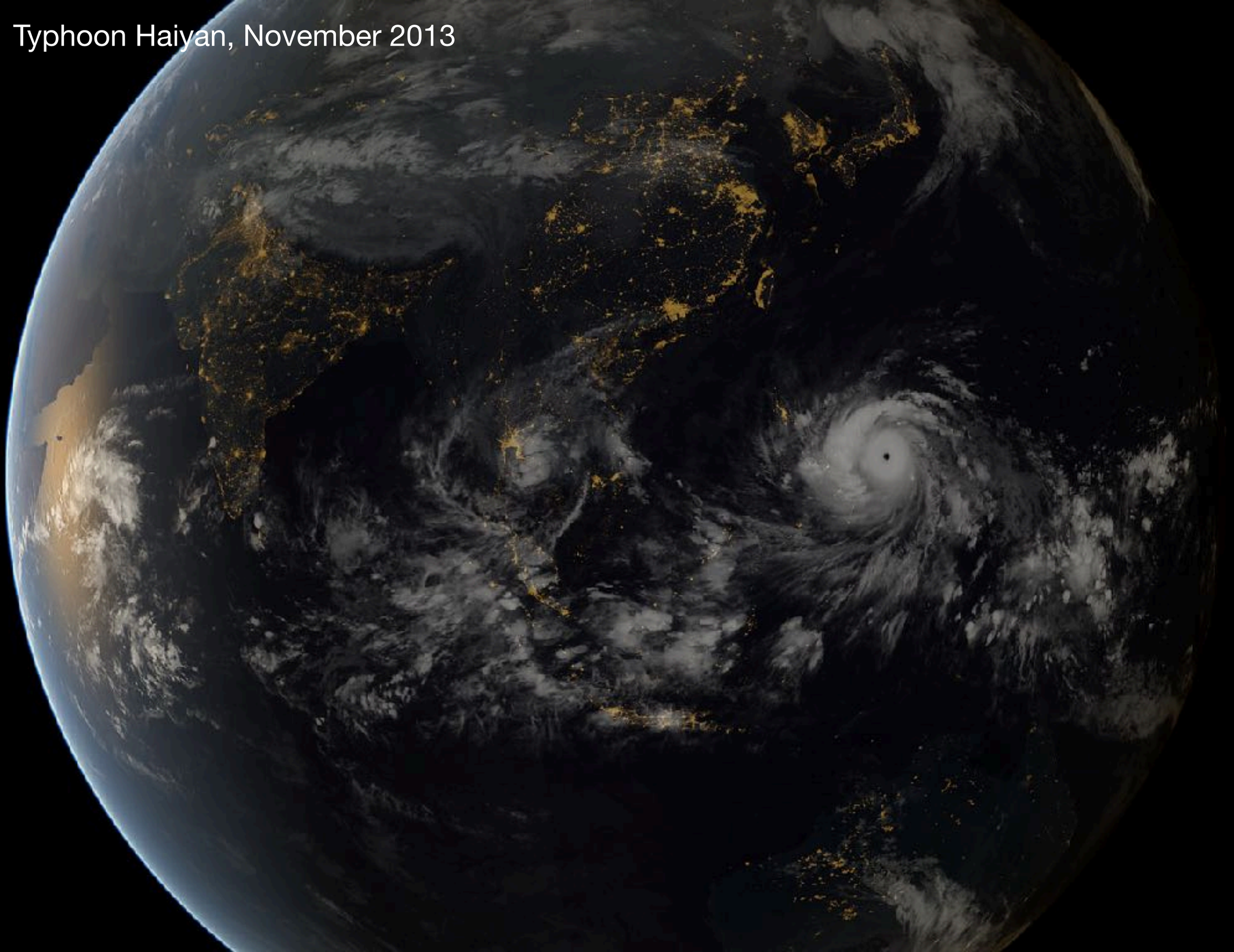
# Air-sea interaction: Hurricane/Typhoon

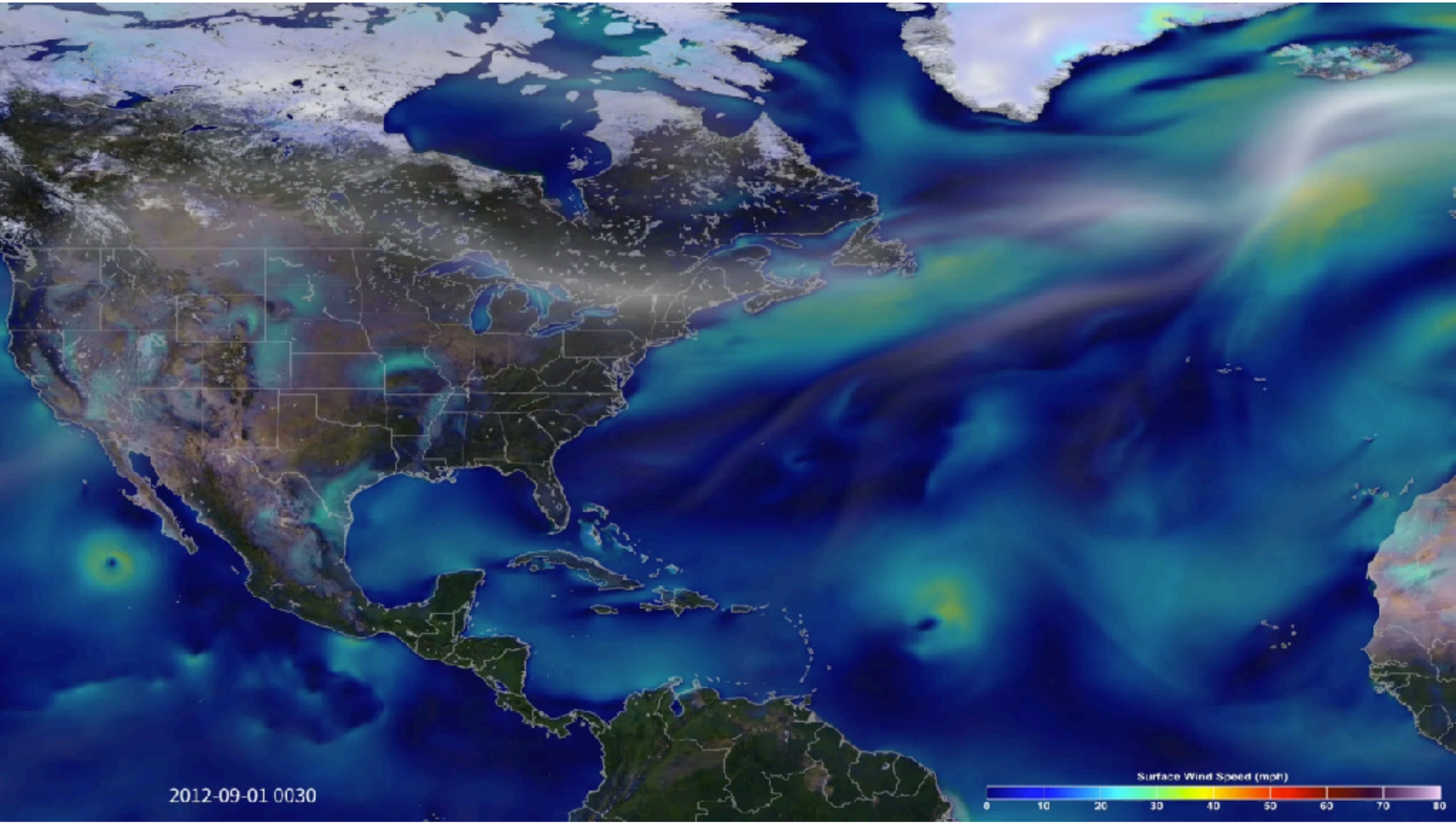
ATM2106

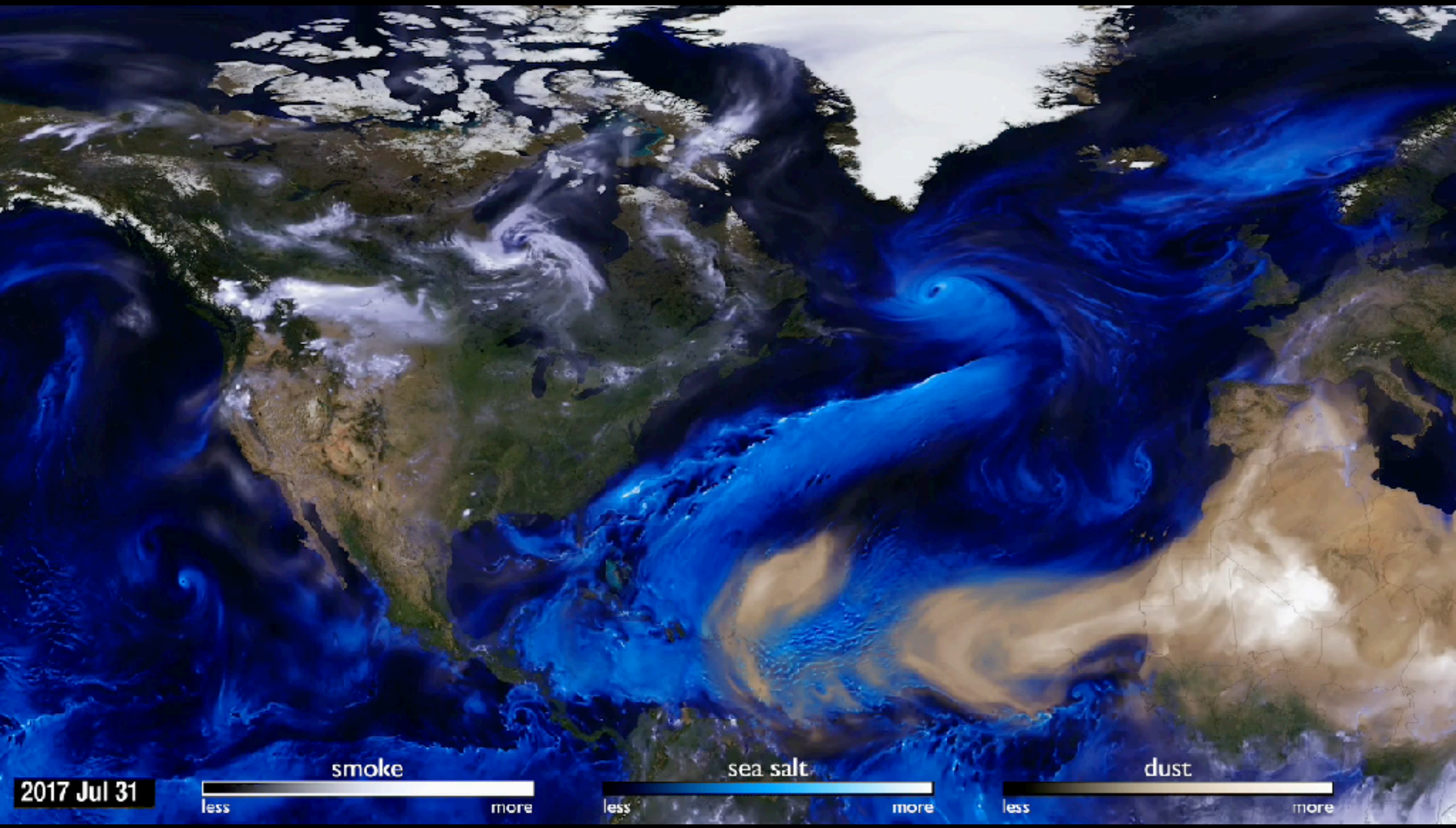
Typhoon Haiyan, November 2013



Typhoon Vongfong, October 2014


https://youtu.be/WjxZd7fPSVI

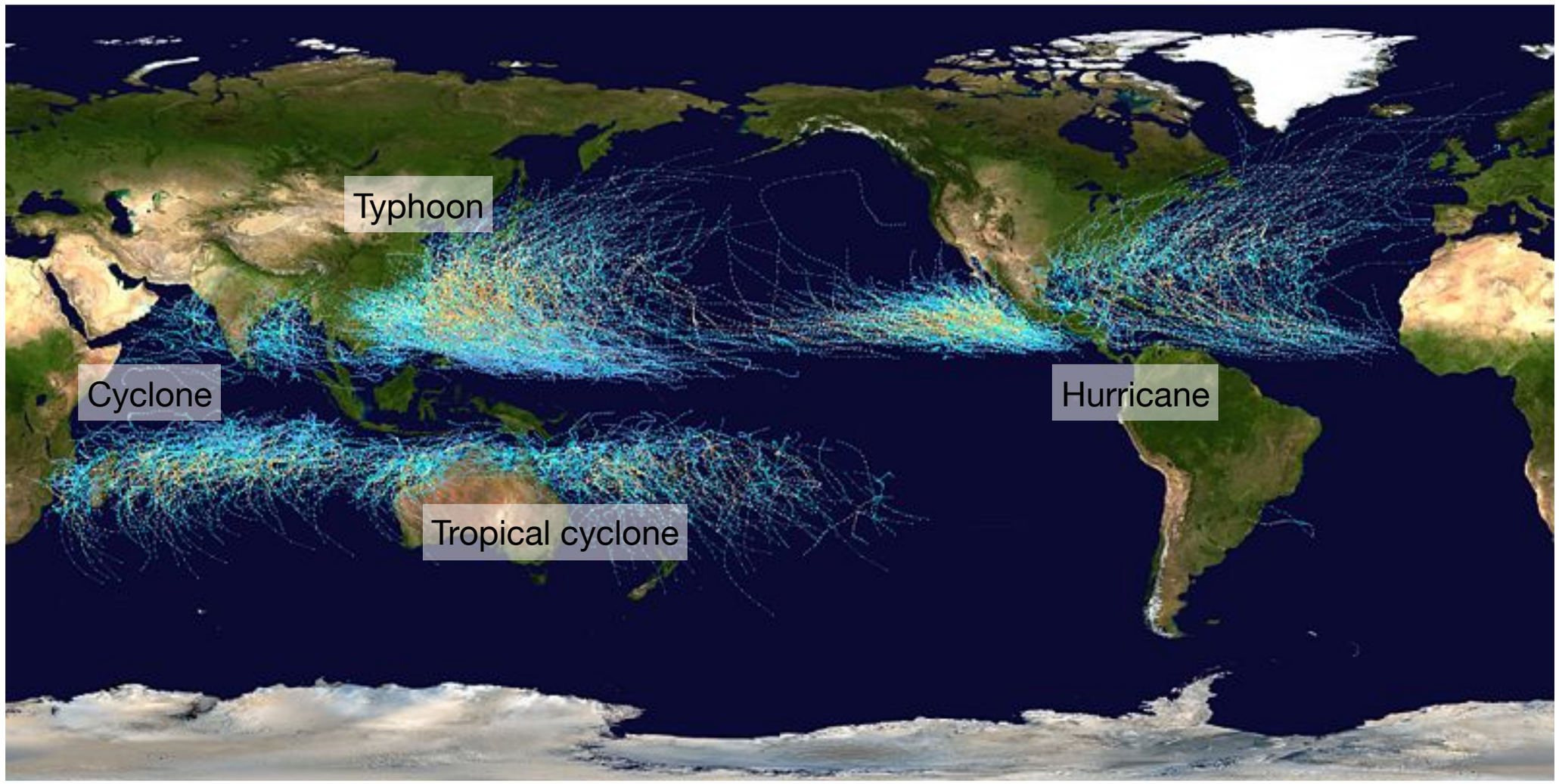

2012-09-01 0030
Surface Wind Speed (mph)
0
10
20
30
40
50
60
70
80



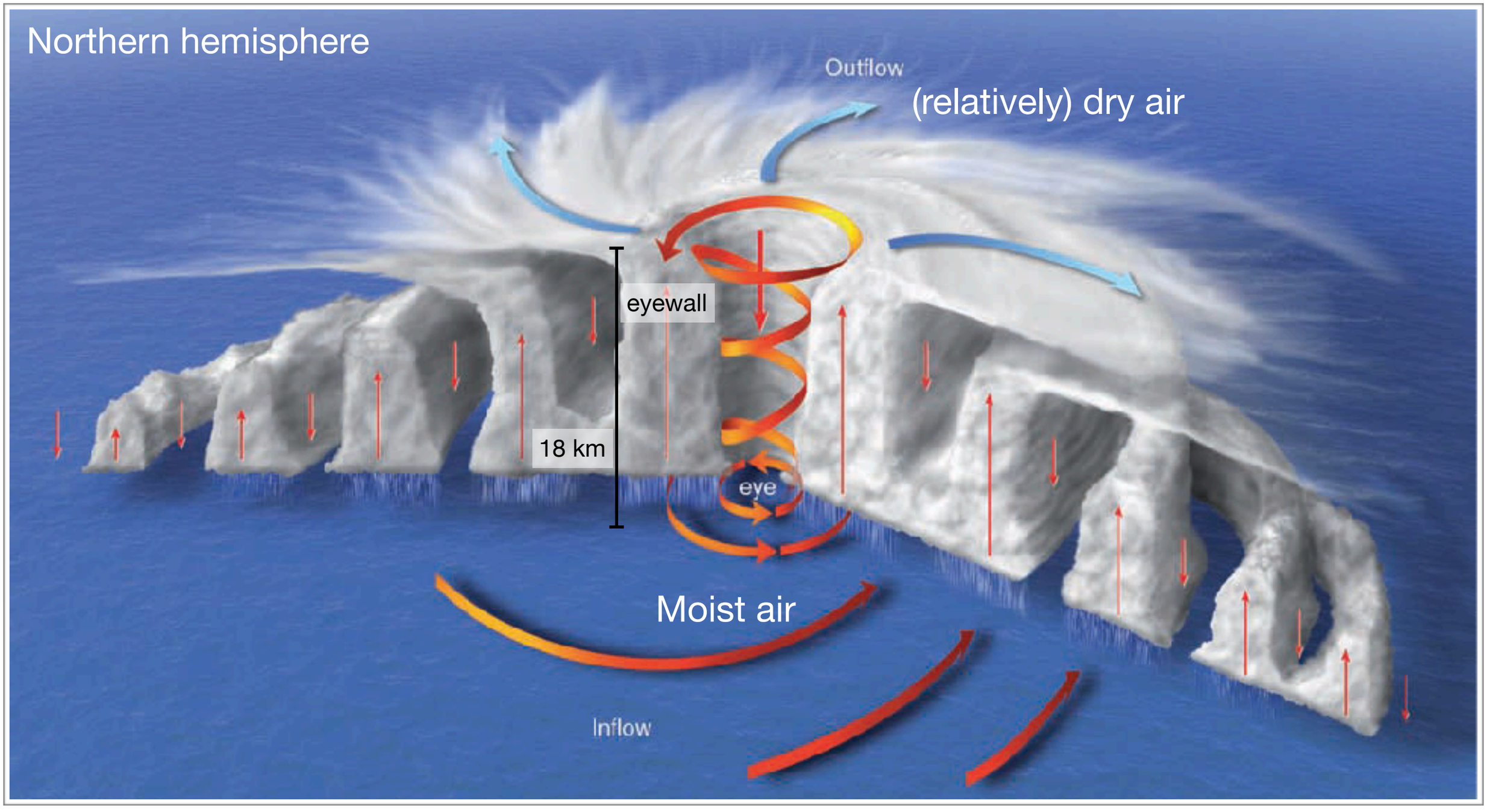

Movie from https://svs.gsfc.nasa.gov/12772

# Hurricane

- An intense storm of tropical origin
- Winds exceeding 64 knots (74 mph, 119 km/h)

