Geophysical Fluid Dynamics Laboratory Review

June 30 - July 2, 2009

WELCOME TO NOAA / OAR / GFDL

Former GFDL Directors:
Drs. Joseph Smagorinsky, Jerry Mahlman, Ants Leetmaa

Geophysical Fluid Dynamics Laboratory (GFDL) Overview

Presented by

V. Ramaswamy

Director

Geophysical Fluid Dynamics Laboratory Review

June 30 - July 2, 2009

OUTLINE OF PRESENTATION

- Who are we, and what is our role in NOAA?
- GFDL organization
- GFDL's customers and collaborators
- Evolution of GFDL research
- Quality of the research
- Relevance of the research
- How do we plan and perform our research, and fulfill NOAA's objectives?
- What are the challenges faced?

(Additional details about the Review at http://www.gfdl.noaa.gov/2009Review)

GFDL Mission Statement
Department of Commerce Order 2-B (29 July, 1969)

"…the Geophysical Fluid Dynamics Laboratory is to conduct investigations of the dynamics and physics of geophysical fluid systems to develop a theoretical basis, by mathematical modeling and computer simulation, for the behavior and properties of the atmosphere and ocean."

GFDL Objectives

Directly supports the DOC and NOAA strategic goals

Be a world leader for the production of timely and reliable knowledge and assessments on natural climate variability and anthropogenic changes and in the development of the required earth system models.

Work in NOAA to advance its expert assessments of changes in national and global climate through research, improved models, and products.

Address key NOAA overarching issues:
"Causes and consequences of climate variability and change…., factors, human and otherwise,……..uncertainties……."

One of 2 climate modeling centers called for in the nation's Climate Change Science Program*

***now Global Change Research Program (GCRP)**

GFDL Research directly supports:

NOAA Mission:

"To understand and predict changes in Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social and environmental needs"

NOAA Vision:

"An informed society that uses a comprehensive understanding of the role of the oceans, coasts and atmosphere in the global ecosystem to make the best social and economic decisions"

(from NOAA Strategic Plan FY 2009-2014)

GFDL Research directly supports:

OAR Mission:

"To conduct environmental research, provide scientific information and research leadership, and transfer research into products and services to help NOAA meet the evolving economic, social, and environmental needs of the Nation."

OAR Vision:

"A society that uses the results of our research as the scientific basis for more productive and harmonious relationships between humans and the environment."

(from NOAA Research Matters)

GFDL's Research and Products

Support the Climate Mission Goal

- "***Understand climate variability and change to enhance society's ability to plan and respond***"
- **Leading to the following outcomes of the Goal:**

  - *Predictive understanding of the global climate system*

  - Document and understand changes in climate forcings and feedbacks, thereby reducing uncertainty in climate projections

  - Improve skill of climate predictions and projections and increase range of applicability for management and policy decisions

Contribute to the Weather and Water Mission Goal

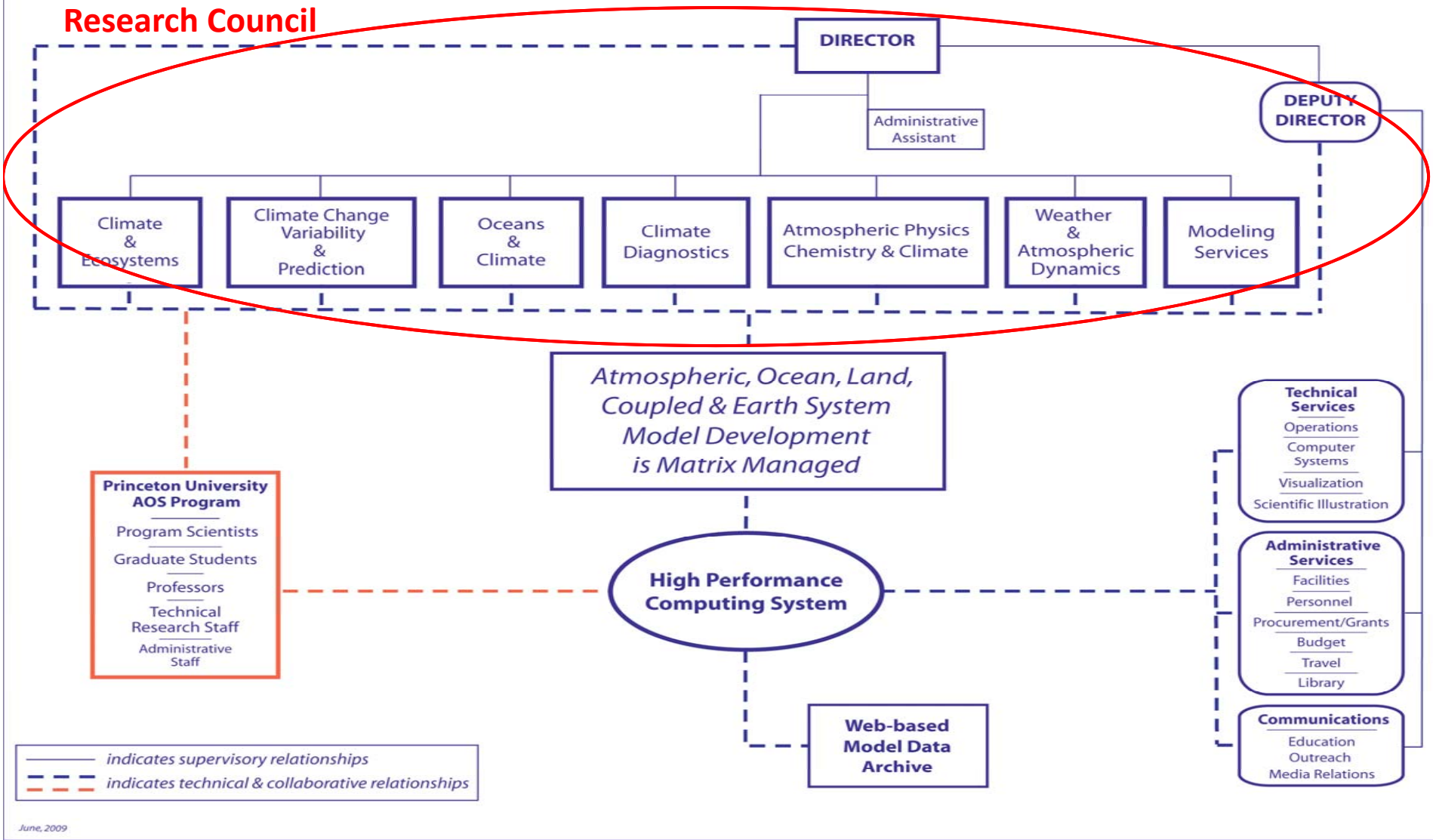
- ***"Serve society's needs for weather and water information***"

Contribute information to the Ecosystems Mission Goal:

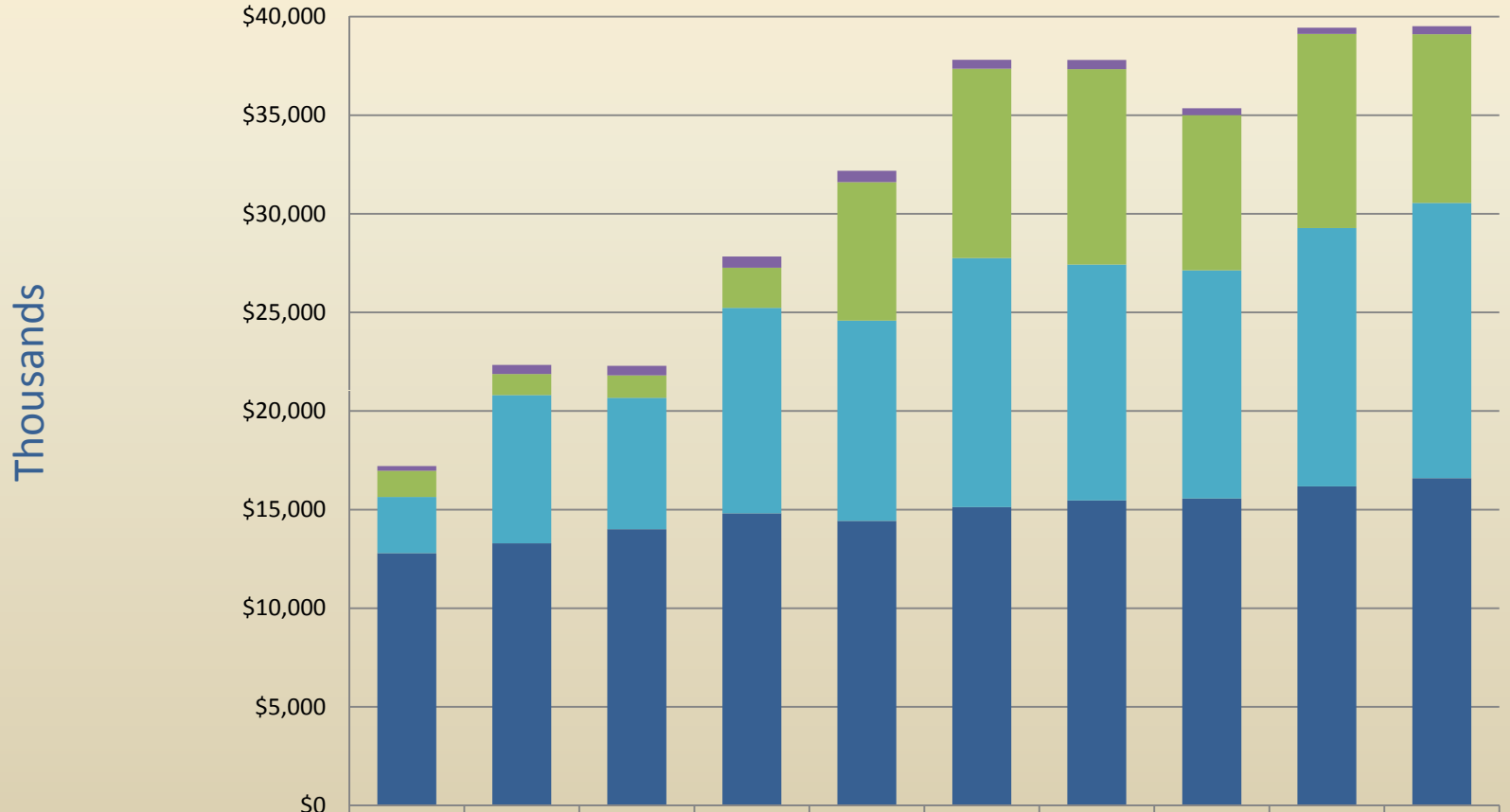
- "***protect, restore, and manage the use of coastal and ocean resources through ecosystem approaches to management……***"

