Improving Seasonal-to-Decadal Climate Understanding and Prediction

WSWC/ CDWR Workshop
May 27-29, 2015

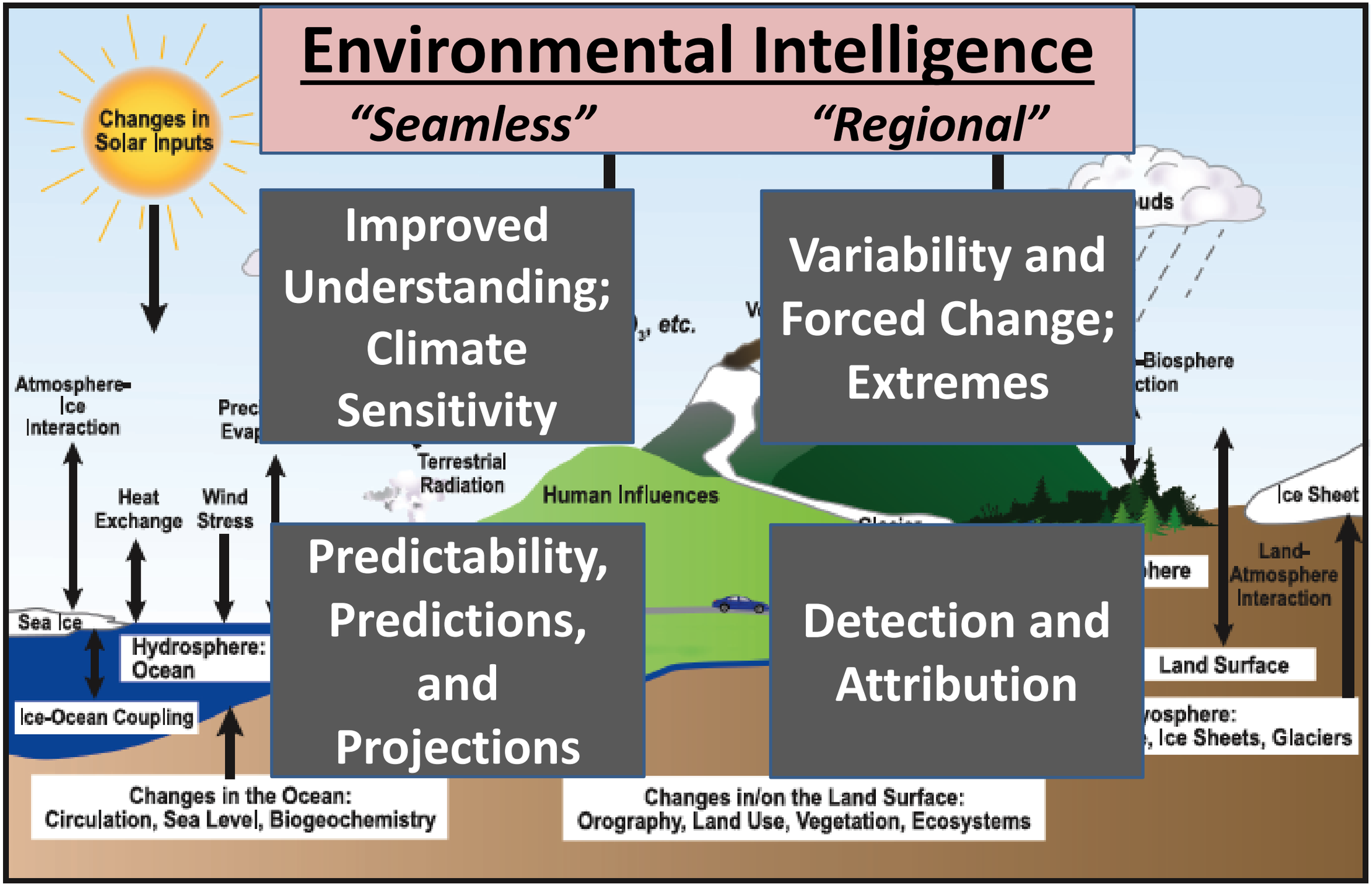
V. Ramaswamy

Lead Scientists:
Liwei Jia, Sarah Kapnick, Gabriel Vecchi (Group Leader

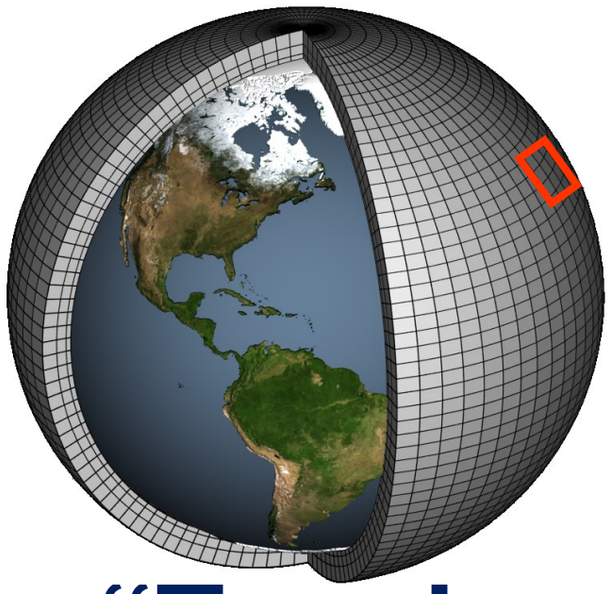
amics Laboratory

Princeton, NJ

The Earth System (Atmosphere, Oceans, Biosphere, Cryosphere)



GFDL Mission Statement

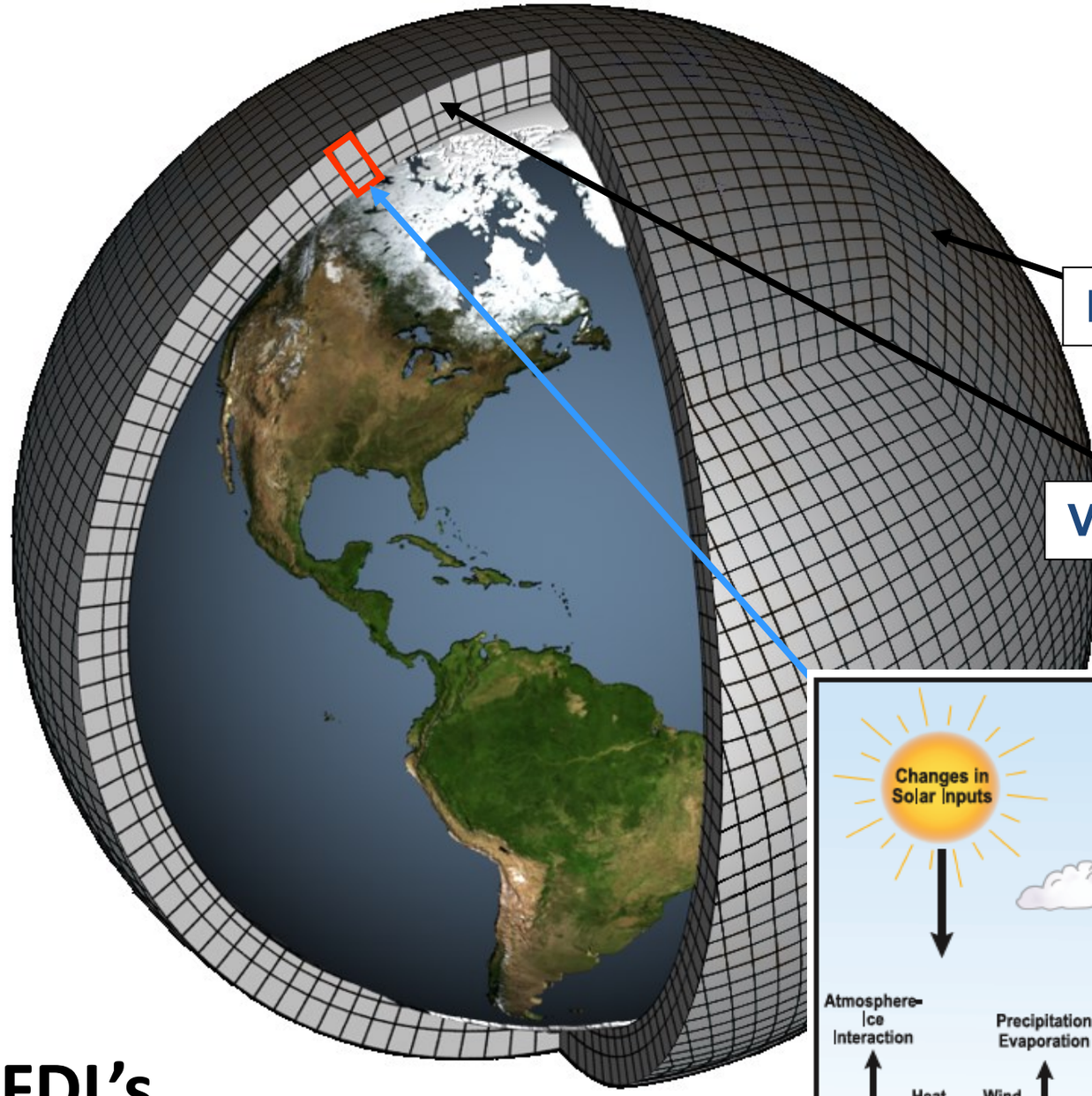


Directly supports the DOC, NOAA and OAR Objectives

"To advance scientific understanding of climate and its natural and anthropogenic variations and impacts, and improve NOAA's predictive capabilities, through the development and use of world-leading computer models of the Earth System."

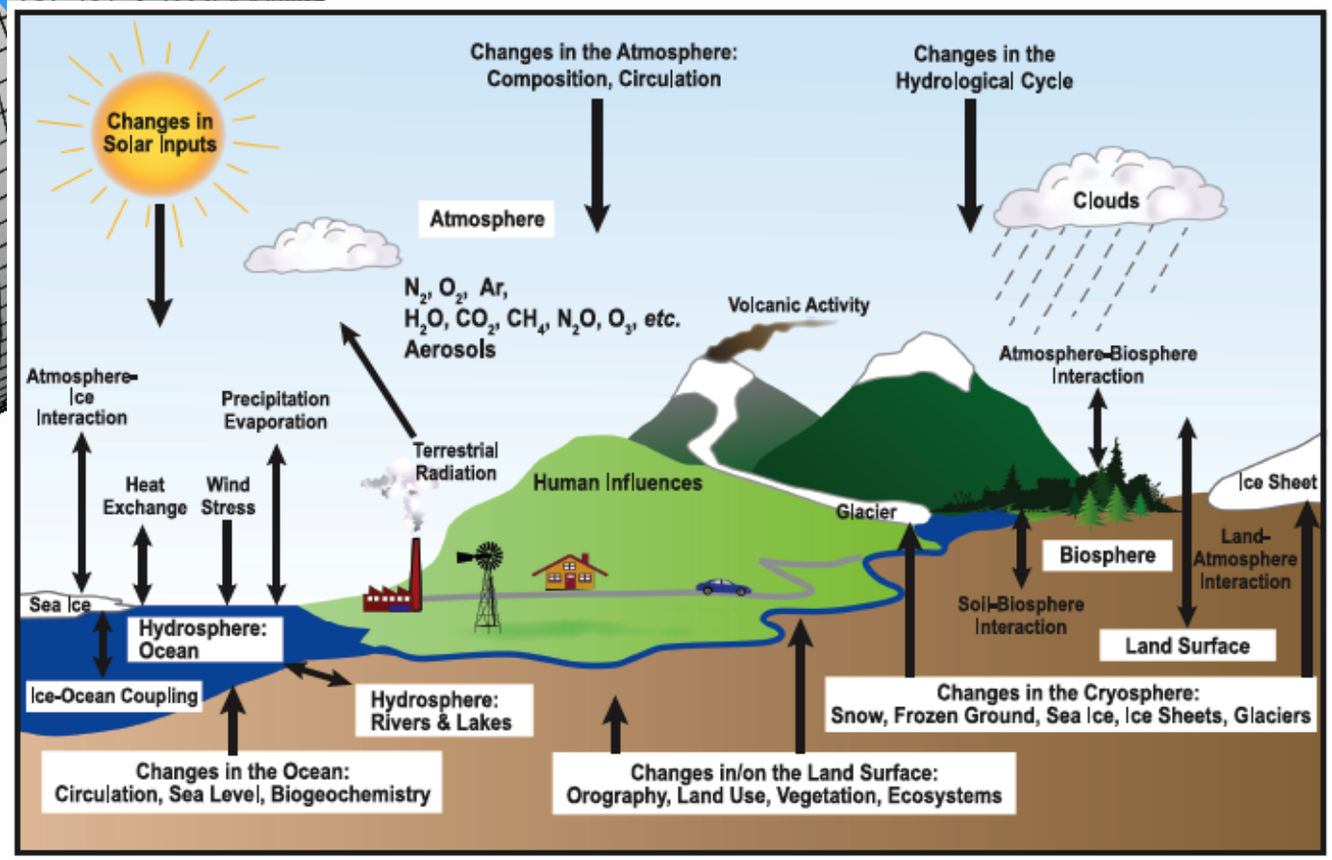
GFDL initiated in 1955

Global Earth System Model



Horizontal Grid (Cubed Sphere)

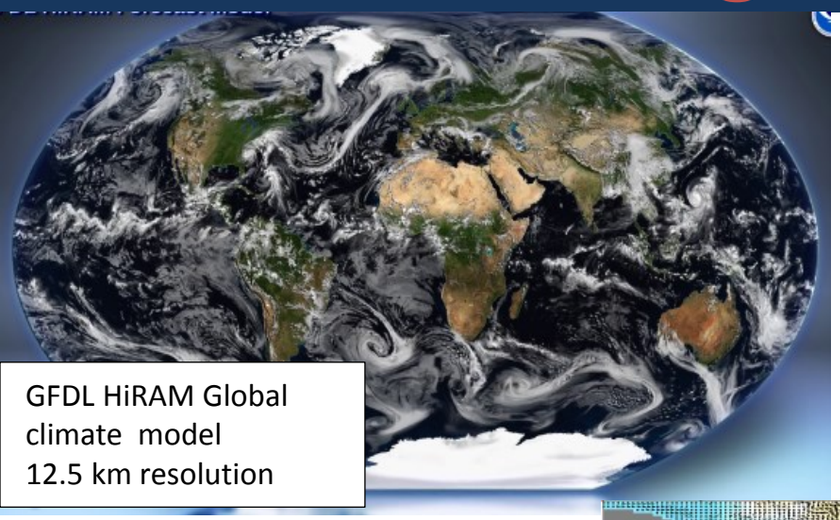
Vertical Grid (Height or Pressure)



