# Ultra-High Resolution Modeling

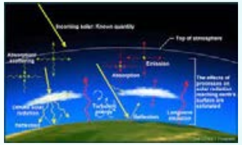
L. Ruby Leung
Pacific Northwest National Laboratory

# 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.

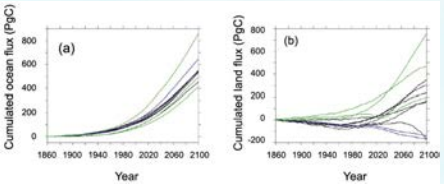
# Challenges in Earth system modeling require many tools

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



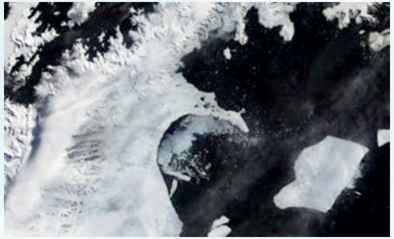
Modeling **carbon and nutrient cycles and human influence** is a major source of uncertainty in projecting 21st century warming

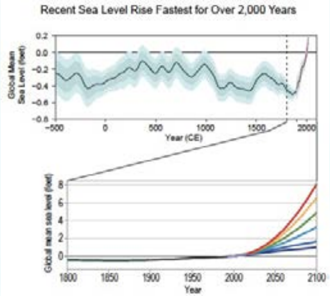
(Burrows et al. 2020 JAMES)




(Friedlingstein et al. 2014 JCLIM)

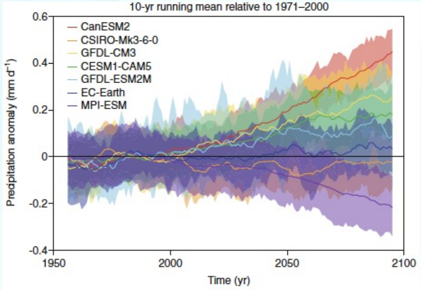
Modeling **ice shelf and ice sheet instability** is a major source of uncertainty in projecting sea level rise



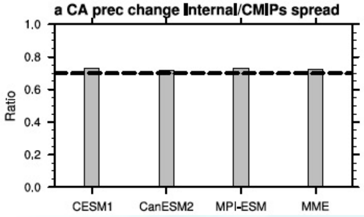



(Climate Science Special Report 2016)

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




(Deser et al. 2020 NCC)

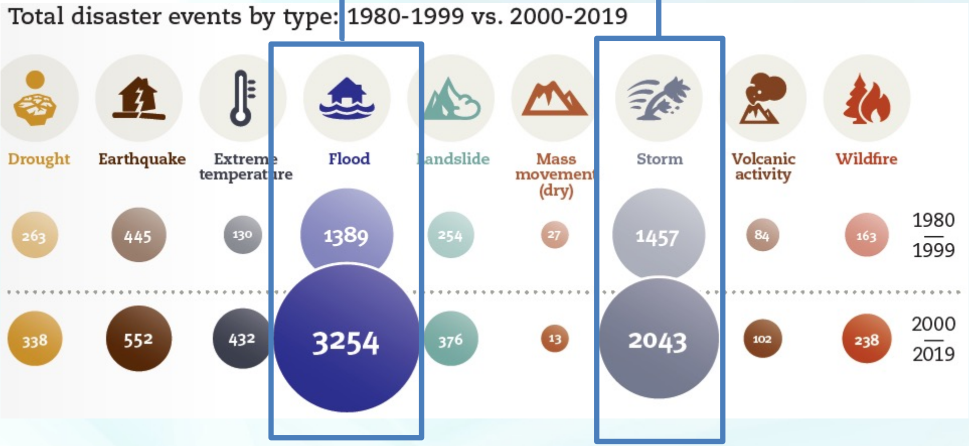



(Dong et al. 2021 NCOMM)

