Hurricanes = Typhoons = Tropical Cyclones

(LG: 5d)

A video "Teaser", while students enter the classroom.

YouTube clip

Category 5 Hurricane Michael. Oct 2018, striking Panama City Beach

https://www.youtube.com/watch?v=wSXvcveNSTQ

(4:12)

Optional: watch on your own (not testable):

YouTube clip

Day5-02 Hurricane Harvey. Texas. 2017 (4:22)

https://www.youtube.com/watch?v=tMGLMOyu6Ow

(LG: 5d)

Storm Hazards

Thunderstorm Hazards

- lightning
- tornado
- hail
- downpours (of rain) / local flooding
- downbursts (of air) / gustfronts

Hurricane Hazards

- contain thunderstorms
- storm surge / coastal flooding
- high waves
- coastal erosion

Today's Learning Goals

Hurricane = Typhoon = Tropical Cyclone

By the end of this period,
you should be able to:

5a) describe the anatomy of a hurricane, and how it looks in weather radar and satellite images and videos

5b) explain how sea-surface temperature, winds, waves, condensation, and a "warm core" affect hurricanes

5c) describe the evolution and movement of hurricanes, and locate times and places of greatest risk

5d) explain the main hazards of a hurricane and appropriate safety procedures

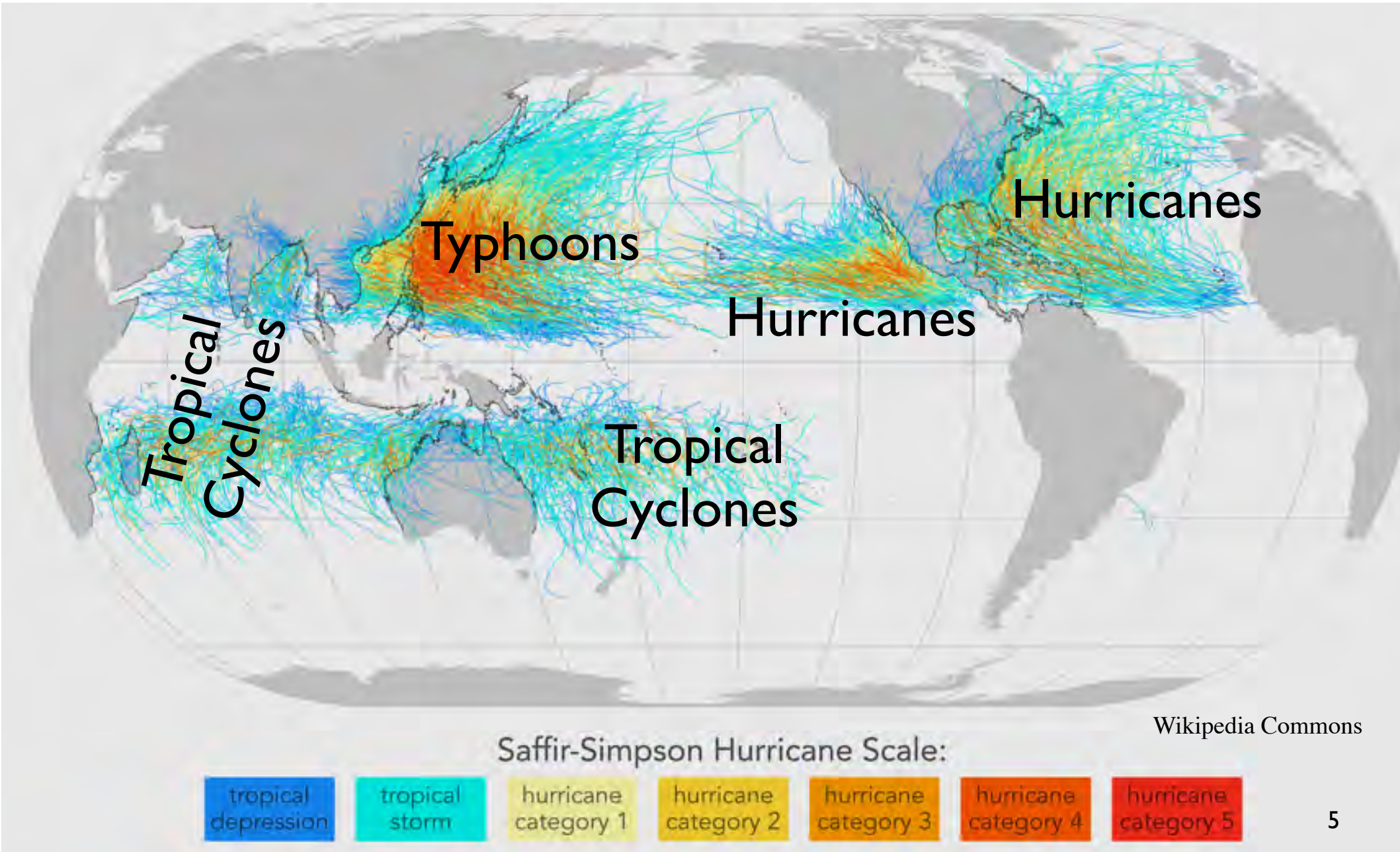
5e) describe the nature and skill of hurricane forecasting, and explain why Canada has few hurricanes.

Road-map to Storm topics

Learning Goals (LG): 1-5

Day	Hazards Risk & Safety	Fundamentals Appearance & Evolution	Energy makes storms
1	Lightning	Thunderstorm basics	sun, radiation, surface heating
2	Rain Downpours, Air Downbursts	Supercells, mesocyclone. Observ.: radar, satellite	moisture, condensation, latent heating
3	Tornadoes	Wall cloud, striations, Doppler radar	
4	Hail	Clouds at Tstorms: flanking line, mammatus	heat to motion, forces, winds
5	Flooding, winds, waves, storm surge	Hurricanes	energy in warm ocean, Coriolis

Names



Wikipedia Commons

Hurricanes = Typhoons = Tropical Cyclones

Prof. Roland Stull
Earth, Ocean & Atmos. Sciences Dept., UBC

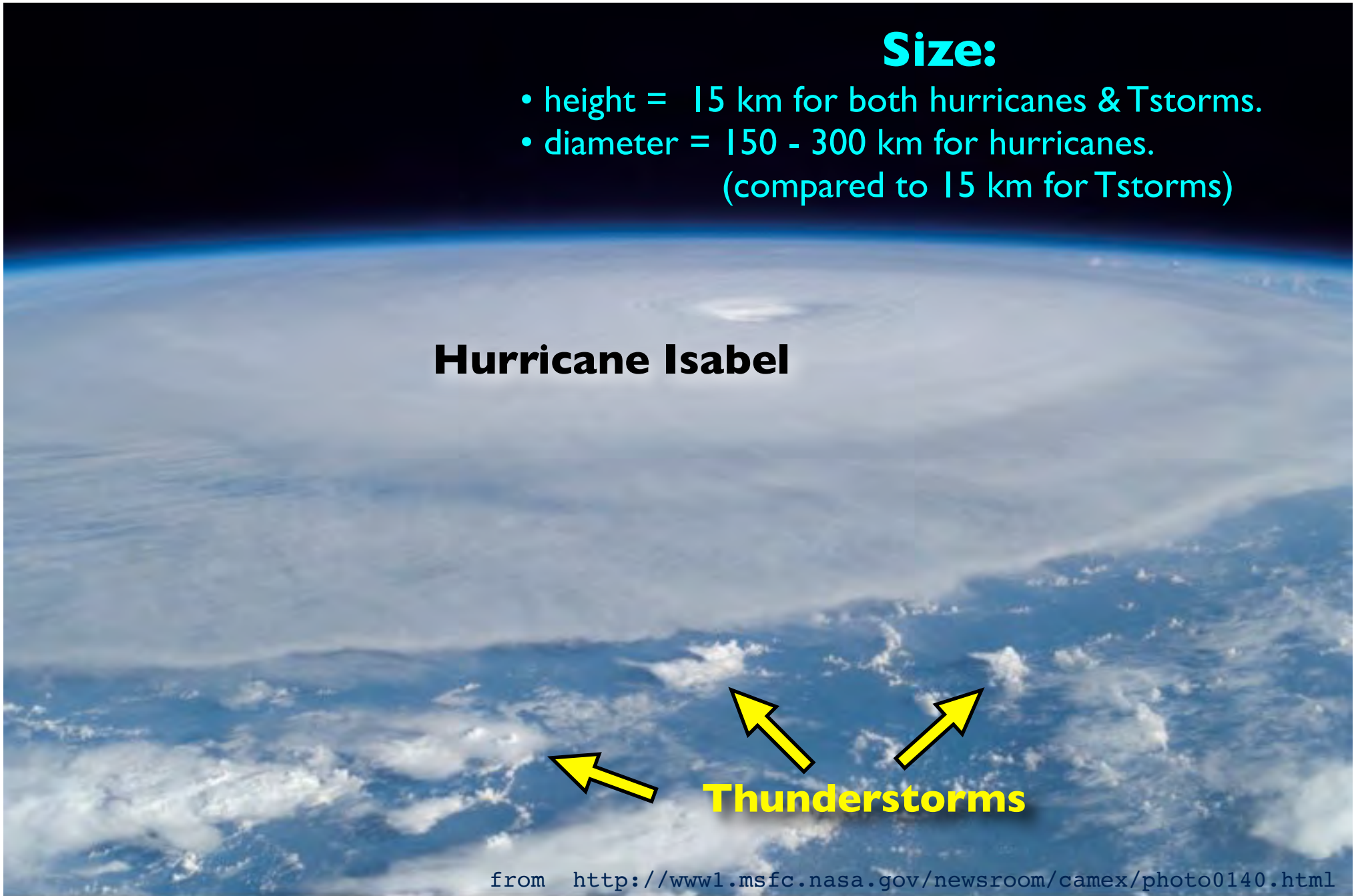
- **A. Description & Fundamentals**
  1. Anatomy of a hurricane
  2. Observations by satellite and radar
  3. Saffir-Simpson hurricane wind scale
- **B. Processes & Energy**
  4. Tropical cyclones: organized to create their own fuel
  5. Formation & movement
  6. Warm core systems: the key to long life
- **C. Hazards**
  7. Storm surge: the atmosphere drives an ocean disaster
  8. Hurricane prediction and safety
  9. Hurricanes in Canada

A. Description & Fundamentals

1. Anatomy of a Hurricane

(LG: 5a)

Hurricane Floyd
14 Sep 1999
(from NASA GSFC)


Size:
• height = 15 km for both hurricanes & Tstorms.
• diameter = 150 - 300 km for hurricanes.
(compared to 15 km for Tstorms)
Hurricane Isabel
Thunderstorms
from http://www1.msfc.nasa.gov/newsroom/camex/photo0140.html

Horizontal Structure

Hurricanes & typhoons are tropical cyclones, with surface winds turning counterclockwise (in N. Hem.) & spiraling in.

Eye = center of hurricane
- relatively clear
- relatively calm
- low pressure at sea level

Hurricanes are made of thunderstorms:
- eye wall = ring of thunder-storms around the eye.
- spiral bands = bands of Tstorms extending out from the eye wall.

Simplified Diagram of a Hurricane

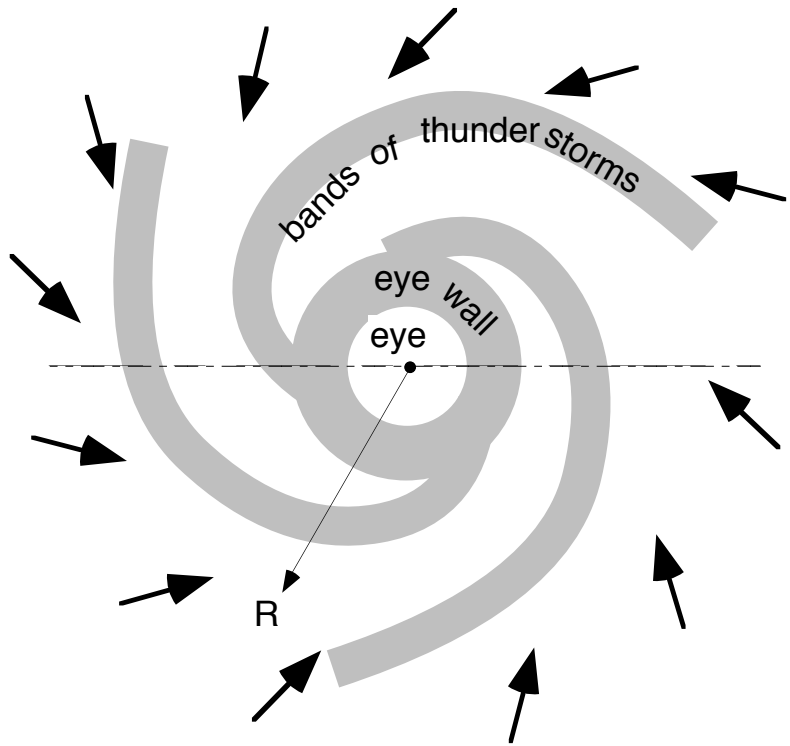
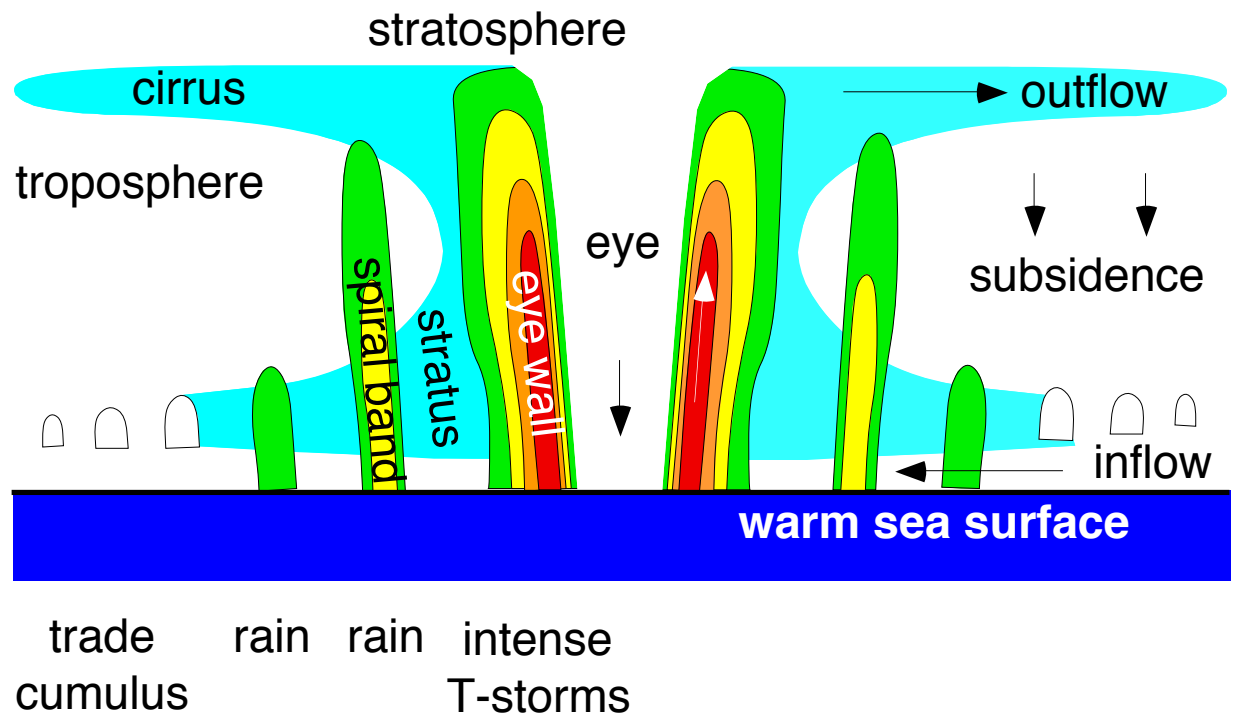


photo by R. Stull

R is radial distance from center of the eye, and arrows represent wind direction near the ocean surface. Gray represents bands of thunderstorms.

Vertical Cross-section Through a Hurricane

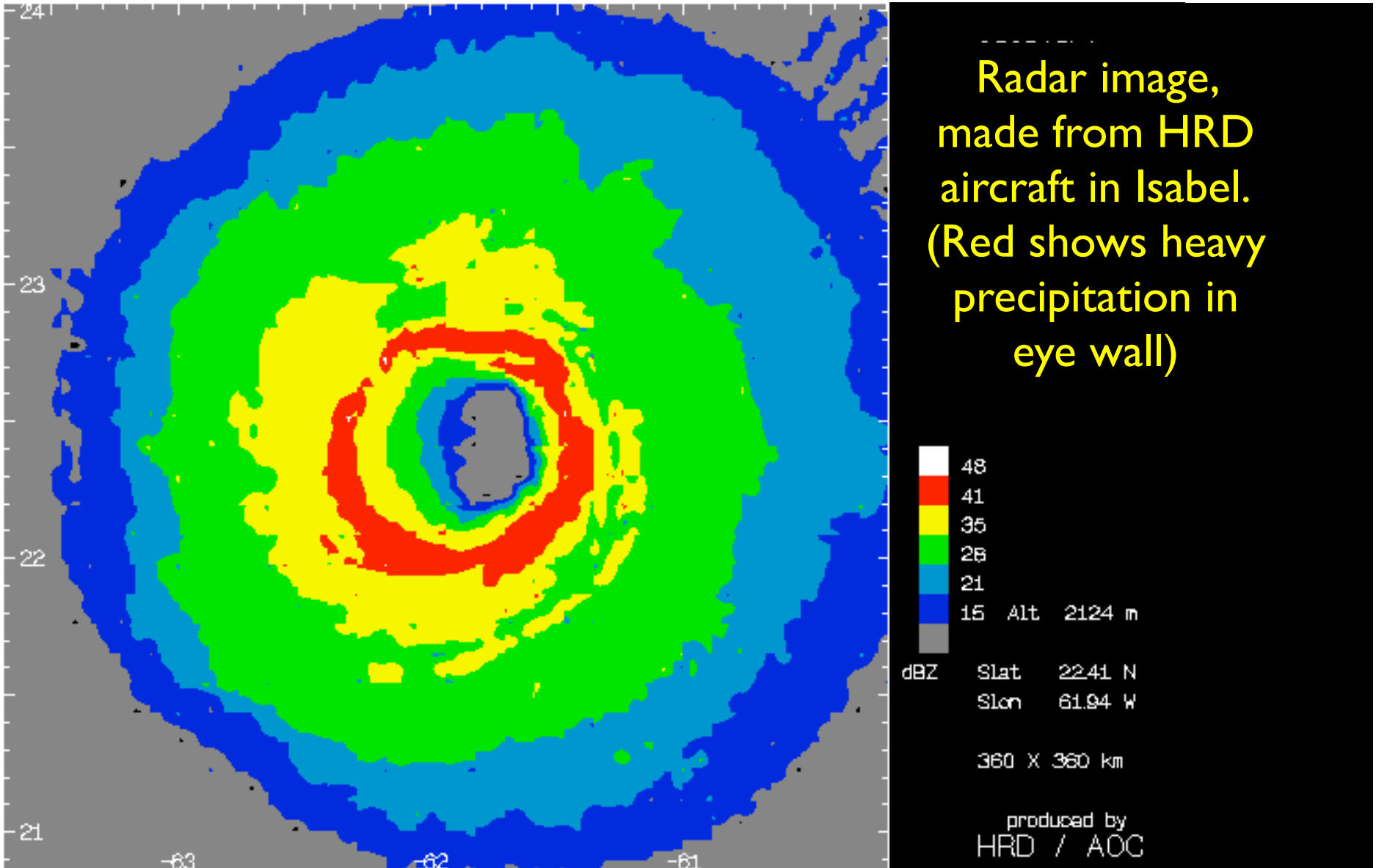


Light blue represents clouds, red through green represents decreasing radar-echo intensity (proportional to precipitation rate), and dark blue is the ocean.

image by R. Stull

(LG: 5a)

The Eye Wall, a Ring of Tstorms



Hurricane eye wall as viewed from the ground.

YouTube Video Day 5-11

View of Hurricane Michael eye wall on 10 Oct 2018

as a Category 5 intensity hitting the Florida panhandle.

