GFDL and CMIP5:

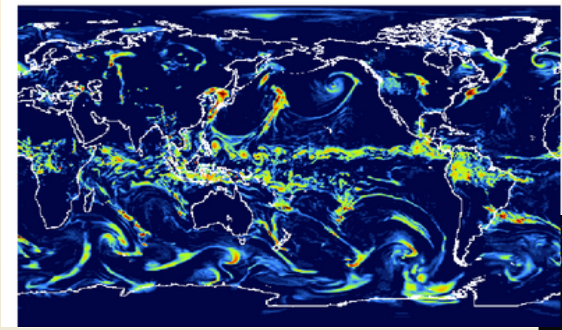
Process, Results, Experience

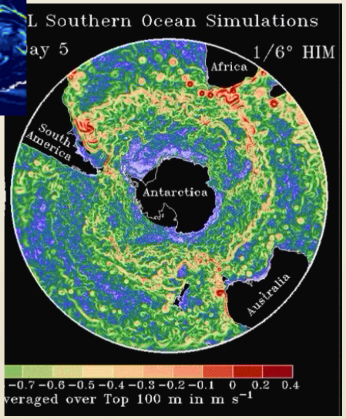
V. Ramaswamy, R. Stouffer
and *everyone* at NOAA's

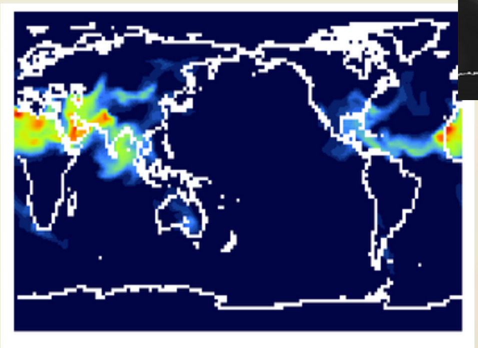
Geophysical Fluid Dynamics Laboratory

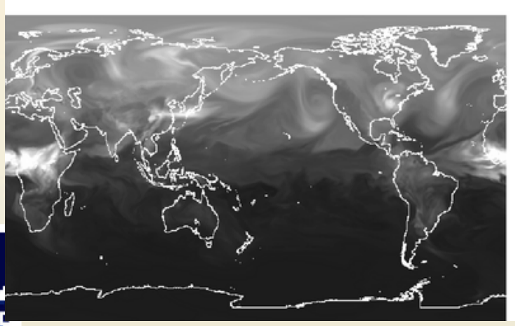
October 2, 2012

NOAA/ GFDL Climate Modeling
CMIP5/ IPCC AR5



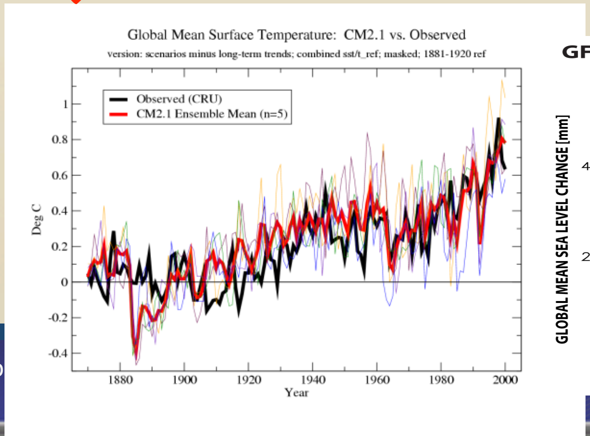


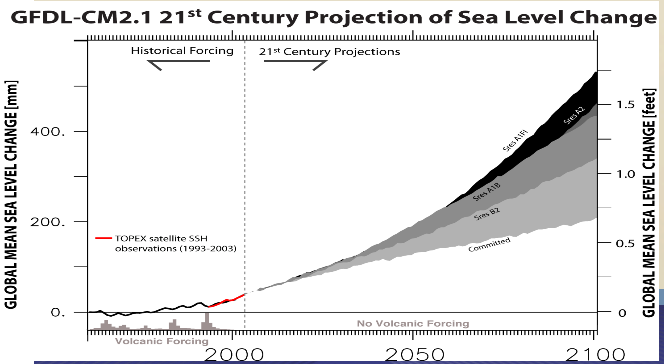




Resolution

Earth System Complexity





NOAA/ GFDL Climate Modeling

Contributions to CMIP5 and IPCC AR5 [Report in 2013]

Advancing the understanding** of the climate and Earth System - the **processes, mechanisms, and interactions

➔ ***reliable global- to regional-scale projections and predictions:***

1. **Role of pollutant particulates and other short-lived species compared to long-lived gases such as carbon dioxide.**
2. **Carbon and other biogeochemical cycles, uptake of carbon by land and oceans, and their roles in climate change.**
3. **High-resolution, atmosphere-ocean models for seasonal- to-centennial variability, predictability and regional change.**
4. **High-resolution models for understanding "weather extremes" in climate (e.g. hurricanes, heat waves and droughts).**

GFDL "4 Streams"

- ESM – closes carbon cycle by adding ocean and land carbon components
  - ESM2M – MOM (depth vert coor) based ocean
  - ESM2G – GOLD (layer vert coor) based ocean
- CM3 – New aerosol-cloud interactions, HI-TOP and atmospheric chemistry
- Decadal Prediction – used CM2.1 (AR4 model)
- High resolution atm-only: 50 and 25km grids

GFDL 4 “Streams” Data

- All data from at least one ensemble member are available.
- Other ensemble members available in future
- LGM run being set up using ESMs now. At least 1 year away from being available.
- Had to reprocess a few variables to fix problems – fco2…unfortunately

CMIP5/ IPCC AR5 Accomplishments

Stream	Total Model Years	CMIP5 Data (TB)
Physical Climate	6800	15.3
Earth System	18,500	119.2
High-resolution	500	22.3
Decadal Prediction	5000	7.3
TOTAL	**30,800**	**164.1**

More than the entire world's model data archive for CMIP3/ IPCC AR4 (2007)

	Publications
FY11	**~70**
FY12	**39 to date (+55 submitted)**

GFDL Issues

- - the process of CMORizing the vbls, QC, and etc was very time consuming/labor intensive
  - Size of task way underestimated at start of process
- Volume of runs and variables requested are very large
- In-house “curator” software either untested or missing parts - written while data publishing occurring
- Variable list kept changing well into process
- METAFOR questionnaire
  - Hard to figure out (bindings!)
  - Questions did not “fit” our models => models not well documented or misleading or both in questionnaire
  - Not clear if METAFOR is of any use to anybody

