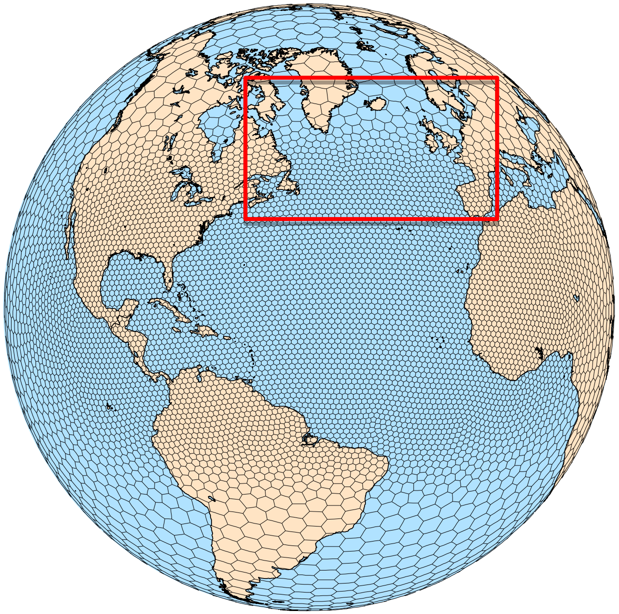
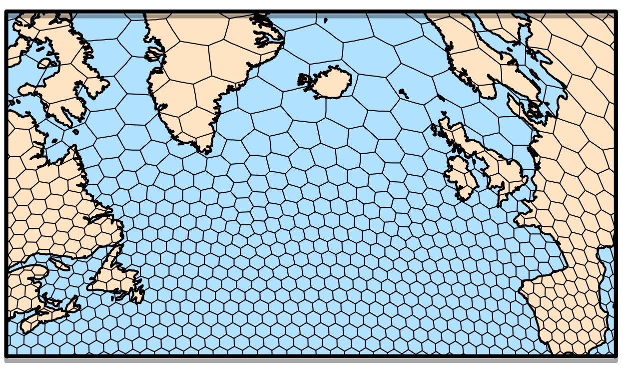
MPAS
Model for Prediction Across Scales

Variable-Resoluiton Global Atmospheric Modeling Spanning Convective to Planetary Scales

Bill Skamarock, NCAR/MMM





MPAS consists of geophysical fluid-flow solvers based on unstructured centroidal Voronoi (hexagonal) meshes using C-grid staggering and selective grid refinement.

MPAS-Atmosphere:

- Nonhydrostatic global atmospheric model
- Time integration as in Advanced Research WRF
- Spatial discretization similar to ARW except for Voronoi mesh accommodations.

Regional refinements embedded within global models will be the first nonhydrostatic climate applications.

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What problems are we trying to circumvent with MPAS?

- Expense of climate/weather simulations – regional refinement cuts costs by an order of magnitude
- Problems with traditional nesting
  - Nested-grid systems are non-conforming
  - Abrupt changes in resolution are bad
  - Fixes are ad hoc (e.g. sponge layers)
- Regional climate/weather modeling problems
  - Different driving models and different physics lead to solution mismatches at the lateral boundaries
  - Global driving solution, nest solution can diverge over long simulations
  - Fixes are ad hoc (e.g. spectral nudging)

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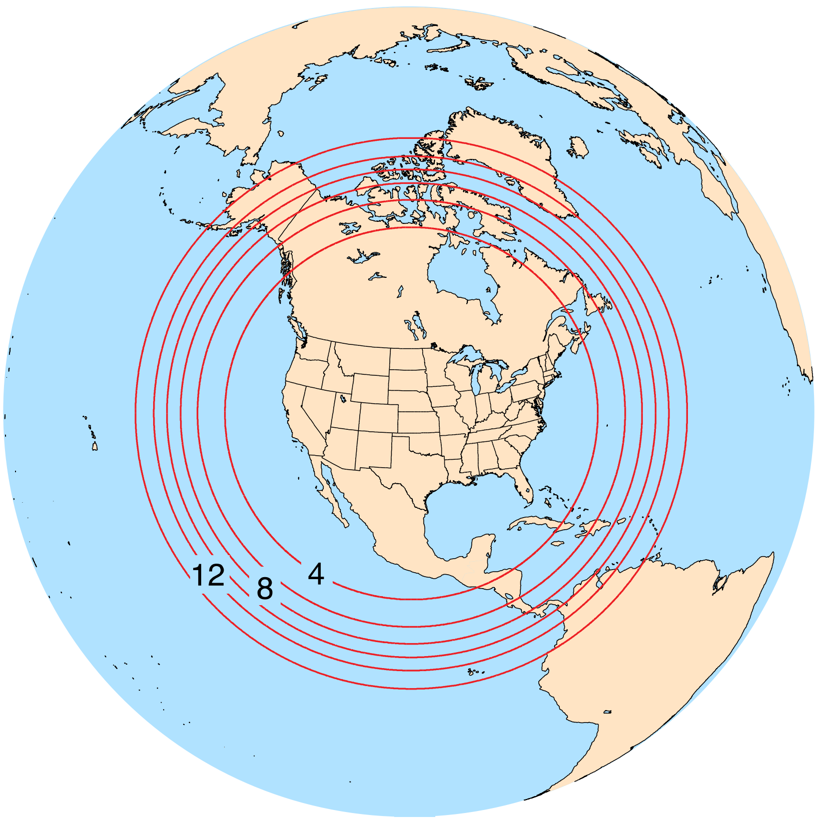
Hazardous Weather Testbed
Spring Experiment 2015, 2016
Forecasts Results from MPAS

Application Test
NOAA SPC/NSSL HWT
May 2015, May 2016
Convective Forecast Experiment
Daily 5-day MPAS forecasts
00 UTC GFS analysis initialization

Application question:
Can a global variable-resolution convection permitting model provide extended range severe weather guidance?

Modeling question:
Will the physics behave appropriately in the different regions of the mesh (coarse, fine, and transition region)?

MPAS 2016 mesh



3-15 km mesh, δx contours 4, 6, 8, 10, 12, 14 km
approximately 6.49 million cells (horz.)
50% have < 4 km spacing
(194 pentagons, 182 septagons)

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MPAS meshes:

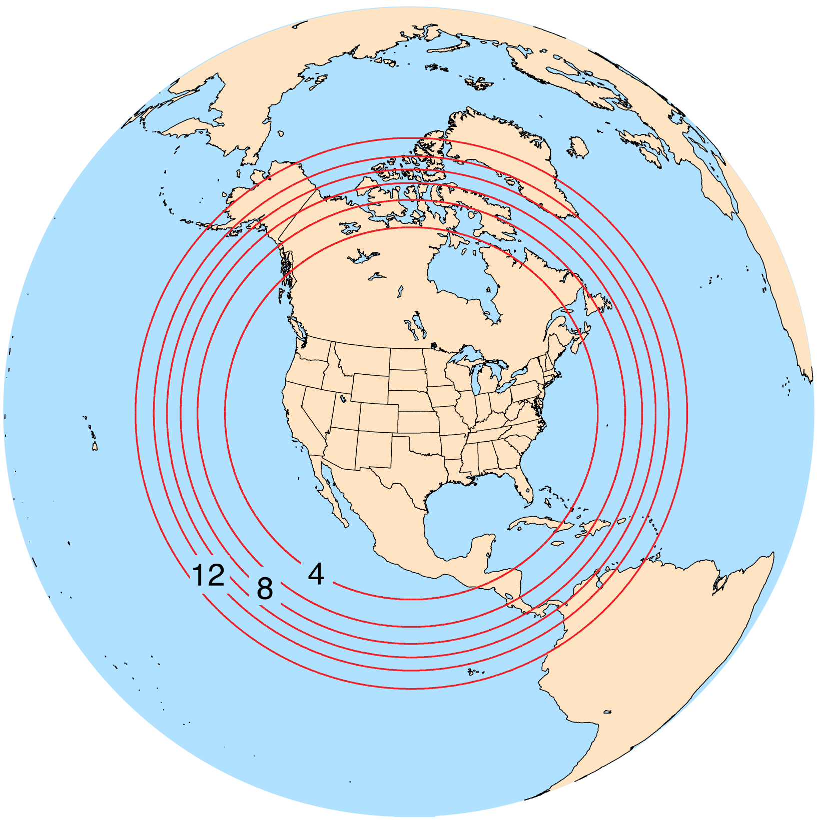
50 – 3 km (2015) and 15-3 km (2016) variable resolution.
CONUS is the 3 km regions.

MPAS Physics:

- *WSM6 cloud microphysics (2015)*
- *Thompson microphysics (2016)*
- Grell-Freitas convection scheme (scale-aware)
- Monin-Obukhov surface layer
- MYNN PBL
- Noah land-surface
- RRTMG lw and sw.

