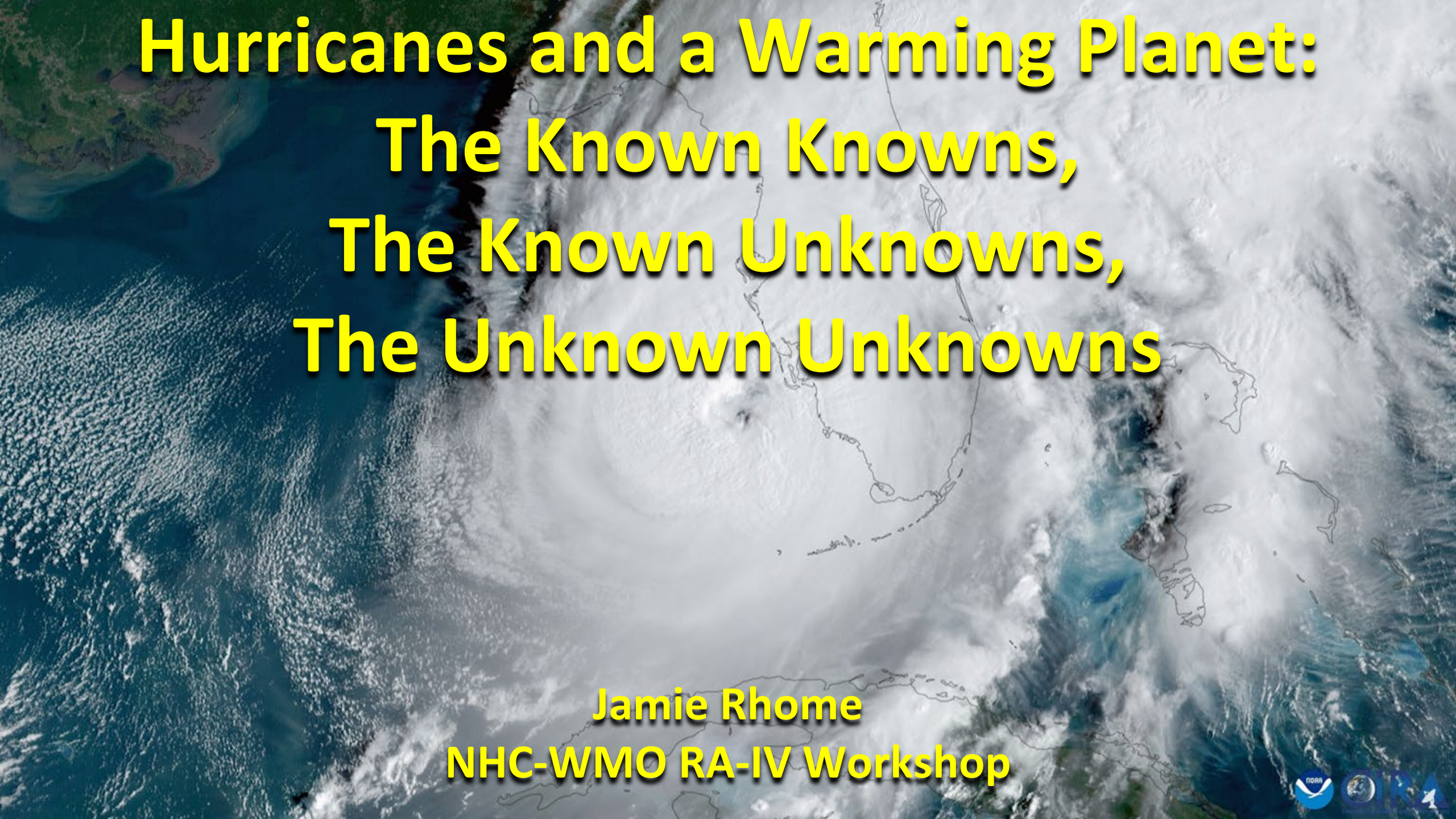


Hurricanes and a Warming Planet: The Known Knowns, The Known Unknowns, The Unknown Unknowns

Jamie Rhome
NHC-WMO RA-IV Workshop

Donald Rumsfeld: Former USA Secretary of Defense

Eating Bacon

Is eating bacon bad for you?

Eating Bacon

Harvard University Study

- 28-years long, 120,000 people
- Eating one serving of:
  - unprocessed red meat (e.g., steak, pork chops) daily increased risk of dying by 13%
  - processed red meat (e.g., bacon) daily increased risk of dying by 20%

Eating Bacon

Harvard University Study

- 28-years long, 120,000 people
- Eating one serving of:
  - unprocessed red meat (e.g., steak, pork chops) daily increased risk of dying by 13%
  - processed red meat (e.g., bacon) daily increased risk of dying by 20%
- Consistent with Harvard 2010 study showing people who eat processed red meats daily are at much higher risk of developing coronary heart disease and diabetes

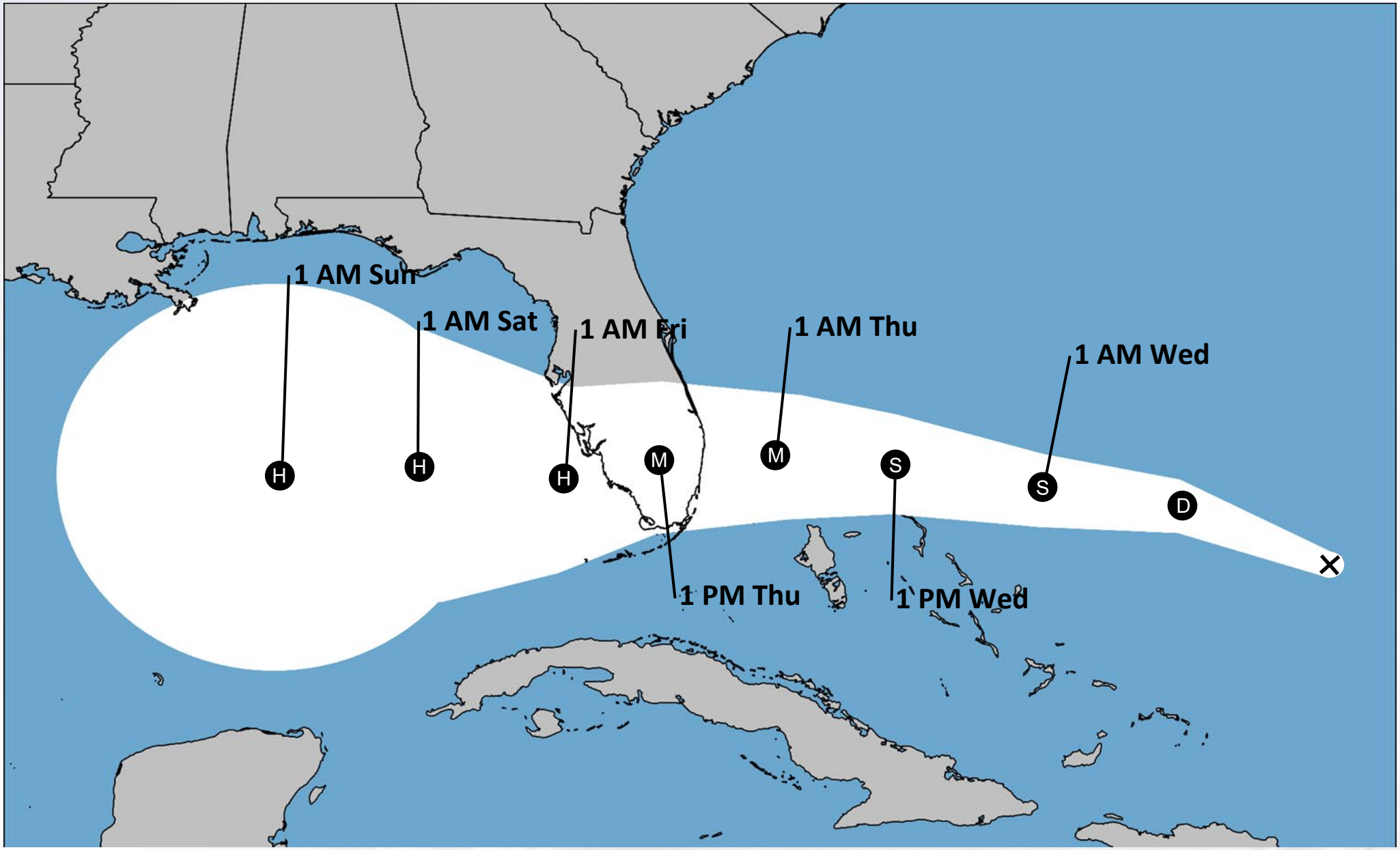
Longest Living Person

Susannah Mushatt Jones

- Lived 116 years
- Loved bacon
- Ate 4 strips per day
- A sign in her kitchen read “Bacon makes everything better.”

Sources: Live Science, Another Live Science article

Exceptionally Unlikely	Very Unlikely	Unlikely	About as Likely as Not	Likely	Very Likely	Virtually Certain
0-1%	0-10%	0-33%	33-66%	66-100%	90-100%	99-100%



Exceptionally Unlikely	Very Unlikely	Unlikely	About as Likely as Not	Likely	Very Likely	Virtually Certain
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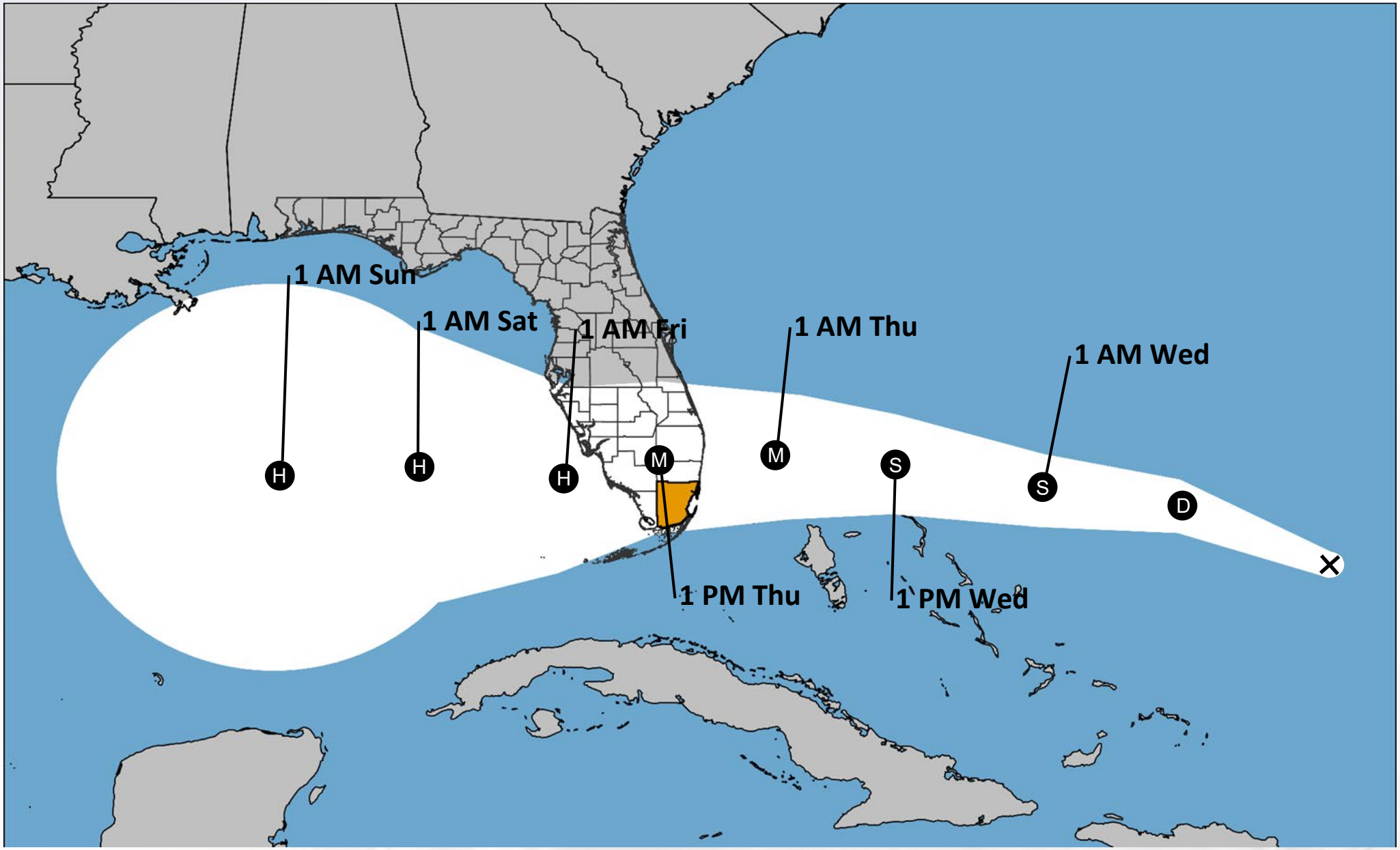

Exceptionally Unlikely	Very Unlikely	Unlikely	About as Likely as Not	Likely	Very Likely	Virtually Certain
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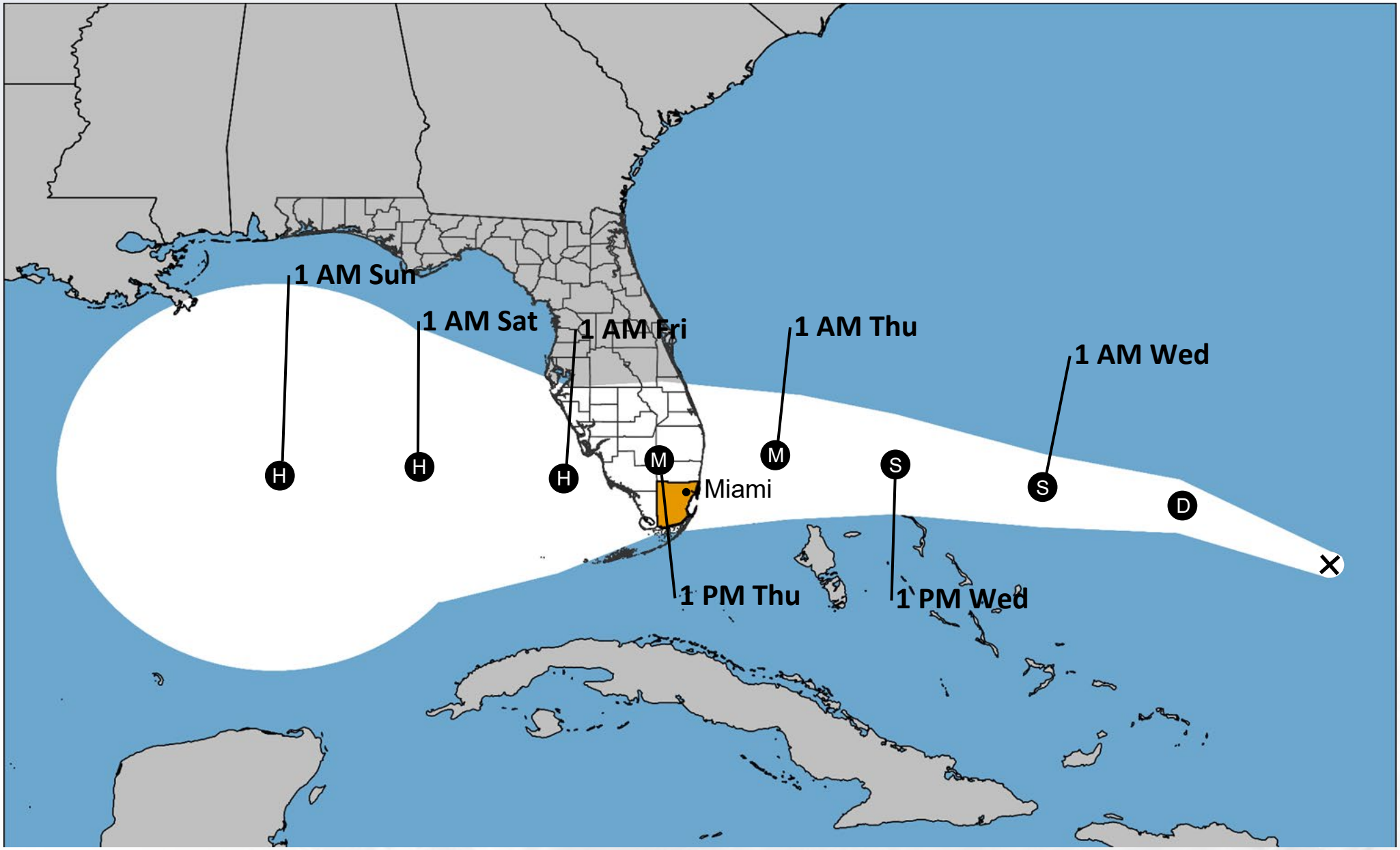
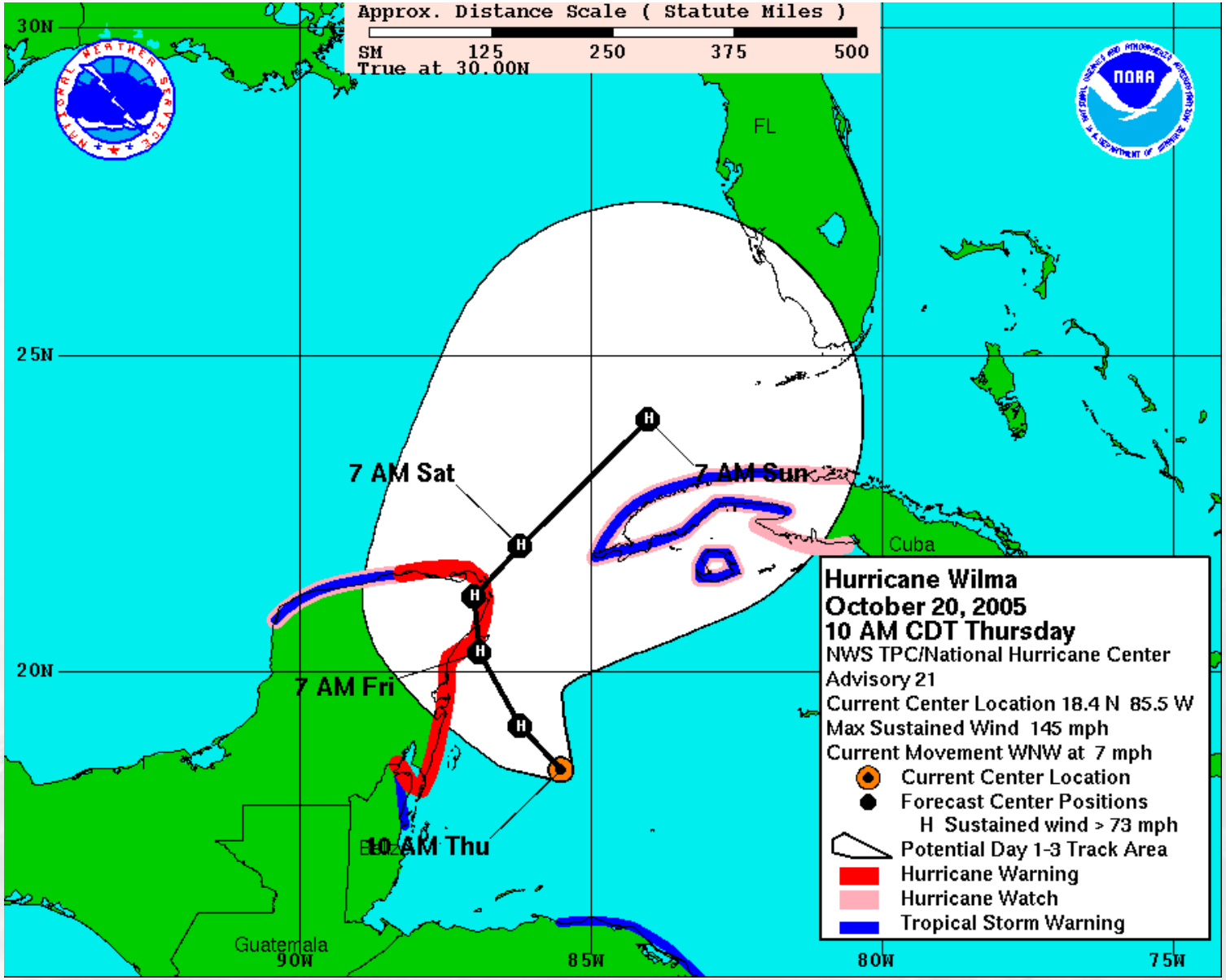


Scaling Risk Information

The depiction of tropical cyclone risk went through a scaling evolution.



