Past and Future Tropical Cyclone Activity

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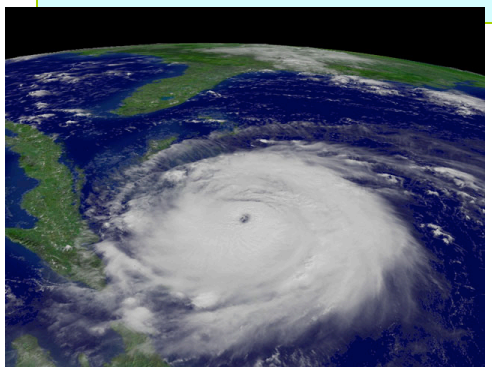
- What is a tropical cyclone?
- What is cyclone “activity”?
- How has activity changed in the past? Why?
- How do we expect it to change in future? Why?

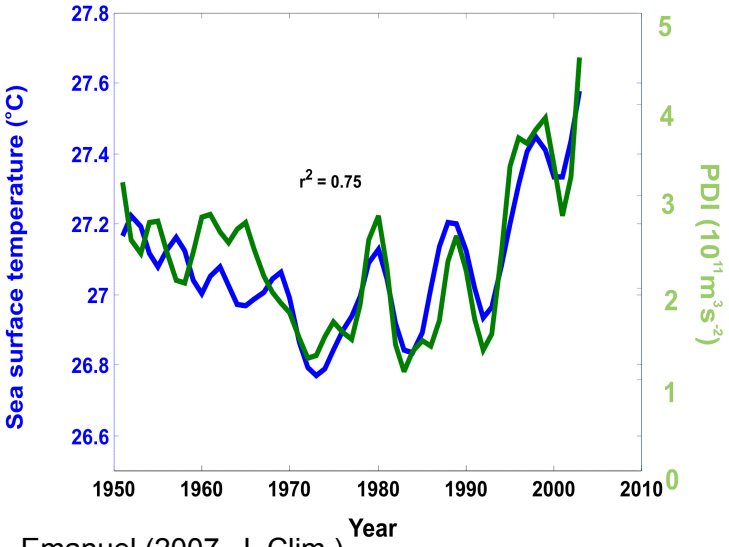
Miami After Hurricane Andrew

Source: wikimedia.org

North Atlantic tropical cyclones



- Recent increase in activity
  - Including extreme 2004-2005 seasons
- Why? Implications for future?



Emanuel (2007, J. Clim.)

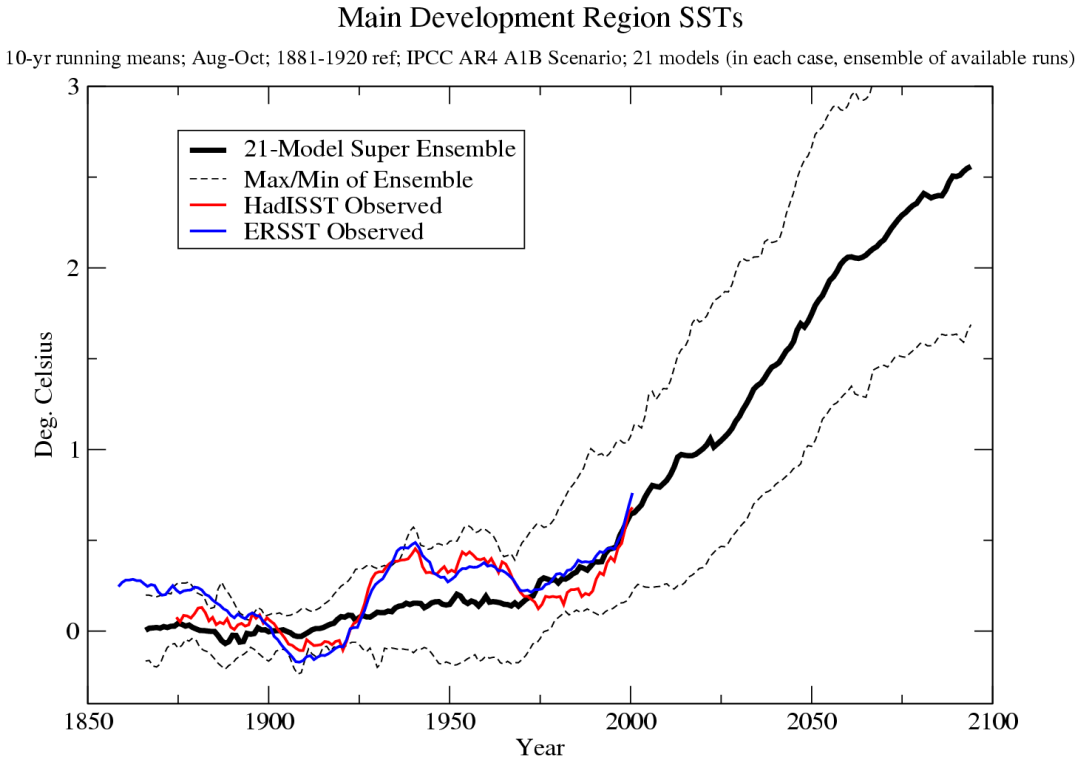


Figure: Tom Knutson

Key concepts

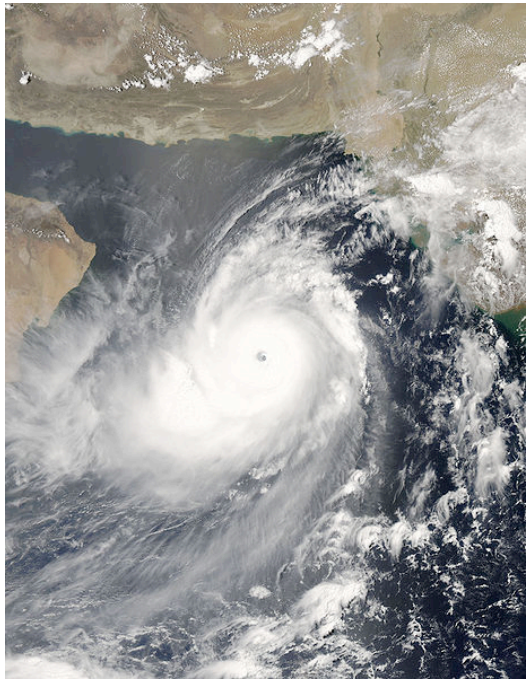
- Established vs. Developing understanding
  - Multiple factors impact hurricanes
  - Observational uncertainties
  - Pushing the limits of our theory and computers
- False choice: global warming **OR** climate variability
- Not about one storm or one season ("Katrina effect").
- How do we develop our understanding?
  - Observations
  - Theoretical understanding
  - Numerical Modeling
- As we learn more the interpretation of total evidence changes: this is how science works
- Interpretations of sum of evidence can differ between scientists: not a "debate" - an ongoing inquiry

Tropical cyclones

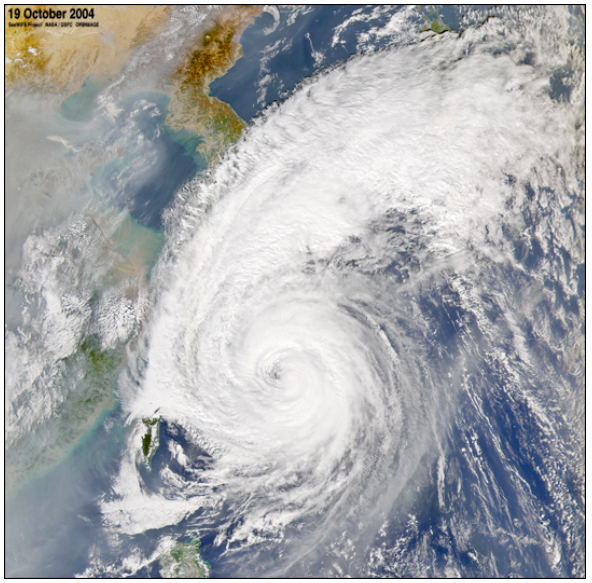
- Tropical cyclone not a big tornado
- Tropical cyclone, hurricane and typhoon same phenomenon, different location.

