NOAA/ GFDL State-of-the-Science

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Frontiers in Climate and Earth System Modeling: Advancing the Science

Geophysical Fluid Dynamics Laboratory

May 20, 2013

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 Research → Addressing NOAA NGSP Objectives

Climate Adaptation and Mitigation

- *Improved scientific understanding of the changing climate system and its impacts*
- *Assessments of current and future states of the climate system that identify potential impacts and inform science, service, and stewardship decisions*
- *Mitigation and adaptation efforts supported by sustained, reliable, and timely climate services*
- *A climate literate public that understands its vulnerabilities to a changing climate and makes informed decisions*

Weather-Ready Nation

- *Reduced loss of life, property, and disruption from high-impact events*

Healthy Oceans

- *Improved understanding of ecosystems to inform resource management decisions*

Science and Technology Enterprise

- *A holistic understanding of the Earth system through research*
- *An integrated environmental modeling system*

Lead-up to this Symposium

- Successes and limitations in IPCC AR4 (2007) led to critical appraisal, learning process, and innovative research.
- Development of newer models over the past 5 years to address emergent challenges in climate science.
- *NOAA high-performance computing systems (ARRA-2010)*.
- *WCRP/ CMIP5* ➔ Numerical integrations, applications of newer models to key questions. Inputs to CMIP5 archive on schedule. Several publications (~100), more on the way.
- Data and findings made available to the *National Climate Assessment* and *IPCC AR5 (2013)*.

A major guidepost ➔ "Advancing Climate Modeling" [NRC, 2012]

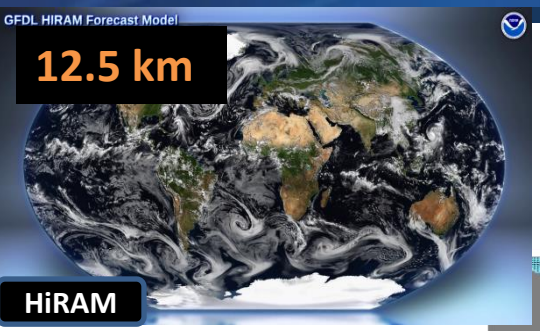
What this Symposium is about

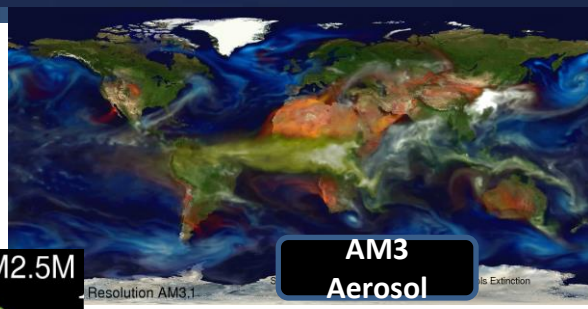
- *Presenting some of GFDL's latest scientific findings on the key science questions*
- Principal focus on the scientific advances made since the GFDL October 2011 Symposium
- How are the advances contributing to NOAA's Mission?

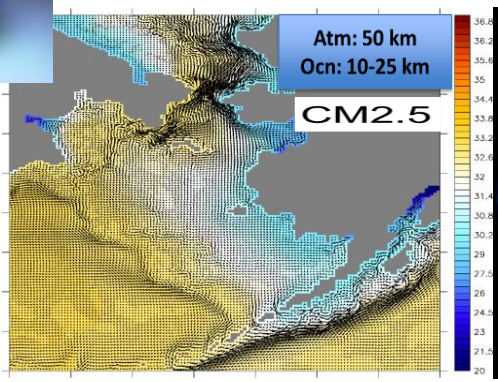
Visit:

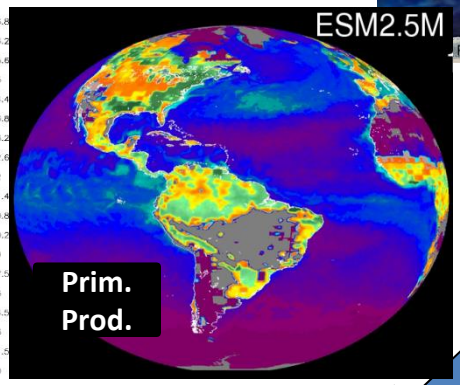
- **GFDL Strategic Science Plan [June, 2011]**
- **www.gfdl.noaa.gov**

NOAA/ GFDL Climate Modeling ➔ Advancing the Science ➔ Meeting the NGSP Climate Objectives



