Past & Future Hurricane Activity

Gabriel A. Vecchi
NOAA/GFDL
Princeton, NJ

Gabriel.A.Vecchi@noaa.gov

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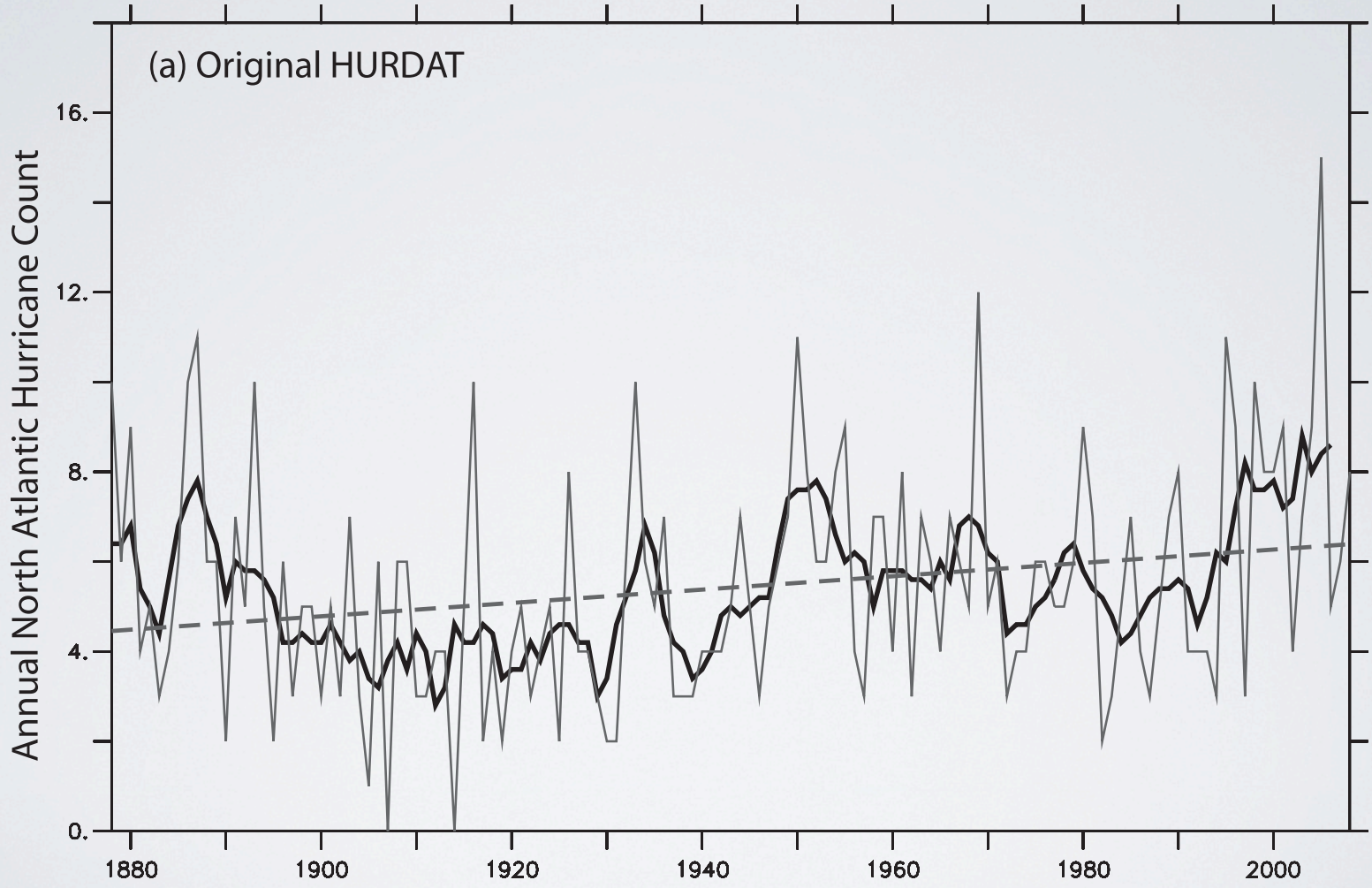
Image: NASA.

Topics to be addressed

To what extent:

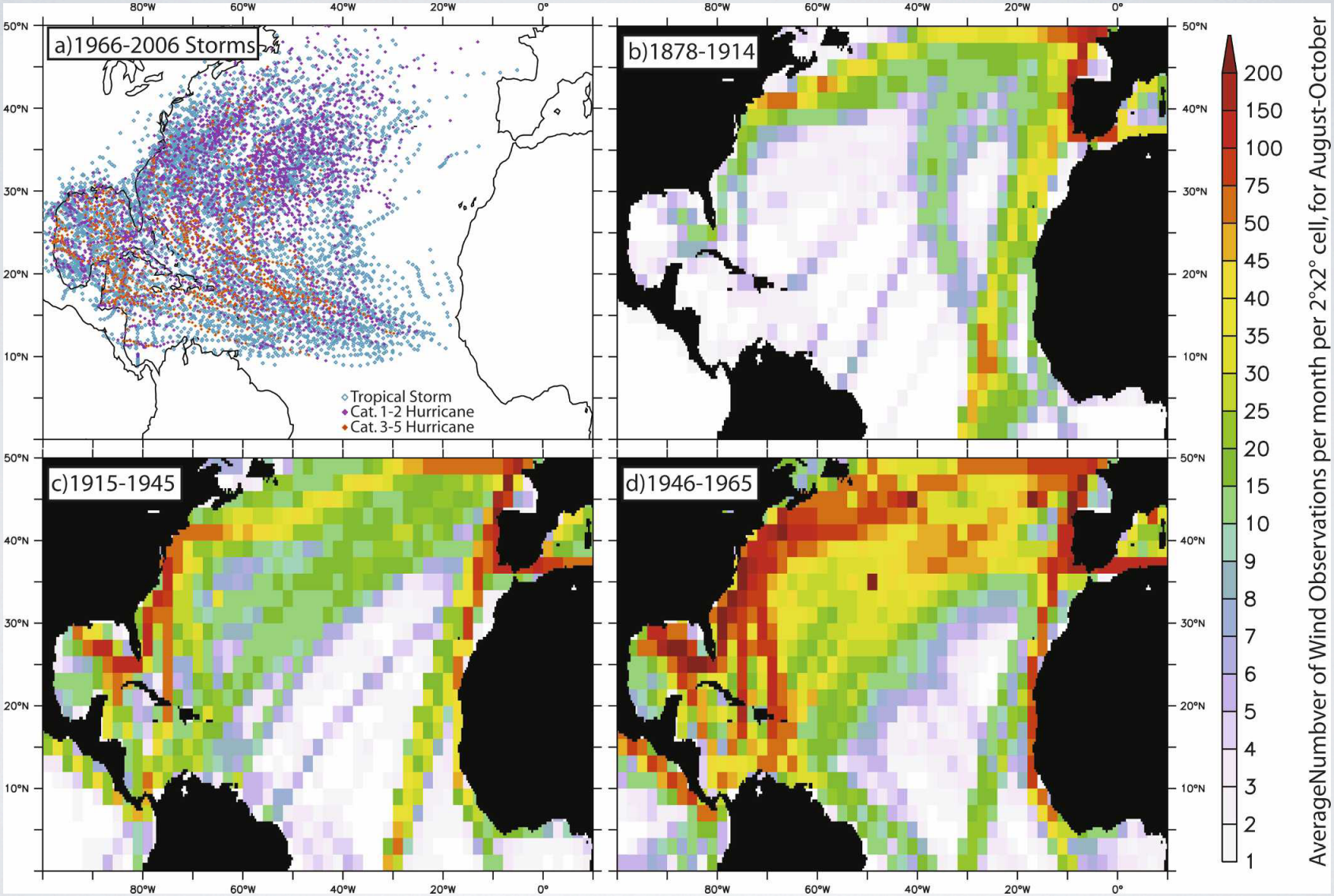
- are hurricane activity records representative of the past?
- can we make skillful multi-year predictions of hurricane activity?
  - Internal climate variability (*e.g.*, El Niño, Atlantic Multidecadal Variation)
  - Forced climate change (*e.g.*, CO_2, soot, dust & other aerosols…)
  - Key sources of uncertainty

Recorded basin-wide North Atlantic hurricane counts have exhibited variability and a trend. Is this real?