Hurricane Isabel (2003)
Atlantic Ocean
source: wikimedia.org

Cyclone Gonu (2007)
North Indian Ocean
source: wikimedia.org



Typhoon Tokage (2004)
Northwest Pacific Ocean
source: NASA



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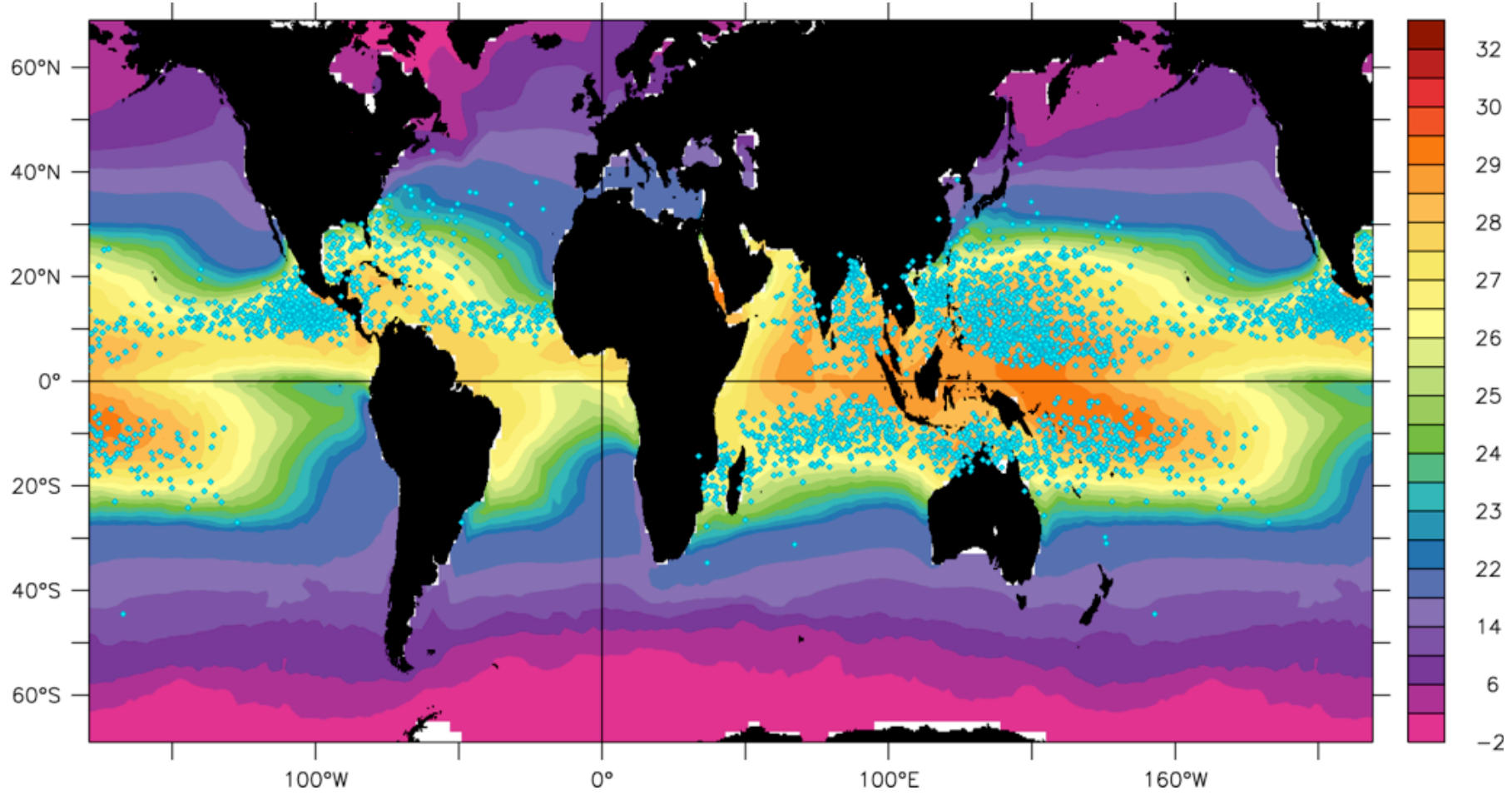
Warm water necessary for storm formation.



But warm water not enough, *e.g.* cyclones need a “calm” environment (without strong “wind shear” to disrupt them)

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Measure of Activity

Measure of Activity

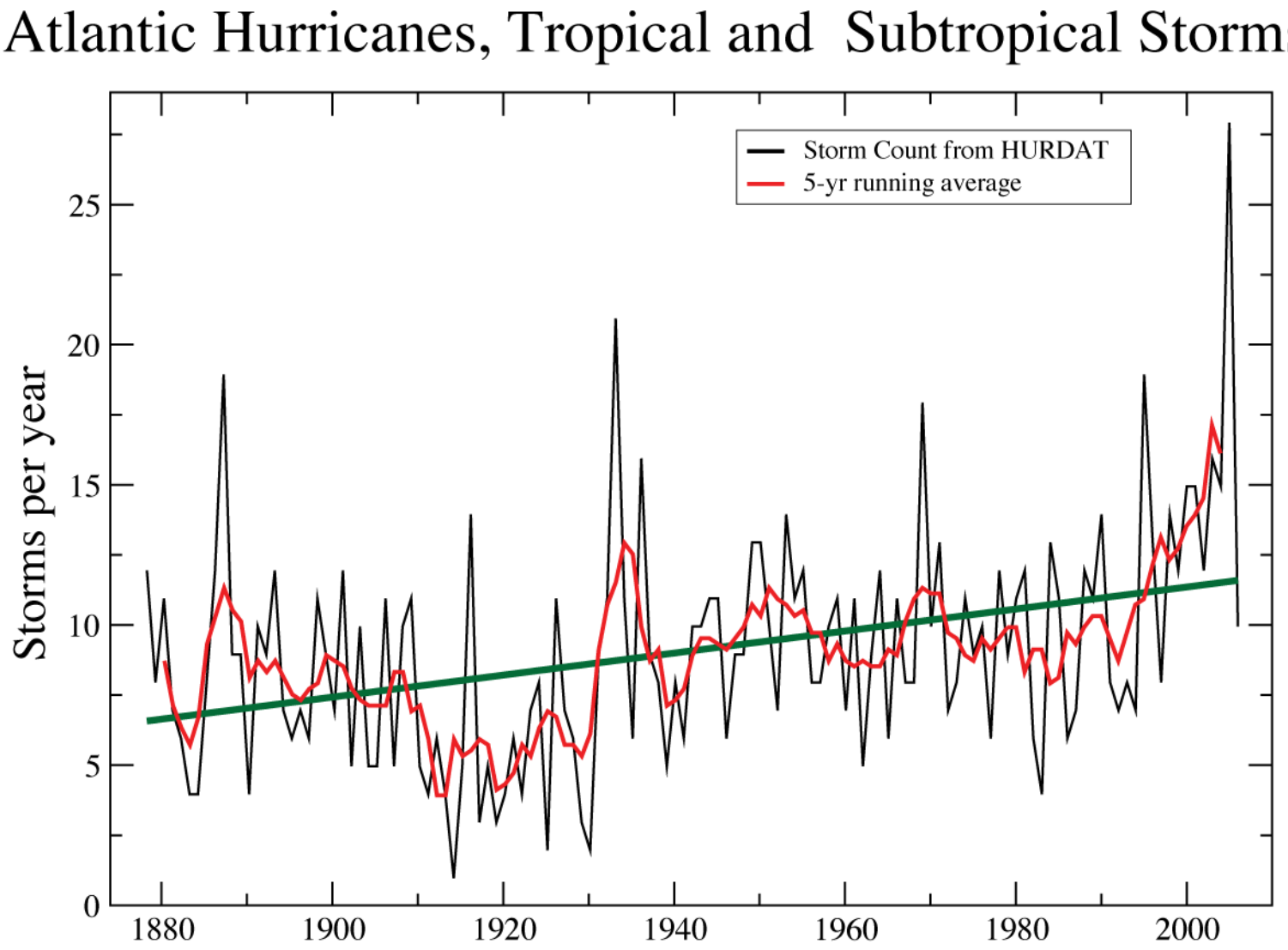
- Which measure?
  - Hurricane count
  - Landfalling storm count
  - Extremes in intensity
  - Shifts in average intensity
  - Sum of intensity
- Must balance demand with current understanding
  - Observations, models and theory limit.
- Differences must be communicated and understood

How can we know what hurricanes did in the past?

How can we *estimate* what hurricanes did in the past?

- Weather maps and reports
- Satellites
- Historical records (newspapers, etc)
- Sediments in marshes
- Etc.

What does historical record of storms tell us?



Vecchi and Knutson (2008)

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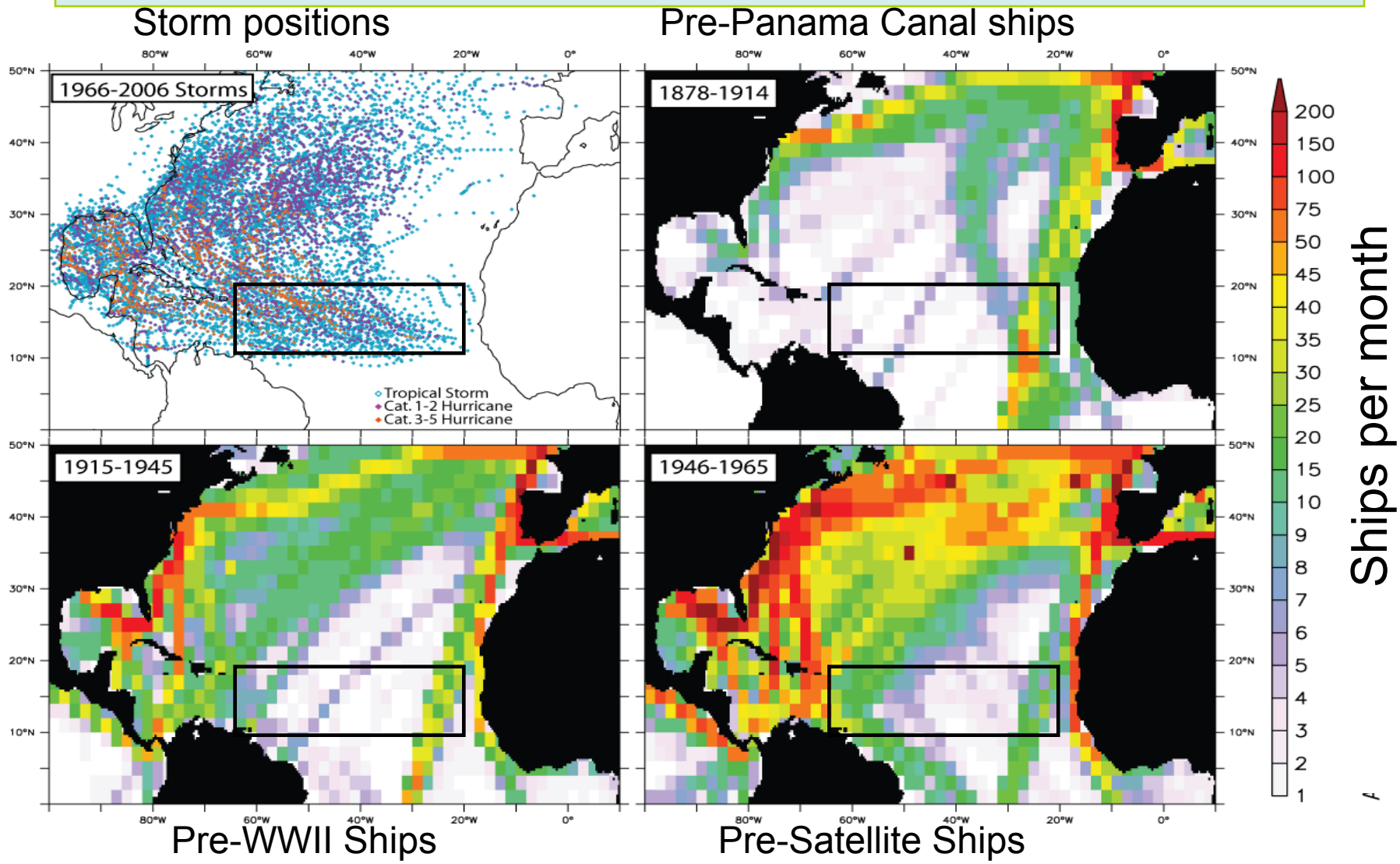
Can we be sure the long-term increase is real? Observational methods have changed with time….



