Planning, Execution, Results, Lessons

KNOWLEDGE & UNDERSTANDING

MODEL DEVELOPMENT

THEORY

OBSERVATIONS

Assessments

Geophysical Fluid Dynamics Laboratory
Accounting for the complexity of the system with increasing realism

Increased resolution and rigor to capture the physics, chemistry, dynamics, and biogeochemistry of the system

Obtain results at increasingly finer spatial scales with accuracy and credibility

Characterizing, understanding and explaining uncertainties

Leadership and managing expectations

Coupled Chemistry-Aerosol-Climate model

Clear Sky  Cloudy Sky

SW Radiation  Activation  Droplets

LW Radiation

Aerosols

Evaporation

Surface Flux

Precipitation

Sea Ice  Ocean  Land

Mixed-Layer  Deep Ocean

Atmosphere

Global Air Quality and Climate

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

Stratospheric O₃

Free Troposphere

Hemispheric Pollution

Direct Intercontinental Transport

Boundary layer (0-3 km)

air pollution (smog)

CONTEST 1  OCEAN  CONTEST 2

hv

NO₂  NO

OH  HO₂

VOC  CH₄  CO

NOₓ  VOC

O₃  O₃

O₃  air pollution (smog)
Climate to Earth System Modeling (ESM): Chemistry- and Carbon-Climate Interactions

Atmospheric circulation and radiation

Land physics and hydrology

Ocean circulation

Sea Ice

Chemistry – CO$_2$, NO$_x$, SO$_4$, aerosols, etc

Land Ice

Atmospheric circulation and radiation

Plant ecology and land use

Sea Ice

Ocean ecology and Biogeochemistry

Ocean circulation

Land Ice

Land physics and hydrology

Climate Model

Earth System Model
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
20 centuries of NINO3 SSTs

annual means & 20yr low-pass
NOAA/ GFDL Modeling

Conceptualization about five years ago............
FOUR GFDL Model Streams for CMIP5, 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.
CM3 Coupled Climate Model

- **Forcing**
  - Solar Radiation
  - Well-mixed Greenhouse Gases
  - Volcanic Aerosols

- **Ozone-Depleting Substances (ODS)**

- **Pollutant Emissions**
  - Anthropogenic, ships, biomass burning, natural, & aircraft

- **Atmospheric Dynamics & Physics**
  - Radiation, Convection (includes wet deposition of tropospheric species), Clouds, Vertical diffusion, and Gravity wave

- **Atmospheric Chemistry**
  - Chemistry of $O_3$, $HO_y$, $NO_y$, $Cly$, $Br_y$, and Polar Stratospheric Clouds
  - Chemistry of gaseous species ($O_3$, $CO$, $NO_x$, hydrocarbons) and aerosols (sulfate, carbonaceous, mineral dust, sea salt, secondary organic)

- **Land Model**

- **Ocean and Sea Ice Model**
  - Cubed – sphere grid (~200km)
  - 48 vertical levels
  - IPCC – AR5 anthropogenic and biomass burning emissions of short-lived species
  - Constant natural emissions except for lightning $NO_x$, dust and sea-salt (meteorology dependent)

- **Dry Deposition**

- **Aerosol-Cloud Interactions**

- **Donner et al., J. Climate, 2011**
Interactive microphysics, chemistry and dynamics in the GFDL AM3/CM3 (used for AR5)

• **Aerosol-Liquid Cloud Interactions**
  A prognostic scheme of cloud droplet number concentration (Ming et al., 2007) with an explicit treatment of aerosol activation at cloud base (Ming et al., 2006).

• **Convection Parameterization**
  Move from the relaxed Arakawa-Schubert (RAS) in AM2 to the Donner deep convection scheme (Donner, 1993) and the University of Washington (UW) shallow convection scheme (Bretherton et al., 2003). By providing in-plume updraft velocity, the latter two are ideal for implementing aerosol/cloud microphysics.

