NSF StormSPEED: Enabling Convection-Permitting Simulations with CESM3

Presented by Nicholas Forcone, University of Michigan

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Earthworks collaborators: David Randall, James Hurrell

StormSPEED: Storm-resolving SPEctral Element Dycore for CESM3

Port the existing non-hydrostatic spectral element dynamical core from the Department of Energy (E3SM/SCREAM) into CAM

Advance CESM3 readiness for GPU acceleration. Fortran → C++/Kokkos.

Science goals: MCS climate experiments, Ocean-atmosphere interaction, DYAMOND-type kilometer-scale simulations

Timeline

Project start

Feb 2024

Nonhydrostatic SE prototype in CAM

Feb 2025

This talk: Idealized test cases, variable resolution

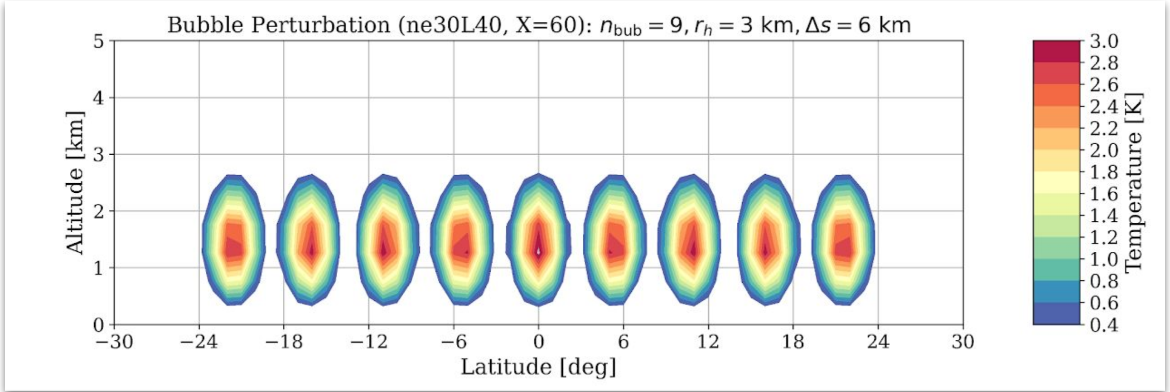
Future:
DYAMOND-style global km-scale simulations,
ocean-coupled km-scale simulations

2026

2027

Idealized squall line from Dynamical Core Model Intercomparison Project (DCMIP)

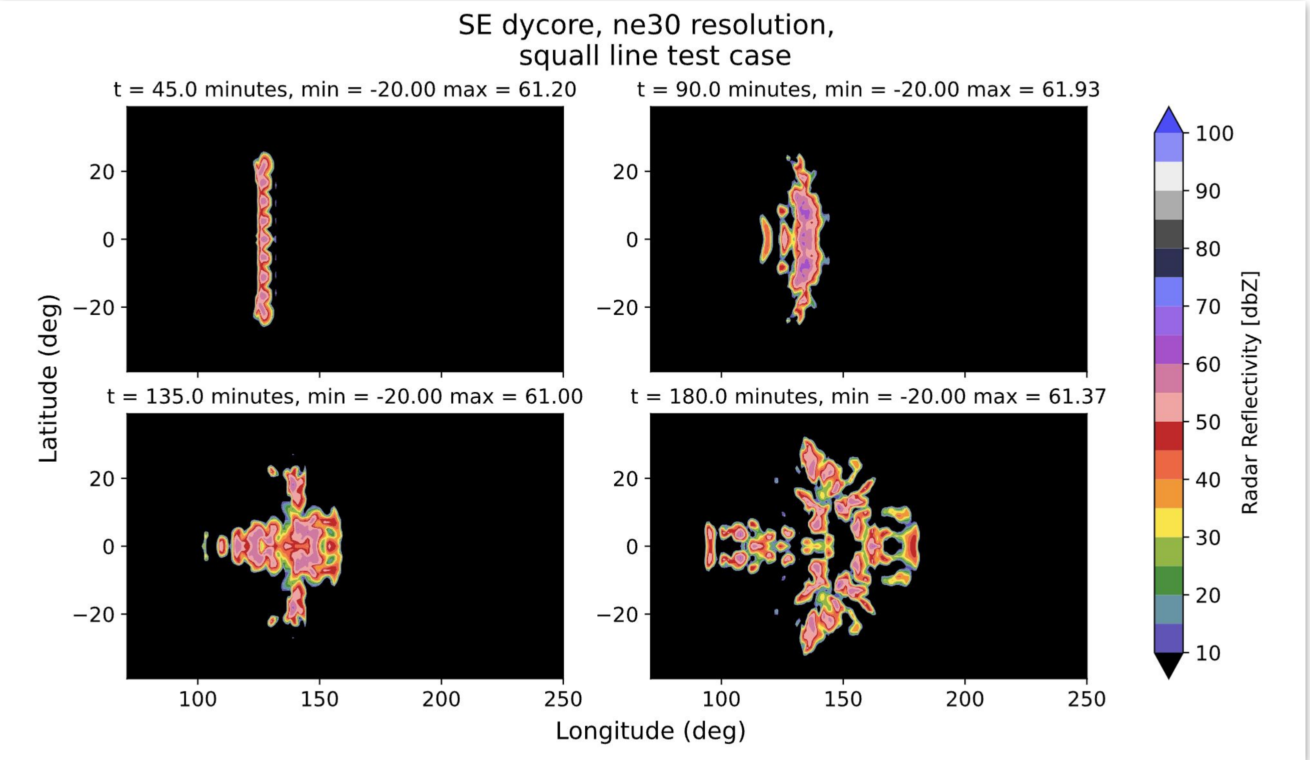
- ➔ Analytic initial condition in cyclostrophic balance (no Coriolis force) with 9 warm perturbations in a line
- ➔ Ran on a reduced radius Earth: 1° grid ~1.8 km horizontal spacing and 500 m vertical spacing