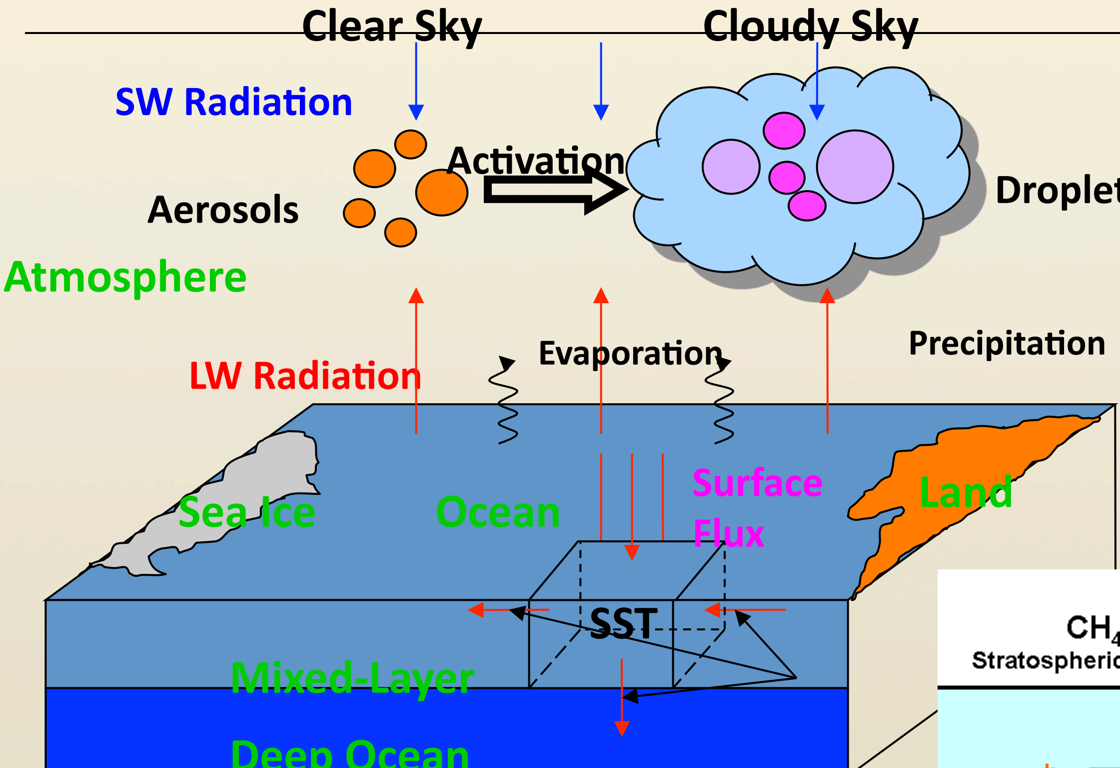
Climate Change

New NOAA/ GFDL
Climate Model; AM3/ CM3

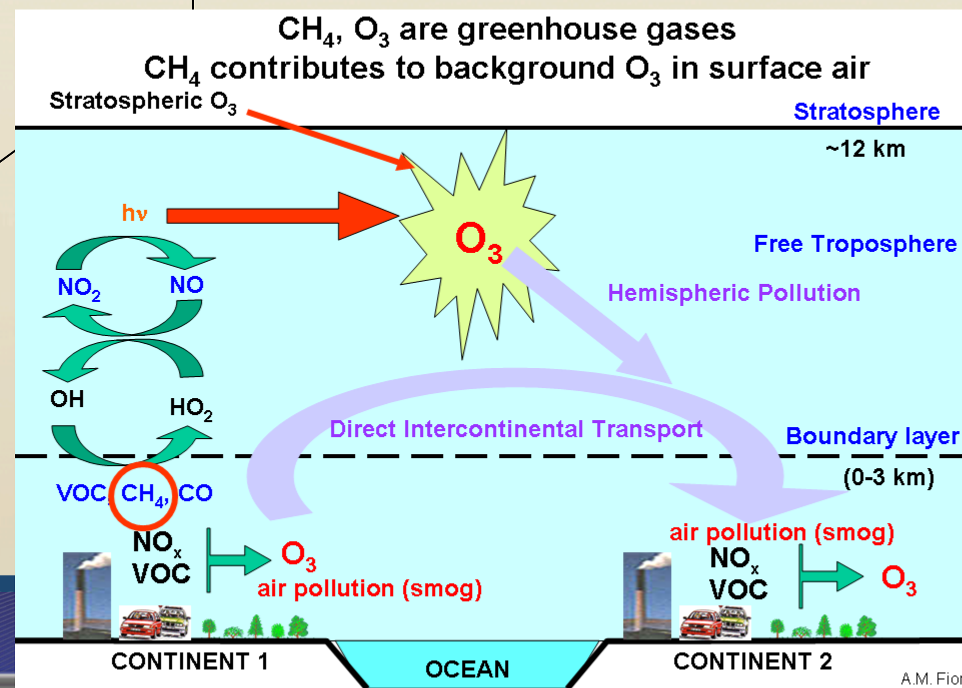
{Donner et al., 2011; Bollasina et al., 2011}

Greenhouse gases versus Aerosols

Coupled Chemistry-Aerosol-Climate model



Aerosols and Climate

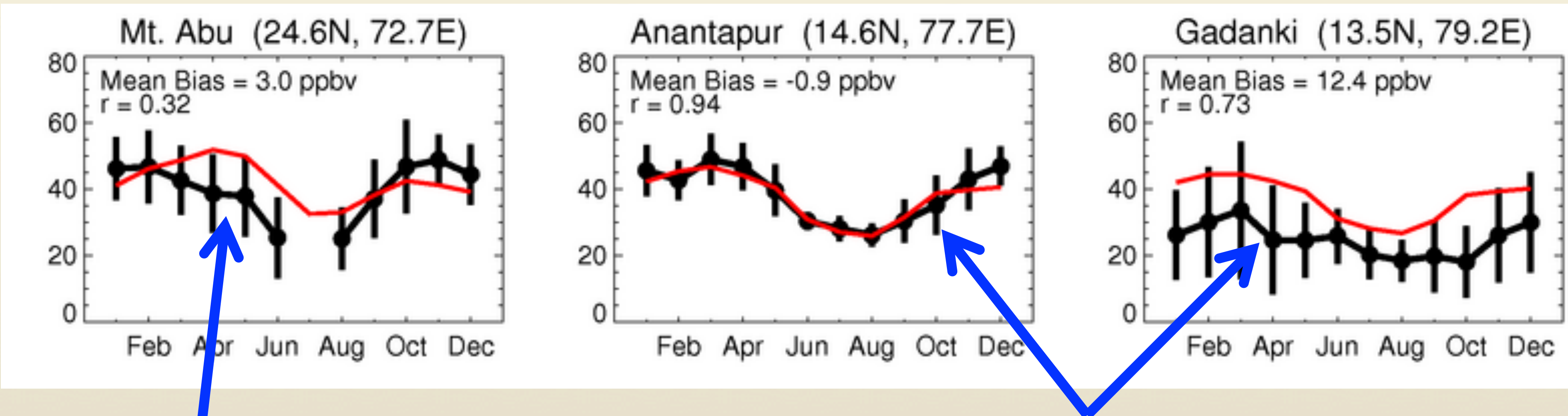


Global Air Quality and Climate

Evaluation of AM3 chemistry-climate model with published measurements

Free troposphere (1.7 km)

Low-elevation sites, classified as rural



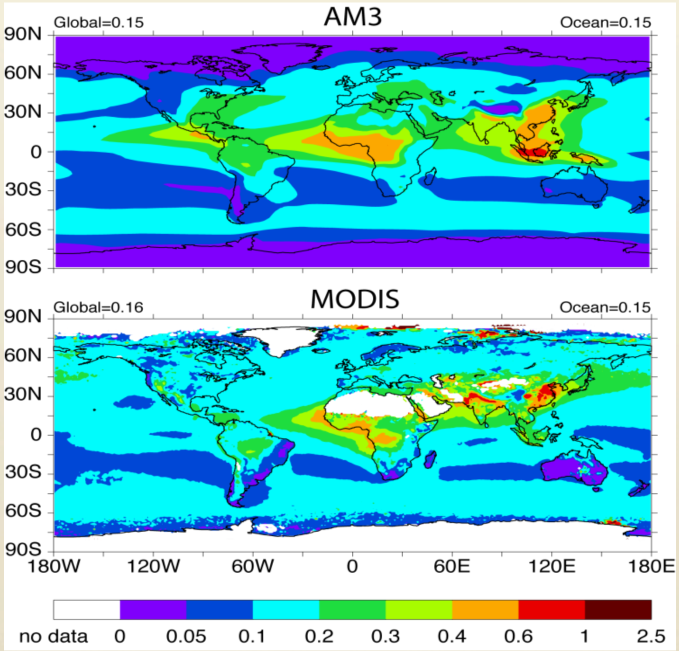
Model ~10 ppb high
in free troposphere April-June
(consistently occurs
throughout N mid-latitudes)

