

State of GFDL

Presented by

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Geophysical Fluid Dynamics Laboratory Review

May 20 – May 22, 2014



WELCOME TO NOAA/OAR/GFDL

The Legacy (our former Directors):

Drs. Joseph Smagorinsky, Jerry Mahlman, Ants Leetma

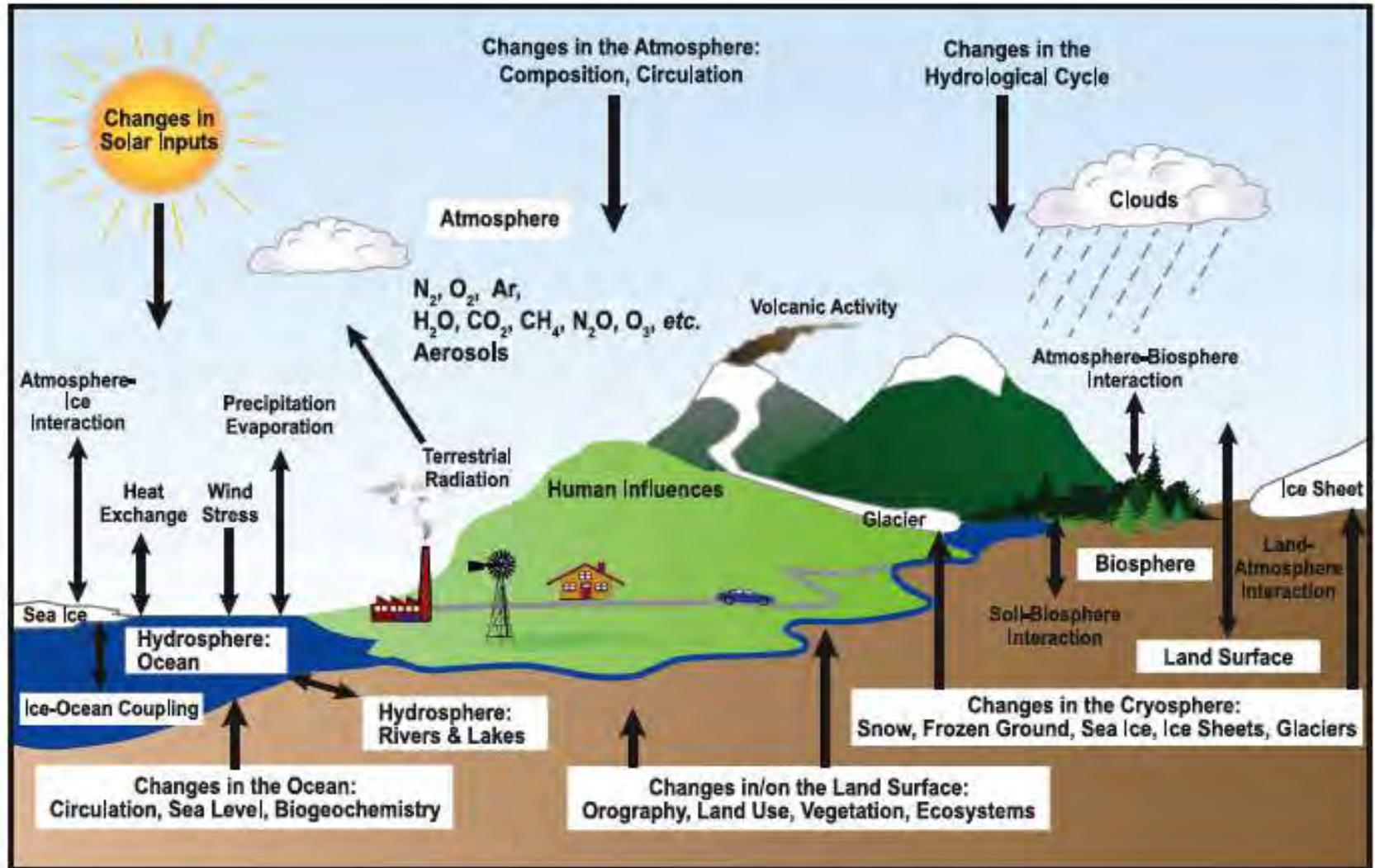


GFDL Mission Statement

*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.”

Capturing the complex Earth system ...