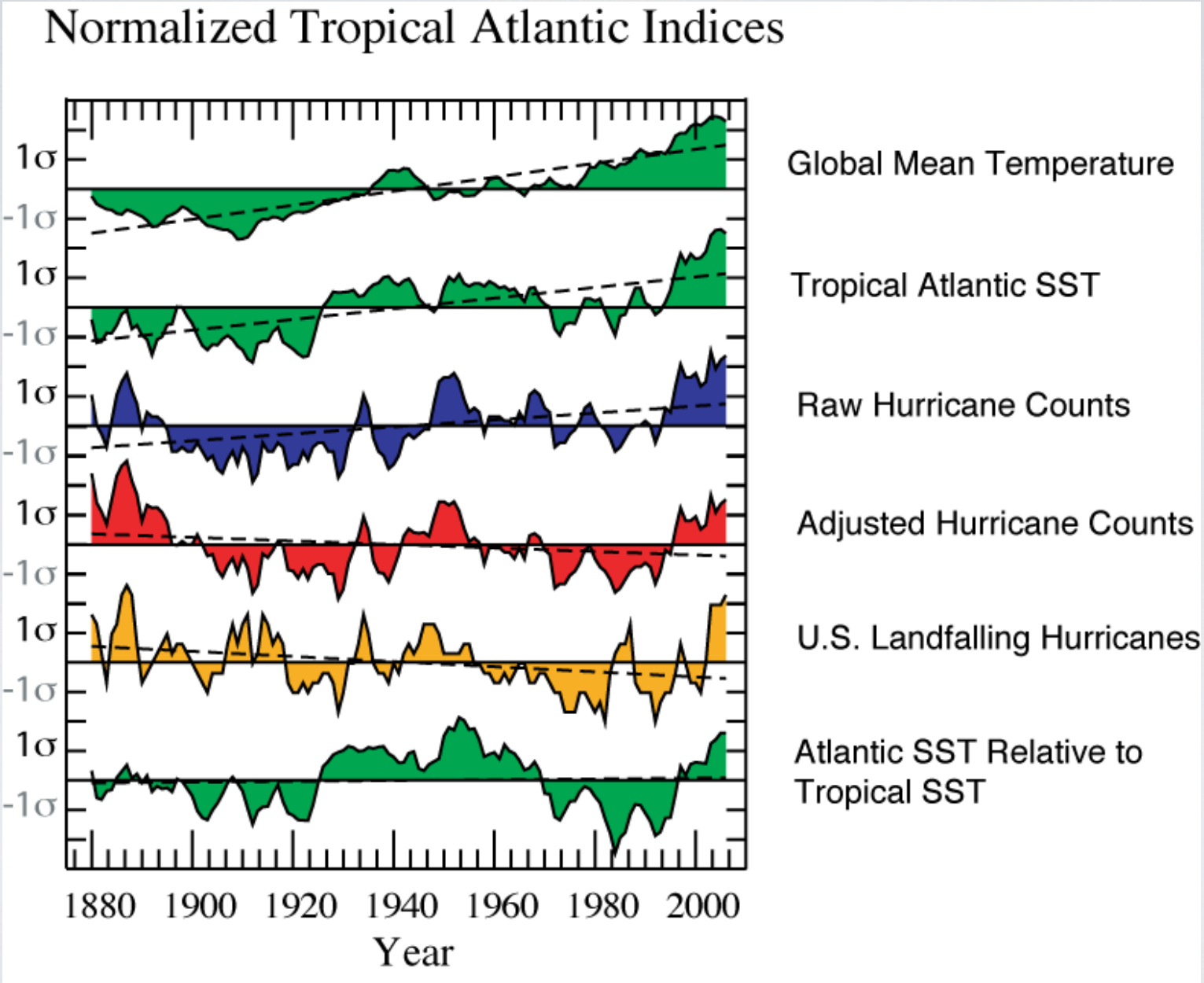


Vecchi and Knutson (2011, J. Climate)

Ship tracks have changed in density and location over time



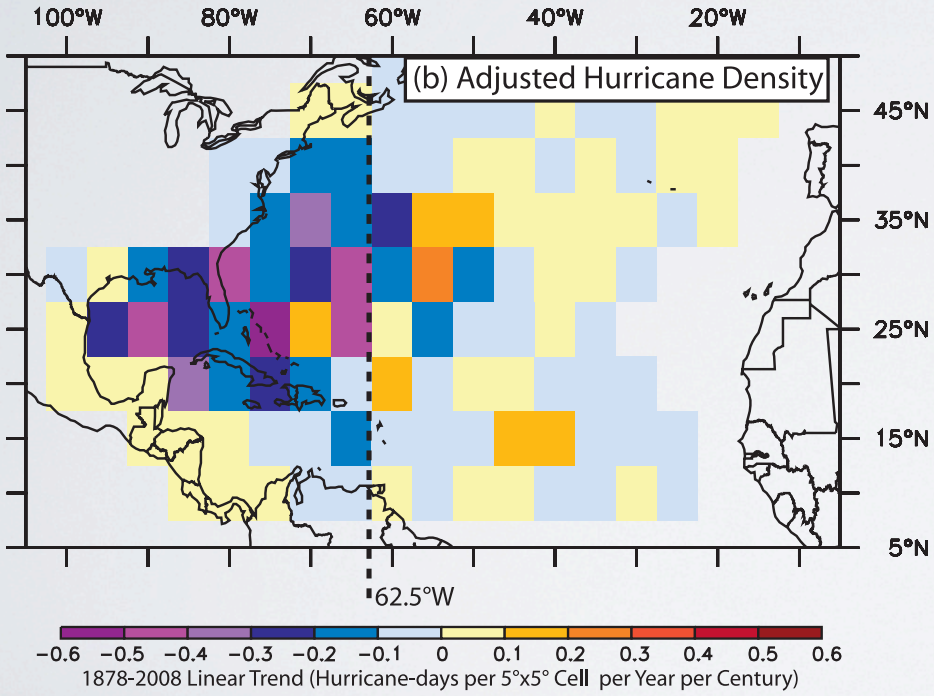
Source: Vecchi and Knutson , J. Climate, 2008.



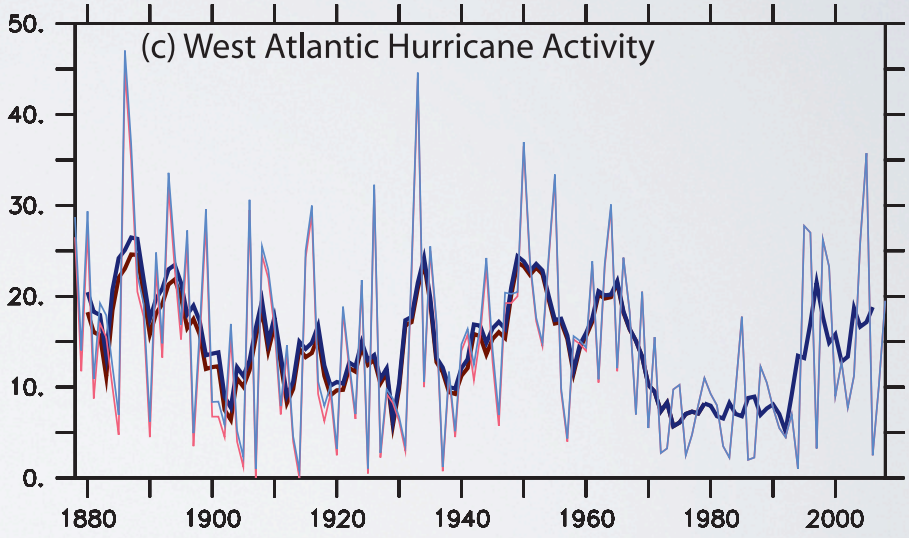
Vecchi and Knutson (2008, J. Clim.); Landsea et al. (2009, J. Clim.); Vecchi and Knutson (2011, J. Clim.)

Long-term changes in hurricane activity spatially heterogeneous: nominal decrease in West Atlantic, including "deep well" in 1970s-1980s

1878-2008 trend in hurricane ·days



hurricane ·days in West Atlantic

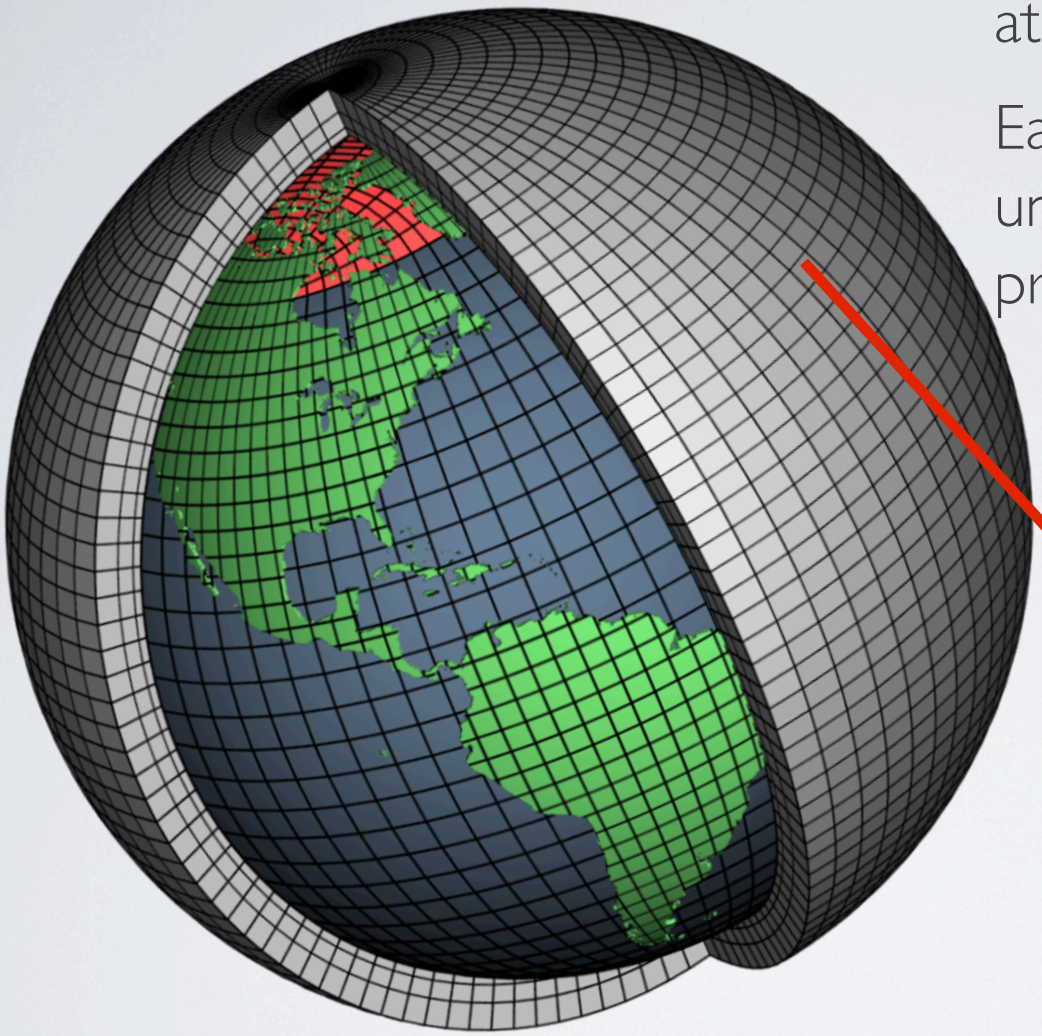


Vecchi and Knutson (2011, J. Climate)

Climate-induced changes in hurricane activity

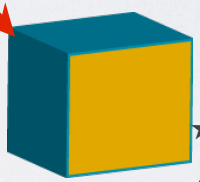
- Forced climate change:
  - greenhouse gases: forcing changes slowly, global impact better constrained than regional impact, incremental impact over next decade may be smaller than variability. Sea level rise
  - aerosols: could be influential, can change rapidly (*i.e.,* uncertain), impacts not yet fully understood, spatially heterogeneous.