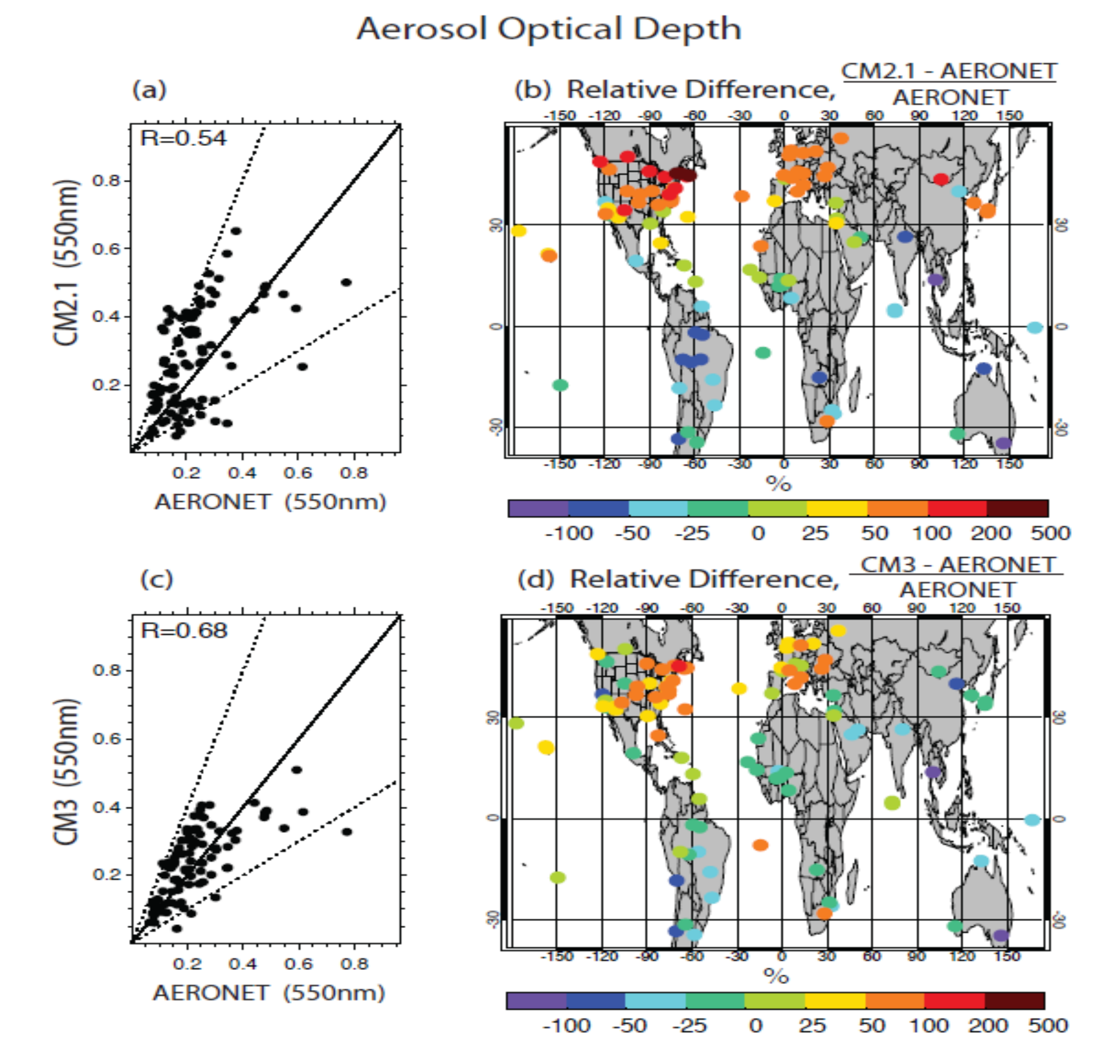
These 2 sites fall in same model grid cell;
illustrates sub-grid variability

Model captures general features of observed seasonal O_3 cycle: summer minimum, broad winter-spring maximum

V. Naik et al., submitted, JGR.

Evaluate aerosol properties simulated with CM3 for IPCC-AR5 using in-situ and remote sensing data

