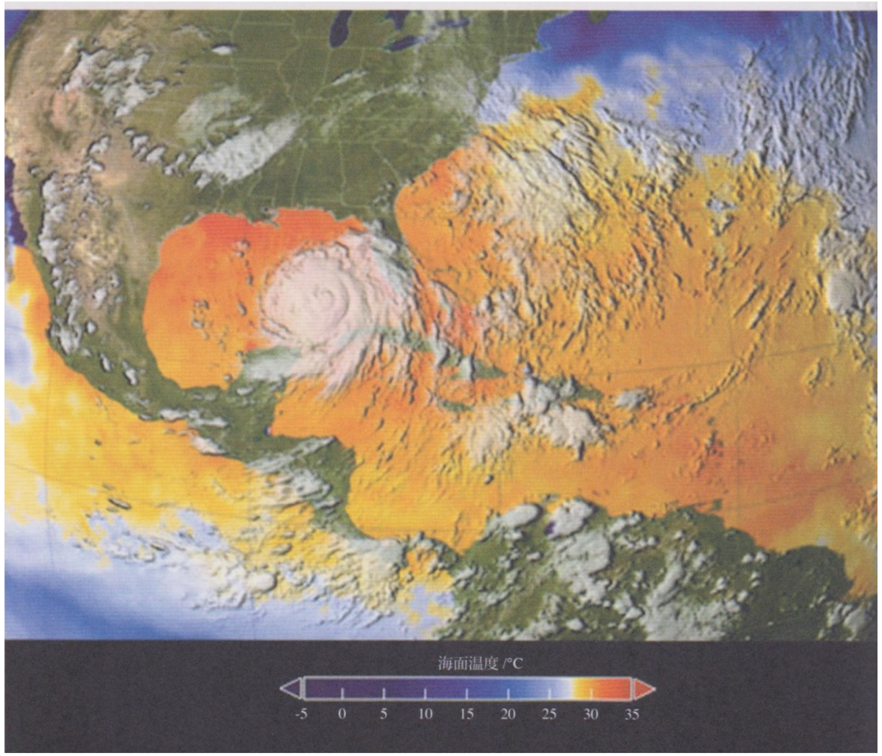
Effects of global warming

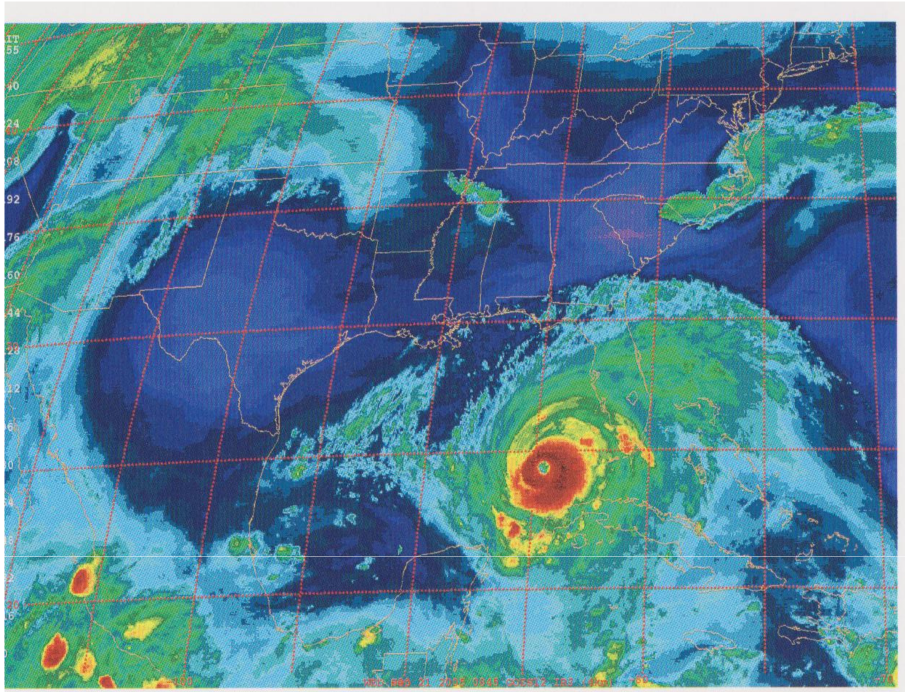
- Researches in 2006 reveal the trend of increase in Category 4 or 5 hurricanes (based on satellite data) over a 30-yr period- correlates well with increase in sea surface temp
- Increase in CO_2 may produce more intense storms & rainfall