(5:50. Show first 1 minute.)

https://www.youtube.com/watch?v=H-iRXYRRGXQ

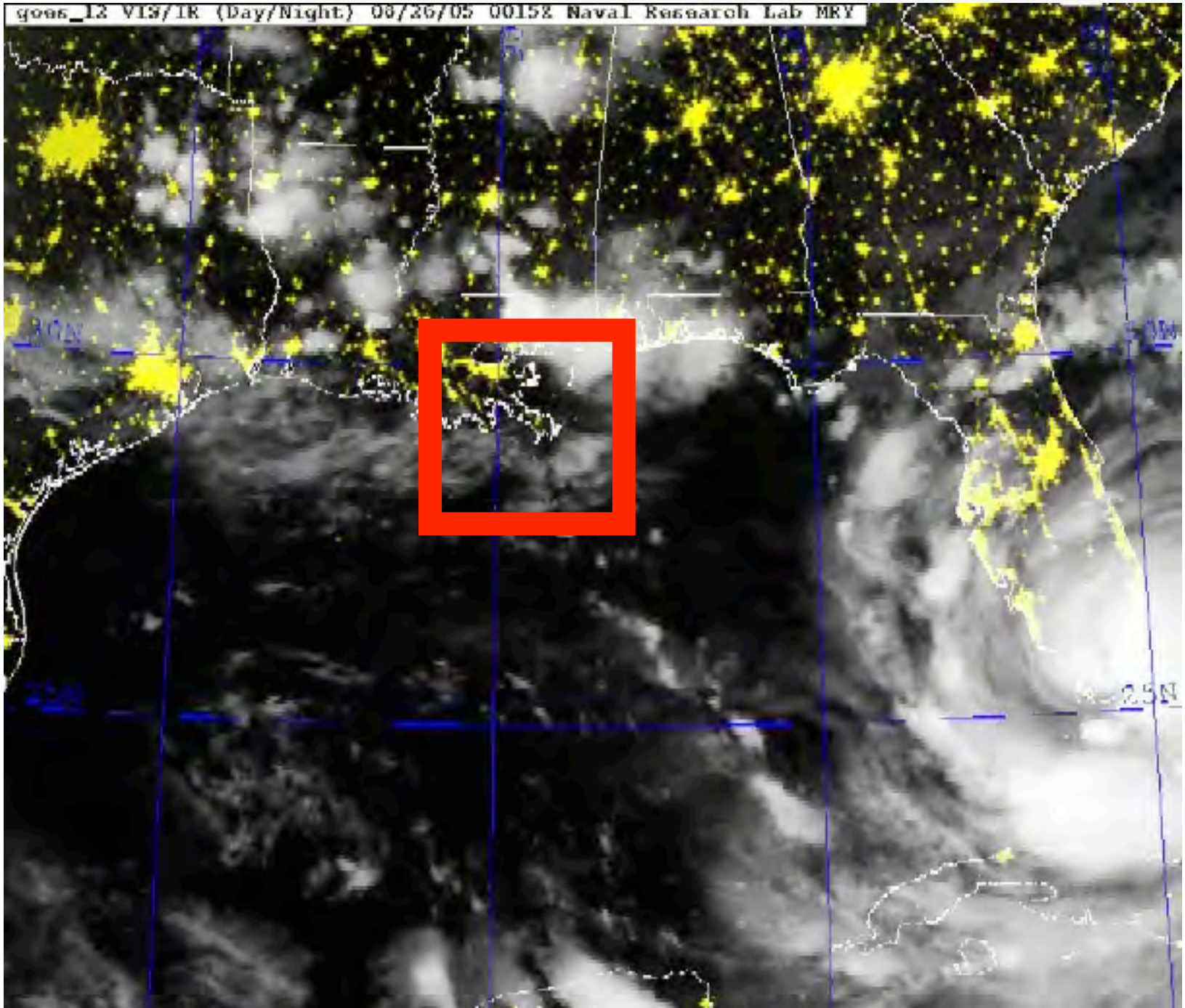
The Eye, as viewed by Hurricane Hunters (Katrina, Aug 05)

NOAA and http://

2. Observations

by satellite

Hurricane
Katrina
2005



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Hurricane
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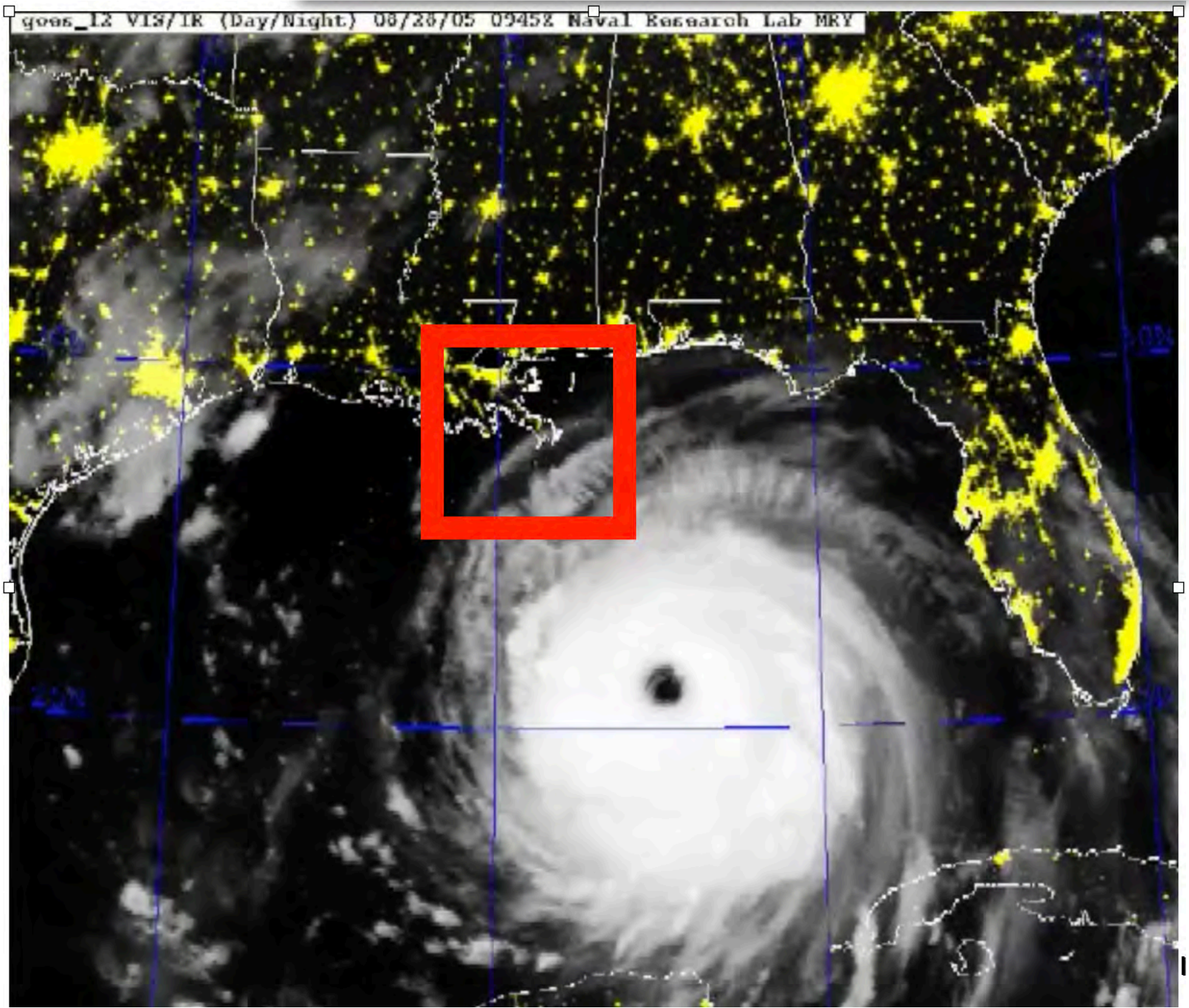

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Hurricane
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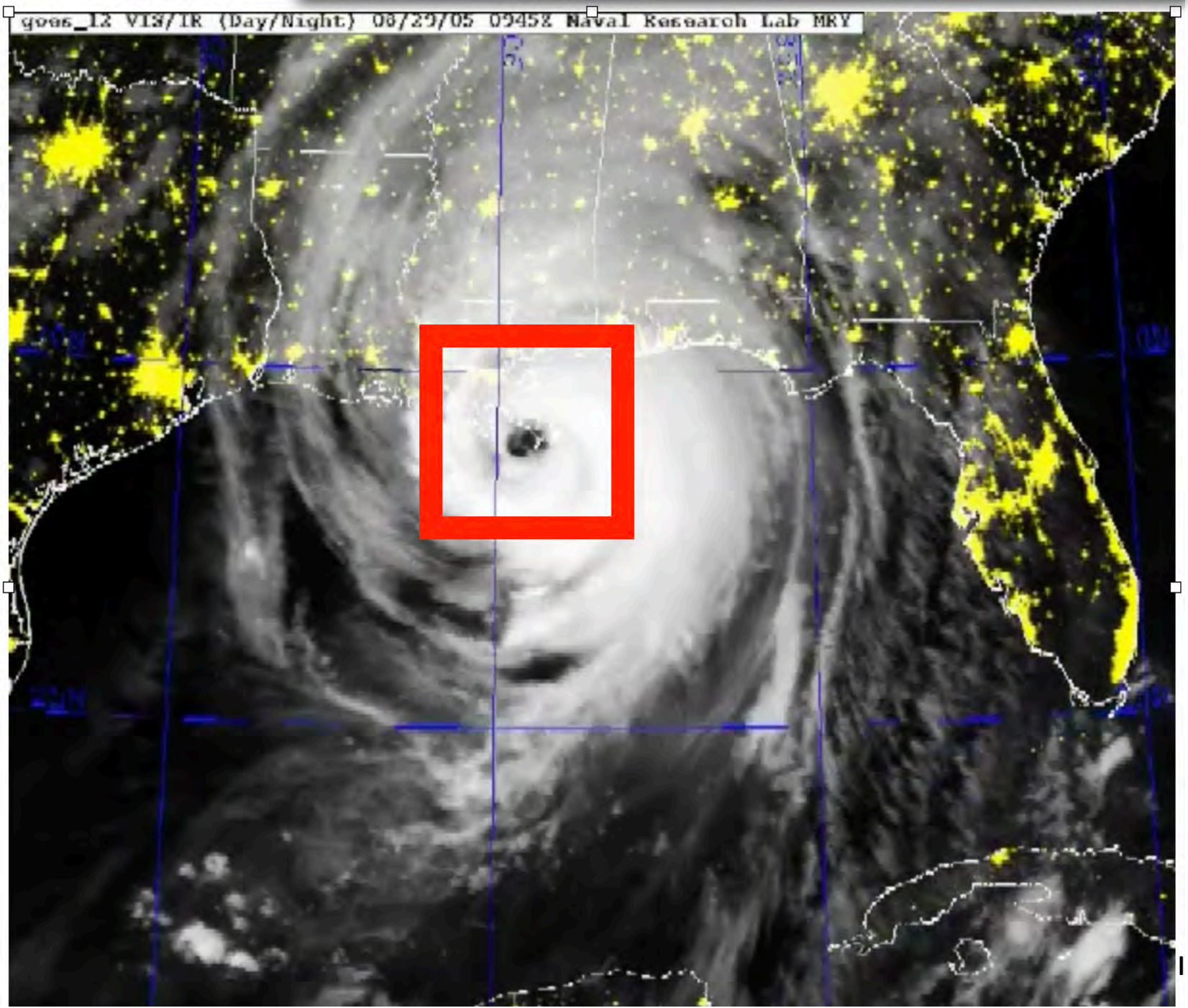
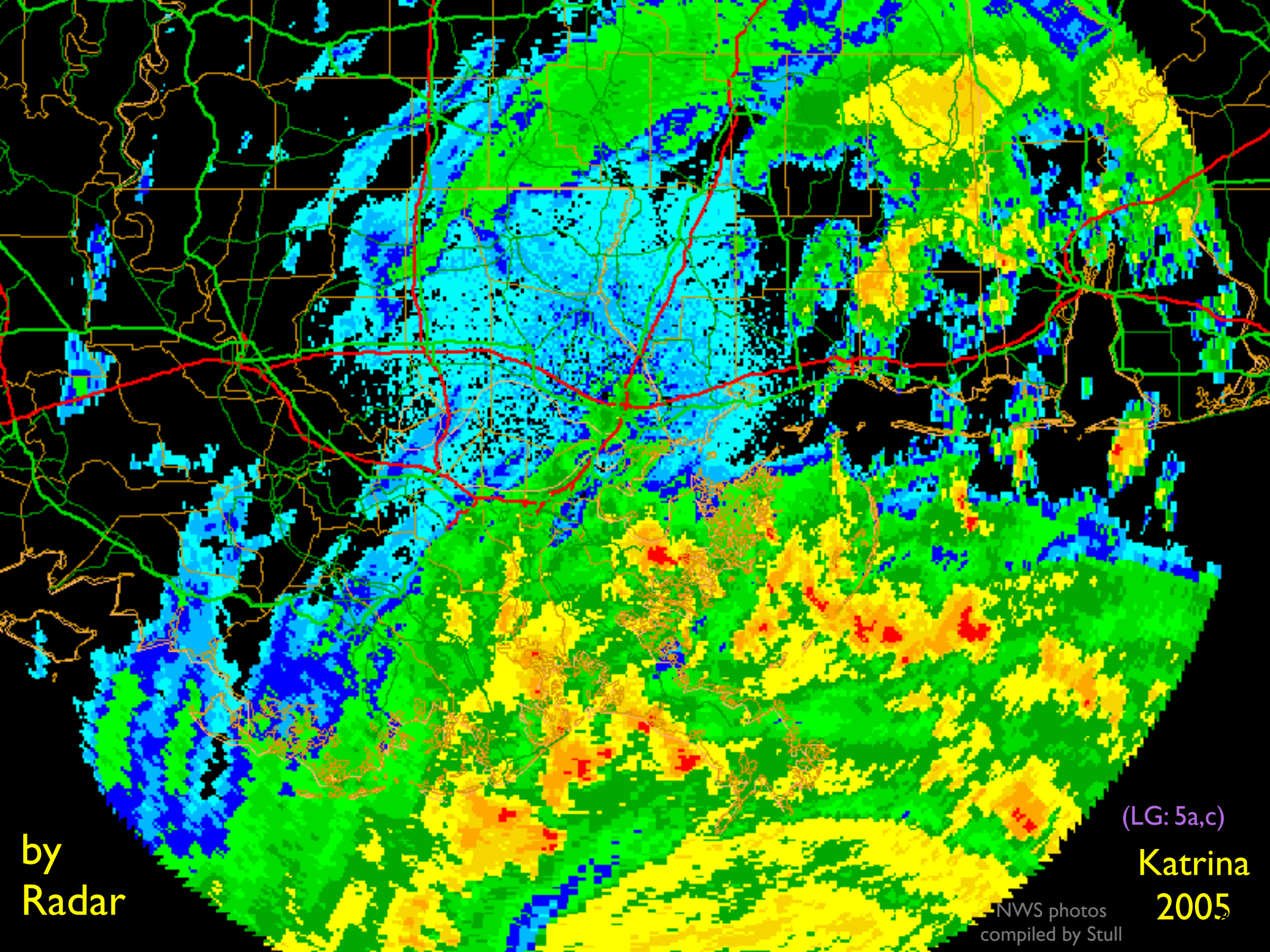
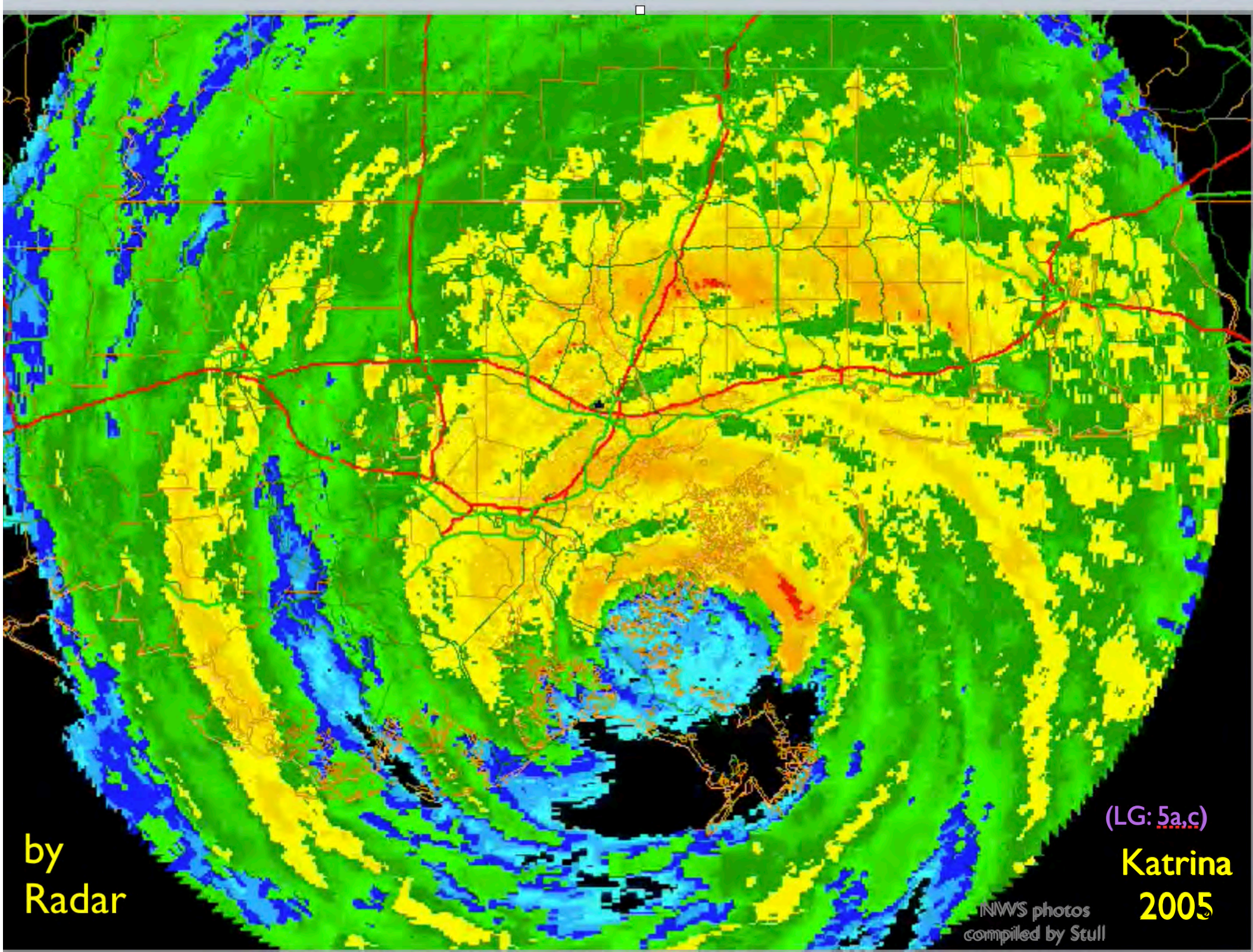



by
Radar
(LG: 5a,c)
Katrina
2005
NWS photos
compiled by Stull


by
Radar
(LG: 5a,c)
Katrina
2005
NWS photos
compiled by Stull

(revised in 2010 by NHC)

3. Saffir-Simpson Hurricane **Wind** Scale

Faster winds indicate stronger hurricanes.

Definition					Typical Characteristics	
Hurricane Category	Wind Speed at least km/h	mi/h	knots	m/s	Eye Pressure (kPa)	Storm Surge (m)
(TD)					-	-
(TS)	61	38	33	17	-	-
1	119	74	64	33	≥ 98.0	1.2 - 1.6
2	154	96	83	43	97.9 - 96.5	1.7 - 2.5
3	178	111	96	50	96.4 - 94.5	2.6 - 3.9
4	210	131	114	58	94.4 - 92.0	4.0 - 5.5
5	250	156	136	70	< 92.0	> 5.5

(TD = Tropical Depression; TS = Tropical Storm)

table by R. Stull

B. Processes & Energy

(LG: 5a,b)

NASA

4. Tropical Cyclones – Organized to Create their own Fuel

Compare with individual thunderstorms:

- use the warm, humid boundary-layer air as fuel.
- consume nearby supplies of fuel.
- run out of fuel and die.
- are short lived (about 15 - 30 **minutes**).

Exceptions (longer-lasting thunderstorms) if properly organized:

- ambient atmosphere happens to have right amount of wind shear that:
  - continually blows fresh fuel into storm.
  - or blows Tstorm to new regions having boundary-layer fuel.
- namely, Supercell that can last for **hours**.

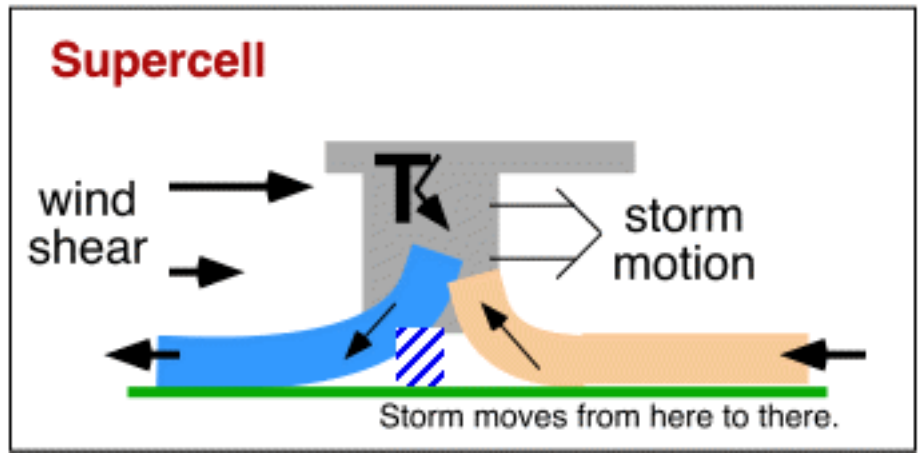


photo by R. Stull

Hurricanes (& their Tstorms) can last for **weeks**, because...

- they manipulate the environment to continually create new fuel of warm humid air from heat stored in the ocean.

Fuel Creation Method

- Low pressure in eye sucks in boundary-layer (BL) air (i.e., air in the bottom 1 km of the atmosphere)
- As air gets closer to eye, it moves faster
- Faster winds create larger ocean waves ...

