Hurricane Predictions and Projections

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4. University of Iowa

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Image: NASA.

Summary

- Premature to conclude we have seen hurricane change due to CO_2
- Models allow estimates of future activity:
  - Next couple of decades: internal variability dominant player
    (some may be predictable, some not)
  - NA Hurr. Response to CO_2: maybe fewer, probably stronger.
  - Aerosol forcing and response a key to next few decades.
- Encouraging results from long-lead (multi-season and multi-year) experimental forecasts using hybrid system:

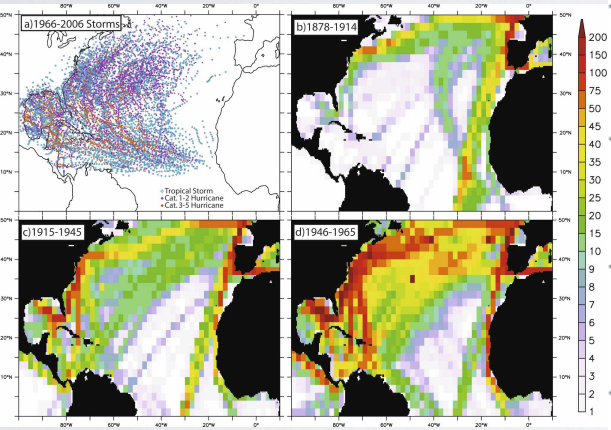
  "past performance no guarantee of future returns"
  but good past performance nice start…
- High-resolution coupled and atmospheric models enable the next generation of hurricane prediction and projection.

Outline

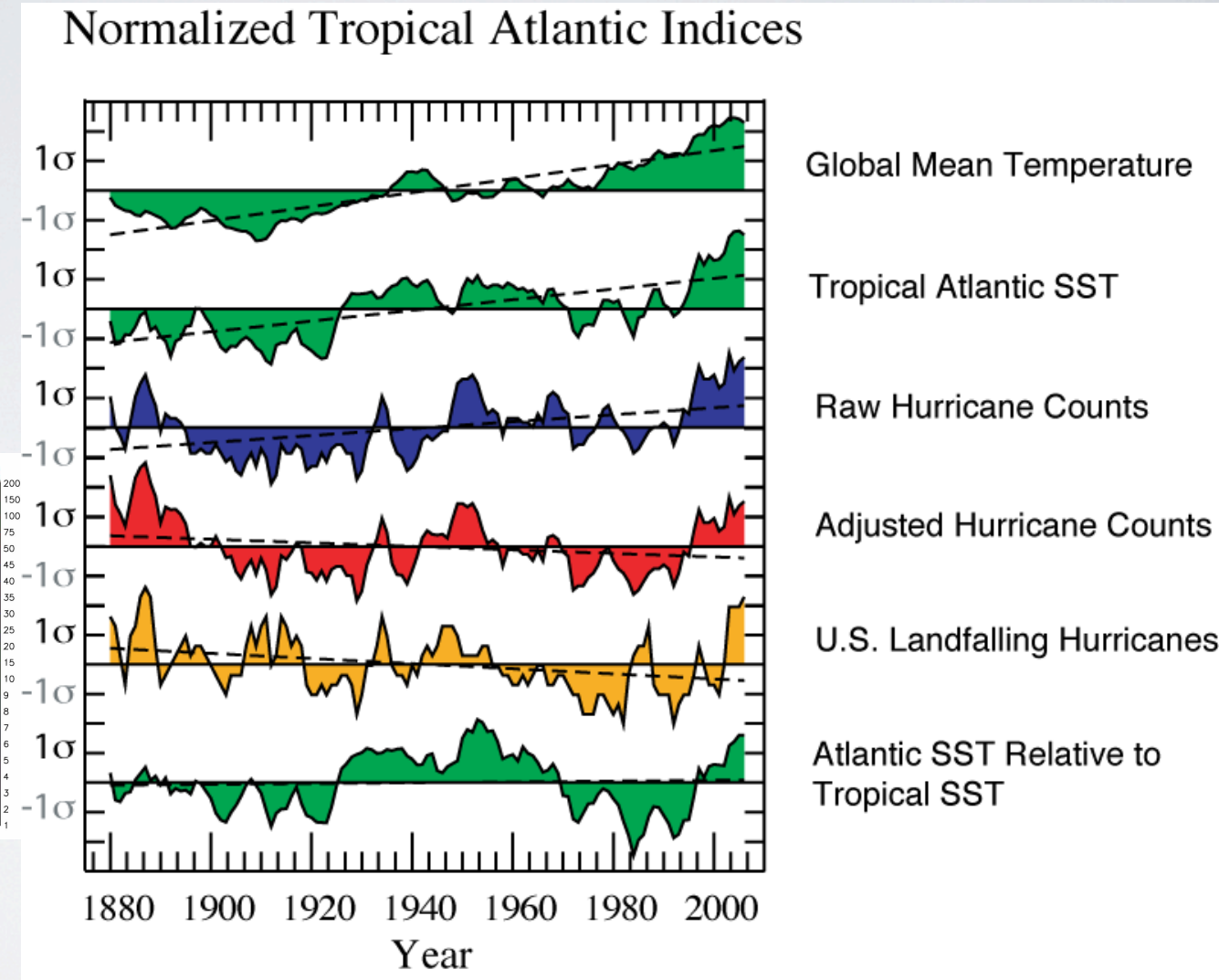
- Historical hurricane records
- Projecting decadal to centennial hurricane activity
- Predicting seasonal hurricane activity
- Predicting multi-year hurricane activity

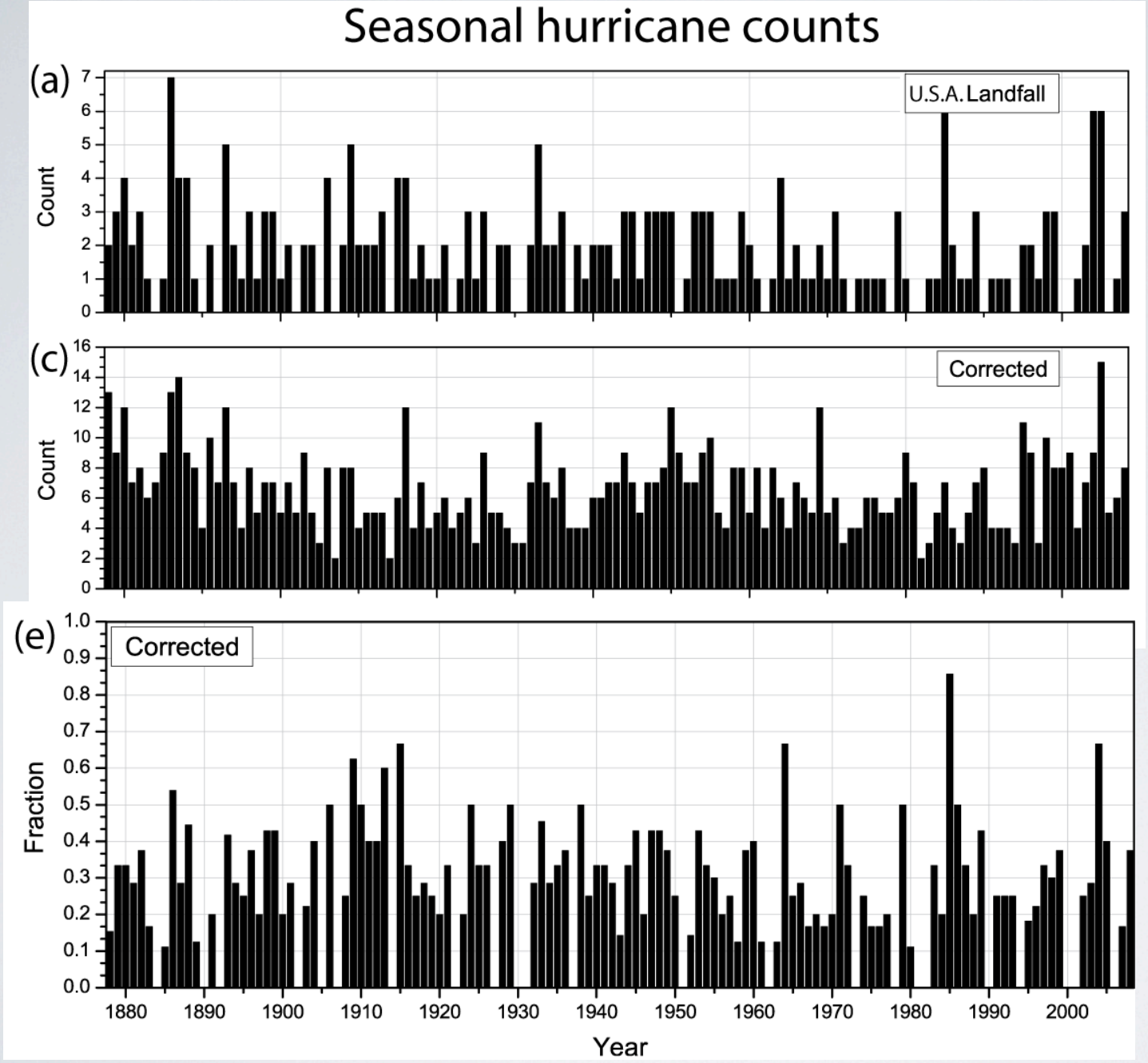
Historical Hurricane Records

Adjustments to storm counts based on ship/storm track locations and density



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





U.S. Landfalling Hurricanes

Basinwide Hurricanes

Fraction of Basinwide Hurricanes Making U.S. Landfall

Vecchi and Knutson (2011, J. Clim.); Villarini et al. (2012, J. Clim.)

Sources of & Limitations on climate predictability

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

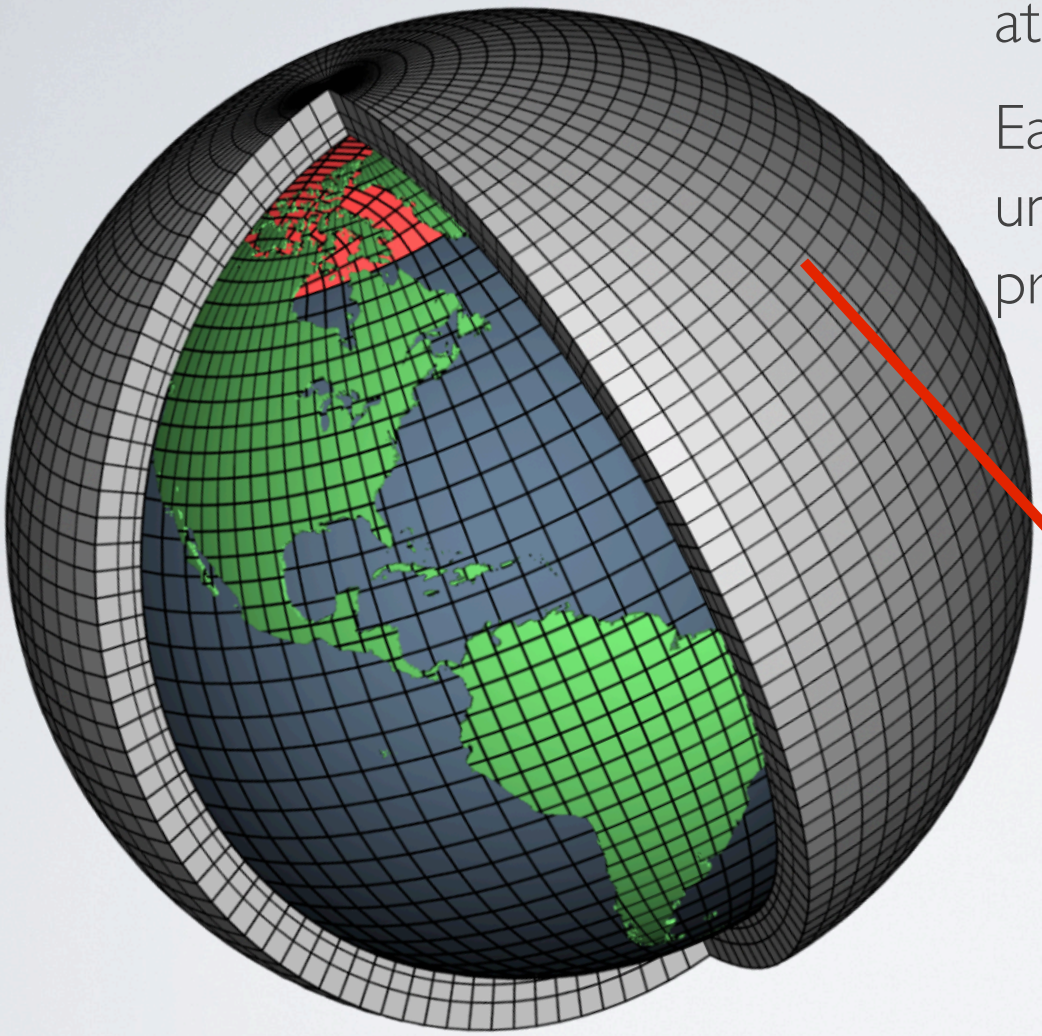
Many decades to centuries

Climatology

Climate response to forcing

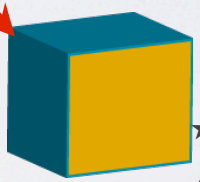
(*e.g.*, CO_2, aerosols, sun, volcanoes)

need good models and estimates of forcing



Models have land, ocean, atmosphere and ice components.