Effects of global warming

- Diminishing the braking mechanism of churning up colder water from below the ocean surface. Data from Hurricane Katrina shows that the warm sea surface temp in the Gulf of Mexico was responsible for the intensification of hurricane strength along its entire path before land-falling.





Water vapor satellite image of Hurricane Rita.

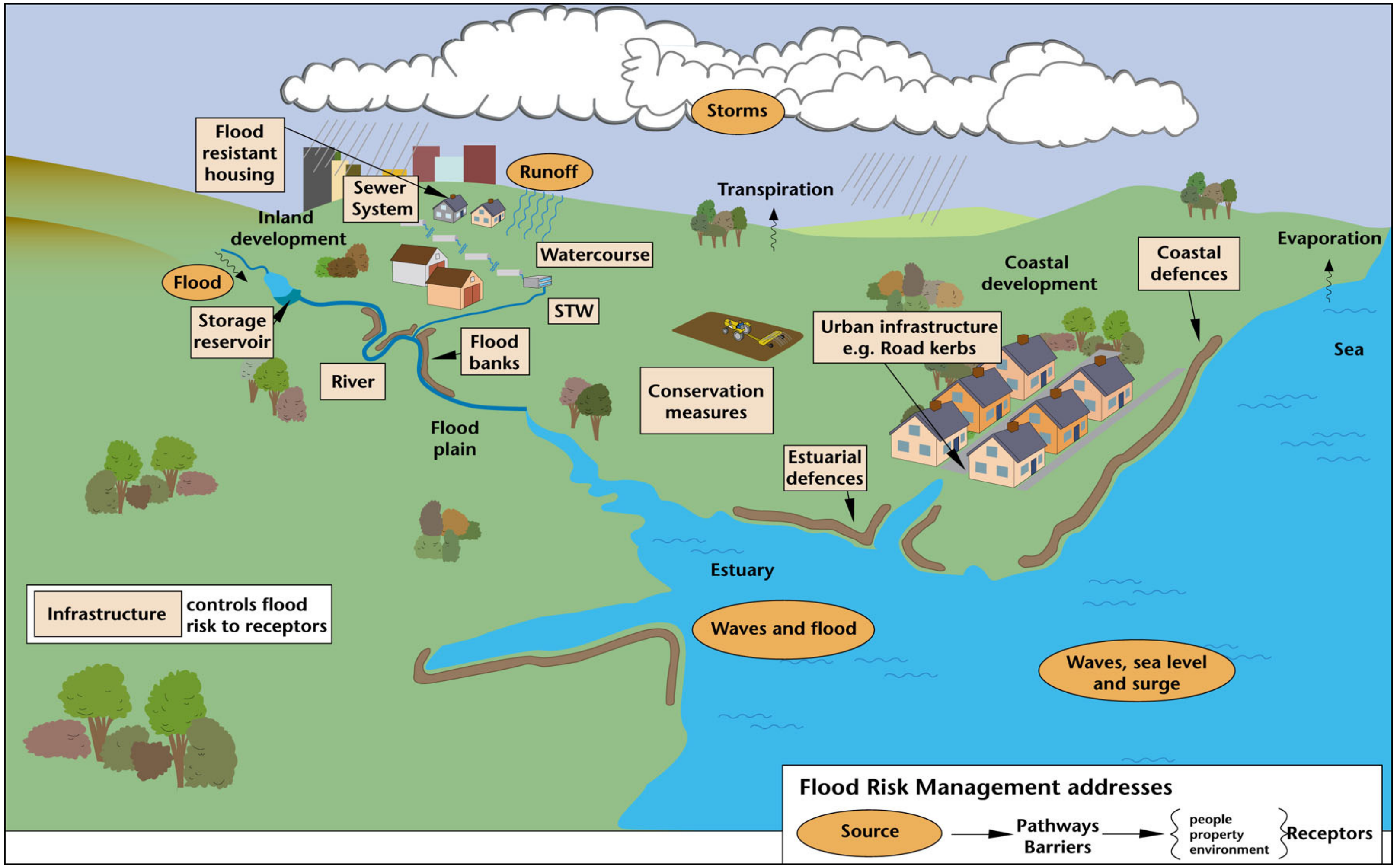
Satellite image of Hurricane Katrina & sea surface temperature