(from Research in NOAA, January 2008)

GFDL Organizational Chart

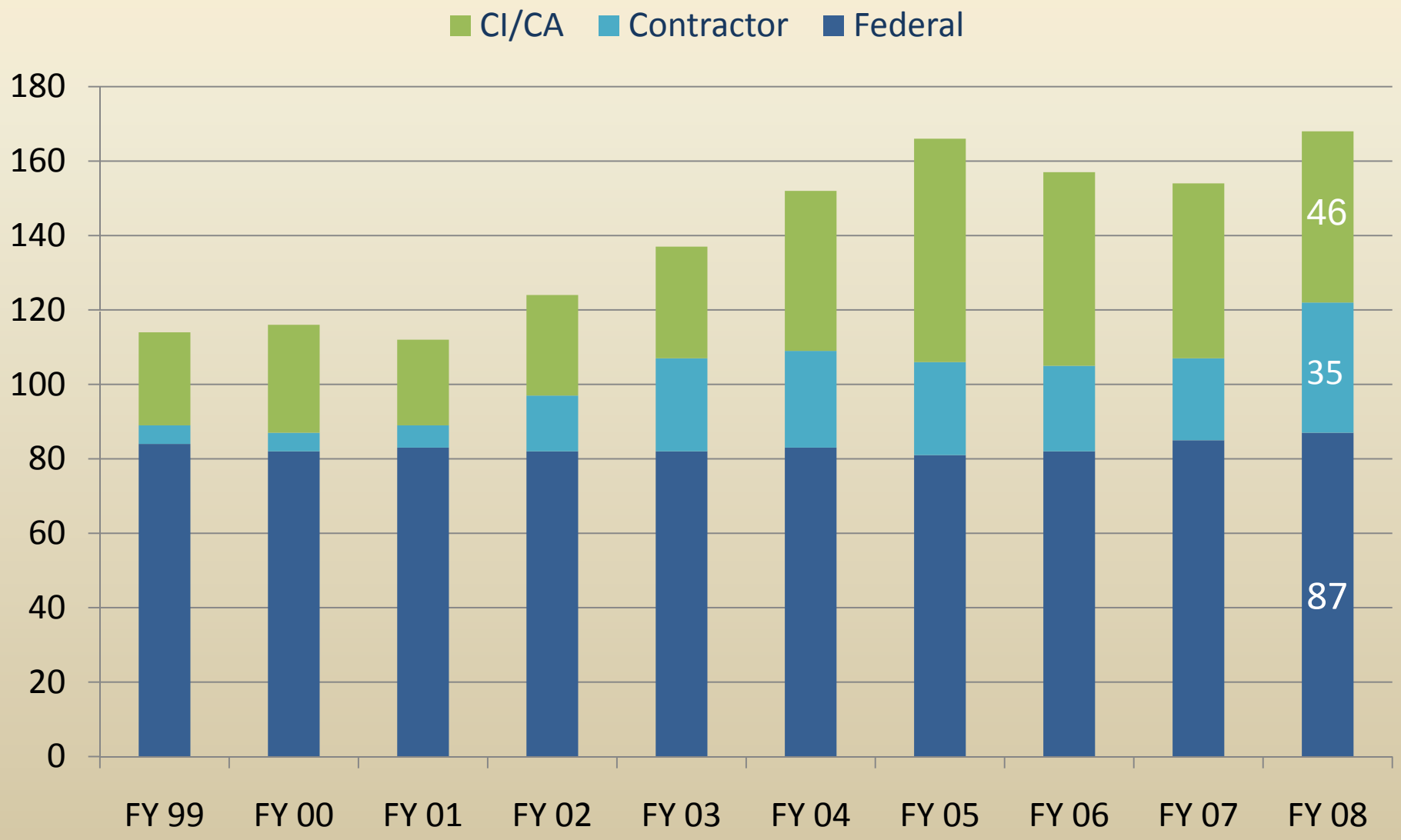


Geophysical Fluid Dynamics Laboratory
10-Year History Income Profile, FY99-FY08



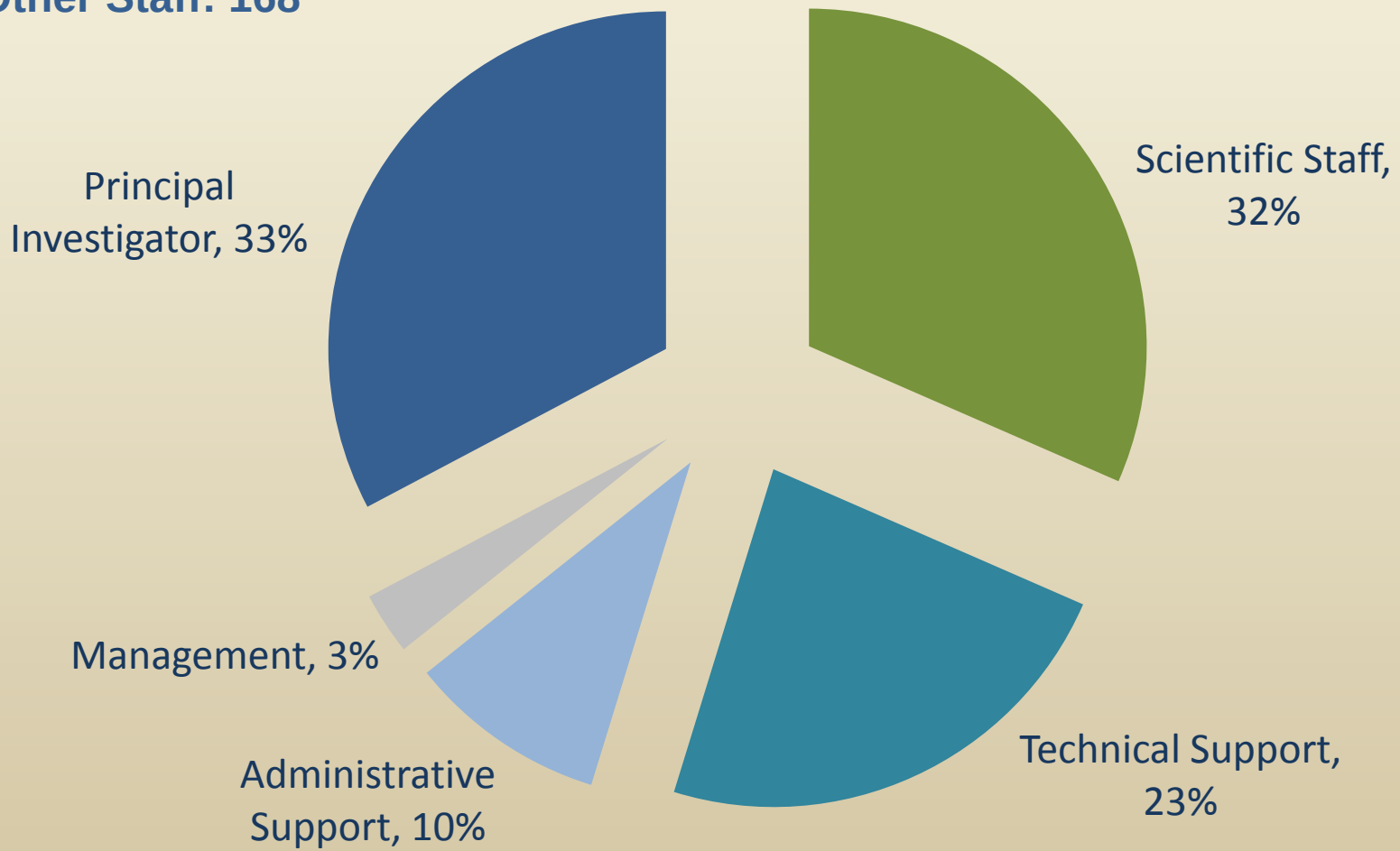
	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08
Other Agency	$237	$459	$483	$570	$580	$450	$468	$344	$316	$408
Other NOAA non-HPCS	$1,327	$1,066	$1,138	$2,033	$7,016	$9,596	$9,906	$7,870	$9,840	$8,549
Other NOAA HPCS (PAC, HPCC, and ORF)	$2,850	$7,521	$6,670	$10,419	$10,156	$12,632	$11,964	$11,569	$13,106	$13,959
Base	$12,795	$13,290	$14,004	$14,815	$14,432	$15,131	$15,462	$15,568	$16,176	$16,598