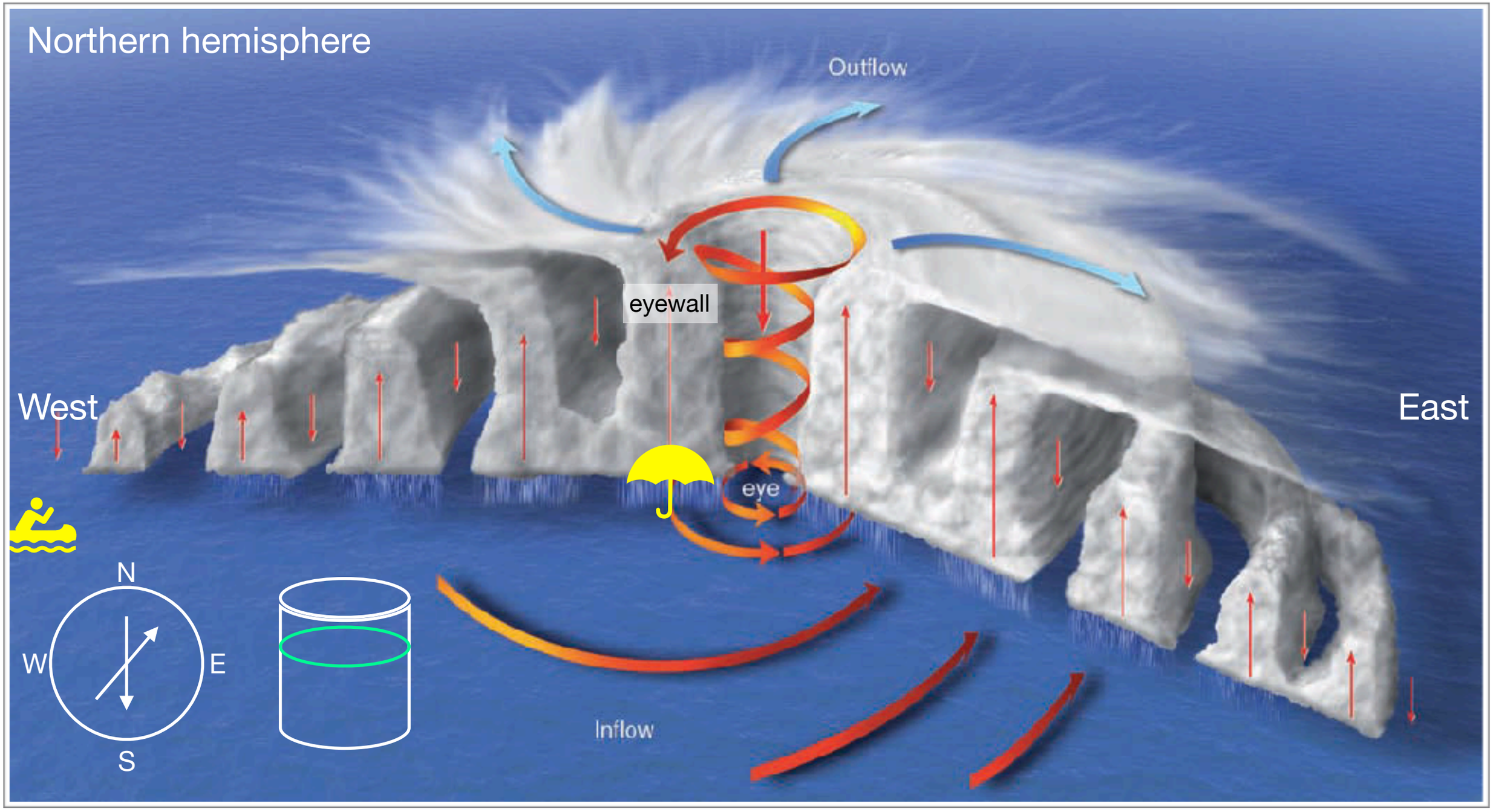


# Hurricane structure



# Hurricane tour

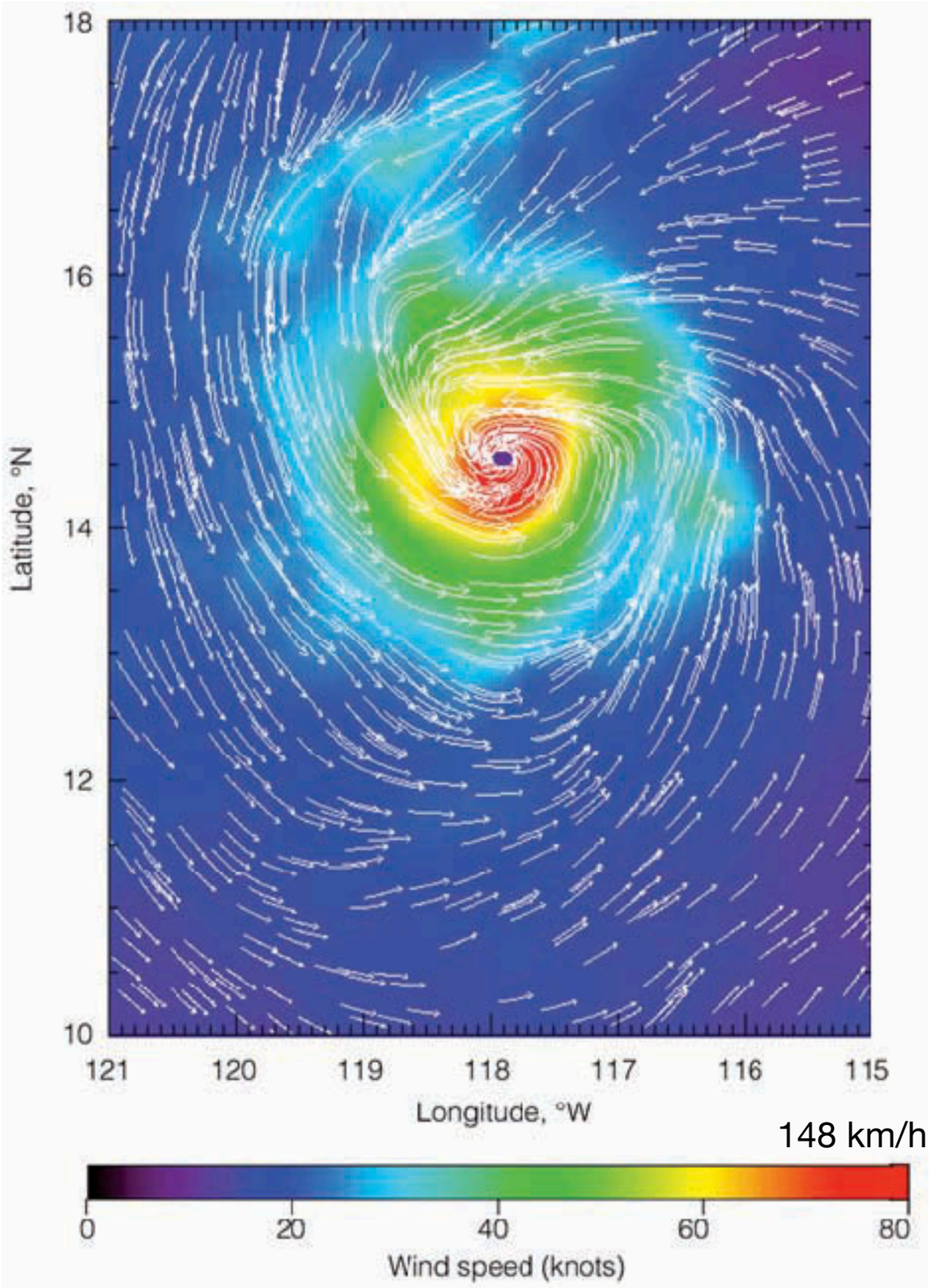
North



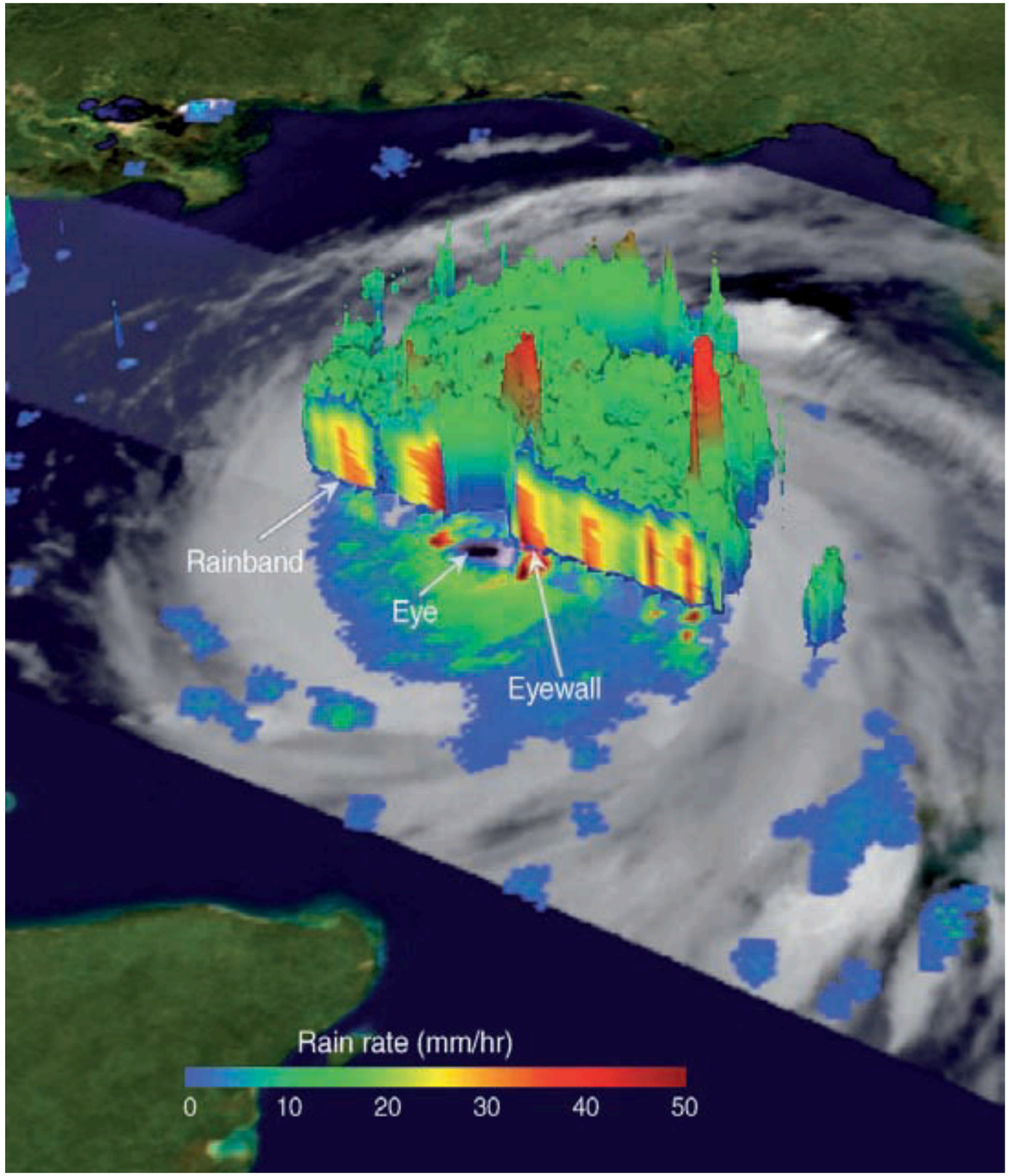

South

Hurricane Katrina over the Gulf
of Mexico on August 28, 2005

## Wind



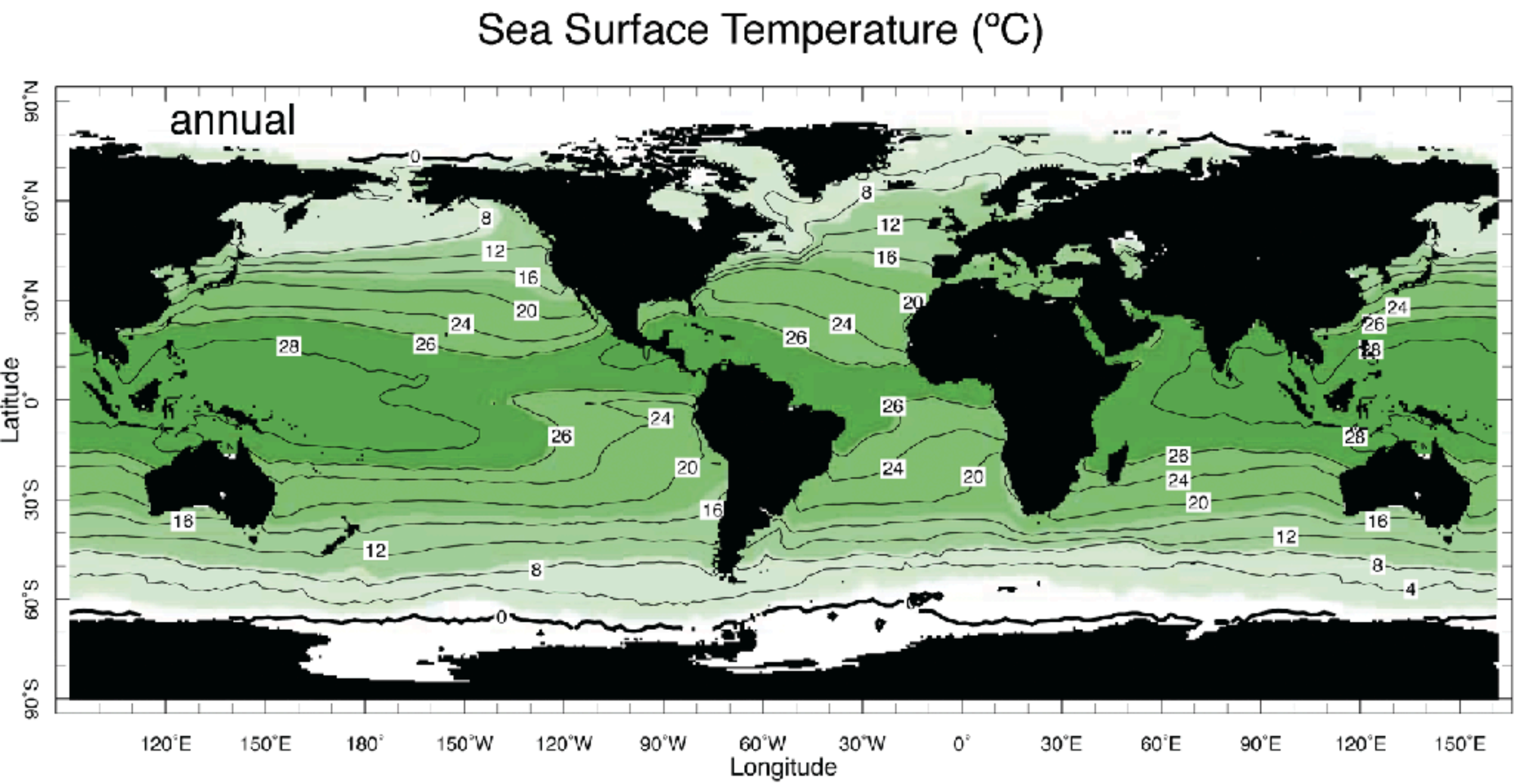

## Precipitation rate



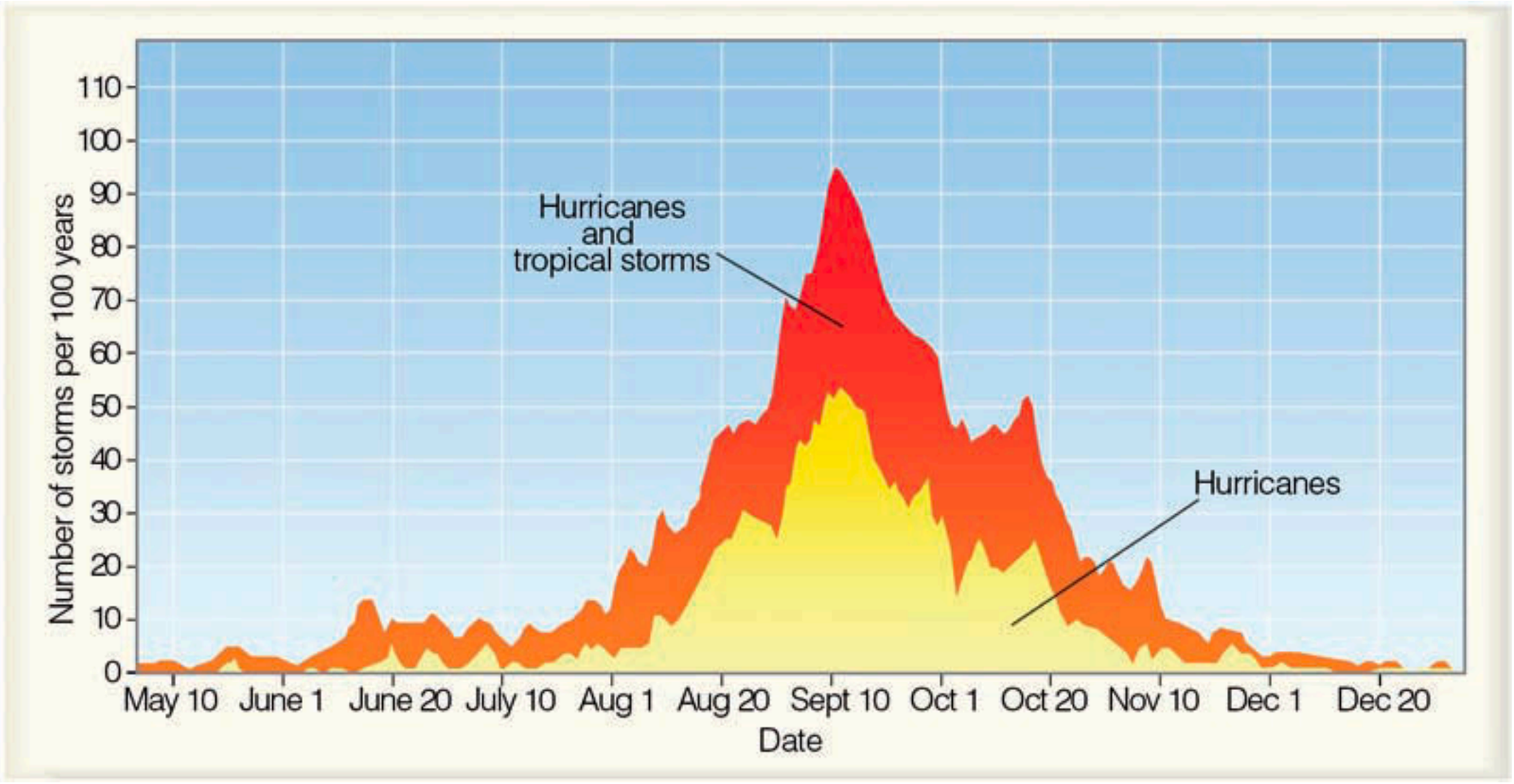
# Hurricane Formation

- Hurricanes form over tropical waters where
  - The winds are light
  - The humidity is high
  - The surface temperature is warm (>26.5 °C)
- A convergence of the air and a force for the spin
  - Usually between 5° and 20° where $f \neq 0$

# Sea surface temperature



# Number of storms



# Hurricane Formation

- Conditions that prohibit the hurricane formation
    - Sinking air: near 20°, the air is open sinking associated with the subtropical high.
    - Strong upper-level winds: strong wind shear tends to disrupt organized convection and disperses heat and moisture.

# Hurricane Development

1. Sensible heat flux and latent heat release
2. Warmer T aloft near the cluster of thunderstorms
3. Pressure gradient forcing outward
4. A drop of the surface pressure from the warming and diverging the air in the small surface area.
5. The air begins to spin counterclockwise in the northern hemisphere and moves to the center
6. As the area of the circulation decreases, the wind speed increases.