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



In each grid cell:

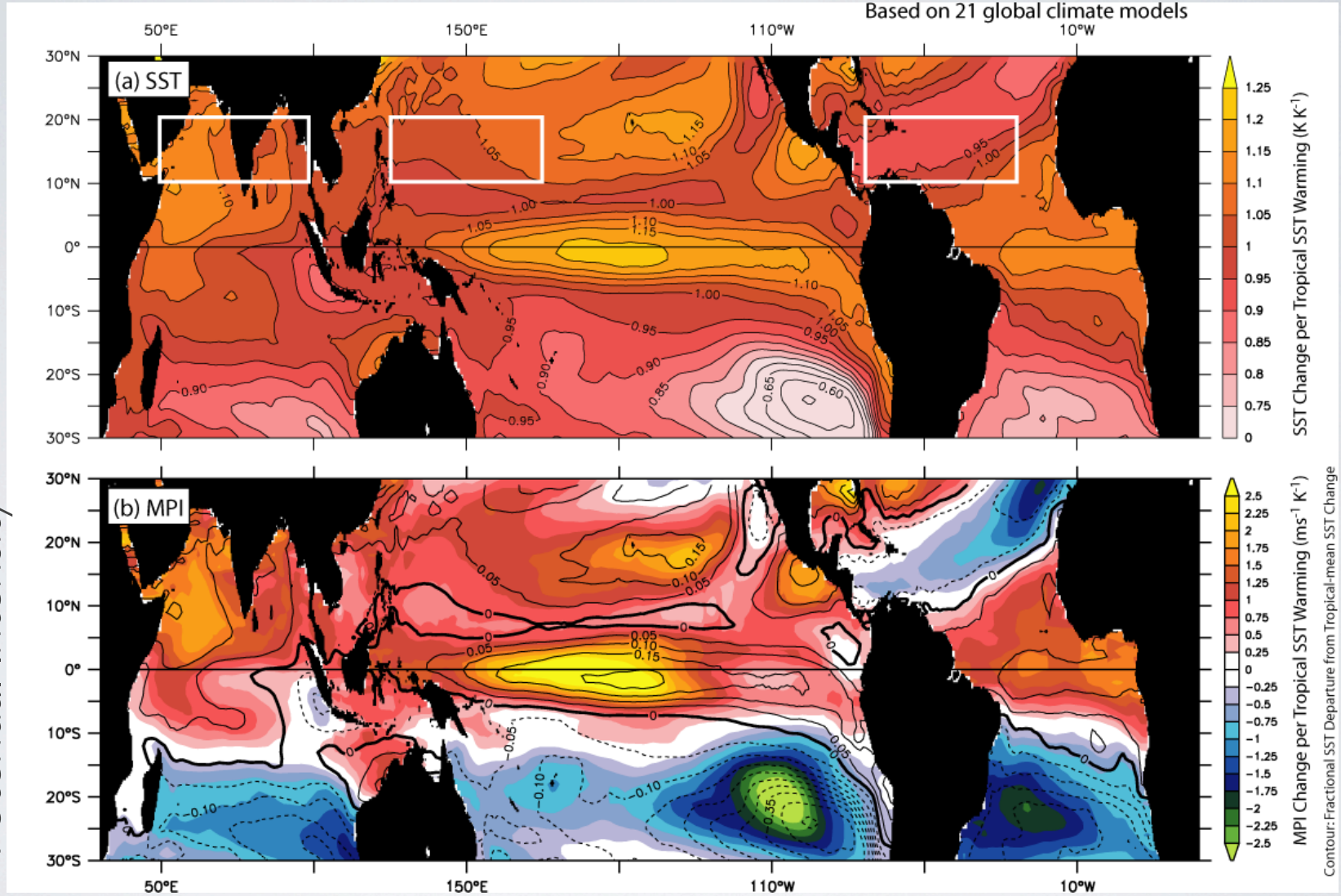
- ⋆conserve momentum ($F=m \cdot a$)
- ⋆account for changes in mass and composition
- ⋆conserve energy (radiation, latent, etc...)

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

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

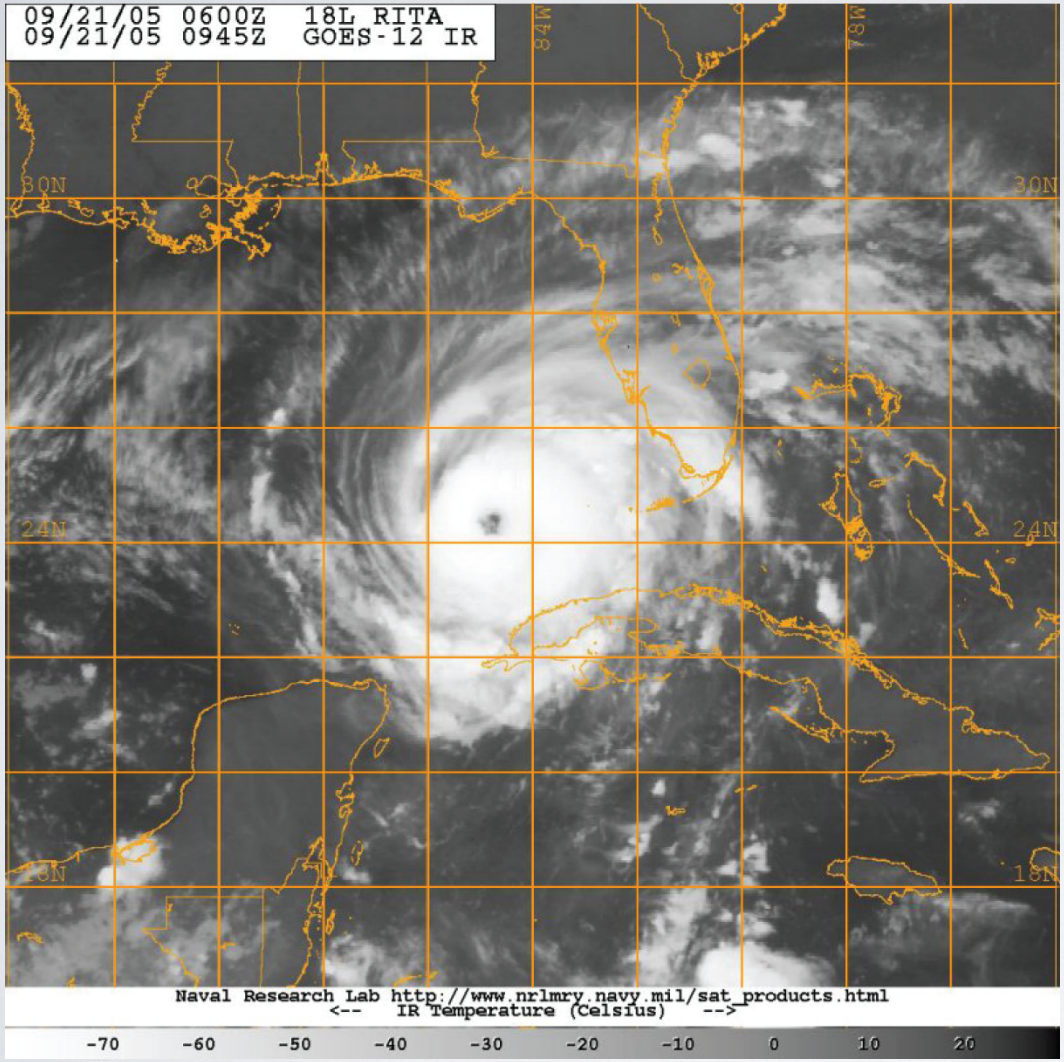
Surface Temp.

Tropical Cyclone Potential Intensity



Vecchi and Soden (2007, Nature)

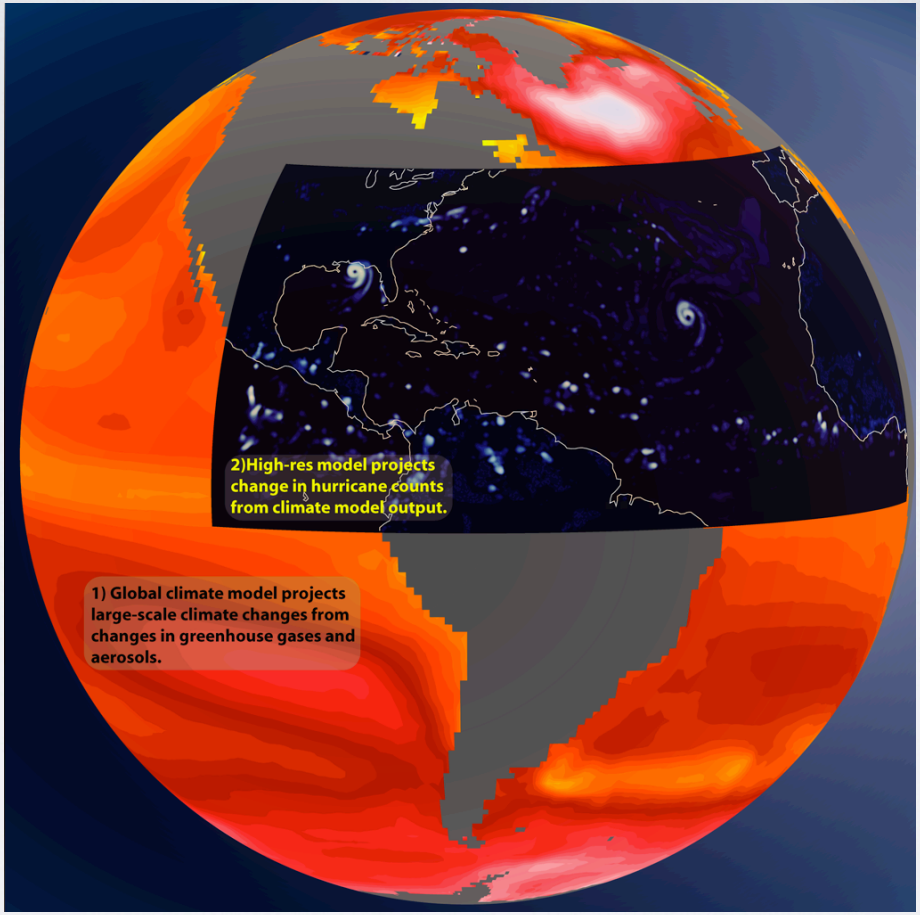
But, current computing power limits ability of coupled global climate models to represent hurricanes



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

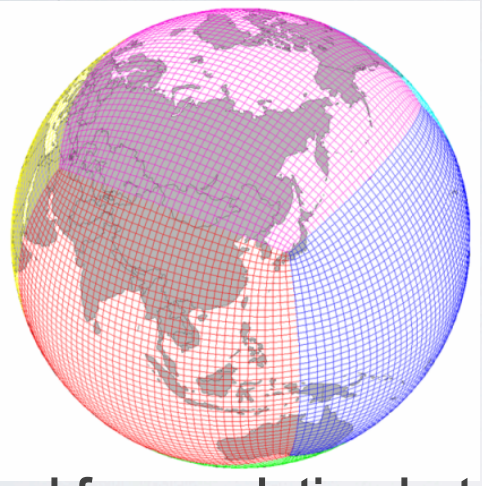
Large-scale TS Frequency

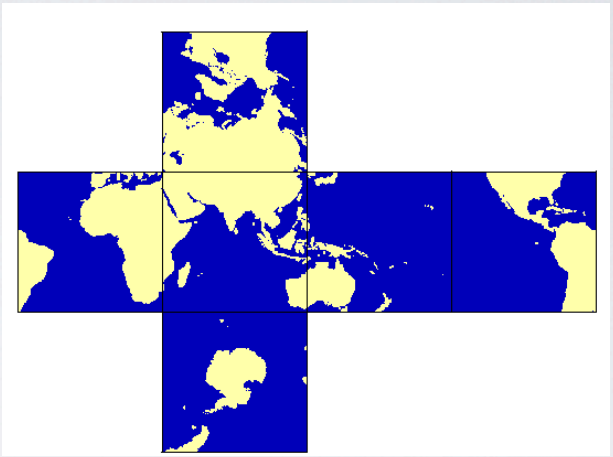
Downscaling techniques for TC activity

- High-resolution global dynamical models (*e.g.*, GFDL-HiRAM)
- High-resolution regional dynamical models (*e.g.*, GFDL-ZETAC)
- Statistical models (*e.g.*, Freq = F(SST,shear,…))

The GFDL High-Resolution Atmosphere Model (HiRAM)

