E3SM Science Goals and Priorities

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E3SM all-hands meeting, June 2021

Overarching plan

Goals

Understand Earth system variability and change

Simulations, predictions, and projections to support DOE's energy mission

Prepare for and overcome the disruptive transition to next era of computing

Science Drivers

Water cycle: water availability, storms, floods and droughts

Biogeochemistry: temperatures, heat extremes, wildfires

Cryosphere: sea level rise, coastal inundation

Strategies

- Push the high-resolution frontier of Earth system modeling
- Represent natural, managed and manmade systems across scales
- Quantify uncertainty using ensemble modeling

Implementations

- Regional refinement using unstructured grids
- Global cloud resolving modeling
- Coupled human-earth system modeling
- Coastal modeling
- Large-ensemble modeling
- Use of ML/AI

Science questions → **Model development** → **Simulation and analysis**

Implementations through project phases

- Water cycle
- Biogeochemistry
- Cryosphere

V2 development and integration, v1 and v2 simulation campaigns, analysis to address science questions of the coupled system

- Infrastructure
- Performance

Code and data management, automated testing, timing and profiling, diagnostics, computational performance

- Software and algorithm
- NH atmosphere model
- Atmosphere physics
- Energy and land
- Ocean modeling
- Dynamic ice sheet
- Large ensemble modeling

Development towards v3 and v4, focusing on component models

E3SM goal: support actionable science

- Actionable science:
  - Enable societally (particularly energy-sector) relevant science (e.g., capabilities to evaluate decarbonization strategies)
  - Model fidelity and spatial specificity (physics + resolution)
  - Uncertainty quantification (ensemble simulations)
- Science questions for simulation campaigns:
  - Broad science questions to showcase multiple key capabilities and support many types of analysis
  - DECK and ScenarioMIP experiments will be done for each model version – such simulations already support many types of analysis
  - Going beyond DECK experiments to advance actionable science goal and to understand model biases/behaviors

Push and Pull

Science questions ⟷ Model capabilities

Progress in high resolution modeling

Capabilities:

- Low resolution (100 km)
- High resolution (25 km)
- Convection permitting (CP) resolution (3 km)
- ECP: Multiscale modeling framework: CRM embedded in low or high resolution E3SM

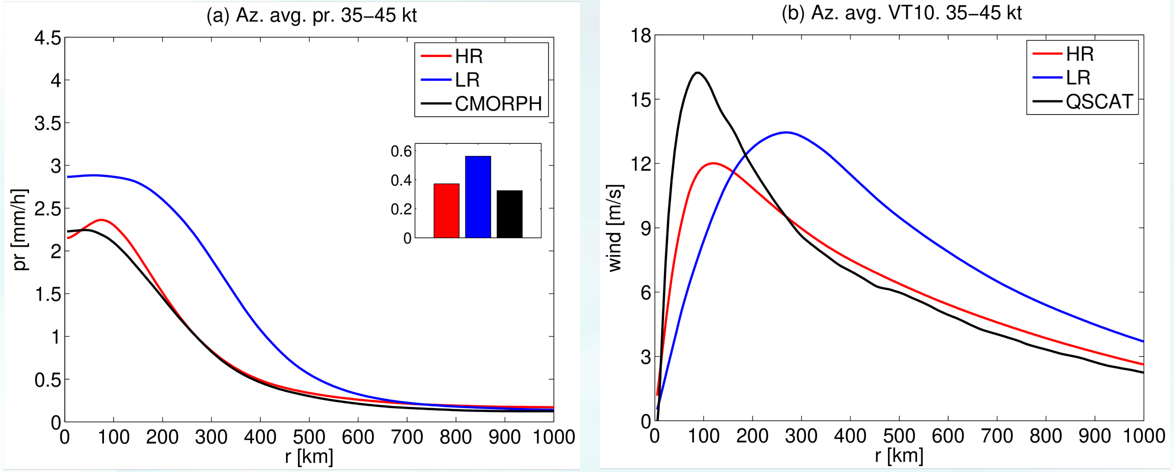
} Regional refinement

What can be gained by using high and CP resolutions?
Examples: tropical cyclones (TCs) and mesoscale convective systems (MCSs)