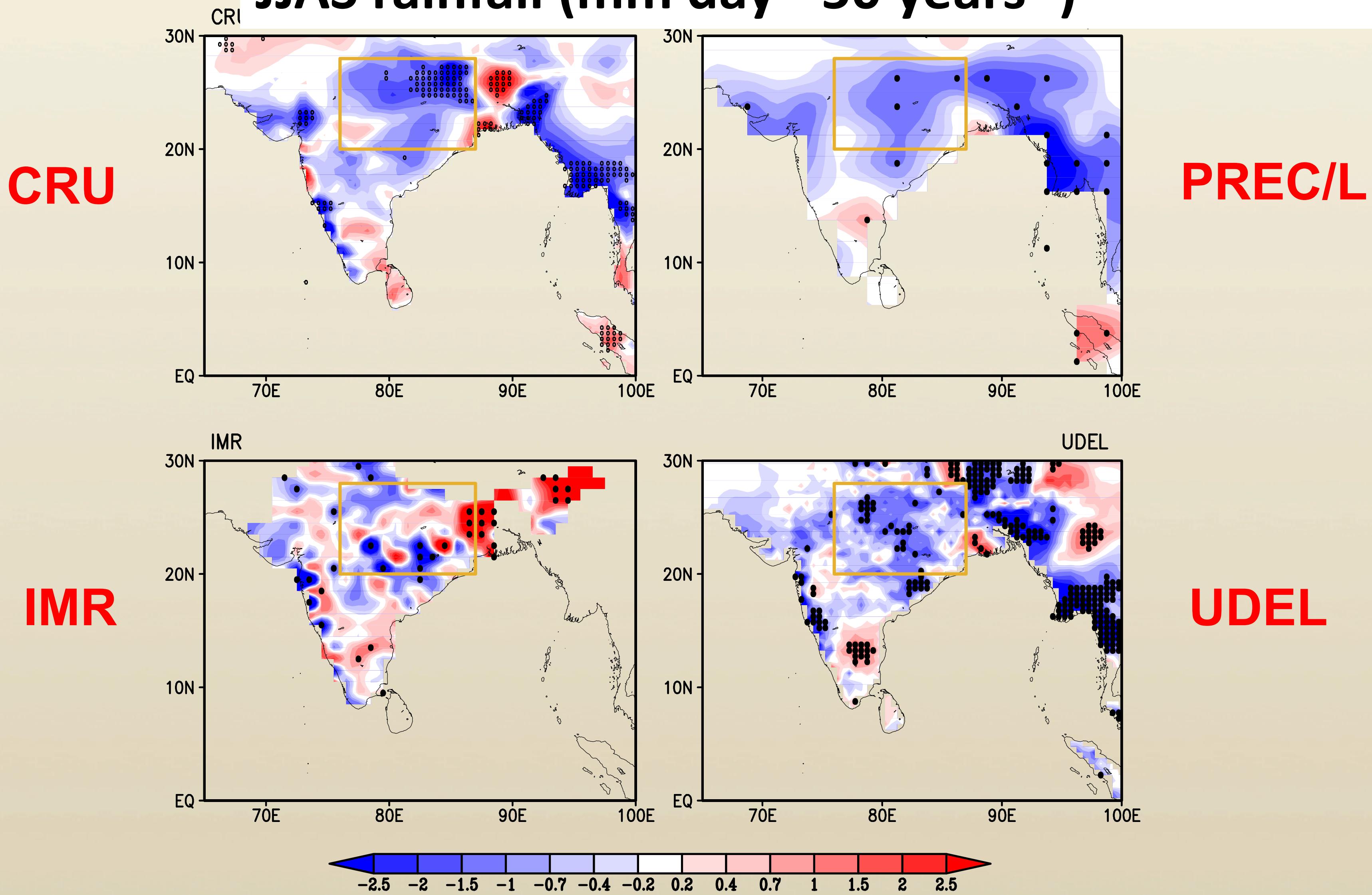




Donner et al., J. Climate (2011)

A drying trend over central-northern India during the second half of the 20th century

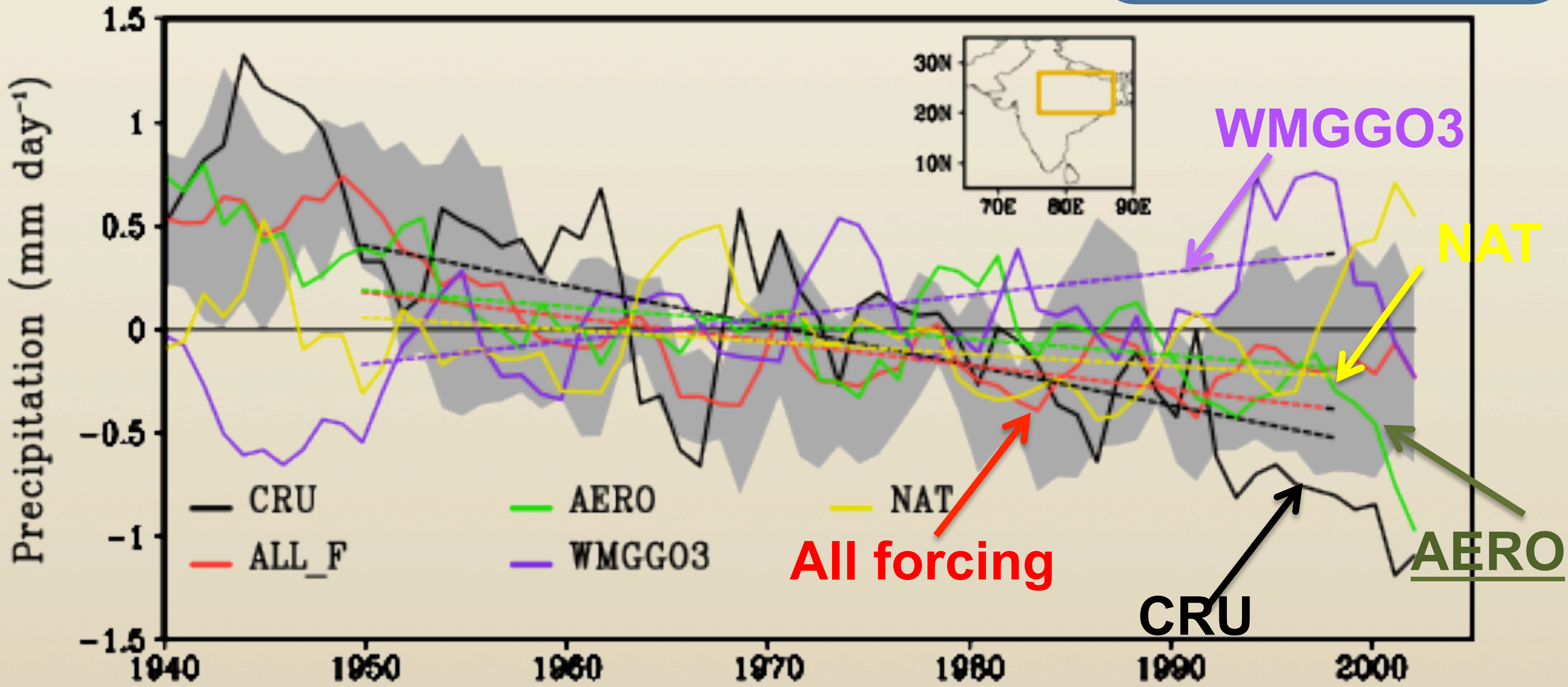
JJAS rainfall (mm day^{-1} 50 years^{-1})



Attribution of the recent trend of the S. Asian summer monsoon using CM3 historical simulations

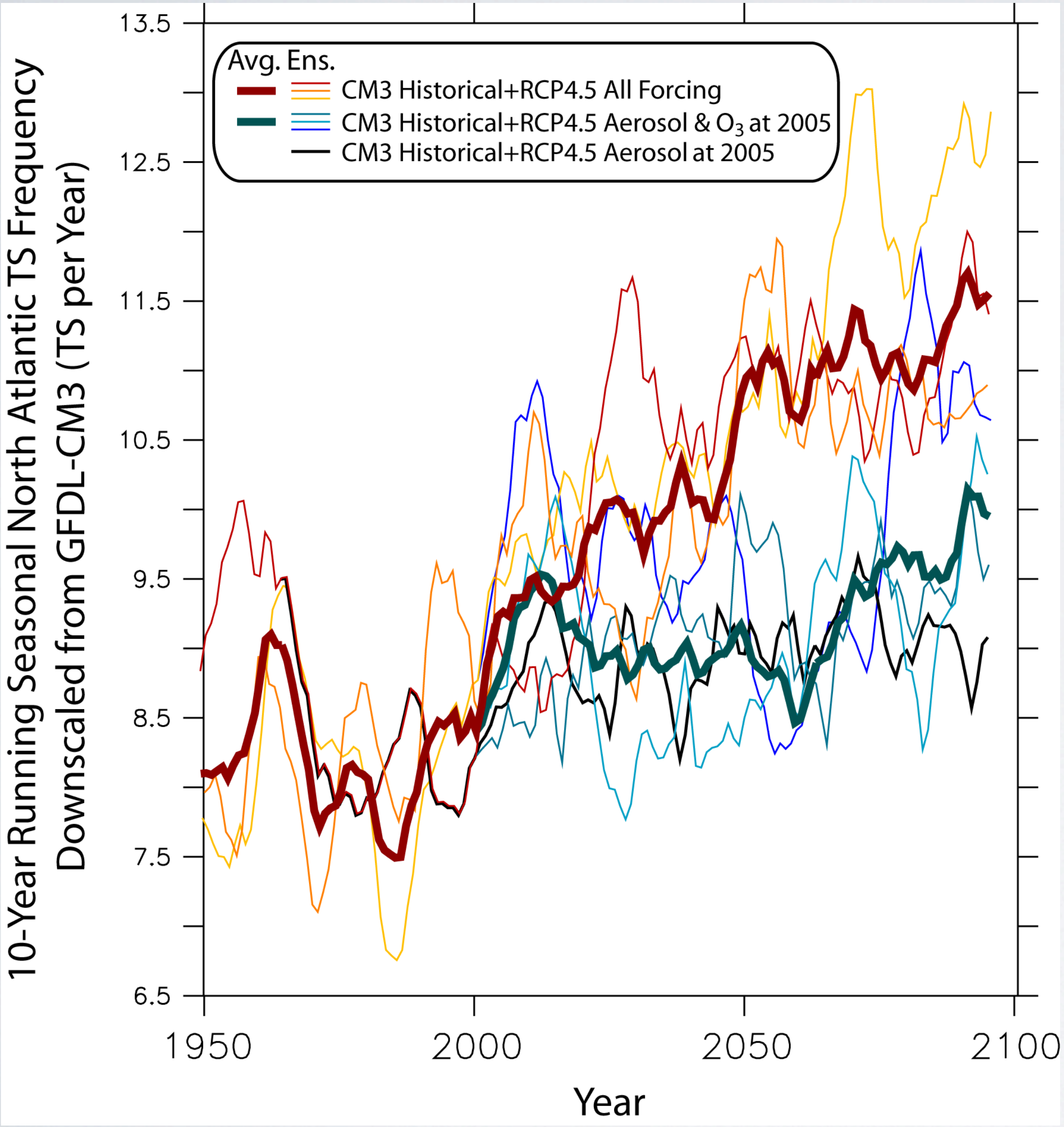
Linear trends of average JJAS rainfall over central-northern Indian (mm day^{-1})