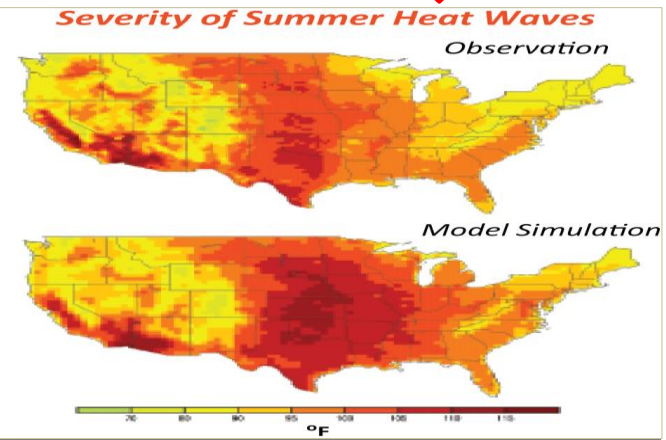


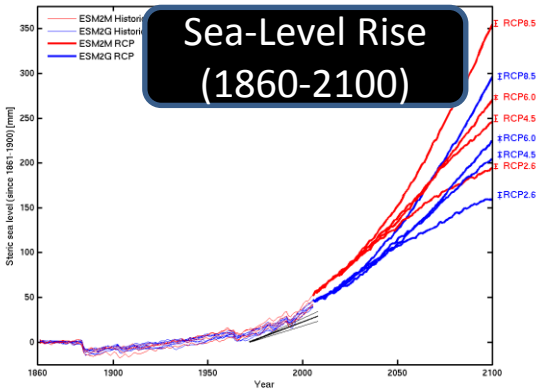


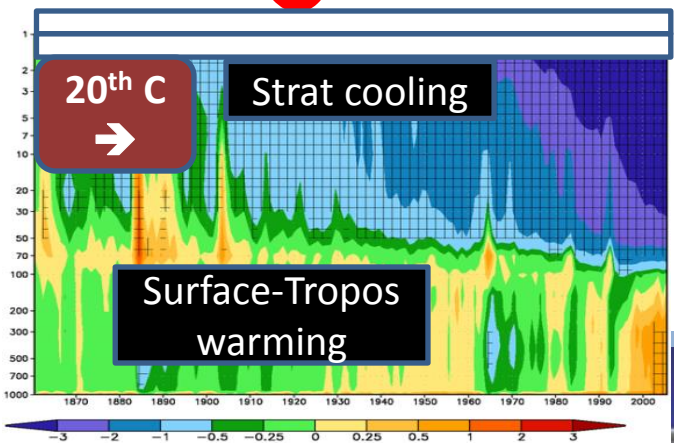


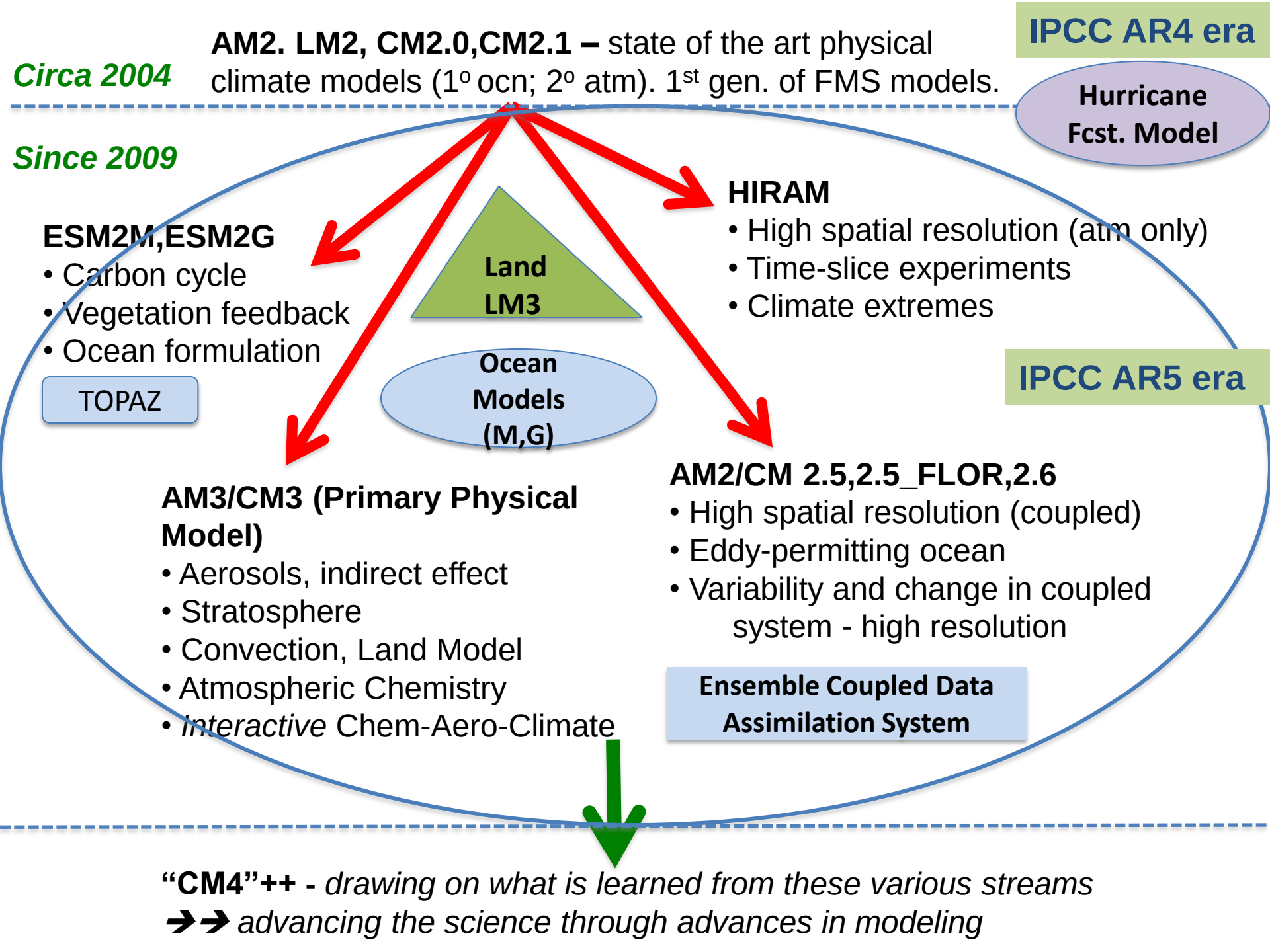
Resolution

Earth System Complexity

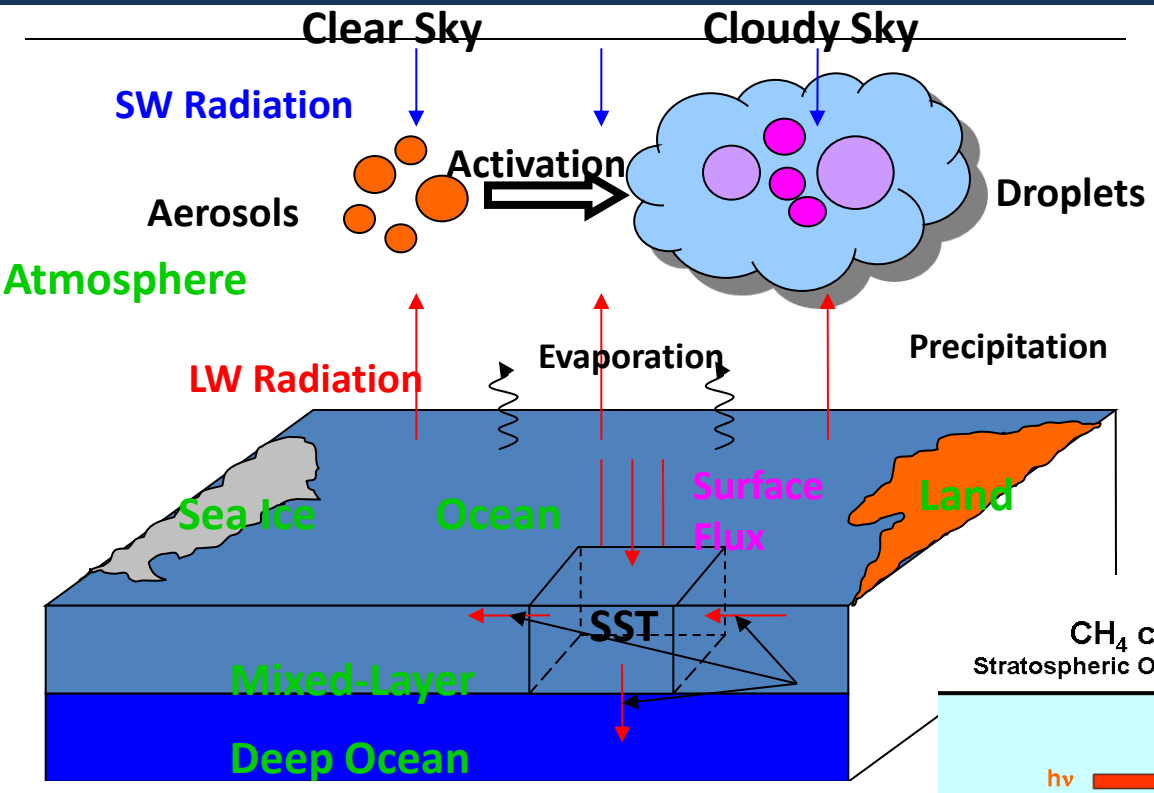






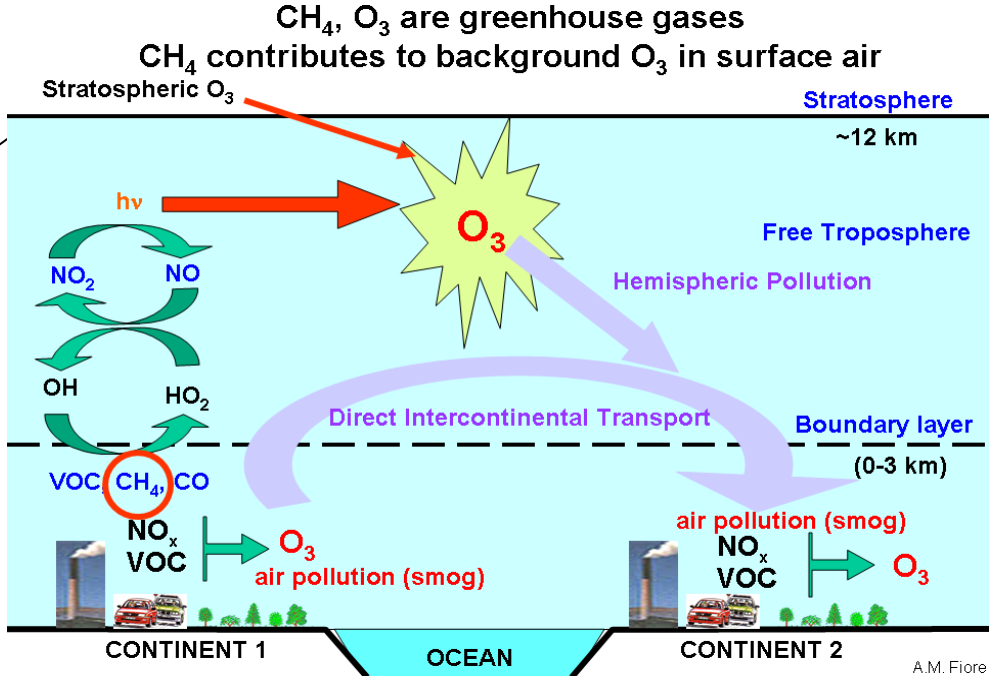

IPCC AR4 era
Circa 2004
AM2. LM2, CM2.0,CM2.1 – state of the art physical climate models (1º ocn; 2º atm). 1st gen. of FMS models.
Hurricane Fcst. Model
Since 2009
HIRAM
• High spatial resolution (atm only)
• Time-slice experiments
• Climate extremes
ESM2M,ESM2G
• Carbon cycle
• Vegetation feedback
• Ocean formulation
TOPAZ
Land LM3
Ocean Models (M,G)
IPCC AR5 era
AM3/CM3 (Primary Physical Model)
• Aerosols, indirect effect
• Stratosphere
• Convection, Land Model
• Atmospheric Chemistry
• Interactive Chem-Aero-Climate
AM2/CM 2.5,2.5_FLOR,2.6
• High spatial resolution (coupled)
• Eddy-permitting ocean
• Variability and change in coupled system - high resolution
Ensemble Coupled Data Assimilation System
"CM4"++ - drawing on what is learned from these various streams
➔➔ advancing the science through advances in modeling

Interactive Chemistry-Aerosol-Climate
[The Short-lived Climate Forcers]