- Non-hydrostatic Finite-Volume dynamical core on the cubed-sphere



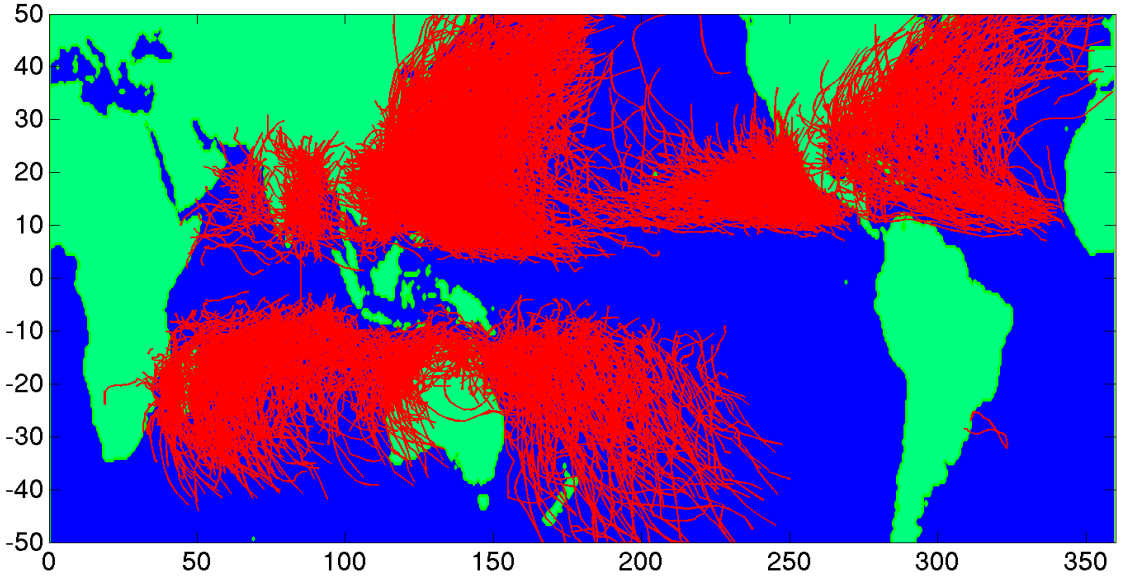


- Designed for resolution between 1– 100 km, capable of direct cloud simulation
- A PDF based 6-category cloud micro-physics with finite-volume vertical sub-grid reconstruction allowing vertically & horizontally sub-grid cloud formation
- A "non-intrusive" shallow convective parameterization (Bretherton scheme modified by Zhao *et al.* 2009)
- Options to couple with ocean and wave models

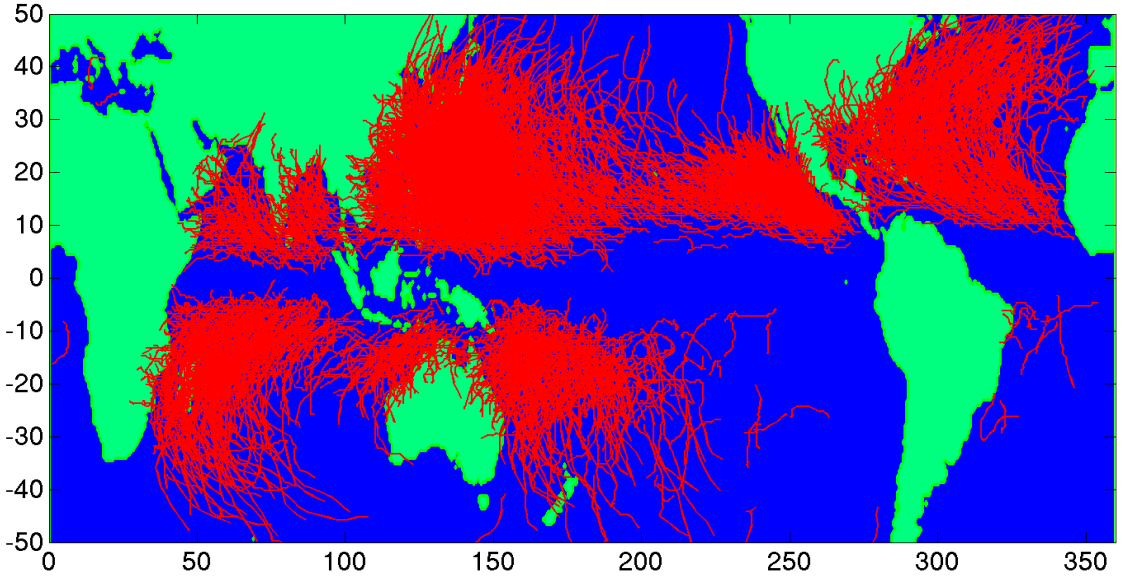
Slide: S-J Lin

Geographical distribution of TC tracks (1981-2009)

Observation

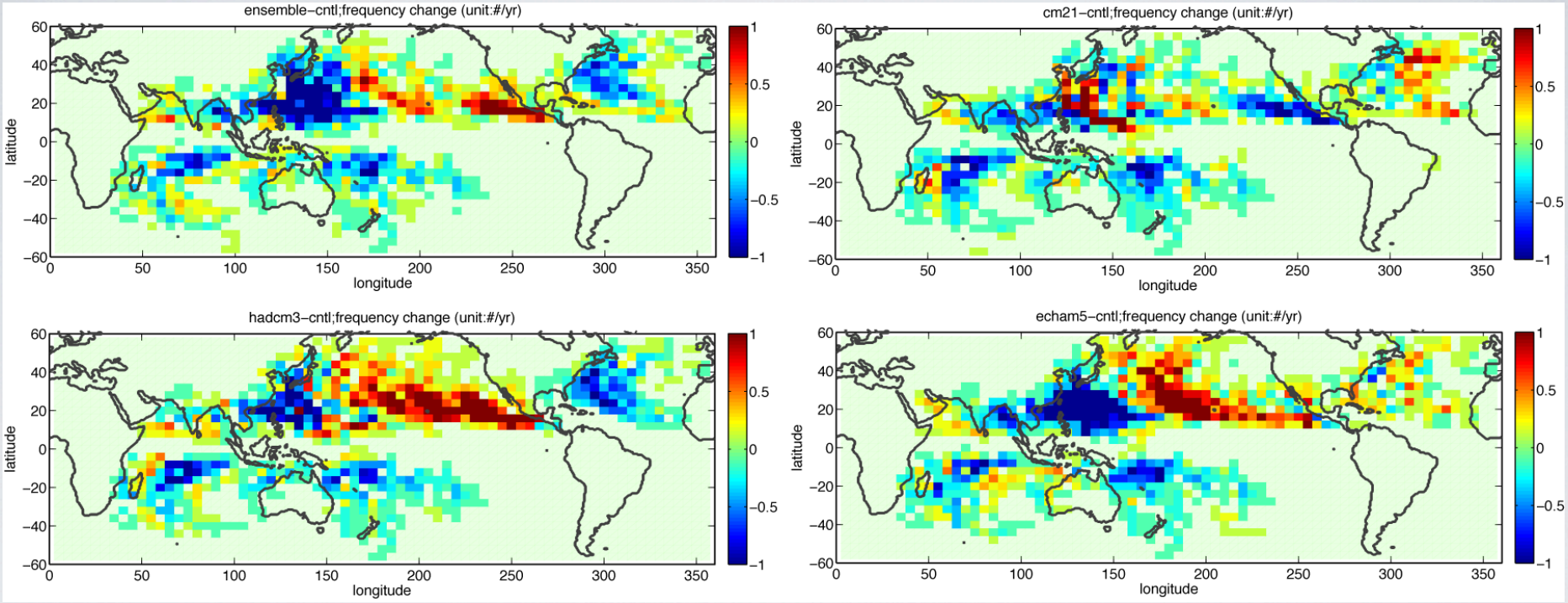


HiRAM-C180 AMIP simulation



Zhao et al. (2009)

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, Knutson et al. 2013, etc.

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

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

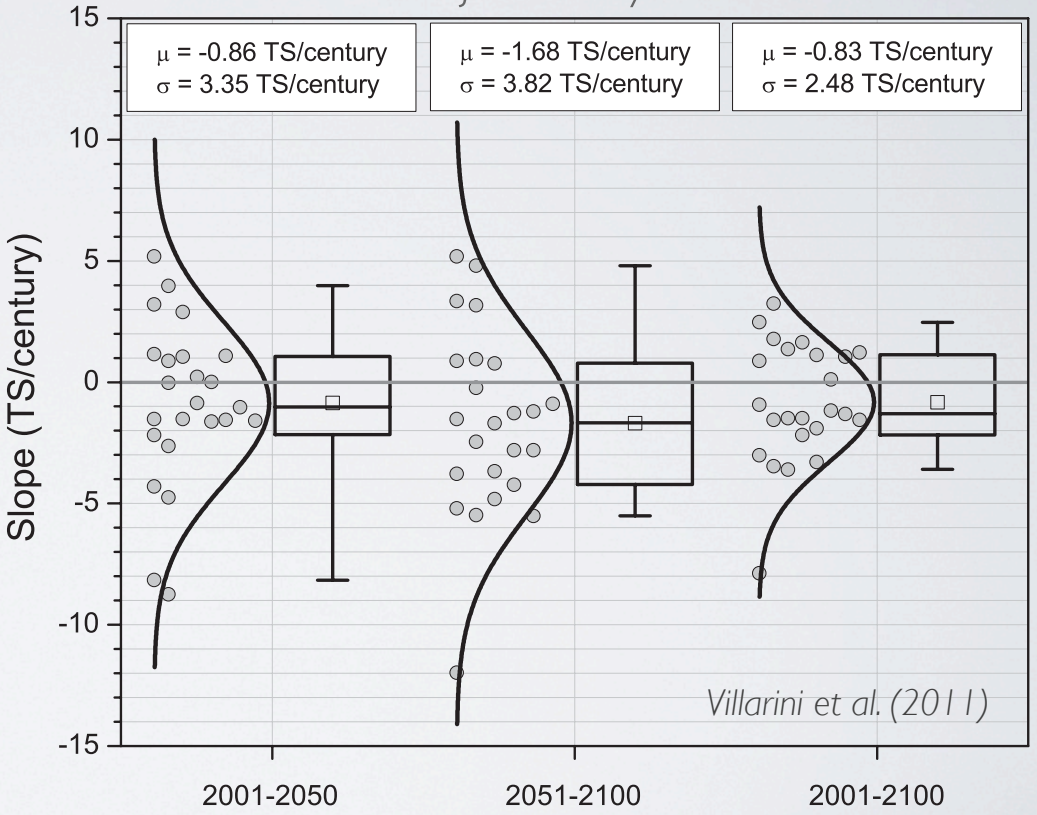
Family of statistical models based on observed and high-res. model hurricane activity and SST.

Use two predictors:

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

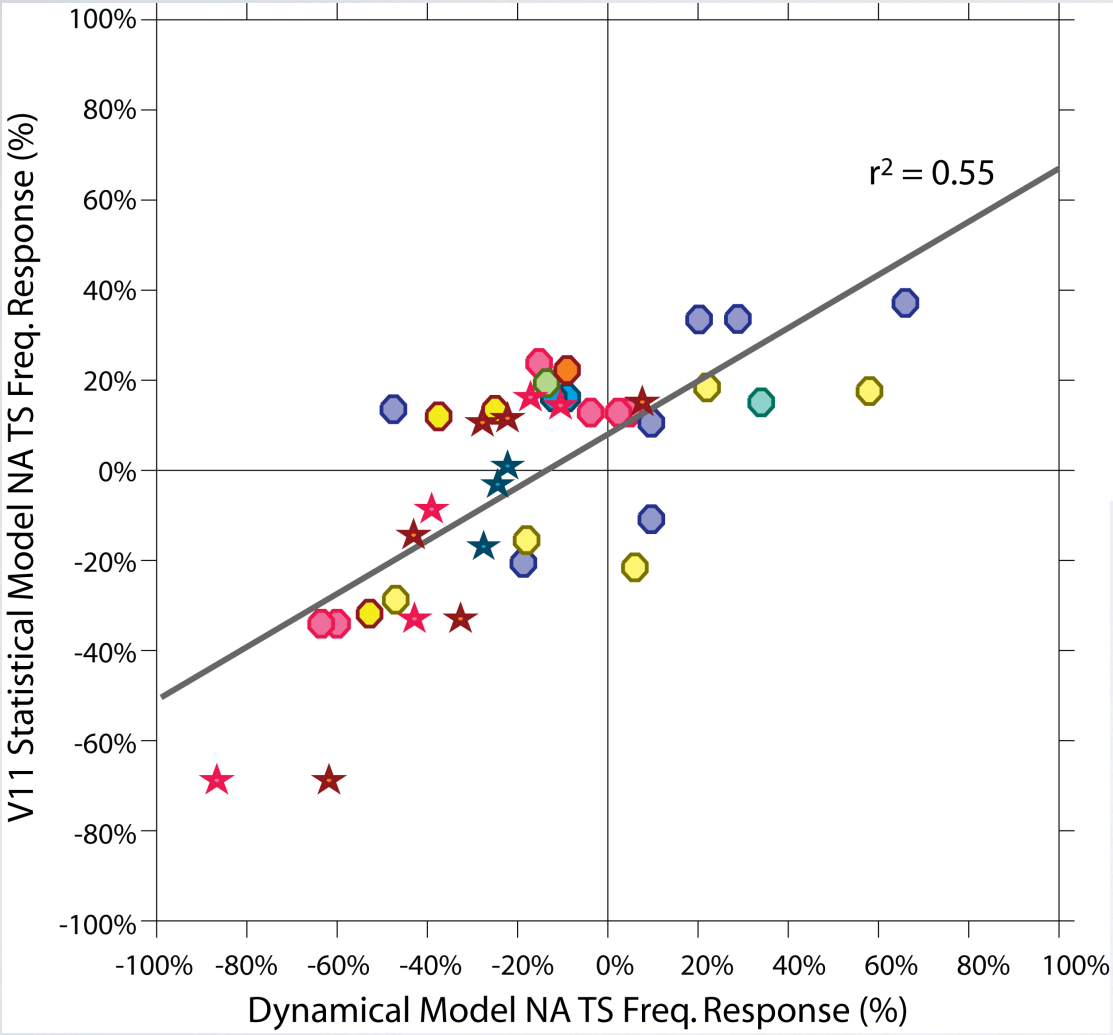
Consistent with high-res dynamical models, understanding on controls to hurricanes & "cheap".