2015-2016: One step closer to the HRRR physics

MPAS 2016 mesh



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Grell-Freitas Convection Scheme in MPAS

<u>Scale-aware/aerosol-aware (Grell and Freitas, 2014, ACP)</u>

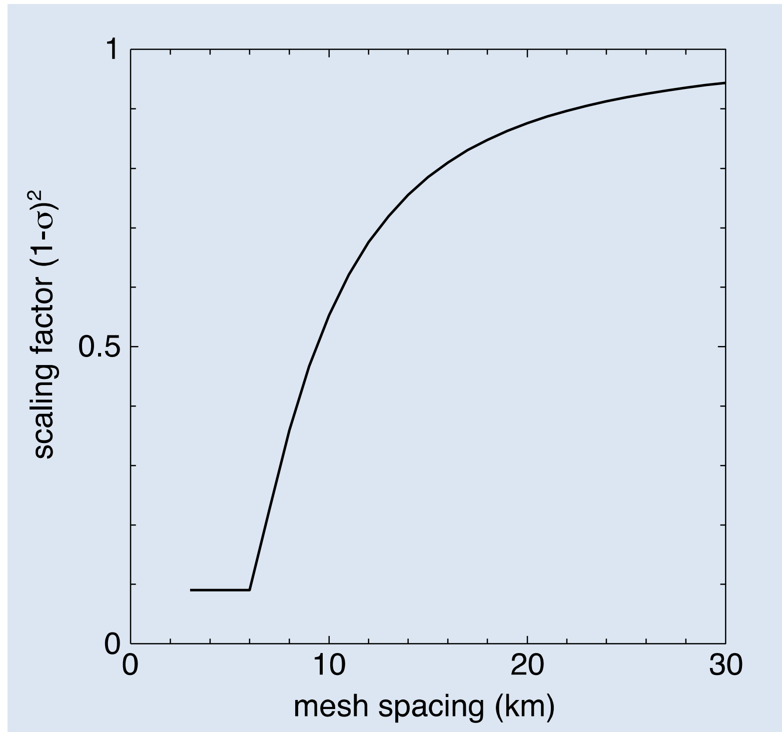
- Stochastic scheme (Grell and Devenyi, 2002).
- Scale aware by adapting the Arakawa et al approach (2011).
  - Relates vertical convective eddy transport to convective updraft/downdraft fraction σ:

$$\rho\overline{w\psi} = (1-\sigma)^2 \, M_c(\psi_c - \bar{\psi})_{adj} \quad \text{with} \quad M_c \equiv \rho\sigma w_c$$

  - GF: σ is the fractional area covered by active updraft and downdraft plume.

$$\sigma = \frac{\pi R^2}{A_{grid\,cell}}, \quad \boldsymbol{R_{conv}} = 3\,km, \; \sigma_{max} = 0.7 \qquad \boldsymbol{R_{conv}} \sim \frac{0.2}{\varepsilon}, \; \varepsilon = 7 \times 10^{-5}\,m^{-1}$$

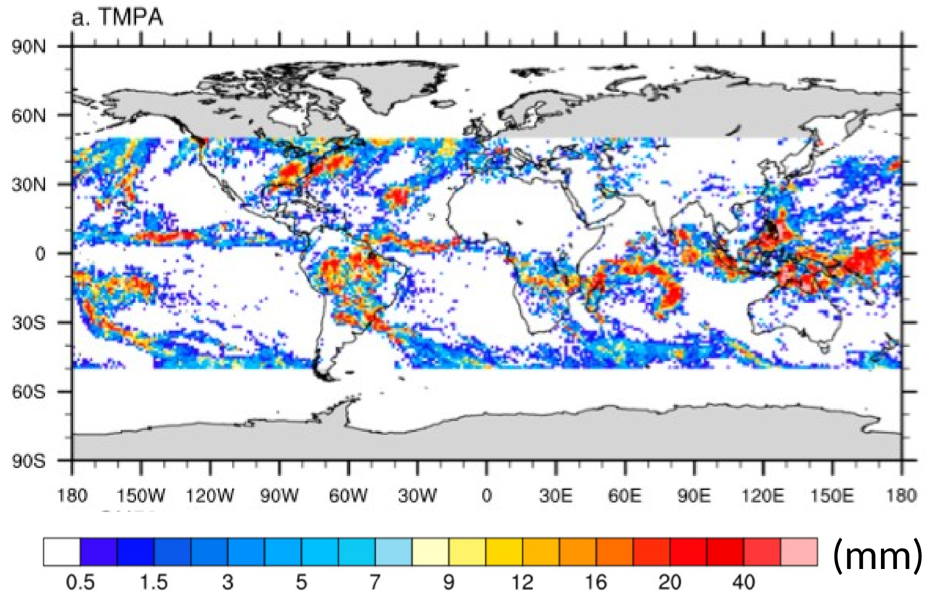
  - At convection-permitting resolution, parameterized convection becomes much shallower – cloud tops near 800 mb (down from 200-300 mb).
  - Temperature & moisture tendencies decrease as resolution increases.



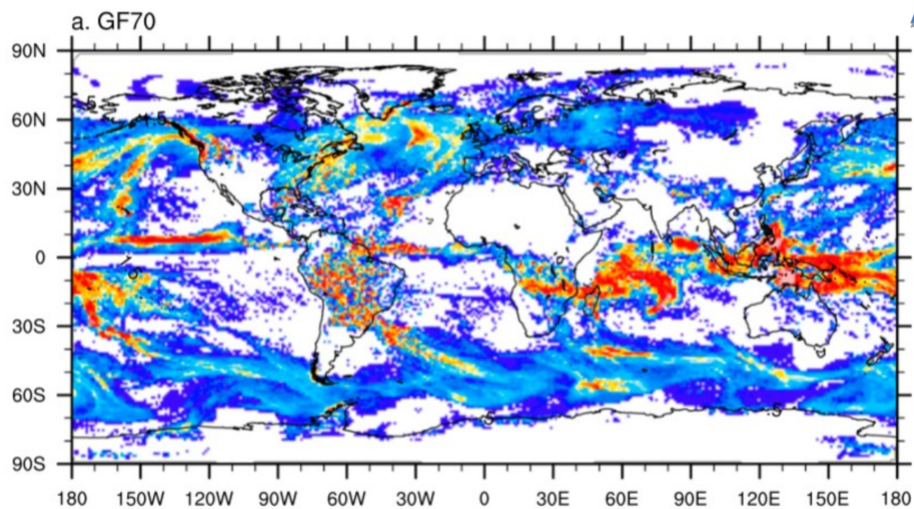
Grell-Freitas Convection Scheme in MPAS

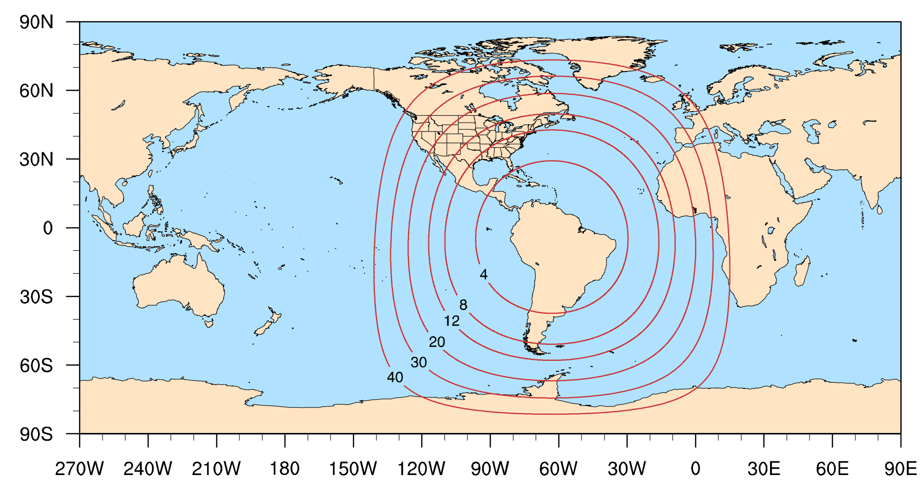
Precipitation rate over the period
00 UTC 11 Jan and 00 UTC 14 Jan 2014
Fowler et al (2016, MWR)

TRMM precipitation analysis



50-3 km var-res MPAS using Grell-Freitas convective scheme





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Grell-Freitas Convection Scheme in MPAS

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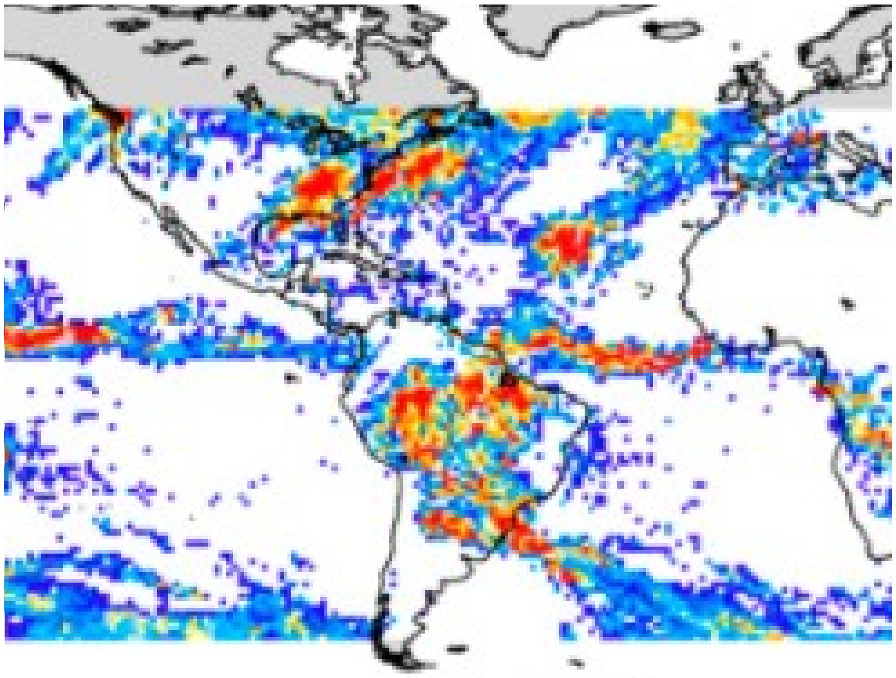