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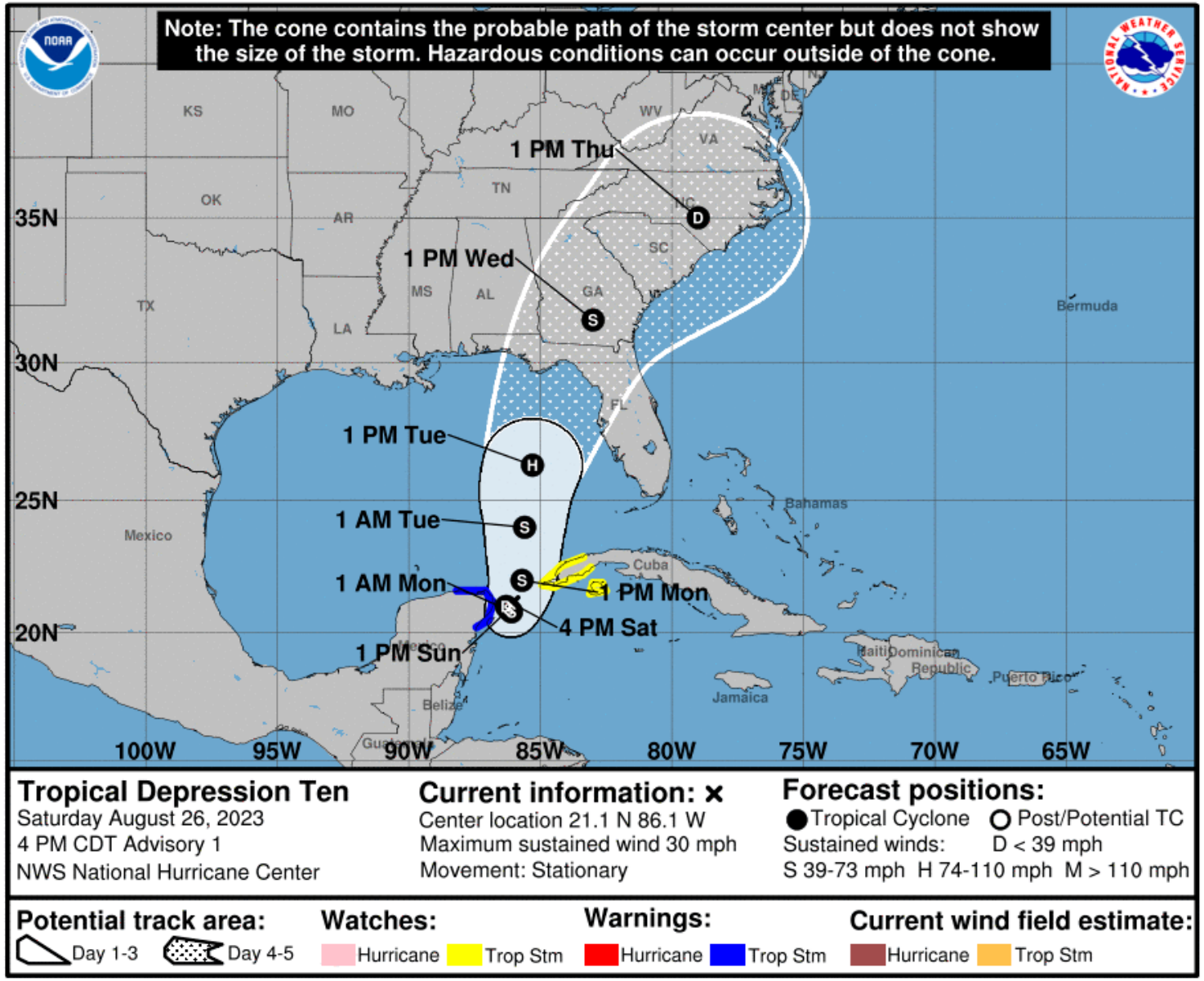

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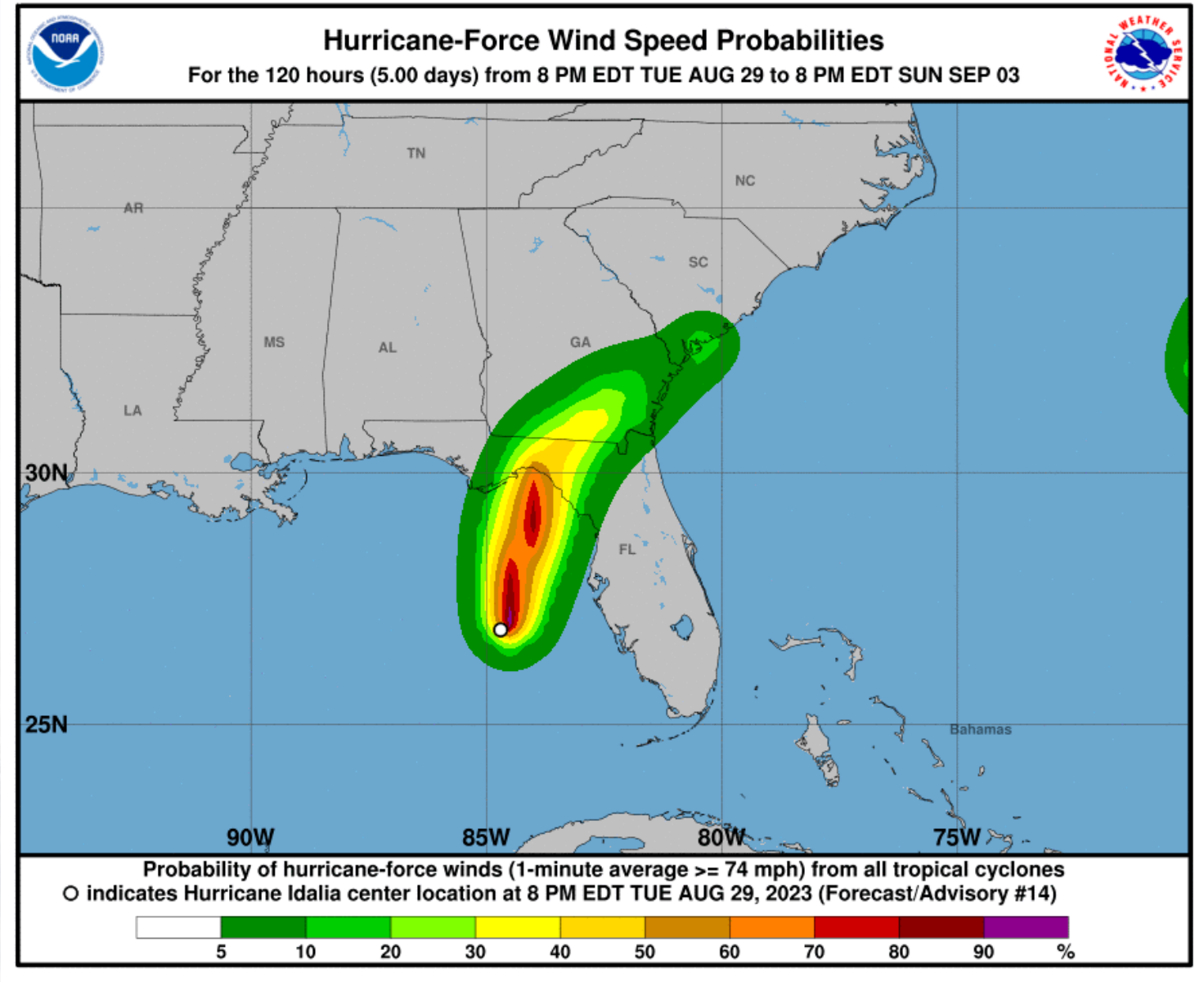

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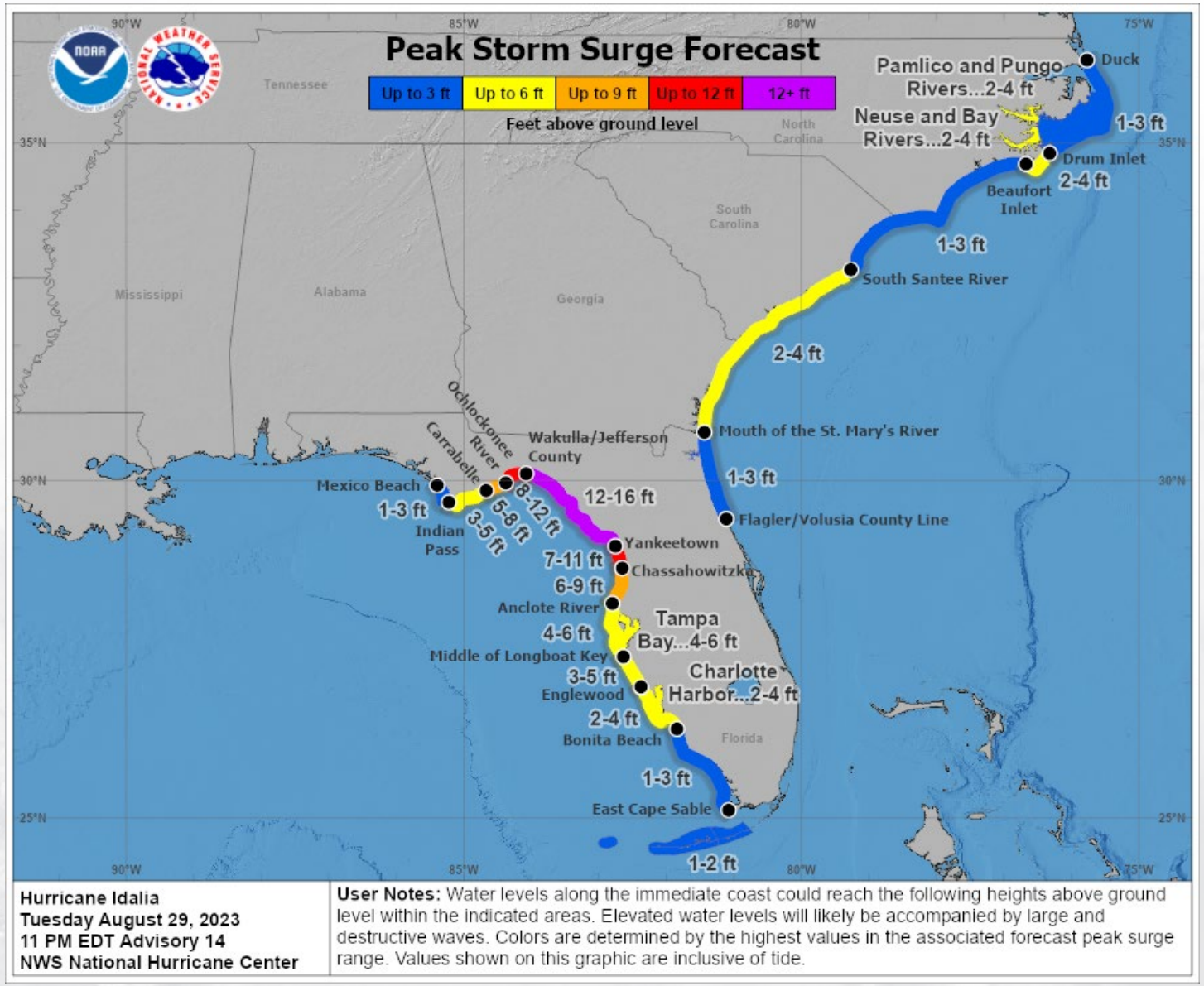
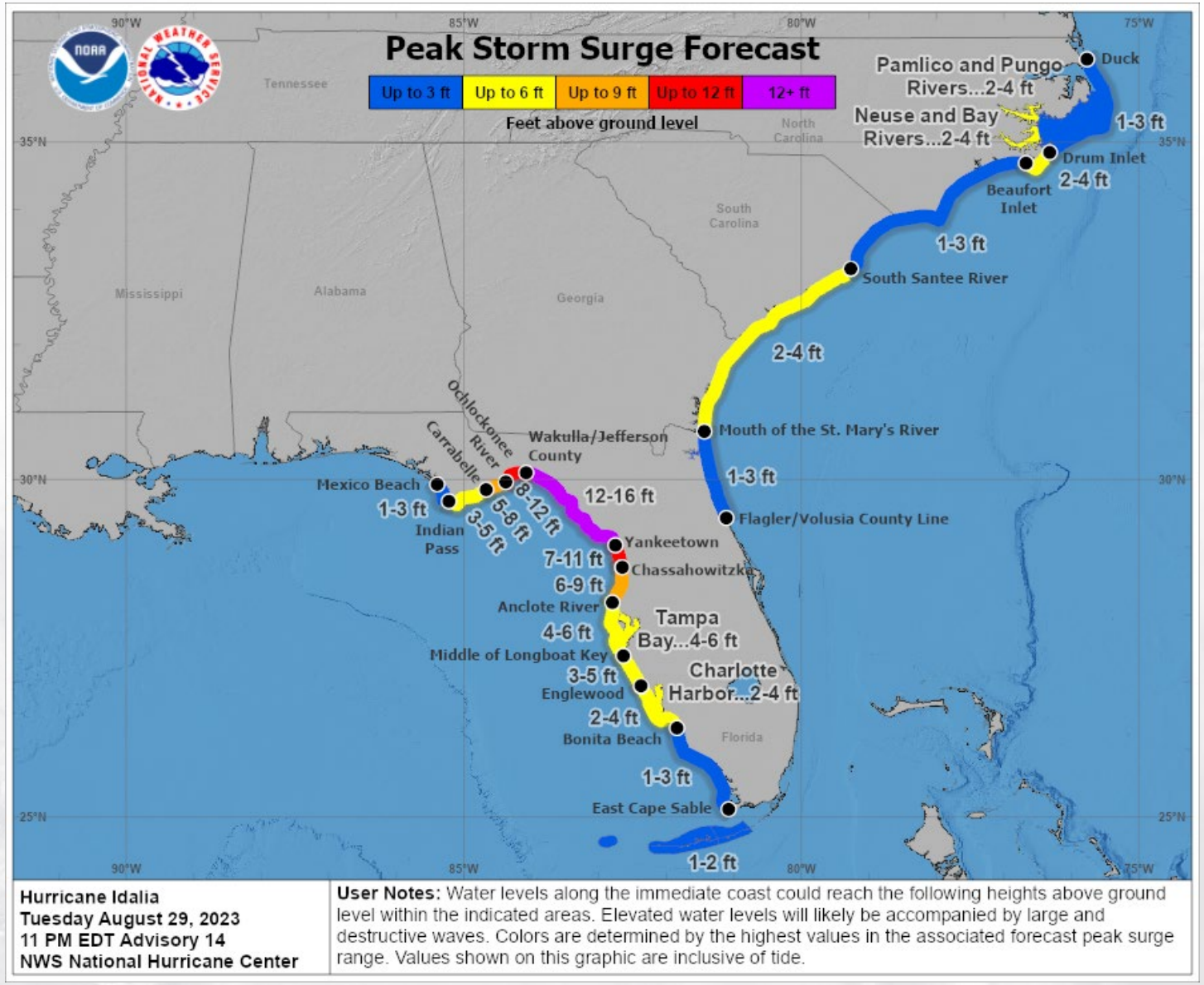


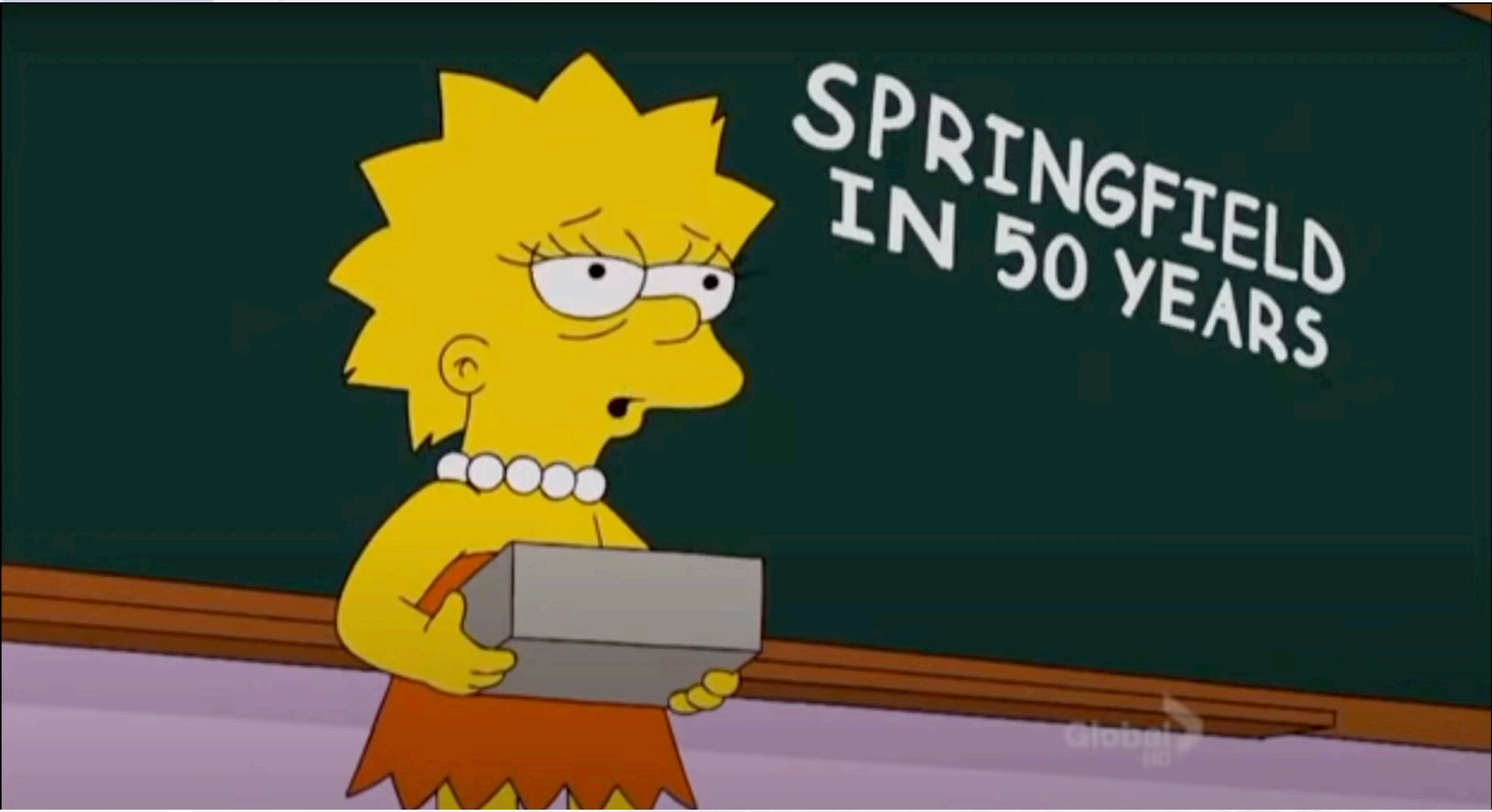
Scaling Risk Information

The depiction of tropical cyclone risk went through a scaling evolution.

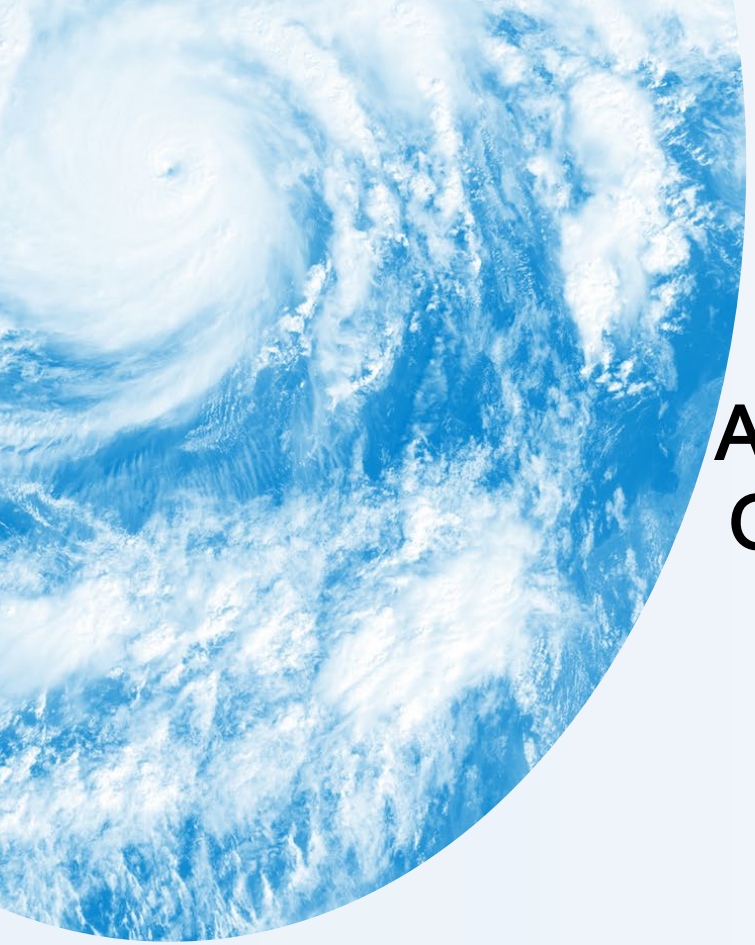
A similar scaling evolution is happening now to depict tropical cyclone risk in a changing climate.



The Simpsons


SPRINGFIELD
IN 50 YEARS

Known Knowns



Known Knowns

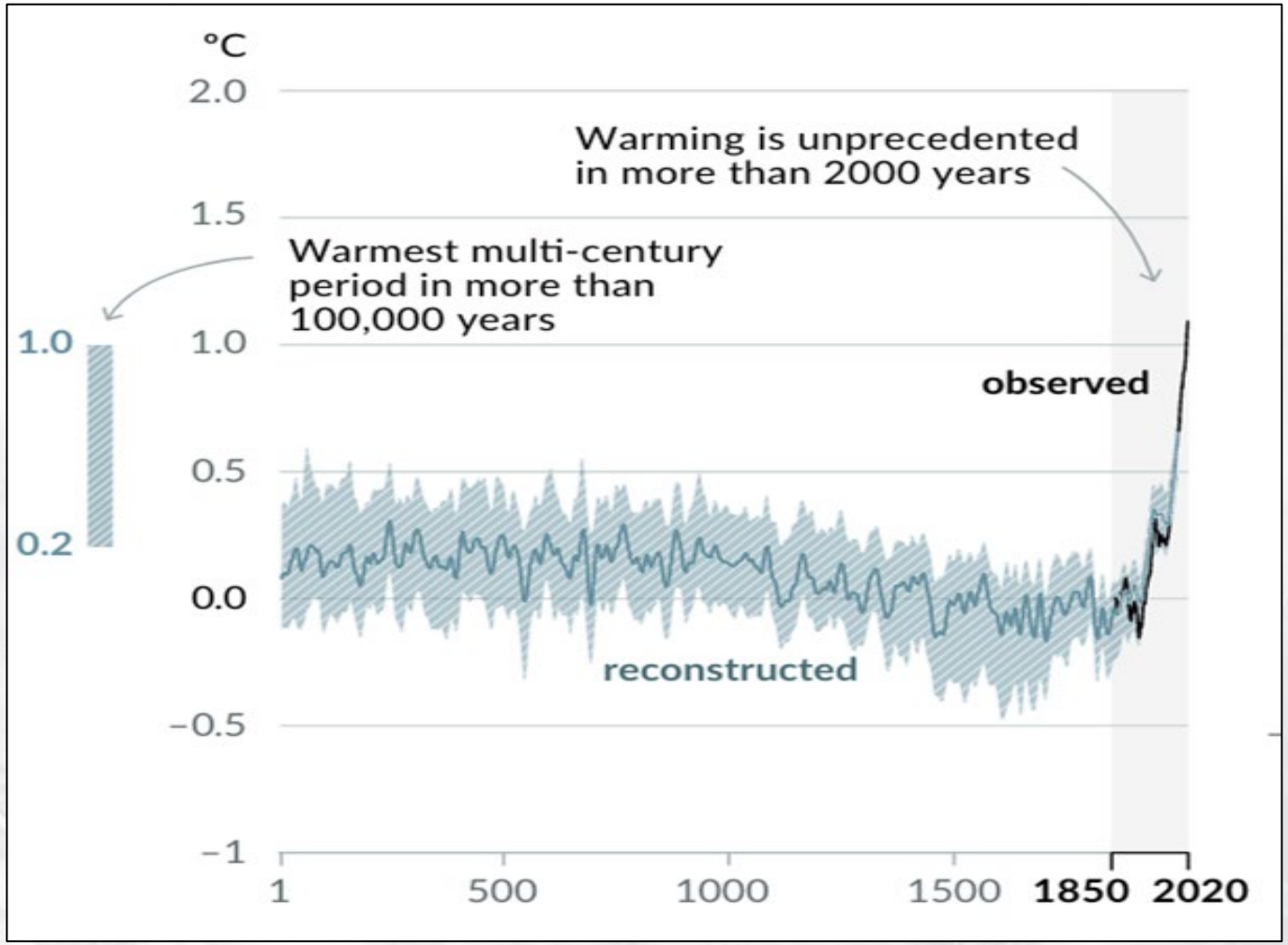
Atmosphere and Ocean Warming

01

The Atmosphere is Warming Globally

IPCC 6th Assessment Report

- The warming is unequivocal and human influenced
- Last four decades have been successively warmer