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*

GFDL Research ⇒ Addressing NOAA Goals and Objectives

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*

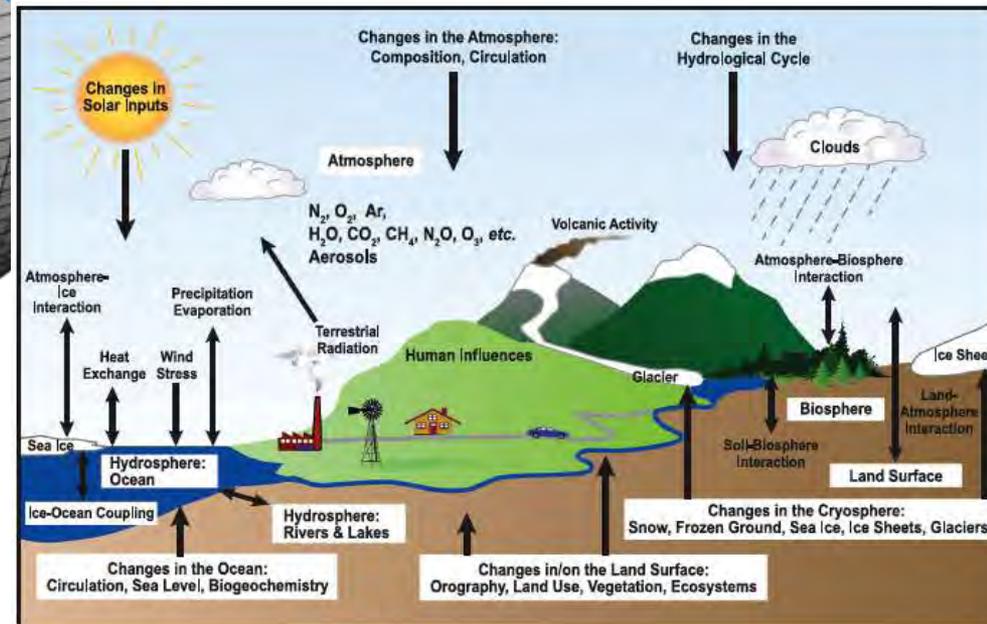
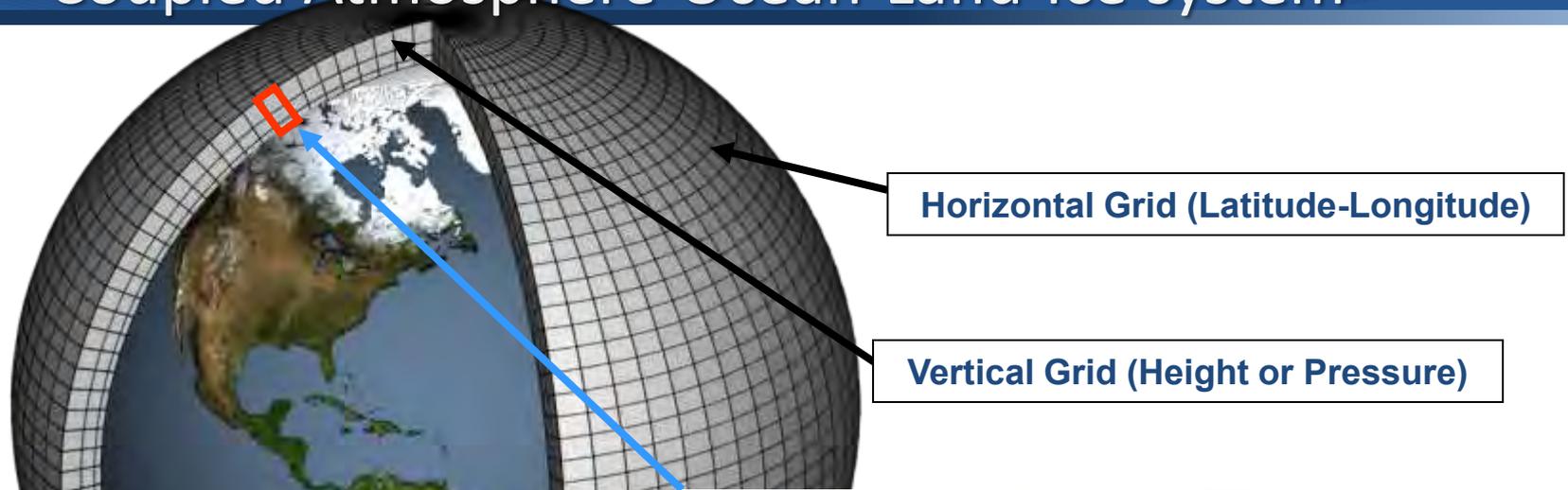
Science and Technology Enterprise

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

For GFDL to be a world leader:

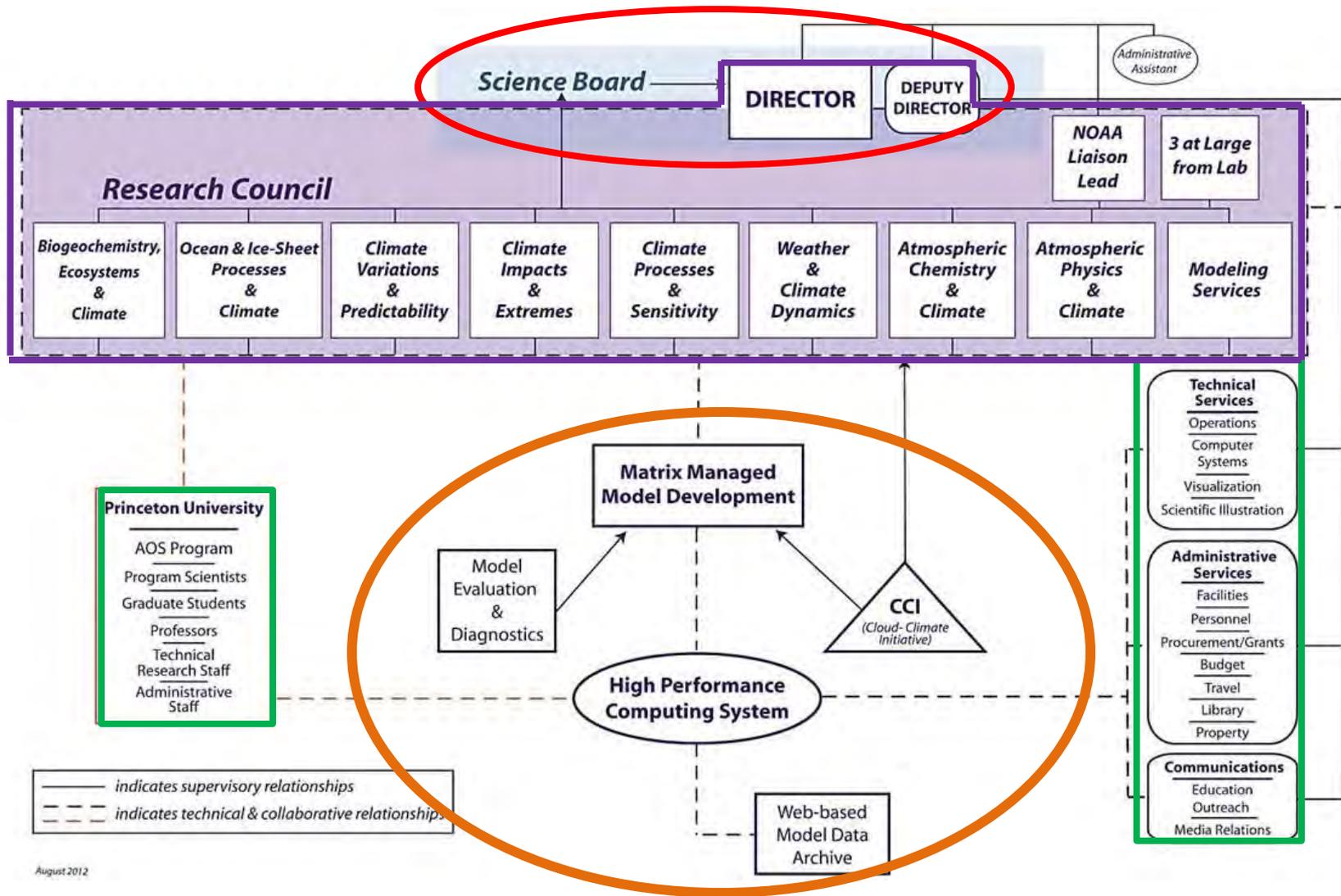
- **Recognition by the peer science community**
 - Journal publications
 - Assessments
 - Departmental/Agency internal and external acclaim
 - Lab reviews
- **Accomplish NOAA's objectives in**
 - Science directed to applications
 - Research towards operational purposes

Global Climate Model: Mathematical representation of the Coupled Atmosphere-Ocean-Land-Ice system



NOAA/ OAR/ GFDL
CLIMATE and
EARTH SYSTEM
MODELING

Geophysical Fluid Dynamics Laboratory Organizational Chart



How do we plan our scientific research?