# Hurricane Development

- Hurricanes need energy to develop
- Energy sources
  - Sensible heat from the ocean

$$Q_S = \rho_{air} c_p c_S u_{10} (SST - T_{air})$$

- Latent heat from condensation

$$Q_L = \rho_{air} L_e c_L u_{10} (q^*(SST) - q_{air})$$

# Hurricane Development

$$Q_S = \rho_{air} c_p c_S u_{10} (SST - T_{air})$$

$$Q_L = \rho_{air} L_e c_L u_{10} (q^*(SST) - q_{air})$$

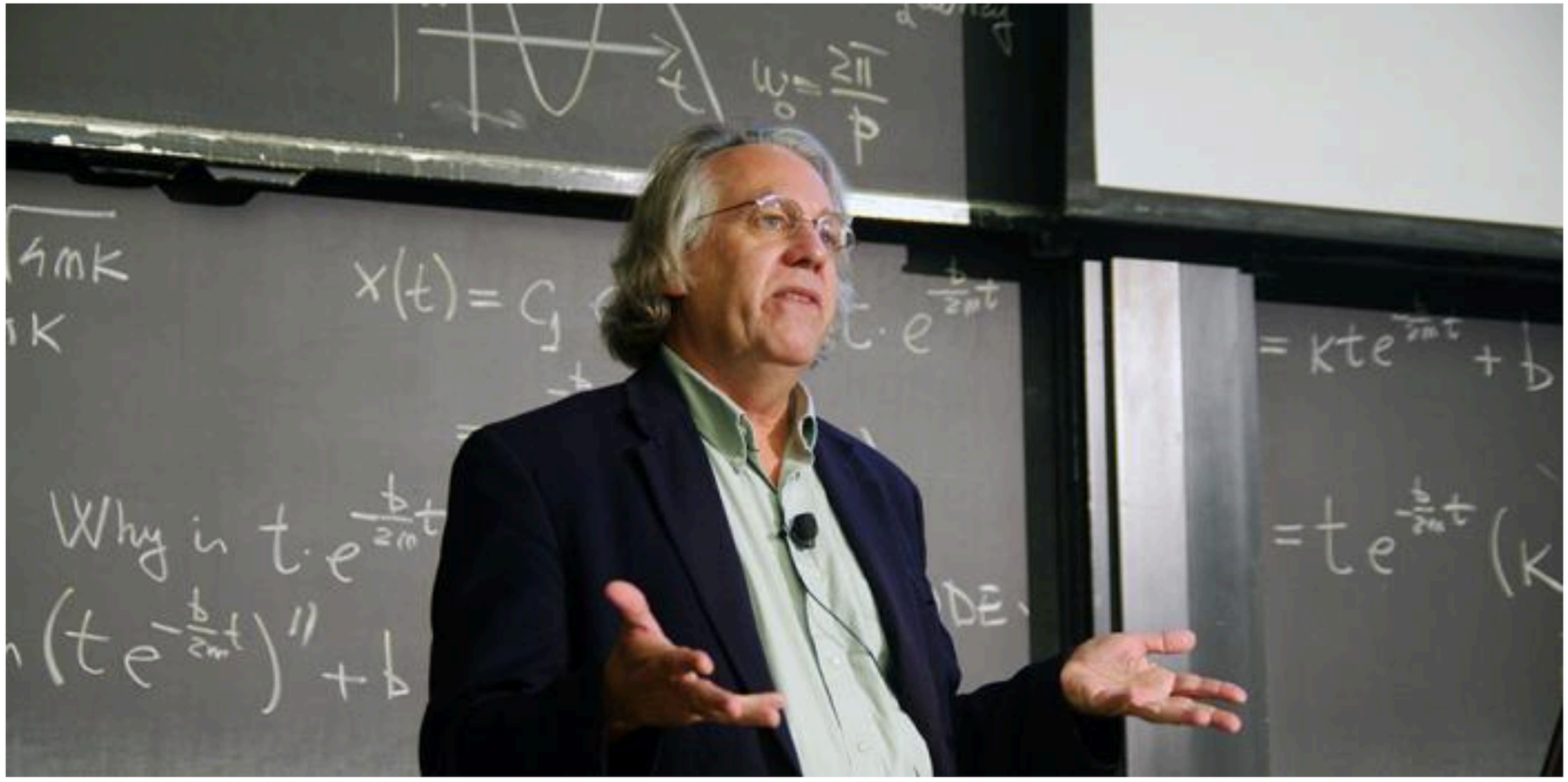
- The warmer the water, the greater the transfer of sensible and latent heat into the air above
- Greater wind speed promotes higher sensible and latent heat flux from the ocean to the atmosphere.
- As the air moves in toward the center, it gains the speed, leading to more energy flux to the atmosphere.
- Upward motion of the air, the decrease of the air pressure and so on

# Hurricane Development

- Energy in from the warm water at bottom of the clouds
- Energy out to the space at the top of the clouds (radiative cooling)
- The energy is consumed inside of the thunderstorms.
- ($T_{bottom}$ - $T_{top}$) of the clouds is proportional to the work done by thunderstorms.
- Warmer water often associates with higher winds.

# A short lecture by Prof. Kerry Emanuel, MIT

- https://youtu.be/aR7a3ET5uws#t=22m47s



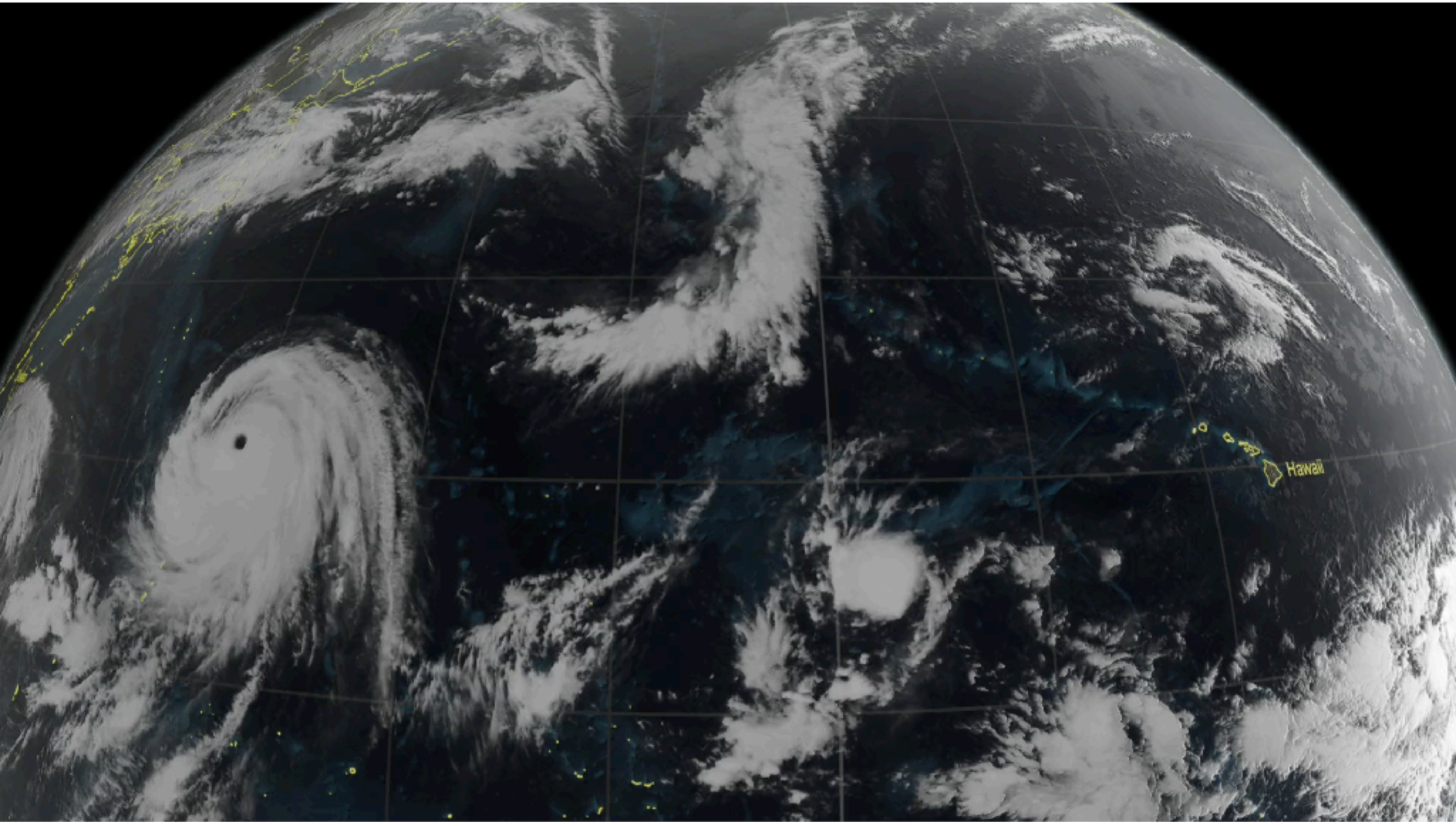
# From a hurricane to a typhoon

- If the hurricane remains over the warm water, it may survive for a long time.

- Kilo (August, 2015)
  - formed in the eastern North Pacific and traveled to the western North Pacific crossing the international dateline.

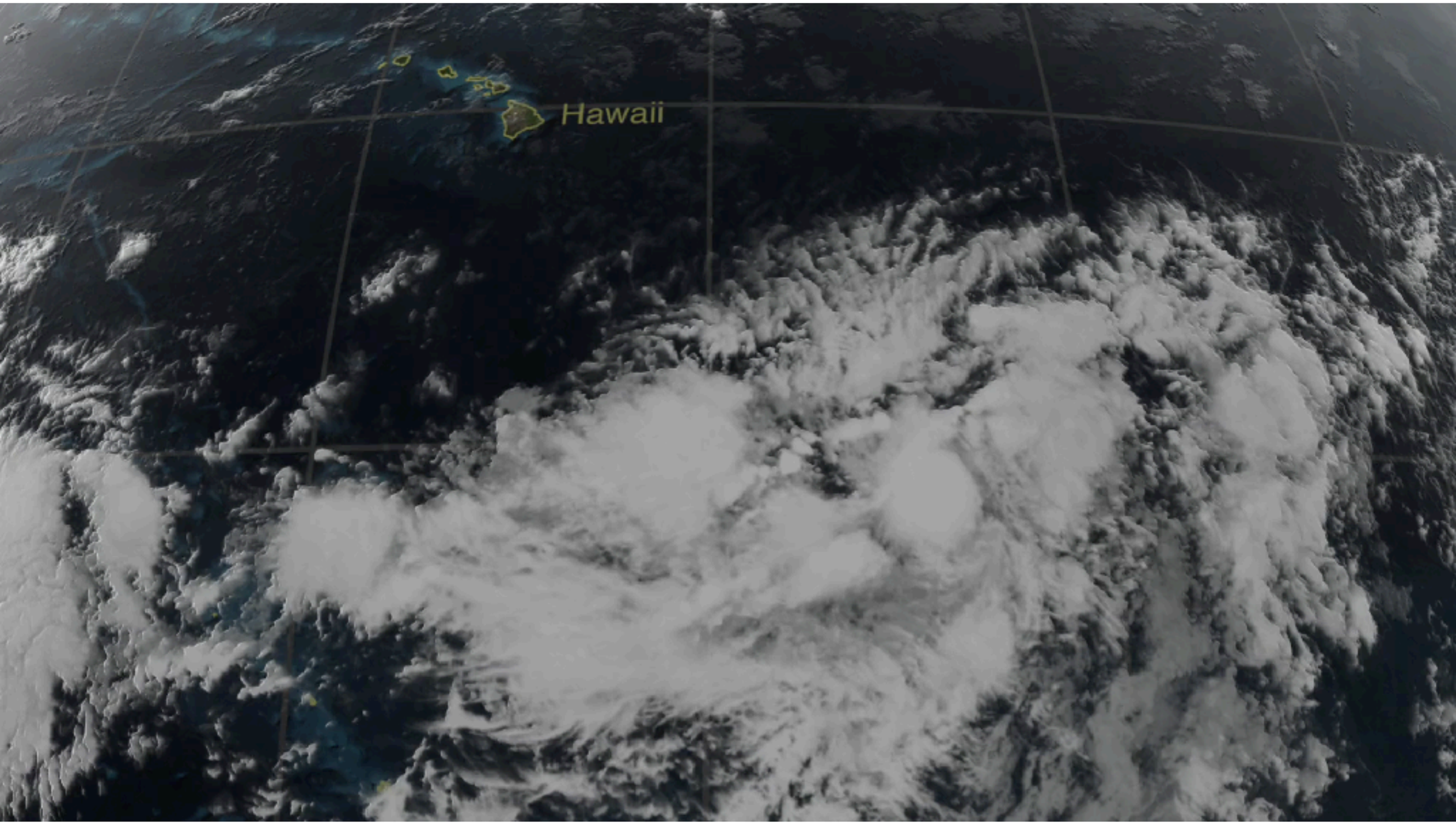
  - It was sustained for 21 days.

# A track of Kilo



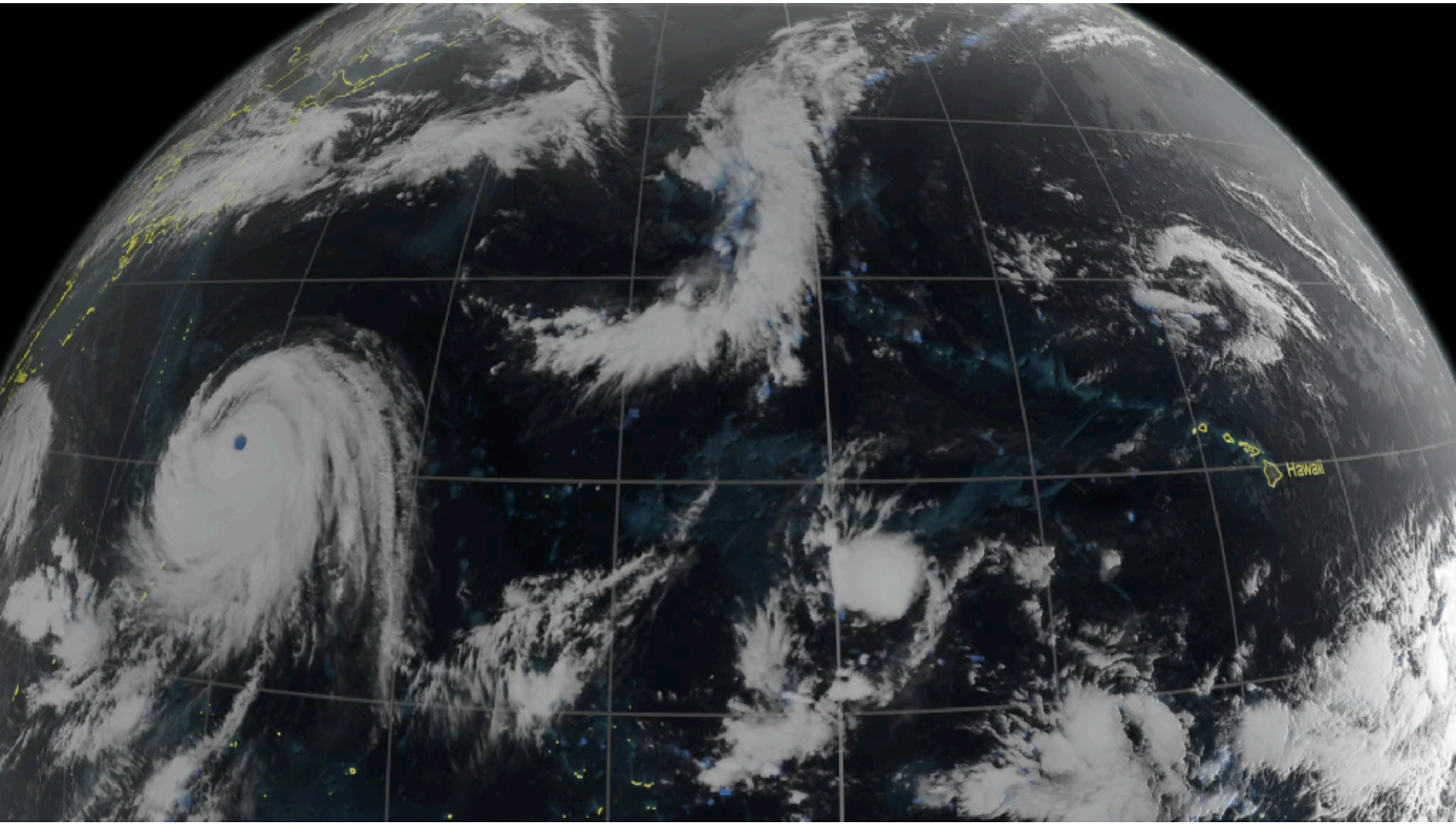

From https://svs.gsfc.nasa.gov/4358

# A track of Kilo: Close up



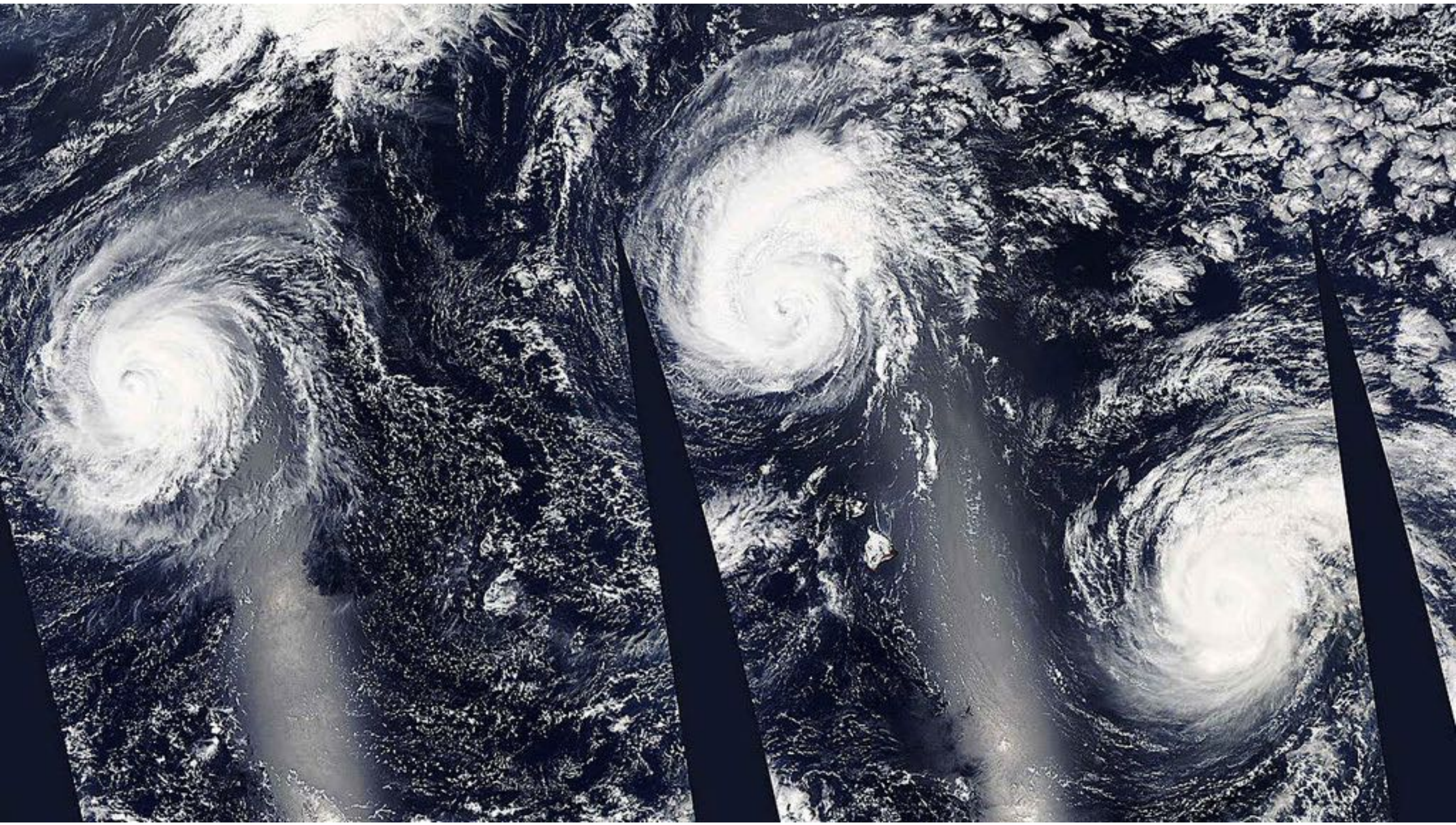

From https://svs.gsfc.nasa.gov/4358

# A track of Kilo: Precipitation




From https://svs.gsfc.nasa.gov/4359

# Three in a row!



**Kilo** **Ignacio** **Jimena**

# Hurricane Dissipation

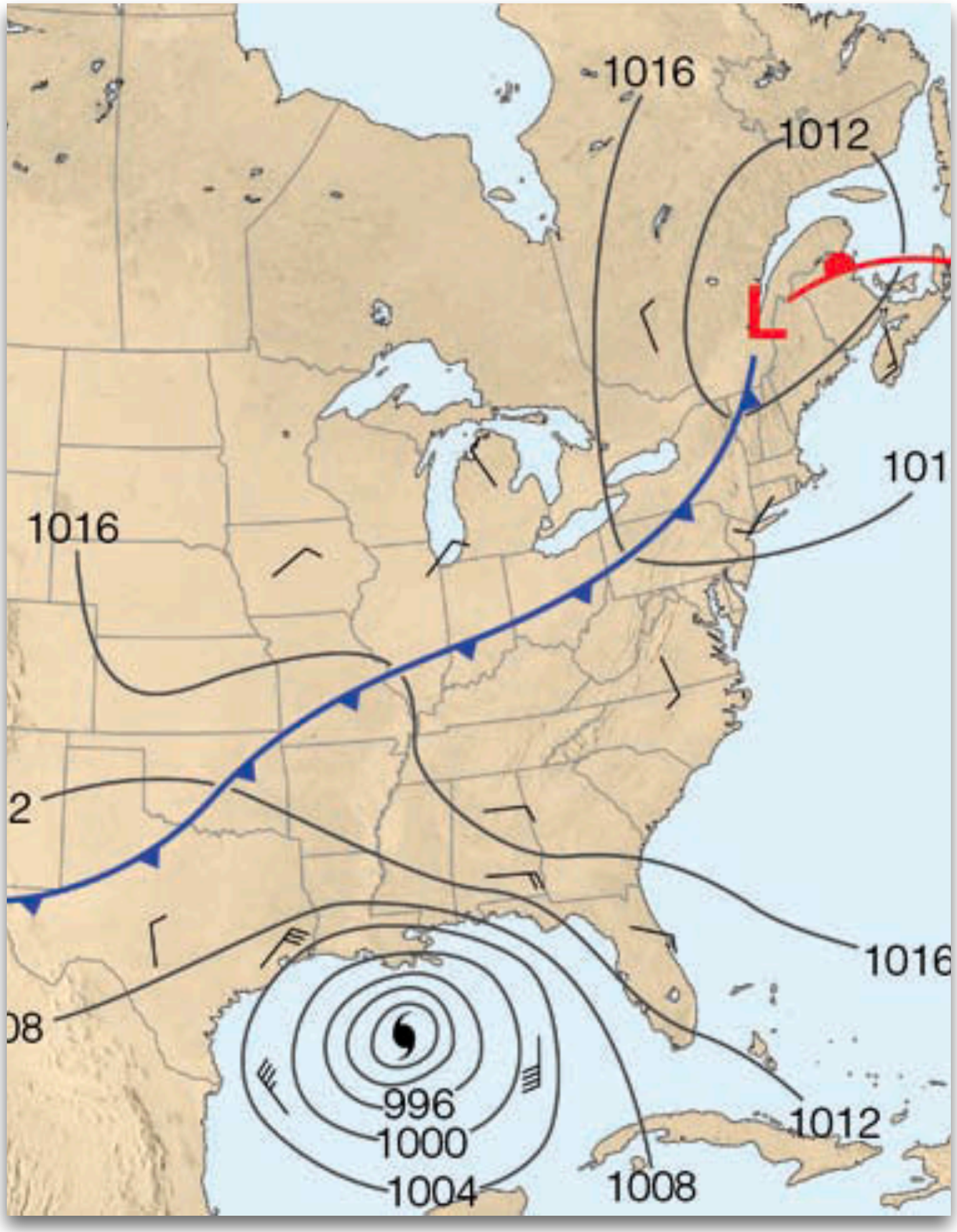
- The hurricanes weaken rapidly when they lose the energy input.
    - Over the cold water
    - Over the water with a shallow warm layer
        - Because the active mixing under the hurricanes drops the water temperature.
- When they move slowly (vertical mixing decreases T.)