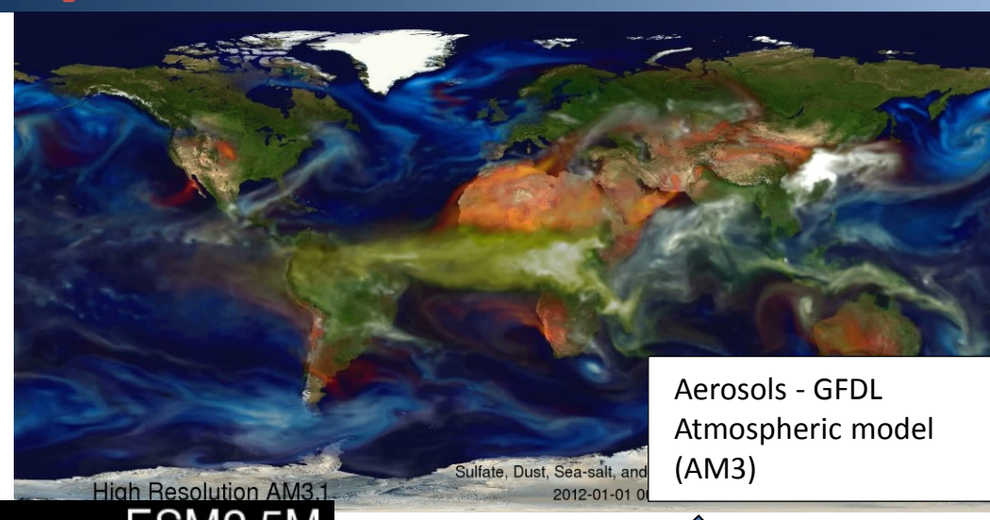
NOAA/GFDL's CLIMATE and EARTH SYSTEM MODELING

NOAA/ OAR/ GFDL Modeling:

Advancing the Science - *Use-inspired research*

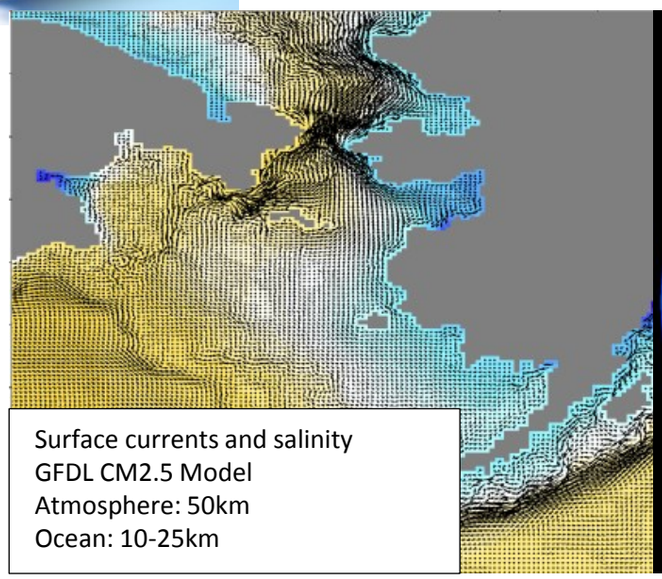


GFDL HiRAM Global climate model
12.5 km resolution

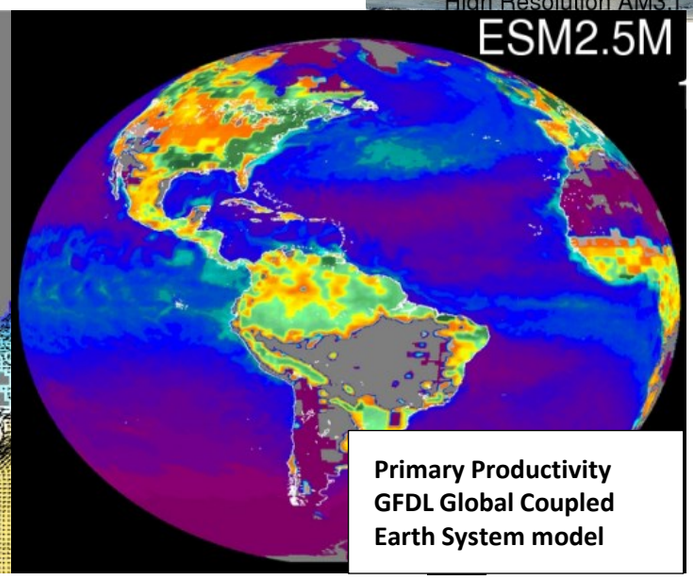


Aerosols - GFDL Atmospheric model (AM3)

Resolution

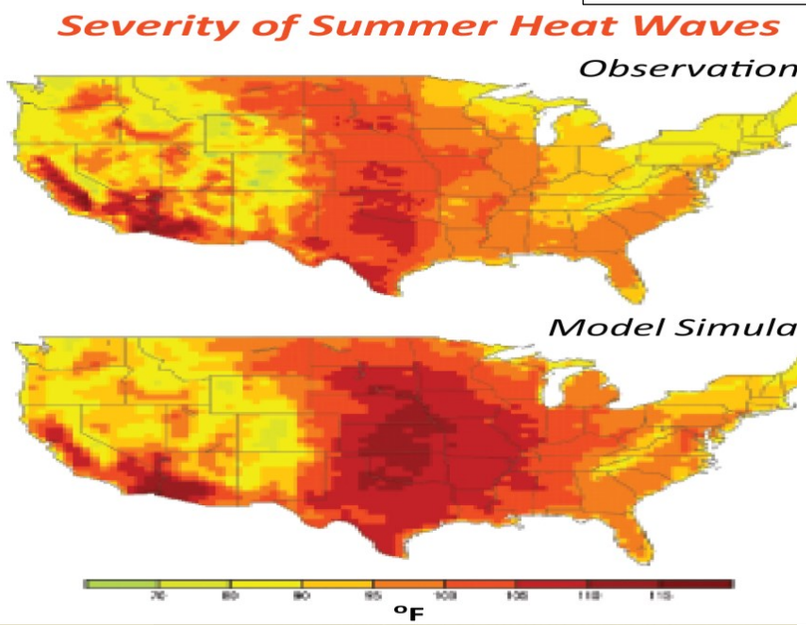


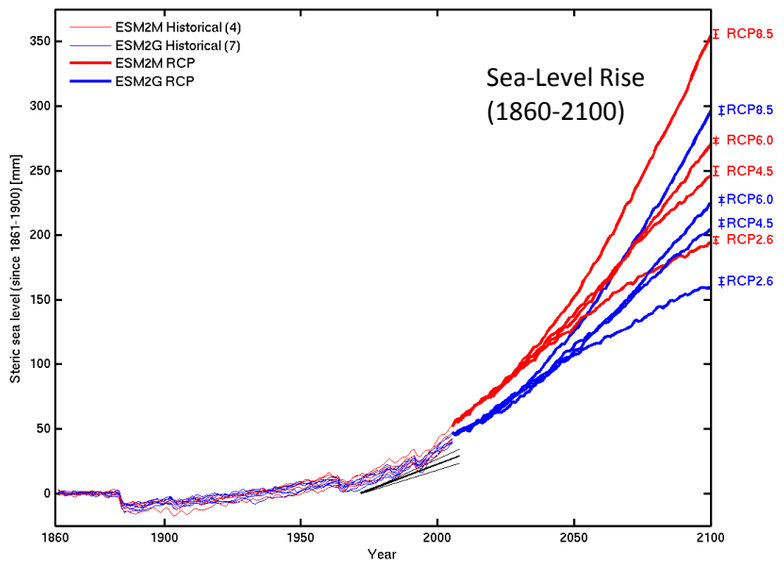
Surface currents and salinity
GFDL CM2.5 Model
Atmosphere: 50km
Ocean: 10-25km

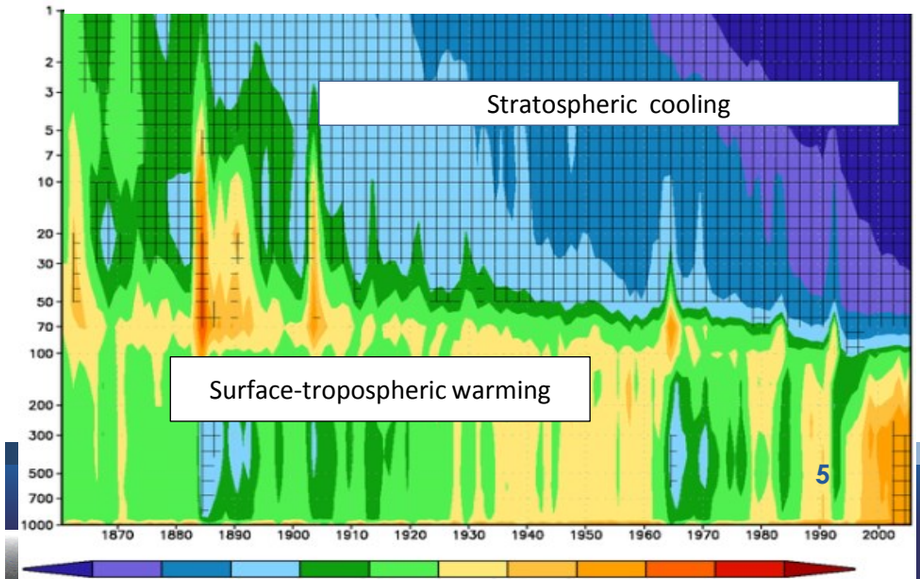


Primary Productivity
GFDL Global Coupled Earth System model

Earth System Complexity







What Climate Phenomena do we address?

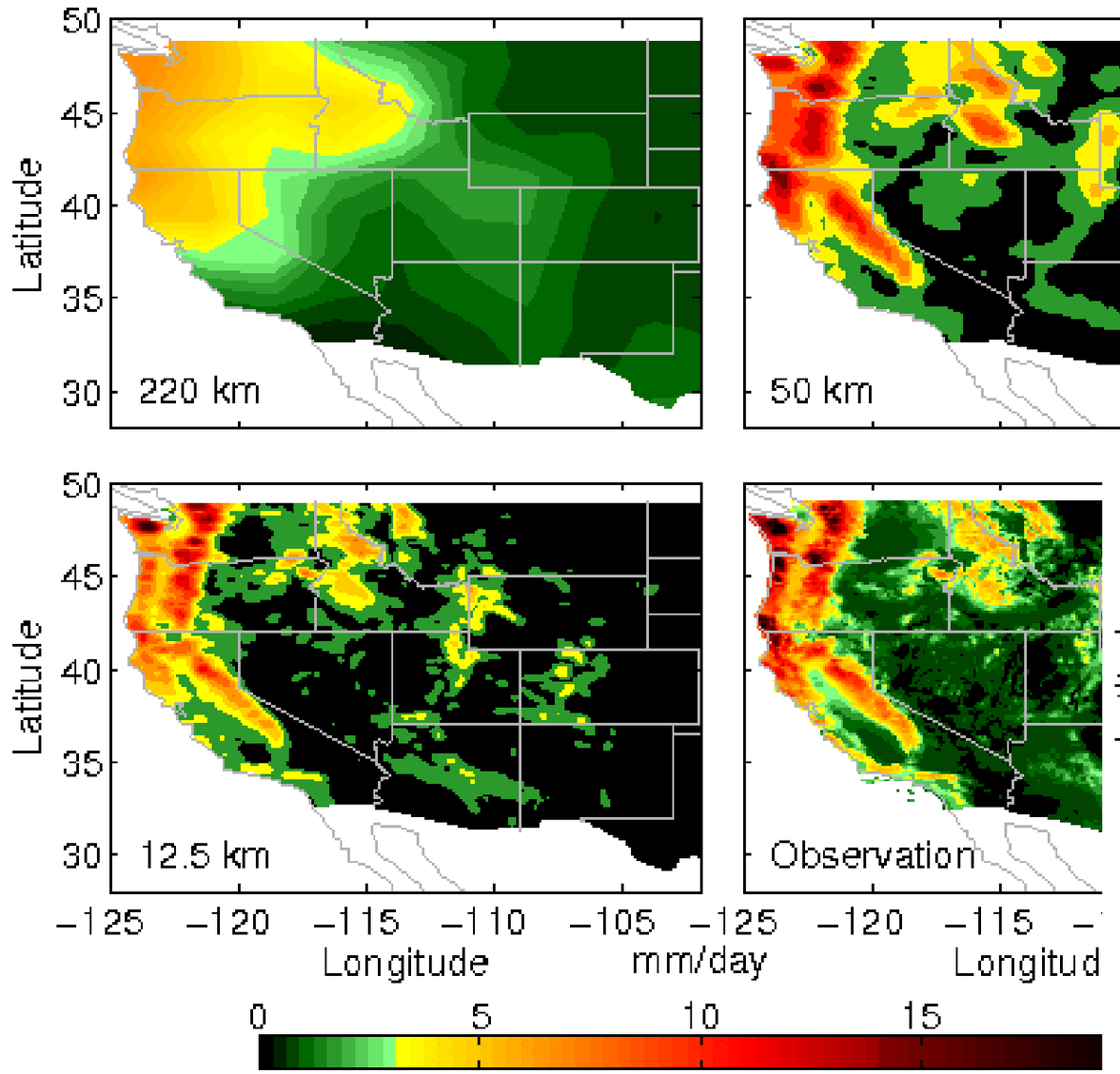
Climate Variability and Change are Linked

Tornadoes
Heat Waves
El Niño-Southern Oscillation
Decadal to multi-decadal Variability
Snowstorms
Storm Track Variations
Precipitation extremes
Solar Variability
Hurricanes
Madden-Julian Oscillation
Seasonal-Interannual
Ocean Circulation
Typhoons
Greenhouse Gases and Aerosols

NRC (2012): Need for *Unified model across timescales*

And Weather to Climate is a Continuum…..

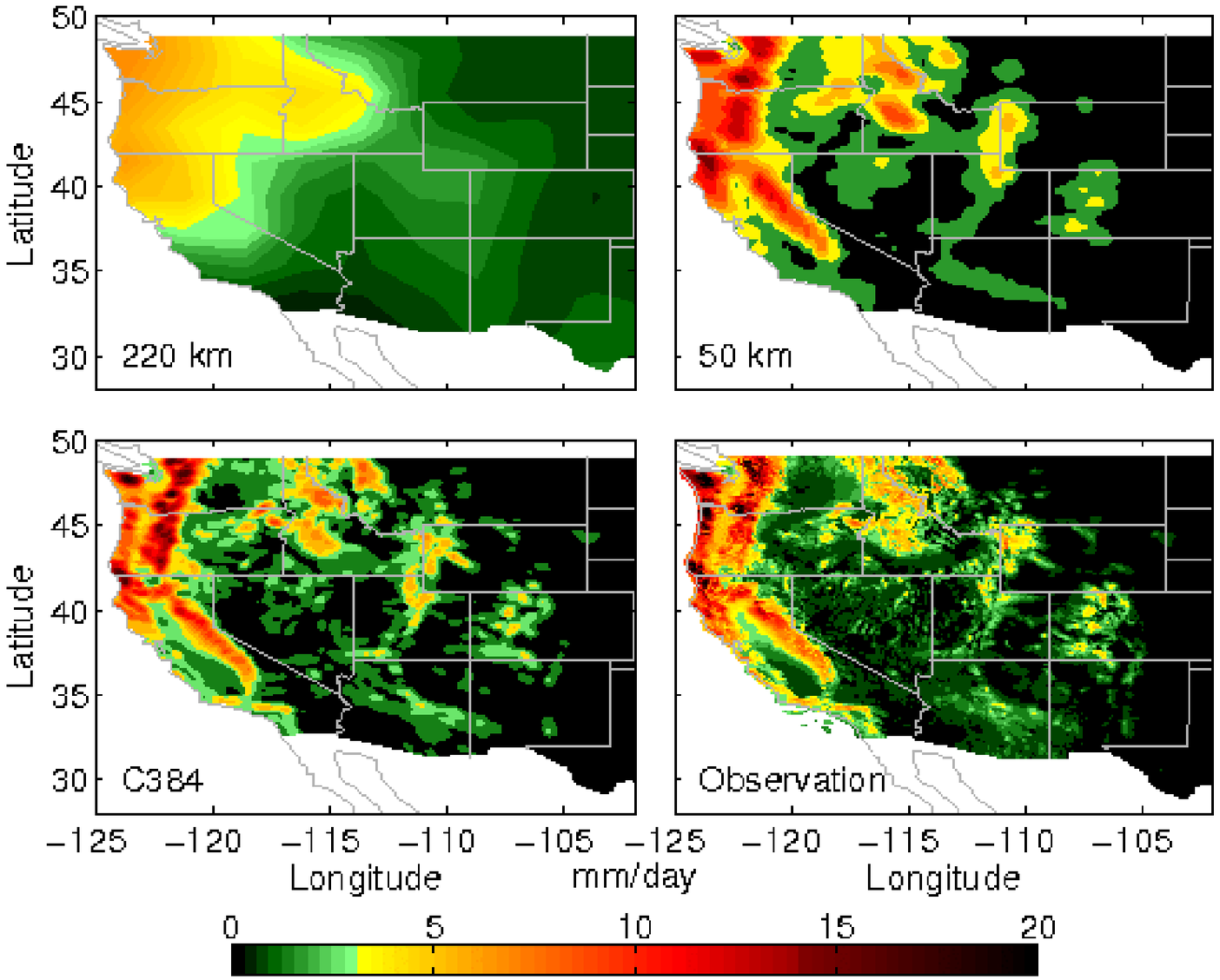
DJF precipitation: GFDL HiRAM vs. Observation