Idealized test case and plot provided by Nicholas Androski (nandrosk@umich.edu)

More information on DCMIP-2025: http://dcmip.org/

Warm perturbations are unstable and develop a squall line signature



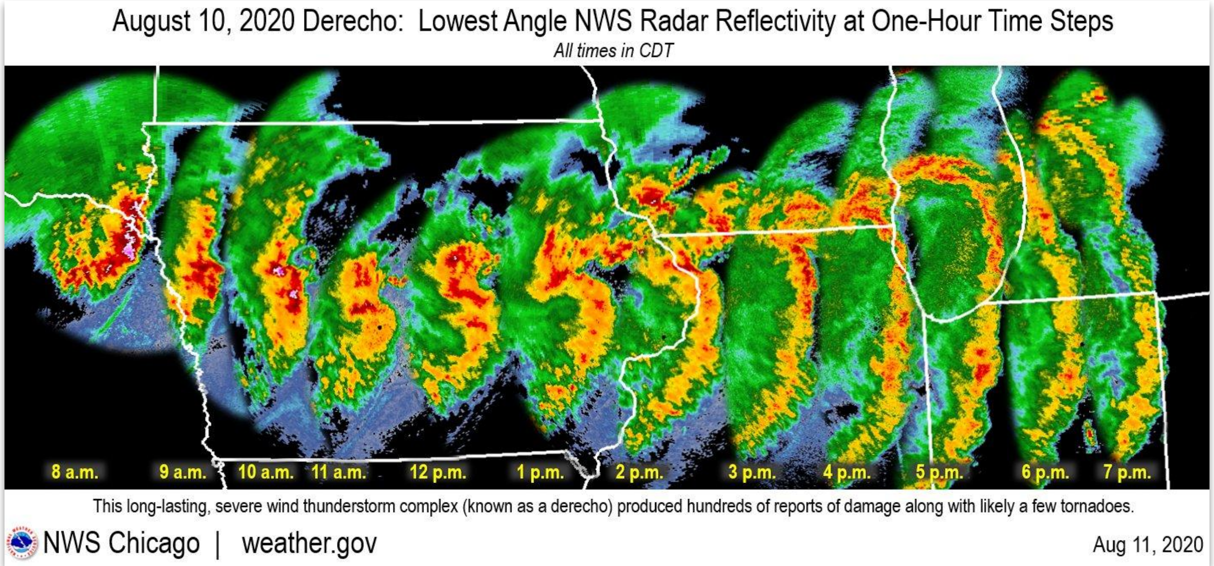
- ➔ 2.5 K perturbation
- ➔ 12 m/s wind shear in lower 2.5 km
- ➔ Simple Kessler warm rain microphysics scheme

Serves as a stepping-stone for more complex simulations

Idealized test case developed by Nicholas Androski
Plotting script from Anthony Chen