Geophysical Fluid Dynamics Laboratory
10-Year Staffing Profile, FY99-FY08

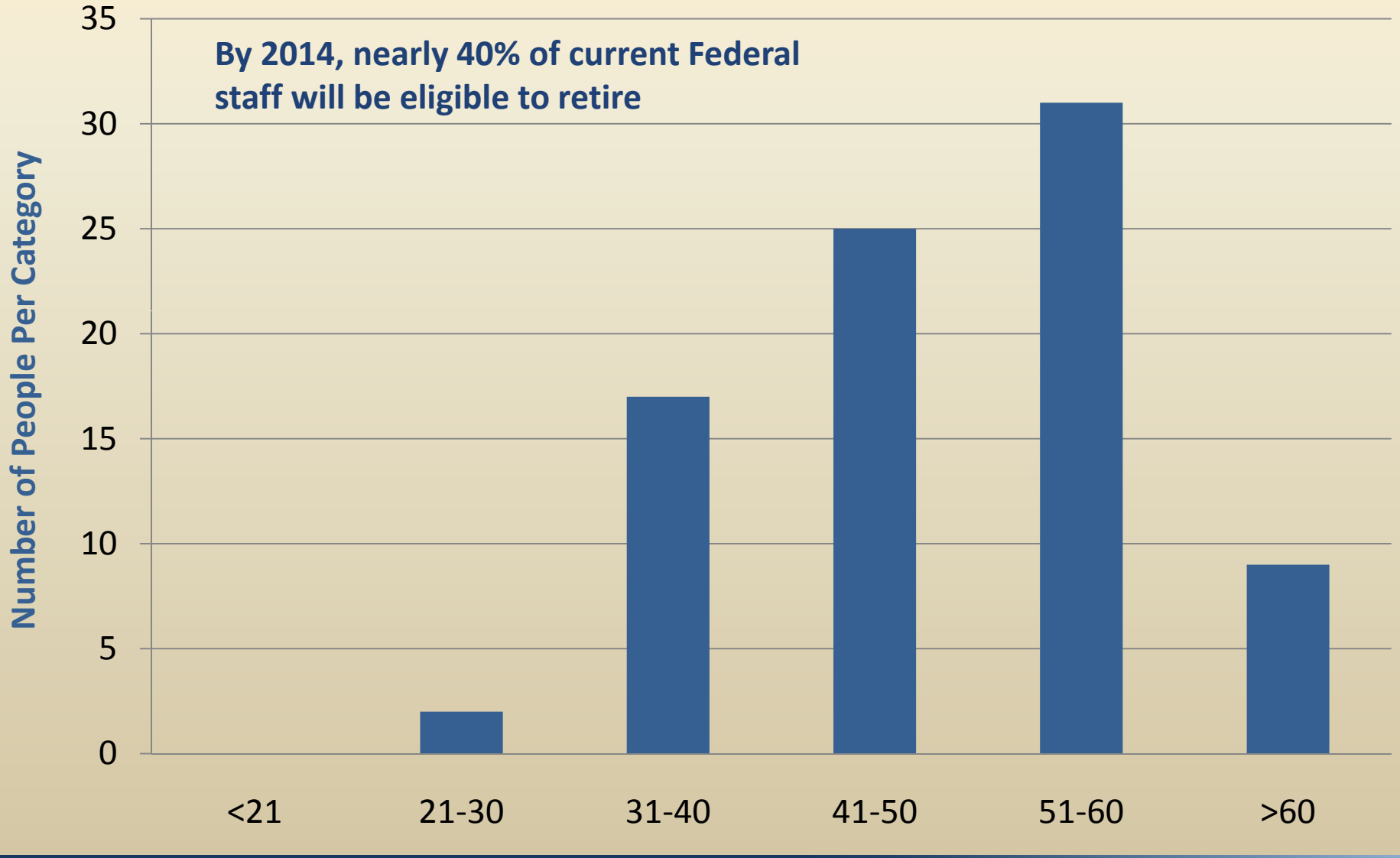


Geophysical Fluid Dynamics Laboratory
2008 Workforce Distribution

TOTAL GFDL, CICS, UCAR, and Other Staff: 168



Geophysical Fluid Dynamics Laboratory
2009 Federal Employee Staff by Age Grouping



GFDL's principal products and contributions

- New Knowledge
  - Published in peer-reviewed scientific journals
- State-of-the-Art Climate & Earth System Models, and Process Modules
  - Publicly available through GFDL's Data Portal
- Transition to Applications: Model Outputs
  - Publicly available through GFDL's Data Portal (19 TB of AR4 data)
  - Used for assessments of climate change and its impacts (over 5000 years of model integrations)
- Transitioning specific products for purposes of the Operational agencies
  - NCEP, Navy, IRI, Taiwan, Australia
- Leadership /Participation: GARP/ IPCC/ NAS/ WMO/ CCSP*/, other Assessments, Reports
  - E.g., **AR4** → 1 Synthesis (Summary across 3 working groups) Author, 3 Authors of Summary for PolicyMakers, 1 Coord. Lead Author, 3 LAs
- Presentations, Workshops, Colloquia, and Outreach at Academic institutions, National, and International forums (130 in FY08-09)

*now GCRP

QUALITY

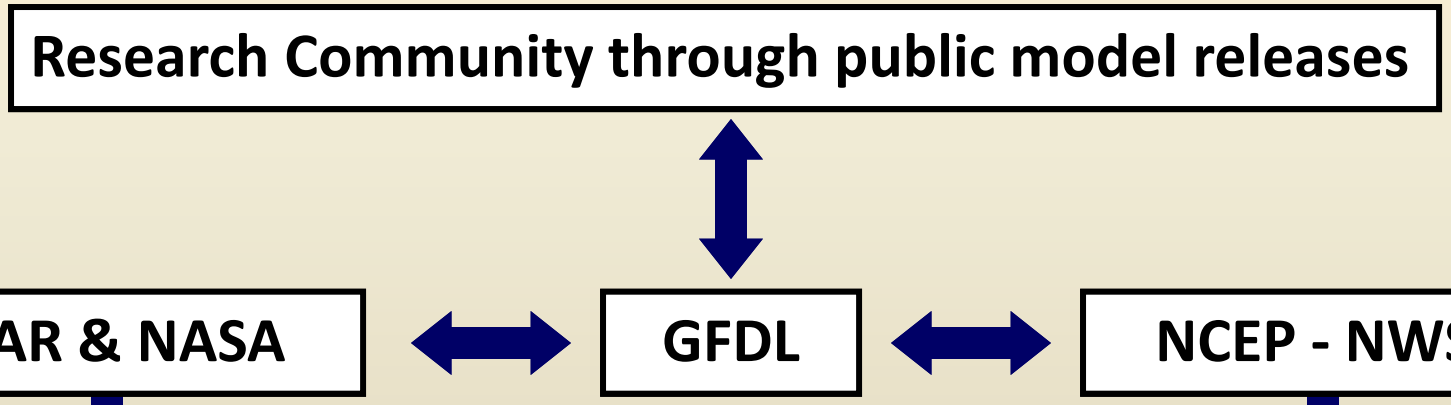
GFDL's Primary University Partners

- Graduate Teaching, Education & Visiting Scientists Programs:
  - **10 GFDL scientists serve on PU Faculty; 20 Ph. D. dissertations (1999-2009), 85 since inception; 241 Visiting Scientists to-date; 64 Summer interns (13 in 2009); 4 Text Books**
- Earth System Research: Ocean Biogeochemistry, Land-Surface Modeling
- Leveraging PU Carbon Mitigation Initiative (BP & Ford) – enhanced focus of developing capability to monitor carbon sources and sinks
- New Earth System Modeling CI Awarded to Princeton University in FY08

- Climate diagnostics and Climate change

COOPERATIVE INSTITUTE FOR CLIMATE APPLICATIONS AND RESEARCH
THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY

GFDL: Major Modeling Collaborators and Customers



Activities:

