



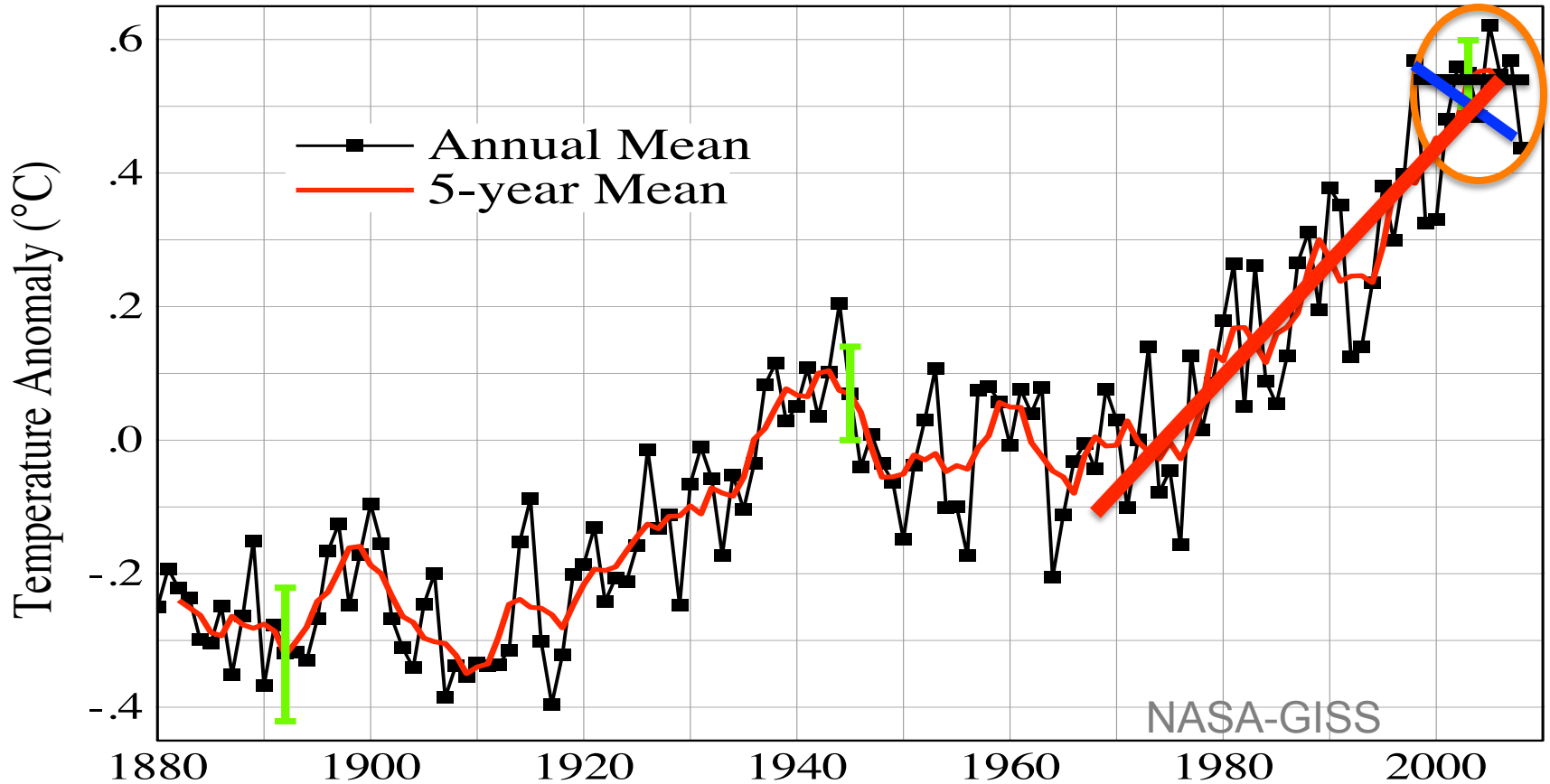
Decadal climate variability, predictability, and high-resolution coupled modeling

T. Delworth, W. Anderson, K. Dixon, H.-C. Lee, R. Msadek,
A. Rosati, G. Vecchi, A. Wittenberg F. Zeng, R. Zhang, S. Zhang

Presented by Gabriel Vecchi

- 1. Background on decadal variability and impacts**
- 2. Decadal predictability – sources and assessment**
- 3. Current GFDL efforts at prediction**
- 4. High resolution coupled modeling for predictions and projections**

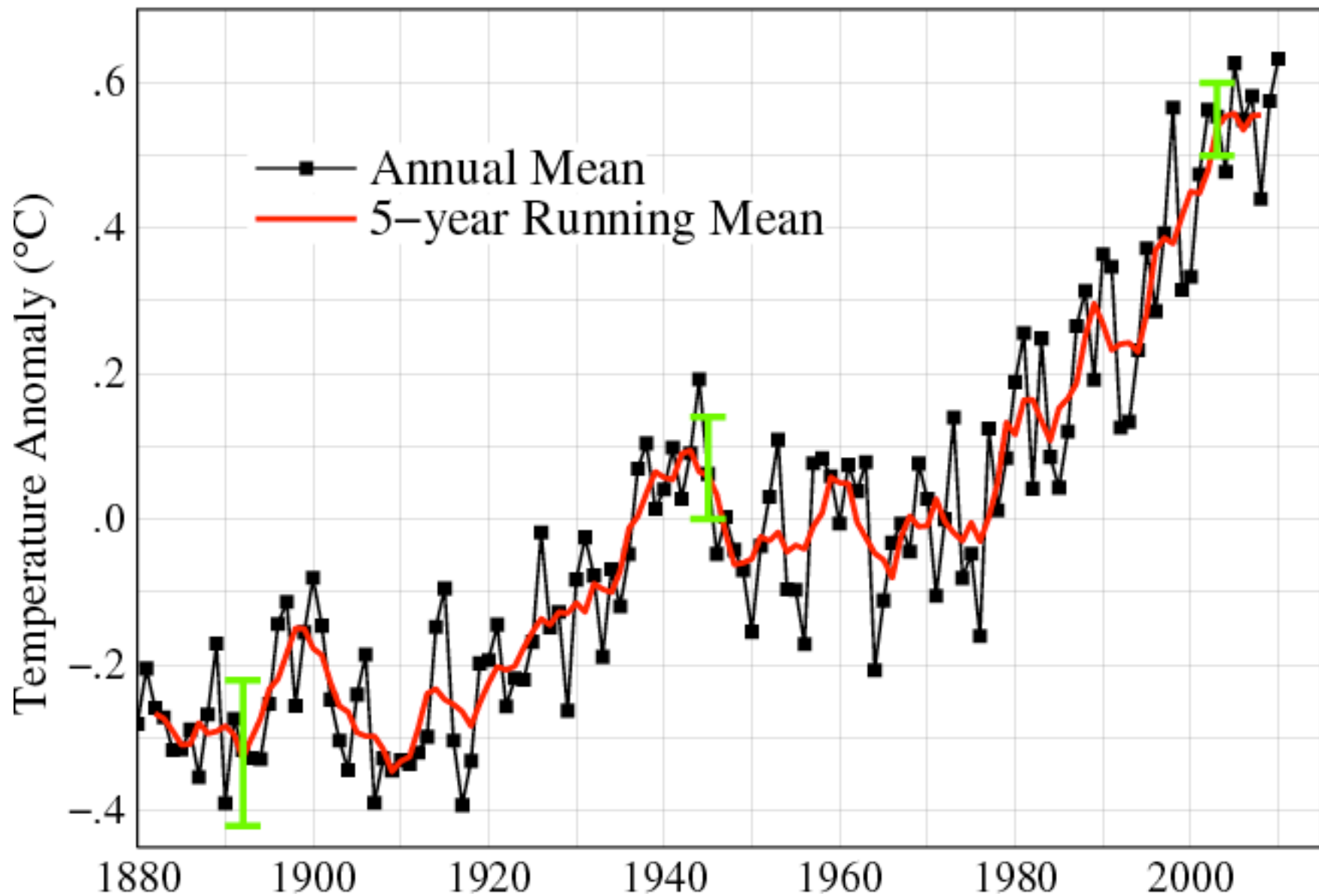
Global Land-Ocean Temperature Index



"If you're 29, there has been no global warming for your entire adult life. If you're graduating high school, there has been no global warming since you entered first grade. There has been no global warming this century. None."

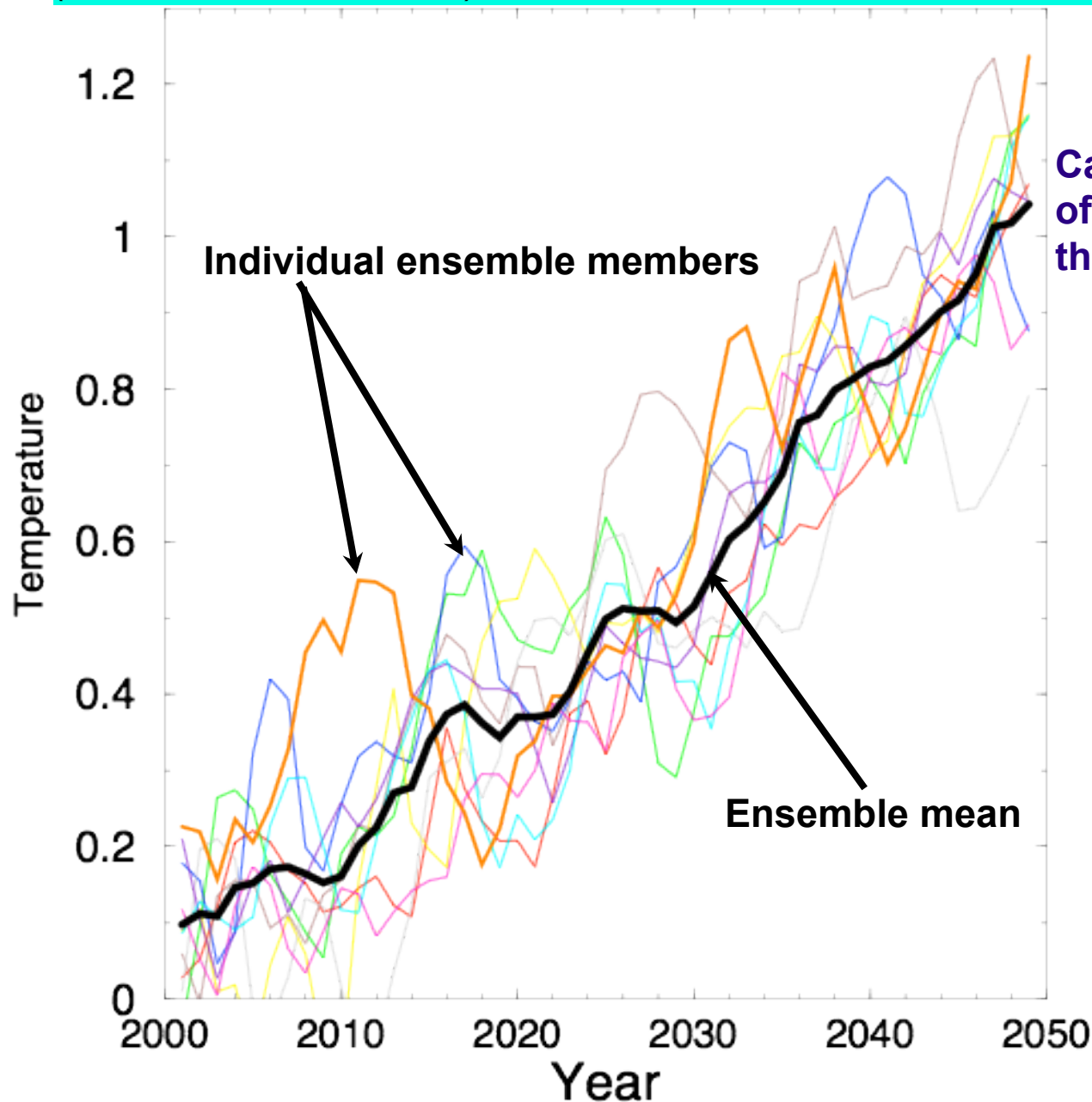
Mark Steyn, National Review online, July 4, 2009, as quoted by syndicated columnist George Will on July 23, 2009 in the Washington Post

Global Land–Ocean Temperature Index



Simulated Atlantic Sea Surface Temperature

(based on GFDL CM2.1)



Individual ensemble members

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

Ensemble mean

Why look to the Atlantic for decadal predictability?

Warm North Atlantic linked to ...