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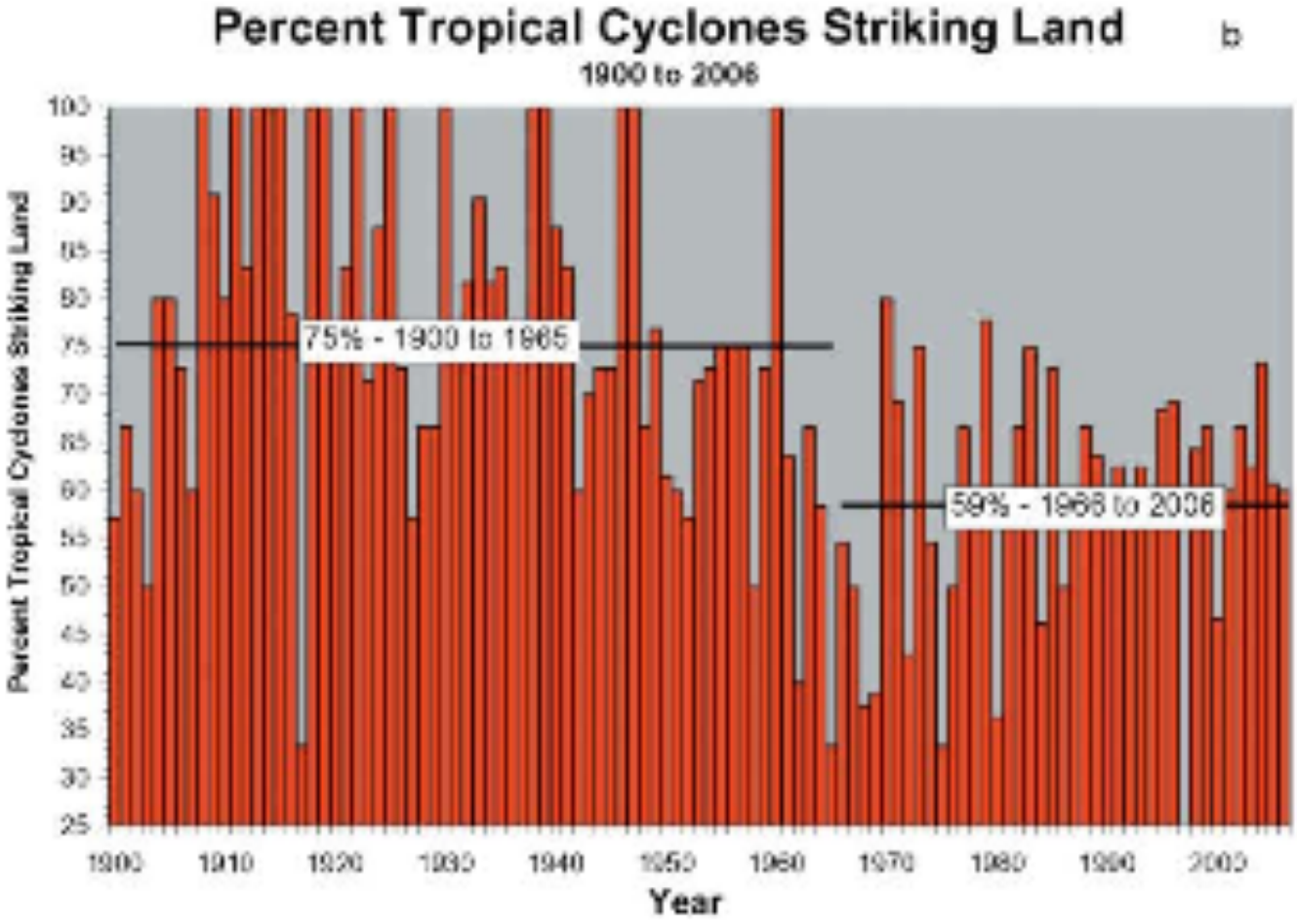
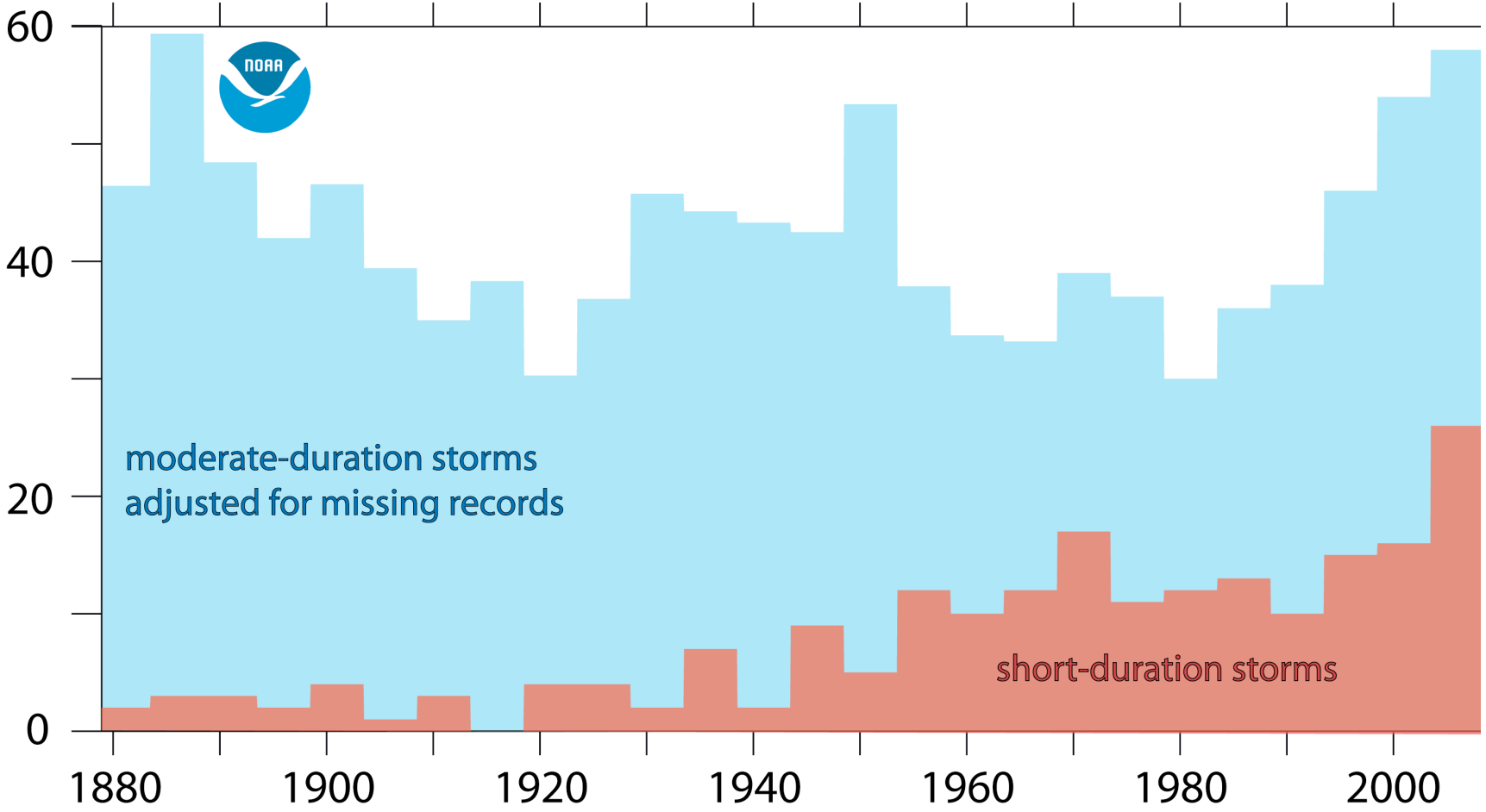
Characteristics of recorded storms exhibit strong secular changes, e.g., fraction of storms hitting land



Source: Landsea, EOS, 2007.

After adjusting for "missed" storms, there's only a trend in the storms of shortest duration.



Vecchi and Knutson (2008, 2011), Landsea et al. (2010)

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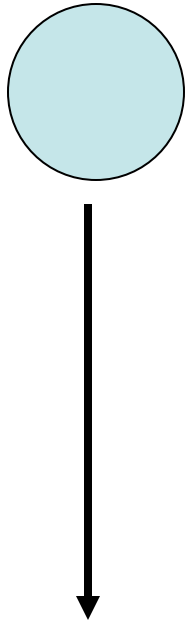
How do we estimate future hurricane activity change?

What is a model?

