MODELS USED IN CLIMATE CHANGE RESEARCH

Keith W. Dixon
research meteorologist / climate modeler
NOAA’s Geophysical Fluid Dynamics Laboratory
Princeton, NJ

www.gfdl.noaa.gov
TOPICS ALONG THE WAY:

- **Climate: One word, many meanings.**  
  Initial value problems (weather & short term climate predictions) vs. boundary value problems (decadal & longer projections). Physics are physics, but...

- **Generational Changes & A Matter of Scale.**  
  Higher spatial resolution & "comprehensiveness" lead to improved climate models, though how one measures "improvement" varies depending on the spatial and time scales of interest (and personal perspectives).

- **Certainty vs. Uncertainty.**  
  Identifying & comparing sources of uncertainty in multi-decadal climate model simulations + the role of the ocean.
Click on the map below to obtain local three-month temperature outlook information.

Please note, as of forecast May 2011, the climatological reference period has been updated from 1971-2000 to 1981-2010.

Would you like to look at your local information? Click on the map above or enter a location and time period below.

Search for a Location ("City, ST" or Zip)
Climate: Multi-year to Decadal

- 100s to 1000 of years
- Multi-decadal to Century
- Multi-year to Decadal
- Seasonal & SI
- Monthly Maps Text
- 8-14 Days T Maps P Maps Text
- 6-10 Days T Maps P Maps Text
- 3-7 Days
- 0-48 Hours
- Ultraviolet Radiation
- Watches/Warnings
Daily Weather Forecasts

Seasonal-
~1 yr Outlooks
(Temperature, Precip, ENSO, Hurricane Outlooks)

Lorenz (JAS, 1963)

INITIAL VALUE PROBLEM

PREDICTION: How does the system evolve from its starting point

PROJECTION: How does the system respond to changes in ‘forcing agents’

http://www.technologyreview.com/article/422809/when-the-butterfly-effect-took-flight/
Initial value problem

Daily Weather Forecasts

Seasonal-~1 yr Outlooks (Temperature, Precip, ENSO, Hurricane Outlooks)

Decadal Climate Predictability

Multi-Decade to Century Projections

For more info, see “Weather Prediction, Climate Prediction. What’s the Diff?” by Bill Chameides on the PopSci web site…
Though weather and long term climate models are similar in many ways (physics is physics....) they are used to address different questions.

"An Initial Value Problem" vs. "A Boundary Value Problem"
Though weather and long term climate models are similar in many ways (physics is physics....) they are used to address different questions.

"An Initial Value Problem" vs. "A Boundary Value Problem"
Radiative Forcing Agents: things that change the flow of solar & terrestrial (infrared) radiation though the climate system.

Source: IPCC 2013 WG1 SPM, http://www.climatechange2013.org/images/figures/WGI_AR5_FigSPM-5.jpg
Atmospheric Lifetimes & Warming Potentials

& http://cdiac.ornl.gov/pns/current_ghg.html

100-year global warming potentials, describe the effects that occur over a period of 100 years after a particular mass of a gas is emitted.

<table>
<thead>
<tr>
<th>Greenhouse gas</th>
<th>Average lifetime in the atmosphere (1/e = 37% remains)</th>
<th>100-year global warming potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>complex due to interactions (ballpark ~100 to 300 yr)</td>
<td>1</td>
</tr>
<tr>
<td>Methane</td>
<td>12 years</td>
<td>28</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>121 years</td>
<td>265</td>
</tr>
<tr>
<td>Fluorinated gases</td>
<td>A few weeks to thousands of years</td>
<td>Varies (highest = sulfur hexafluoride at 23,500)</td>
</tr>
</tbody>
</table>

Several factors determine how strongly a greenhouse gas will affect the climate. One factor is the length of time that the gas remains in the atmosphere. A second factor is each gas’s unique ability to absorb energy. By considering both, one may calculate a gas’s global warming potential, as compared to an equivalent mass of carbon dioxide.
AOGCMs represents the climate system’s physical components. An Earth System Model (ESM) closes the carbon cycle.
1980s
Atmospheric Model Resolution:
Weather vs. Dec-Cen Climate Models

- The Limited Fine Mesh Model II (LFMII) grid points were ~116 km apart at 45° latitude (7 vertical layers).
- The Nested Grid Model (NGM) had 3 grids. Its coarsest grid covered N. Hemisphere. The finest-mesh grid covered the east Pacific and N America with a resolution of 84 km at 45° (16 vertical layers).

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- GFDL CM2.5 (2011) atmospheric grid resolution of 50 km (32 vertical layers).
3 climate science questions & the role of climate variability & change models

1. Is the planet’s climate changing in significant ways?  [DETECTION]

2. If so, what is causing it to change? (people, natural, both?)  [ATTRIBUTION]

3. How might the Earth’s climate change in the coming decades & centuries?  [PROJECTION]
Decadal Avg. Observations....

Global Scale
Climate Change Attribution for...

Physical Climate?
Other Physical Systems?
Ecosystems?
Human Systems?

Global Scale?
Regional Scale?
Local Scale?

Over Decades?
Over A Few Years?
Over A Season?
Individual Events?