Drought

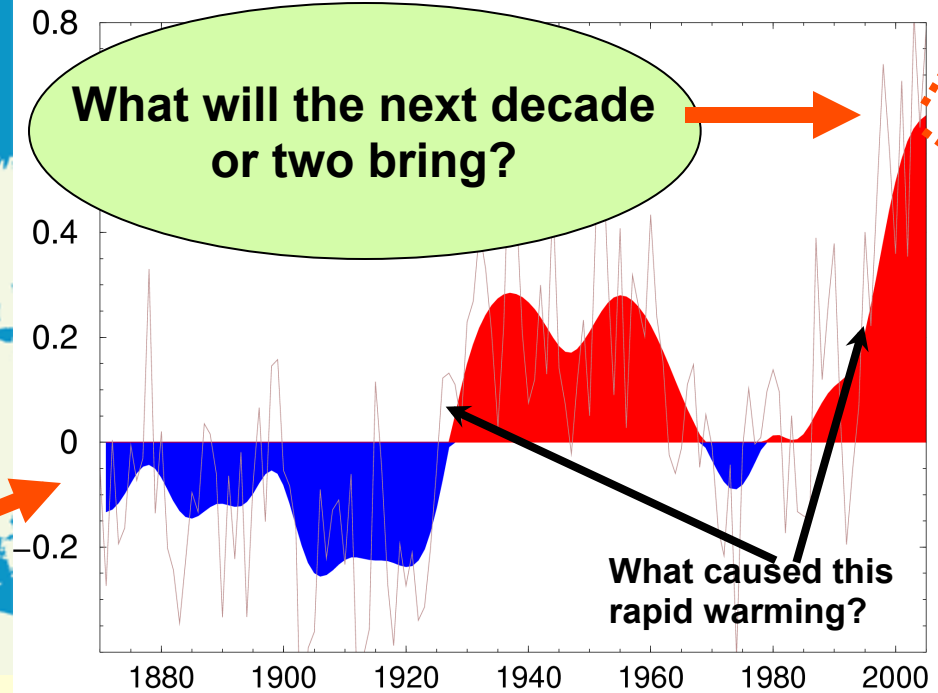
More intense hurricanes

More rain over Sahel and western India

Other examples include:

- Multidecadal Arctic variability
- US drought
- African drought

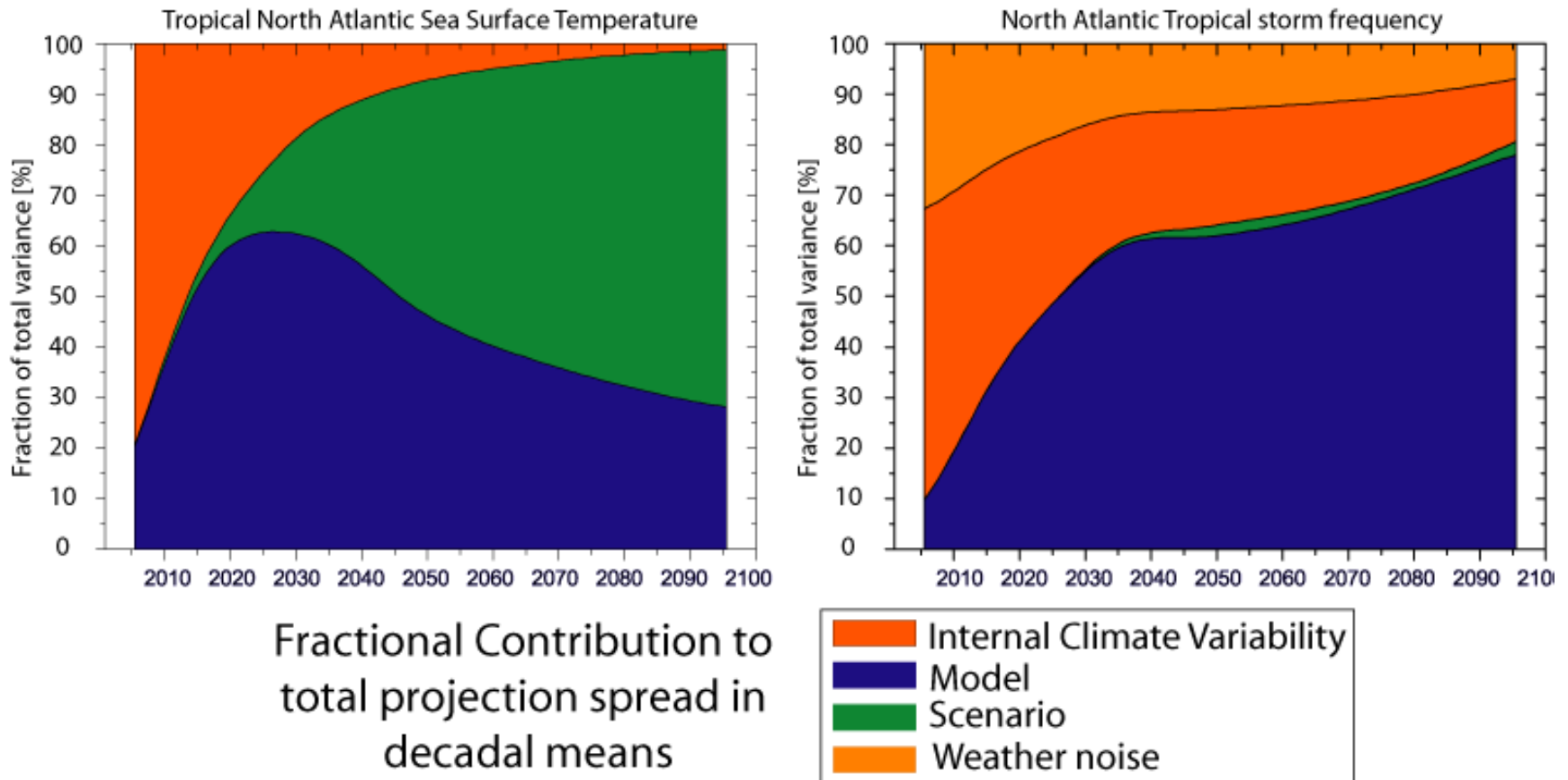
North Atlantic Temperature



Decadal variability:

- *Significant climate influences - regional to hemispheric*
- *Can phase with longer term warming to cause abrupt change*
- *Some predictability possible*
- *Crucial need to attribute observed changes*

Over the next few decades internal variability is a dominant source of uncertainty in climate projections



Uncertainties arising from differences in model response to forcing other key source of uncertainty for coming decades (whole century for TS's)

Key questions:

What are the relative roles of radiative forcing and natural climate variability in these variations?

Are these variations potentially predictable?

How can we realize any potential predictability?

Would such predictions be “useful”?

To address these questions we require:

Improved understanding of decadal variability and its predictability

Development of the capability to make decadal-scale (2-20 years) projections and predictions of climate variability and change on both global and regional scales.

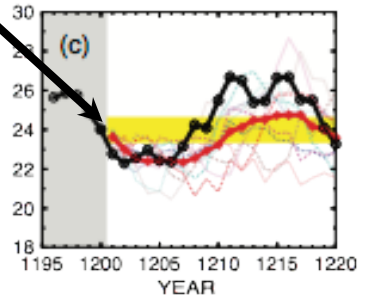
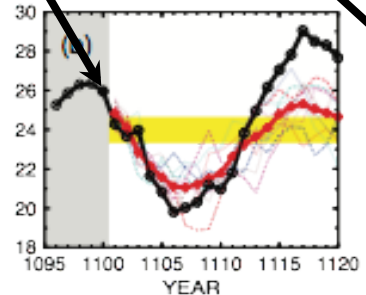
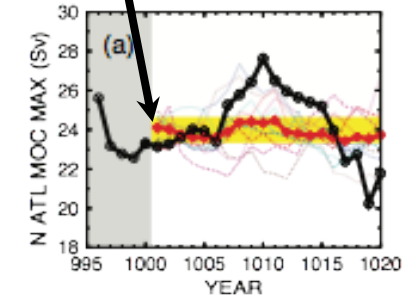
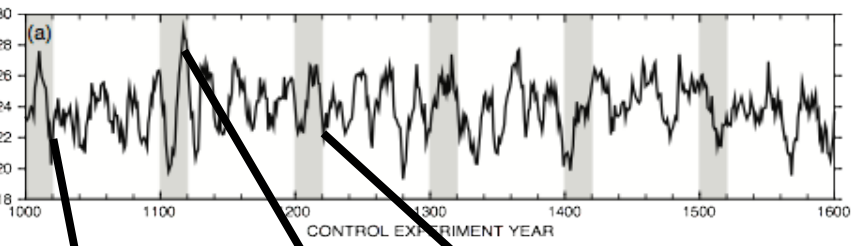
==> Includes state of the art models, as well as advanced assimilation and observing systems

Approaches:

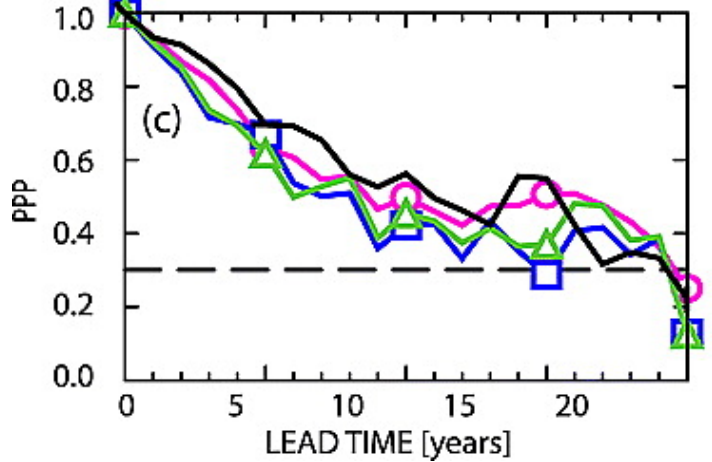
1. Use theory, observations (instrumental and paleo) to improve understanding of decadal variability and its mechanisms

Examples include:

- Collaboration between GFDL, NCAR and MIT on decadal variability across a hierarchy of models
- Collaboration between GFDL, PMEL, Univ Washington, Univ Miami on aspects of simulated and observed Atlantic



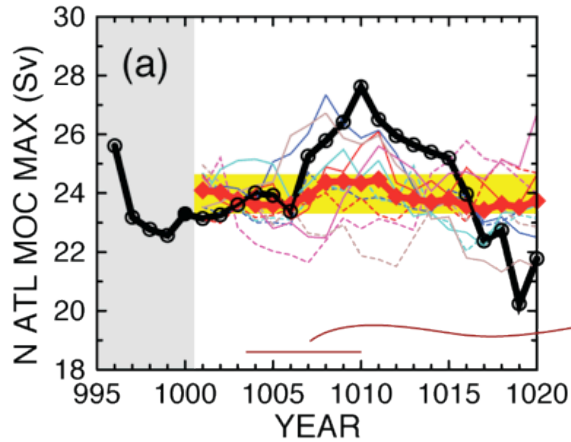
Statistical estimate of predictability
Msadek et al., 2010



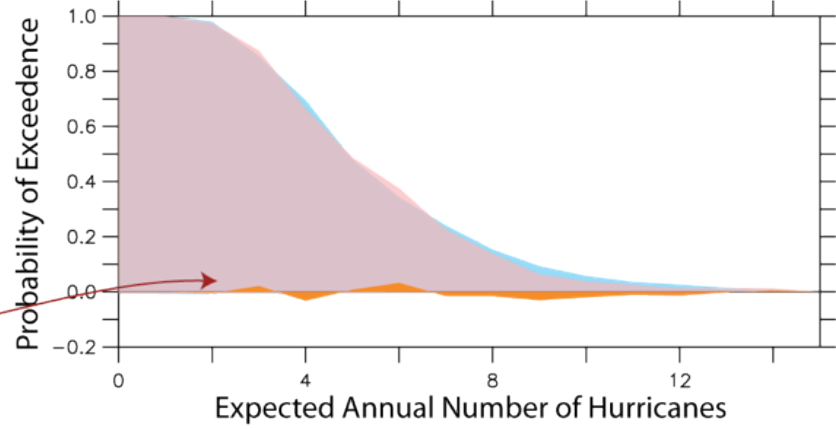
These suggest oceanic fluctuations could be predictable a decade in advance

Comparing Two Cases in CM2.1: Hurricane Index Has Some Predictability When MOC Does

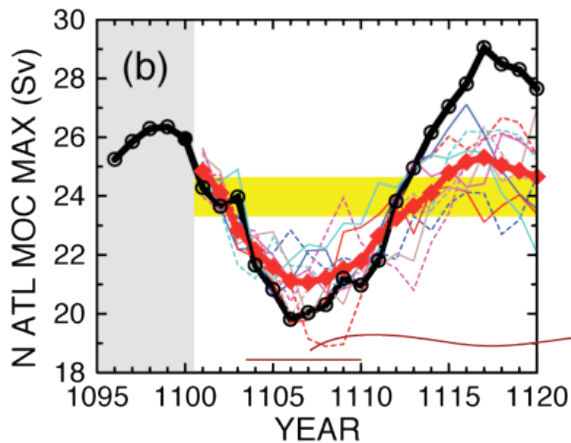
Idealized Predictions of MOC
Msadek, Dixon, Delworth and Hurlin (2010)



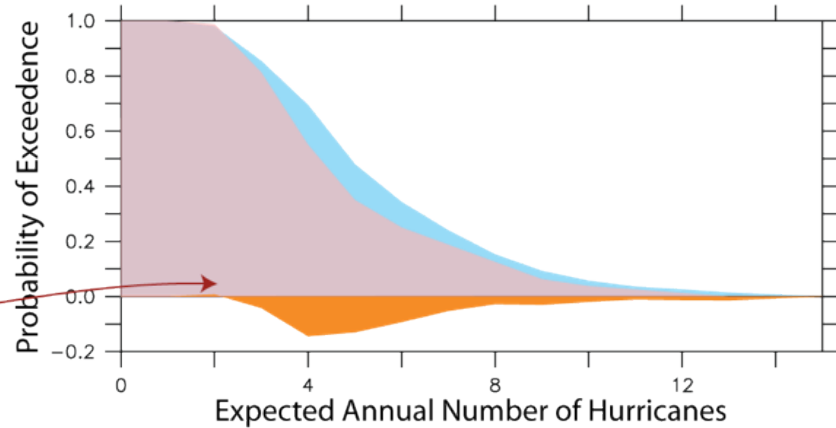
"Unpredictable MOC" Case



Uninitialized Experiments Year 3-10 Initialized (10 Ens.)
Impact of Initialization



"Predictable MOC" Case



At GFDL, long history of research on prediction systems for seasonal to interannual time scales (ENSO).

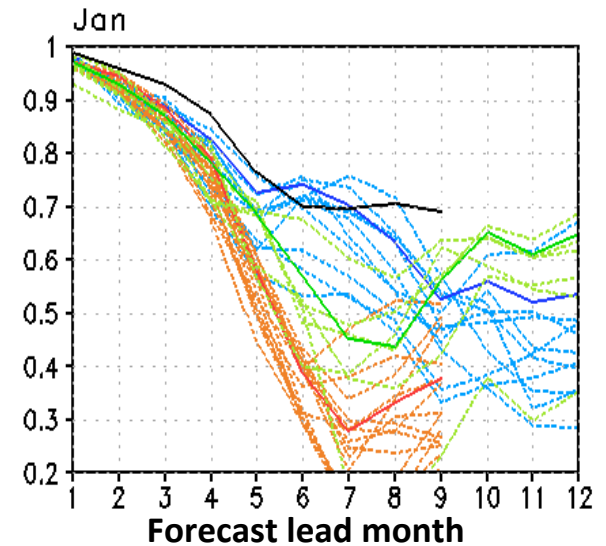
Requires:

- *adequate, sustained observing system*
- *assimilation system to initialize models*
- *models to make predictions*
- *conduct large sets of hindcasts to evaluate skill*

GFDL research has contributed to NCEP seasonal forecast systems, and is now contributing to a developing national Multi-Model Ensemble (MME).

