An Overview of the Standalone Regional Version of FV3

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Acknowledgments

Jim Abeles, Dusan Jovic, Ben Blake, Jacob Carley, Logan Dawson, George Gayno, Jim Purser

- Motivation
- Preprocessing
- The regional domain / code
- Forecast Examples
- Precipitation statistics
- Computational efficiency
- An improved grid
- Ongoing work

Motivation

- GFDL added a single nest capability to the global FV3 to allow for enhanced resolution over a limited area.
- Yet there has been a desire for a standalone regional option in FV3 to complement its nest capability in limited area forecasting.
  - Extra resources are not needed for a global parent.
  - Rapid updates in DA are much more feasible.

Drawbacks: - *Boundary data from an external forecast cannot be as accurate as those provided by a parent to a nest every timestep during the integration.*

- *Wind tendencies for physics at the boundary are artificial.*

Primary Steps to Set Up a Regional FV3 Forecast

- Clone and build NCEPLIBS.
- Clone and build fv3sar_workflow executables.
- Download necessary ‘fix’ files.
- Run run_fv3gfs_driver_grid.<machine> to generate the grid and orography.
- Download atmospheric data and surface files.
- Run run_chgres_regional.<machine> to generate atmospheric, surface, and boundary files for the forecast.
- Clone FV3GFS model code and build the executable.

https://docs.google.com/document/d/1KkL3mHnDGKHwjpBV98QLYRWtxGKEUWuqy5cy5udZct0/edit#

Some Preprocessing Details

- The user specifies the generation of the grid and orography for either:

  1) A nest on the global cube.

  2) A standalone regional domain that ***is on the parent cube's projection*** like a nest

  OR

  is unrelated to any parent domain and is modified to reduce spatial variation of grid cell area (in progress; described later).

- The initial data and the boundary files for the regional domain are generated based simply on the geographic latitude/longitude of the grid cell centers and edges.

- Topography is filtered with a scheme by SJ Lin and requires at least five extra rows/columns of data beyond the integration domain.

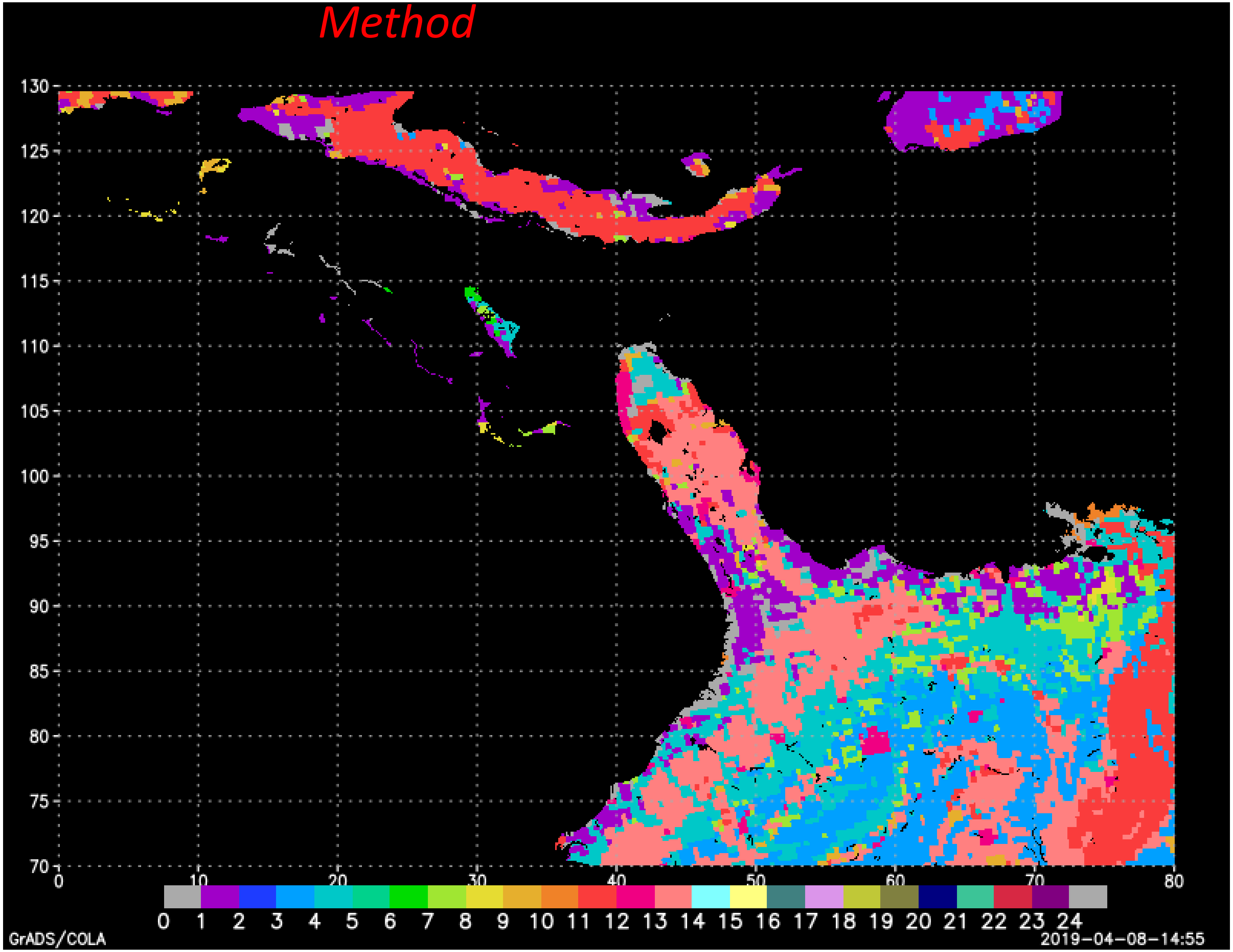
- At EMC the initial and boundary data can be generated from FV3GFS data, from GSMGFS nemsio data, or from old GSM spectral data.

Static and Climatological Fields

Improvements are being made in generating these data fields in the pre-processing step.

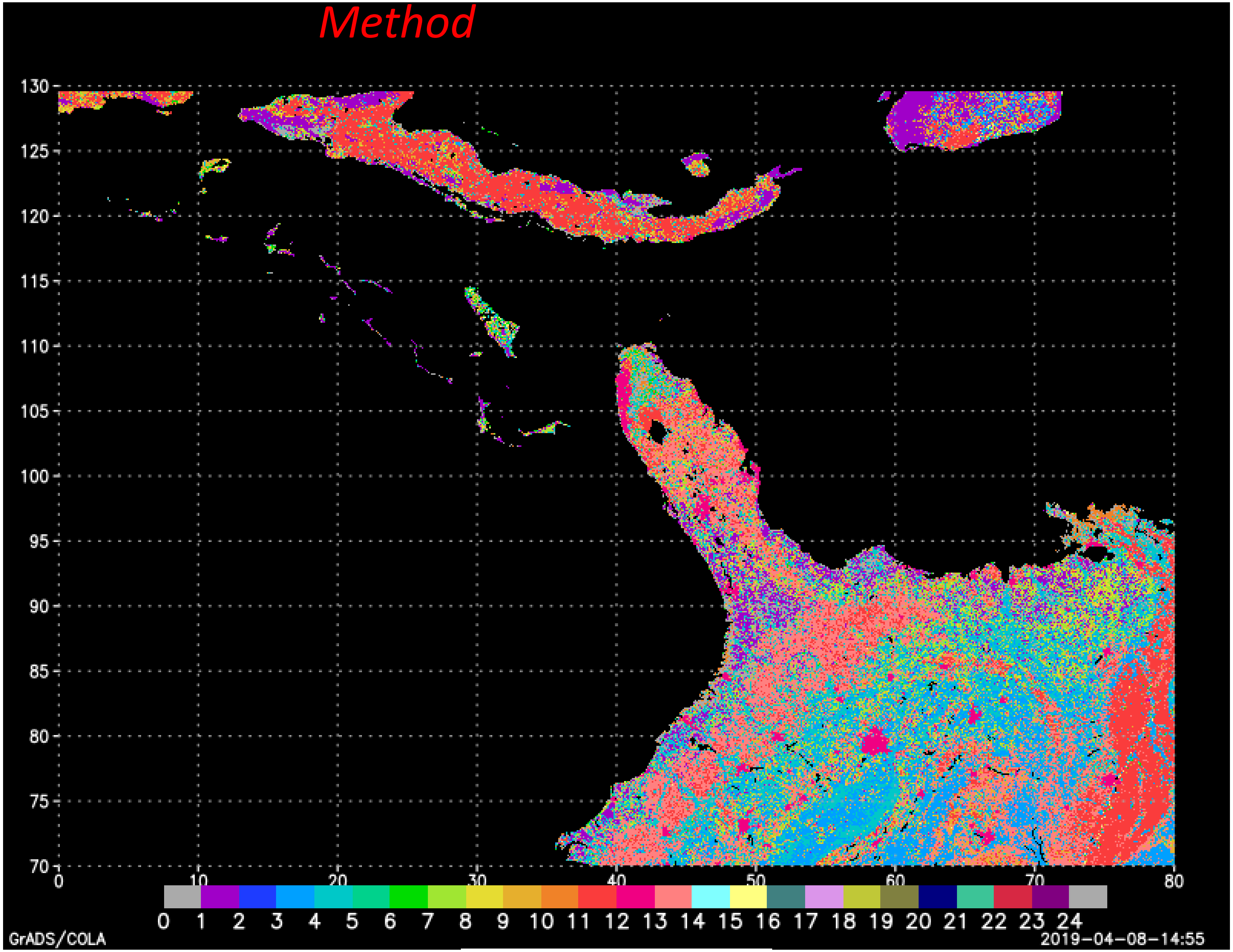
This is important in enhancing skill of high resolution forecasts.