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)

Simple statistical model explains much of the spread across many high-res modeling studies



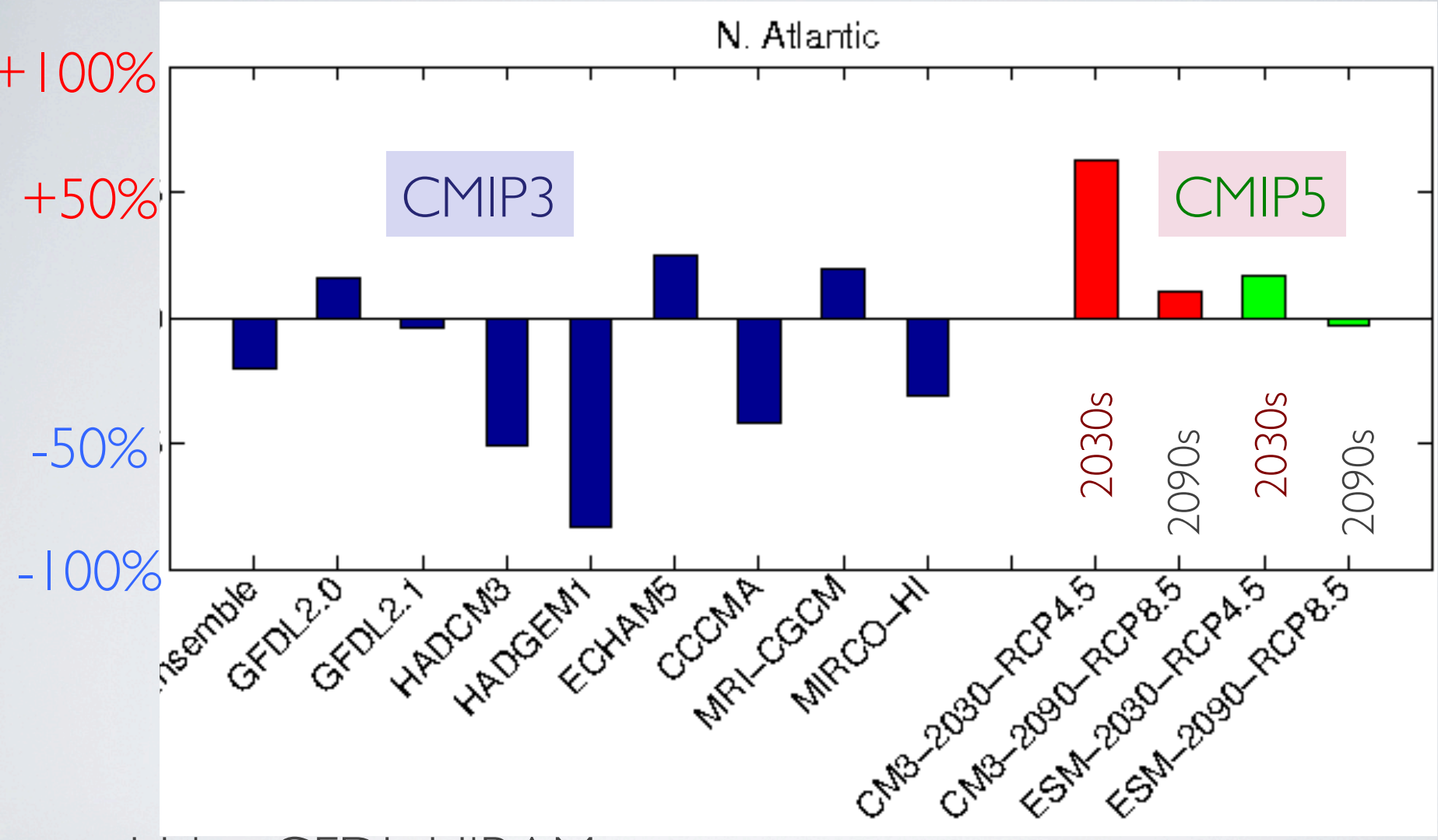
- Knutson et al (2008)
- Bender et al. (2010)
- ZETAC - present study (single)
- ZETAC - present study (MME)
- Zhao et al. (2010)
- HiRAM - present study
- Emanuel et al. (2008)
- Bentsson et al. (2006)
- Oouchi et al. (2006)
- Gualdi et al. (2008)
- Sugi et al. (2009)

Differences in projected patterns of surface warming drive large uncertainties in hurricane projections

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

Knutson et al. (2013, J. Clim.)
See also Villarini et al. (2011, J. Clim.)
Vecchi et al. (2008, Science)

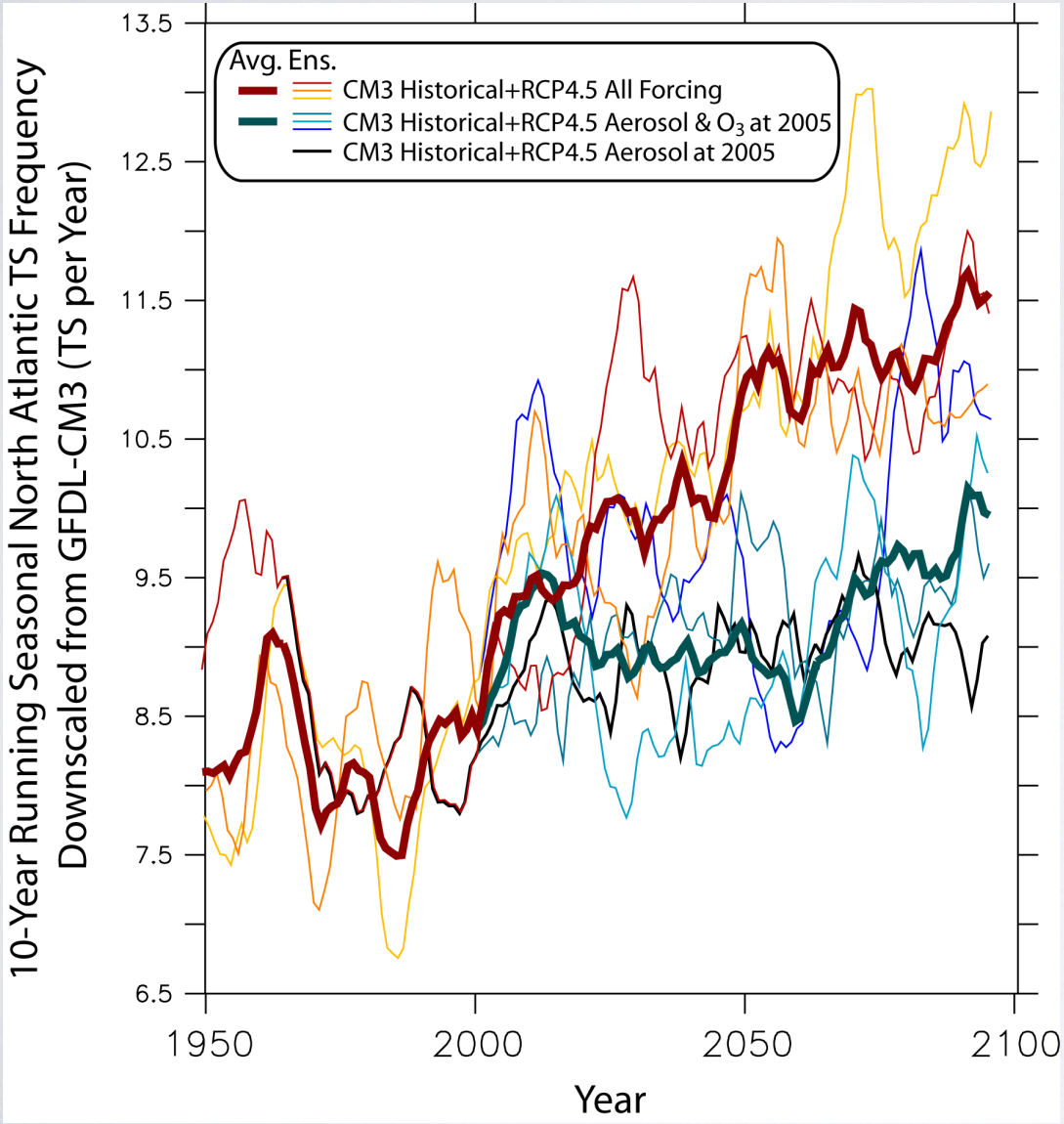
Dynamical Projections of Atl. Hurricanes for end of 21st Century



Using GFDL-HiRAM

Adapted from Zhao et al. (2009, J. Clim.) and Held et al. (2013, submitted)

GFDL-CM3 indicates aerosols key for NA TS projections (projected aerosol clearing -> more storms)



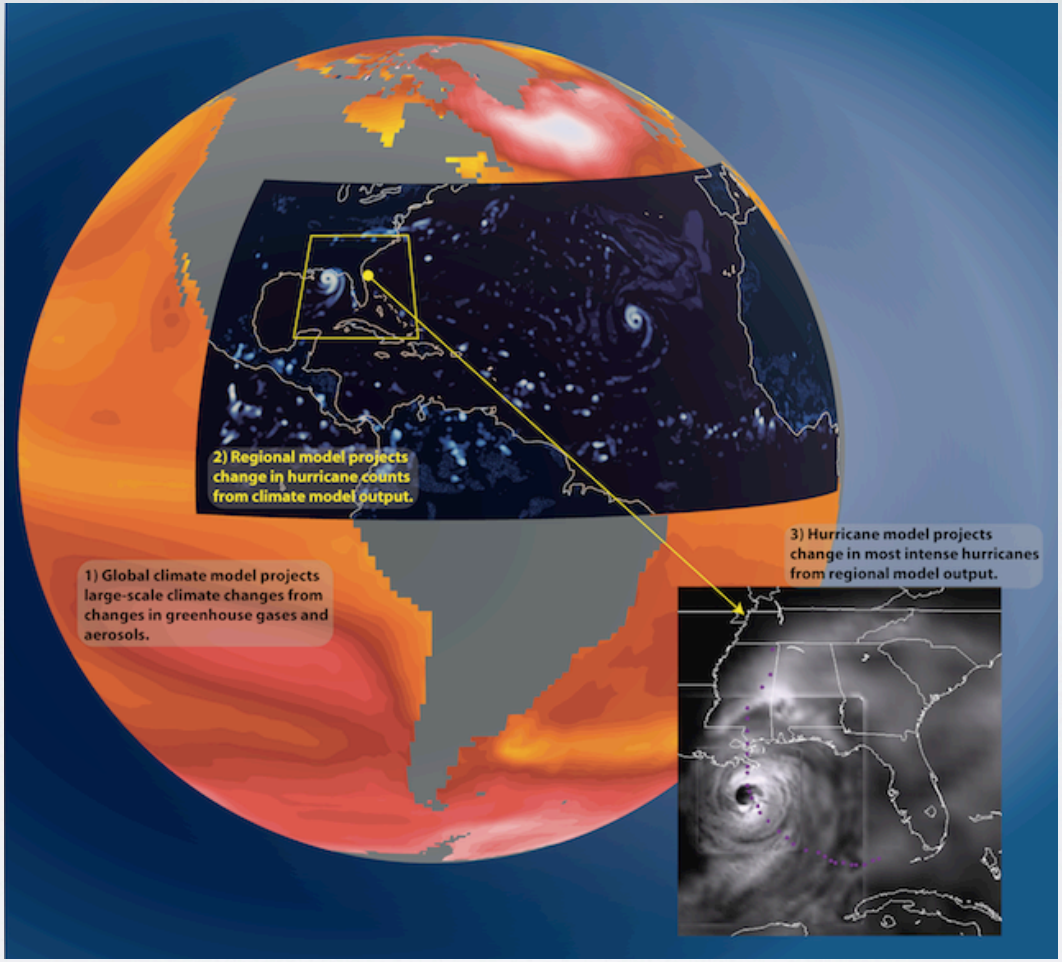
All Forcing

No future aerosol or O_3

No future aerosol

Villarini and Vecchi (2012, Nature C.C.)