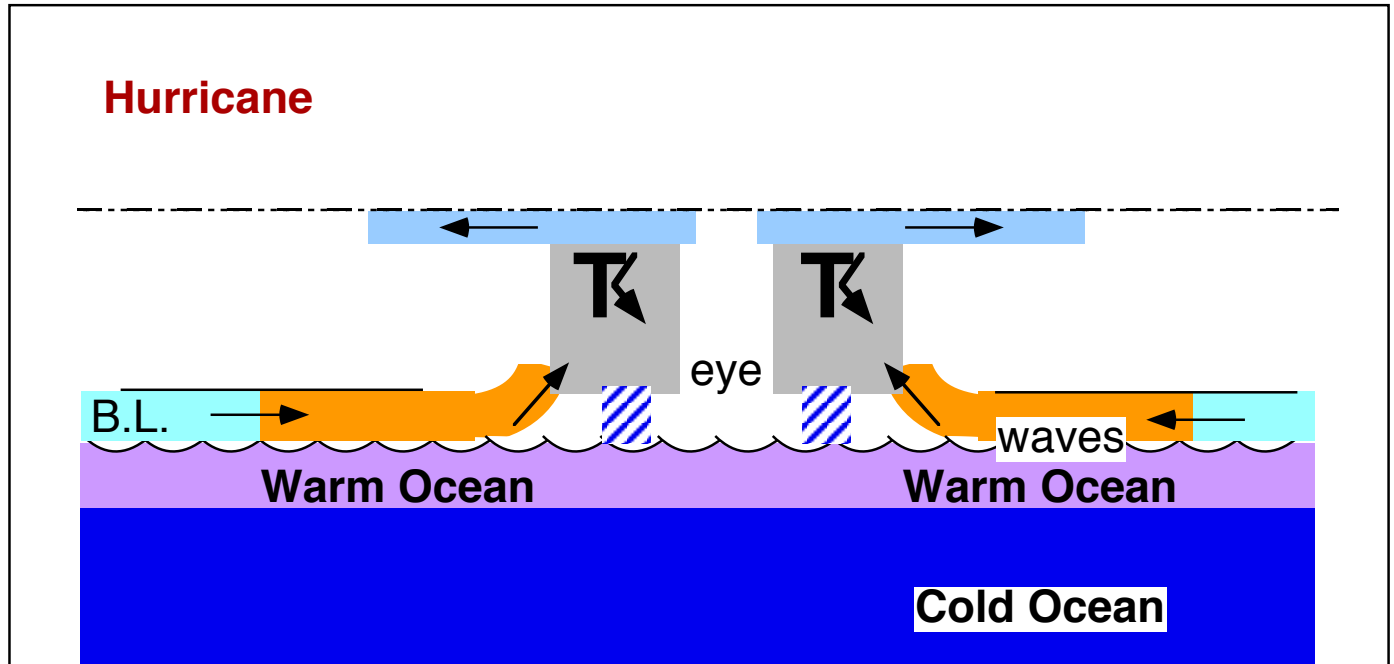
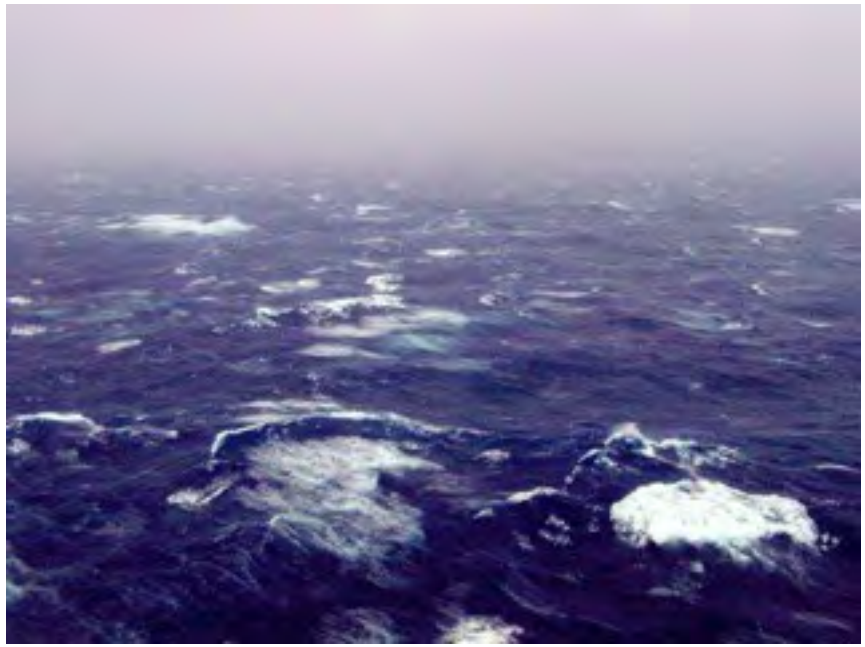
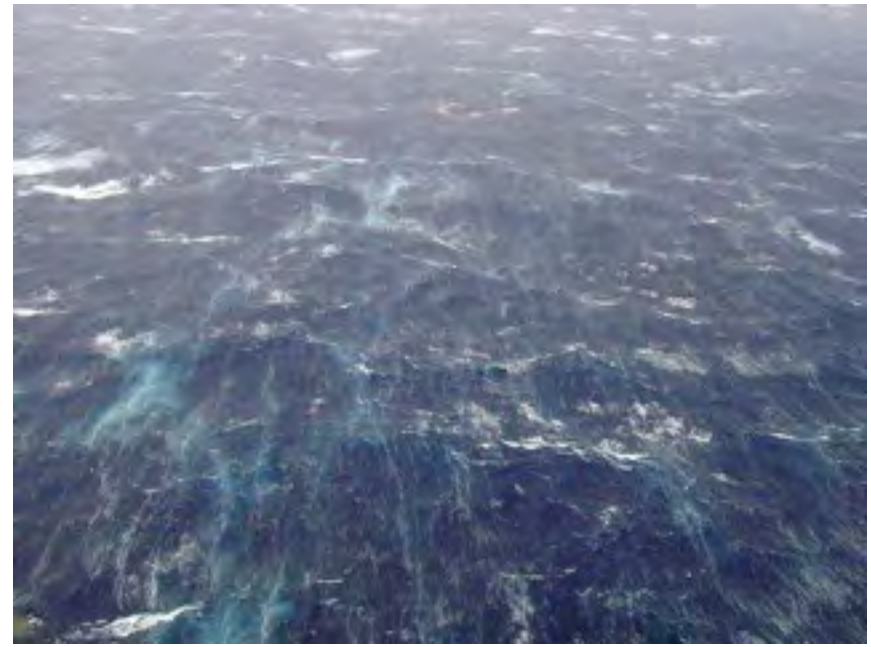


photo by R. Stull

Fuel Creation Method (continued)





from http://www.aoml.noaa.gov/hrd/Storm_pages/isabel2003/photo.html

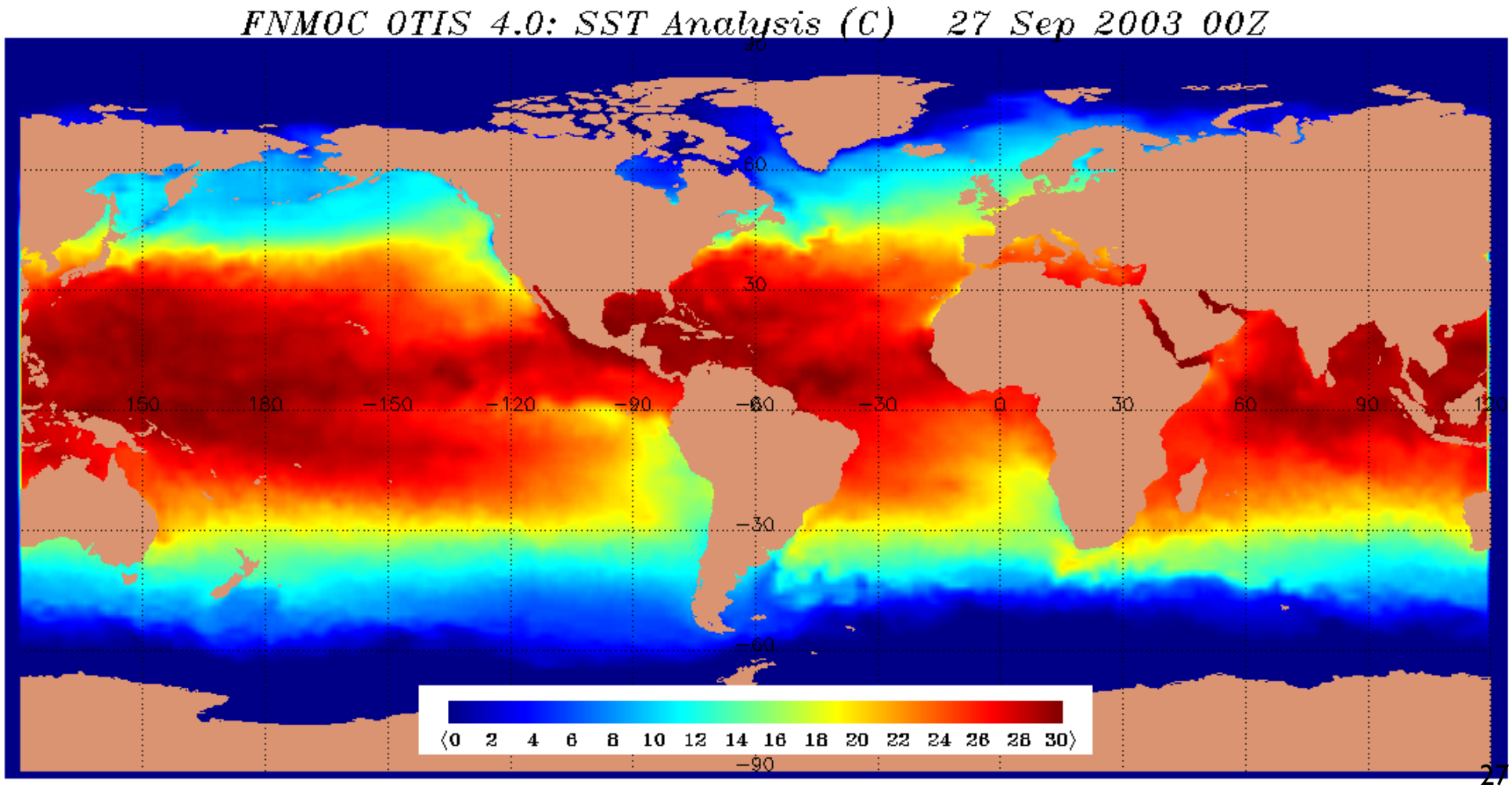
- Evaporation from ocean surface is enhanced with spray from waves
- Adds significant amounts of moisture into boundary-layer air
- Finally, when boundary-layer air reaches base of eye wall, it is:
  - warm
  - exceptionally humid (near 100 % relative humidity)
  - contains tremendous amounts of sensible and latent-heat fuel.

Warm Sea Surface is Needed

Self-fueling method works (i.e., hurricanes form) ONLY if:

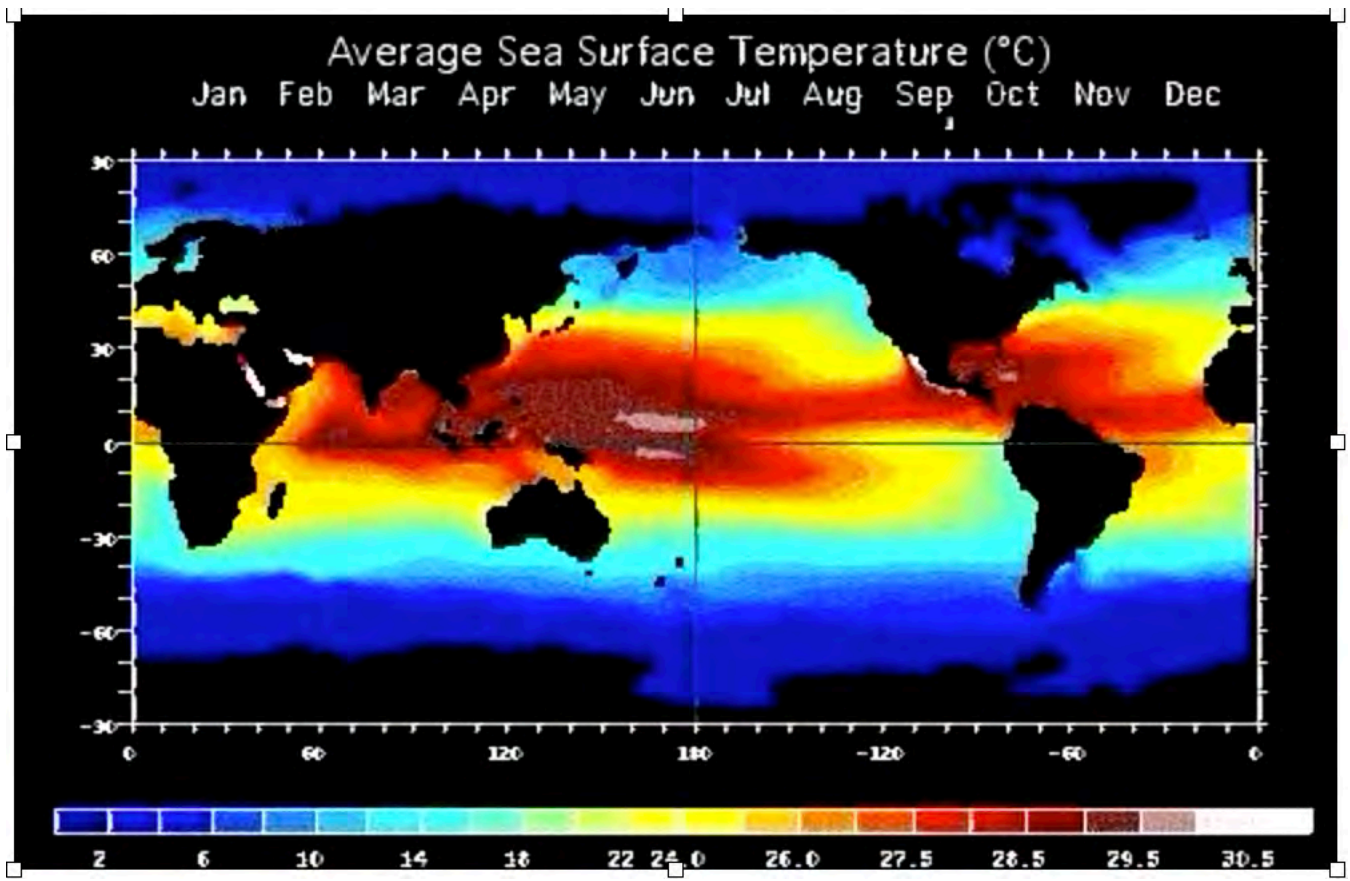
- ocean surface temperatures > 26 °C, AND
- warm surface waters are > 60 m deep

(so that turbulence within the ocean caused by surface waves doesn't mix cold waters up to surface)



Warm Sea Surface Shifts with Seasons

Watch for regions where
ocean surface temperatures > 26 °C
(shown in orange, red, and white here)



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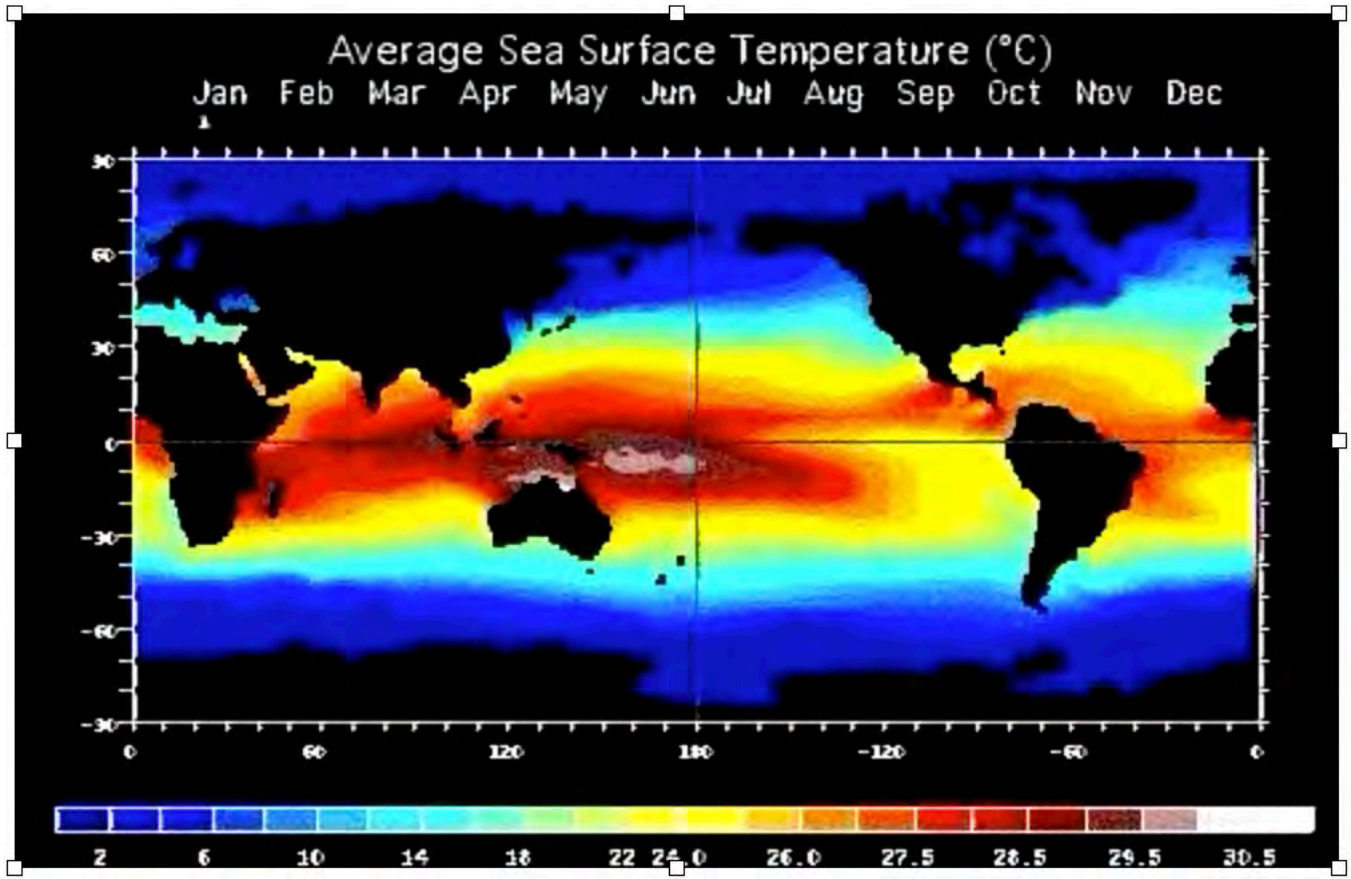
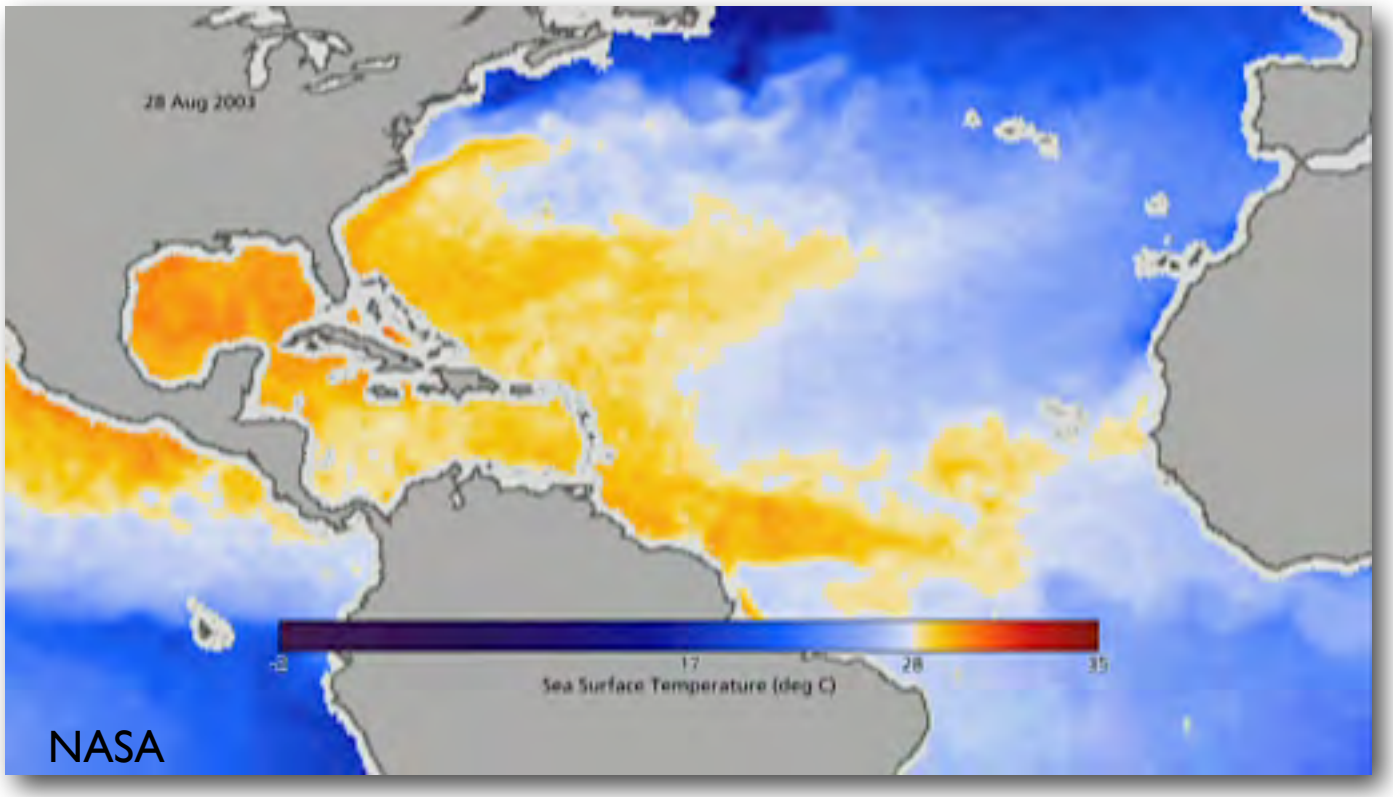
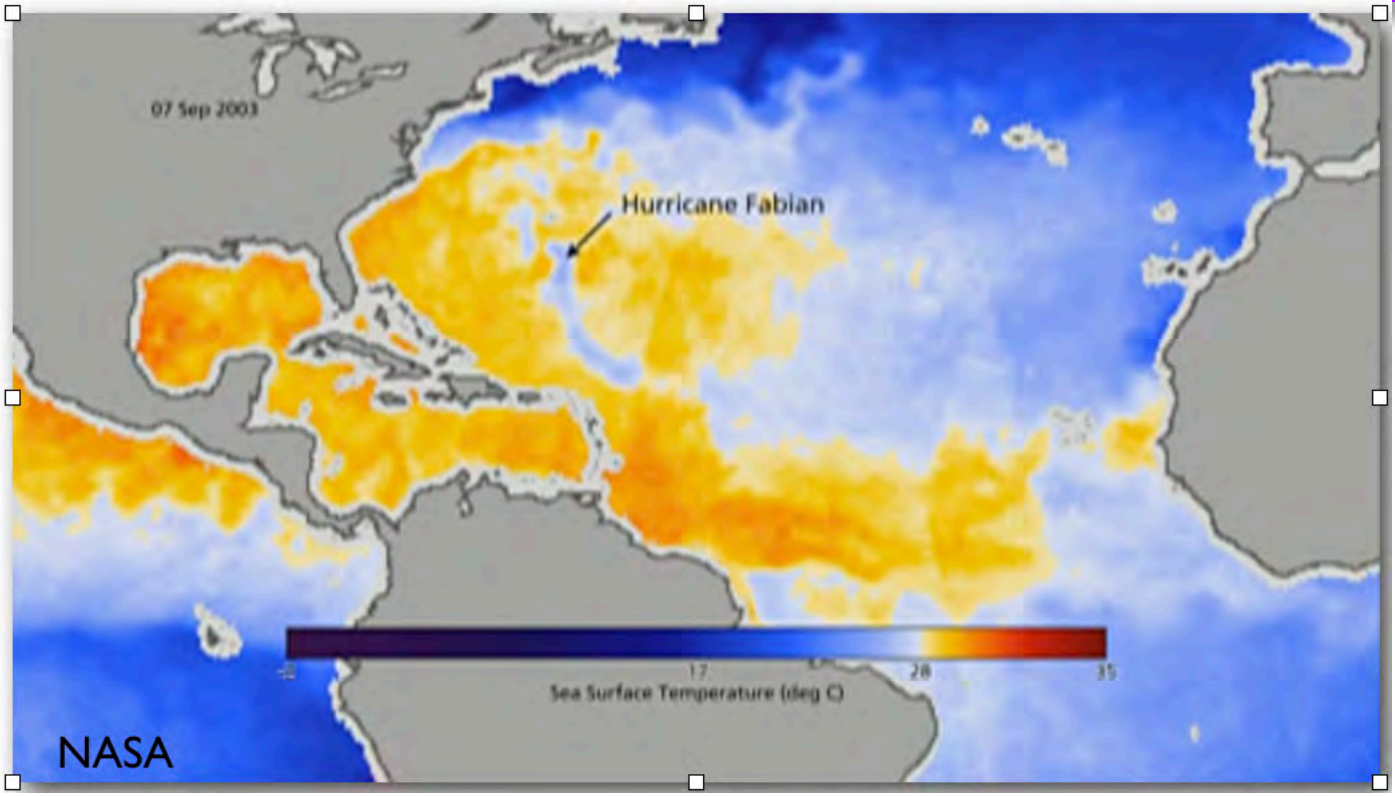