- *AERO trend opposite in sign to WMGGO3*
- *AllForc trend compares well with CRU (Obs)*



Bollasina et al. (Science, 2011)

Aerosols key for NA TS projections
(“Cleaning” out aerosols ➔ More storms)



All Forcing

No future aerosol or O_3

No future aerosol

Projected aerosol changes lead to increase in NA TS frequency over 1st half of 21st century

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

Advancing with enhanced spatial resolution:

- Tropical storm frequency
- Heat waves
- Intercontinental transport of pollutants (*Global climate and air quality*)

Courtesy: I. Held, S. J. Lin, M. Lin, N-C. Lau

Set of AR5 Time-slice simulations at 50and 25km complete

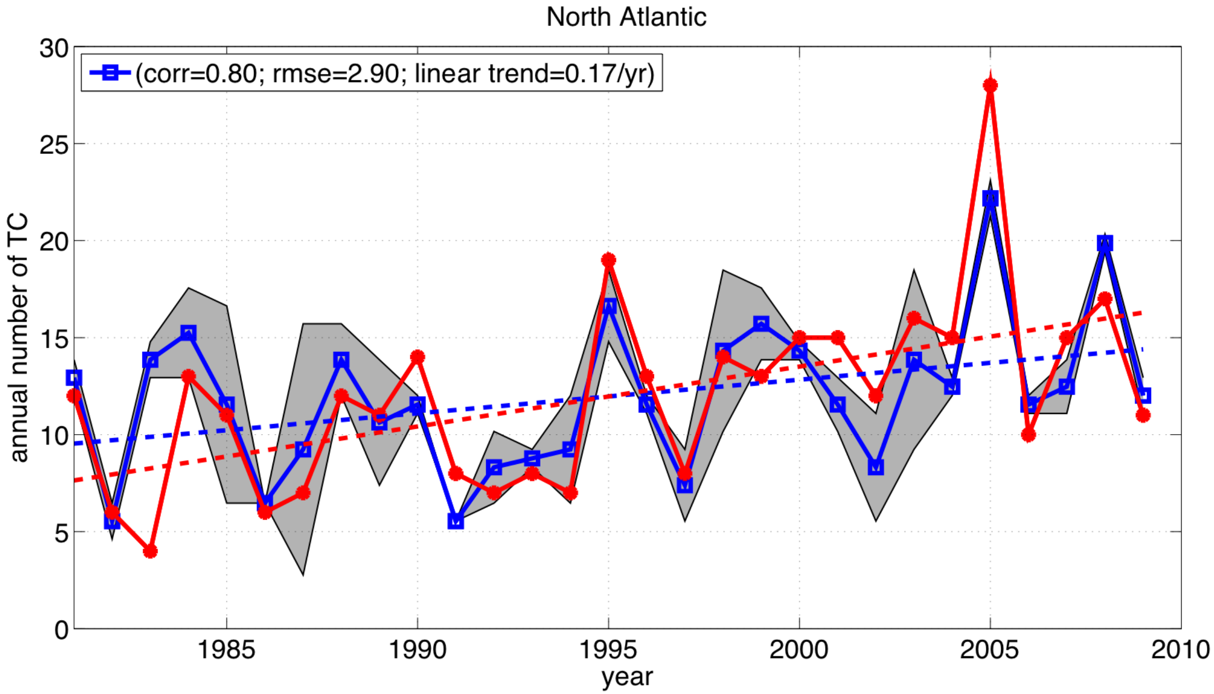
Time-slice = atmosphere/land model running over prescribed ocean temperatures and sea ice distribution

3 "AMIP" simulations with 50km model and 2 at 25 km with observed boundary conditions for 1979-2008

Multiple future simulations with both 50 and 25km models
for early period (2025-2035) for RCP 4.5
for late period (2085-2095) for RCP 8.5
using projected ocean and ice states from CM3 and ESM –M

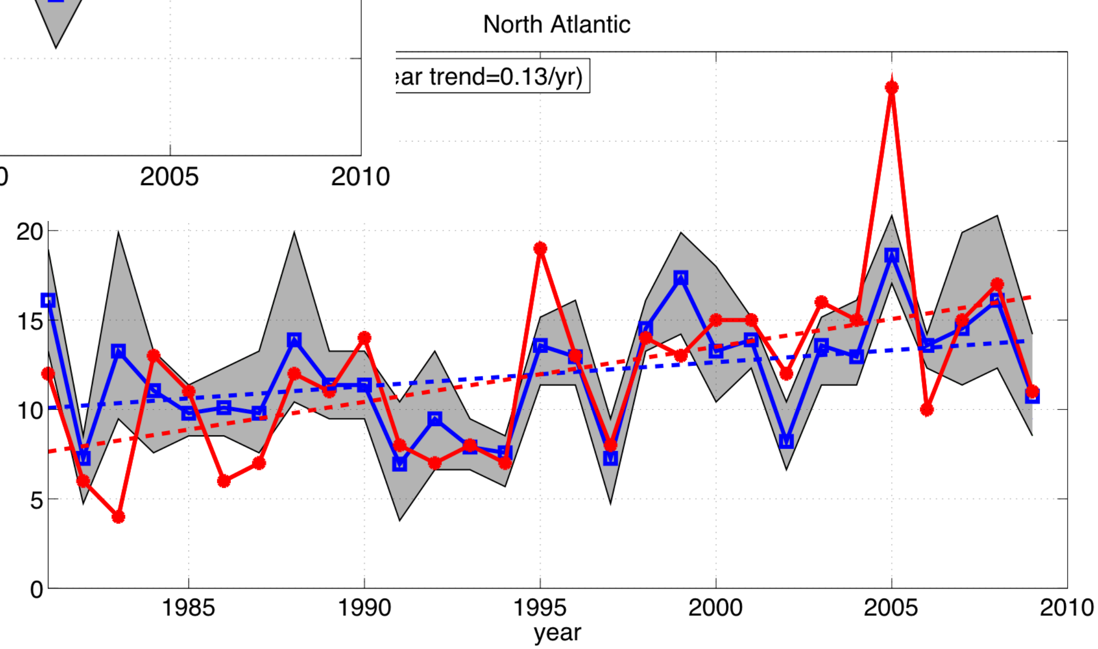
Also have multiple C180 simulations using boundary conditions projected by various AR4 models for A1B