Vegetation Type: *Old Method*



Uses T1534 gaussian data (~13 km)

Vegetation Type: *New Method*



Uses 1 km data

Currently setting up regional FV3 runs from scratch is difficult outside of NOAA.

EMC's Engineering and Implementation Branch plans to establish a group to determine everything needed to make this a relatively easy process for anyone in the modeling and forecasting community.

Internal Initialization

When the model execution begins there are a variety of key steps that occur to prepare for the forecast.

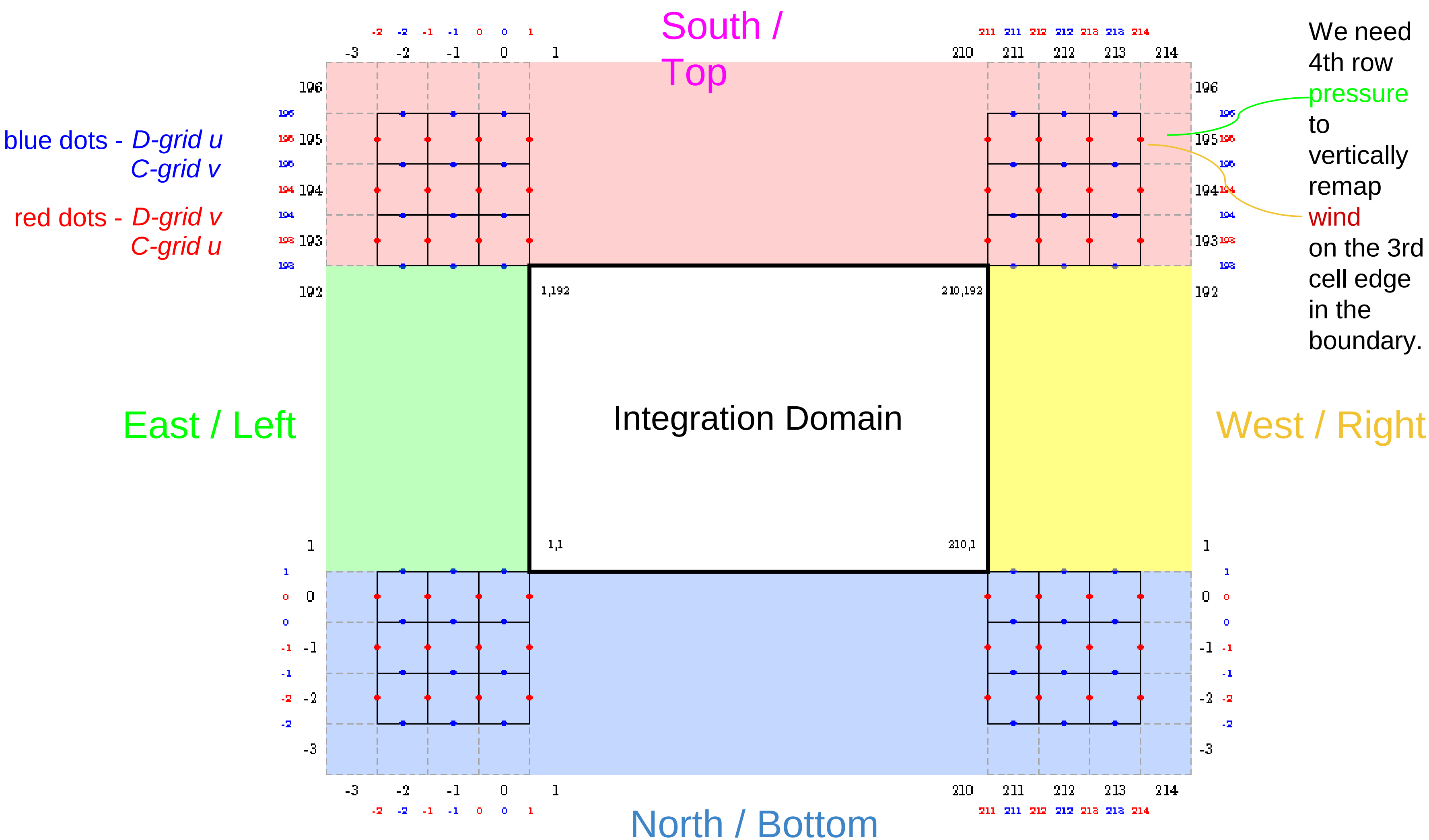
- Properly incorporate geographic latitude/longitude and orography for the full regional domain including the boundary rows.
- Read in the data from the external BC files.
- Vertically remap scalars and wind components in the BC data from the structure of the external forecast to the FV3 forecast's structure.

The regional boundary requires fields to have 3 or 4 rows of data outside the integration domain (depending on the variable) in order to fill the boundary arrays properly given the finite differencing in the model.

Primary Modifications Made to the FV3 Code

- The vast majority of changes to enable the regional capability have been placed into ***a single new module*** and largely deal directly or indirectly with boundary conditions.

- Changes in other FV3 modules that already existed include:
  - Calling the boundary update routines for relevant variables during the integration.
  - Calling the setup of the regional domain.
  - Calling the routine to read external data and generate BC data every N forecast hours.
  - Passing the ‘regional’ flag to distinguish action different from that needed for a nest or for a parent cube.
  - Restarting.