# Hurricane Dissipation

- Over the land
  - Cutoff of the energy input
  - Friction with the land surface
- In the area with strong vertical wind shear

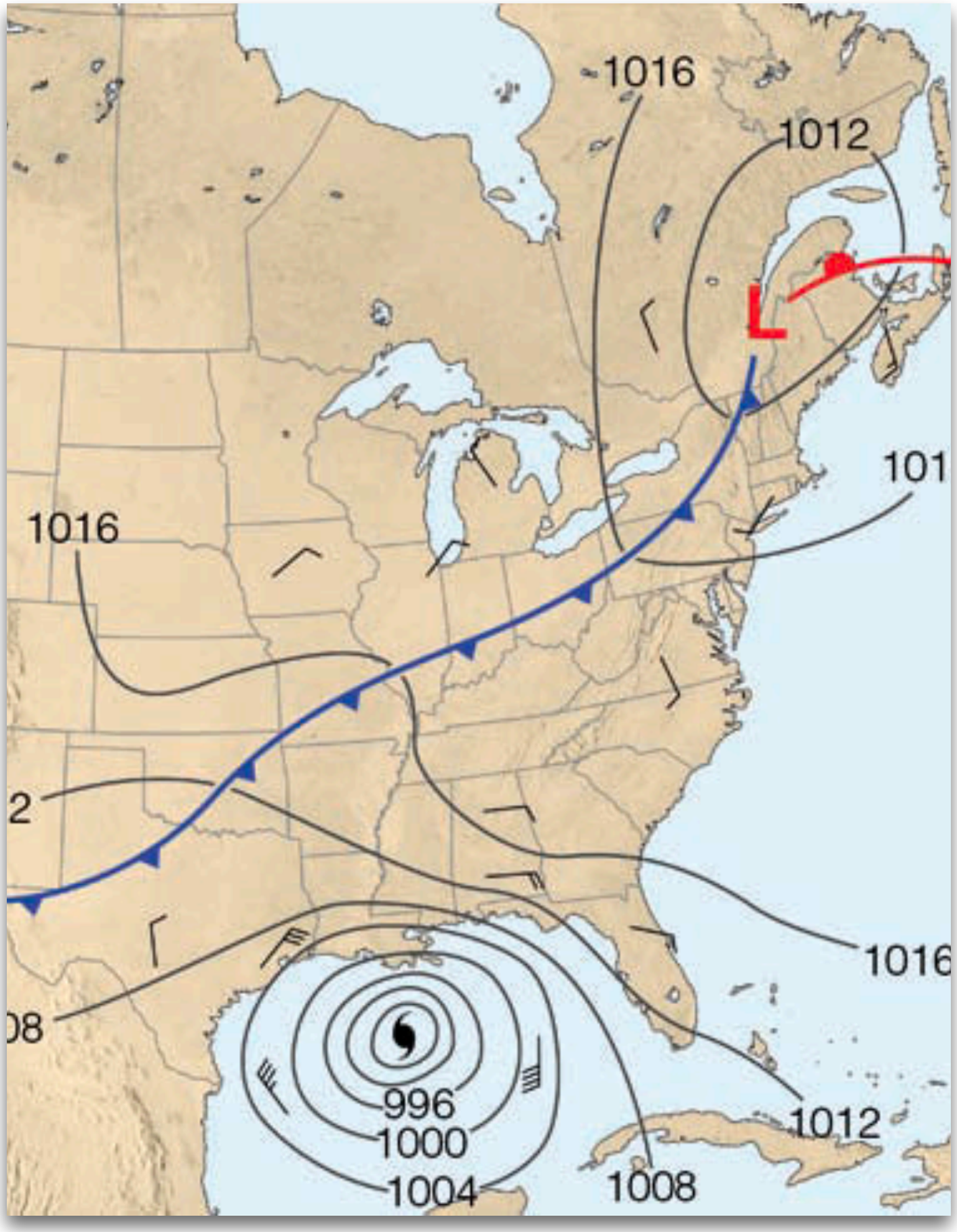
# Hurricanes v.s. mid-latitude cyclones

- Energy source
  - Hurricanes: warm water
  - Mid-latitude cyclones: horizontal temperature gradient
- Center
  - Hurricanes: warm-core lows
  - Mid-latitude cyclones: cold-core lows



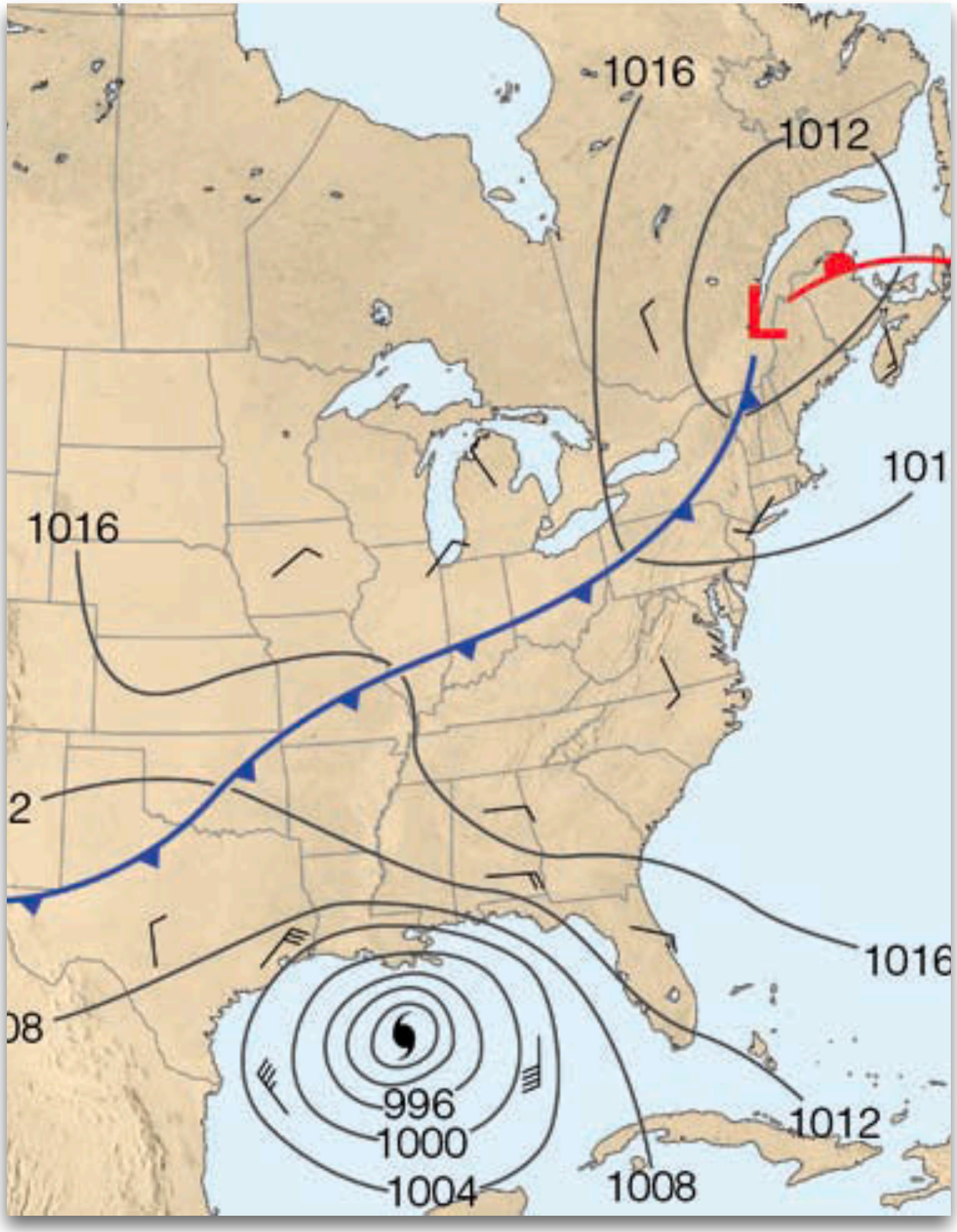
# Hurricanes v.s. mid-latitude cyclones

- Vertical motion at the center
  - Hurricanes: sinking associated with an eye
  - Mid-latitude cyclones: rising air
- Wind
  - Hurricanes: strongest near the surface
  - Mid-latitude cyclones: strongest aloft



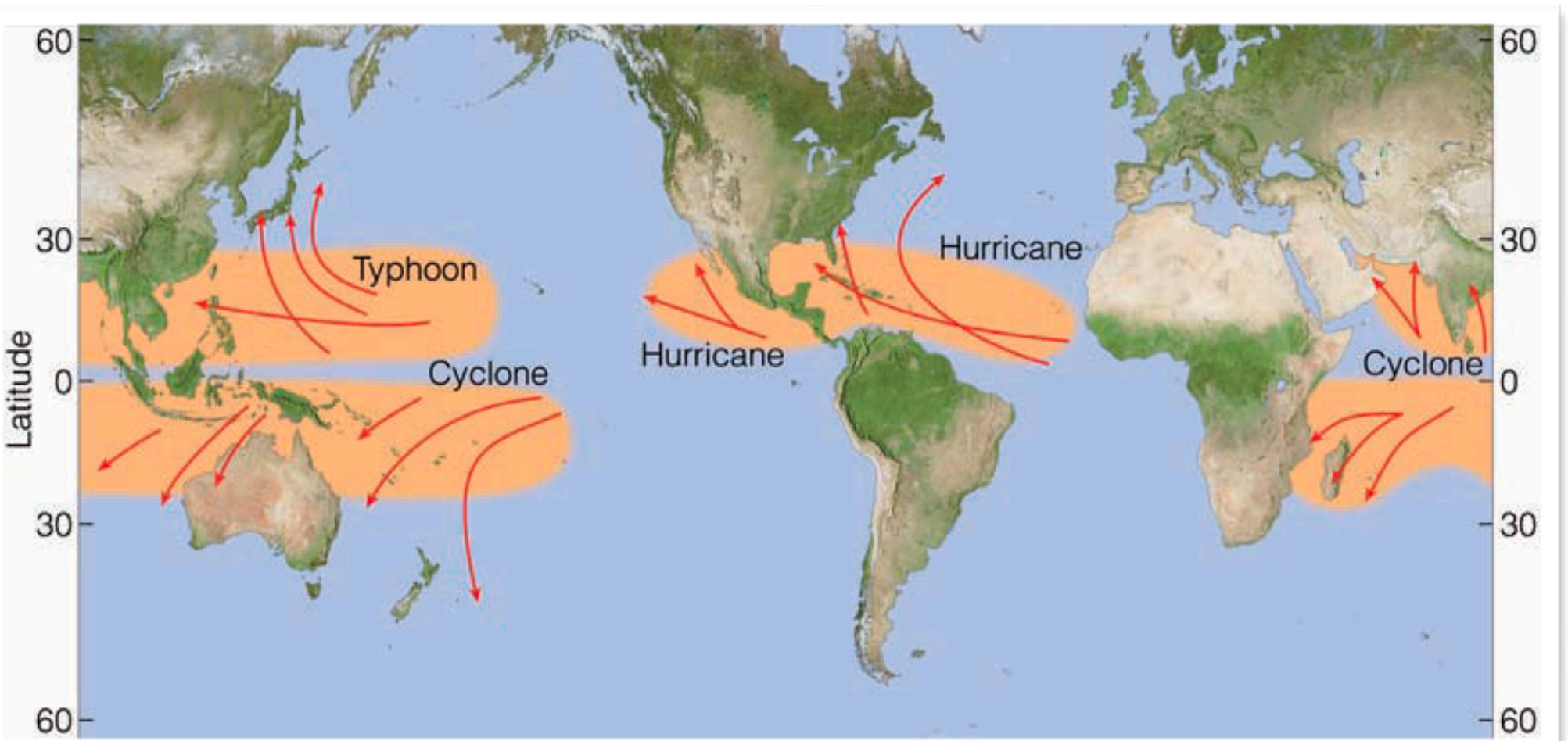
# Hurricanes v.s. mid-latitude cyclones

- Isobars
  - Hurricanes: a circular shape, steeper pressure gradient
  - Mid-latitude cyclones: have fronts and less steep pressure gradient.
- Similarities
  - Surface low pressure
  - Counterclockwise winds



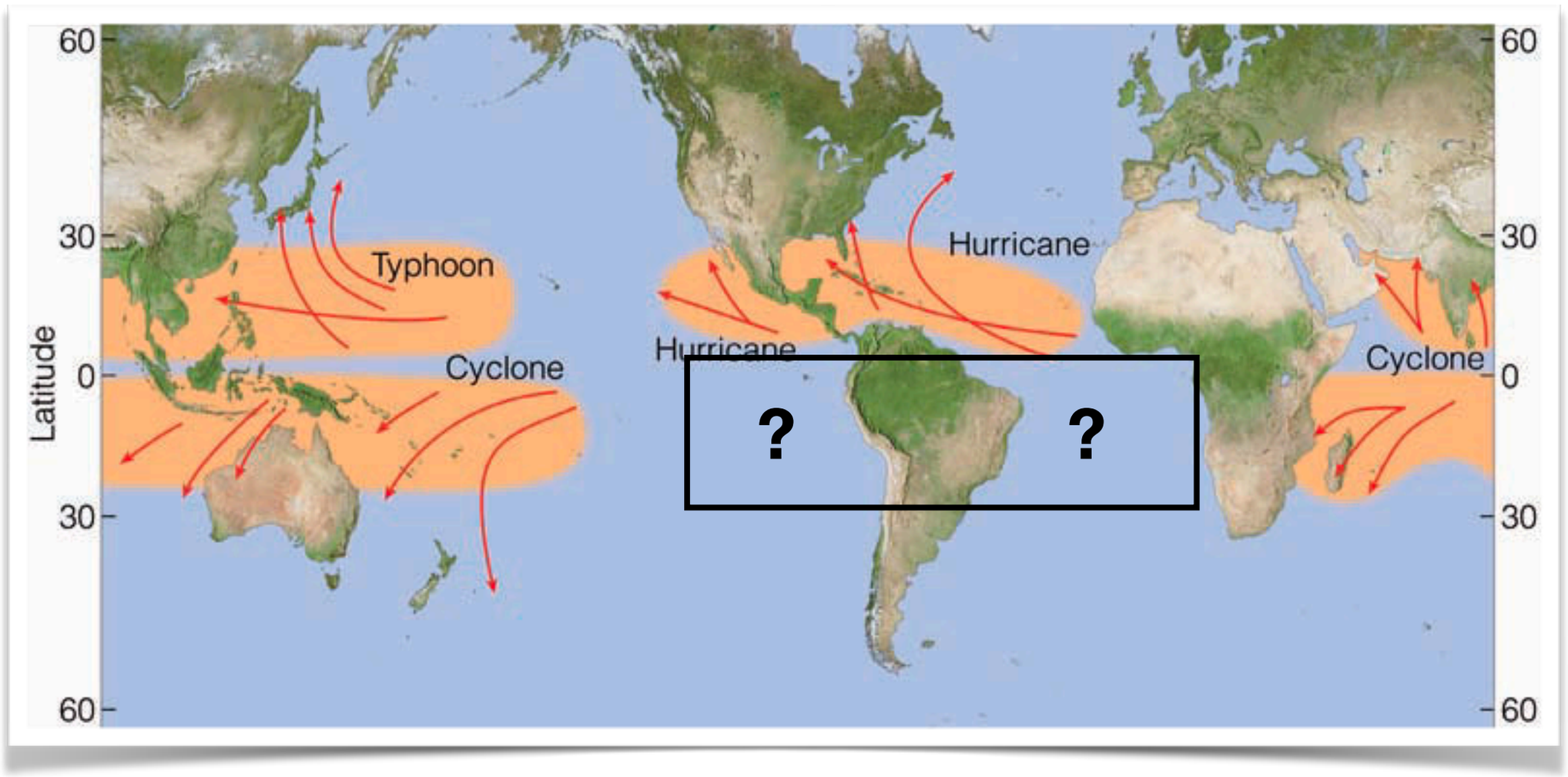
# Hurricane movement

- Slowly moving westward (10 knots = 18 km/h) for a week
- Steering to north or northeast with increased speed
- Weather systems can impact the paths.



# Rare hurricane events

- No hurricanes seen in the south Atlantic Ocean until 2004.
- After hurricane Catarina, no hurricanes until now.



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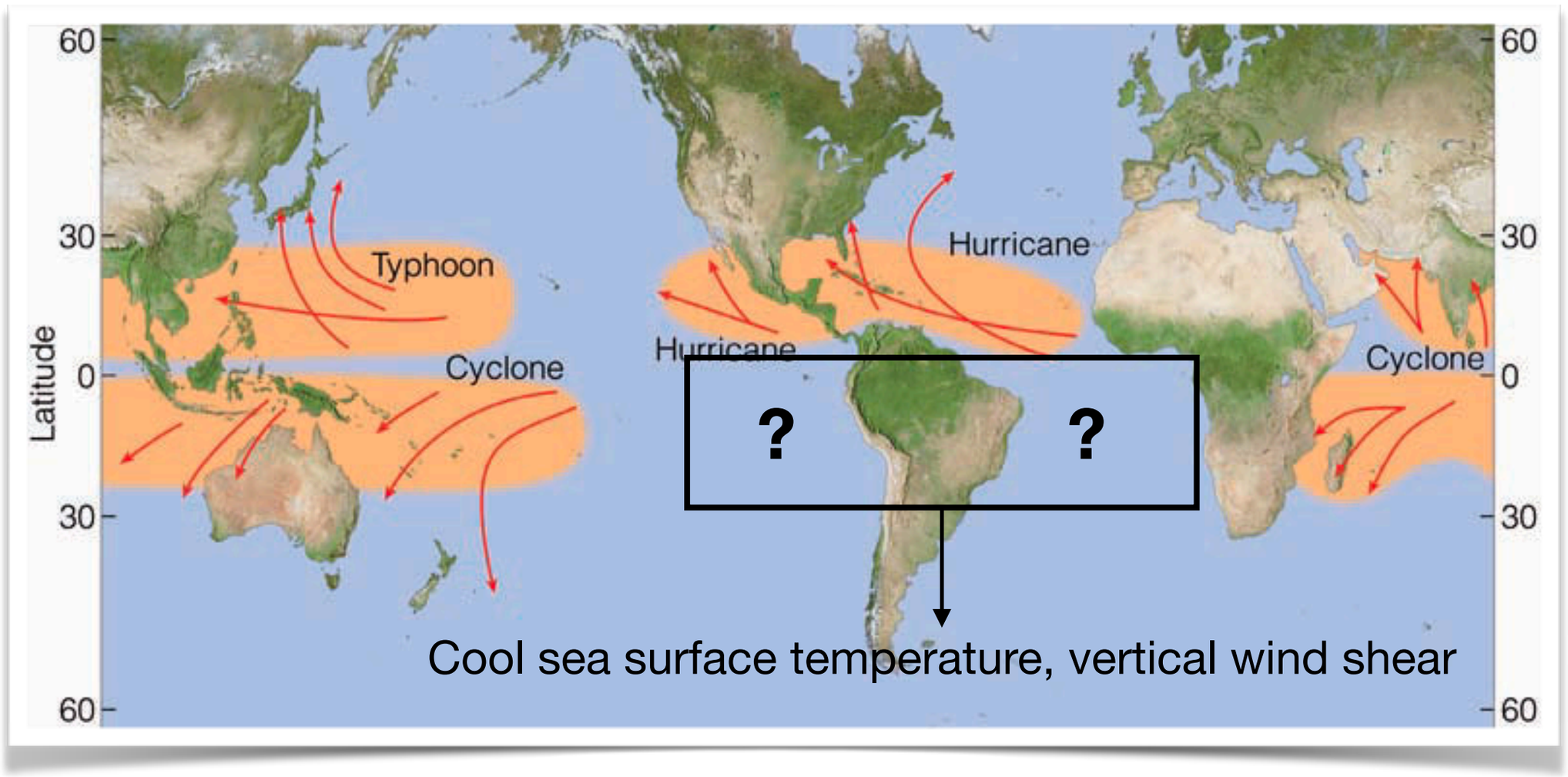


Break!