- **Use-inspired research** (*"Pasteur's Quadrant"*), guided by:
 - NOAA Next-Generation Strategic Plan
 - NOAA 5-year R&D Plan and Objectives
 - NRC documents (recent: "Advancing Climate Modeling", 2012)
 - GFDL 5-10 year Strategic Plan
 - Outstanding issues raised by major assessments and reports
- Ideas and discussions: experts, Groups, Research Council, Science Board
- Long-lead-time required to address the scientific challenge, and high-performance computing resources needed
- Consultations with experts at other institutions
- Monitoring developments, course revisions, and calibrating expectations

NOAA Climate Objectives

[Exec. Summary: GFDL 5-10 year Strategic Science Plan, 2011]

GFDL HIRAM Forecast Model



Atmospheric
Dynamics, Physical
and Chemical
Processes

Marine and
Terrestrial
Biospheric
Processes

Role of Oceans in
Climate, and Sea-Level
change

Prediction and
Attribution

Model Development
and Infrastructure

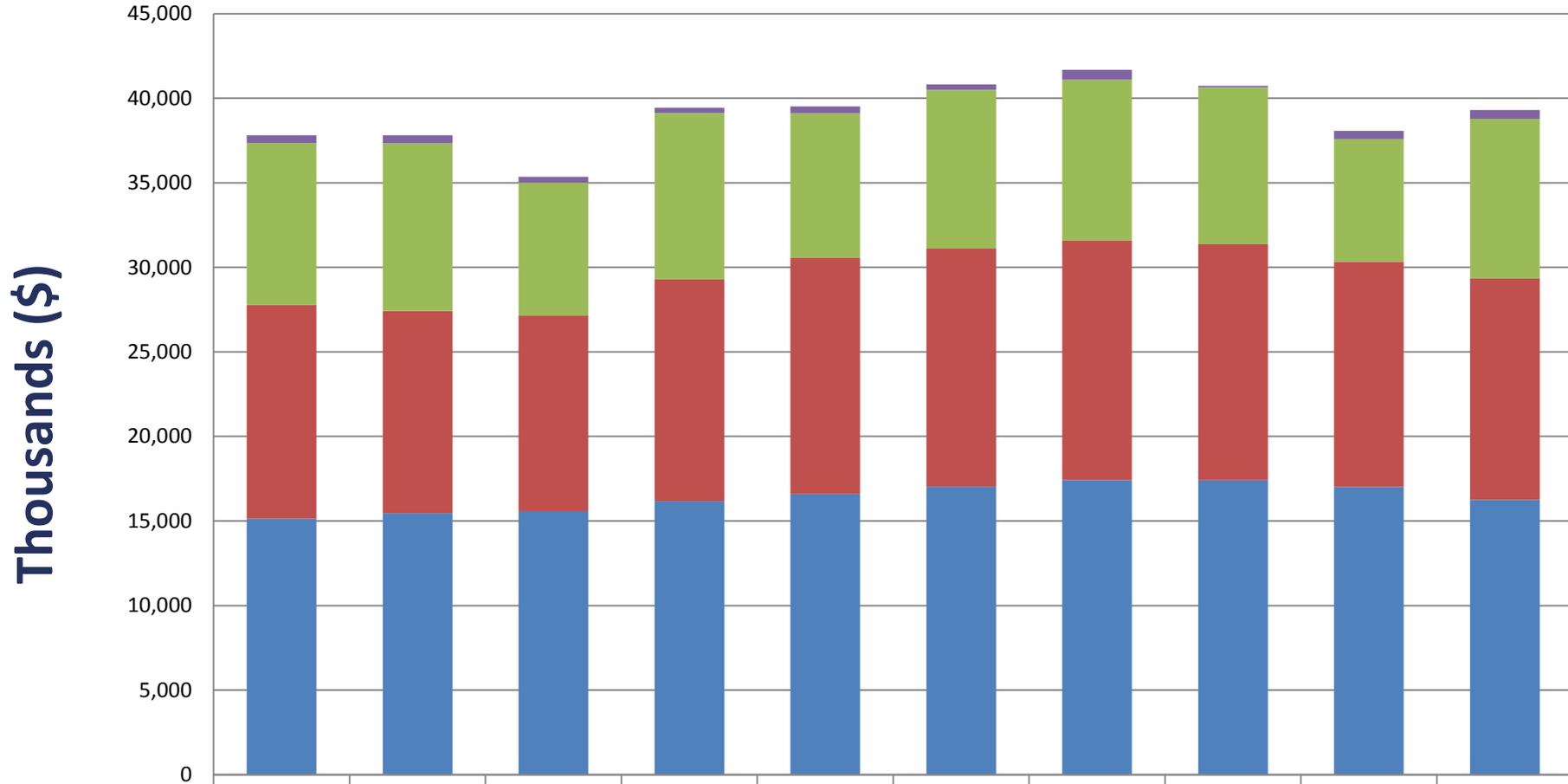


August 26, 2008



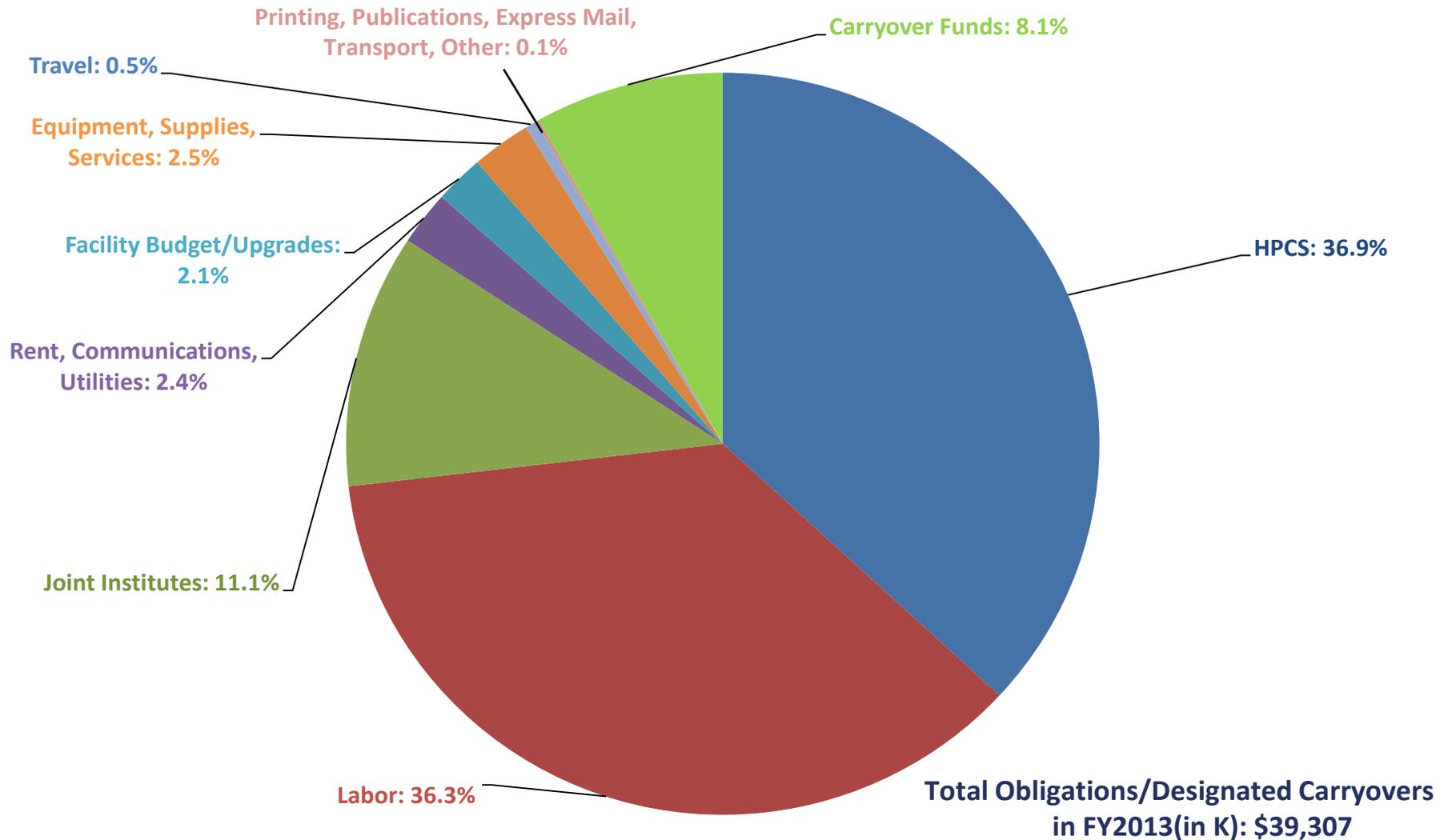
Budget (1k)

Geophysical Fluid Dynamics Laboratory 10-Year History Income Profile



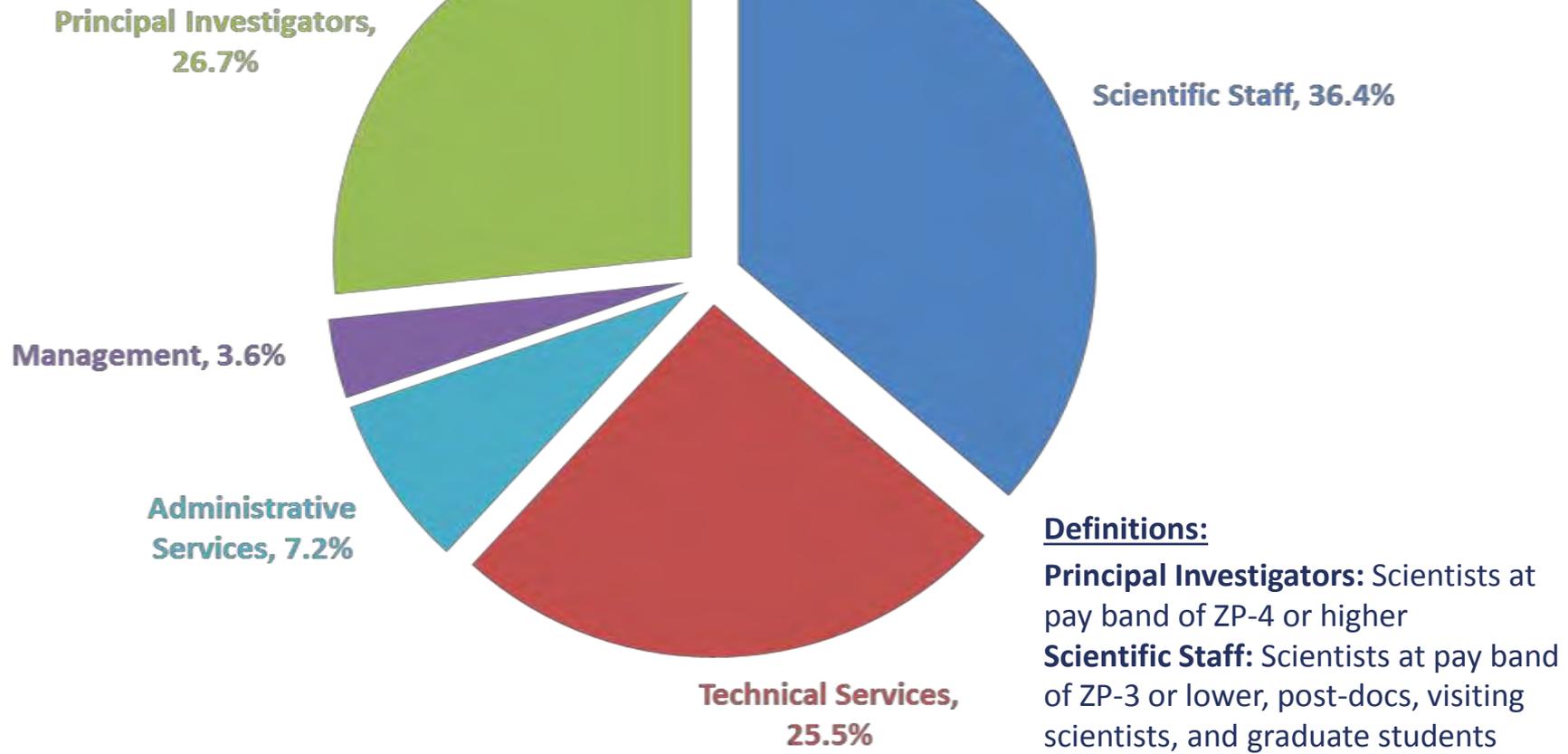
	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13
Other Agency	450	468	344	316	408	332	593	106	492	528
Other NOAA non-HPCS	9,596	9,906	7,870	9,840	8,549	9,379	9,481	9,258	7,254	9,447
Other NOAA HPCS	12,632	11,964	11,569	13,106	13,959	14,069	14,180	13,971	13,315	13,073
Base	15,131	15,462	15,568	16,176	16,598	17,038	17,422	17,405	17,012	16,258

