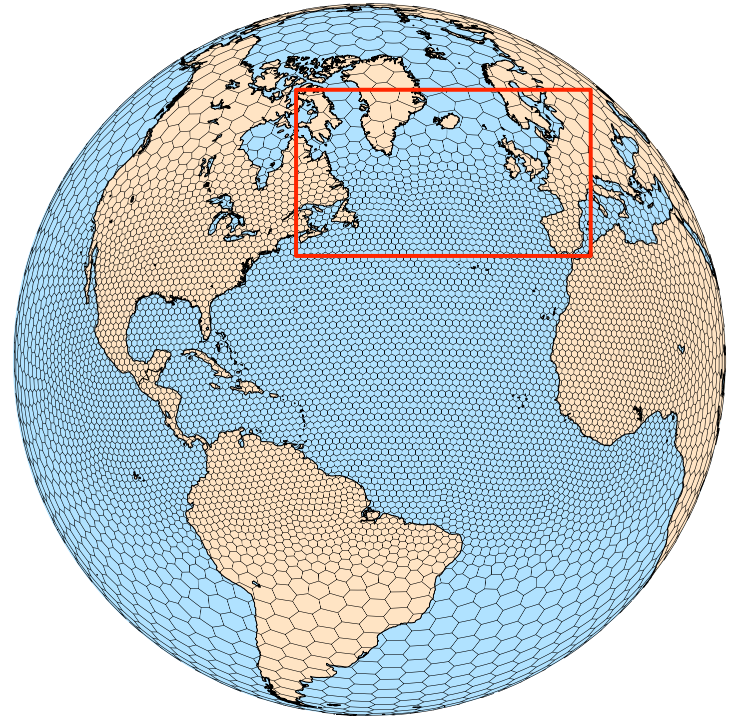
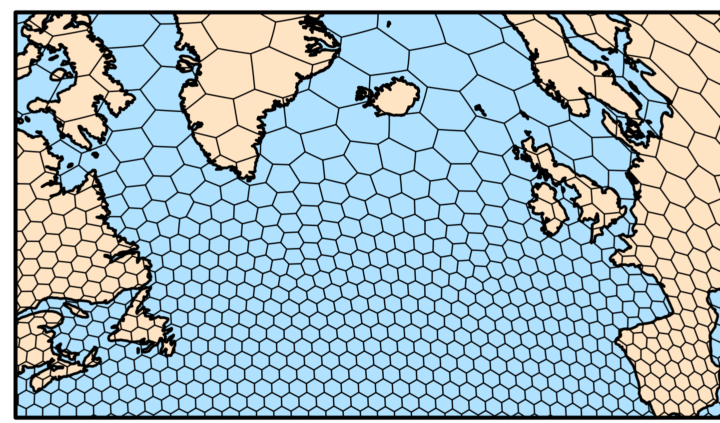
Variable-Resolution Global Atmospheric Simulations Bridging the Hydrostatic and Nonhydrostatic Regimes



MPAS
Model for Prediction Across Scales

Bill Skamarock, Joe Klemp, Michael Duda,
Laura Fowler, Sang-Hun Park
National Center for Atmospheric Research



Based on unstructured centroidal Voronoi (hexagonal) meshes using C-grid staggering and selective grid refinement.

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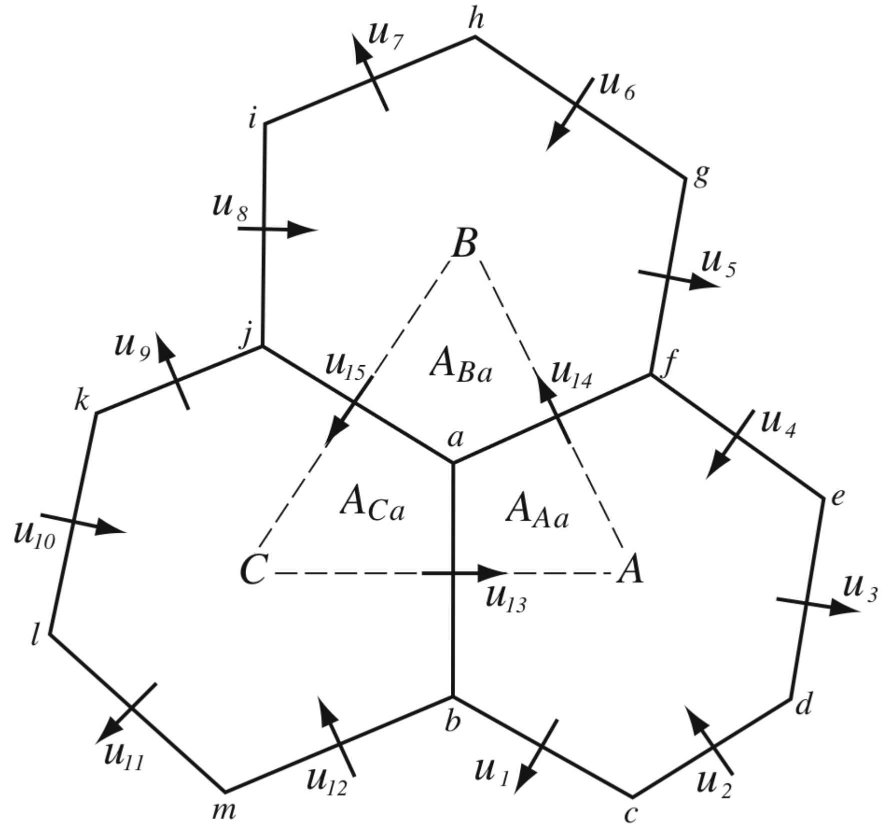
Centroidal Voronoi Meshes

<u>Unstructured spherical centroidal Voronoi meshes</u>

- Mostly *hexagons*, some pentagons and 7-sided cells
- Cell centers are at cell center-of-mass (centroidal).
- Cell edges bisect and are orthogonal to the lines connecting cell centers.
- Uniform resolution – traditional icosahedral mesh.

<u>C-grid</u>

- Solve for normal velocities on cell edges.
- Gradient operators in the horizontal momentum equations are 2nd-order accurate.
- Velocity divergence is 2nd-order accurate for edge-centered velocities.



MPAS
Model for Prediction Across Scales

MPAS Nonhydrostatic Atmospheric Solver

Nonhydrostatic formulation

Equations

- Prognostic equations for coupled variables.
- Generalized height coordinate.
- Horizontally vector invariant eqn set.
- Continuity equation for dry air mass.
- Thermodynamic equation for coupled potential temperature.

Time integration

- Split-explicit Runge-Kutta (3rd order), as in Advanced Research WRF.
- Single time-step for the global mesh, CFL limited by highest resolution.

Spatial discretization

- Similar to Advanced Research WRF except for a few critical terms.