25 km CMIP5 N. Atlantic tropical cyclone frequencies



2-member ensemble
CMIP5 25km model

3-member ensemble
CMIP5 50km model



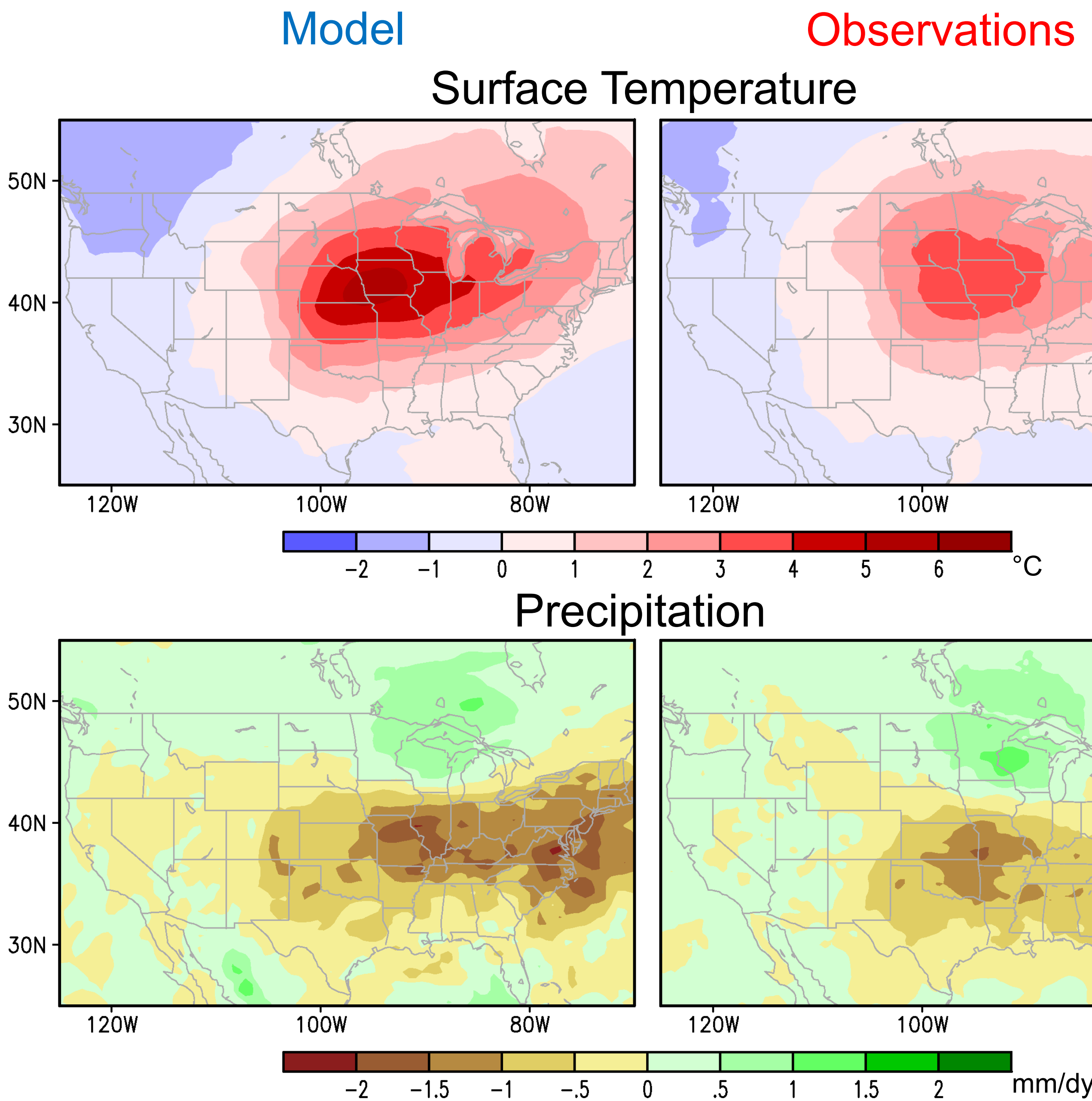
Red: observations

Blue: model ensemble mean

Shading: model spread

Midwest Heat Waves

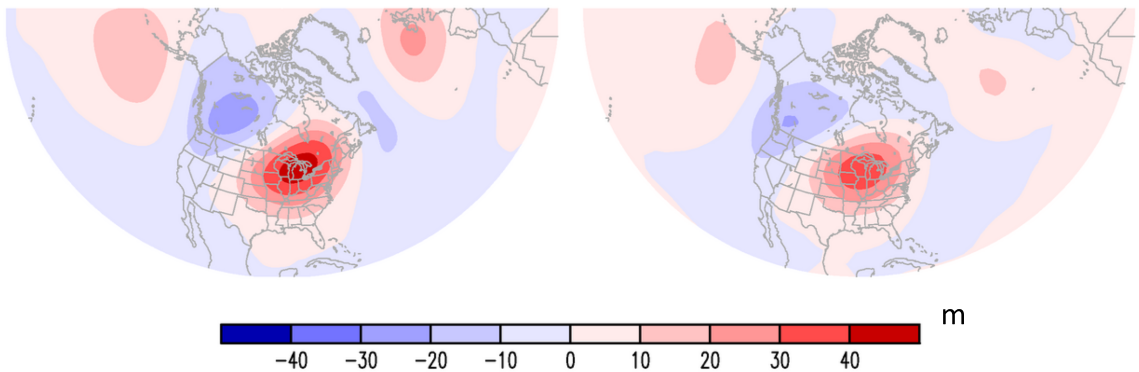
Lau et al. (J. Climate, 2012)



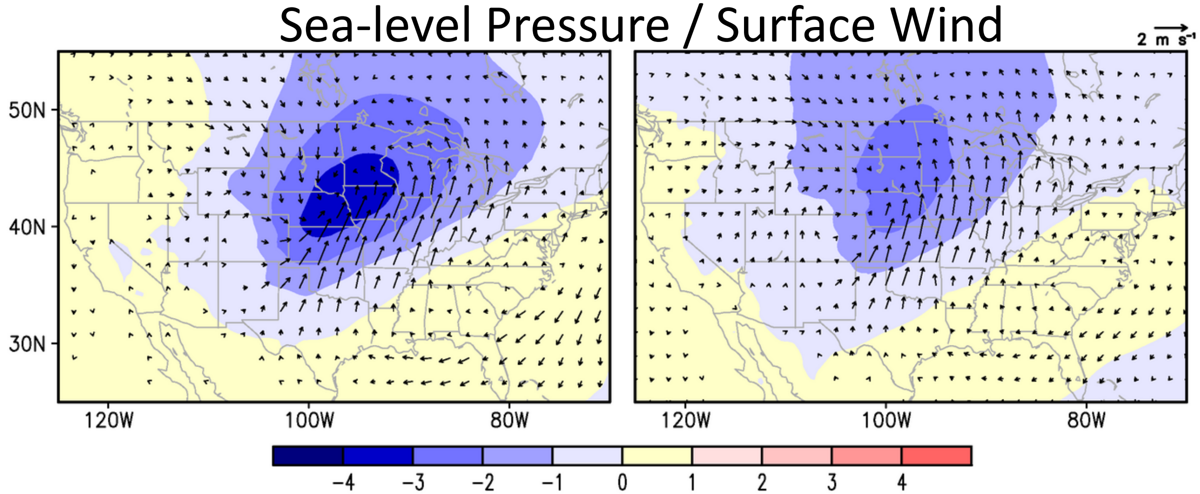
Large-scale circulation context of Midwest Heat waves well simulated