Water vapor satellite image of Hurricane Rita

Impact of Landfalling Tropical Cyclones

- **Coastal Flooding**: storm surges-wind setup, wave setup & tides; assessment of probability of occurrence
- **Inland Flooding**: storm intensity & pattern, flood magnitude & frequency analysis; impact of urban development & other natural/man-made disturbances
- **Estuarine Flooding**

The coastal and river flooding



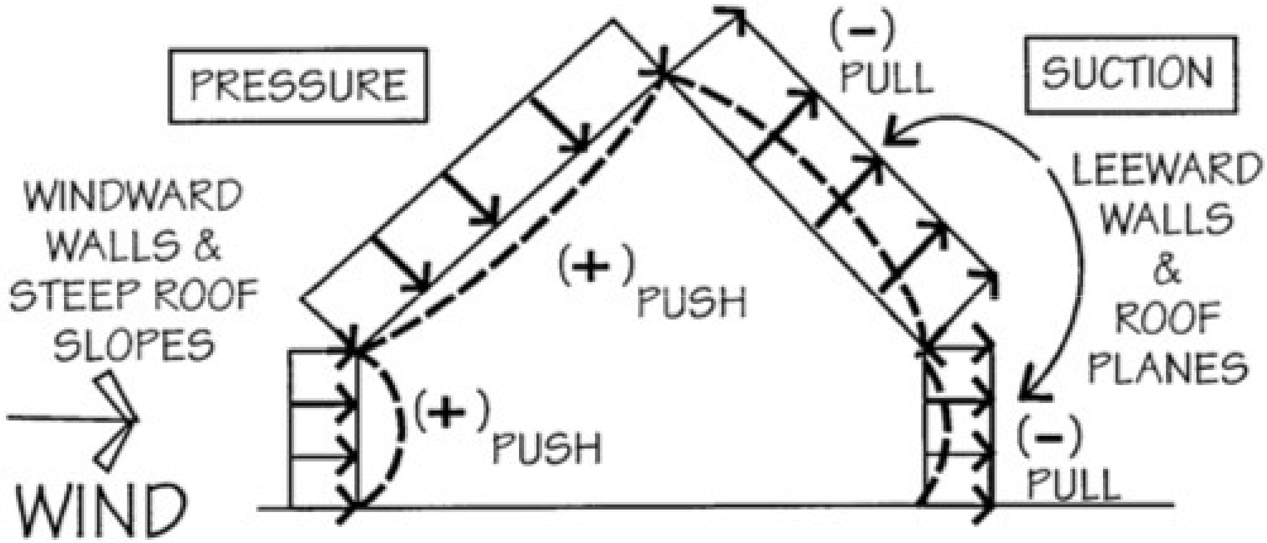
Source: UK Foresight project on Flooding and Coastal Defence 2004

Prof Colin Thorne, University of Nottingham

Impacts of Tropical Cyclones

- Destructive **winds/gusts**
- **Surges, waves & tides** along coastal and estuarine areas- greatest contributor to coastal flooding
- **River floods** generated from storm rainfalls on the watershed
- **Interior flooding** associated with direct storm rainfall into localized areas
- **Debris floods** associated with rainfall , landslides & flood discharge