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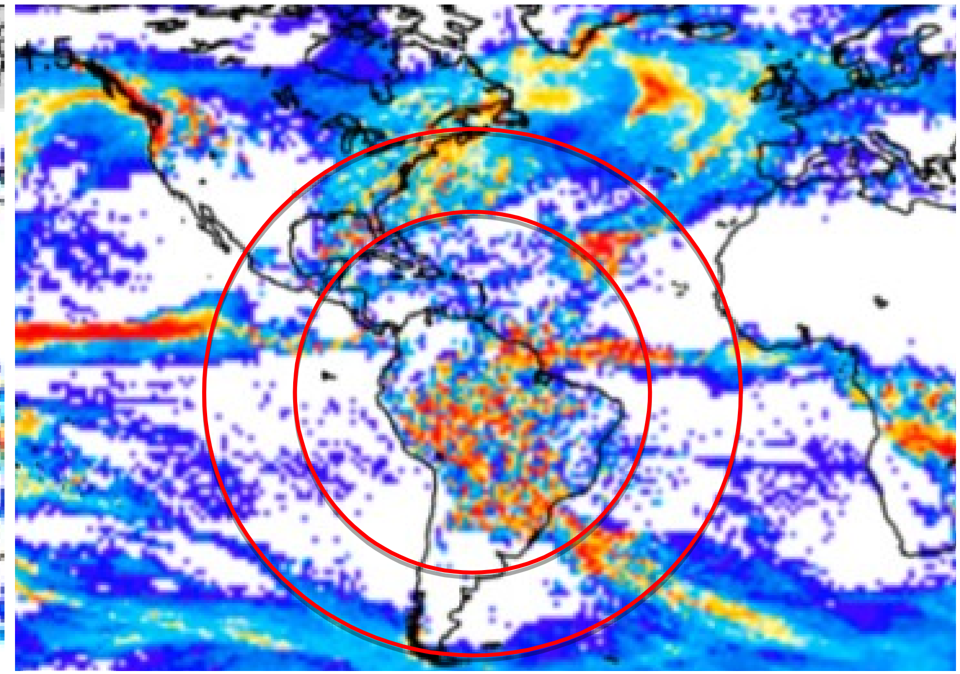
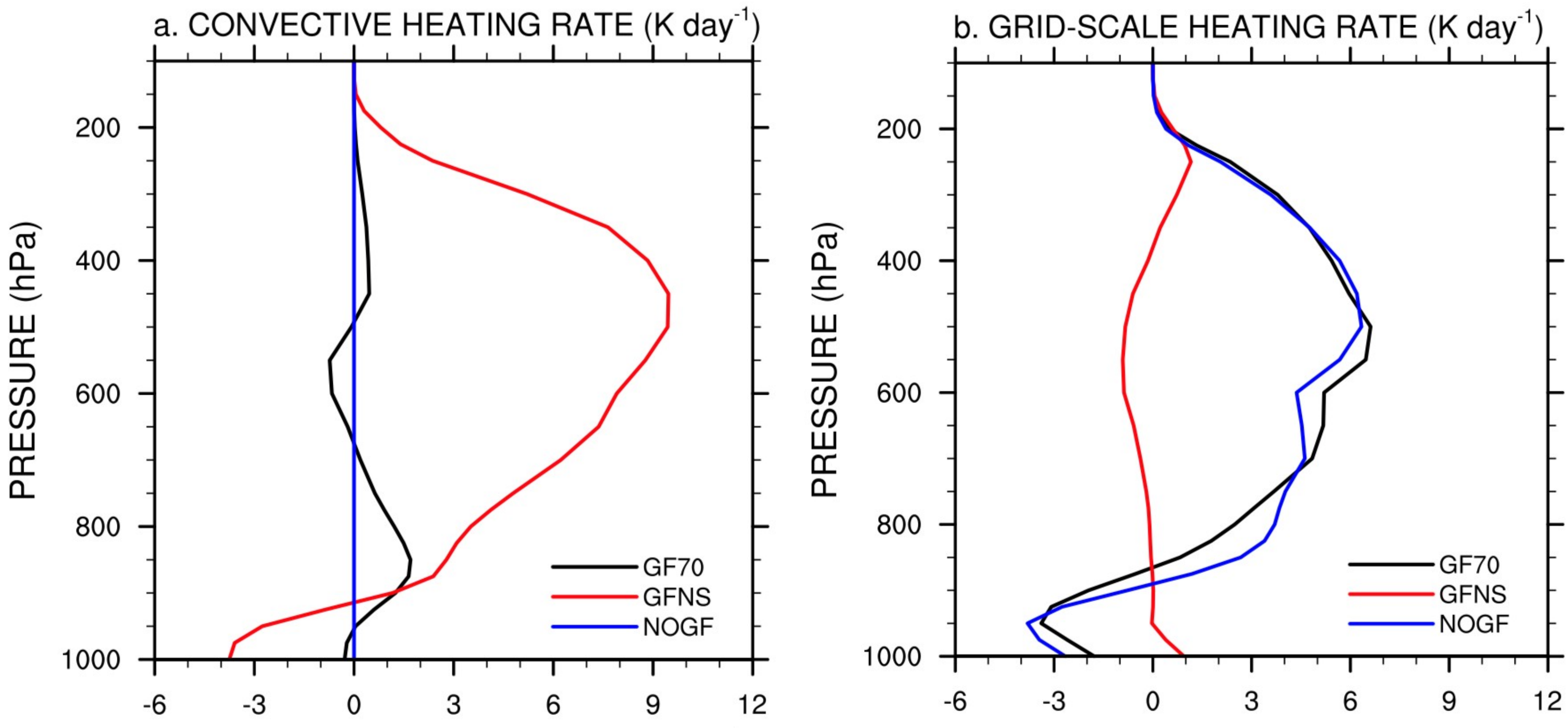


4 and 8 km cell spacing (red contours)

Grell-Freitas Convection Scheme in MPAS

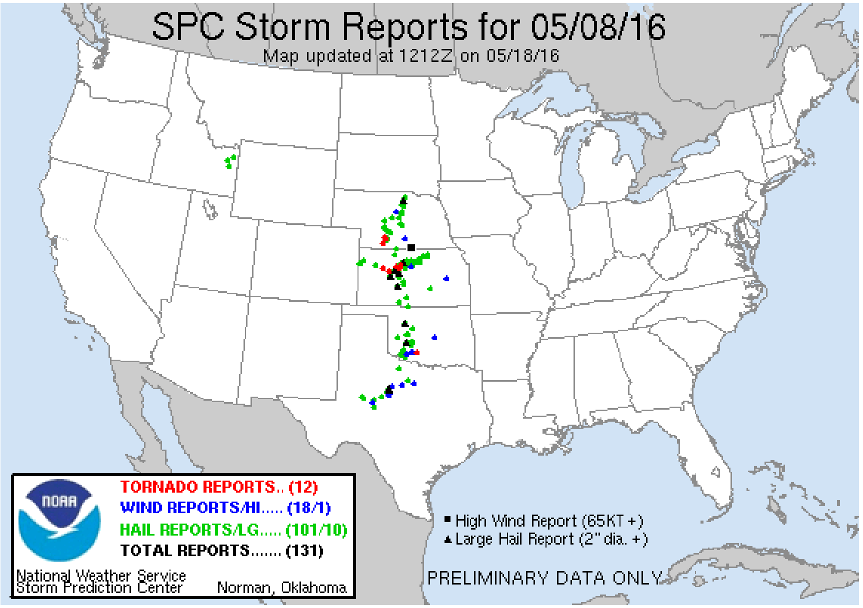


Scale-aware Grell-Freitas scheme

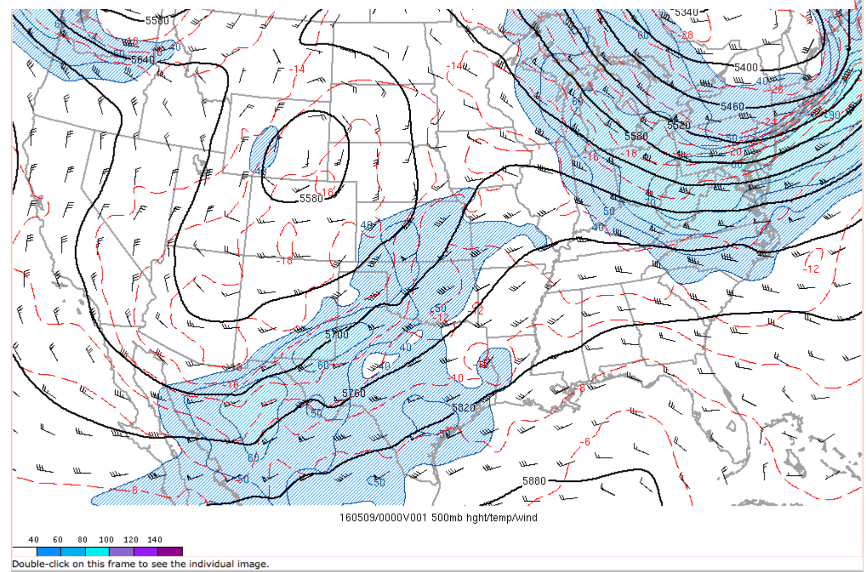
Grell-Freitas scheme, non-scale-aware

No convection scheme

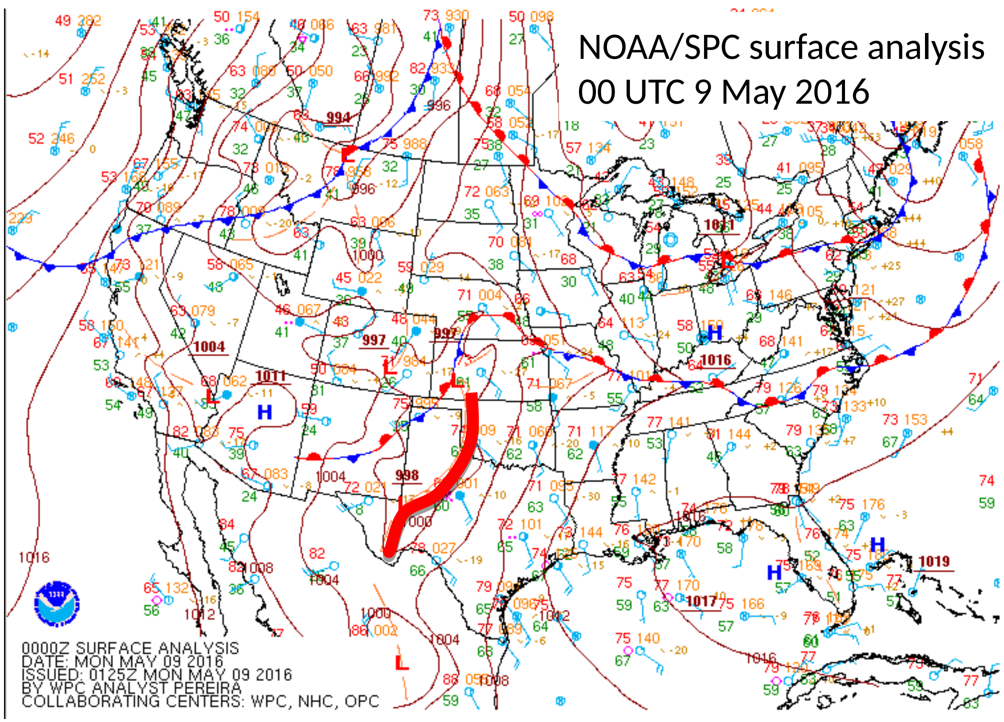
Fowler et al (2016, MWR)