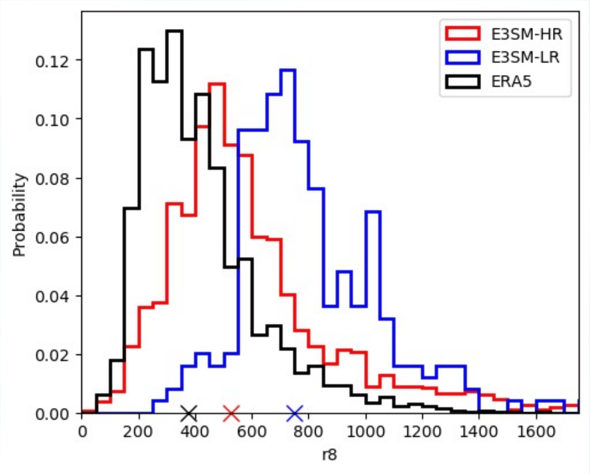
Improvements from low to high resolution

Tropical cyclone structure is much more realistically simulated at high resolution

Radial profile of azimuthally-averaged precipitation rate and surface tangential winds

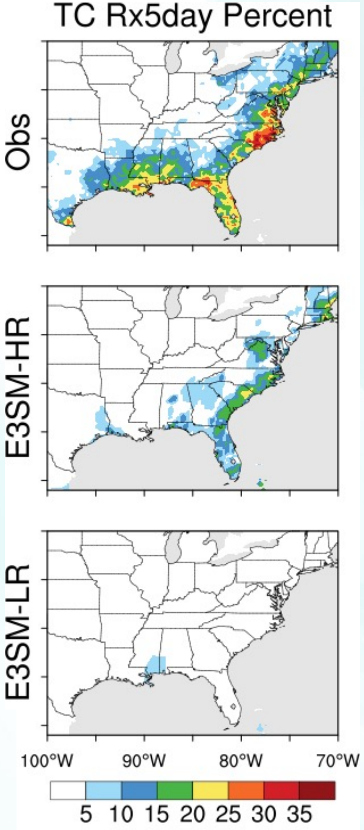


Normalized distribution of storm size (outermost radius of winds exceeding 8 m/s)



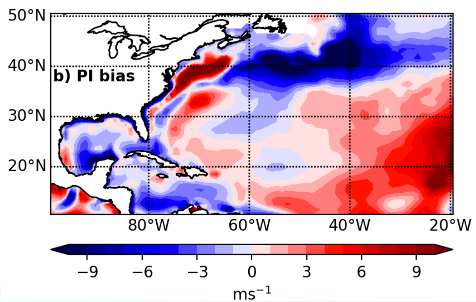
Quarterly metric report (March 2021)

Improvements from low to high resolution

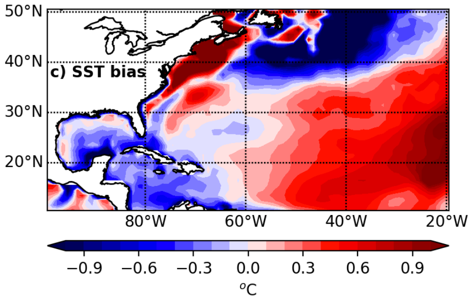


Biases in TC genesis and tracks reduce the contribution of TCs to extreme rainfall in coastal regions