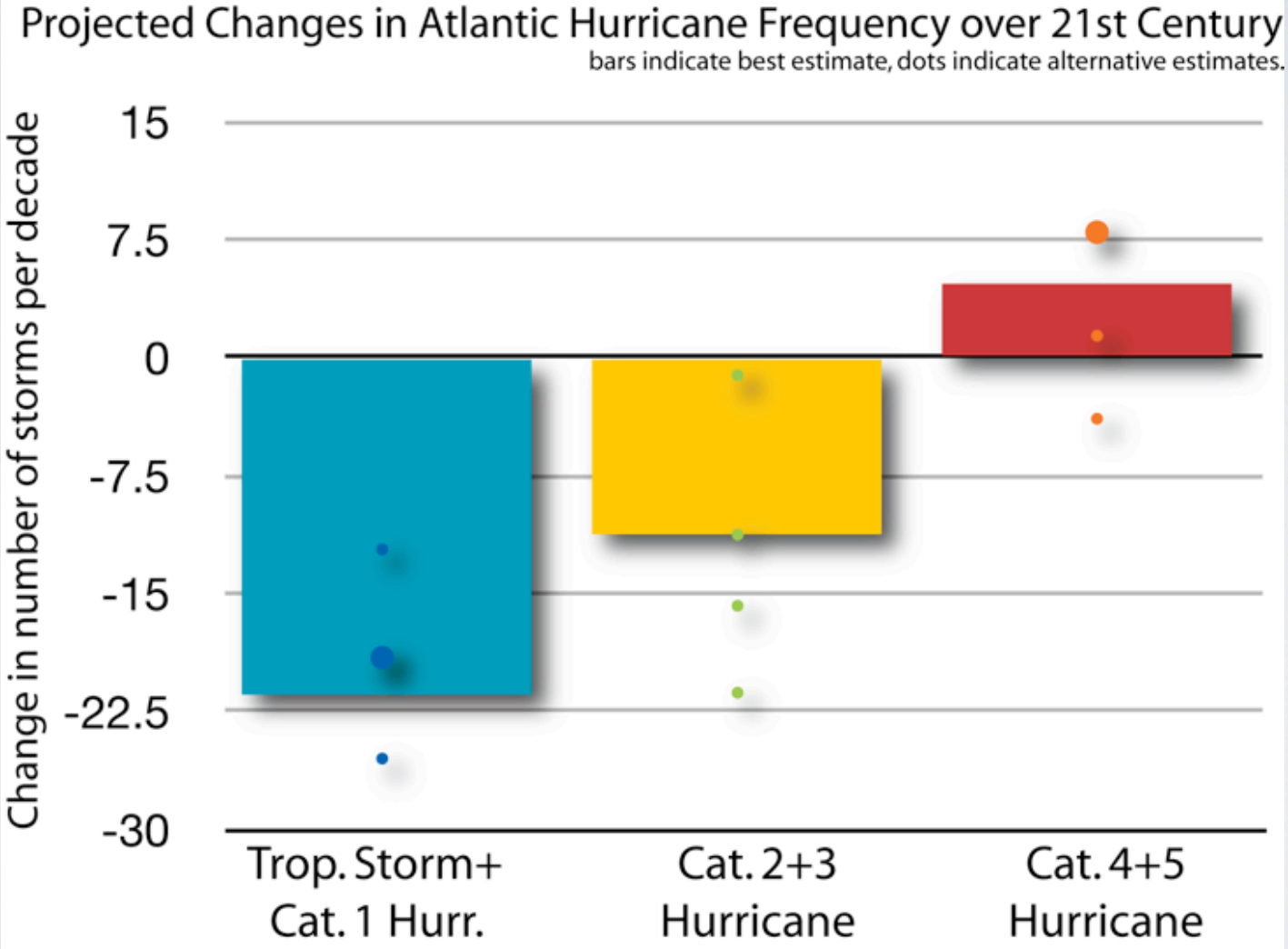
Multi-decadal projections



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

Large-scale TS Frequency Intensity

Dynamical double downscaling for Atlantic: Overall frequency decrease projected, but more of the strongest storms

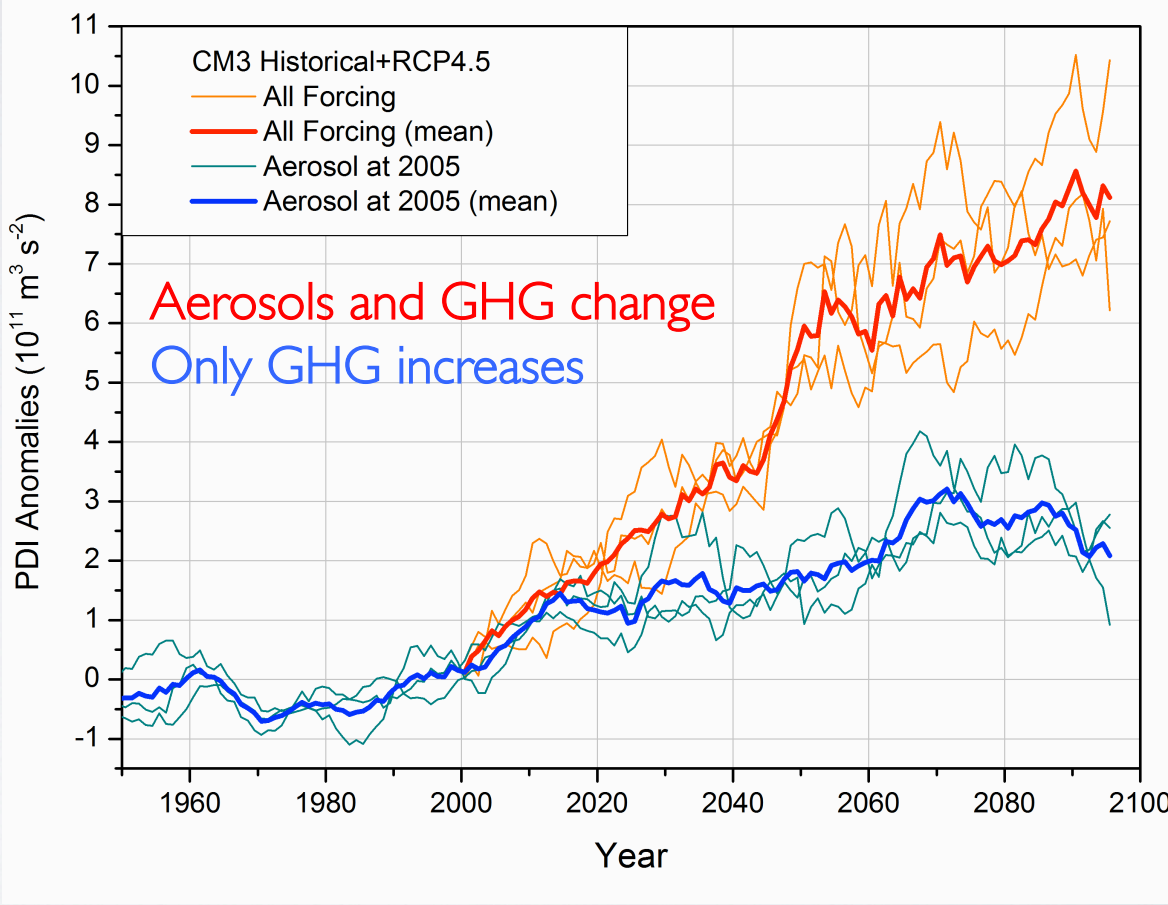


Adapted from Bender et al (2010, Science)
see also Knutson et al. (2008, Nature Geosci.); Knutson et al. (2013, J. Clim., in press)

Projections of reductions in atmospheric aerosols contribute to projected increases in Atlantic hurricane activity

Power Dissipation Index

$$PDI = \sum_{storms} U_{\max}^3$$



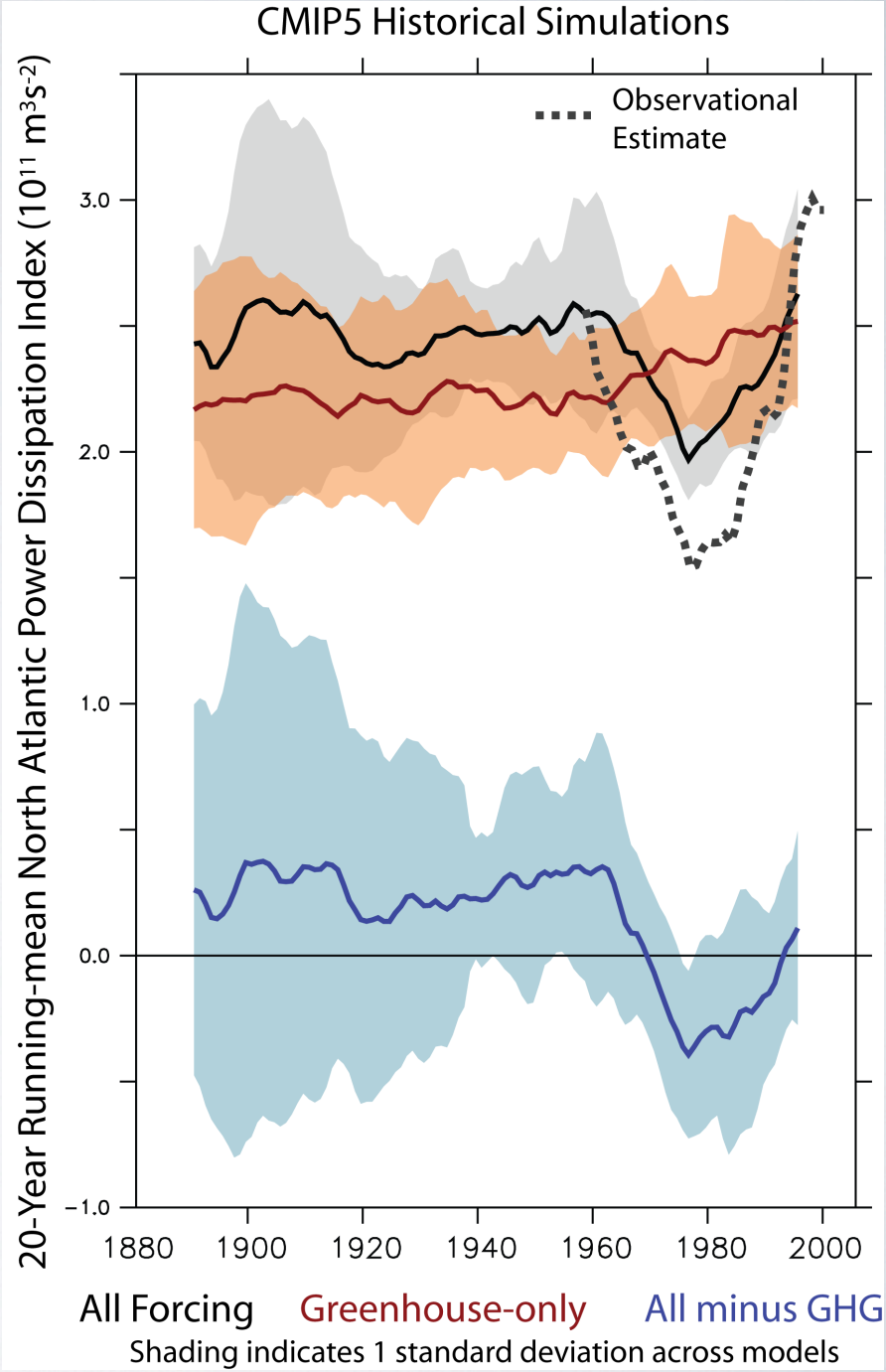
Villarini and Vecchi (2013, J. Climate)
See also Knutson et al. (2013, J. Climate)

Historical aerosol forcing may have masked century-scale greenhouse-induced intensification in Atlantic

Power Dissipation Index

$$PDI = \sum_{storms} U_{\max}^3$$

Villarini and Vecchi (2013, J. Climate)

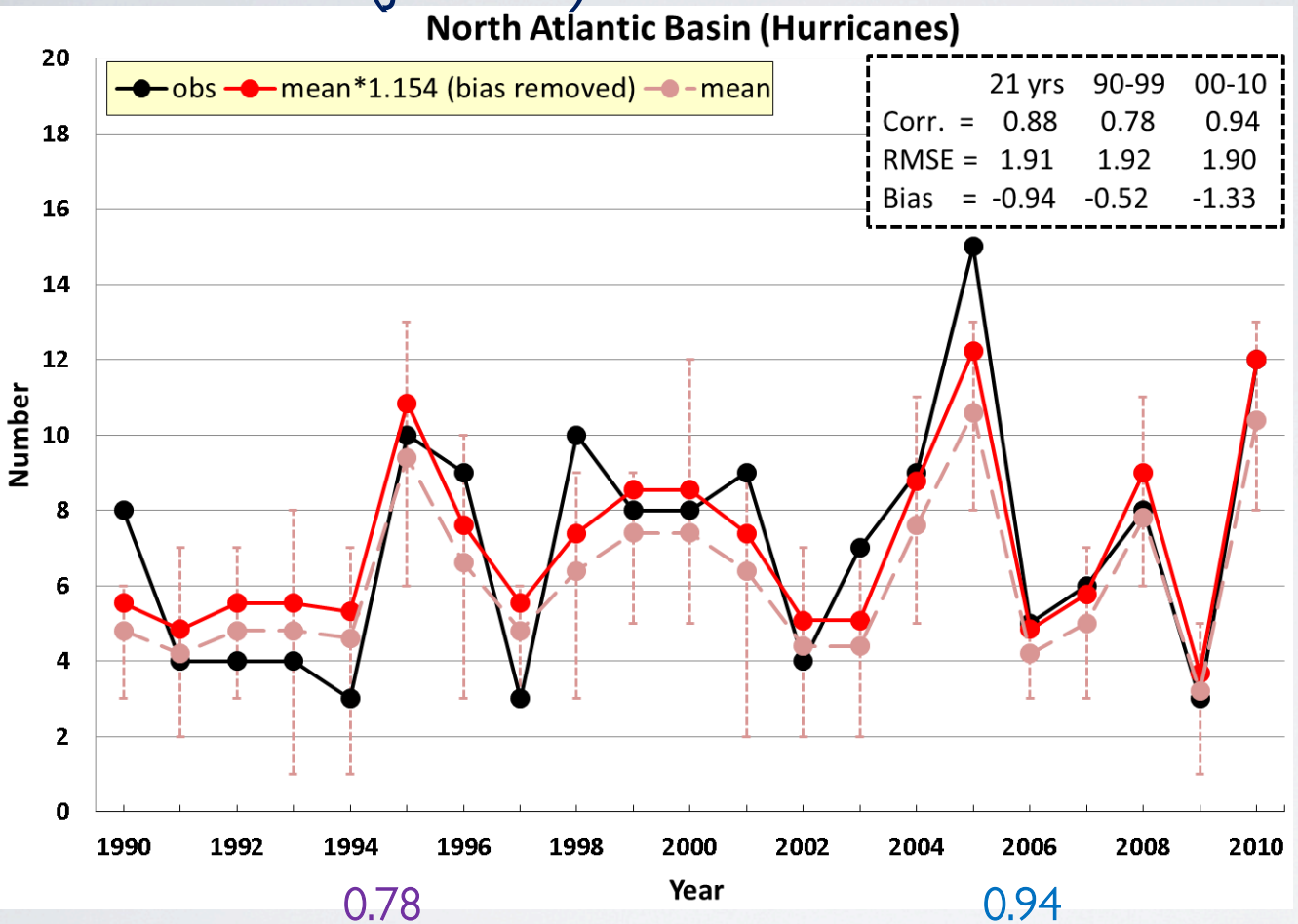


Seasonal Hurricane Prediction

- What can we say about the character of the upcoming hurricane season months or seasons in advance?