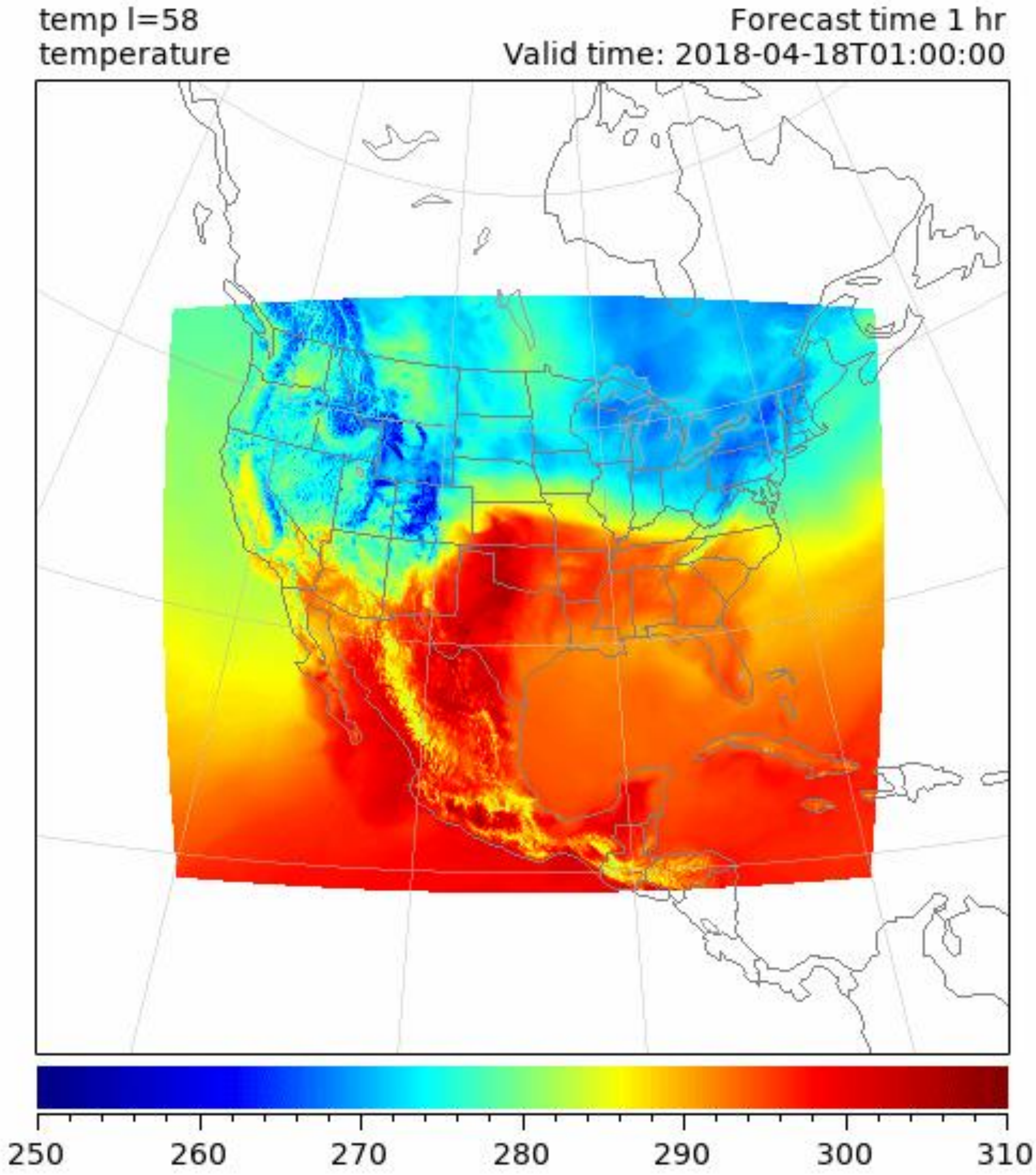


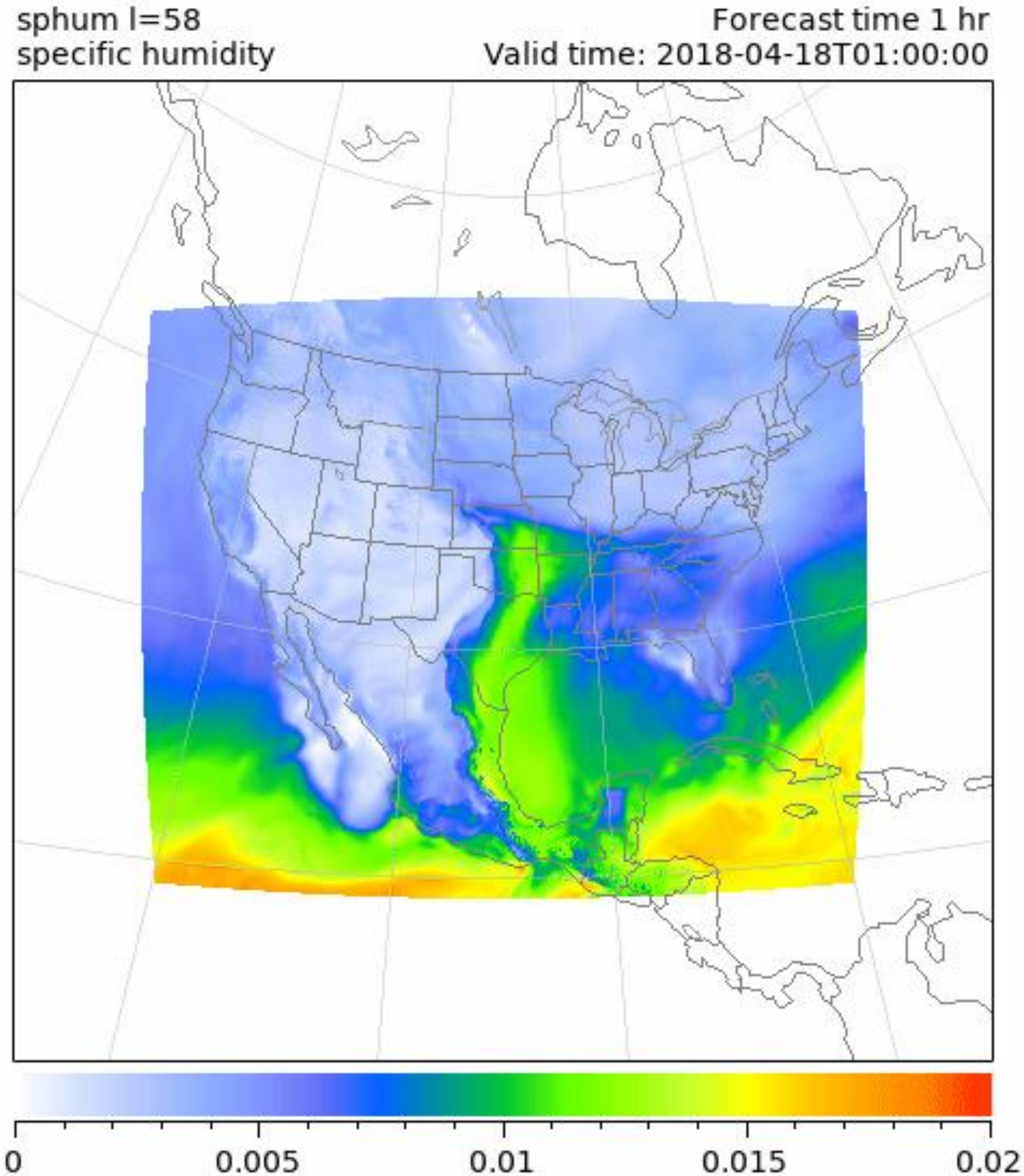
Orientation of the grid is based on tile 6 of the global cube over North America.