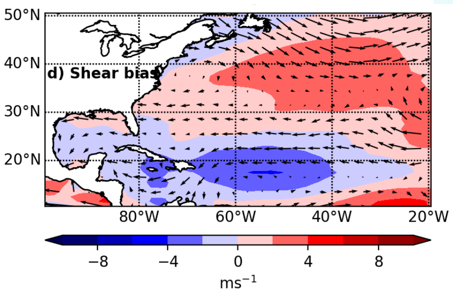
Bias in genesis



Bias in SST



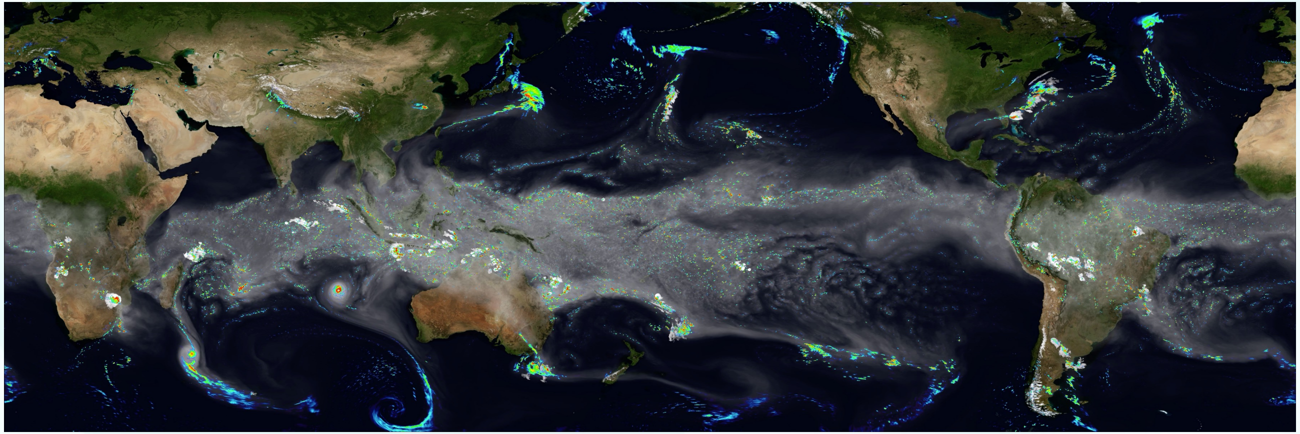
Bias in steering flow



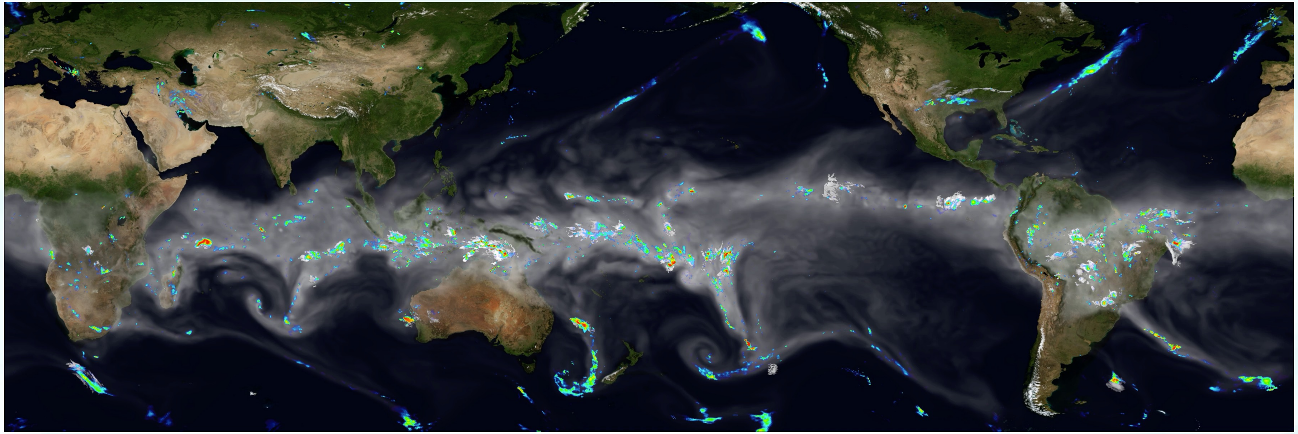
SST bias dominates the bias in TC genesis and combined with bias in steering flow, reduce likelihood of TC landfall particularly in the Gulf coast