- Climate model development
- Understand GFDL/NCAR model differences
- Working towards community based modeling framework (with NASA)
- Joint NASA projects on next generation high resolution models

Activities:

- NOAA common modeling framework for Earth System Models
- Seasonal forecasting
  - Routine experimental forecasts
  - "joint" model (MME) on climate testbed
- Modular Ocean Model (MOM)
- Hurricane model

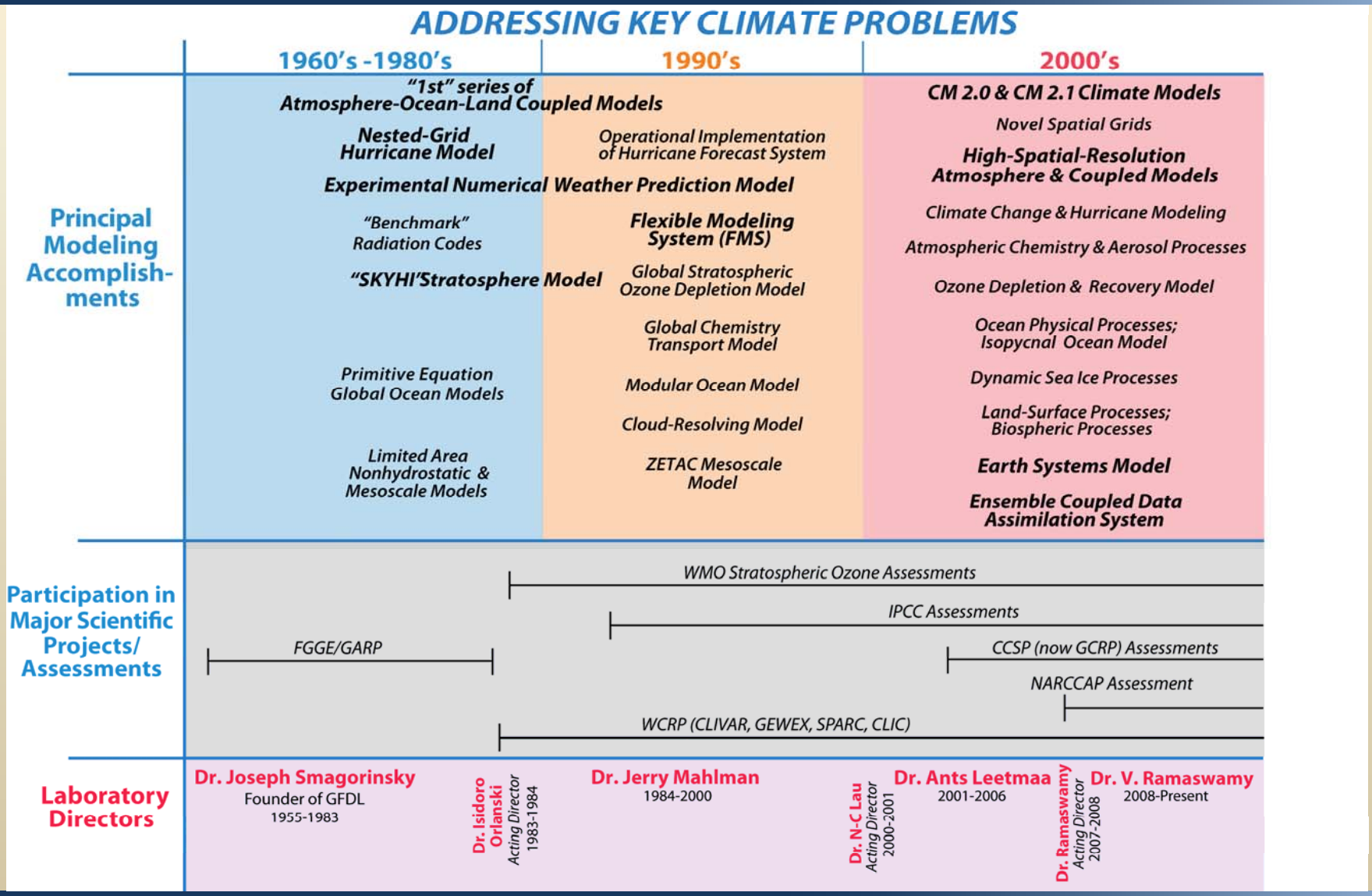
Other partnerships, customers, productive collaborations and scientific citizenship in major programs

- NOAA (e.g., COM, CSD; NMFS)
- OAR (e.g., ESRL, PMEL)
- USGS, DoE (PCMDI, LBL, ARM), EPA, NASA (diff. centers); IRI
- NCAR, Universities, and UCAR-funded collaborations
- Collaborations with leading Universities and Agencies abroad (e.g., UK, Germany, France, Canada, Australia, Japan, India)
- World Climate Research Program projects (CLIVAR, GEWEX, SPARC, CLiC); IGBP; WMO Projects
- Climate Process Teams
- Field campaigns [e.g., ICARTT, VOCALS]
- Advisory, Editorial, Steering, Trustee Boards

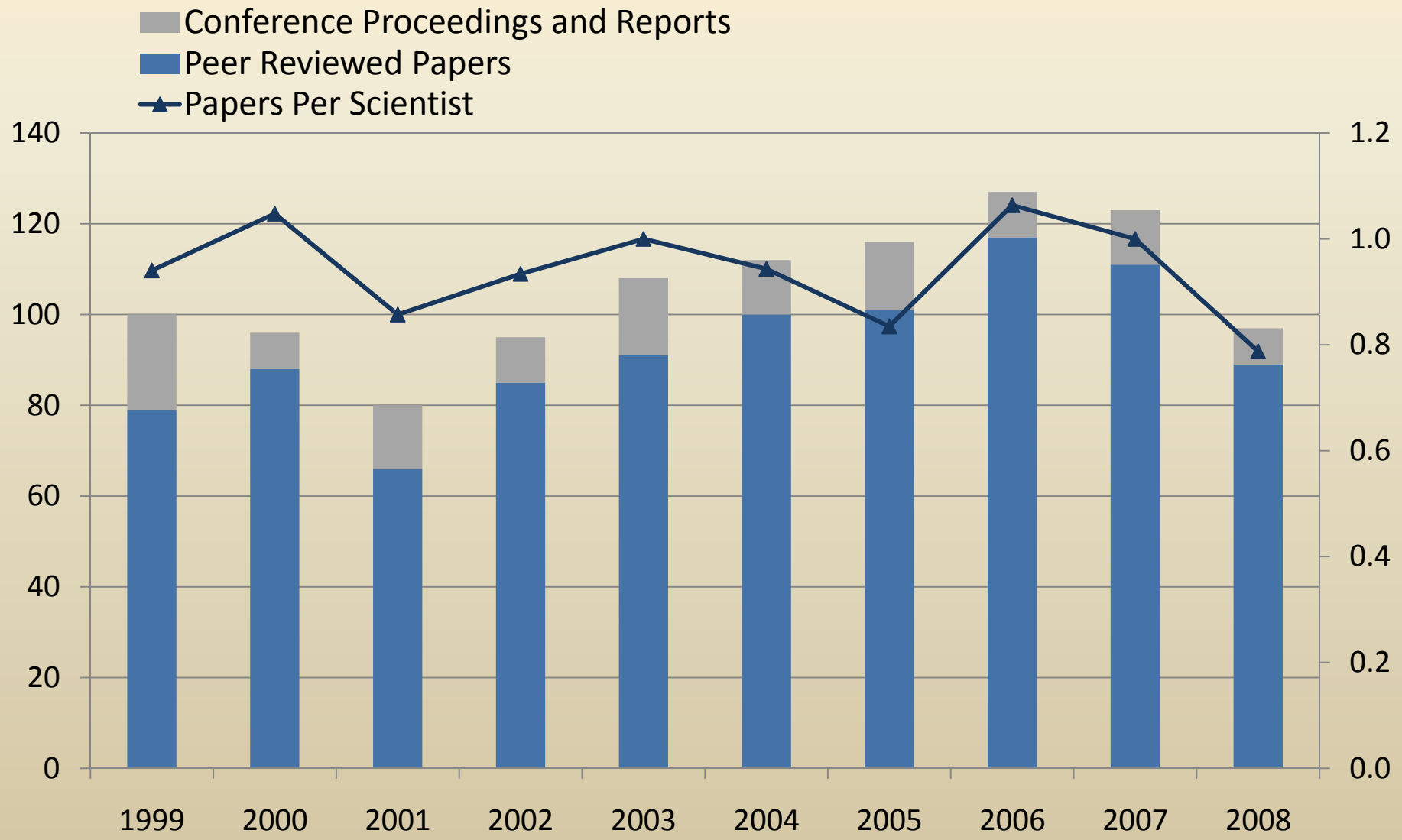
➔ *Collaborations (institutions): Universities (92); Governmental (35)*

➔ *Over 300 peer-reviewed co-authored publications (2005-08)*

NOAA / GFDL MODELS: The Evolution



Geophysical Fluid Dynamics Laboratory Publications, FY99-FY08



50 years of success

- **1955**: Collaboration established between Princeton's Institute for Advanced Study, the Weather Bureau, Air Force, and Navy to generate a computerized model of atmospheric circulation
- **1967**: First model estimate of the impact of carbon dioxide on global temperature
- **1969**: First model coupling the ocean and atmosphere completed (cited as a "Milestone in Scientific Computing" by Nature, 2006)
- **1985**: First diagnosis of weakening ocean circulation in a warming world
- **1990**: First simulation of Antarctic ozone hole
- **1991**: First community global ocean model completed (MOM1)
- **1995**: GFDL Hurricane Prediction System made Operational at NWS/NMC
- **2002**: First realistic model-based study of the impact of global warming on hurricane intensity
- **2005**: Development of CM2.0 and CM2.1 completed, two of the world's leading climate models used in 2007 IPCC-AR4.