MPAS

Model for Prediction Across Scales

Variable Resolution Tests with the Grell-Freitas Convection Scheme

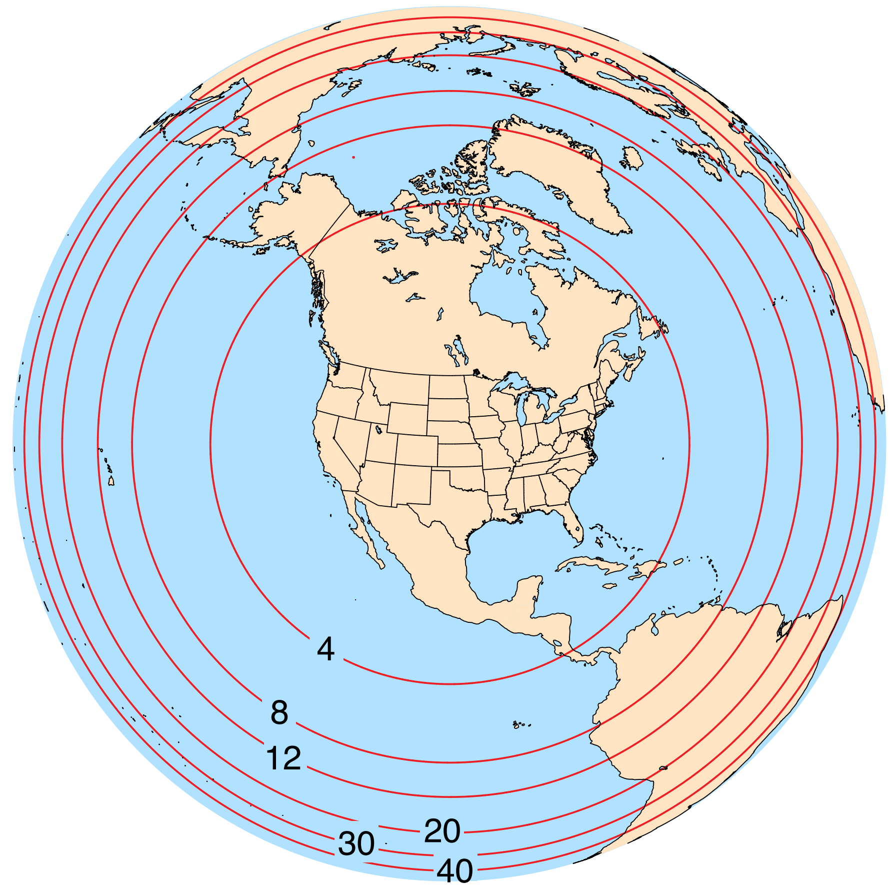
(Laura Fowler, Bill Skamarock, GF group)

MPAS mesh:

50 – 3 km variable resolution.
CONUS is the 3 km region.
Very smooth transition to the 50 km region.

MPAS Physics:

- WSM6 cloud microphysics
- Grell-Freitas convection scheme
- Monin-Obukhov surface layer
- YSU PBL
- Noah land-surface
- RRTMG lw and sw.



3-50 km mesh, Δx contours 4, 8, 12, 20, 30 40 km
approximately 6.85 million cells
68% have < 4 km spacing
(158 pentagons, 146 septagons)

MPAS
Model for Prediction Across Scales

Grell-Freitas Convection Scheme in MPAS

Scale-aware/Aerosol-aware (Grell and Freitas, 2014, ACP)

- Stochastic approach from Grell and Devenyi, 2002.

- Scale aware by adapting the Arakawa et al approach (2011).
    - Arakawa et al (2011): developed a relation between vertical convective eddy transport and convective updraft/downdraft fraction σ:

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

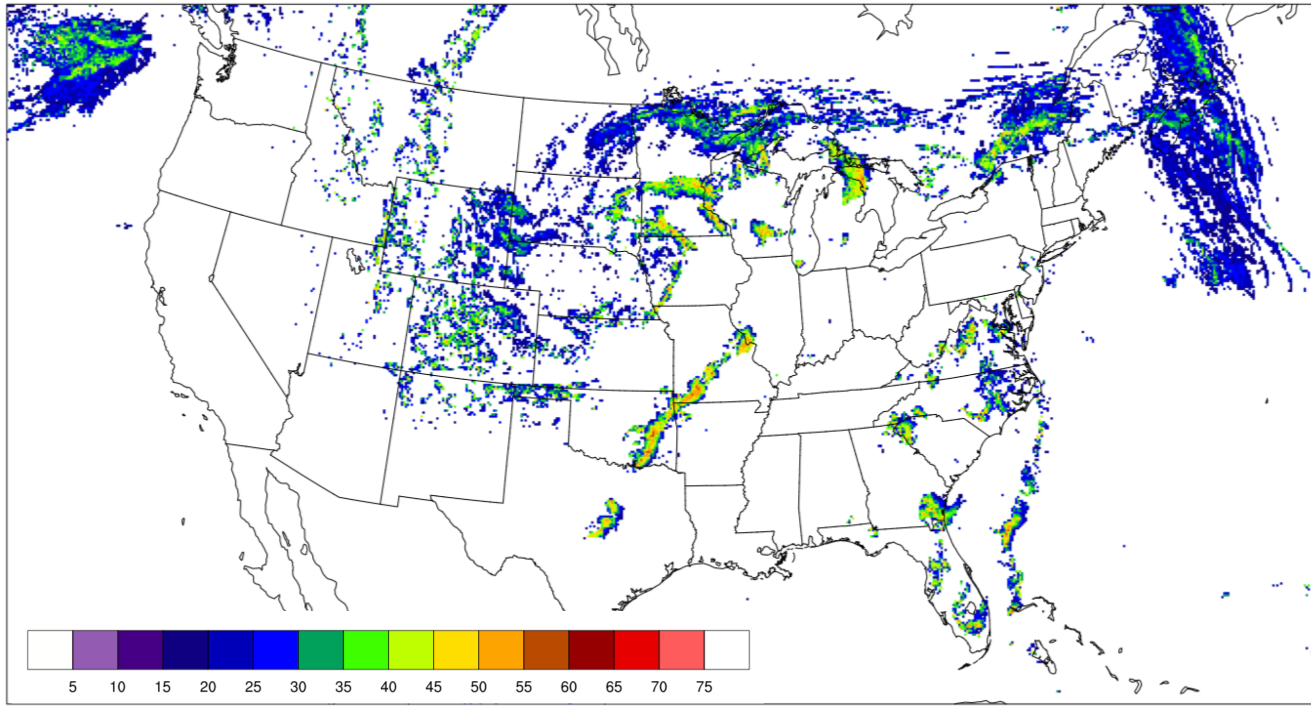
    - GF: σ is the area covered by active updraft and downdraft plume.
    - GF closure uses a simple relationship between σ and the entrainment rate (related to radius of plume).

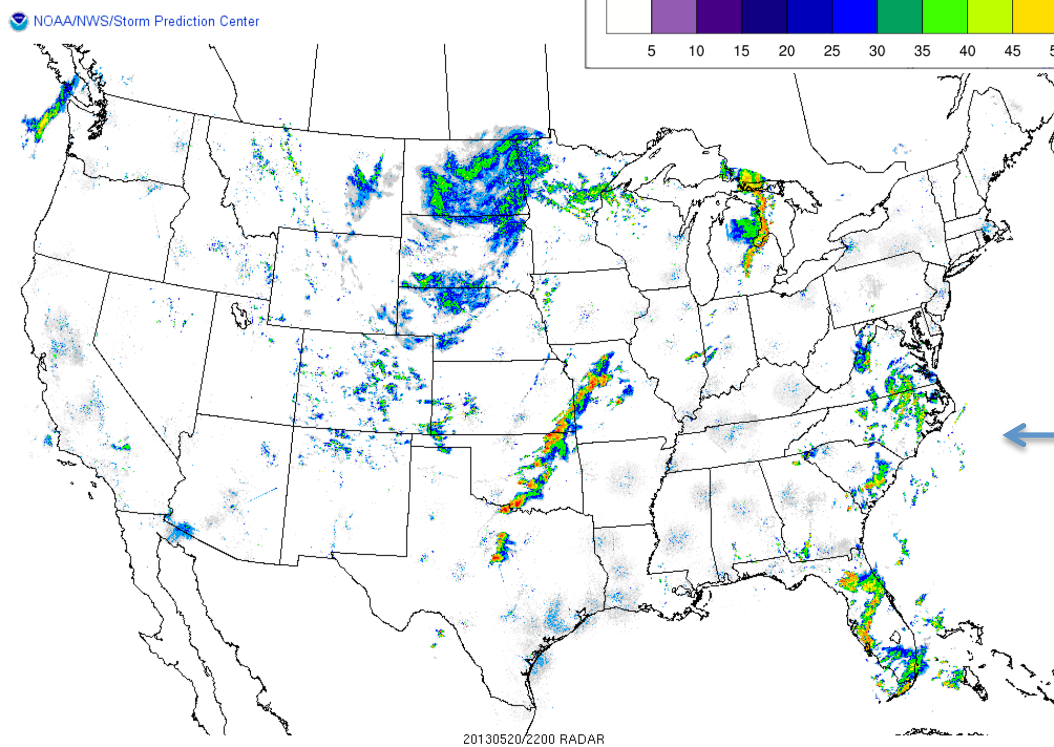
- Transitions to precipitating shallow scheme as grid spacing decreases.
    - At very high resolution (dx < 3km) parameterized convection becomes much shallower – cloud tops near 800 mb (down from 200-300 mb).
    - Temperature & moisture tendencies decrease as resolution increases.

