Computational Challenges for Climate Modelling

Markus Jochum
Niels Bohr Institute, Copenhagen

with

R. Nuterman and TeamOcean
B. Vinter and e-Science
M. Vertenstein and CSEG at NCAR/Colorado
Outline

Latest CO₂ reading
January 11, 2016

300 years of atmospheric CO₂ concentration

- the climate challenge
- ocean turbulence
- long time scales
- how can you help?

NCAR supercomputing, 2012: Yellowstone, IBM iDataPlex
72,000 cores, 145 TB memory
Computing: 5 MW
Cooling: 3 MW
Carbon dioxide, and deuterium/hydrogen ratio from the Vostok Ice core; and global ice volume from sediment cores (inverted). (Sigman & Boyle, 2000)
The Global Carbon Cycle
Leading Hypotheses to explain the observed variations in Atmospheric carbon dioxide:

- temperature dependent solubility
- changes in Southern Ocean winds
- dust driven iron fertilization of phytoplankton
- change of biologically productive shelf area
- coral reef driven change of calcium-carbonate concentration
- change in ocean stratification
- interaction between icesheets and volcanism
Physical Oceanography
Probing the Unknown

Walter Munk, 1917-

100 yrs of water catching

Henry Stommel, 1920-1992

USS San Francisco after crushing into seamount
Real Ocean, Real Men

Figure 3.4.6 | Distribution of oxygen measurements at 300 dbar for the decades 1950 to 1960 (upper left) to 2000 to 2010 (lower right frame). (From Stammer et al., 2012.) (Note that additional oxygen data have become available for the 2000–2010 period since that study was completed.)
A Mathematician's Ocean
The Golden Age – one big happy family

Cox '85

Luyten et al. '83
The Rise of the Machine ...

The resolution of global climate models has improved

1. First IPCC assessment report (1990)
3. Third IPCC report (2001)
The Case Against Observations I

Observations, Schott et al. '98

Model, Jochum & Malanotte Rizzoli '03
The single realization problem

SAT Linear Trends DJF 1979-2012

Deser et al.'14
How can you help?

- order of magnitude faster and energy efficient chips
- more intuitive software, plug & publish
- better data management
Example: The Southern Ocean Hypothesis

Observed Eddy Kinetic Energy

Circulation in the Southern Ocean
One integration ...

4 million grid points, 1000 years with 1 hour time steps

-18 months ... faster (x10) chips ... less energy
- reproducible = no OS or compiler changes
- several months coding and testing

2011-12: spinup
'12: experiment
'14: funding
'15: found student
'16: implementation
... to accept the things one cannot change.
The Eddy-Resolving Model

Ocean-Ice configuration of CESM (Small et al. 2014):
1/10 degree, 62 vertical layers, CORE forcing.

3-day means, 1 Tb/day, 0.1 yrs/day on 4096 cores at FSZ Juelich
A month per picture!

Control $\times 1.5$

Residual Overturning

Steady

Transient

Standing

Eulerian
Time Slabs to Time Series

A B C D E F T5
A B C D E F T4
A B C D E F T3
A B C D E F T2
A B C D E F T1

120 x 10 x 100 GB →

A1 A2 A3 A4 A5 ...
B1 B2 B3 B4 B5 ...
.
.
.

50 x 2TB

- better storage strategies
- parallel post-processing and visualization software
Conclusions

To address the climate challenge, we do not need bigger computers, but we do need:

- a science/ python/ fortran interface

- faster chips

- better data management