Preliminary results on
forecast skill from MME

ACC of NINO3.4 Index (Jan IC)



NCEP ensemble mean
NCEP members
GFDL ensemble mean
GFDL members



NCAR ensemble mean
NCAR members
MME (NCEP+GFDL+CCSM)



Courtesy of Tony Rosati

Key goal: assess whether climate projections for the next several decades can be enhanced when the models are initialized from observed state of the climate system.

Strategy: Conduct suites of climate hindcasts/predictions starting from observed state, and compare to similar simulations starting from arbitrary initial conditions.

A. Generate Initial Conditions - use ECDA (Zhang et al, 2007, 2010) for initial conditions from “observed state”; produce ocean reanalysis 1961-2011

Uses: Atmosphere (NCEP reanalysis2, T,u,v,ps)

Ocean (xbt,mbt,ctd,sst,ssh,ARGO)

Radiative forcing (greenhouse gases, aerosols, solar, volcanoes); observed to 2005, RCP4.5 projections from 2006 onward

B. Conduct ensembles of simulations with radiative forcing and initialized from observations, starting in January each year from from 1961 – 2011 (5000+ simulated years)

C. Conduct parallel simulations with radiative forcing but no initialization

Use the following models:

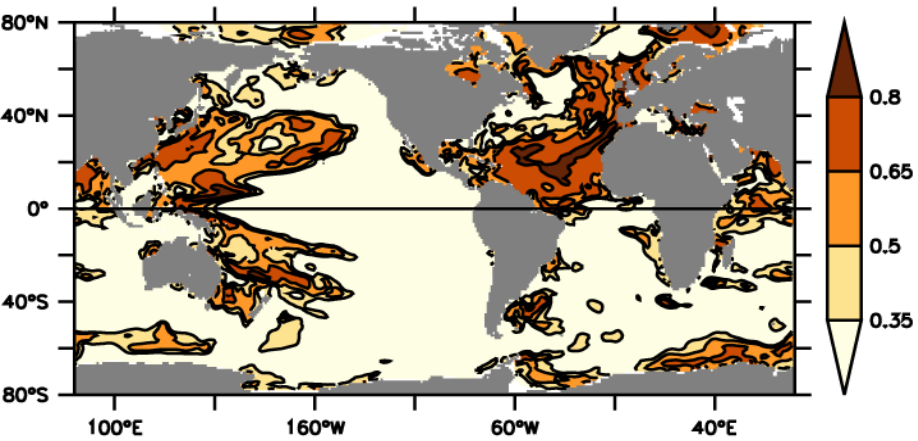
CM2.1 (primary model for decadal prediction studies)

CM2.5 (new high-resolution coupled model, described later)

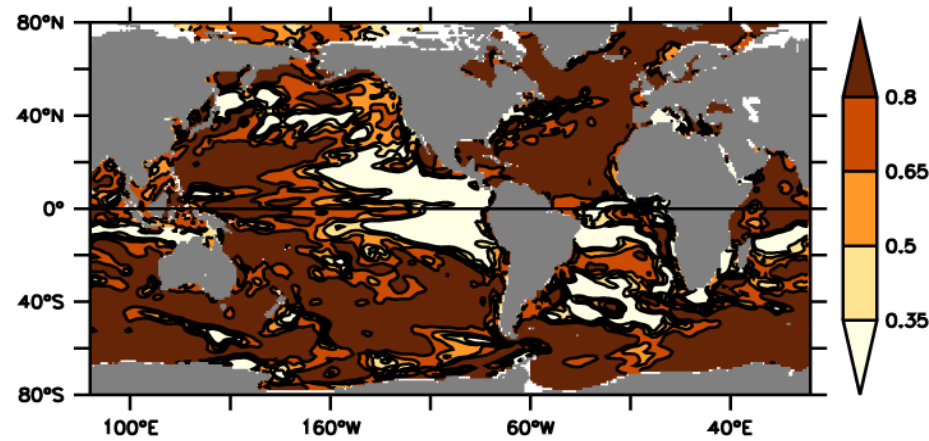
CM3 (depending on resources and assessment of preliminary results)

→ **Contributing results to CMIP5/IPCC AR5 database**

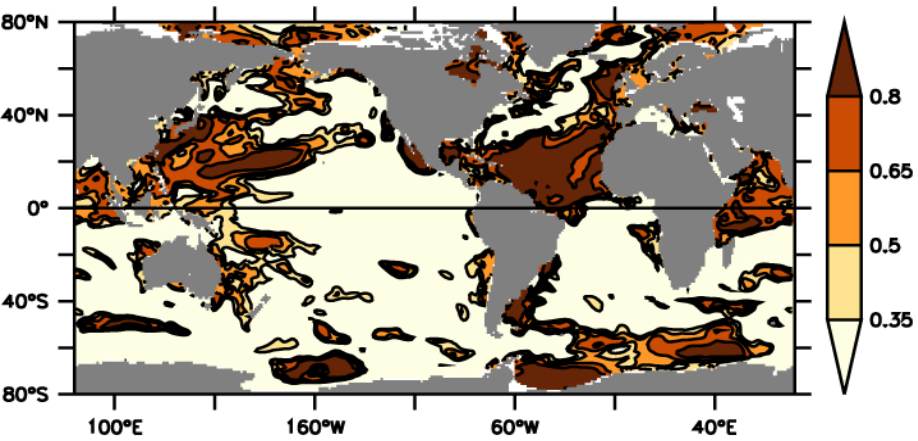
SST CORR between OBS and Hindcasts



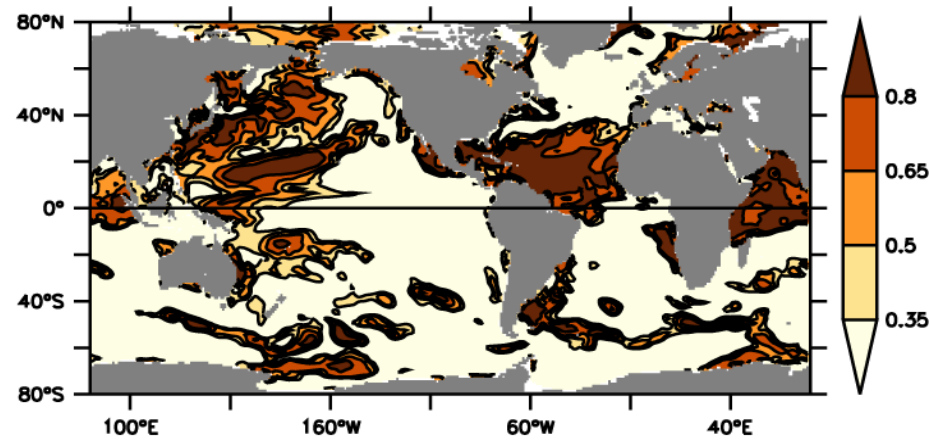
NOASSIM



YR1



YR5



YR10

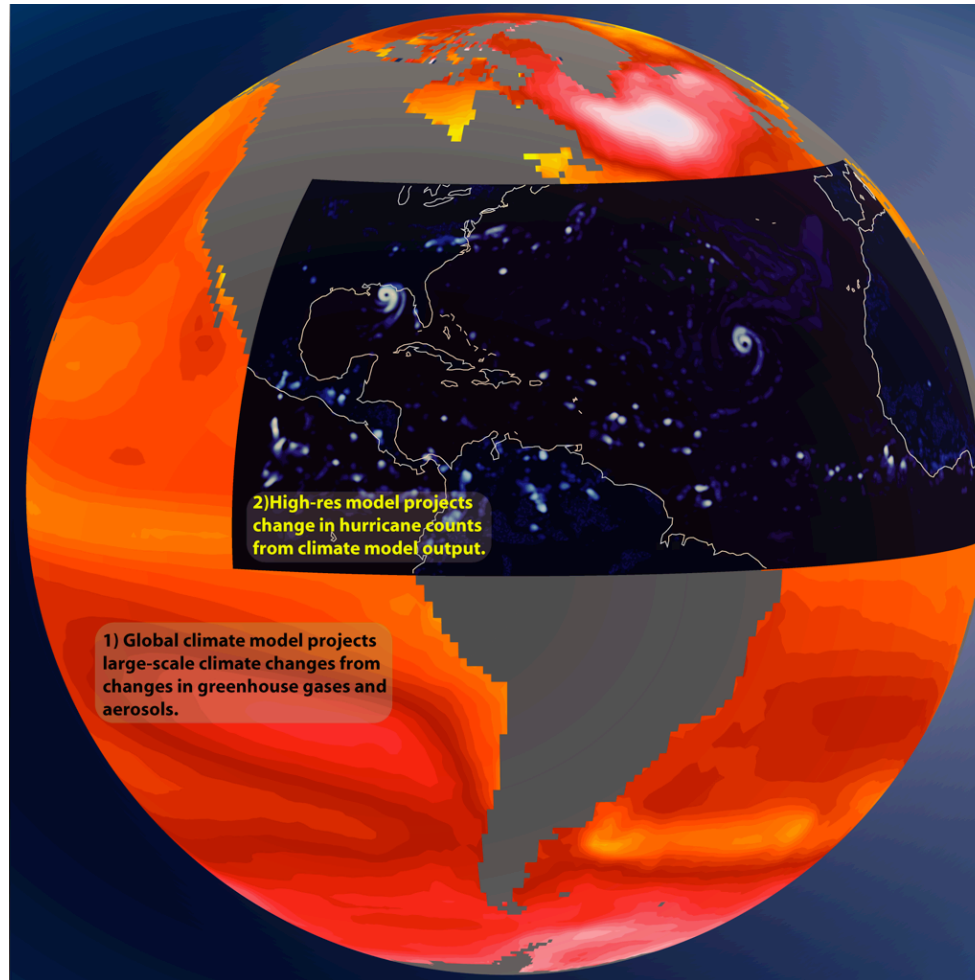
- Robust predictions will require **sound theoretical understanding** of decadal-scale climate processes and phenomena, and a high-quality **sustained observing system**
- Assessment of predictability and its climatic relevance **may have significant model dependence**, and thus may evolve over time (with implications for observing and initialization systems).

But ... even if decadal fluctuations have limited predictability, it is still important to better understand them to aid in the interpretation of observed climate change.

High-resolution modeling: motivation

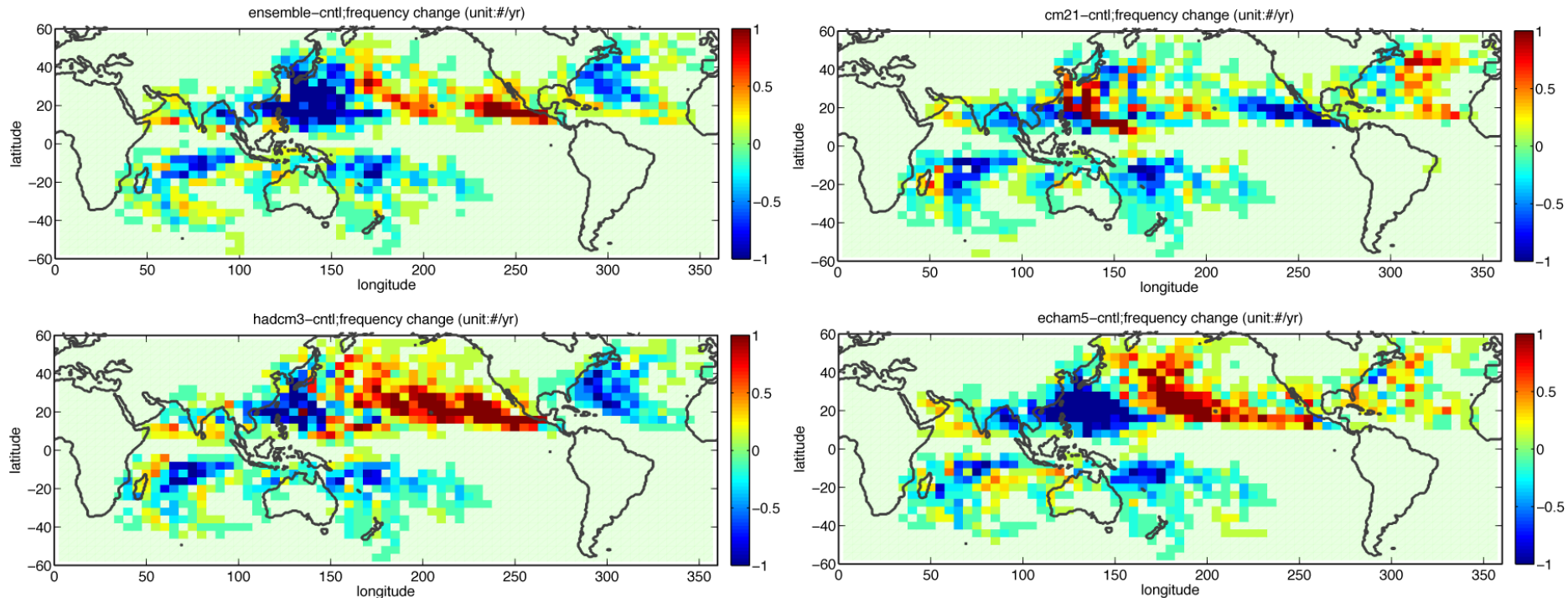
- **To resolve phenomena:** Certain phenomena of interest (e.g., tropical cyclones, regional precipitation) are tied to small spatial scale processes.
- **To represent processes:** Model fidelity influences decadal variability and predictability: models with much higher resolution *may* have more realistic simulations of decadal variability.
- A hypothesis is that as more processes (such as oceanic eddies) are explicitly resolved, the model's physics becomes more robust.

“Downscaling” of Climate Model Projections Using High-Resolution 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.