- Internal climate variability
  - Interannual and decadal "modes" of variation: El Niño, AMO, …
  - Ongoing efforts to build basis for multi-year prediction of climate and its impacts –predictability depends on region and phenomenon.
  - Random, unpredictable "weather" can impact even multi-year changes.



Models have land, ocean, atmosphere and ice components.

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



In each grid cell:

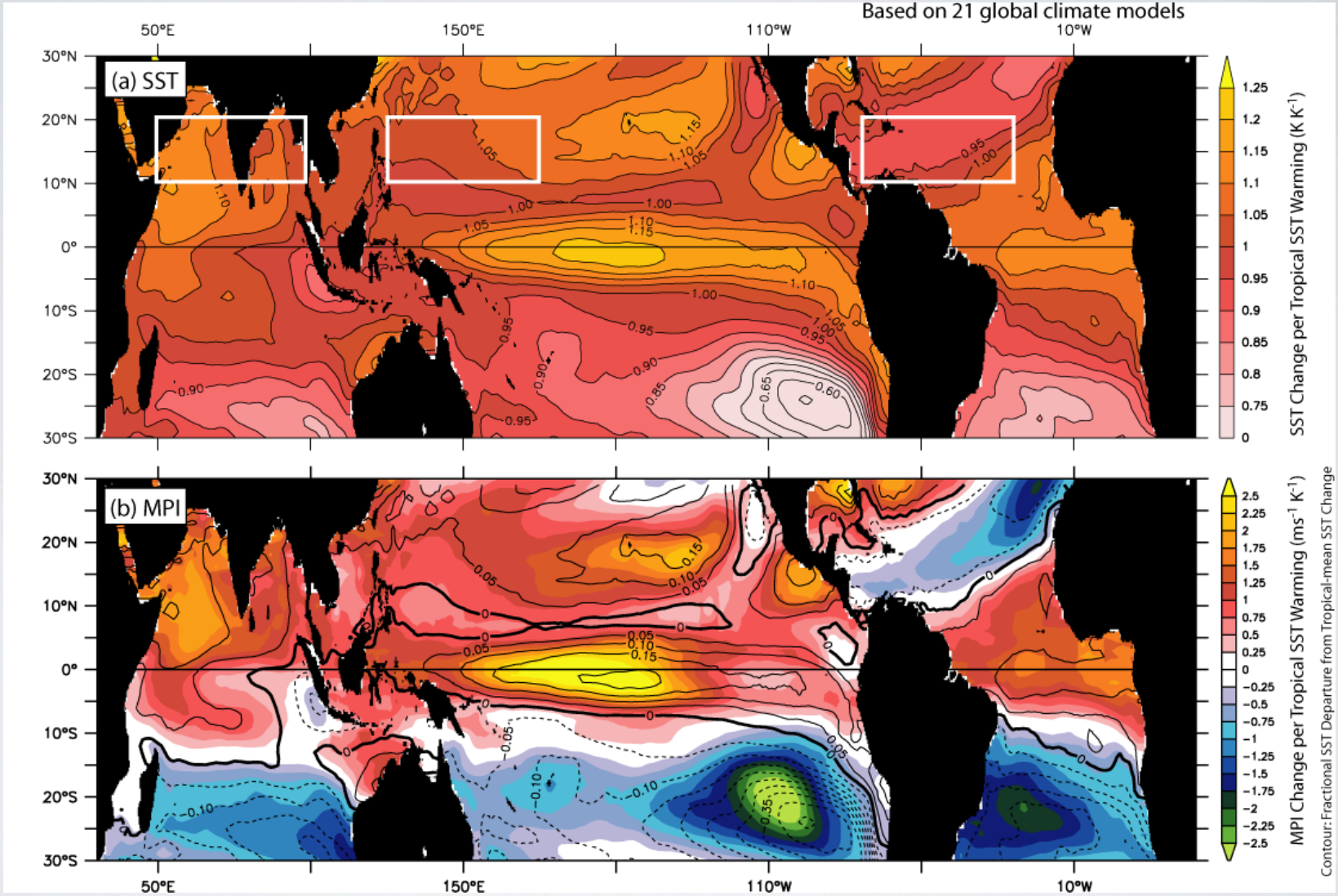
- ⋆conserve momentum ($F=m \cdot a$)
- ⋆account for changes in mass and composition
- ⋆conserve energy (radiation, latent, etc...)

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

GCM Projections of 21st Century Changes in Large-Scale Environment

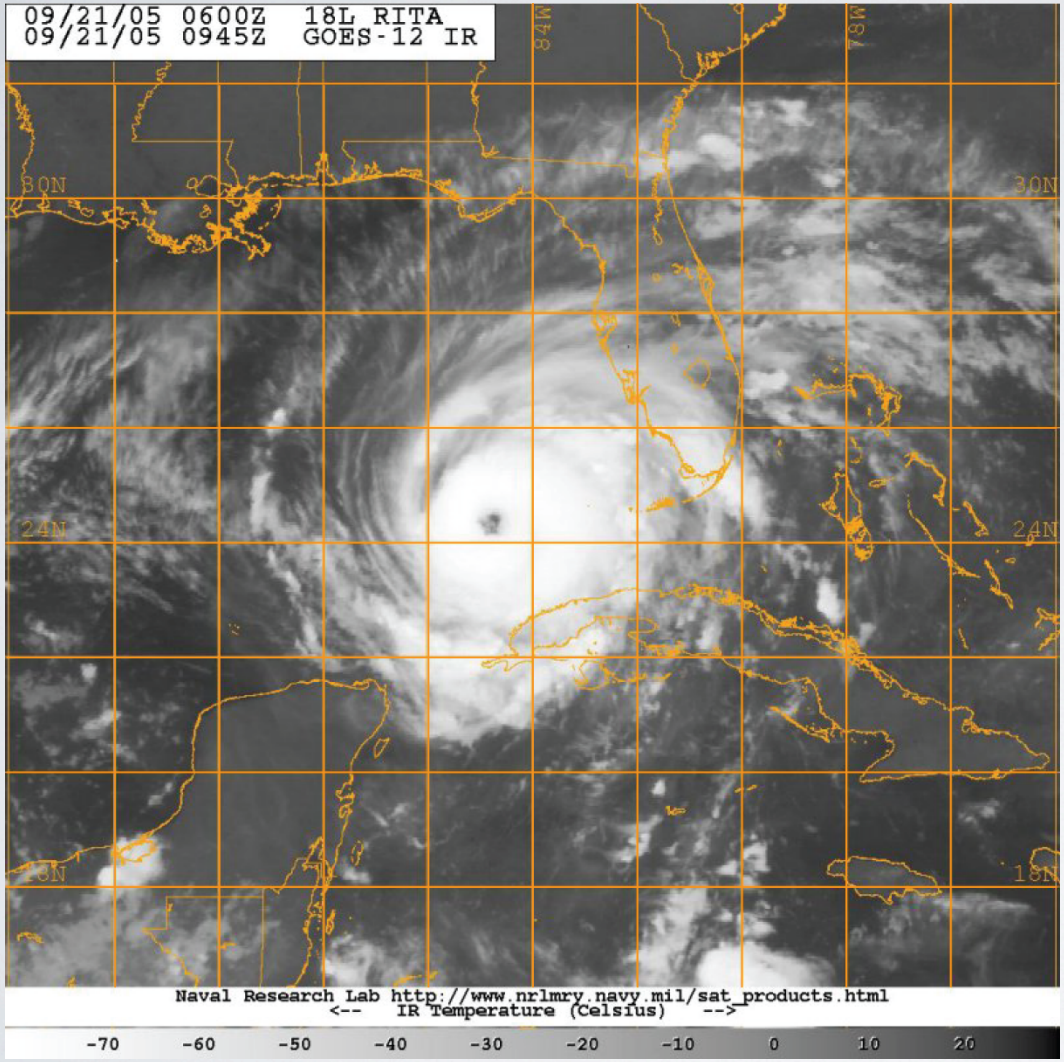
Surface Temp.

Potential Intensity



Vecchi and Soden (2007, Nature)

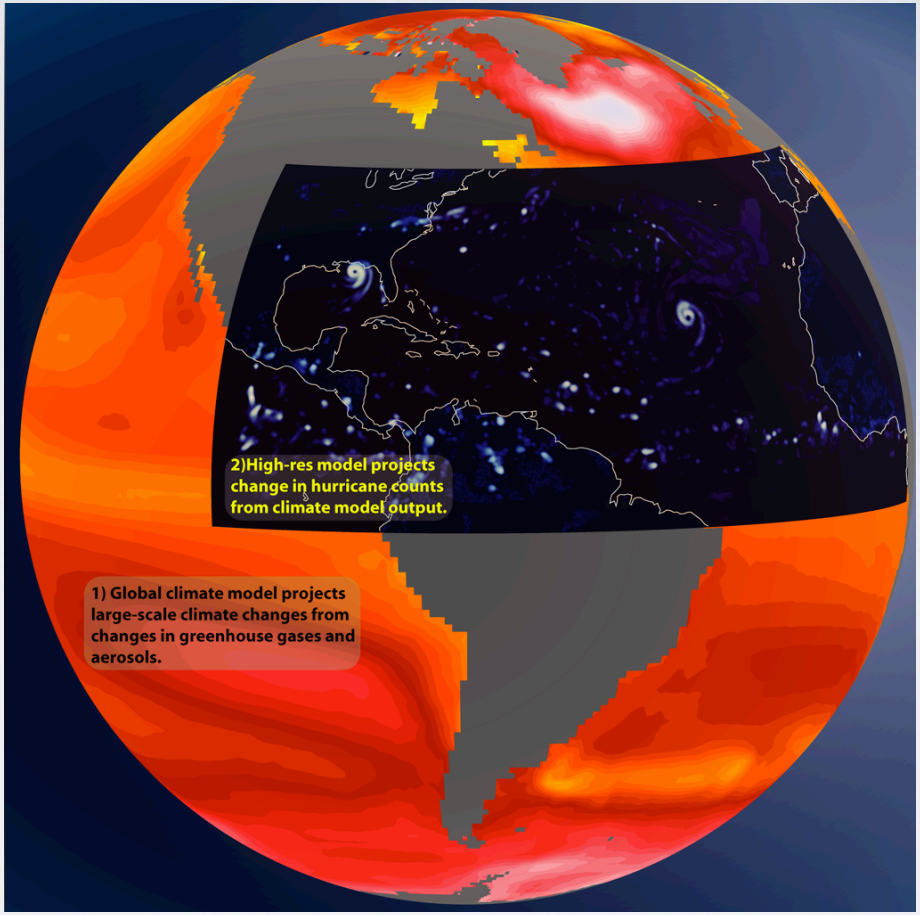
But, current computing power limits ability of coupled global climate models to represent hurricanes



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

Size of grid limited by power of computers.

