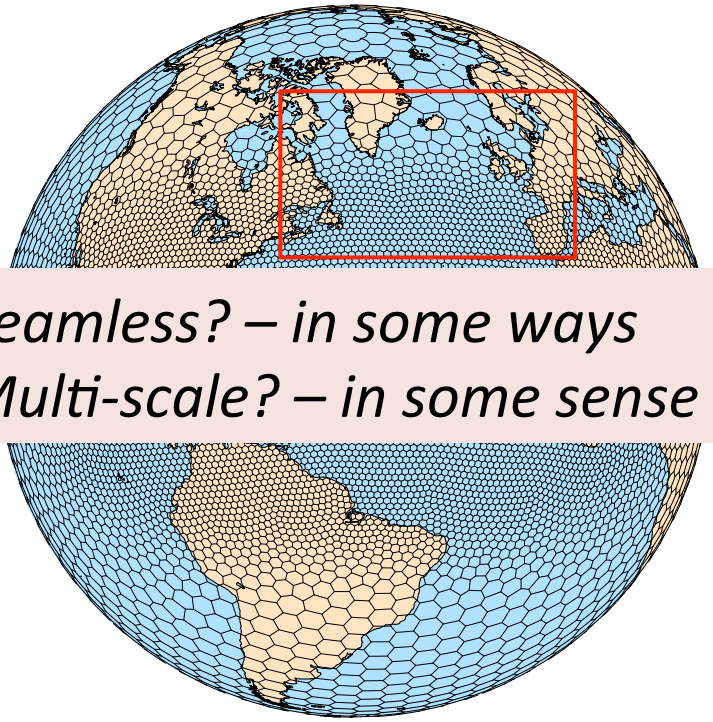
Extended-Range Severe Weather Guidance Using a Global Convection-Permitting Model

Bill Skamarock
NCAR/MMM

Special Symposium on Seamless Weather and Climate Prediction—Expectations and Limits of Multi-scale Predictability

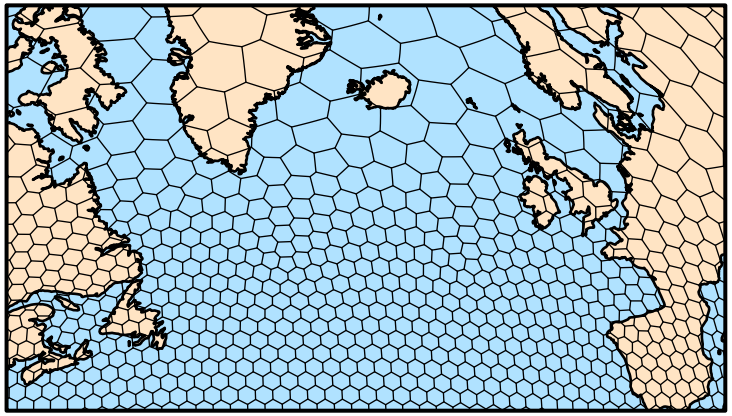
Extended-Range Severe Weather Guidance Using a Global Convection-Permitting Model



Seamless? – in some ways
Multi-scale? – in some sense

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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Seamless Weather and Climate Prediction — Expectations and Limits of Multi-scale Predictability

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Seamless … Prediction:
Where are the *seams* in our existing research and operational prediction systems, and what can be done about them?

Seamless Weather and Climate Prediction — Expectations and Limits of Multi-scale Predictability

Seamless … Prediction:
Where are the *seams* in our existing research and operational prediction systems, and what can be done about them?

Multi-scale:
What is multi-scale about the atmosphere, and how well do our prediction systems treat these multi-scale aspects?

Where are the seams in our NWP forecast systems?

Spatial and temporal seams in our forecast model configurations.

- Regional models and nested configurations.
- Coupling among earth-system components.

Seams in and between our sub-grid physics.

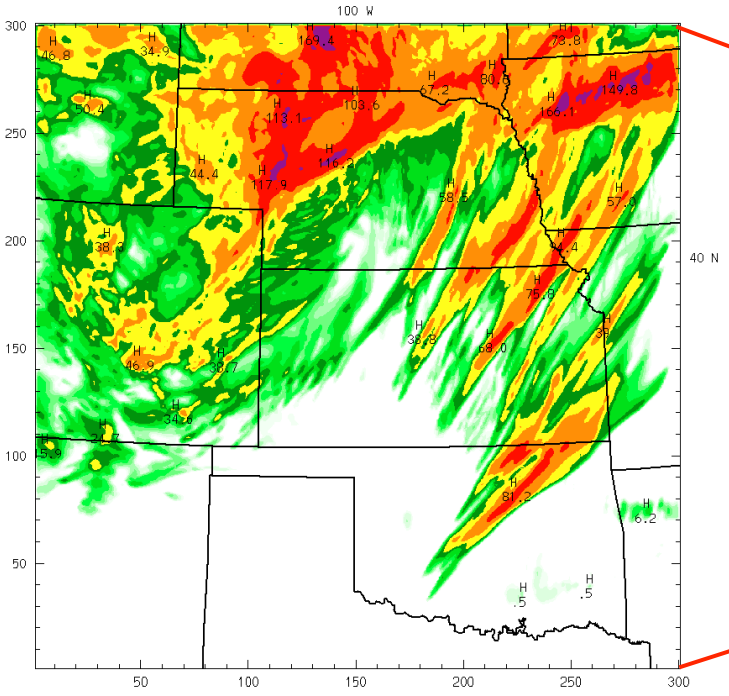
Seams between our sub-grid physics and resolved motions.

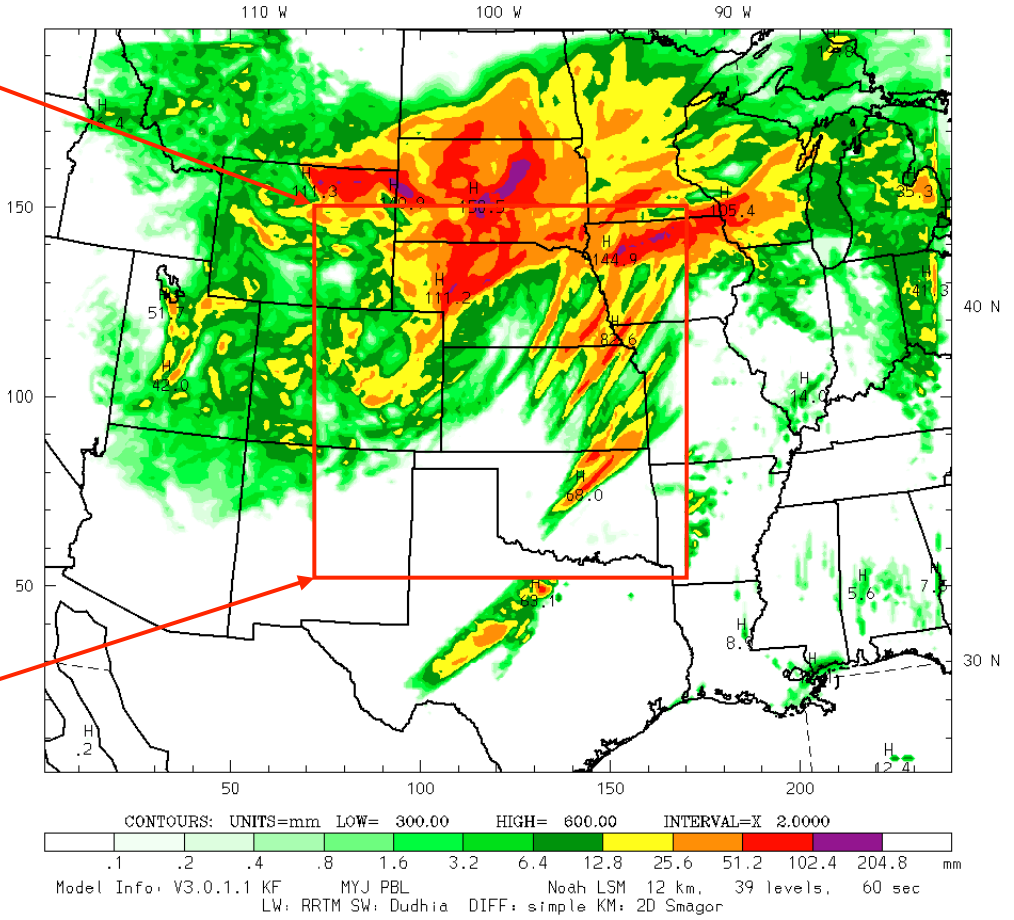
Problems with Grid Nesting Advanced-Research WRF (ARW)

Limited area models (two-way nests)

4 km nest

12 km parent





30 hr forecast
accumulated precipitation
valid 6 UTC 20080606

Problems with Grid Nesting Advanced-Research WRF (ARW)

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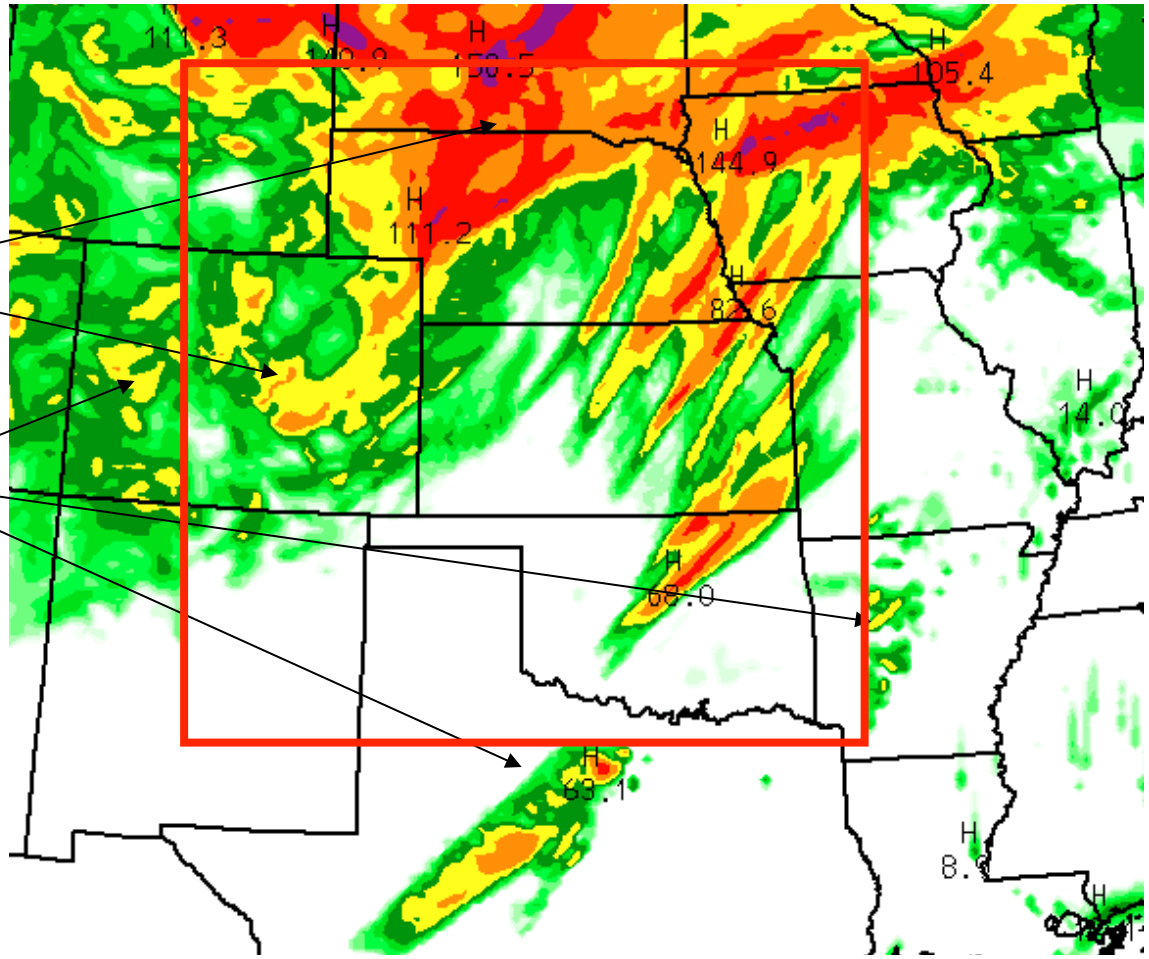
4 km nest, explicit precip

12 km parent, parameterized precip

The grid imprinting is obvious.