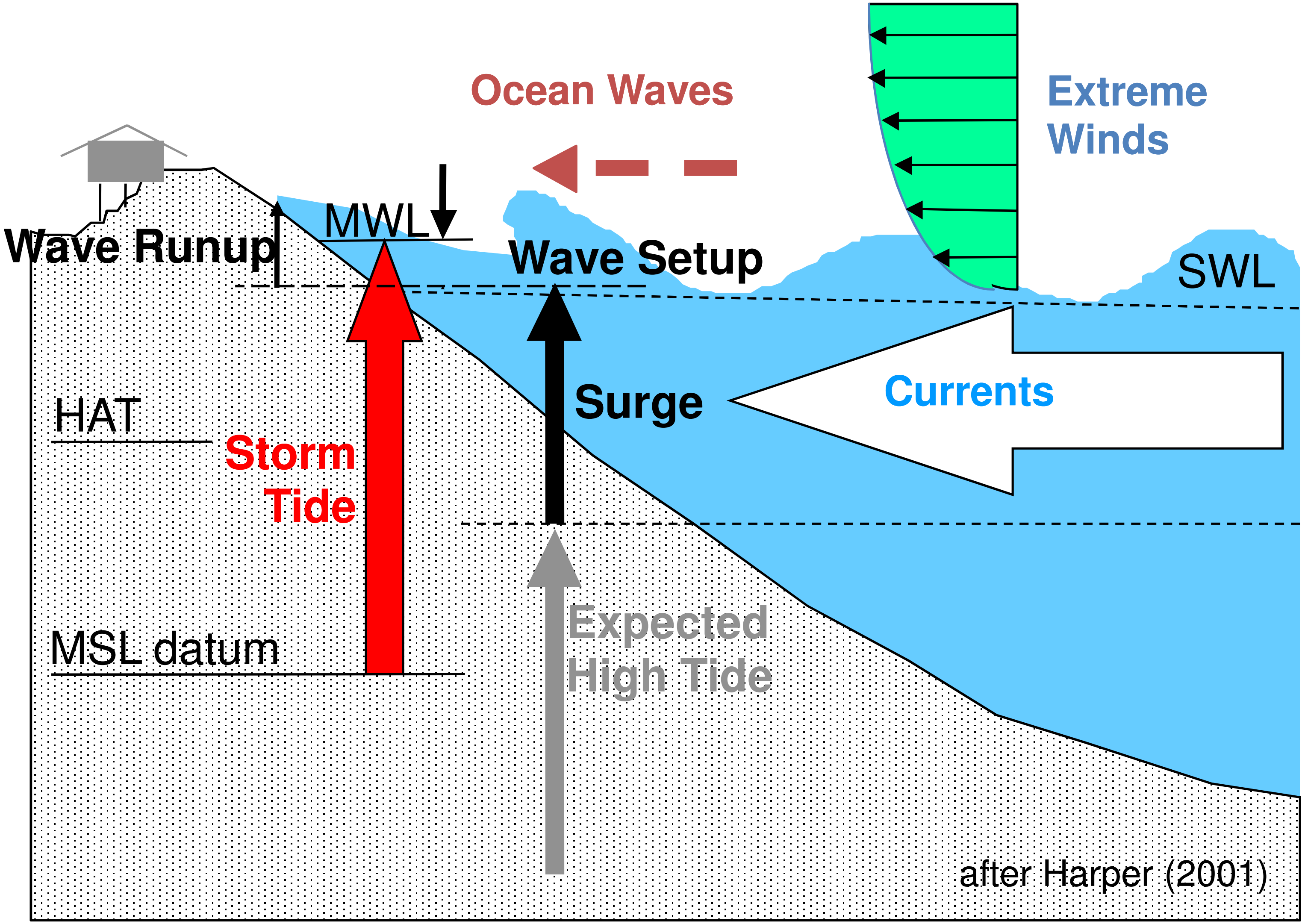
Destructive Wind Forces



PRESSURE VS. SUCTION

Wind damages to buildings

Tropical Cyclone



Wind generated waves

Empirical formula for

Estimating Deepwater Significant Wave Ht, Ho,