500mb Geopotential Height

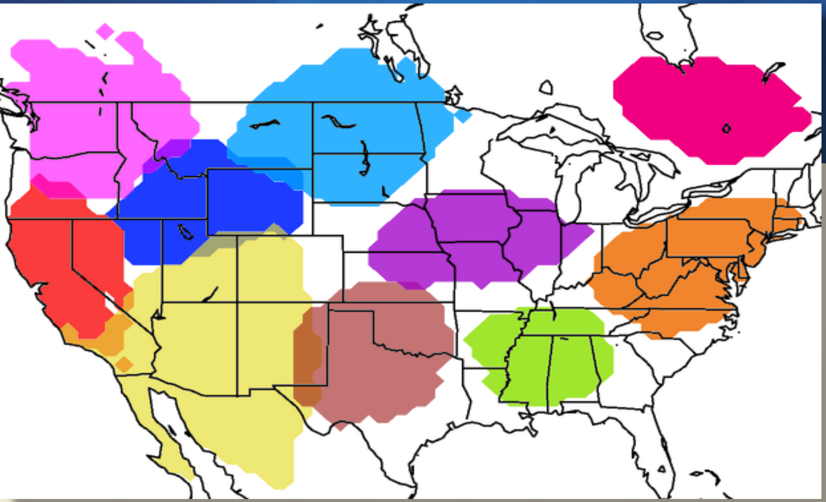
Model Observations



Sea-level Pressure / Surface Wind



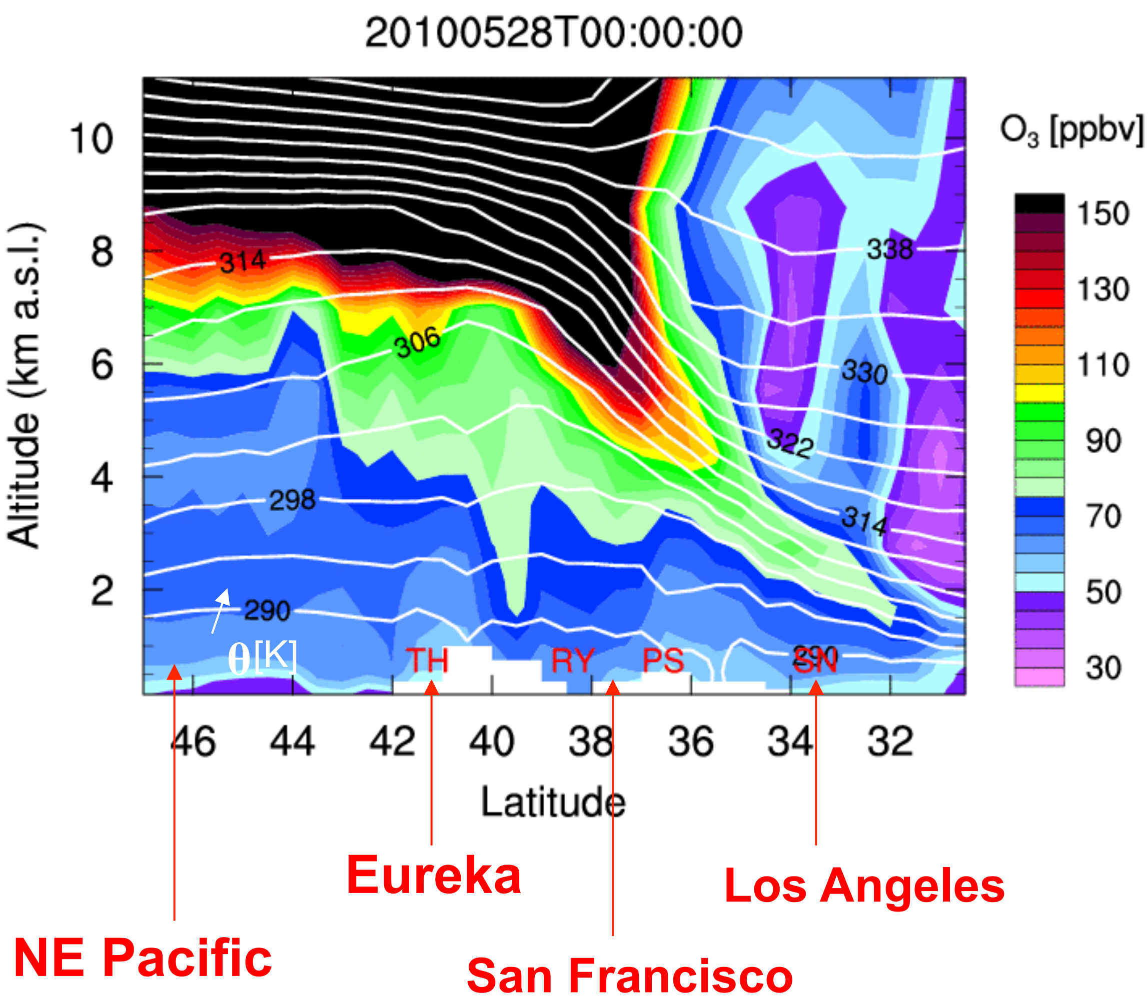
Model Projections
Ratio: 2041-2070 vs 1971-2000



	Duration	# Events/yr	# Heat wave days/yr
Midwest	1.5	2.7	4.0
Northern Plains	1.3	3.8	4.8
Pacific Northwest	1.3	2.4	3.0
SE Canada	1.2	2.5	2.9
Texas-Oklahoma	1.8	2.6	4.5
Mid-Atlantic	1.4	2.7	3.8
California	1.9	2.3	4.3
Gulf Coast	1.2	3.2	4.0
Southwest	2.2	2.9	6.4
Wyoming/Montana/Idaho	2.2	2.6	5.7