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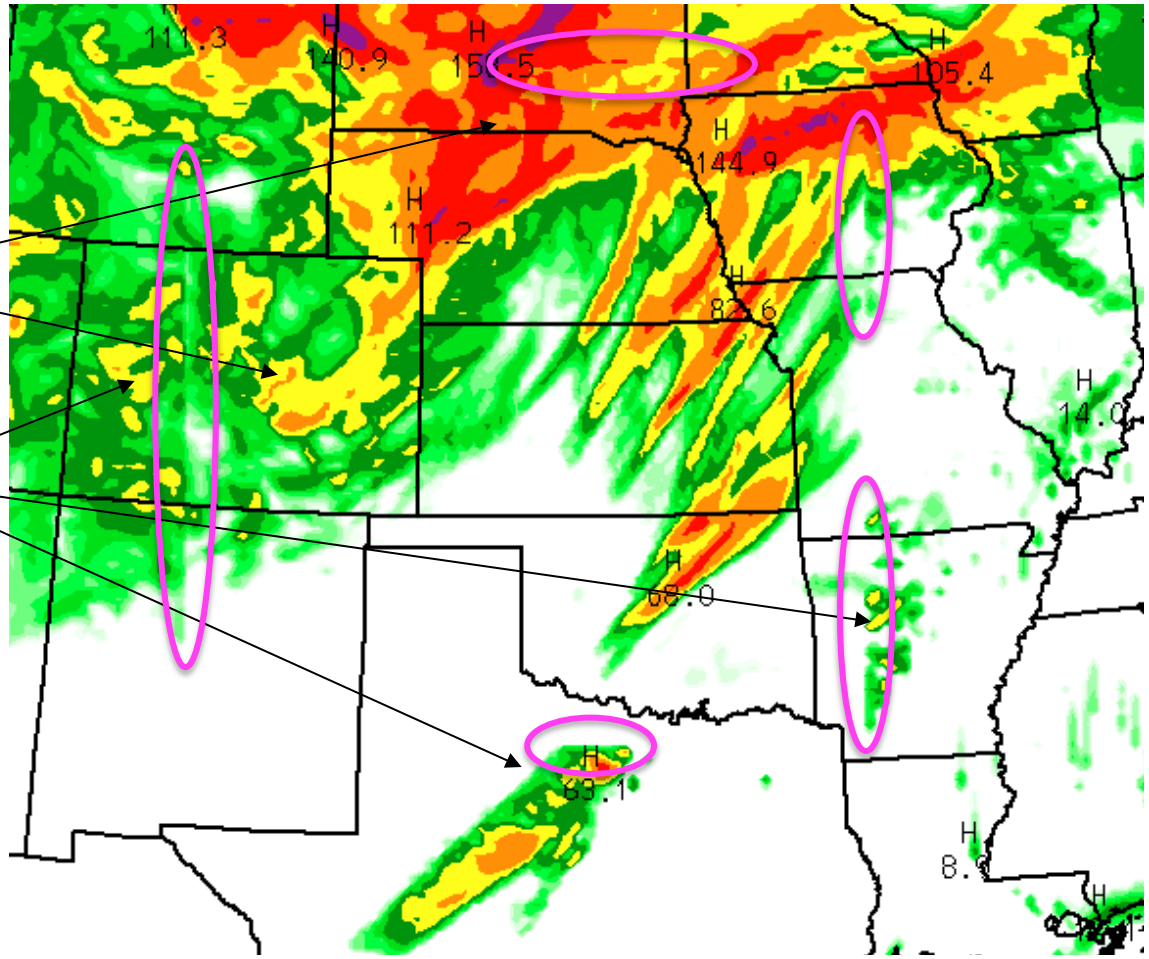

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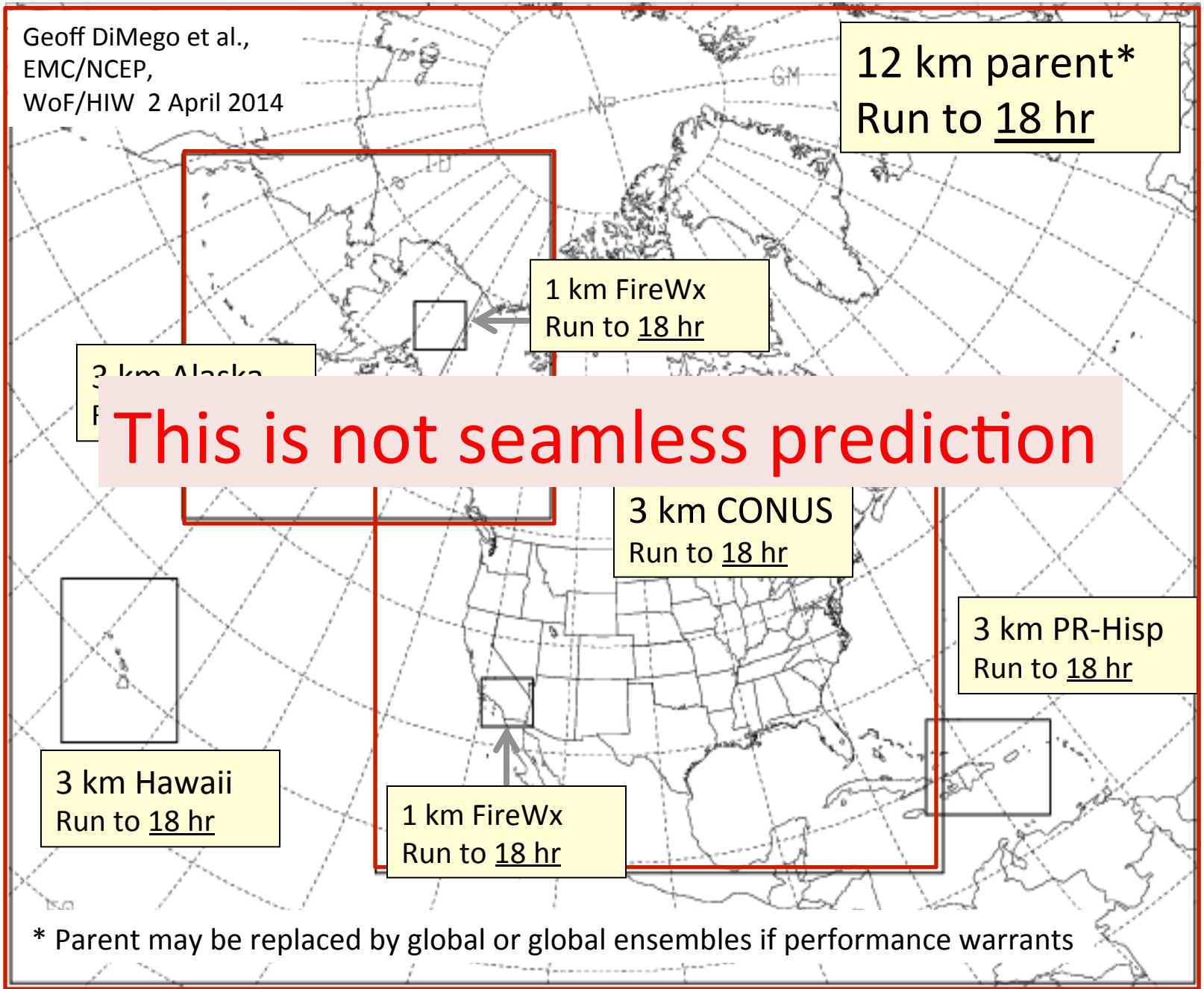
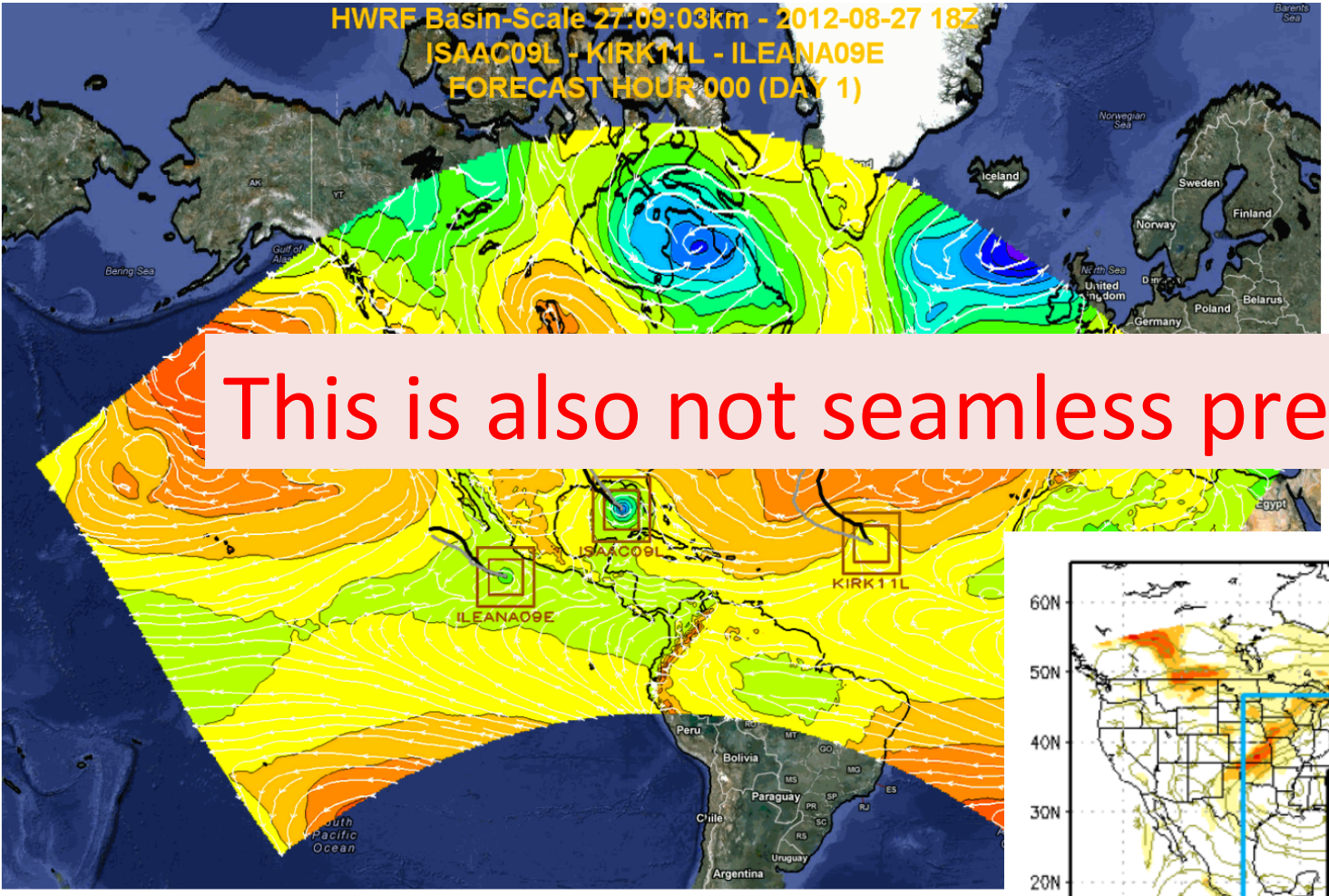
Every NMMB-based member of the hourly HRRRE will have this makeup