Source: IPCC

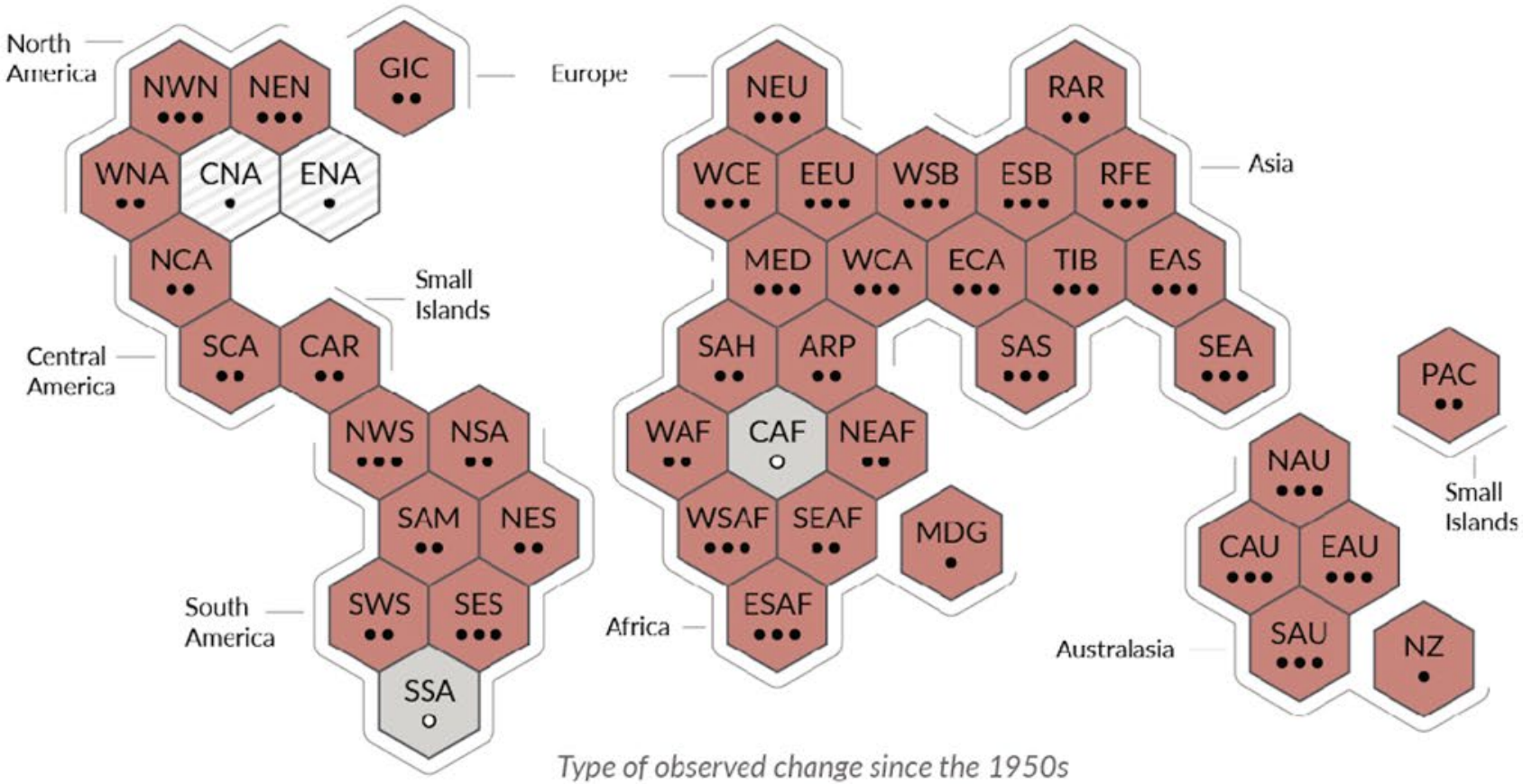
The Atmosphere is Warming Regionally

Type of observed change
in hot extremes

- Increase (41)
- Decrease (0)
- Low agreement in the type of change (2)
- Limited data and/or literature (2)

Confidence in human contribution
to the observed change

- ●●● High
- ●● Medium
- ● Low due to limited agreement
- ○ Low due to limited evidence

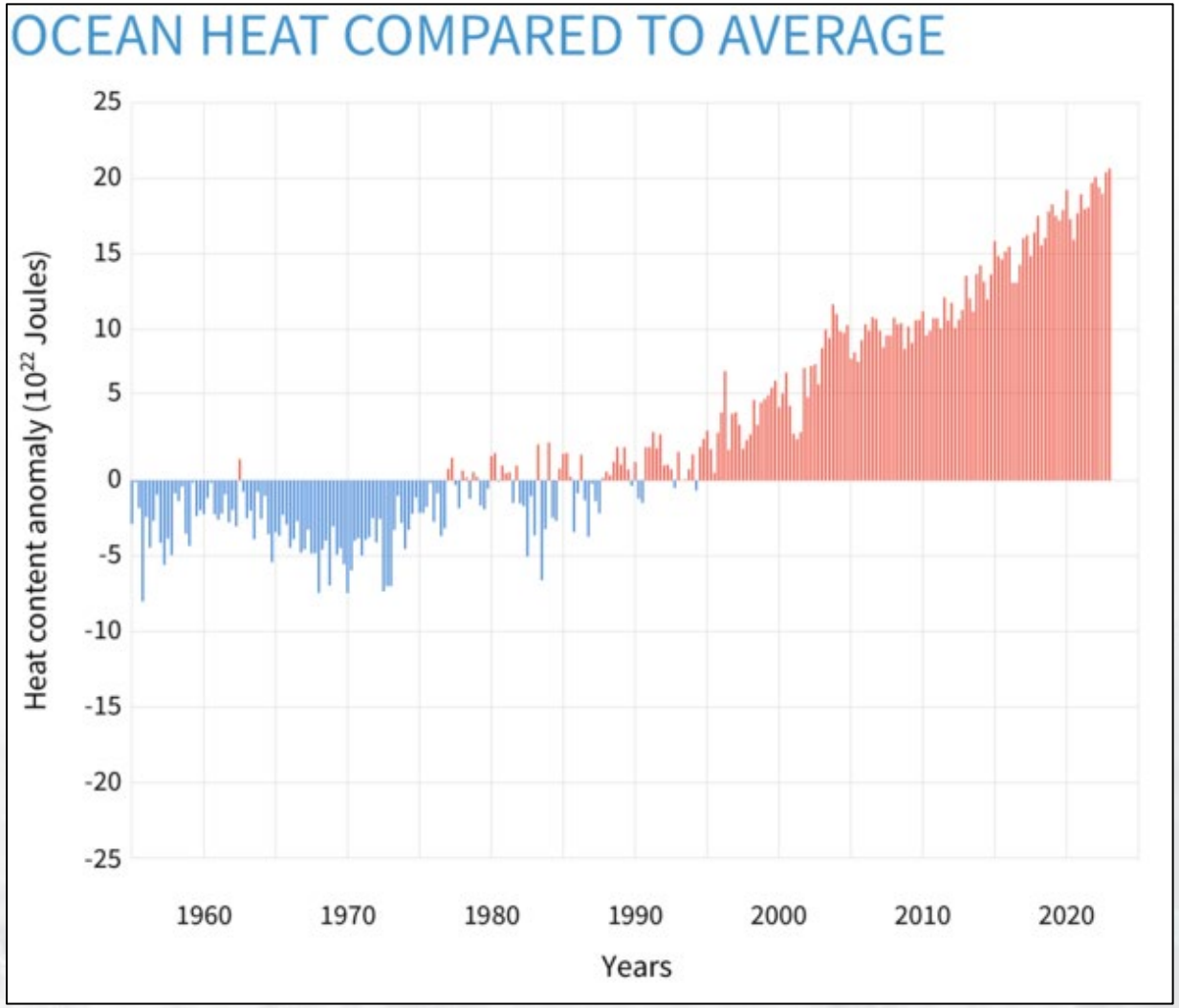


Type of observed change since the 1950s

Source: IPCC

The Ocean is Warming Globally

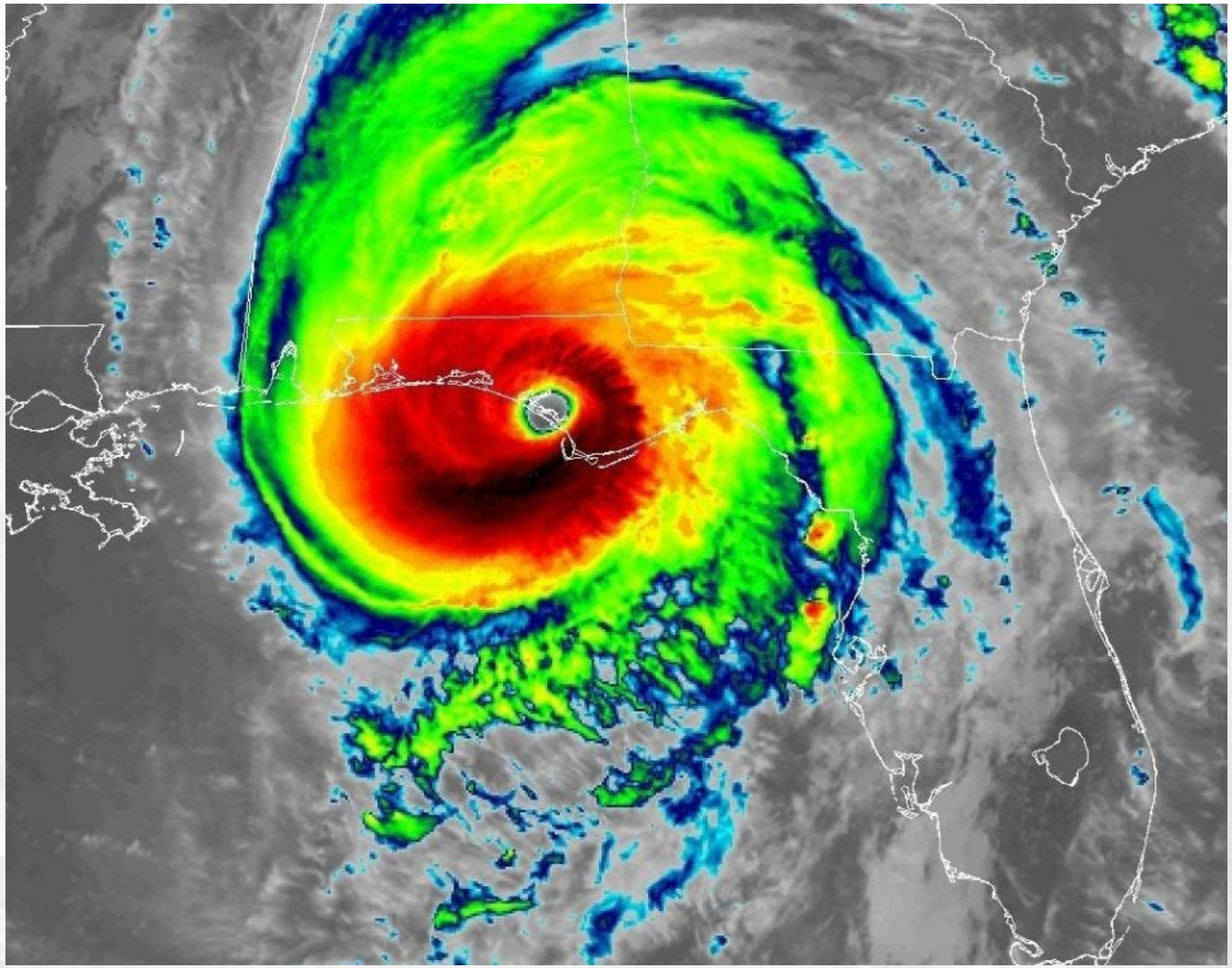
- Hurricanes get their energy from the ocean
- Increase in tropical cyclone intensity is consistent with potential intensity theory (observation + theory support)
- Projected changes in regional ocean patterns are highly uncertain.



Source: NOAA

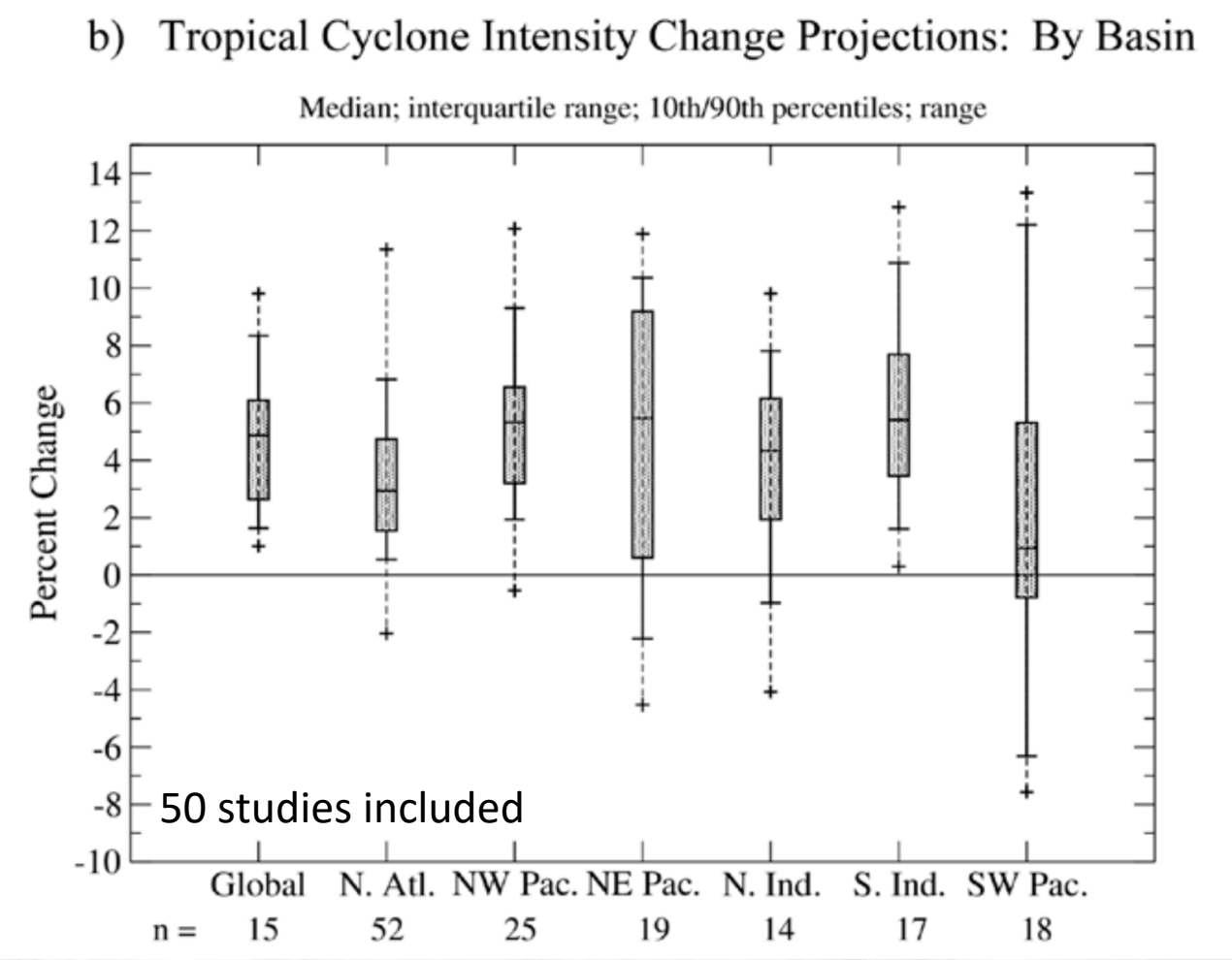
Warmer Ocean = Stronger Tropical Cyclone Intensity

- Increased proportion of the strongest hurricanes (Categories 4 and 5)
- Strongest winds expected to increase between 1-10%



Warmer Ocean = Stronger Tropical Cyclone Intensity

- Increased proportion of the strongest hurricanes (Categories 4 and 5)
- Strongest winds expected to increase between 1-10%
- Image: Summary of 50 studies projecting intensity change globally and by basin.
  - Global increase, regions have more variability but still show an increase
- Among 29 Caribbean islands, 22 were affected by at least one Category 4 or 5 TC in 2017

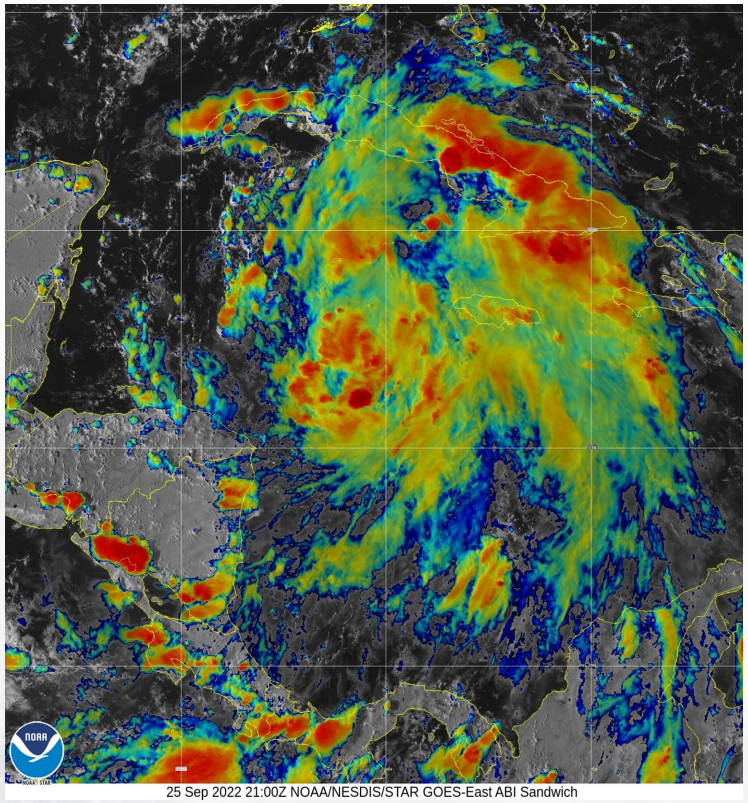


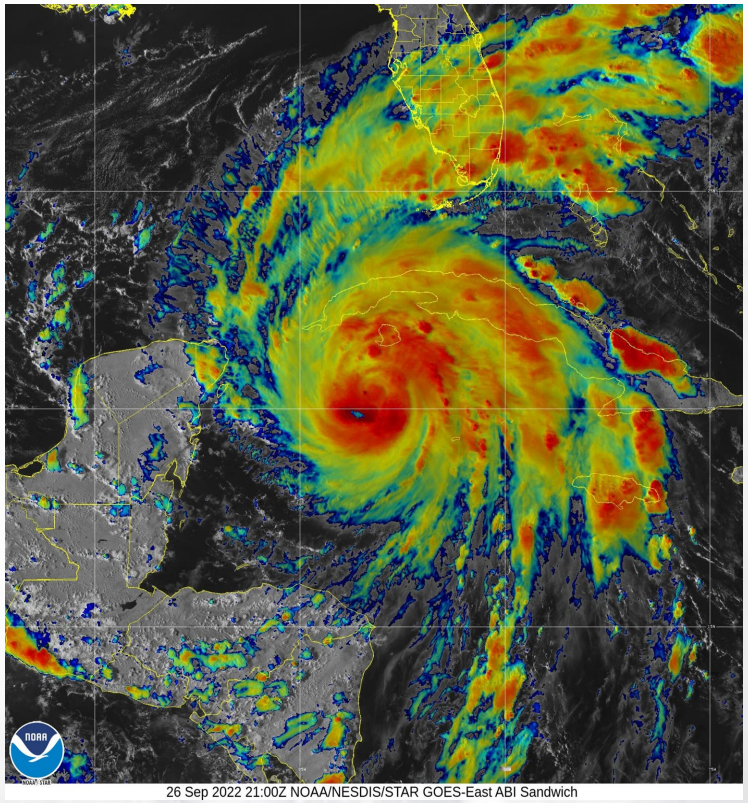
Source: WMO Taskforce

Hurricane Intensification

- Frequency of rapid intensification has increased
- Intensification rate has increased (~29% increase between 2001-2020 compared to 1971-1990)

Hurricane Ian

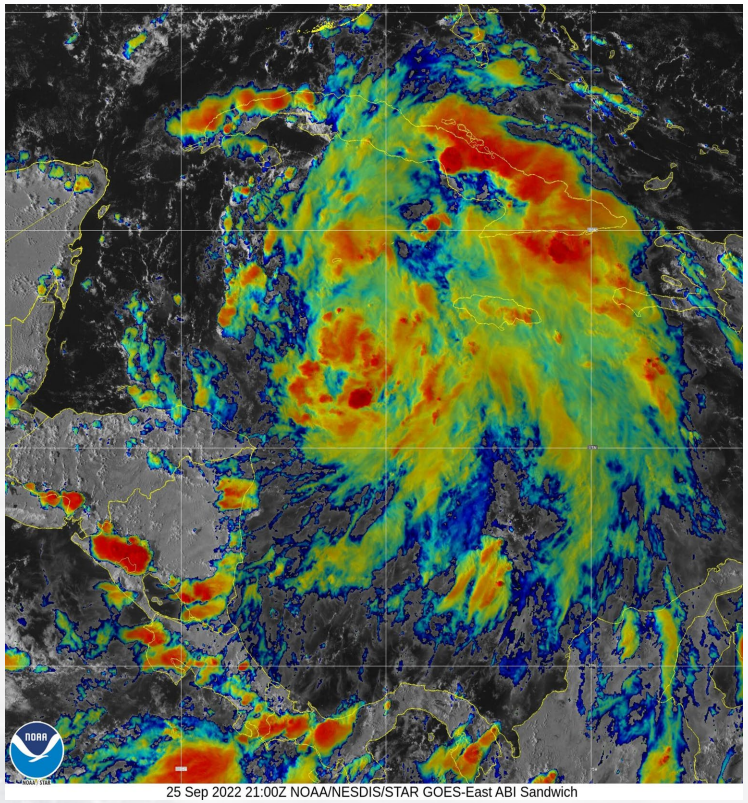


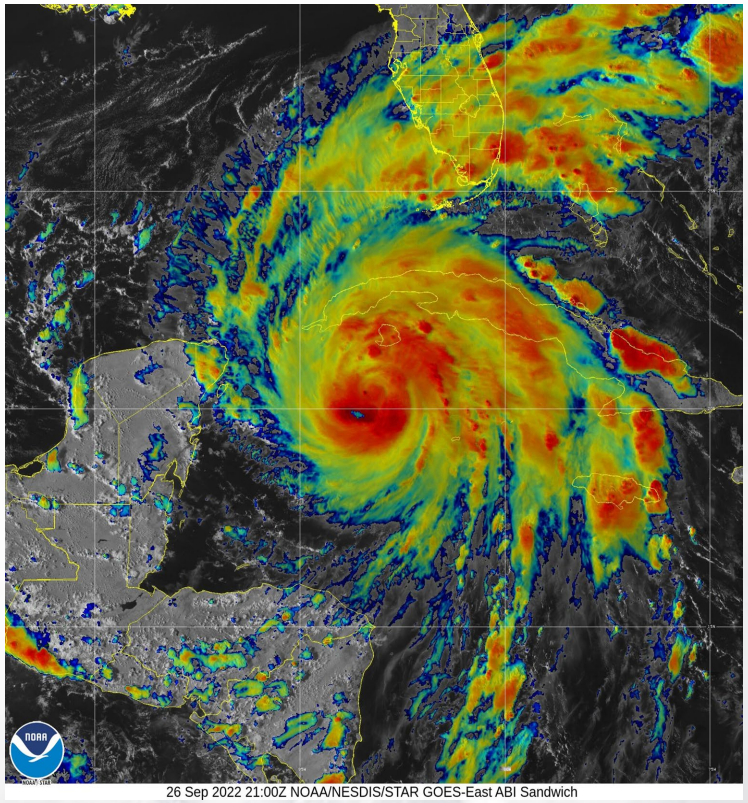


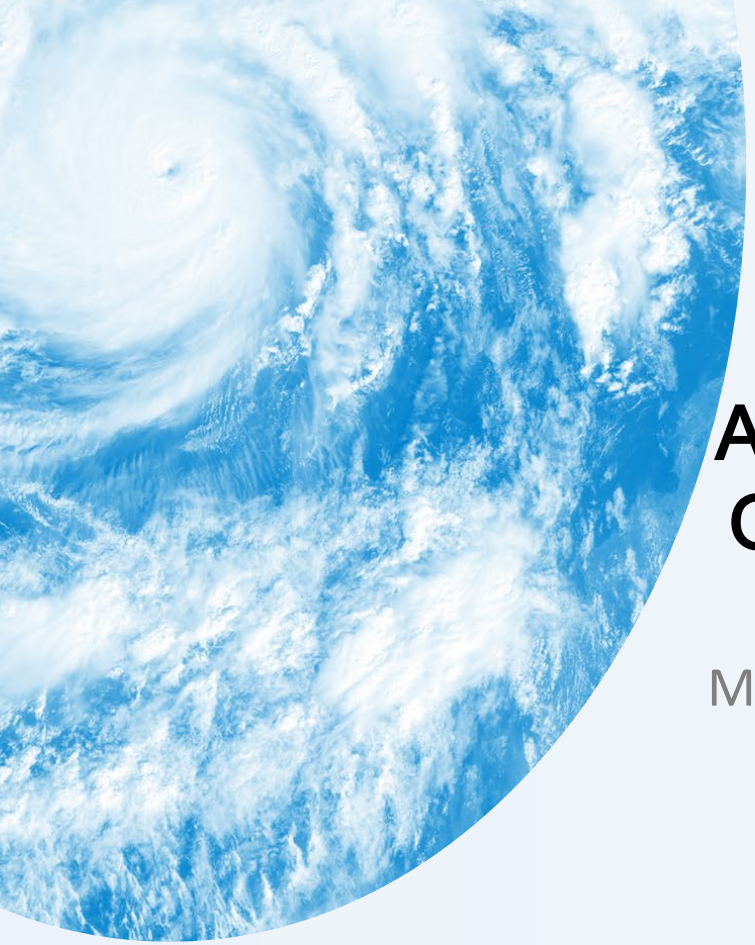
Hurricane Intensification

- Frequency of rapid intensification has increased
- Intensification rate has increased (~29% increase between 2001-2020 compared to 1971-1990)
- Connects to potential intensity theory
- Potentially less time for coastal communities to prepare for severe hurricanes

