Climate models

Tools for understanding the Earth system

Climate change is one of the most important environmental issues we face this century. The top research priority for the Natural Environment Research Council is to gather knowledge about climate and what controls it, and then use that knowledge to predict future changes.

Predictions are made using climate models. Here we describe what climate models are, what they do and how much we can trust them.

Coupled Ocean-Atmosphere Processes and European Climate (COAPEC)
This brochure is a product of the Natural Environment Research Council's COAPEC programme. COAPEC aimed to determine how coupling between the atmosphere and the Atlantic Ocean over seasons to decades effects climate, especially in Europe. A major focus of COAPEC research has been developing and evaluating climate models and their use to understand climate processes.

pressure

What is a climate model?

A climate model is a computer program designed to simulate Earth's climate. Climate models are based on mathematical equations that describe the behaviour of the atmosphere and ocean, and their interactions with other components of the Earth system, such as the cryosphere (ice sheets, glaciers and sea-ice), the land surface and the biosphere (living organisms, particularly plants).

A model's core equations, which are derived from the laws of physics, describe how temperature, pressure, winds (or currents) and other variables in the atmosphere and oceans change over time. Additional equations describe chemical and biological aspects of the climate system.

In a model, the climate variables are represented on a three-dimensional grid covering the atmosphere and the oceans. The spacing between grid points in the atmosphere is typically a few hundred kilometres horizontally and 500 metres vertically. Figure 6 shows the grid structure of a climate model schematically.

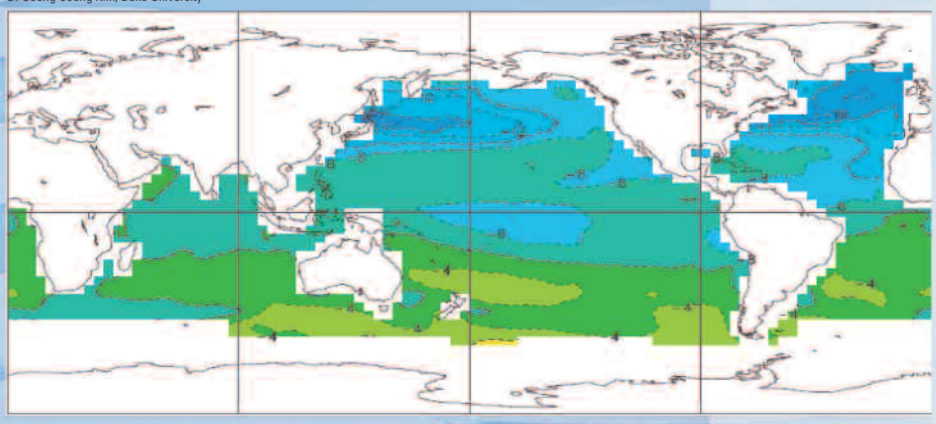
How do climate models help us understand climate?

The climate system is very complex, and this makes understanding it difficult. To make scientific progress, we need to explore mechanisms and test theories by carrying out experiments. It is not feasible to experiment on the climate system itself, nor is it possible to reproduce the full complexity of the climate system in a laboratory. Climate models offer us the best possible alternative – a numerical laboratory where we can address vital questions.

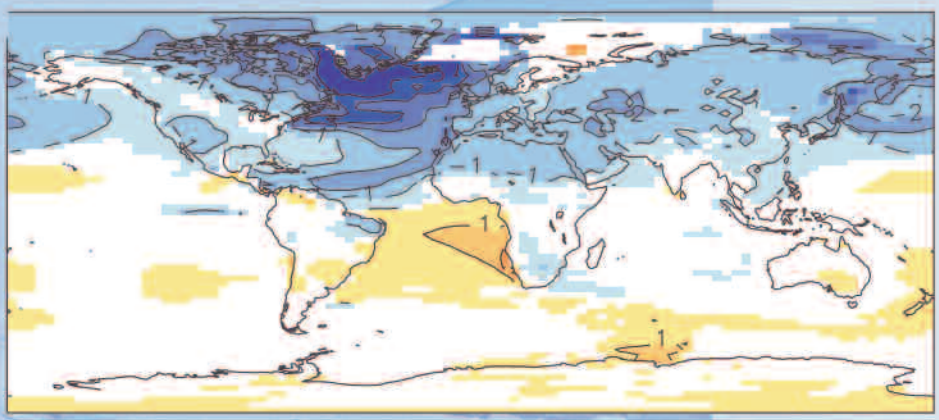
- How will the climate change in response to rising levels of greenhouse gases?
- What would happen to the climate of Europe if the Atlantic Ocean's thermohaline circulation (the current that carries warm water to northwestern Europe) were to stop?
- What controlled Earth's climate in the past?