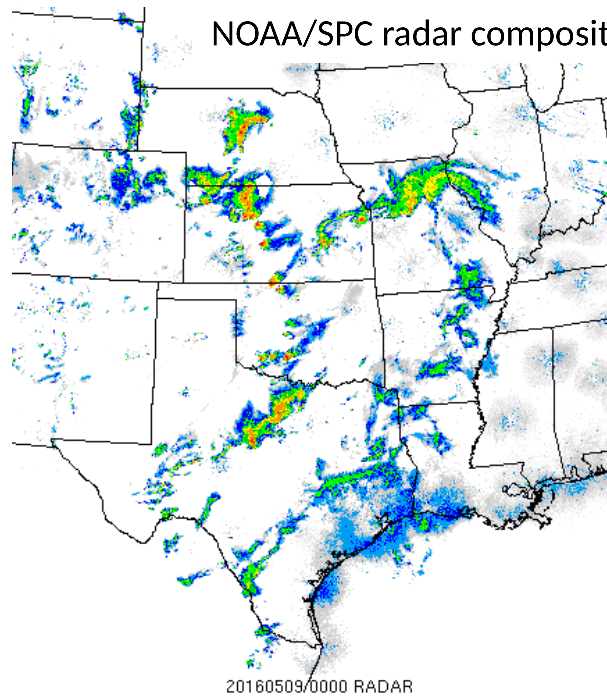
500 hPa winds, heights, temps (NOAA/SPC)
00 UTC 09 May 2016



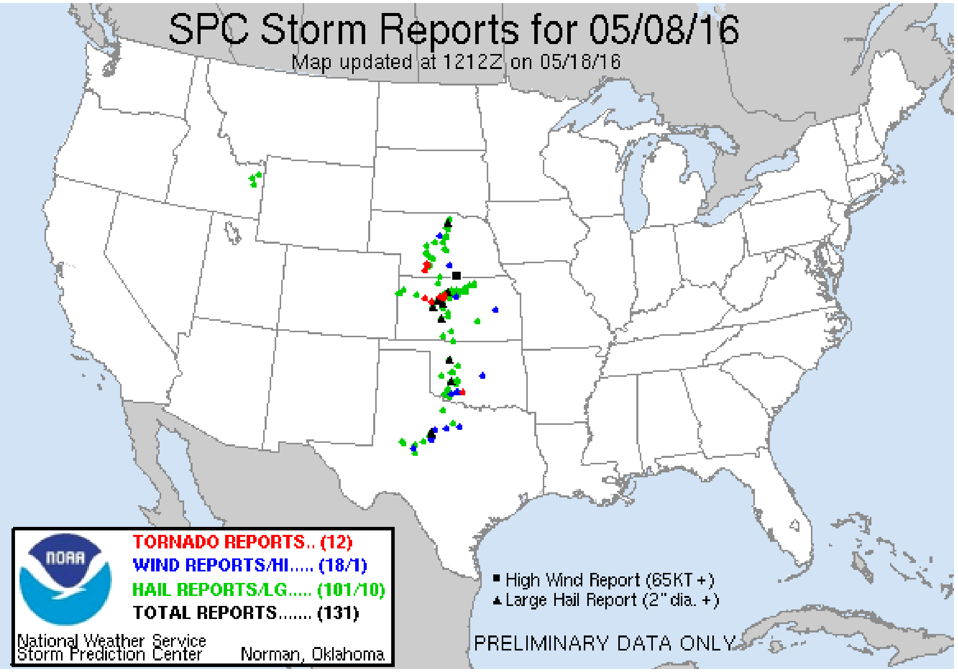
NOAA/SPC surface analysis
00 UTC 9 May 2016



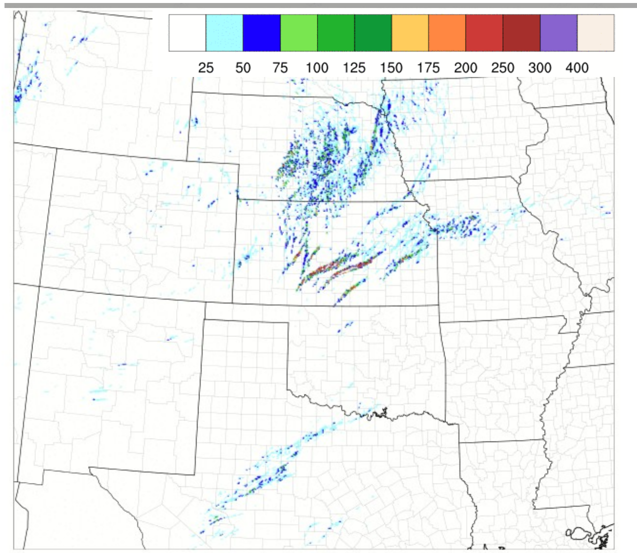
NOAA/SPC radar composite



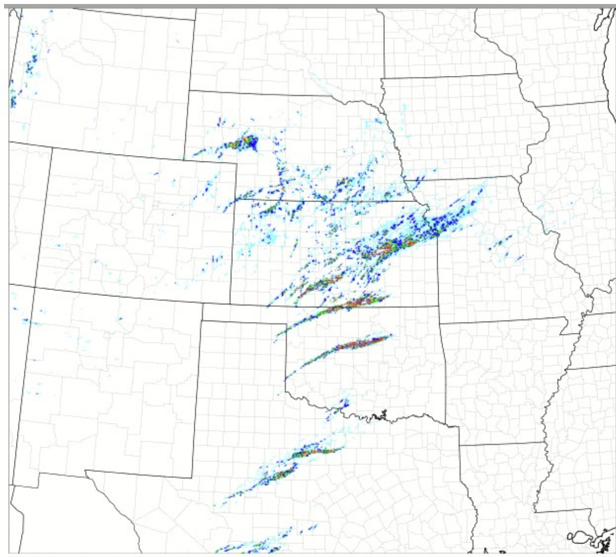
MPAS 24h Max Updraft Helicity (m^2/s^2)