MPAS
Model for Prediction Across Scales

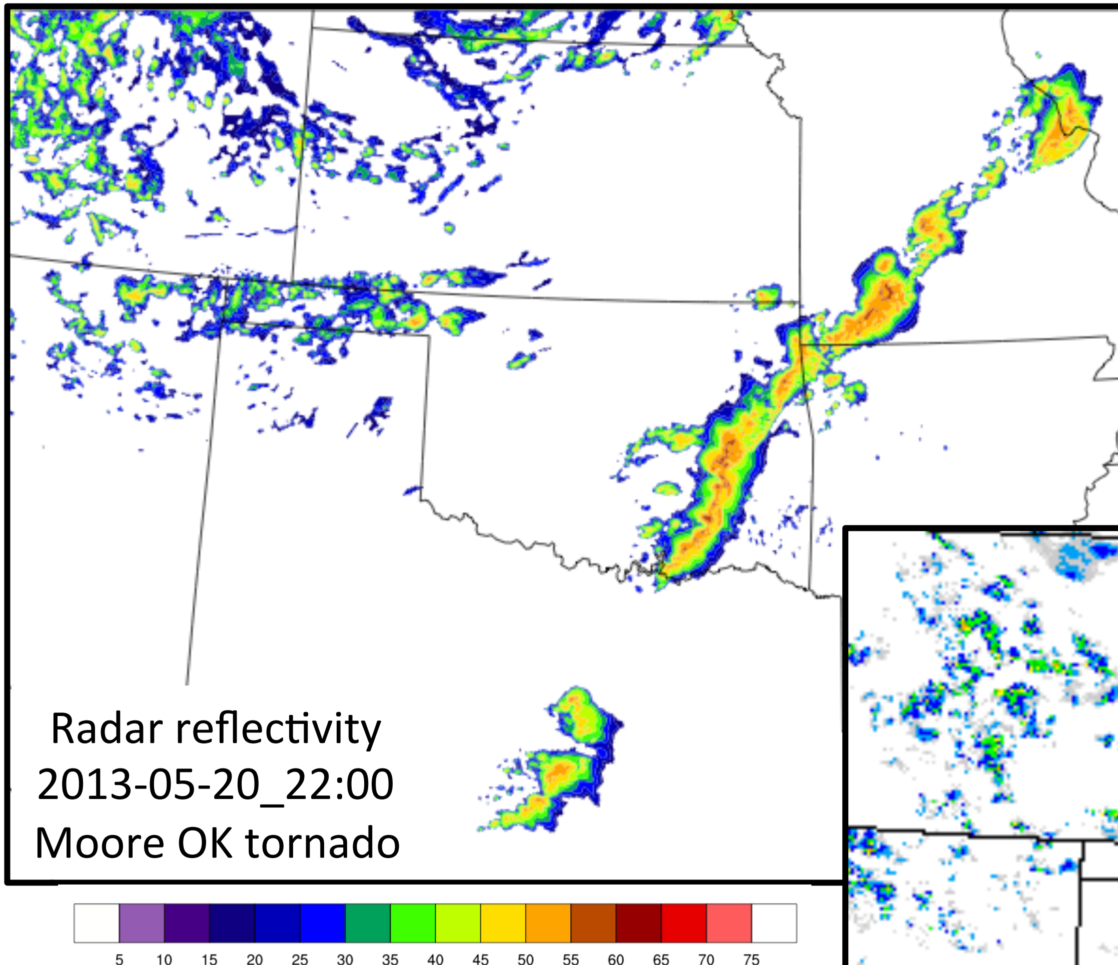
Radar reflectivity
2013-05-20_22:00
Moore OK tornado