based on hurricane characteristics

$$H_o = 16.5\, e^{(R\Delta p/100)}\, [1+(0.208\, V_f / U_m^{0.5})]$$

R- radius of max. wind

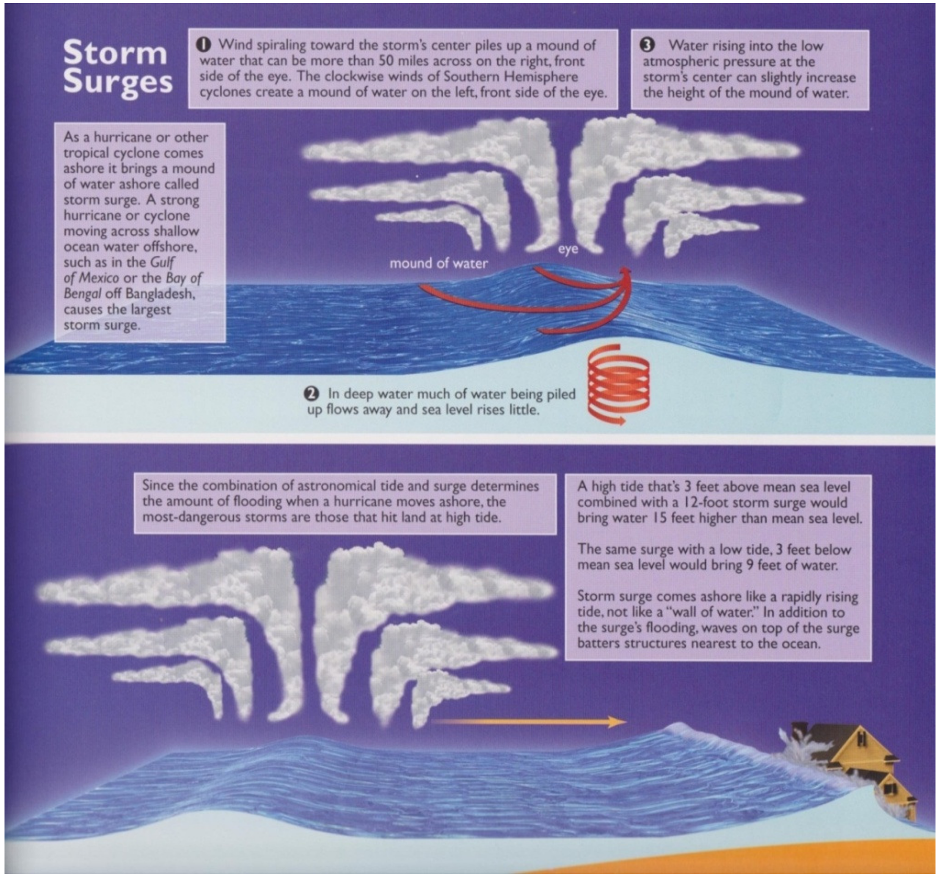
Δp- diff pressure between normal & central pressure