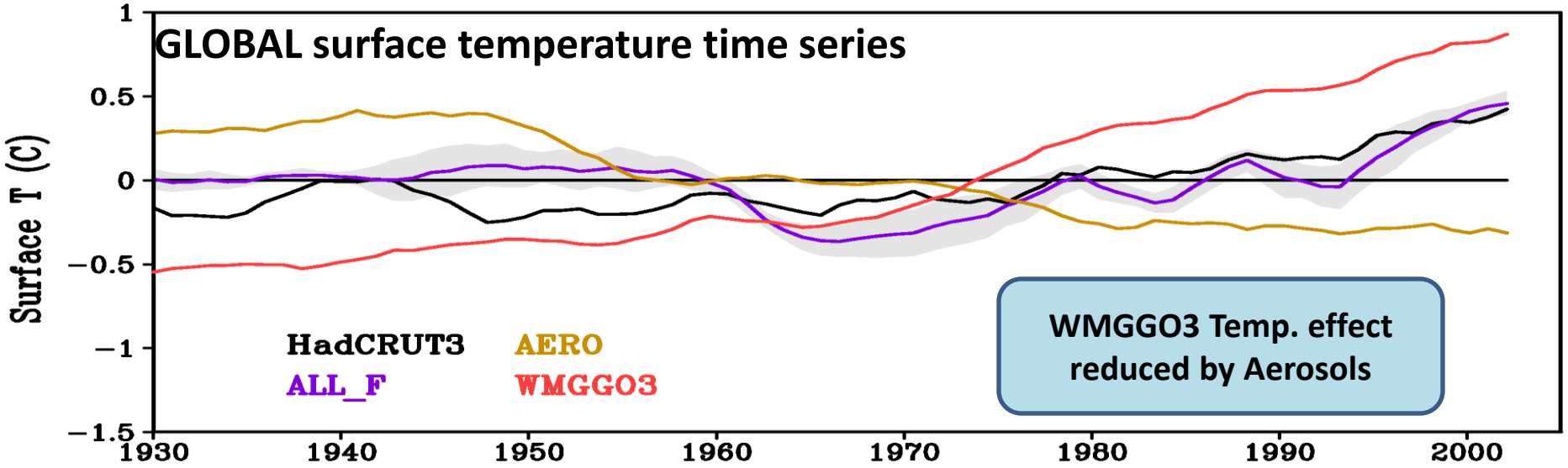
Aerosols and Climate

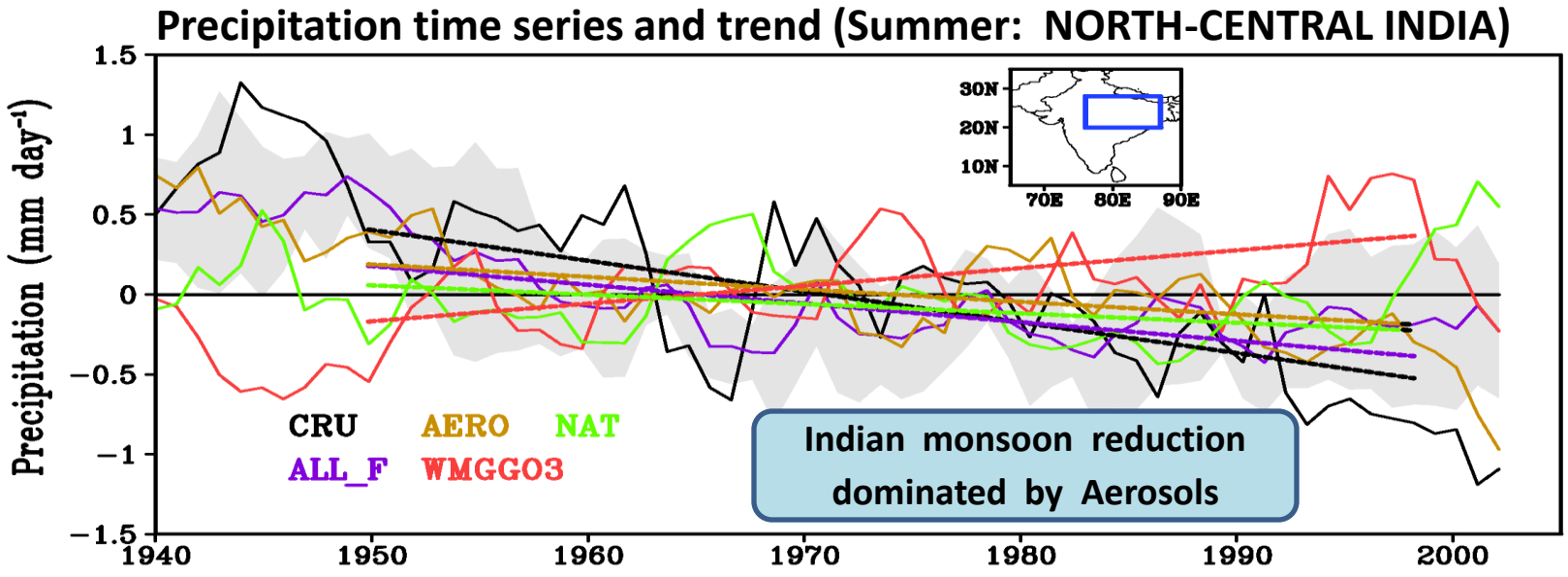
Global Air Quality and Climate



A.M. Fiore

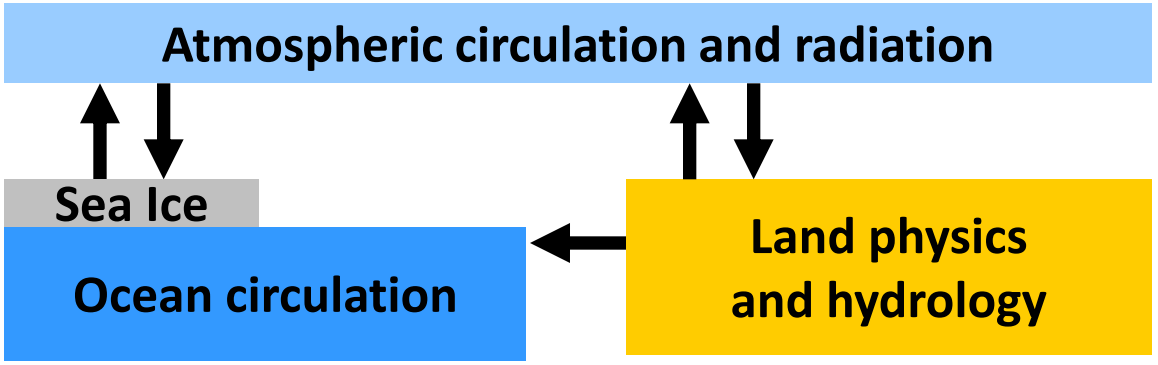