Geophysical Fluid Dynamics Laboratory FY 2013 Expenditures



Geophysical Fluid Dynamics Laboratory 2013 Workforce Distribution

**TOTAL GFDL, CICS, UCAR,
and Other Staff: 165**



50+ years of success

- **1955:** Collaboration established between Princeton's Advanced Study, the Weather Bureau, Air Force, and MIT to develop a computerized model of atmospheric circulation
- **1967:** First model estimate of the impact of CO₂ on global temperature
- **1969:** First model coupling the atmosphere and oceans completed (cited as a "Milestone in Scientific Progress")
- **1985:** First diagnosis of the impact of CO₂ on a warming world
- **1990:** First simulation of the impact of CO₂ on the climate system
- **1991:** First coupled ocean-atmosphere-land model completed (MOM1)
- **1995:** First coupled ocean-atmosphere-land-ice model made Operational
- **1996:** First coupled ocean-atmosphere-land-ice-chemistry model based study of the impact of global warming on the climate system
- **2006:** Development of CM2.0 and CM2.1 completed, two of the world's leading climate models used in 2007 IPCC-AR4.

50+ years [1955-2009] of developing and applying global models of atmosphere, oceans, and climate, and continuing

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).**

IPCC AR4 era
Circa 2004

AM2, LM2, CM2.0, CM2.1 – state of the art physical climate models (1° ocn; 2° atm). 1st gen. of FMS models.

Opernl.
Hurricane
fcst model

IPCC AR5 era (> 2009)

Improvements: Atmos.,
Ocn., Land, Sea-ice

ESM2M, ESM2G

- Carbon cycle
- 2 Ocean codes (M,G)
- Sea-level rise
- Terrestrial and marine ecosystems

HIRAM

- Hi-res atmos.
- Circulation patterns
- Extremes: hurricanes heat waves, pollution transports

Improved
Hurricane
fcst model

AM3/CM3 (“Operational” Climate Model)

- *Interactive* Tropospheric and Stratospheric chemistry
- Aerosol-Cloud interactions

Extensions of CM2.1

- Hi-res coupled model (coupled)
- Eddy-permitting ocean
- Ensemble coupled data assimilation
- Variability and change, prediction, attribution, seasonal fcst (NMME)



Lessons from the “streams” (or “branches”) →→ NEXT-GEN state-of-the-art models for advances in scientific understanding, predictions and projections

GFDL's principal products and contributions

- State-of-the-art Climate & Earth System Models; Components; Process modules
 - Made publicly available after vetting process
- Model Output
 - Publicly available through GFDL's Data Portal
- Transitioning products for Operational agencies in U.S. and other countries
 - **MOM** ⇒ NCEP, Australia, Brazil, India, South Africa
 - **Hurricane model** ⇒ NCEP, U.S. Navy
 - **CM2.1 and FLOR** ⇒ North American MultiModel Ensemble [NMME]
 - **Hi-res atmospheric model** ⇒ Taiwan
 - **Dust-generation model** ⇒ Air Force
- Participation/ Leadership: IPCC/ NAS/ WMO Special Reports
 - **AR5 WG1** ⇒ 1 Lead Author (Summary for Policymakers), 2 Lead Authors, 2 Review Editors; **SREX**
- NRC Report on “Advancing Climate Modeling” (1 GFDL, 1 CICS)
- Presentations: Academic; National, International (exceeds 400 since last Review)

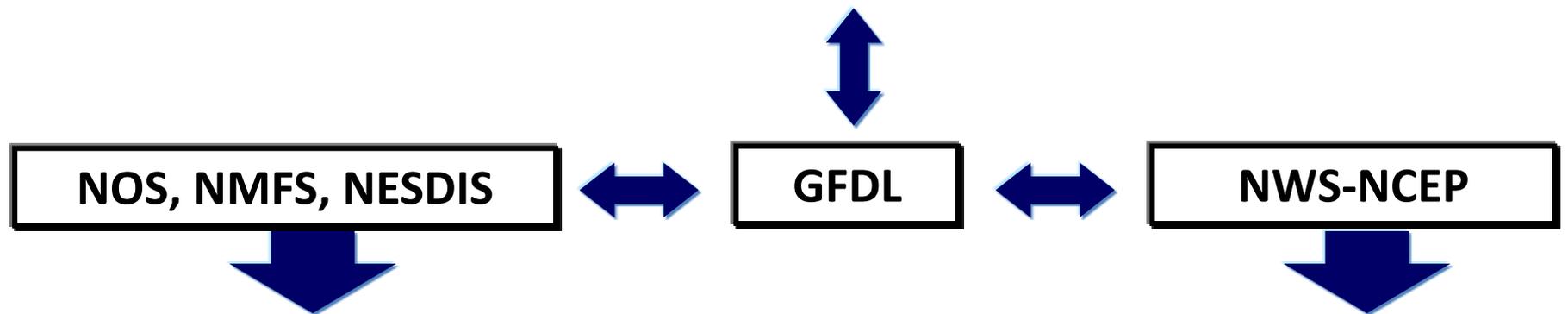
→ A Vibrant, Synergistic and Productive Relationship