Hurricanes Cause Sea-Surface Temperature to Cool, Due to Wave-induced Turbulence in Upper Ocean



This is why the depth of warm surface waters should be > 60 m (to avoid having the hurricane kill itself by making SST < 26°C).

Hurricanes Cause Sea-Surface Temperature to Cool, Due to Wave-induced Turbulence in Upper Ocean

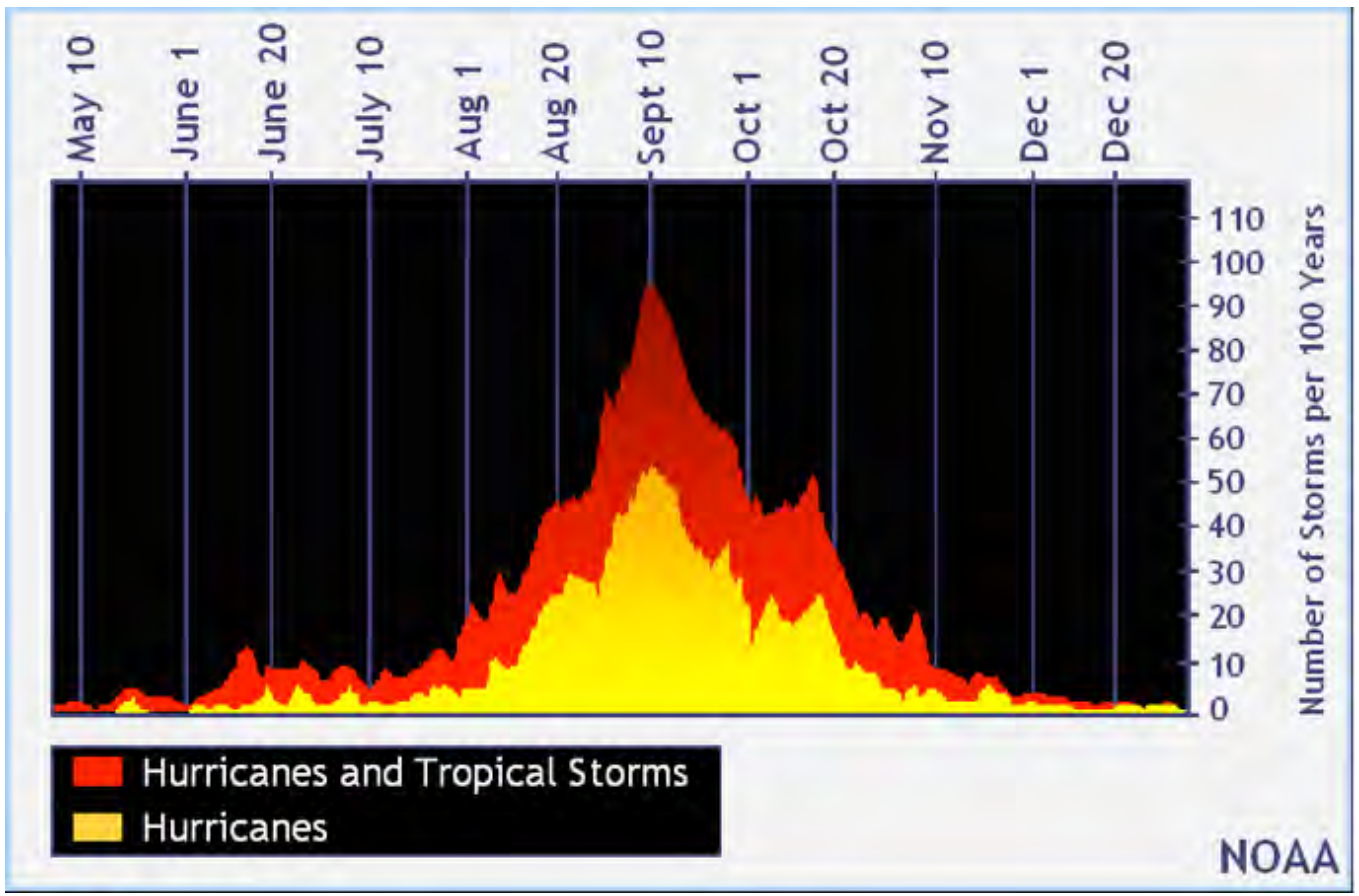


NASA

This is why the depth of warm surface waters should be > 60 m (to avoid having the hurricane kill itself by making SST < 26°C).

Hurricane Season (in N. Hemisphere)

- late summer and in early Fall, when waters warmest with maximum extent and depth



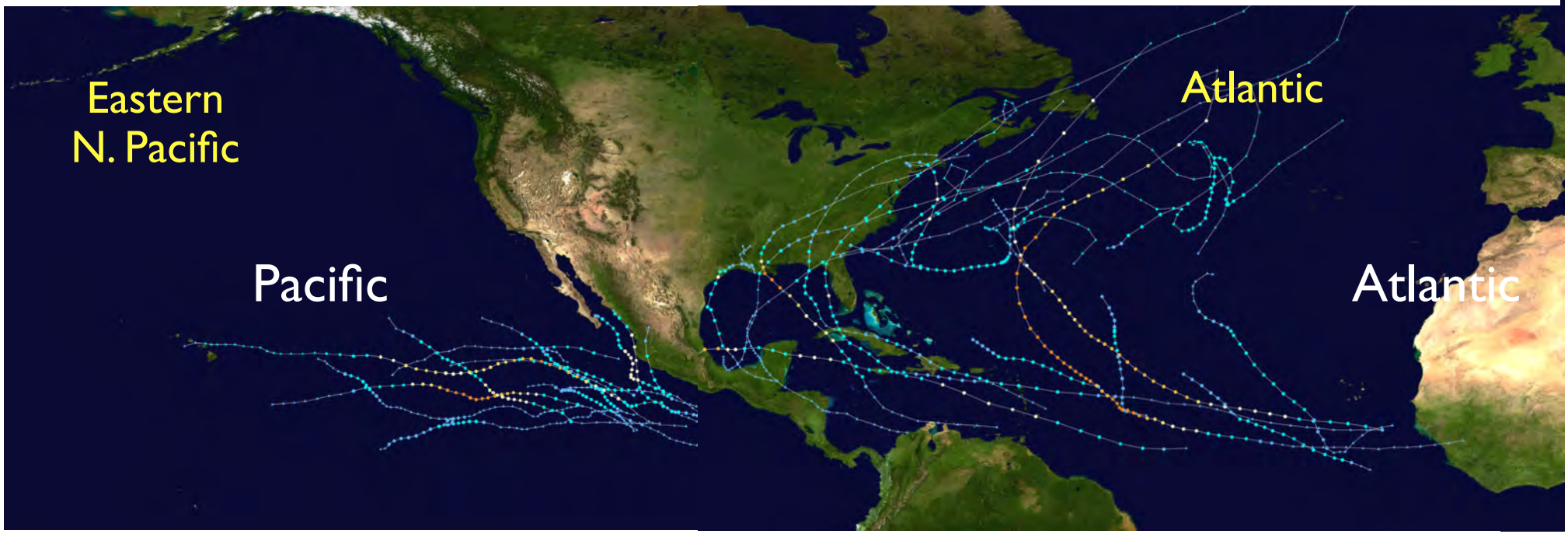
Month	Number of recorded storms making landfall in Canada while still tropical since 1950
January	0
February	0
March	0
April	0
May	0
June	0
July	4
August	6
September	12
October	5
November	1
December	0

wikipedia

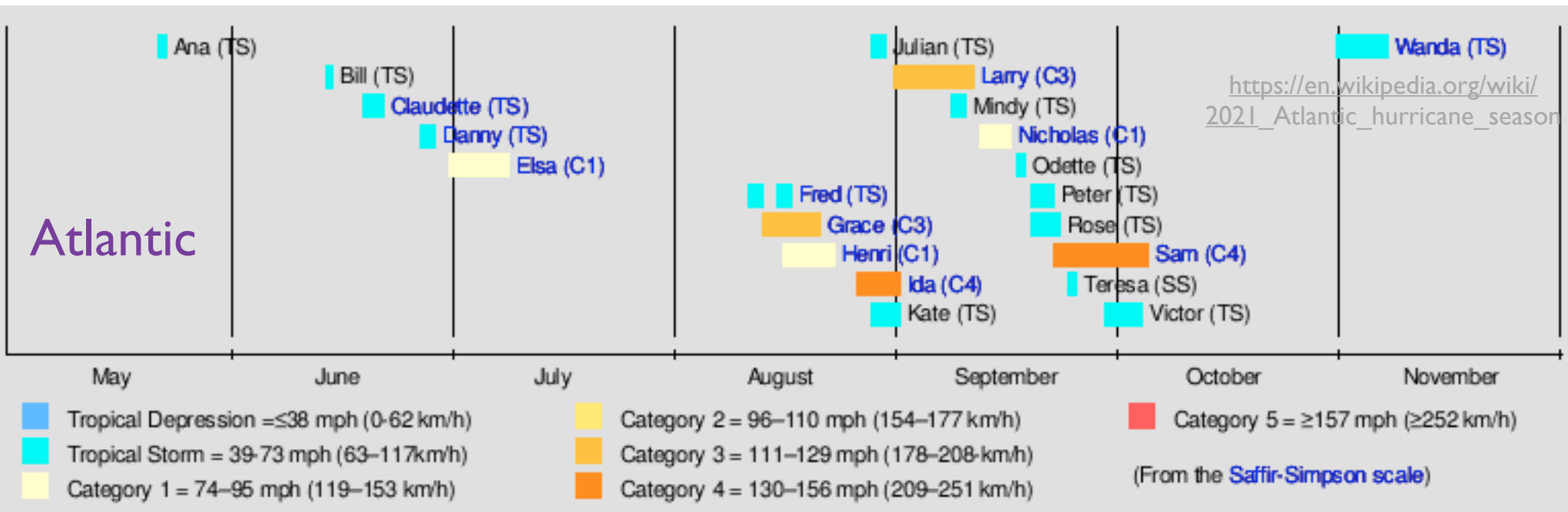
- Official N. Atlantic "hurricane season" is June through November.
- Most N. Atlantic hurricanes occur August through October

2021 Hurricane Tracks

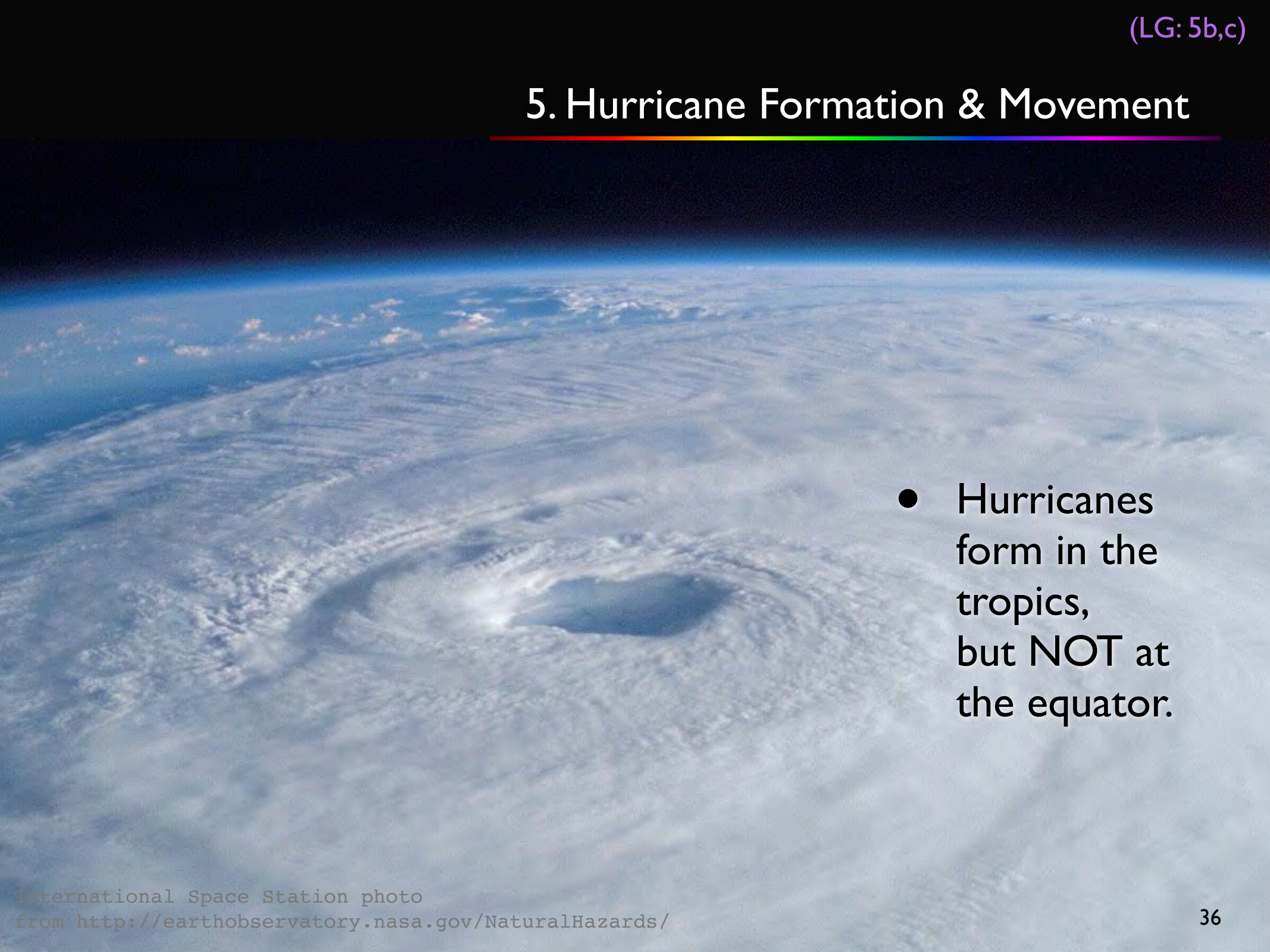
(LG: 5c)



By Cyclonebiskit - Created using WikiProject Tropical cyclones/Tracks. The background image is from NASA [1]. The tracking data is from the National Hurricane Center and the Central Pacific Hurricane Center's Northeast and North Central Pacific hurricane database, Public Domain, https://commons.wikimedia.org/w/index.php?curid=58210675



5. Hurricane Formation & Movement



- Hurricanes form in the tropics, but NOT at the equator.

International Space Station photo
from http://earthobservatory.nasa.gov/NaturalHazards/

Favored Hurricane Locations

(LG: 5b,c)

Coriolis (earth's rotation) effect is stronger near poles **(shown in blue)**.