V_f - forward speed of translation

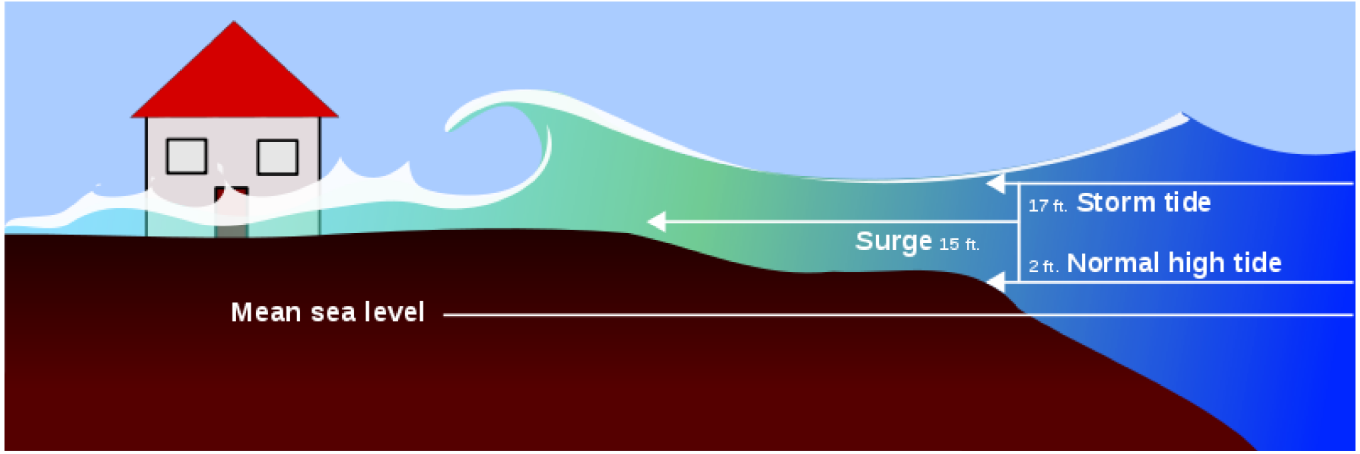
U_m- max wind speed

Factors influencing magnitude of storm surges

- **Storm intensity-** central pressure deficit of the storm controls wind velocity & stress over ocean surface, and inverse barometric effects
- **Storm size** (radius from eye to max wind)
- Translational speed
- **Angle of approach** to coastline
- **Landfall location** & its **bottom slope**



•Source: Hurricanes-causes, effects & future, by Leatherman & Williams, Voyageur Press, 2008



- Storm surge is caused by sustained winds over the ocean water surface, and low pressure of the cyclone
- It's also influenced by waves, tides, topography, and bathymetric and setting of the coastal zone
- Storm tide is the sum of storm surge & astronomical tide

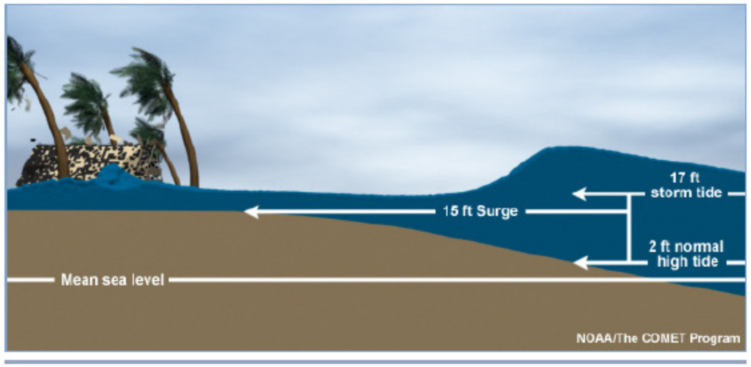
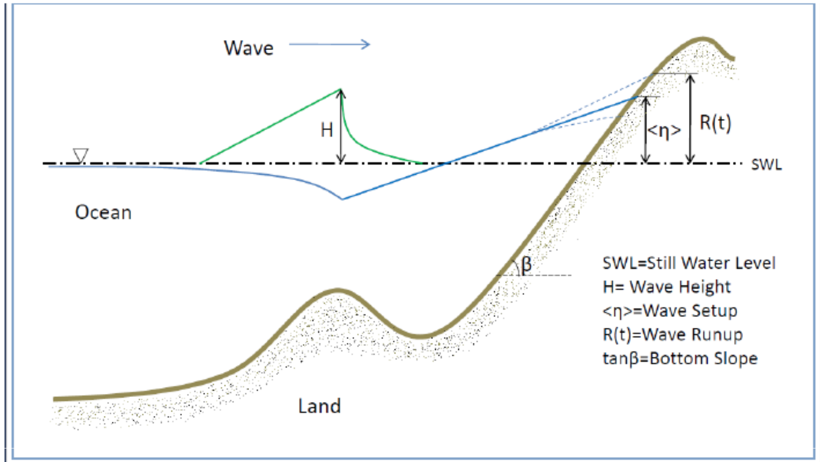


Image credit: NOAA/UCAR/The COMET Program.