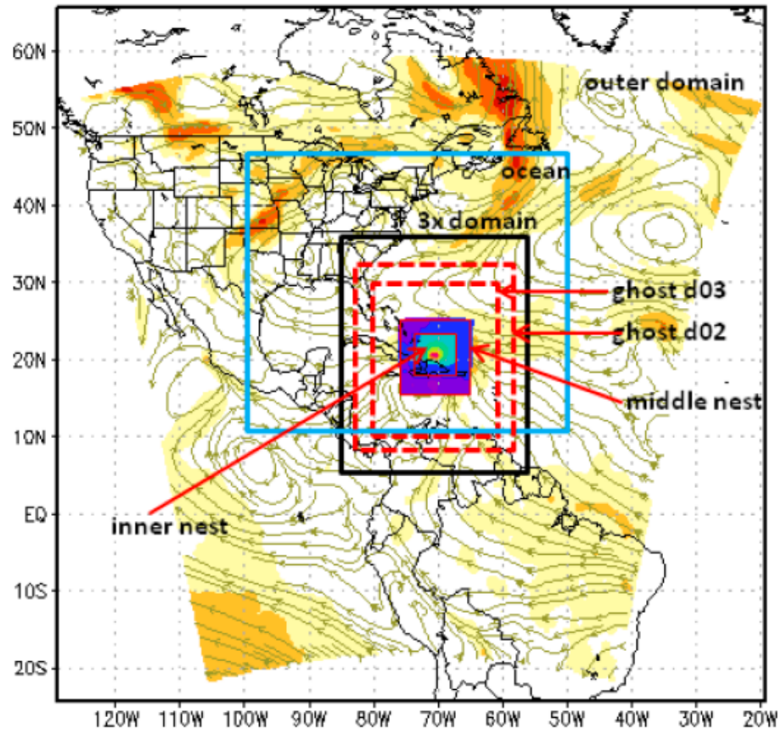
Every ARW-based member of the hourly HRRRE will have this makeup



* Parent may be replaced by global or global ensembles if performance warrants



This is also not seamless prediction



From 2014 HWRF tutorial
Taipei, Taiwan
Vijay Tallapragada & the HWRF Team

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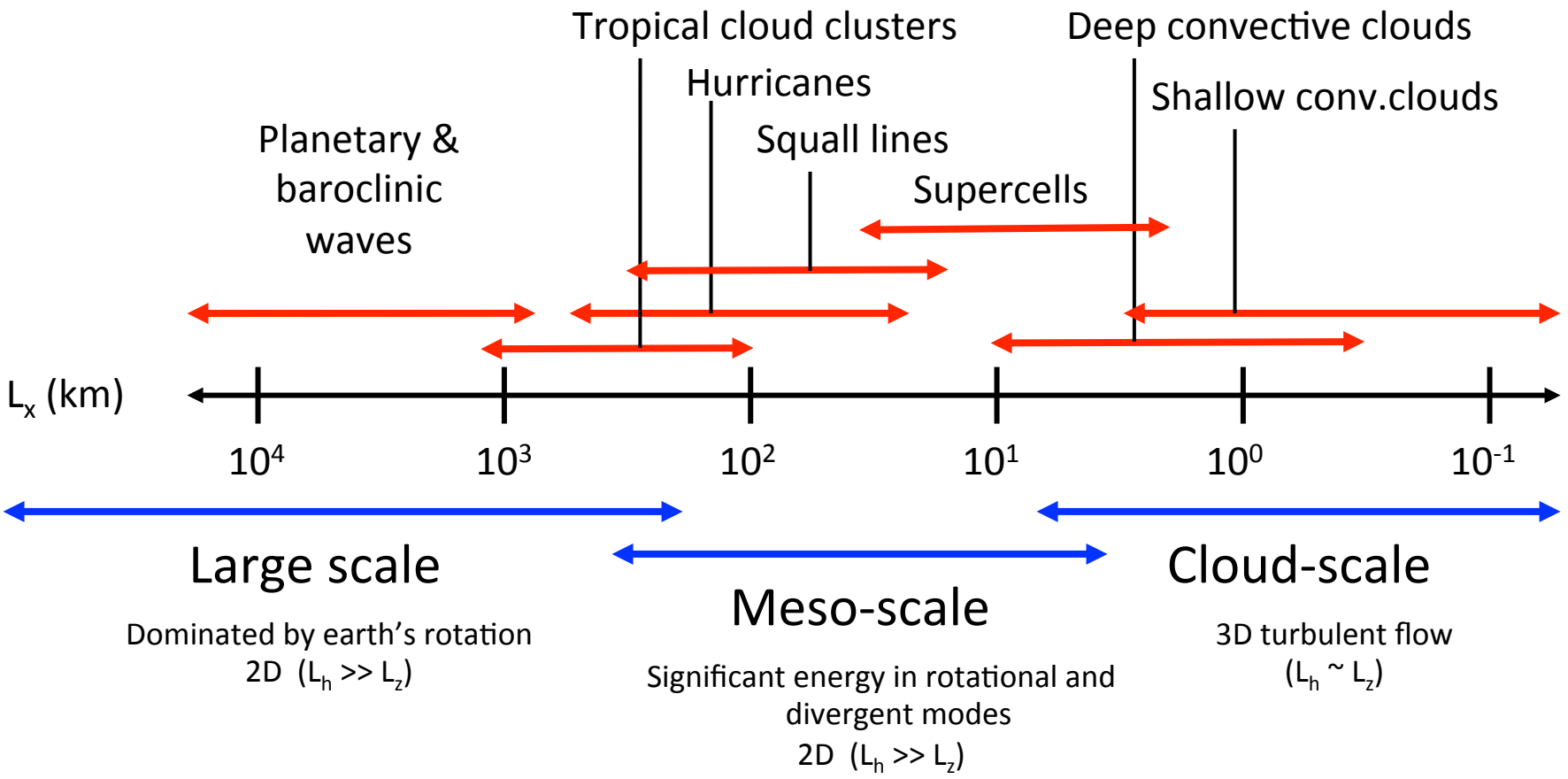

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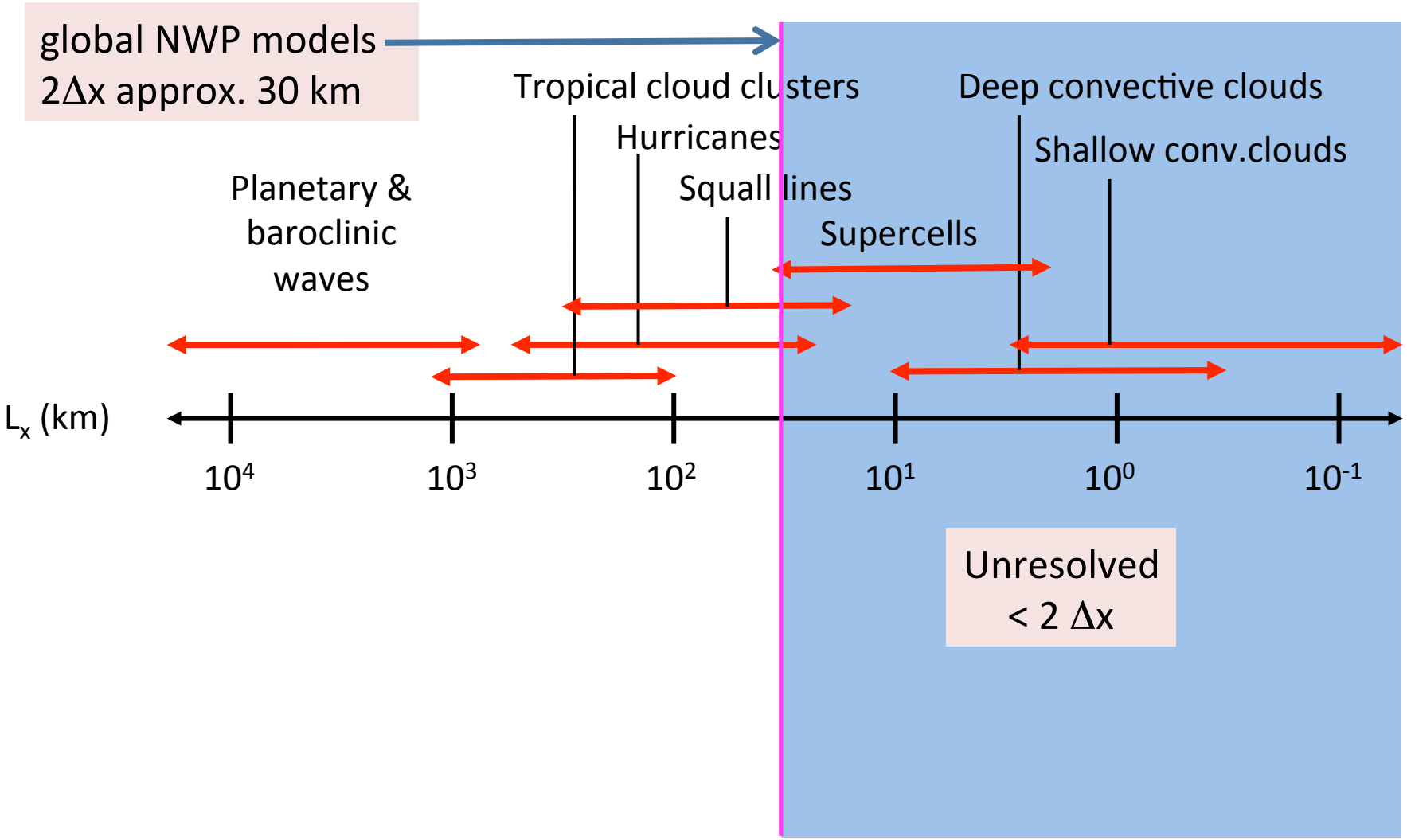

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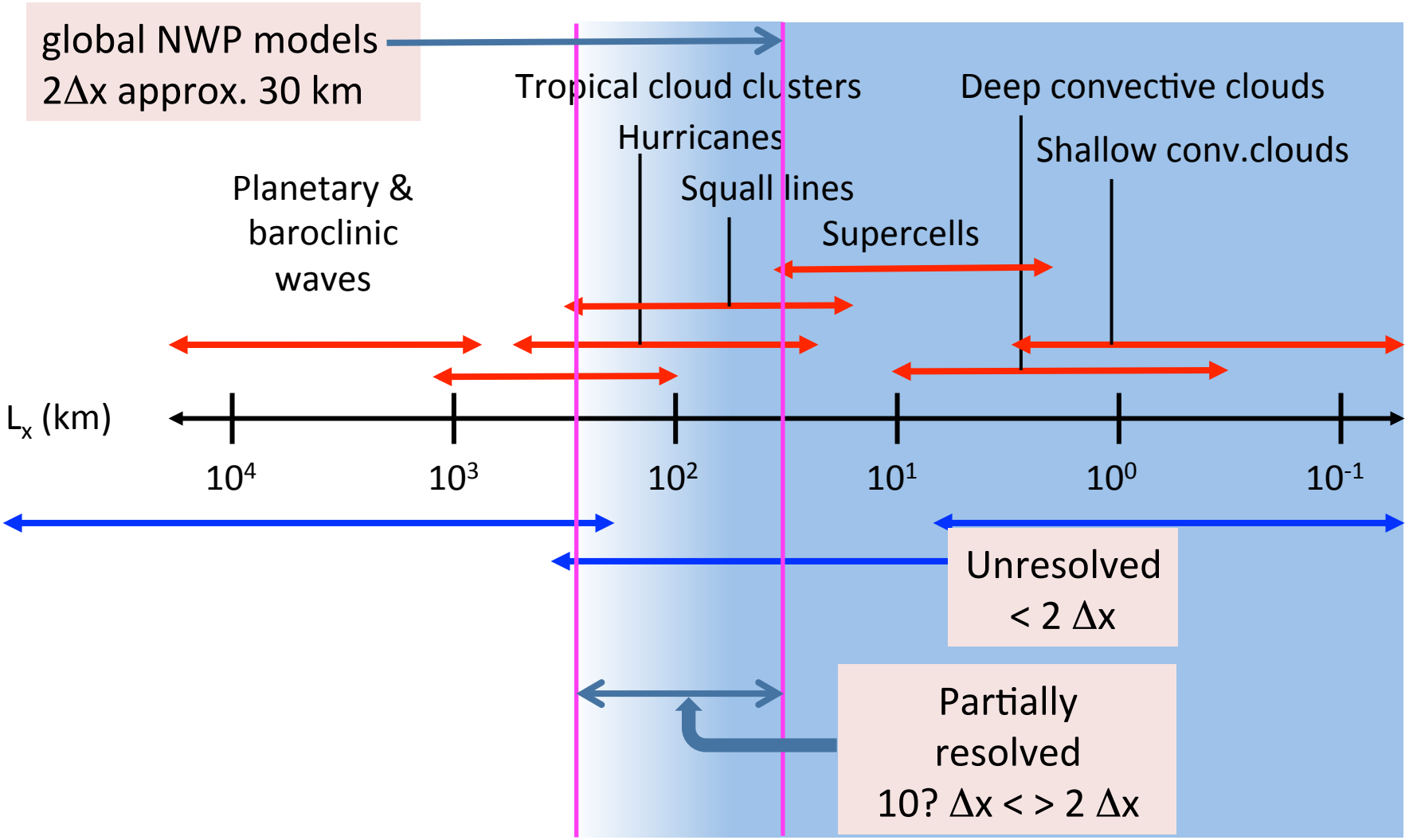