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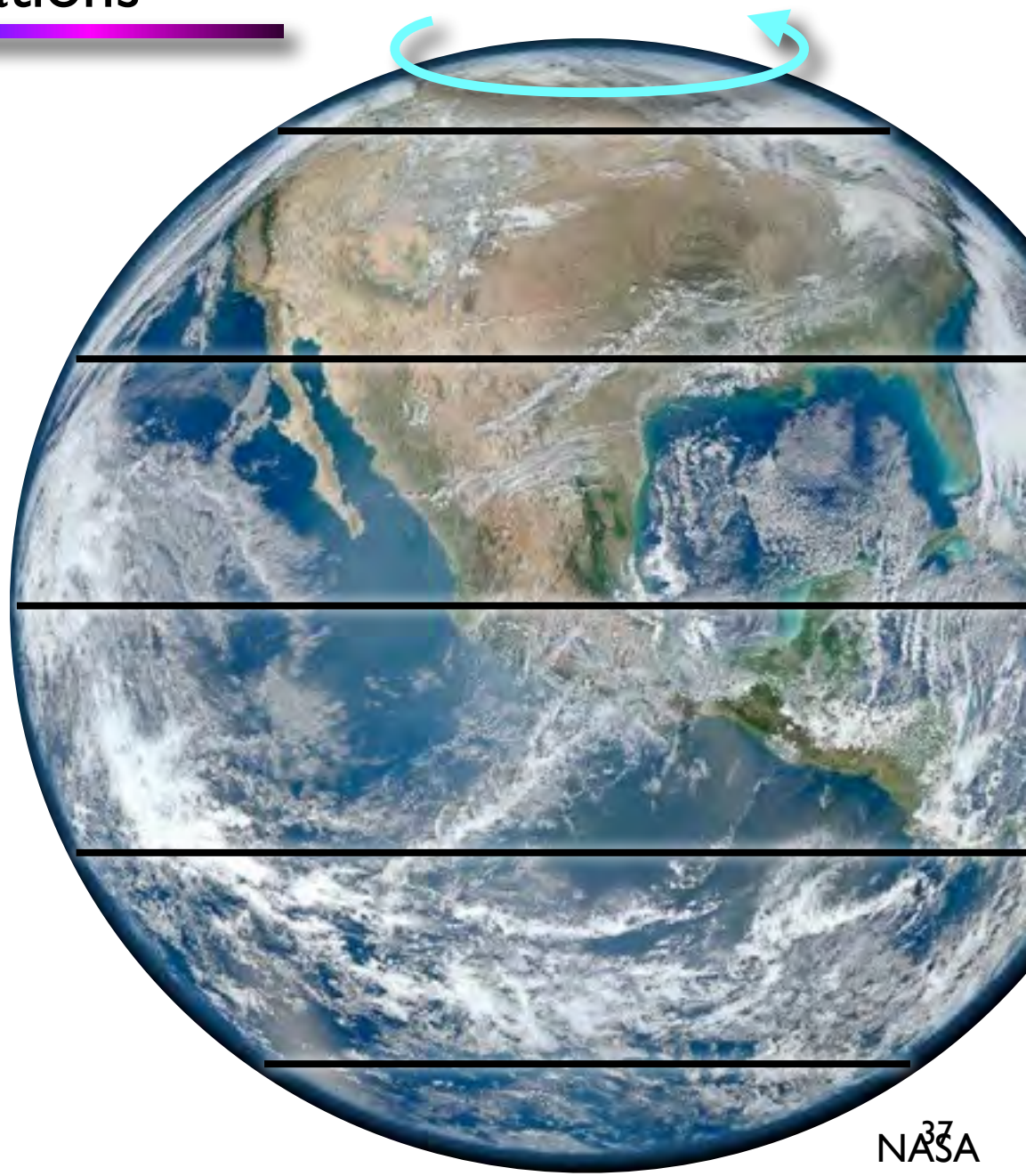

NASA

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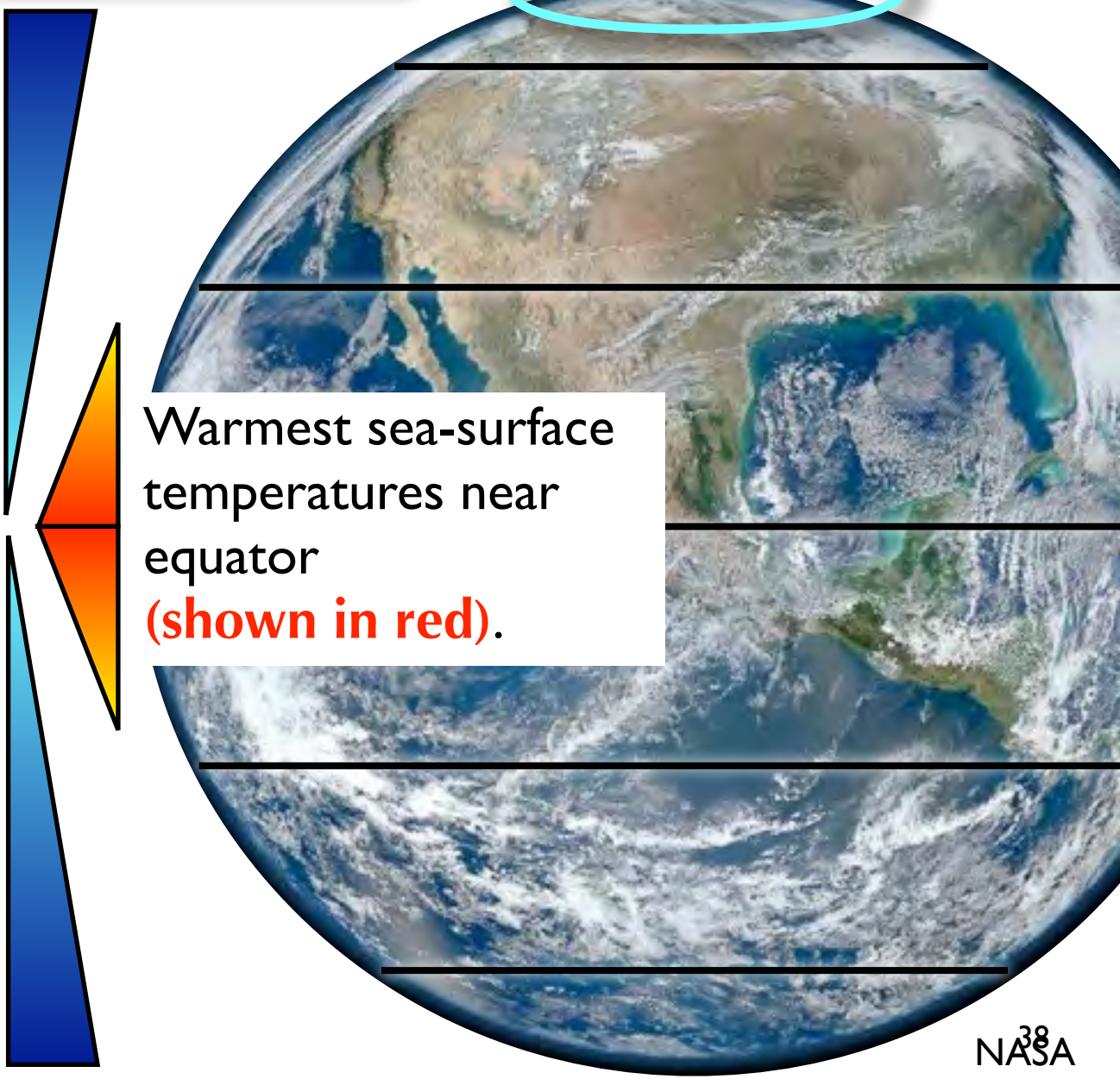

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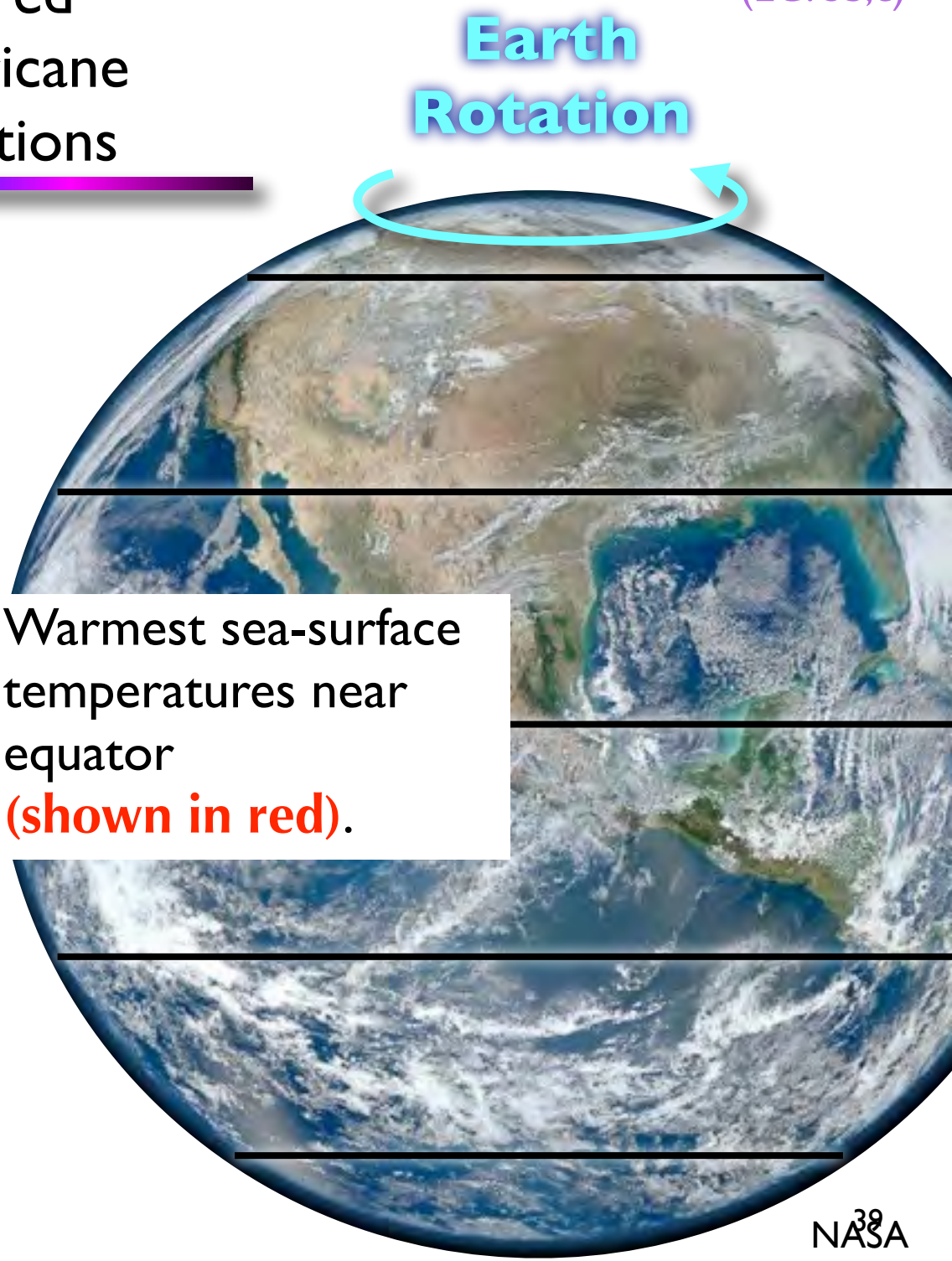
NASA

Favored Hurricane Locations

(LG: 5b,c)



Coriolis (earth's rotation) effect is stronger near poles (shown in blue).

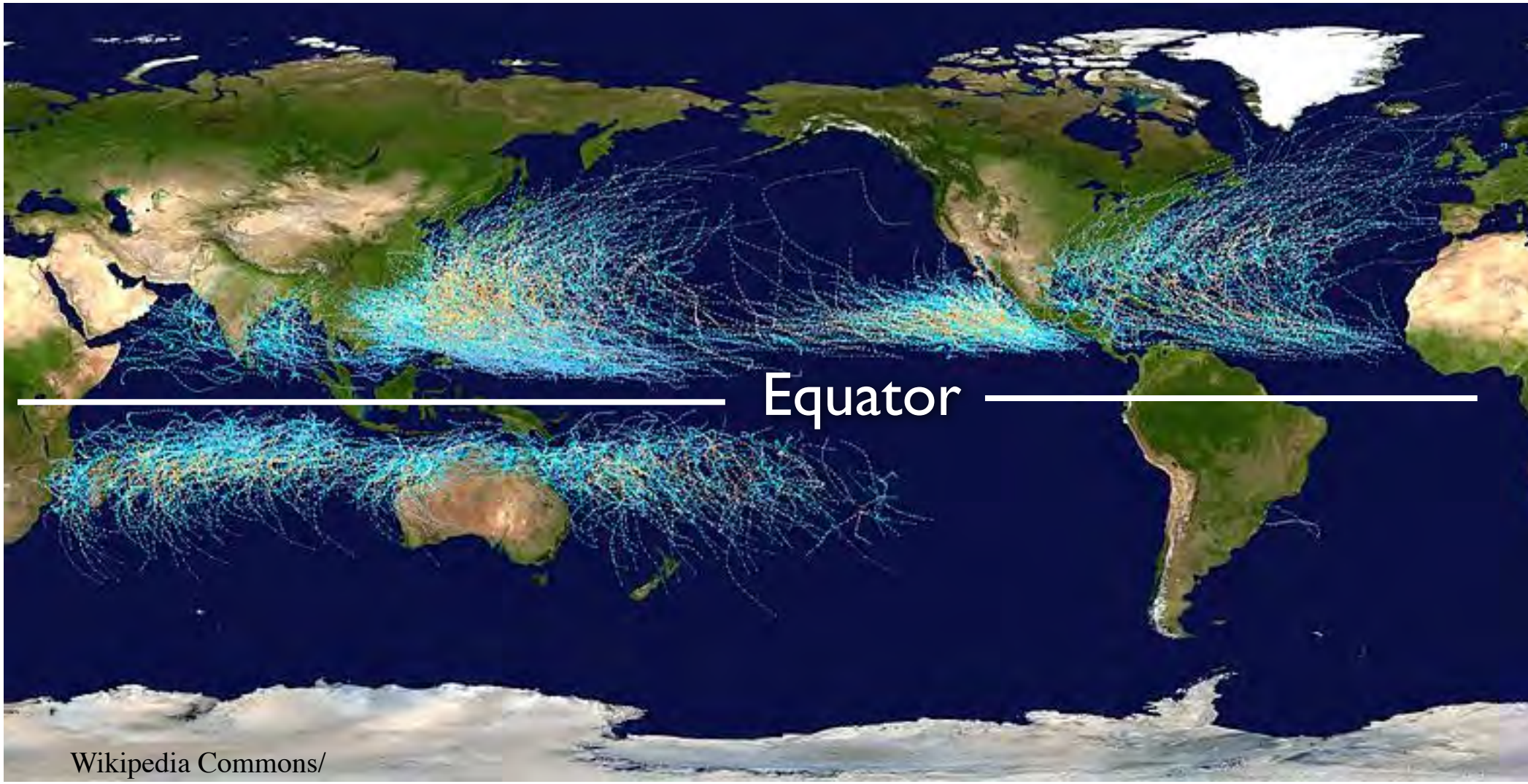
Favored hurricane formation latitudes (shown in green) are where there is BOTH warm SST & nonzero Coriolis

Warmest sea-surface temperatures near equator (shown in red).

Coriolis (earth's rotation) effect is stronger near poles (shown in blue).

NASA

Favored Hurricane Formation Latitudes are 10° - 30°



NO hurricanes at equator, because no Coriolis effect there.

(LG: 5b,c)

Hurricane Existence

Hurricanes can persist only if :

- central pressure in eye remains low (to create wind, waves, and to suck in fuel of warm humid air), AND
- the hurricane remains over the warm ocean.

Hurricanes weaken and die if :

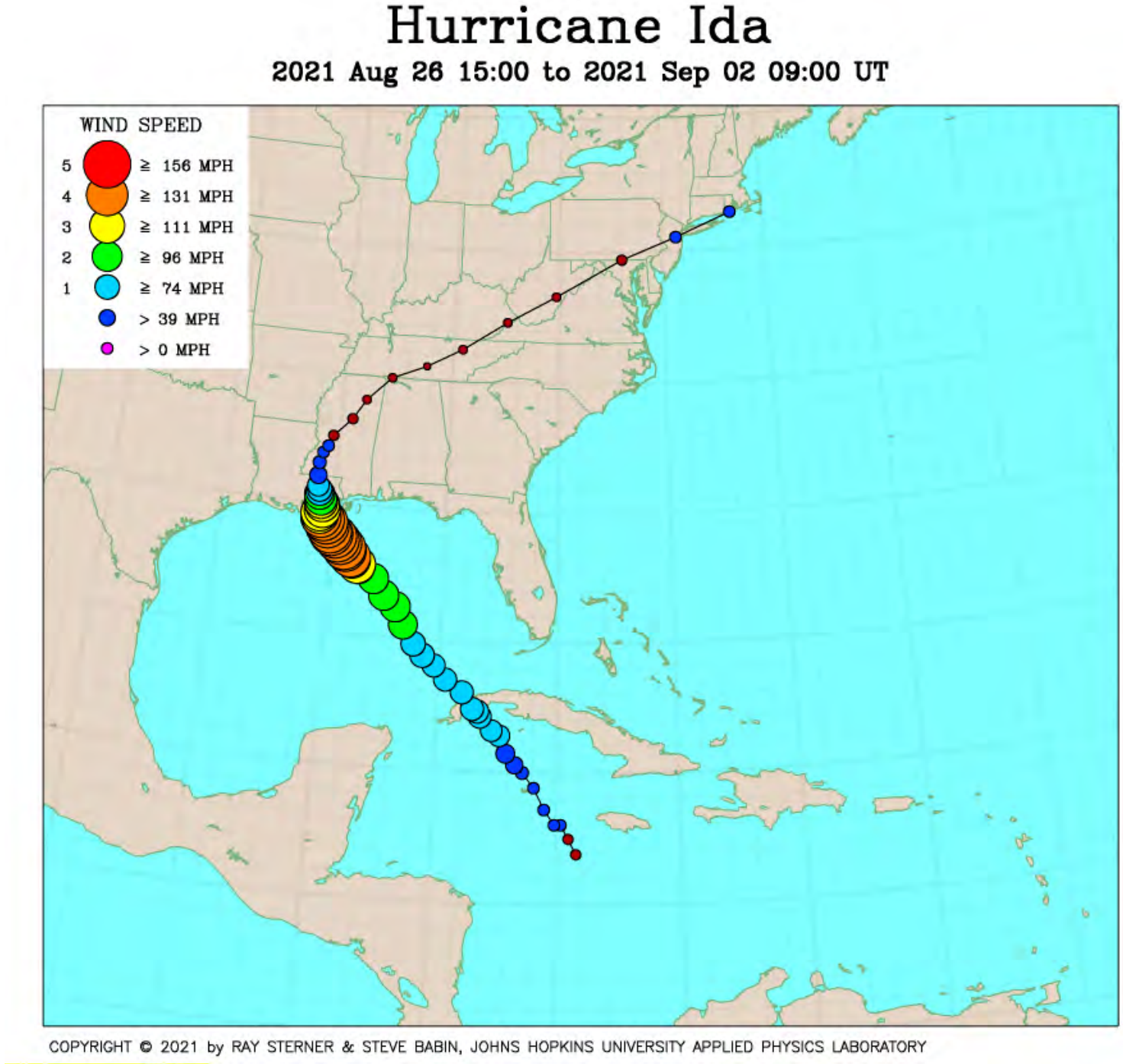
- cannot generate sufficient fuel of warm, humid air.

  This happens when hurricanes move over:

  - colder water, or
  - land.
- larger-scale weather systems interfere.

(LG: 5b,c)