temperature

Dr Seong-Joong Kim, Duke University



1. Results from a climate model experiment estimating how global sea-surface temperature at the last glacial maximum, approximately 21,000 years ago, differed from the present day.



2. A climate model experiment that shows how turning off the thermohaline circulation could affect surface temperatures across Europe.

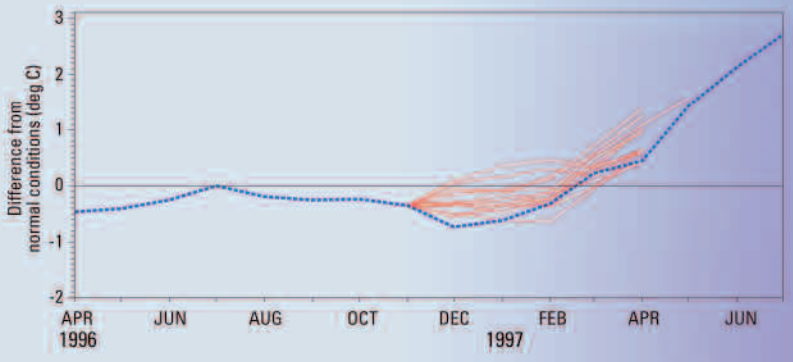
Dr Michael Vellinga, Met Office, Hadley Centre

What makes scientists trust climate models?

Climate researchers are confident that climate models can accurately represent key aspects of the climate system:

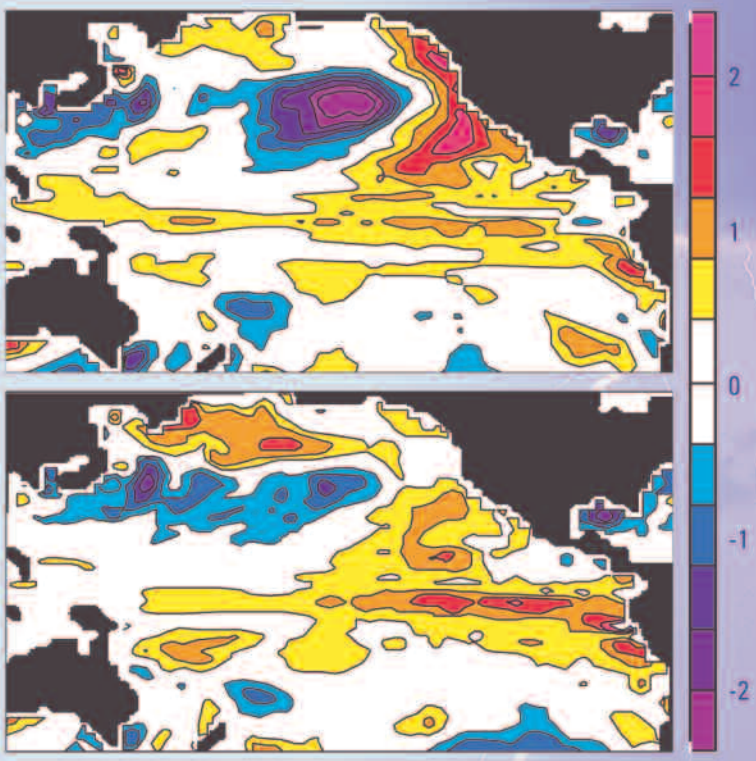
- The core of a climate model uses well-understood physical, chemical and biological equations and principles.
- Climate models are continually evaluated against datasets of real observations. The results show that the models can reproduce many aspects of present and past climate, including the overall strength and pattern of recent observed climate change.
- Prediction is often considered the ultimate test of understanding. It has been shown that climate models can successfully forecast the weather, and even major climate phenomena such as El Niño (see figures below).