2-day 22 h forecast



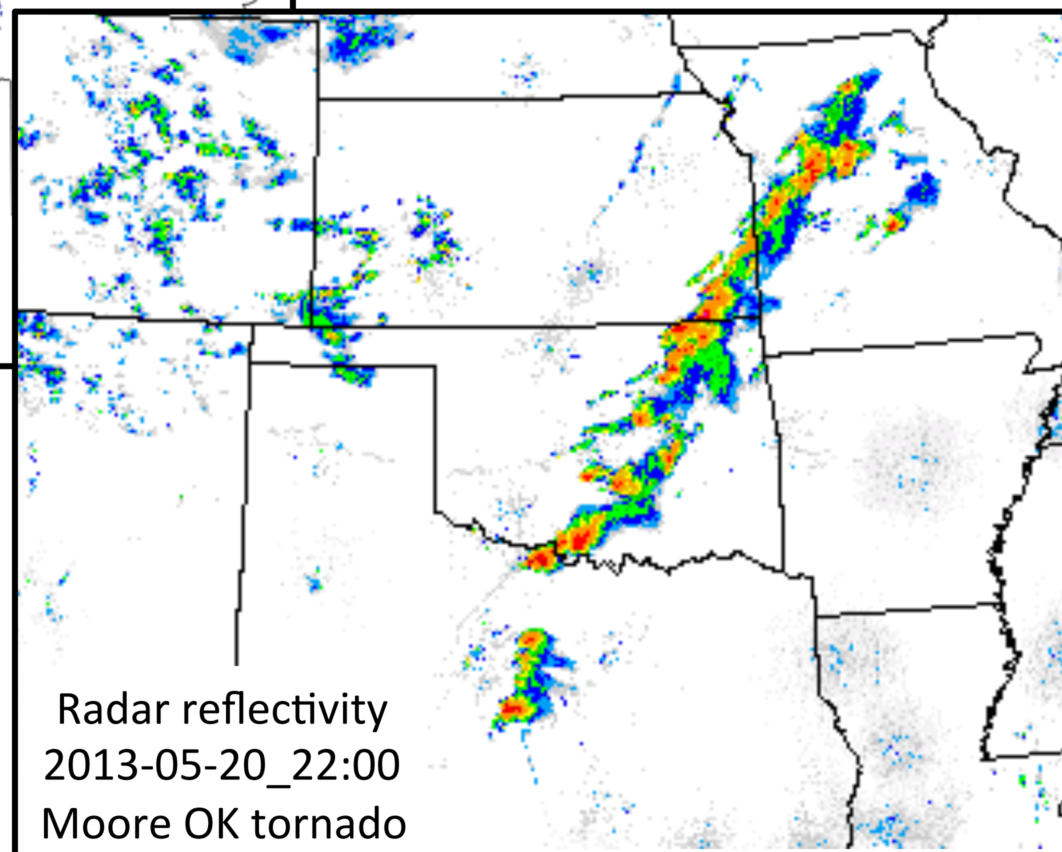


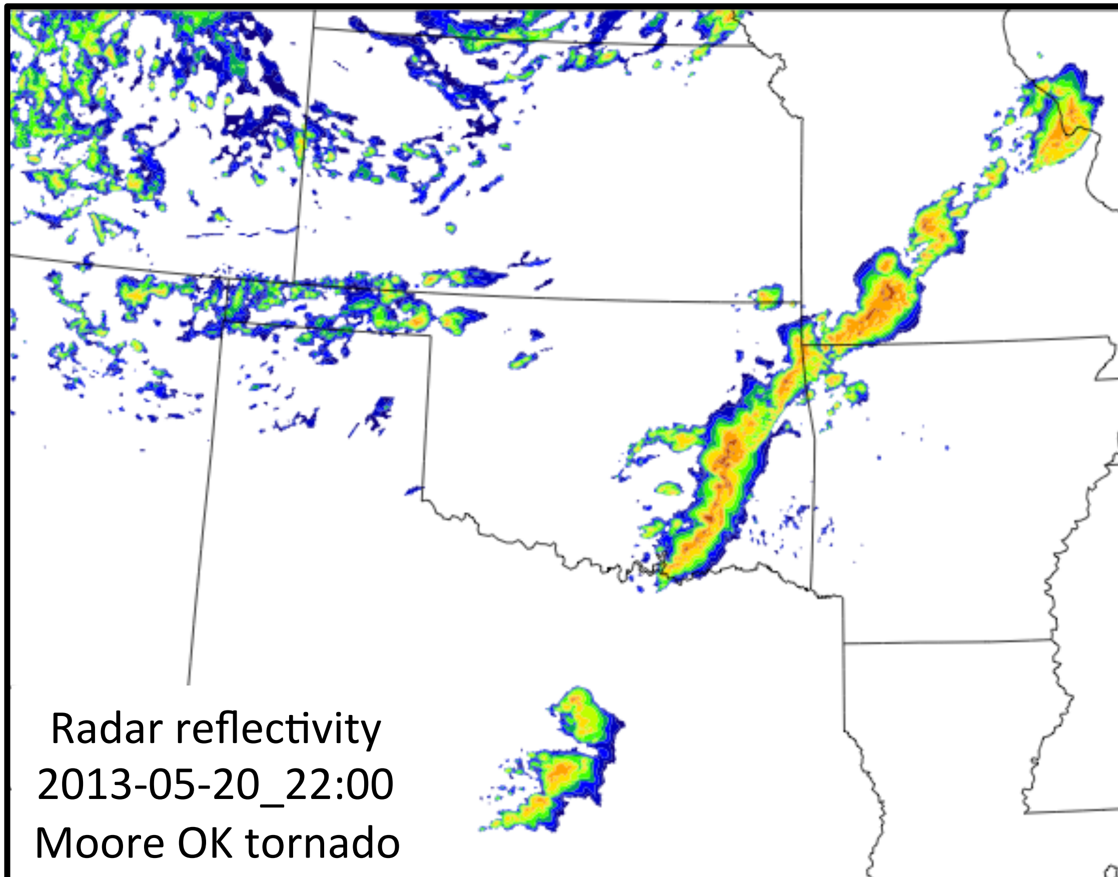
Radar reflectivity composite from NOAA/NWS/SPC



MPAS 50-3 km mesh
GF convective scheme

NOAA/NWS composite





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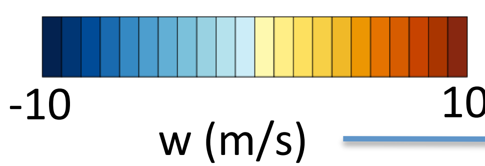
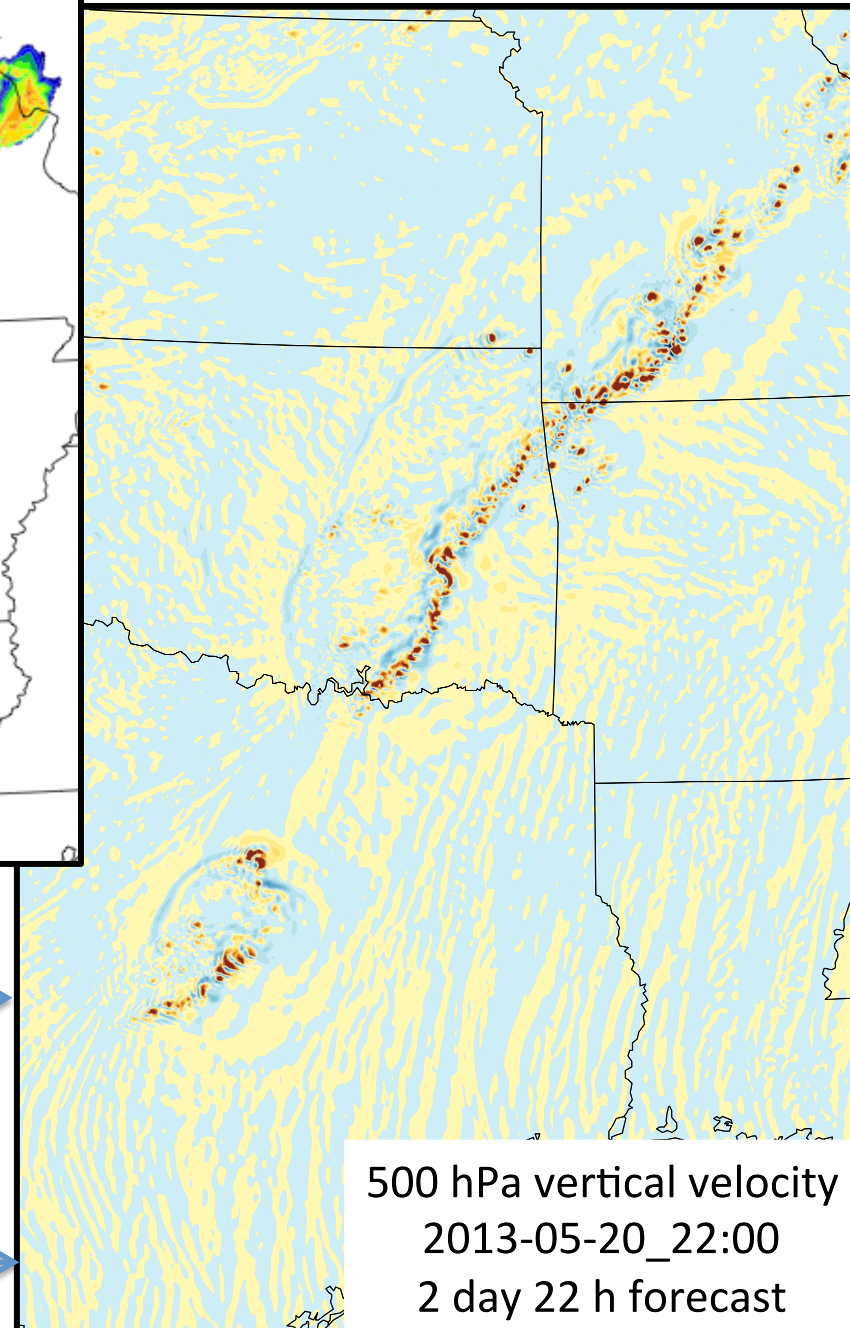
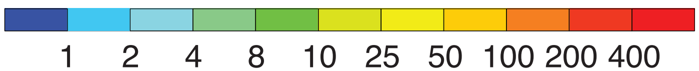
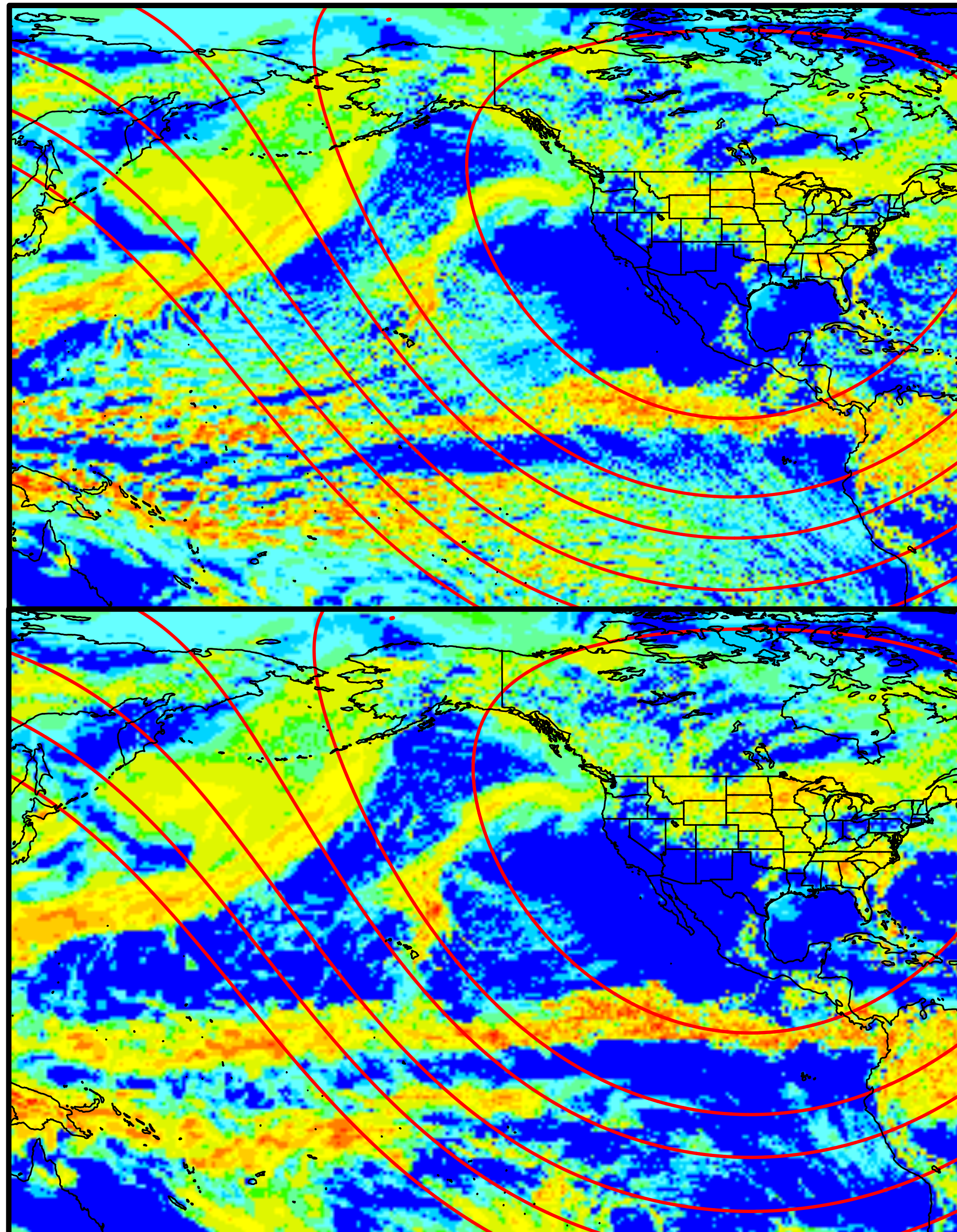