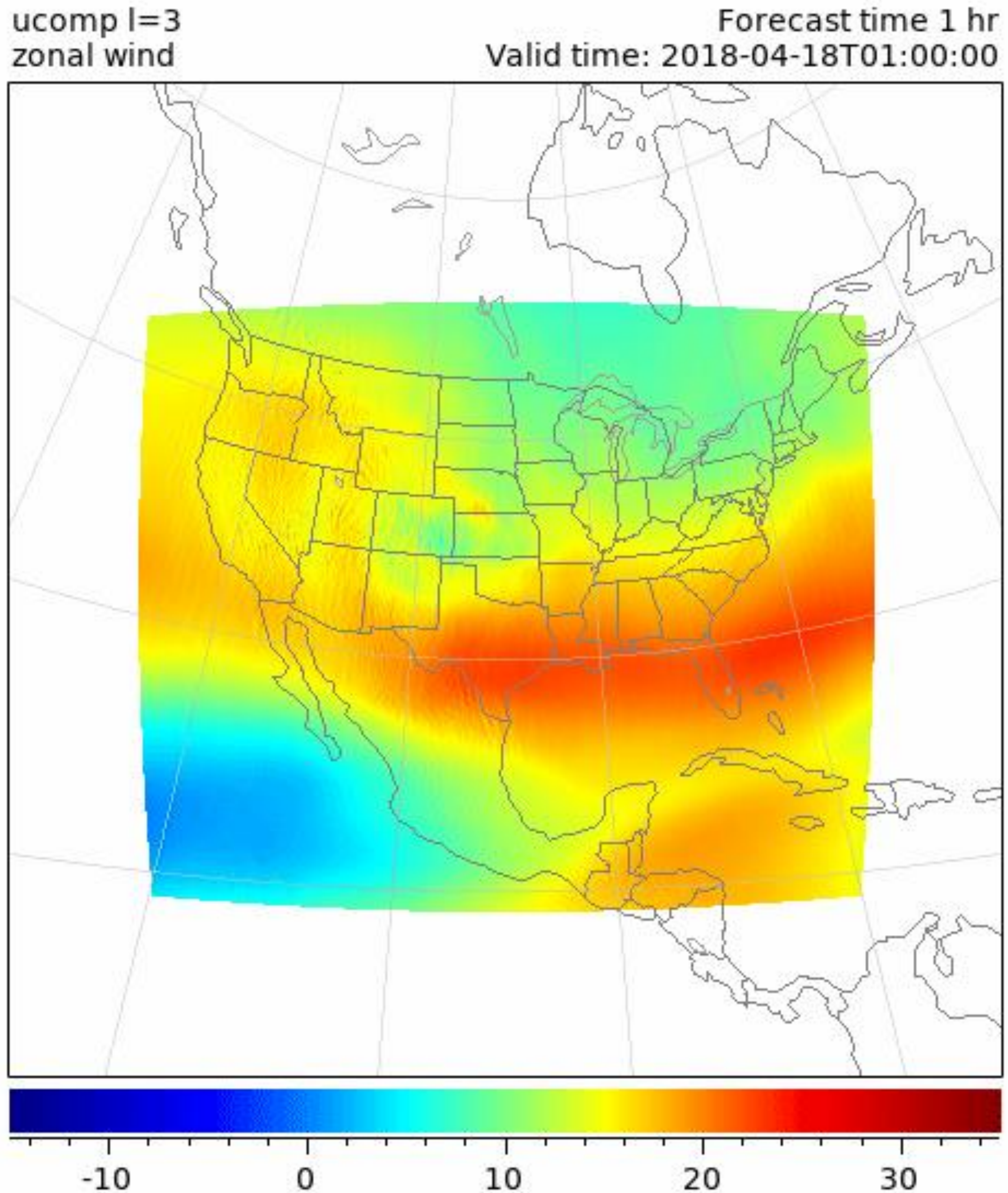
General Forecast Example

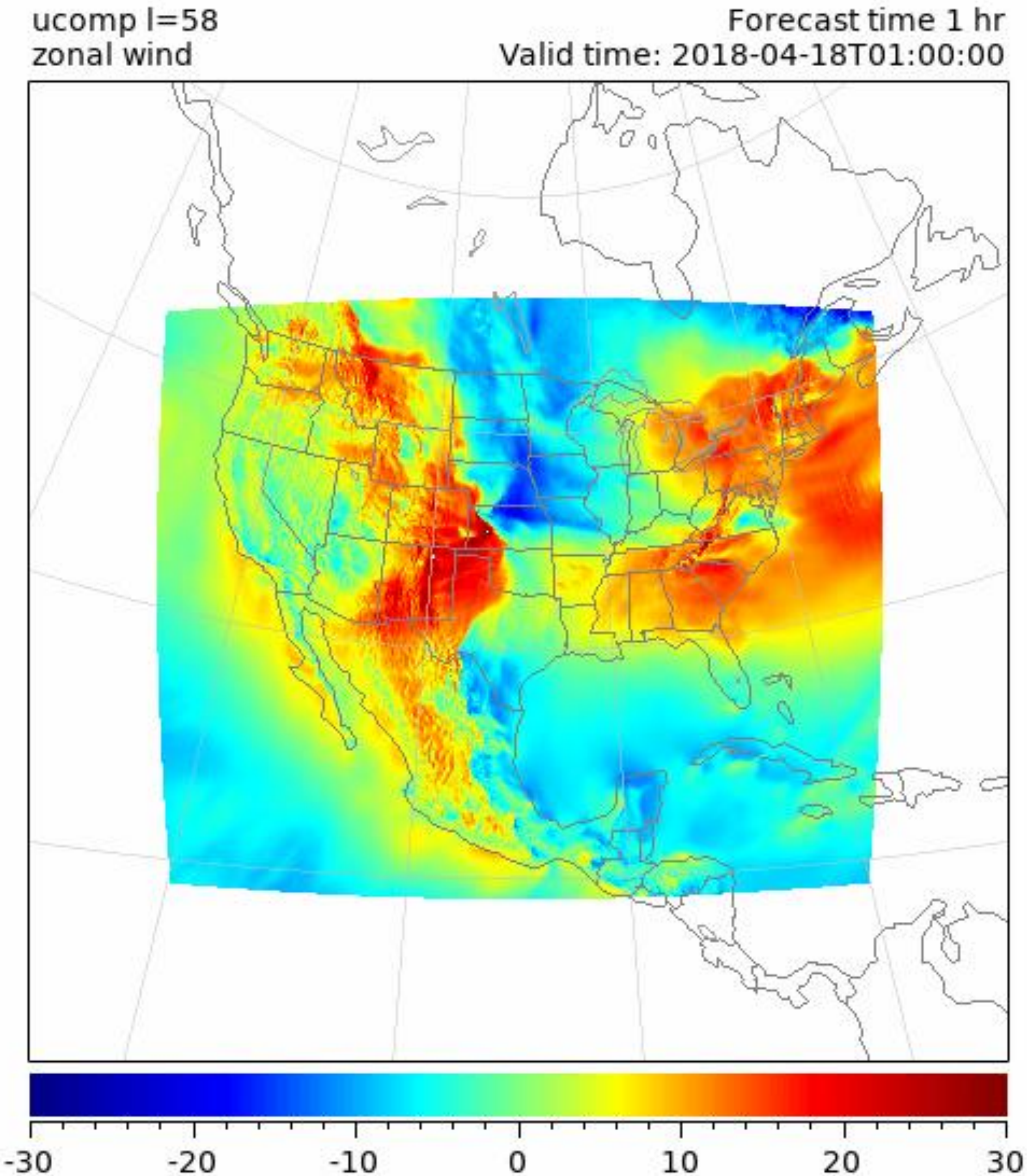
- 84-hr regional forecast from 0000 UTC 18 April 2018 using operational GFS BCs.

- The domain is the same as a ~3km nest on a c768 stretched cube.


temp l=58
temperature
Forecast time 1 hr
Valid time: 2018-04-18T01:00:00
250
260
270
280
290
300
310


sphum l=58
specific humidity
Forecast time 1 hr
Valid time: 2018-04-18T01:00:00
0
0.005
0.01
0.015
0.02


ucomp l=3
zonal wind
Forecast time 1 hr
Valid time: 2018-04-18T01:00:00
-10
0
10
20
30


ucomp l=58
zonal wind
Forecast time 1 hr
Valid time: 2018-04-18T01:00:00
-30
-20
-10
0
10
20
30

Hurricane Florence

This storm caused catastrophic damage in the Carolinas in September 2018. Peak intensity occurred on 10 September with a central pressure of 939 mb.

Sea Level Pressure Forecasts

In August the FV3GFS switched from using FV3's horizontal advection method 6 to method 5 for the forecast job. This change was recommended by GFDL to improve tropical cyclone intensity forecasts.

All plots shown are for method 6 configuration unless noted otherwise.

SLP values for method 5 are included for comparison. It remains unclear if we want to move to method 5 in the regional model.

Estimated central pressure from NHC is used for verification.

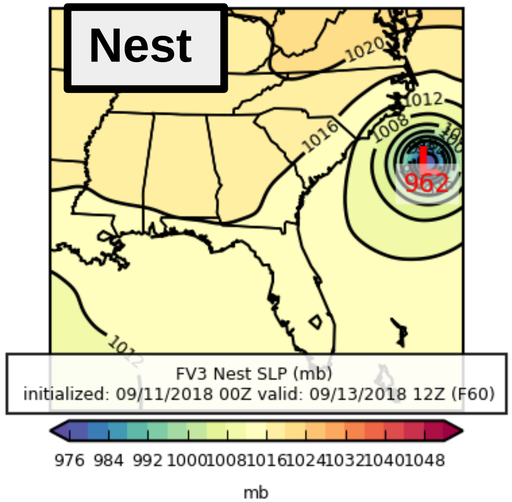
method 5 - uses Huynh's 2nd constraint to enforce monotonicity

method 6 - unlimited "fifth-order" piecewise parabolic method

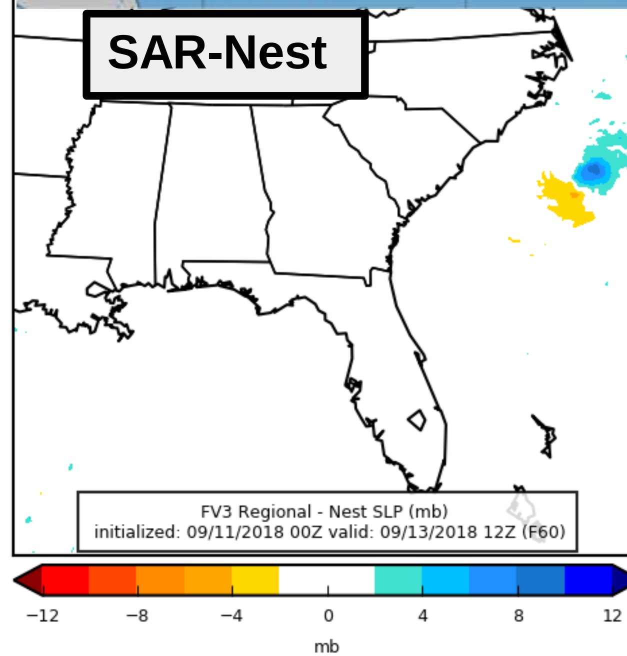
9/11 00z Cycle
Valid 9/13 12z (f60)

Hord = 6: **962 mb**

Hord = 5: **964 mb**

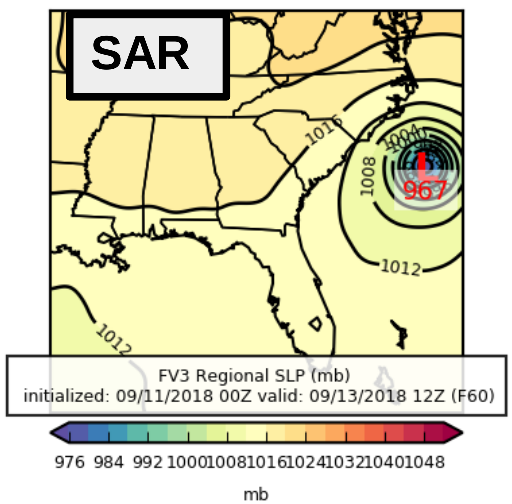


Estimated Central Pressure from NHC: **956 mb**

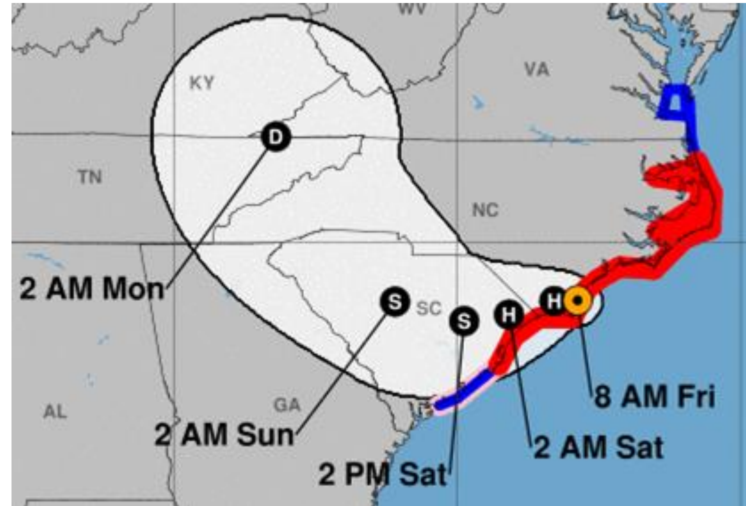


Hord = 6: **967 mb**

Hord = 5: **968 mb**



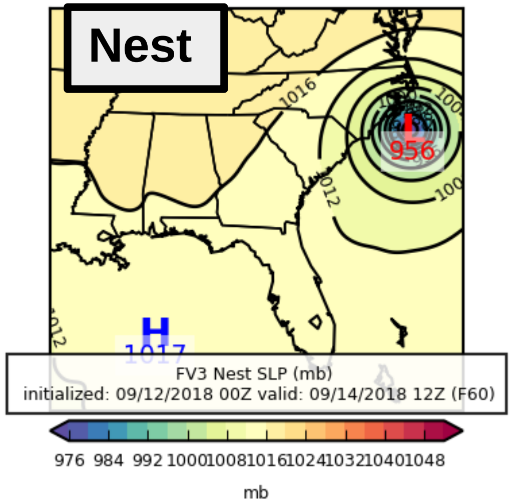
9/12 00z Cycle
Valid 9/14 12z (f60)