Climate models are the only scientifically credible tools for making detailed predictions about climate on a regional scale. Nonetheless, because climate models are mathematical approximations of the climate system and not the system itself, their results must be treated with due scientific caution.



3. It is clear from this graph that climate models can correctly predict climate events, such as the onset of the 1997-1998 El Niño. The graph shows the actual (blue) and forecast (red) sea-surface temperature in the equatorial Eastern Pacific; the red lines represent several different forecasts, all of which predict the timing accurately.

Figure from ECMWF Newsletter, no 7.



4. This model correctly forecast the main pattern of warmer- and cooler-than-usual sea surface temperatures (anomalies) during the 1997-1998 El Niño six months before they occurred. The upper panel shows the actual temperature anomalies in the Pacific Ocean in May 1997. The lower panel is the prediction made in December 1996 – before the onset of the El Niño.

Fgure from ECMWF Newsletter, no 7.

cryosphere
osphere

Questions asked about climate models

Are climate models too simple? They ignore lots of things…

Climate models include as many physical, chemical and biological processes as possible. If a particular climate model is to be a useful tool, researchers must be sure it adequately describes the phenomena of interest. Current models are certainly good enough to simulate large-scale climate phenomena. Identifying the limitations of a particular model is part of the process that stimulates further improvements and advances our understanding. Developing climate models is a 'grand challenge' and, over time, they have become much more comprehensive and accurate. But there is still a long way to go!

Are climate models too complex? Don't we need simpler models to understand processes properly?

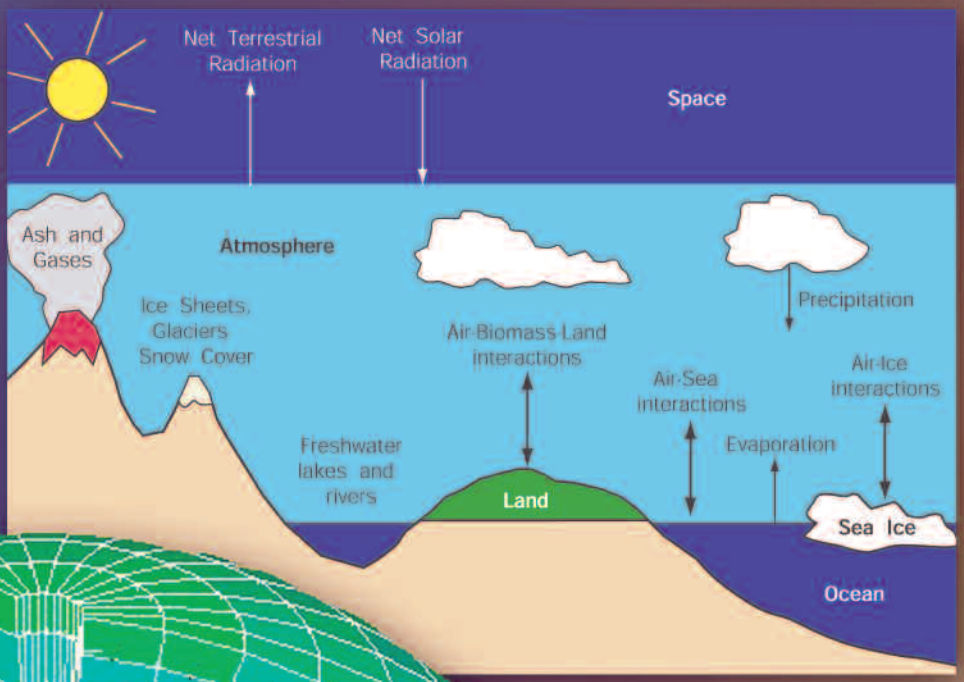
Simple models, perhaps based on only one or two equations, can give valuable insight into a particular mechanism. However, they are not in themselves sufficient. They inevitably neglect or greatly simplify a host of interactions that operate in the real climate system. So scientists use a hierarchy of mathematical models for climate research, ranging from the simplest to the most complex. Climate models provide tools to describe climate complexity, and explore the extent to which particular mechanisms might be relevant. Because of the numerous interactions and feedbacks in a climate model, experiments can produce unexpected results, and scientists sometimes go back to simpler models to investigate these. Climate models can also be a useful source of new ideas.