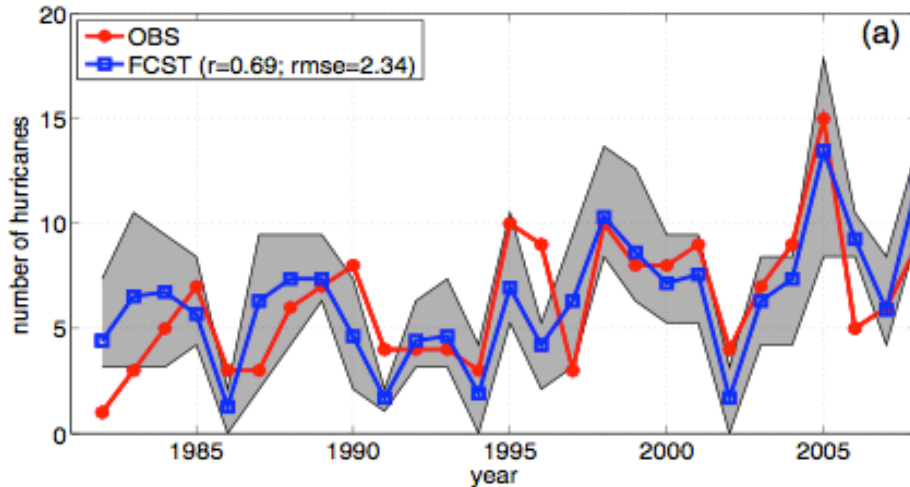
Pattern depends on details of ocean temperature change.

Sensitivity of response seen in many studies

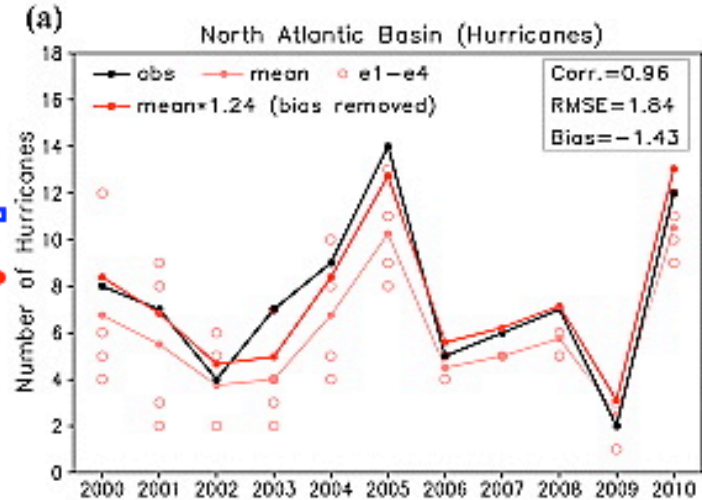
e.g., Emanuel et al 2008, Knutson et al 2008, etc

High-Res AGCMs Basis for Experimental Hurricane Forecast Systems

Forecasts from June



Zhao *et al.* (2010, MWR)

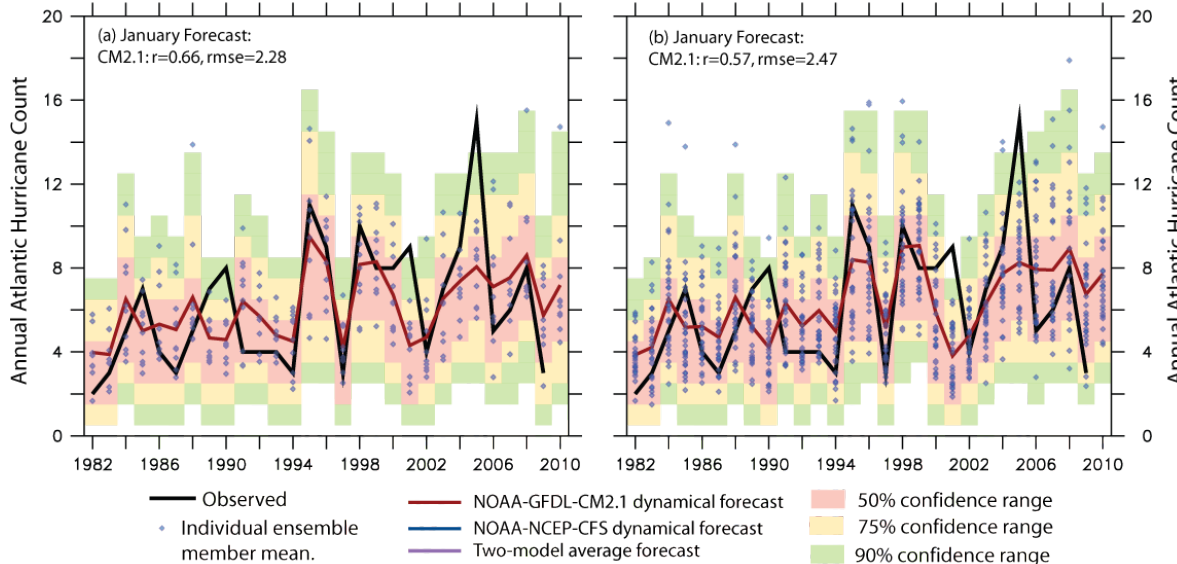


Chen and Lin (2011, GRL)

Forecasts from January (as early as previous Oct.)

Monthly forecasts

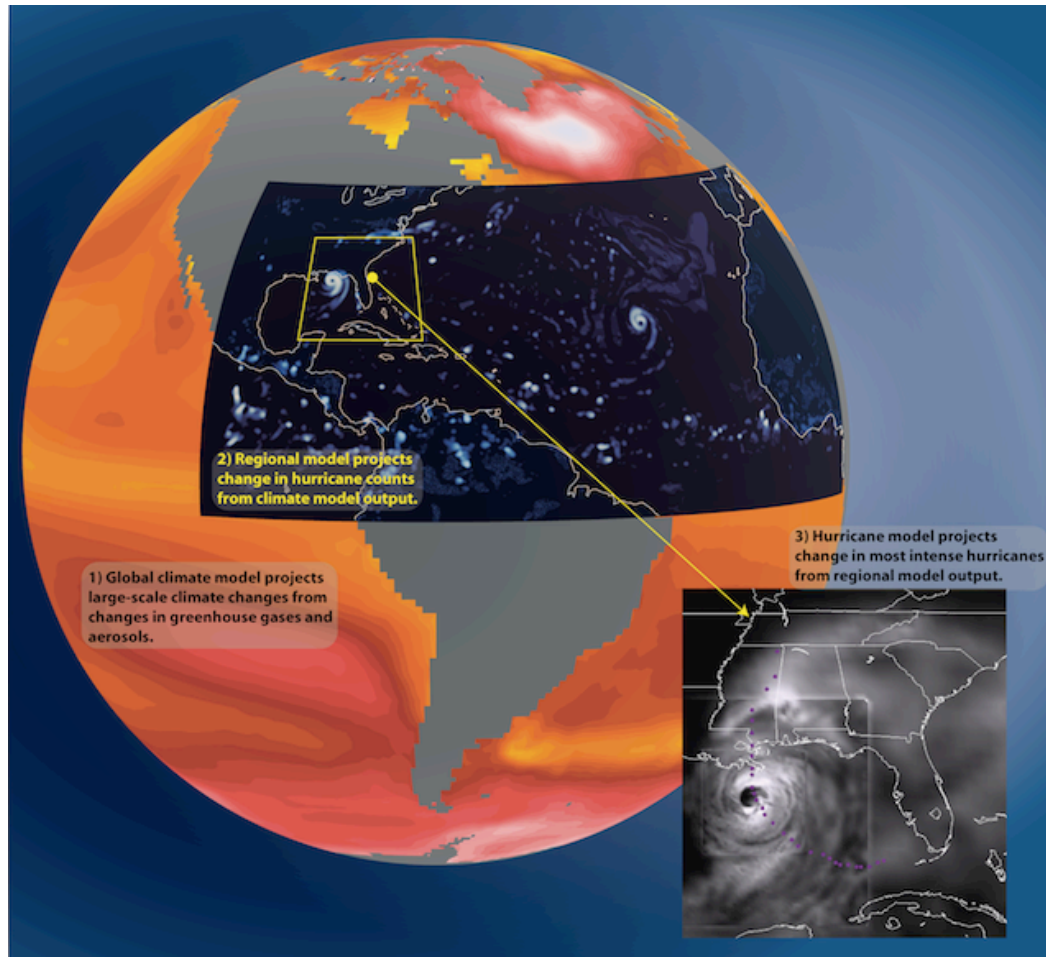
30-member lagged ensemble forecasts



GFDL experimental forecast output provided to NCEP to help inform their seasonal hurricane outlooks.

Vecchi *et al.* (2011, MWR)

Strongest cyclones projected with double downscaling



*Adapted from
Bender et al (2010, Science)*

Global Climate Models -> Regional Model -> Hurricane model

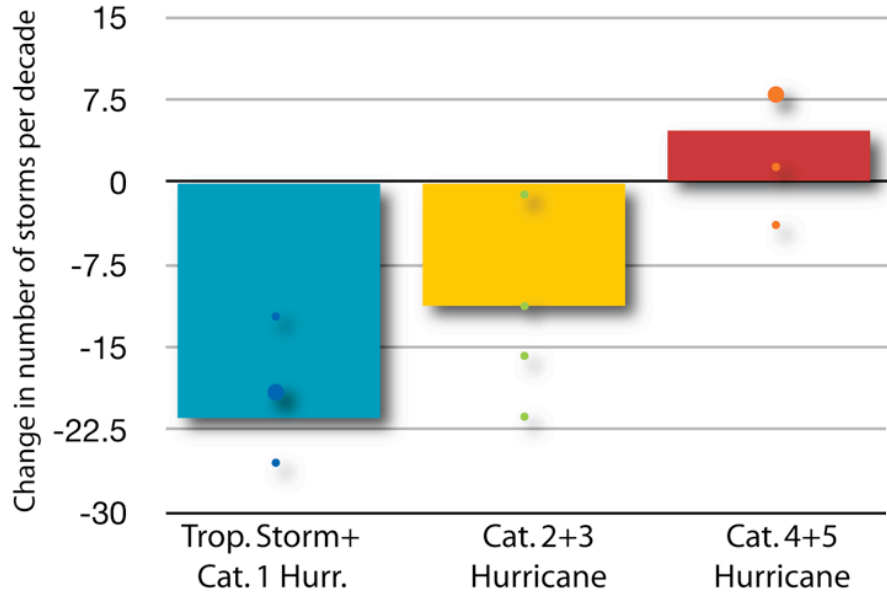
Large-scale

TS Frequency

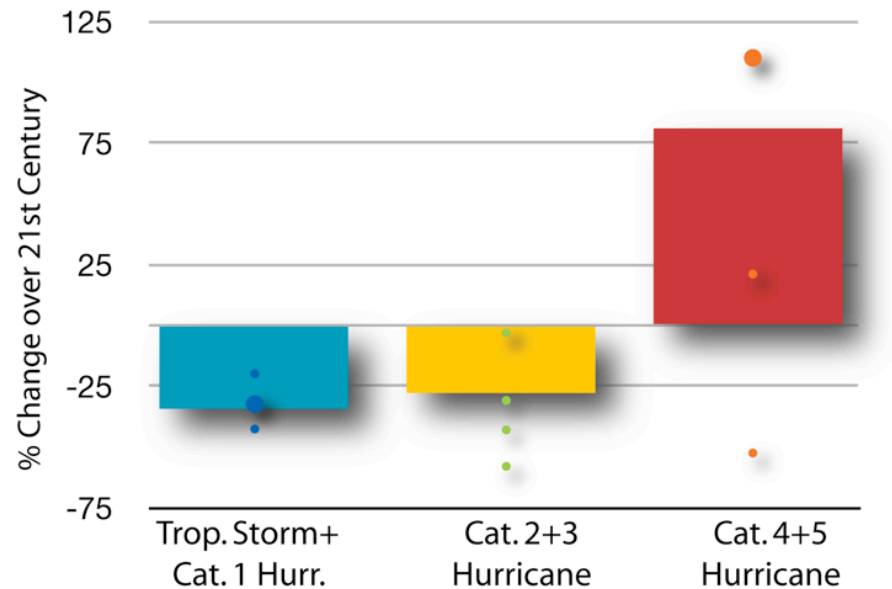
Intensity

Overall frequency decrease, but strongest storms may become more frequent

Projected Changes in Atlantic Hurricane Frequency over 21st Century
bars indicate best estimate, dots indicate alternative estimates.



Projected Changes in Atlantic Hurricane Frequency over 21st Century



Adapted from Bender et al (2010, Science)

High Resolution Coupled Model Development

Scientific Goals:

- Developing improved models (higher resolution, improved physics and numerics, reduced bias) for studies of variability and predictability on intra-seasonal to decadal time scales
- Explore impact of atmosphere and ocean on climate variability and change using a high resolution coupled model
- New global coupled models: CM2.4, CM2.5, CM2.6, ...