Deep stratospheric ozone intrusions in the new, high-resolution GFDL AM3 model

AM3/C180 simulation of a deep stratospheric O_3 intrusion over California

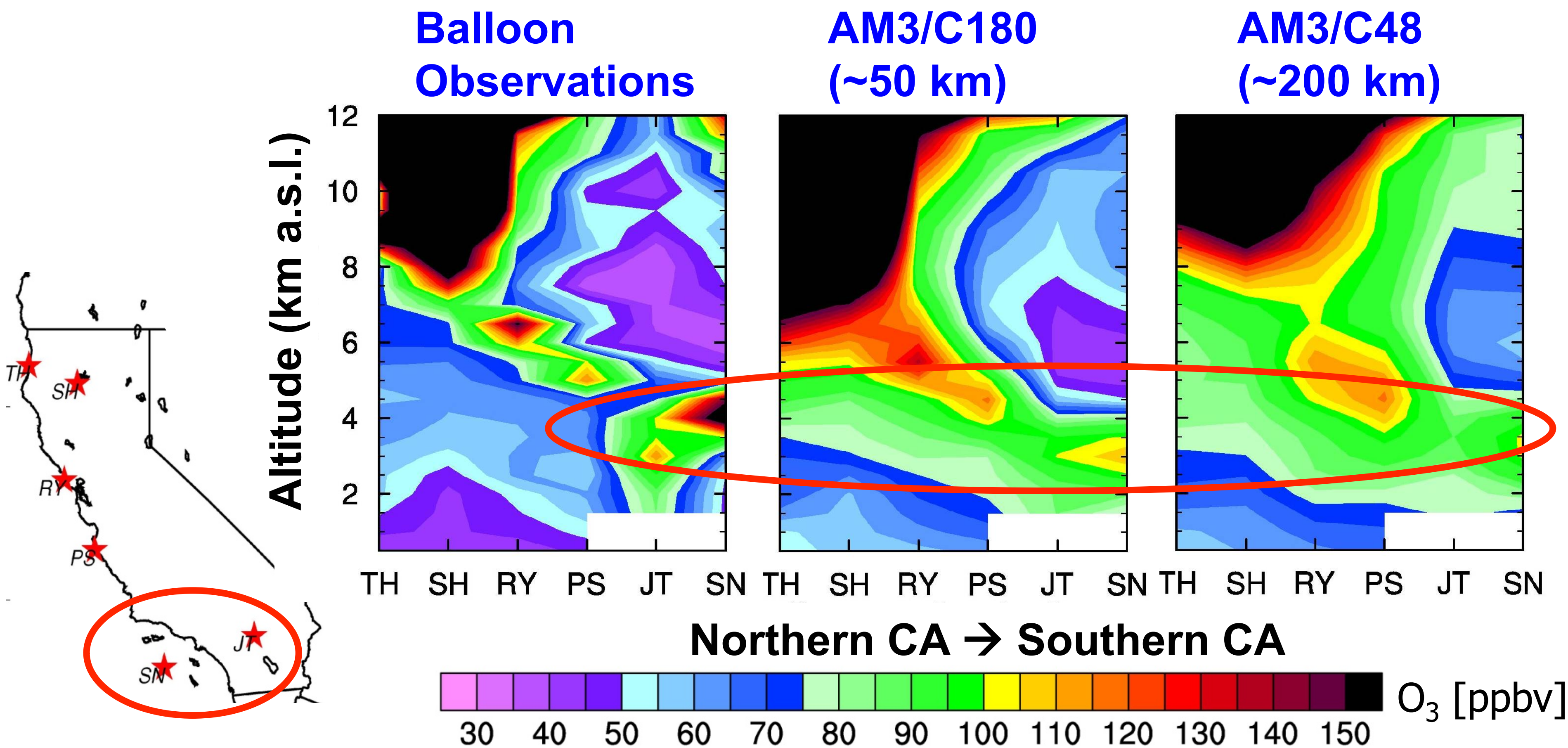


Key model features:

- **C180 horizontal resolution (~50x50 km²)**
- **Full strat & trop chem** [*Donner et al., 2011, J. Climate*]
- **Nudged to NCEP/GFS U and V** [*M. Lin et al., JGR, 2012*]

Extensive evaluation with satellite and *in situ* measurements during NOAA CalNex 2010

Subsidence of stratospheric ozone to the lower troposphere of southern California (May 28, 2010)



- High O_3 (>100 ppbv) just 2-4 km above southern California
- Affecting surface air quality in densely populated regions

Advancing predictability with increase in spatial resolution:

- Seasonal-to-decadal predictability

Courtesy:
T. Delworth and
G. Vecchi

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

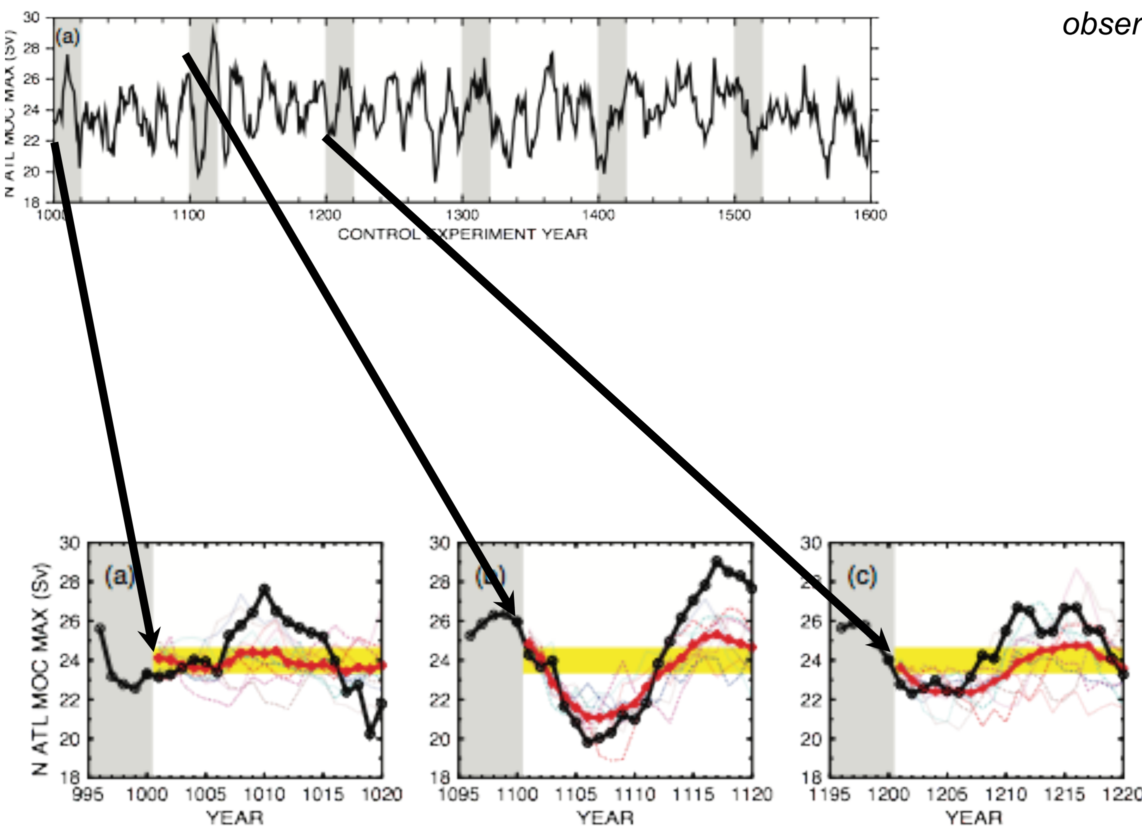
Approaches:

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

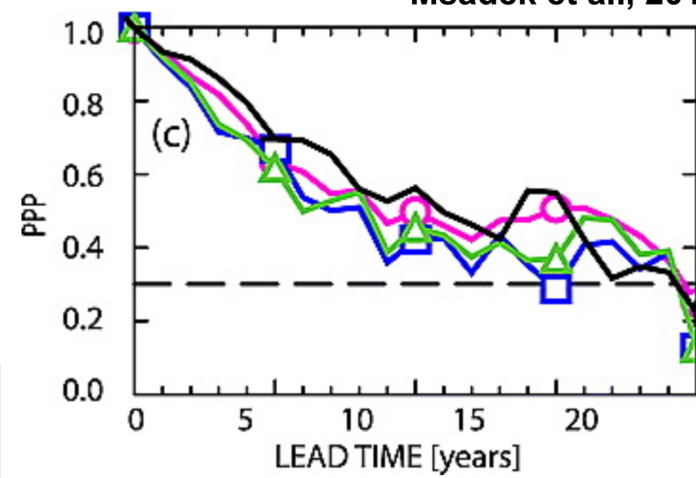
Examples include:

•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

High Resolution 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

GFDL Response for Future CMIPs

- Attempt to reduce CMIP commitment
  - People
  - Computer resources
- Change model code to output variables in CMIP names, units and conventions
  - => Every analysis script in building needs changed
- Have only 1 or 2 models go through IPCC process
- Disentangle model development from IPCC cycle

The END

Thank you for your attention !