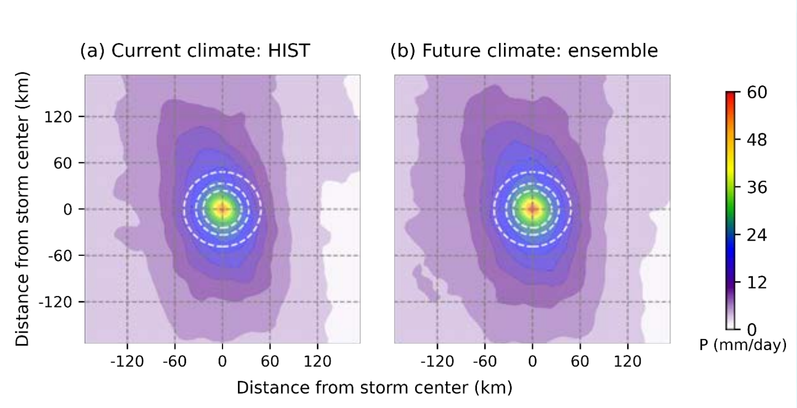
# Ultra-high resolution modeling for projecting changes in extreme weather events

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

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




(UN report 2020)

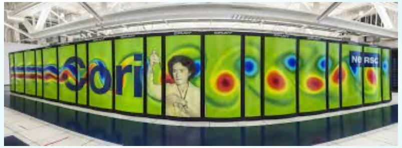



Dashed white circles: 10th, 50th, and 90th percentile HUC8 watershed size

(Chen et al. in review)

# E3SM: Modeling across scales on DOE computers

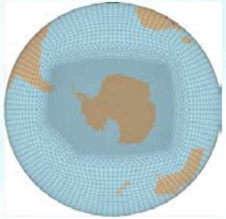
| Model component | Low resolution (LR) | High resolution (HR) | Storm-resolving resolution | Regional refined meshes (RRM) |
|---|---|---|---|---|
| Atmosphere & Land | 100 km | 25 km | 3 km | variable |
| Ocean & Ice | 30-60 km | 6-18 km | 6-18 km | variable |
| River | 50 km | 12 km | 12 km | variable |

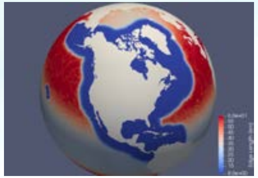


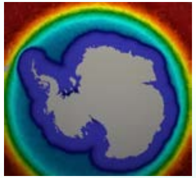


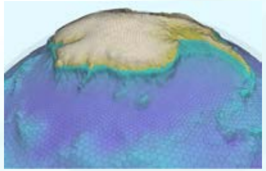

North America RRM

Antarctica RRM









# Global cloud resolving modeling

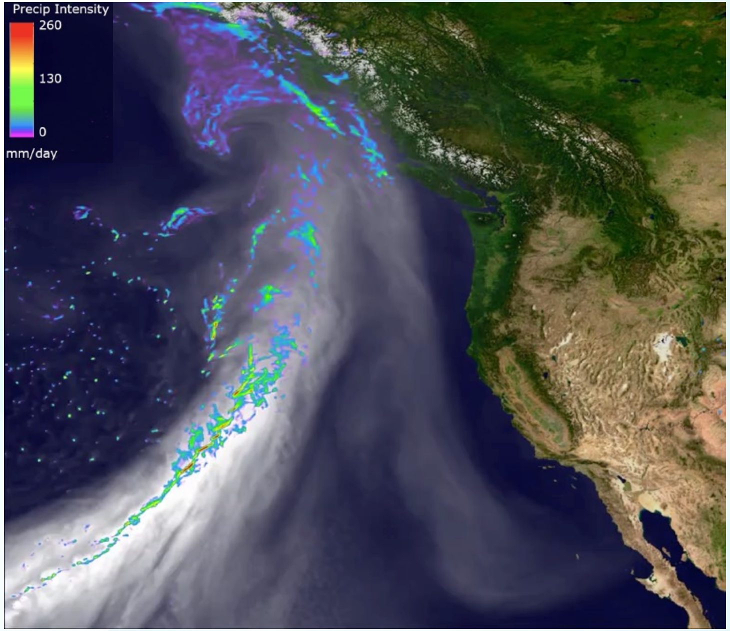
- **SCREAM** (Simple Cloud Resolving E3SM Atmosphere Model) uses a **NH dycore and targets ~3 km grid spacing** run globally or using regional refined meshes
- SCREAM v0 (F90 version) has been used to participate in **DYAMOND2**
- **C++ dycore** achieves **1.38 SYPD on Summit** - best performance we 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**)