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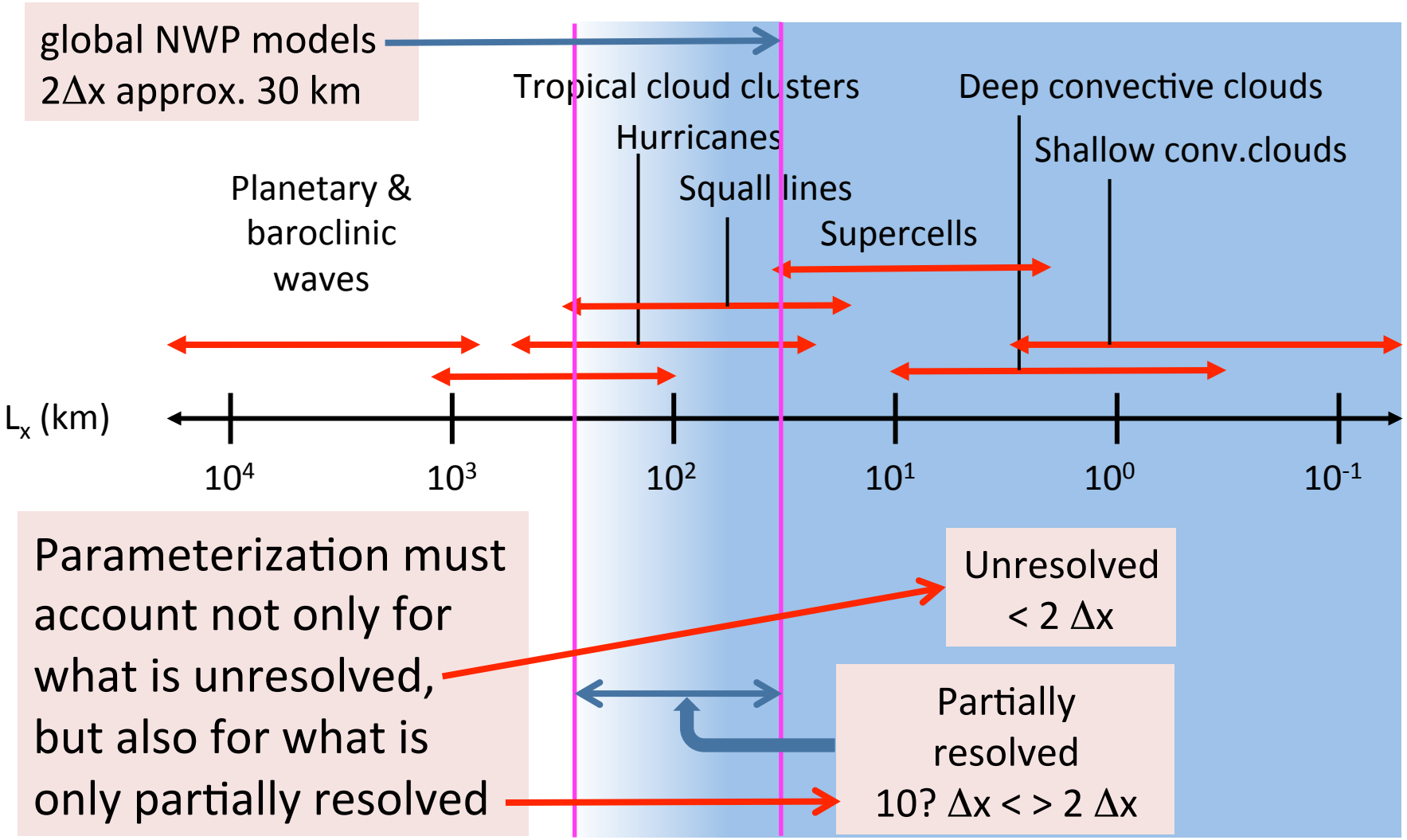
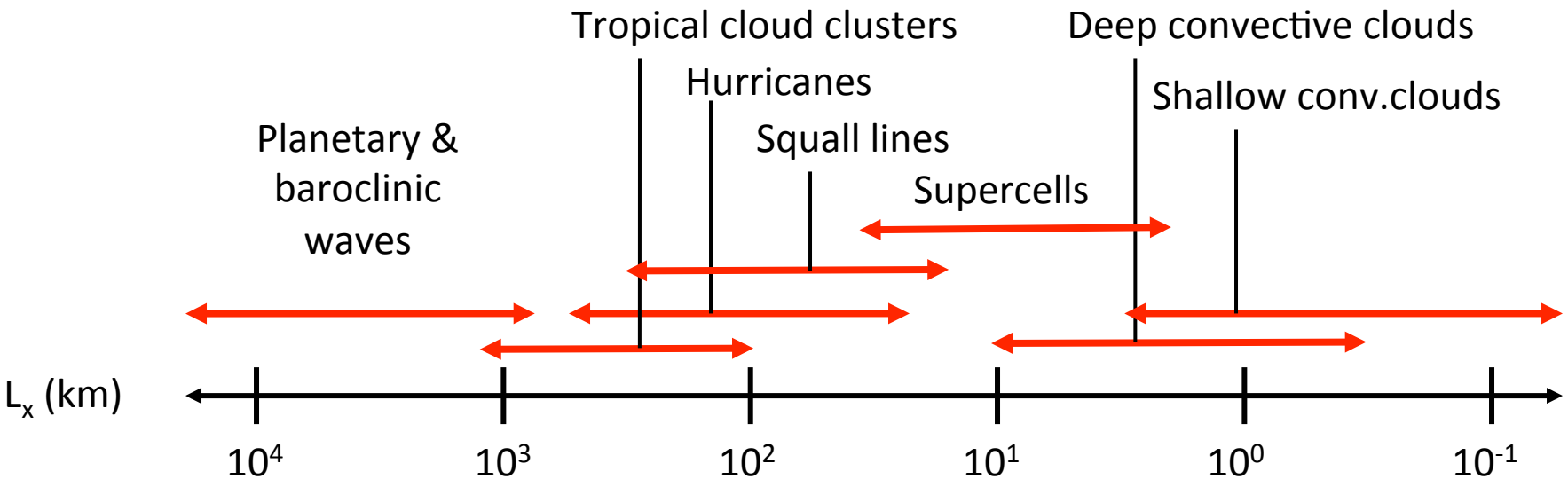


What is multi-scale about the atmosphere?



Important questions

How do phenomena on the different scales interact?

What is needed to simulate them for prediction purposes?

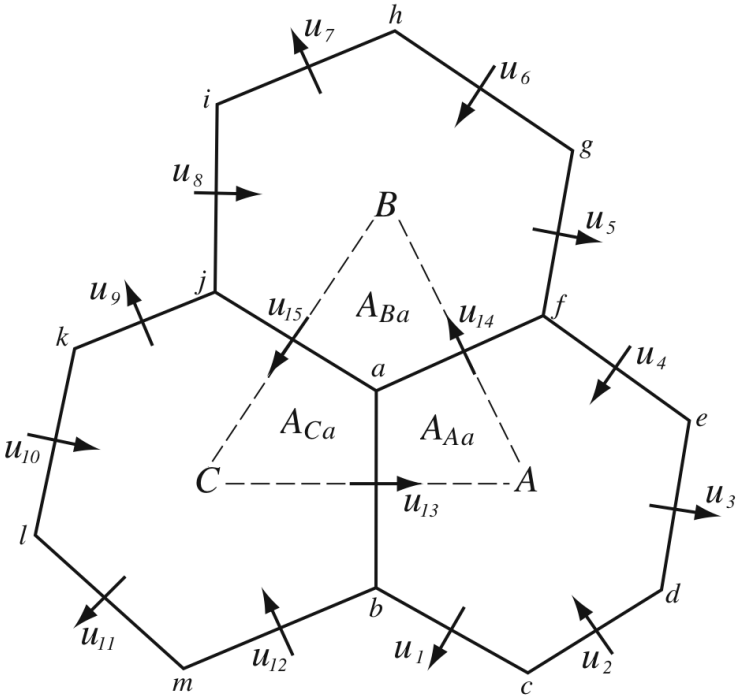
(Either parameterized or resolved)

MPAS
Model for Prediction Across Scales

Centroidal Voronoi Meshes and the Atmospheric Solver

Unstructured spherical centroidal Voronoi meshes

- 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.
- C-grid: Solve for normal velocities on cell edges.
- Horizontal discretization uses the *TRSK* scheme.



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.

MPAS
Model for Prediction Across Scales

Hazardous Weather Testbed Spring Experiment 2015

Forecasts Results from MPAS

Application Test

NOAA SPC/NSSL HWT

May 2015

Convective Forecast Experiment

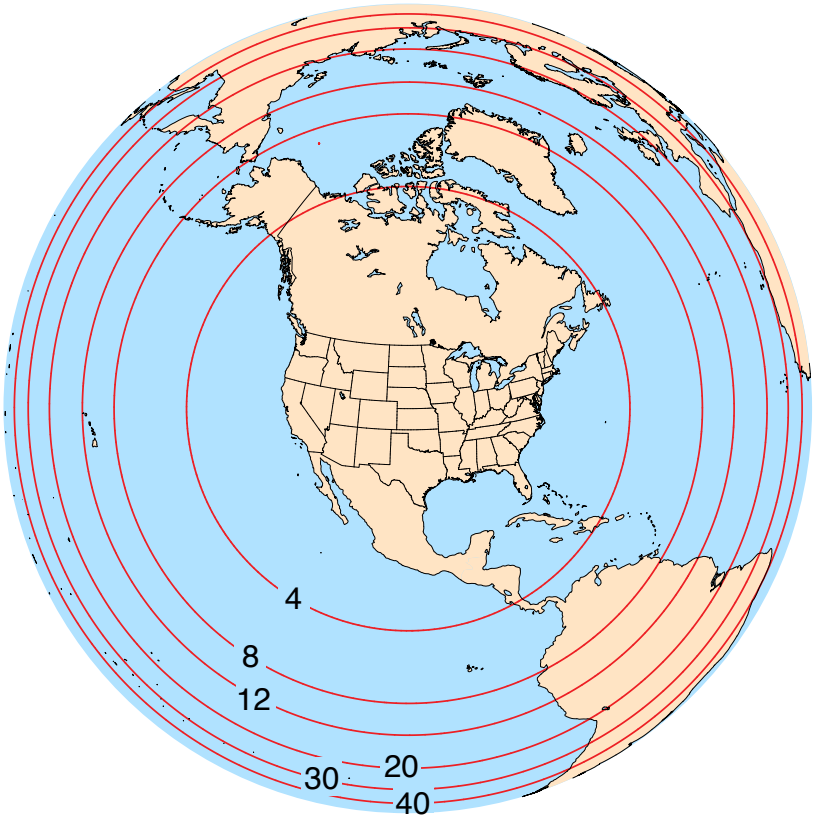
Daily 5-day MPAS forecasts

00 UTC GFS analysis initialization

Questions:

1. Are the solutions clean in the variable-resolution portion of the mesh?
2. How can we parameterize deep convection?
3. Does the Voronoi-mesh-based solver produce good convective realizations and forecasts in the convective permitting region of the mesh?