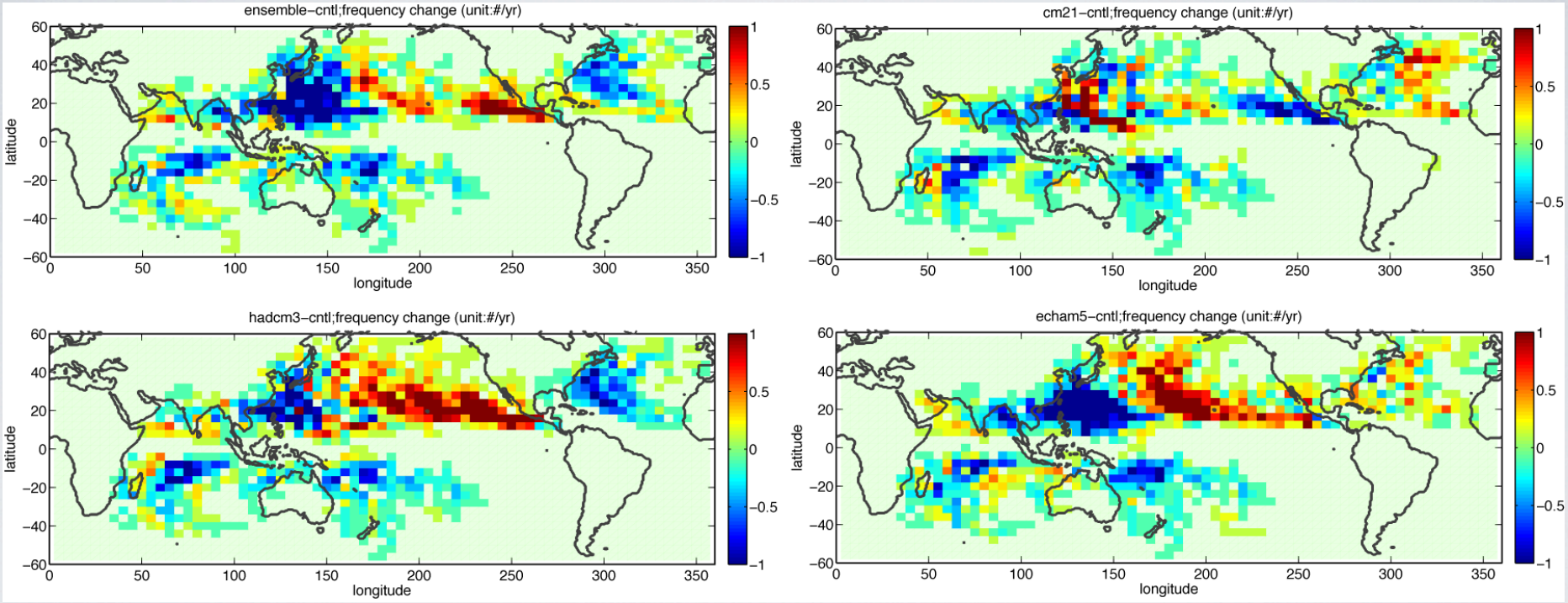
"Downscale" Climate Model Projections With High-Resolution or Statistical Models



Global Climate Models -> High-resolution Model

Large-scale TS Frequency

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



Red/yellow = increase
Blue/green = decrease

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

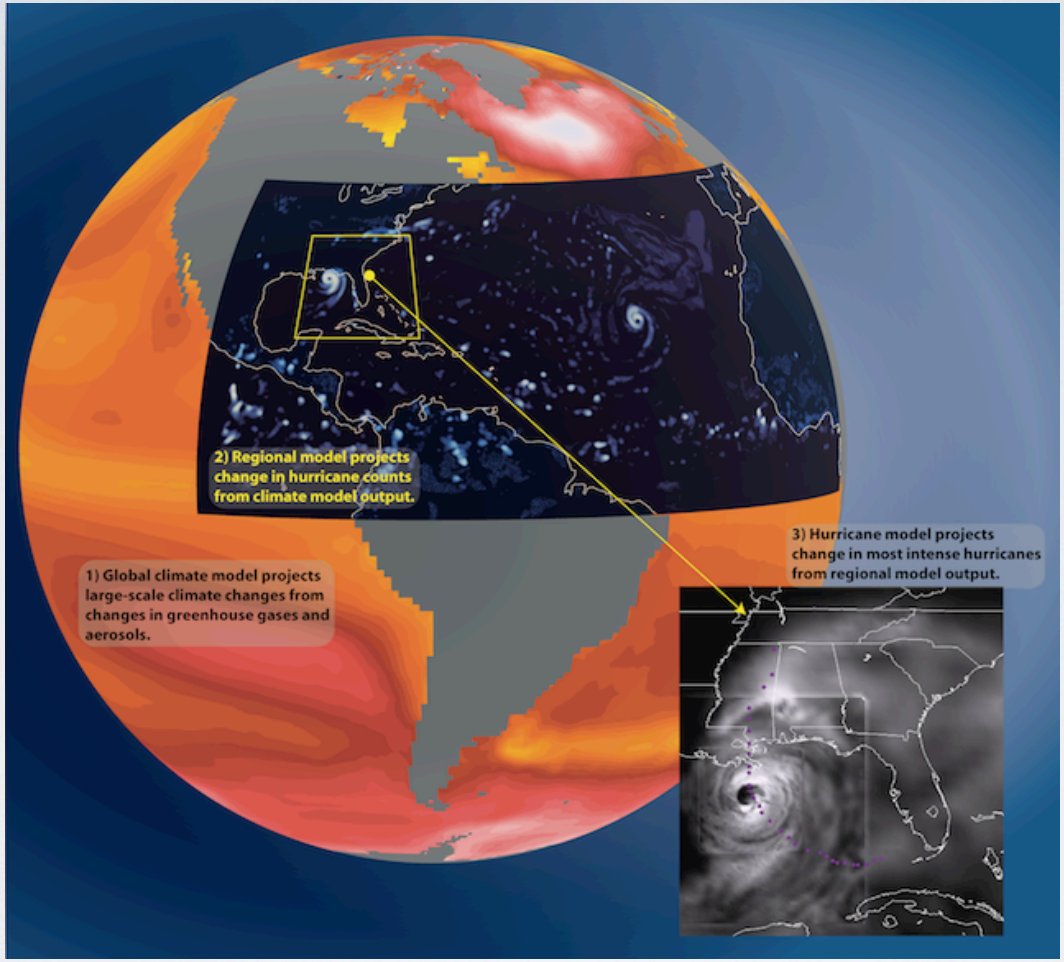
Regional increase/decrease much larger than global-mean.

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, setc

Strongest cyclones projected with double downscaling

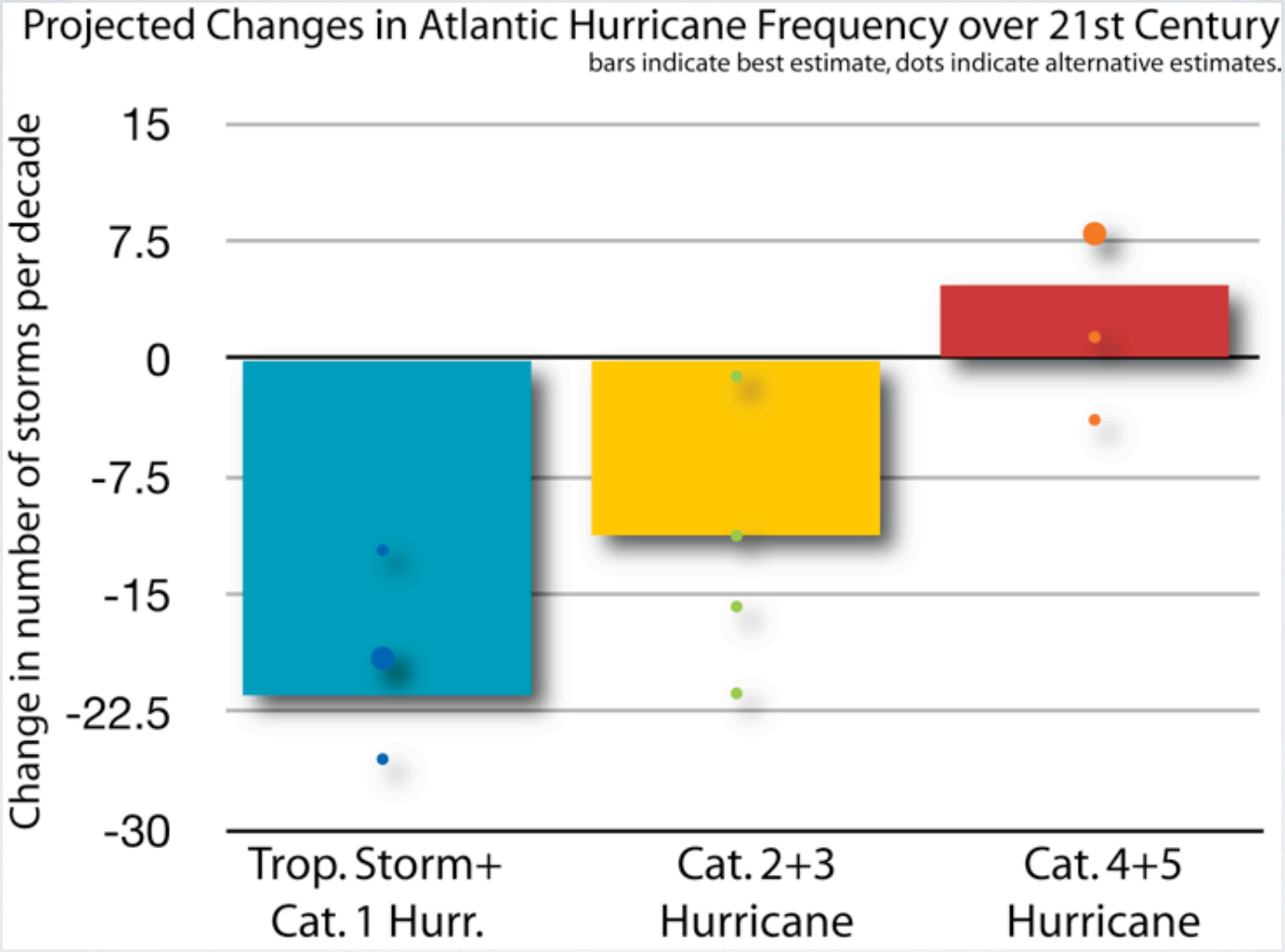


Adapted from
Bender et al (2010, Science)