MPAS 50-3 km mesh,
No deep convection scheme
3 day 12h forecast valid at
2013-05-21_12:00



Accumulated precipitation (mm)

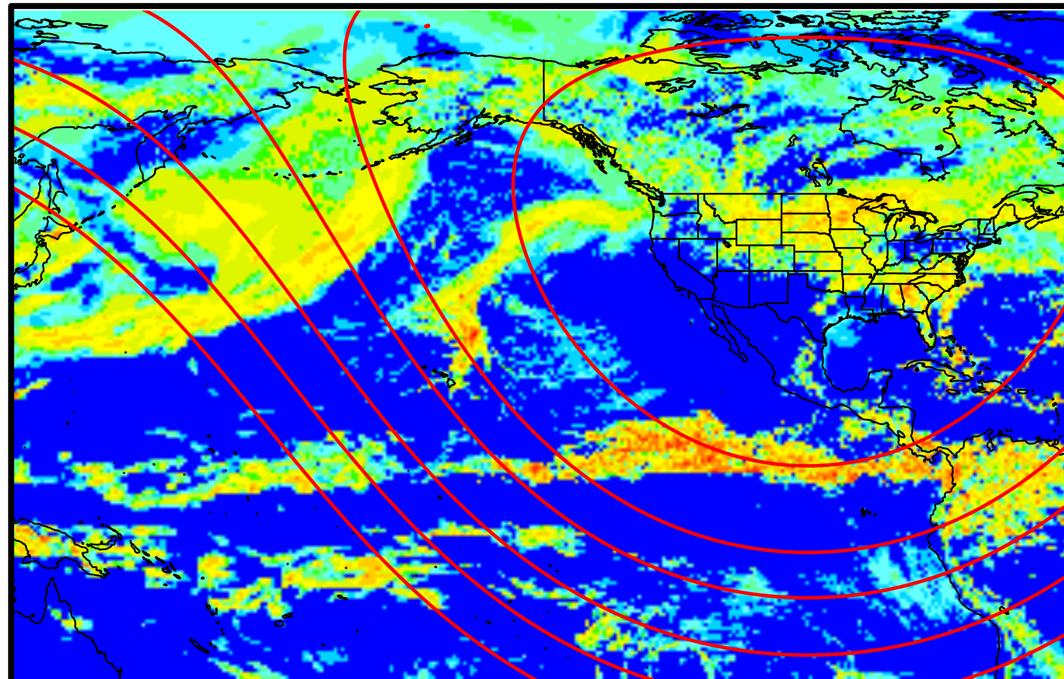


MPAS 50-3 km mesh,
Grell-Freitas convection scheme
3 day 12h forecast valid at
2013-05-21_12:00

Mesh spacing
(4, 8, 12, 20, 30 40 km)

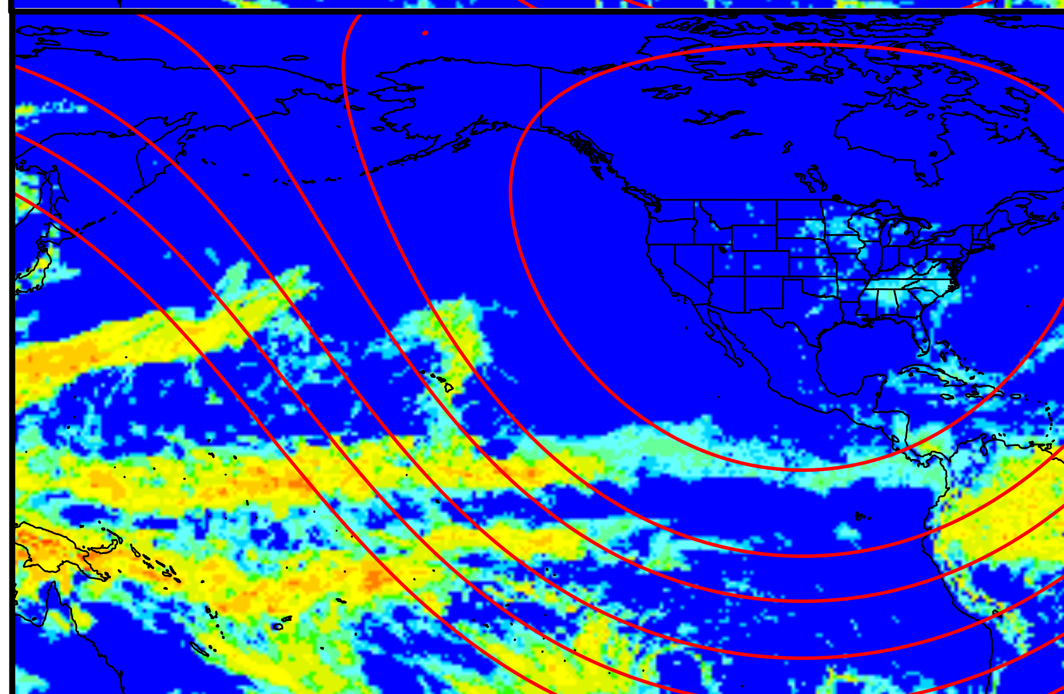
MPAS 50-3 km mesh,
Grell-Freitas convection scheme
3 day 12h forecast valid at
2013-05-21_12:00
Explicit precipitation