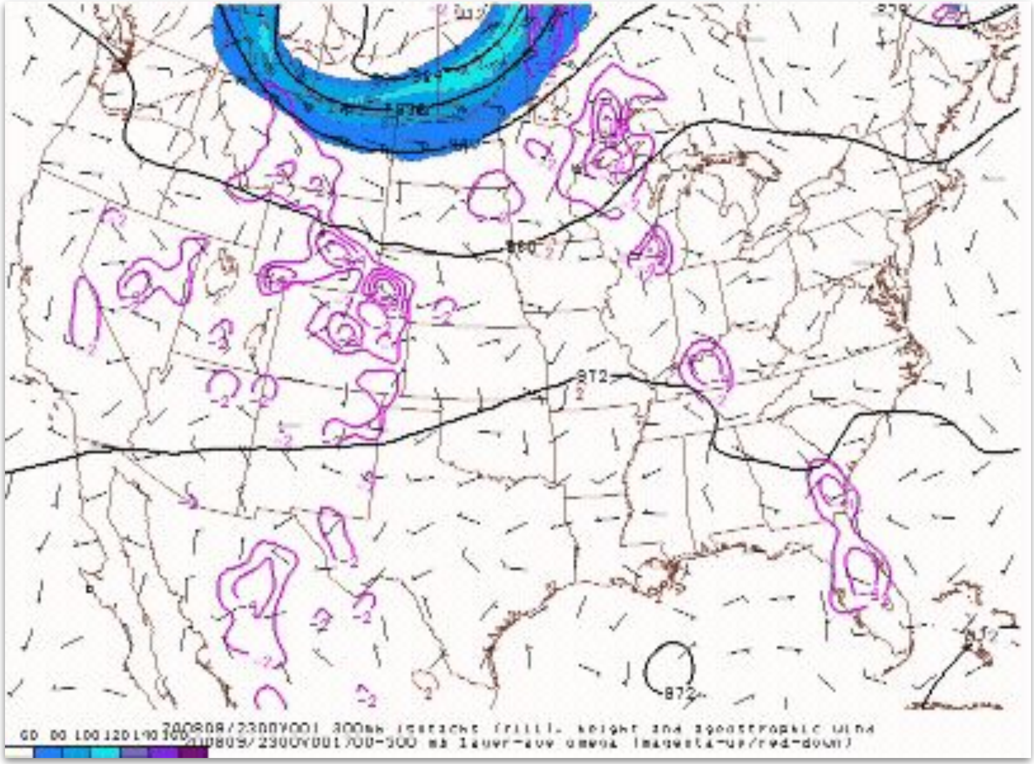
Next step: Variable resolution August 2020 Midwest Derecho

- ➔ Widespread, severe windstorm that originates from a mid-latitude mesoscale convective system (MCS) that is driven by a cold pool and other possible internal forcing mechanisms[1]
- ➔ Costliest severe thunderstorm event in U.S. history



[1]NOAA Storm Prediction Center

Upper-level trough and strong vertical motion (pink contours)

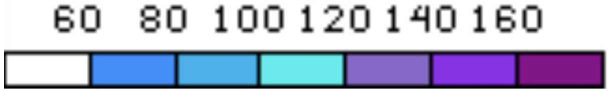


NOAA Storm Prediction Center (SPC) hourly mesoscale analysis

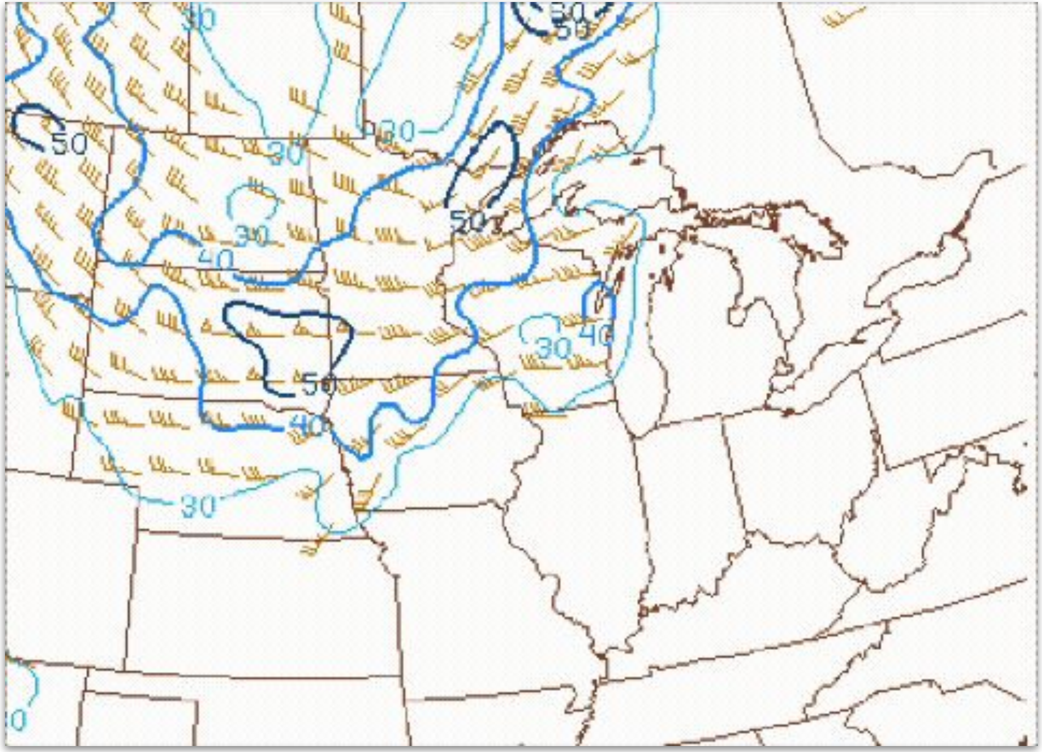
700-500 mb layer average vertical pressure velocity