Improvements from high to CP resolution

SCREAM
DYAMOND2
simulation



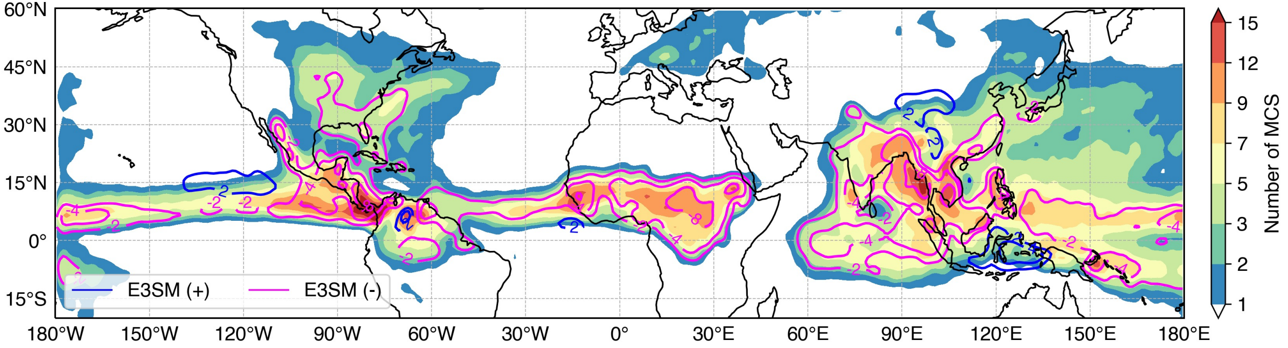
Observations



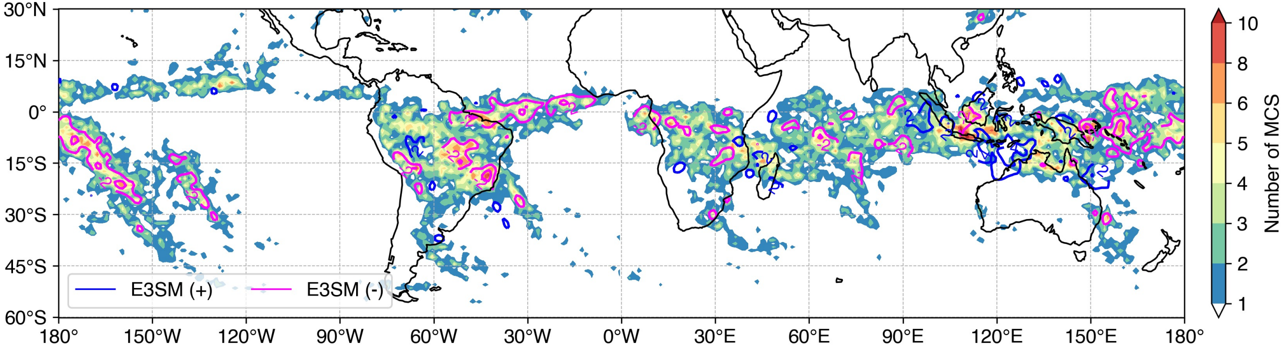
Improvements from high to CP resolution

Much smaller biases of mesoscale convective system (MCS) number at 3 km compared to 25 km

E3SM at **25 km** (JJA) 20-year mean



E3SM at **3 km** (40 days in Jan-Feb)

