NOAA/ GFDL Climate Modeling: Global-to-regional Climate Information

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Schematic Global Climate Model

NOAA/ GFDL’s CLIMATE and EARTH SYSTEM MODELING
Scientific challenges

- Capturing the *Climate and the Earth System* (i.e., physics, dynamics, chemistry, biogeochemical cycles, ecology) with rigor and high-resolution
  - Advancements in the understanding of the processes and interactions
  - Increasing the realism of the complex “System” in model simulations
- Model verification against observations, intercomparisons, and synthesis.
- Time-scales (weeks to century-scale)
- Accurate predictions including the regional aspects
- Initial-value AND the Boundary-value nature of the problem (viz., “Forcing” of the system, initialization, assimilation, reanalysis)
- Characterization, quantification and resolution of uncertainties
- Increased ensemble members in model integrations for studies of extremes.
- Meeting timelines (e.g., Assessments, transition of well-vetted science to routine operations, multi-model ensemble analyses)
NOAA/OAR/GFDL Model Simulations

Geophysical Fluid Dynamics Laboratory

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

Projected global warming

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

20th Cent. continental warming likely due to human activity

Projected pattern of rainfall changes in 21st Century

Proj. warming pattern in early and late 21st Cent.
RECENT HIGHLIGHTS [IPCC AR4 Simulations]
Attribution to CO2, Other GREENHOUSE GASES and AEROSOLS

20th Century Global-mean Surface Temperature change

Total Anthropogenic $\rightarrow$ 0.8K

All Gases $\rightarrow$ 0.9K; CO2 only $\rightarrow$ 0.5K

Anthro. Aerosols $\rightarrow$ - 0.2K
(BC+OC) $\rightarrow$ 0.2K; (Sulfate) $\rightarrow$ - 0.4K
Projected changes in temperature and precipitation in 21st century A1B emission scenario; averaged over ~20 models with spatial resolutions of ~200km

Winter: wetter in Northeast - drier in Southwest -
Summer: Drying extends northward, with larger uncertainty

Warming everywhere

Green => wetter
Brown => drier
White => uncertain
Cooling due to aerosols has balanced part of the warming due to CO$_2$ in the 20$^{th}$ century.

Many air quality ↔ climate connections

**Earth System Pipeline**

Goals of our next major model upgrade for climate change projection include:

*Simulating the uptake of carbon dioxide by oceans and land*

*Coupling of tropospheric and stratospheric chemistry into climate model*

*Simulating atmospheric aerosols (particles) and their interactions with clouds*
NOAA/ GFDL Modeling
What do we have in the pipeline?

Resolution pipeline

Earth system pipeline

Climate projections
resolution Pipeline

especially demanding of **computational** resources

**Why is resolution important?**

1) *Need to increase the quality of our climate projections on the regional scales that impact economy/society*

2) *Resolving smaller scales improves the entire climate simulation/projection - because small and large scales interact*

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**IPCC AR4 global models**

- Atmosphere: 200 km, 50 km, 20 km, 5 km
- Ocean: 100 km, 10 km

**Atlantic hurricane model**
NOAA/GFDL is making advances on 4 streams of modeling activities:

1. A coupled climate model with more complex physics and interactive atmospheric chemistry (CM3).
2. Earth System Models that achieve a closed carbon cycle (ESM2M and ESM2G).
3. High resolution ensemble runs for decadal-scale predictions (based on CM2.1).
4. Time-slice experiments with high resolution atmospheric models for research into regional climate projections and the impact of small-scale processes on climate (e.g. clouds and water vapor).
Winter mean precipitation in Western U.S. improves dramatically with horizontal resolution

Source: NOAA/GFDL
NOAA/ GFDL high-resolution global model (~50 km) used to simulate the severity and duration of summer heat waves. This model was used to produce the bottom figure, from a 30-year simulation of present-day climate. Top figure is based on observational data for a 24-year period.
Most recent GFDL downscaling study (Bender et al, Science, 2010)

Uses two downscaling steps:
- Global CMIP3 models => regional model of Atlantic hurricane season
- Regional model => operational GFDL hurricane prediction system
Conclusion: Best estimate is for doubling of cat 4-5 storms in Atlantic by end of century.

Much of the uncertainty arises from global model input.
Preliminary results suggest resolving processes on finer spatial scales may lead to significant improvements in climate simulation.
Enhanced Resolution and Coupling Improve Monsoon Representation

Observations
Courtesy of D.S. Pai, IMD

GF DL CM2.5
25km Oc.; 50km Atm.

GF DL CM2.4
25km Oc.; 100km Atm.