300 mb geopotential height (black contours)

Wind speed (kt)



Strong surface-6 km wind shear to support convective organization

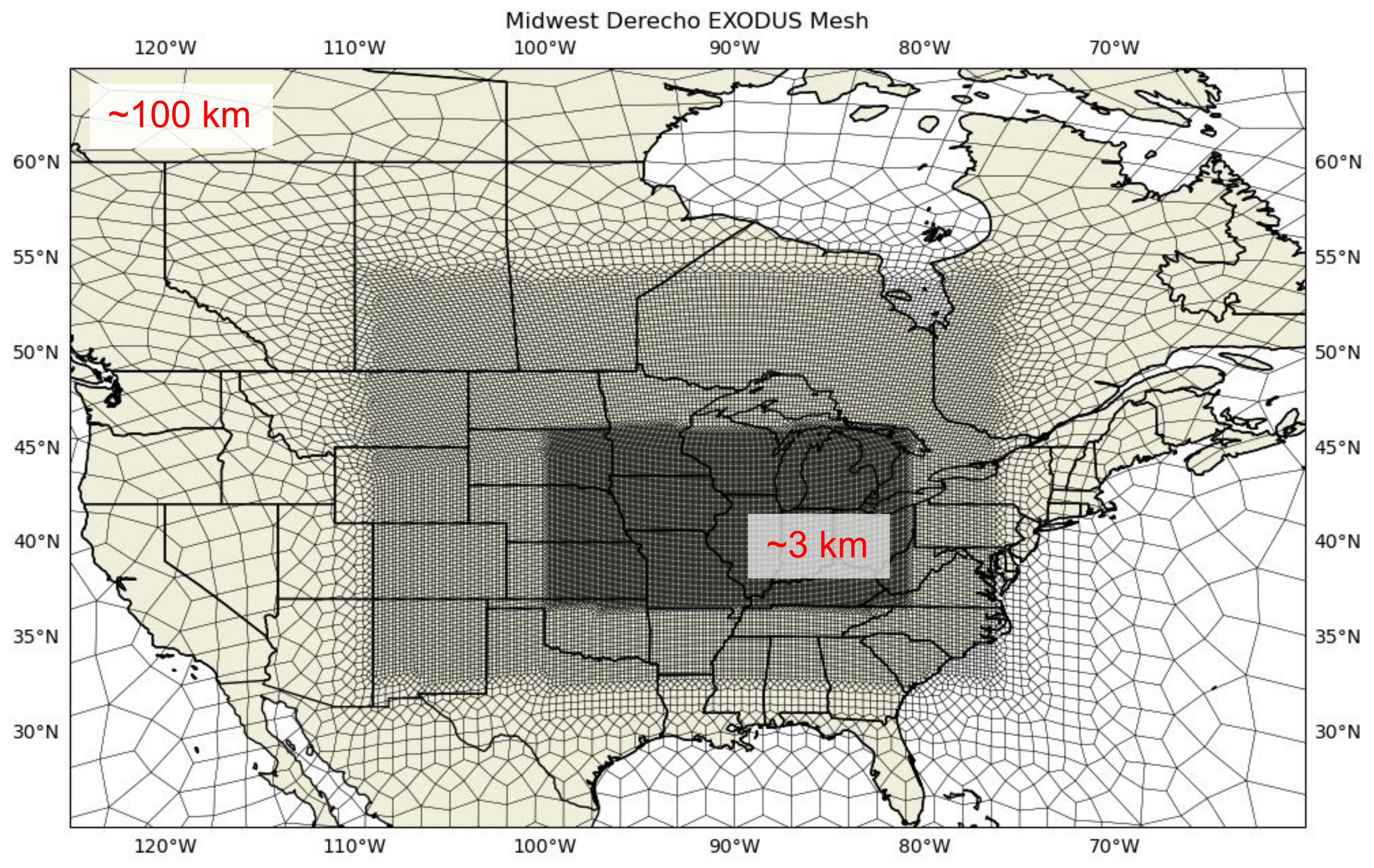


NOAA Storm Prediction Center (SPC) hourly mesoscale analysis

Surface to 6 km wind shear vector (wind barbs, kt)