Factors influencing magnitude of storm surge

- **Bathymetry & topography** of coastal shores affect coastal response & flood hazard areas



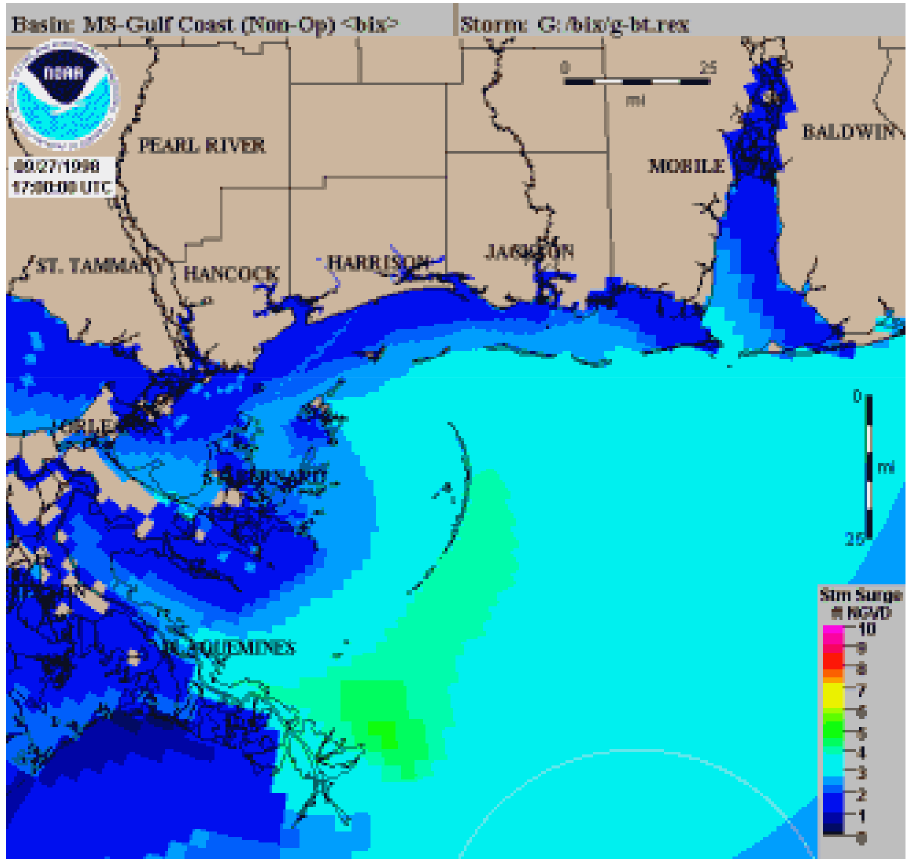
Hurricane winds generate waves in the ocean. As these waves propagate into shallow water, wave heights increase due to a process called "shoaling". As the wave heights increase, the waves eventually break and impart their momentum to the water, causing onshore flow near the surface and offshore flow or "undertow" near the bottom, and an overall elevation in water level at the coast ("wave setup" – the rise in the water surface caused by breaking waves, and "wave runup" - the rush of wave water up a slope or structure).

- **Pacific coasts** is characterized by steep bathymetry & narrow coastal shelf: flooding is mainly by wave run-up
- **Atlantic & Gulf coasts** are characterized by wide, shallow coastal shelves: flooding is dominated by **storm surge** and **breaking waves**
- Water surface elevations at shoreline are combination of **wind setup, wave setup and wave run-up**

- Local topographic features, such as buildings, levees, wetlands, sand dunes, barrier islands may reduce storm surge, wave forces, and thus coastal flooding
- However, these features may be re-shaped or moved during severe storms
- Shapes and profiles of estuaries may also affect surge characteristics- e.g. funneling effect.
- Due to these complexities, **Saffir-Simpson wind scale** *no longer associates with storm surge value of any category*.