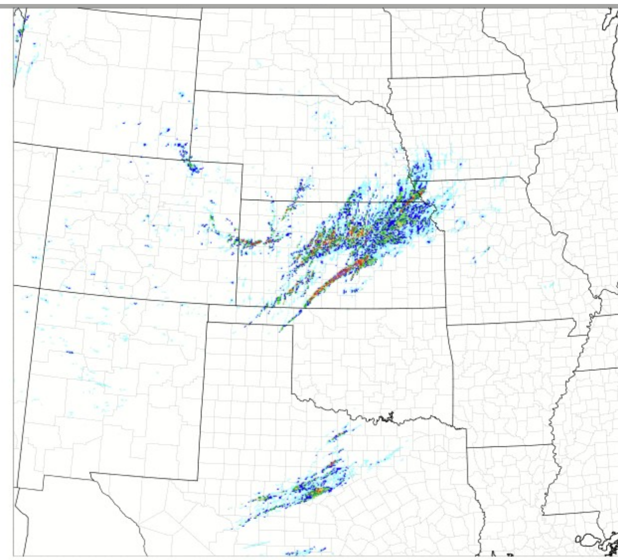
MPAS 36h forecast



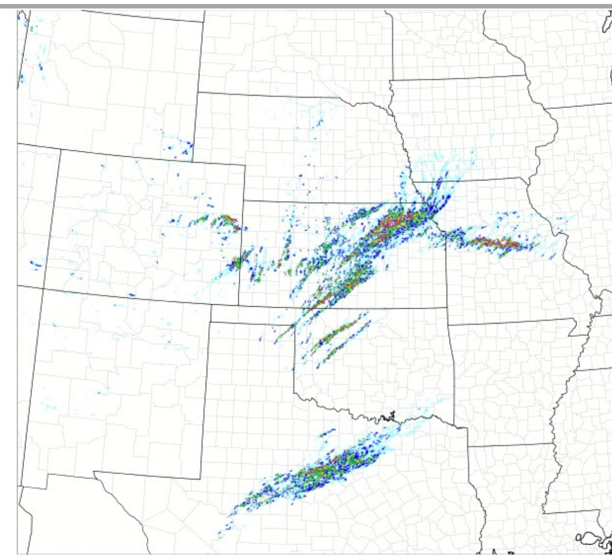
MPAS 60h forecast



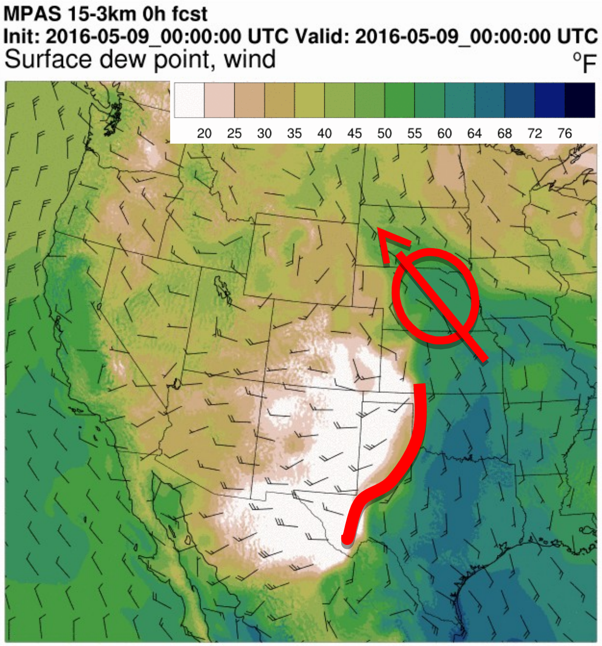
MPAS 84h forecast

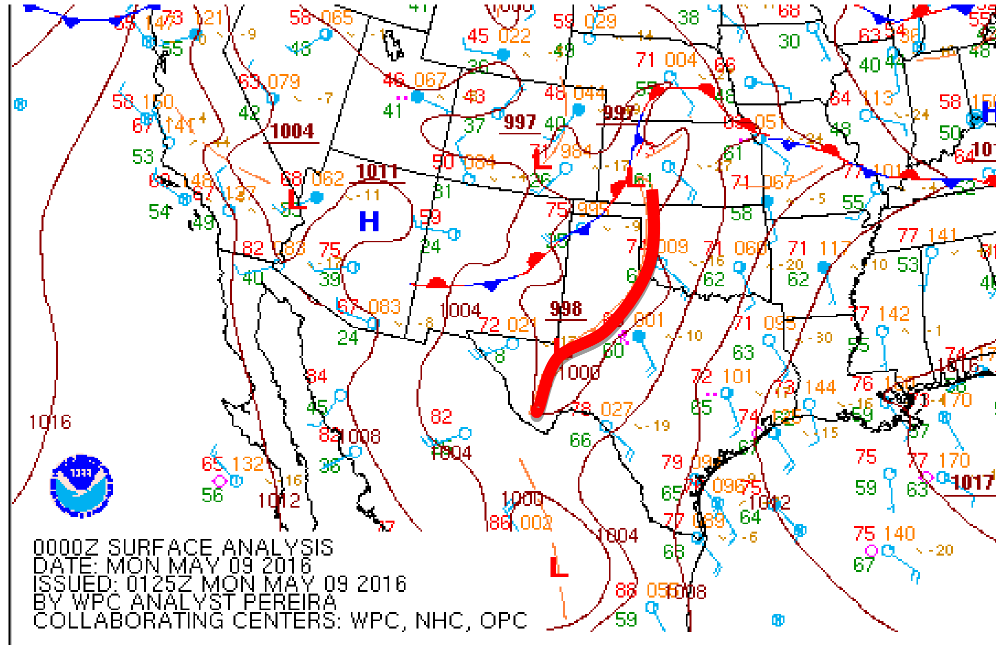


MPAS 108h forecast

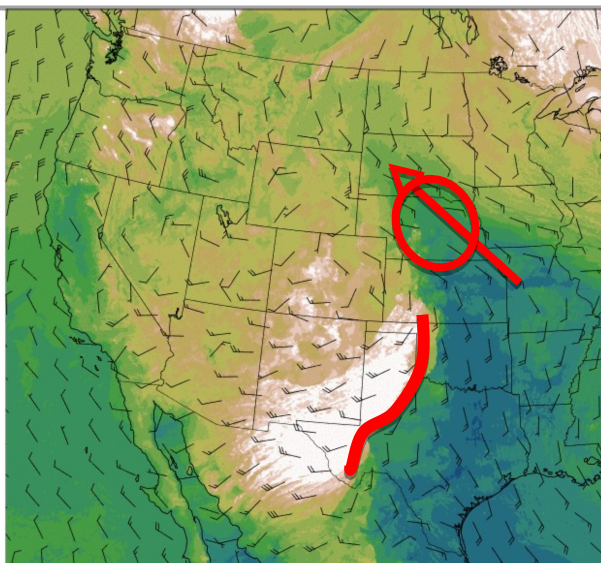


GFS analysis, 00 UTC 9 May 2016

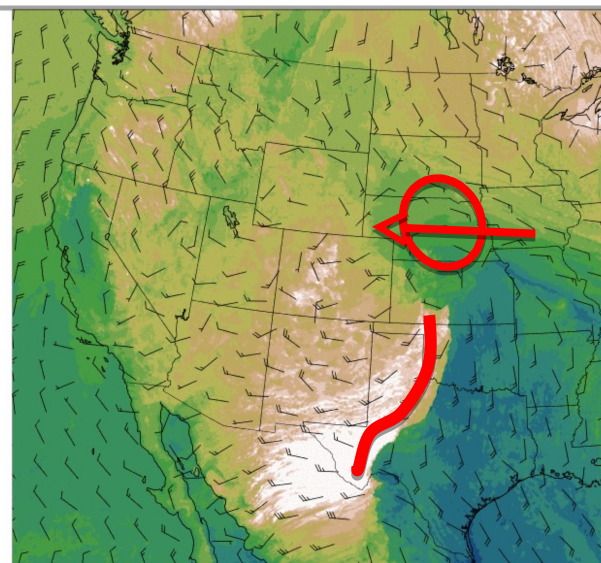




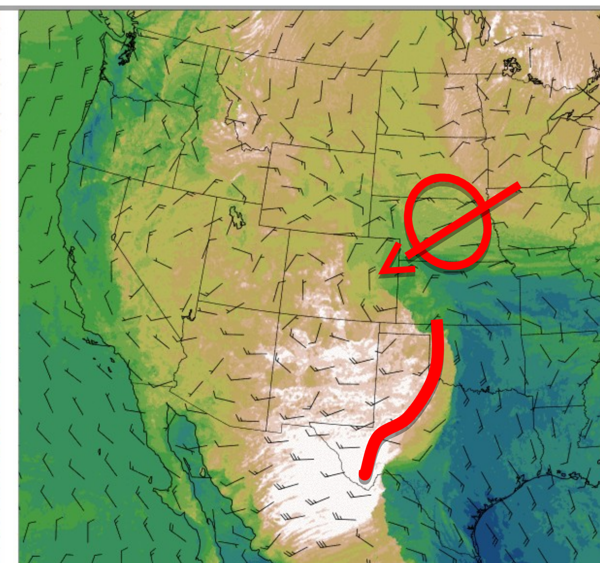
MPAS 24h forecast