Greenhouse Gases vs. Aerosols [Bollasina et al., 2011]



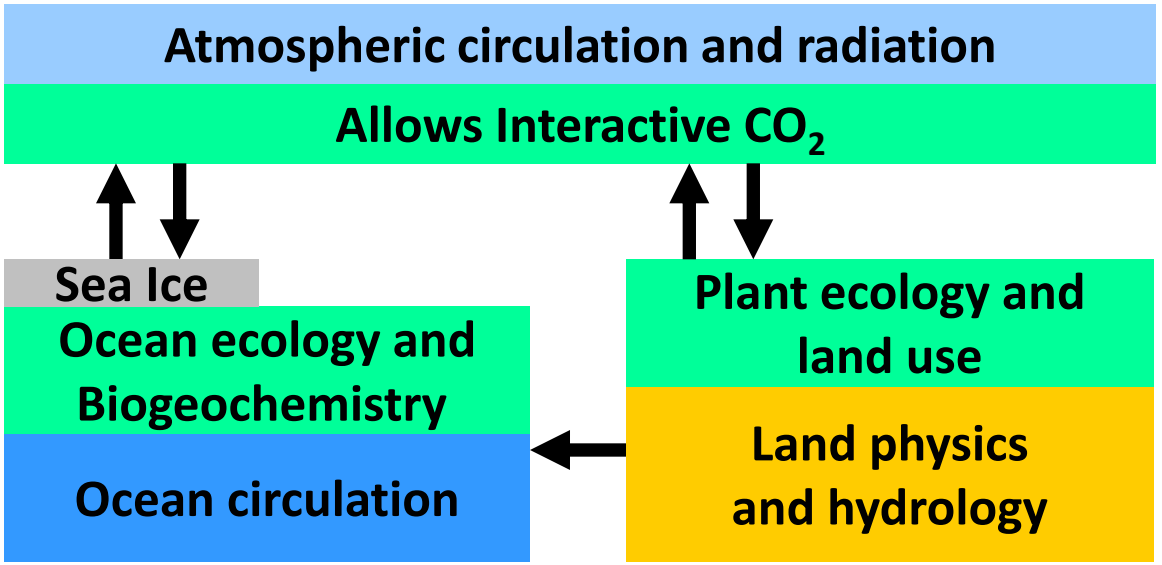


From Physical Climate to Earth System modeling
[An Earth System Model (ESM) closes the carbon cycle]