- **Useful simplified representation of a system**
  "All models are wrong, some are useful" G.E.P. Box

- Includes the "essential" characteristics of a system:
  - As simple as possible
  - No more simplified than necessary

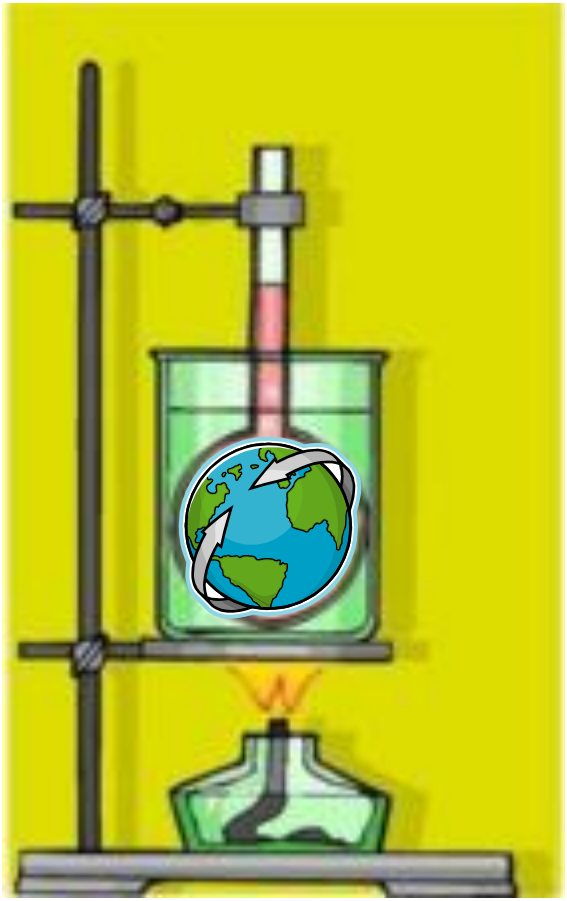
- Flavors: (*apply to a dropped ball*)



  - Statistical ("empirical") models:
    - *Drop a rock, see what happens*
    - *Drop ball, measure height with time, repeat many times, fit curve*

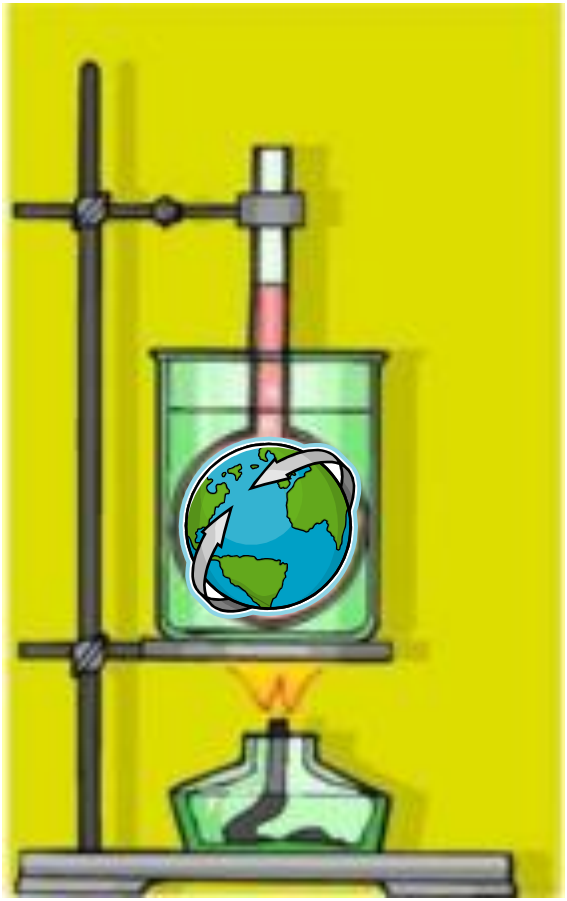
  - Dynamical models:
    - Analytic $x(t) = x(0) + v(0)\cdot t + g\cdot t^2$
    - Numerical *computer model of ball*

What is a State-of-the-Art Global Climate Model?

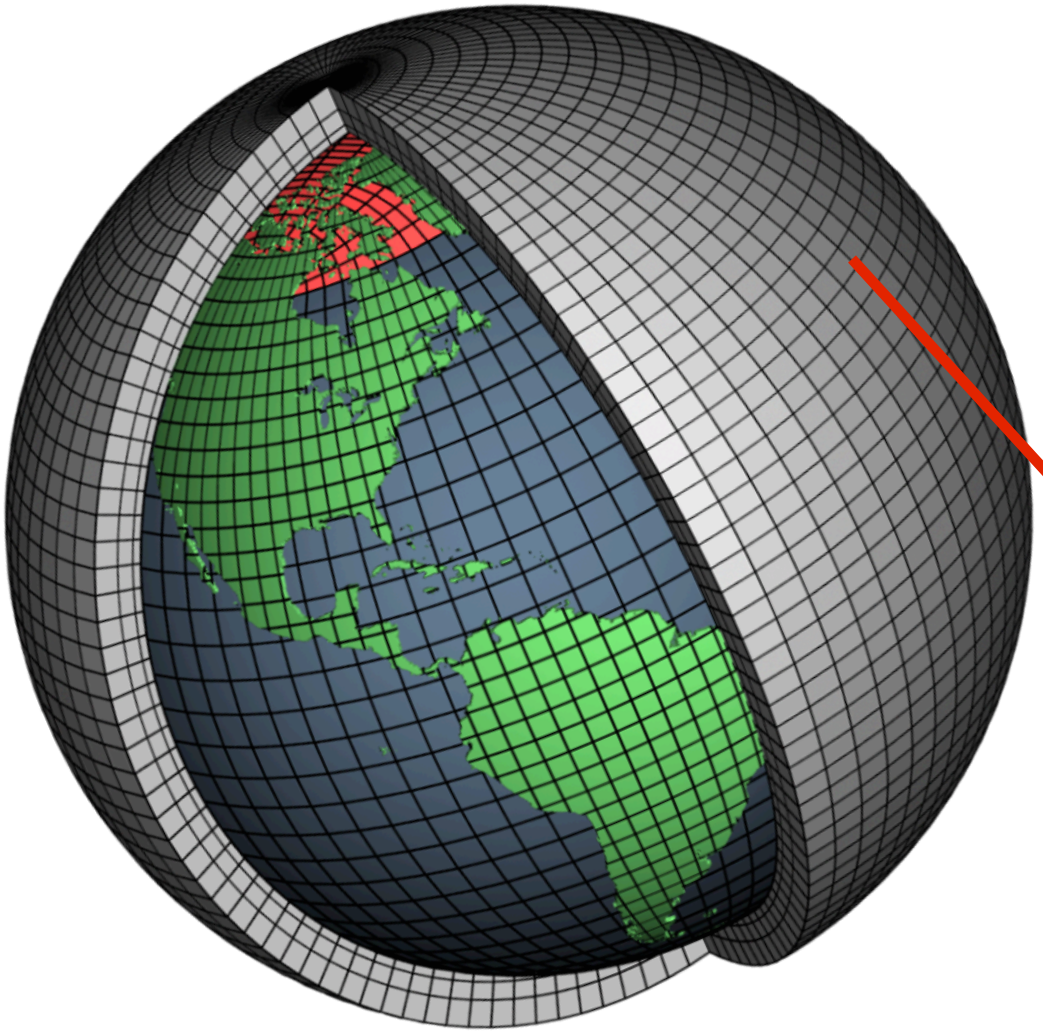


Unfortunately, we don't have a twin planet earth that we can use to perform laboratory experiments.

What is a State-of-the-Art Global Climate Model?



- At GFDL, the computer is our lab.
- The computer model is our research tool.



Models have land, ocean, atmosphere and ice components.

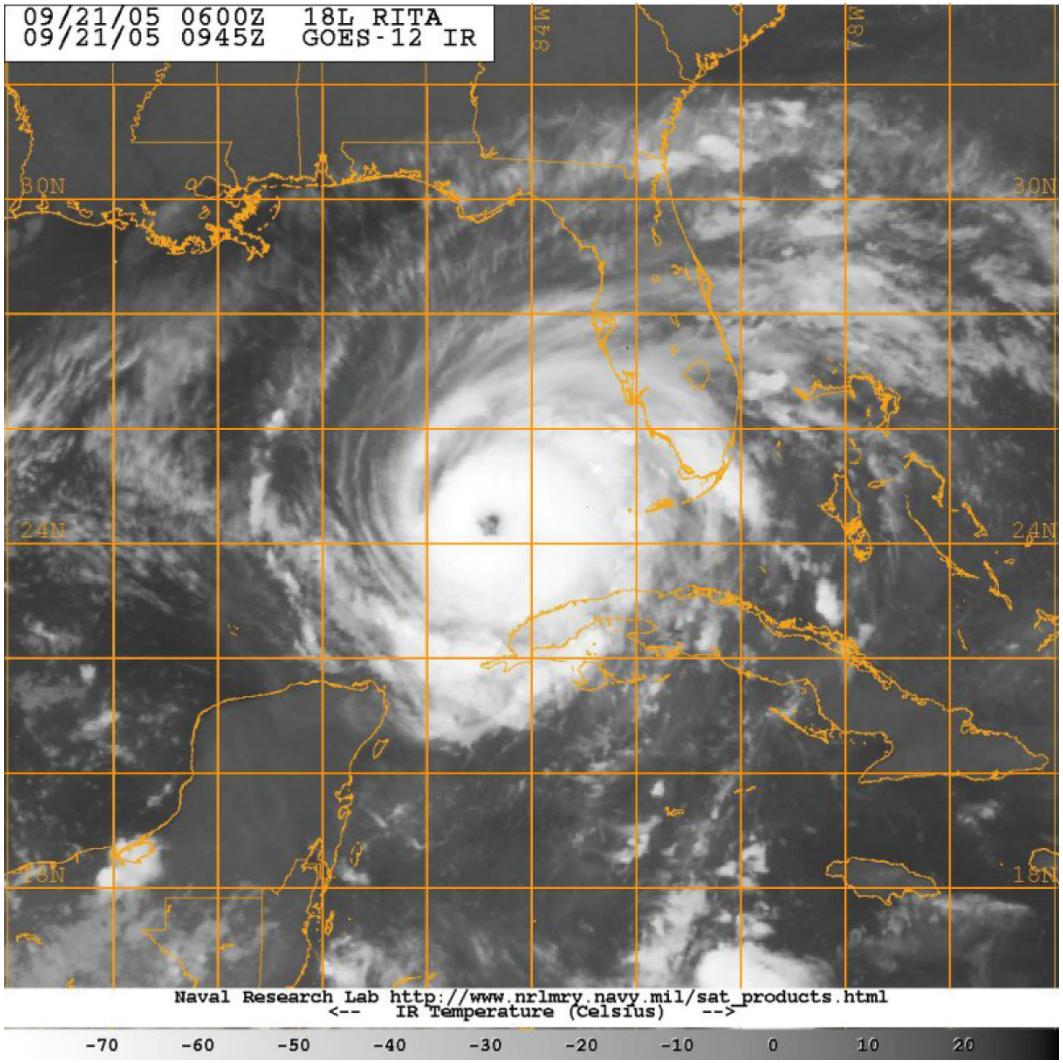
Each encapsulates our best understanding of underlying processes controlling its evolution.