Global Climate Models -> Hi-Res Model -> Hurricane model

Large-scale TS Frequency Intensity

Overall frequency decrease projected for North Atlantic, but strongest storms may become more frequent



Adapted from Bender et al (2010, Science)

Use homogenized data and high-res models to build statistical models for exploration and projections

$$Rate = e^{a+bSST_{ATL}-cSST_{TRO}}$$

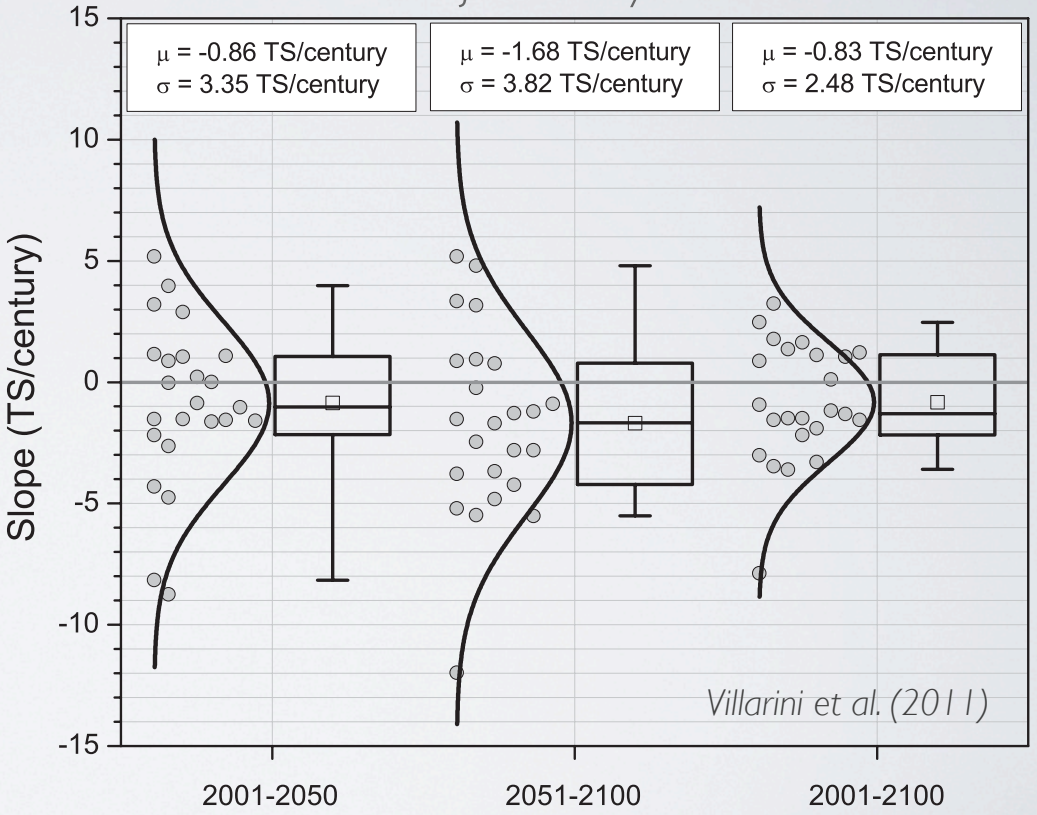
Family of statistical models based on observed and high-res. model hurricane activity and SST.

Use two predictors:

- Tropical Atlantic SST (positive)
- Tropical-mean SST (negative)

Consistent with high-res dynamical models, understanding on controls to hurricanes & "cheap".

Projections of North Atlantic TS Count Trends Using Observationally-based Statistical Model and SST Projected by 23 CGCMs



Knutson et al. (2008) Swanson (2008), Vecchi et al. (2008), Zhao et al. (2009, 2010), Villarini et al. (2010, 2011.a.,.c), Villarini and Vecchi (2011)

Key sources of uncertainty for decadal hurricane activity projections

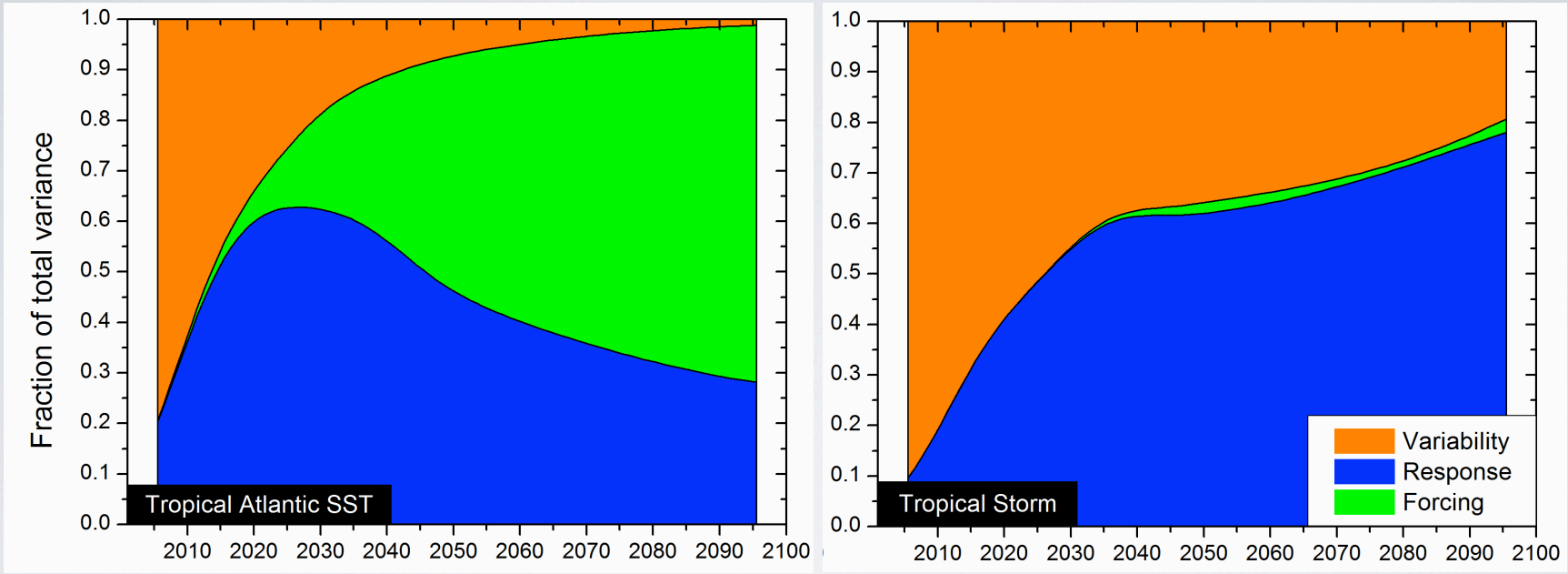


Figure adapted from Villarini et al. (2011), see also Villarini and Vecchi (2012, in press)

Sources of uncertainty (after Hawkins and Sutton, 2009)

- Variability: independent of radiative forcing changes
- Response: "how will climate respond to changing GHGs?"
- Forcing: "how will GHGs change in the future?"

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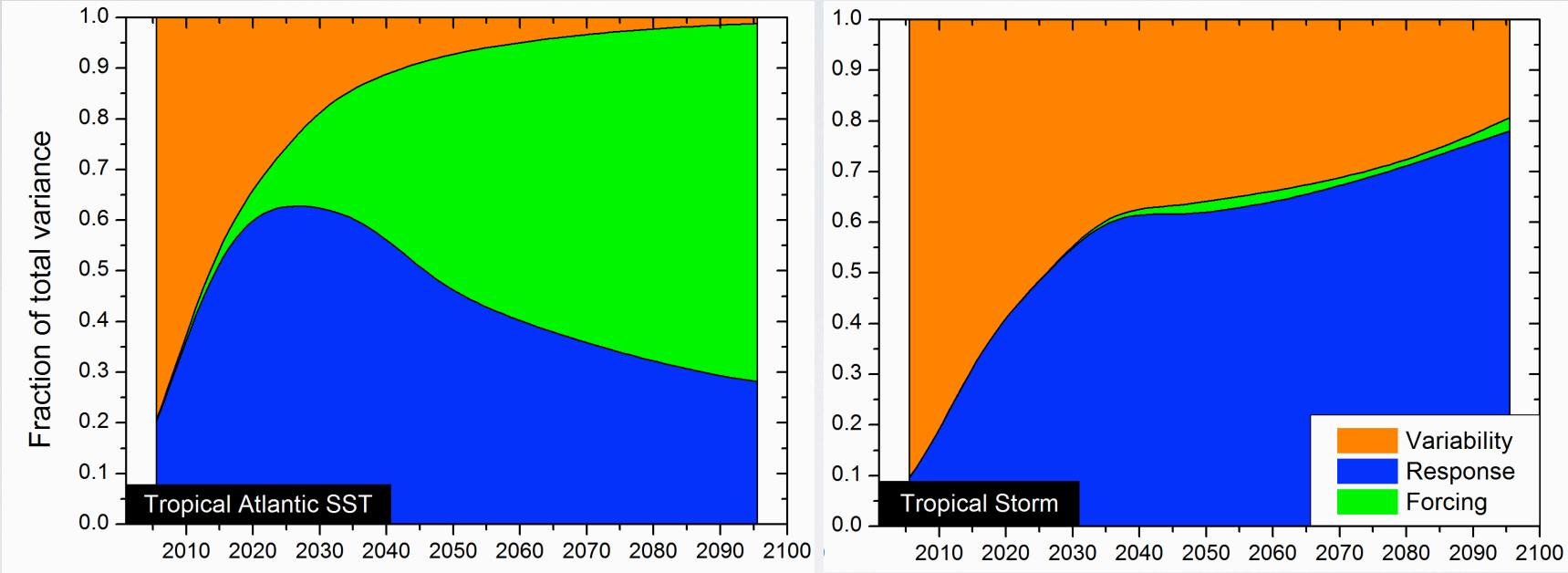