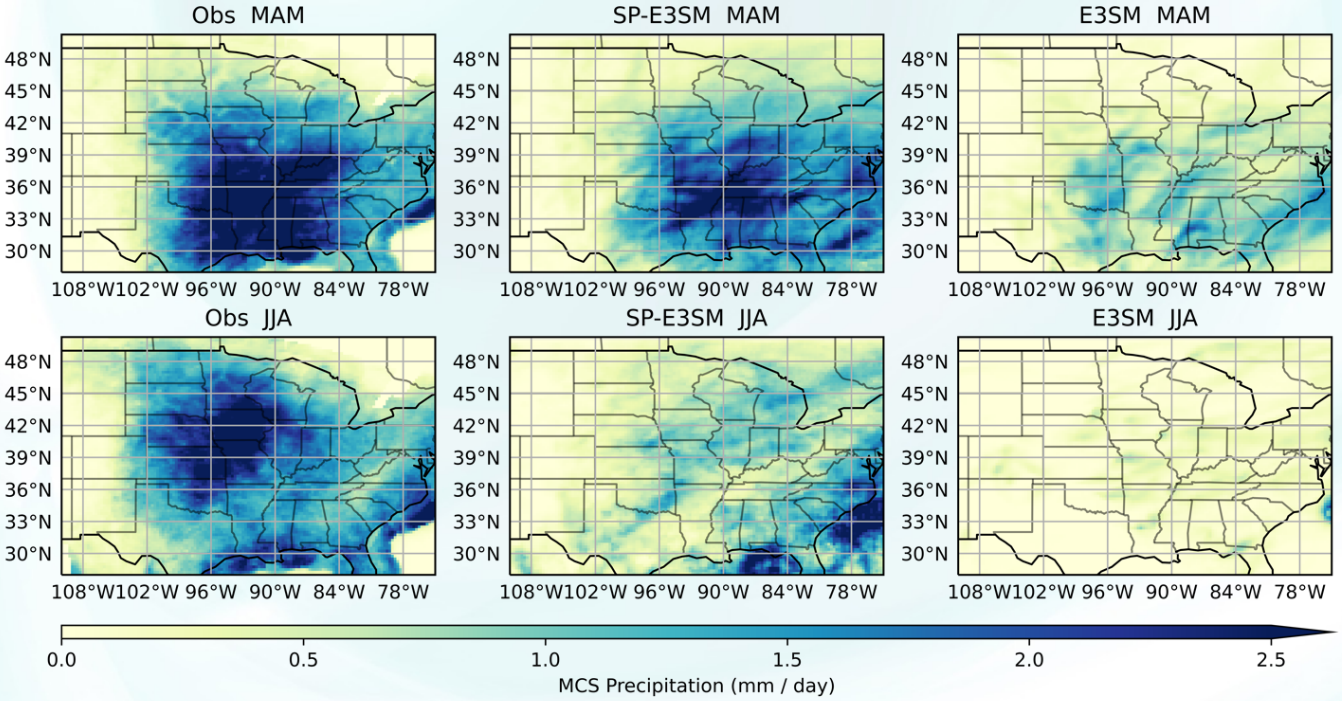


Shading: OBS

Contour: Model Bias

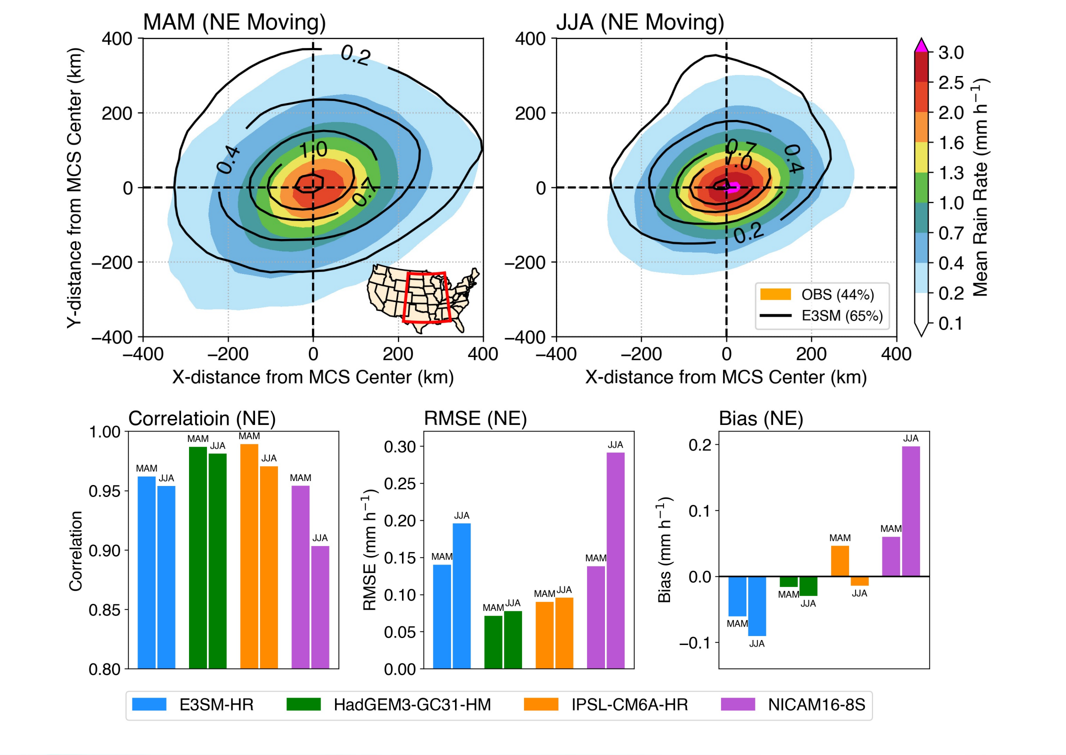
Improvements from high to CP resolution

Much smaller biases of mesoscale convective system (MCS) number with MMF 25 km



Is 25 km inherently too coarse to simulate MCSs?

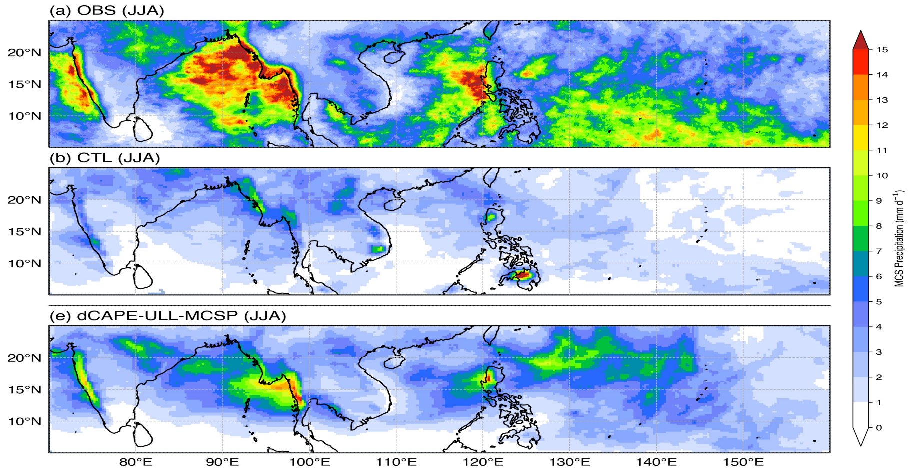
Is it possible to reduce MCS bias at high resolution?
Storms like TCs and MCSs are resolvable at 25 km



Can we improve modeling of MCS at high resolution?

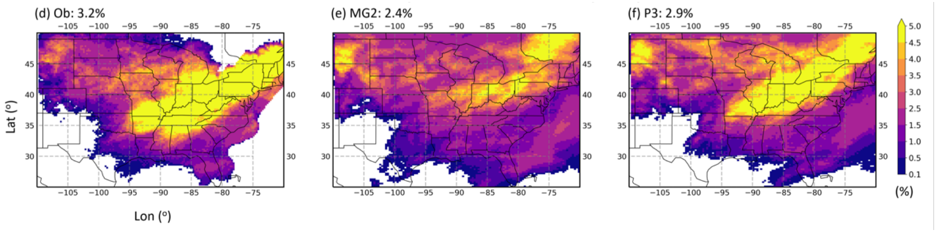
- E3SM v1 AMIP simulations (3 years) at 25 km grid spacing with constant 2000 forcing and climatological SST – all based on Zhang and McFarlane (ZM) deep convection scheme
    - CTL (ZM scheme)
    - dCAPE-ULL (modified convective trigger) + mesoscale coherent structure parameterization (MCSP)