In each grid cell:

- ⋆conserve momentum ($F=m \cdot a$)
- ⋆account for changes in mass and composition
- ⋆conserve energy (heat, light, latent, etc...)

"Force" with solar radiation, structure of continents and atmospheric composition (e.g., CO_2)

But, current computing power limits ability of global climate models to represent hurricanes



Hurricane Rita (2005): orange grid is representative of current ***global*** climate model resolution.

Size of grid limited by power of computers.

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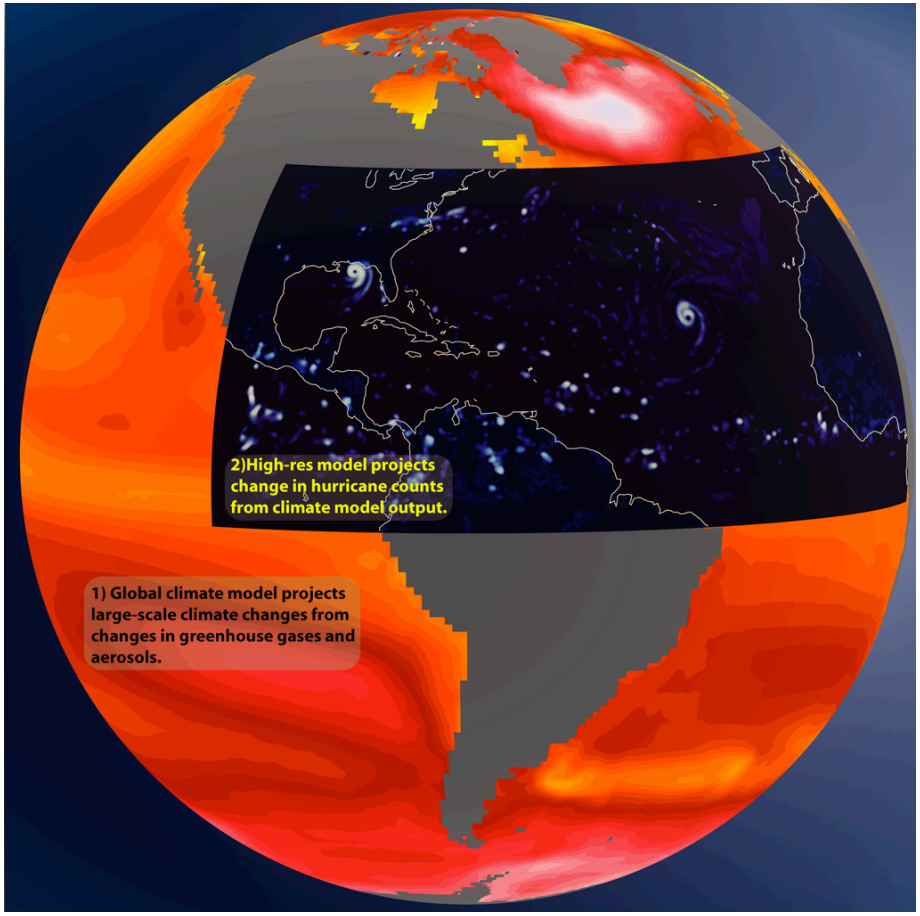
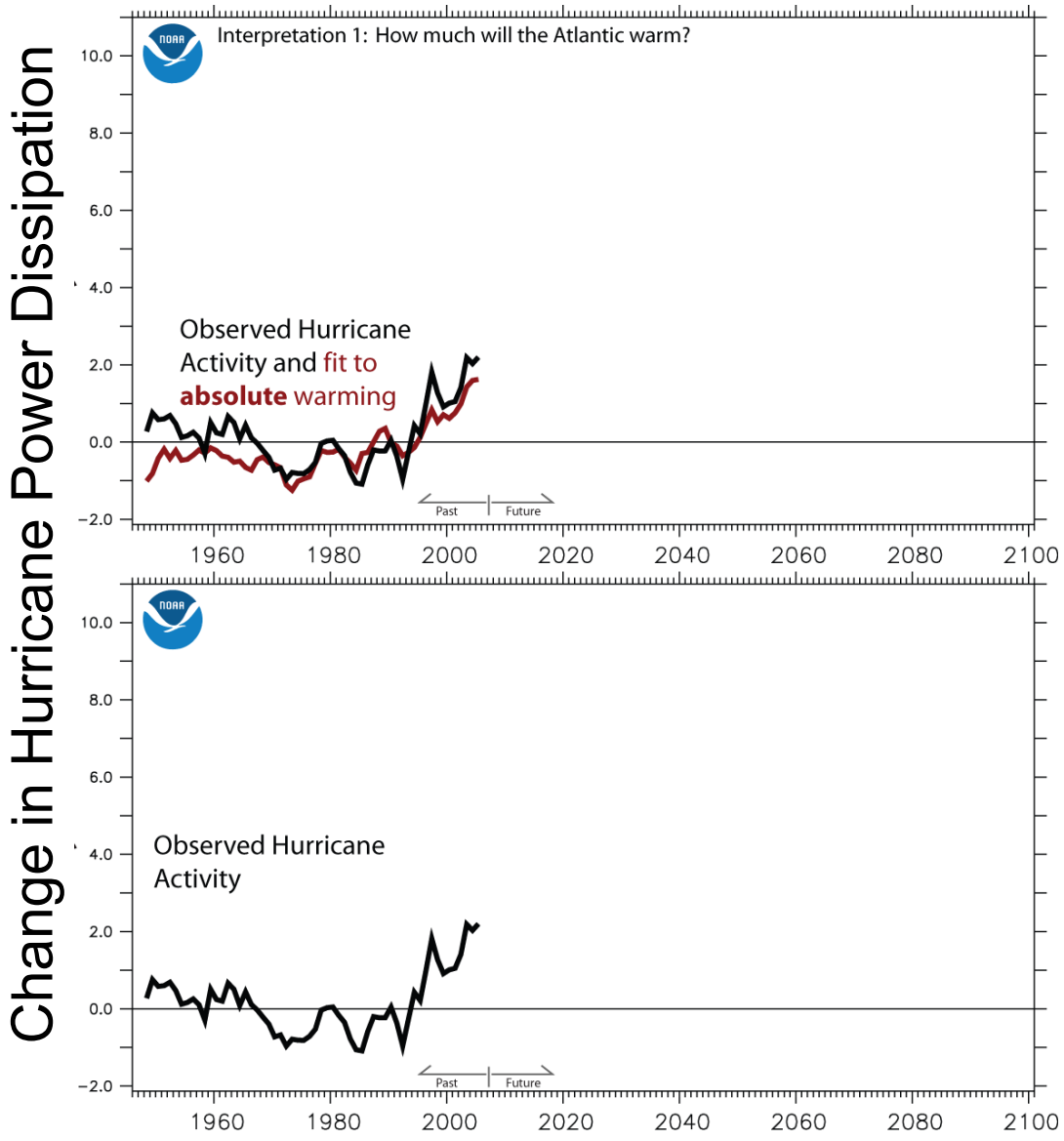
Use High-Resolution or Statistical Models to Extract Small-scale Information About Tropical Storms (TS)



Global Climate Models -> High-resolution Model

Large-scale TS Frequency

One Temperature Predictor of Atlantic Hurricane Activity



Observed Activity

Absolute Atlantic Temperature

Vecchi, Swanson and Soden (2008, Science)

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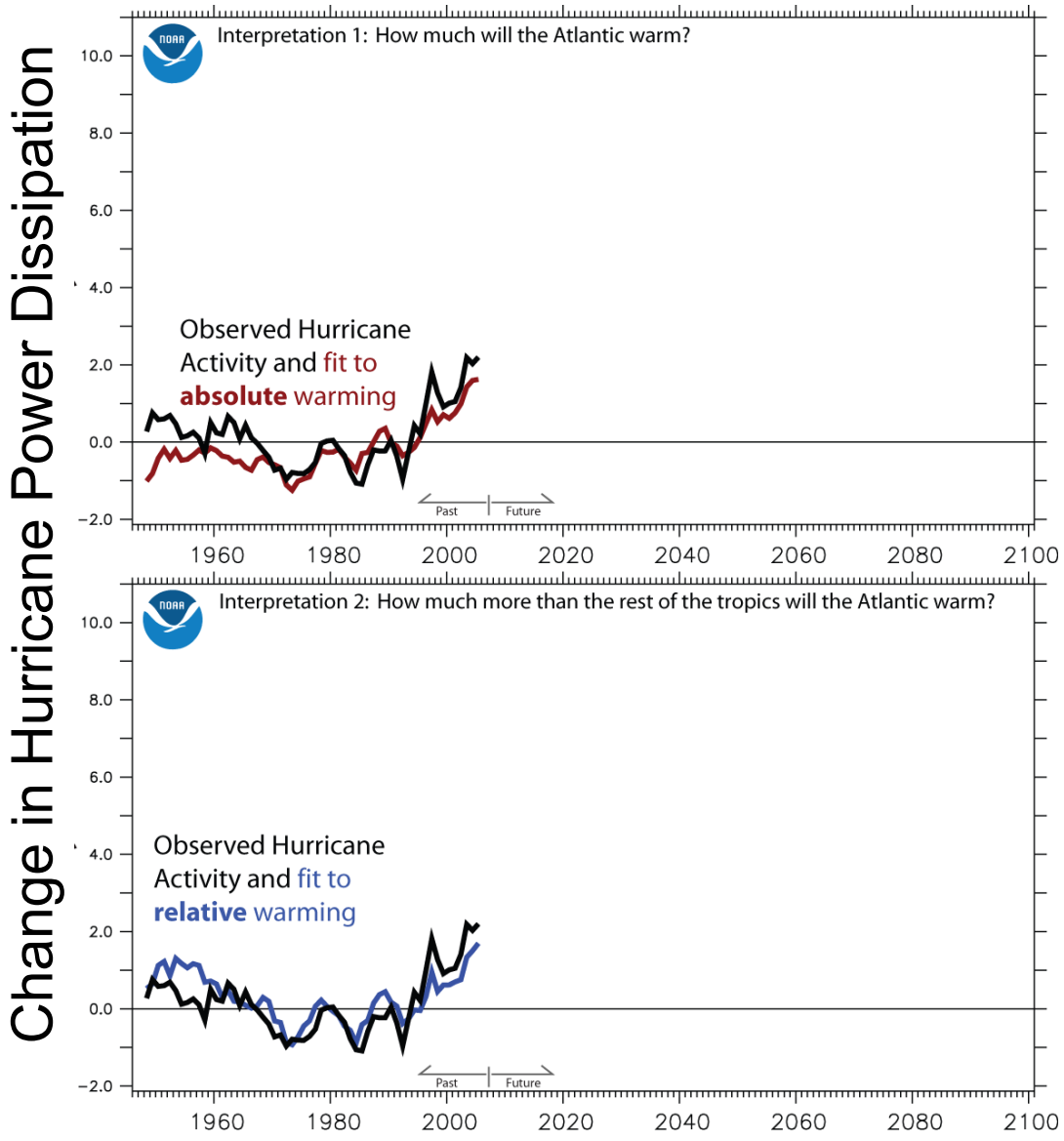
Two Temperature Predictors of Atlantic Hurricane Activity