	Ocean	Atmos	Computer	Status
CM2.1	100 Km	250 Km	GFDL	Running ←
CM2.3	100 Km	100 Km	GFDL	Running
CM2.4	10-25 Km	100 Km	GFDL	Running
CM2.5	10-25 Km	50 Km	GFDL/GAEA	Running ←
CM2.6	4-10 Km	50 Km	GAEA	Running

CM2.0, CM2.1 – state of the art physical
climate models (1° ocn; 2° atm)

Circa 2005

Circa 2010

ESM2M, ESM2G

- Carbon cycle
- Vegetation feedback
- Ocean formulation

HIRAM

- High spatial resolution (atm only)
- Time-slice experiments
- Climate extremes

CM3 (Primary Physical Model)

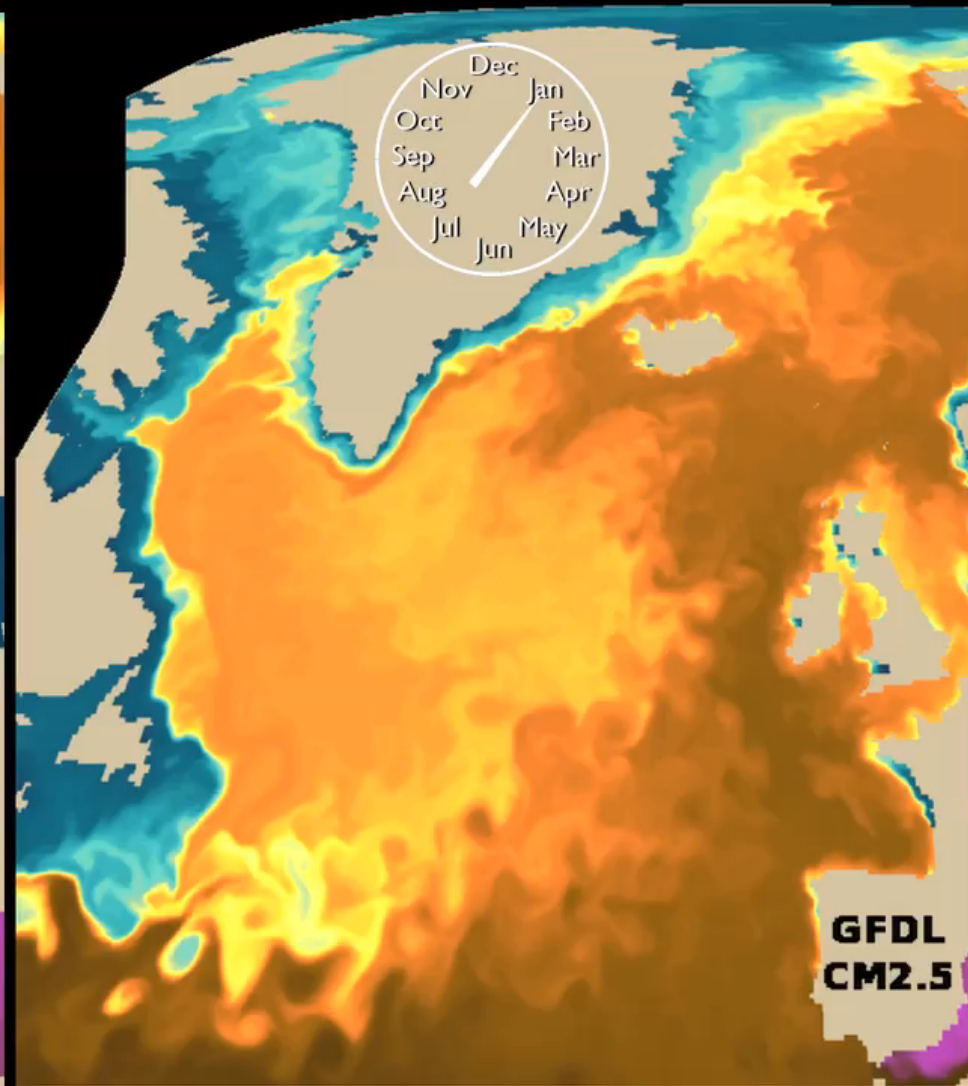
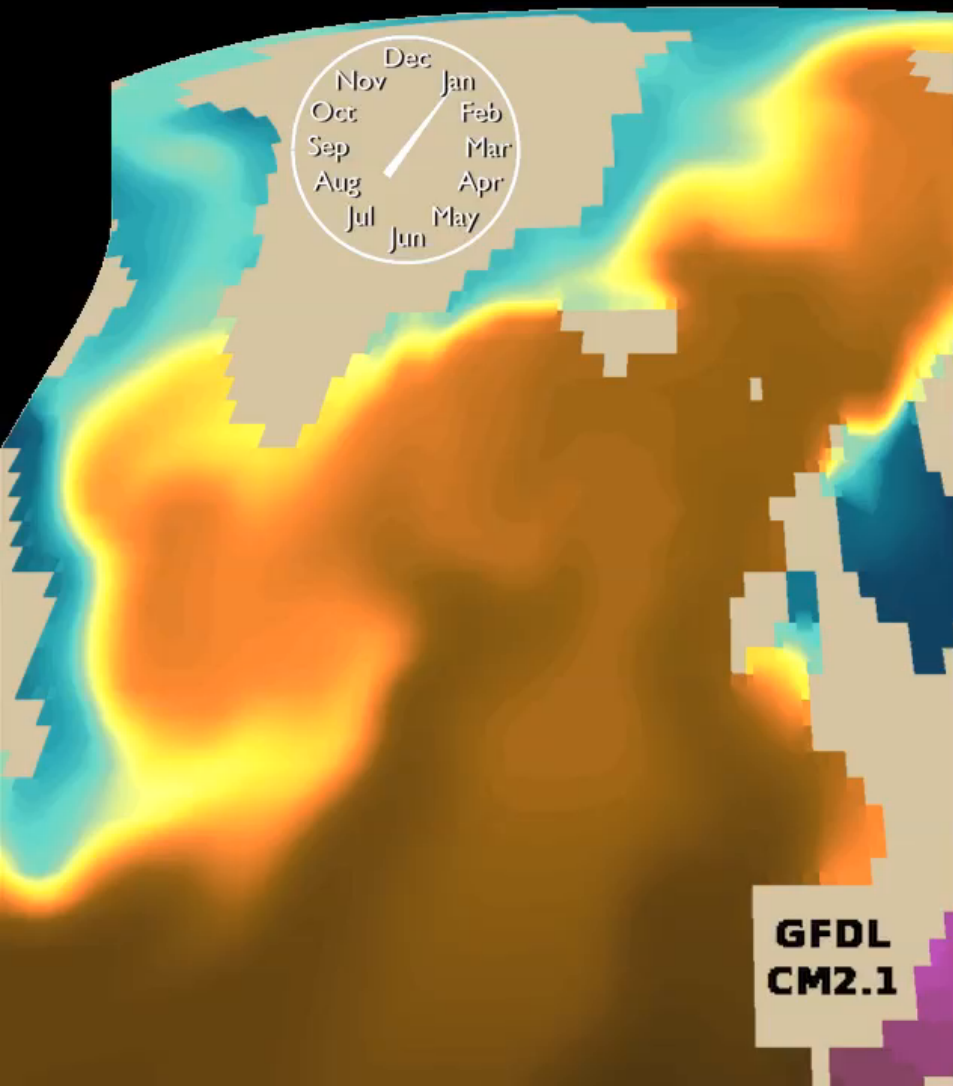
- Aerosols, indirect effect
- Stratosphere
- Convection, Land Model
- Atmospheric Chemistry

CM2.5

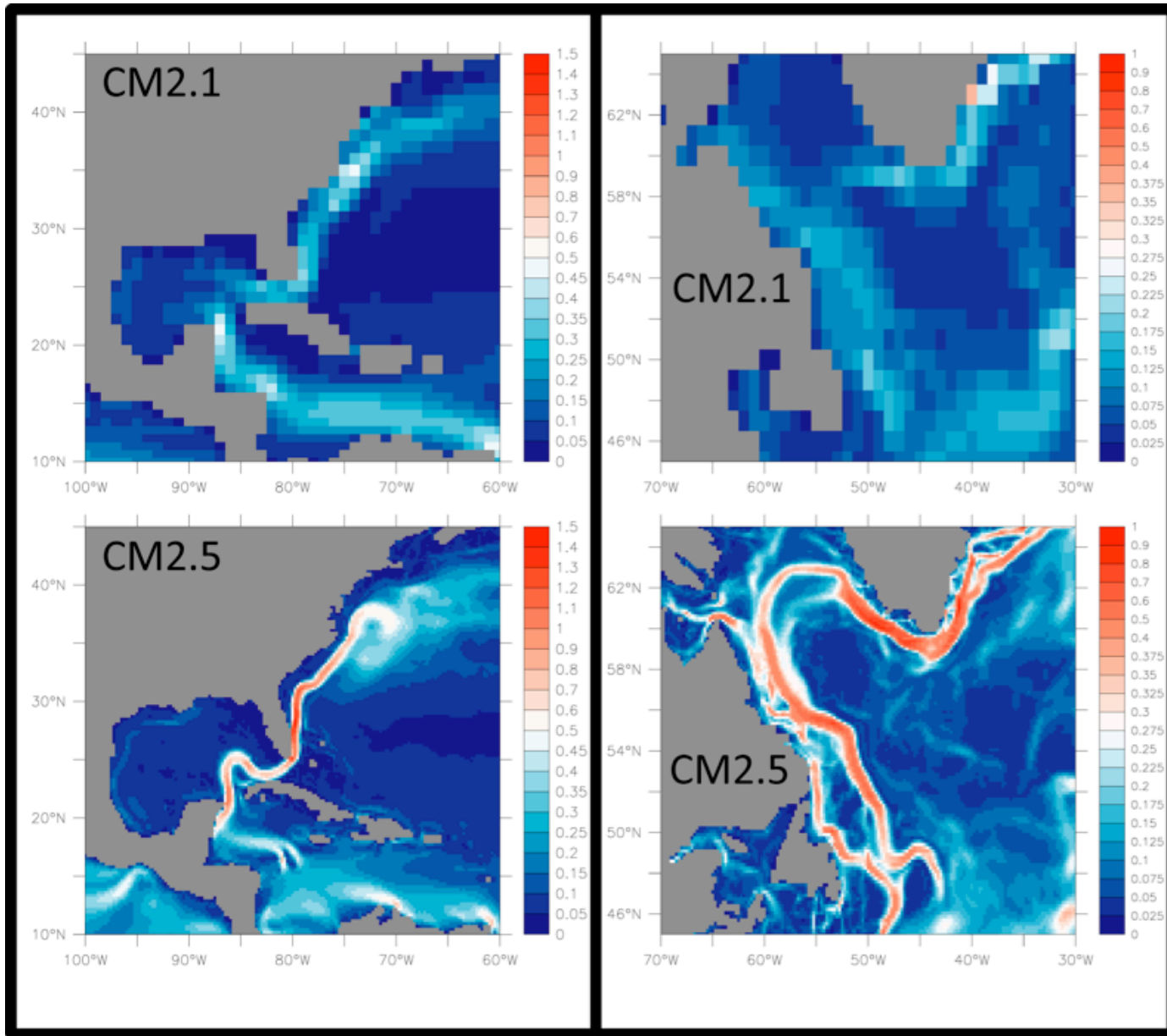
- High spatial resolution (coupled)
- Energetic ocean
- **Variability and change in coupled system at high resolution**



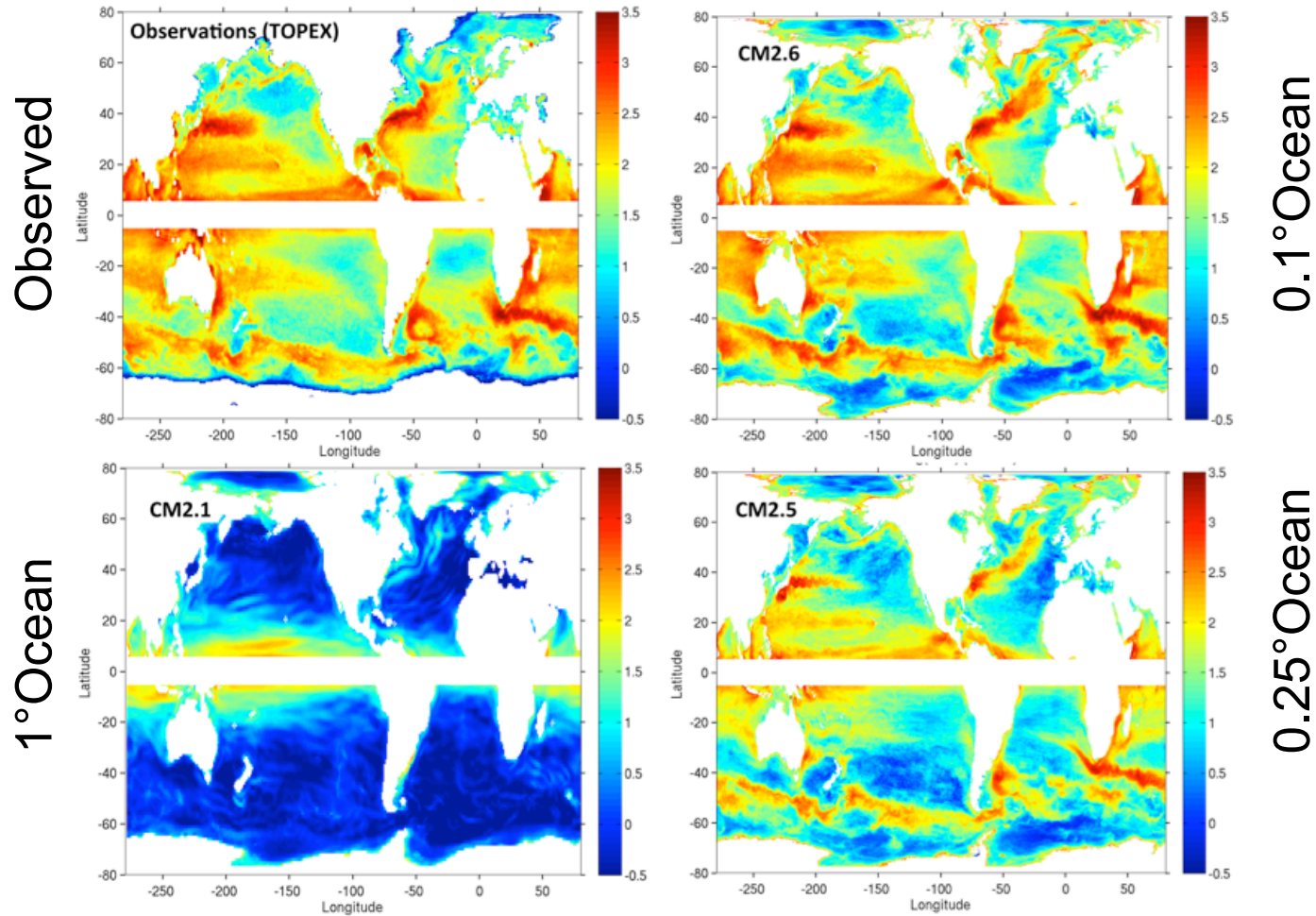
CM4 ?? - drawing on what is learned
from these various streams