1 2 4 8 10 25 50 100 200 400
Accumulated precipitation (mm)



MPAS 50-3 km mesh,
Grell-Freitas convection scheme
3 day 12h forecast valid at
2013-05-21_12:00
Convective precipitation

Mesh spacing
(4, 8, 12, 20, 30 40 km)



MPAS
Model for Prediction Across Scales

Variable Resolution Tests with the Grell-Freitas Convection Scheme

3-50 km mesh, Δx contours 4, 8, 12, 20, 30 40 km
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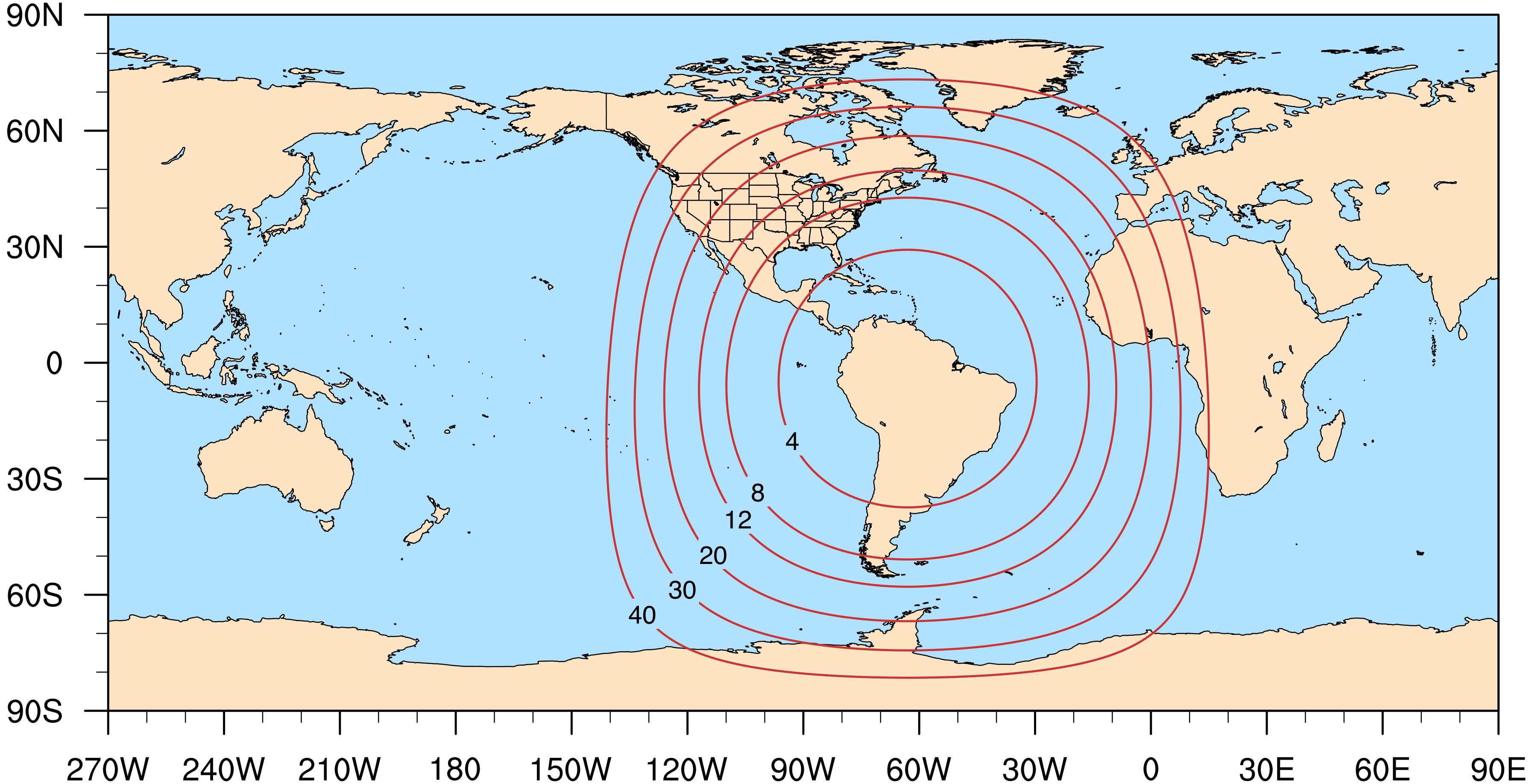
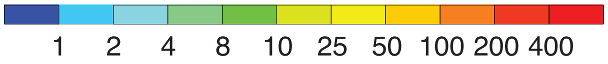
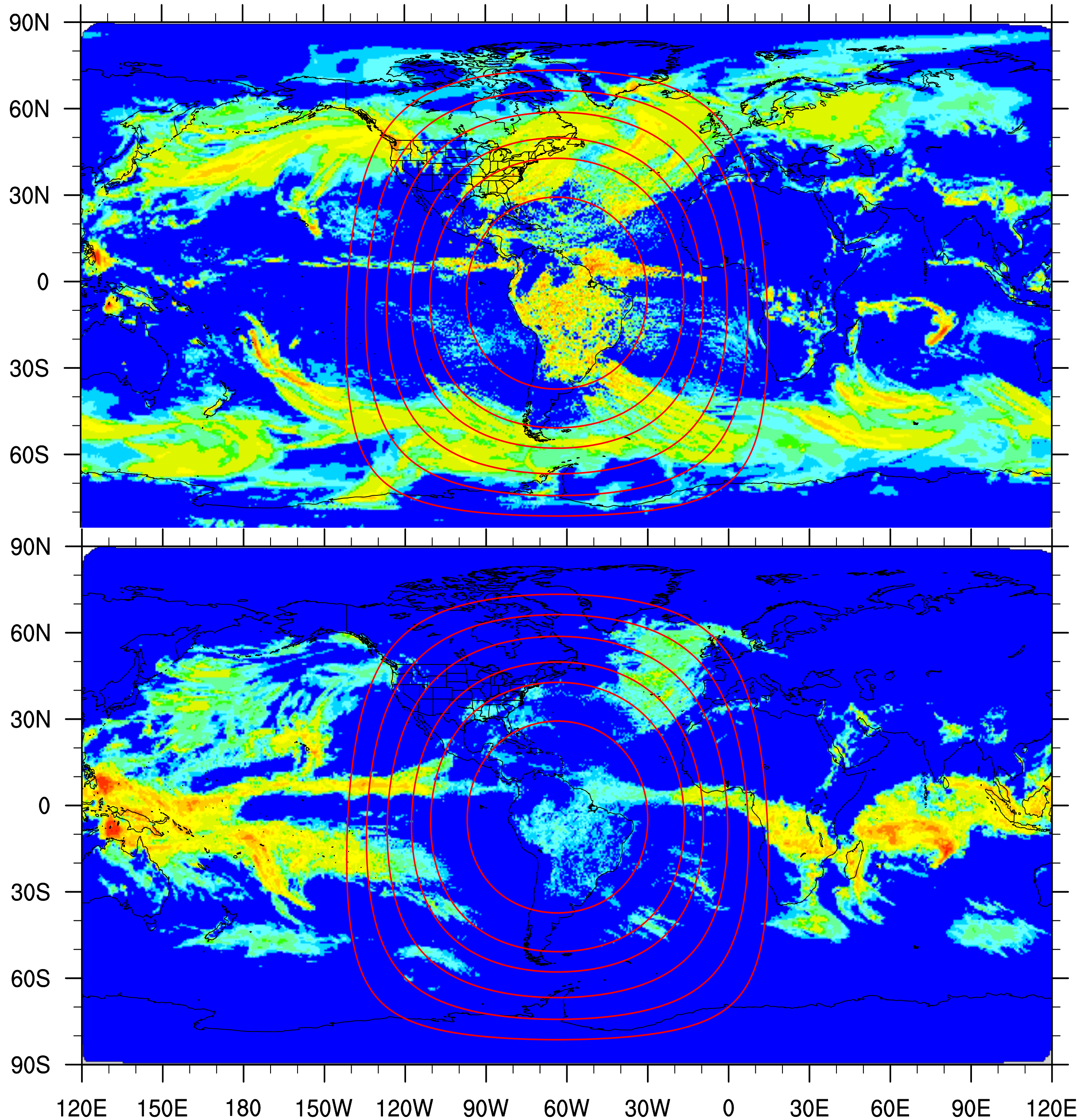
MPAS 50-3 km mesh,
Grell-Freitas convection scheme
10-13 January 2014 forecasts