Climate Model



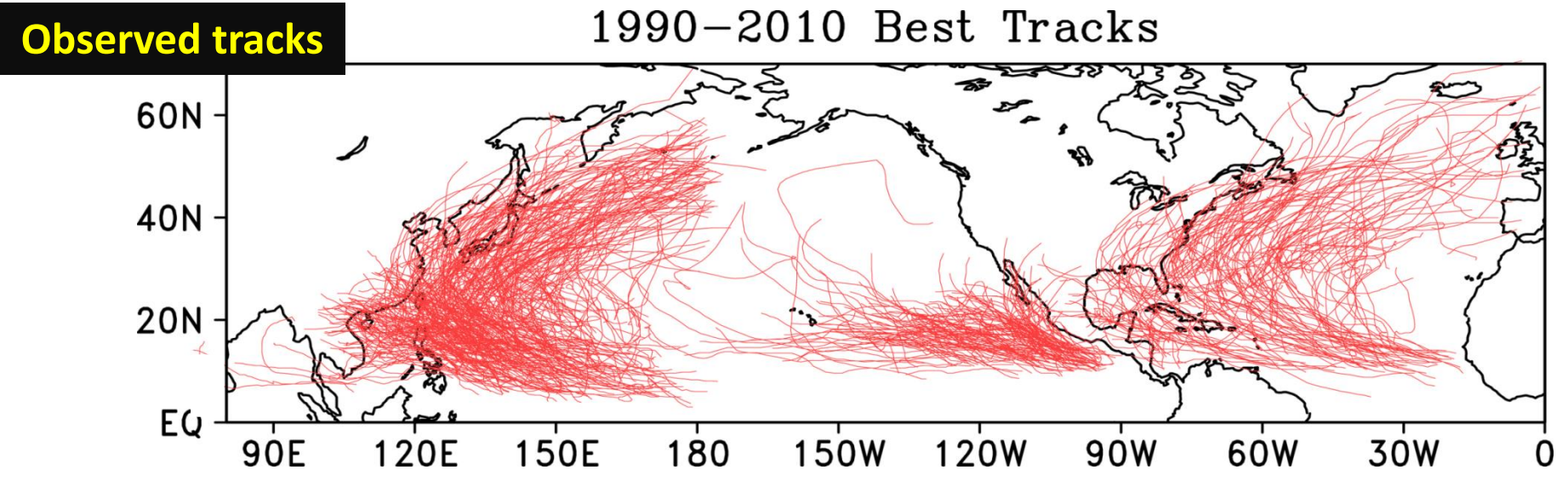
Earth System Model



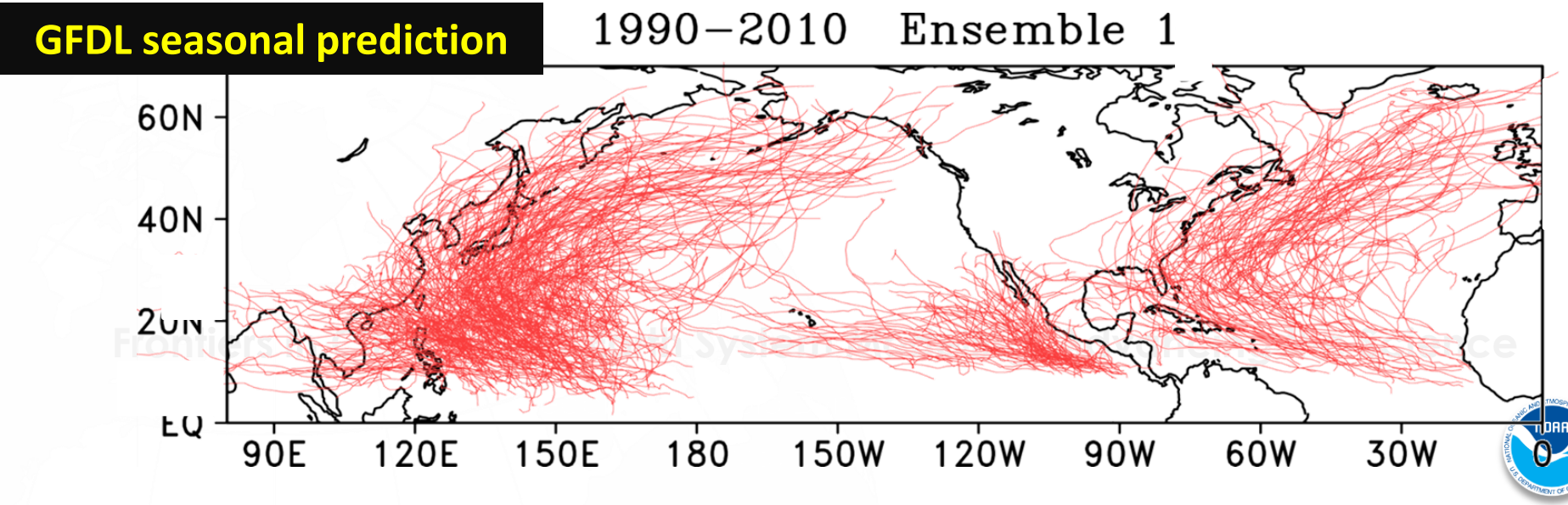
Seasonal hurricane predictions with GFDL's 25-km global model (HiRAM)

(Chen & Lin 2013)