New model features reduce bias in MCS precipitation in the tropics



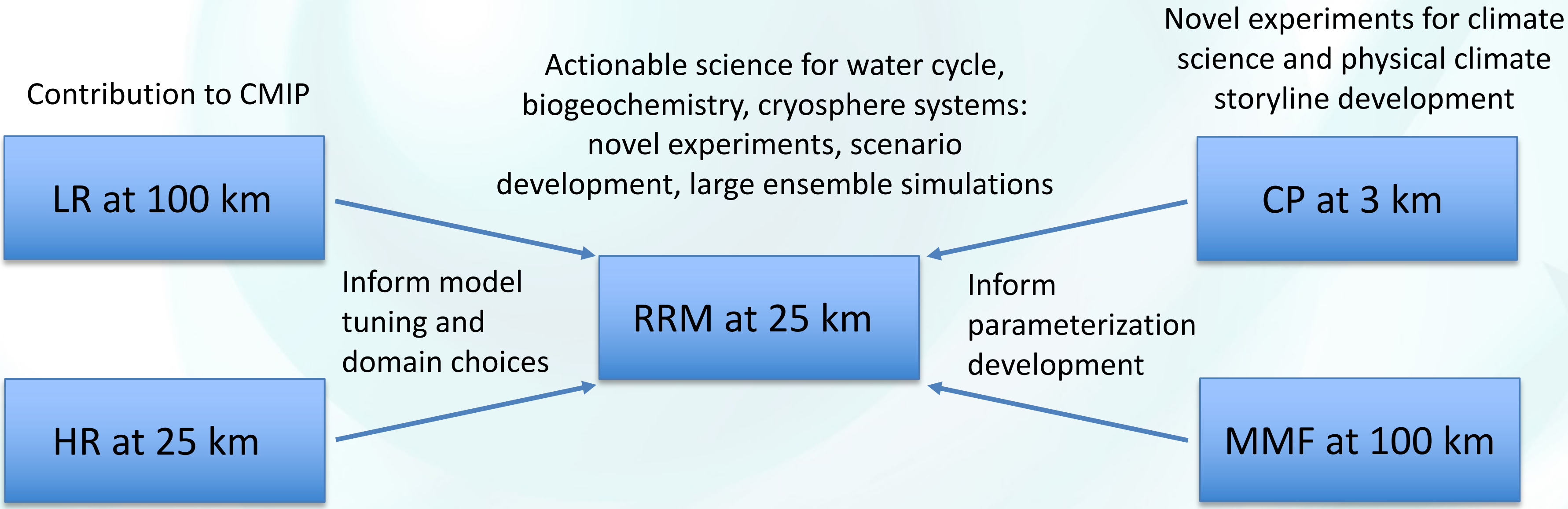
P3 (Predicted Particle Properties) improves simulation of MCS by increasing heavy rain rates

2011 March-May MCS frequency



Quarterly metric report (September 2020)

Paths forward



Contribution to CMIP

LR at 100 km

Actionable science for water cycle, biogeochemistry, cryosphere systems: novel experiments, scenario development, large ensemble simulations

Novel experiments for climate science and physical climate storyline development

CP at 3 km

Inform model tuning and domain choices

RRM at 25 km

Inform parameterization development

HR at 25 km

MMF at 100 km

- Merge all capabilities into a single code base – v4
- Physics parameterizations: better / faster (physics-based and ML)
- Model calibration: techniques and workflows (e.g., ML/AI)
- Large ensemble modeling: approaches, workflows, in-situ analysis, data reduction
- Science questions, novel experiments, analysis

Preliminary thoughts on phase 3 priorities

- E3SM is at a juncture: Significant progress made with multiple approaches to high resolution modeling – how do they contribute to overarching goal of actionable science?
- High resolution modeling at 25 km resolution using RRM may be a sweet spot for actionable science
  - With good physics and effective model calibration, large-scale circulation and extreme weather events can be well simulated at 25 km resolution to support planning and management of resources and evaluate the effectiveness of different decarbonization strategies and implications for societal resilience and well-being of our population
  - Need more efforts in model calibration and RRM domain selection
  - Need more efforts in scale-aware physics using both physical and ML approaches
  - Need to begin efforts in large ensemble modeling and methodological development
- Improving the paradigm of science questions, simulation campaign, and analysis
  - Broad science questions and simulation campaigns + branched off science driven experiments
- Targeted or goal-oriented collaborations with other DOE programs (e.g., model calibration and workflow, ML applications)?

Questions?