Hurricane Ian



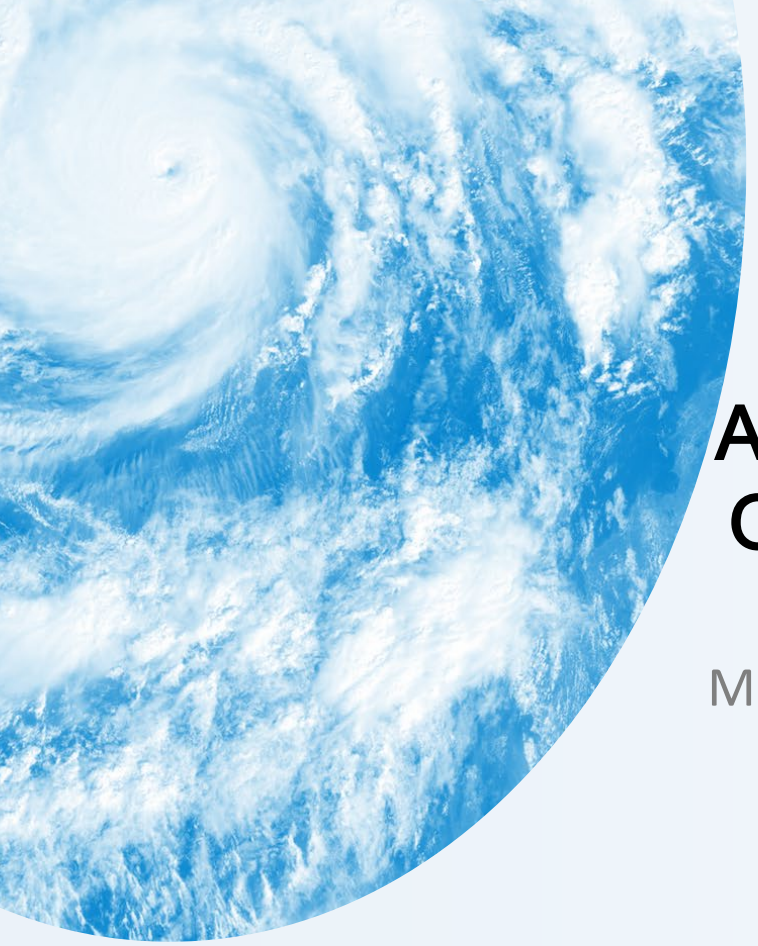




Known Knowns

01 Atmosphere and Ocean Warming

Stronger winds,
More rapid intensification



Known Knowns

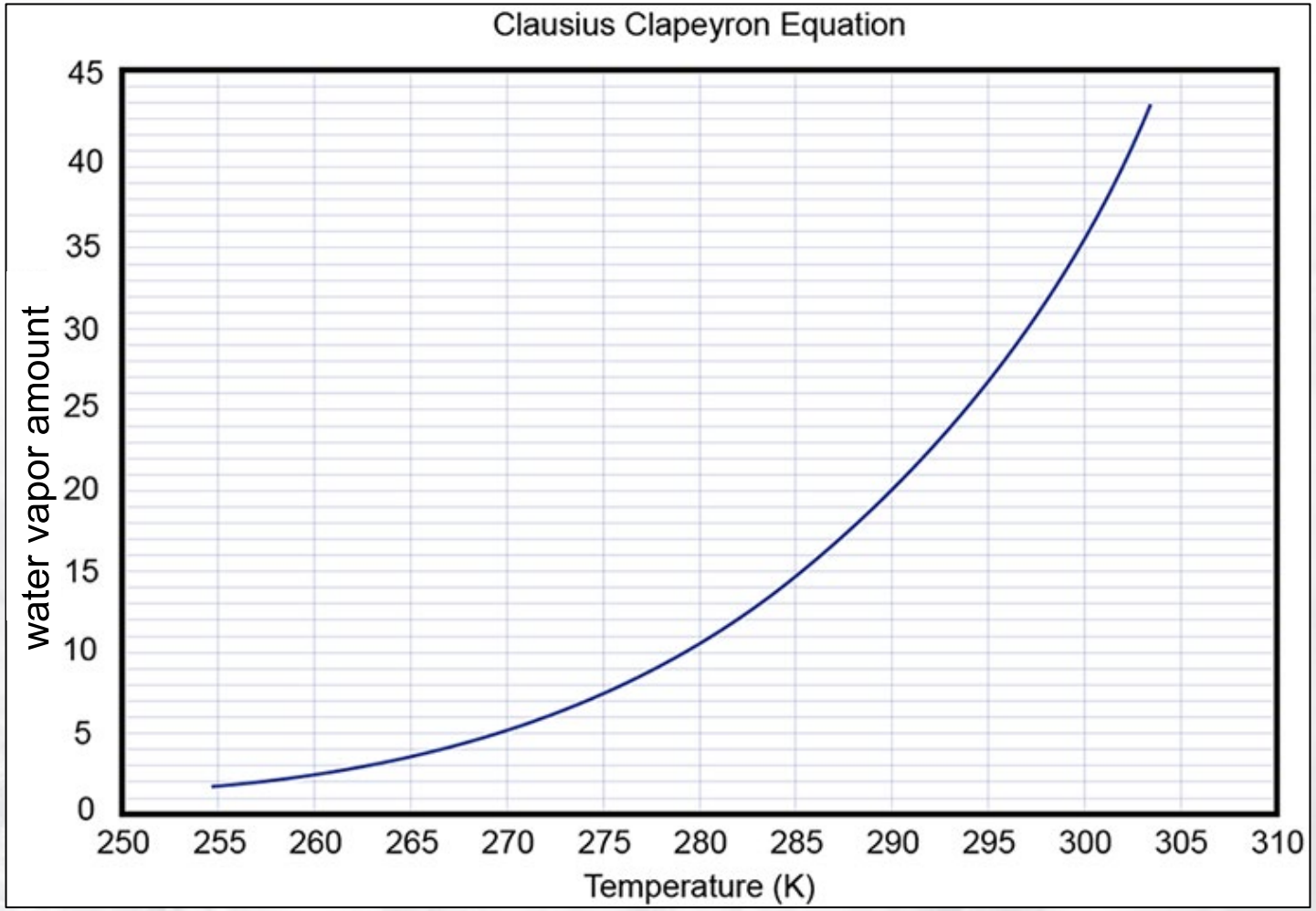
01 Atmosphere and Ocean Warming

Stronger winds,
More rapid intensification

02 More Moisture in the Atmosphere

Moisture in the Atmosphere Globally

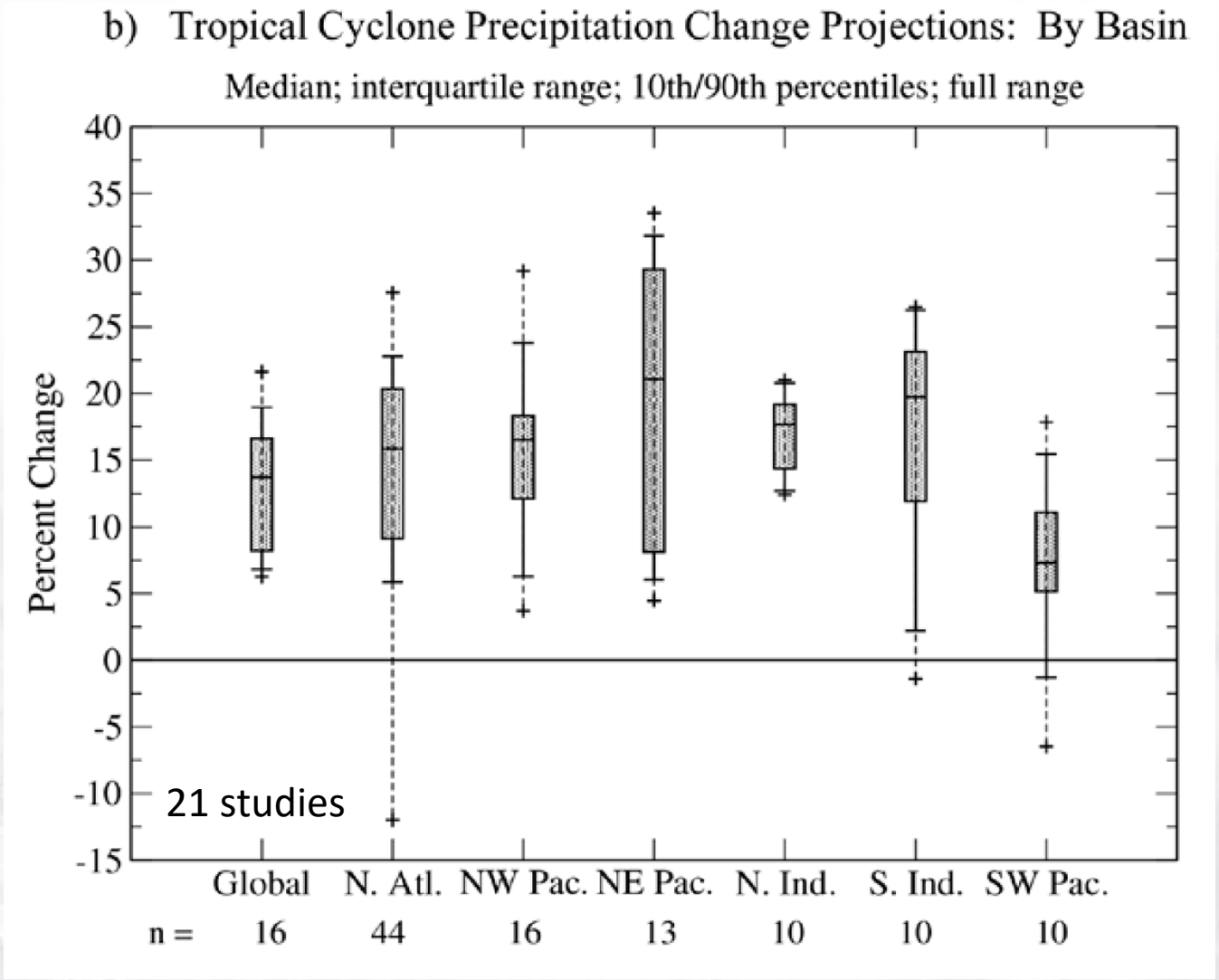
- Clausius-Clapeyron relationship: Warmer atmosphere holds more moisture (observation + theory support)



Source: Penn State

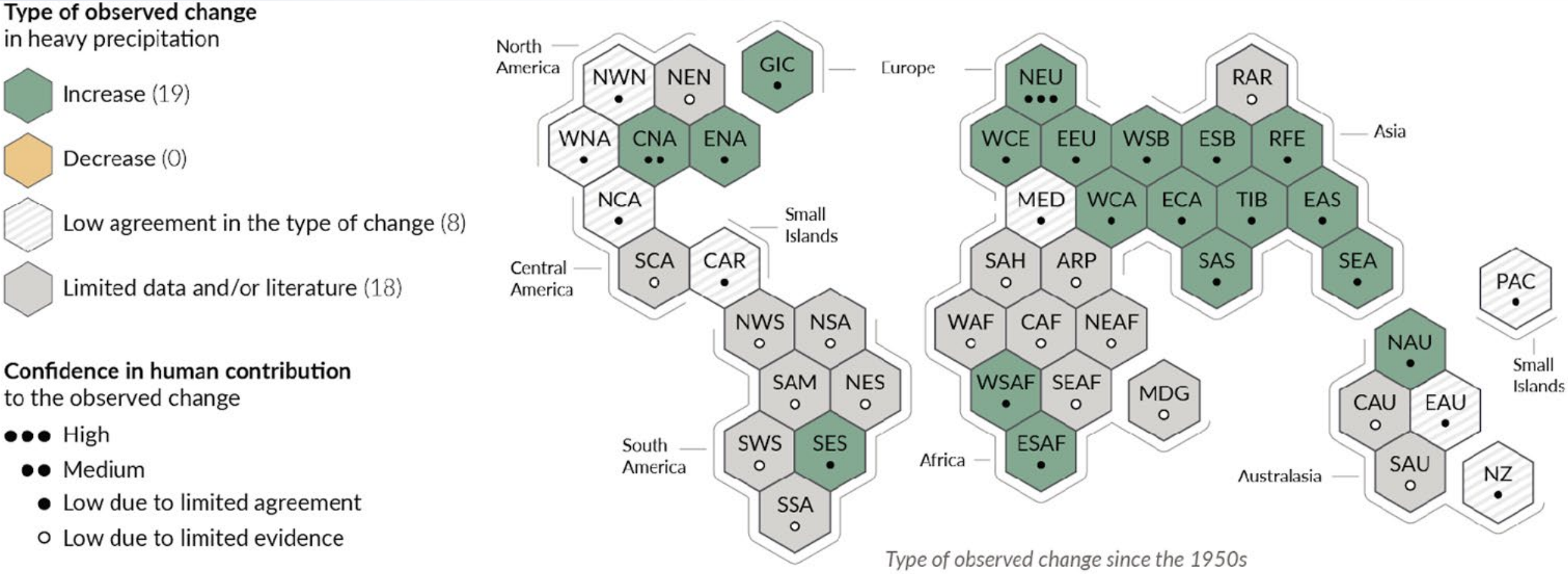
Moisture in the Atmosphere Globally and Regionally

- Clausius-Clapeyron relationship: Warmer atmosphere holds more moisture (observation + theory support)
- Image: Based on 21 studies, rainfall rates globally projected to increase between 6-22%.
  - More variability regionally but still increases
- Impact: Heavier rainfall and more inland flooding

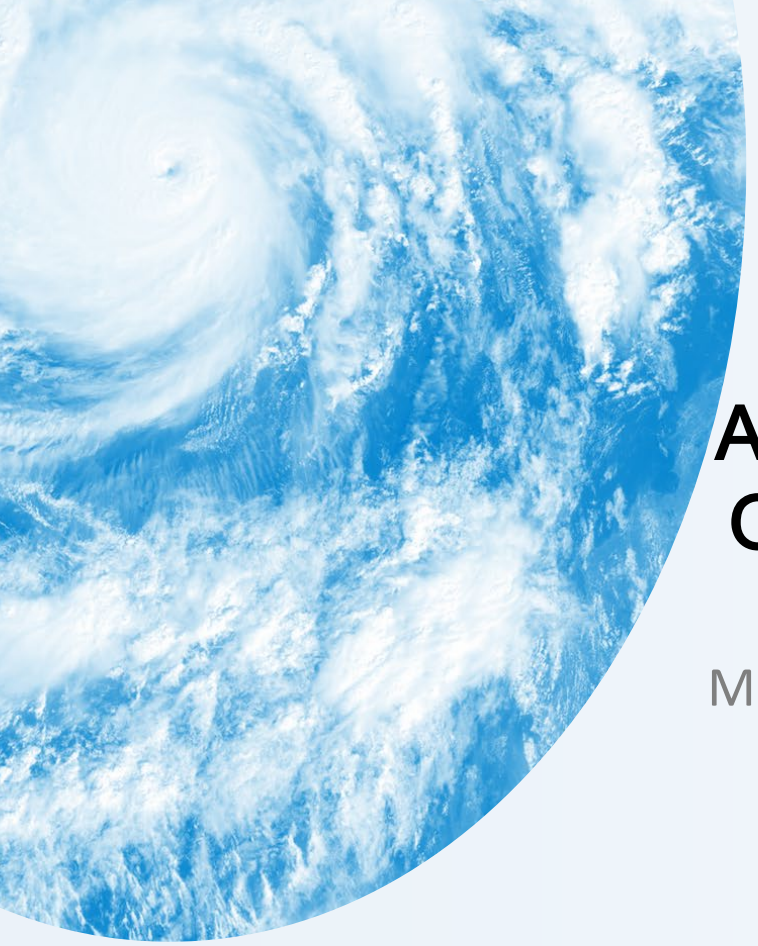


Source: WMO

Moisture in the Atmosphere Regionally



Source: IPCC



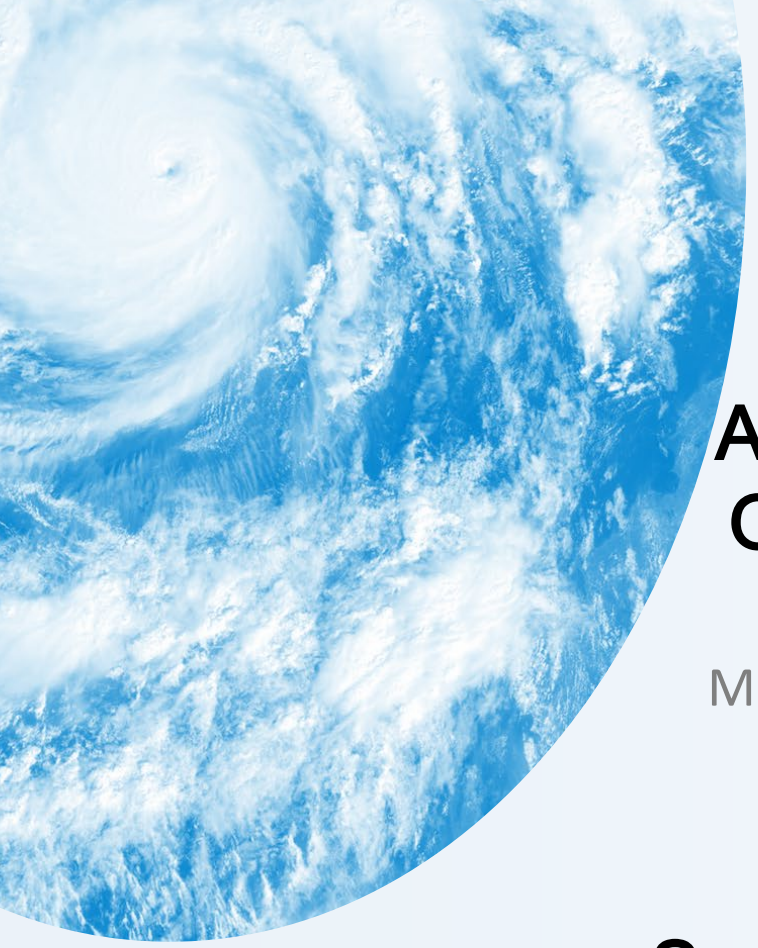
Known Knowns

01 Atmosphere and Ocean Warming

Stronger winds,
More rapid intensification

02 More Moisture in the Atmosphere

Heavier rainfall
More inland flooding



Known Knowns

01 Atmosphere and Ocean Warming

Stronger winds,
More rapid intensification

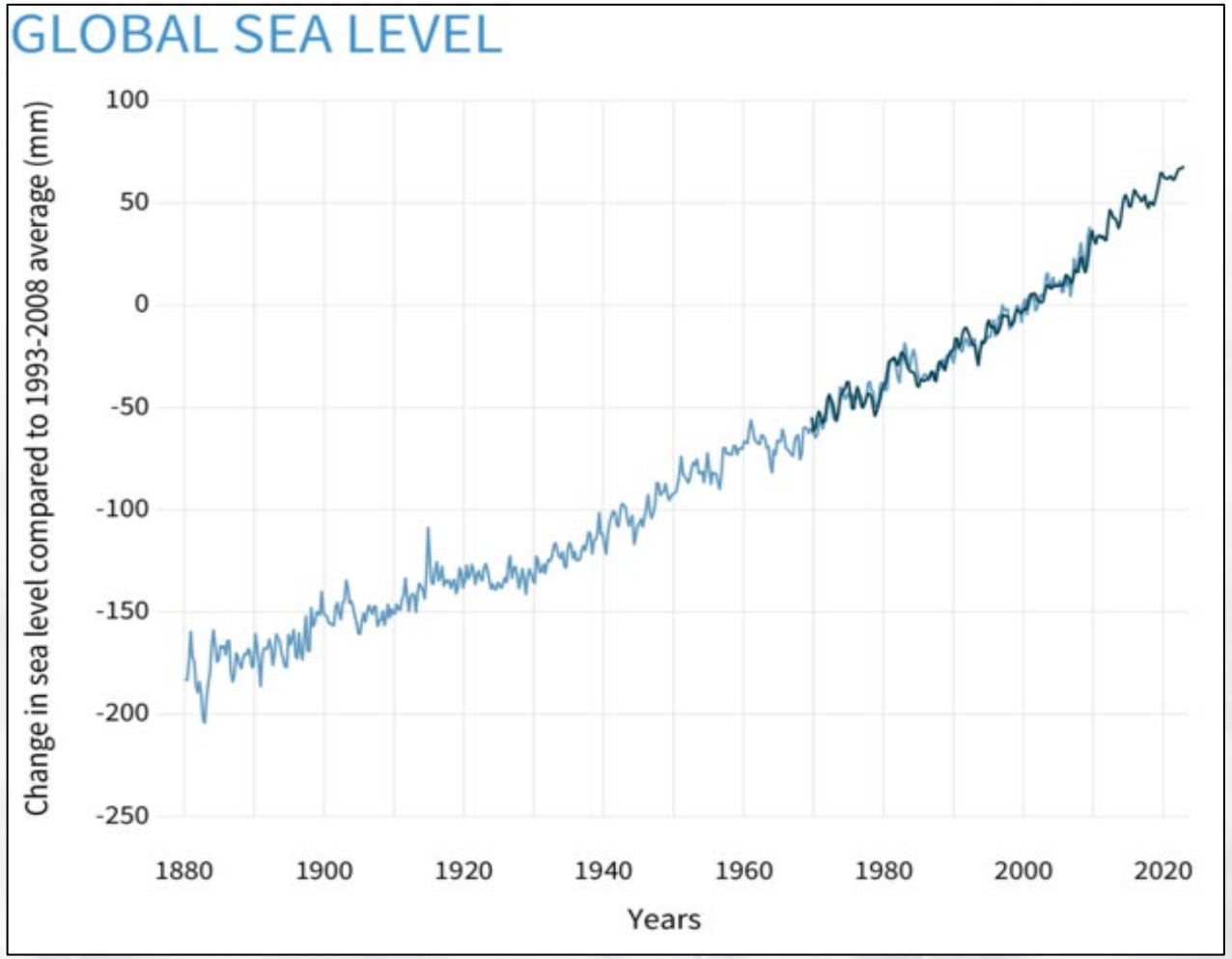
02 More Moisture in the Atmosphere

Heavier rainfall
More inland flooding

03 Sea Level Rise and Sinking Land

Sea Level Rise Globally

- Glaciers and ice sheets are melting, and seawater is expanding as it warms
- As of 2017, an estimated 22 million people in the Caribbean live below 6-m elevation