Need hi-res to provide regional details. But global uniform resolution is still too expensive

→

Make hi-res affordable with variable-res approach



C384 stretched

(~10 km over CONUS)

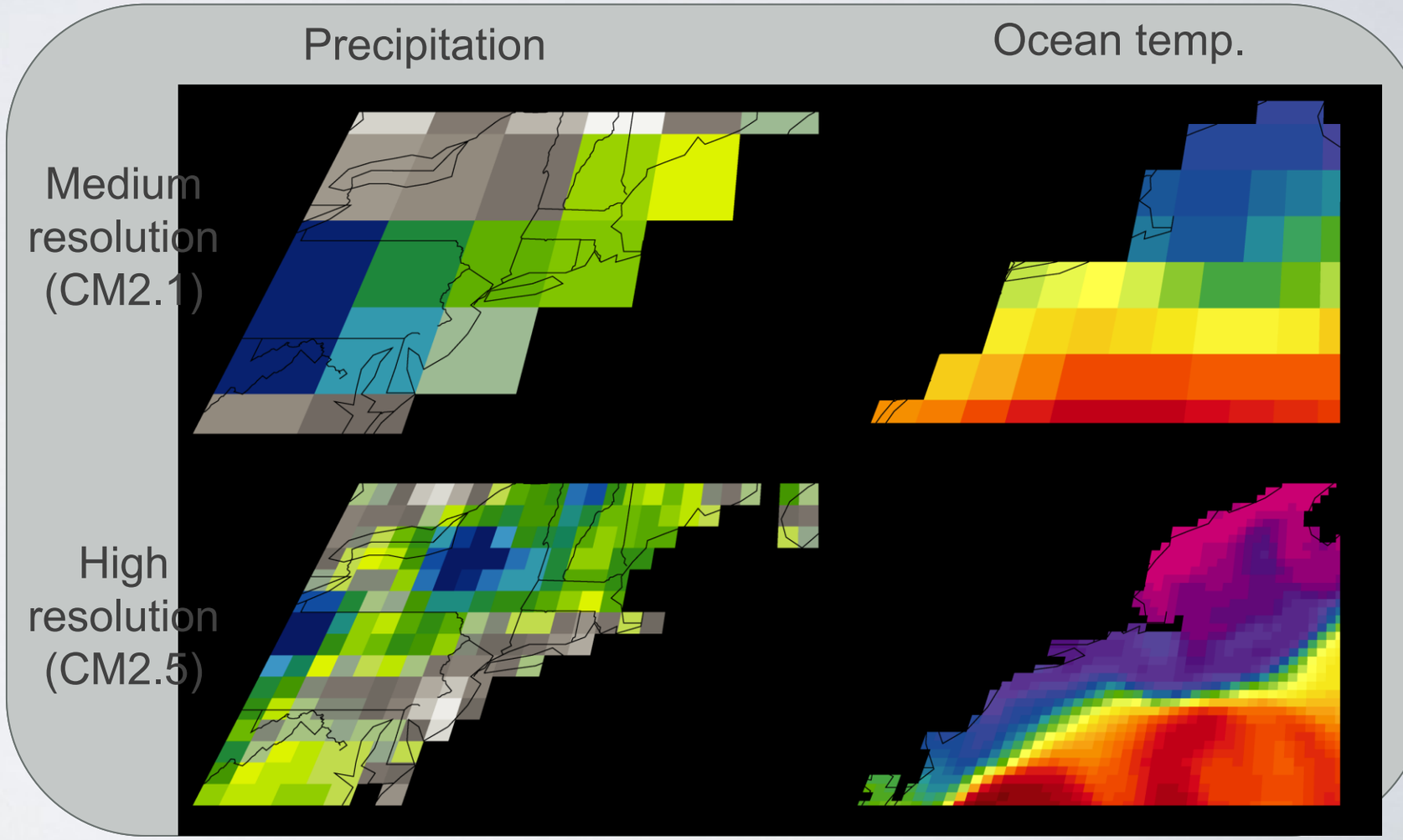
Based on Chen and Lin (2012)

Global Dynamical Models:

Mathematical representation of processes controlling ocean, atmosphere, land, and ice systems (and their interactions)

- GFDL scientific research improves model resolution and accounts for process complexity to better represent phenomena.

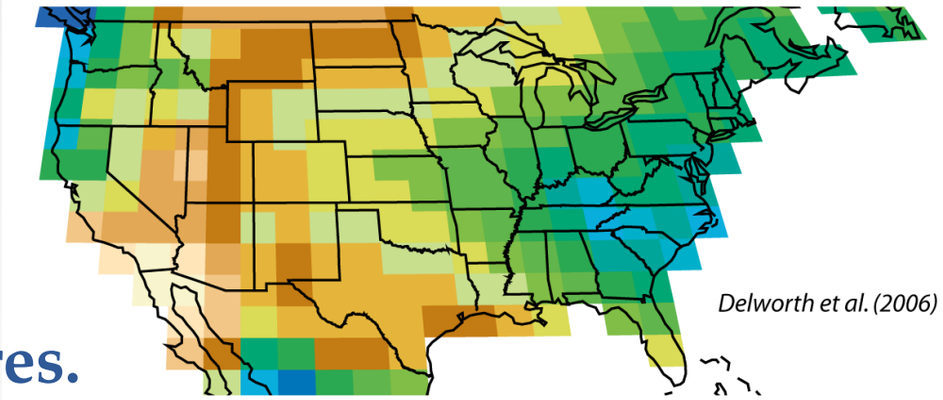
- State-of-the-art models are made possible through increased high-performance computing power, improvements in theory and concepts, and atmosphere and ocean observations.



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

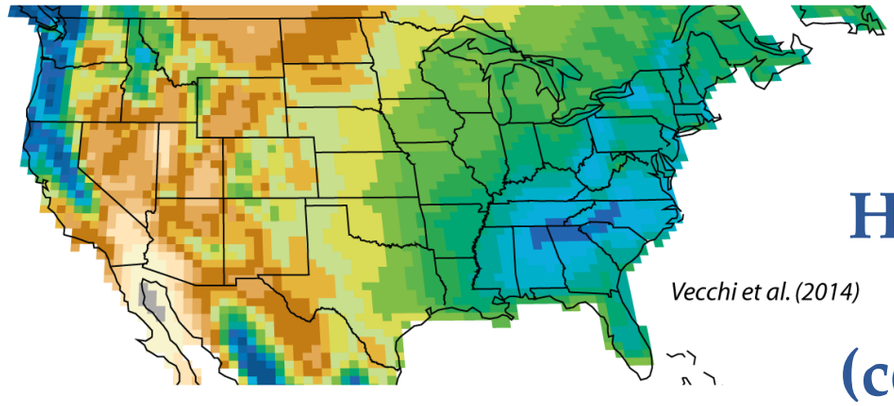
Increasing number of model gridcells improves ability to simulate rainfall over land in North America (and globally)

Real-time seasonal prediction model
160-mile "tiles": CM2.1 (vintage-2006)



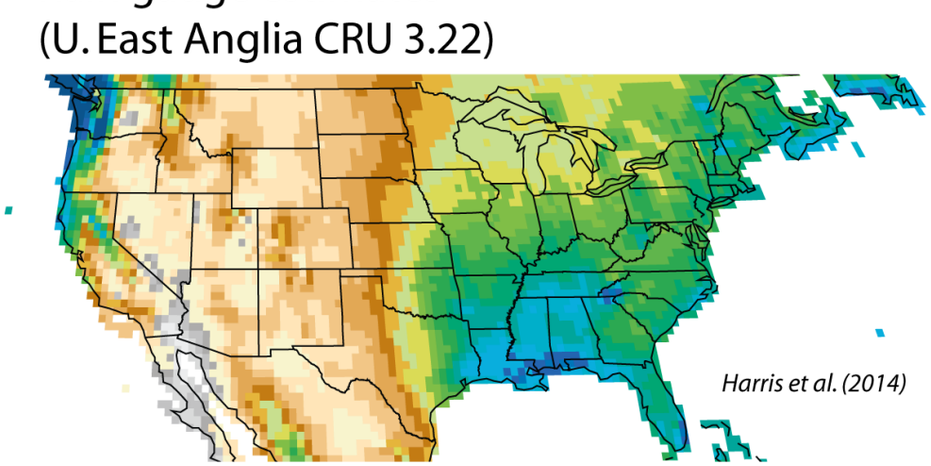
Low-res. Model

Real-time seasonal prediction model
30-mile "tiles": FLOR (vintage-2014)



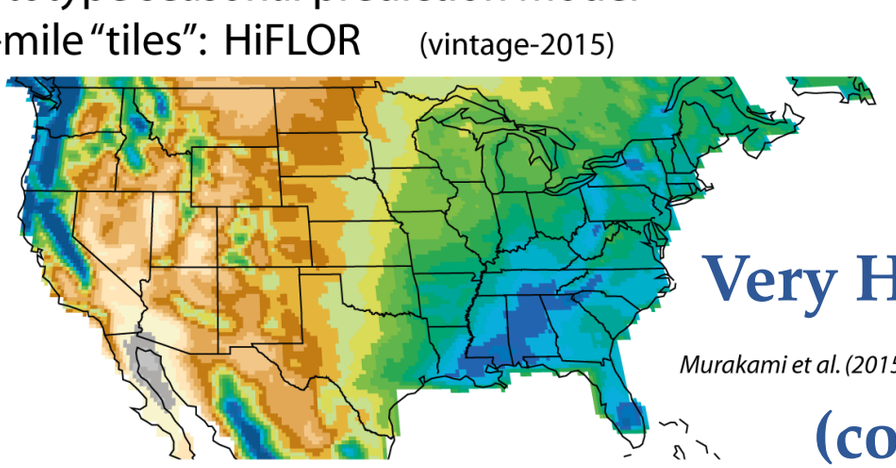
High-res. Model (costs 24x)

Rain gauge estimates
(U. East Anglia CRU 3.22)

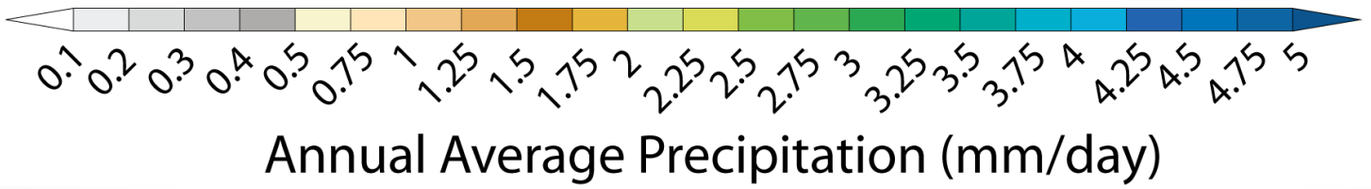


Obs.

Prototype seasonal prediction model
16-mile "tiles": HiFLOR (vintage-2015)



Very High-res. Model (costs 144x)

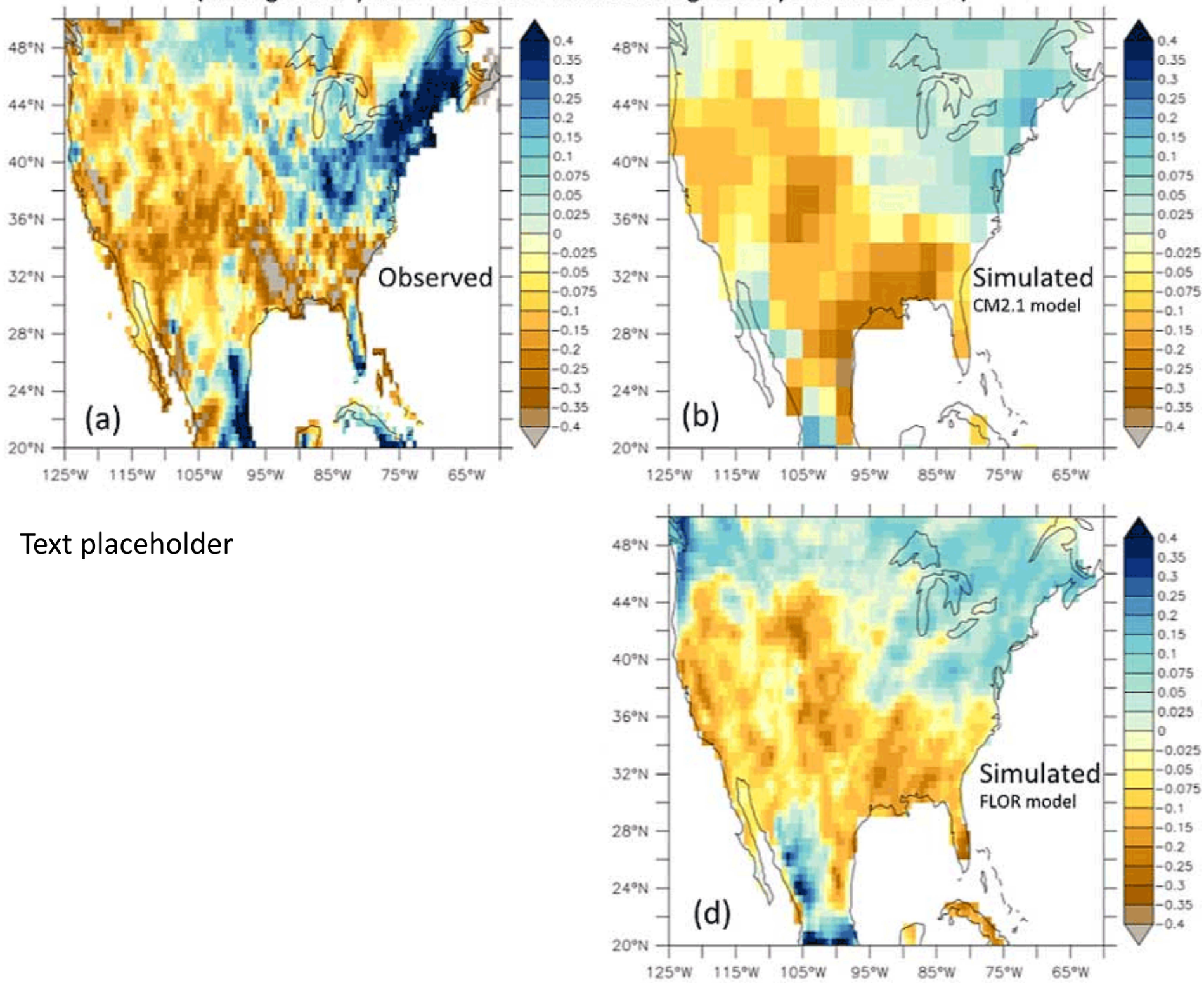


GFDL real-time seasonal prediction models contribute to NMME and are used to understand character, mechanisms and predictability of regional hydrology and extremes.
Prototype 16-mile model improves simulation and prediction further...