Aren't climate models tuned to give the right answer? If so, how can you possibly evaluate them?

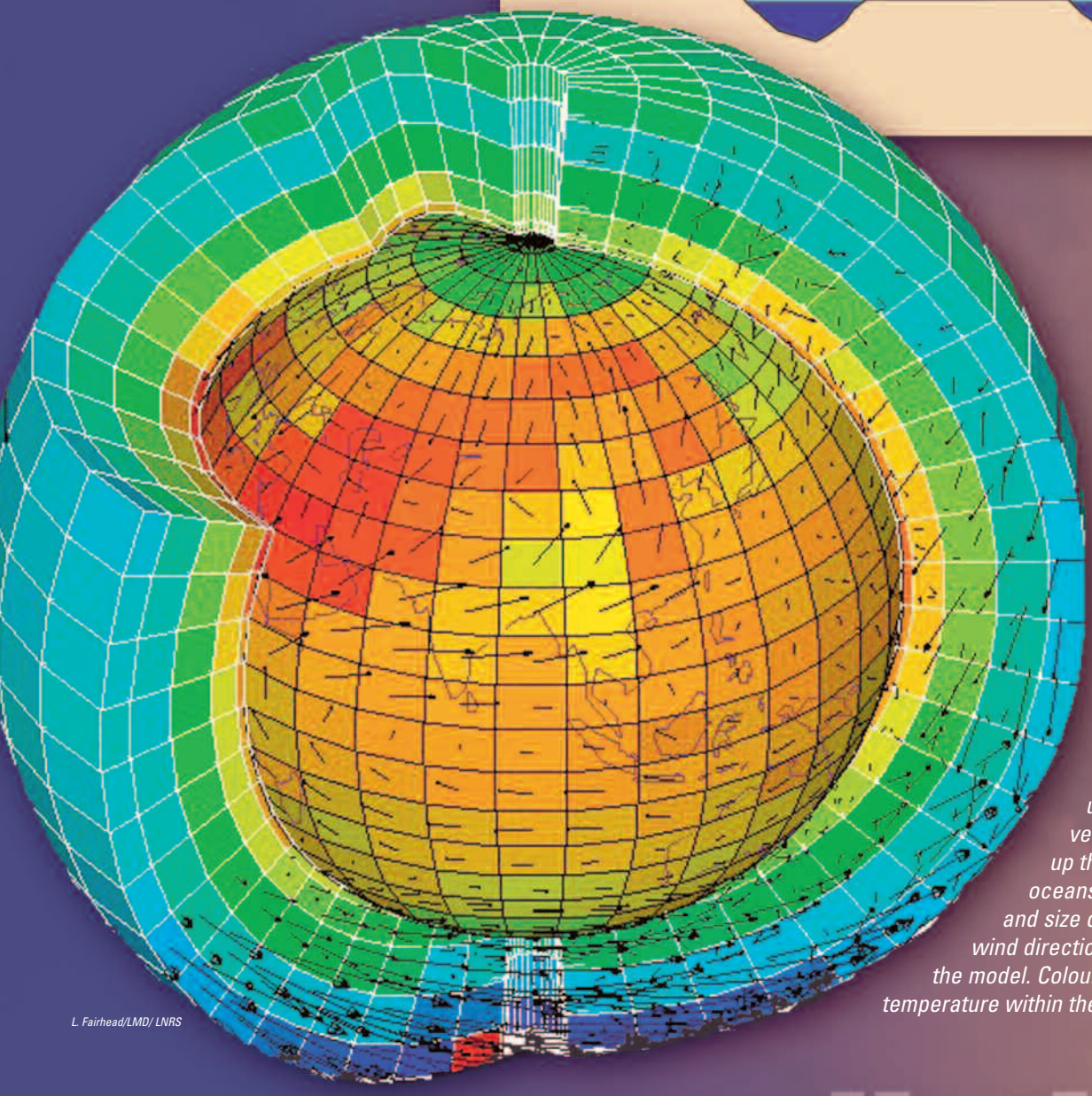
Before a particular climate model is used, it is tuned to reproduce a large-scale average climate that agrees with actual observations. The tuning process does involve fixing values for some variables that we're uncertain about. But tuning does not change the core model equations and these constrain the outcomes the model could produce – so climate models cannot be tuned to give any 'desired' answer. Once set up, models are not re-tuned for different situations without very good physical reasons.