Modeling Approach: Variable-resolution computational mesh

- 1° (ne30) Base resolution
- 5 refinements of grid resolution to achieve near 3 km resolution in the inner refinement region
- Effective resolution O(10 km)



Variable-resolution challenge: physical parameterizations are not scale-aware

- ➔ Kilometer-scale models begin to resolve some mesoscale dynamics and reduce the dependence on physical parameterization (i.e., deep convection)
- ➔ Variable-resolution meshes that span O(100 km) where a deep convective parameterization is needed to O(1 km) where deep convective parameterization can be turned off poses a significant challenge
- ➔ Fractional cloud cover versus all or nothing at a grid cell

CAM7 Physics tuning will be needed for km-scale simulations

Variable resolution challenge: Need high-resolution atmosphere initialization

- ➔ For long-term climate simulations at the kilometer-scale it may be appropriate to interpolate from a “coarse” O(10 km) reanalysis product (e.g. ERA5)
- ➔ To better assess the skill of the SE-NH dycore for this short-term hindcast simulation it is necessary to initialize at kilometer-scale resolution in the domain of interest (e.g. NOAA RAP or HRRR analysis)

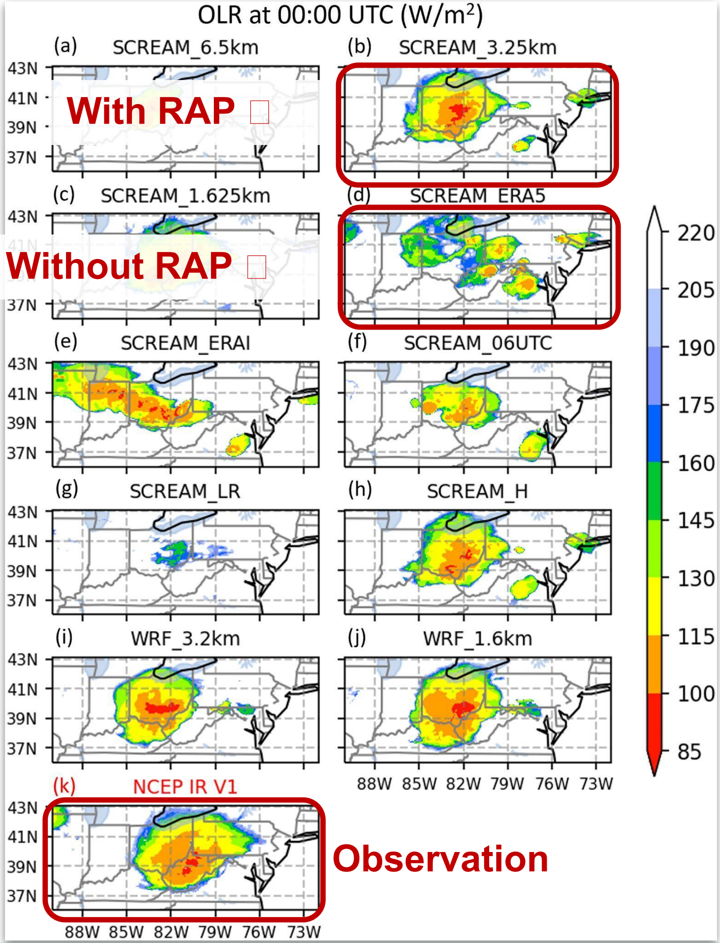


Figure from Liu et al., 2023

Discussion: StormSPEED is an upcoming community tool for CAM to support non-hydrostatic climate experiments

- ➔ The August 2020 Midwest derecho is a recent, societally-impactful extreme weather event with “complicated” mesoscale dynamics
- ➔ This case study will evaluate the level of convective organization produced by the model and sensitivities to initial conditions, physics
- ➔ These idealized and VR simulations serve as proof of concept studies to turn the StormSPEED development version into a tool for community use

DCMIP-2025

Questions?

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