Signal to Noise Issues
Physical Climate, Global Scale, Over Decades

Estimates of Global Avg Surface Temperatures
Produced by 3 Centers
Physical Climate, Global Scale, Over Decades

BLACK = Observational Estimates Re-plotted

Observations (HadCRUT4)
Physical Climate, Global Scale, Over Decades

RED = Climate Model Simulations With Natural & Anthropogenic Forcings
Physical Climate, Global Scale, Over Decades

**BLUE = Climate Model Simulations With Natural Forcings Only** (solar & volcanic)

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**CMIP5: Natural Forcings Only**

- **5th/95th percentiles: multi-model mean**
- **5th/95th percentiles: single model realizations**
- **Observations (HadCRUT4)**

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Year:
- **1900**, **S**anta **M**aria
- **1950**, **A**gung
- **2000**, **P**inatubo, **E**l **C**ichón
Goldilocks’ & The 3 Bears Attribution Conclusions:

• If we consider only the natural forcings (solar and volcanic), the climate simulation is too cold (don’t simulate the late 20th century warming signal).

• If we consider only the GHGs, the climate simulation gets too hot too fast.

• Considering together multiple types of forcing agents (natural & human-induced) the model’s 20th century global average temperature simulations are just about right.
  (1) multiple GHGs (warming)
  (2) Solar(+/-)
  (3) Volcanic (cooling, few years)
  (4) Tropospheric Aerosols (pollutants) (some + & some -, net -, short lived, days to week)
“It is often very difficult to attribute a particular climate or weather extreme, such as a single drought episode or a single severe hurricane, to a specific cause. It is more feasible to attribute the changing “risk” of extreme events to specific causes.” – source: USGCRP/CCSP, Synthesis & Assessment Product 3.3: Weather & Climate Extremes in a Changing Climate (2008).

So while on one hand, one can not attribute a single event as either being 100% a result of -or- to have been 100% unaffected by human-induced climate change…

…there may be plausible mechanisms associated with human-induced climate change that would make a given event more or less likely to occur.

Poses challenges in the realm of the natural sciences and social sciences -- cross-disciplinary communications – ferment & froth --
The Ferment & Froth of Scientific Research

Sources of Scientific Info:
Individual peer-reviewed papers…
The ideas contained in the individual papers are bits of the “fabulous ferment & froth*” of scientific investigation.

It takes time to see what stands up. Assessment reports serve to distill the information & communicate the policy relevant bits that stand up.

(*paraphrase of Richard Alley during Congressional Hearing of 8 Feb 2007)
US National Climate Assessment
http://nca2014.globalchange.gov/

Intergovernmental Panel on Climate Change (IPCC)
How might the Earth’s climate change in the next 50 or 100 years? [PROJECTION]
CMIP5 projected changes in global mean temperature

Global surface temperature change (°C)

Temperature change relative to 1986-2005 [K]

Year

20 models

after IPCC AR5 WG1 Fig. 12-05
Sources of uncertainty in projected global mean temperature

- Observations (3 datasets)
- Internal variability
- Model spread
- RCP scenario spread (emissions)
- Historical model spread

Temperature change relative to 1986–2005 [K]


This and similar images based on work of Hawkins & Sutton, 2009: The Potential to Narrow Uncertainty in Regional Climate Predictions. *Bull. Amer. Meteor. Soc.*
After Hawkins & Sutton

- Uncertainty varies with...
  - Lead time
  - Spatial scale
  - Time averaging length

- Internal variability is...
  - Assumed constant over time
  - More important at smaller spatial scales & shorter timescales

- Some uncertainty will never be resolved

See also
http://barnes.atmos.colostate.edu/COURSES/AT780_F14/handouts_folder/lecture_2.pdf
Uncertainties In Climate Change Projections

Four broad types of uncertainties:

1) What will be the future emissions of greenhouse gases, etc. in the atmosphere? (GREEN on previous figures)
   (these are climate model inputs – they depend on population size, economic growth, energy use efficiency, alternative energy sources, treaties…)

2) How will the climate system respond to the changes in greenhouse gases, etc.? (BLUE on previous figures)
   (these are climate model outputs – they’re valuable, but computer models are incomplete & are not perfect)

3) How will changes in the climate affect crops, viruses, polar bears, coastal erosion, etc., etc., etc.? (climate change impacts – some researchers use climate model output as input to their own analyses)

4) What flaps of the butterfly’s wings will take place? (internal variability, ORANGE on previous figures)
Patterns of projected climate change:
annual mean surface air temperature

Temperature scaled by global T
2081-2100

(°C per °C global mean change)
Patterns of projected climate change: annual mean precipitation

Precipitation scaled by global T

2081-2100

(% per °C global mean change)
On the Ocean’s Role…
Where has the additional heat energy gone? (1971-2010)
Most of it resides in the global ocean.

Heat Energy
- Warm the Ocean: 93%
- Warm the Air: 1%
- Melt Ice: 3%
- Warm Continents: 3%

Percentages are central estimates, adapted from the 2013 IPCC Working Group 1 Report’s Summary for Policymakers (Section B2)
http://www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf
Ocean Heat Uptake Affects The Global Avg. Surface Air Temperature Transient Response

Some Implications

- Because of the ocean’s heat uptake, the atmosphere is far from being in equilibrium with the present levels of atmospheric greenhouse gases.

- Even if atmospheric greenhouse gas concentrations were held constant at today’s levels, the climate system would continue to warm for decades.

“Committed Warming” due to the ocean’s thermal inertia...
What makes a climate model “better”?

A. Ability to reproduce climate observations of the past… determine via ‘objective’ skill scores, etc.

Z. “Comprehensiveness” of the model. Representing physics, biogeochemical processes etc. in a way that reduces reliance on more simplistic, or non-physical parameterizations.

A diversity of options exist in the research community.

Somewhat dependent on the research question of interest.
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