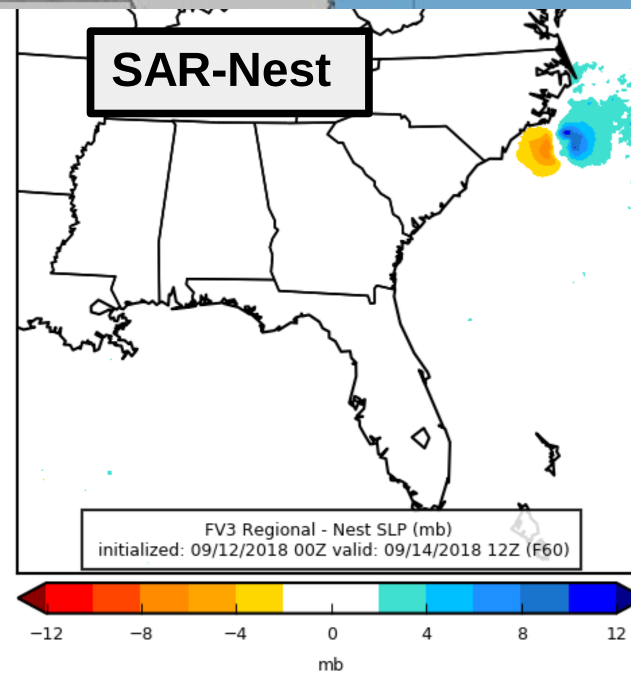


Hord = 6: **956 mb**

Hord = 5: **957 mb**

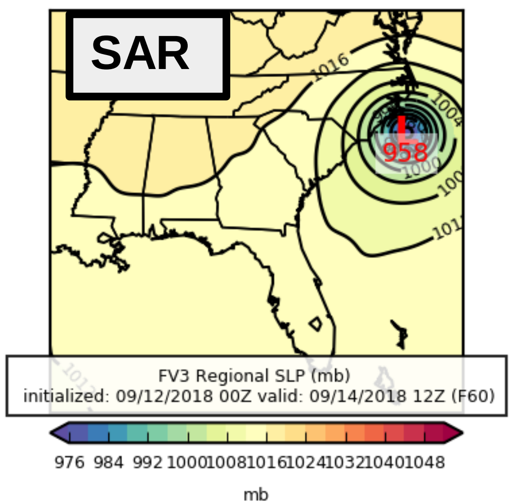
Estimated Central Pressure from NHC: **958 mb**





Hord = 6: **958 mb** ☆

Hord = 5: **956 mb**



Precipitation Forecasts

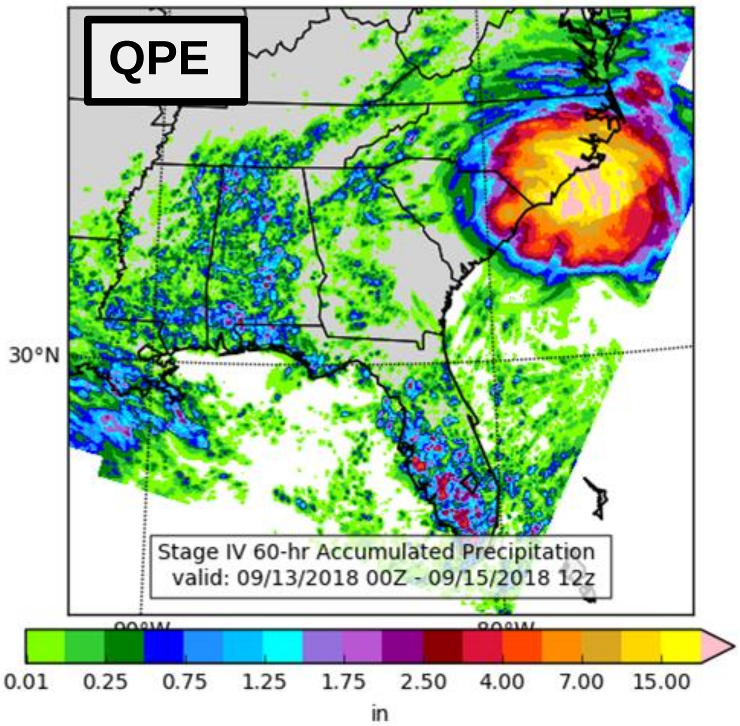
60-hour accumulations valid:

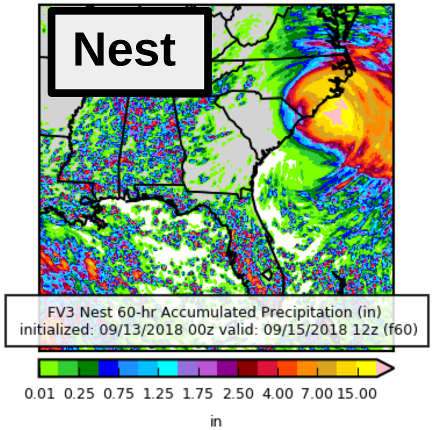
- 9/13 00z – 9/15 12z
- 9/14 00z – 9/16 12z

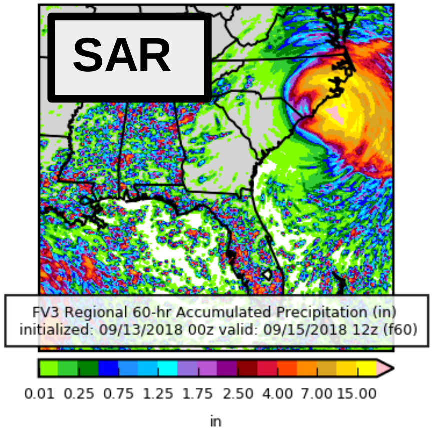
Used advection method 6 for these runs.

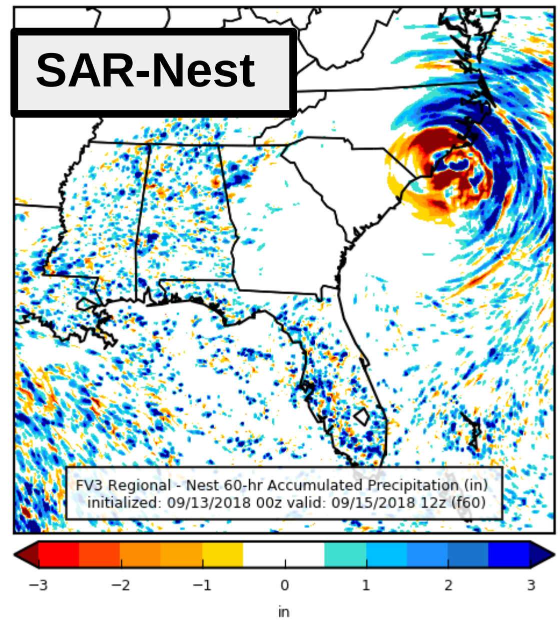
Stage IV data is used for verification.