Awards

Since 1995, GFDL scientists have been recognized with major:

NATIONAL AWARDS

- 1 Member, National Academy of Sciences
- 1 Carl Gustav Rossby Award
- 1 Presidential Distinguished Rank Award
- 2 Presidential Meritorious Rank Awards
- 3 Presidential Early Career Awards
- 1 Henry Stommel Award
- 4 AGU Fellows
- 2 AMS Fellows
- 1 Henry G. Houghton Award
- 1 Bernhard Haurwitz Memorial Lecturer
- 3 Distinguished Lecturer (Thompson; Sigma Xi, Columbia Univ.)
- 1 Banner I. Miller Award
- 1 AGU James R. Holton Junior Scientist Award
- Alumni Award (U. Mich.)

DOC / NOAA / OTHER AGENCY AWARDS

- 7 DOC Gold Medals
- 10 DOC Silver Medals
- 7 DOC Bronze Medals
- 4 NOAA Administrator's Awards
- 1 Daniel L. Albritton Outstanding Science Communicator Award
- 5 Employees of the Year Award
- NASA Awards (Pecora, DAO Special Recognition and Scientific Research, Aqua Team, Aerocenter Citation)
- 1 Meritorious Service (Dept. of the Interior, for USGS/ GFDL scientist)
- Technical Honor's Program (Raytheon)

INTERNATIONAL AWARDS:

- Nobel Peace Prize (IPCC awarded jointly with Albert Gore, Jr.; 37 GFDL scientists recognized for their IPCC contributions)
- 5 WMO Norbert Gerbier-Mumm Awards
- 1 Bert Bolin Lecturer on Climate Research
- 1 Hong Kong Observatory's 120th Anniversary Distinguished Meteorologist Award
- 1 K. R. Ramanathan Distinguished Professor

NOAA/OAR/GFDL Leadership in Climate Science

- As one of two Climate Modeling Centers called for in the Administration's Climate Change Science Program (CCSP*), GFDL provides the best possible scientific information to the Nation's decision makers, resource managers, and the public
- As a principal participant in the IPCC Fourth Assessment Report, GFDL has advanced the understanding of and projections of future global climate change.

– ***"… this particular climate model [GFDL CM2.1] simulates a very realistic climate in comparison to other models, but the present study showed that this model sometimes even surpasses the quality of reanalyses. " (Reichler, T. and J. Kim, 2008: Uncertainties in the climate mean state of global observations, reanalyses, and the GFDL climate model, JGR)***

– ***GFDL CM2.1 is among "the top-performing models for Alaska …." and Greenland. [Walsh, J.E., et al., 2008: Global Climate Model Performance over Alaska and Greenland. J. Climate]***

*now GCRP

NOAA/OAR/GFDL Model Simulations

Anthro. RF > 0 (v. high conf.)

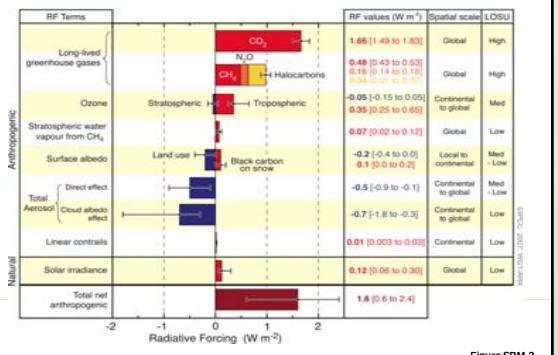


Figure SPM.2

Projected global warming

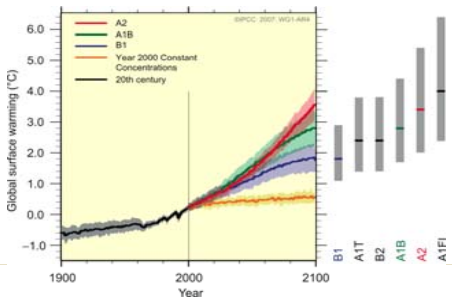


Figure SPM.5

NOAA/ GFDL model simulations contributed to 5 of the key IPCC AR4 AR4 SPM conclusions

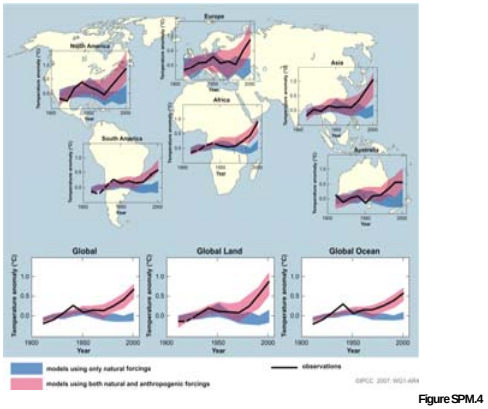
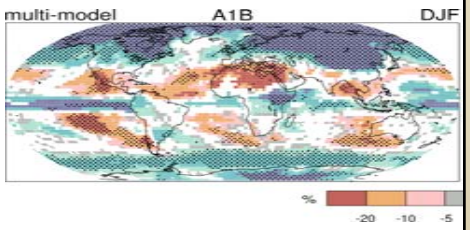


Figure SPM.4

20th Cent. continental warming likely due to human activity



Projected pattern of rainfall changes in 21st Century

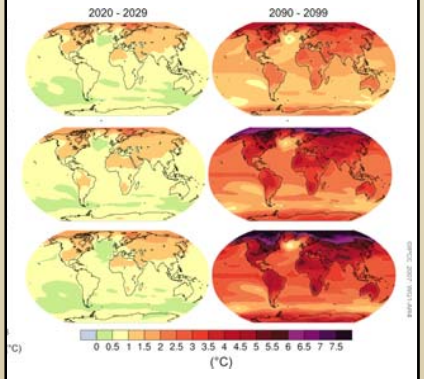
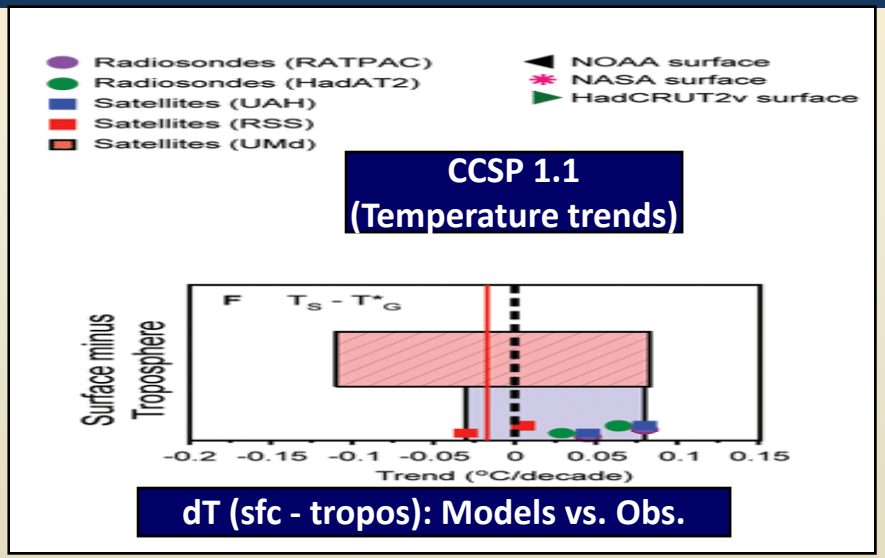
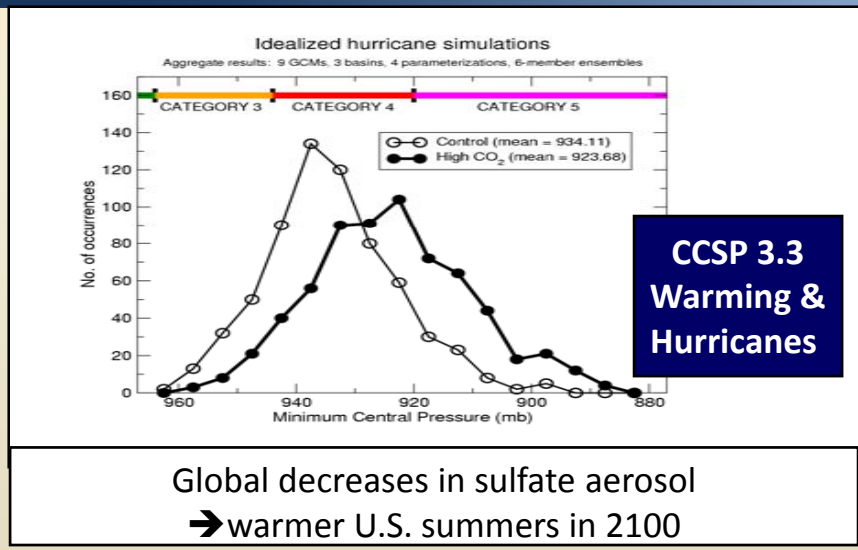