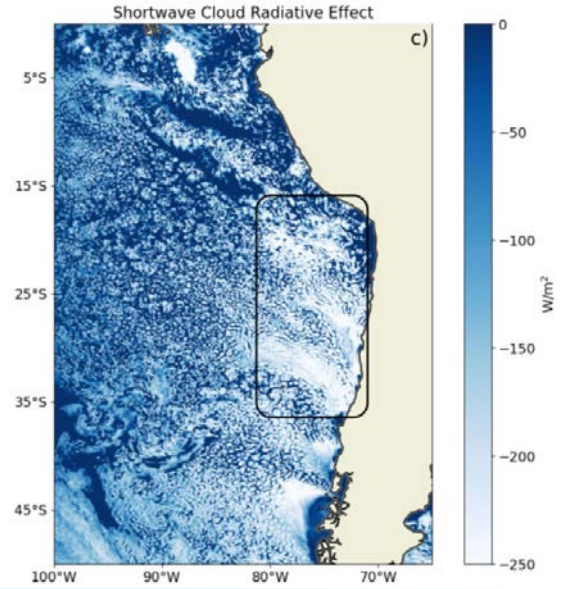

Bertagna, et. al., 2020: A performance-portable nonhydrostatic atmospheric dycore for the Energy Exascale Earth System Model running at cloud-resolving resolutions. SC ‘20: *Proceedings of the International Conference for High Performance Computing, Networking, Storage and Analysis*, Nov. 2020.

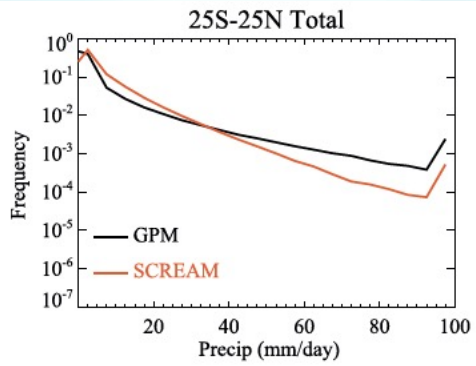
Caldwell et al., 2021: Convection-Permitting Simulations with the E3SM Global Atmosphere Model, *J. Adv. Model. Earth Syst.*, 13, e2021MS002544. https://doi.org/10.1029/2021MS002544.

# 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



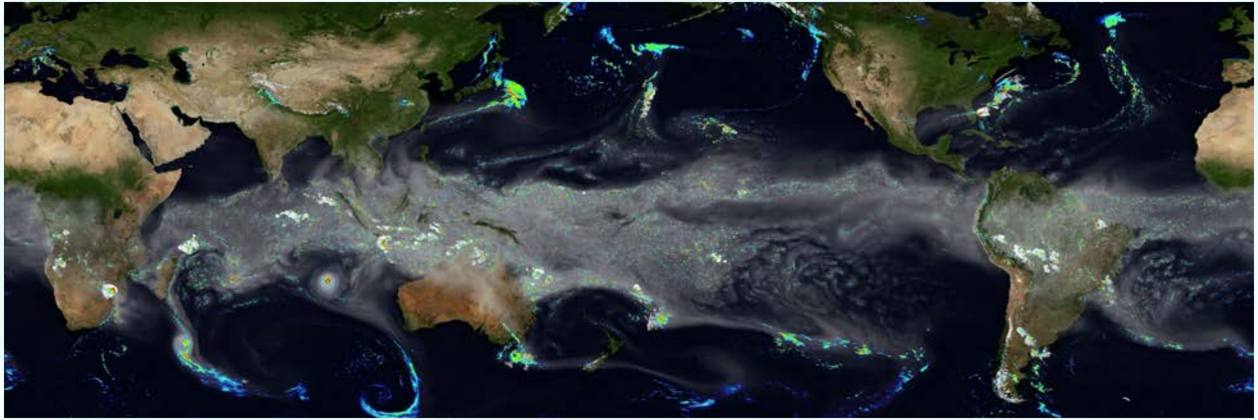




(Caldwell et al. 2021 JAMES)