9/13 00z Cycle
60-hr accumulation ending 9/15 12z

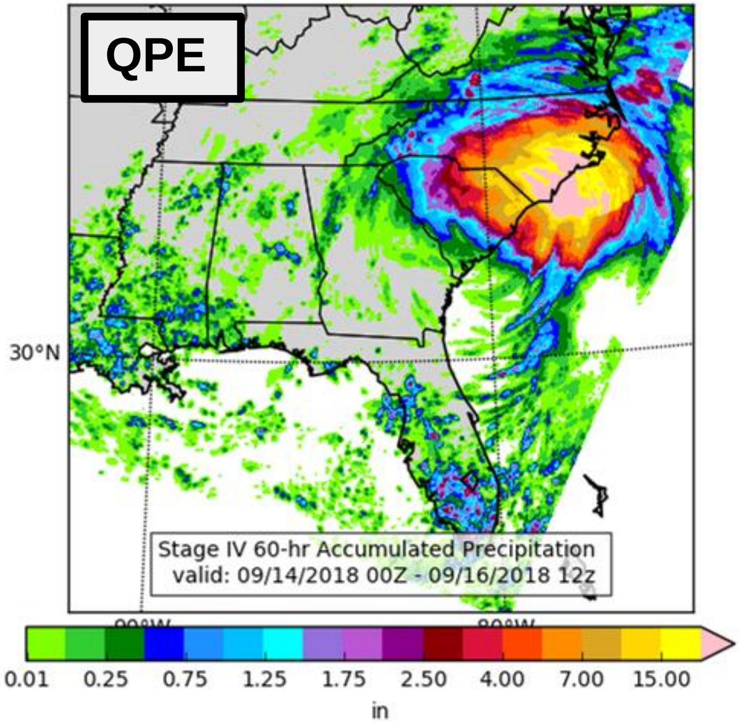


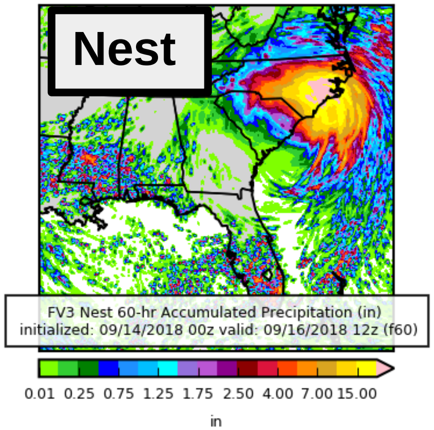


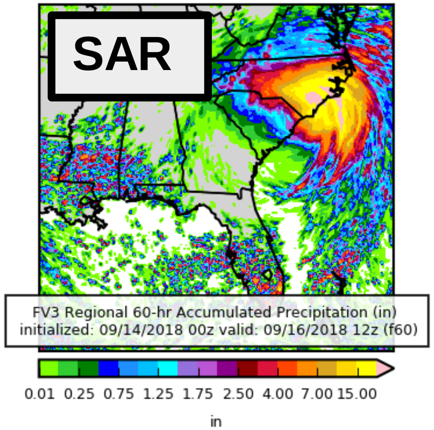


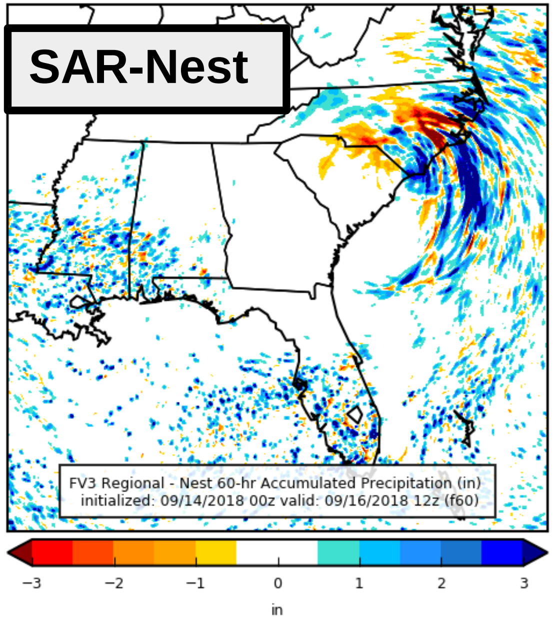


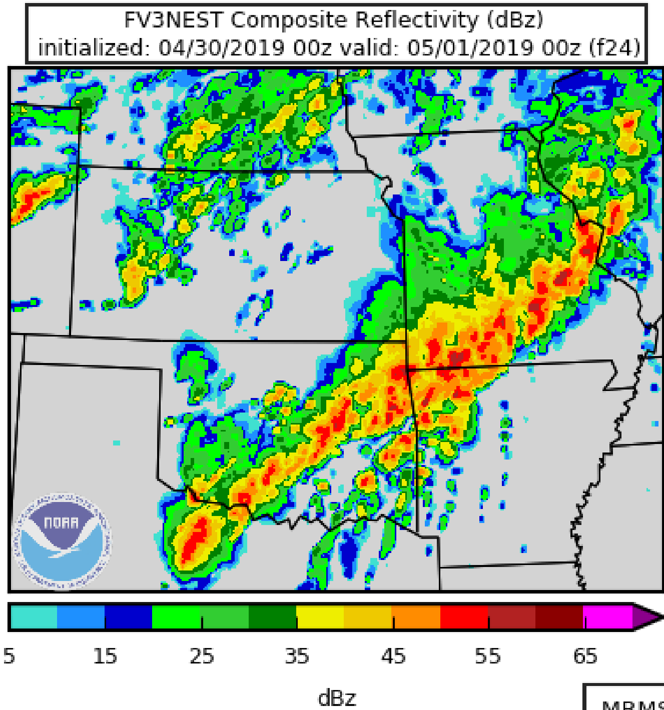
9/14 00z Cycle
60-hr accumulation ending 9/16 12z