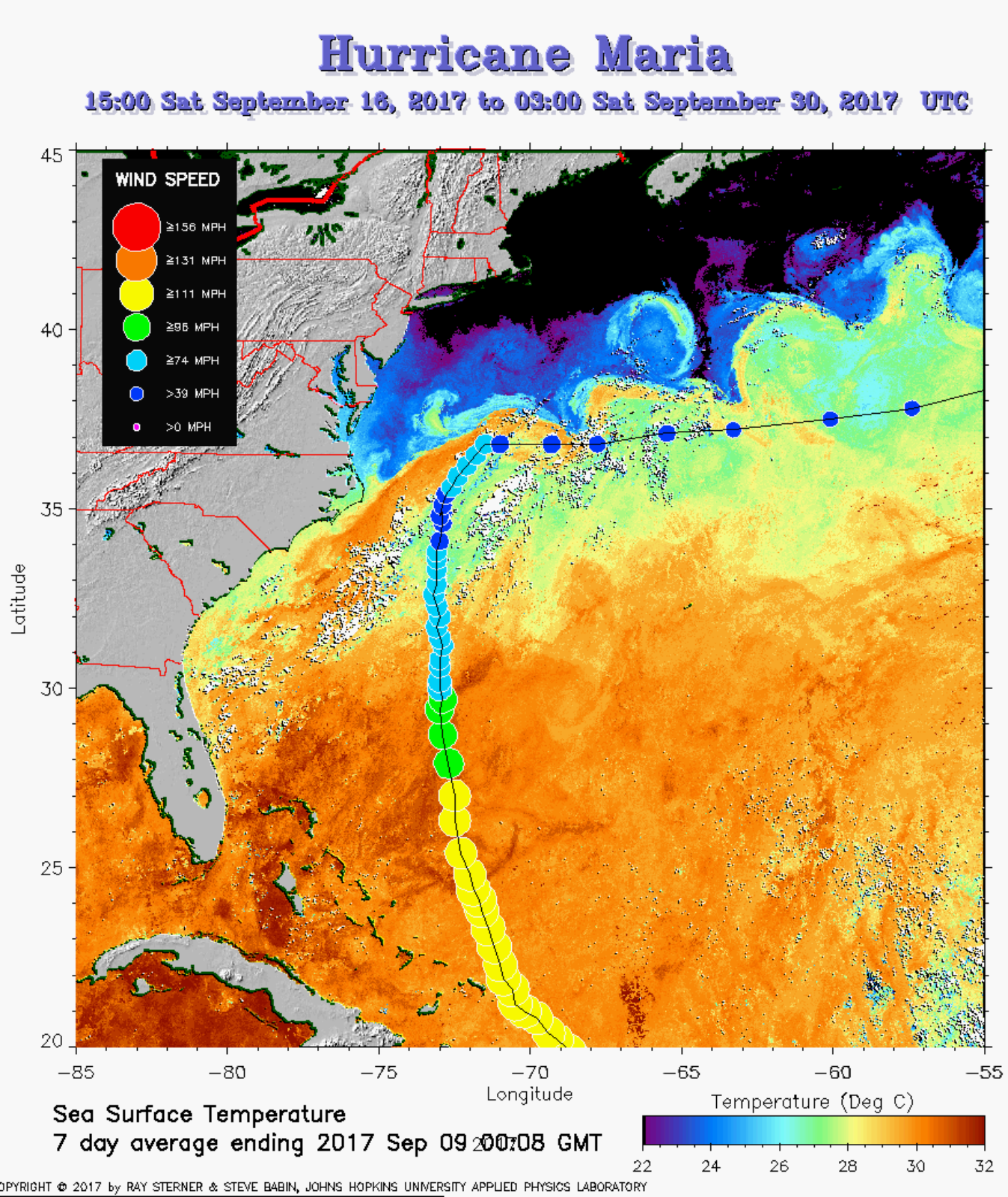
Hurricane Decay by Landfall



JHU
http://fermi.jhuapl.edu/hurr/17/17.html

Hurricane Decay by Cold Water

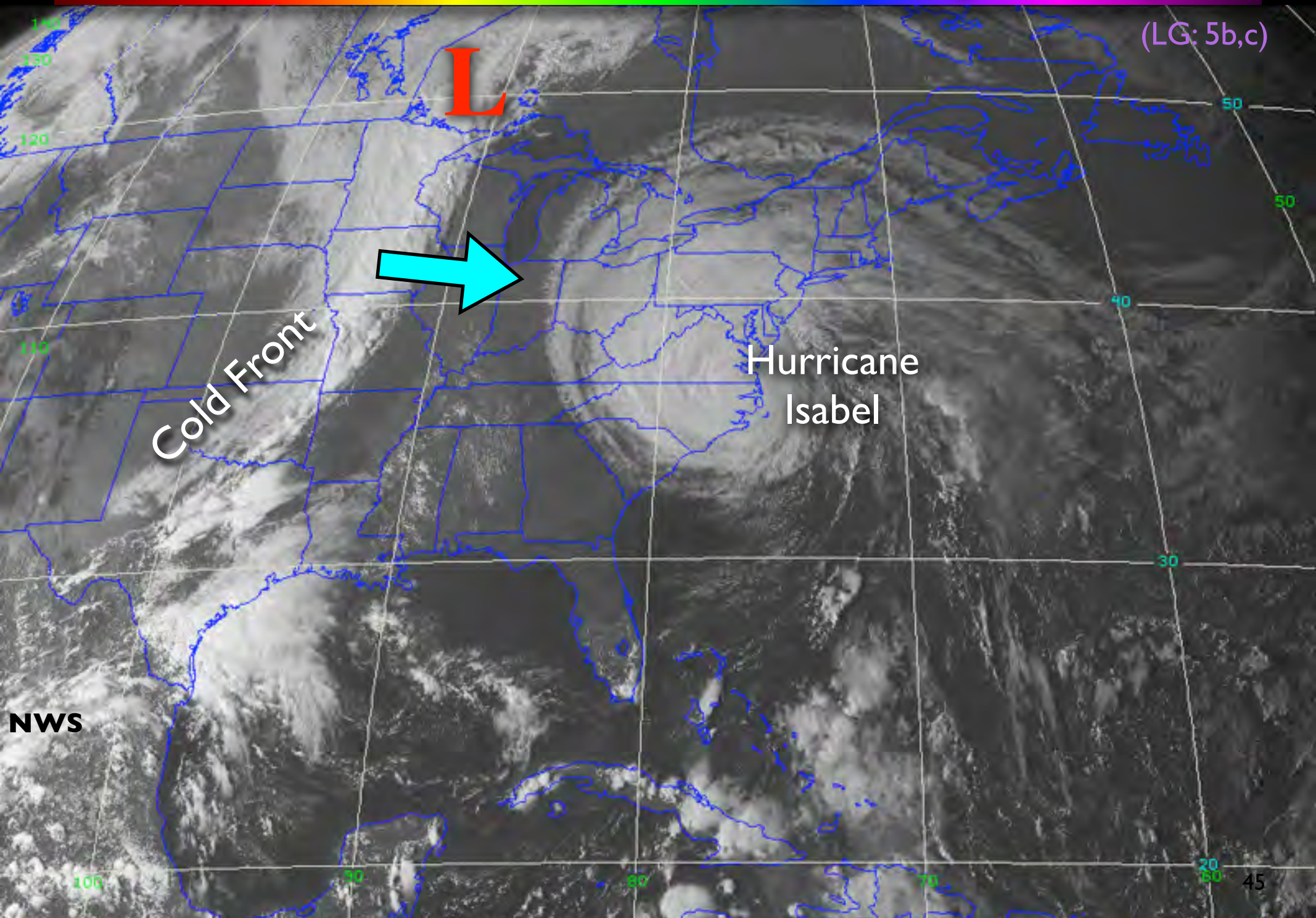
(LG: 5b,c)



http://fermi.jhuapl.edu/hurr/17/17.html

JHU

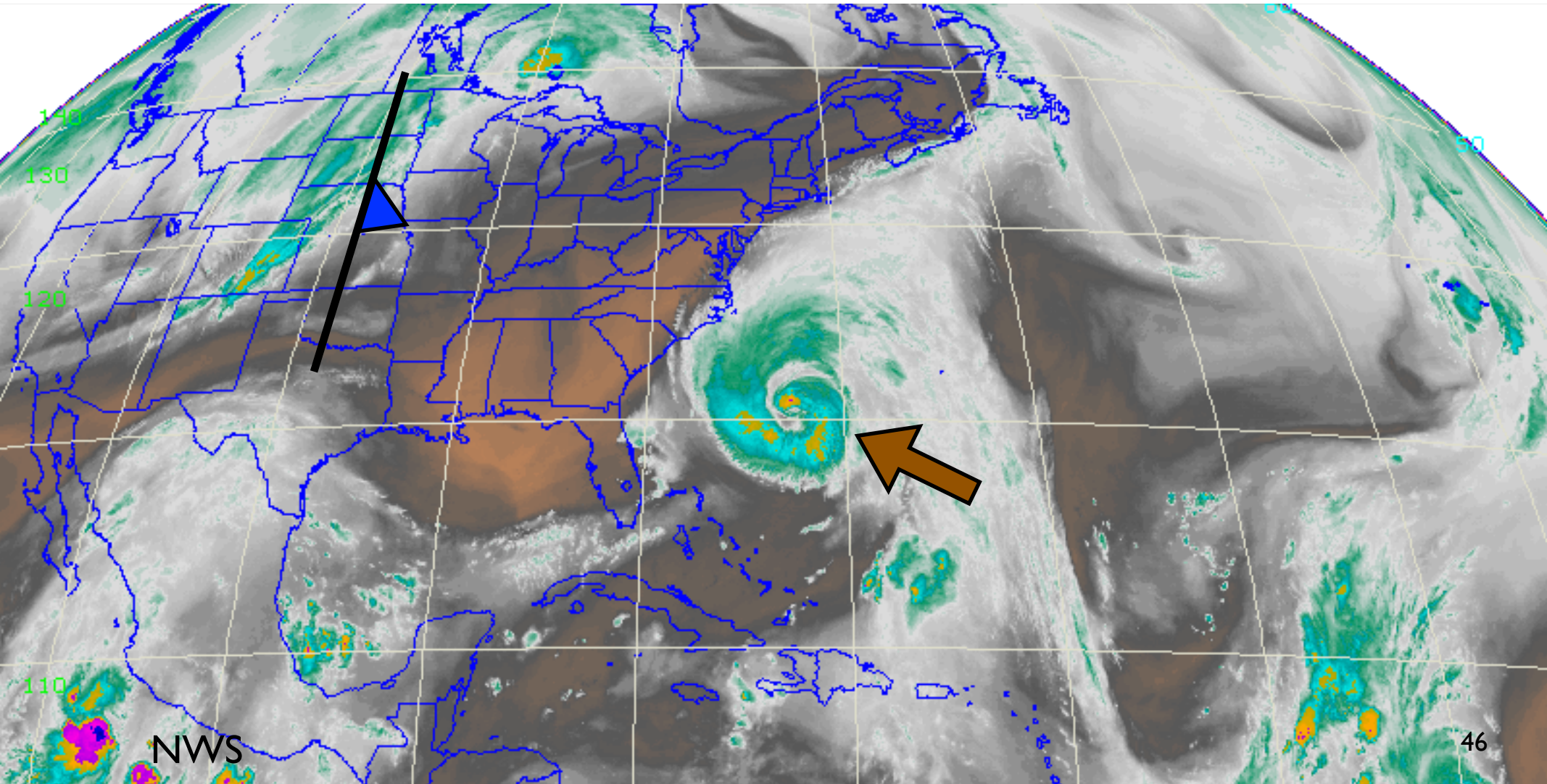
Hurricane Decay by Larger-scale System



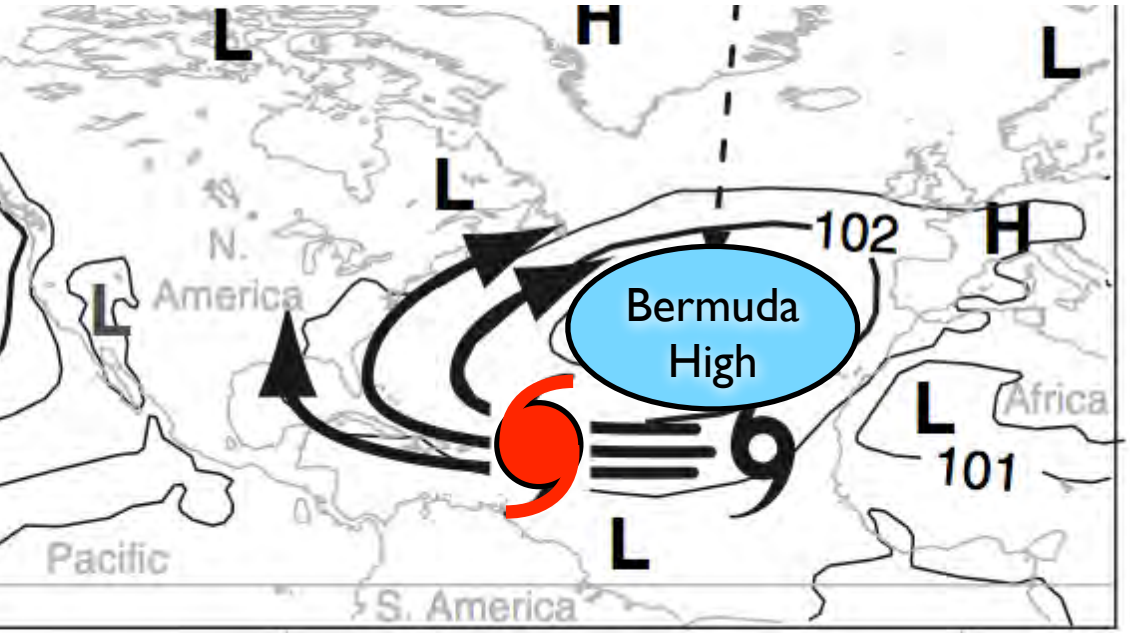
(LG: 5b,c)

Hurricane Decay by Larger-scale System

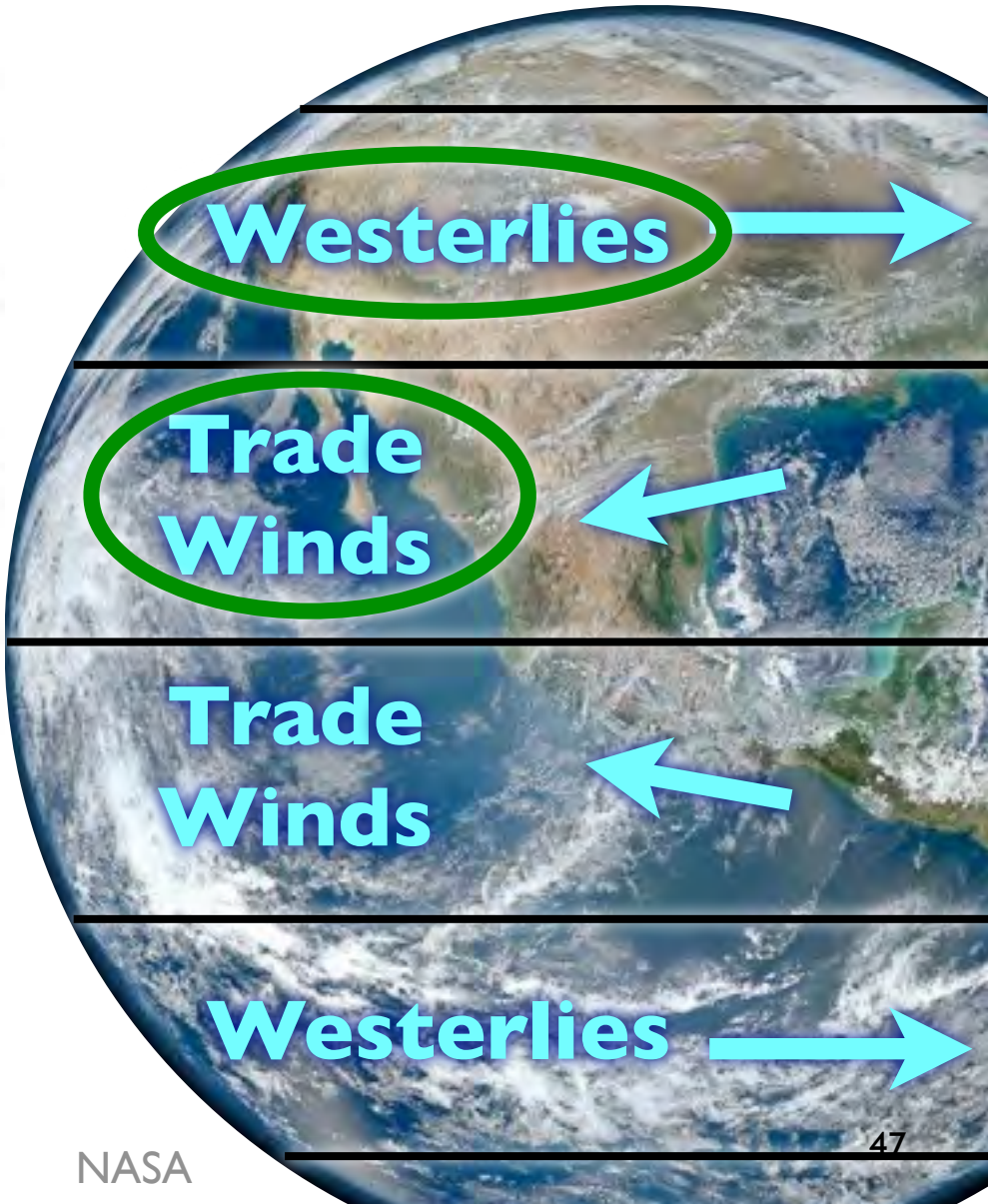
Water-Vapour Satellite Image
Hurricane Isabel, Sep 2003



Hurricane Paths



Stull 2011, used with permission



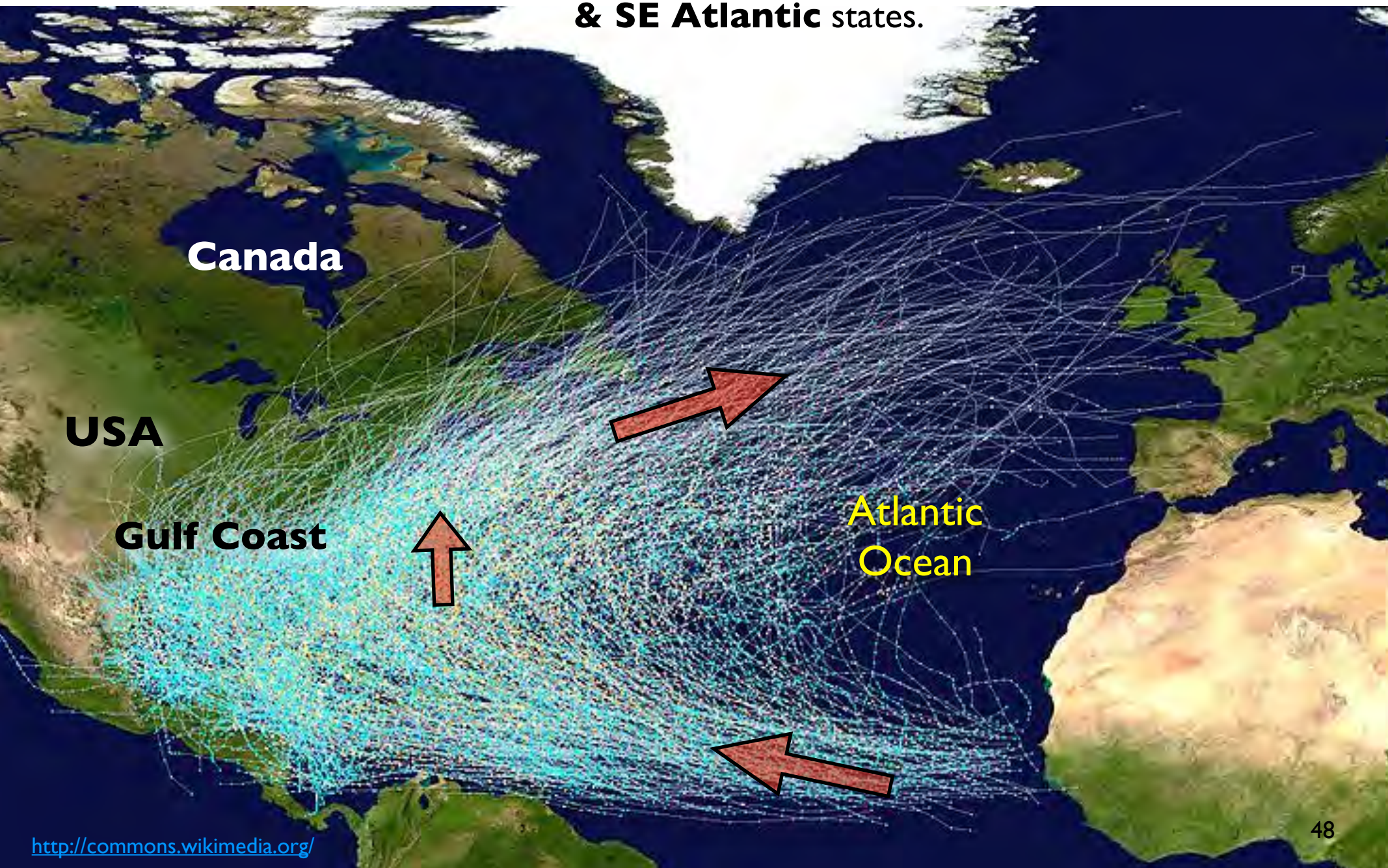
NASA

Steered by the general circulation in the atmos.

- Westerlies
- Bermuda High
- Trade winds

Hurricane Paths (continued)

Net result: hurricanes strike USA at **Gulf coast & SE Atlantic** states.



http://commons.wikimedia.org/

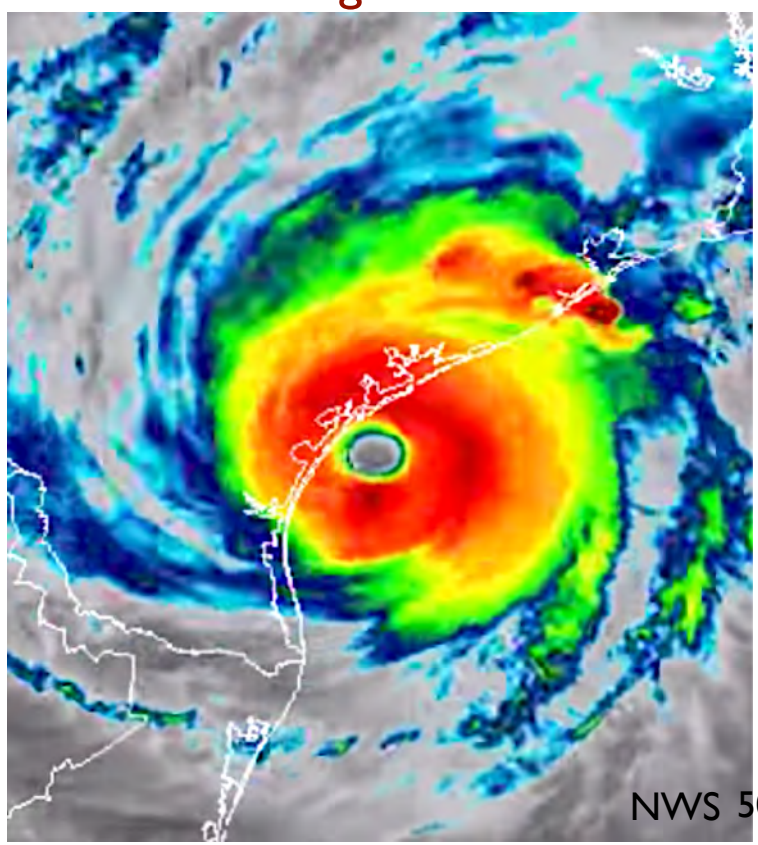
6. Warm Core - the key to long life

Why can hurricanes last for weeks, in spite of all the air molecules continually being blown into the core?

Answer:

Heavy condensation and precipitation from thunderstorms in the eye wall cause the hurricane core (eye + eye wall) to become very warm relative to its surroundings.

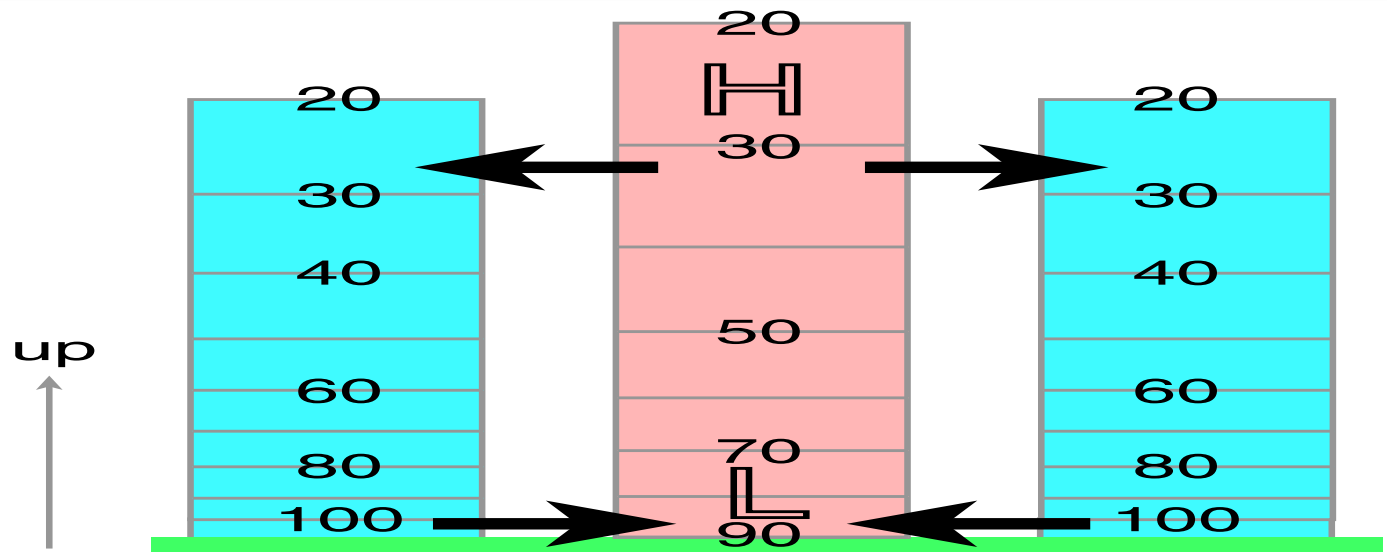
Hurricane Harvey
Aug 2017



NWS

How eye-wall Tstorms warm the core

The **warm core** creates High pressure at the core top, and Low pressure at the core bottom (recall from Day 4).