• **Online aerosol transport and tropospheric and stratospheric chemistry**
Evaluate aerosol properties simulated with CM3 for IPCC-AR5 using in-situ and remote sensing data
CM3 results: Ocean model improvements

Griffies et al. (2011, J. Climate, in press)

reduced coastal warm bias in CM3
CM3 results: Sea ice improvements

CM2.1 had thin sea ice relative to other AR4 models and observations. CM3 agrees better with observations.
### CM3: First NOAA/ GFDL Climate Model with Aerosol-Cloud Interactions


<table>
<thead>
<tr>
<th>Model</th>
<th>Temperature Change (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM2.1 (no indirect effect)</td>
<td>0.66°C</td>
</tr>
<tr>
<td>CM3 (includes indirect effect)</td>
<td>0.32°C</td>
</tr>
<tr>
<td>GISS Observations</td>
<td>0.52°C</td>
</tr>
<tr>
<td>CRU Observations</td>
<td>0.56°C</td>
</tr>
</tbody>
</table>

CM3 results: Total Column Ozone (Dobson Units); comparison with TOMS
Stratospheric Temperature Anomaly (global mean, MSU channel 4, ~80 hPa)
An example of seasonal (JASO) predictions of Atlantic hurricanes (2000-2010)

*(Chen and Lin 2011, manuscript)*

- 25-km GFDL HiRam
- Initialized forecasts
- Correlation = 0.96
- RMSE=0.93 (hurricanes)
Severity of Summer Heat Waves

Observation (last 24 year average)

Model Simulation (30-year average; present climate)

50 km resolution
Challenge: Resolution of Coastal-scale Processes

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

1/8 degree ocean simulation
Many of the oceanic consequences of climate change can best be explored with realistic high-resolution global ocean climate models, like those now being developed at GFDL.

Example below: The roles of ocean transport and microbial decay in determining the impacts of the Deepwater Horizon oil spill, explored with a 1/8° global ocean climate model in a collaboration between NOAA/GFDL & NOAA/OR&R.

Simulated Dissolved Oil Concentrations in the Mixed Layer on July 15, 2010 with Microbial Decay (6 day Half-life) Omitting Microbial Decay

<table>
<thead>
<tr>
<th>MODEL</th>
<th>ATMOSPHERE</th>
<th>OCEAN</th>
<th>LAND</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM2.1</td>
<td>$2^\circ$ lon x $2.5^\circ$ lat 24 levels</td>
<td>$1^\circ$ lon x $1/3-1^\circ$ lat</td>
<td>LM2</td>
<td>IPCC AR4 model</td>
</tr>
<tr>
<td>CM2.1.1</td>
<td>$2^\circ$ lon x $2.5^\circ$ lat 24 levels</td>
<td>$1^\circ$ lon x $1/3-1^\circ$ lat</td>
<td>LM2</td>
<td>Higher order advection in ocean, and low viscosity</td>
</tr>
<tr>
<td>CM2.3</td>
<td>$1^\circ$ lon x $1.25^\circ$ lat 24 levels</td>
<td>$1^\circ$ lon x $1/3-1^\circ$ lat</td>
<td>LM2</td>
<td>Same ocean as CM2.1, higher resolution atmosphere</td>
</tr>
<tr>
<td>CM2.4</td>
<td>$1^\circ$ lon x $1.25^\circ$ lat 24 levels</td>
<td>25Km in Tropics to 9 Km in polar regions Square grid.</td>
<td>LM2-LM3</td>
<td>Same atmosphere as CM2.3, higher resolution ocean</td>
</tr>
<tr>
<td>CM2.5</td>
<td>50 Km atmosphere, 32 levels, cubed sphere grid</td>
<td>Similar to CM2.4, uses z* as vertical coord.</td>
<td>LM3</td>
<td>Uses icebergs in ocean Similar ocean to CM2.4, higher resolution atmosphere</td>
</tr>
<tr>
<td>CM2.6</td>
<td>50 Km atmosphere, 32 levels</td>
<td>10 Km in Tropics to 3 Km in polar regions</td>
<td>LM3</td>
<td>Same atmosphere as CM2.5, higher resolution ocean</td>
</tr>
</tbody>
</table>
Preliminary results suggest resolving processes on finer spatial scales may lead to significant improvements in climate simulation.
The END

Thank you