Source: NOAA

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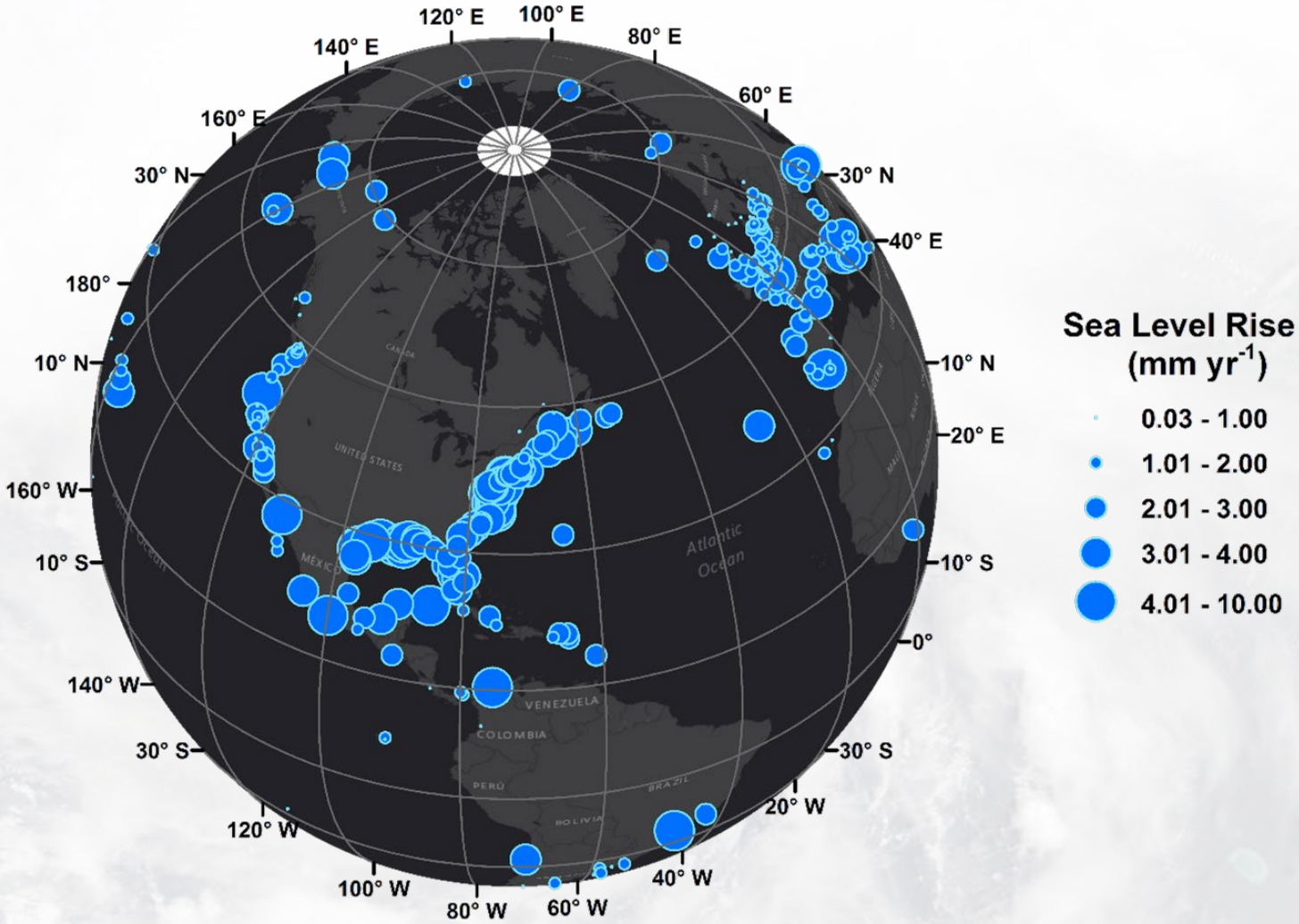
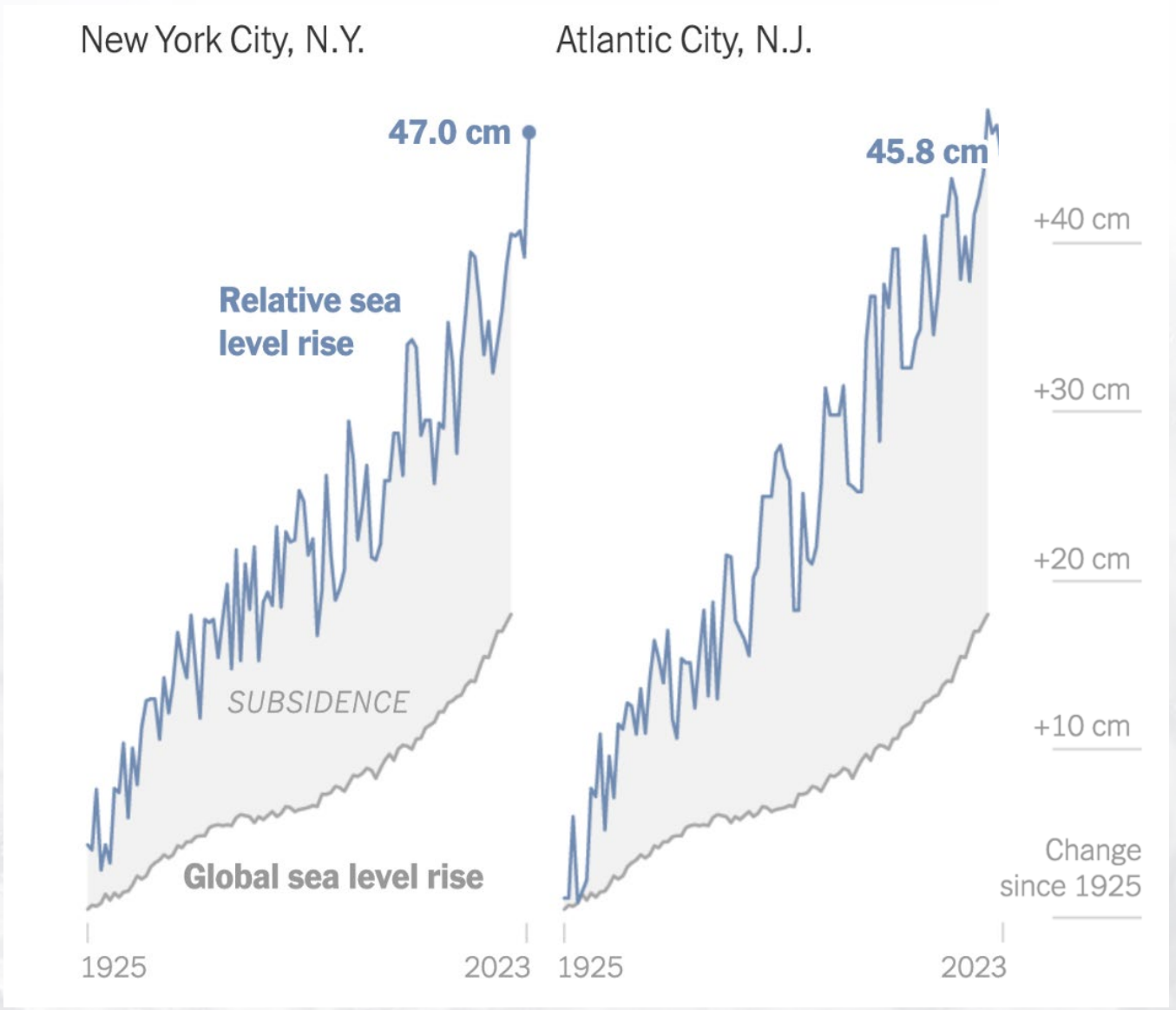


Sinking Land Regionally

- Entire U.S. east coast is sinking due to groundwater depletion
- Some locations are sinking over 10 cm per decade (faster than average global sea level rise of 3.3 cm per decade)

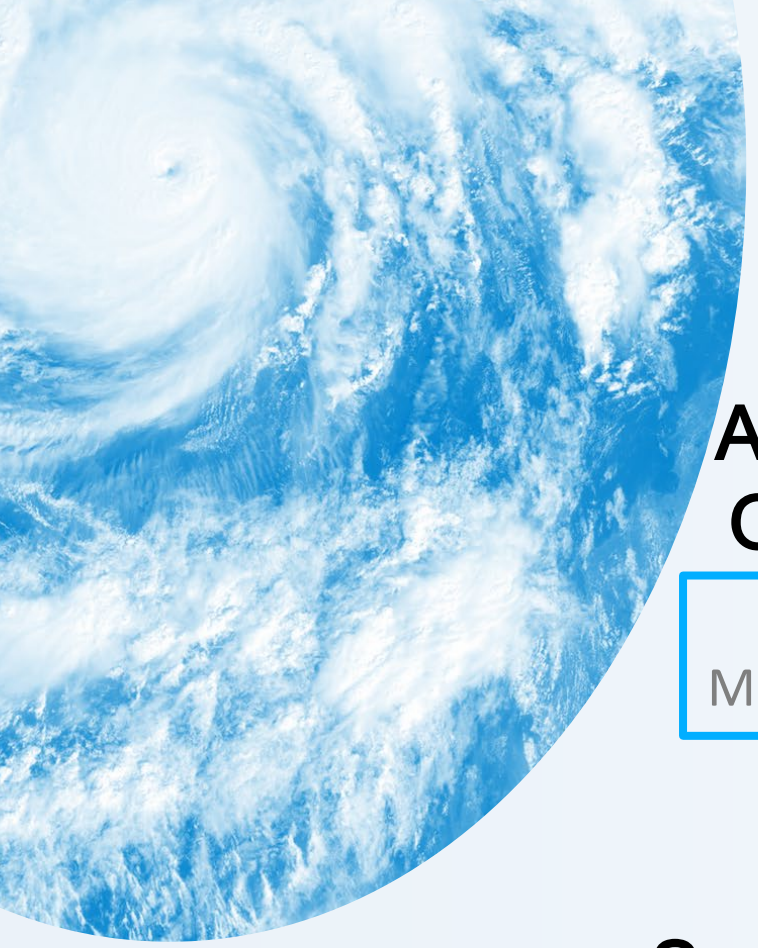


Source: Dangendorf (2019), National Oceanography Centre, NY Times

Sea Level Rise + Land Subsidence = Increased Storm Surge Inundation

- WMO Taskforce: “projected increases in sea level, average TC intensity, and TC rainfall rates will each generally act to further elevate future storm surge risk”
- Observation and theory support for increased storm surge inundation
- Anticipated to rise by about 2 to 3 feet (0.4 to 0.8 meters) by 2100
- Coastal inundation exacerbated in the Caribbean

Storm surge during Hurricane Ian (2022)



Known Knowns : Tropical Cyclone hazards are getting more severe

01 Atmosphere and Ocean Warming

Stronger winds,
More rapid intensification

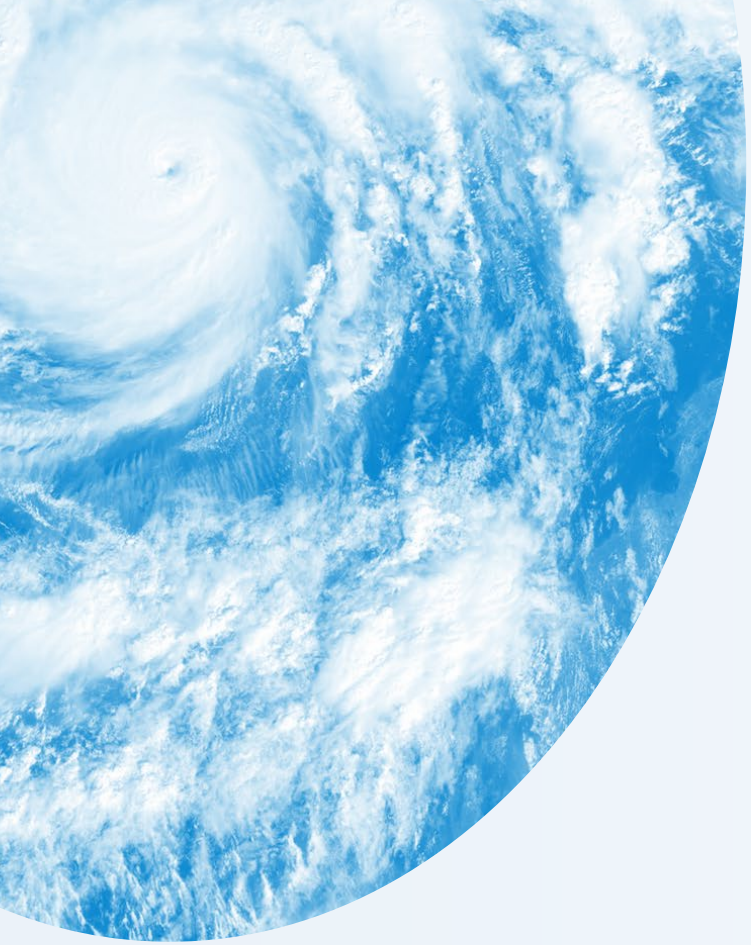
02 More Moisture in the Atmosphere

Heavier rainfall
More inland flooding

03 Sea Level Rise and Sinking Land

More storm surge flooding

Known Unknowns

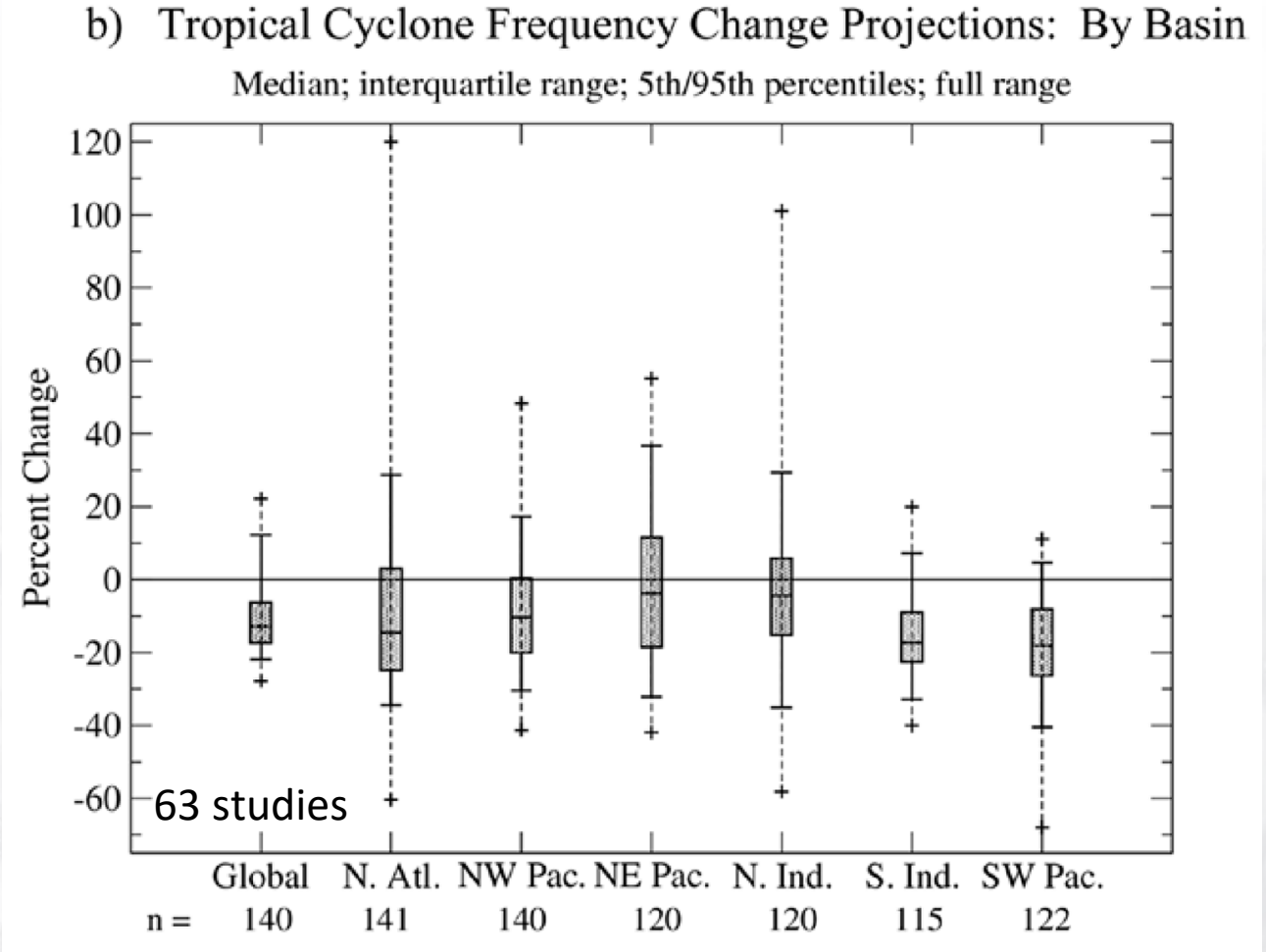


Known Unknowns

Number of Storms 01

Number of Storms: Globally and Regionally

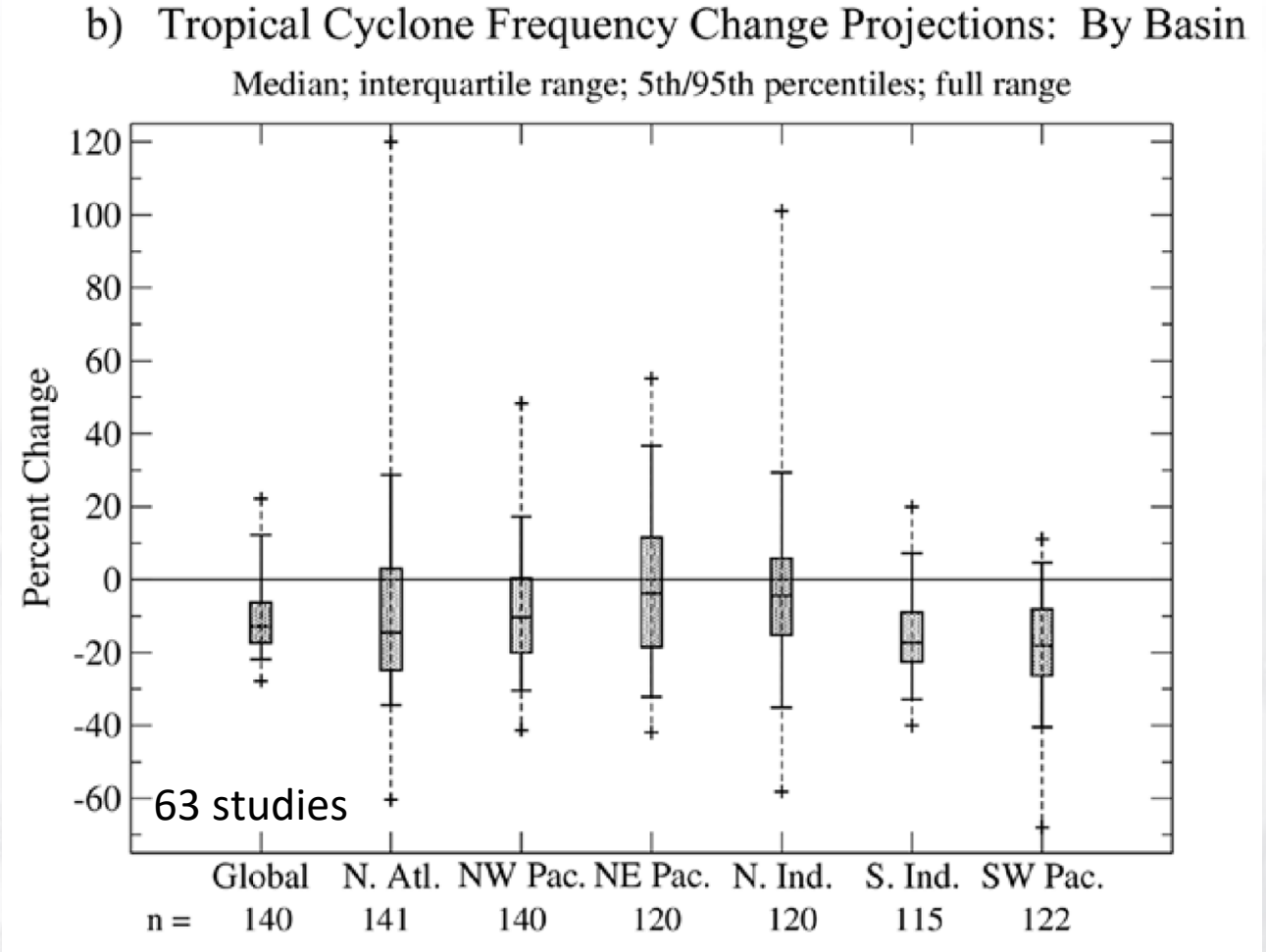
- Image: Summary of 63 studies showing global and regional uncertainty in TC frequency changes.