Climate models sometimes disagree. Can they be trusted?

All climate models are based on the same basic physics, but they differ in some other details. So, although they broadly agree, they can generate different outcomes. Studying what makes models disagree is an important area of research that advances our understanding. Comparing results from different models helps us assess uncertainty, enabling us to estimate the likelihood of various changes to our future climate.



5. The components of the climate system. State-of-the-art climate models include representations of all of these components and the interactions between them.



L. Fairhead/LMD/ LNRS

6. Climate models use horizontal and vertical grids to divide up the atmosphere and oceans. The orientation and size of the arrows show wind direction and strength in the model. Colours denote temperature within the grid box.

modelling predictions

forecasting

Contacts

Natural Environment Research Council (NERC)
Tel: 01793 411500, www.nerc.ac.uk

NERC collaborative centres with a major focus on climate models:

NERC Centres for Atmospheric Science (NCAS)
Tel: 0113 3435158 or 0113 3436408, http://ncas.nerc.ac.uk

National Oceanography Centre, Southampton
Tel: 023 8059 6666, www.noc.soton.ac.uk

Other NERC centres working on climate change:

British Antarctic Survey
Tel: 01223 221400, www.antarctica.ac.uk

British Geological Survey
Tel: 0115 936 3100, www.bgs.ac.uk

Centre for Ecology & Hydrology
Tel: 01305 213500, www.ceh.ac.uk

Centre for Polar Observation and Modelling
Tel: 0207 679 3031, www.cpom.org

Centre for Terrestrial Carbon Dynamics
Tel: 0114 222 3803, www.shef.ac.uk/ctcd

Environmental Systems Science Centre
Tel: 0118 378 8741, www.nerc-essc.ac.uk

Plymouth Marine Laboratory
Tel: 01752 633100, www.pml.ac.uk

Tyndall Centre for Climate Change Research
Tel: 01603 593900, www.tyndall.ac.uk

For more information:

climate*prediction*.net
The largest experiment to produce a forecast of the climate in the 21st century.
www.climateprediction.net

Hadley Centre for Climate Prediction & Research
Tel: 0870 900 0100,
www.met-office.gov.uk/research/hadleycentre

Intergovernmental Panel on Climate Change
www.ipcc.ch

International Geosphere-Biosphere Programme
www.igbp.kva.se

UK Environmental Change Network
Tel: 01524 595800, www.ecn.ac.uk

UK Climate Impacts Programme (UK CIP)
Tel: 01865 285717, www.ukcip.org.uk

World Climate Research Programme
www.wmo.ch/web/wcrp/wcrp-home.html

This brochure was produced by Emily Black, Pierre-Philippe Mathieu and Rowan Sutton in collaboration with the COAPEC steering committee and NERC's Communications team.

Front cover: Surface temperature output from a climate model. Blue indicates low temperature and red indicates high temperature. Simulations like this are used to explore scenarios for future climate.

The UK's Natural Environment Research Council funds and carries out impartial scientific research in the sciences of the environment. NERC trains the next generation of independent environmental scientists. NERC invests 28% of its total expenditure on climate research through collaborative centres, dedicated research centres and in universities across the UK.

NATURAL ENVIRONMENT RESEARCH COUNCIL

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