Surface currents much more energetic



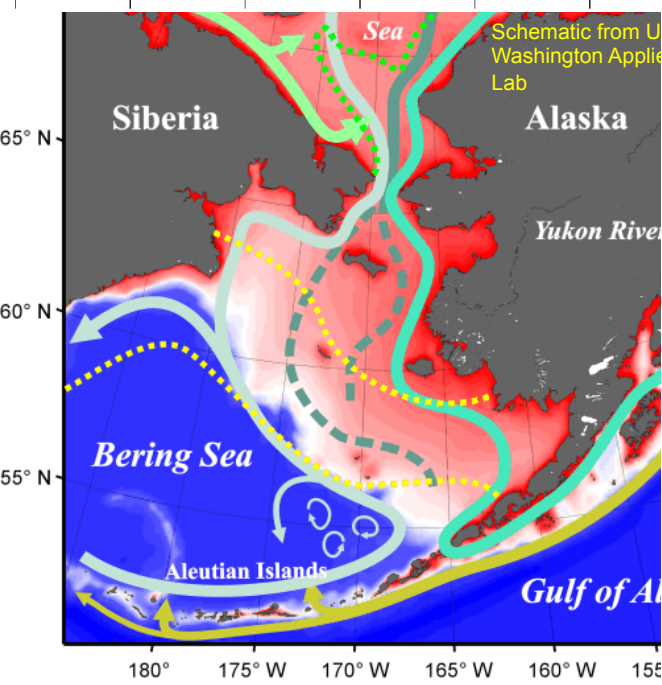
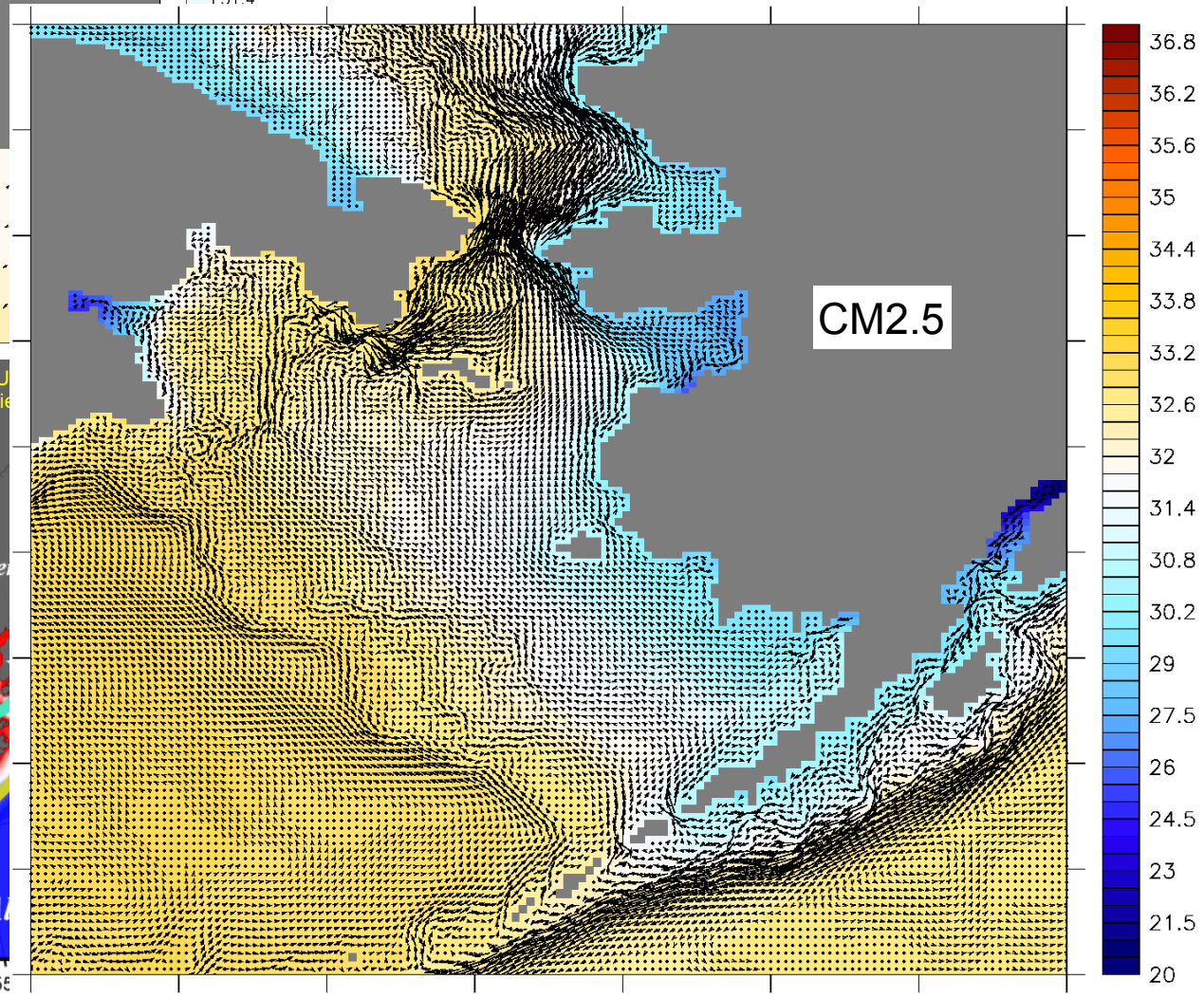
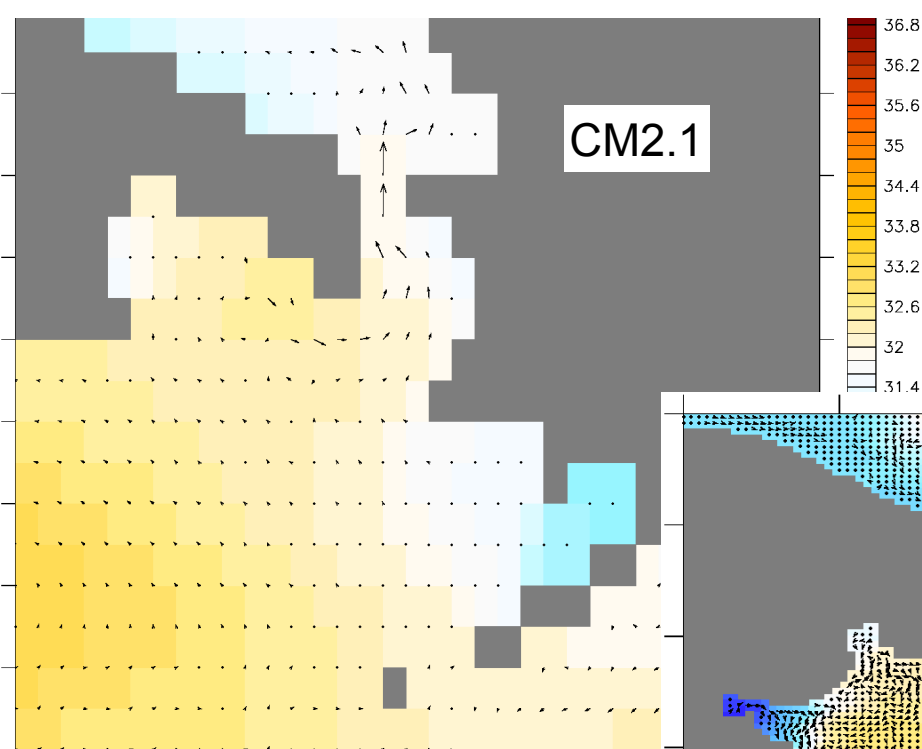
However, to Reproduce Observed EKE Need Higher Resolution Yet



Resolution enhancement allows model to better represent processes

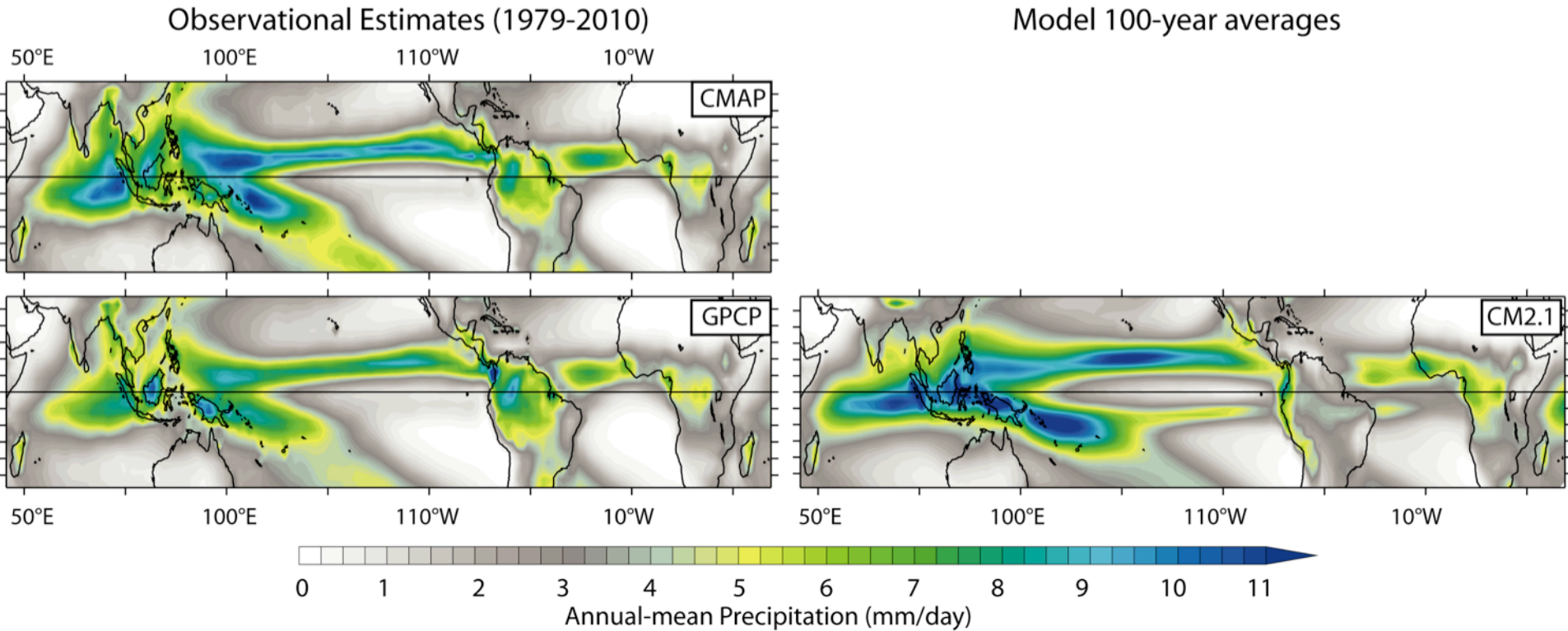
Delworth et al (2011)

Improvement of regional scale circulation SSS and surface currents

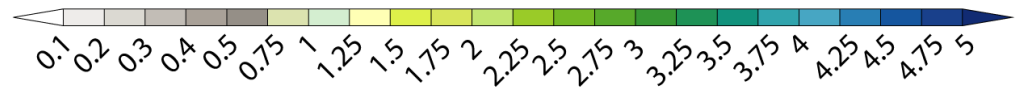
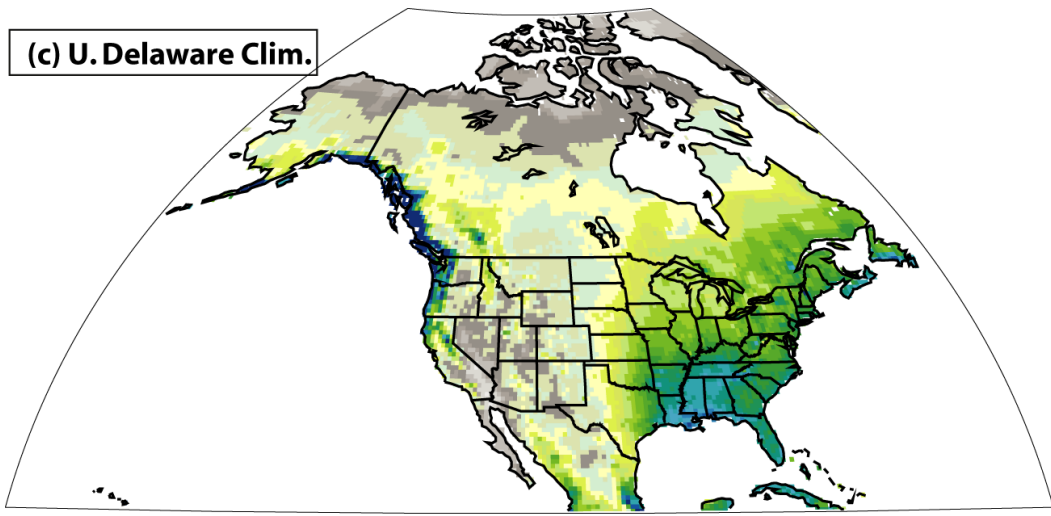
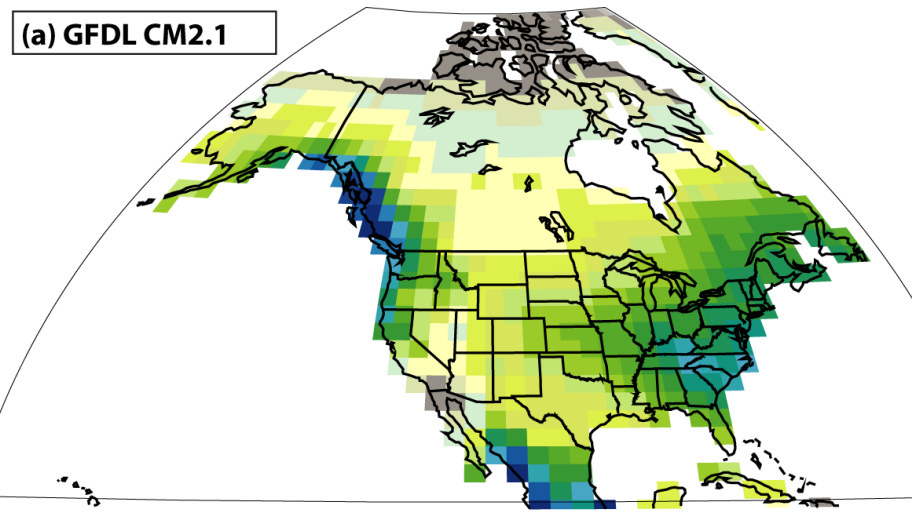