Source: WMO Taskforce

Number of Storms: Globally and Regionally

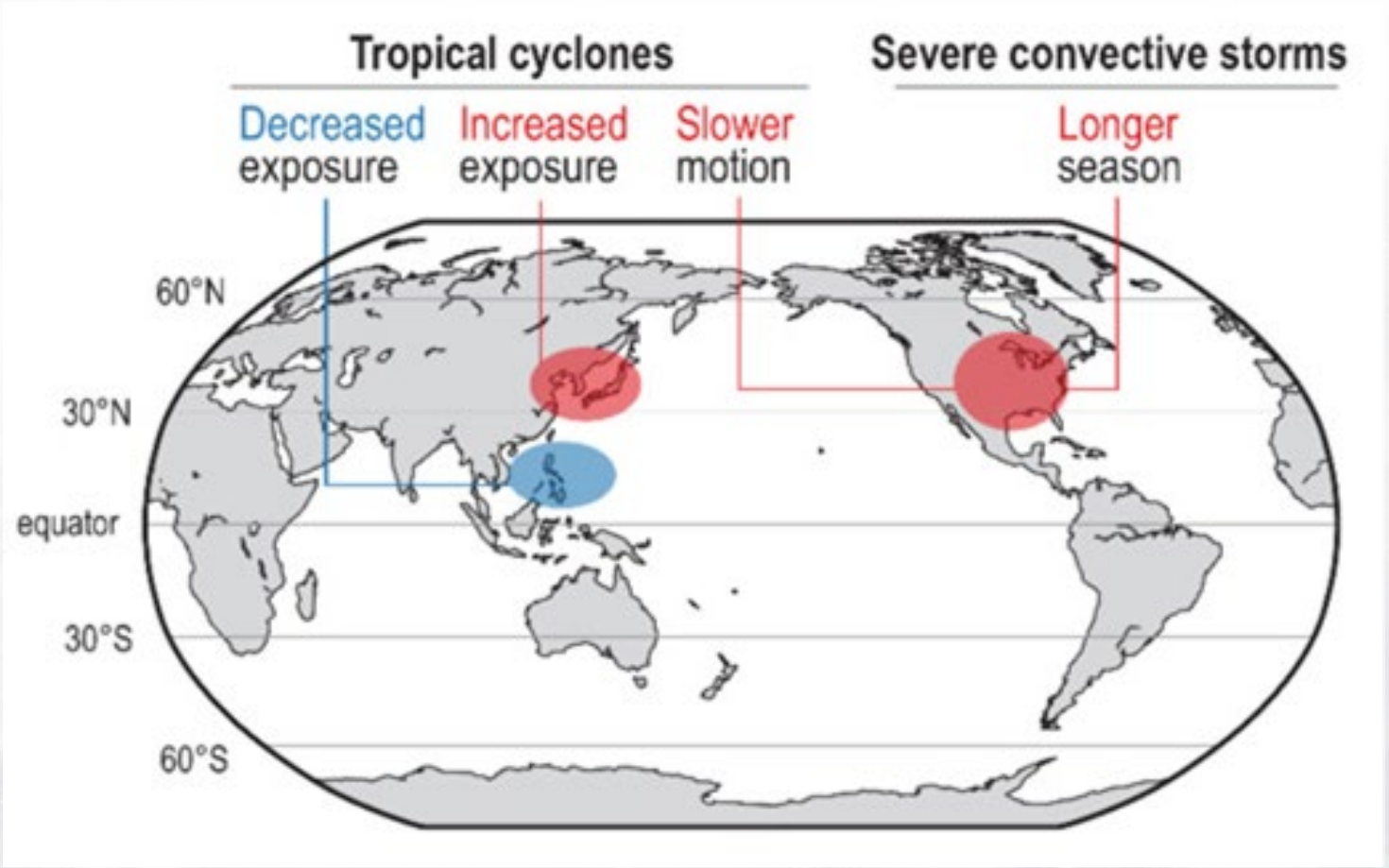
- Image: Summary of 63 studies showing global and regional uncertainty in TC frequency changes. Hard to determine trends due to other factors:
  - Multi-decadal variability in ocean temperatures, vertical wind shear, decrease in aerosols, Saharan dust variability
- Regardless, the proportion of strongest storms is increasing (known known)



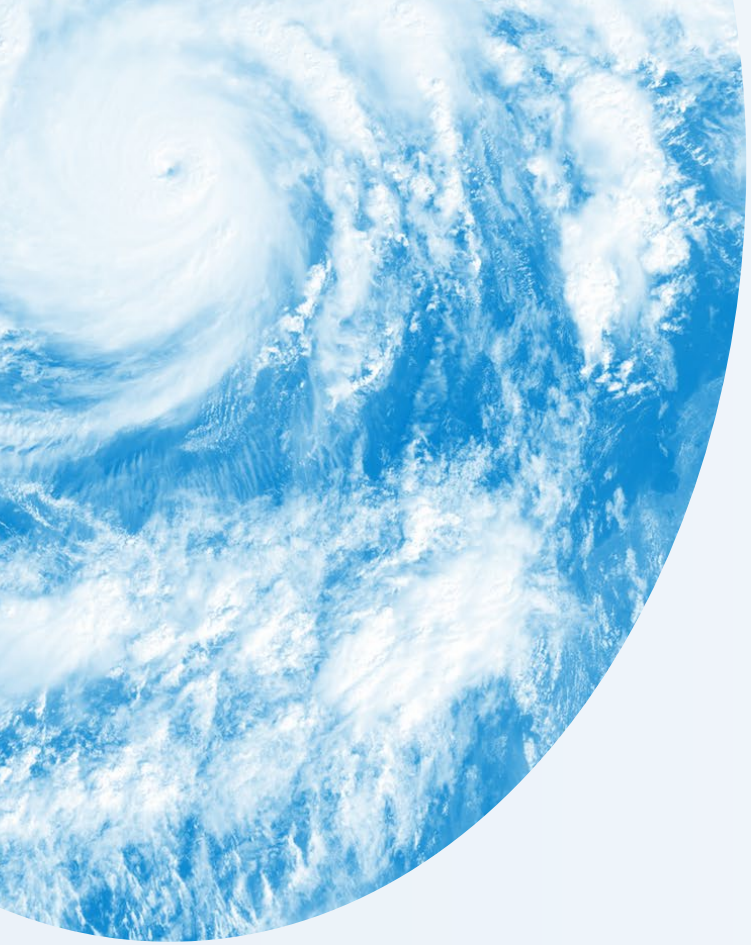
Source: WMO Taskforce

Number of Storms: Globally and Regionally

- From IPCC: *Likely* that "the global frequency of TCs over all categories will decrease or remain unchanged".
- What about the Atlantic Basin? Scaling problem



Source: IPCC



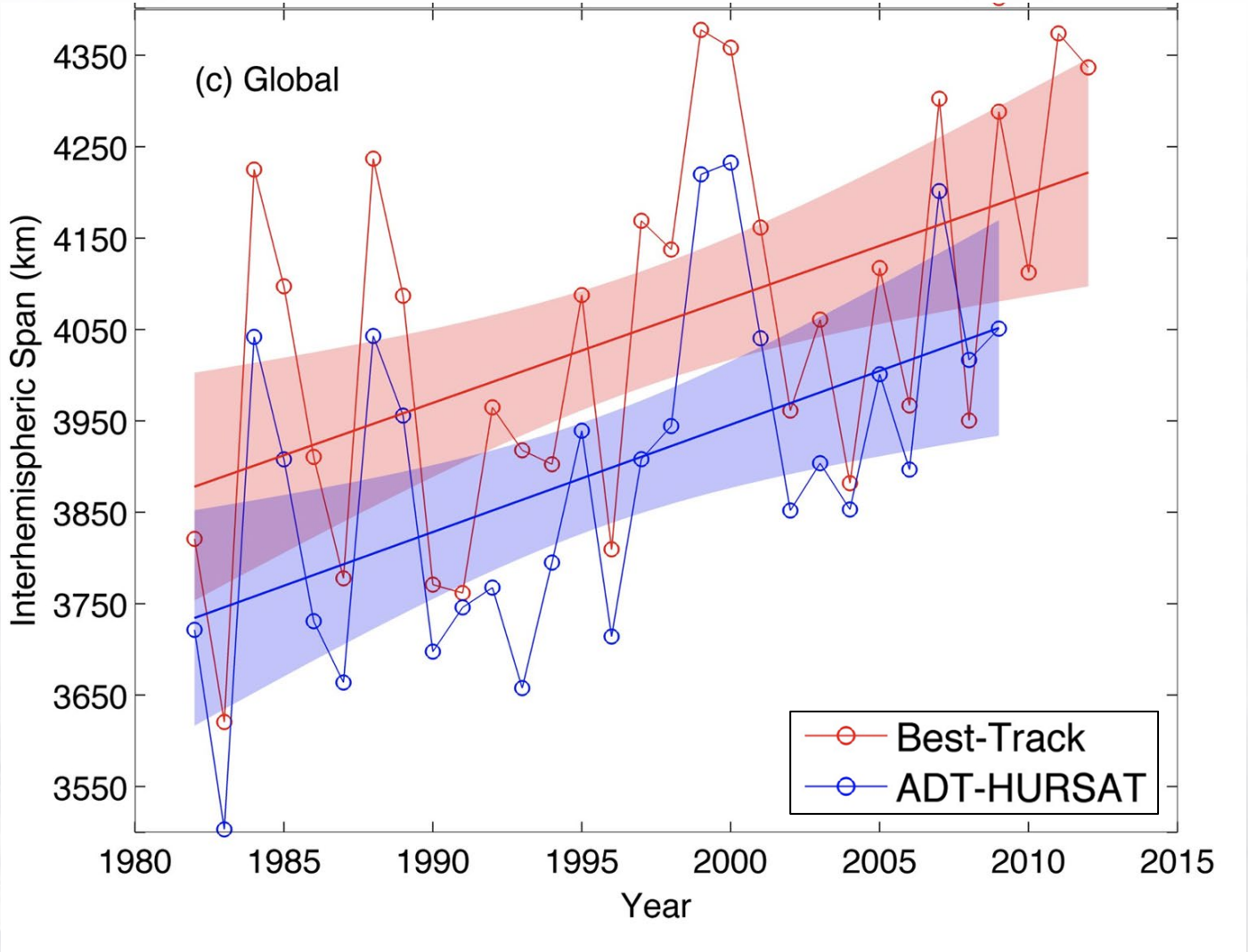
Known Unknowns

01 Number of Storms

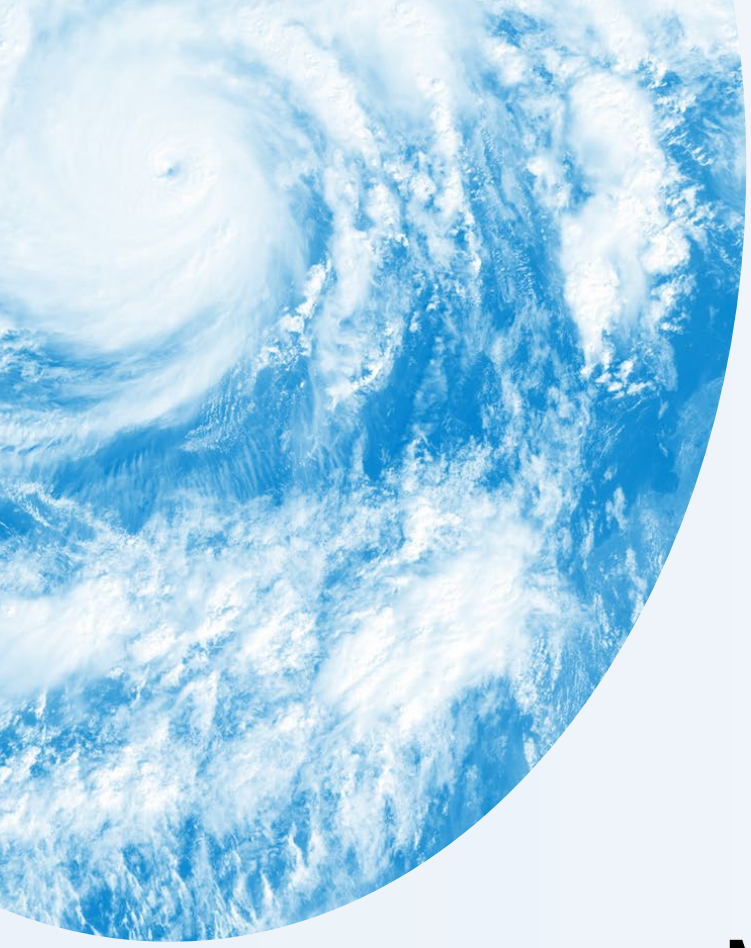
02 Strongest Storms Shifting Location

Strongest Storms Shifting Location Globally

- Image: Observed global poleward shift
- Theoretical reasoning for the shift is unclear, so lower confidence
- United States may have increasing risk of significant impacts, especially on the east coast



Source: Kossin et al. (2014)



Known Unknowns

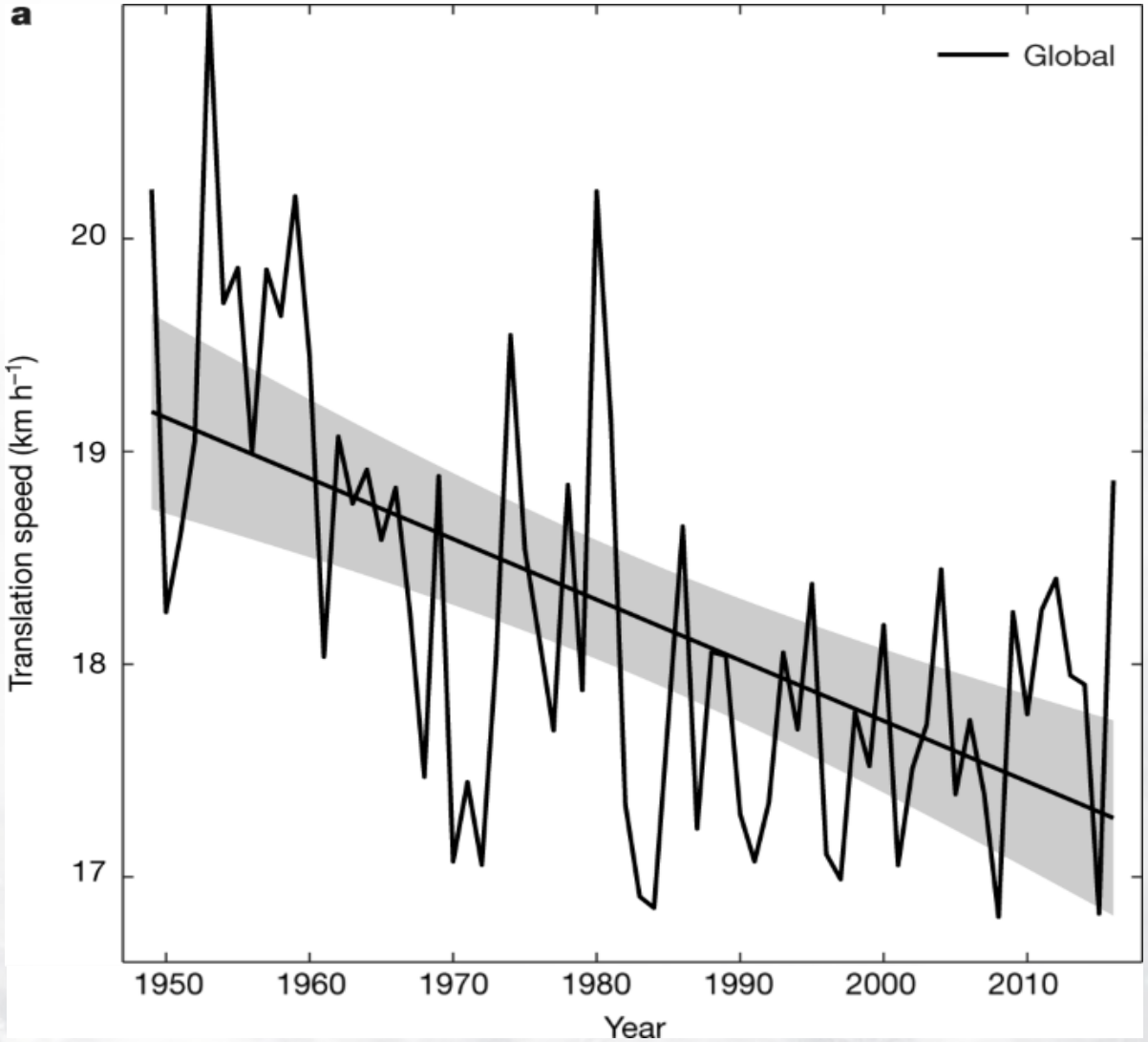
01 Number of Storms

02 Strongest Storms Shifting Location

03 Movement of Storms Changing

Movement of Storms Changing Globally

- Image: Observed global decrease in translation speed
- Limited observational and modeling evidence, so lower confidence
- Longer storm duration means:
  - Increased rainfall-induced flooding
  - Increased storm surge flooding
  - Increased wind damage



Source: Kossin (2018)

Unknown Unknowns

Media Spin

HUFFPOST | HuffPost

Climate Change Deniers Find An Unlikely Hero In Joe Biden's Top Hurricane Expert

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NOAA director shuts down CNN's Don Lemon for linking Hurricane Ian to climate change

By Allie Griffin

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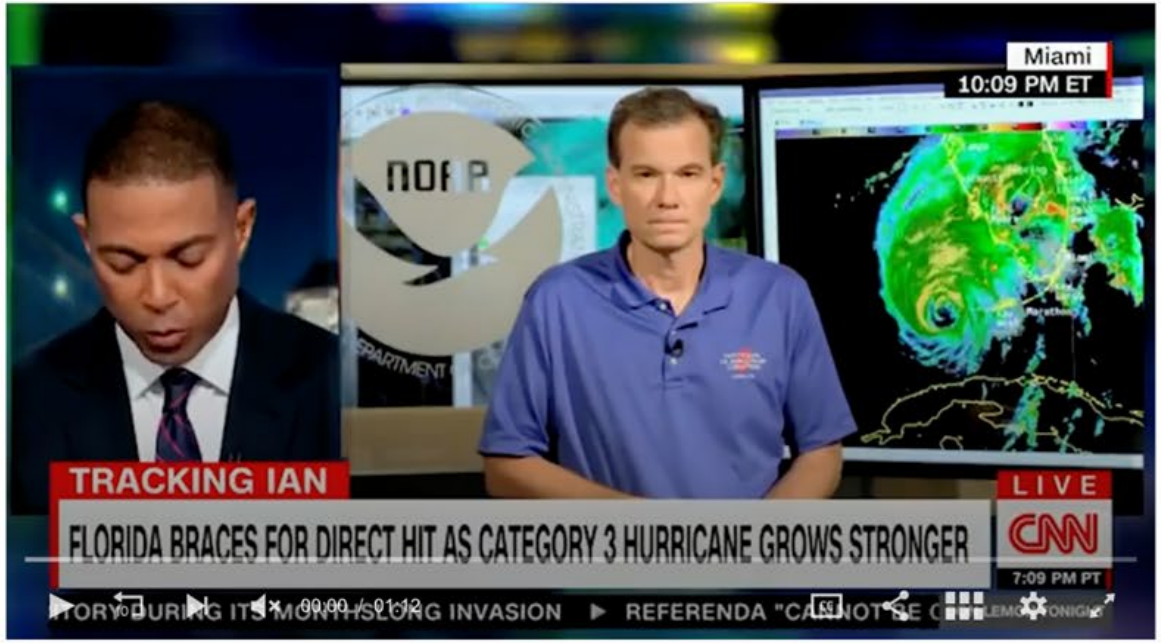


TRENDING NOW
IN US NEWS


53,508
'Killer squatter' leads cops to skeleton of 19-year-old farmer who vanished after phone call with grandma in 2022

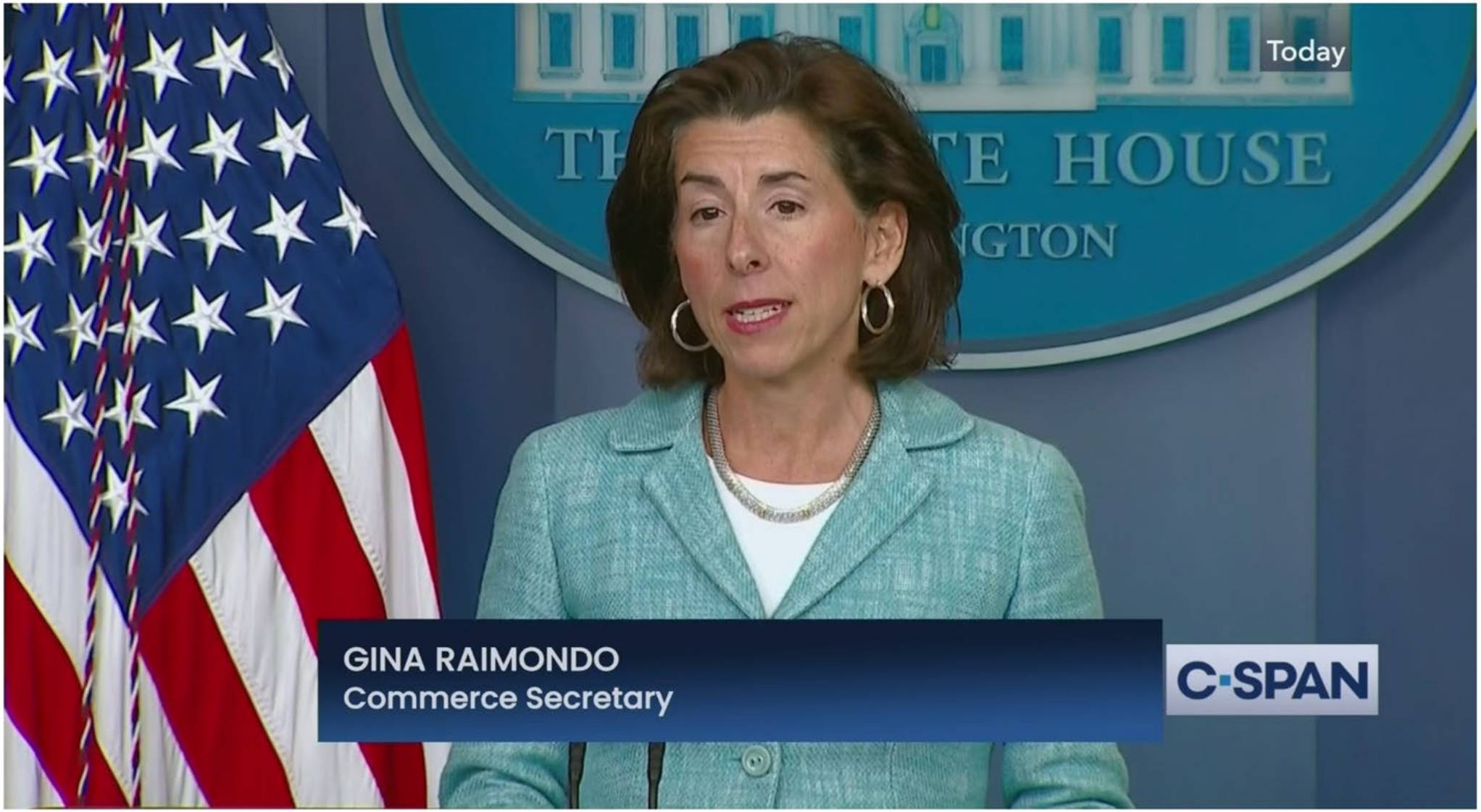

49,729
Missouri death row inmate executed 18 years after killing cousin, her husband: 'Deeply, overwhelmingly sorry'


33,575

Press Release | October 3, 2022

Gina Raimondo: Fire Acting Director of NOAA's National Hurricane Center (NHC) Jamie Rhome

Toni Aguilar Rosenthal Climate Department of Commerce Share



Realtime attribution

- Let's steer clear from realtime attribution.
- IPCC WG1 Chapter 11 on attribution:
  - "Quantifying the effect of climate change on extreme storms is challenging, partly because extreme storms are rare, short-lived, and local, and individual events are largely influenced by stochastic variability."
  - "The high degree of random variability makes detection and attribution of extreme storm trends more uncertain than detection and attribution of trends in other aspects of the environment in which the storms evolve (e.g., larger-scale temperature trends)."
  - "Projecting changes in extreme storms is also challenging because of constraints in the models' ability to accurately represent the small scale physical processes that can drive these changes."