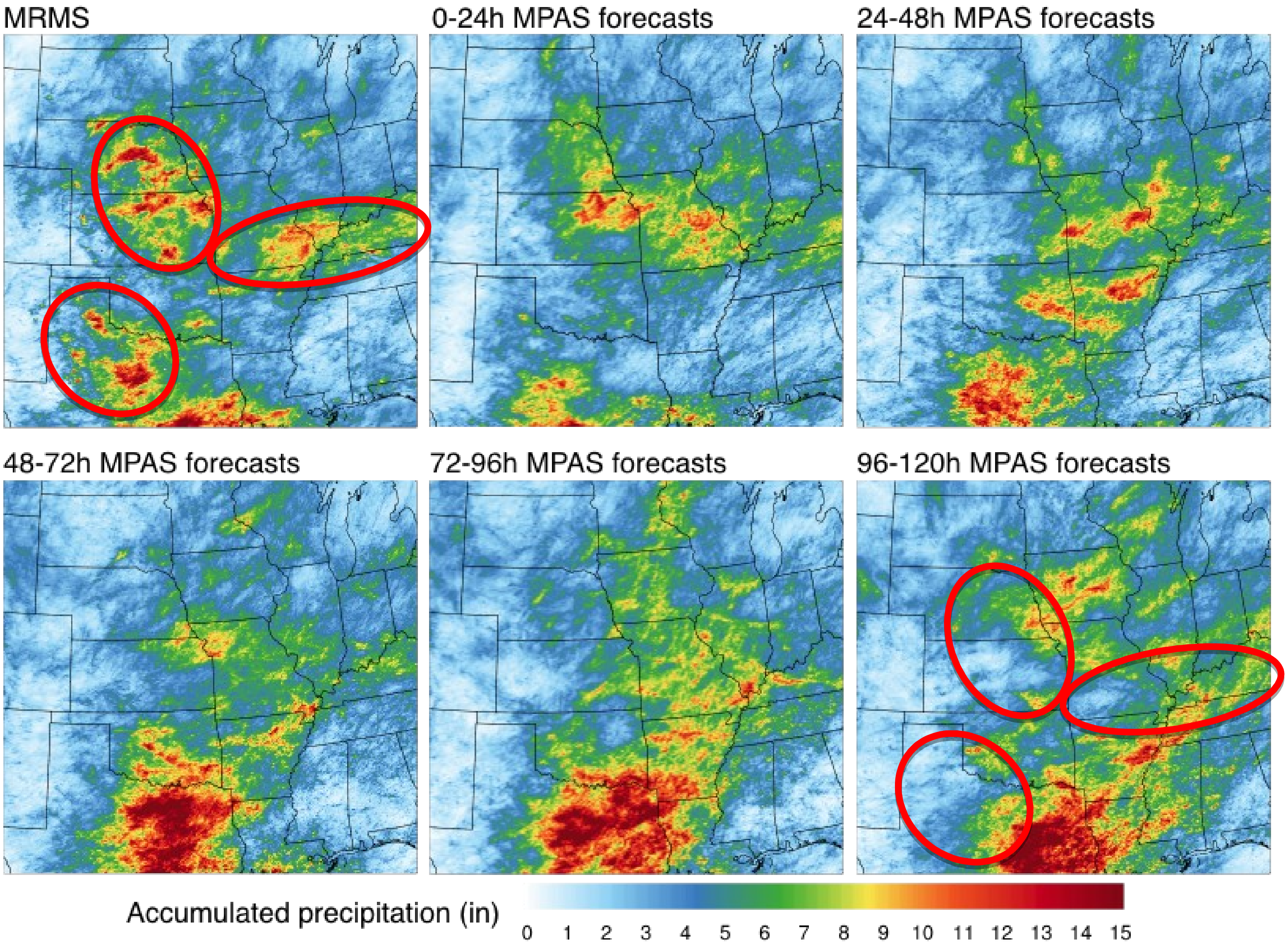
MPAS 72h forecast



MPAS 120h forecast



1-31 May 2016 Accumulated Precipitation
MRMS Analysis and MPAS Forecasts



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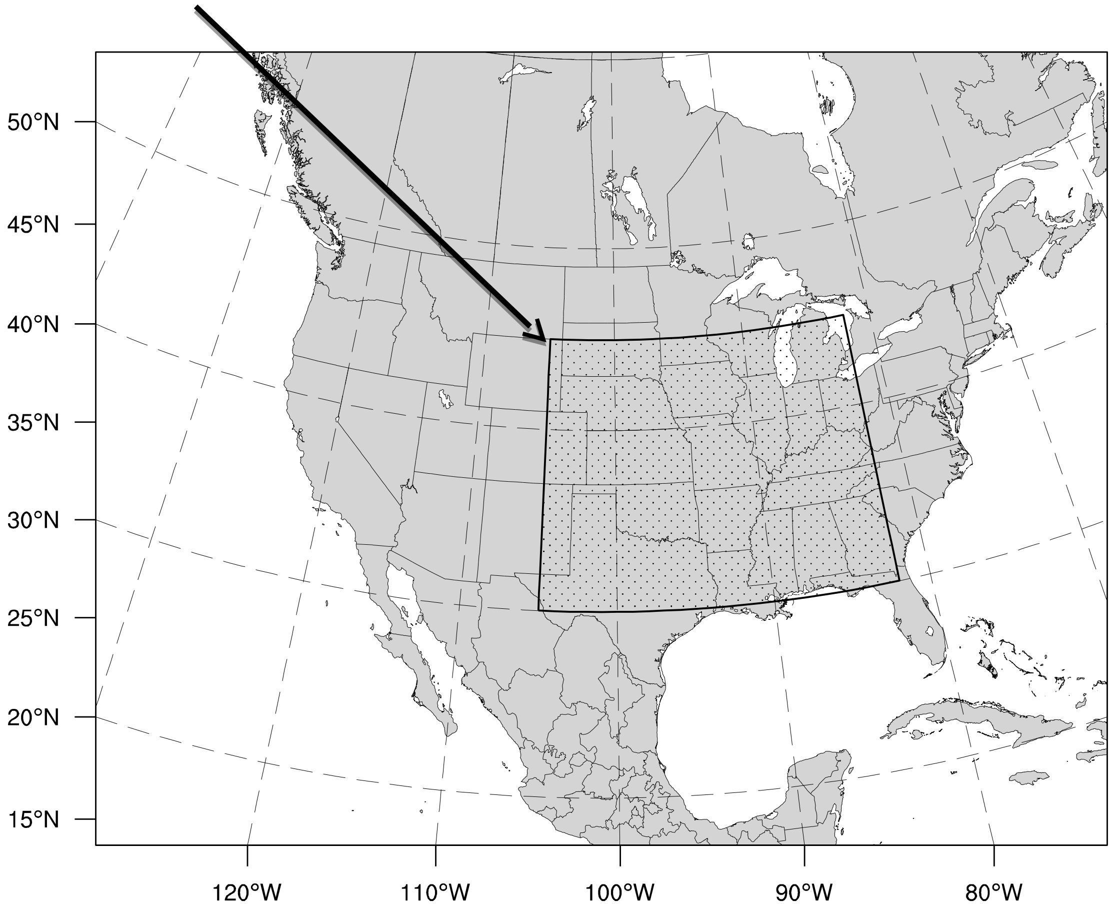
Hazardous Weather Testbed
Spring Experiment 2015, 2016
Forecasts Results from MPAS



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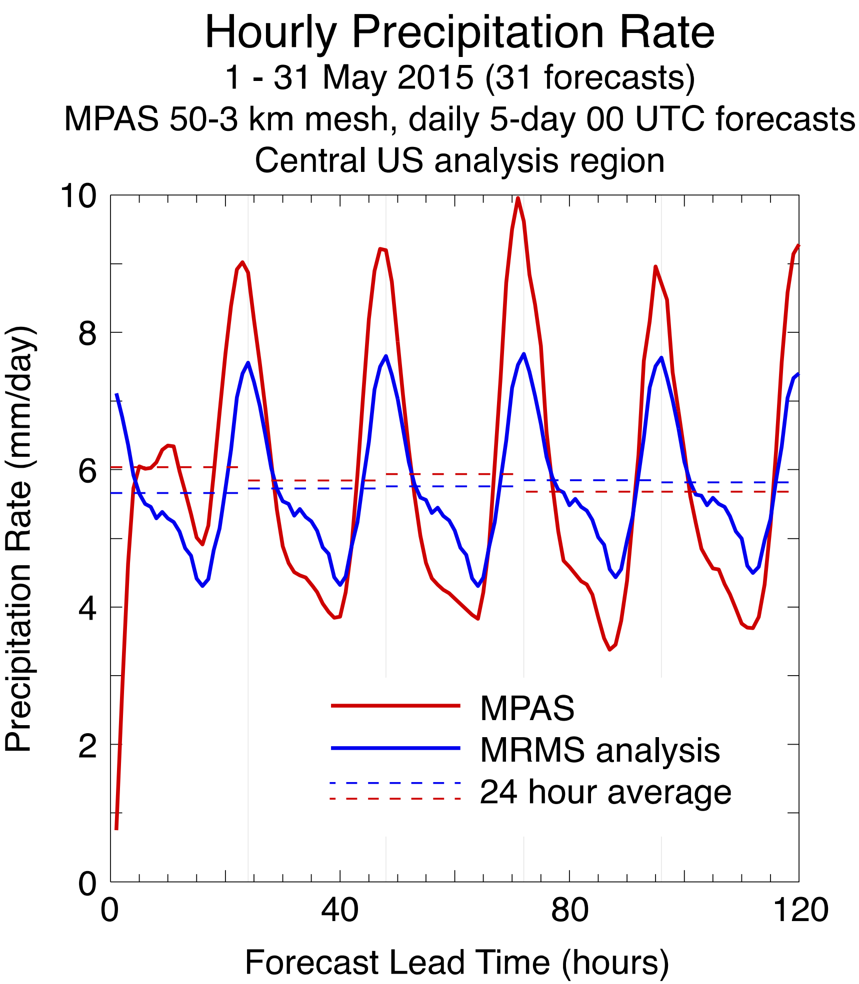