# Names for hurricanes

- Beginning in 1953, the National Weather Service began using female names following alphabetical order.
- Beginning in 1978, tropical storms in the eastern Pacific were alternately assigned female and male names, but not just English names, as Spanish and French ones were used too.
- This practice began for North Atlantic hurricanes in 1979.
- 6 sets of name are used in rotation.
- If a storm causes great damage and becomes infamous as a Category 3 or higher, its name is retired for at least ten years.

# Names for typhoons

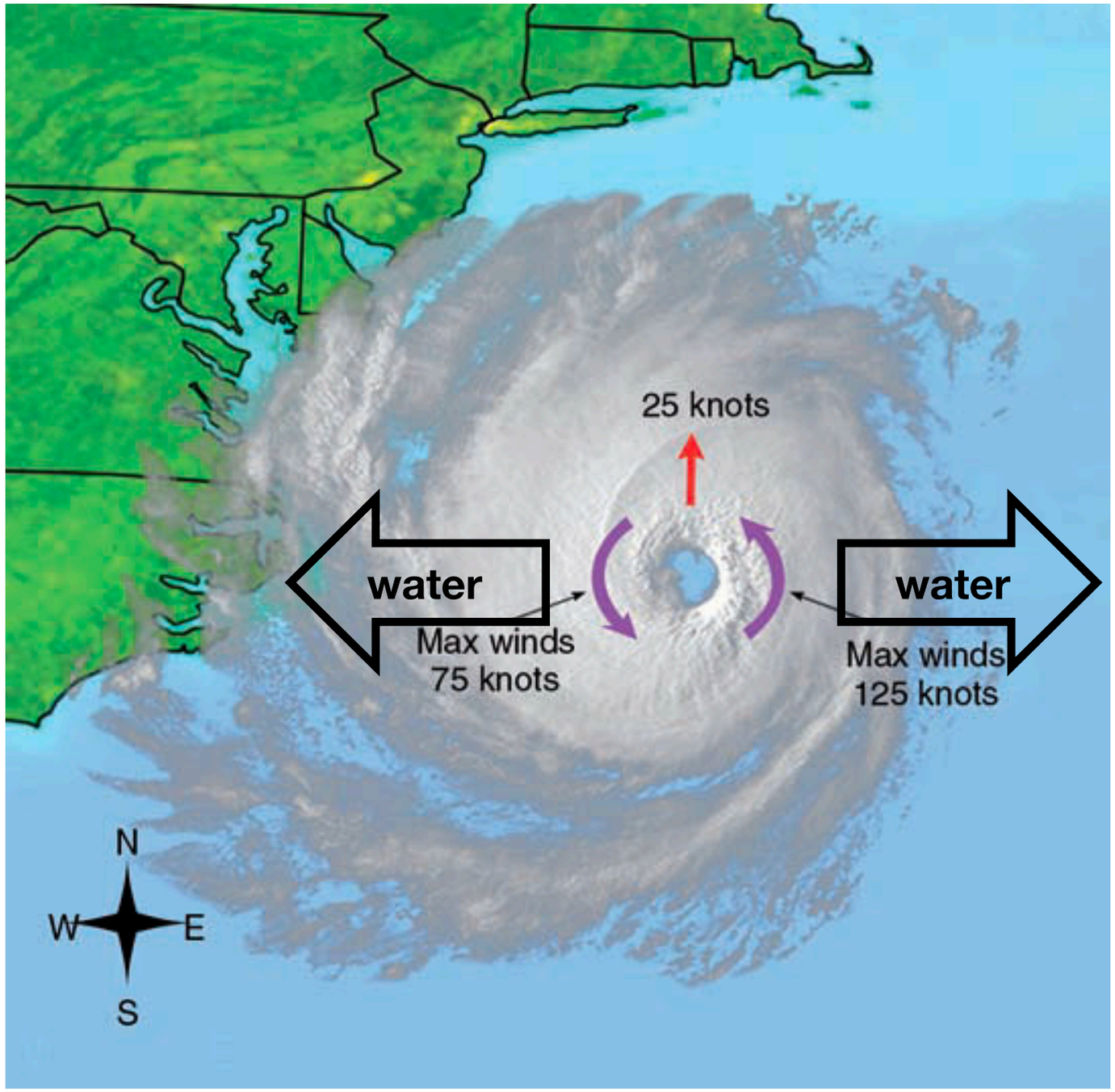
- Before 2000, names were given from 84 names by Joint Typhoon Warning Center.

- Since 2000, Regional Specialized Meteorological center in Tokyo picks the name from the list of 140 names (10 names from 14 countries).

- 140 names were divided into 5 sets, and these names are used sequentially.

- Names from South Korea: ‘개미', ‘나리', ‘장미', ‘미리내', ‘노루', ‘제비', ‘너구리', ‘고니', ‘메기', ‘독수리'

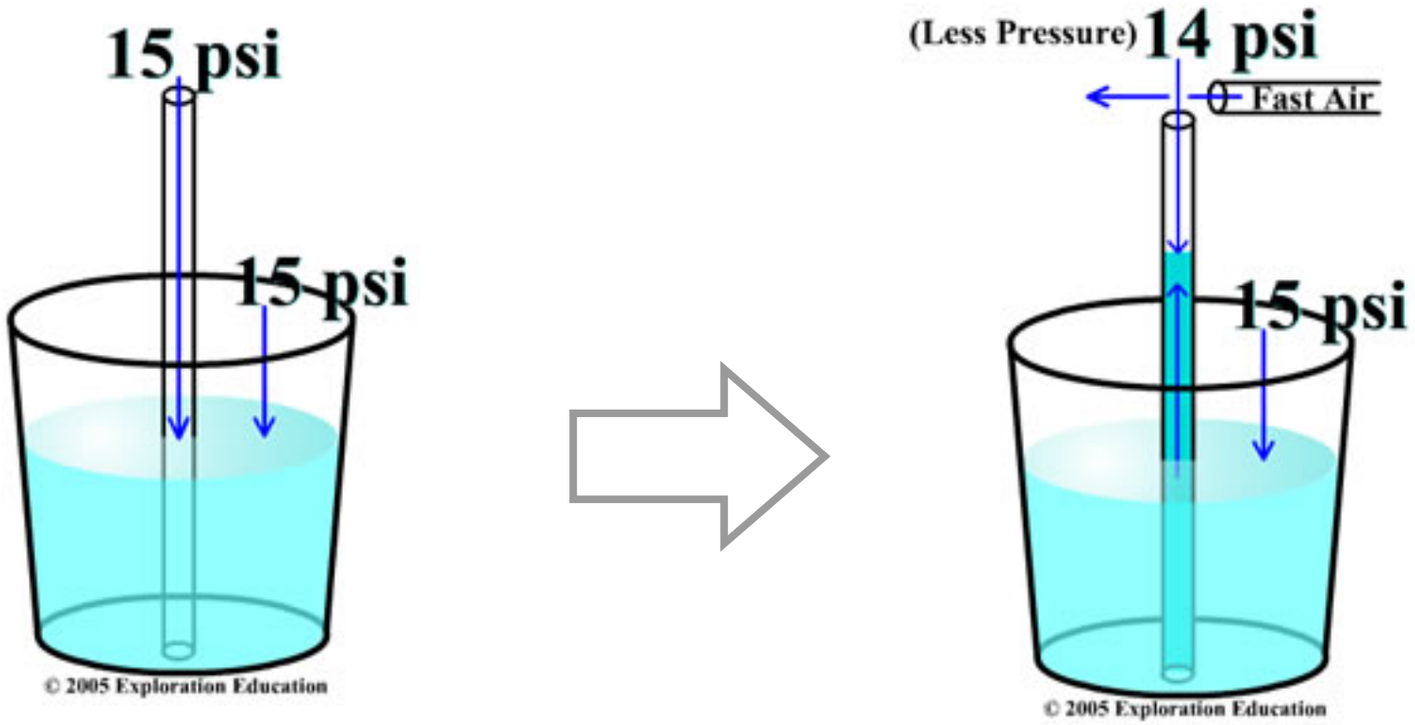
# Damages from hurricanes




with winds of 100 knots swirling counterclockwise about its center

# Storm surge

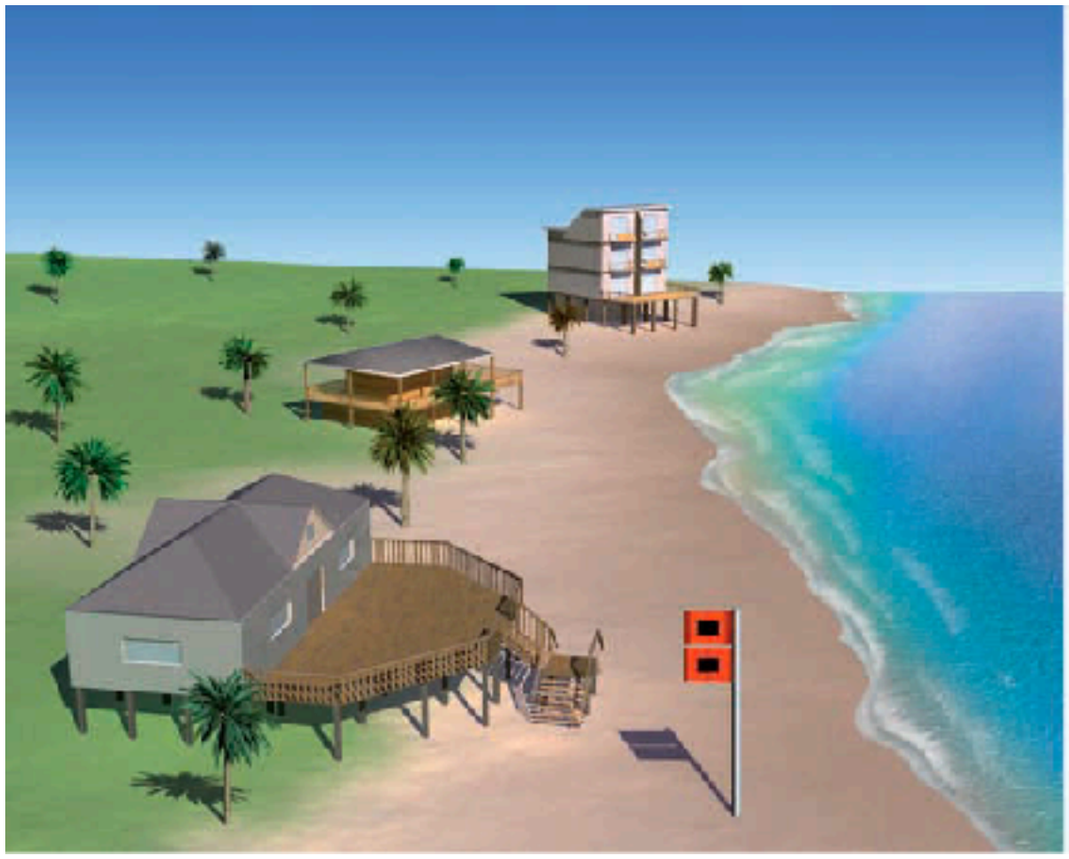
- Ekman transport + High waves + Low pressure $\Longrightarrow$ storm surge

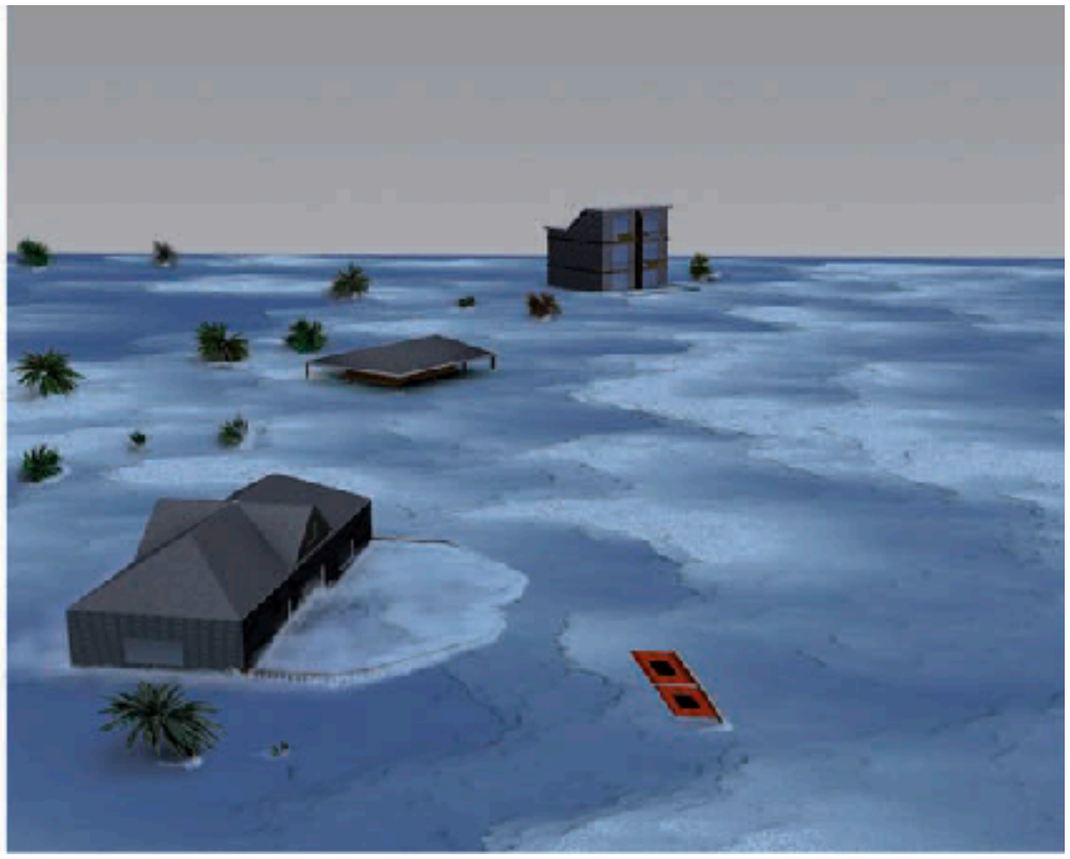


# Storm surge

- Ekman transport + High waves + Low pressure $\Longrightarrow$ storm surge

- Storm surge + rain (+ high tide) $\Longrightarrow$ flooding





# Categorizing hurricanes

- Saffir-Simpson scale

| category | Central pressure | Winds | | storm surge | |
|---|---|---|---|---|---|
| | mb | mph | knots | ft | m |
| 1 | >=980 | 74-95 | 64-82 | 4-5 | ~1.5 |
| 2 | 965-979 | 96-110 | 83-95 | 6-8 | ~2.0-2.5 |
| 3 | 945-964 | 111-130 | 96-113 | 9-12 | ~2.5-4.0 |
| 4 | 920-944 | 131-155 | 114-135 | 13-18 | ~4.0-5.5 |
| 5 | <920 | >155 | >135 | >18 | >5.5 |

# Categorizing hurricanes

Normal high tide

Category 1 [4-foot rise]

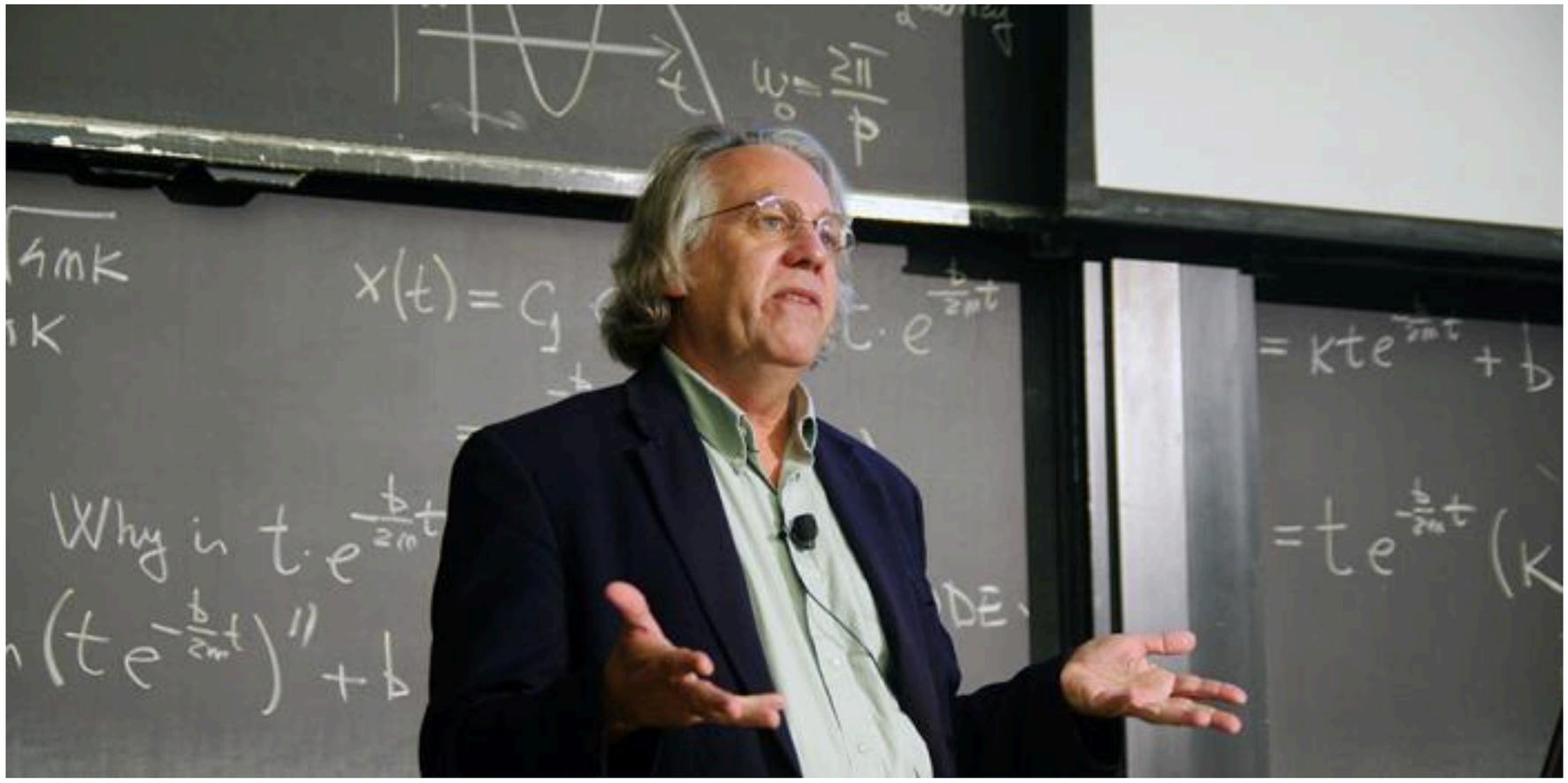
Category 3 [12-foot rise]

Category 5 [20-foot rise]