Some Aspects of Tropical Climate Improve with Resolution

Annual Tropical Precipitation on 2.5x2.5 Grid

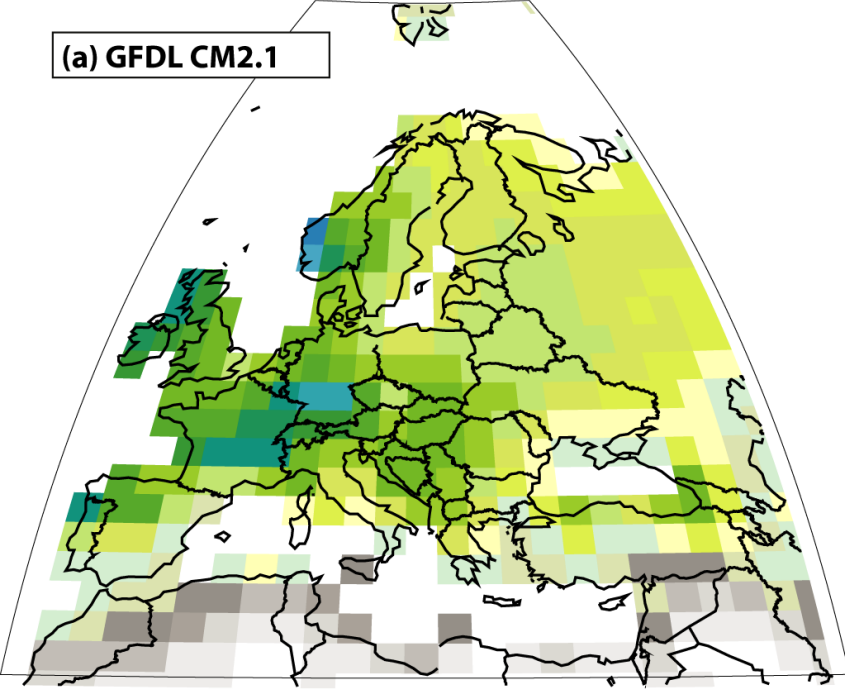


Adapted from Delworth et al (2011)

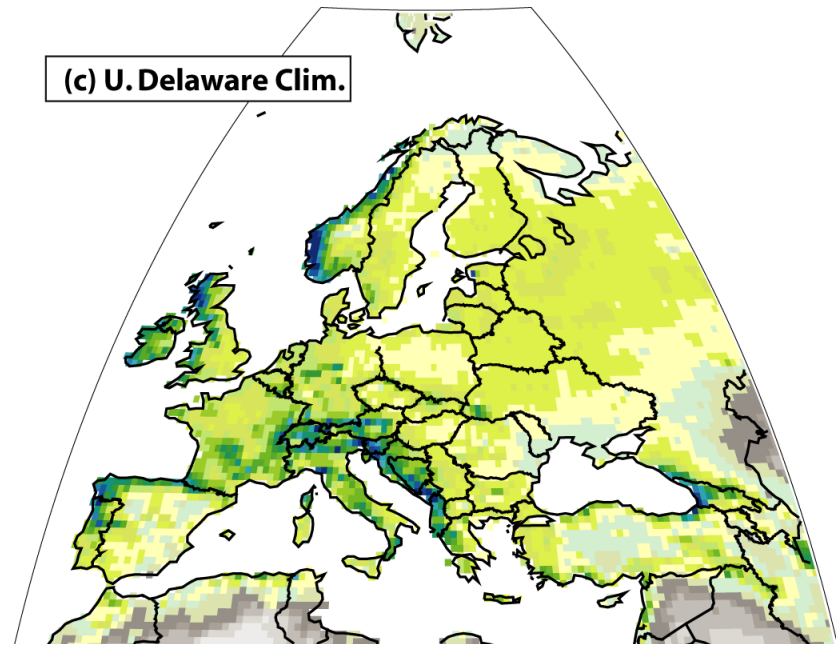


Annual Average Precipitation (mm/day)

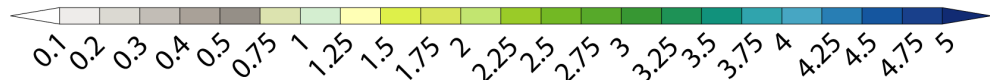
(a) GFDL CM2.1

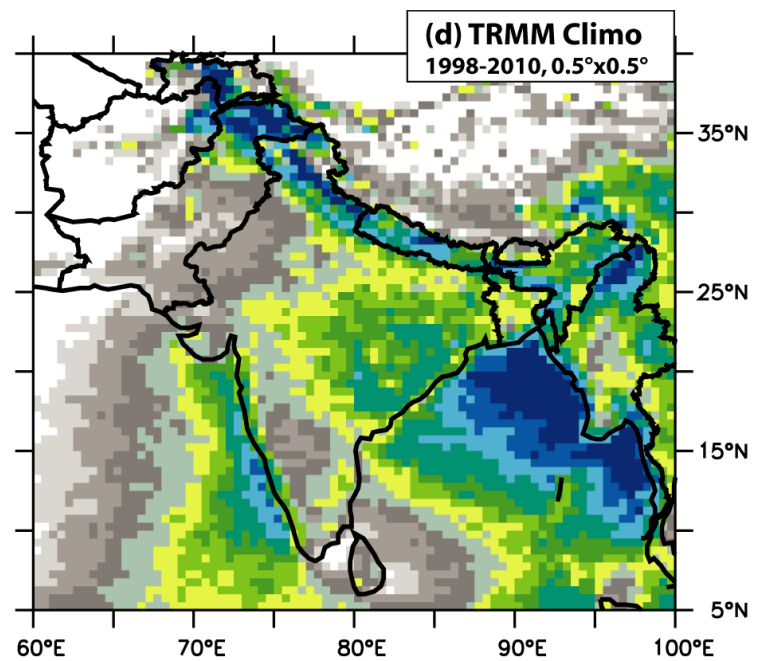
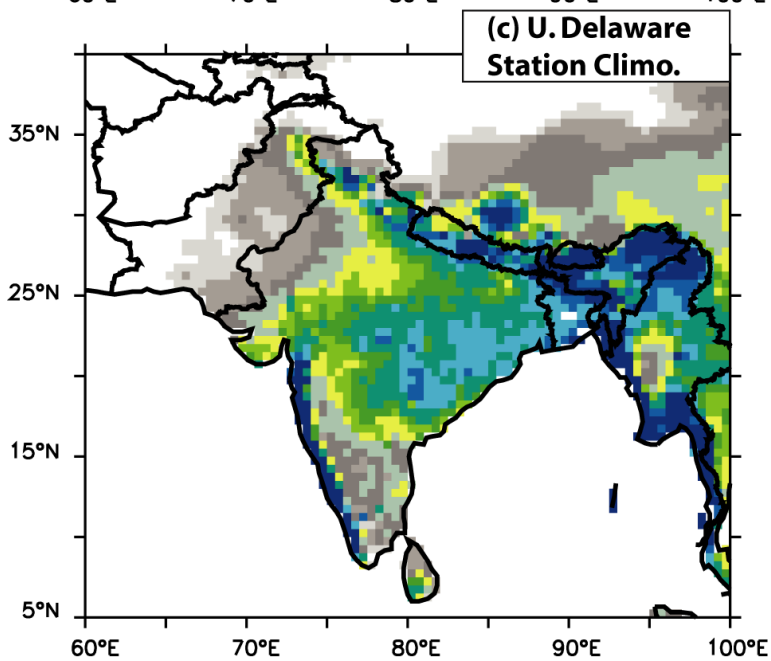
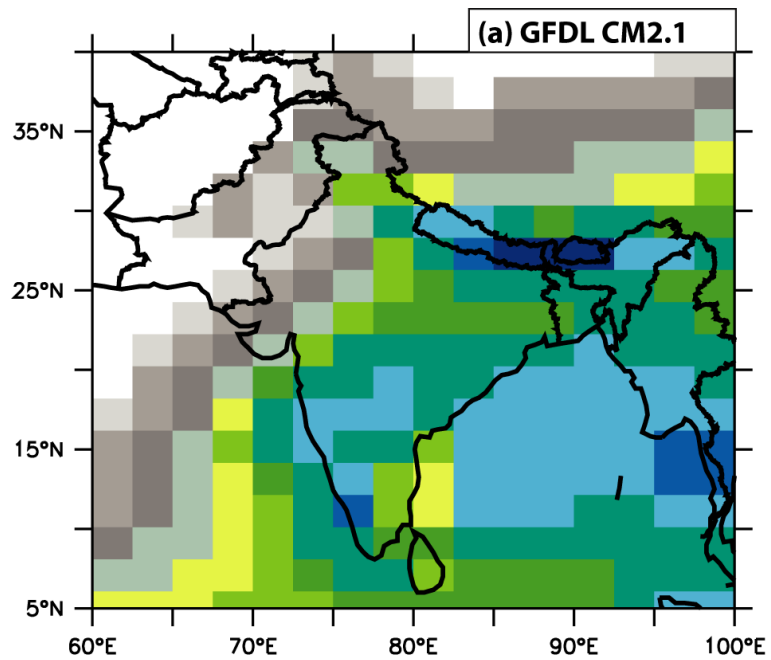


(c) U. Delaware Clim.



Annual precipitation
(mm/day)

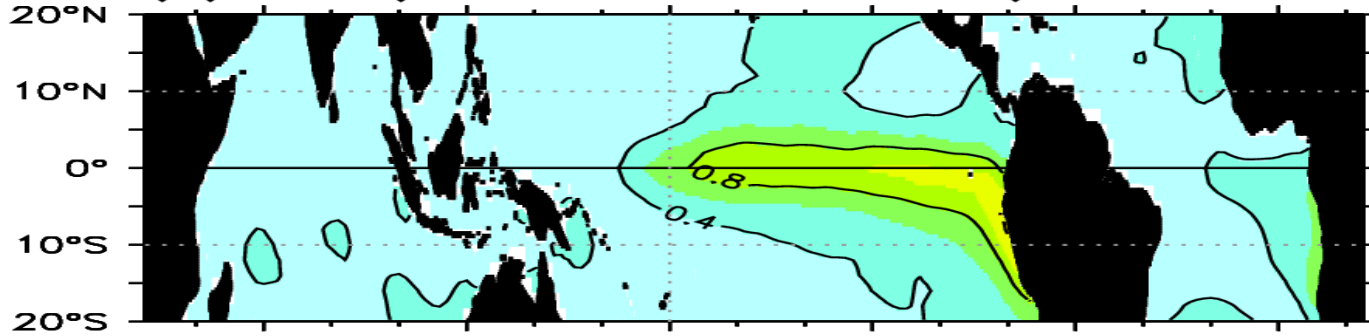




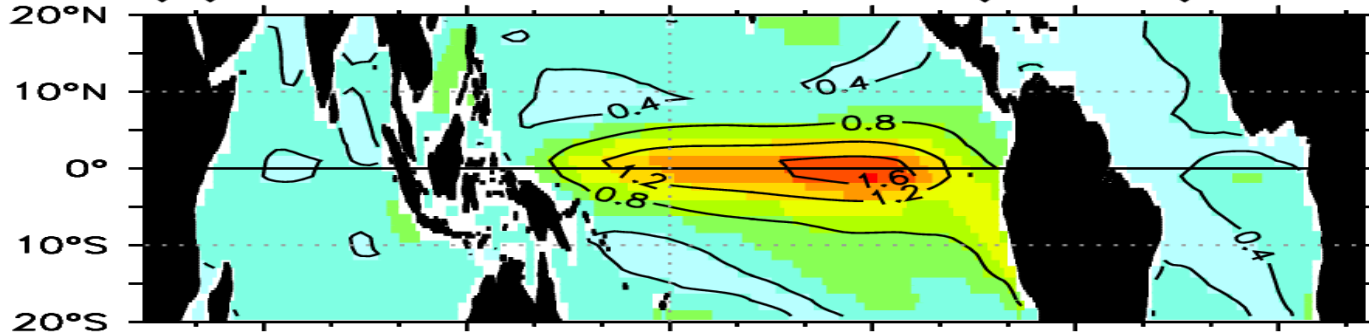
June-September Precipitation (mm/day)

Interannual standard deviation of SST

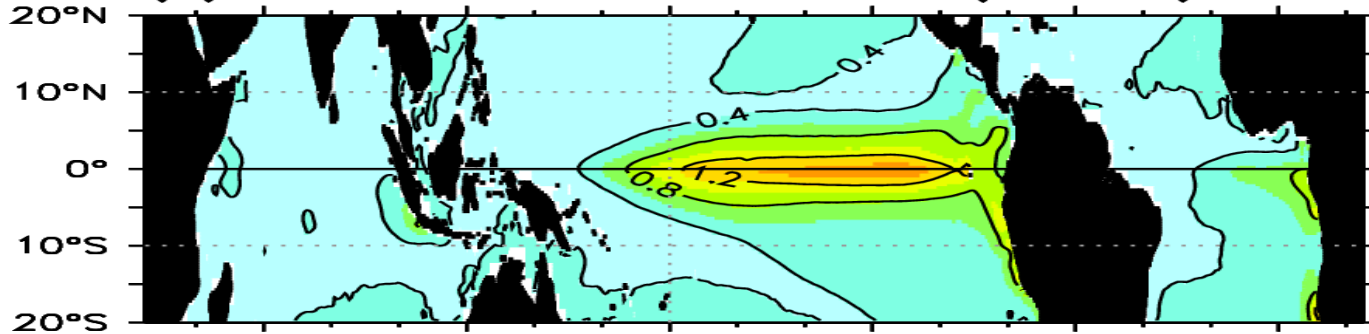
(a) Obs (ERSST.v3 1949–2008)



(b) CM2.1 1990 Control Run (1–300)

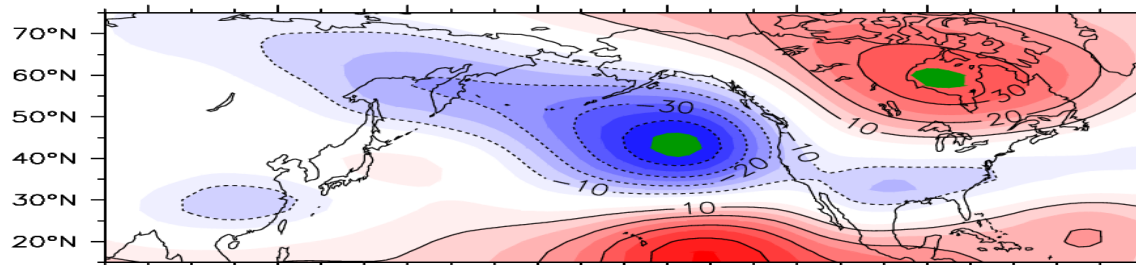


(c) CM2.5 1990 Control Run (1–280)