- **Graduate Teaching, Education & Visiting Scientists Programs:**
 - 10-12 GFDL scientists on Atmospheric and Oceanic Sciences Program Faculty, who teach courses and are mentors or serve on Ph. D. committees.
 - 8 Ph. D. theses (since 2009). AOS Program: 93 Ph. D. degrees awarded.
 - Long-term CICS scientists (7) in key portfolios at GFDL.
 - 68 Visiting Scientists (since 2009). 292 Visiting Scientists since inception.
- **Earth System Research leverage:** Ocean Biogeochem., Land-Surface Modeling, Ecology
- **Leveraging PU Carbon Mitigation Initiative (BP)** – developing capability to monitor carbon sources and sinks
- ❑ **AOS Program (Geosciences), and Princeton Environmental Institute**
- ❑ **Departments:** Ecology and Evolutionary Biology, Civil and Environmental Engineering, Mechanical Engineering, Applied Mathematics, Physics, Woodrow Wilson School, PICSciE (comp. science),...

GFDL's modeling and linkages with NOAA LOs

R & D in OAR: Simulation-Observation synergy, analysis, understanding



Activities (NOS):

- Restoration and Response: DWH plume modeling
- Sea-level rise

Activities (NMFS):

- Climate and Fisheries
- Climate and Marine Ecosystems

Activities (NESDIS):

- Coral bleaching

Activities (NCEP)

- NOAA modeling framework for Earth System Models
- Seasonal-Interannual
 - Experimental forecasts (NMME)
 - Seasonal hurricane outlook
 - ENSO outlook
- Modular Ocean Model (MOM)
- Oper. hurricane model, forecasts

GFDL's Modeling Collaborators, Stakeholders and Customers [Federal Agencies]

R & D, applications: Use of models and simulations

DOE, NASA, NSF(NCAR),
USDA, USGS*, USACE



GFDL



Activities:

- Dynamical cores. Model development
- Understanding model biases
- Community based modeling framework
- Joint projects on high resolution models, model-observation (satellite, surface, aircraft) comparisons,
- Projects on climate, chemistry, carbon cycle, and Earth System modeling
- Weather-climate Impacts and extremes

Inter-agency modeling links → USGCRP - IGIM

GFDL's Collaborators/ Partnerships... continued

- Climate diagnostics; climate change [CICAR/ Lamont, Columbia University]
- Climate Process Teams [“CPTs” on Atmosphere, Oceans]
- South Central Climate Science Center [University of Oklahoma, DOI]
- NOAA (and multi-agency) field campaigns [ICARTT, VOCALS, CalNex, SENEX]
- Joint workshops, research [NOAA (Grand Challenges, CPO, NMFS, CINAR); DOE/ ARM; NASA; EPA]

- UCAR [**41** Visiting Scientists]
- Internships [**102**: NOAA (Hollings, NCAS/CREST), Princeton, MPOWIR,.....]

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

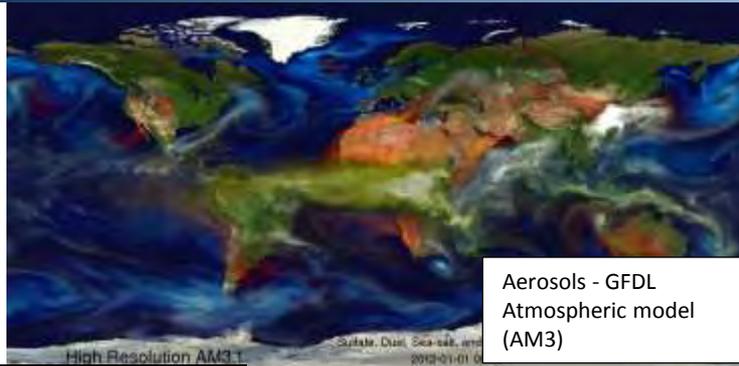
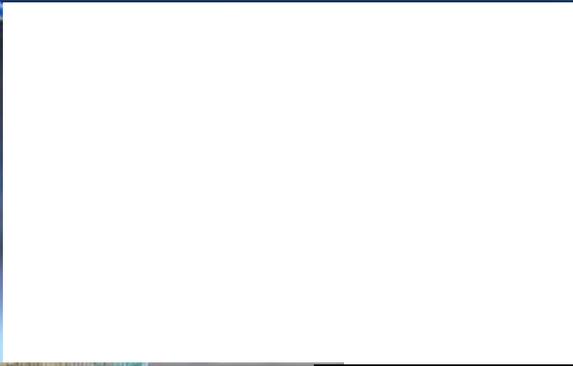
- US Federal and non-Federal partners: **30**. Institutions abroad: **23**
- Private sector: [BP/CMI, Atmos. Research, Willis Re]

NOAA/ OAR/ GFDL Modeling: Advancing the Science

Use-inspired research

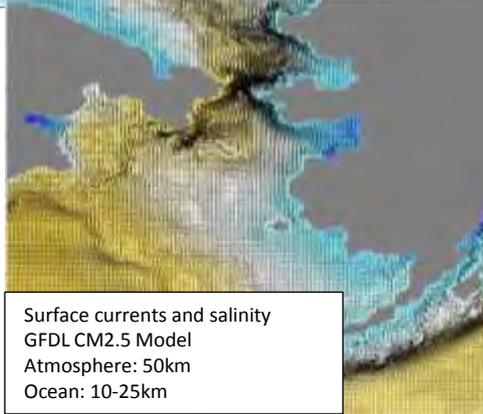


GFDL HiRAM Global climate model
12.5 km resolution

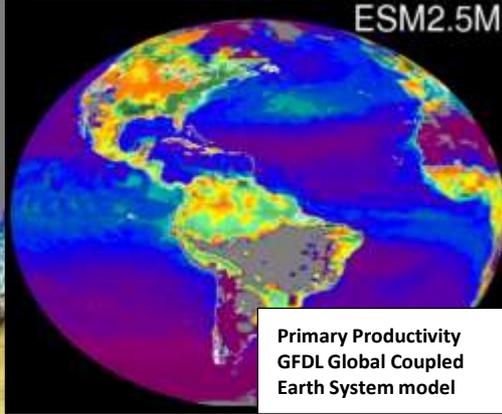


Aerosols - GFDL Atmospheric model (AM3)