MPAS 50-3 km mesh,
Grell-Freitas convection scheme
3 day forecast valid at
2014-01-13_00:00
Explicit precipitation



Accumulated precipitation (mm)

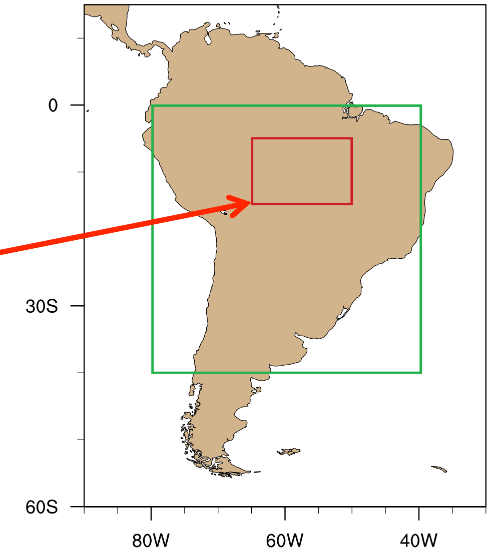


MPAS 50-3 km mesh,
Grell-Freitas convection scheme
3 day forecast valid at
2014-01-13_00:00
Convective precipitation

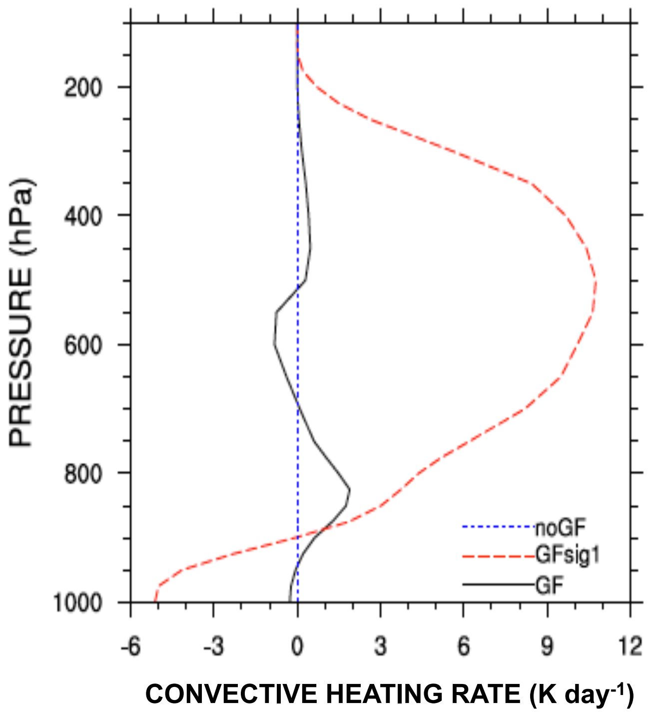
Mesh spacing
(4, 8, 12, 20, 30 40 km)

Variable Resolution Tests with the Grell-Freitas Convection Scheme

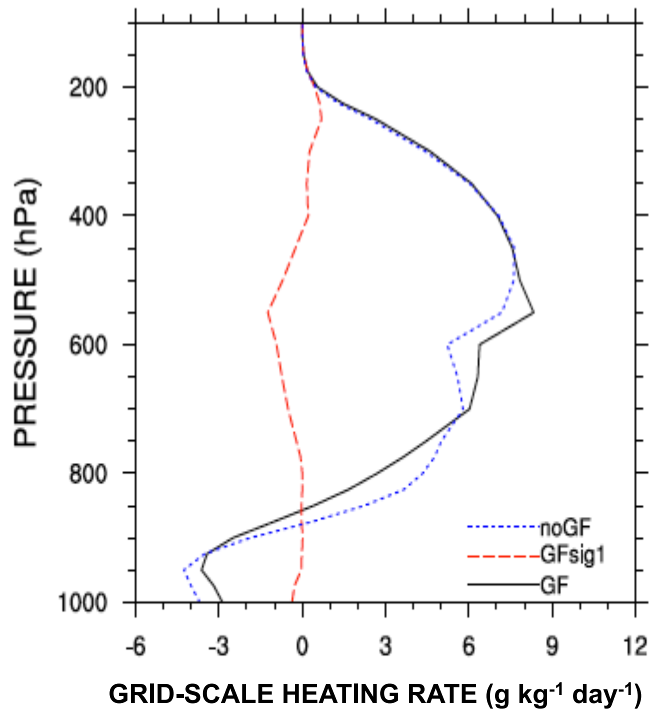
MPAS 50-3 km mesh, Grell-Freitas convection scheme
10-13 January 2014 forecasts, 3-day average heating rates



no parameterization
GF, no scale-awareness
scale-aware GF

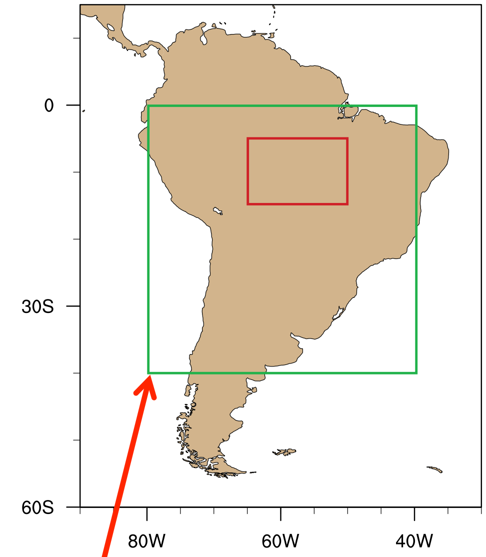


(from the GF scheme)

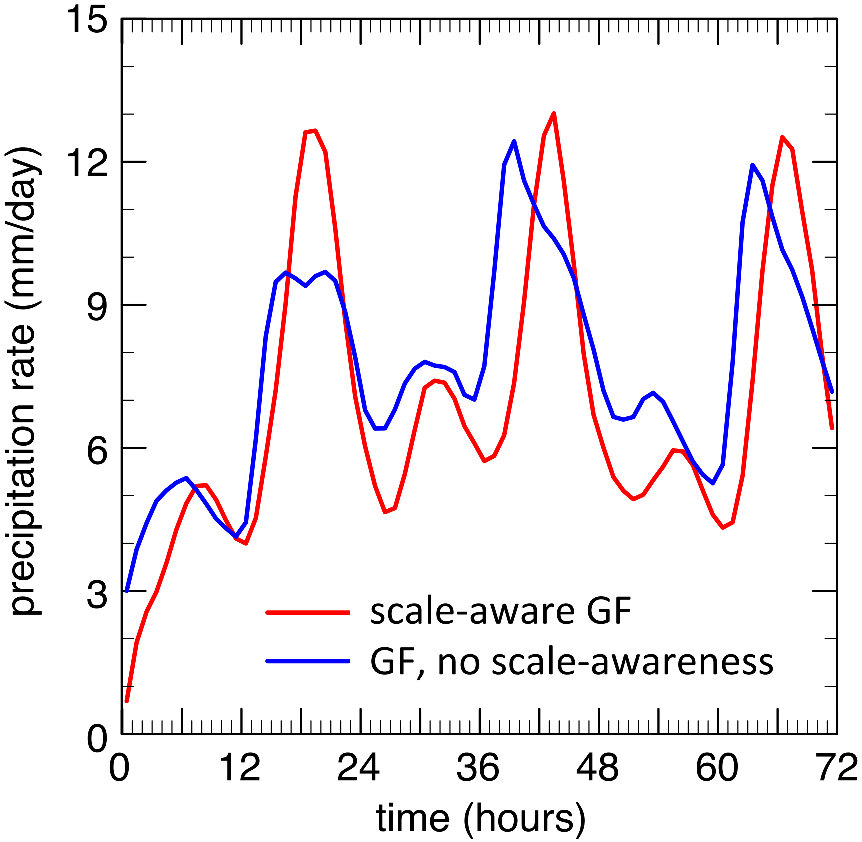


(explicit, from the microphysics)