MPAS mesh mean cell spacing (km)



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)

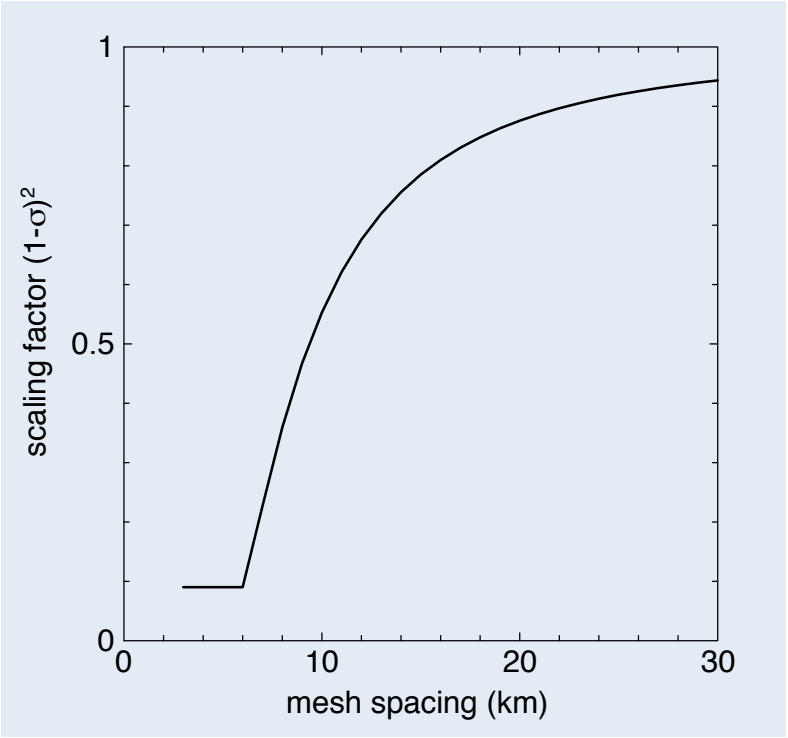
- Stochastic scheme (Grell and Devenyi, 2002).
- Scale aware by adapting the Arakawa et al approach (2011).
  - Relates vertical convective eddy transport to convective updraft/downdraft fraction σ:

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

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

$$\sigma = \frac{\pi R^2}{A_{grid\,cell}},\ R_{conv} \sim 3\,km,\ \sigma_{max} = 0.7$$

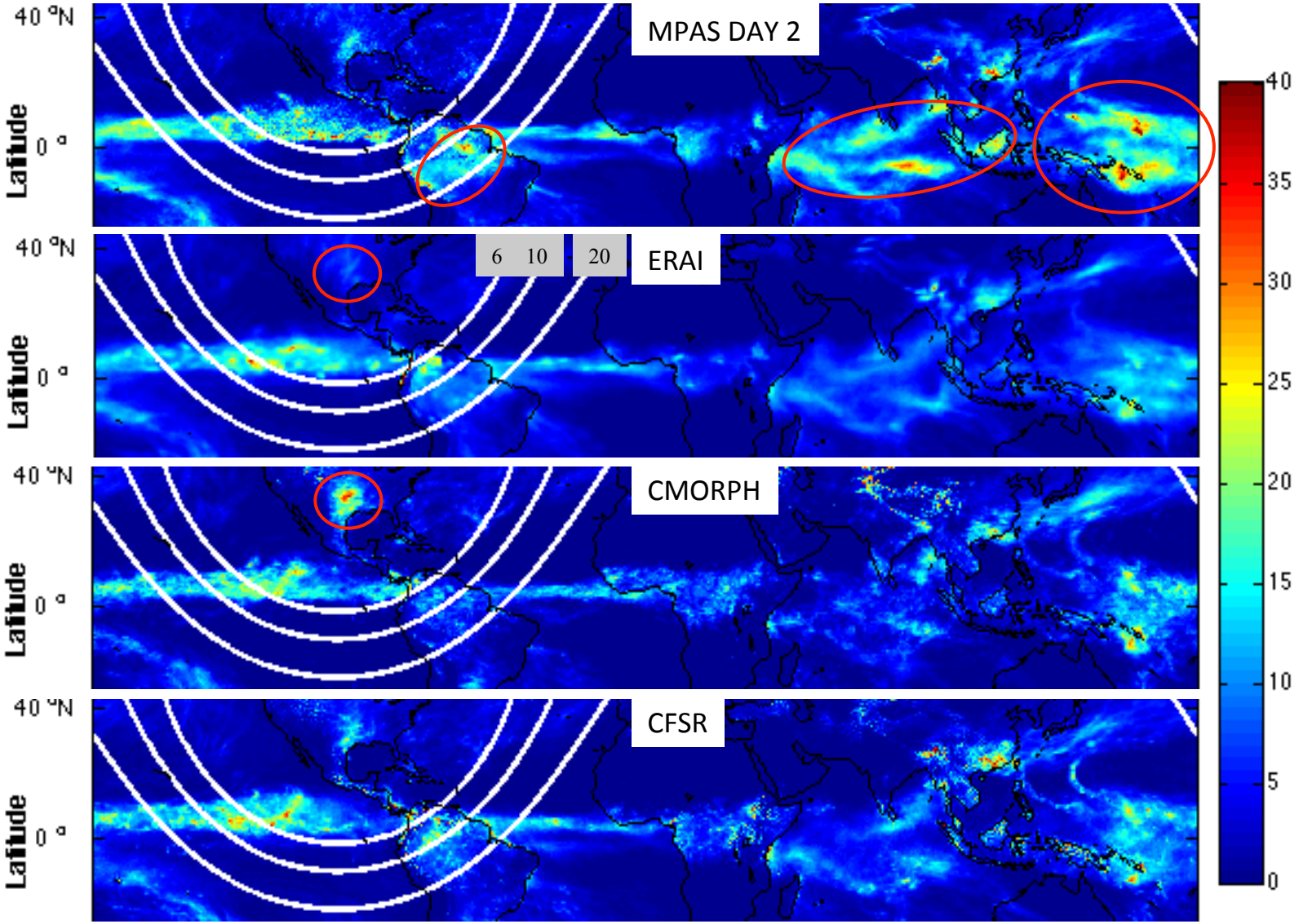
  - At convection-permitting resolution, parameterized convection becomes much shallower – cloud tops near 800 mb (down from 200-300 mb).
  - Temperature & moisture tendencies decrease as resolution increases.



MPAS
Model for Prediction Across Scales

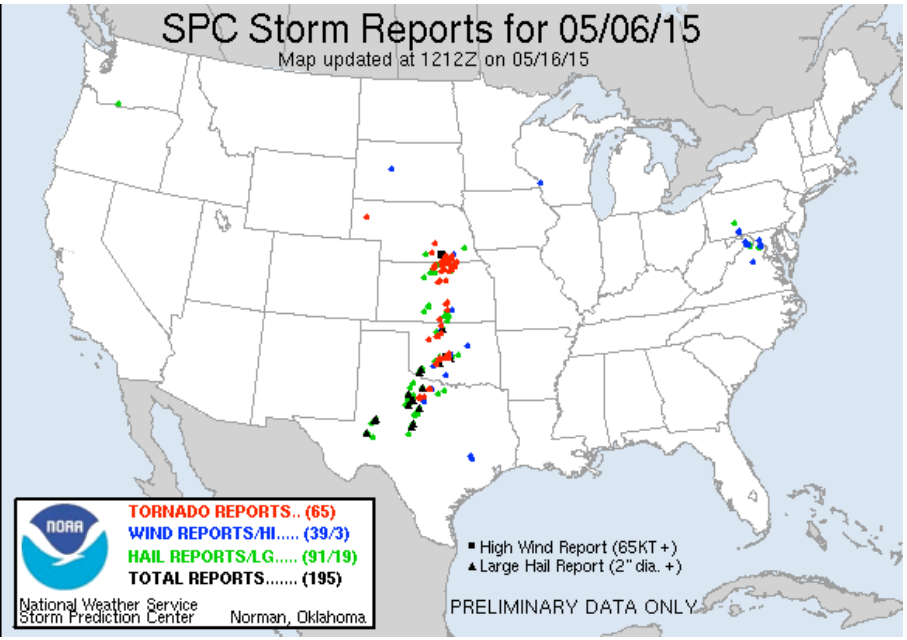
MPAS Precipitation
Spring Experiment 2015

Precipitation rate (mm/day), May 2015

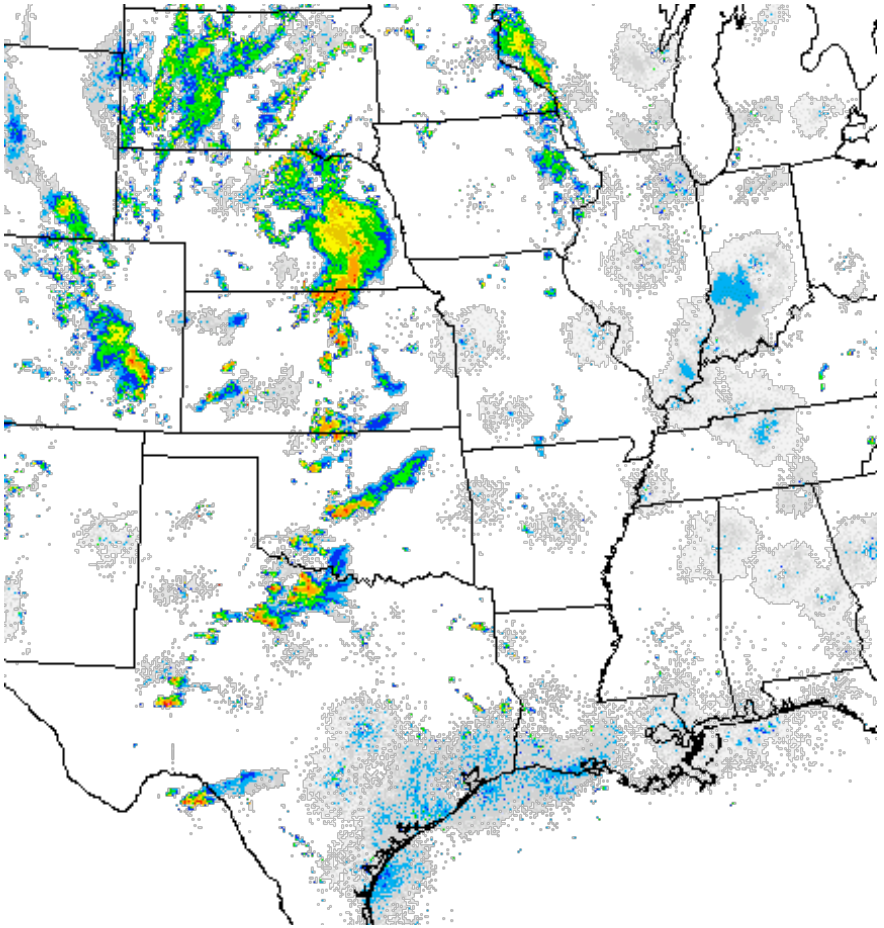


MPAS
Model for Prediction Across Scales

Hazardous Weather Testbed
Spring Experiment 2015
Forecasts Results from MPAS



Reflectivity, NOAA SPC archive
valid 2015-05-07 00 UTC



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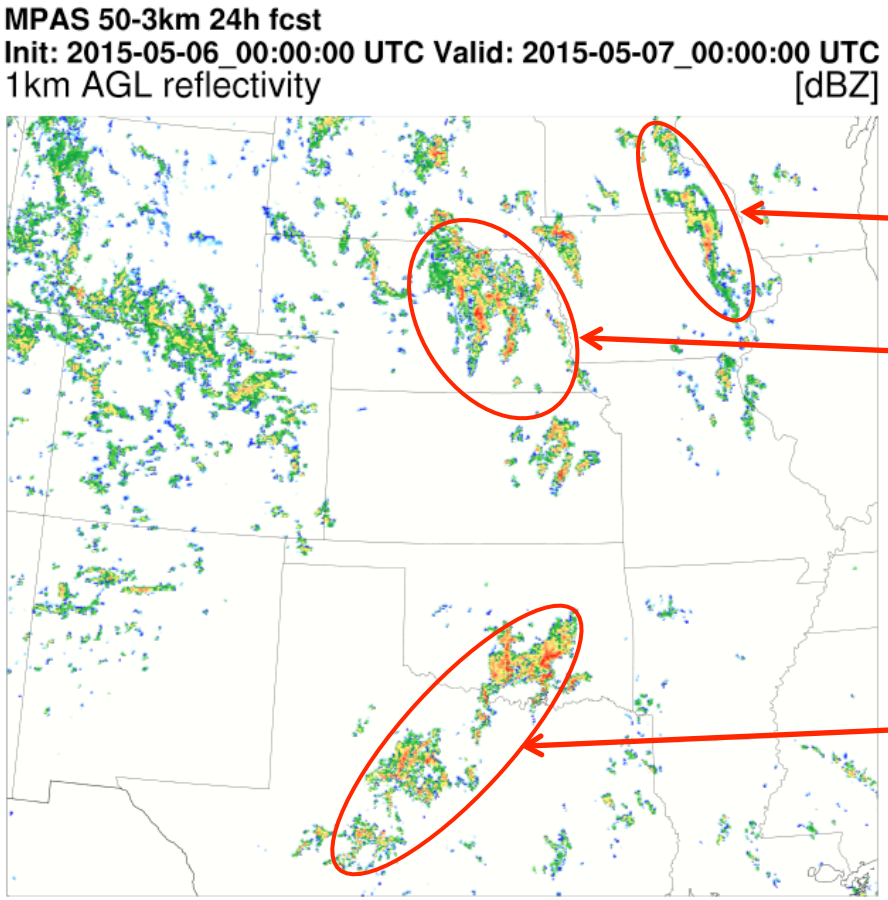