Resolution



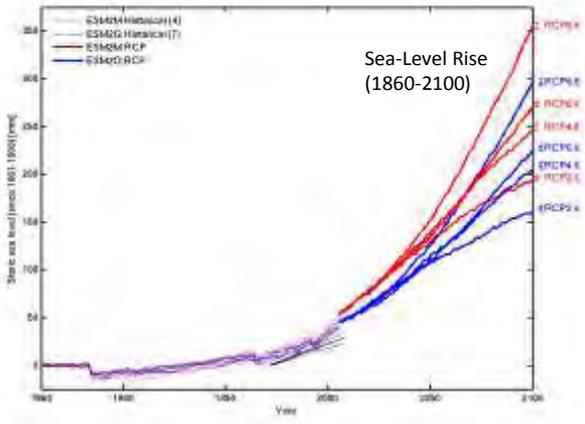
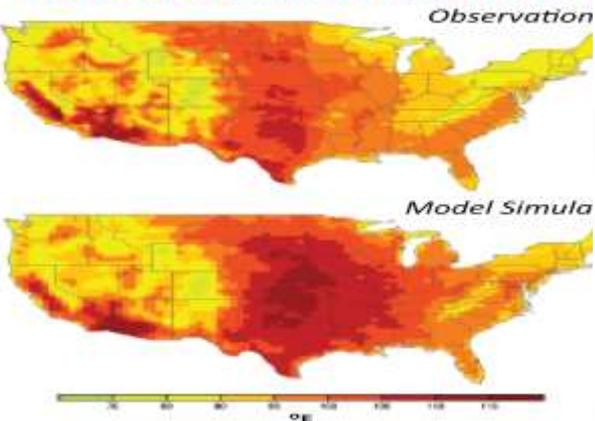
Surface currents and salinity
GFDL CM2.5 Model
Atmosphere: 50km
Ocean: 10-25km



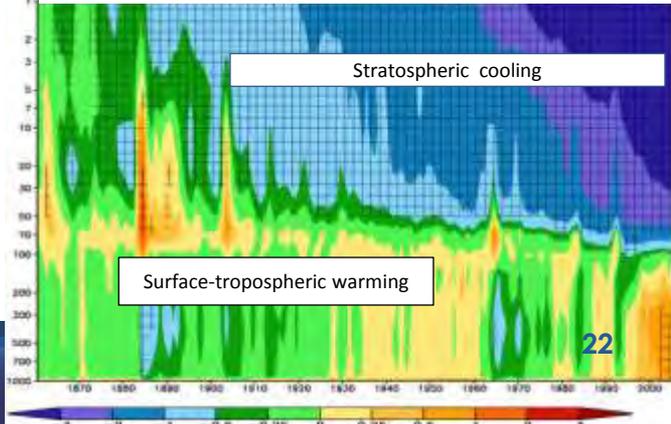
Primary Productivity
GFDL Global Coupled Earth System model

Earth System Complexity

Severity of Summer Heat Waves



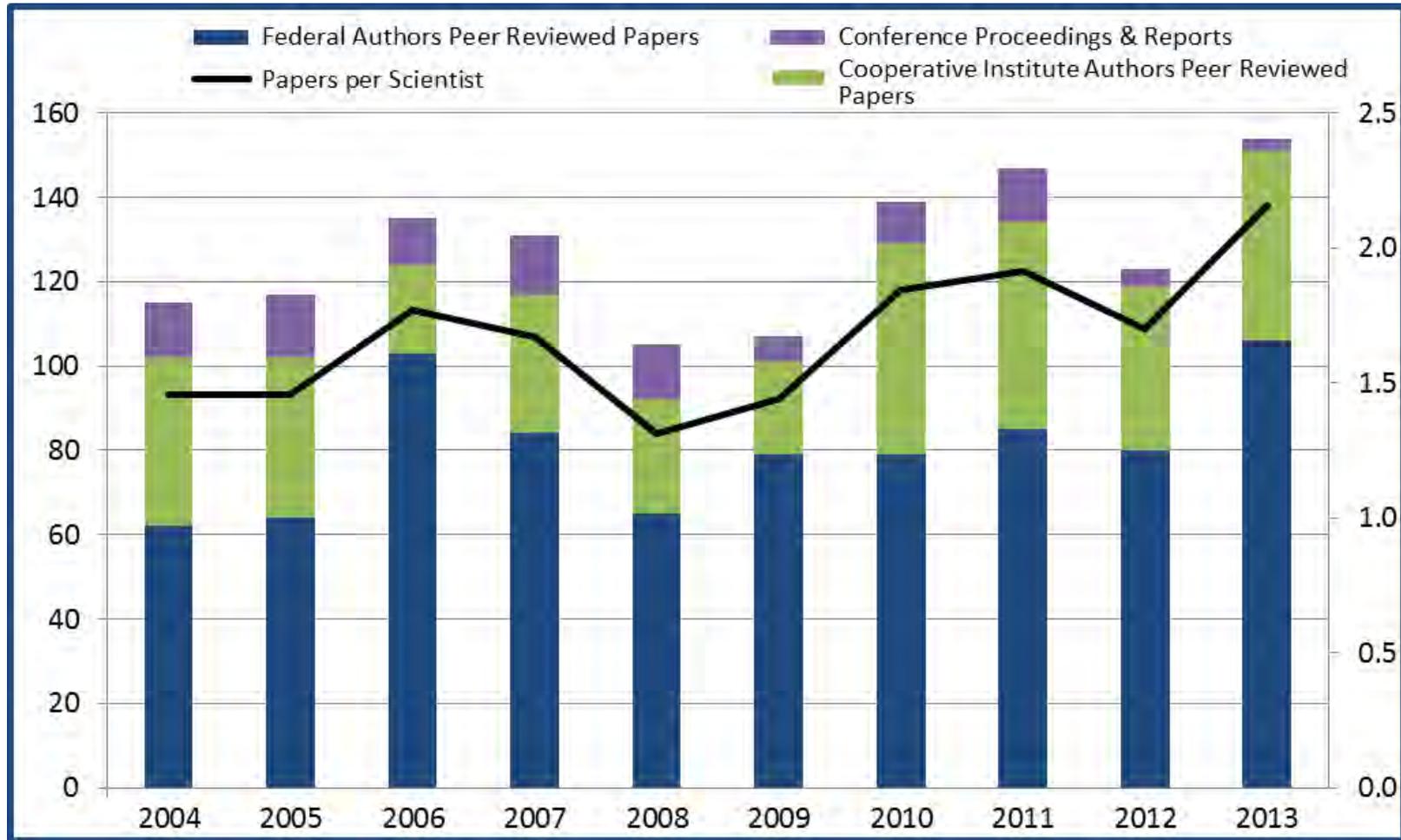
Sea-Level Rise (1860-2100)