GF DL CM2.3
100km Oc.; 100km Atm.

GF DL CM2.1
100km Oc.; 200km Atm.

July-August Mean Rainfall (mm/day)

1  2  4  6  8  10  12
Coupled Chemistry-Aerosol-Climate model

Clear Sky

Cloudy Sky

SW Radiation

Aerosols

Activation

Droplets

Aerosols and Climate

Atmosphere

LW Radiation

Evaporation

Precipitation

Sea Ice

Ocean

Surface Flux

Land

Mixed-Layer

Deep Ocean

Global Air Quality and Climate

CH₄, O₃ are greenhouse gases
CH₄ contributes to background O₃ in surface air

Stratospheric O₃

~12 km

Free Troposphere

Hemispheric Pollution

Direct Intercontinental Transport

Boundary layer

(0-3 km)

Air pollution (smog)

CONTINENT 1

OCEAN

CONTINENT 2

Aerosols and Climate

Global Air Quality and Climate
Capturing the global distribution of the short-lived Aerosols spreading out from the source regions
A fundamental breakthrough occurs at scales of 10 km – ocean models become more realistically turbulent.

High resolution simulation of Southern Ocean (GFDL’s MESO project).
Small vortices affect oceanic carbon uptake heat, transport of heat towards Antarctic continent, marine ecology of Southern Ocean.
Challenge: Resolution of Coastal-scale Processes

1 deg. Resolution (most AR4 and AR5 climate change simulations)

1/8 degree ocean simulation
A1B Warming (GFDL CM 2.1)

2020s

~2050

2070s

2090s
Projected Atlantic SST Change (relative to 1991-2004 mean)

Can we predict which trajectory the real climate system will follow?

- Natural variability
- Forced variations and change

Results from GFDL CM2.1 Global Climate Model
Discontinuous Local and Regional Changes

GFDM CM2.1 Surface Air Temperature
95W–90W, 40N–45N (Upper Midwest)
(anomalies relative to 2001–2005 average)

- B1 scenario
- A2 scenario
Data Serving –
An important part of GFDL plans

• Node on PCMDI’s network (ESG) of data servers for CMIP5
  – Also provides an independent path to GFDL data

• Currently serving tens of TB to external users
  – Potentially hundreds of CMIP5/AR5 TB available

• Time line
  – Sept 2013 – WGI public
  – End of 2010 – data available in archive
Data processing - Status

- **GFDL**
  - Huge effort to get data into proper format
  - Whole software system not working yet
  - Need to read and re-write whole of IPCC data set

- **External**
  - Early tests of network ongoing
  - Data volume a big issue ($$$, infrastructure and software)
The END

Thank you
Work underway on our next generation atmospheric modeling system suitable for simulations at even finer resolutions.

A 25 km model – will allow us to model hurricane/typhoons globally (comparable resolution to the Atlantic simulation that you saw earlier this morning).

A 5 km model that has the potential to reduce our uncertainty in how the Earth’s clouds will respond to global warming.

precipitation

clouds
Multiple modeling efforts are needed because information from an ensemble of multiple models is often better than from even the best single model. This was recognized in the USGCRP’s (and OSTP-endorsed) Strategic Plan for the Climate Change Science Program, where it was recommended that different approaches to unsolved problems be explored, as well as the IPCC’s AR4.

CMIP-1 (~12 yrs ago)
CMIP-2 (~7 yrs ago)
CMIP-3 (AR4) (2007)
Observational uncertainty

Average model is improving more quickly than the best model
Average score is getting better

GFDL’s CM2.1 currently provides the best climate simulations of any of the world’s models, by this metric (T. Reichler, U. of Utah)

Quality of simulation of current climate
What about abrupt climate change?

4 Foci for Abrupt Climate Change (CCSP SAP 3.4)

• Atlantic Meridional Overturning Circulation (AMOC)
• Sustained changes to the hydrologic cycle (droughts, etc)
• Rapid changes in land-based ice sheets (Greenland, Antarctica)
• Rapid release to the atmosphere of methane trapped in permafrost and continental shelves

Decadal predictions system initially address first two foci, expands to encompass additional components as models mature.

Simulated Change in Southwestern U.S. Water Availability (precipitation minus evaporation)

Projected drying trend

Seager et al., 2007
Up to 40% of U.S. warming in summer (2090s-2000s) from short-lived species

Results from GFDL Climate Model [Levy et al., 2008]

From changing well-mixed greenhouse gases + short-lived species

From changing only short-lived species

Warming from increases in BC + decreases in sulfate; depends critically on highly uncertain future emission trajectories