Figure adapted from Villarini et al. (2011), see also Villarini and Vecchi (2012, in press)

Partitioning for North Atlantic SST resemble that for other regional temperatures:

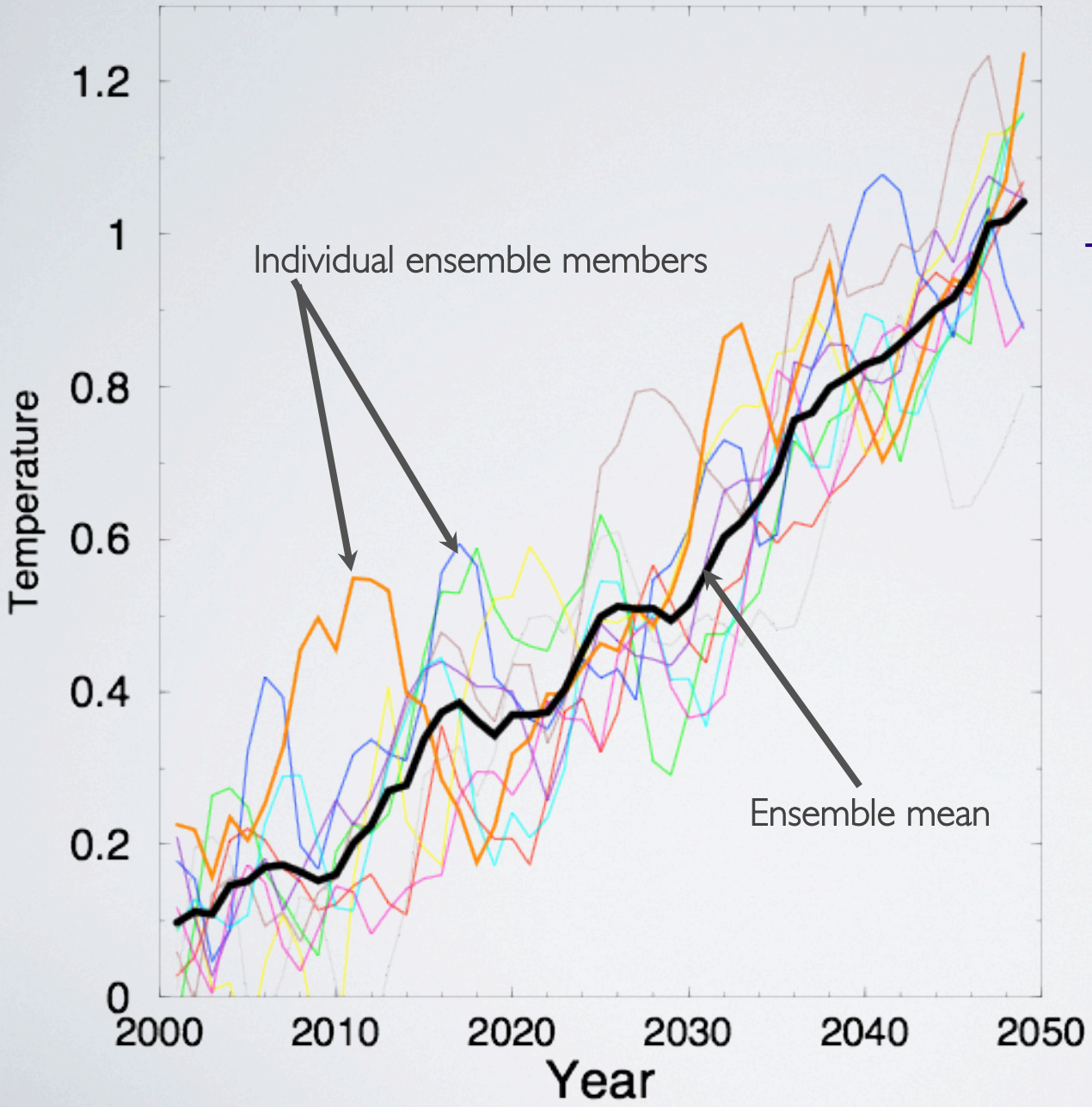
- Short term: Variability
- Medium term: Response
- Long term: Forcing & *Response*

Even though Atlantic SST a predictor, partitioning for NA Tropical Storms distinct:

- Short term: Variability
- Medium term: Response & Variability
- Long term: Response & *Variability*

Simulated Atlantic Sea Surface Temperature

(based on GFDL CM2.1)



Can we predict the trajectory of Atlantic temperatures over the next several decades?

How about hurricane activity?

Slide: Tom Delworth (GFDL)

Decadal prediction: New efforts focused on multi-year/ decadal predictions: a mixed initial/boundary value problem

Sources of & Limitations on climate predictability

years to decade

hours to a year

- Climatology
  (what happens typically, including randomness)
  need good observations
- Evolution of initial conditions
  (e.g., weather or El Niño forecast)
  need good observations, models, initialization schemes

Many decades to centuries

- Climate response to forcing
  (e.g., CO_2, aerosols, sun, volcanoes)
  need good models and estimates of forcing

Merge multiple tools and understanding to build experimental long-lead hurricane forecast system: skill from as early as October of year before

April & onward forecasts fed to NOAA Seasonal Outlook Team

Hi-Res AGCM in many different climates. Count storms.

Build statistical model of the response of hurricanes in HiRAM

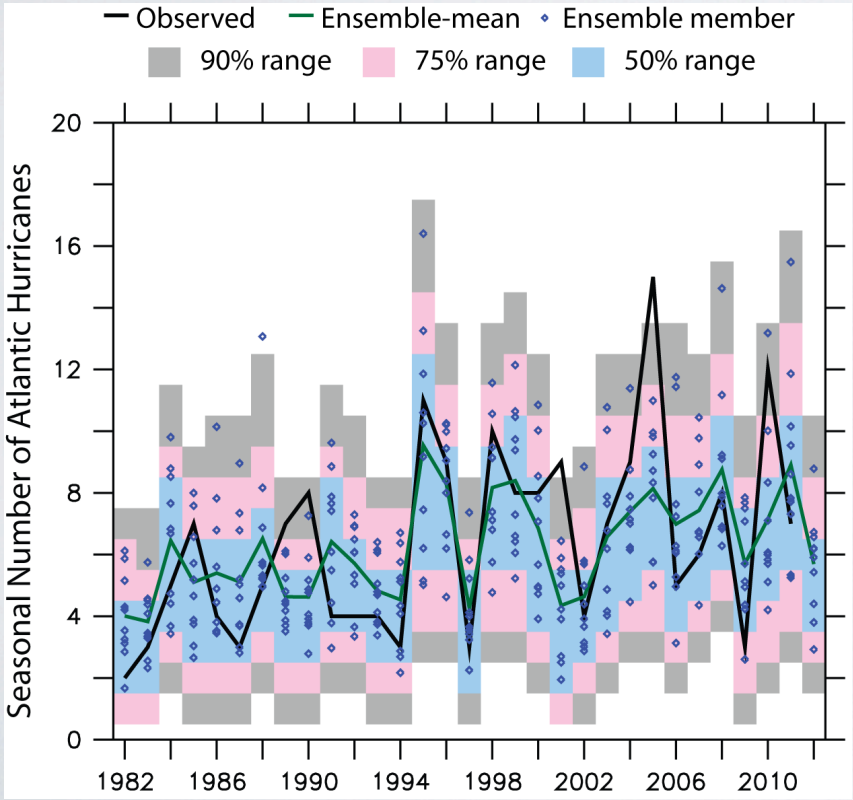
Use initialized coupled model to forecast future values of SST

Apply Stat model to Predicted SST

HyHuFS

Make Prediction of Full PDF of Hurricane Activity

Initialized January: r=0.66



http://gfdl.noaa.gov/hyhufs

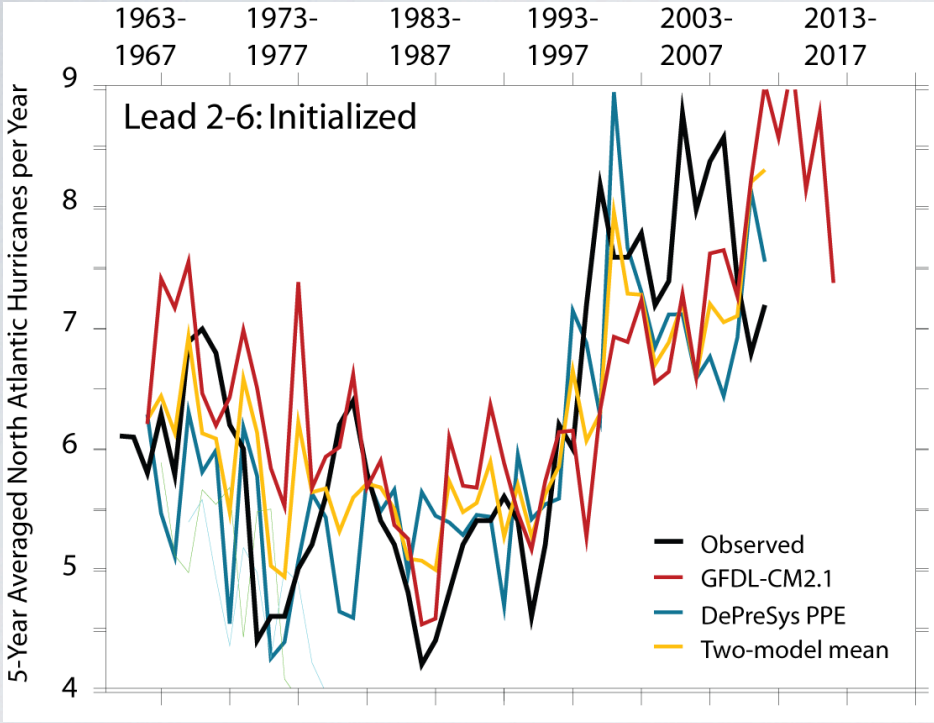
Vecchi et al. (2011)