Observed and model simulated change in annual mean precipitation

(average over years 2002-2012 minus average over years 1979-2000)

Text placeholder



The figure above shows changes in precipitation, calculated as annual mean precipitation for the period 2002-2012 minus the annual mean precipitation for the period 1979-2000. The units are mm of precipitation per day. Shown in the upper left (panel a) are the results from observations, showing relatively drier conditions (yellow to brown shading) over much of the western U.S. for the 2002-2012 period. The other three panels (b-d) show results from various GFDL models when we insert into the models the unusually strong easterly winds that were observed in the tropical Pacific over the 2002-2012 period. All three models reproduce the observed drying over the western U.S. in response to the observed stronger easterly winds in the tropical Pacific. These same simulations also reproduce the hiatus in global warming in response to these wind changes.

Elements of the Prediction System

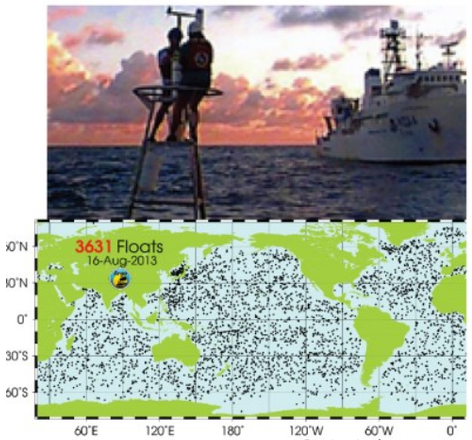
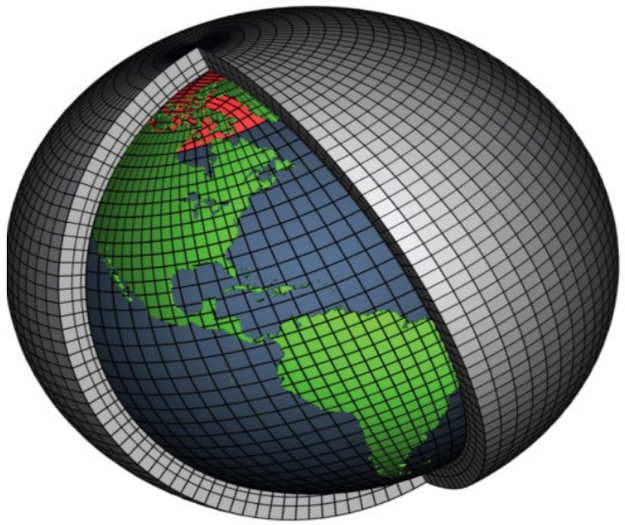


Image sources: NOAA/PMEL and Argo.ucsd.edu

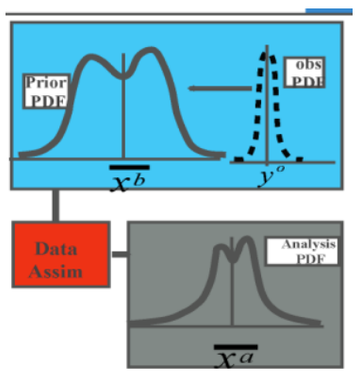
1. GLOBAL OBSERVATIONS

Atmosphere and ocean observations across globe.



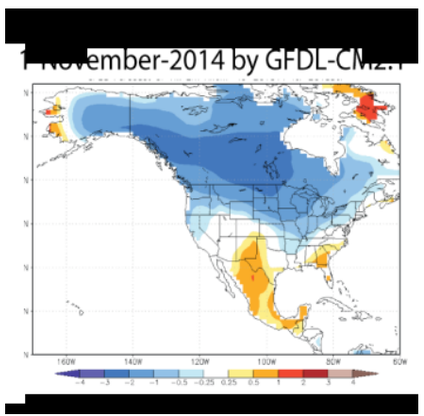
2. DYNAMICAL MODEL

Solving mathematical formulations of the processes in the coupled atmosphere-ocean-land-ice system, using NOAA's High-Performance Computers.



3. DATA ASSIMILATION

Combines sparse observations with model, to estimate present state, using the dynamical model.



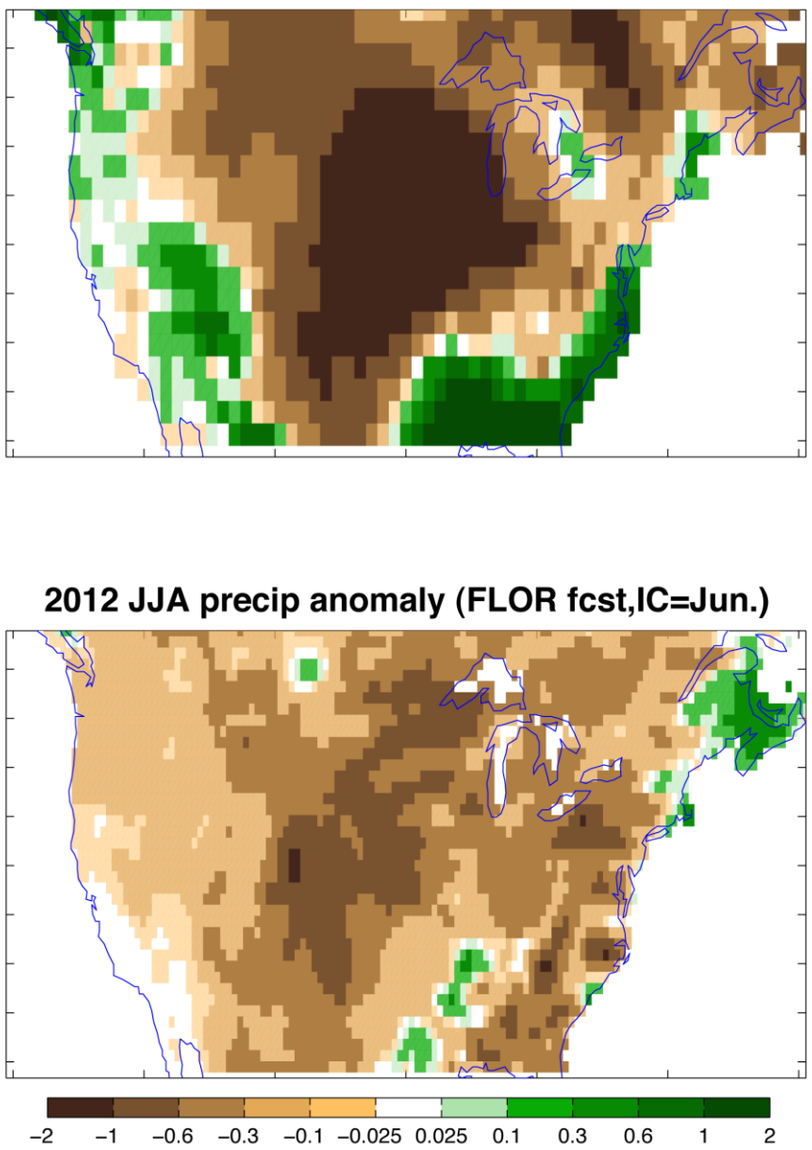
4. ANALYSIS & DISSEMINATION

Output from predictions, produce "useful" information, communicating predictions.

Predicting regional-scale extremes with GFDL's global climate model

Temperature prediction for 2012 looks "better".
This is ensemble mean, so forecast "smudged"

Overland Precipitation during 2012 midwest drought – observed and predicted with the new (FLOR) GFDL model.



Jia et al. 2015

Characteristics of the Forecast-oreiented Low Ocean Resolution (FLOR) model

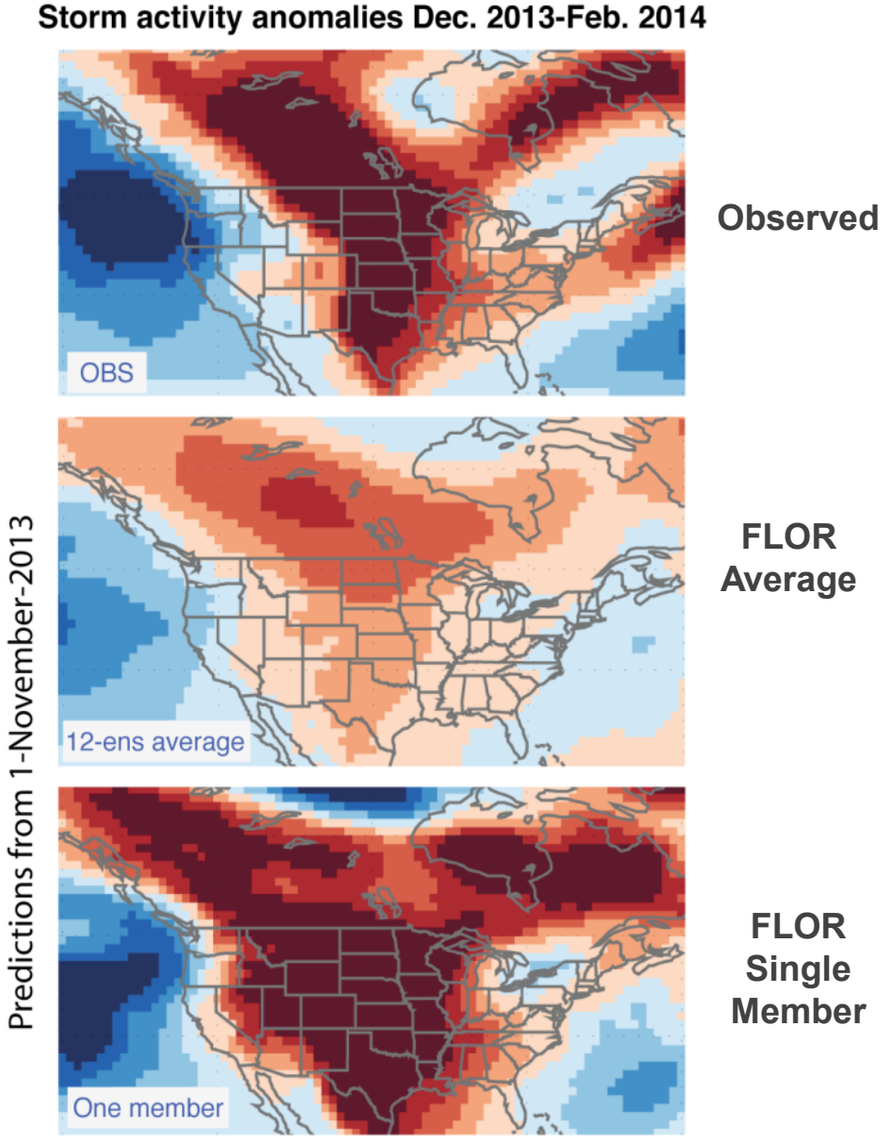
- GFDL's newest model is a ground-breaking forecast system
- The model has 50km atmospheric resolution (compared to 200km resolution in previous version of the model, CM 2.1)
- "sweet spot" of quality, speed, readiness
- Because of the resolution, this model has regional applications with regards to extreme weather
- The model provides for seamless predictions from intraseasonal to decadal time scales
- Produces the highest-resolution seasonal forecasts in the world

Uses of Model

- The model is used to produce real-time seasonal predictions, contributing to the North American Multi-Model Ensemble
- It has been used to better understand and predict tropical cyclones, arctic sea ice, and precipitation and temperature over land
- Outputs from the model are incorporated into NOAA's seasonal hurricane outlook, El Nino forecasts produced for the International Research Institute for Climate and Society (Columbia University) and annual sea ice outlooks

Predicting regional-scale extremes with GFDL's global model

Storm track activity during 2013-4 winter – observed and predicted with the new (FLOR) GFDL model. Note:
Enhanced storminess over much of North America
Reduced storminess over Pacific coast (incl. California)



Adapted from Yang et al. (2015)

Characteristics of the Forecast-oriented Low Ocean Resolution (FLOR) model

- GFDL's newest model is a ground-breaking forecast system
- Has 50km atmospheric resolution (compared to 200km resolution in previous version of the model, CM 2.1)
- "Sweet spot" of quality, speed, and readiness
- Because of the resolution, this model has regional applications with regards to extreme weather
- Provides for seamless predictions from intraseasonal to decadal time scales
- Produces the highest-resolution seasonal forecasts in the world

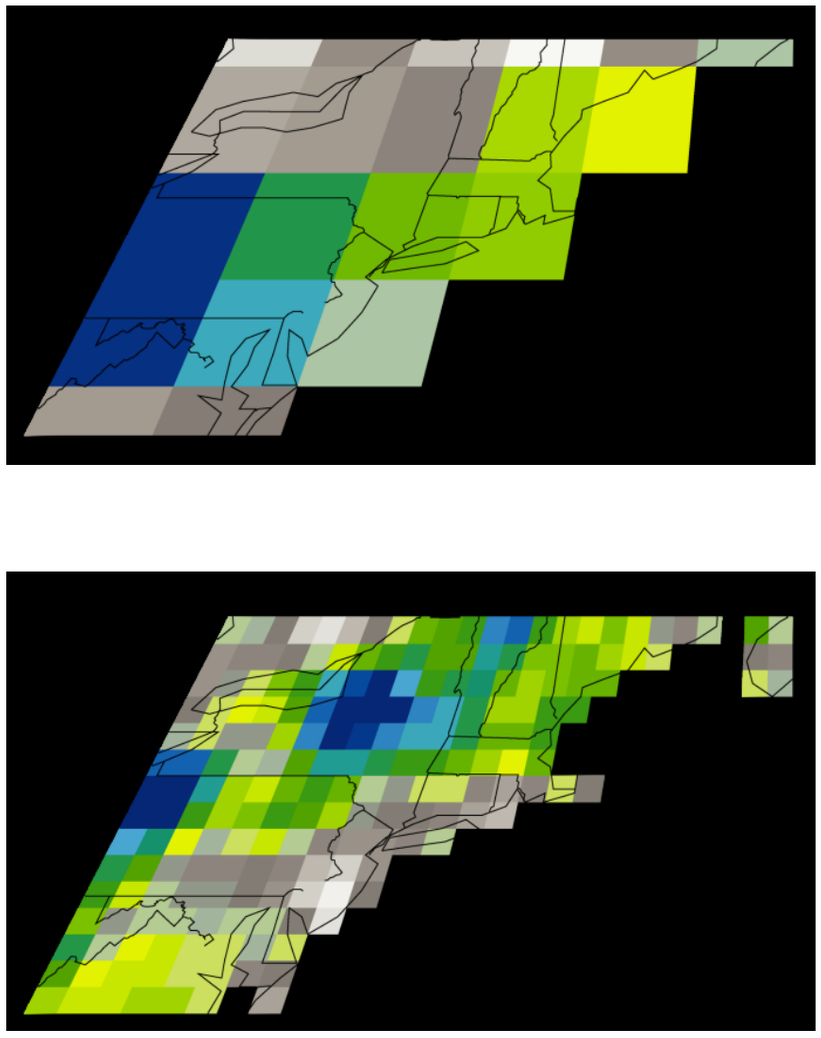
Uses of Model

- Produces real-time seasonal predictions, contributing to the North American Multi-Model Ensemble (NMME), which is led by NOAA
- Has been used to better understand and predict tropical cyclones, Arctic sea ice, and precipitation and temperature (including extremes) over land
- Outputs are incorporated into NOAA's seasonal hurricane outlook, El Nino forecasts and annual sea ice outlooks