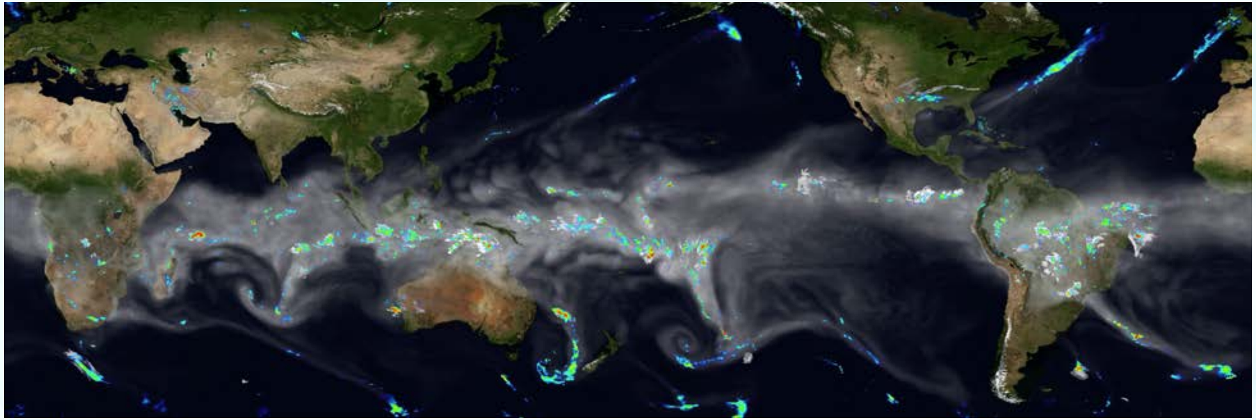
# Global cloud resolving modeling – realistic simulation of convective storms

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

SCREAM simulation at ~3 km grid spacing

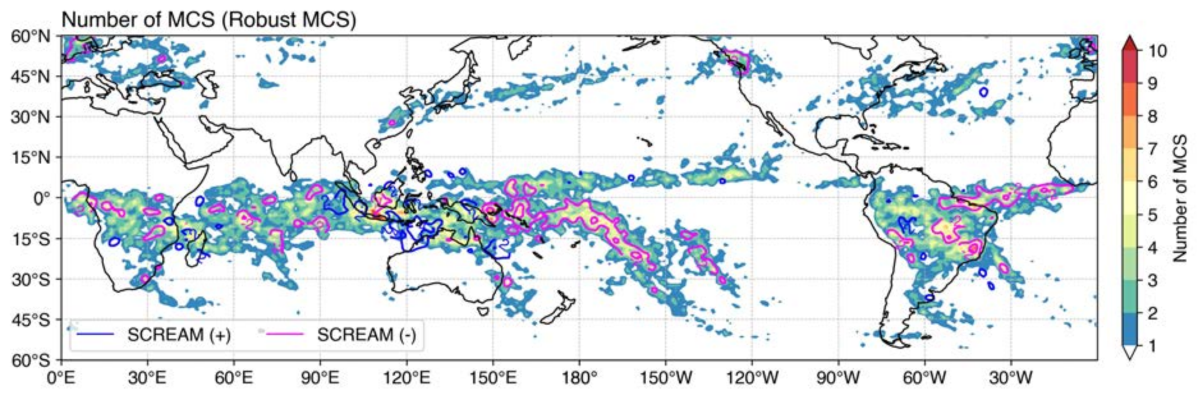


Observations



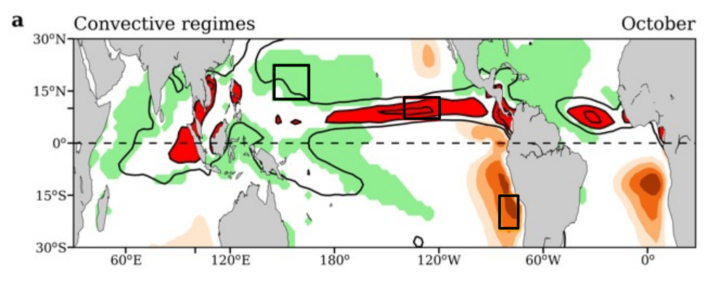
(Feng, Leung, Caldwell, Terai, in prep)

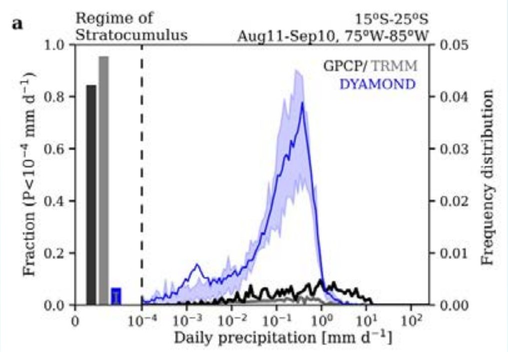
# Much better simulation of MCS in SCREAM (~3 km) than HR E3SM (~25 km)