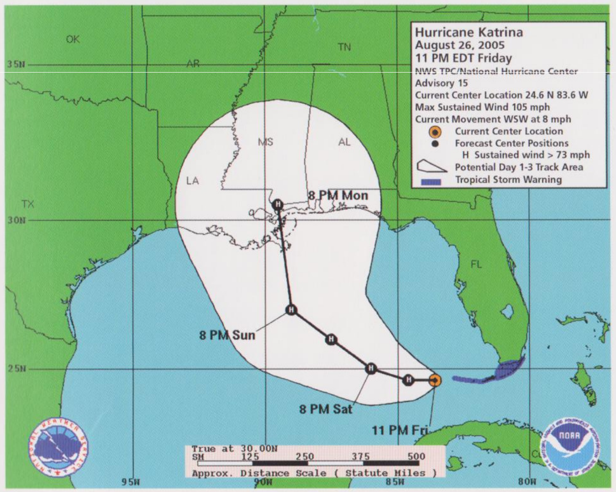
Pattern of storm surge

- Storm surge is 3-D with vertical rise of water surface elevation which spreads across the coast line and reaches far inland
- Peak surge may occur at landfall of a storm, but also occur as a ‘fore-runner’ or ‘post runner’ which could cause unexpected coastal flooding & damages



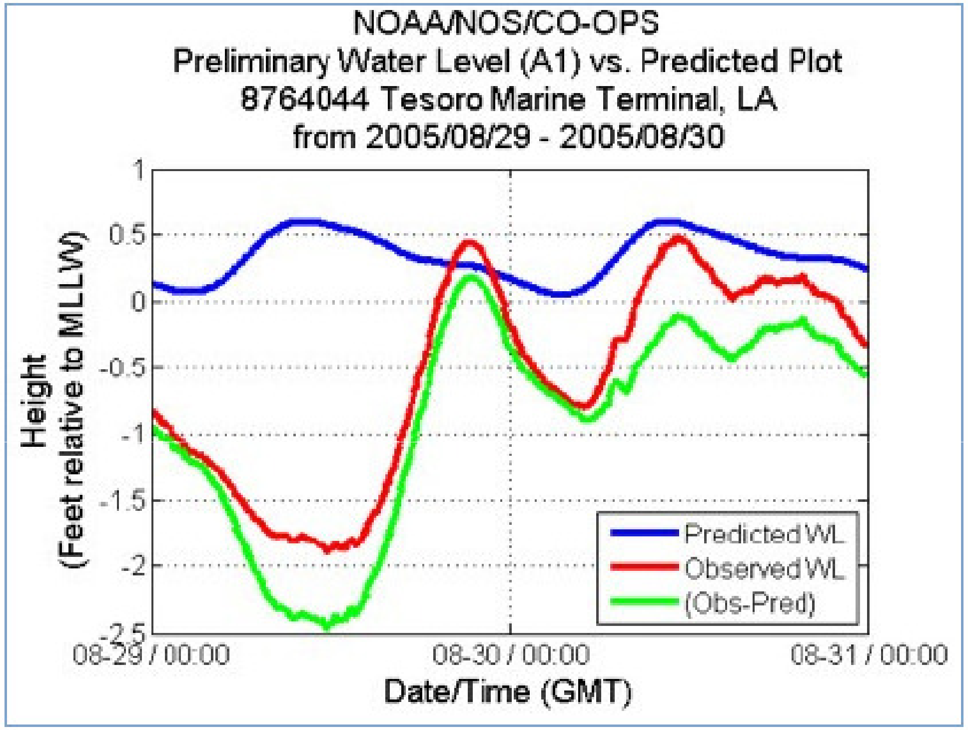
Predicted vs Observed Water Level

NOAA Tidal Station 8761305 at Shell Beach, LA.
Image credit: NOAA.



Katrina's forecast and cone of uncertainty before it hit land.

•Source: Hurricanes-causes, effects & future by Leatherman & Williams, Voyageur Press, 2008



Observed water level, predicted tide, and storm surge (obs-pred) at Tesoro Marine Terminal, Louisiana, during Hurricane Katrina (2005). Source: NOAA/NOS/CO-OPS.