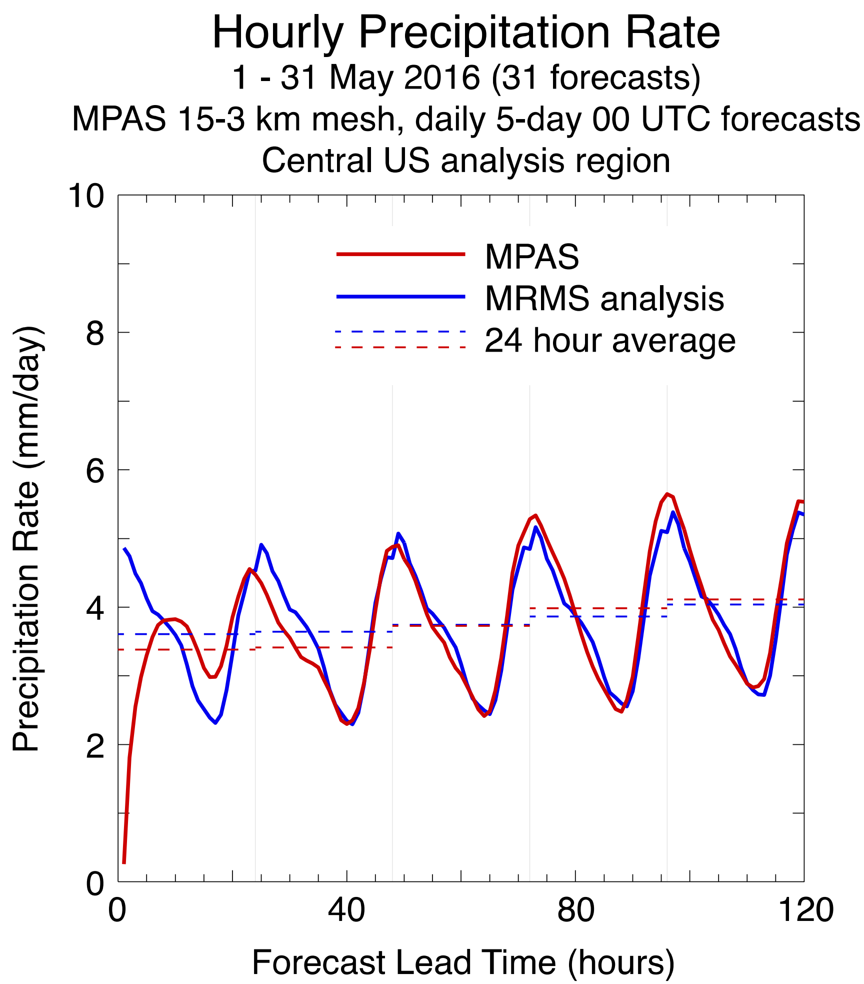

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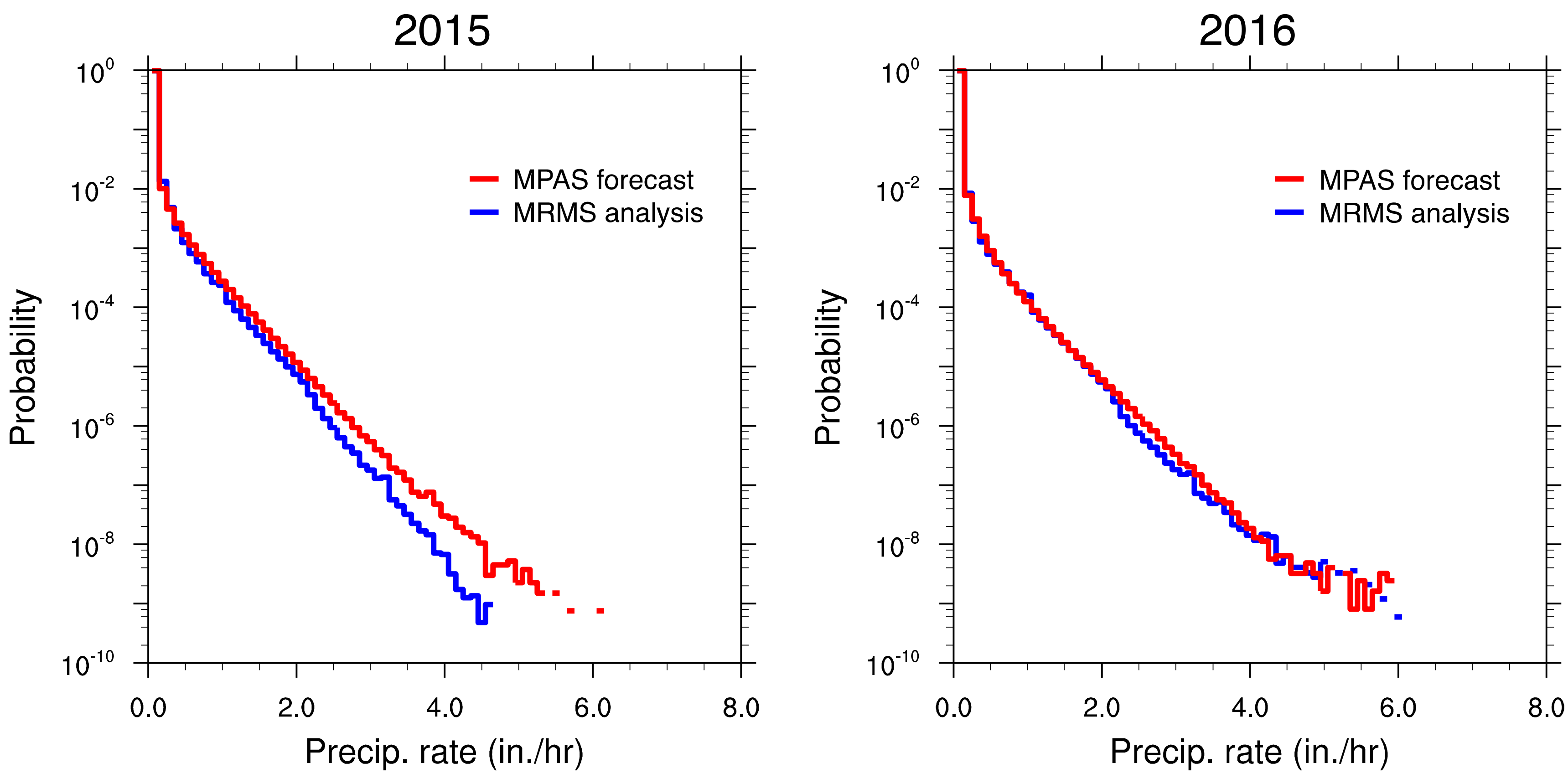
Precipitation Rate PDF
1 - 31 May 2015, 2016 (31 forecasts each year)
MPAS 50-3 and 15-3 km meshes, daily 5-day 00 UTC forecasts
Central US analysis region



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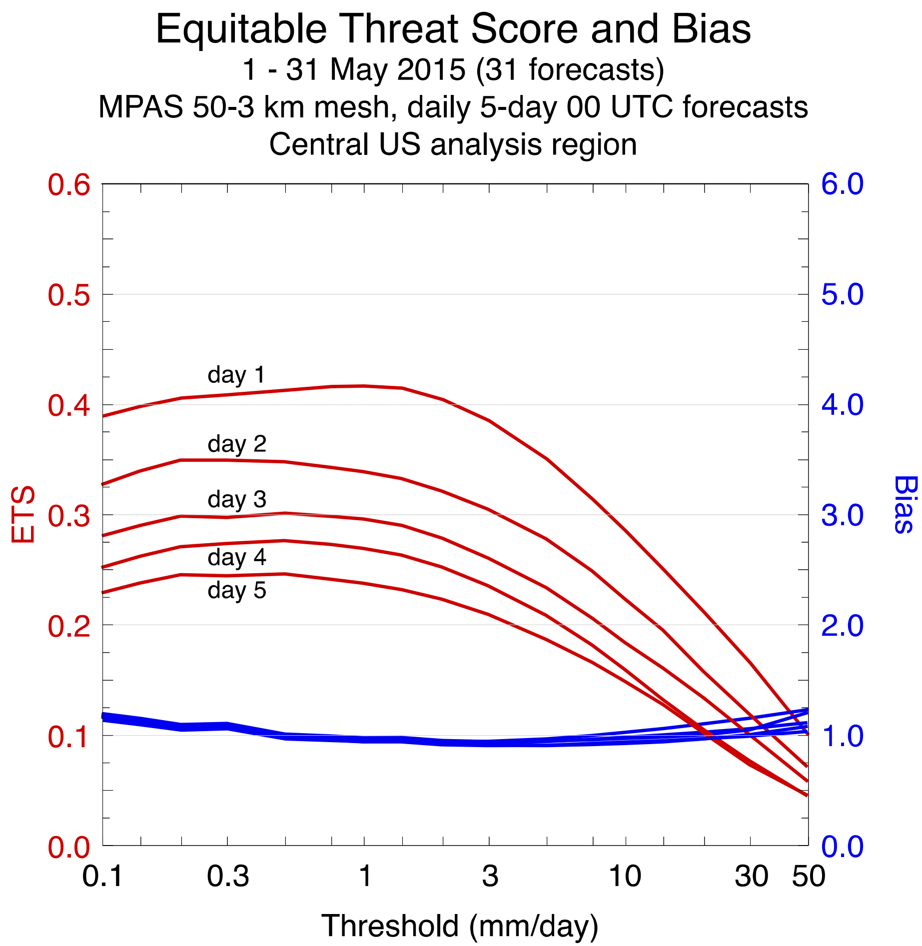