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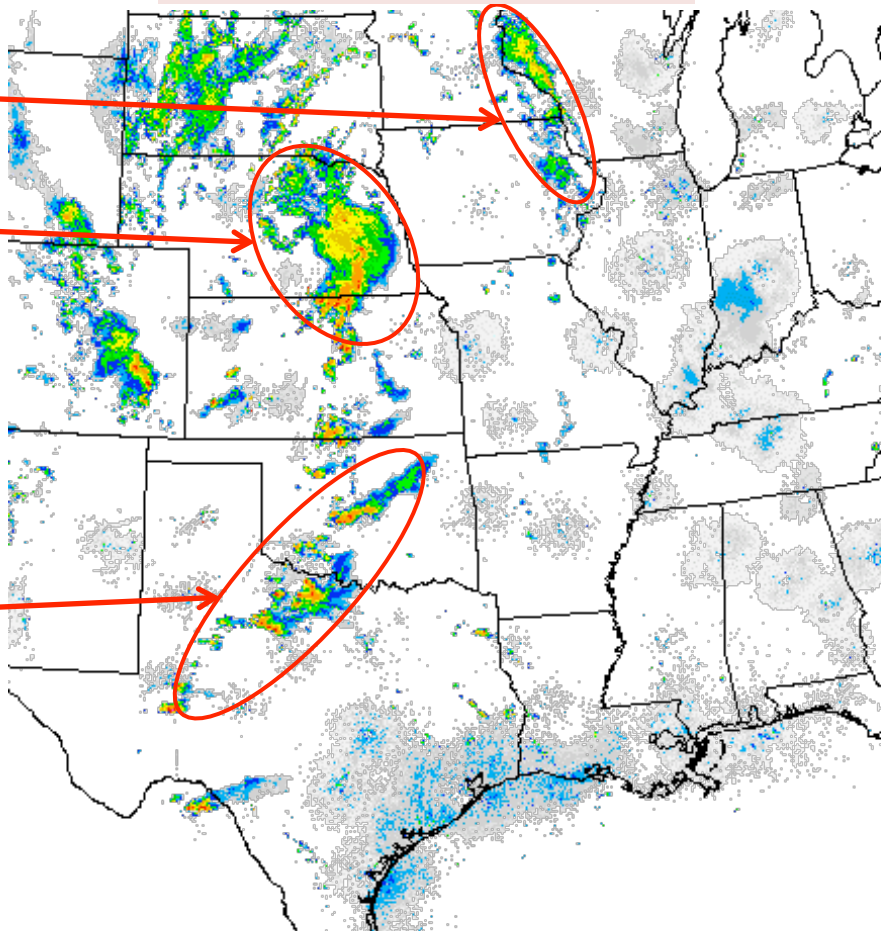
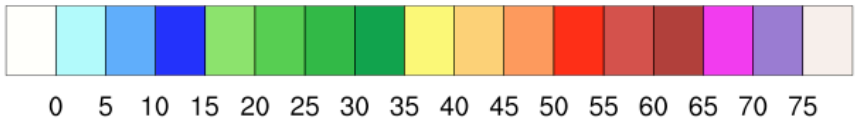


NCAR



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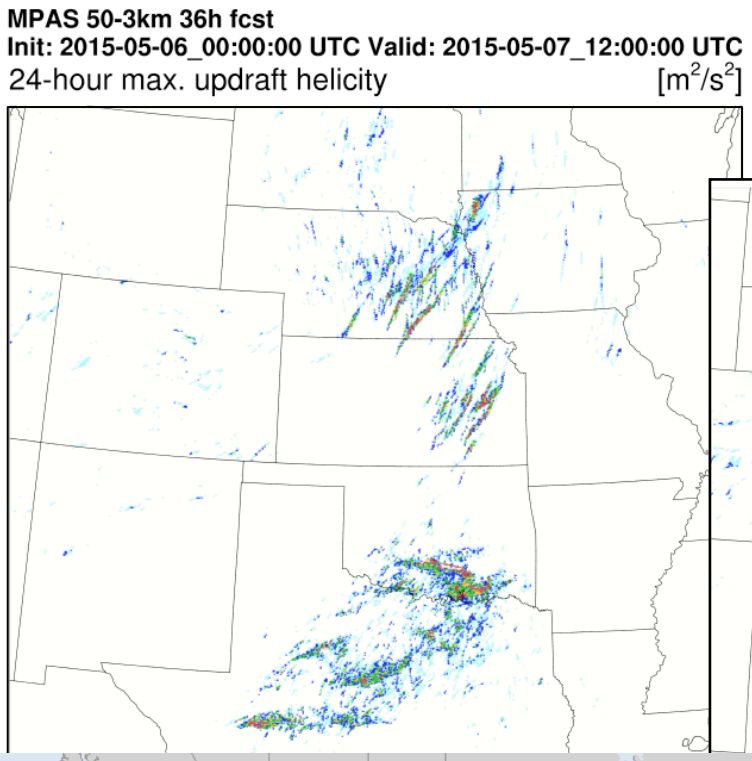
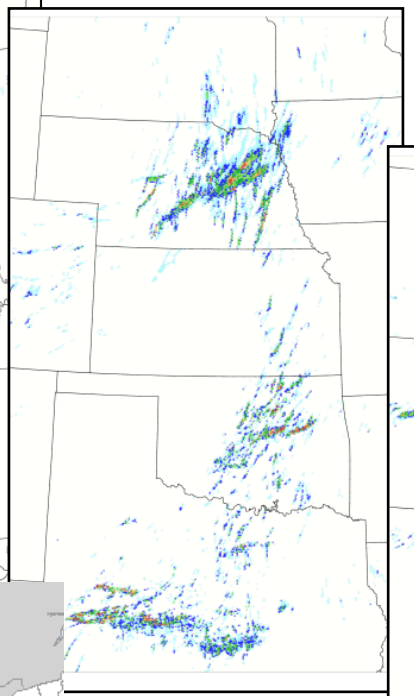
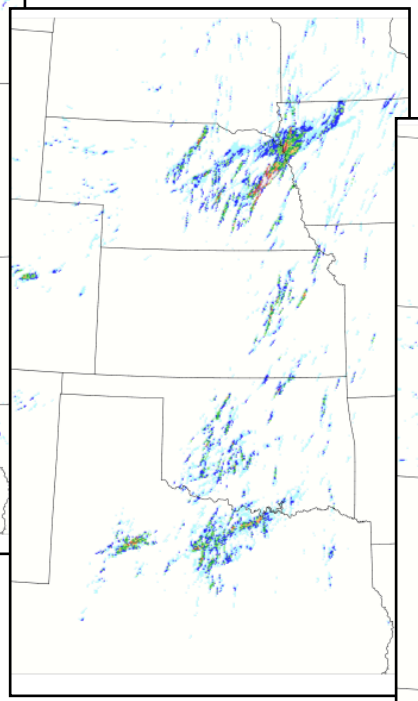