- 25km HiRAM Seasonal hurricane predictions – initialized July 1

- 1990-2010 (Jul-Nov)



Resolution: 25 km, 32 levels

- 5-members initialized on July 1 with NCEP analysis
- SST anomaly is held constant during the 5-month predictions
- Climatology O3 & greenhouse gases are used

1. Chen and Lin 2011, GRL
2. Chen *et al.*, submitted

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

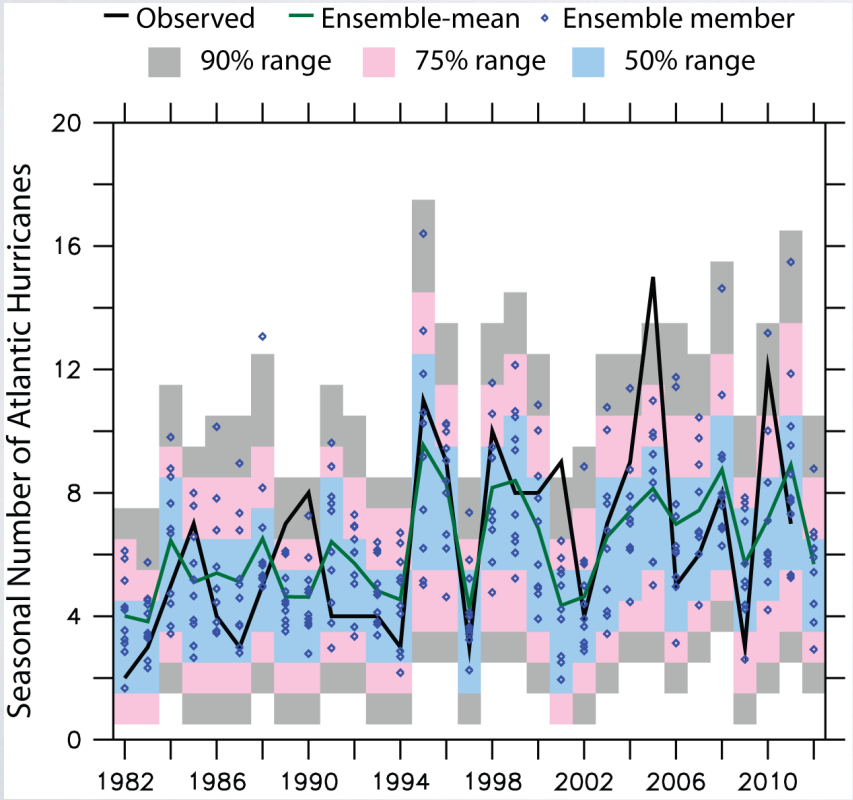
Use initialized coupled model to forecast future values of SST

Apply Stat model to Predicted SST

HyHuFS

Make Prediction of Full PDF of Hurricane Activity

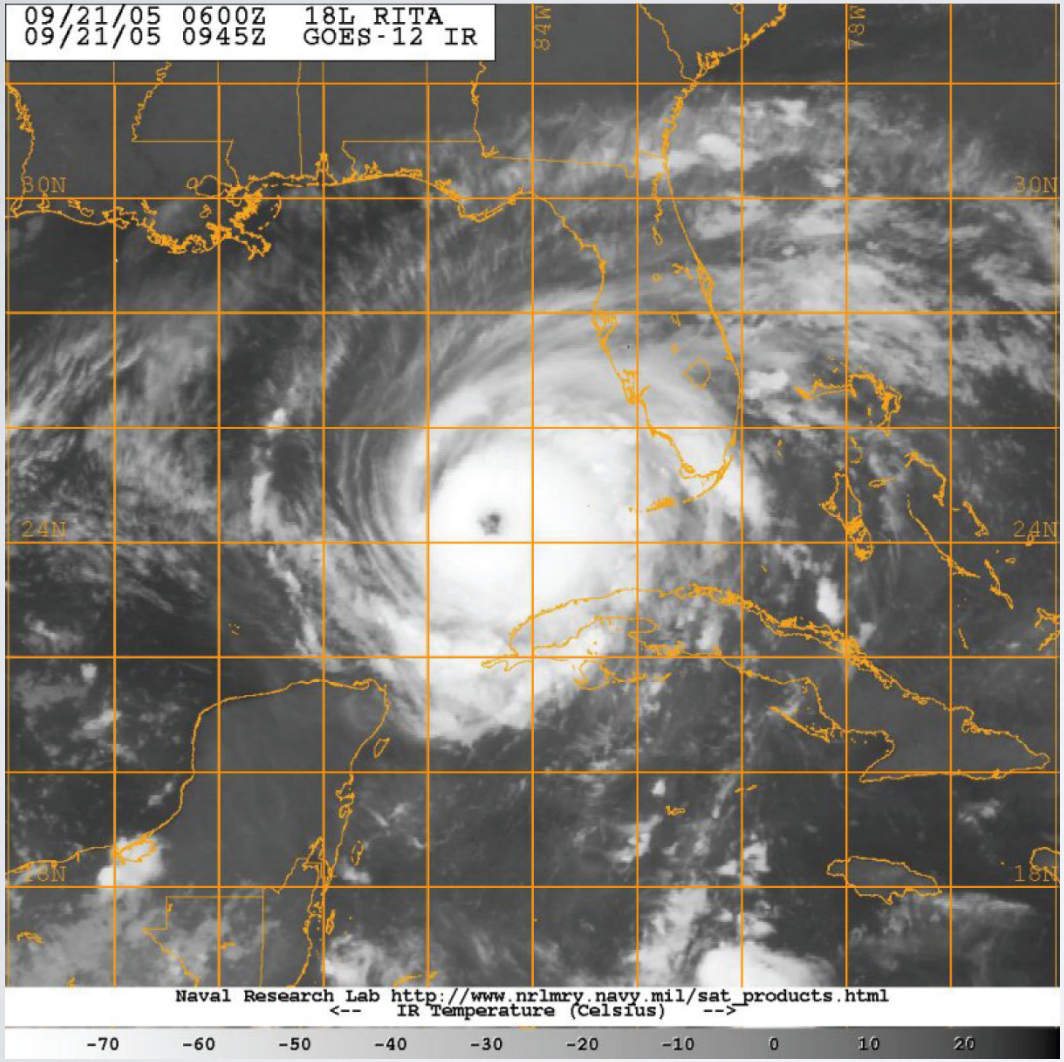
Initialized January: r=0.66



http://gfdl.noaa.gov/HyHuFS

Vecchi et al. (2011); Villarini and Vecchi (2012, submitted)

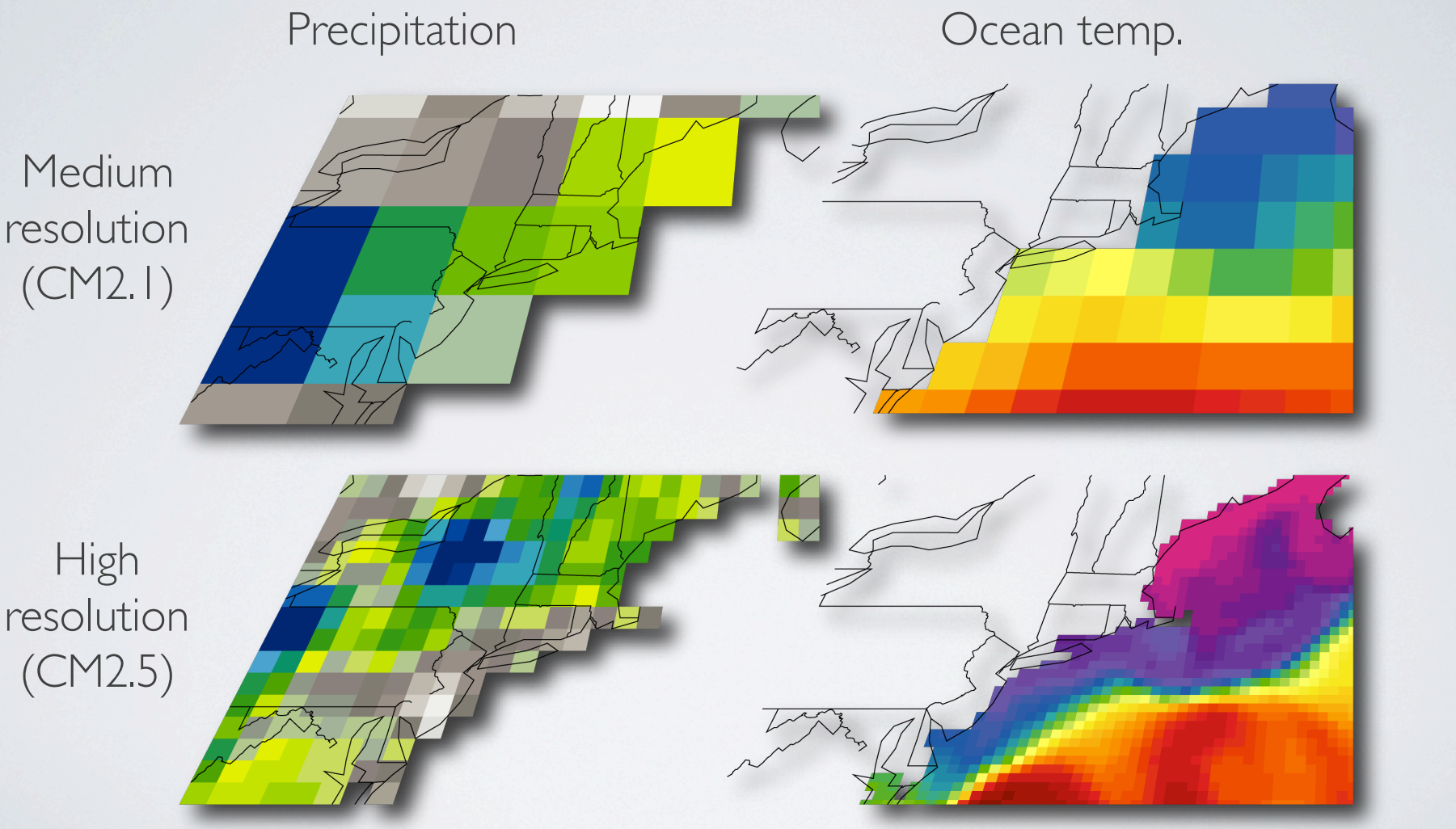
But, current computing power limits ability of coupled global climate models to represent hurricanes



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

Size of grid limited by power of computers.

Resolution (computer power, good models & hard work) can help represent processes and phenomena

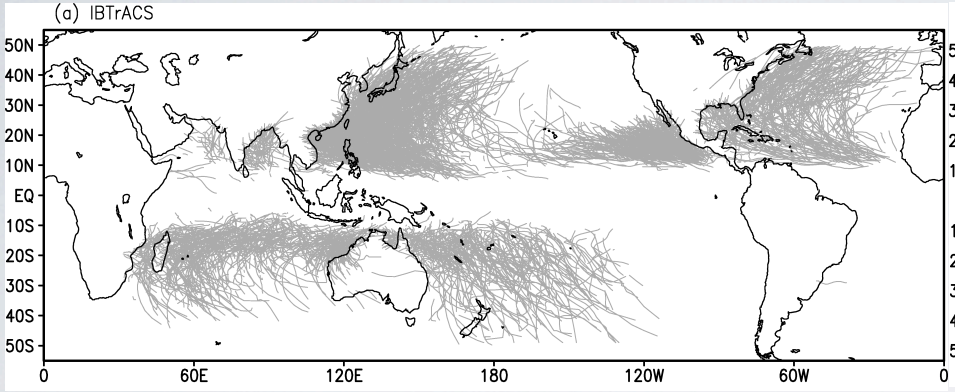


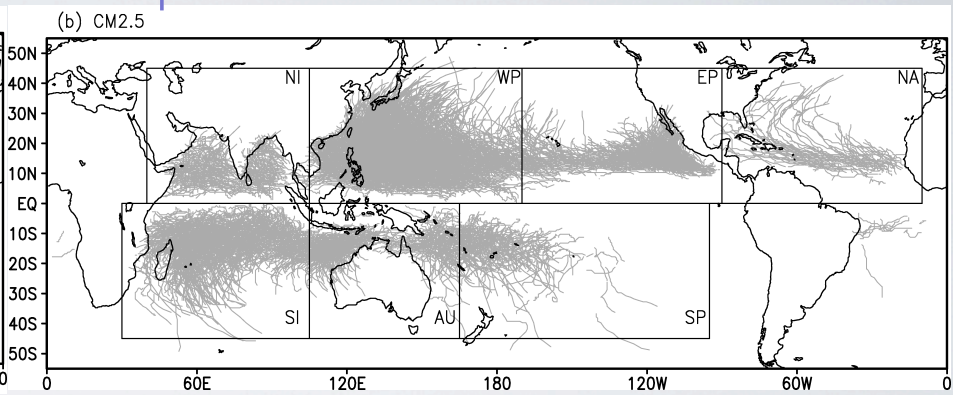
Adapted from Delworth et al. (2012, J. Clim.)