Surroundings Core Surroundings

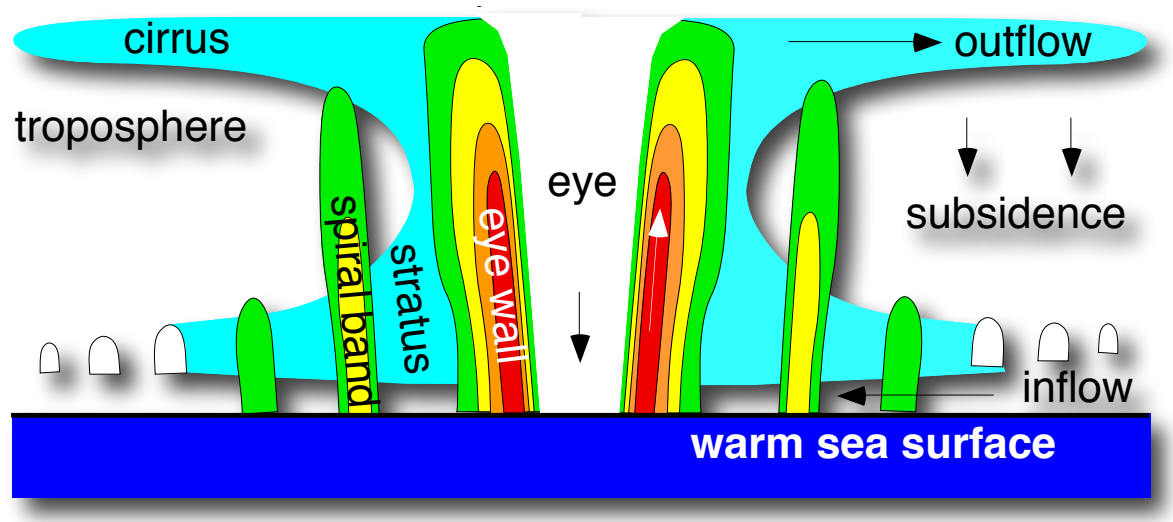
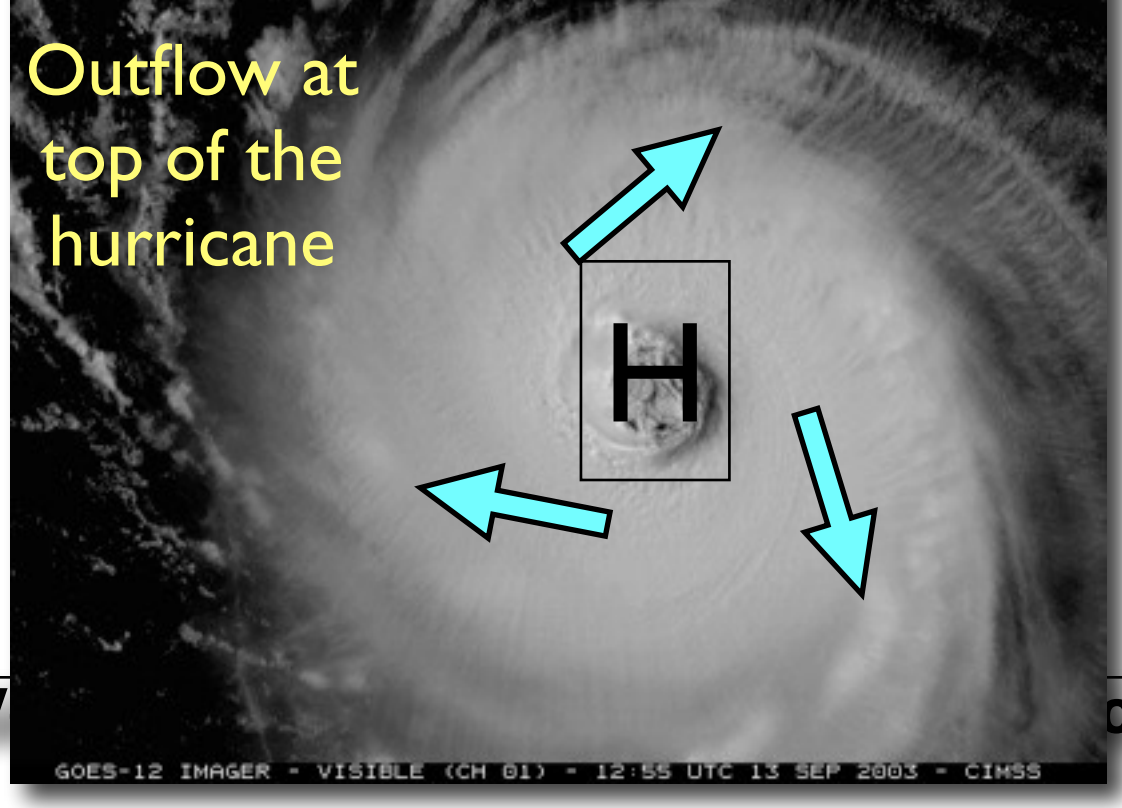


photo by R. Stull

(LG: 5b)



Result is a Vertical Circulation

- strong updrafts in the eye-wall thunderstorms
- outflow at hurricane top away from core
- weak downward motion (subsidence) in the eye and outside the hurric.
- inflow at hurric. bottom

  towards core
- cycles back into base of eye-wall Tstorms as a complete circulation.

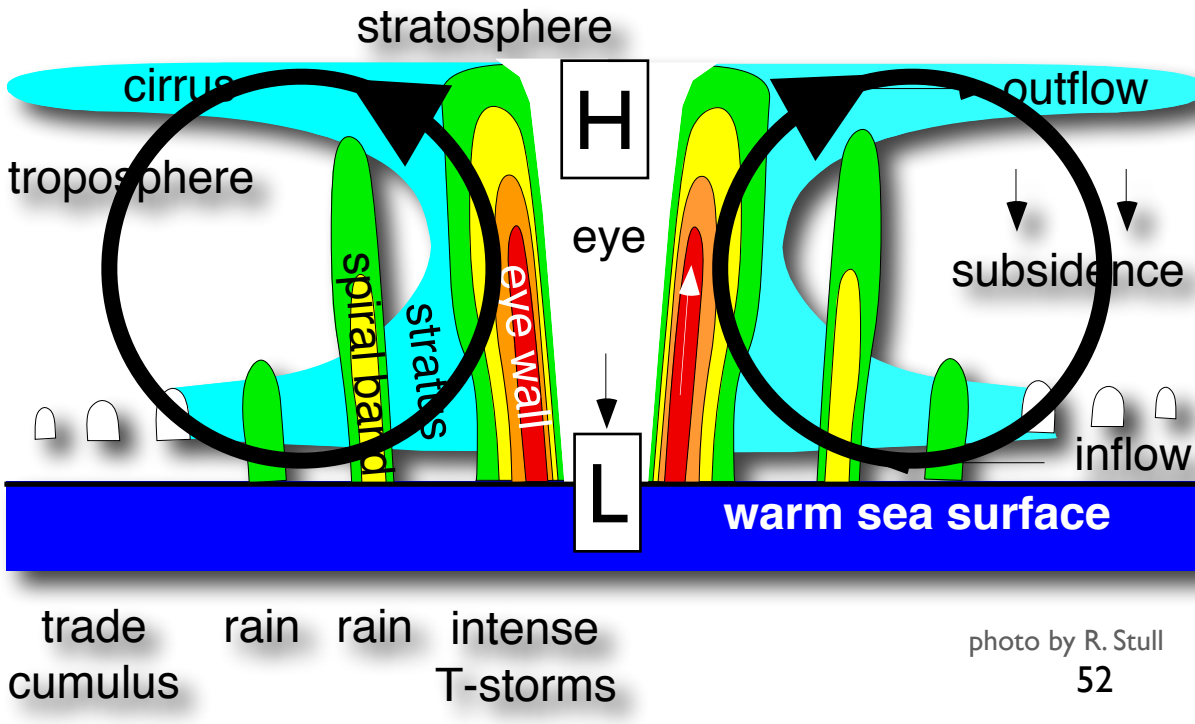


photo by R. Stull

Announcements

- Consider majoring in Atmospheric Sciences (ATSC). The ATSC program focuses on weather-related big societal issues and the associated tools:

- Issues:
  (1) air quality
  (2) renewable energy
  (3) climate change

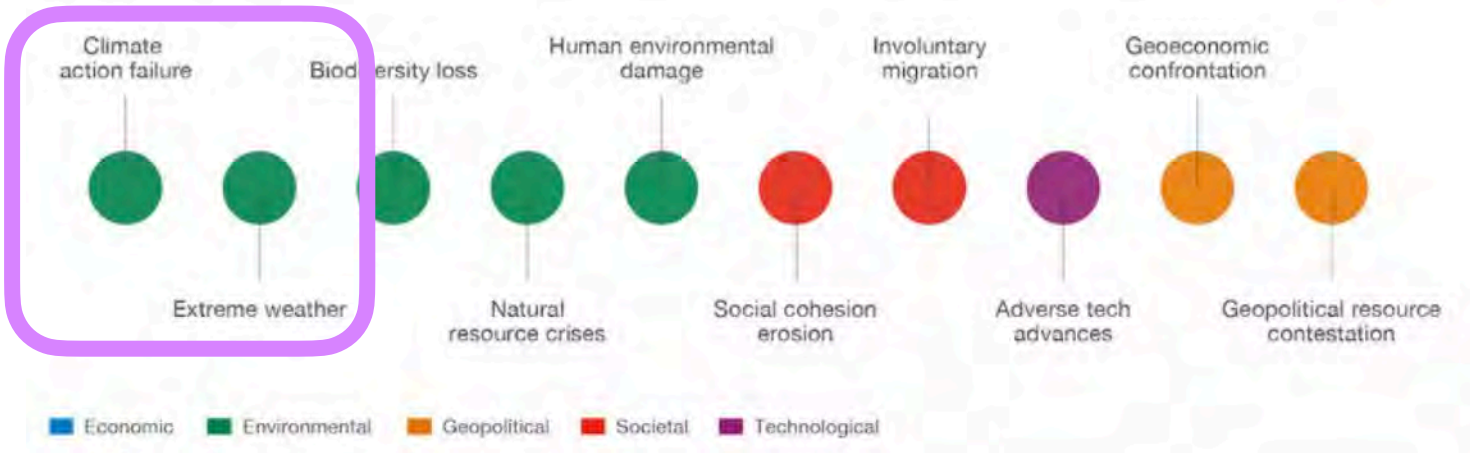
- Tools:
  (4) big data (statistics, machine learning, scientific programming)
  (5) Geographic Information Systems (GIS) & remote sensing

- ATSC is an interdisciplinary program spanning the faculties of Science, Applied Science (Engr.), Arts, and Land and Food Systems (Ag.).

Top Long-Term Global Risks

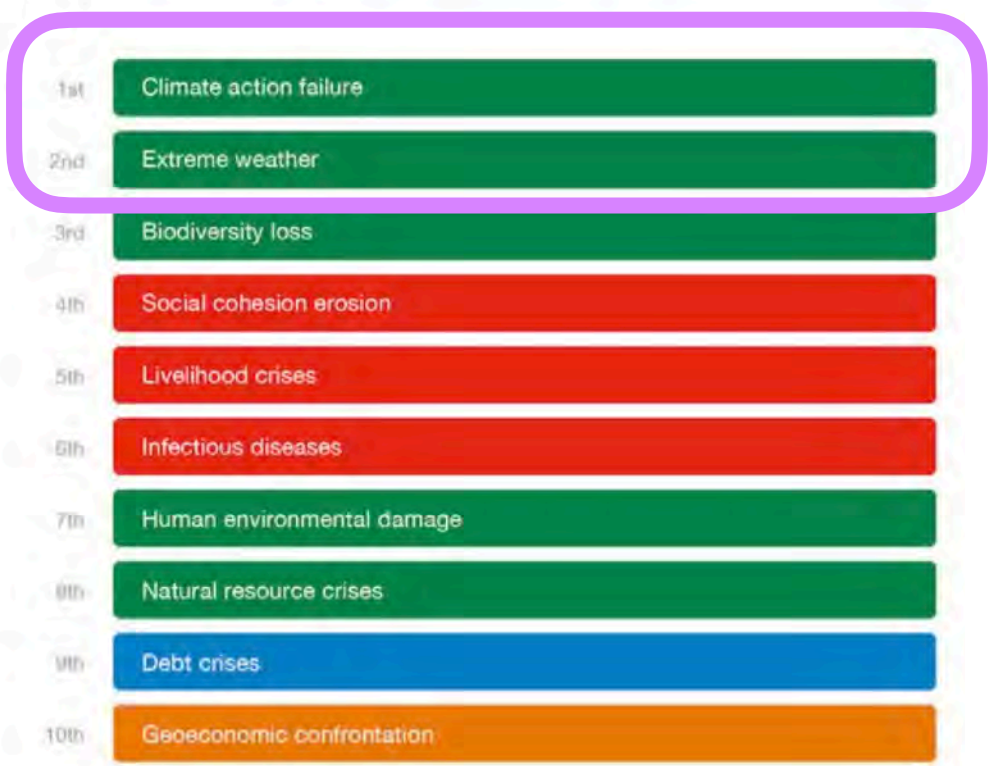
(LG: 5c,d)

Over the next 5-10 years



Top 10 Global Risks by Severity

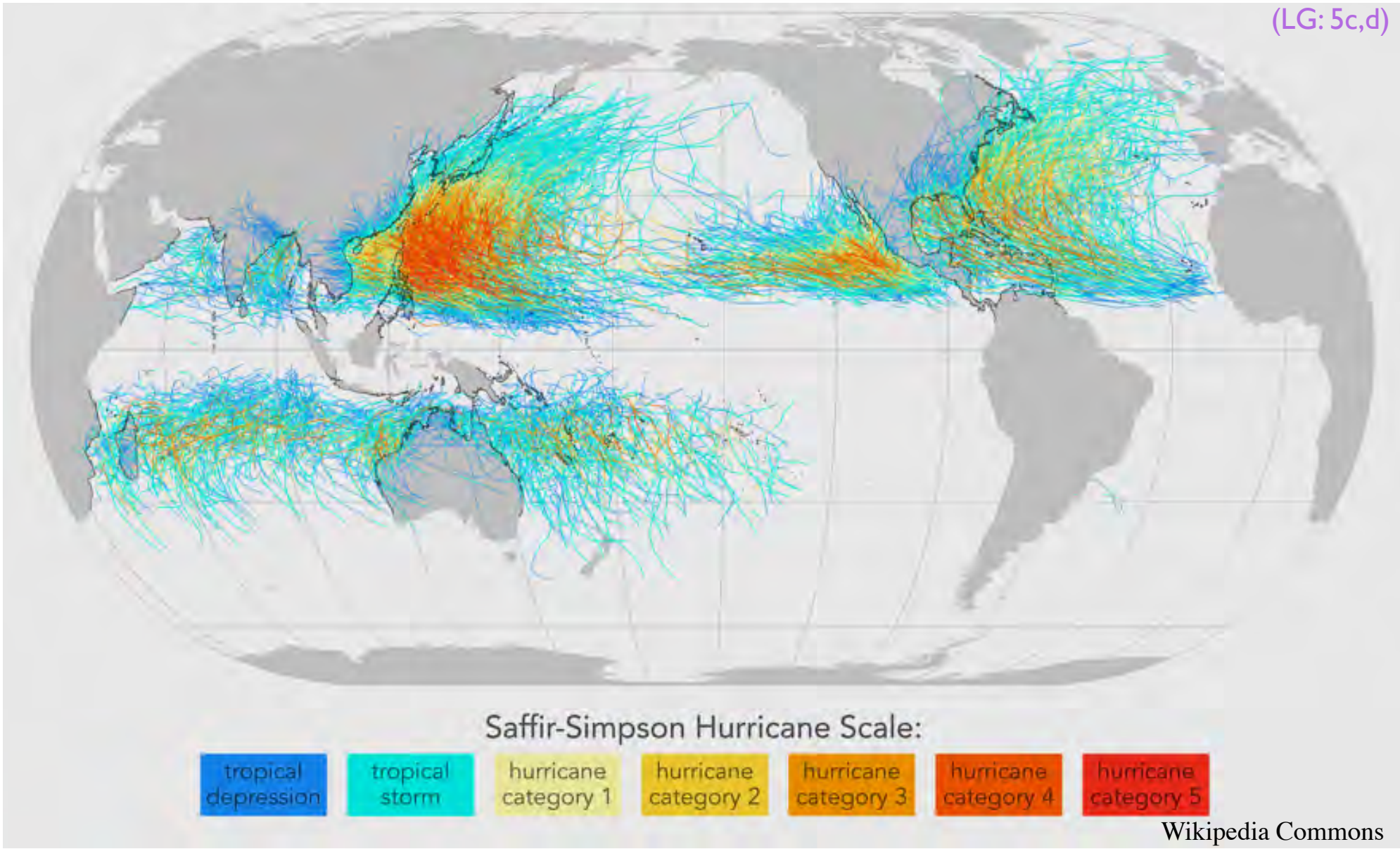
Over the next 10 years



https://www.weforum.org/reports/global-risks-report-2022

C. Hazards. Hurricane Risk

(LG: 5c,d)



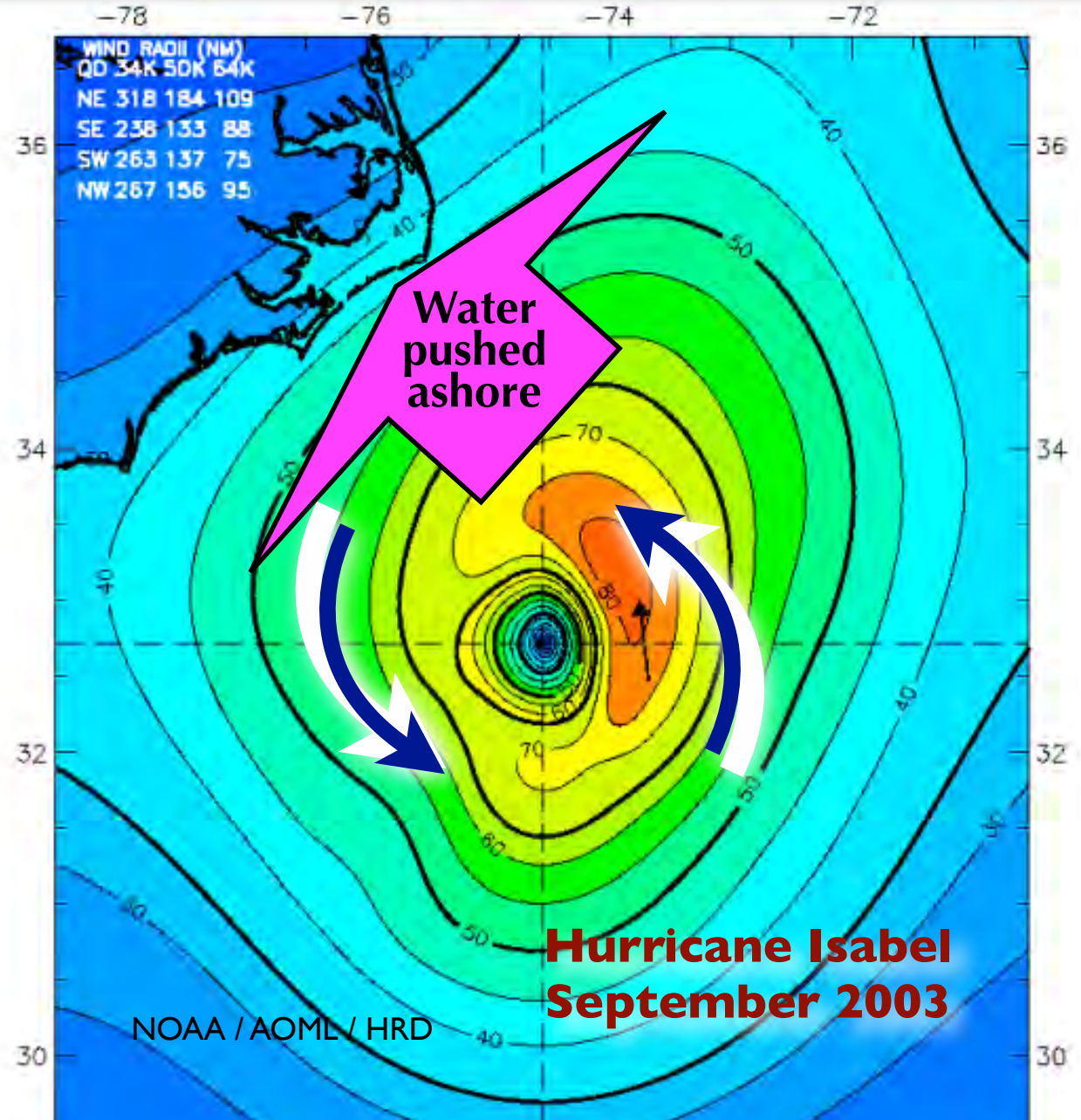
Wikipedia Commons

7. Storm Surge –
The atmosphere drives an ocean disaster

Strong winds drag ocean water, raises sea level, & causes water to pile up against shore.

