How climate Models Work: Building Future Weather

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Outline

1. What is Climate (and climate change)?
2. What is a model?
3. Climate v. Weather Models?
4. Sources of Uncertainty
5. ‘Evaluation’ of models
6. Natural v. ‘Human Caused’ Events
Climate is what you Expect, Weather is what you get

- Climate = distribution of possible weather, and its probability
- Weather = Chaos
  - Chaos theory ‘developed’ by a meteorologist (Edward Lorenz) in 1961
  - Simple model to explain why the weather is not predictable
Chaos Theory: Lorenz Attractor

- Graph of the solution of a 2 variable model
- If you start from very near the same place, you can get to very different places
- The overall pattern is stable (climate)
- But the individual trajectories can be very different (weather)
‘Climate Change’

• What does ‘Climate Change’ mean?
• More importantly: who cares if the ‘global’ climate changes by 1-3°C?
• The ‘weather’ changed more than that last night or since yesterday
• What does it mean for weather extremes?

No one gets killed by the mean climate
Climate change and its manifestation in terms of weather (climate extremes)
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Physics of Climate

Laplace

Newton

Carnot

Kelvin

Maxwell

Arrhenius

Clausius
Principles of Weather and Climate Physics

- Laws of Motion (Newton 1687)
- Mathematical basis (Laplace 1776)
- Thermodynamics
  - (Carnot 1824, Clausius 1850, Kelvin 1851)
- Radiation (Maxwell, 1865)
- Chemistry: Arrhenius (1896)
Fundamentals of Climate & Weather (and climate modeling)

- Conservation of Mass and Energy
- Laws of Motion on a rotating sphere
- Fluid Dynamics
- Mathematical integration & Statistics
- Radiative transfer
  - Absorption and Scattering of Solar Energy
  - Thermal Transfer, Conduction & Convection
- Thermodynamics: humidity, salinity
- Chemistry
Ceci n’est pas une pipe.
All models are wrong. But some are useful.

-George E. P. Box, 1976 (Statistician)

What is a model?

A model is an imperfect representation
Model of a Building
Models of a Car
Physical Model of San Francisco Bay
Spreadsheets (Numerical Model)
What is a Numerical Weather/Climate Model?

A numerical model of budgets (mass, energy)
Governed by equations (physical Laws)
At every point in a 3D area
Numerical Weather/Climate Modeling
An accounting exercise constrained by a myriad of physical laws

How does a climate model work?
• A giant spreadsheet with entries for ‘water’, ‘heat’, ‘wind’ (also ‘salt’, ‘carbon’)
• Account for each process in each grid box (water in a cloud)
• Solve equations for processes at every point
• Advance in time (and move variables around in space with the wind/gravity).
• Repeat

Common Problems:
• Many processes hard to describe at the right scale: imperfect representations
• Try to observe the processes (e.g. clouds) to derive physical laws at the right scale
Stepping ‘Spreadsheet’ Forward in Time

1. Get changes at each point
2-3. Interact changes locally
4. Changes in energy
5. Compute motion and movement
Repeat

(1) Physical Processes (e.g., plant growth, condensation)
(2) Column Interactions: precipitation
(3) Exchange between land, ocean, atmosphere (surface fluxes)
(4) Radiation: heat exchange
(5) Dynamical Core (motions)

Chemical Transformations
Weather v. Climate Models
Key Uncertainties Differ

- Differences in focus (e.g. where computing time goes)
  - Weather models:
    - Short time horizon (1 week)
    - Detailed processes & resolution, ensembles
    - Uncertainty for tomorrow: where we are today
  - Climate models:
    - Decades to centuries
    - Absolute energy/mass conservation

D. Lorenz, Univ. Wisconsin
Uncertainty and the difference between Climate and Weather

- Initial Conditions = Today’s weather
- Model Uncertainty = Model approximations/‘errors’
- Scenario Uncertainty = ‘forcing’ (total emissions)

Initial condition uncertainty fades over time
Scenario Uncertainty grows
Uncertainty varies by time and space

GLOBAL

United (more or less) Kingdom
Initial Condition Uncertainty
Examples from Weather Forecasting

• THE problem of weather forecasting
• Errors in the initial state propagate
How to deal with initial uncertainty?
Ensembles (multiple) simulations

Ensemble Weather Forecasting

Can also do ensembles (multiple simulations) for climate
Reducing uncertainty in Weather Forecasting

• Better resolution in time/space
  • Processes affected by resolution

• Critical processes (model uncertainty)
  • Clouds. Distributions of clouds

• Data assimilation: better inputs (initial condition uncertainty)

• Ensemble forecasting take advantage of model and initial condition uncertainty
Initial condition uncertainty fades over time. Scenario Uncertainty Grows.
Scenario Uncertainty

What parts of the future are we specifying, what are we predicting?

Global average surface temperature change

- Historical
- RCP2.6
- RCP8.5

Mean over 2081–2100

Year

1950 2000 2050 2100

(°C)
How do we know models are right?

• They can predict the weather (sort of)
  • Evaluate by ‘re-running’ forecasts (=Hindcasts)
• They are evaluated against present observations (weather and climate)
• Climate models can predict the historical period (hindcast)
  • Start in 1850, run to present
Model Hindcast: Global Average Temperature Observed and Simulated
But: Models are ‘good enough’

Scenario Uncertainty dominates for Climate Change

Initial condition uncertainty fades over time. Scenario Uncertainty Grows

- Total Uncertainty
- Scenario Uncertainty
- Model Uncertainty
- Initial Condition Uncertainty

Graph:
- X-axis: Lead Time (years)
- Y-axis: Uncertainty
- Weather vs. Climate
Is this climate change?

Houston, Aug 31 2017

Santa Rosa, CA, Oct 11th

Puerto Rico, Sep 20th

Ireland, Oct 16th

US Wildfires, Sept 6 2017
Is an event ‘caused’ by climate change?

• ‘No one is killed by the global average mean temperature’
• Climate change is how the ‘tails’ are going to change
• When the tails change, the weather starts to get ‘unfamiliar’

Examples
• Warm winters
• Larger number of intense Hurricanes
• More extreme rainfall
• Hotter summers (including more records)
HIGHHS BEATING LOWS

Ratio of Daily Temperature Records

MORE HIGHS
MORE LOWS

As of August 2015
Source: Guy Walton, NOAA/NCEI

CLIMATE CENTRAL
Feel Locally, Related Globally

Local records tied to global temperatures:
More daily high records set when global temps warm
The story of Hurricanes and Climate Change

• Hurricanes get energy from warm oceans
• Warmer oceans mean possibly more intense storms, and/or more storms (not sure): Science part.
• The Gulf and Atlantic were really warm this year
  • That could be random
• Warm oceans consistent with climate change
• Note: more people live near coastlines (more damage)
  • But, development has not kept pace with climate change
  • Adaptation is necessary

August 21 SST Anomaly: Orange = +4°F
Summary

• Climate and weather models are very similar
• Climate is the distribution of possible weather at any place
• Climate change is how that distribution changes
• Critical uncertainties are different for weather & climate
  • Weather = Initial conditions, Climate = scenarios
• Extreme event frequency changes with climate change.
  • Extreme events and ‘unfamiliar weather’ are CONSISTENT with climate change
"Uncertainty is not a weakness. Understanding uncertainty is a strength, and a key part of using any model, including climate models."

Section 1:  
What is climate?

Section 2: How to build a Model

Section 3: Uncertainty

Want more? “A users guide” to models
A. Gettelman and R. B. Rood

www.demystifyingclimate.org