GFDL Experimental High-resolution Coupled Prediction (*Initialized, with forcings*)

Goal: *Build a cutting edge intra-seasonal to decadal forecasting system to*: Yield improved forecasts of large-scale climate extremes

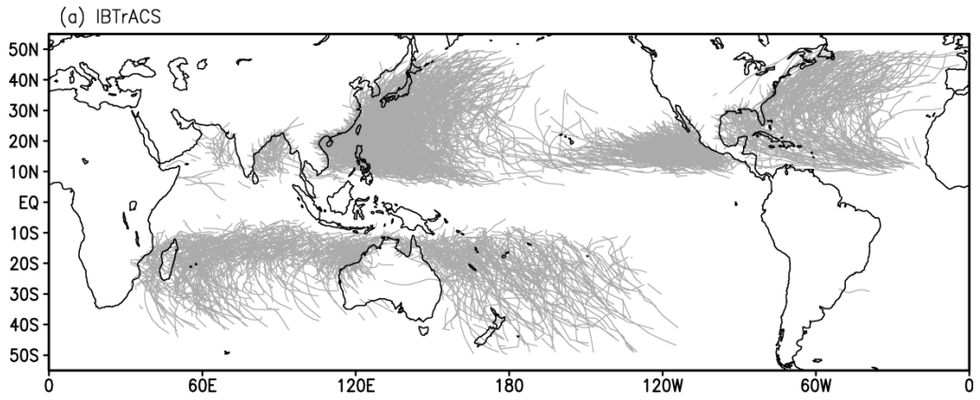
- Enables exploration of regional weather, hydroclimate (including extremes)



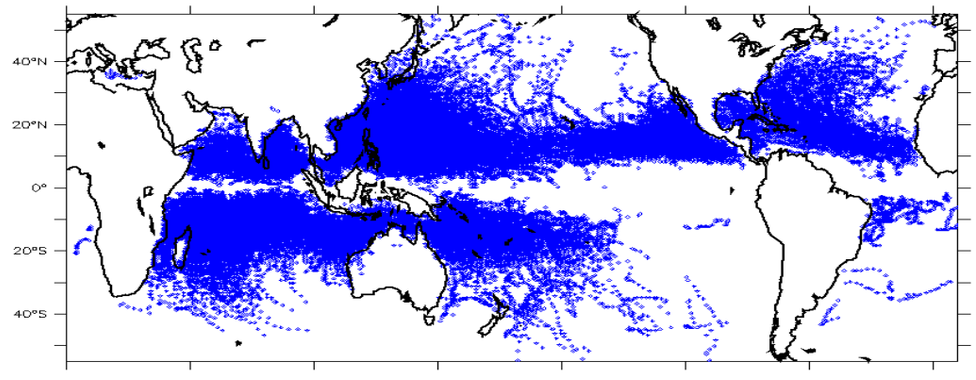
Enable forecasts of regional climate and

- Enables seamless seasonal-to-decadal hurricane research & predictions

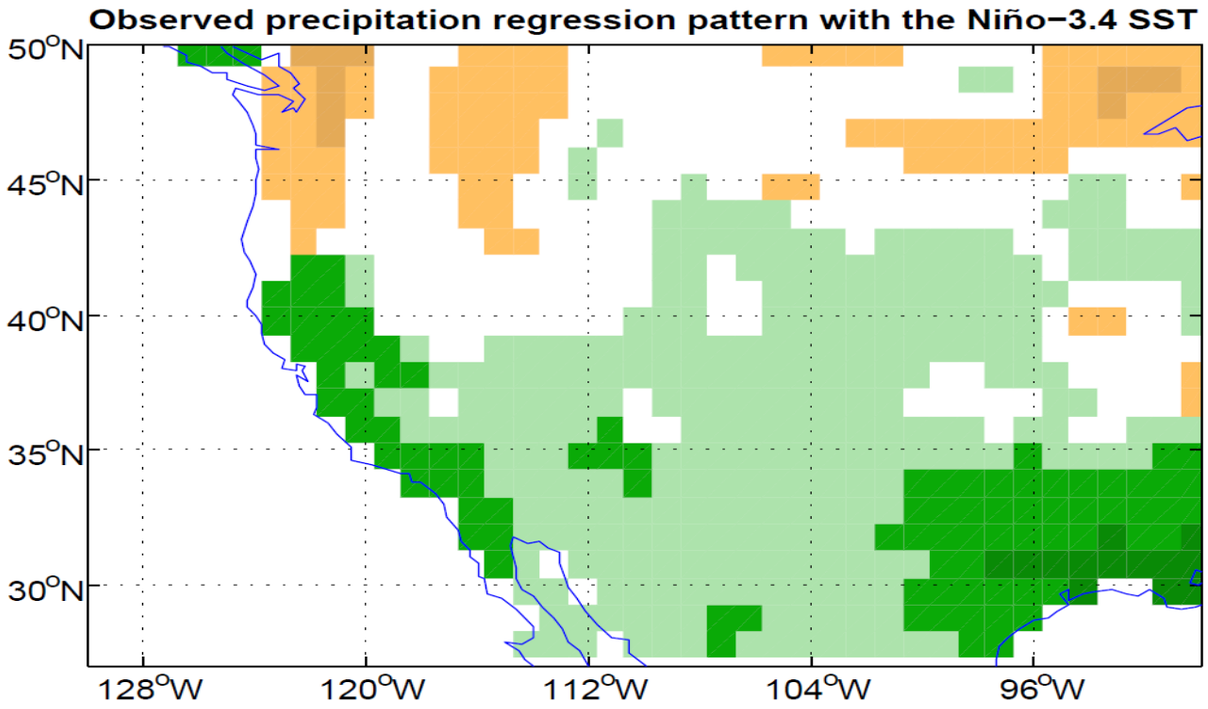
Observed Tracks

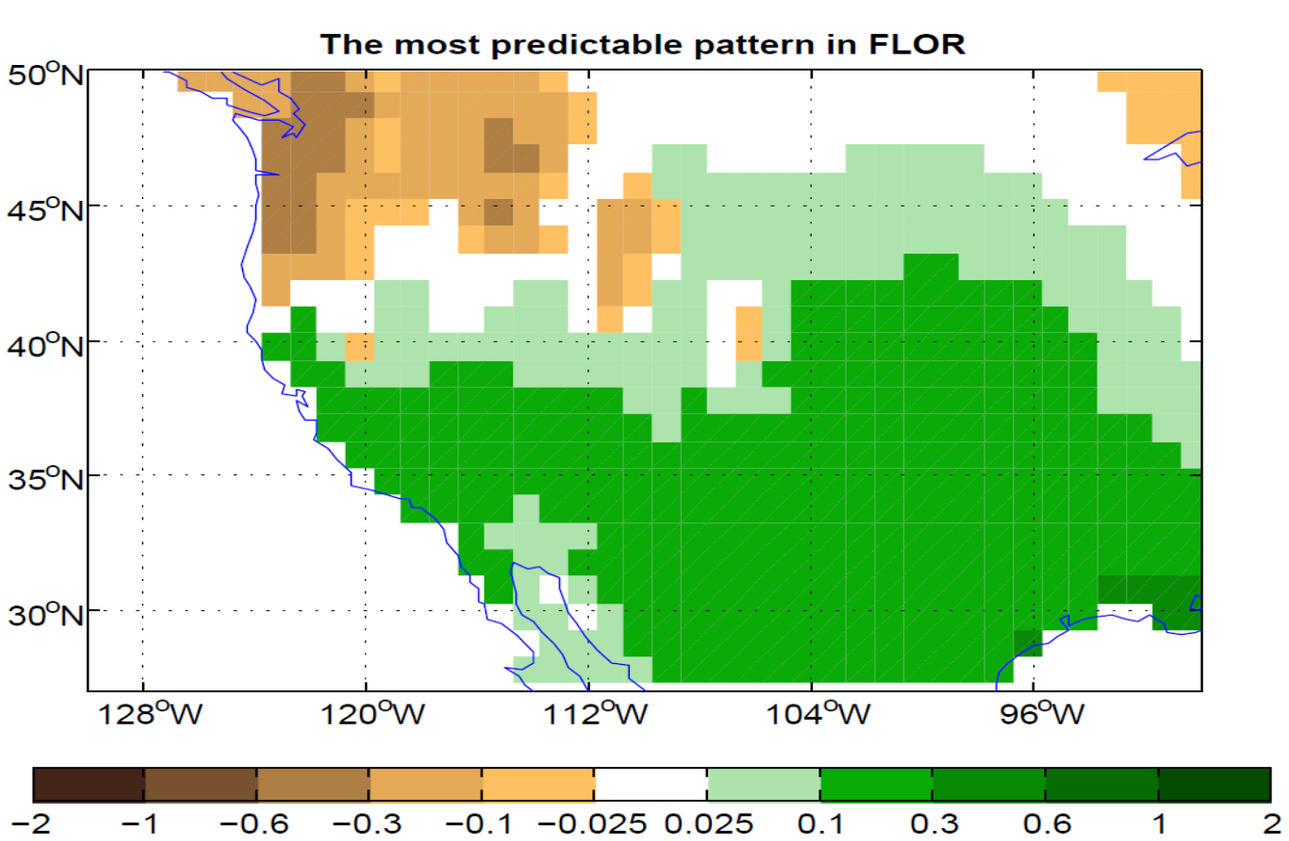


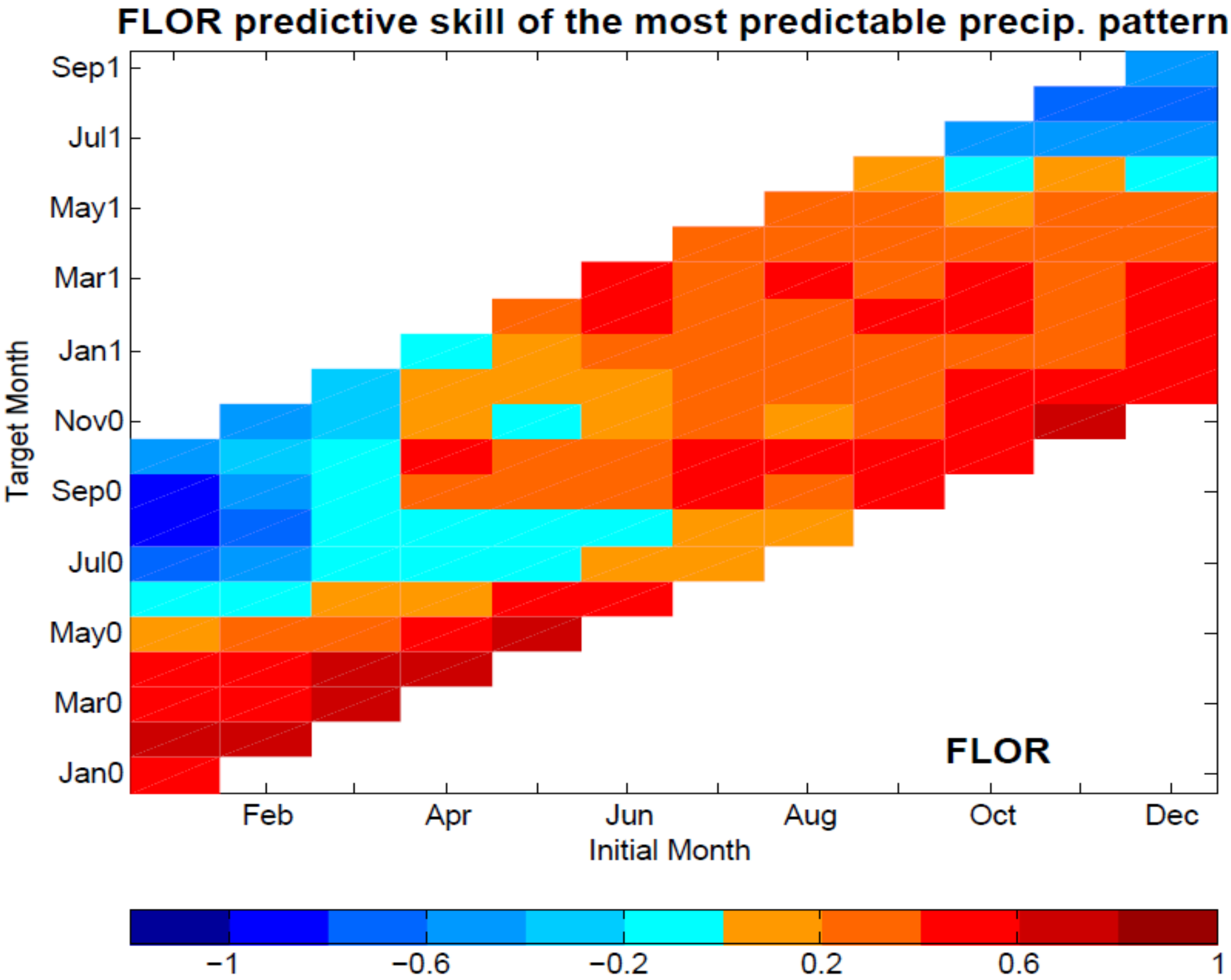
Coupled Model Tracks (396 seasonal forecasts)



Vecchi et al. (2013),Delworth et al. (2012)


Observed precipitation regression pattern with the Niño−3.4 SST
50°N
45°N
40°N
35°N
30°N
128°W
120°W
112°W
104°W
96°W


The most predictable pattern in FLOR
50°N
45°N
40°N
35°N
30°N
128°W
120°W
112°W
104°W
96°W
−2
−1
−0.6
−0.3
−0.1
−0.025
0.025
0.1
0.3
0.6
1
2