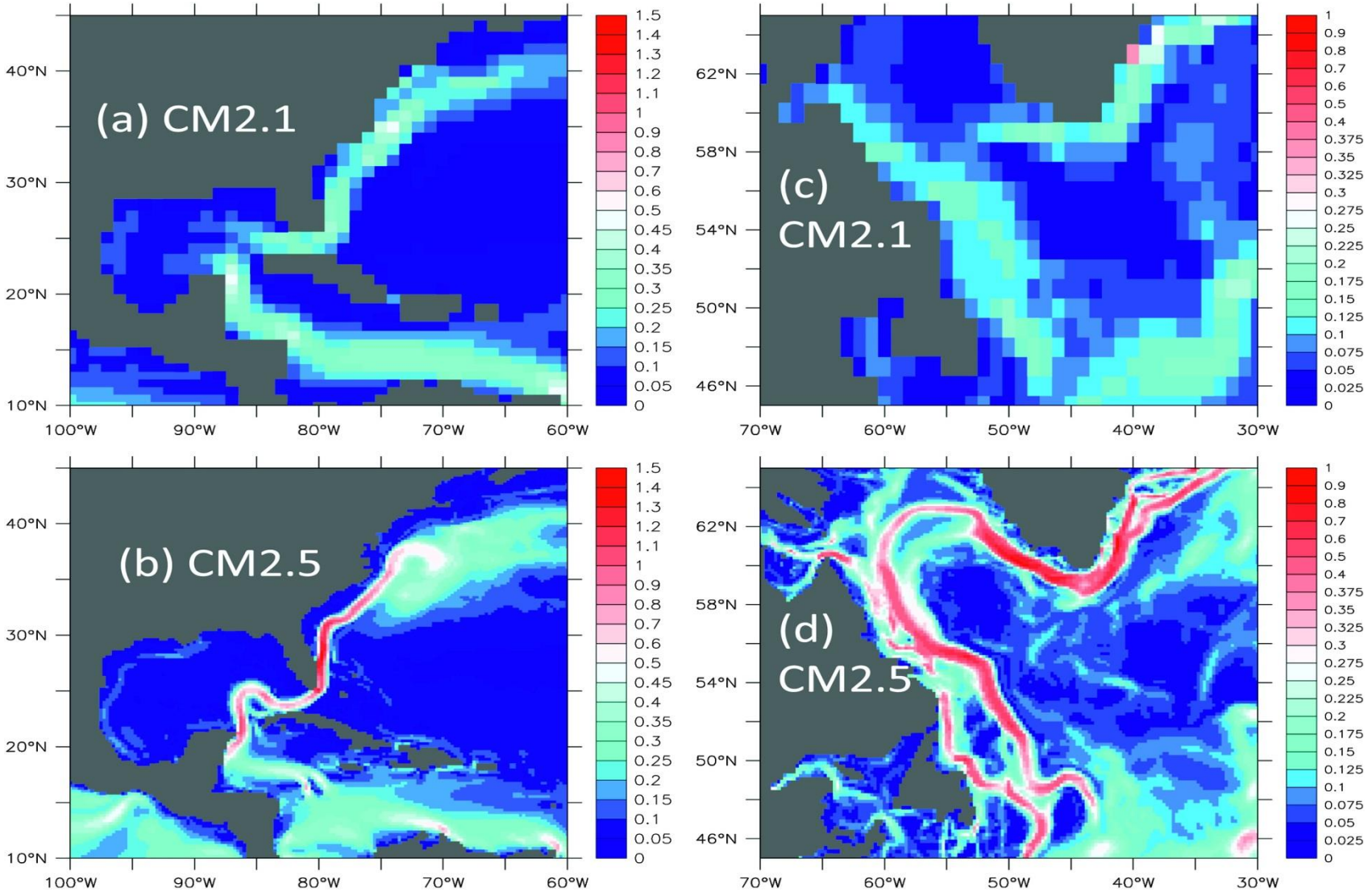
Observed tracks



GFDL seasonal prediction



Annual mean surface current speed (m/s) in the Gulf Stream region and Labrador Sea region



Delworth et al. (J. Climate, 2012)

Components of Dynamical Prediction and Projection Systems

- **Observing Systems**
- **Assimilation Systems**
- **Models**
- **Changing radiative forcing**

Initial Value Problem
(synoptic to seasonal prediction)

Boundary Value Problem
(multi-decadal to centennial projection)

Decadal Predictions and Projections

Goal: ***Unified system for predictions and projections. Seasonal -decadal -centennial***
"Seamless" ➔ ➔ "NRC Report: Advancing Climate Modeling" (2012)

Point: System also relevant for understanding and attribution of observed change

GFDL's Modeling Collaborators and Customers [Federal Agencies]

R & D with OAR/ NOAA: Observational and model simulations analysis

DOE, NASA, NSF(NCAR), USDA, USGS ⟷ **GFDL** ⟷ **NWS-NCEP**

Activities:

- Dy-cores. Climate model development
- Understanding model differences
- Community based modeling framework
- Joint projects on next-gen high resolution models, model-obs comparisons
- Projects on climate, chemistry and carbon cycle, and Earth System modeling
- Use of satellite, surface obs. with models

Activities:

- NOAA common modeling framework for Earth System Models
- Seasonal forecasting
  - Routine experimental forecasts
  - NMME
- Modular Ocean Model (MOM) *sustained developments*
- Hurricane model

Inter-agency modeling links → USGCRP - IGIM

PU/ CICS and NOAA/ GFDL
➔ A Vibrant, Synergistic and Productive Relationship

- Graduate Teaching, Education & Visiting Scientists Programs:
  - **10 GFDL scientists on PU Faculty and on Doctoral dissertation committees;**
  - **26 Ph. D. dissertations (1999-2012), 98 since inception;**
  - **Long-term CICS scientists in key portfolios;**
  - **272 Visiting Scientists to-date;**

- **Earth System Research**: Ocean Biogeochemistry, Land-Surface Modeling, Ecology
- **Leveraging PU Carbon Mitigation Initiative** (BP & Ford) – focus on developing capability to monitor carbon sources and sinks

- **Collaborations** : Princeton Environmental Institute, Ecology and Evolutionary Biology, Civil and Environmental Engineering, Mechanical Engineering, Applied Mathematics, Physics, Woodrow Wilson School, PICSciE (computational science),….

