An efficient and portable climate system model for studying past, present and future climate

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23 February 2006
Acknowledgements

- Nathan Bindoff, TPAC/University of Tasmania/CSIRO
- Bill Budd, University of Tasmania
- Scott Power, Bureau of Meteorology Research Centre
- Jason Roberts, TPAC
- Tas van Ommen, Australian Antarctic Division
- CSIRO Marine and Atmospheric Research
- APAC
- iVEC
Overview

1. Climate variability and change
2. The CSIRO Mk3L climate system model
3. Present climate
4. Past climate
5. Future climate
Climate variability and change
1. Climate variability and change
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1. Climate variability and change

What is climate?

• mean state of the climate system ("average weather")
1. Climate variability and change

What is climate?

- mean state of the climate system ("average weather")
- a measure of the variability within that state
1. Climate variability and change

What is climate?

• mean state of the climate system ("average weather")
• a measure of the variability within that state
• timescale?
1. Climate variability and change

Climate variability or climate change?

- climate *variability*
  - refers to natural variations around the mean state
1. Climate variability and change

Climate variability or climate change?

- **climate variability**
  - refers to natural variations around the mean state

- **climate change**
  - refers to a change in the underlying mean state
  - often used to refer to changes arising from human activity
1. Climate variability and change

The Earth's climate exhibits variability on all timescales...

Global land-surface air temperature 1861-2000
1. Climate variability and change

The Earth’s climate exhibits variability on all timescales...

Global-mean surface air temperature over the past 100,000 years
1. Climate variability and change

External influences include the sun ...

Total solar heat output 1600-2000

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1. Climate variability and change

... the Earth’s orbital geometry ...
1. Climate variability and change

... and us!

Atmospheric CO$_2$ concentration over the past 1000 years
1. Climate variability and change

Understanding climate variability and change

Fundamental questions include:

- What is the magnitude of natural climate variability?
1. Climate variability and change

Understanding climate variability and change

Fundamental questions include:

- What is the magnitude of natural climate variability?
- To what extent are recent changes due to human influences?
1. Climate variability and change

Understanding climate variability and change

Fundamental questions include:

- What is the magnitude of natural climate variability?
- To what extent are recent changes due to human influences?
- What can we expect in the future?
1. Climate variability and change

There are two ways that we can address these questions:

- Data
- Models
1. Climate variability and change

Data

Sources of data on past climates include:

- Direct measures
  - observations
- Indirect measures
  - ice cores
  - marine/lake sediments
  - tree rings
  - coral
1. Climate variability and change

Models

- based upon the physical laws describing the processes occurring within the climate system
- underlying equations are solved numerically
- enable direct simulation of past, present and future climate states
- can be used to study both the mean climate state, and the degree of climate variability
- can help to understand past climate change
- require large computer resources
1. Climate variability and change

Can we trust the models?

- models are limited by the representation of the underlying physical processes, which is restricted by:
  - the understanding of the processes
  - the comprehensiveness of the model
  - computational resources
1. Climate variability and change

Can we trust the models?

- models are limited by the representation of the underlying physical processes, which is restricted by:
  - the understanding of the processes
  - the comprehensiveness of the model
  - computational resources
- models require validation before we can trust the results
1. Climate variability and change

Model validation

• compare simulated climate with observational or historical data

• the *maximum* extent to which we can have confidence in a model is the extent to which it can reliably simulate a range of climate states

• desirable to validate the model over as wide a range of climate states as possible

• the only feasible way of doing this is to simulate past climates
2. The CSIRO Mk3L climate system model

The CSIRO Mk3L climate system model
2. The CSIRO Mk3L climate system model

Model description

- Low-resolution version of the CSIRO Mk3 climate system model
- Includes:
  - Three-dimensional model of the atmosphere
  - Three-dimensional model of the ocean
  - Sea ice model
  - Land surface model
- $64 \times 56$ horizontal grid
- 18 vertical levels in the atmosphere
- 21 vertical levels in the ocean
2. The CSIRO Mk3L climate system model

Horizontal grid
2. The CSIRO Mk3L climate system model

Model source code

- Mostly Fortran 77 (plus some Fortran 90 and C)
- Over 85,000 lines of code
- Designed for maximum portability across computer architectures
- Should compile on any UNIX/Linux platform
- Shared-memory parallelism achieved using OpenMP
- Dependence on external libraries restricted to netCDF and FFTW
- Loop structure optimised for serial architectures
2. The CSIRO Mk3L climate system model

Benchmarks on APAC Facilities

<table>
<thead>
<tr>
<th>Facility</th>
<th>Processor type</th>
<th>Number of processors</th>
<th>Speed (years/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlphaServer SC</td>
<td>1GHz EV68</td>
<td>1</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
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<td></td>
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<td>4</td>
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<tr>
<td>Linux Cluster</td>
<td>2.66GHz Pentium 4</td>
<td>1</td>
<td>4.6</td>
</tr>
</tbody>
</table>
Present climate
3. Present climate

Present climate

• Control simulation conducted for pre-industrial conditions
• Constant boundary conditions:
  – Atmospheric CO₂ concentration = 280ppm
  – Present-day orbital parameters
• Integrated for 2000+ years
3. Present climate

Annual-mean surface air temperature (°C)
3. Present climate

Annual precipitation (mm)
3. Present climate

Global meridional overturning streamfunction (Sv)
3. Present climate

Global-mean surface air temperature
3. Present climate

Deep water formation

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3. Present climate

EOF1 of sea surface temperature (°C) – 22.3%
3. Present climate

Nino 3.4 SST anomaly and the Southern Oscillation Index

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3. Present climate

Correlation between SST and the Southern Oscillation Index

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Past climate
4. Past climate

Past climate

- Simulation conducted for the mid-Holocene (6,000 years ago)
- Constant boundary conditions
  - Orbital parameters for 6,000 years ago
- Integrated for 1200+ years
4. Past climate

Change in insolation ($W/m^2$)

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4. Past climate

Difference in August surface air temperature (°C)
4. Past climate

Difference in February surface air temperature (°C)
4. Past climate

Difference in annual precipitation (mm)

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Future climate
5. Future climate

Future climate

• Stabilise the atmospheric CO$_2$ concentration at three times the pre-industrial value

• Variable boundary conditions:
  – Increase the CO$_2$ concentration at 1% per year
  – Once it reaches 840ppm, hold it constant thereafter

• Integrated for 2000+ years
5. Future climate

![Graph showing atmospheric CO$_2$ concentration over model years.](image)

Atmospheric CO$_2$ concentration

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5. Future climate

Change in global-mean surface air temperature

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5. Future climate

Change in annual-mean SAT (°C) – years 211–260
5. Future climate

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5. Future climate

Deep water formation

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5. Future climate

Change in annual-mean SAT (°C) – years 1951–2000

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5. Future climate

(a) Years 211–260

(b) Years 811–860

(c) Years 1411–1460

(d) Years 1951–2000

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5. Future climate

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Thanks for coming!