Major hurricanes

# Talk by Professor Kerry Emanuel at MIT

- video



# More vulnerable to hurricanes

Miami Beach 1926

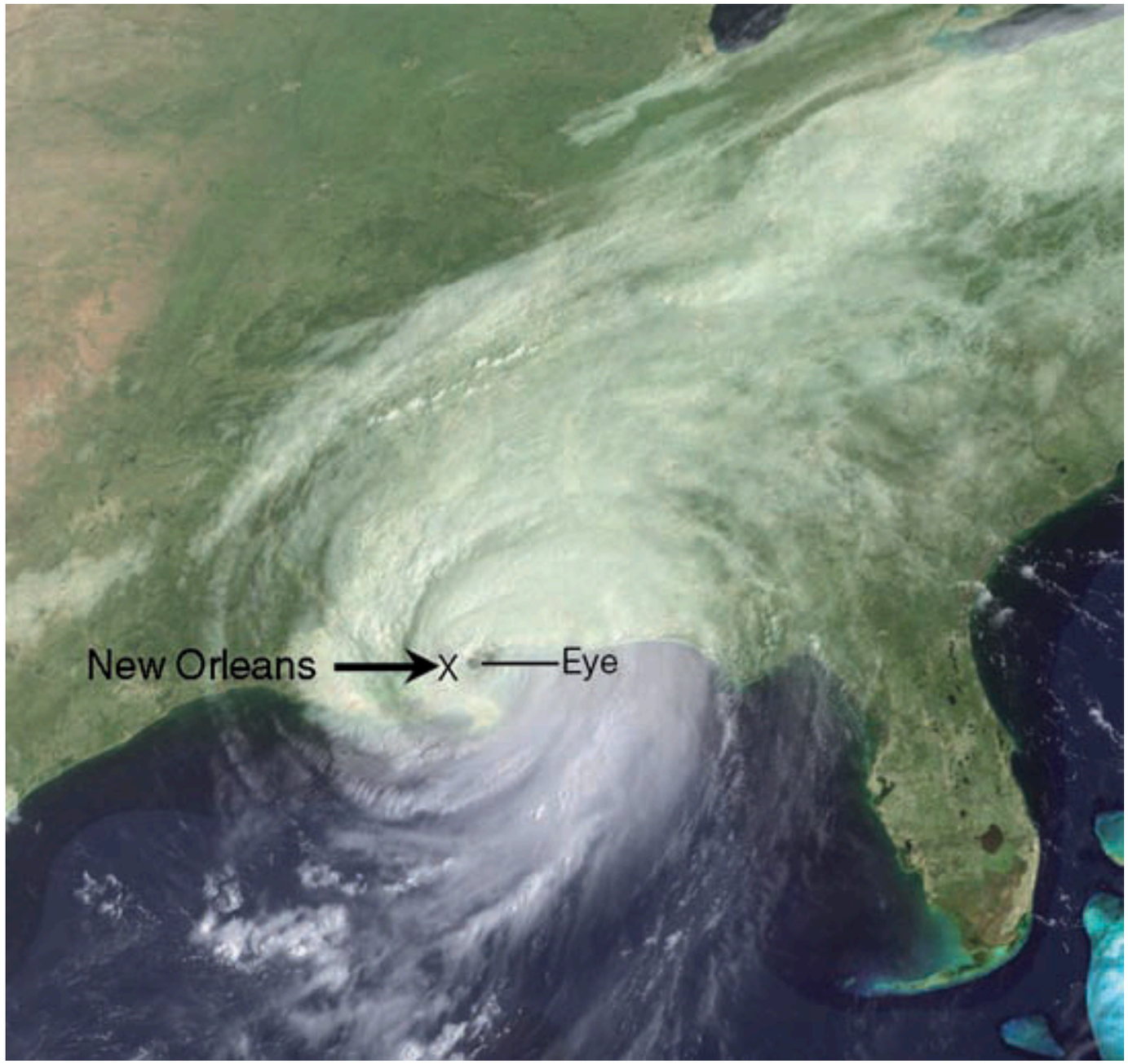
Wendler Collection

Miami Beach 2006

Joel Gratz © 2006

# Hurricane Katrina, 2005

August 29, 2005

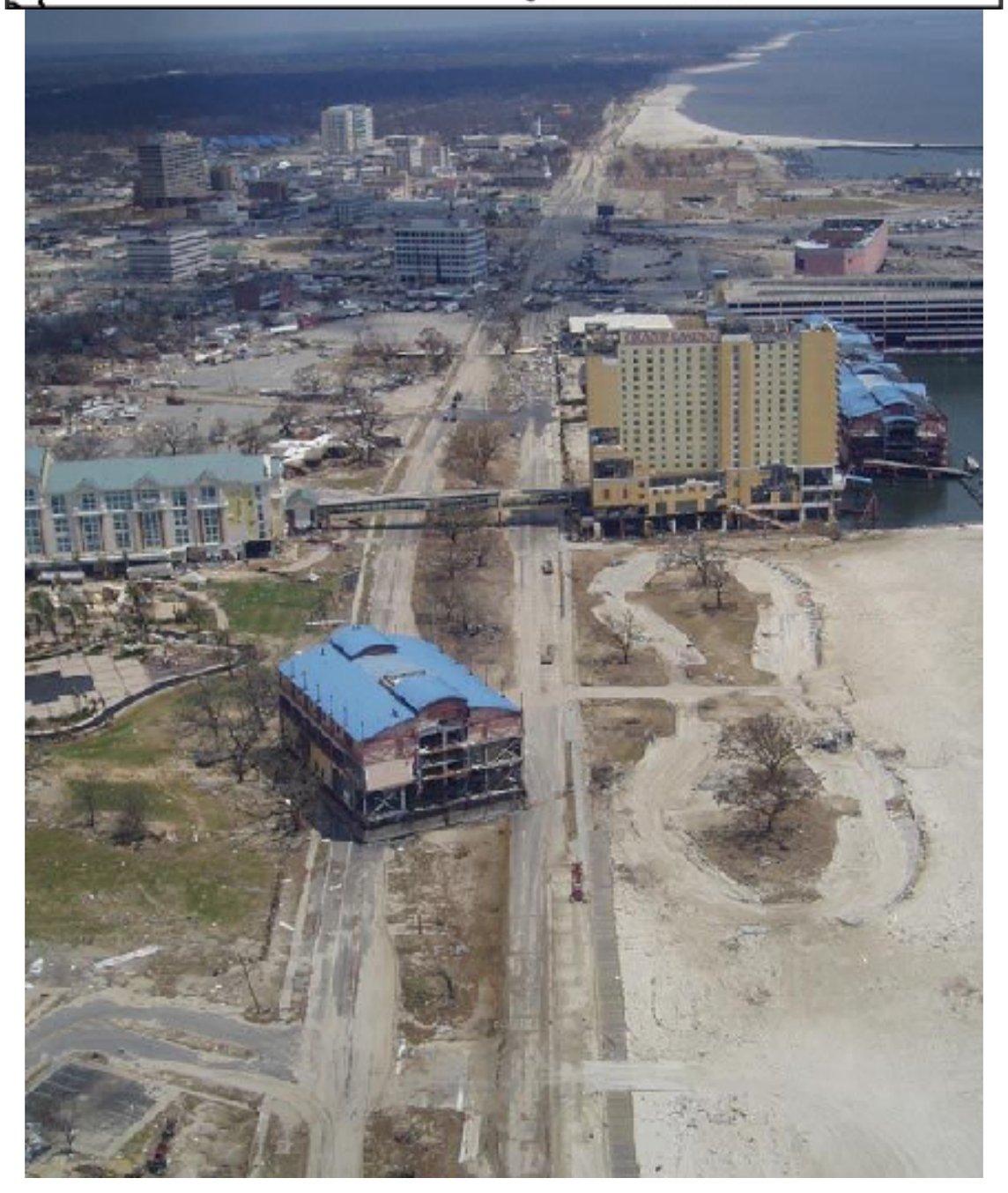



At landfall, Katrina had sustained winds of 110 knots, a pressure of 920 mb, and a storm surge over 20 feet (6 m).

# Hurricane Katrina, 2005

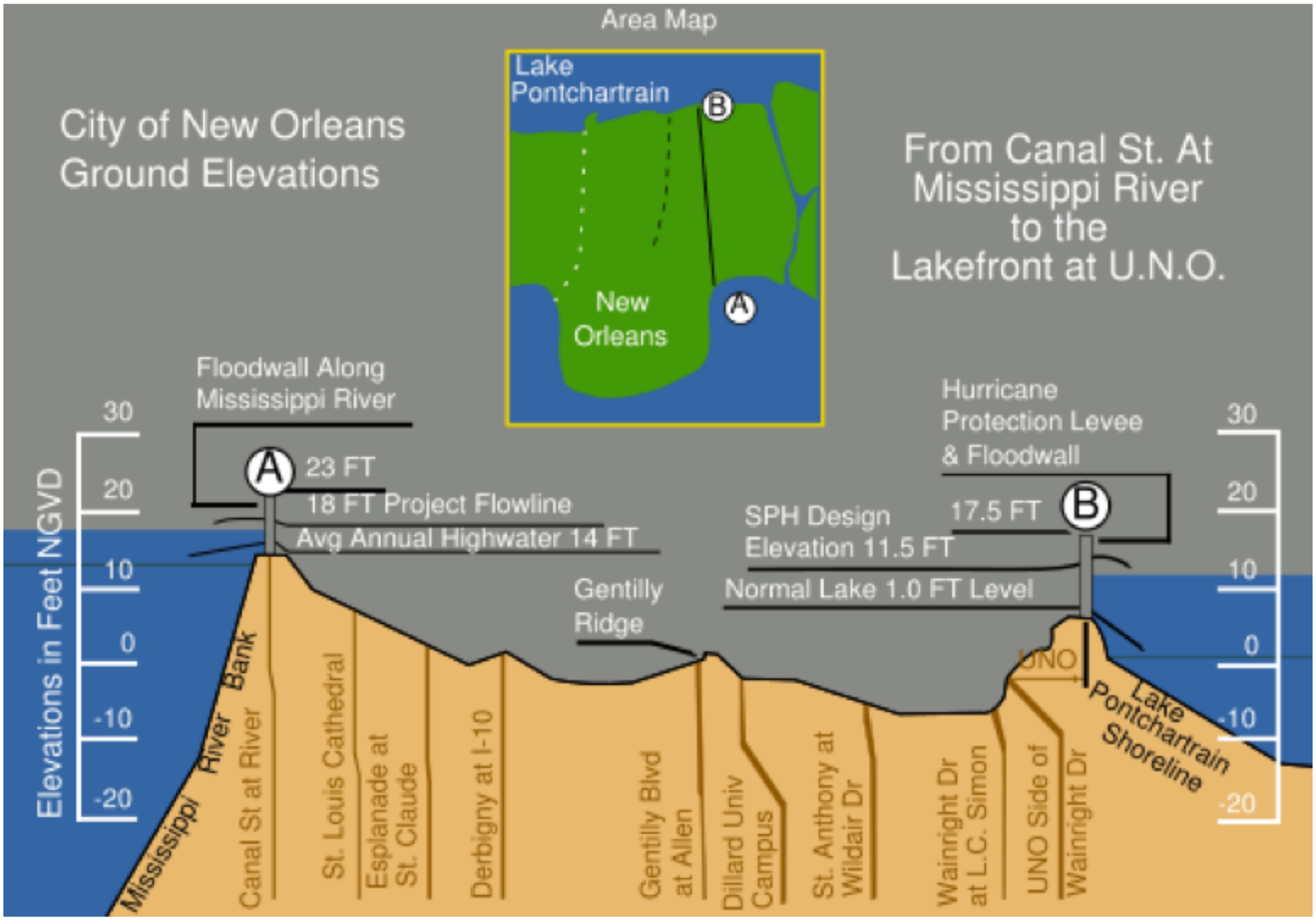
# Hurricane Katrina, 2005





# April, 2013, Gulfport, Mississippi

# Hurricane Katrina, 2005



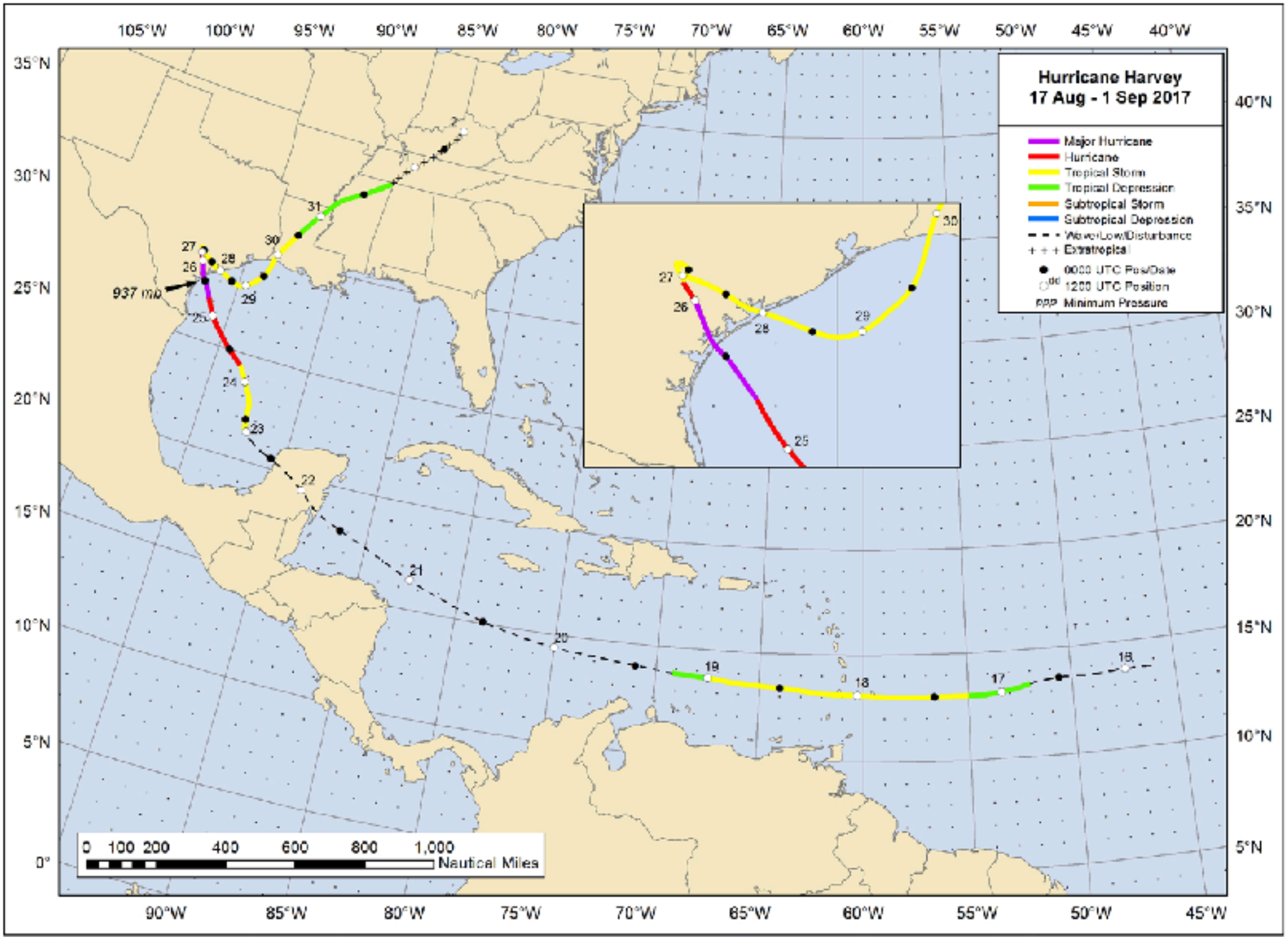
# Hurricane Katrina, 2005

Flood waters inundate New Orleans, Louisiana, during August, 2005, after the winds and storm surge from Hurricane Katrina caused several levee breaks.

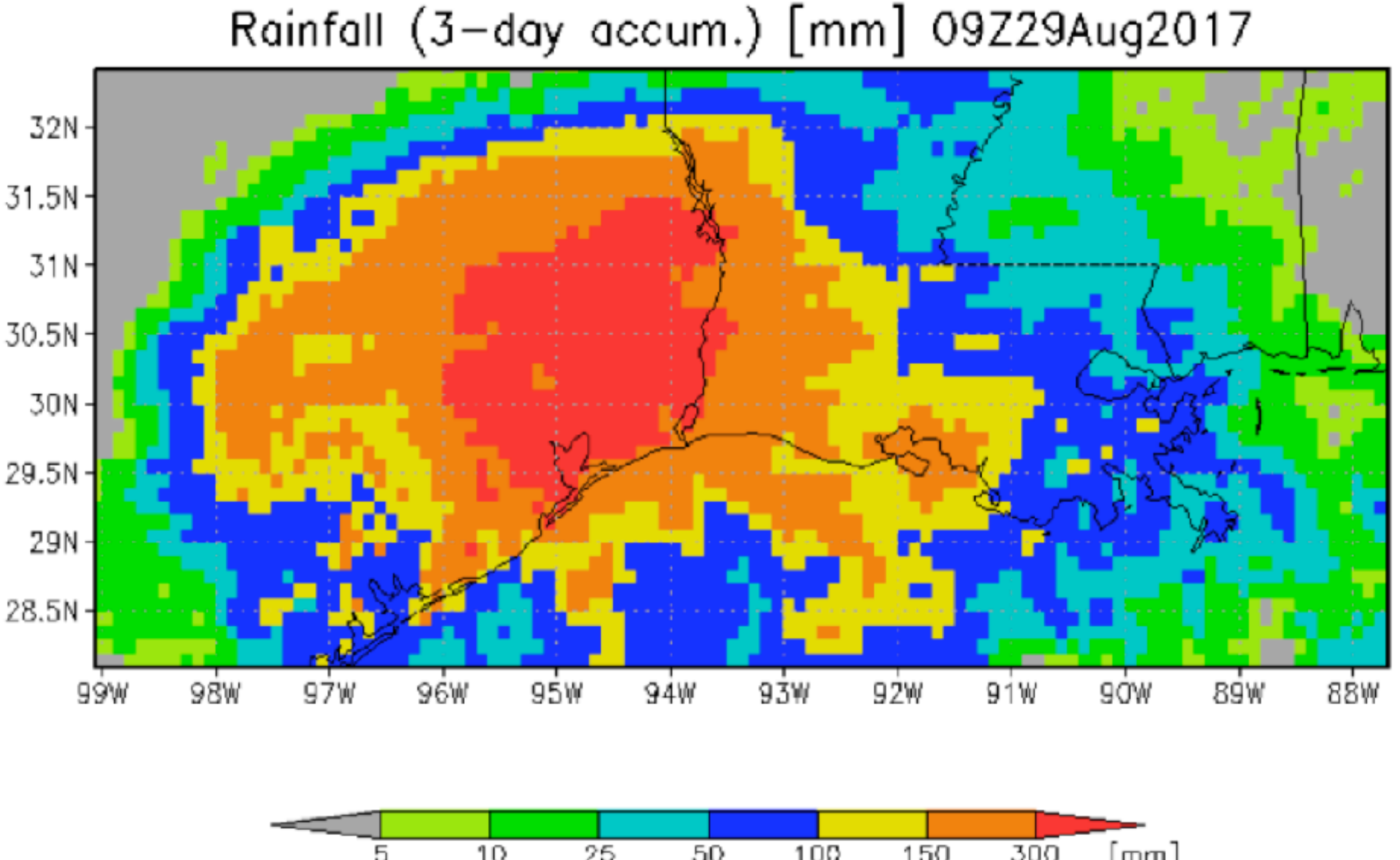
# Hurricane Harvey, 2017

Astronaut Randy Bresnik took this photo of Tropical Storm Harvey from the International Space Station on Aug. 28 at 1:27 p.m. CDT

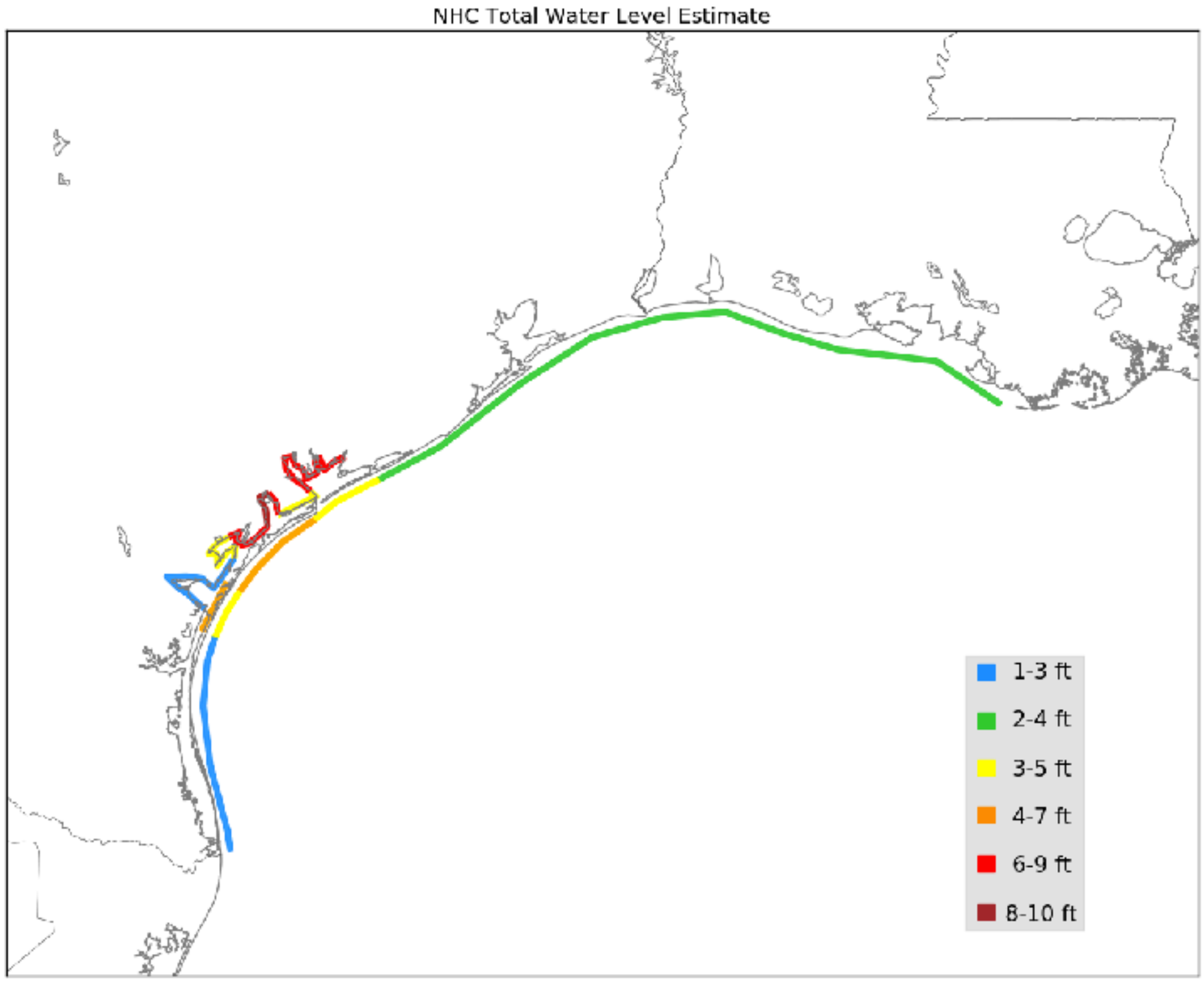
# Hurricane Harvey, 2017



# Hurricane Harvey, 2017



# Hurricane Harvey, 2017



# Hurricane Harvey, 2017


An example of the water rescues that were ongoing during Harvey in Houston on 27 August 2017. Photo credit David J. Phillip