Observed Activity
Absolute Atlantic Temperature

Observed Activity
Relative Atlantic Temperature

Vecchi, Swanson and Soden (2008, Science)

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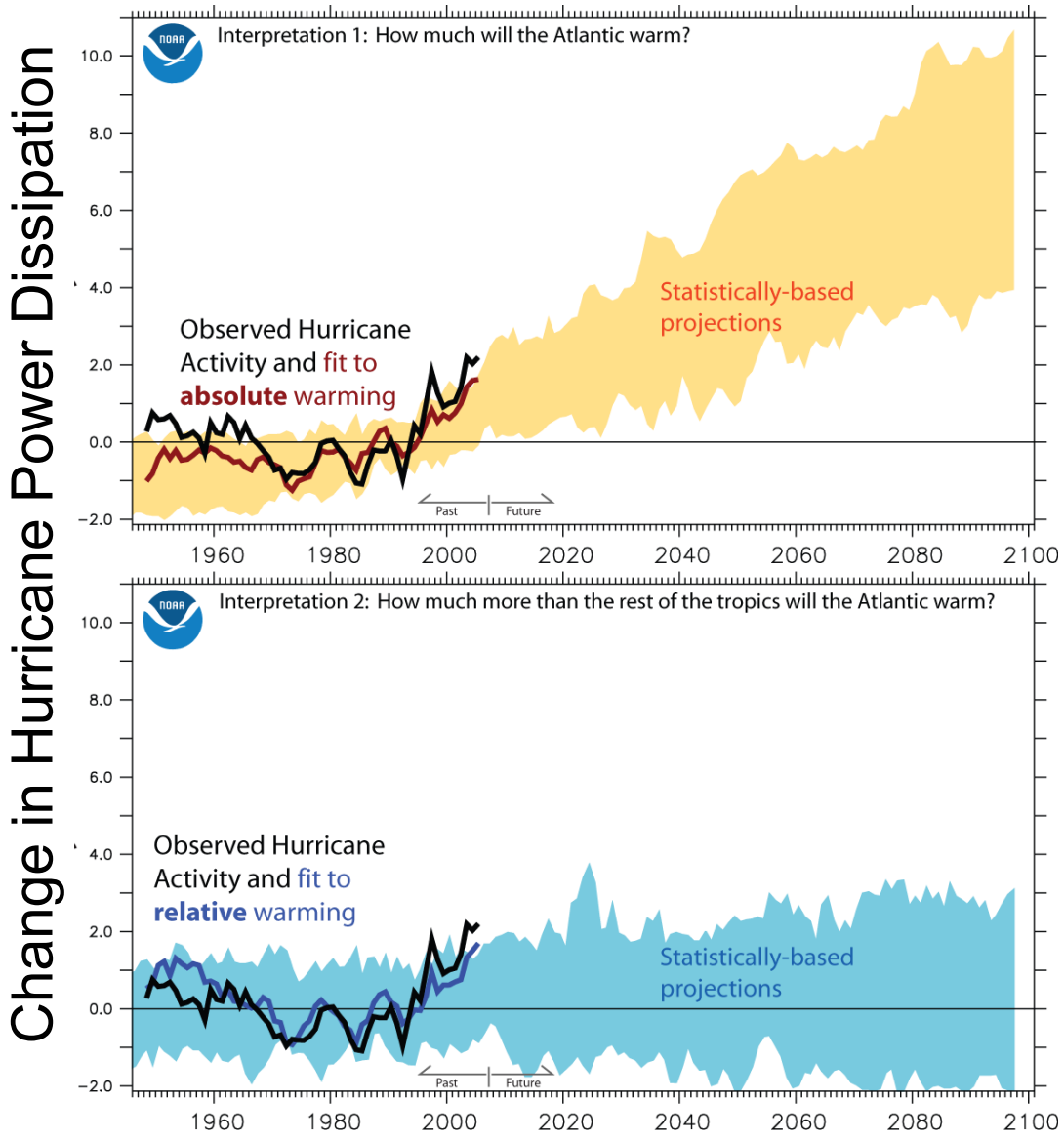
Two Statistical Projections of Atlantic Hurricane Activity



Observed Activity
Absolute Atlantic Temperature

Observed Activity
Relative Atlantic Temperature

Vecchi, Swanson and Soden (2008, Science)

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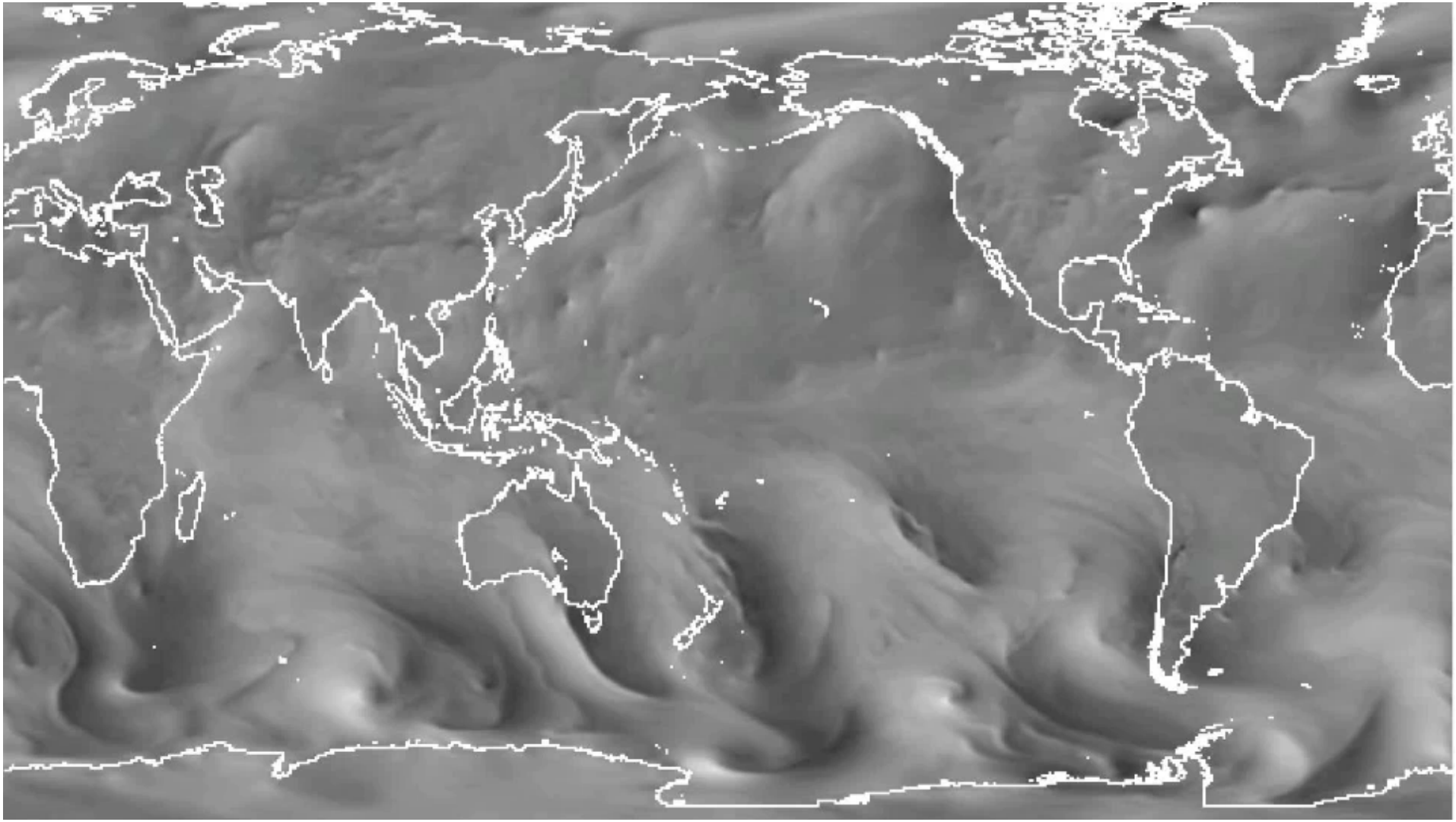
High resolution models (with many “pixels”) resolve hurricanes