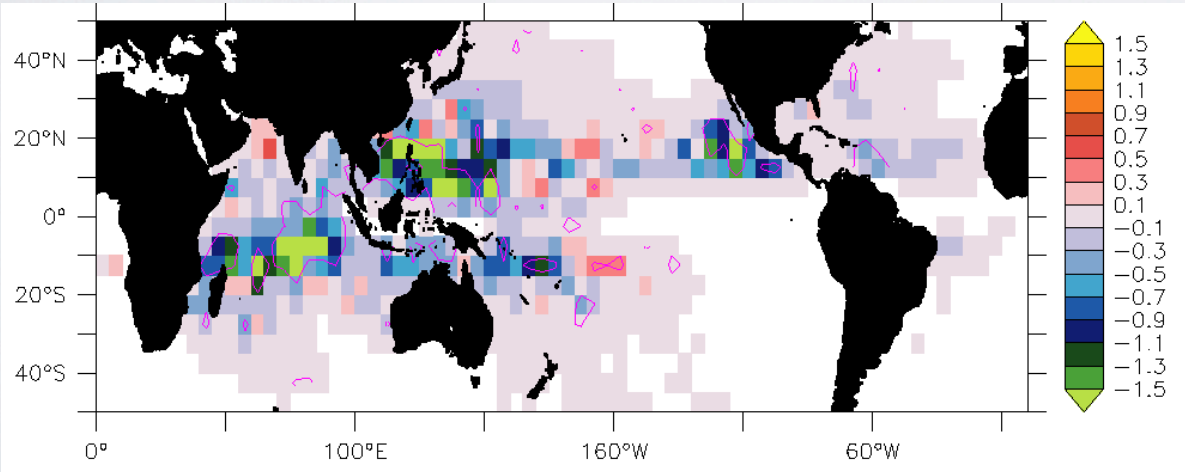
Response of TCs in high-resolution global coupled model (GFDL CM2.5, *Delworth et al. 2012, J. Climate; Kim et al. 2013 in prep.*)

Observed Tracks

Coupled Model Tracks







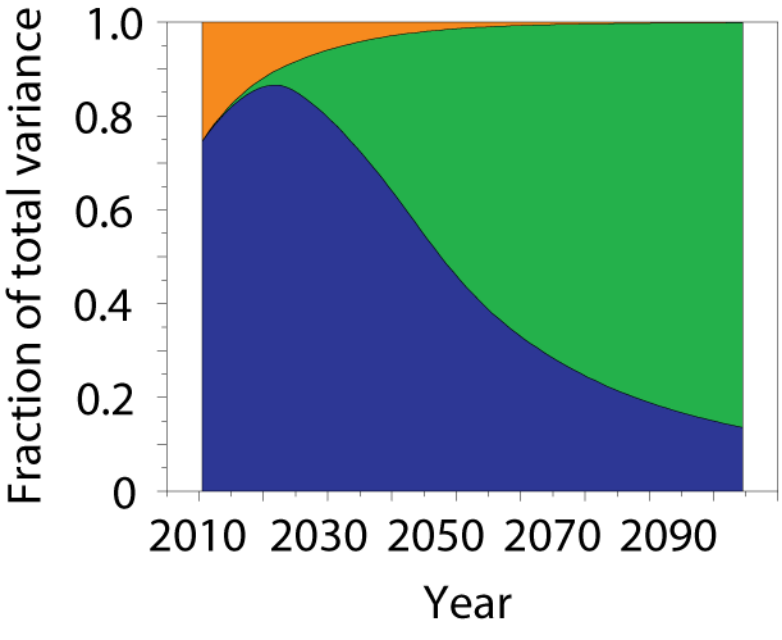
More storms

Fewer storms

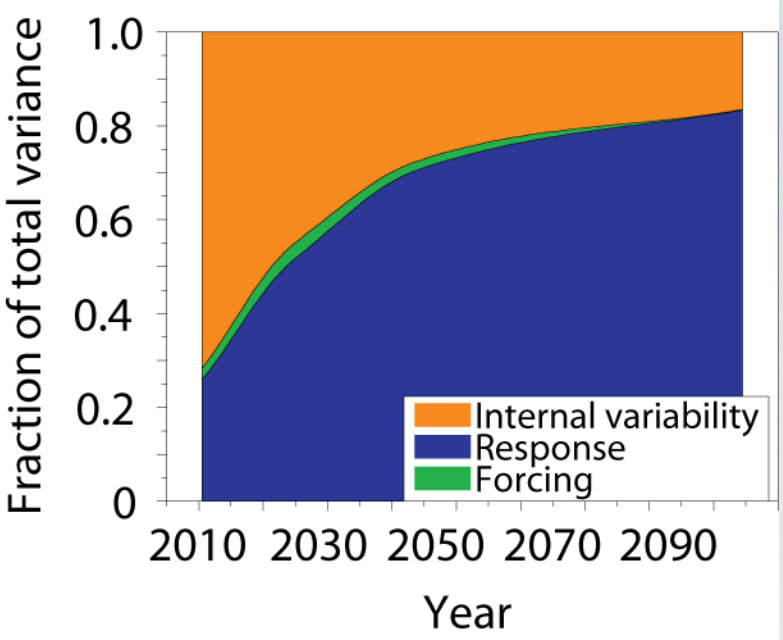
CM2.5 Tropical storm density response to CO_2 doubling

Key uncertainty sources to projections of decadal TS activity

Tropical Atlantic SSTA



NA TS Frequency



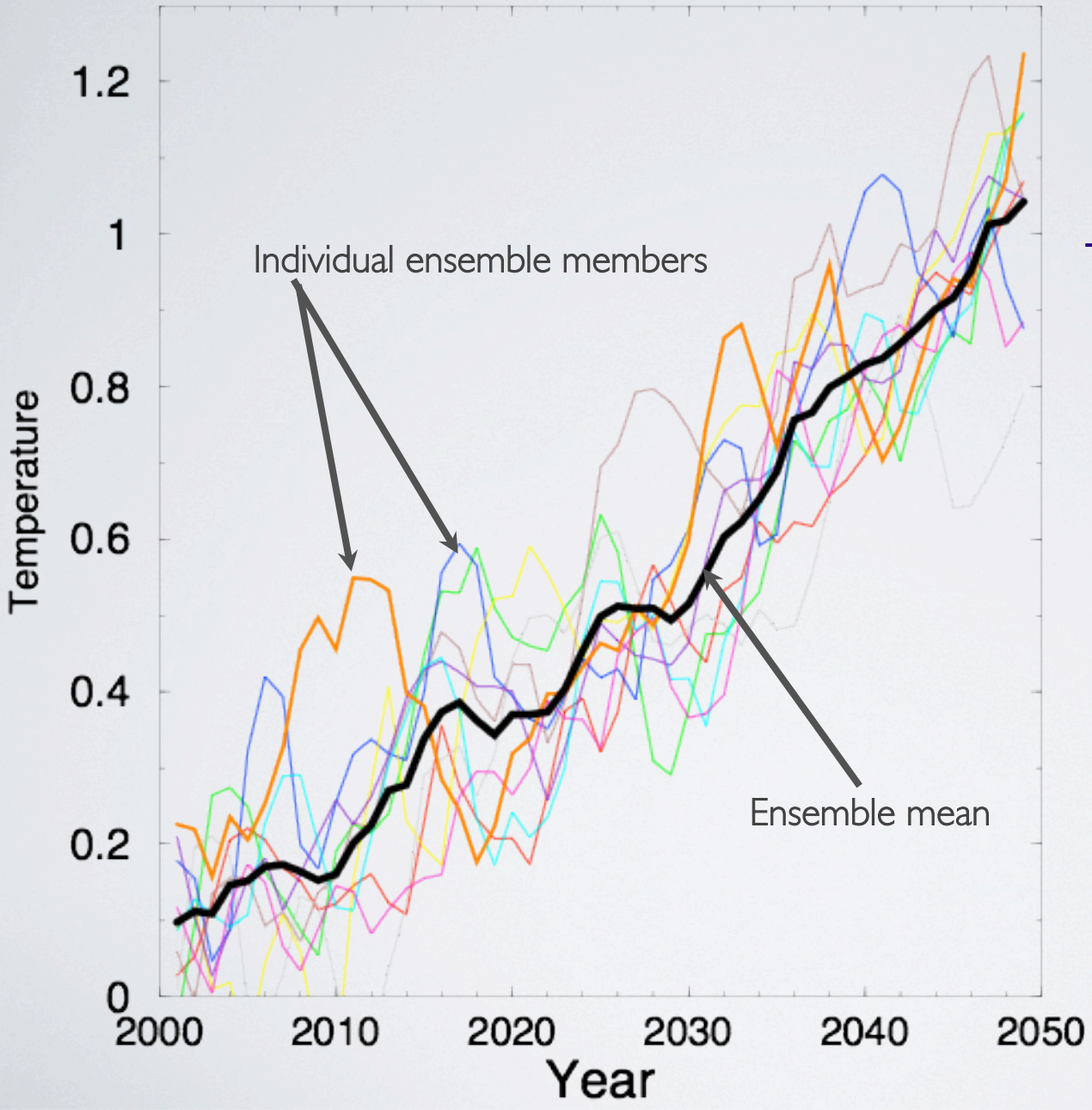
Villarini et al. (2011), Villarini and Vecchi (2012)

Sources of uncertainty (after Hawkins and Sutton, 2009)

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

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)

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

Climatology

Climate response to forcing

(*e.g.*, CO_2, aerosols, sun, volcanoes)

need good models and estimates of forcing

Decadal/multi-year prediction: New efforts focused mixed initial/boundary value problem

Experimental decadal predictions

Hybrid system: statistical hurricanes, dynamical decadal climate forecasts

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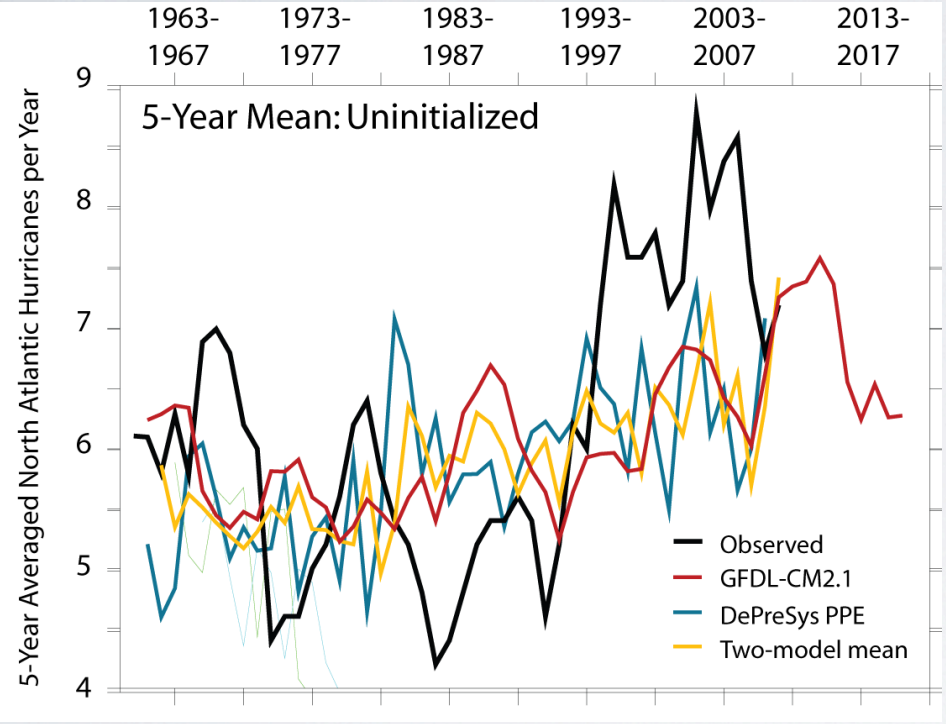

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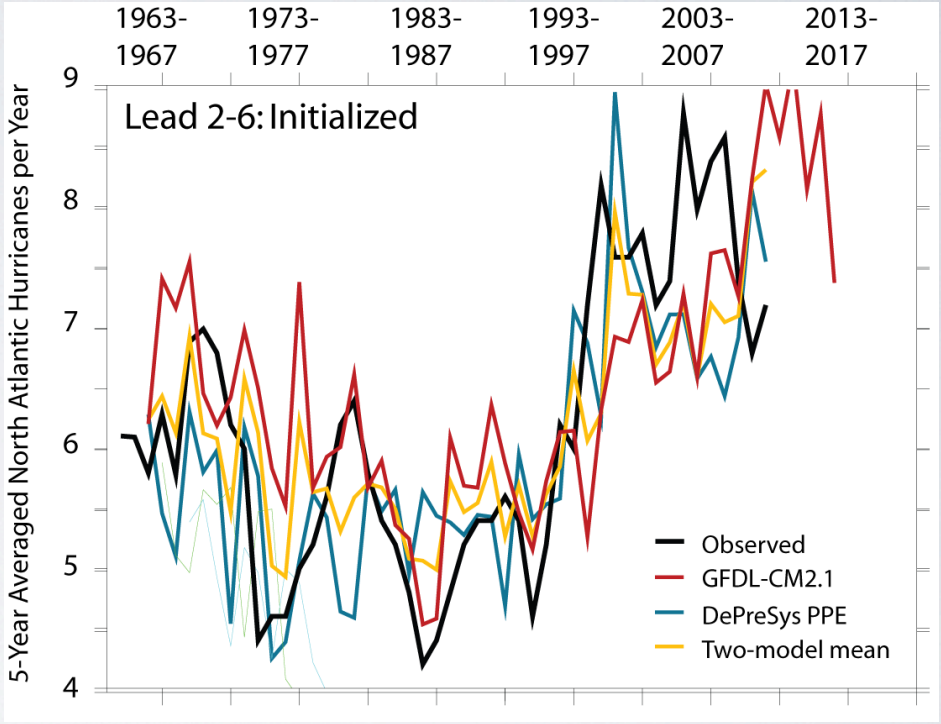

- Retrospective predictions encouraging.
- However, small sample size limits confidence
- Skill arises more from recognizing 1994-1995 shift than actually predicting it.
- This is for basinwide North Atlantic Hurricane frequency only.