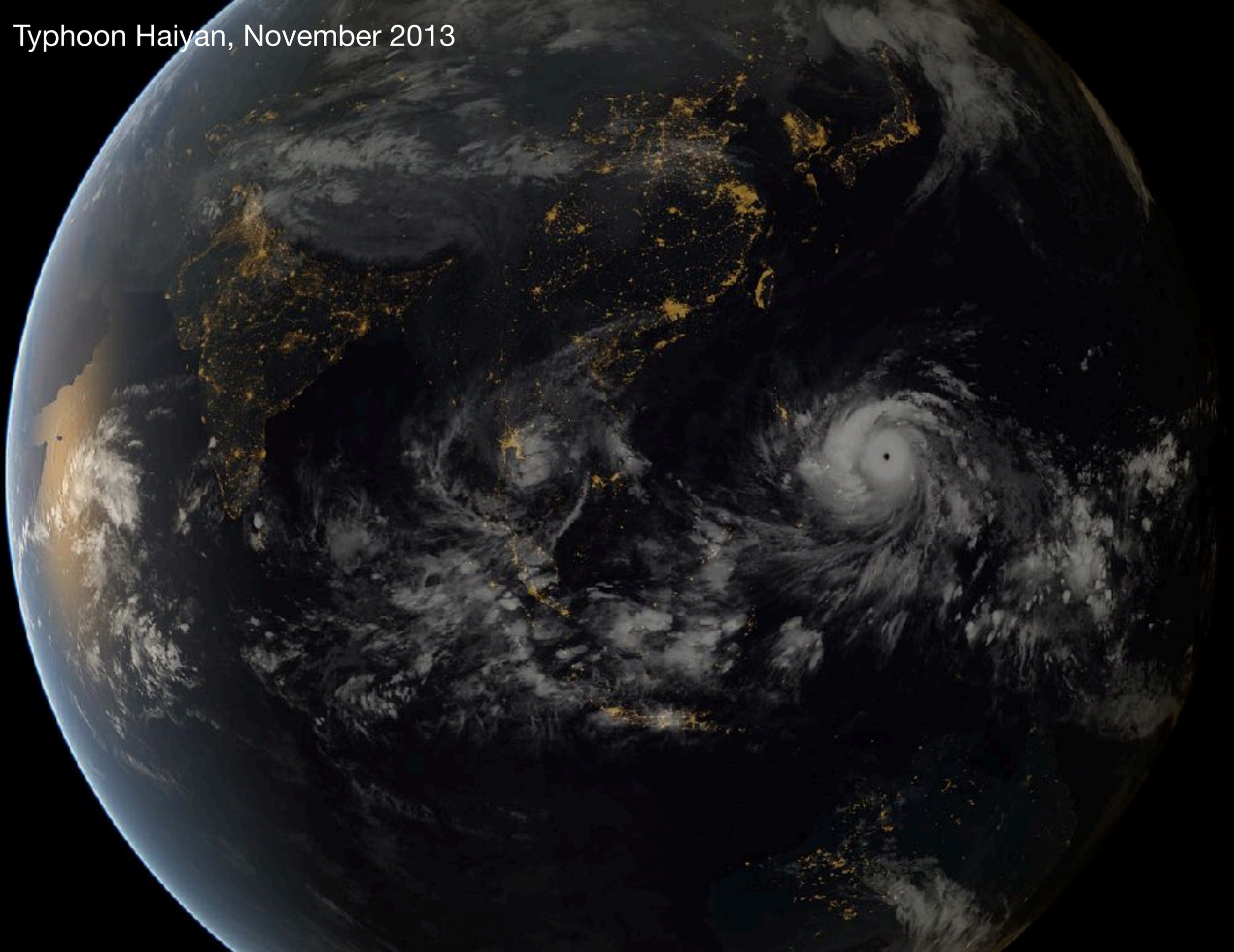
# Hurricane Harvey, 2017

Texas World Speedway after Harvey being used to store flooded cars.
Photo credit Brazos Drones.

# Hurricane Harvey, 2017

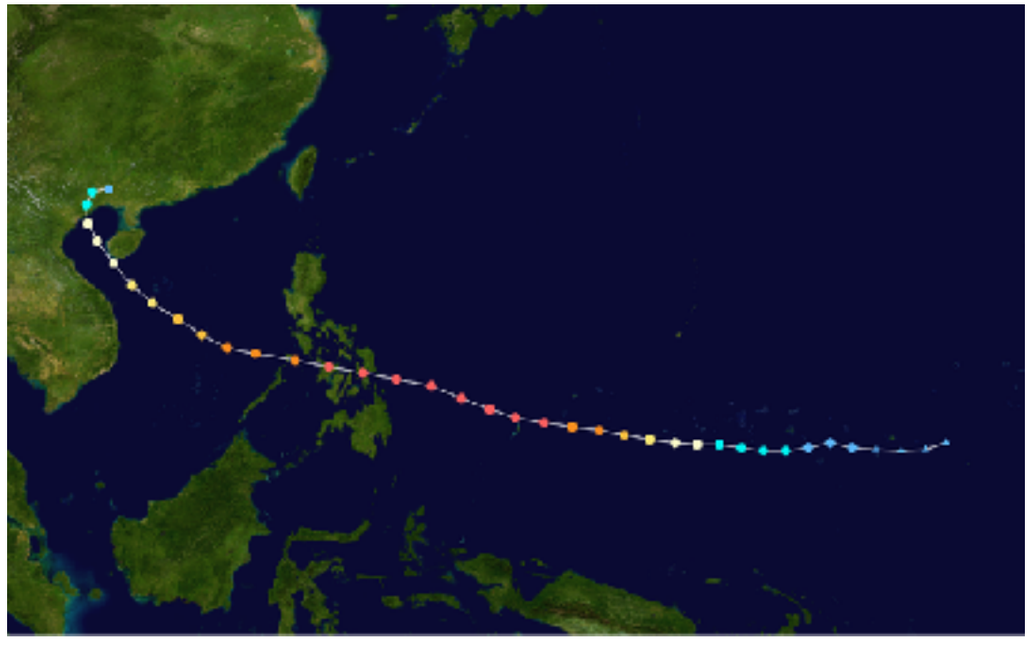
https://youtu.be/T0tcrzO83Mg

Typhoon Haiyan, November 2013

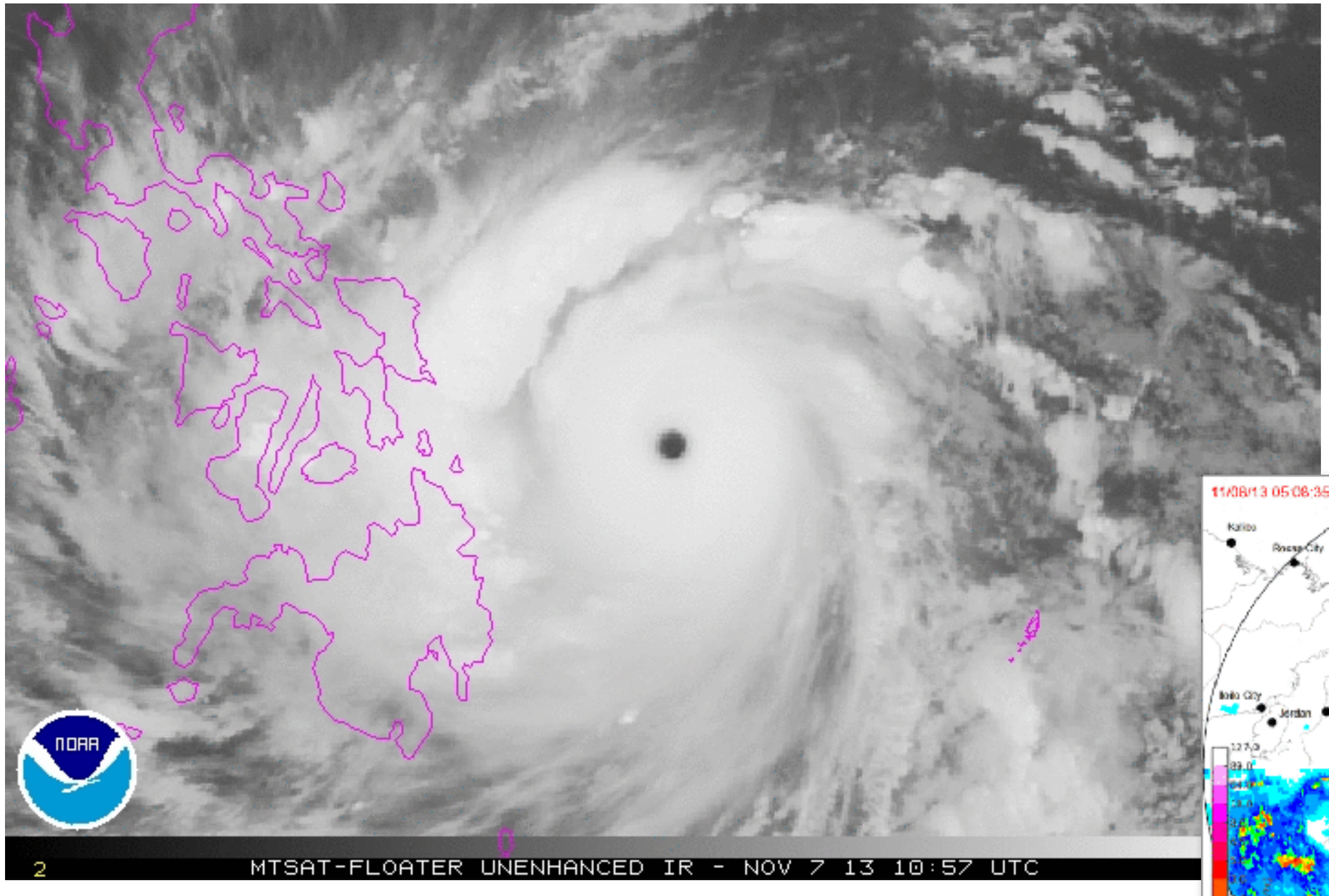


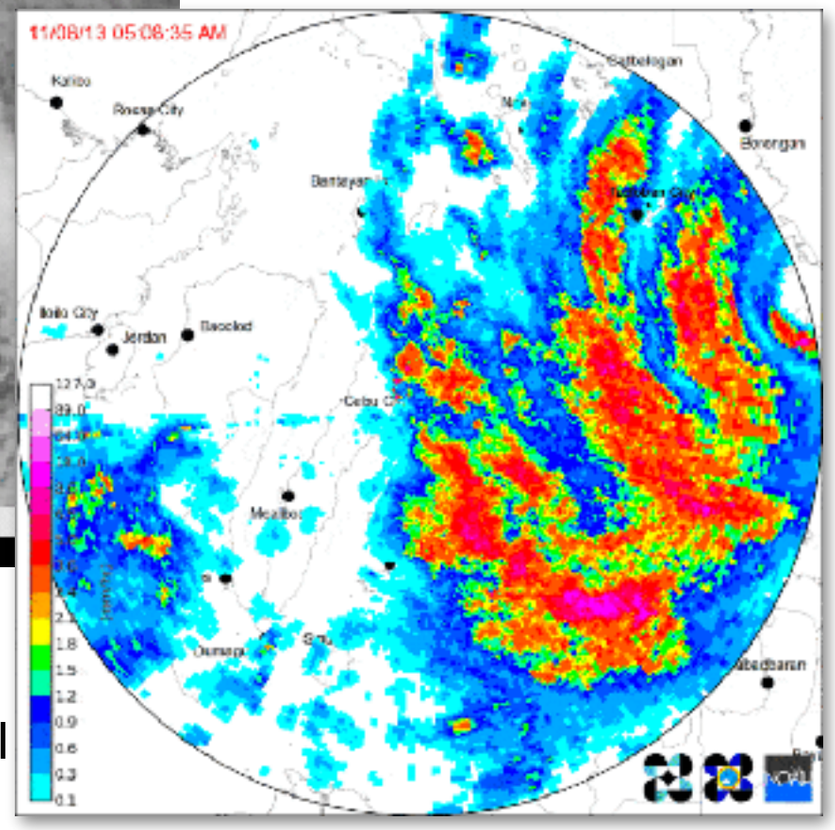
# Typhoon Hayyan, 2013

- The system was generated on Nov. 2, 2013.
- Became category 5-equivalent typhoon on Nov. 5, 2013.
- On Nov. 7, the wind speeds were faster than 315 km/h with the minimum pressure of 895 mb.



# Typhoon Hayyan, 2013




http://www.ospo.noaa.gov/Organization/History/imagery/Haiyan/index.html

# Typhoon Hayyan, 2013

| Country | Deaths | Missing |
|---|---|---|
| Philippines | 6300 | 1061 |
| Vietnam | 13 | 4 |
| China | 8 | 9 |
| Taiwan | 8 | 0 |
| Total | 6329 | 1074 |

Basey, Samar

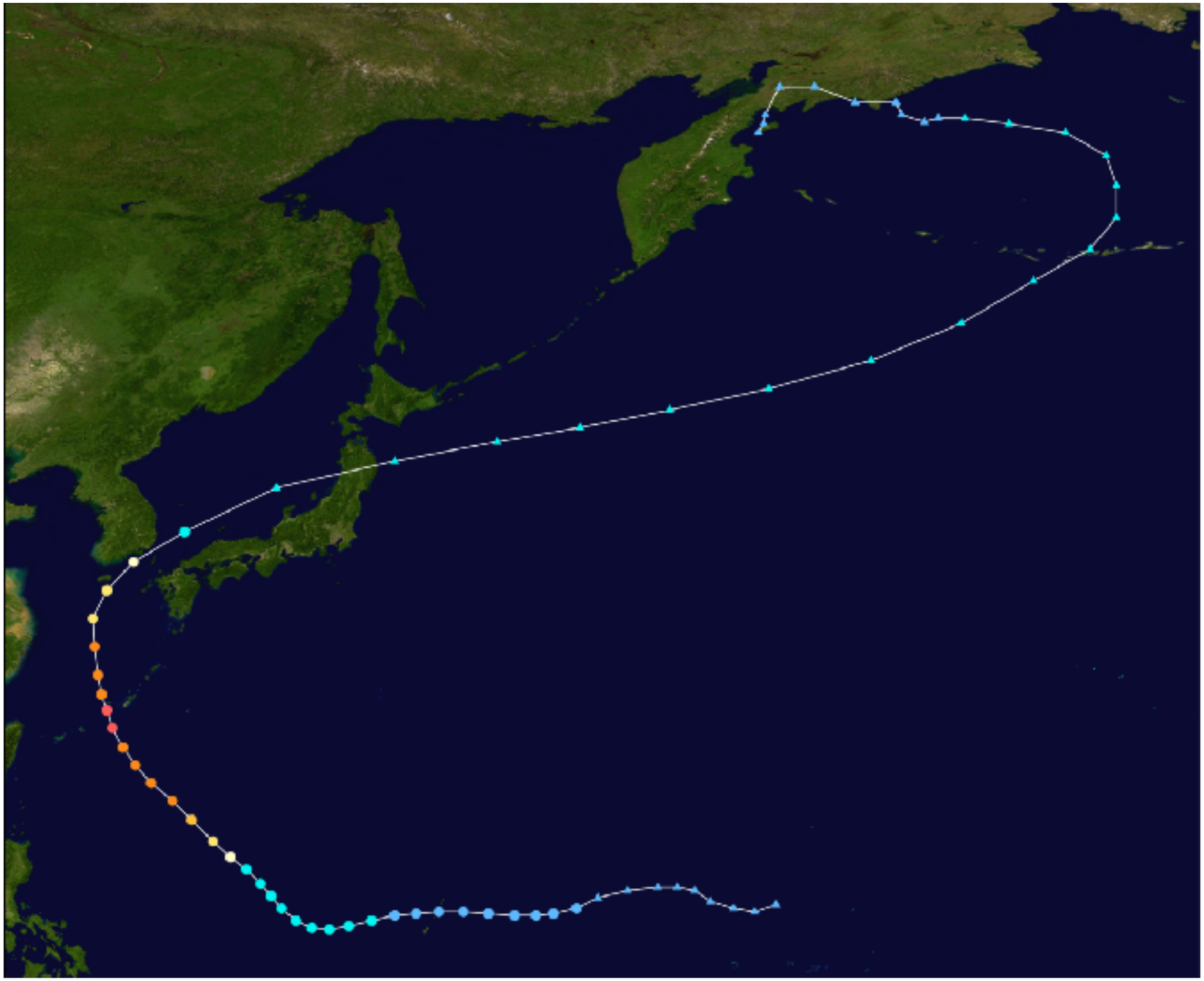
From: https://en.wikipedia.org/wiki/Typhoon_Haiyan

# Super Typhoon Chaba, 2016

- Chaba intensified into a super typhoon (category 4) on October 3.
- Maximum wave heights reached 36 feet (10 meters) late on the following day.