Figure SPM.6

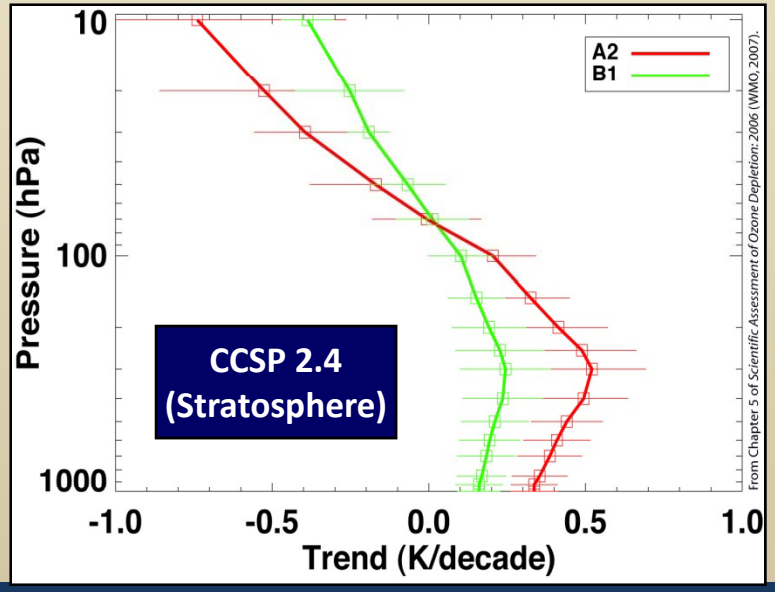
Proj. warming pattern in early and late 21st Cent.

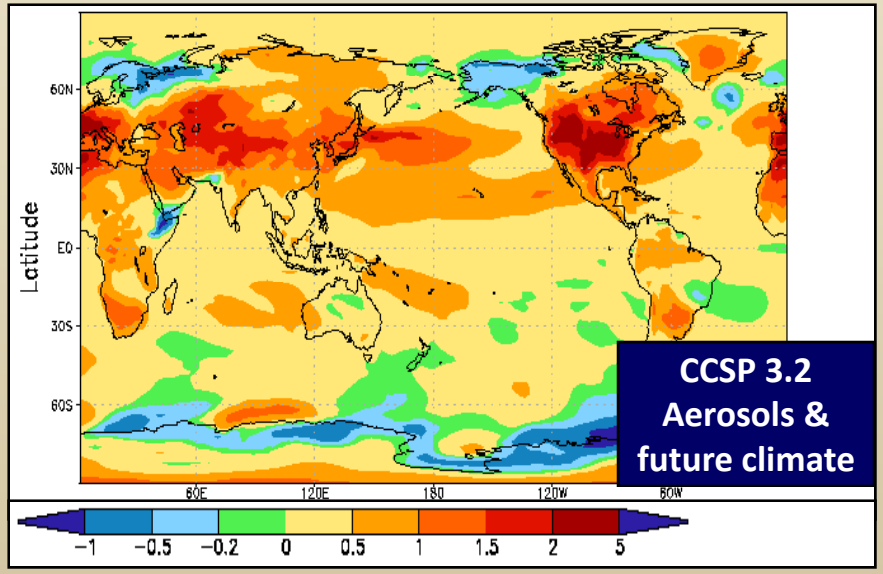
NOAA/OAR/GFDL contribution to key CCSP (now GCRP) conclusions





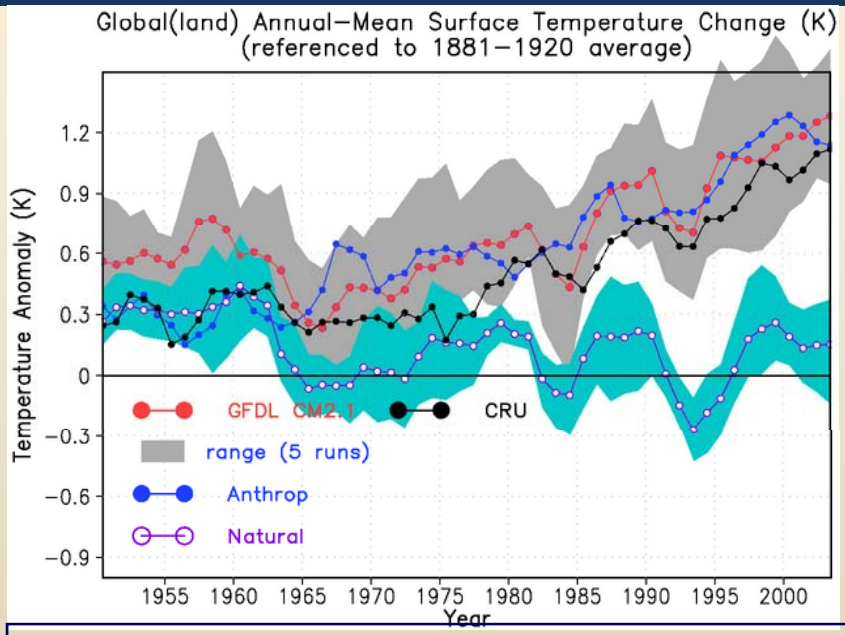
Global decreases in sulfate aerosol
➔warmer U.S. summers in 2100





RECENT HIGHLIGHTS – I [AR4 Simulations]

Delineating and quantifying the impacts of CO2, Other GREENHOUSE GASES and AEROSOLS in the 20th Century CLIMATE CHANGE