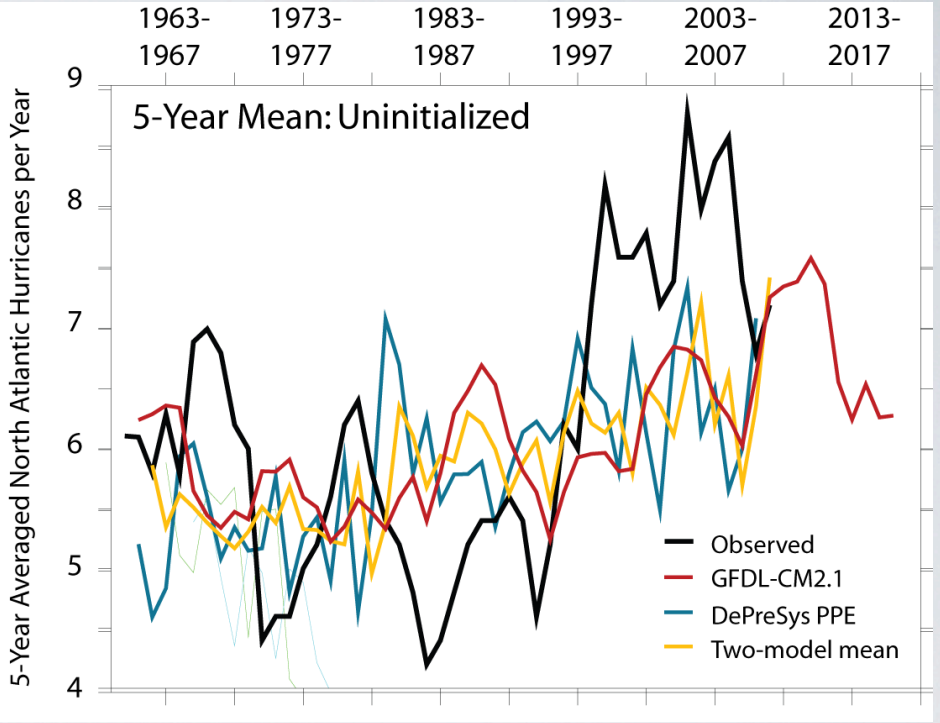
Apply HyHuFS to multi-year climate model forecasts

- Part of CMIP5 experiment suite
- Multiple climate models running initialized + forced experiments 1960-present
- Experiments aim at assessing retrospective prediction skill up to 10 years out.

Experimental decadal predictions

Hybrid system: statistical hurricanes, dynamical decadal climate forecasts





- Retrospective predictions encouraging.
- However, small sample size limits confidence
- Skill arises more from recognizing 1994-1995 shift than actually predicting it.
- This is for basinwide North Atlantic Hurricane frequency only.

EXPERIMENTAL: NOT OFFICIAL FORECAST

Vecchi et al. (2012 in prep.), see also Smith et al. (2010, Science)

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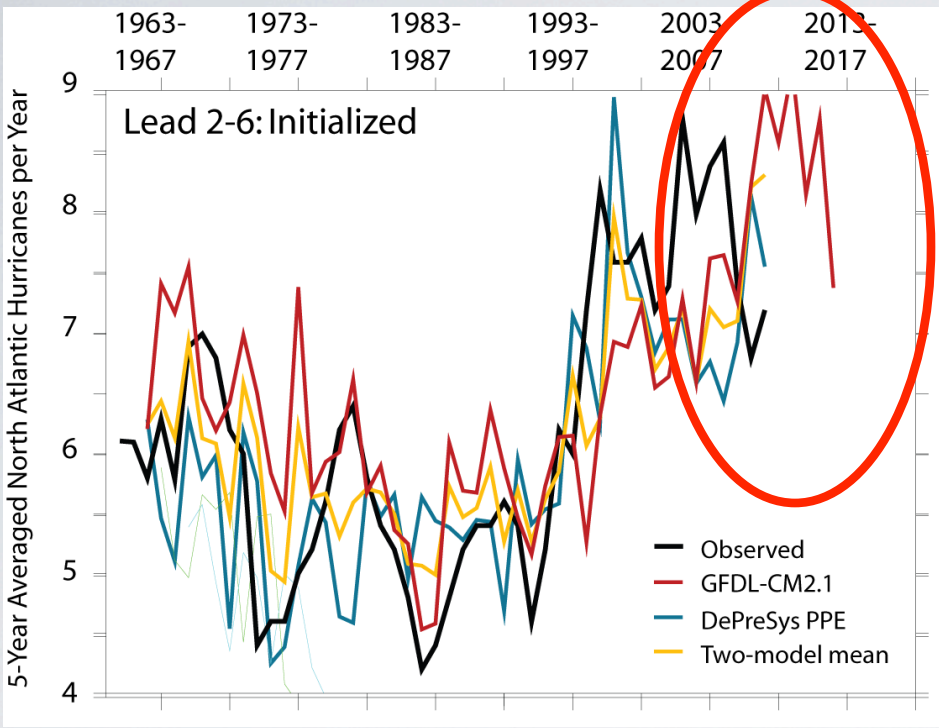

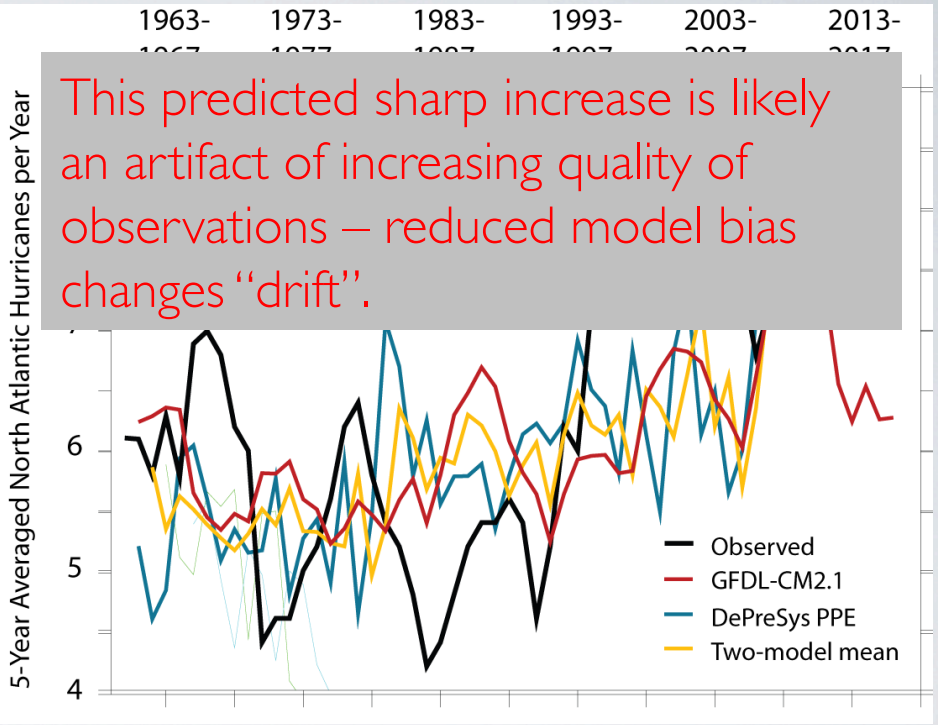

This predicted sharp increase is likely an artifact of increasing quality of observations – reduced model bias changes "drift".

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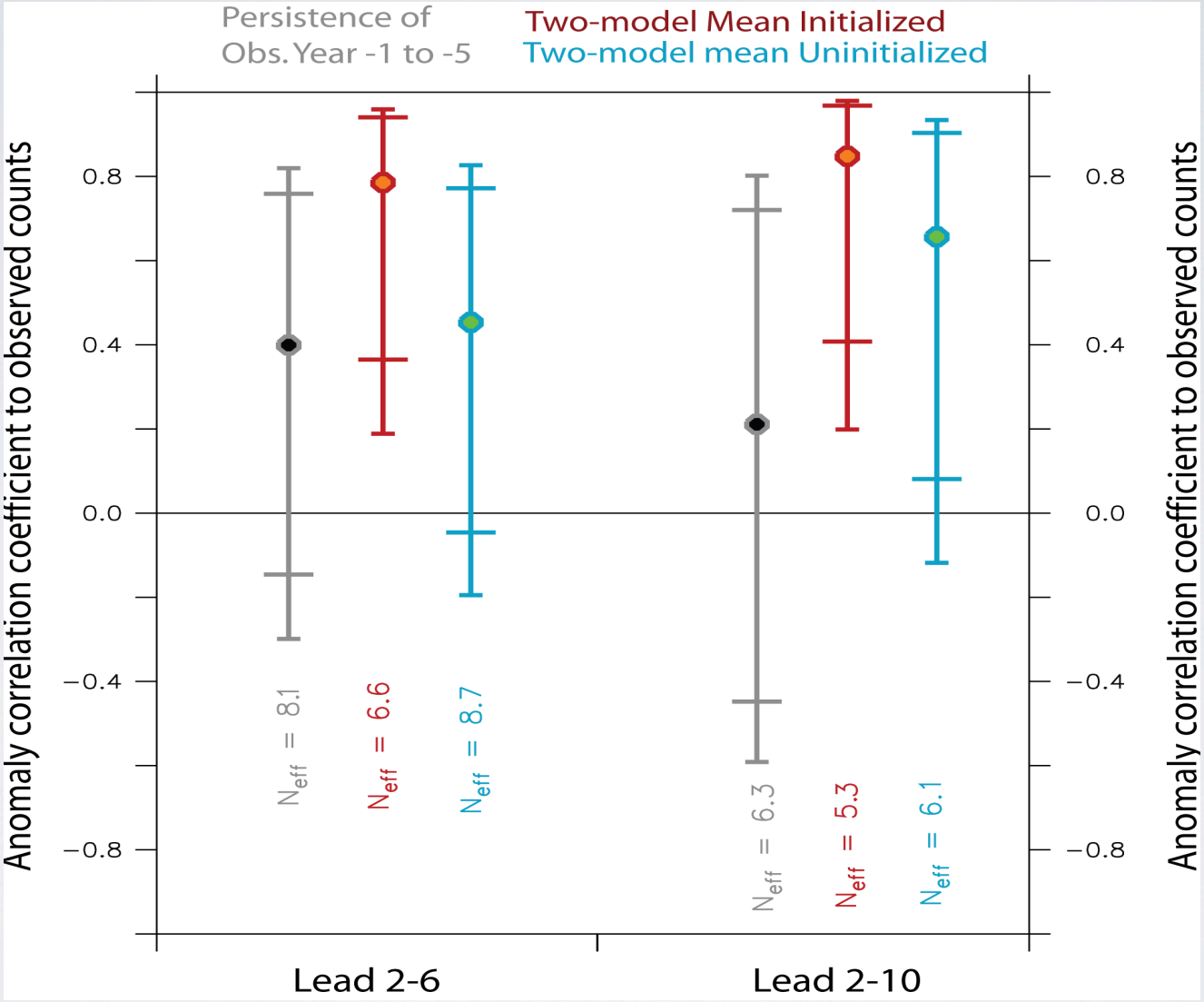