Variable Resolution Tests
with the Grell-Freitas Convection Scheme

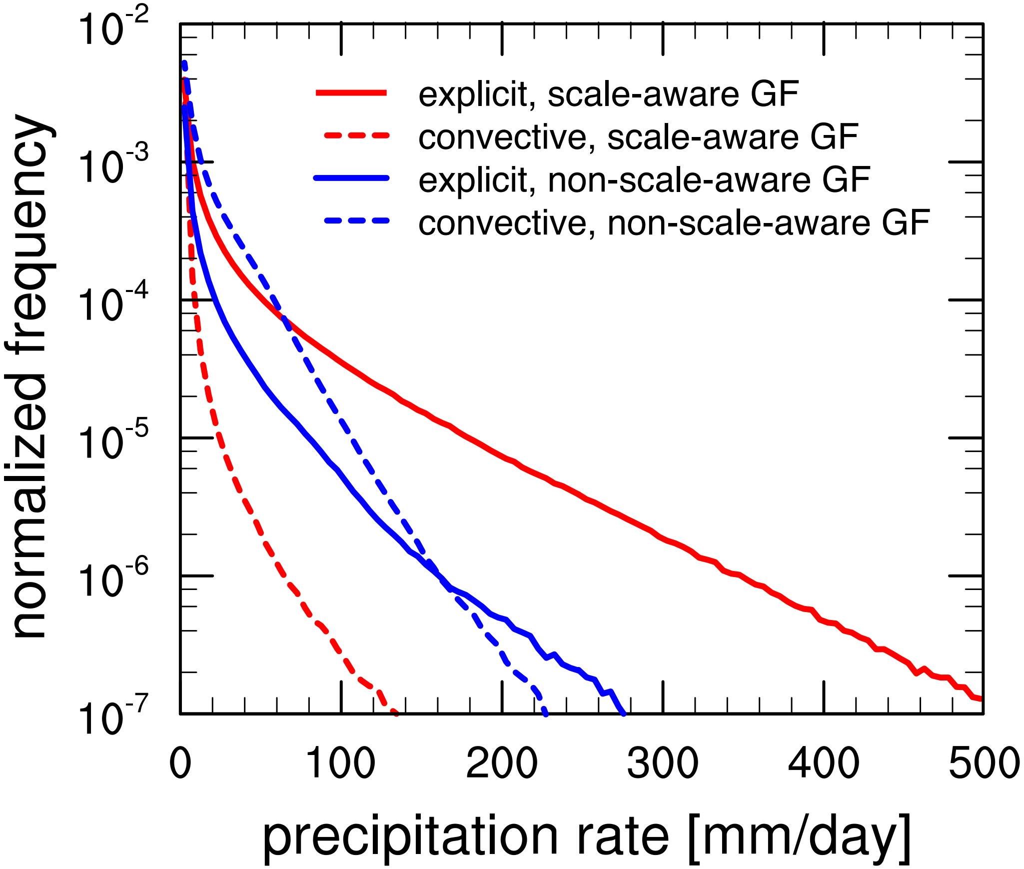


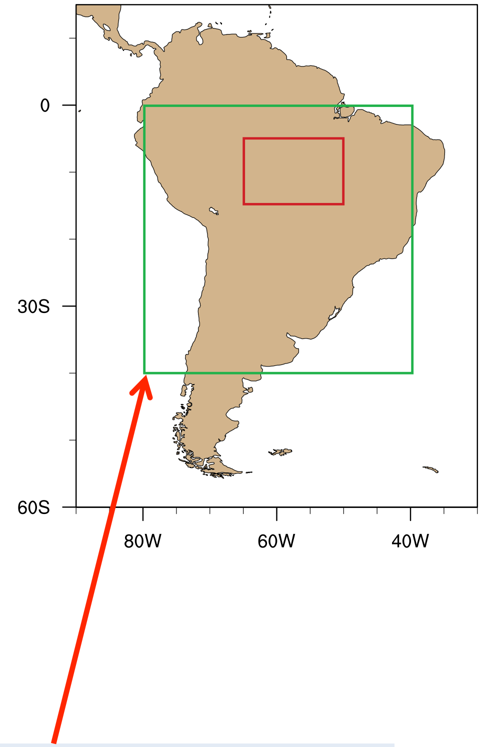
0 UTC 10 January 2014 - 0 UTC 13 January 2014
270 - 310 E, -40 - 0 N (South America)



MPAS 50-3 km mesh,
Grell-Freitas convection scheme
10-13 January 2014 forecasts
Precipitation rates

Variable Resolution Tests with the Grell-Freitas Convection Scheme





MPAS 50-3 km mesh,
Grell-Freitas convection scheme
10-13 January 2014 forecasts
Precipitation frequency

Where are we going?

Variable-resolution, nonhydrostatic-scale atmospheric simulations are viable

Full-physics simulation rates >100 days/day are attainable on candidate meshes

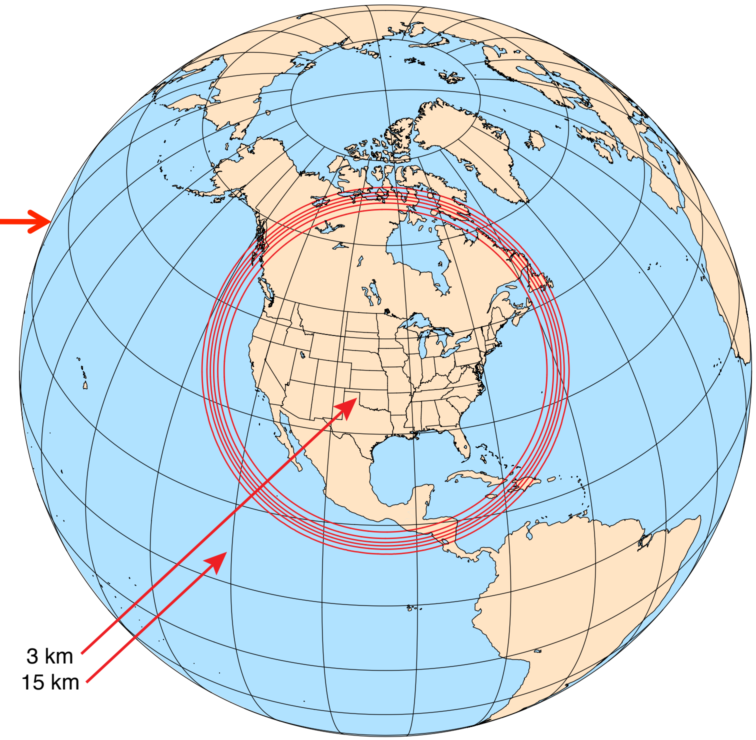
Regional climate and NWP applications testing is underway

Challenges

Scale-aware physics:

- *Convection*
- Microphysics
- Boundary layer

Data assimilation on variable meshes



3-15 km mesh, Δx contours 4 - 14 by 2 km.
approximately 5.9 million cells
60% in the 3 km region; 40% in the 15 km region

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