Ultra-High Resolution Modeling

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Key messages

• Ultra-high resolution (UHR) modeling is a useful tool to add to our earth system modeling toolbox, but many tools are needed to address different facets of climate science and provide actionable climate information

• Without much tuning, UHR models are more skillful than their lower resolution counterparts, but more efforts are still needed to address model biases

• More research is needed to explore new uses and demonstrate the usefulness of UHR models
  • Storyline development; understanding mechanisms for extreme events and their future changes; constraining cloud feedback; understanding mesoscale air-sea interactions and role in energy/water cycle; training data for AI/ML parameterizations; etc.
Challenges in Earth system modeling require many tools.

Modeling subgrid processes of convection, clouds, and aerosols represents a major source of uncertainty in projections of climate and water cycle changes.

Modeling carbon and nutrient cycles and human influence is a major source of uncertainty in projecting 21st century warming.

Modeling ice shelf and ice sheet instability is a major source of uncertainty in projecting sea level rise.

Internal variability represents a major source of uncertainty in regional projections.

(Friedlingstein et al. 2014 JCLIM)

(Burrows et al. 2020 JAMES)

(Climate Science Special Report 2016)

(Deser et al. 2020 NCC)

(Dong et al. 2021 NCOMM)
Ultra-high resolution modeling for projecting changes in extreme weather events

Sharpening of storms (peak intensity increases at a higher rate than area) with warming alters area-intensity relationships used in safe design

Storm structure, besides storm frequency and intensity, is important for infrastructure planning

Dashed white circles: 10th, 50th, and 90th percentile HUC8 watershed size

(UN report 2020)

(Chen et al. in review)
**E3SM: Modeling across scales on DOE computers**

<table>
<thead>
<tr>
<th>Model component</th>
<th>Low resolution (LR)</th>
<th>High resolution (HR)</th>
<th>Storm-resolving resolution</th>
<th>Regional refined meshes (RRM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere &amp; Land</td>
<td>100 km</td>
<td>25 km</td>
<td>3 km</td>
<td>variable</td>
</tr>
<tr>
<td>Ocean &amp; Ice</td>
<td>30-60 km</td>
<td>6-18 km</td>
<td>6-18 km</td>
<td>variable</td>
</tr>
<tr>
<td>River</td>
<td>50 km</td>
<td>12 km</td>
<td>12 km</td>
<td>variable</td>
</tr>
</tbody>
</table>

**North America RRM**

**Antarctica RRM**
Global cloud resolving modeling

- **SCREAM** (Simple Cloud Resolving E3SM Atmosphere Model) uses a **NH dycore and targets ~3 km grid spacing** run globally or using regional refined meshes.
- SCREAM v0 (F90 version) has been used to participate in **DYAMOND2**.
- C++ dycore achieves **1.38 SYPD on Summit** - best performance we know of for a global cloud resolving dycore + tracers at 3 km resolution.
- **GPU-enabled version** (C++ and Kokkos library) will be operational in 2022 for exascale computing (E3SM Atmosphere Model - **EAMXX**).


Global cloud resolving modeling - DYAMOND2 run

- F90 version achieved 4-5 simulated days per wall clock day on Cori-KNL
- Great skill with no tuning

(Caldwell et al. 2021 JAMES)
Global cloud resolving modeling – realistic simulation of convective storms

MCS (mesoscale convective system): bright white shading; Precipitation: color shading; CWV: faint white shading

SCREAM simulation at ~3 km grid spacing

Observations

(Feng, Leung, Caldwell, Terai, in prep)
Much better simulation of MCS in SCREAM (~3 km) than HR E3SM (~25 km)

- Many observed MCS characteristics and relationships with large-scale environments are reasonably reproduced
- Model produces frequent and strong deep convective systems in tropical ocean, but they are not sufficiently organized into MCS
- MCS rainfall amount and fraction to total rainfall is underestimated, bias is compensated by unorganized deep convection
DYAMOND1 simulations: biases in local-scale precipitation characteristics

An ensemble of 5 models in DYAMOND1 with resolution between 3 – 5 km

- Overly active convection and frequent drizzling remain an issue, with implications for cloud forcing and interhemispheric asymmetry of energy input

(Zhou, Leung, Lu, in prep)
Cloud resolving modeling for storyline development

June 2012 derecho in West Virginia: Power transmission infrastructure damages exceeded $170 million

Regional refined meshes for derecho simulations: 7km, 3.5km, 1.75km

(Source: Paul Ullrich and Weiran Liu)

How may this event unfold in the future with warming?
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