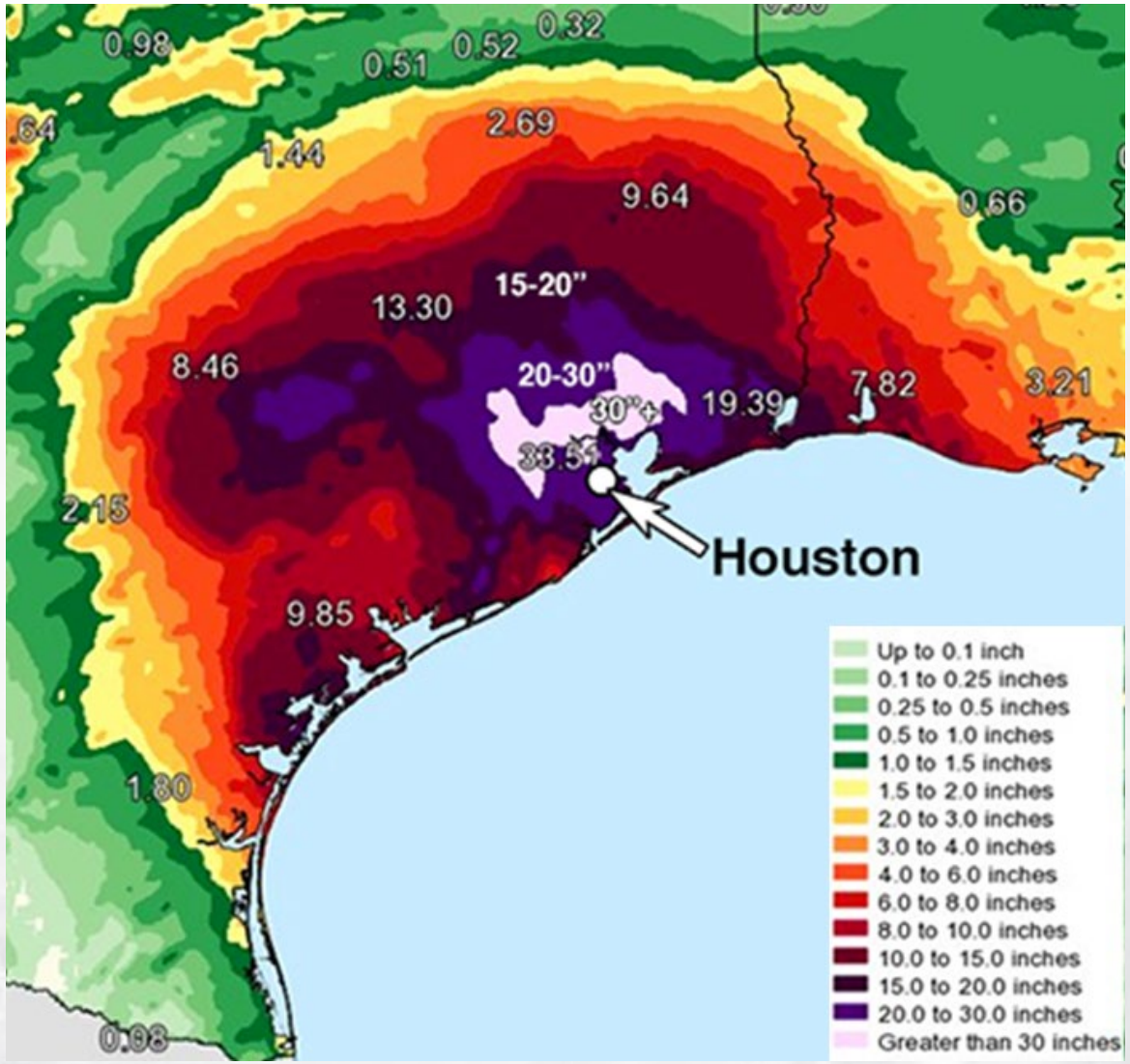
Other Reasons Why Detection and Attribution are Difficult

- No clear centennial-scale trends or do not cover enough years to assess century-scale trends.
- Difficulty obtaining accurate and temporally consistent measures of TC properties for climate studies, particularly in the pre–satellite era.
- Regional TC activity changes are strongly affected by projected changes in SST warming patterns, which are highly uncertain.
- Lots of internal variability that affects TCs:
  - intra-seasonal (e.g., the Madden–Julian and Boreal Summer Intraseasonal oscillations and equatorial waves)
  - interannual (e.g., the El Niño–Southern Oscillation and Pacific and Atlantic Meridional Modes)
  - inter-decadal (e.g., Atlantic Multidecadal Variability and Pacific Decadal Variability)
  - Aerosol forcing

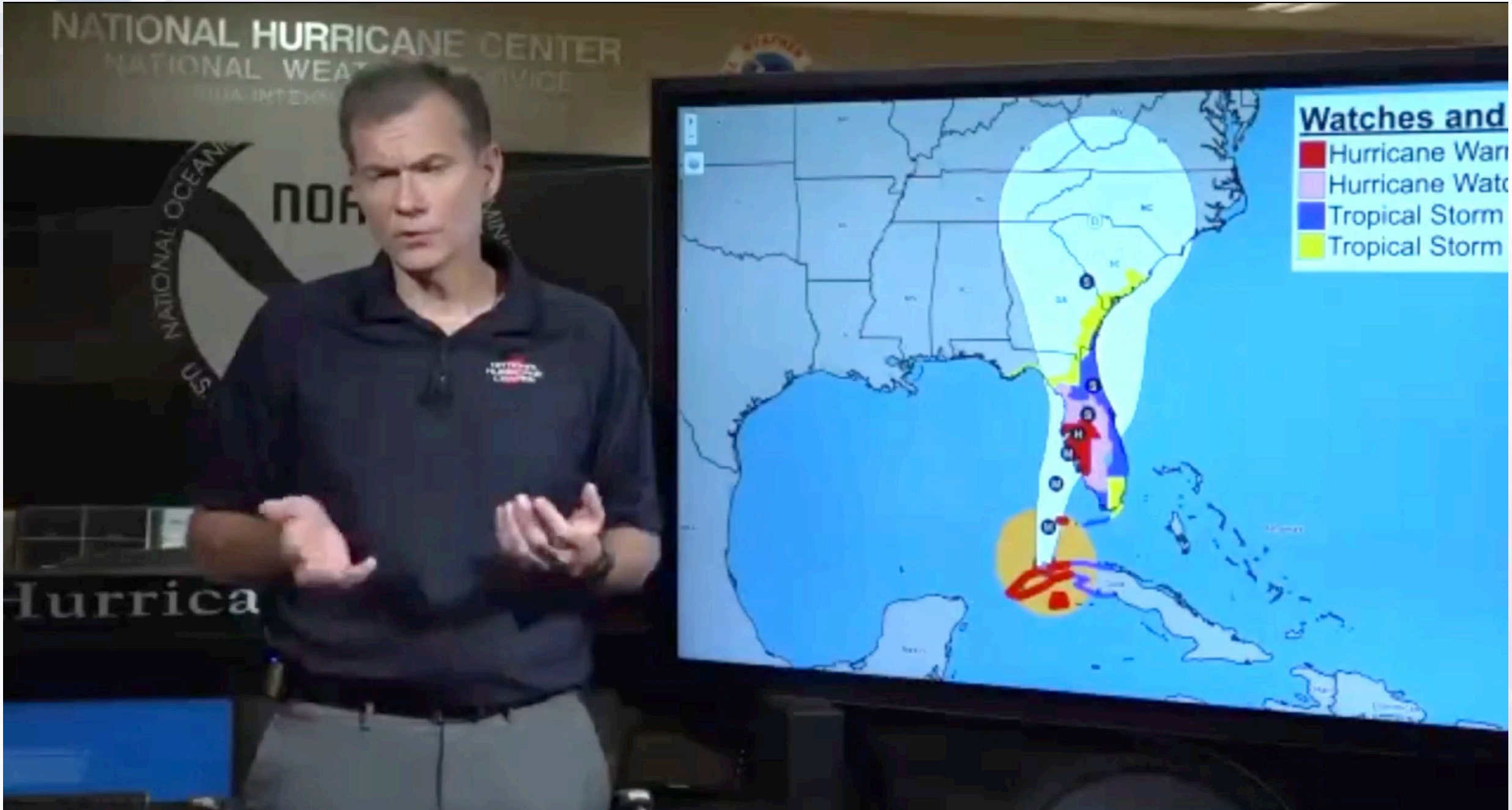
Attribution Case Study (takes time to complete)

Hurricane Harvey

- Climate change was estimated to have increased the rainfall of Hurricane Harvey by about 15% to 20%.
- The impacts of Hurricane Harvey were exacerbated by extensive residential development in flood-prone locations.
- Racial and ethnic disparities were shown to impact post-disaster needs, ranging from household damage to mental health and recovery.



Refute Media Hype



Recommendations

- Stick to known-knowns (consensus findings)
  - Hazards-first approach (i.e., focus on the hazards), not on changes to storm strength, numbers of storms, or potential attribution to climate change

Recommendations

- Stick to known-knowns (consensus findings)
  - Hazards-first approach (i.e., focus on the hazards), not on changes to storm strength, numbers of storms, or potential attribution to climate change
- During a storm, focus on the storm, not on potential link to climate change
  - Be the calm, trusted voice
  - Example: “The science is clear that climate change can influence storms. To what extent (storm name) was influenced will be a focus of future research. Today I'm focused on getting life-saving warnings into the hands of people in harm's way.”

Summary assessments

- IPCC 2022: The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change
- IPCC 2022: Impacts, Adaptation, and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change
- National Academy of Sciences 2023: Fifth National Climate Assessment
- NOAA 2023: State of the Science Fact Sheet on Atlantic Hurricanes and Climate Change
- WMO Working Group: Tropical Cyclones and Climate Change Assessment
  - Part 1: Detection and Attribution
  - Part II: Projected Response to Anthropogenic Warming
- GFDL: Global Warming and Hurricanes

Other literature

- NOAA Climate reports:
  - Ocean Heat Content
  - Sea Level Rise
- NOAA Office for Coastal Management
- Kossin et al. 2014: The poleward migration of the location of tropical cyclone maximum intensity
- Kossin 2018: A global slowdown of tropical cyclone translation speed.
- Dangendorf et al. 2019: Persistent acceleration in global sea-level rise since the 1960s
- Garner 2023: Observed increases in North Atlantic tropical cyclone peak intensification rates
- OFDA/CRED International Disaster Database

Extra Slides

What we Know: Risk Equation

- Risk: the potential of gaining or losing something of value

Risk = Probability × Consequence × Vulnerability

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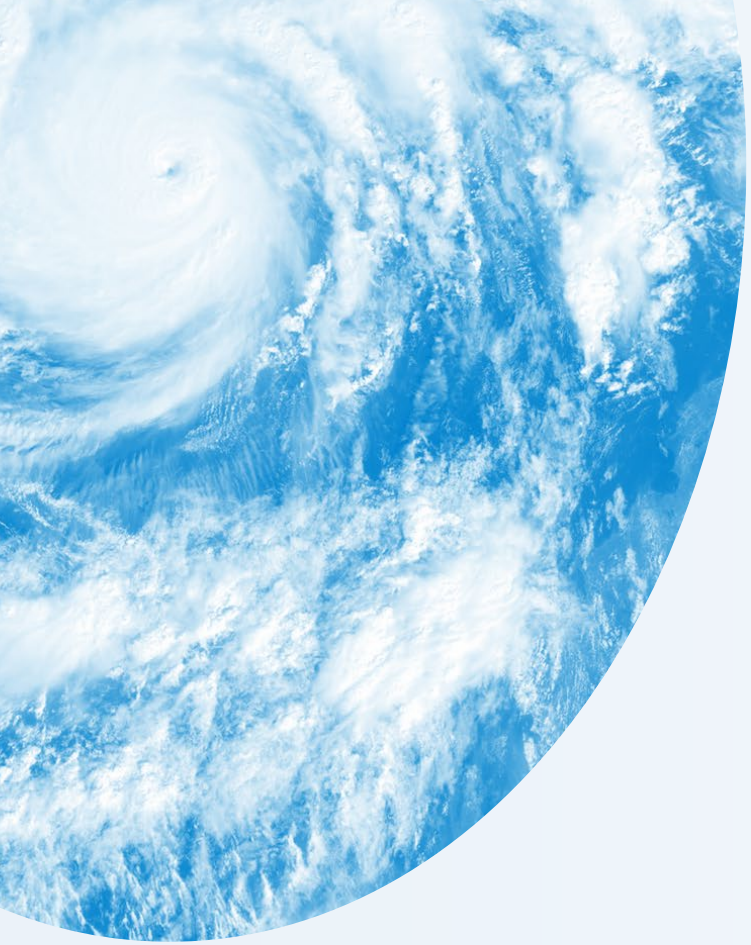
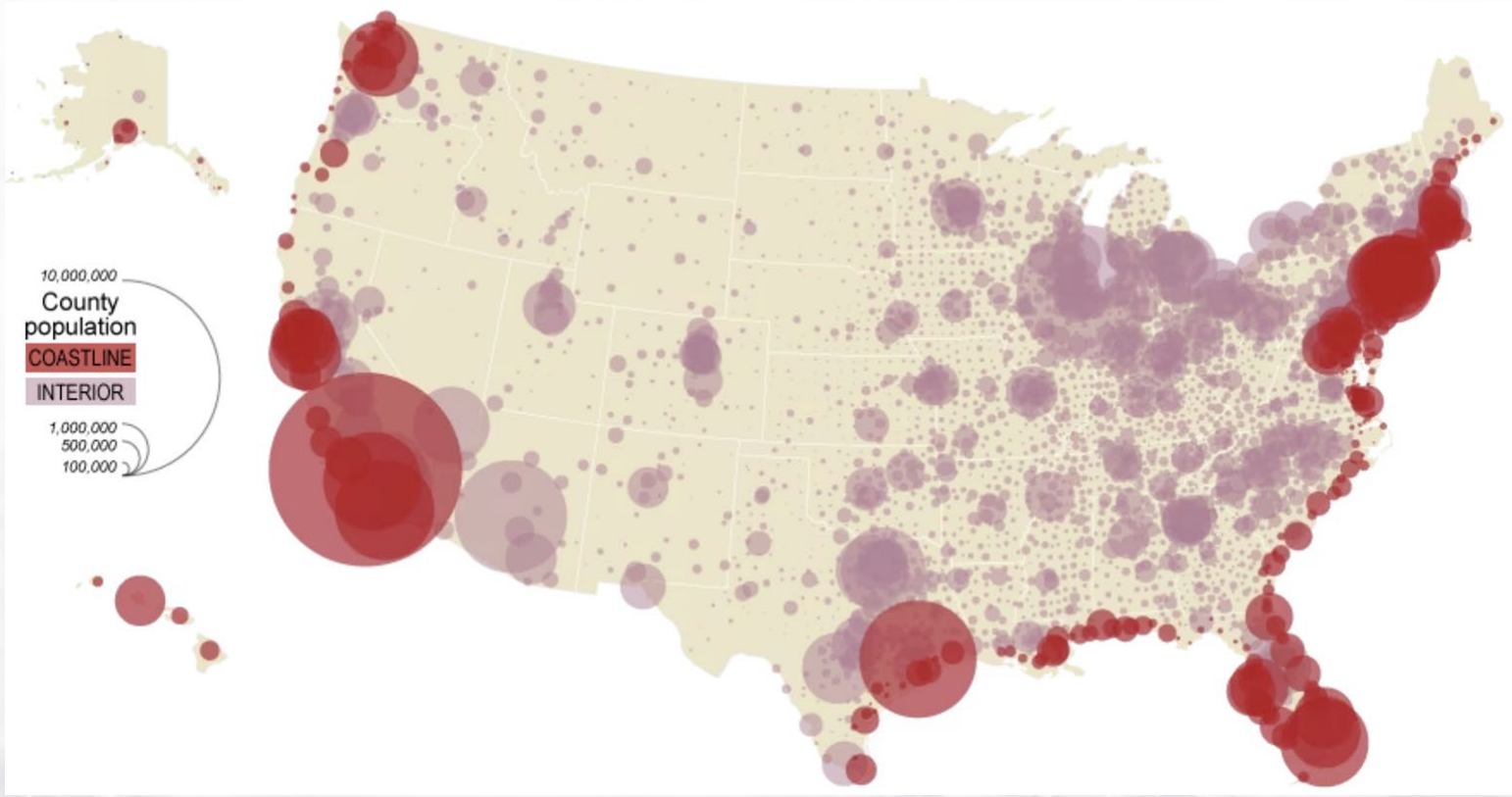


Known Knowns (vulnerability)

More People Along the Coast

40% increase in coastal population from 1970 to 2010 (34.8 million people)

40% of population (128 million people) live on the coast even though it is less than 10% of the land mass



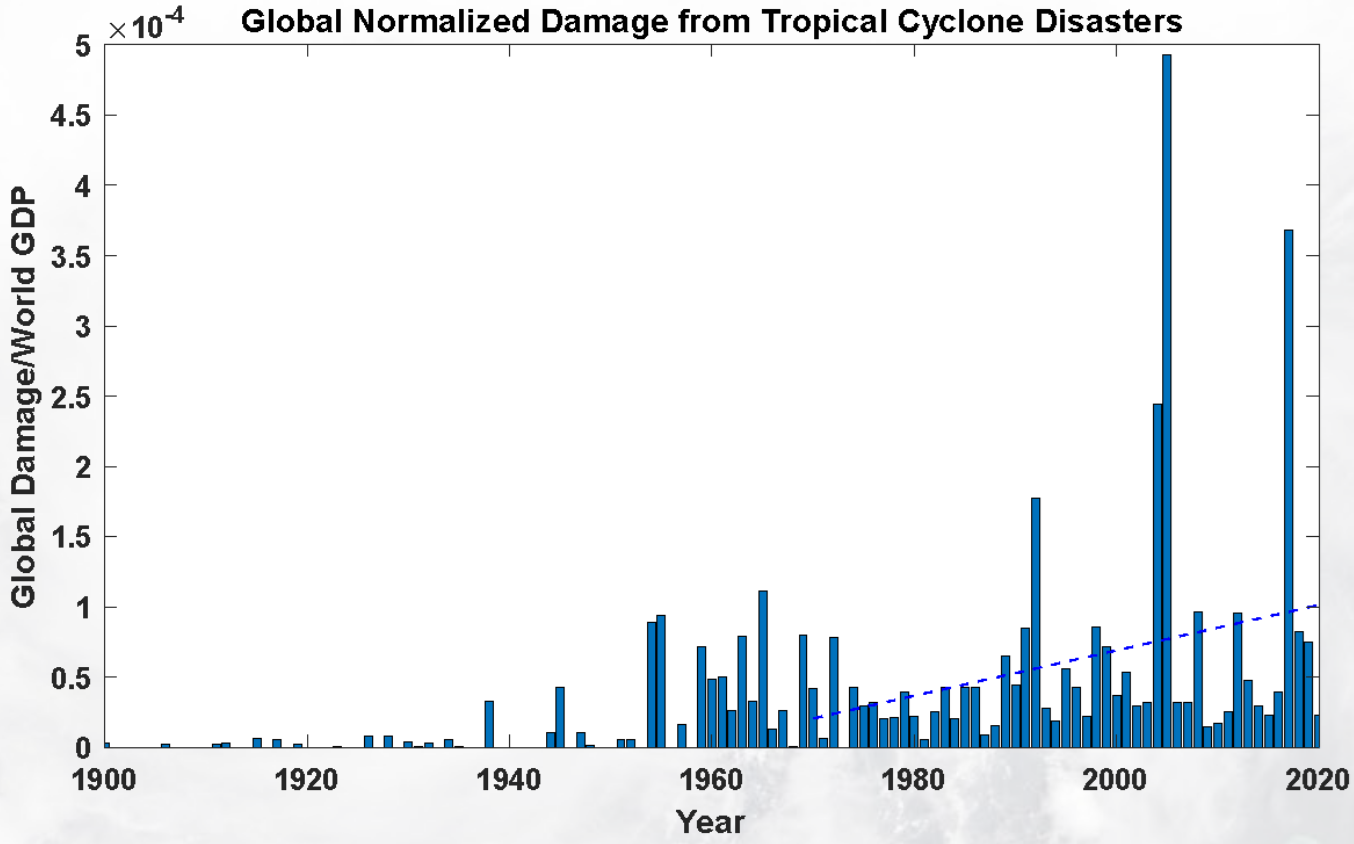
Source: US Census

More Infrastructure Along the Coast

380% increase in damage from tropical cyclones since 1970

Population and infrastructure are dominant over hurricane changes in explaining the increase over the past century

High confidence that islands are already reporting losses and damages from hurricane changes

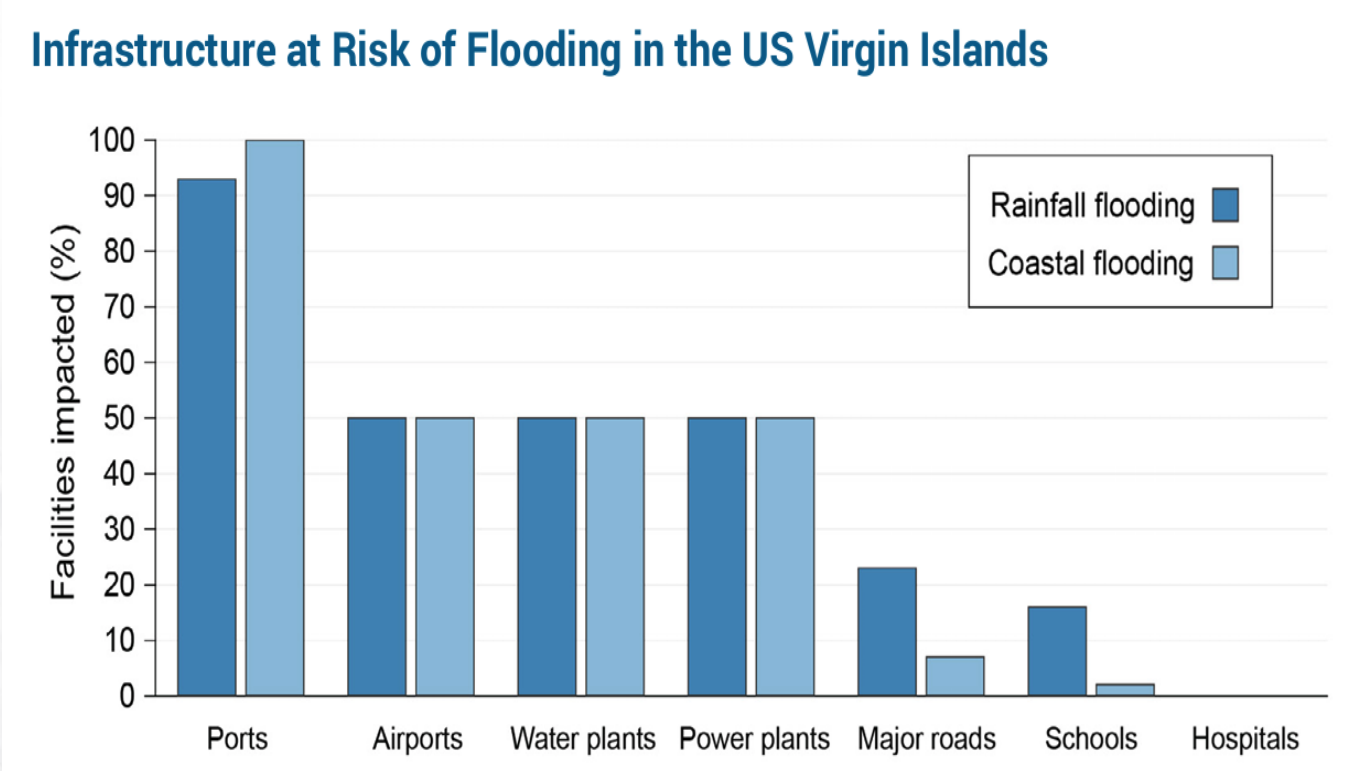


Graph Source: Kerry Emanuel
Data Source: OFDA/CRED International Disaster Database

Vulnerability of Caribbean Islands

Risk is highly modulated by structural, economic, and social vulnerabilities.