20th Century Surf. Temperature change

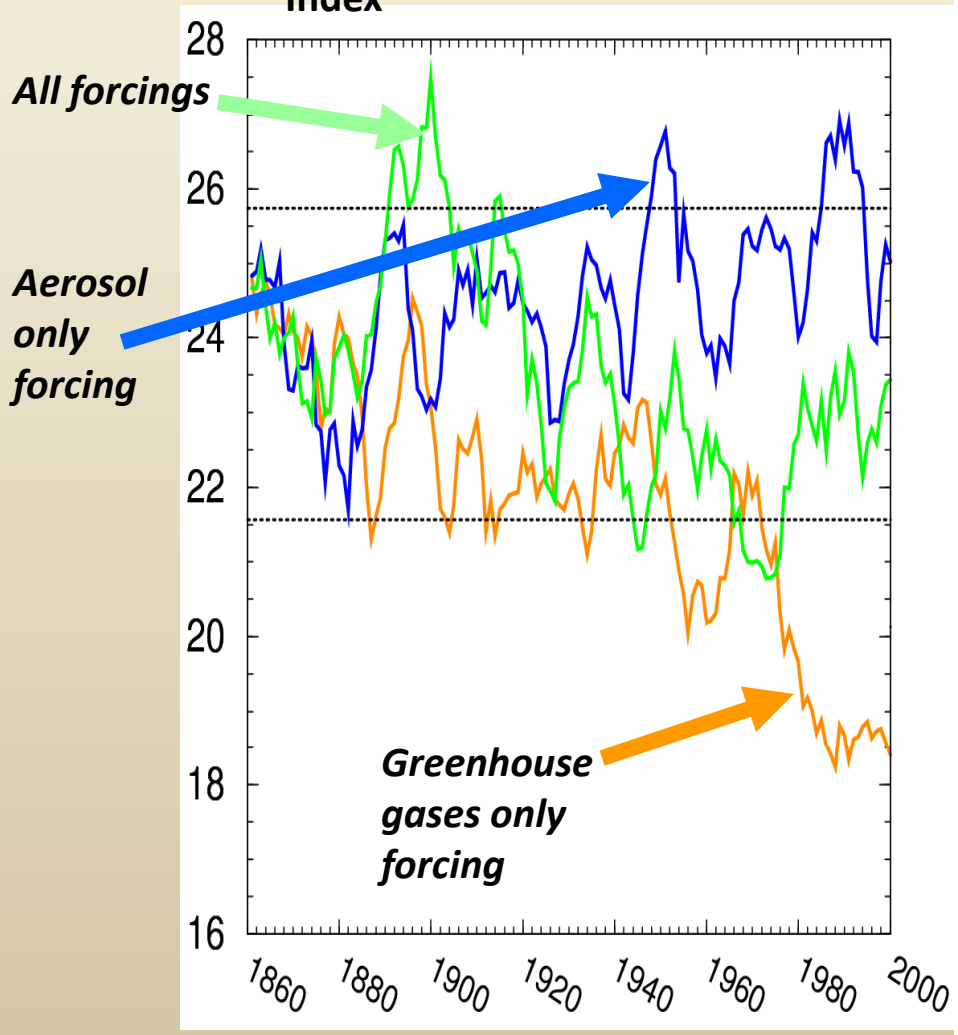
Total Anthropogenic → 0.8K

All Gases → 0.9K; CO2 only → 0.5K

Anthro. Aerosols → - 0.2K

(BC+OC) → 0.2K; (Sulf) → - 0.4K

Simulated North Atlantic AMOC Index



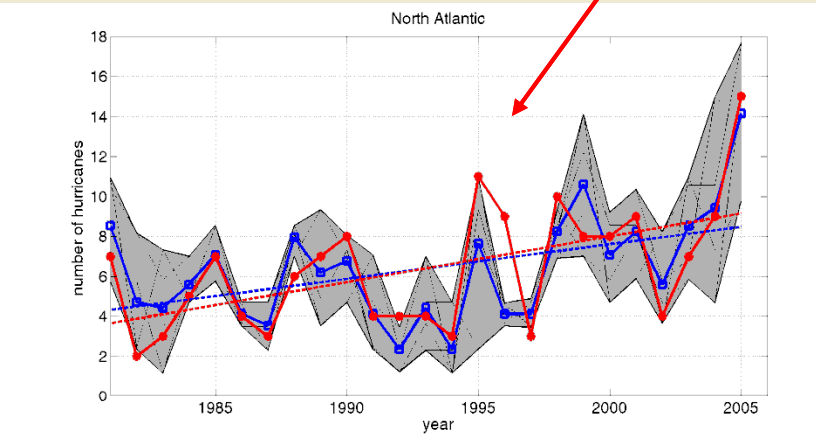
Emerging research areas

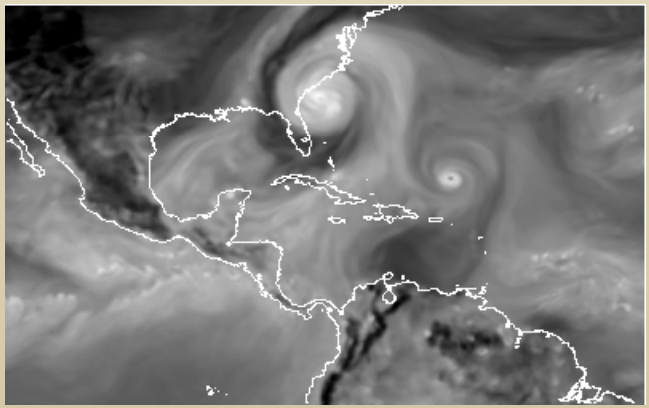
- New spatial grid and high-spatial-resolution atmosphere modeling
- Climate change and hurricane frequency
- Stratospheric ozone depletion and recovery, and links to climate
- Interactive tropospheric chemistry; linkages to air quality
- Aerosol-cloud-climate interactions and short-lived species' forcing
- Climate feedbacks (water vapor, cloud, sea-ice); new satellite and model diagnostics
- Advances in ocean modeling (parameterizations; isopycnal model)
- Land-surface processes and land-climate interactions
- Carbon-climate interactions
- Development of Earth System Models
- Ensemble coupled data assimilation system and Decadal Predictability research

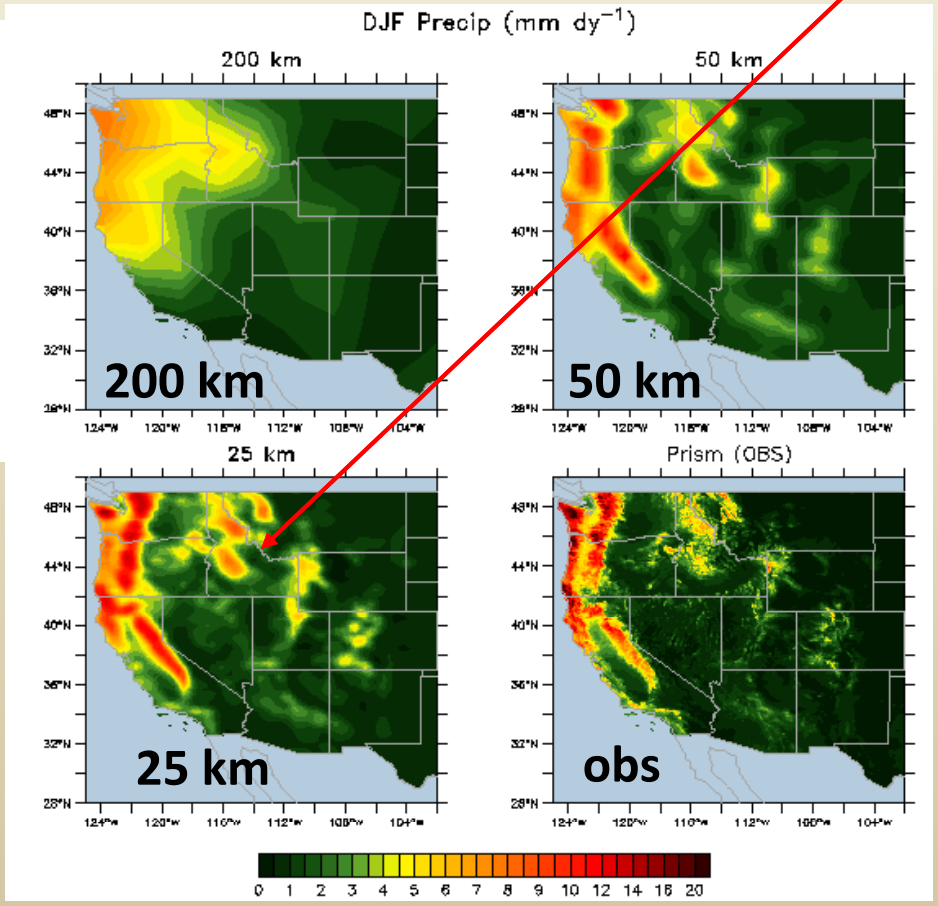
Ideas developed through individuals and groups, steered by the Research Council

RECENT HIGHLIGHTS – II
High-resolution global atmospheric modeling

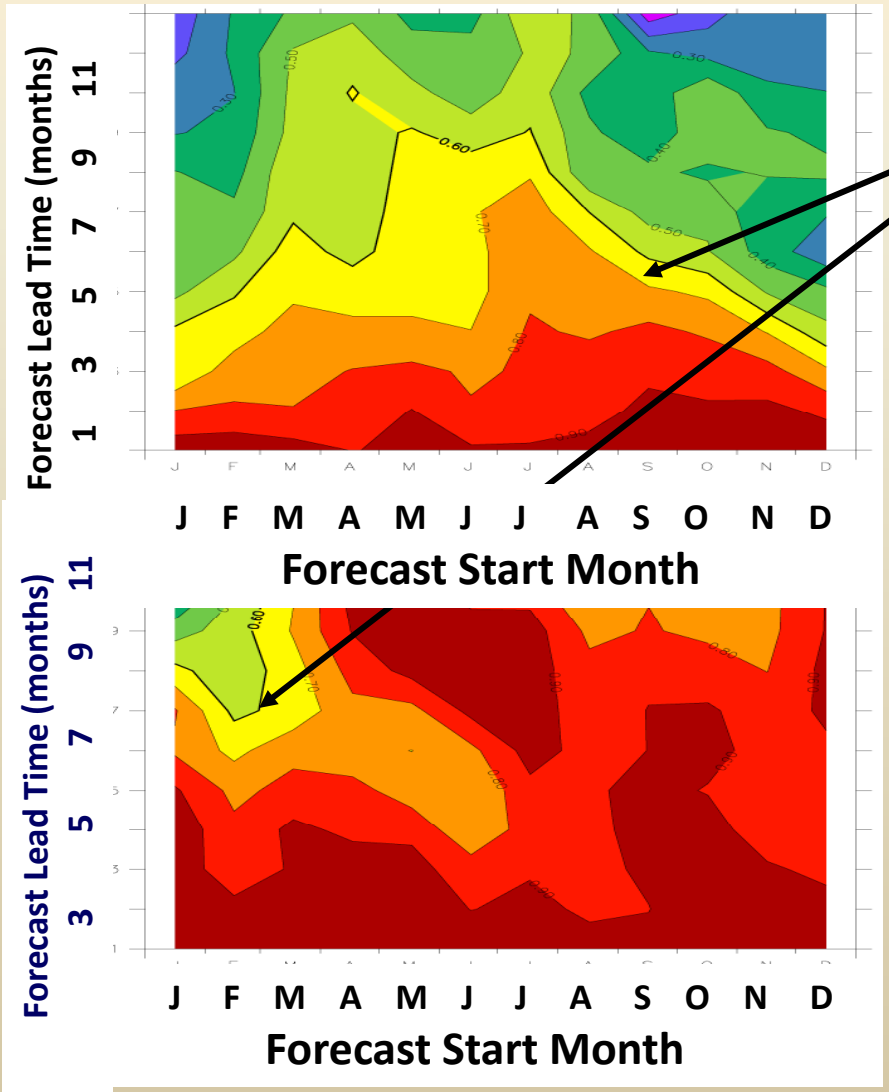
GFDL will contribute "time-slices" to AR5 at 25 km resolution
Initial emphases include tropical storms and regional climate change over US