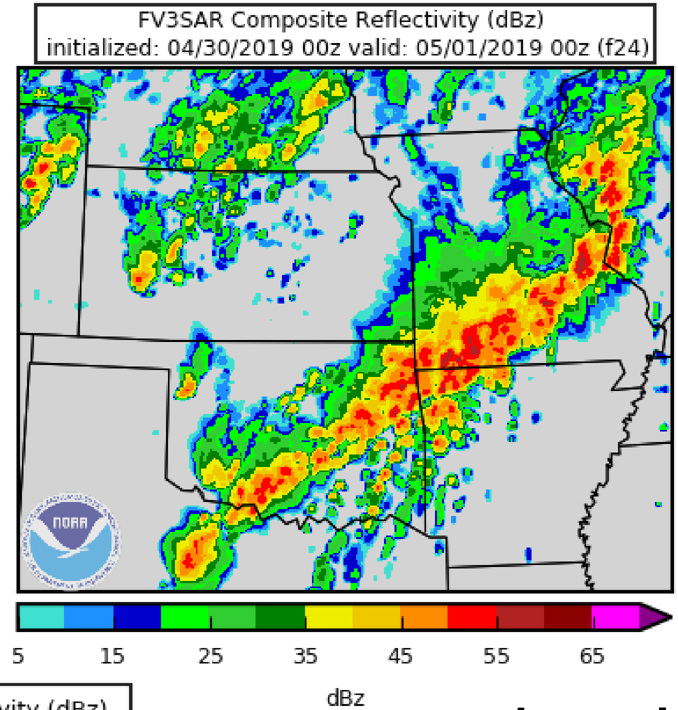






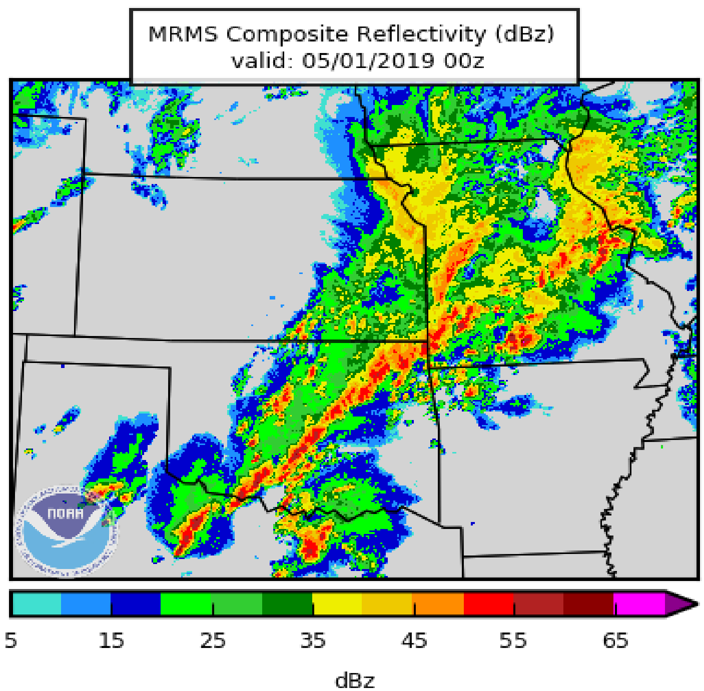


24 Hr
Fcsts



Nest

Regional



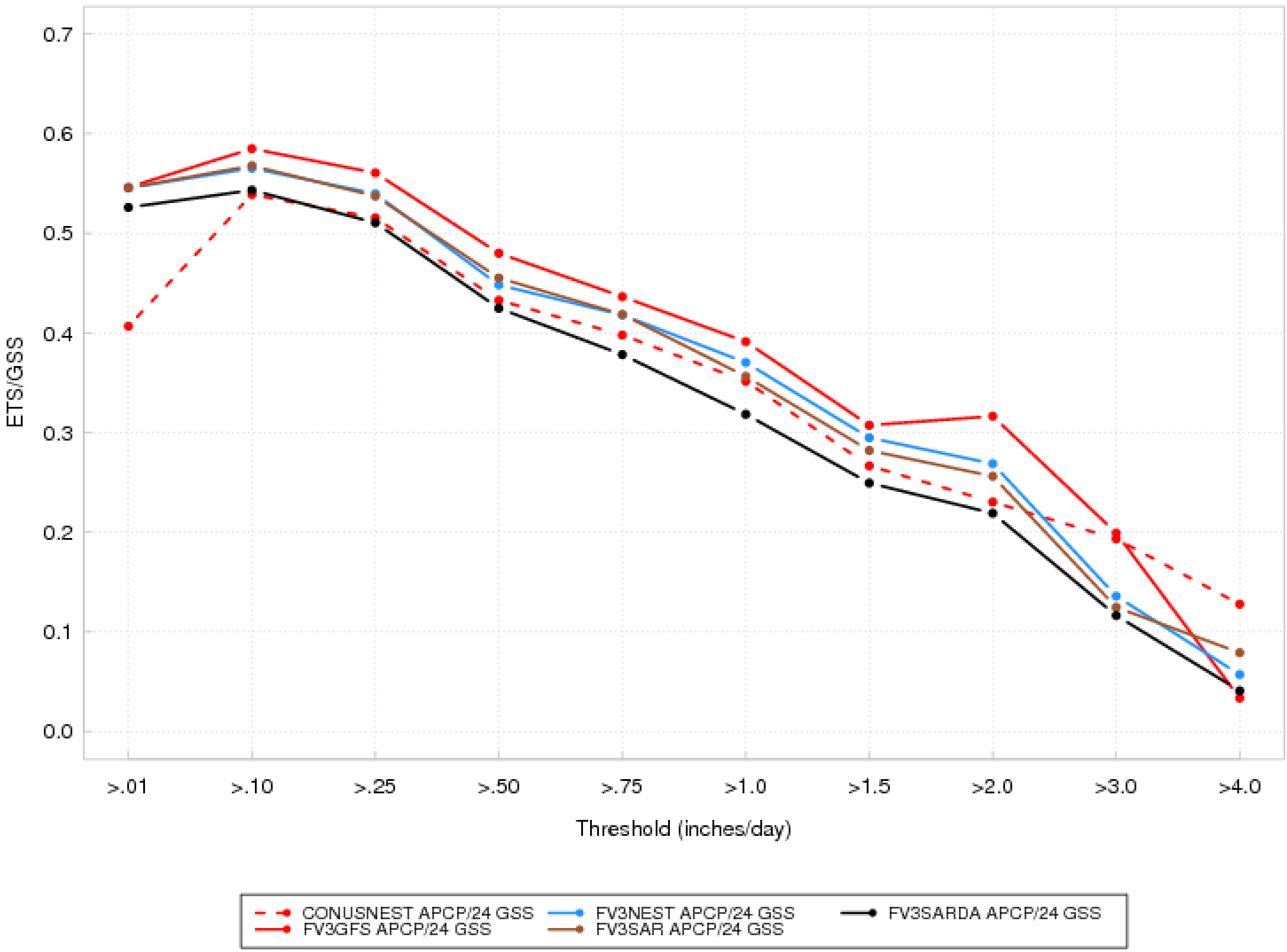
Composite
Reflectivity

1 May 2019
0000 UTC

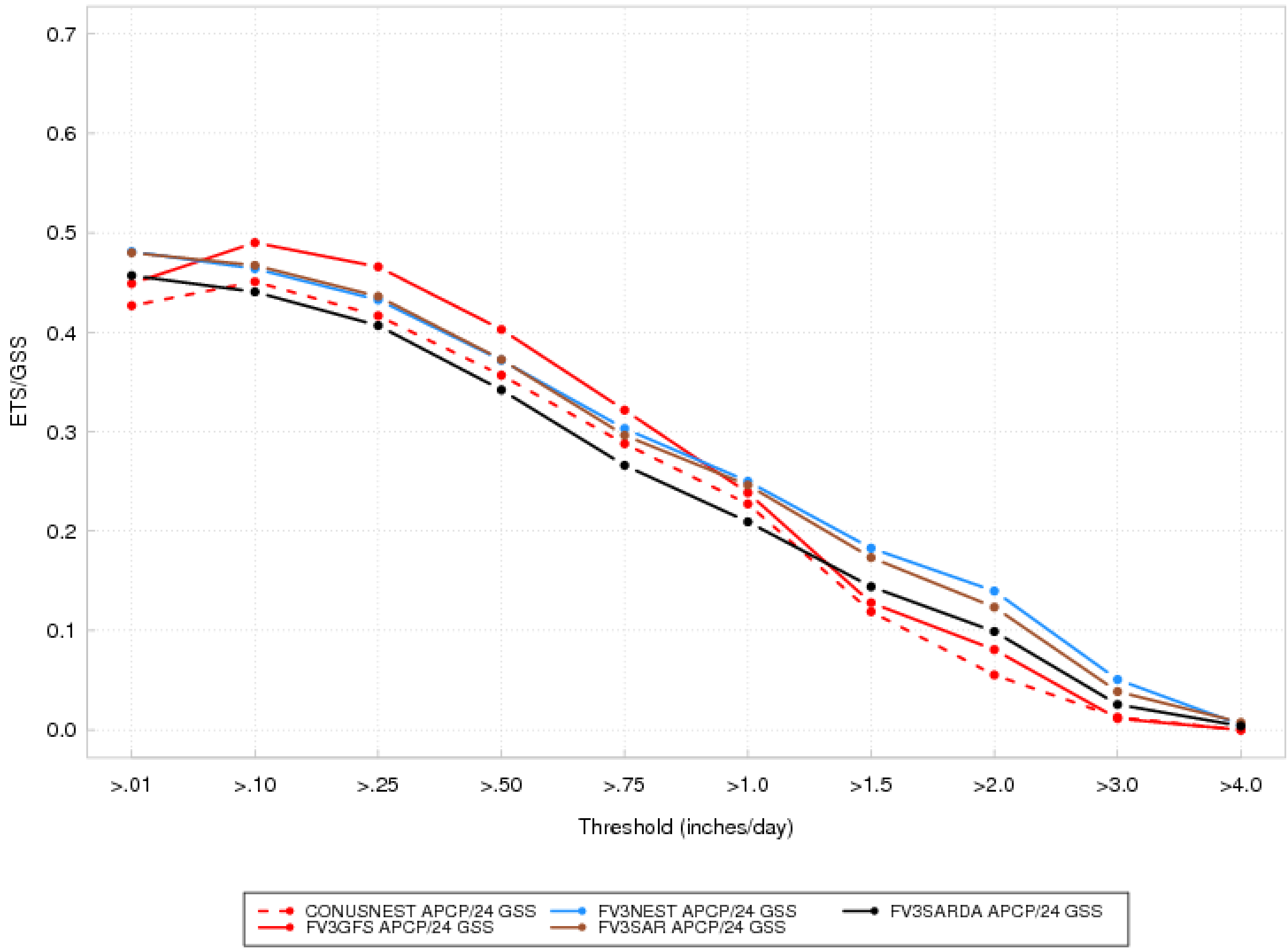
Compare FV3 regional and nest precipitation statistics with FV3GFS and NAM CONUS Nest

Equitable Threat Score and Bias

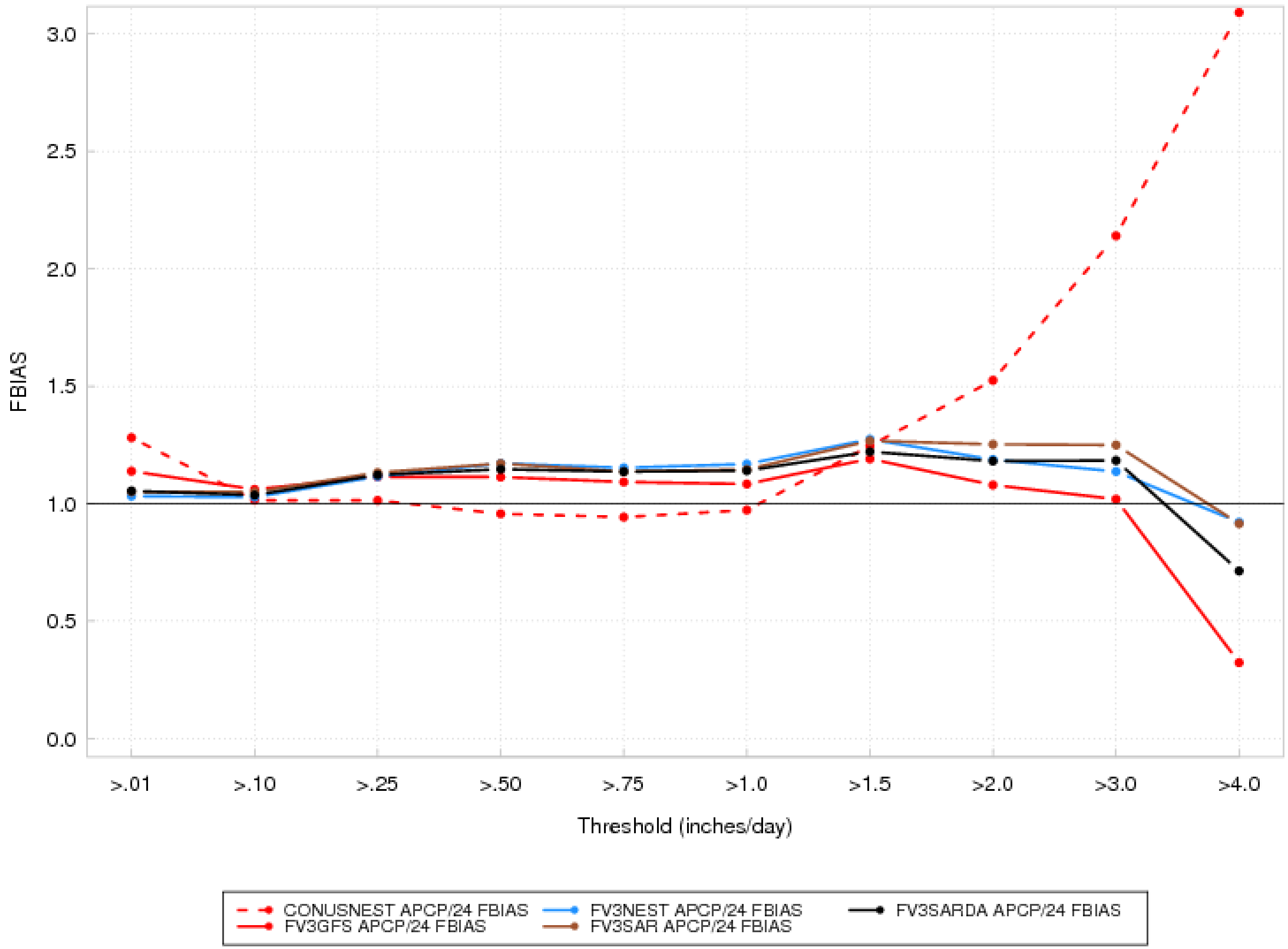
24h ETS, 36/60h fcsts valid January 2019