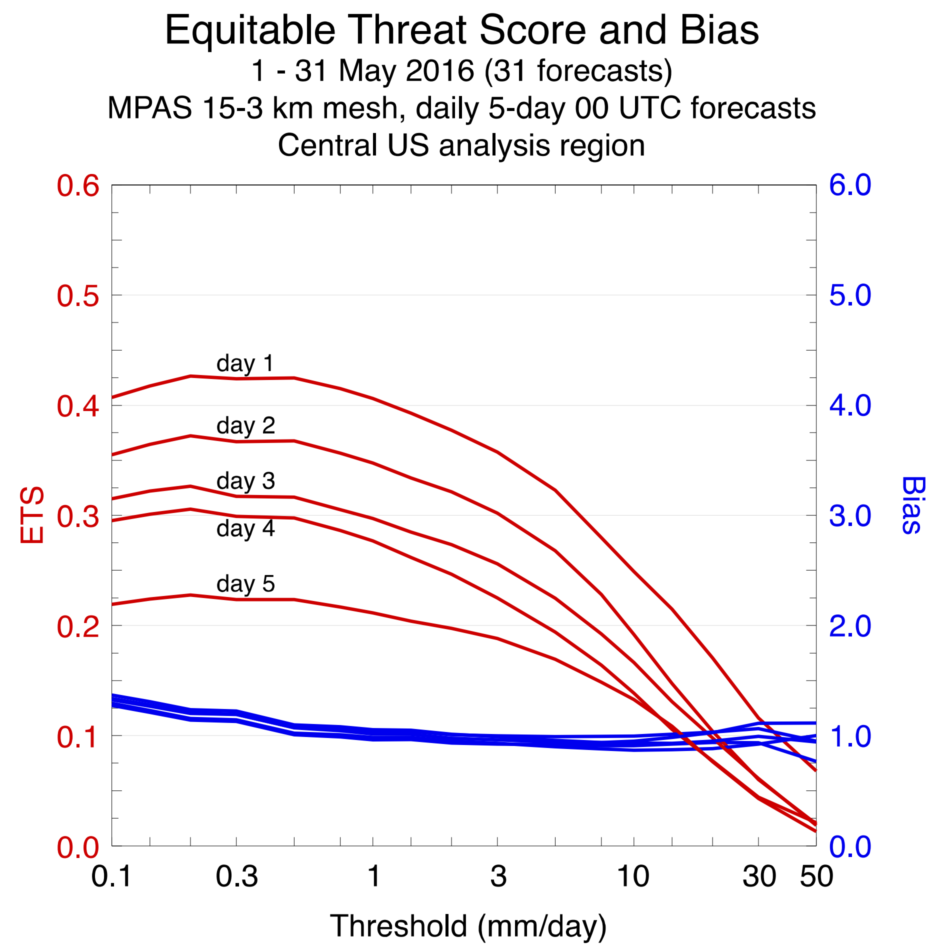

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Summary

Variable-resolution, nonhydrostatic-scale atmospheric simulations are viable

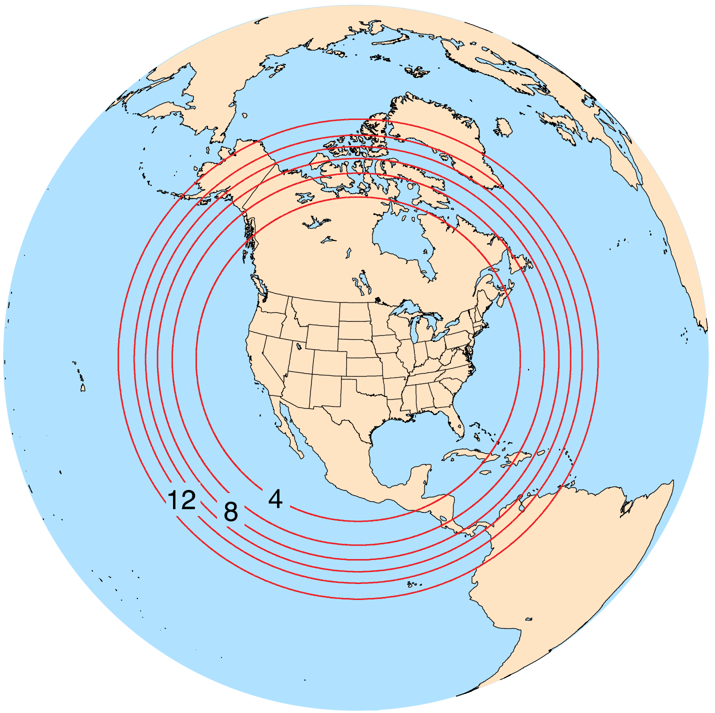
- Variable-resolution mesh is producing clean solutions in the mesh transition region.
- GF convection scheme appears to be viable for hydrostatic-nonhydrostatic scale-aware applications. Further work/tuning needed, particularly in the tropics.
- Fidelity of convection similar to that in ARW.
- Simulation rates >100 days/day are attainable. (operational centers could do this today)

Challenges

Scale-aware physics:

- *Convection*
- Microphysics
- Boundary layer

Data assimilation on variable meshes.
Physics for climate applications?



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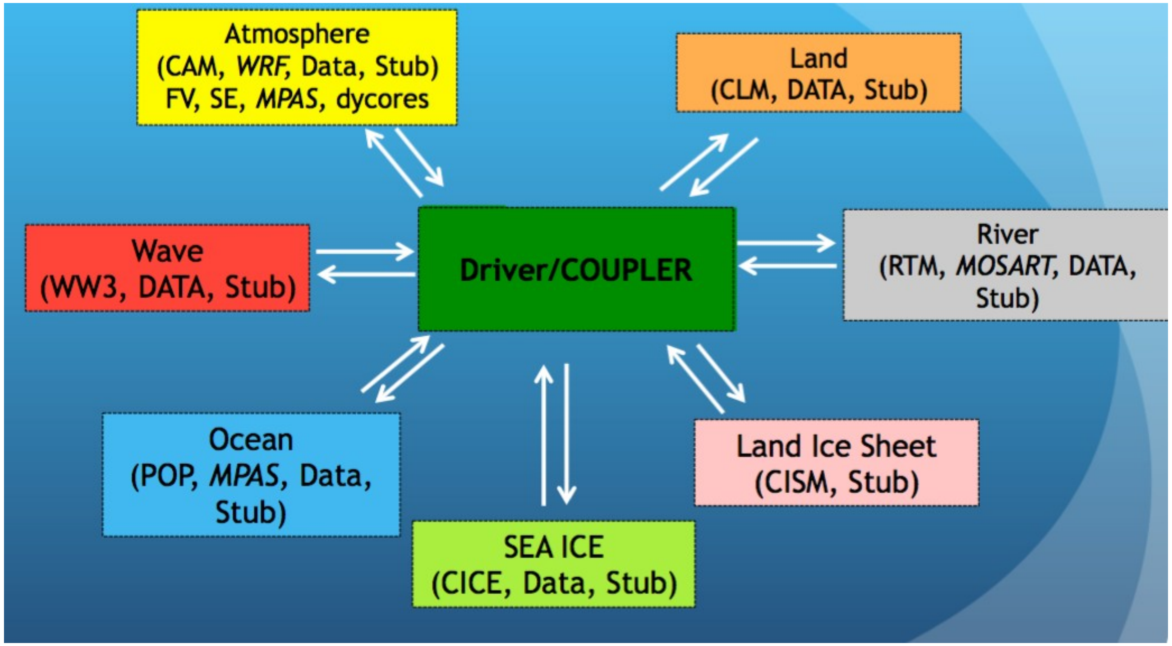
MPAS Development Plans

Community Earth System Model (CESM)

- MPAS-A is an atmospheric dynamical core in CAM
- NWP testing is underway, focused on tropical cyclones
- Coupled model simulations are underway (w/ocean)
- Physics evaluation for NWP is major focus of early testing



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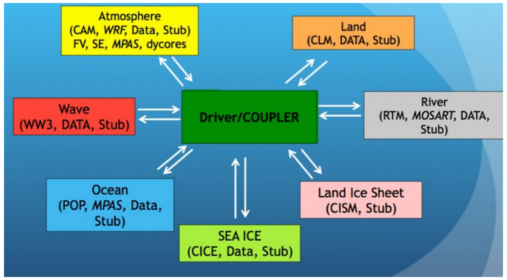

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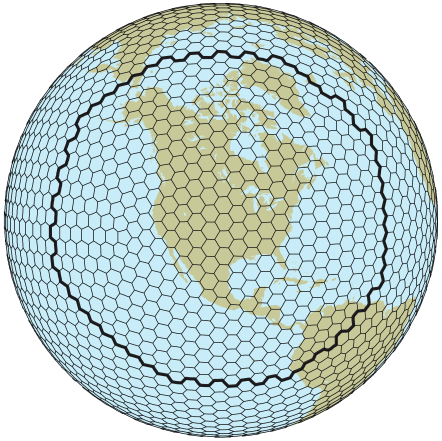
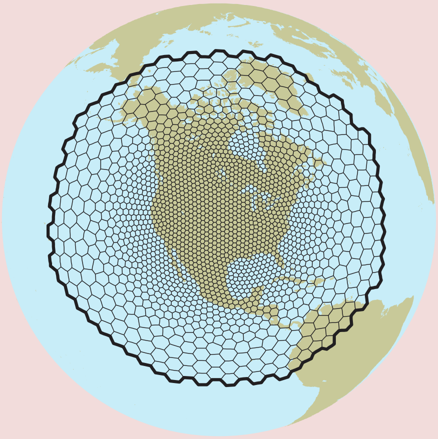
Regional MPAS-Atmosphere

- We are constructing a regional version of MPAS-A
- General release (MPAS Version 6) mid-late 2017

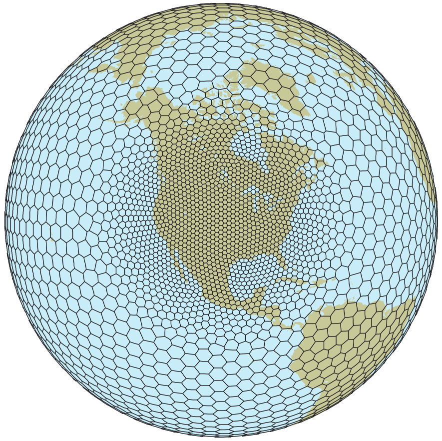
quasi-uniform icosahedral mesh



regional mesh with
matching boundary cells



single global mesh combining
global uniform and regionally-refined meshes



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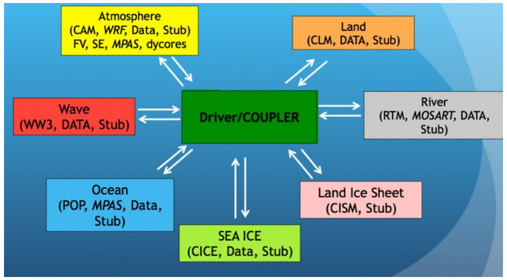

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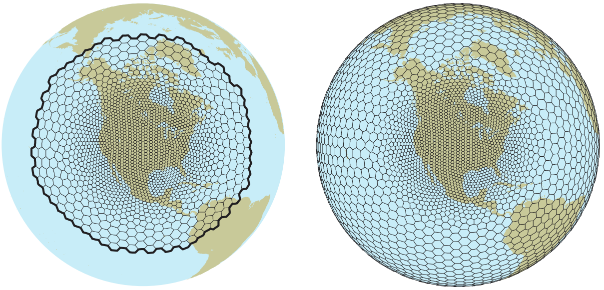

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MPAS-Atmosphere and Data Assimilation

- DA work underway with DART and NCEP/GSI

MPAS-Atmosphere and shared model components

- We are developing a common physics repository for MPAS and WRF
- We are planning to link CAM build to MPAS-A from the MPAS-A development/release repository

MPAS-Atmosphere drives regional WRF (one-way) – MPAS V5 release (late 2016).

MPAS-Atmosphere optimizations

- Current development dycore is now multithreaded and hybrid (OpenMP and MPI), and is bit-reproducible regardless of parallel configuration
- Recent optimizations – development dycore is twice as fast as current (V4) release. Available in V5 release.
- Ongoing work for next generation architectures (Intel MIC, GPUs)

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