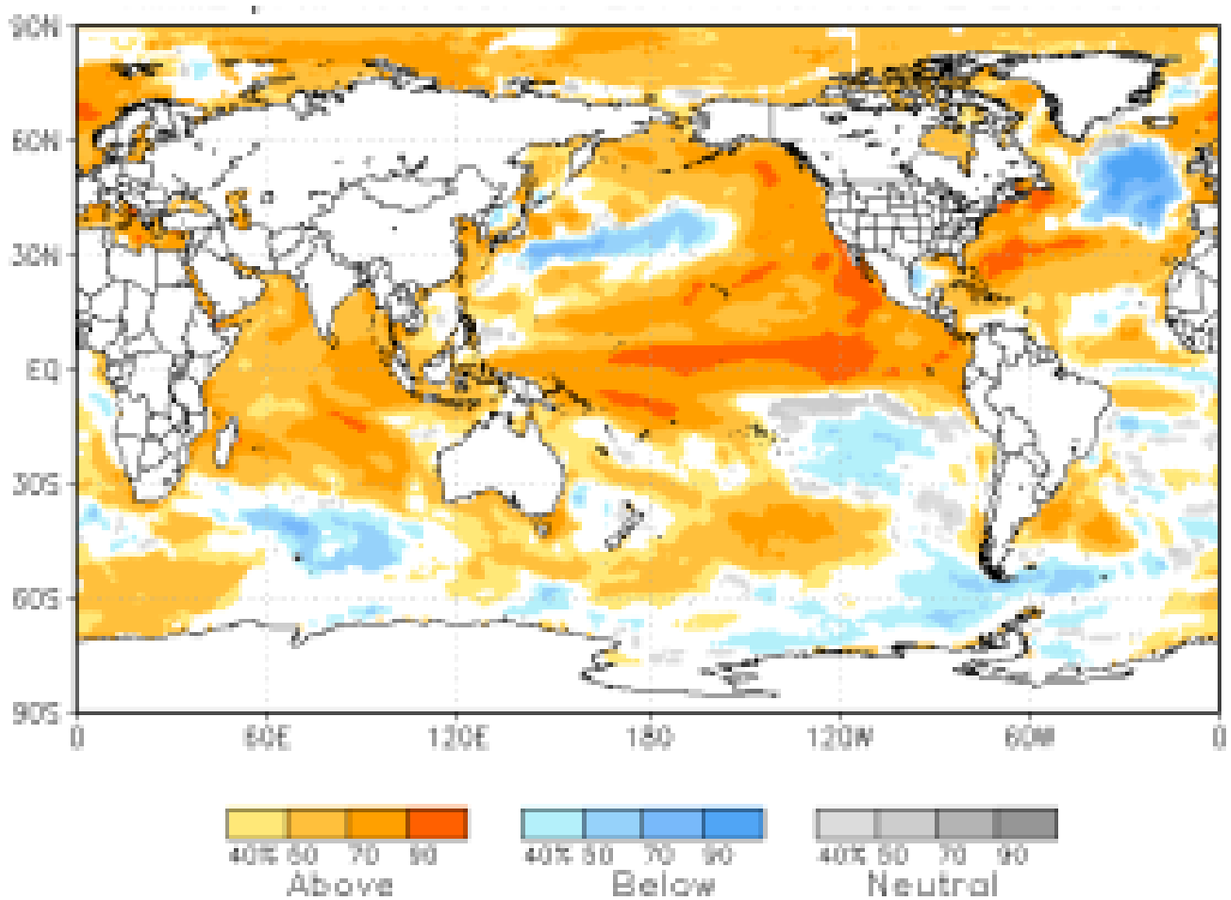

FLOR predictive skill of the most predictable precip. pattern
Target Month
Sep1
Jul1
May1
Mar1
Jan1
Nov0
Sep0
Jul0
May0
Mar0
Jan0
FLOR
Feb
Apr
Jun
Aug
Oct
Dec
Initial Month
−1
−0.6
−0.2
0.2
0.6
1

The North American Multi-Model Ensemble

NMME - An unprecedented multi-model system to improve seasonal climate prediction

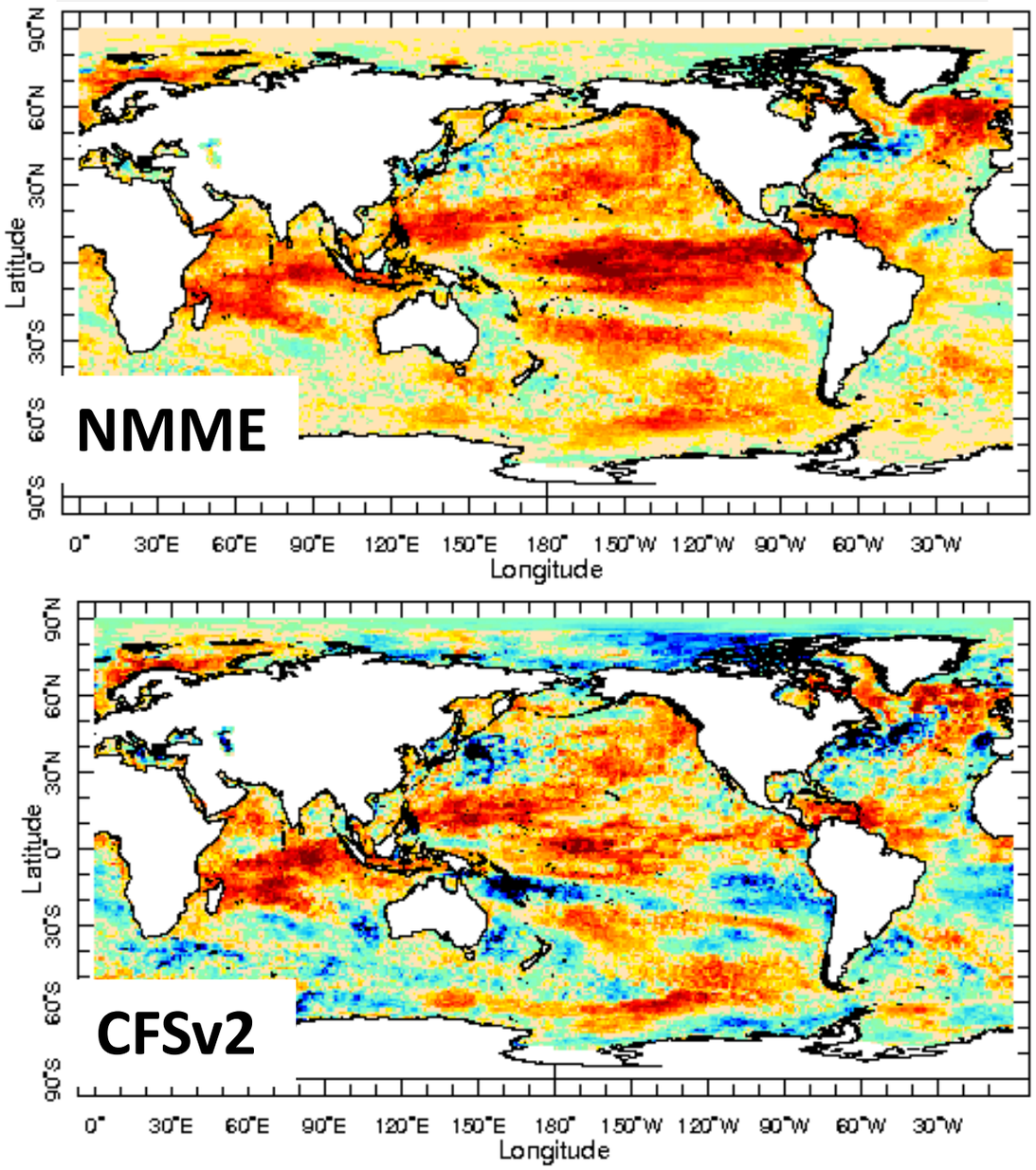
- Based on leading climate models in the US and Canada
- Research supported by NOAA and other US agencies.
- Participating Organizations
  - NOAA/NCEP
  - NOAA/GFDL
  - NASA/GMAO
  - NCAR
  - Environment Canada
  - U. Miami
  - IRI
  - COLA

Developing ENSO forecast Winter 2014 – 2mo lead



NMME – Key Achievements

DJF SST Forecasts July IC (B. Kirtman)



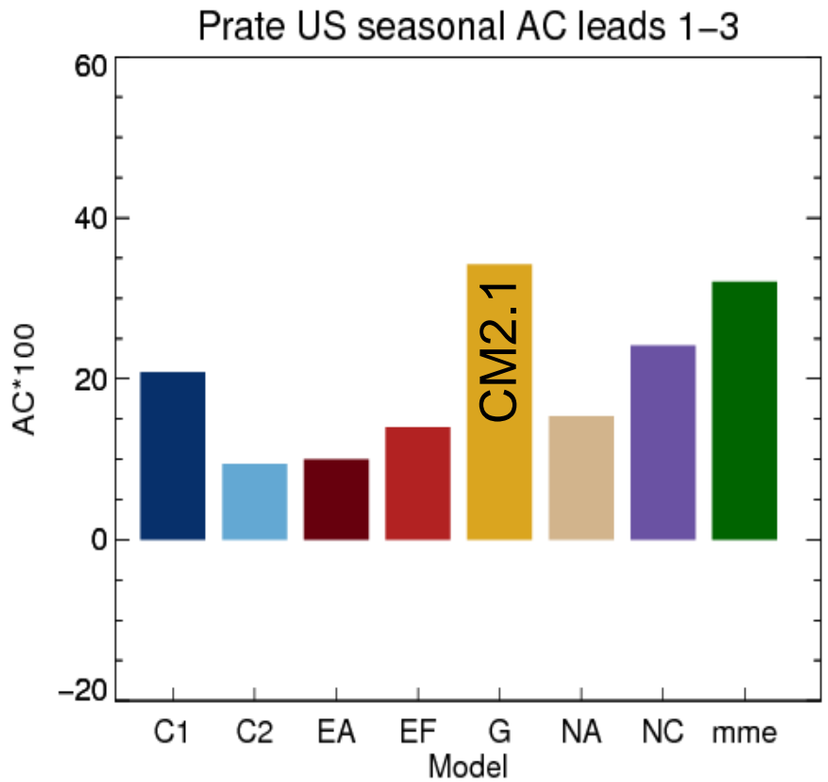
The diversity of models in NMME enhances seasonal prediction skill, beyond individual model forecasts.

- Contributing experimentally to NOAA operational seasonal outlooks since 2011
- Most comprehensive seasonal prediction data set accessible to the public
- Enabling prediction and predictability research and informing model improvement

High-resolution coupled prediction

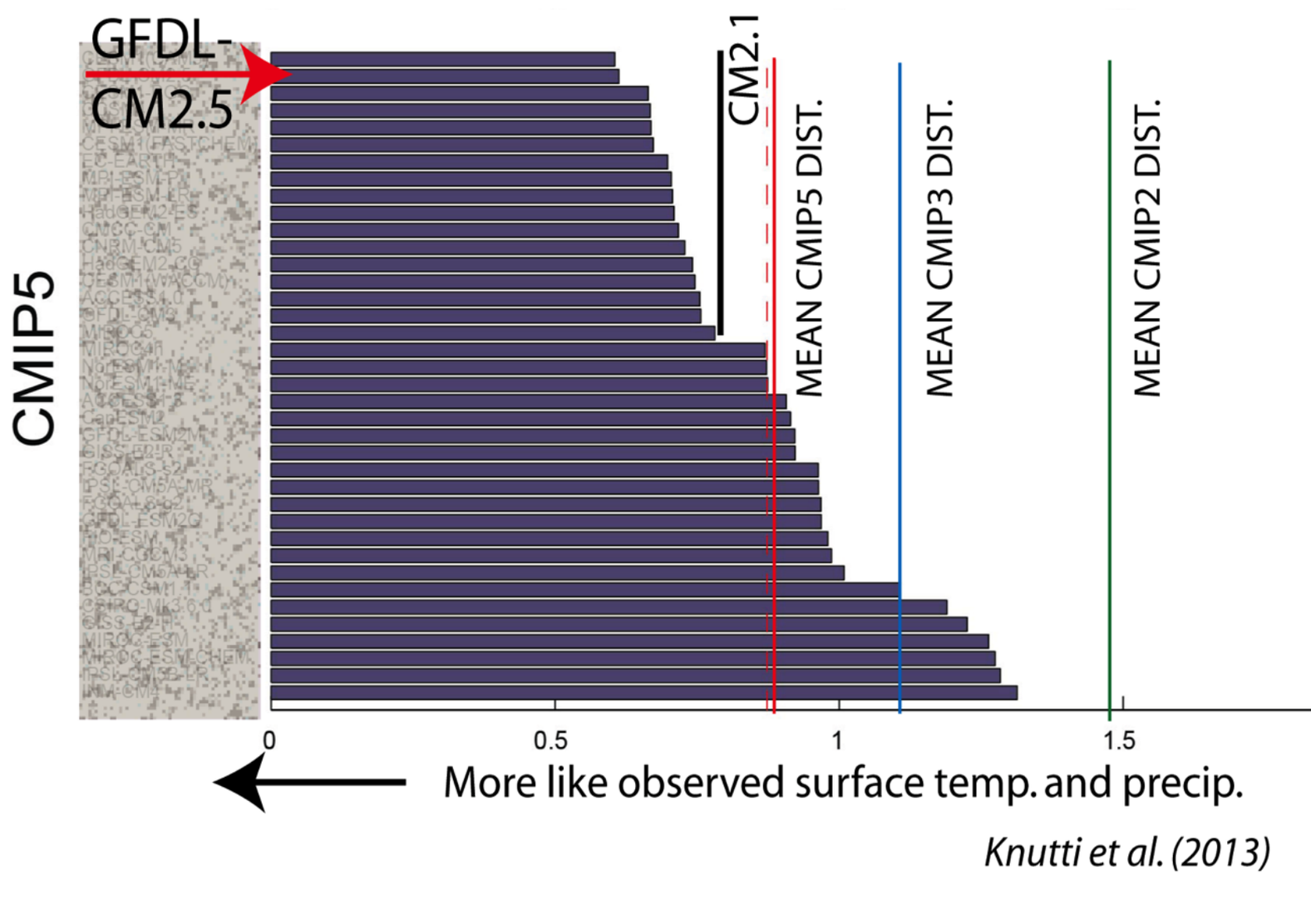
GFDLs CM2.1 model was considered by some to be the best model used in the IPCC CMIP3/AR4 activity in 2007. It remains one of the most skillful models participating in the North American MultiModel Ensemble (NMME).

"Real-time" skill of first year of NMME Continental US Precip Forecasts



Van den Dool et al. (2013)

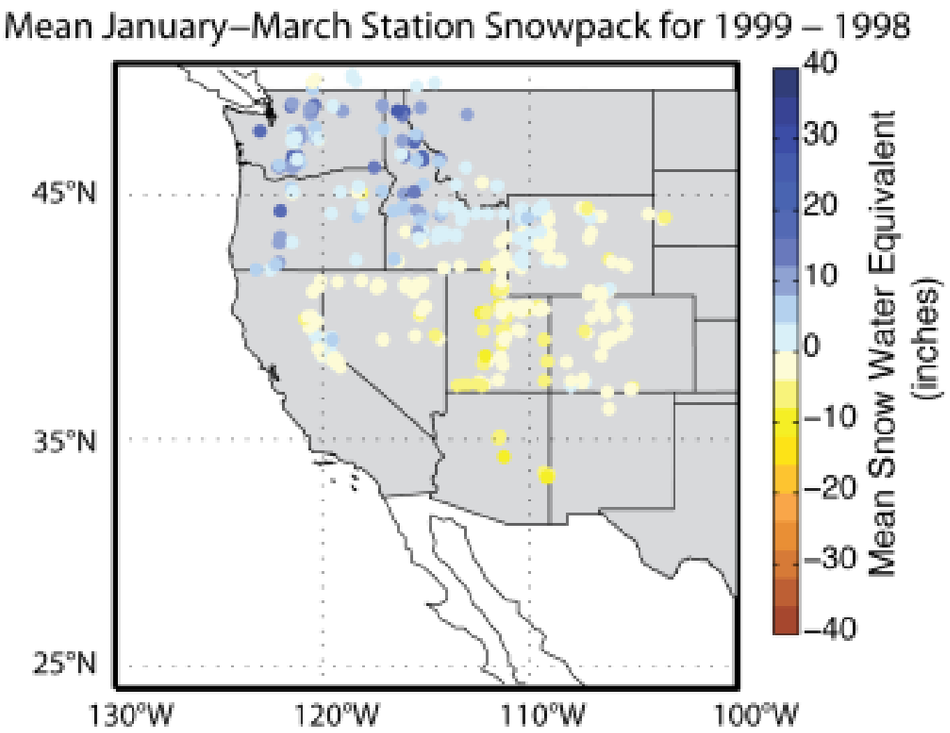
CM2.5, a direct descendant of CM2.1, has quadruple the resolution in the atmosphere and ocean component models and markedly enhanced skill in simulating current climate.