Detrended DJF 200 hPa height anomaly
regressed onto detrended DJF NINO3 SSTA

(a) NCEP/NCAR Reanalysis (1961–2001)



(b) CM2.1 1990 Control Run (11–290)

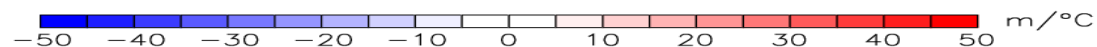
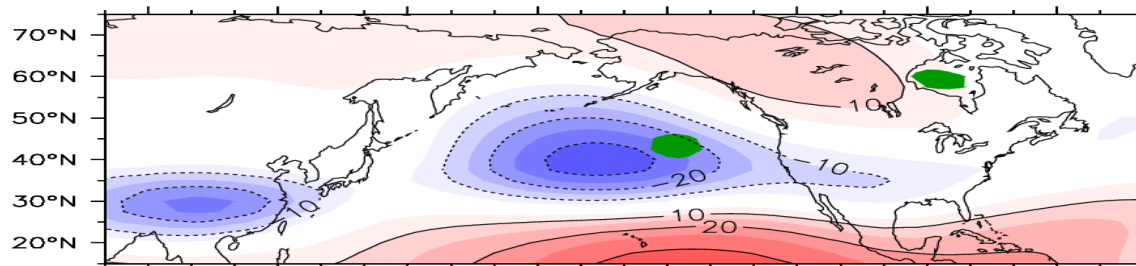
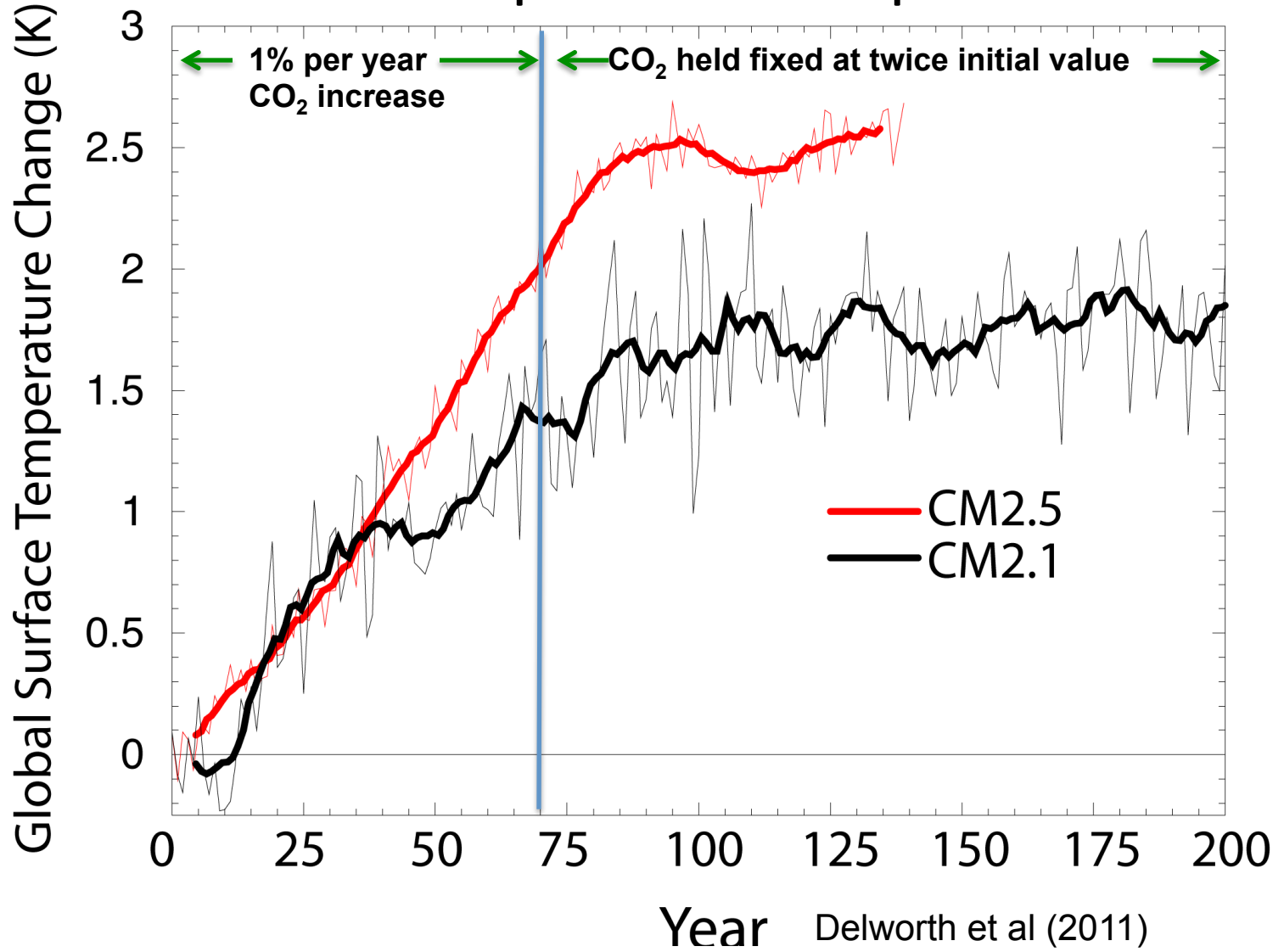


Figure 17 DJF 200-hPa geopotential height anomalies regressed onto DJF NINO3 SSTAs, computed using (a) the NCEP/NCAR Reanalysis (Kistler et al. 2001) for 1961-2001; (b) the CM2.1 1990 control run for years 11-290; (c) the CM2.5 1990 control run for years 11-0270. The zero contour is omitted. Green shading in all panels indicates the positions of the observed extrema over the North Pacific and Canada. Prior to computing the seasonal anomalies and regressions, all time series were detrended by removing a 20-yr running mean.

Global Surface Temperature Response to 2xCO₂



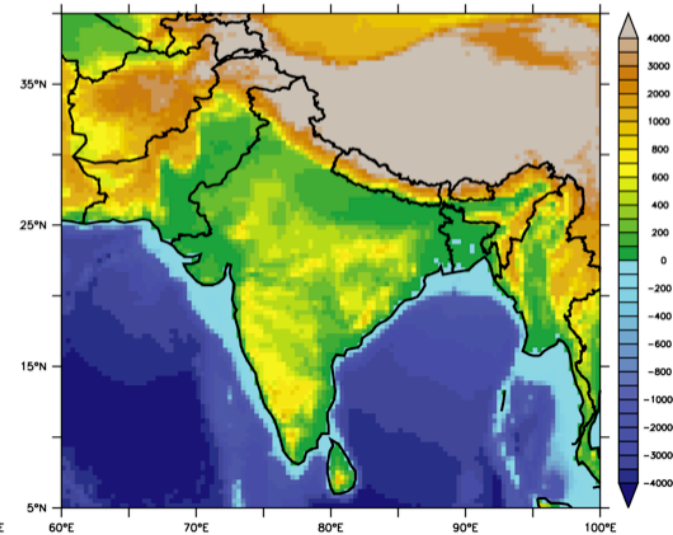
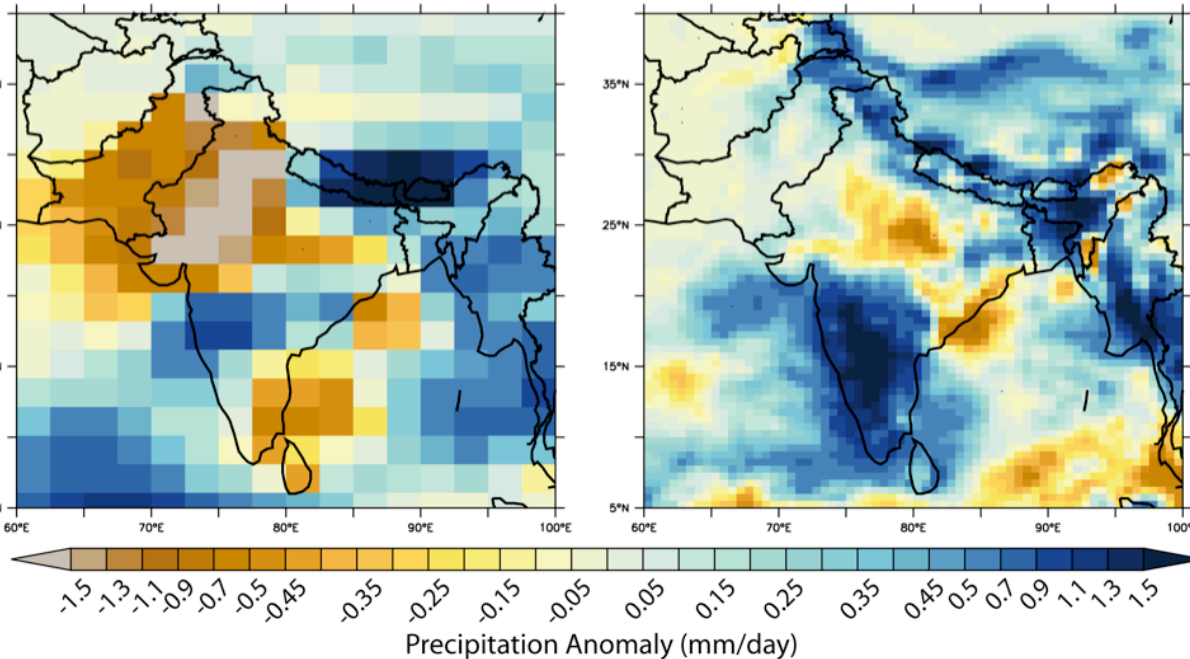
South Asian Monsoon Response to 2xCO₂

Response model dependent, hi-res model shows orographically-tied features

June-September Precipitation - 60 year averaged response to 2xCO₂

CM2.1 (Lo-Res)

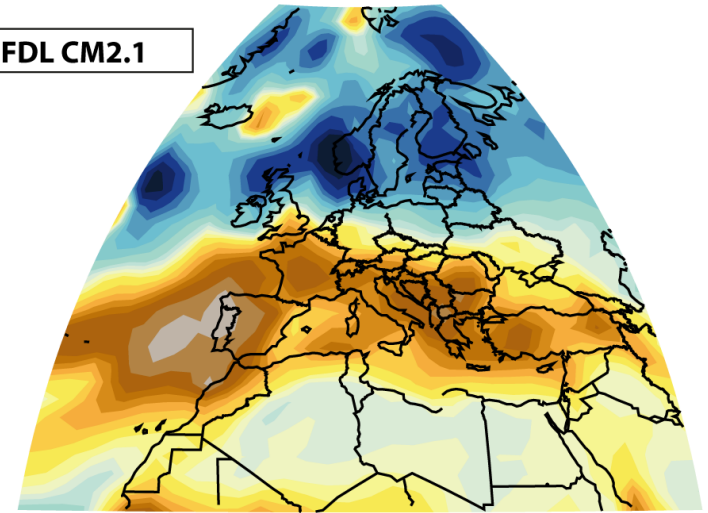
CM2.5 (Hi-Res)



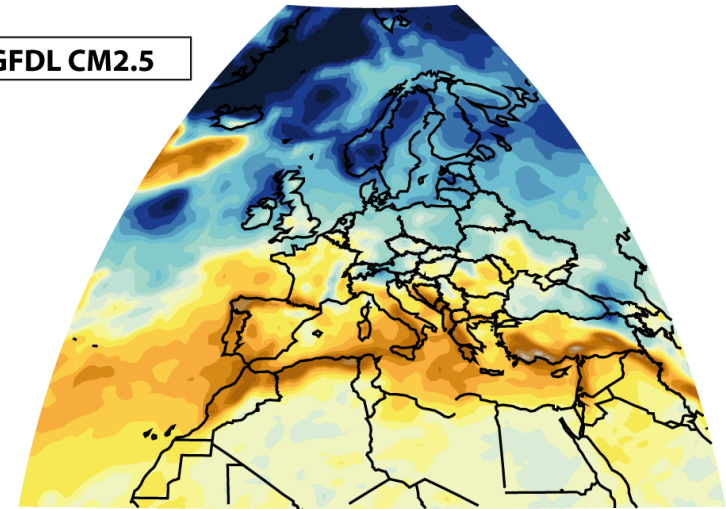
Adapted from Delworth et al (2011)

Why is response different?

) GFDL CM2.1



) GFDL CM2.5



Annual-mean Precipitation Response to $2xCO_2$ (mm/day)

ANNUAL MEAN RAINFALL RESPONSE TO DOUBLED CO₂:

The response in Mediterranean precipitation appears different in the high-resolution model ... is that difference in regional climate response “random” or a consequence of the higher resolution?

Plans for high resolution coupled model CM2.5

- Preliminary decadal prediction experiments
- Extended control simulation and idealized climate change
- Ensemble of 19th-21st century simulations (1860-2100)

- Coupled reanalysis with CM2.5 (large resource requirement)
- Extensive set of hindcasts with CM2.5 to evaluate seasonal to decadal predictive skill

- In addition ... exploratory simulations with even higher resolution (CM2.6 and beyond) to study critical processes in the climate system (ocean eddies, small-scale air-sea coupling and feedbacks, etc.)

Summary

1. Decadal and multidecadal variability is an integral part of the climate record, with significant societal relevance – especially for hydrology, and for **regional scales**.
2. Ocean processes (such as the **Atlantic Meridional Overturning Circulation**) may be crucial for decadal variability.
3. An important goal is to gain a better understanding of the **mechanisms of decadal variability**, thereby improving our ability to understand the observed climate record.
4. Can we **predict decadal scale fluctuations**? Probably to some degree. However, estimates of decadal predictability are model dependent and may evolve over time.
5. A **sustained observing system** is critical to any potential predictive skill.
6. Decadal-scale variability and predictability, in concert with regional climate change, provides part of the motivation for moving to **much higher-resolution global coupled models**.
7. We are moving to a new class of models with substantially higher resolution, more energetic ocean circulation, and substantially improved tropical climate. These will be used extensively, in concert with other models, for **seasonal to decadal to centennial scale predictions and projections**.