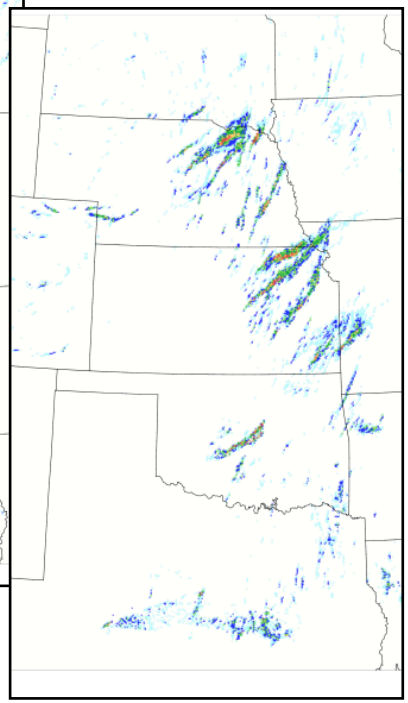
60h forecast

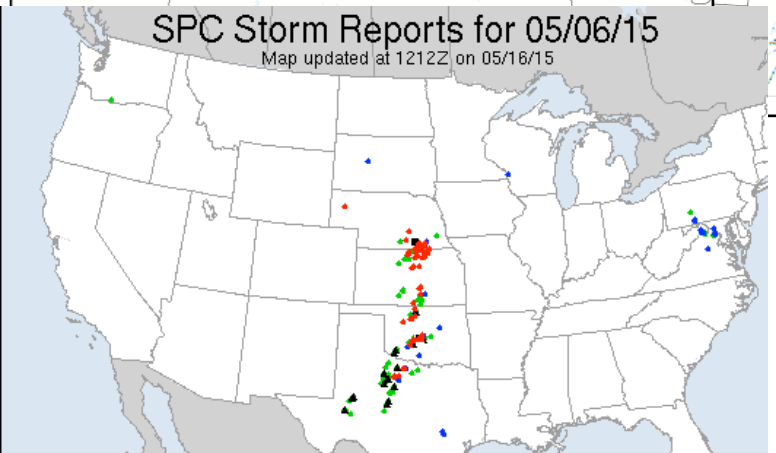


84h forecast



108h forecast





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Spring Experiment 2015
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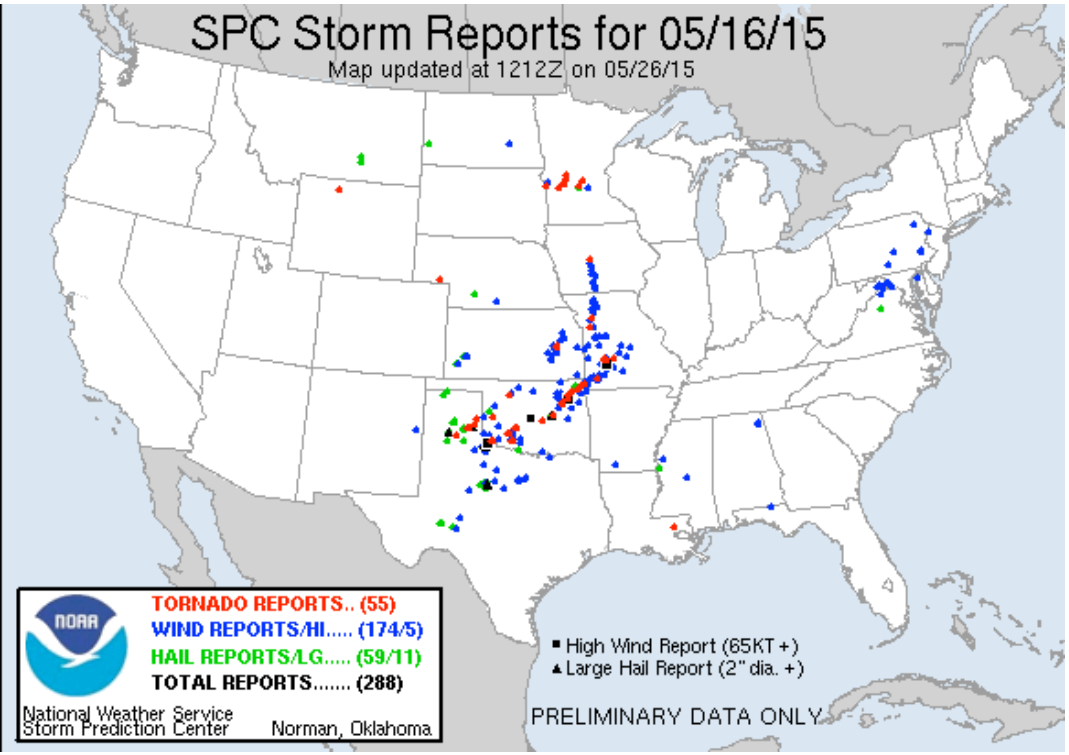
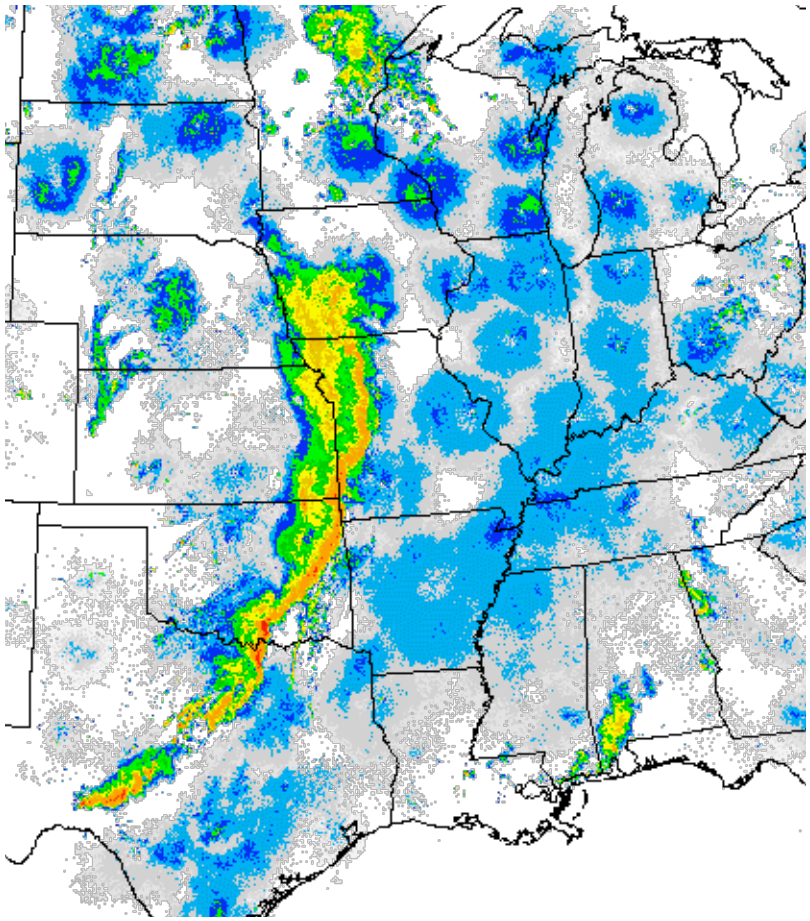


Reflectivity, NOAA SPC archive
valid 2015-05-17 06 UTC



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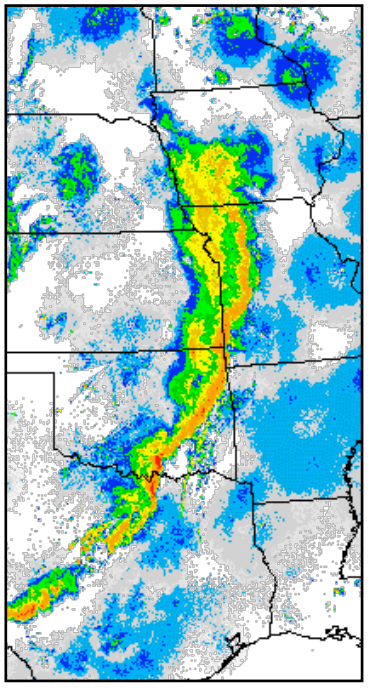
Hazardous Weather Testbed
Spring Experiment 2015
Forecasts Results from MPAS



Reflectivity
NOAA SPC archive
2015-05-17 06 UTC

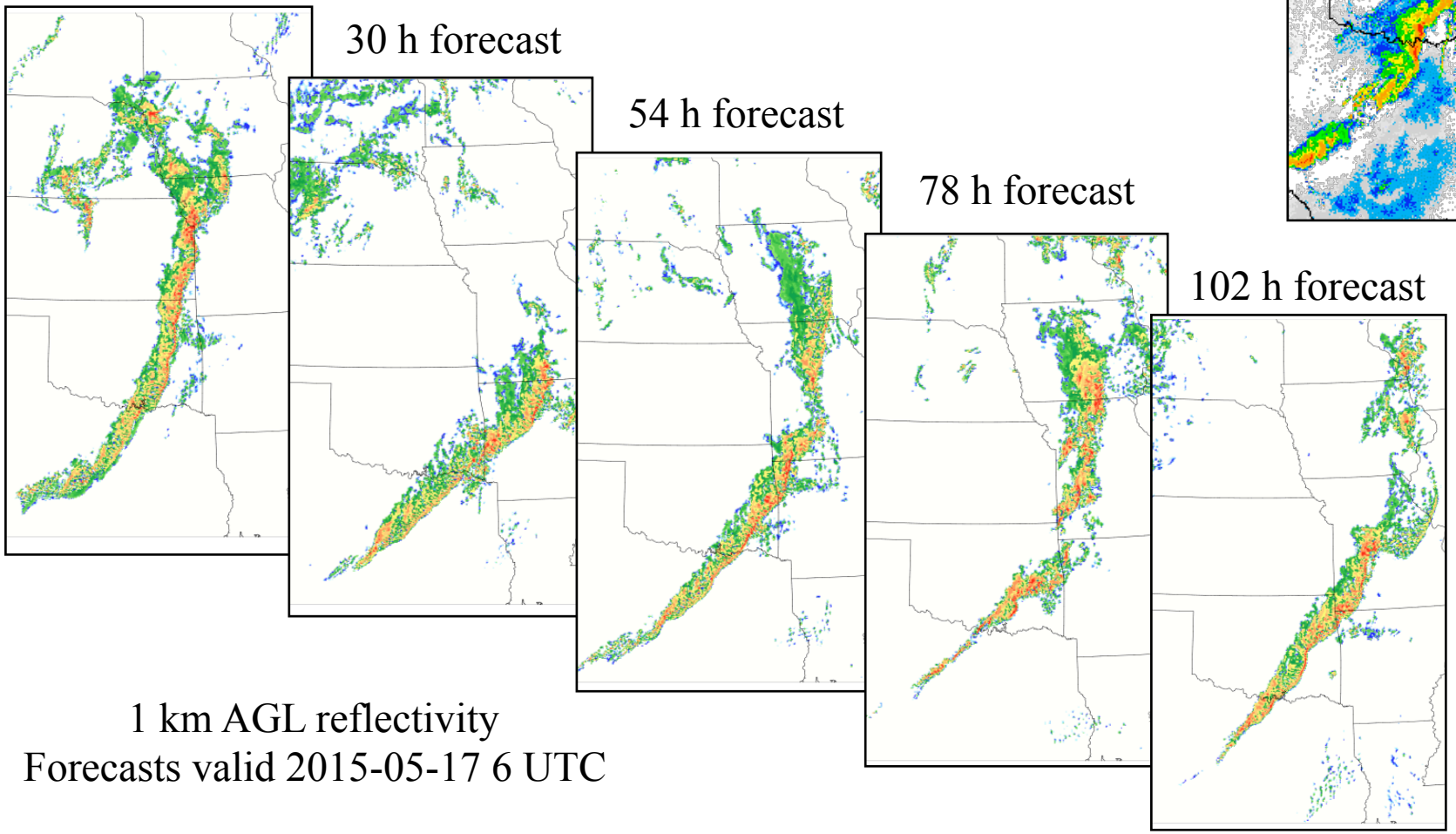
6 h forecast

30 h forecast

54 h forecast

78 h forecast

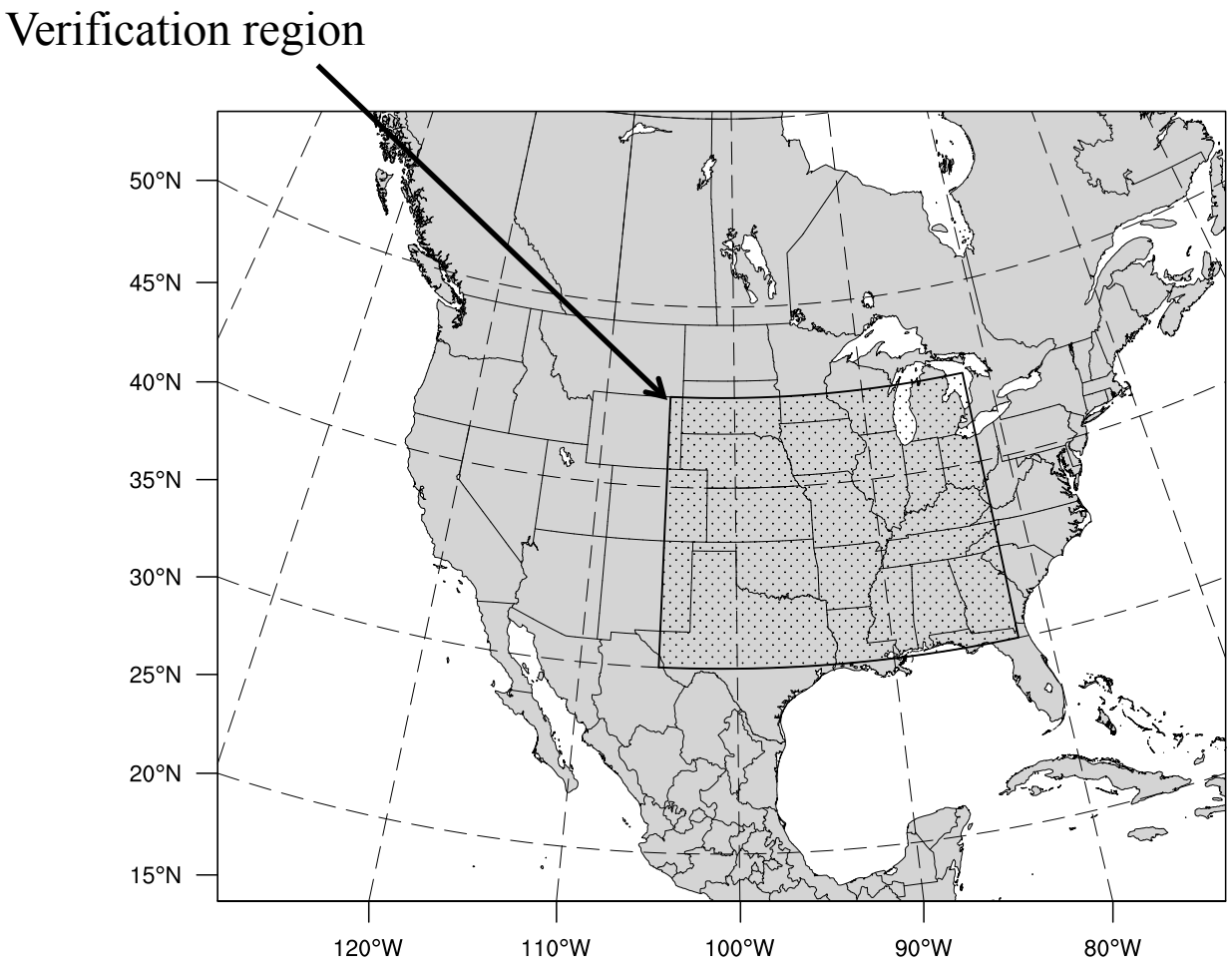
102 h forecast



1 km AGL reflectivity
Forecasts valid 2015-05-17 6 UTC

MPAS
Model for Prediction Across Scales

Hazardous Weather Testbed
Spring Experiment 2015
Verification against ST4 precipitation analyses