Stratospheric cooling

Surface-tropospheric warming

Geophysical Fluid Dynamics Laboratory Publications, FY 2004 - FY 2013



Response to the 2009 Review

- Move to the Main Campus
- National Climate Service
- Preserving core strengths
- Strategic Plan
- Recruit leader in biogeochemistry for ESM
- More engagement with the Decadal Prediction problem
- Expand partnerships: NOAA, Feds, and academia
- Strengthen opportunities for junior scientists
- Nominations committee for achievement awards
- Address minority and gender balance
- Greater transparency and wider Lab participation
- *Review*: synthetic assessment; informal meeting time

Honors, Awards (since 2009)

Major recognitions:

NATIONAL

- Presidential Rank for Distinguished Sr professional
- Bowie Medal (Emeritus)
- Roger Revelle Medal (CICS)
- AGU Hydro. Sciences (USGS)
- 2 AGU Fellows (1 USGS)
- 2 AMS Fellows
- AMS Hydology (USGS)
- AGU Macelwane
- AMS Meisinger
- Presidential Early Career
- Bernhard Haurwitz Lecturer
- Houghton Lecturer (MIT)
- AGU James Holton Young Sc.
- AGU Ascent
- Penn State Alumni Fellow
- 4 Foreign Policy's Leading Global Thinkers of 2013
- 4 Journal Editors' citations
- Student presentation recognitions (AMS, AGU)

DOC / NOAA / OAR

- 17 DOC Gold Medalists
- 15 DOC Silver Medalists
- 32 DOC Bronze Medalists
- NOAA Administrator award (2)
- Distinguished Career award (2)
- Employee of the Year (2)
- NOAA General Counsel (2)
- OAR Graduate Studies Program
- Green Steward
- EEO Counselor
- Energy and Water Management (9)

Models in 3 of the 4 "streams" for CMIP5 have won DOC medals (4th submitted)

INTERNATIONAL

- Kyoto Earth Hall of Fame (Emeritus; Japan)
- BBVA Frontiers of Science (Spain)
- 3 WMO Norbert Gerbier-MUMM Awardees
- Sir Gilbert Walker Chair Professorship (India)
- EGU Nansen Medal (Europe)
- Noble Lecturer – University of Toronto (Canada)
- Bert Bolin Lecturer (Sweden)
- WCRP Open Science Conference: Oral papers (3)
- RAICES Prize (Argentina)
- CSIRO Distinguished Visiting Scientist (Australia)
- Wei Lun Distinguished Visiting Professor (Hong Kong)
- SPARC Conference paper

Understanding, leading to improved Projections and Predictions [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
- Detection-and-Attribution
- Land-ice and cryosphere; polar (Arctic , Antarctic) climates
- Extremes and abrupt changes in the 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” → Next HPC... 2016??



Computational challenges

Capability: Maximum simulated years per day of a single model instance.

Capacity: Aggregate Simulation Years Per Day (SYPD) on available hardware.

Computational capacity gets consumed along 3 axes

- **Resolution**: N^4 increase in capacity → only N increase in resolution
- **Complexity**: new processes and components
- **Ensemble size**: quadratic in resolution (increased resolution → larger ensembles)

Model choices (*resolution, complexity, ensemble size*) based upon

- capability requirements (e.g., 5-10 SYPD for Dec-Cen, 50-100 SYPD for Carbon Cycle)
- available allocation

→ **balanced investment between hardware and software**

Challenges in sustaining world-leading science

- State-of-the-art, high-end, climate and Earth System models – science, service, and stewardship in modeling and applications
- Demand for increased realism → complexity, increased resolution, and ensemble runs
- Uncertainties in budgeting process
- Barriers impeding clarity of purpose e.g., “weather vs climate”
- Matching Lab internal and external expectations
- Federal-level shakiness e.g., shutdown/ furlough, travel restrictions, hiring freezes

GFDL credo

- Strive for exceptional scientific quality and integrity
- Scientific underpinning of NOAA 's Mission through creative, focused research, delivering timely products
- Recruit the best talent, and nurture a healthy environment for research into the hard, long lead-time problems
- Maintain a healthy “brainware-to-hardware” ratio
- Recognize that new opportunities occur at existing boundaries and across traditional disciplines
- Do not compromise on quality and rigor for short-term illusory gains

Arrangement of this Review

TUESDAY

THEME I. Modeling the Earth System

AM: Component models with applications.

Lunch: Hurricane model and CMIP presentation.

PM: GFDL's next-gen model development. Posters.

Panel meets with selected scientists. Review panel (CLOSED). GFDLEA cookout (ALL).

WEDNESDAY

THEME II. Climate Variability and Change: Understanding and Prediction

AM: Prediction.

Understanding internal variability and forced change.

Lunch: Posters. Panel meets with AOS/ CICS graduate students.

THEME III. Chemistry, Carbon, Ecosystems, and Climate

PM: Presentations.

PM: Review Panel meets with Stakeholders.

Concurrent meeting of OAR, Director, Deputy Director with LO reps.

Panel meets with RC, SB, OAR AA and DAA [Dinner].

THURSDAY [ALL sessions CLOSED]

- Panel meets with Cooperative Institute for Climate Science [Princeton University]
- Q&A with GFDL and OAR Management

Acknowledgements

Special thanks to Mary Ann Whitcomb , Michael Uhart, and Anne Hermes for the arrangements leading to this review.

Thanks to Brian Gross, Francis Lazauskas, Steve Mayle and Marian Westley for assistance with this presentation.

Special thanks to the entire GFDL Administrative, Facilities, IT, Scientific and Technical staff for the organization, facilitation, and presentations.



“Climate science has its own stamp” - Earth Day, April 22, 2014