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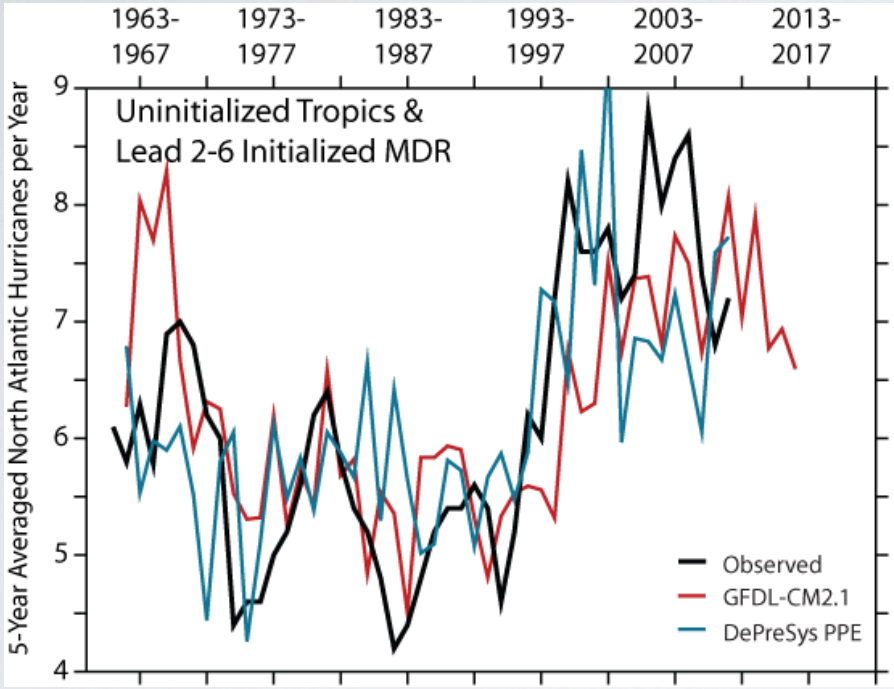
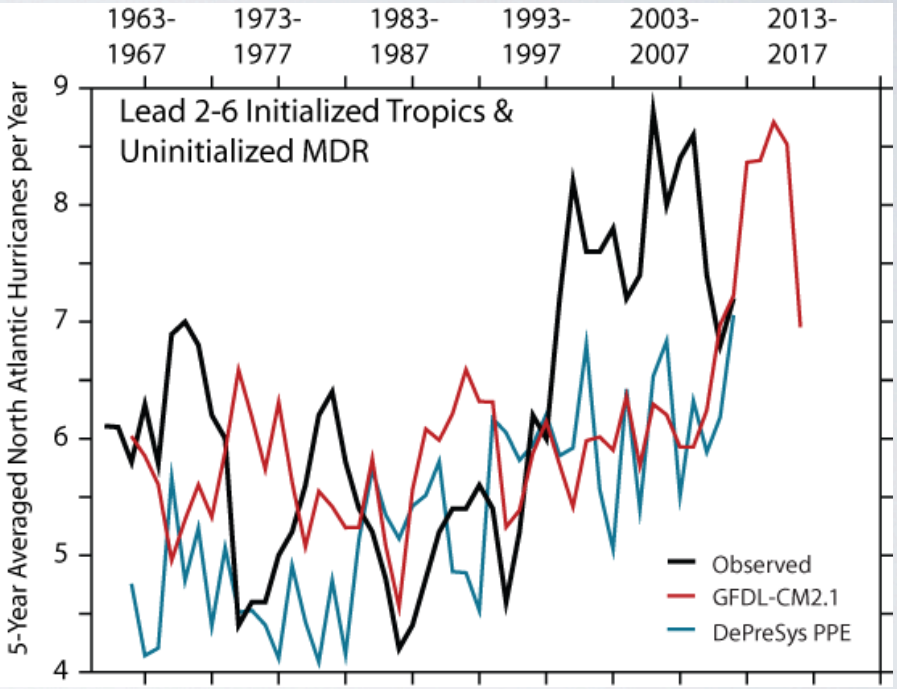
Retrospective skill dependent on improvements in North Atlantic from initialization



Impact of Atlantic

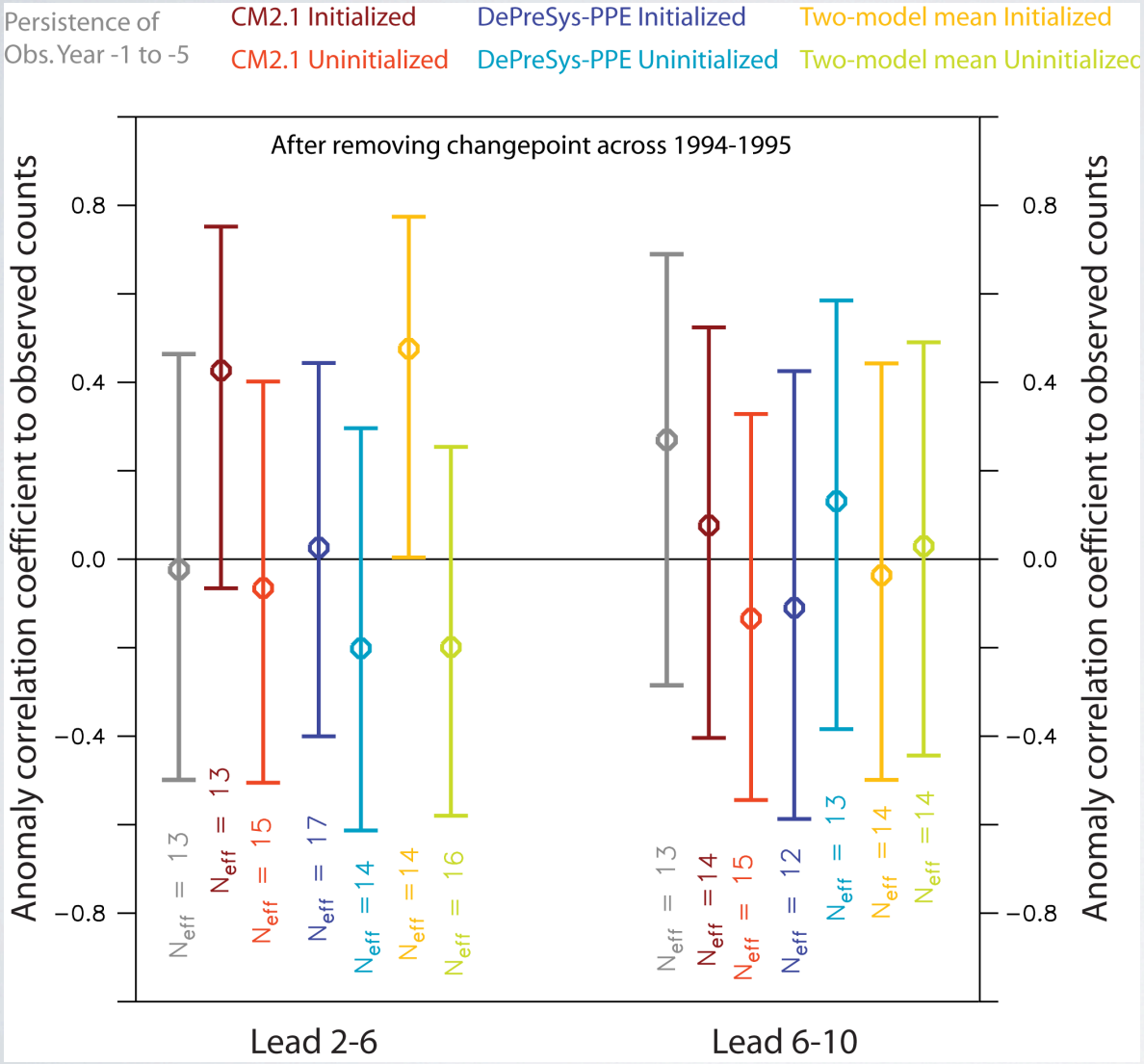


Impact of Tropics

To get right answer, getting Atlantic right was key.
Getting rest of tropics wrong can hurt model.

Vecchi et al. (2012 in prep.)

Change-point in 1994-1995 crucial for retrospective skill, particularly on decadal scales: limitation on future skill?



It is currently unclear whether retrospectively predicted 1994-95 shift, or whether initialized models "acknowledge" its occurrence.

How often should we expect similar swings in future?

Vecchi et al. (2012 in prep.)

Topics addressed

- Recorded century-scale increase in Atlantic hurricane frequency consistent with observing system changes.
  - Historical probability of extreme years (*e.g.*, 2005) higher than in raw data
  - Issues with intensity records remain.
  - It is premature to conclude we have seen hurricane change due to CO_2
- Statistical and dynamical models allow estimates of future activity:
  - Next couple of decades: internal variability dominant player (some may be predictable, some not)
  - NA Hurr. Response to GHG: likely fewer, probably stronger.
  - Aerosol forcing and response a key uncertainty.
- *Encouraging* results from long-lead (multi-year) experimental forecasts using hybrid system, but research must continue: *"past performance no guarantee of future returns"*…

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