New coupled assimilation system dramatically improves ENSO prediction skill



Correlation of observed and predicted NINO3 SST (measure of forecast skill)

3D-variational assimilation system

New coupled assimilation system

GFDL participating CTB/NCEP/National MME, IRI and APCC

Planning, Execution, Results, Lessons

THEORY

OBSERVATIONS

KNOWLEDGE & UNDERSTANDING

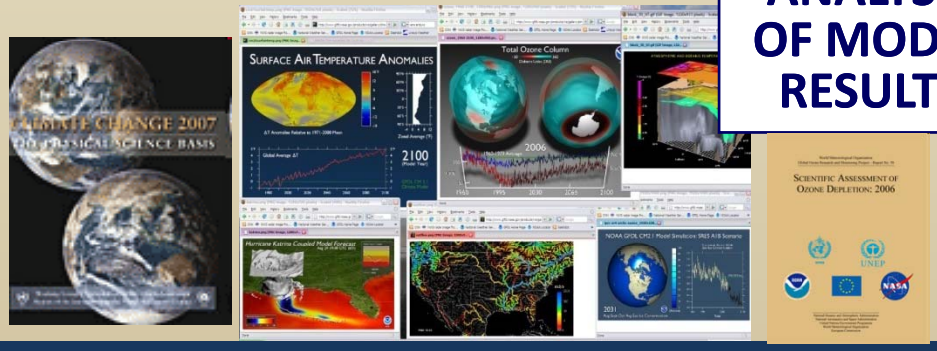
MODEL DEVELOPMENT

```
if (diagts .and. eots) then
  do 1500 m=1,nt
    do 1490 k=1,km
      fx = cst(j)*dyt(j)*dzt(k)/(c2dtts*dtxcel(k))
      do 1480 i=2,imtm1
        boxfx           = fx*dxt(i)*fm(i,k,jc)
        sddt            = (ta(i,k,m)-t(i,k,jc,nm,m))*boxfx
        svar            = (ta(i,k,m)**2-t(i,k,jc,nm,m)**2)
                          *boxfx
        n               = 0
        termbt(k,1,m,n) = termbt(k,1,m,n) + sddt
        tvar(k,m,n)     = tvar(k,m,n)     + svar
        n      = nhreg*(mskvr(k)-1) + mskhr(i,j)
        if (n .gt. 0 .and. mskhr(i,j) .gt. 0) then
          termbt(k,1,m,n) = termbt(k,1,m,n) + sddt
          tvar(k,m,n)     = tvar(k,m,n)     + svar
```

WELL DESIGNED MODEL EXPERIMENTS

ANALYSIS OF MODEL RESULTS

Assessments



Performance: Guiding Principles

- What are the key issues and scientific questions, consistent with the NOAA Mission objectives?
- Lessons learned from previous accomplishments and assessments and participation in national and international dialogs and activities.
- What can we do in a novel and unique sense? How do we advance the frontiers and NOAA aims in a sustained manner?
- Assess the resources – computational, human, data capacity

Performance: Research Leadership and Planning

- Fostering the necessary basic research and creativity
- Building process-level modules
- Seeking, engaging, and building partnerships with academic and other national and international experts to fill important gaps and bring in new and proven scientific insights.
- **Development of Components through lab-wide, cross-cutting, Model Development Teams (MDTs) for building the Atmosphere (AM), Ocean (OM), Land (LM), Coupled CM) and Earth System Models (ESM).**
  - testing, calibrating, verifying against observations and observation-derived products;
  - checking for accuracy in the simulation of the interactions between processes
  - ensuring physical consistency of the simulations

Performance: Preparing for the Assessments

- Lab-wide discussions on plans for assessments and steered by the Research Council
- Scoping the research needed to address the key scientific questions

- **HALLOWEEN report (Oct. 2000)** → the plan to develop the models to address key questions consistent with the anticipated resources, with timelines for completing the model, the runs, and the dissemination of the output data . This report determined *GFDL's strategy for the IPCC 4th Assessment Report (AR4).*

- **VALENTINE report (Feb. 2006)** → similar plan for GFDL's model development, simulations, and outputs are guiding *GFDL's strategy for the IPCC 5th Assessment Report (AR5).*

FOUR GFDL Model Streams for AR5: *Differences relative to CM2.1 indicated below*
[CM2.1 components → AM2, LM2, MOM4, SIS]

1. CM3

New atmosphere model (AM3). Interactive tropospheric and stratospheric chemistry, aerosols & aerosol-cloud interactions.
New land model and hydrology (LM3).

2. ESM2

~~Carbon biogeochemistry (land and ocean),~~
2 ocean configurations: MOM4.1 (ESM2M) and GOLD (ESM2G, isopycnal model).

3. CM2.x

Decadal predictability research using GFDL's ensemble Kalman-filter analysis.
Begin with CM2.1, possibly advancing to higher resolution/ complexity.

4. HiRAM

High resolution (25 km) time slice integrations with AM2 (incl. alternative physics), forced by SSTs and sea-ice.

Extensions to current research and plans for the future

- Higher spatial resolution and increased physical realism in models
- Hydrologic cycle: the regional aspects
- Cloud-climate feedbacks and tropical storm simulations
- Land-ice and cryospheric modeling; polar (Arctic and Antarctic) climate variations and trends
- Decadal Predictability: influences of anthropogenic forcing and natural variability
- Extremes and abrupt climate change
- Biosphere-atmosphere-cryosphere-climate interactions (CO2, methane, and other greenhouse gases; dust, soot)
- Climate change impacts on sea-level rise and ecosystems
- Biogeochemical cycles, and the exchanges of carbon between atmosphere, ocean and land

[Directly supporting NOAA Research objectives and Climate Goal plans for FY09-FY11 (and prospectively for FY12)]

A PERENNIAL CHALLENGE: Sustaining world-class science in the "Predictive understanding of the global climate system"

- Taking on demanding scientific problems, which require long lead-time thinking, research planning and execution
- Development of credible state-of-the-art models
- Model parameterizations based on state-of-the-art knowledge, observations (satellite, ground, in situ, reanalyses), and available resources
- "Community" (e.g., IPCC, CCSP*, WMO)-driven model integrations (e.g., the various "MIPS" such as AMIP, CMIP etc.; future projections based on emissions scenarios)
- Analyses of the integrations → model-observation comparisons of climate variations and change → publications, assessment chapters → interactions with users and dissemination of data

*now GCRP

Balancing Critical Science Factors

- Framing the outstanding questions and encouraging creative ideas
- Increasing the realism of models by
  - Capturing complexity
  - Performing high-resolution simulations

  without degrading the quality of the simulations
- Increased ensemble member integrations
- Identifying and quantifying the key uncertainties
- Meeting timelines (e.g., for major assessments)

Management Challenge

Due to improved understanding of climate variability and change, there is now

- Greater awareness and concern
- Increasing demand for reliable, timely knowledge on magnitude and severity
- The need for authoritative information and data to stakeholders

GFDL will meet this challenge by continuing to advance the science that underpins NOAA's climate products.

Scientific Information and Applications Challenges

- Brainware-to-Hardware ratio
- Operations-to-Research ratio
- Short-term demands
- Rigor and clarity in delivering policy-relevant research results
- Effective communication and dissemination of information while sustaining the research commitment

GFDL credo (that has stood the test of time)

- Strive for and maintain exceptional scientific quality and integrity.
- Do not compromise on quality and rigor for short-term gains.
- Provide NOAA with creative, focused research and deliver the scientific products in a timely manner.
- Recruit the best talent, and nurture a healthy environment for the research into the hard, long lead-time problems.
- Attack new challenges, which frequently occur at the boundaries and across traditional disciplines.
- Cross-disciplinary traversal is not easy. It has to be rooted in science and motivated by realistic expectations.

Arrangement of This Review

THEME I. Atmospheric and Oceanic Modeling	[TUESDAY]
- Atmospheric Chemistry and Physics	[AM]
- Atmospheric Dynamics	[PM]
- Ocean Modeling	[PM]
THEME II. Physical Climate Change: Understanding and Prediction	[WEDNESDAY AM]
THEME III. Carbon, Biogeochemistry, and Climate	[WEDNESDAY PM]

- **Cooperative Institute for Climate Science [Princeton University]** [THURSDAY AM]
- **Computational infrastructure and Modeling Services**
- **GFDL, AR5 and CMIP5**
- **GFDL research and NOAA's Climate Goal**

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Geophysical Fluid Dynamics Laboratory Review

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