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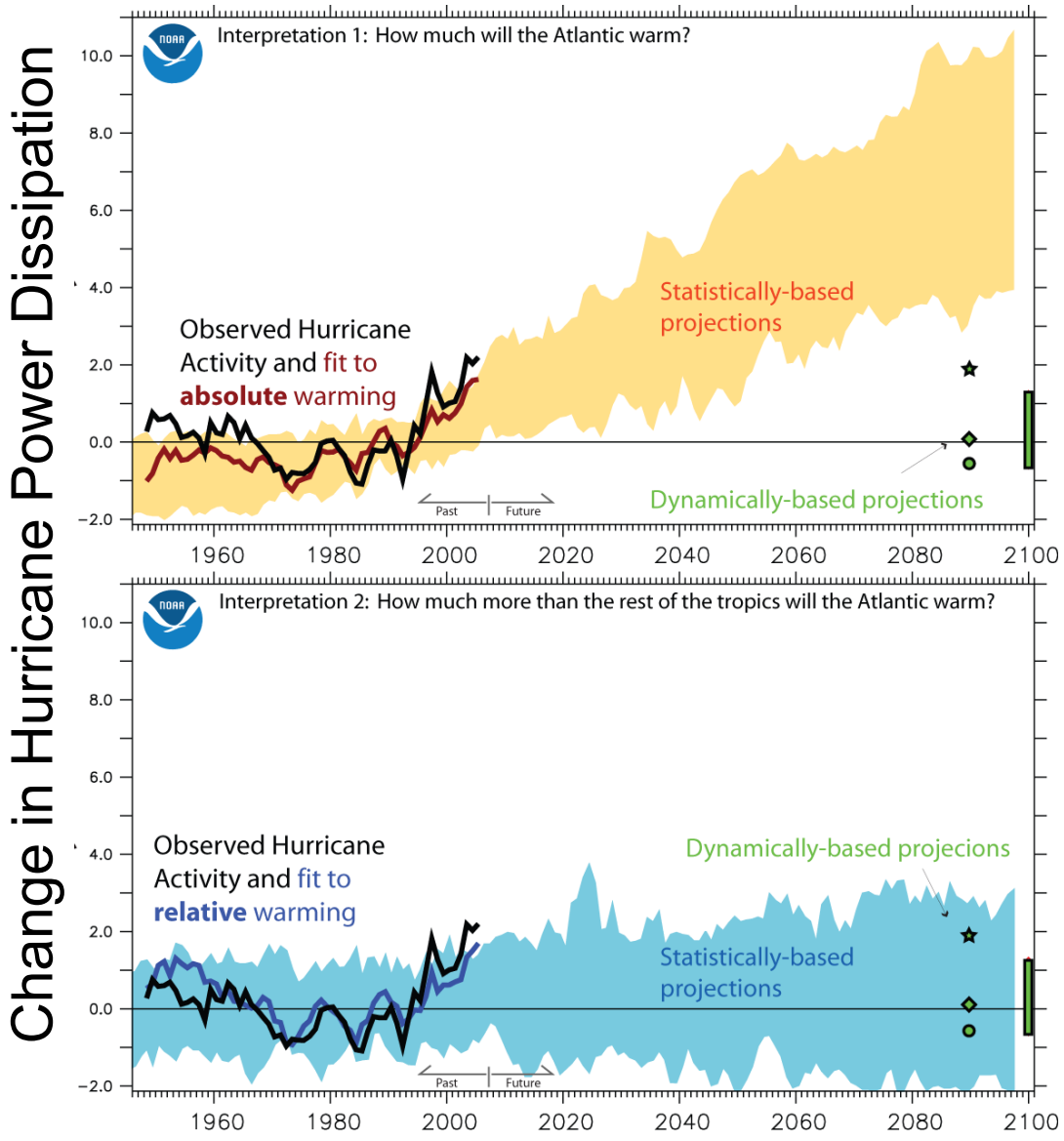
…Add Dynamical Projections of Atlantic Hurricane Activity



Observed Activity
Absolute Atlantic Temperature

Dynamical Model Projections

Observed Activity
Relative Atlantic Temperature

Vecchi, Swanson and Soden (2008, Science)

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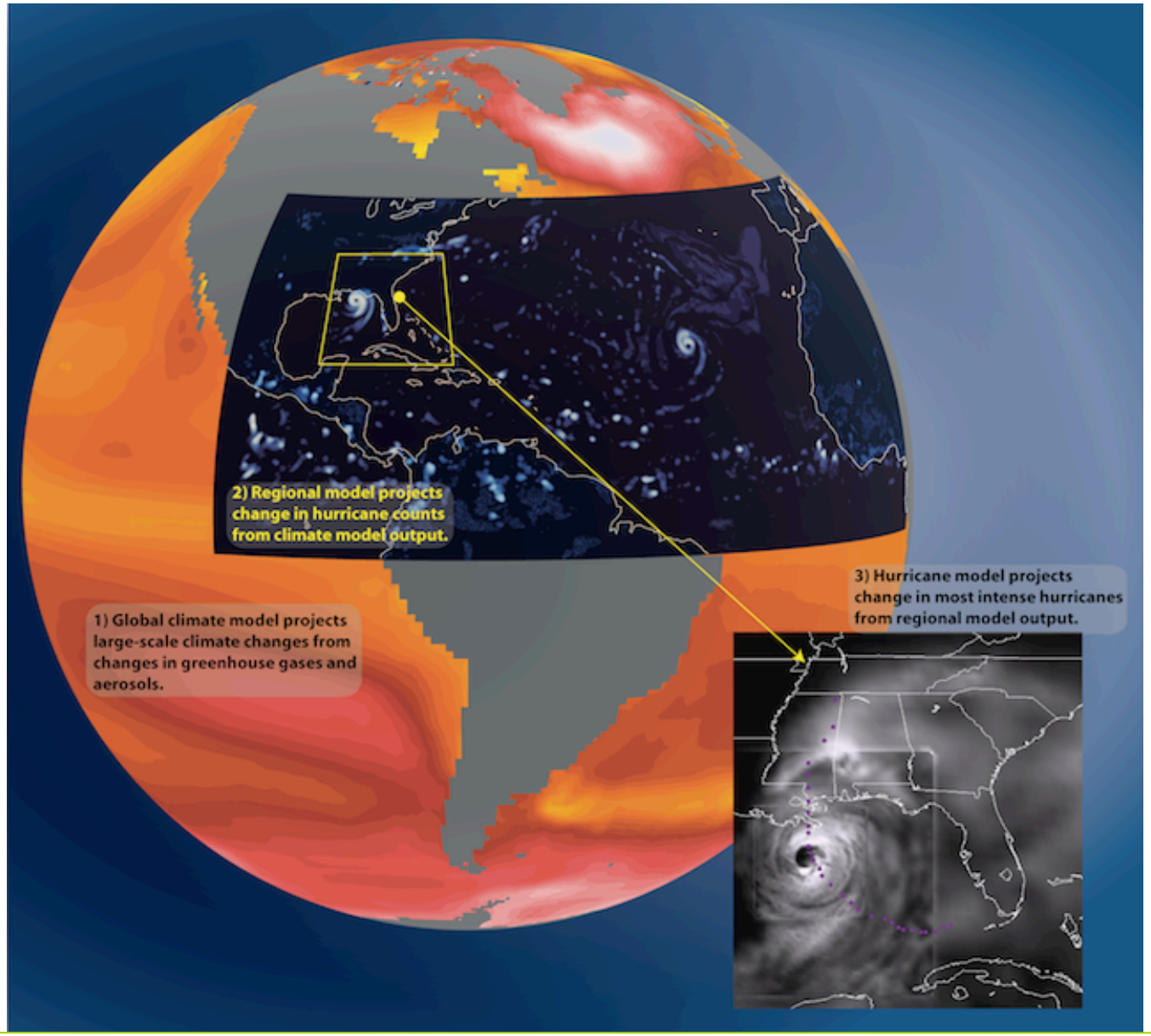
Three-step assessment of impact of global warming on strongest storms



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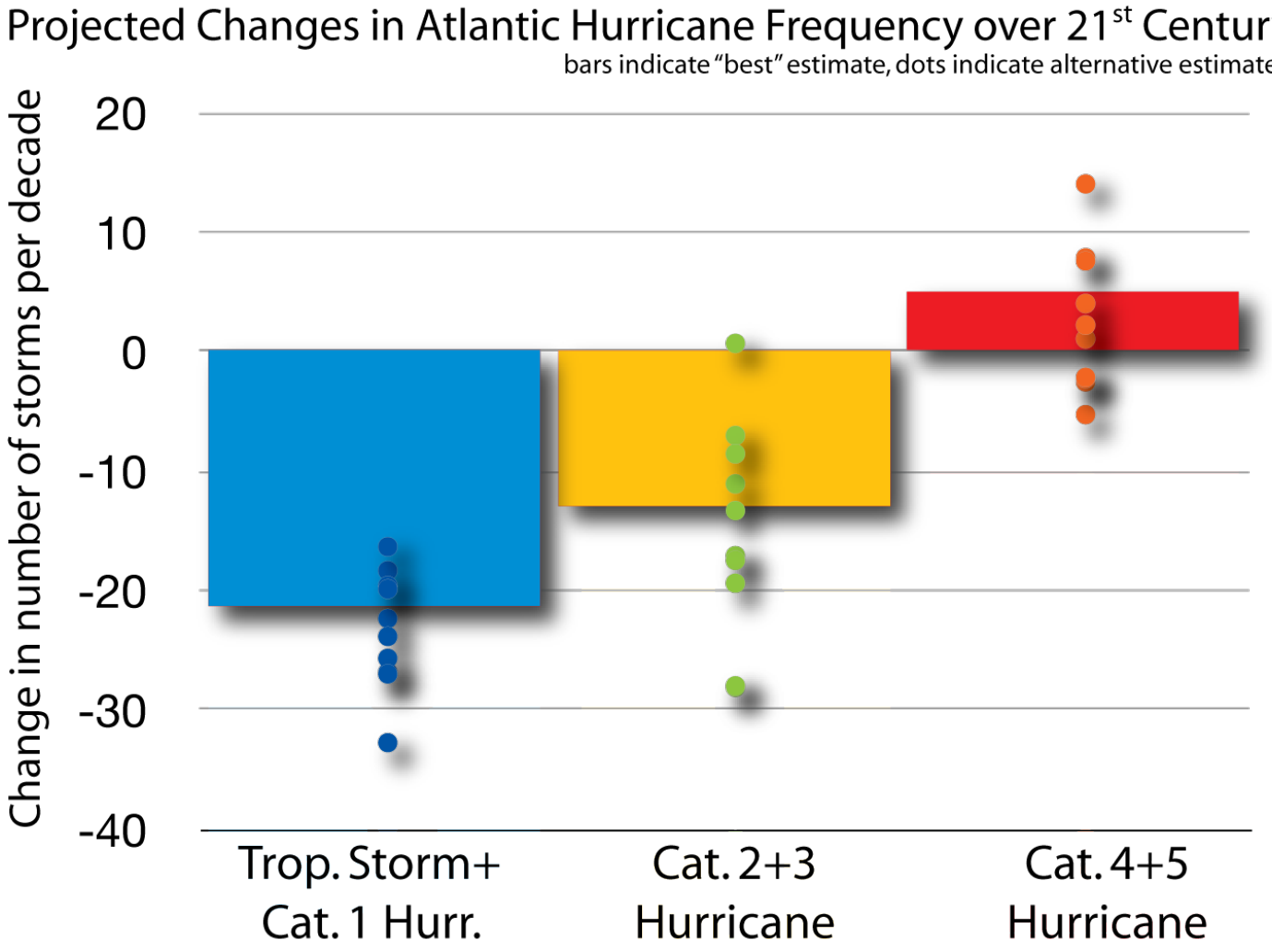
North Atlantic frequency decrease & intensity increase, so strongest storms may become more frequent