EXPERIMENTAL: NOT OFFICIAL FORECAST

Vecchi et al. (2013 in press), see also Smith et al. (2010, Science)

Experimental decadal predictions

Hybrid system: statistical hurricanes, dynamical decadal climate forecasts

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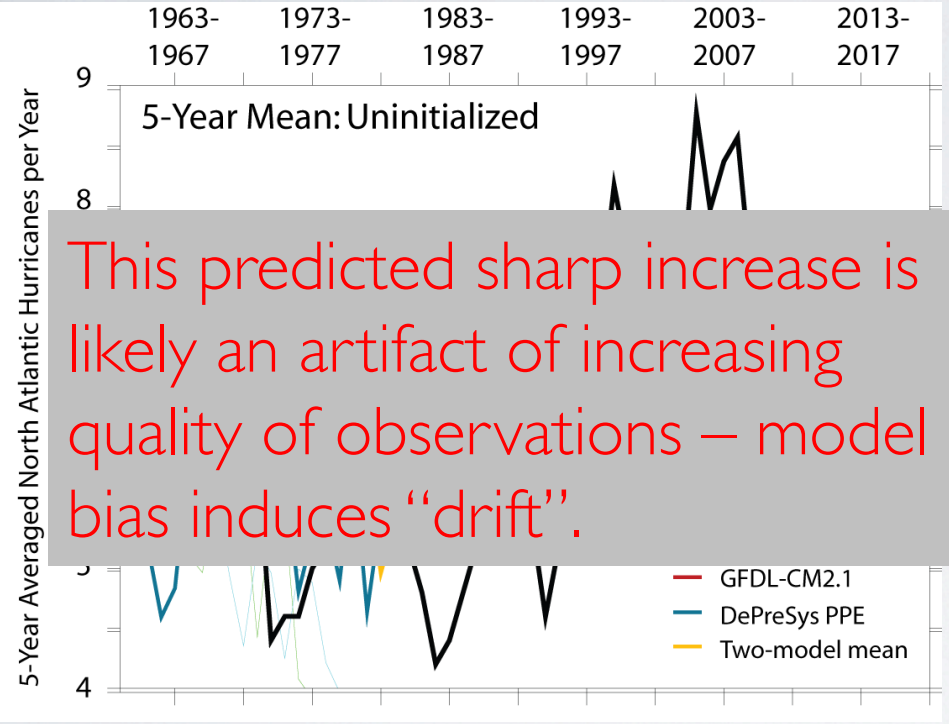
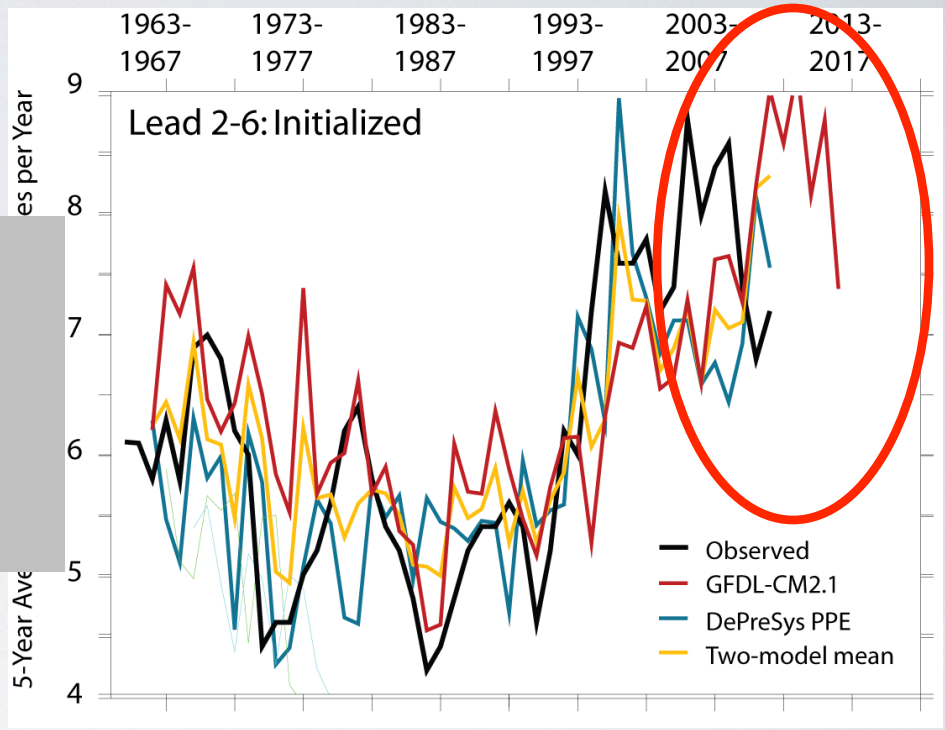


This predicted sharp increase is likely an artifact of increasing quality of observations – model bias induces "drift".

FORCED & INTIALIZED



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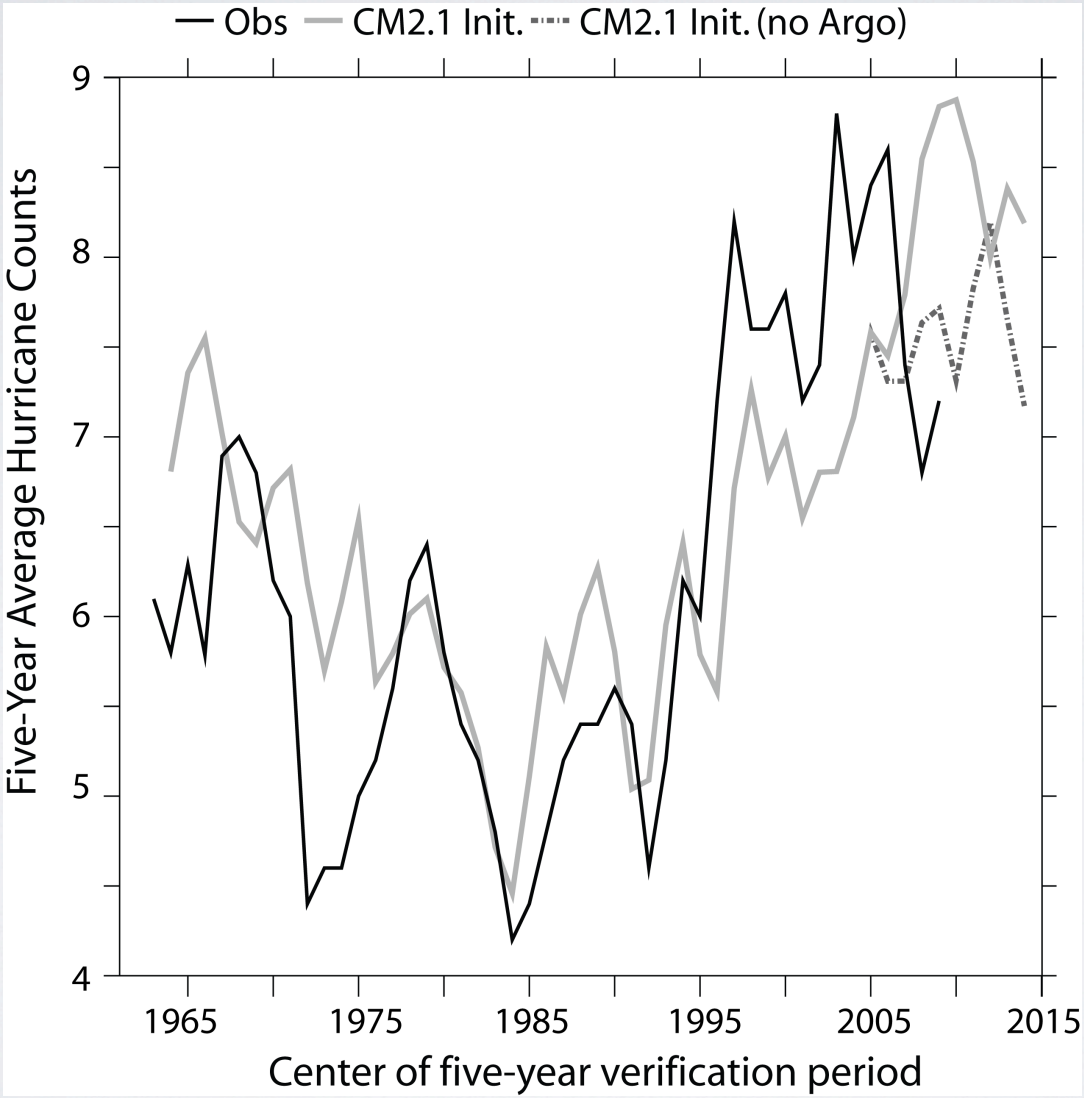
Removing observational inhomogeneity removes post-2004 upswing:

need stable, sustained observations



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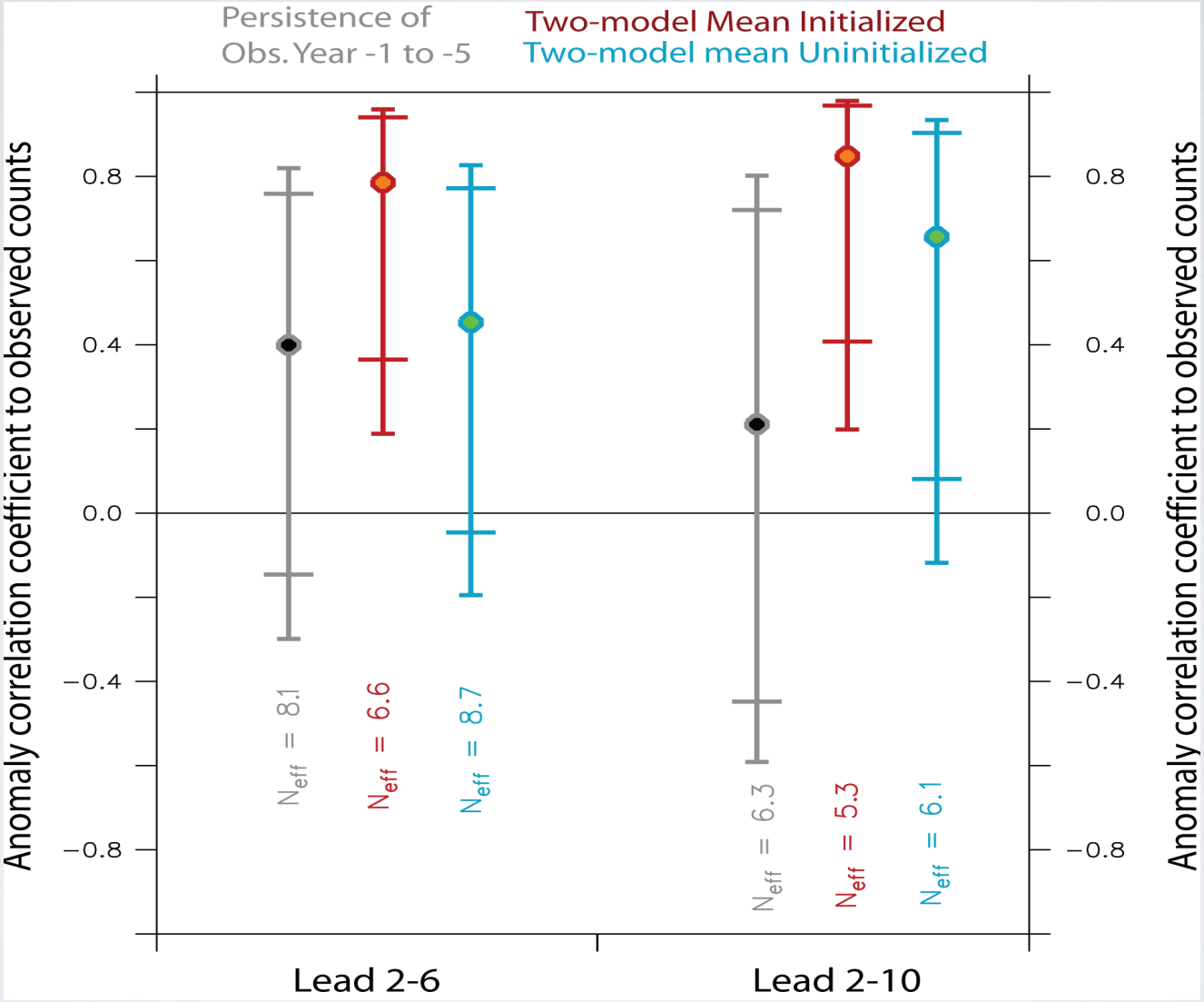

Vecchi et al. (2013 in press); Msadek et al. (2013, submitted)

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- Encouraging results from long-lead (multi-season and multi-year) experimental forecasts using hybrid system:

  "past performance no guarantee of future returns"
  but good past performance nice start…
- High-resolution coupled and atmospheric models enable the next generation of hurricane prediction and projection.

References

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