Knutti et al. (2013)

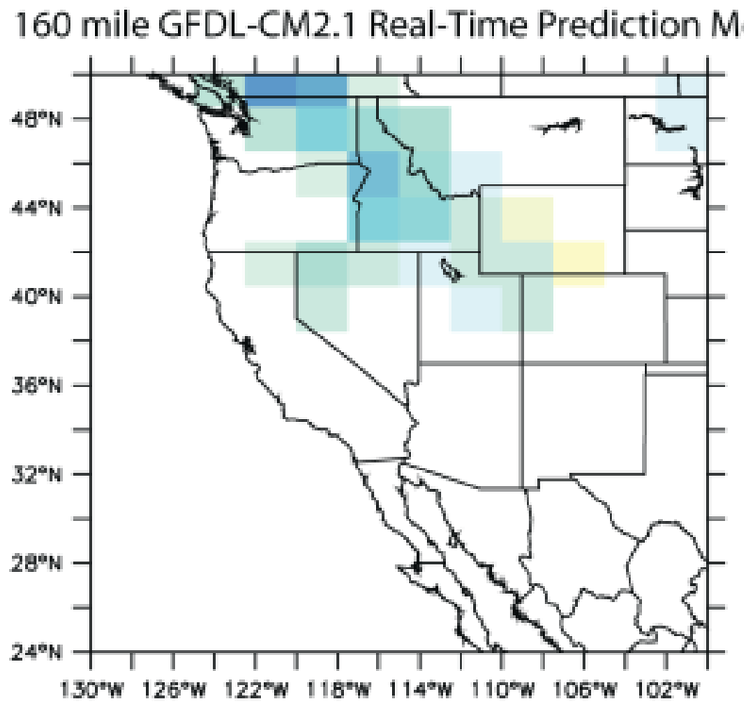
Improved prediction of western snowpack seasons during El Niño events

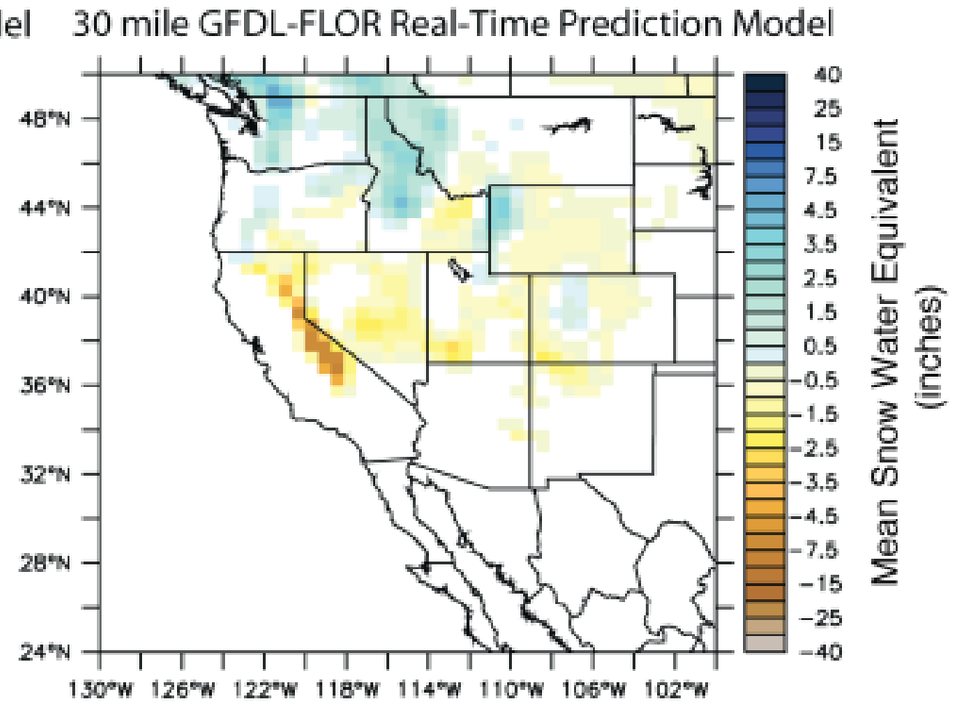
Observed



- Figures show the difference between La Niña and El Niño winter snowpack, predicted from July
- Further improvements seen in prototype 16-mile HiFLOR predictions *(Not pictured)*

Low-resolution Model

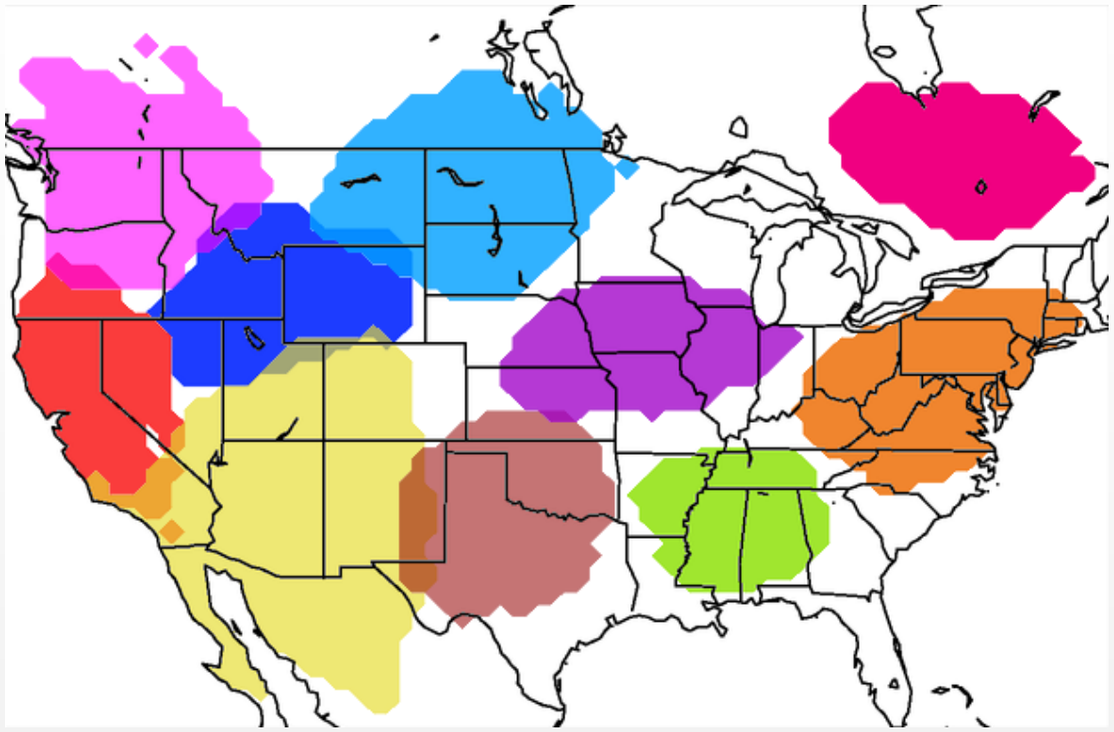




High-resolution Model (costs 24x)

Vecchi et al. (2014), Kapnick et al. (2015)

Heat Extremes over the US



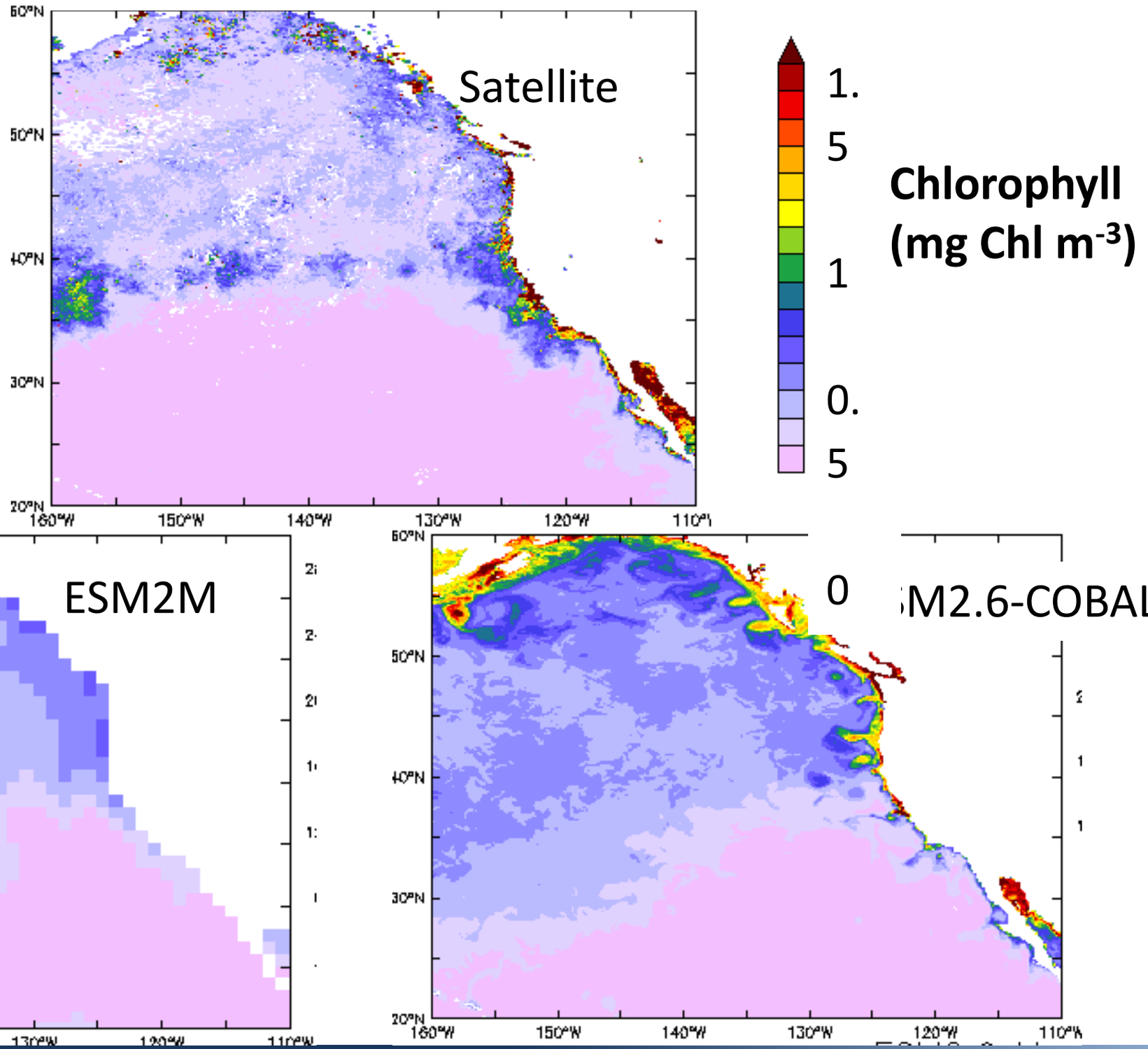
Lau and Nath (2012), A Model Study of Heat Waves over North America: Meteorological Aspects and Projections for the 21st Century, *Journal of Climate*.

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

Pushing the envelope: Decadal high resolution prototype with next generation biogeochemisty

California Current Upwelling Signature vastly improved from 1° to 1/10° Resolution



Pathways to Predictability

SST anomalies → **Global-Scale Atmospheric Changes** → **Regional Forcing and land feedbacks** → **Local Impacts, Info needs**

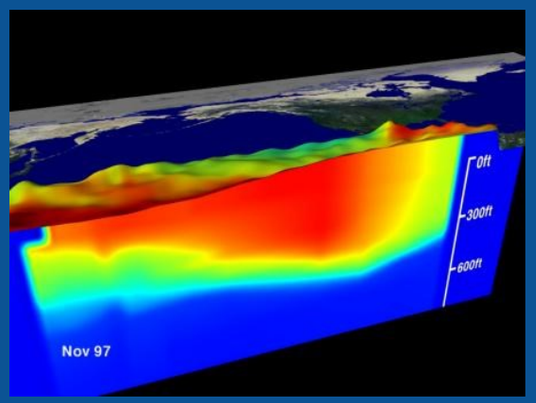
Key Phenomena, variables

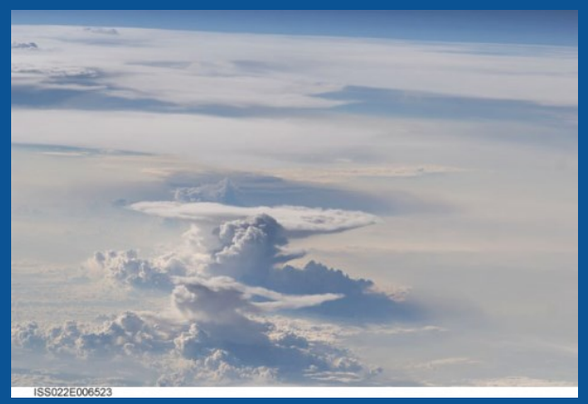
ENSO, PDO, AMO, warm pool variability, Global Warming, etc

Planetary waves, hydrological cycle, monsoons, Hadley Cell, Walker Circulation

Precipitation, soil moisture, snow, low level jets, dust, vegetation, land/atmosphere contrasts, changes in weather

Soil moisture, stream flow, precipitation, ground water, lakes, reservoirs





Modeling Issues

Improvements in global coupled models, estimates of ocean variability and predictability, GHGs

Reduce uncertainties in atmos. response to SST, water cycle, atmos. variability and predictability

Reduce uncertainties in modeling land/atmosphere interactions, predictability of weather “regimes”, regional climate phenomena

Improved modeling of “downstream” impacts on land hydrology, higher resolution

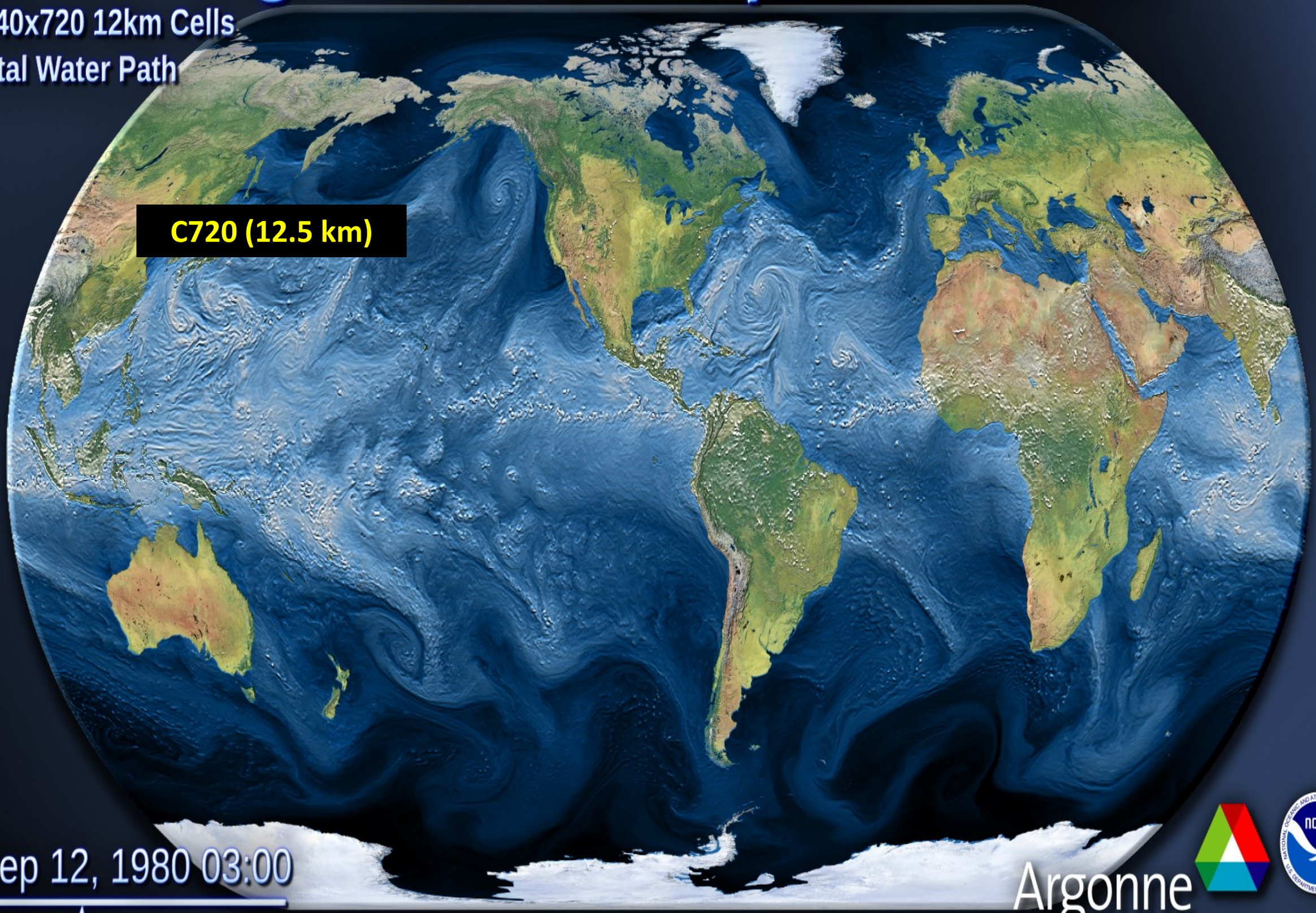
The END

Thank you for your attention!