Adapted from Knutson et al (2008, Nature Geosci.), Bender et al (2010 Science), Knutson et al. (2013, J. Climate)

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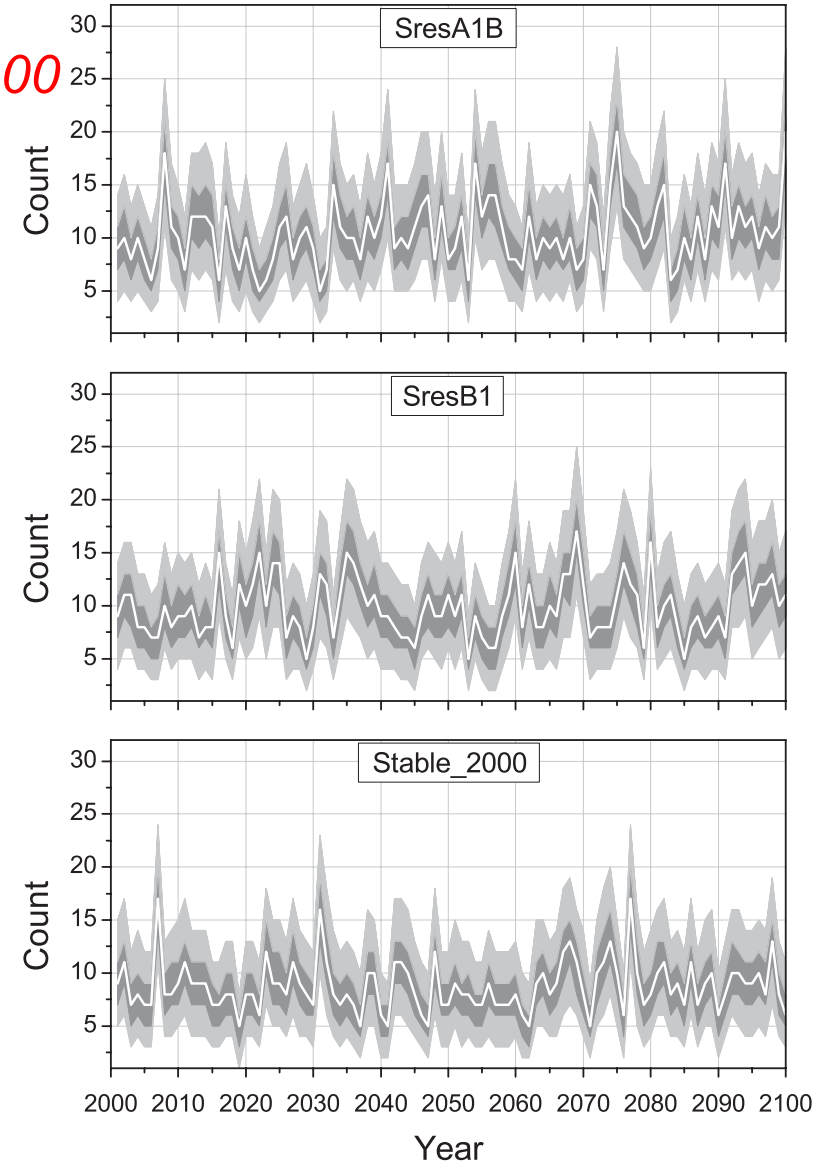
We expect continued variation of tropical storm frequency

2x CO_2 by 2100



Stable CO_2 by 2000

Projected Atlantic Tropical Storm Frequency

(statistical downscaling of GFDL-CM2.1)

source: Villarini et al (2010)

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My current interpretation of evidence

- Observations: can't reject possibility of no change in frequency
  - Data issues and short records
  - We will never know how many storms we didn't see, or what they were like. We can only estimate it.
- Multiple factors affect change in hurricane activity:
  - Pattern of temperature changes is key.
- Projected changes depend on measure chosen, *e.g.:*
  - Atlantic TC Frequency: small change, possible **decrease**
  - Atlantic TC Intensity: projected **increase**
- Year-to-year and decade-to-decade variations will still exist.
- Increased coastal population and wealth: increased vulnerability
- Sea level rise: same storm greater potential impact.
- This is a topic of vigorous scientific inquiry.

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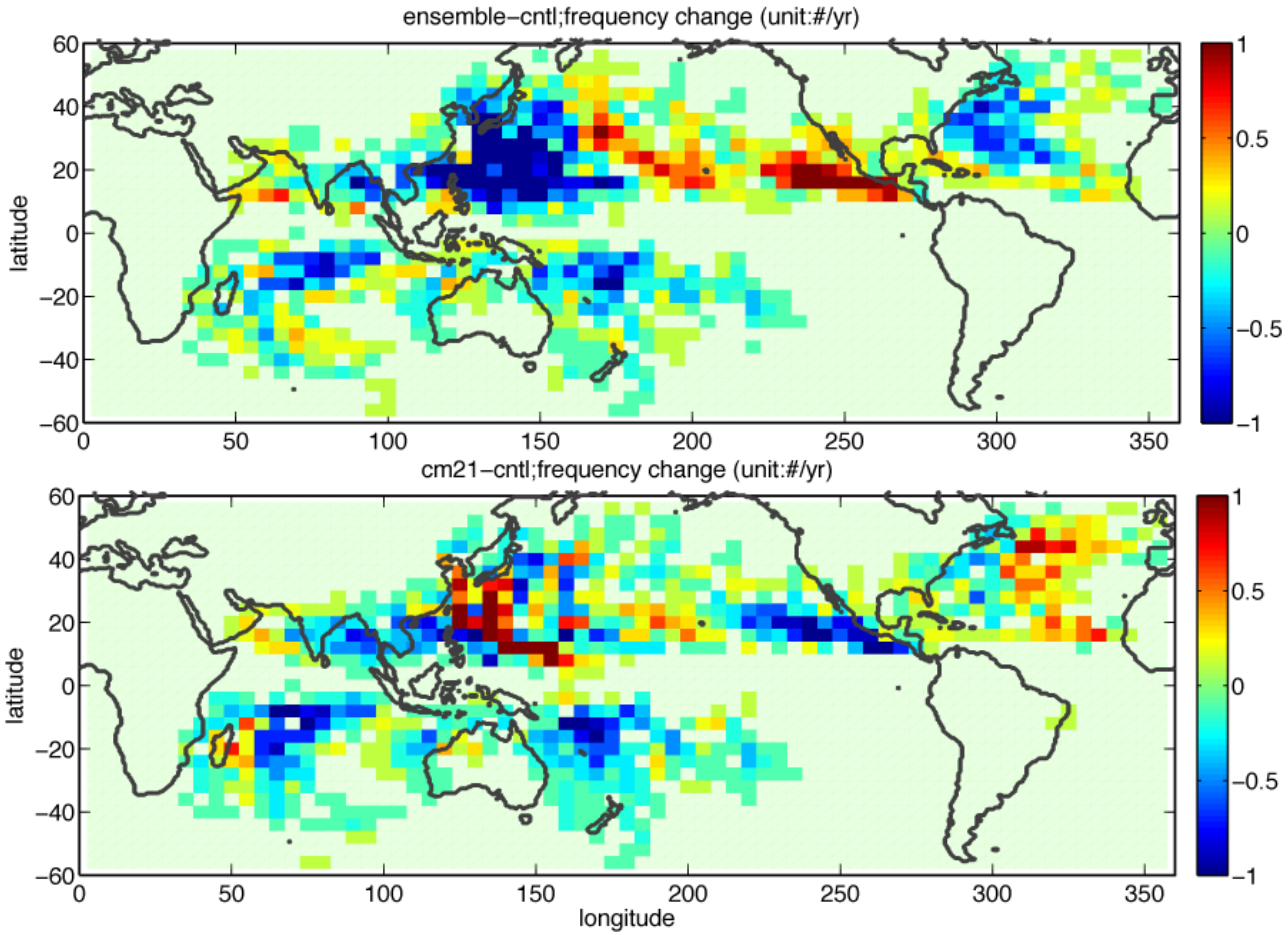
Response of TC frequency in single 50km global atmospheric model forced by two climate projections for 21st century



Red/yellow = increase
Blue/green = decrease

Adapted from
Zhao et al. (2009, J. Climate)

Regional increase/decrease much larger than global-mean.

Pattern depends on details of ocean temperature change.

Sensitivity of response seen in many studies

e.g., Emanuel et al. 2008, Knutson et al. 2008, Sugi et al. 2010, Villarini et al. 2011, etc.