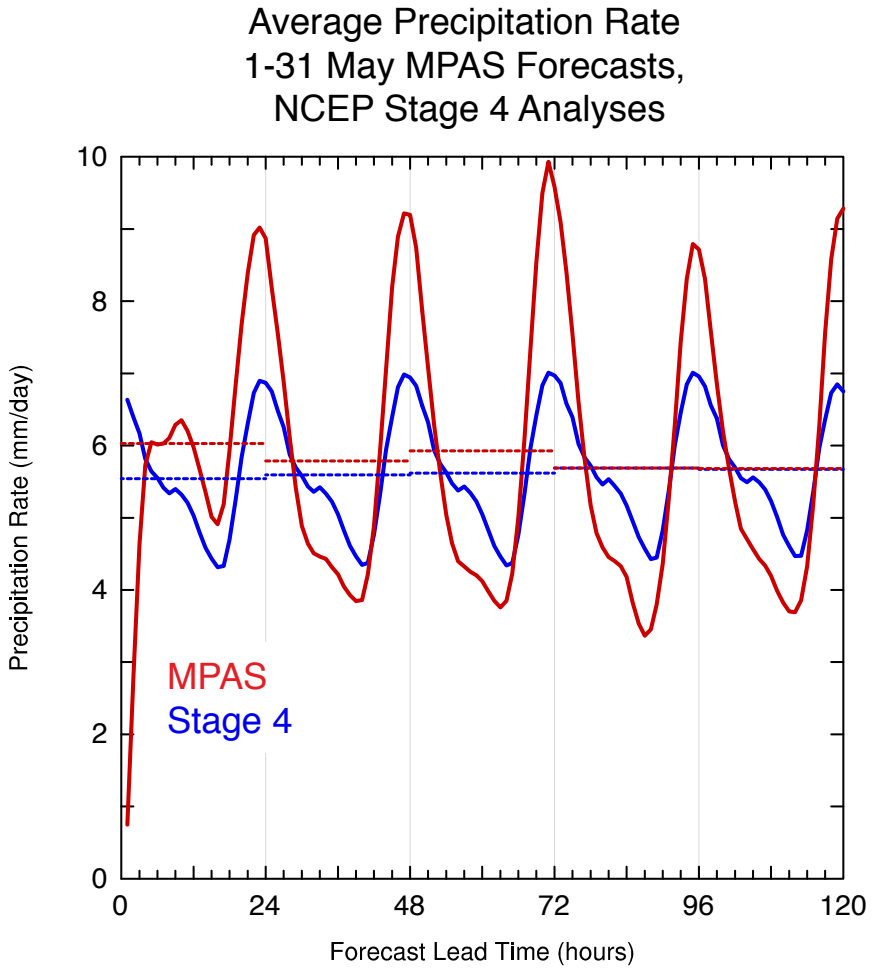
MPAS
Model for Prediction Across Scales

Hazardous Weather Testbed Spring Experiment 2015

Verification against ST4 precipitation analyses

- Timing of diurnal precipitation maxima and minima is very good.
- Significant over-estimation of diurnal precipitation maxima.
- Significant underestimation of diurnal precipitation minima.
- Over (under) estimation does not improve over time.

- Daily average precipitation (dashed lines) shows a small positive bias early, decreasing over time.



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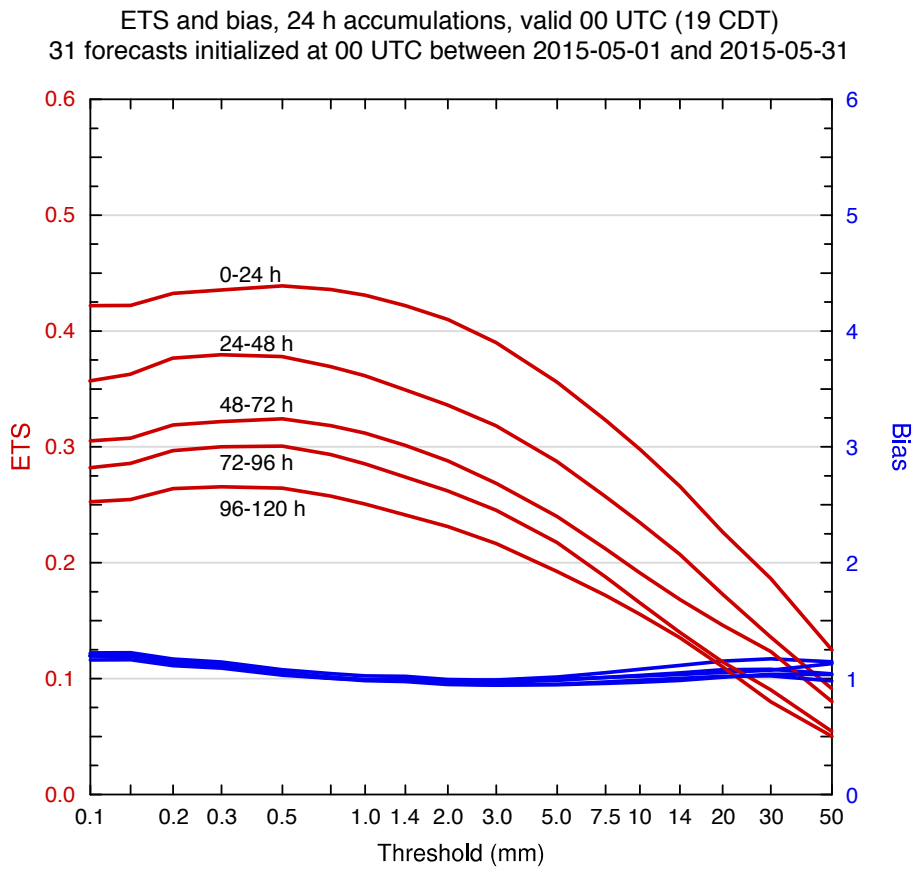
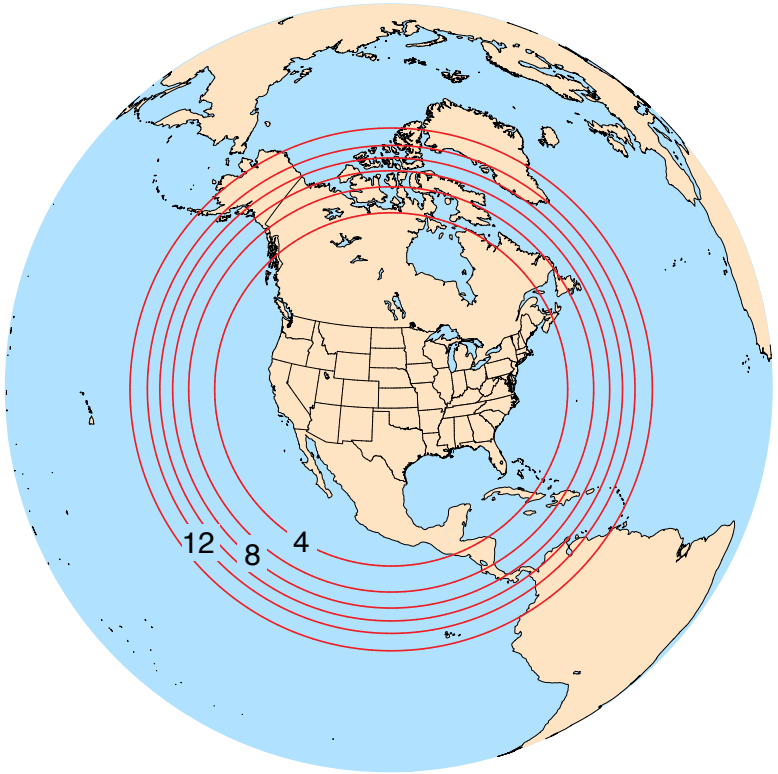


24 h accumulations

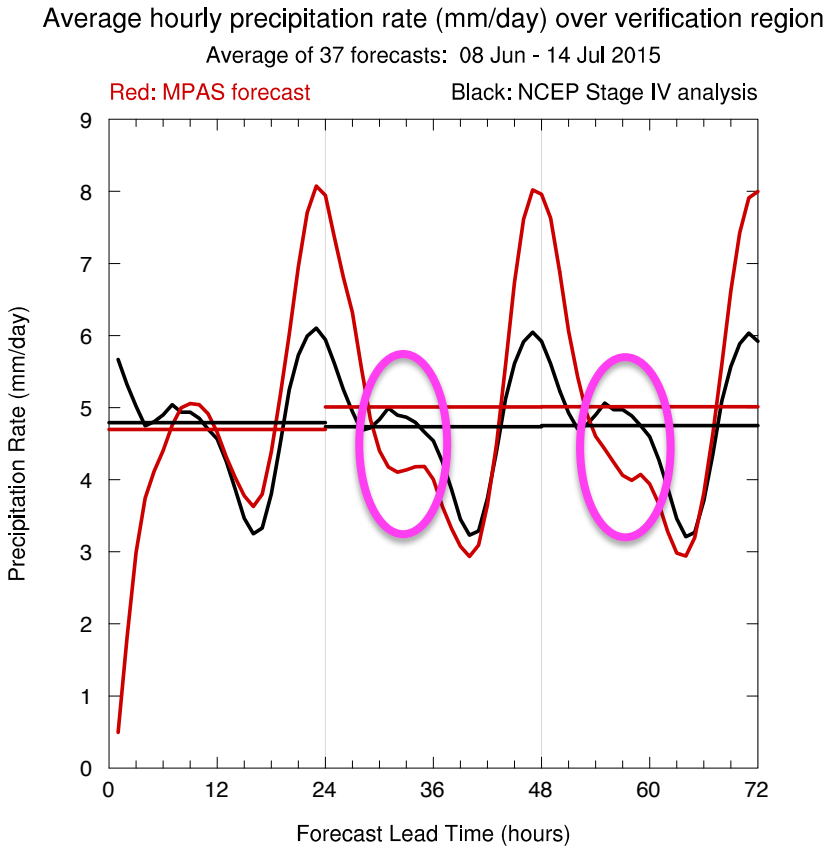
MPAS
Model for Prediction Across Scales

Seamless Modeling Across the Hydrostatic-Nonhydrostatic Scales

PECAN field campaign
3-day forecasts, 15 – 3 km mesh
7 June – 15 July 2015



3-15 km mesh, Δx contours
approximately 6.5 million cells
50% have < 4 km spacing



MPAS
Model for Prediction Across Scales

Summary

Seamless? Multi-scale? Scale-aware?

Variable-resolution, nonhydrostatic-scale global atmospheric simulations are viable

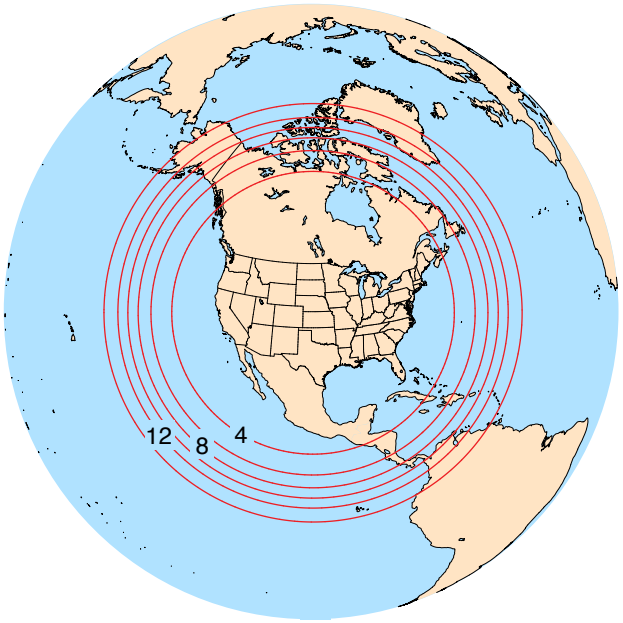
- MPAS-A addresses one *seam* in NWP models.
- Another *seam:* GF convection scheme appears to be viable for scale-aware applications. Further work needed.
- Fidelity of convection similar to that of WRF.
- MPAS variable-resolution forecasts *may* contain some extended-range convective guidance.

Challenges

Scale-aware physics – addressing another *seam:*

- *Convection*
- Microphysics
- Boundary layer

Data assimilation on variable meshes



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Forecasts available at
http://wrf-model.org/plots/realtime_main.php

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