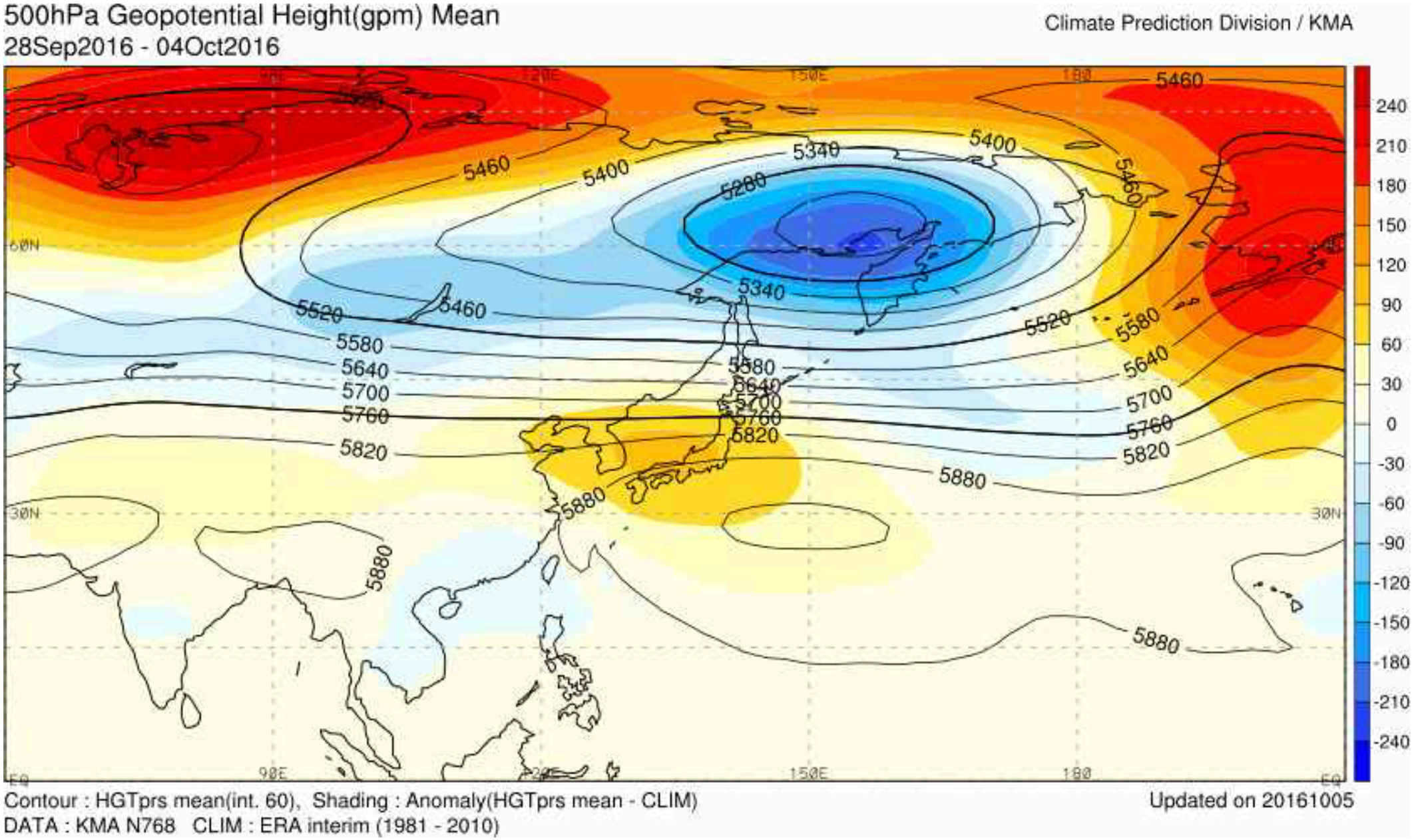

October 4, 2016 from MODIS satellite

# Super Typhoon Chaba, 2016

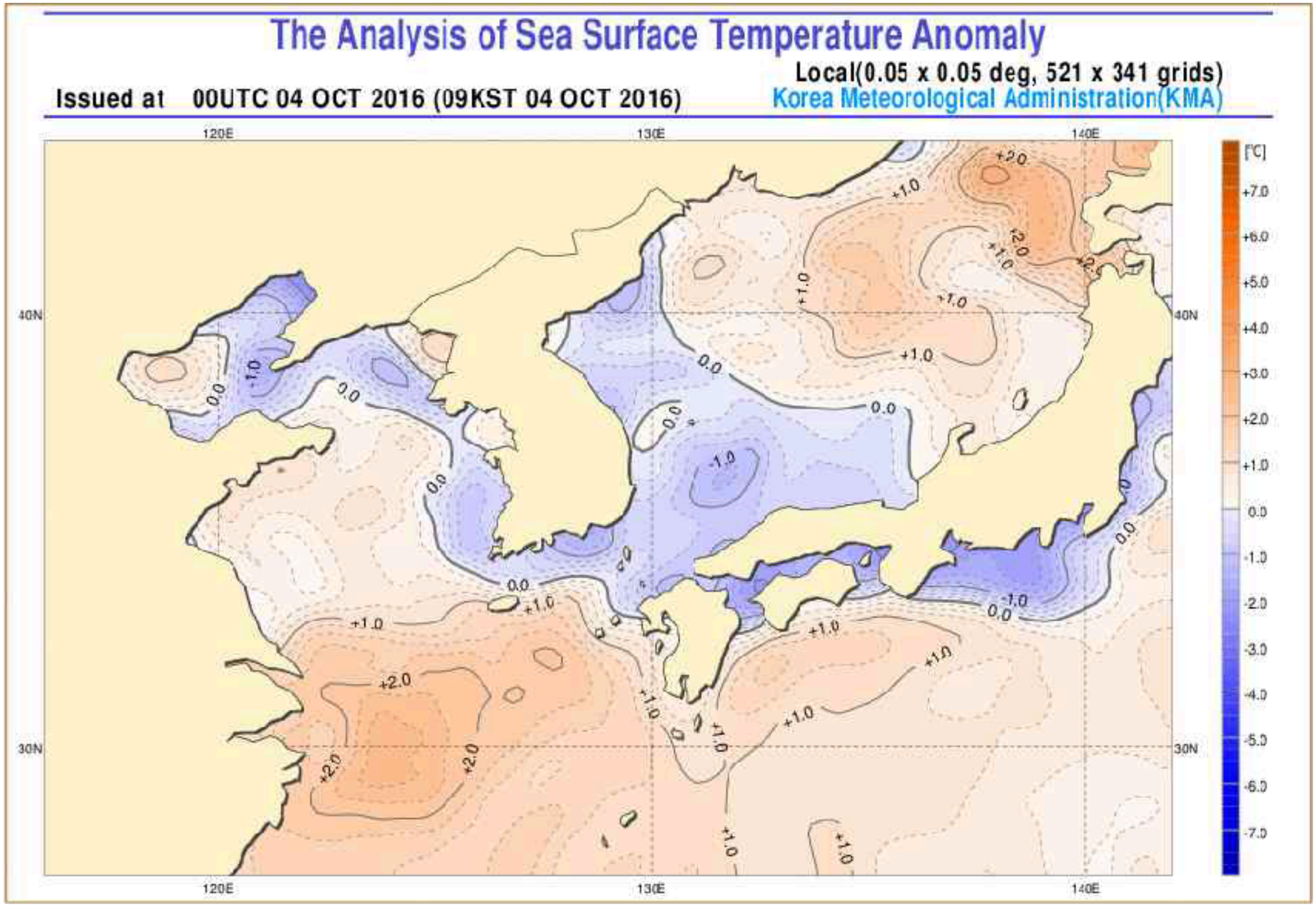


The points shows the location of the storm at every 6 hours.

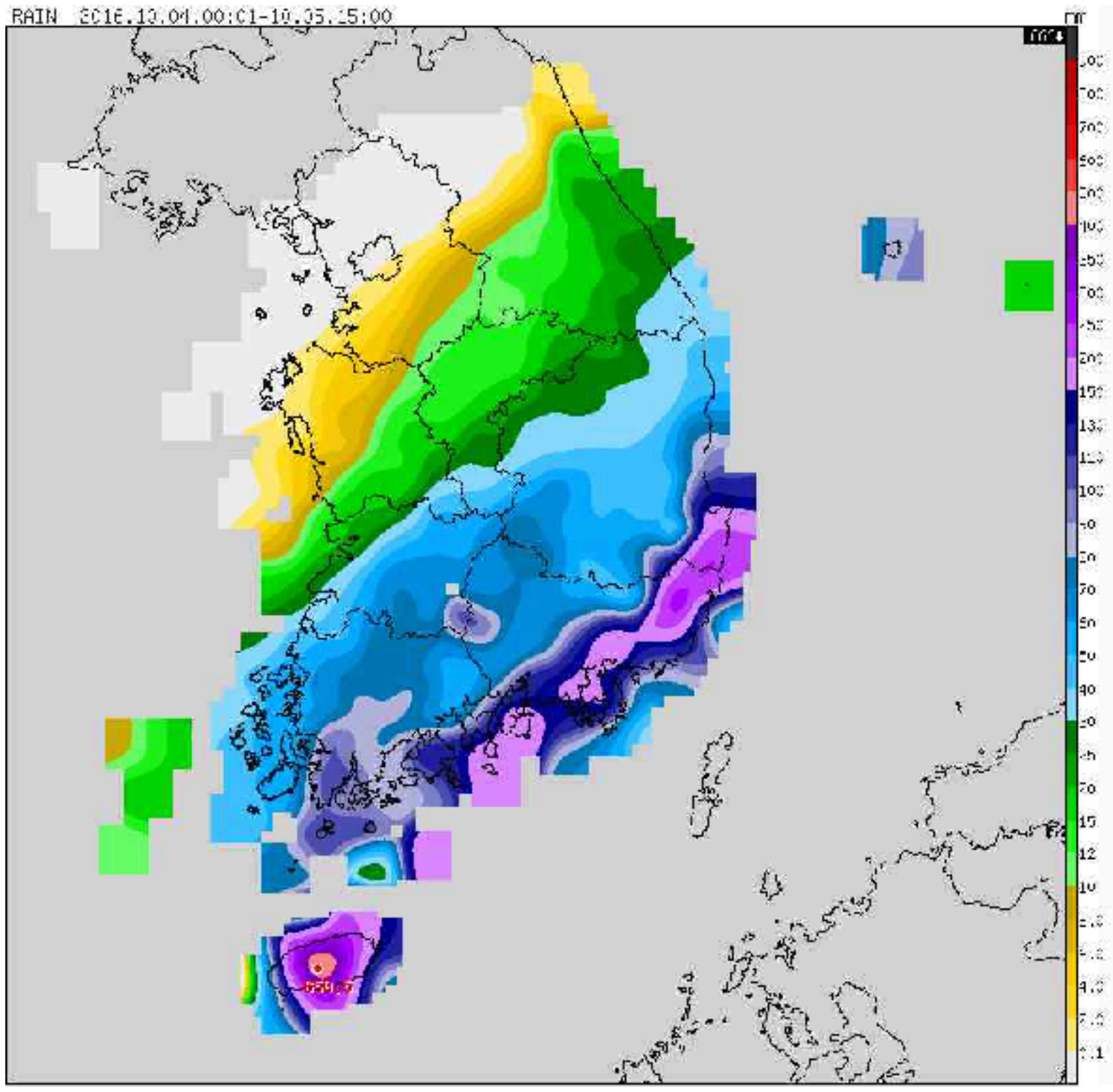
# Super Typhoon Chaba, 2016



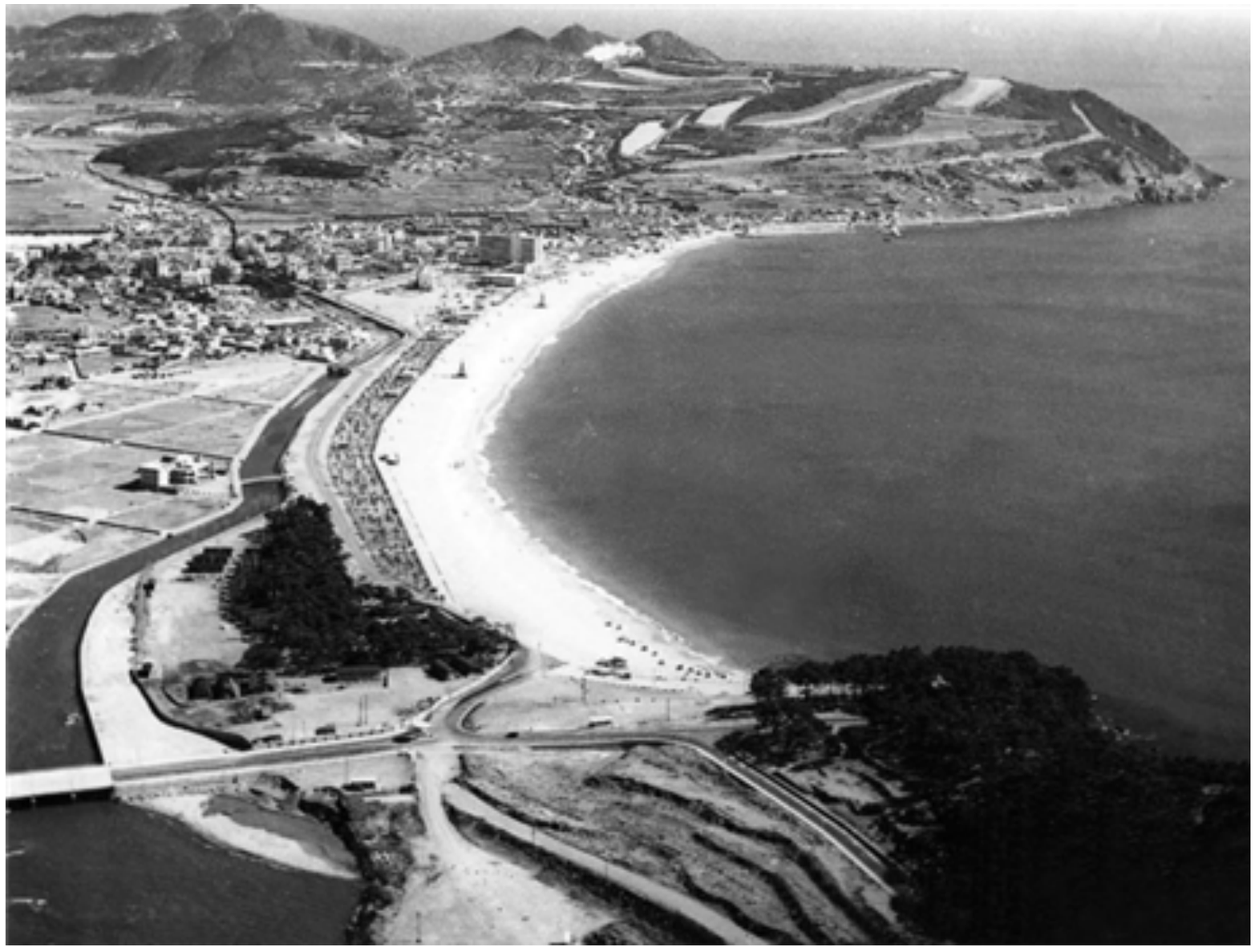
# Sea surface temperature anomaly, Oct 04, 2016



# Precipitation by typhoon Chaba



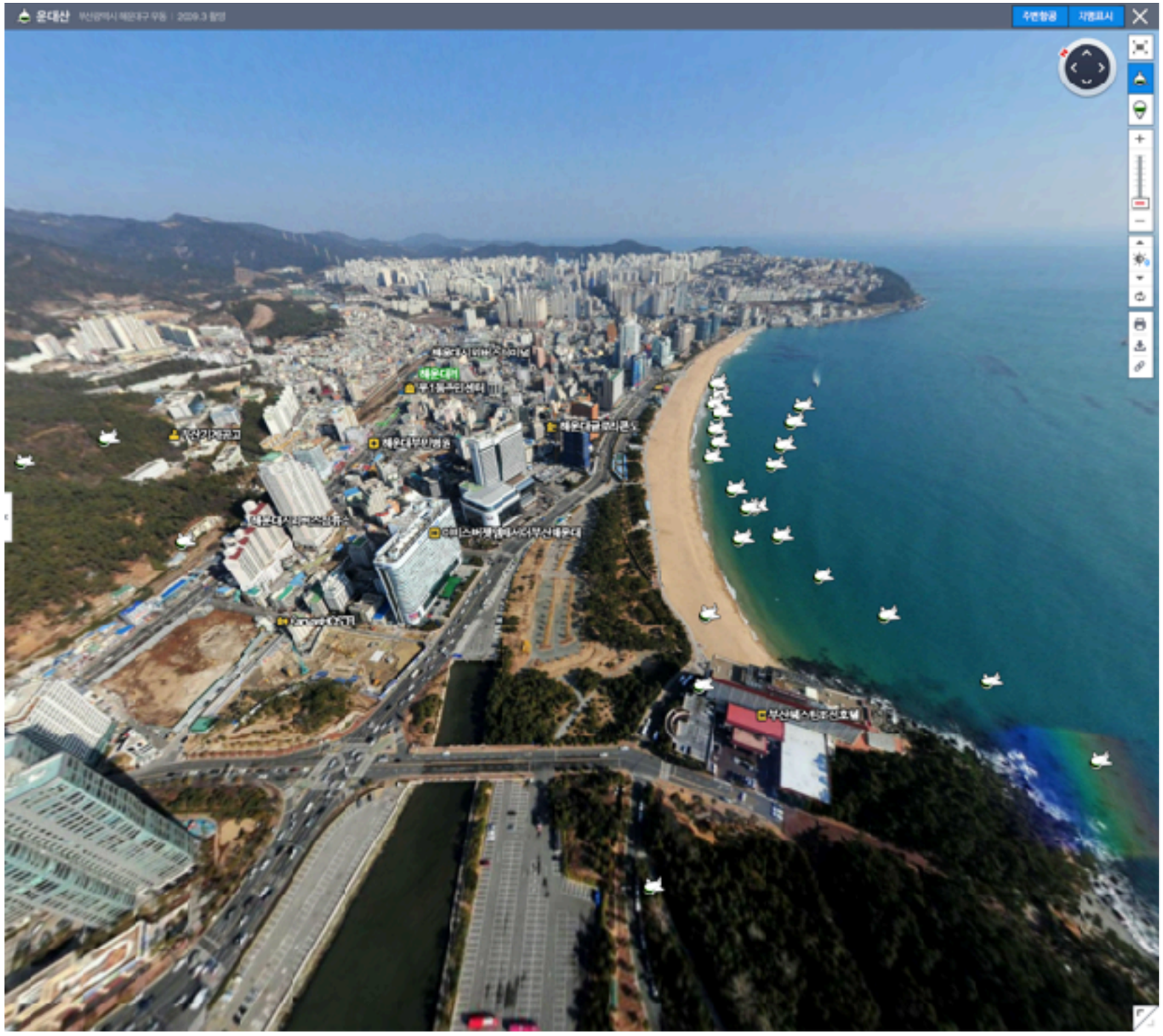
# Haeundae in 1960, Busan



http://www.asiae.co.kr/news/view.htm?idxno=2017060110503569138

# Haeundae in 2009, Busan

Naver map



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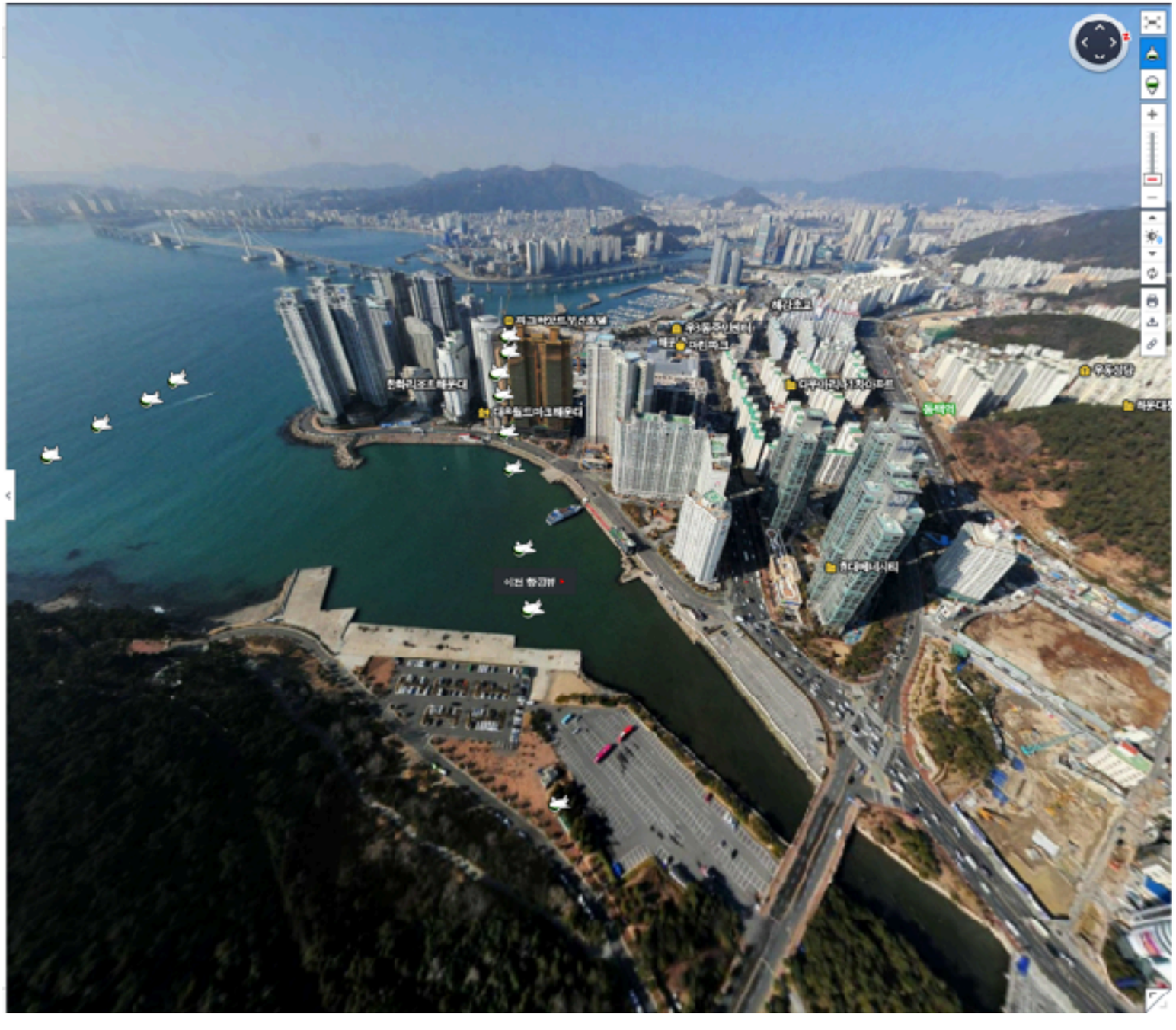

Naver map

# Vulnerability in Busan, South Korea

- video

- Number of typhoons that affected South Korea (1904-2010)

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | - | - | - | - | 2 | 20 | 97 | 126 | 84 | 9 | - | - | 3.1 |

- Insurance company investigating possible damages from typhoons (http://www.air-worldwide.com/Publications/AIR-Currents/2010/Managing-Typhoon-Risk-in-South-Korea/)