GFDL High-Res Atmosphere Model

1440x720 12km Cells

Total Water Path

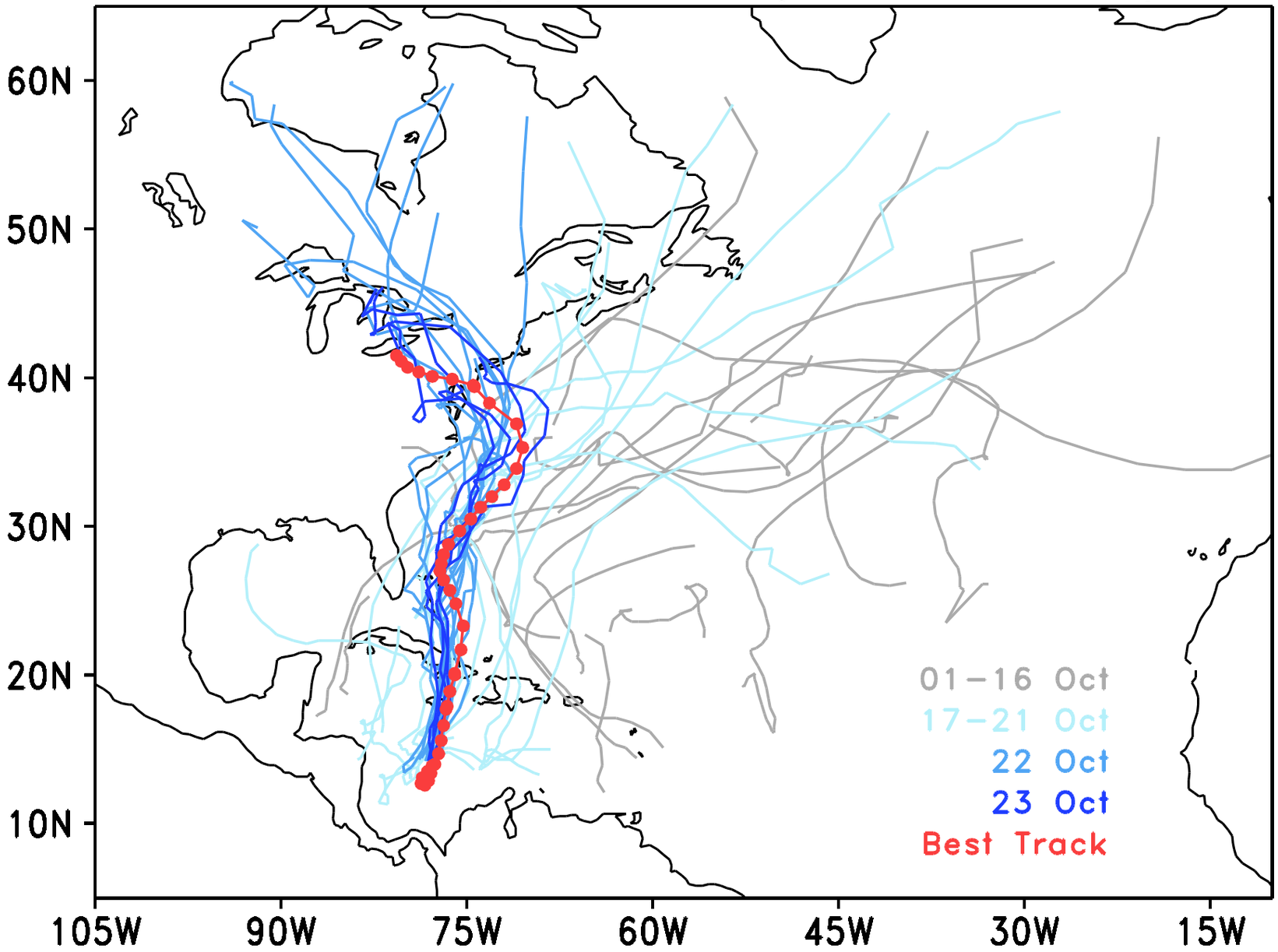


Argonne NATIONAL LABORATORY

NOAA

Long-range predictions of hurricane Sandy from 1-23 Oct

(25-km non-hydrostatic HiRAM)



Hurricane Sandy (2012)

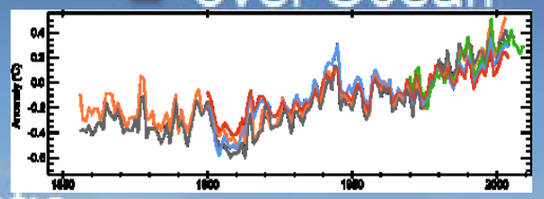
- **Genesis: 22 Oct**
- **US landfall: 30 Oct**

1. Genesis locations are skillful predicted after 17th (5 days before genesis)
2. Forecasts initialized after 21 Oct (9 days before landfall) started to exhibit westward turn (the left hook)
3. Skillful landfall locations predicted after 22 Oct

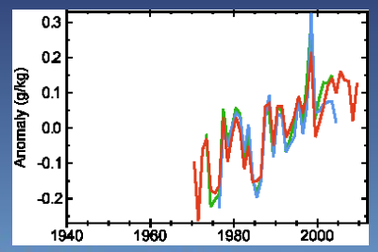
What do we know?

Ten Indicators of Changing Conditions:

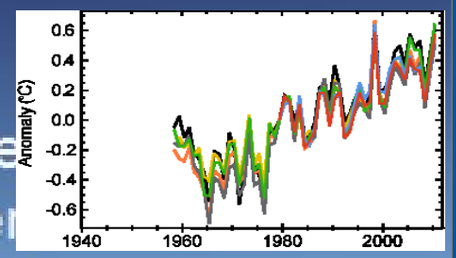
Air Temperature over Ocean



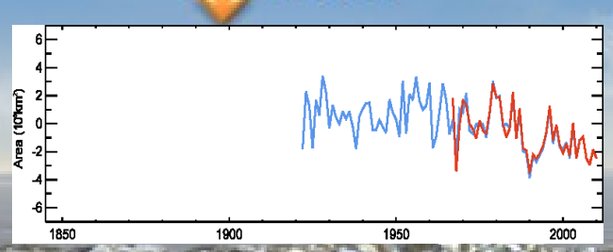
Humidity



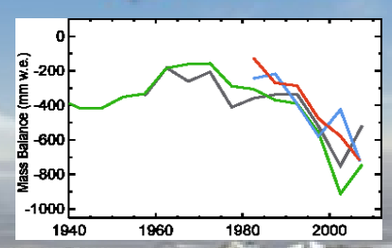
Temperature of the Lower Atmosphere



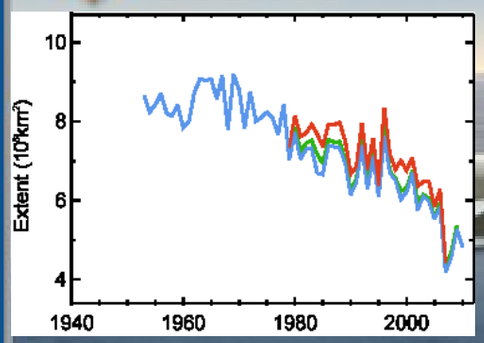
Snow



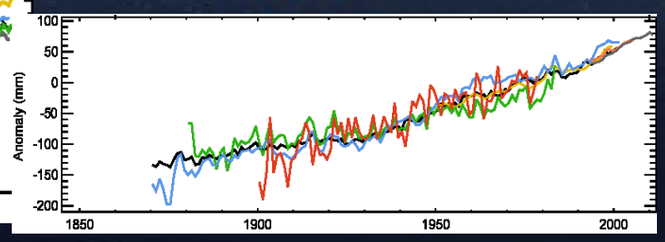
Glaciers



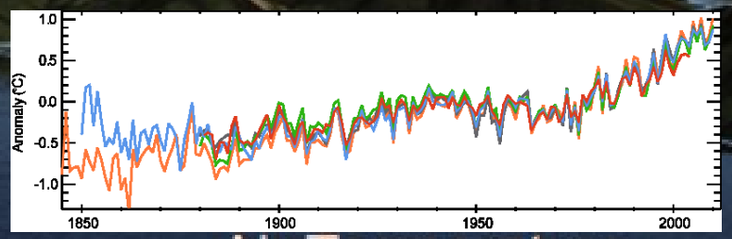
Arctic Sea Ice



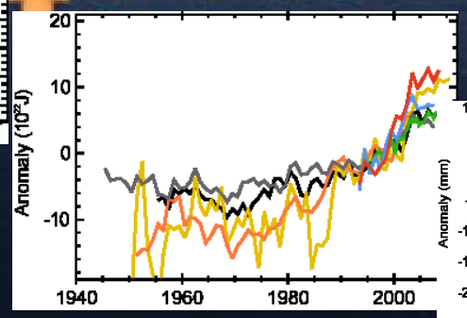
Global Sea Level



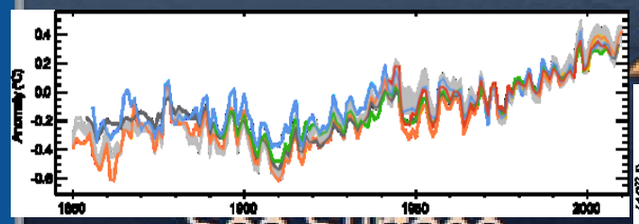
Air Temperature over Land



Ocean Heat



Sea Surface Temperature

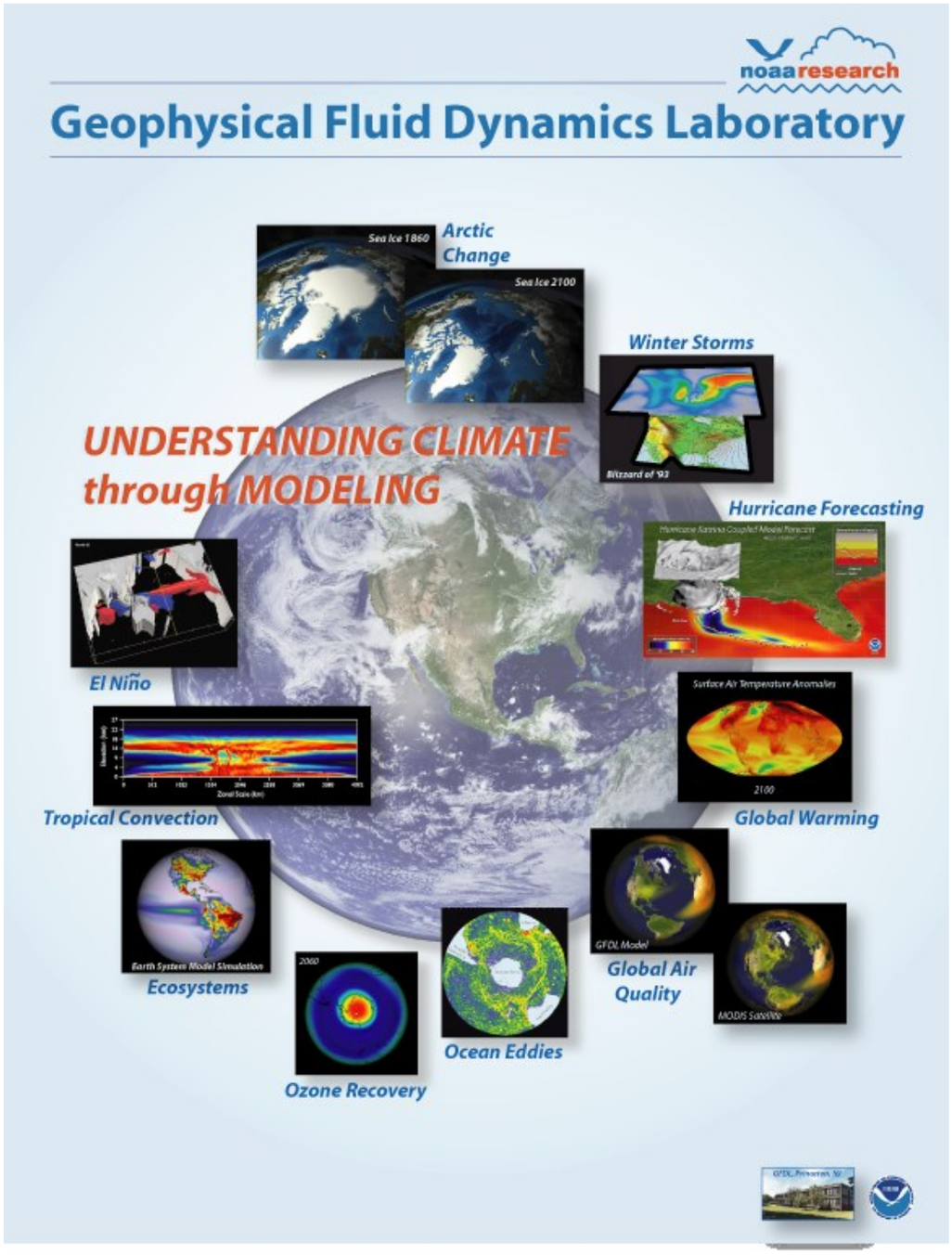


Source: National Climatic Data

A World-Class Modeling Capability to Address Critical Environmental Issues Exists Now in NOAA/GFDL

Presentation to Commerce Dep. Sec.

Aug 25, 2007



NOAA/GFDL has one of the best climate models in the world

An Earth System Modeling capability to address complex environmental global change issues is coming on line, with additional applications in ecosystems based management, global air quality and climate, and exploration of technological mitigation proposals

GFDL, with its University partners is positioned to make rapid progress on: hurricanes and climate; droughts in the past and in the future; role of oceans in climate and ocean-related changes