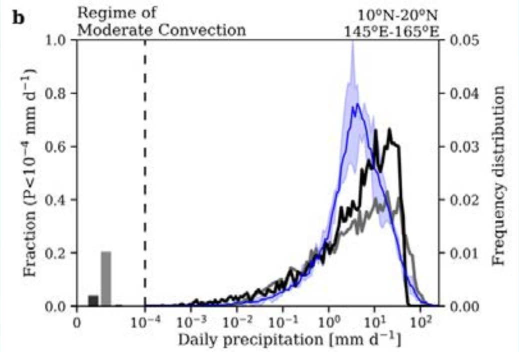


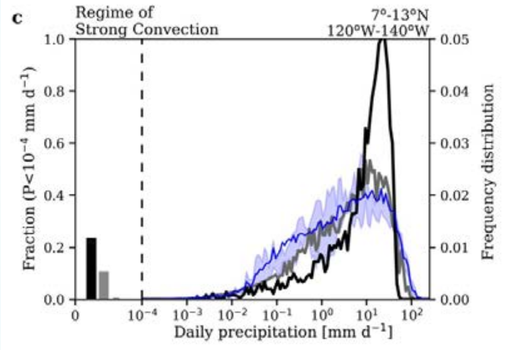

- Many observed **MCS characteristics and relationships with large-scale environments are reasonably reproduced**
- Model produces frequent and strong deep convective systems in tropical ocean, but they are not **sufficiently organized into MCS**
- **MCS rainfall amount and fraction to total rainfall 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

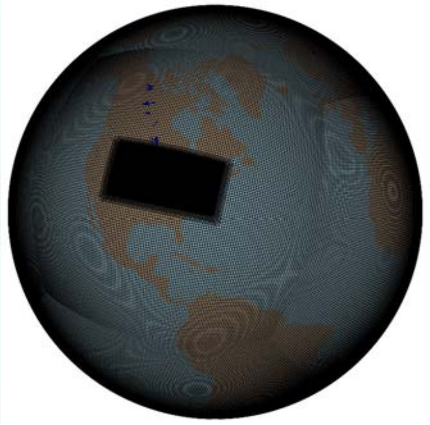
- Overly active convection and frequent drizzling remain an issue, with implications for cloud forcing and interhemispheric asymmetry of energy input

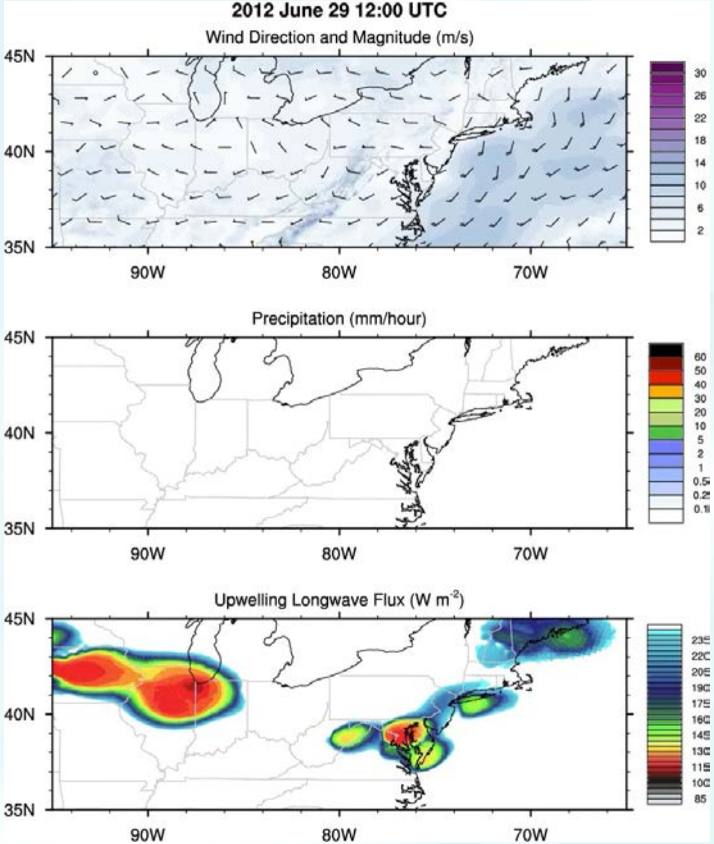
(Zhou, Leung, Lu, in prep)

# 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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