Do-It-Yourself Climate Prediction

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The Day After Tomorrow
The science of climate change

- What is “climate” and why do we think it is changing?
- How can we predict climate when we can’t predict the weather?
- What are the main uncertainties in climate prediction?
- Simulating climate change: the science of climate modelling.
- Using spare capacity on personal computers for global climate prediction.
Climate Change: Fact or Fiction?
What is the Weather?

climateprediction.net
What is the Climate?

“Climate is what we expect; weather is what we get”

Climate is the statistics of the weather

• Mean annual Indian Rainfall
• Average December temperature in Slough
• How often Florida hurricanes happen
"Climate is what we expect, weather is what we get"

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<td>Time (Ma)</td>
<td>Mean Global Surface Temperature</td>
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<td>Triassic</td>
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<td>250</td>
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<td>286</td>
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</tr>
<tr>
<td>350</td>
<td>Devonian</td>
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<td>408</td>
<td>Silurian</td>
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“In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations”

Source: IPCC Third Assessment Report, 2001
Climate is determined by factors like:

• Solar irradiance (power output of the sun)
• Volcanic activity
• Atmospheric composition (greenhouse gases etc...)
• Positions of continents, ice-sheets etc.

We call these the ‘boundary conditions’
Sunlight passes through the atmosphere and warms the earth. Most escapes to outer space and cools the earth. But some IR is trapped by some gases in the air, thus reducing the cooling.

Infra-red radiation is given off by the earth.

Source: Ellie Highwood
Leaky Water Tank

What happens if the tank is filled with water?
Energy in the climate system

Diagram showing energy flow in the climate system, including:
- Reflected Solar Radiation: 107 W m²
- Incoming Solar Radiation: 342 W m²
- Outgoing Longwave Radiation: 235 W m²
- Reflected by Clouds, Aerosol, and Atmosphere: 77 W m²
- Reflected by Surface: 30 W m²
- Absorbed by Surface: 168 W m²
- Absorbed by Atmosphere: 67 W m²
- Evapotranspiration: 24 W m²
- Surface Radiation: 390 W m²
- Greenhouse Gases: 40 W m²
- Latent Heat: 78 W m²
- Back Radiation: 324 W m²
- Atmospheric Window: 40 W m²

climateprediction.net
Atmospheric Carbon Dioxide Concentration

Source: IPCC Third Assessment Report
What is a Model?

• Models are simplified versions of real systems
• To predict and understand the climate of the Earth, we can use a model
• In the case of climate prediction, what we mean by a model is a set of equations that represent how the atmosphere and oceans behave – how temperature patterns develop, how winds blow etc.

A way to represent a system for the purposes of reproducing, simplifying, analyzing, or understanding it (sometimes on a smaller scale).
Weather/ climate model

MODEL

What we know will change in the future

observations

Physics

climatemodelprediction.net
General Circulation Model of the Atmosphere:

3 Equations of Motion
Equation of State
Energy Equation
Mass Conservation

{ 3D wind field
  Temperature
  Pressure
  Density
}

The Model also includes:

- Convection scheme
- Cloud scheme
- Radiation scheme
- Sulphur cycle
- Precipitation
- Land surface and vegetation
- Gravity wave drag scheme

Each of these equations is evaluated at each point in the model [96 longitudes by 73 latitudes by 19 vertical levels] every half hour timestep
Factors affecting climate - II

4-member ensemble, anthropogenic forcing
Factors affecting climate - III

4-member ensemble, solar and volcanic forcing
Factors affecting climate - IV

4-member ensemble, all forcings included
(d) Temperature change

Source: IPCC Third Assessment Report, 2001
We can produce very detailed predictions of climate change with no idea of how reliable they might be.

Source: Dr. Mat Collins, Hadley Centre
Record hot events are more likely in a generally warmer world.
Was the hot summer of 2003 due to climate change?

Anthropogenic emissions of greenhouse gases have doubled the risk of a summer like 2003.

By 2050, it could be that hot every other summer.
Do you trust a weather forecast?
Double Pendulum

Initial speed
400.1 degrees/sec

Initial speed
400.0 degrees/sec

Courtesy of Ross Bannister
Does the Flap of a Butterfly's Wing in Brazil Set Off a Tornado in Texas?

Ed Lorenz
The climate is like a game of roulette…
Climate of a Chaotic System- Lorenz Attractor

- Three 1st order ODEs.

\[ \begin{align*}
  \dot{x} &= \sigma(y - x) \\
  \dot{y} &= rx - y - xz \\
  \dot{z} &= xy - bz
\end{align*} \]
Time averaged Histogram

PDF of unit-time-averaged Lorenz (1963) model, unforced
The climate may be predictable even if the weather is not.
Parameters perturbed

- Critical Relative Humidity (RHcrit)
  - related to the cloud cover distribution in a grid box.
- Accretion constant (CT)
  - related to growth of rain droplets and lifetime of clouds.
- Condensation nuclei concentration (CW)
  - affects water holding capacity and lifetime of clouds.
- Ice fall velocity (VF1)

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<tr>
<th>Parameter</th>
<th>Range:</th>
<th>“Standard” values</th>
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<tr>
<td>RHcrit</td>
<td>0.5 – 0.95 (0.6 – 0.9)</td>
<td>0.7</td>
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<tr>
<td>CT</td>
<td>5x10^-5 - 4x10^-4</td>
<td>1x10^-4</td>
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<tr>
<td>CW - land</td>
<td>1x10^-4 – 2x10^-3</td>
<td>2x10^-4</td>
</tr>
<tr>
<td>CW - sea</td>
<td>2x10^-5 – 5x10^-4</td>
<td>5x10^-5</td>
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<tr>
<td>VF1</td>
<td>0.5 – 2.0</td>
<td>1</td>
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Climate Sensitivity

Climate sensitivity for various parameter perturbations

ΔT on doubling CO₂ (K)

Max RHcrit, Max CW, Max VF1, Max CT, Linear sum, Max all

Standard
So for a complete climate forecast, we need to find out what hundreds of thousands of models do….

Initial conditions: all the possible ‘butterflies’

Boundary conditions: carbon dioxide, volcanoes …

‘Parameters’ – climate models aren’t perfect
Embedded Ensembles

- Standard model set-up
- Perturbed physics ensemble
- Initial condition ensemble
- Boundary Conditions (forcing) ensemble
- Overall embedded-ensemble
Climateprediction.net experiment design

Experiment 1 (September 2003 – end 2004)

How does each model react when carbon dioxide is doubled?

→ Throw away models which are ridiculous because of their particular combination of parameters

Experiment 2 (2005)

How well does each model do at reproducing the climate of 1900-2000?

→ Find out which models we believe more than others

Experiment 3 (2006)

What climate does each model predict for 2000 - 2050?

→ A probability-based climate forecast for the 21st century
Experiment 1

Pre-industrial Carbon dioxide

Double carbon dioxide

Surface temperature

Total precipitation

climatemodeling.org

climateprediction.net
The results so far……
Standard Visualisation Package

www.climateprediction.net
11th-18th December 1828, London
Since September 2003, 90,000 participants in 142 countries have completed 42,000 45-year GCM runs. They have computed 3 million model years and donated 8,000 years of computing time.
Will the results of experiment 3 look like this made up figure?