This is called a storm surge, causing coastal flooding.

Learn more about it in Waves segment of EOSC114.



Hurricane Flooding & Storm Surge

(LG: 5d)

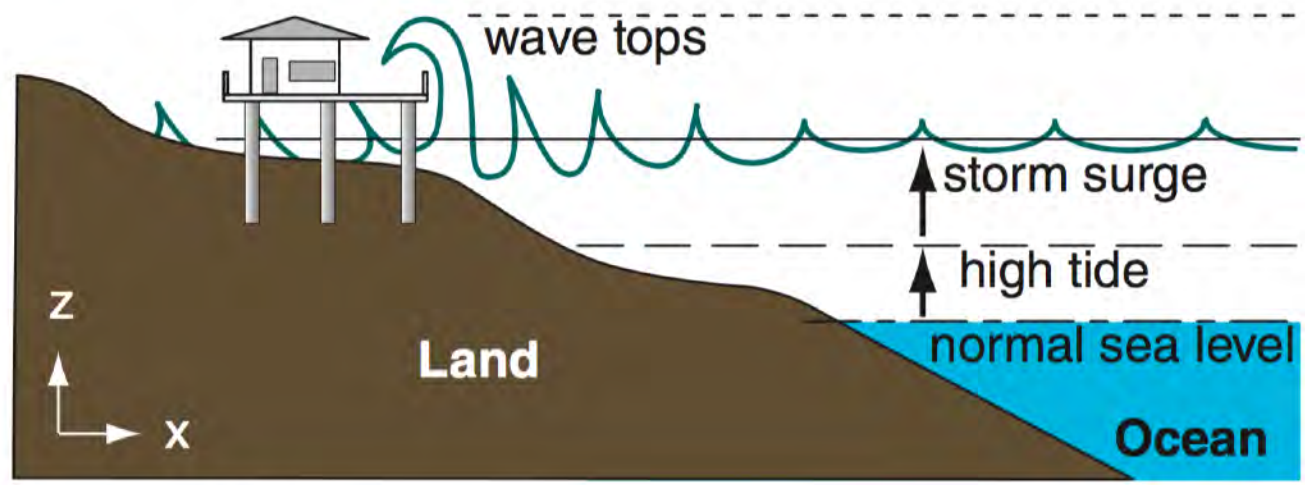


photo by R. Stull

Figure 16.47
Tides, storm surge, and waves are additive.

YouTube clip: Day5-30 Storm surge in Philippines from Super Typhoon Haiyan (Yolanda) in 2013 (1:45).

https://www.youtube.com/watch?v=rS0gv4Xbw7w

Other Excellent videos of Storm Surge hitting northeast US (not testable in Storms module)

Video 5-40 A nice storm surge and extremely high breaking wave video from 2-3 March 2018 in Scituate, MA.
https://www.youtube.com/watch?v=gc-R9ZcfGls

Video 5-45 and excellent aerial shot from drone of storm surge at the same location:
https://www.youtube.com/watch?v=JLOSBJIREVg

Hurricane-caused Fatalities: Drowning & Disease

(LG: 5d)

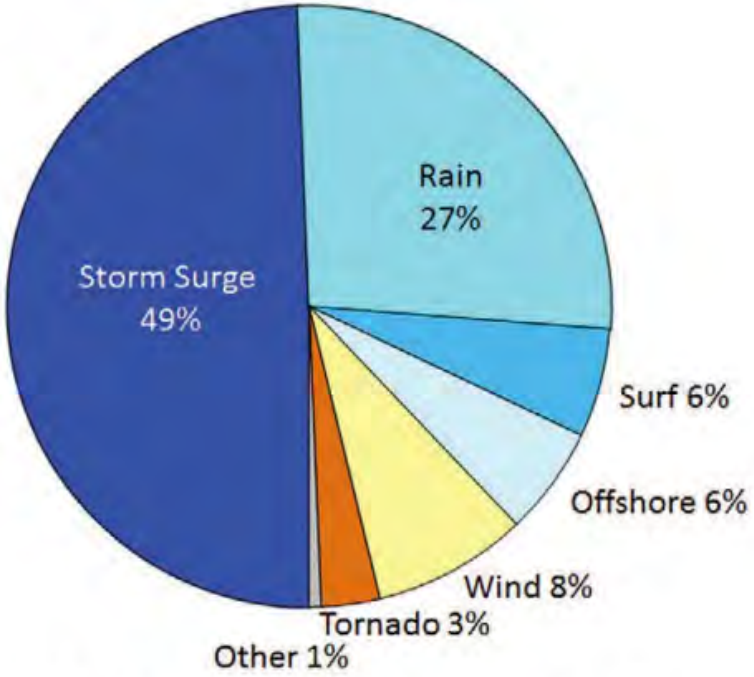
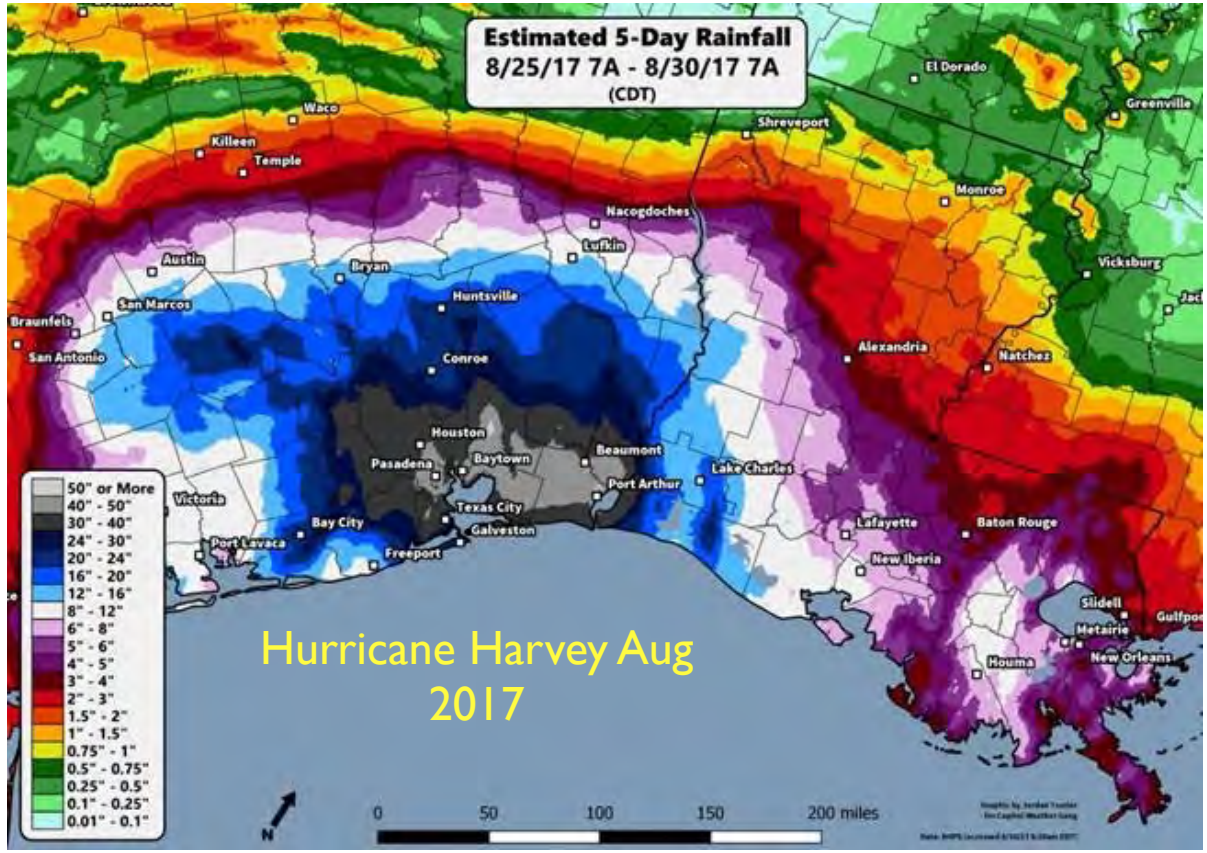


FIG. 1. Cause of death in the United States directly attributable to Atlantic tropical cyclones, 1963–2012.



- Coastal flooding caused by the hurricane storm surge causes the most deaths. E.g., Bangladesh has been hard hit.
- In countries such as the USA, inland and urban flooding caused by heavy rains cause the 2nd most hurricane-related deaths.

(LG: 5c,d,e)

YouTube Video

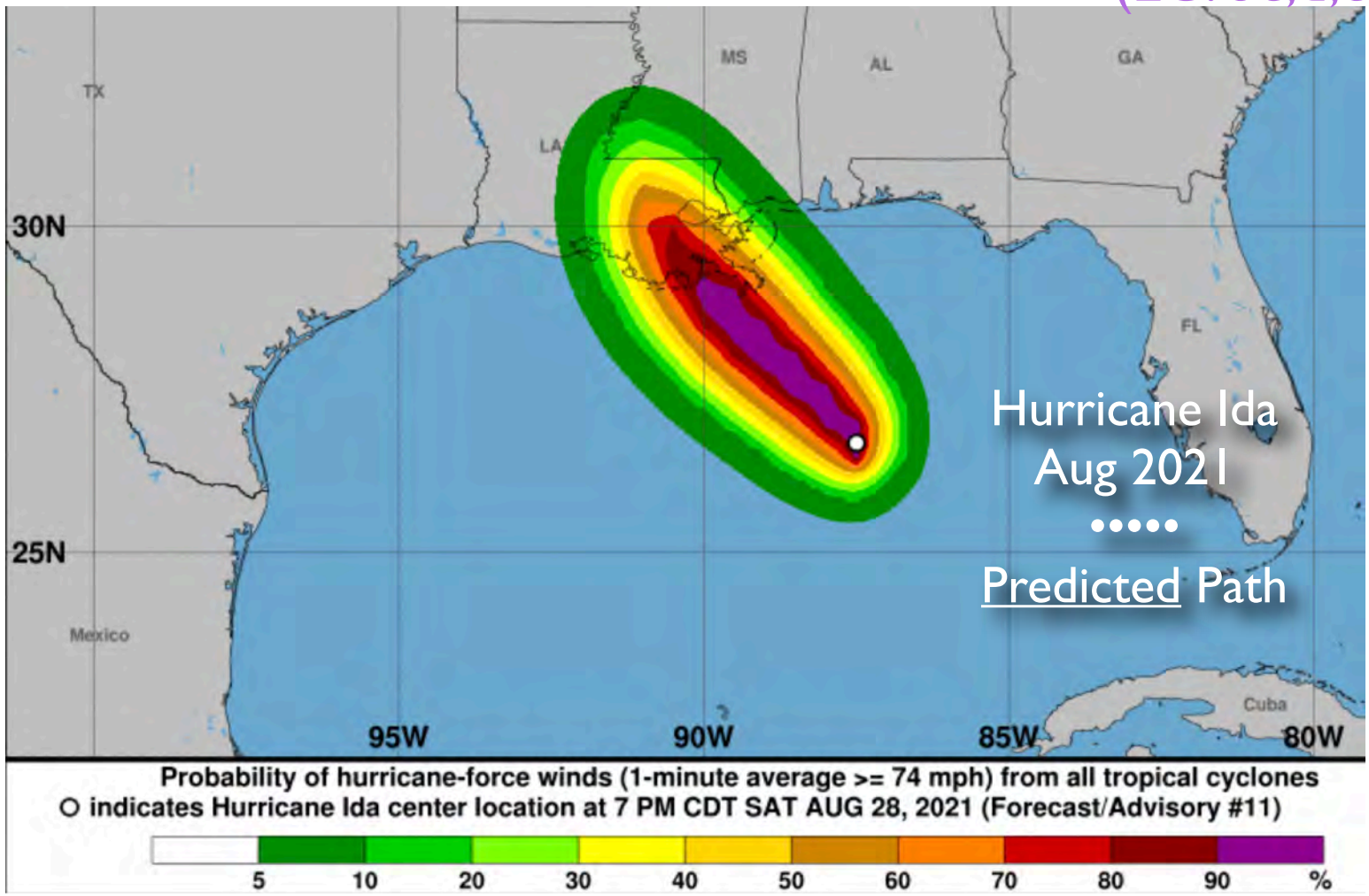
Day 5-22. Health Dangers after Hurricane Flooding

https://www.youtube.com/watch?v=nc3lCtxH3qU

(2:03)

(LG: 5c,d,e)

8. Hurricane Prediction & Safety



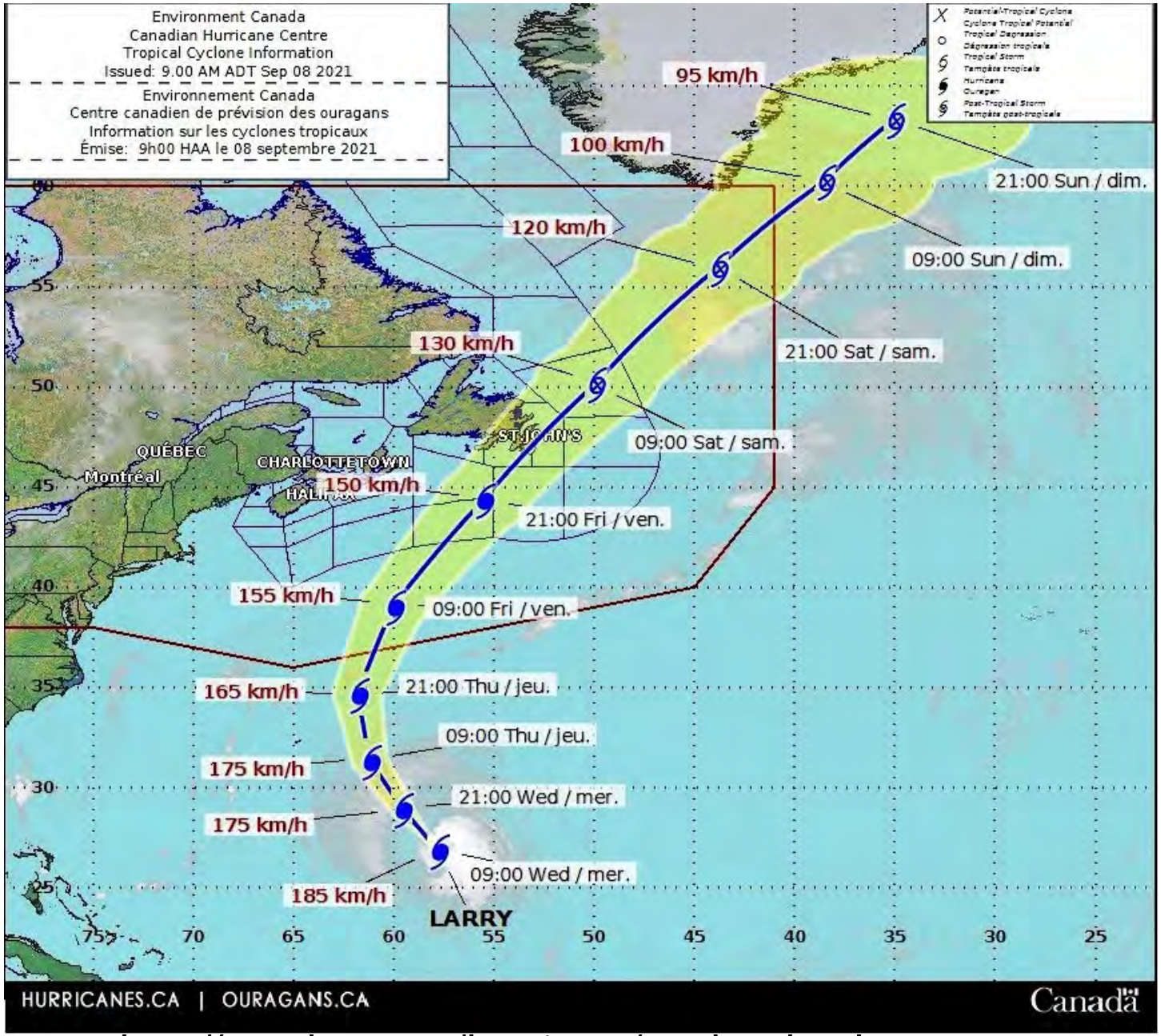
Hurricane predictions are inaccurate. Therefore, forecast maps of hurricane danger usually include probabilities.

Recommendations for your Safety:

- Don't buy or build houses on or near the beach in SE USA.
- Plan in advance for evacuation. Don't "ride out" the storm.

9. Canadian Hurricane Centre

(LG: 5c,d,e)



http://weather.gc.ca/hurricane/track_e.html

Example of Forecast Map

Hurricane Larry Sep 2021

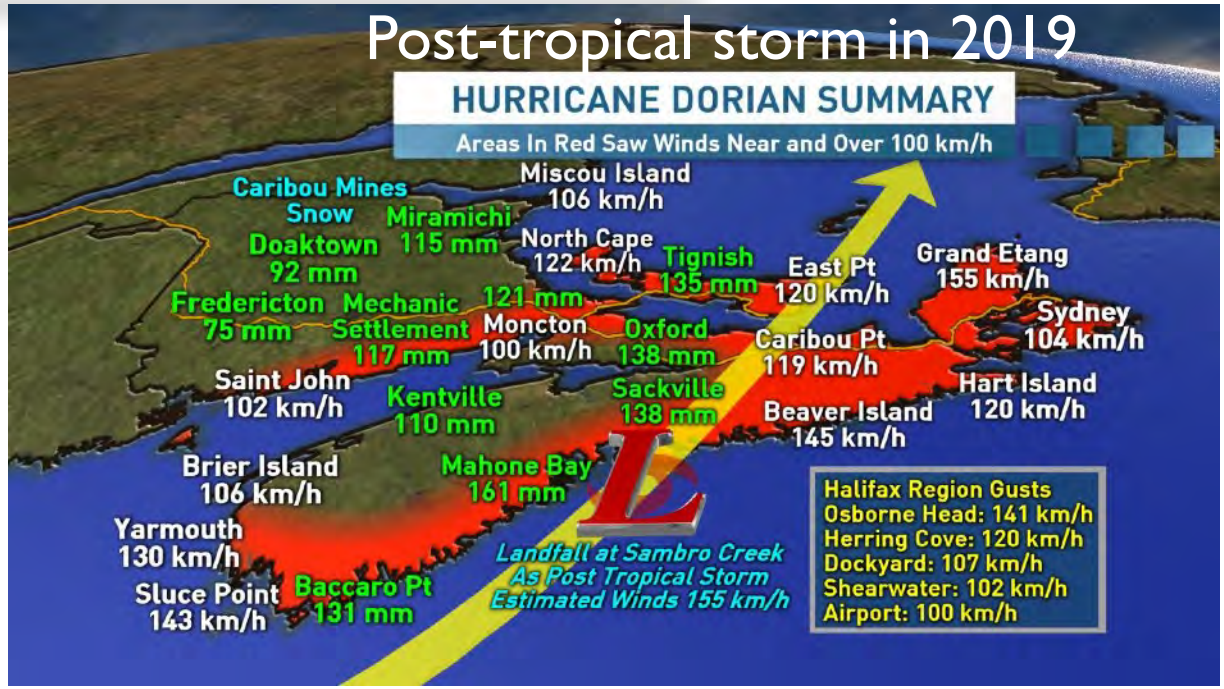
Cat. 1

(LG: 5c,d,e)

9. Hurricanes are Rare in Canada

About 4 to 5 hurricanes per decade, but we get more "former" hurricanes.

Most of those rare hurricanes hit Atlantic provinces. Some former hurricanes cause heavy rain and flooding over ON & QC.



Some other recent hurricanes include:

2021 - Hurricane **Larry** - Cat. 1 at Newfoundland
2010 - Hurricane **Earl** - Cat. 1 at Nova Scotia
2010 - Hurricane **Igor** - Cat. 1 at Newfoundland
2009 - Hurricane **Bill** - Cat. 1 at Nova Scotia & Newfoundland
2008 - Hurricane **Kyle** - Cat. 1 at Nova Scotia
2007 - former Hurricane **Noel** - Cat. 1 at Nova Scotia & New Brunswick
2006 - former Hurricane **Florence** - Cat. 1 at Newfoundland

Noteworthy Storms:

2003 - Hurricane **Juan** - Cat. 1 to 2 at Nova Scotia. 20 m waves.
1954 - former Hurricane **Hazel** - Toronto 225 mm rain, killed 81 people.

End of Storm Topics

NASA

Prof. Roland Stull
Earth, Ocean & Atmospheric Sciences Dept., UBC

We covered:

Thunderstorm Hazards
- lightning
- tornado
- hail
- downpours (of rain) / local flooding
- downbursts (of air) / gustfronts

Hurricane Hazards
- contain thunderstorms
- storm surge / coastal flooding

Any Questions?