GFDL's Collaborators/ Partners…….continued

- Climate diagnostics and Climate change research

- National Climate Process Teams [CPTs – Oceans, Atmosphere]
- South Central Climate Center [University of Oklahoma, DOI]
- NOAA and multi-agency Field Campaigns [e.g., ICARTT, VOCALS, CalNex]
- Joint workshops, research [NOAA/ CPO, NMFS, CINAR; DOE/ ARM,…..]

- UCAR [Visiting Scientists – 35 to date]
- Internships [NOAA/Hollings, NOAA/NCAS, Princeton, MPOWIR,……]

- International [WMO, WCRP (*CLIVAR, GEWEX, SPARC, CLiC*) , IGBP, UNEP,….]
- Governmental [Australia, Taiwan, South Korea, India, China/Hongkong, Japan, UK, European Union, France,……..]

- Other Universities: Over 50 in US. Over 20 abroad
- Private sector: [Willis Re, DuPont]

Major research challenges
[*from the GFDL 5-10 year Strategic Science Plan, June 2011*]

➔ **Higher spatial resolution and increased Earth System realism**

- Short-lived species effects in the 21st C (Aerosols, Ozone)
- Aerosol-cloud-precipitation-climate feedbacks

- Hydrologic cycle: regional-to-local aspects
- Tropical storms : frequency, trajectory, landfall, trends
- Seasonal-to-decadal Predictability: natural variation and forcing

- Land-ice and cryosphere; polar (Arctic , Antarctic) climates
- Extremes and abrupt changes in climate and Earth System

- Biogeochemical cycles, exchanges between atmosphere, ocean and land, and interactions with the physical climate
- Climate change impacts on sea-level rise and ecosystems

Gaea……beyond ??

Computational challenges

- ❑ **Processor speeds have stalled, all increases from increased concurrency**
- ❑ **Large software challenge as new hardware paths may contain unattainable flops!**

Different scientific goals have different throughput requirements

- Process studies, weather to seasonal prediction: ***0.5-1 year/day***
- Dec-Cen studies, IPCC: ***5-10 years/day***
- Carbon and nitrogen cycles, paleoclimate: ***50-100 years/day***

Computational capacity gets consumed along 3 axes

- **Resolution:** N^4 increase in capacity ➔ only N increase in resolution
- **Complexity:** new processes and components e.g AM3/AM2=8; ESM/CM=3
- **Ensemble size:** quadratic in resolution (increased resolution ➔ larger ensembles)

Requires: judicious, balanced investment between hardware (flops) and software (parallelism at multiple depths; concurrent algorithms)

Building credibility and trust

- Providing NOAA with world-leading research, and delivering state-of-the-art products in a timely manner.
- *Balancing* ➔resources, resolution, complexity
- Aiming for robustness, and quantifying the uncertainties
- Maintaining a healthy *brainware-to-hardware* ratio
- Lead-time and commitment to the research challenges
- Recognizing the science opportunities, which occur at disciplinary interfaces and at boundaries of domains
- Sustaining the quality, integrity and rigor

Frontiers in Climate and Earth System Modeling: Advancing the Science

Agenda

Time	Theme	Speaker	Panel	Moderator
8:30 - 8:55 am	**NOAA/GFDL STATE -OF-THE-SCIENCE**	*V. Ramaswamy*		
9:00 - 9:35 am	**GFDL CONTRIBUTIONS TO THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 5th ASSESSMENT (IPCC AR5)**	*R. Stouffer* *L. Horowitz*		
9:40 - 10:35 am	**CLIMATE VARIABILITY AND SENSITIVITY:** ***OCEAN AND ICE PERSPECTIVES***	*M. Winton* *R. Zhang*	*S. Griffies* *M. Harrison* *J. Russel* *O. Sergienko*	*A. Broccoli*
10:35 - 11:00 am	*Coffee Break*			
11:00 - 11:55 am	**CLIMATE PREDICTABILITY ON SEASONAL, INTERANNUAL AND DECADEL SCALES**	*G. Vecchi* *S. Zhang*	*M. Zhao* *X. Yang* *B. Stern* *T. Marchok*	*A. Rosati*
12 pm - 1:00 pm	*Lunch*			
1:00 - 1:55 pm	**AEROSOLS, CHEMISTRY, CLOUDS AND RADIATION**	*Y. Ming* *C. Golaz*	*M. Lin* *P. Ginoux* *D. Paynter* *V. Naik*	*L. Donner*
2:00 - 2:55 pm	**REGIONAL CLIMATE, EXTREMES AND IMPACTS**	*K. Dixon* *A. Wittenberg*	*T. Knutson* *S Kapnick* *K. Findell* *PCD Milly*	*G. Lau*
2:55 - 3:20 pm	*Coffee Break*			
3:20 - 4:15 pm	**CLIMATE, CARBON AND ECOSYSTEMS INTERACTIONS**	*J. Dunne* *C. Stock*	*R. Hallberg* *E. Shevliakova* *J. John* *V. Saba*	*R. Toggweiler*
4:20 - 5:30 pm	**NEW MODELING CAPABILITIES ADVANCING NOAA CLIMATE SCIENCE**	*I. Held* *S. J. Lin* *S. Adcroft*		*T. Delworth*
5:30 pm	*Adjourn*			

The END

Thank you for your attention !