- Entire islands are exposed

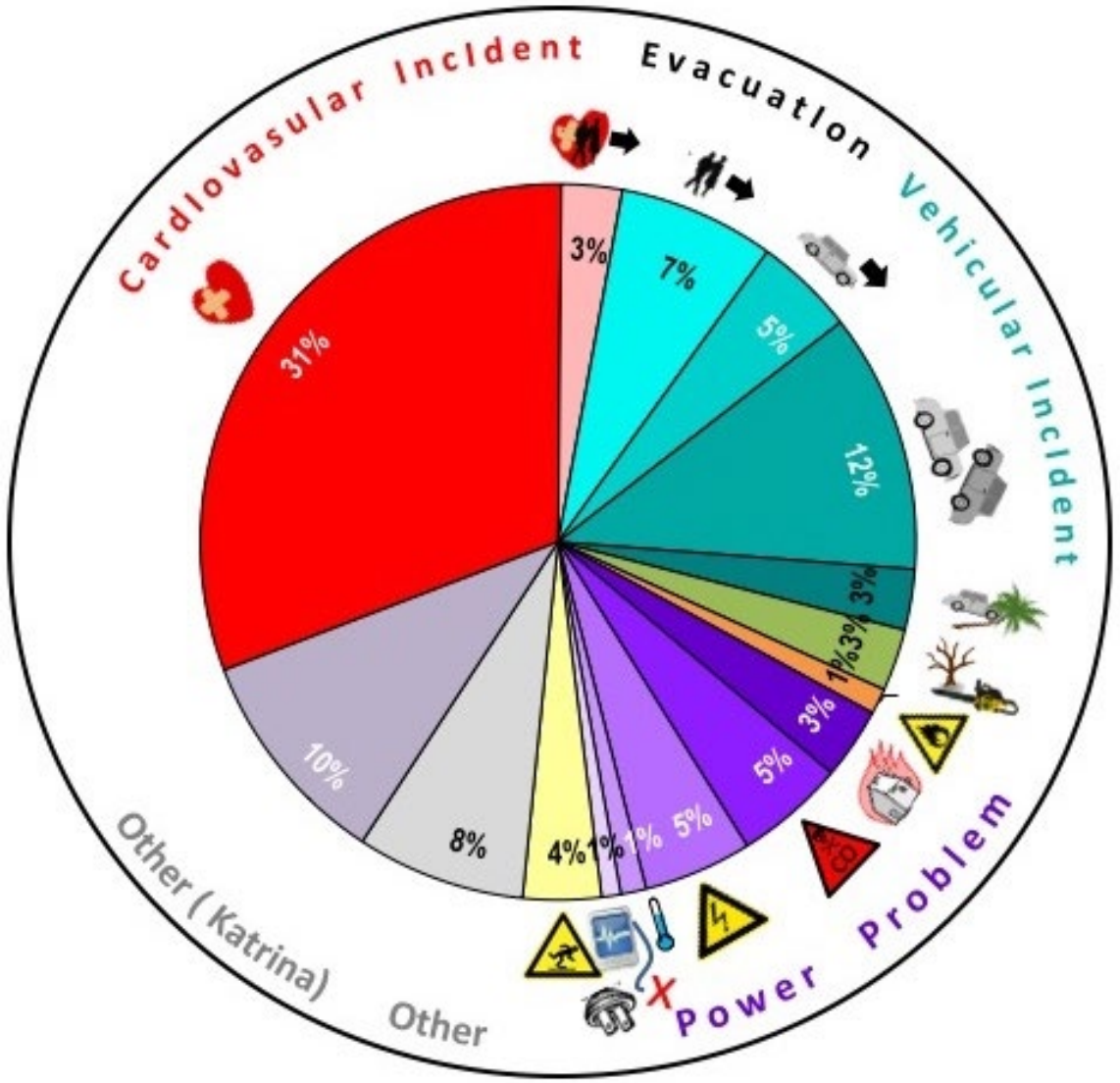


Source: National Academy of Sciences

Vulnerability of Caribbean Islands

Risk is highly modulated by structural, economic, and social vulnerabilities.

- Entire islands are exposed
- Large concentration of utility, public services (e.g., hospitals), and transportation routes in flood-prone areas
  - Lack of food, water, medicine, fuel
  - Cascading public health consequences

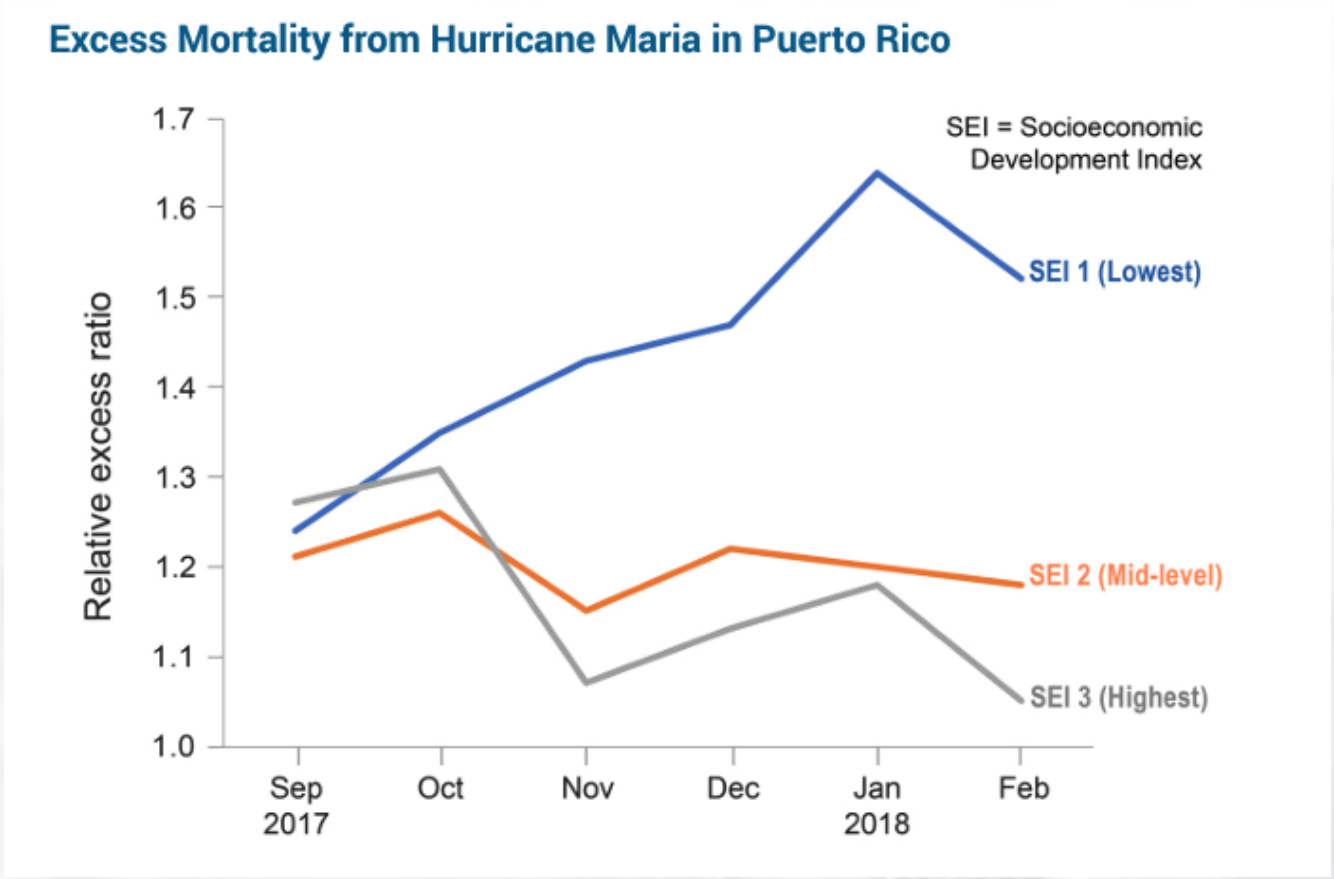


Rappaport and Blanchard, 8/7/2015

High Vulnerability: Hurricane Maria

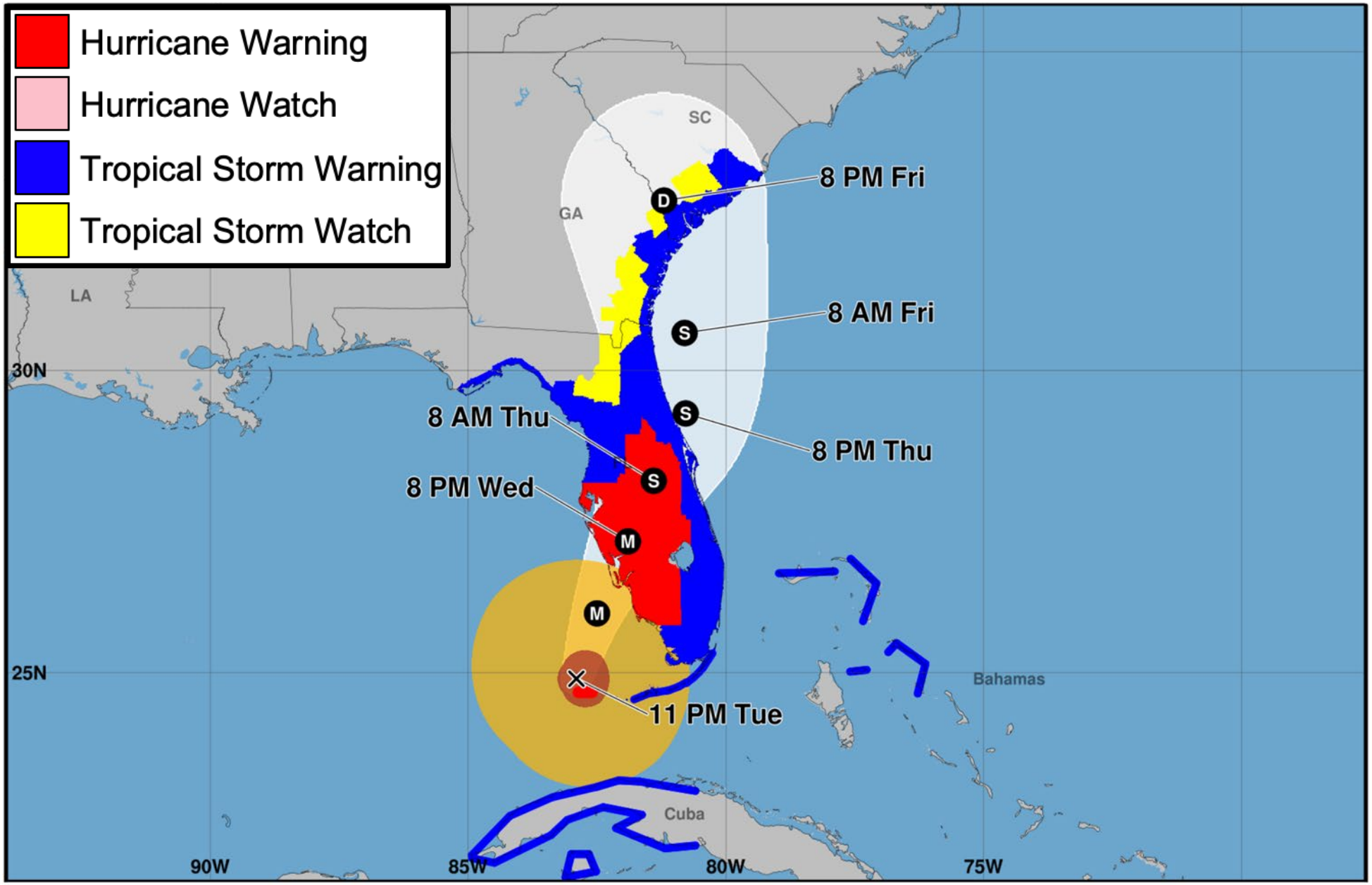
Hurricane Maria

- Uneven access to information and resources
- In Puerto Rico, excess mortality was highest for lower socioeconomic status
- Nearly all of Dominica's infrastructure and losses amounted to over 225% of the annual GDP



Source: National Academy of Sciences

Hazards-First Approach



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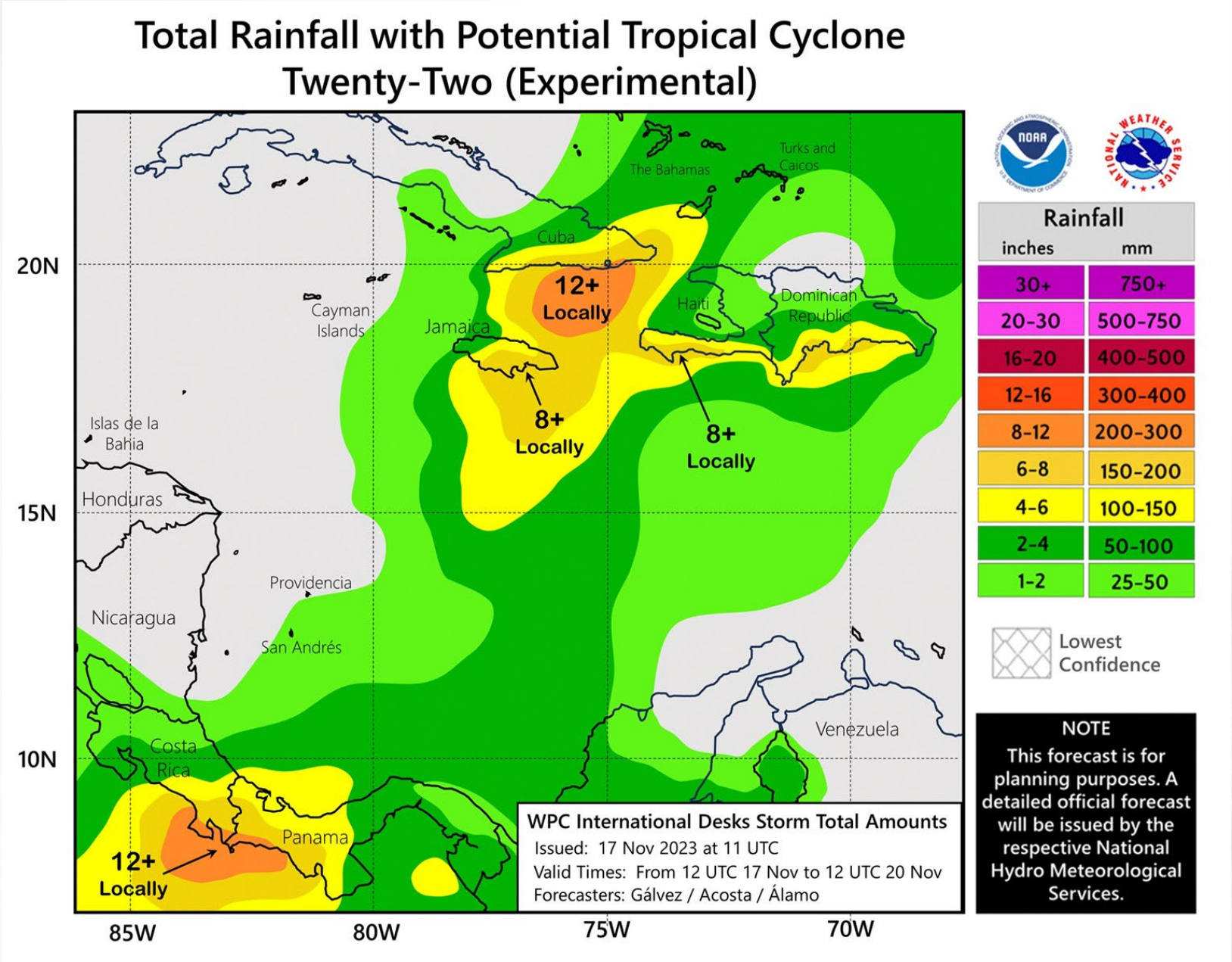

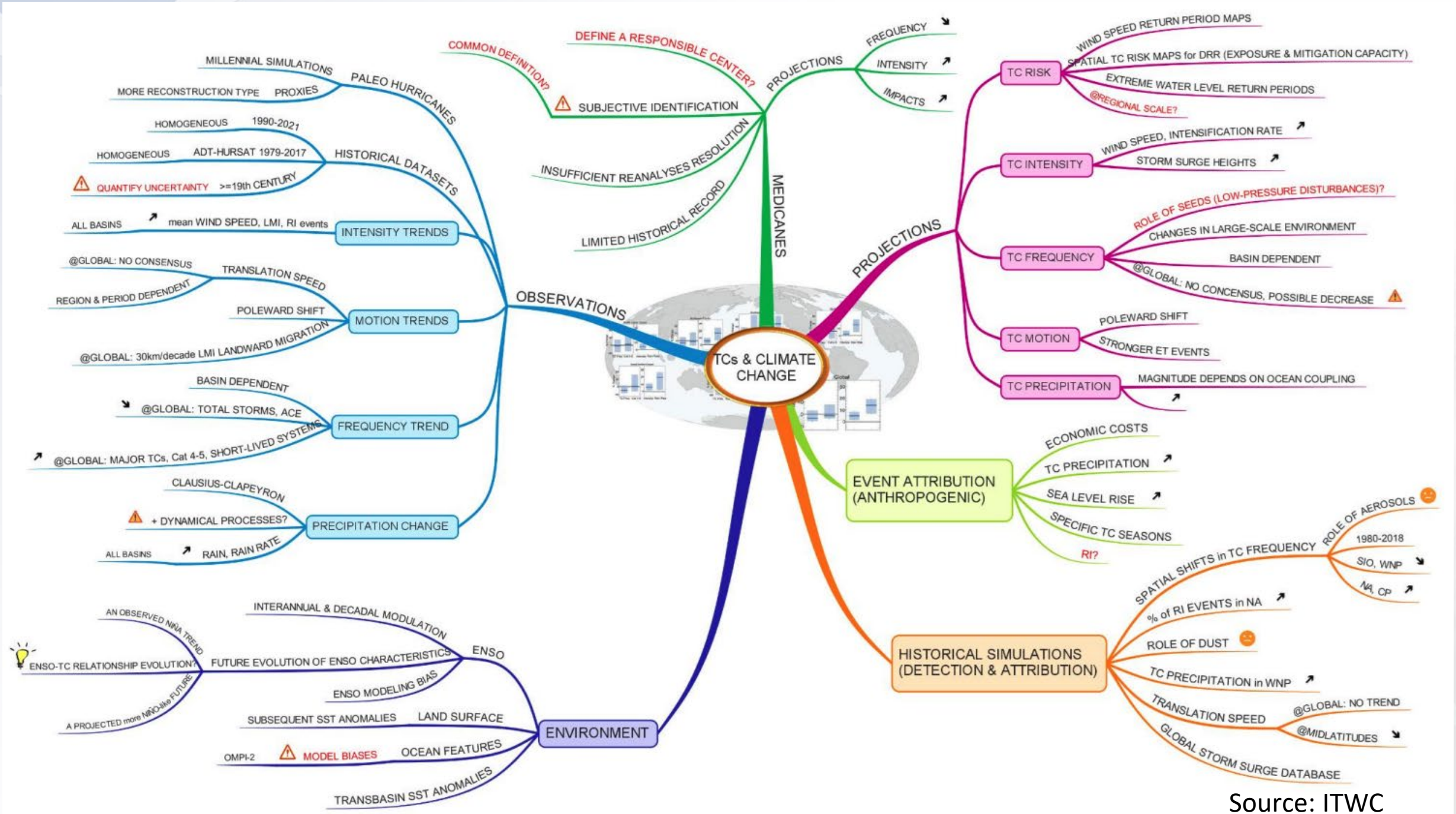
TCs & CLIMATE CHANGE
OBSERVATIONS
PALEO HURRICANES
MILLENNIAL SIMULATIONS
MORE RECONSTRUCTION TYPE
PROXIES
HISTORICAL DATASETS
HOMOGENEOUS
1990-2021
HOMOGENEOUS
ADT-HURSAT 1979-2017
QUANTIFY UNCERTAINTY
>=19th CENTURY
INTENSITY TRENDS
ALL BASINS
mean WIND SPEED, LMI, RI events
MOTION TRENDS
@GLOBAL: NO CONSENSUS
TRANSLATION SPEED
REGION & PERIOD DEPENDENT
POLEWARD SHIFT
@GLOBAL: 30km/decade LMI LANDWARD MIGRATION
FREQUENCY TREND
BASIN DEPENDENT
@GLOBAL: TOTAL STORMS, ACE
@GLOBAL: MAJOR TCs, Cat 4-5, SHORT-LIVED SYSTEMS
PRECIPITATION CHANGE
CLAUSIUS-CLAPEYRON
+ DYNAMICAL PROCESSES?
ALL BASINS
RAIN, RAIN RATE
MEDICANES
COMMON DEFINITION?
DEFINE A RESPONSIBLE CENTER?
SUBJECTIVE IDENTIFICATION
INSUFFICIENT REANALYSES RESOLUTION
LIMITED HISTORICAL RECORD
PROJECTIONS
FREQUENCY
INTENSITY
IMPACTS
PROJECTIONS
TC RISK
WIND SPEED RETURN PERIOD MAPS
SPATIAL TC RISK MAPS for DRR (EXPOSURE & MITIGATION CAPACITY)
EXTREME WATER LEVEL RETURN PERIODS
@REGIONAL SCALE?
TC INTENSITY
WIND SPEED, INTENSIFICATION RATE
STORM SURGE HEIGHTS
TC FREQUENCY
ROLE OF SEEDS (LOW-PRESSURE DISTURBANCES)?
CHANGES IN LARGE-SCALE ENVIRONMENT
BASIN DEPENDENT
@GLOBAL: NO CONCENSUS, POSSIBLE DECREASE
TC MOTION
POLEWARD SHIFT
STRONGER ET EVENTS
TC PRECIPITATION
MAGNITUDE DEPENDS ON OCEAN COUPLING
EVENT ATTRIBUTION (ANTHROPOGENIC)
ECONOMIC COSTS
TC PRECIPITATION
SEA LEVEL RISE
SPECIFIC TC SEASONS
RI?
HISTORICAL SIMULATIONS (DETECTION & ATTRIBUTION)
SPATIAL SHIFTS in TC FREQUENCY
ROLE OF AEROSOLS
1980-2018
SIO, WNP
NA, CP
% of RI EVENTS in NA
ROLE OF DUST
TC PRECIPITATION in WNP
TRANSLATION SPEED
@GLOBAL: NO TREND
@MIDLATITUDES
GLOBAL STORM SURGE DATABASE
ENVIRONMENT
ENSO
INTERANNUAL & DECADAL MODULATION
AN OBSERVED NiNA TREND
ENSO-TC RELATIONSHIP EVOLUTION?
FUTURE EVOLUTION OF ENSO CHARACTERISTICS
ENSO MODELING BIAS
A PROJECTED more NiNO-like FUTURE
SUBSEQUENT SST ANOMALIES
LAND SURFACE
OMPI-2
MODEL BIASES
OCEAN FEATURES
TRANSBASIN SST ANOMALIES

Source: ITWC

Hazards-First Approach

- Mention anything about Spanish translation of graphics
- Mention anything about expansion of storm surge in the Caribbean?