Prospects for converting climate models from macrosopes to microscopes

William Collins
Berkeley Laboratory and University of California, Berkeley
Key space and time scales of the water cycle as case study

Leung et al, 2012
Greater resolution ≠ greater multi-model consensus

(a) Change in average surface temperature (1986–2005 to 2081–2100)

(b) Change in average precipitation (1986–2005 to 2081–2100)

(c) Northern Hemisphere September sea ice extent (average 2081–2100)

420 ppm

940 ppm

RCP 2.6
Change in average surface temperature (1986–2005 to 2081–2100)

RCP 8.5

CMIP5 multi-model average 2081–2100
CMIP5 multi-model average 1986–2005
CMIP5 subset average 1986–2005
CMIP5 subset average 2081–2100

IPCC AR5
Traditional atmospheric model schematic

Schematic for Global Atmospheric Model

Horizontal Grid (Latitude-Longitude)

Vertical Grid (Height or Pressure)
New types of climate models can bridge to local scales

Figure 7.8: Model and simulation strategy for representing the climate system and climate processes at different space and time scales. Also shown are the ranges of space and time scales usually associated with cloud processes (orange, lower left) and the climate system (blue, upper right). Classes of models are usually defined based on the range of spatial scales they represent, which in the figure is roughly spanned by the text for each model class. The temporal scales simulated by a particular type of model vary more widely. For instance, climate models are often run for a few time steps for diagnostic studies, or can simulate millennia. Hence the figure indicates the typical timescales for which a given model is used. Computational power prevents one model from covering all time and space scales. Since the AR4 the development of global cloud resolving models (GCRM), and hybrid approaches such as GCMs using the "super-parameterization" approach (sometimes called the multiscale modelling framework or MMF), have helped fill the gap between climate system and cloud process models.

IPCC AR5 WG1
Computing has enabled regional to continental projection

Historical impacts of computing power
Exascale will enable localized projection

- **Terascale (2000s)**
- **Petascale (today)**
- **Exascale (2020s)**

- **Actual Growth**
- **Projected Growth**

- 2002-2004: ~200km
- 2006: ~200km
- 2012: ~25km
- 2022: ~1km

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Technology is disruptive – and that can be empowering
Variable resolution can accelerate progress

Resolving features at the onset of non-hydrostatic, 3D motion in the atmosphere will require resolutions of $O(1 \text{ km})$.

**Ullrich, QJR Met Soc, 2012**

Regional static mesh refinement is being developed to increase resolution only where such features must be resolved.

**Zarzycki et al, J. Climate, 2015**

Similar research is underway in ocean modeling to provide regional, high-resolution, “eddy-allowing,” codes.

**Ringler et al, Ocean Modeling, 2013**
Localized models are demanding

Computational throughput

Memory usage

Models of this class will break the atmosphere into 100 billion cells.

... Imagine averaging 100 billion numbers just to get the mean temperature.
Critical role of numerical software package

<table>
<thead>
<tr>
<th>Factor</th>
<th>Trend</th>
<th>App Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concurrency</td>
<td>$10^8$ PEs</td>
<td>1000x improvement</td>
</tr>
<tr>
<td>Reliability</td>
<td>Much shorter MTBF</td>
<td>Adaptive error management</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>Must be $\leq 25$ MW</td>
<td>100x improvement</td>
</tr>
</tbody>
</table>

Challenges faced by applications will require major advances in technology.

Dongarra et al, 2011
Imagine coordinating the work of $O(100$ million people) working on a single problem...

...That’s the number of tasks to be coordinated for exascale climate projection.
• On July 29, 2015, President Obama signed an Executive Order establishing the *National Strategic Computing Initiative*. 

• The NCSI has 5 strategic themes:

1. *Create systems that can apply exaflops of computing power to exabytes of data*
2. *Keep the United States at the forefront of HPC capabilities.*
3. *Improve HPC application developer productivity*
4. *Make HPC readily available*
5. *Establish hardware technology for future HPC systems.*
Questions?