Predicting future changes in climate and sea level

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How can we predict the future of our planet?
No full-sized control experiment
Dynamic Earth
More usually...

HadCM3
The Earth System

“A simplistic conceptual model”
General Circulation Models (GCMs)

$\frac{dV}{dt} + fk \times V + \nabla \phi = F$

$C_p \frac{dT}{dt} - \omega \alpha = Q$

$\frac{dq}{dt} = S$

$\nabla \cdot V + \frac{\partial \omega}{\partial p} = 0$

$\frac{\partial \phi}{\partial p} = -\alpha$

$p \alpha = RT$

Newton’s laws

Laws of thermodynamics

Conservation of mass, energy, water

UK Met Office
Hadley Centre
GCM in 2000
History

- **1990:**
  - Mid-1970s: CO₂ emissions, rain
  - Mid-1980s: Land surface, prescribed ice

- **1996:**
  - FAR (1990): Volcanic activity, Sulphates, "Swamp Ocean"
  - SAR (1996): Ocean

- **2001:**
  - TAR (2001): Carbon cycle, aerosols, rivers, overturning circulation

- **2007:**

- **2007:**
  - Maps showing distances: ~500 km (T21), ~250 km (T42), ~180 km (T63), ~110 km (T106)
Complexity

One million lines

Sloooow....

HadCM3

HadGEM1
Modelling Antarctica

Steph Cornford
How do we know if the models are RIGHT?
All models are WRONG

...but some are USEFUL

George Box

allmodelsarewrong.com
Parameter uncertainty
models need tuning

clouds
convection
radiation

land surface
boundary layer
sea-ice
Structural uncertainty
tuned models are still imperfect

winter temperature change

Stippled: 80% or more of models agree on sign of change

winter precipitation change

winter cloud cover change
Initial condition uncertainty
imperfect knowledge of today’s weather
How do we predict OUR future?
“Prediction is very difficult, especially if it’s about the future”
(thanks Niels)

“Trying to predict the future is a mug's game”
(thanks Douglas)
Boundary condition uncertainty
imperfect knowledge of the future drivers of change
How do we know how WRONG the models are?
Climate hindcasts

IPCC Working Group 1 (2007), Fig 9.5
Climate hindcasts

Observations

HadCM3

IPCC (2007) WG1, Chap 8 Supp. Mat., Figs 8.1a, b
Climate forecasts

The first (1988)

Hargreaves et al. (2010), WIREs Climate Change
In 2007:
How do we incorporate model success into predictions?
Incorporating success in predictions

Bayes to the rescue

“first guess” probability + observations
= better prediction of probability

probability as belief
Detuning the model

Stainforth et al. (2005), Nature

Stone et al. (2010) The Cryosphere

climatereprediction.net
Stainforth et al. (2005), Nature
Bayes’ Theorem

**prior probability:** ensemble of detuned model versions...

*likelihood: score with observations*

=> **posterior probability**

\[
\text{posterior} = \frac{\text{prior} \times \text{likelihood}}{\text{normalisation}}
\]
1. Likelihood function: Gaussian

- Model errors normally distributed
- If multiple observations: independent

\[ w(\theta) \propto \exp \left[ -\frac{1}{2} \sum_i \frac{(z_i - f_i(\theta))^2}{(\sigma_o^i)^2 + (\sigma_m^i)^2} \right] \]

2. Calculate scores

- Don’t need normalising constant

3. Normalise scores

\[ \sum_{\theta} w(\theta) = 1 \]

- Expected success at best parameter values; can tune to distribute weights
Simple application

4. Use scores to reweight histograms

(a) observed quantity
(b) future prediction

**Antarctic contribution to sea level**

(a) 2006

- decrease

(b) 2200

- increase

Antarctic contribution to sea level

Ritz et al.
UK Climate Projections

Sexton et al. (2011) Climate Dynamics
Your future

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allmodelsarewrong.com

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