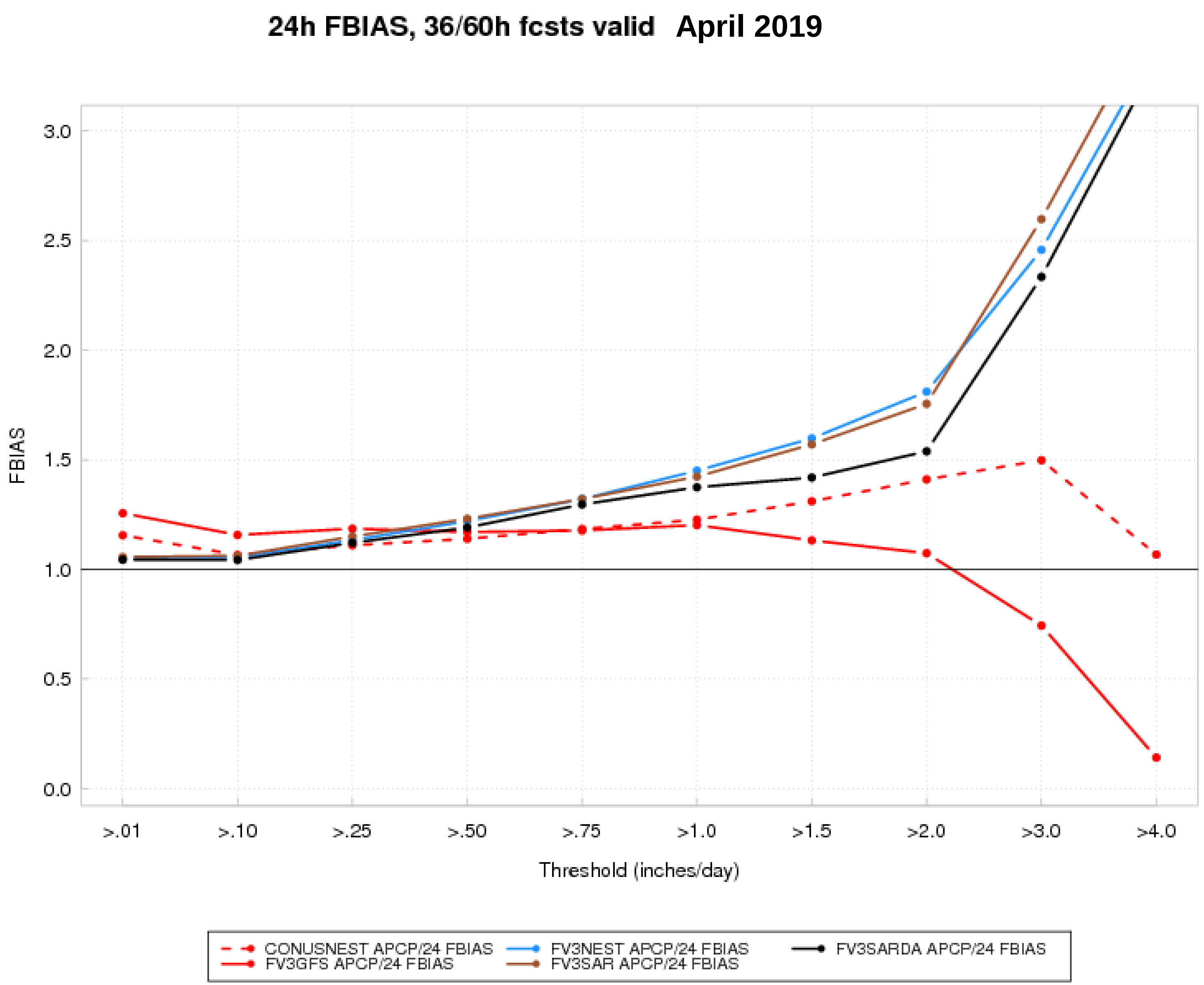


24h ETS, 36/60h fcsts valid April 2019



24h FBIAS, 36/60h fcsts valid January 2019




24h FBIAS, 36/60h fcsts valid April 2019
FBIAS
3.0
2.5
2.0
1.5
1.0
0.5
0.0
>.01
>.10
>.25
>.50
>.75
>1.0
>1.5
>2.0
>3.0
>4.0
Threshold (inches/day)
CONUSNEST APCP/24 FBIAS
FV3GFS APCP/24 FBIAS
FV3NEST APCP/24 FBIAS
FV3SAR APCP/24 FBIAS
FV3SARDA APCP/24 FBIAS

FV3NEST vs. FV3SAR 24-h Precipitation Scorecard

0000 UTC 18 Dec 2018 to 0000 UTC 20 Mar 2019

Large green (red) **triangles**:

Nest is better (worse) at 99.9% significance level.

Small green (red) **triangles**:

Nest is better (worse) at 99% significance level.

Green (red) **shading**:

Nest is better (worse) at 95% significance level.

Gray **shading**:

No significant difference.

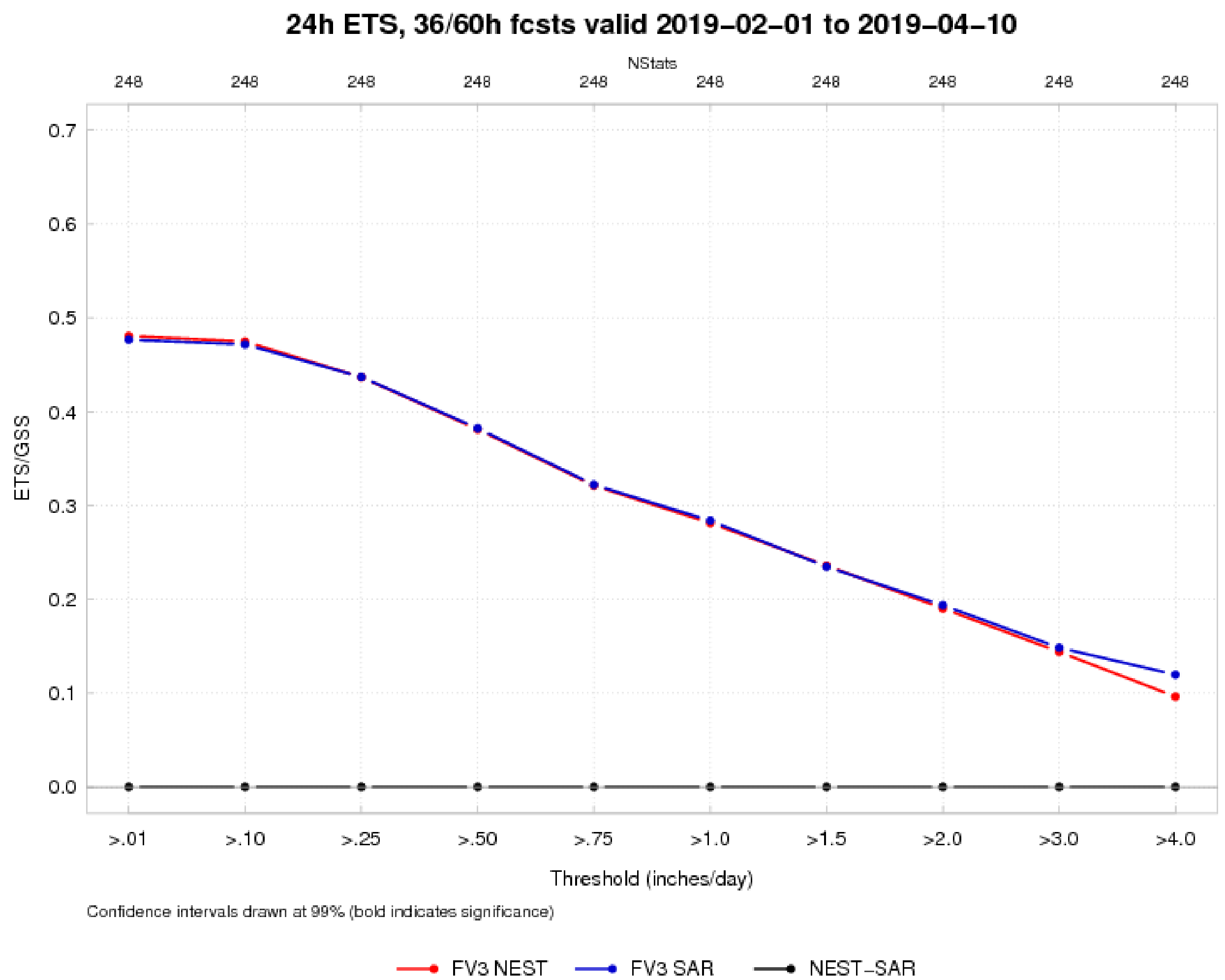
			CONUS	
			F36	F60
ETS	24-h Precip.	> .01 in.	▲	
		> .10 in.	▴	
		> .25 in.		
		> .50 in.		
		> .75 in.		
		> 1.0 in.		
		> 1.5 in.		
		> 2.0 in.		
		> 3.0 in.		
		> 4.0 in.		
Bias	24-h Precip.	> .01 in.	▲	▲
		> .10 in.	▲	▲
		> .25 in.	▲	
		> .50 in.		
		> .75 in.		
		> 1.0 in.		
		> 1.5 in.		
		> 2.0 in.		
		> 3.0 in.		
		> 4.0 in.		

36-h and 60-h forecasts

Contiguous U.S.

FV3-Nest vs. SAR

- FV3NEST vs SAR runs at 3km show *no statistically significant differences in QPF*
  - Confidence that SAR configuration is correct with no major issues
- Next steps:
  - Extending the analysis into the lateral boundaries for consistency
  - Blending algorithms



Computational Speed / Resources

The regional FV3:

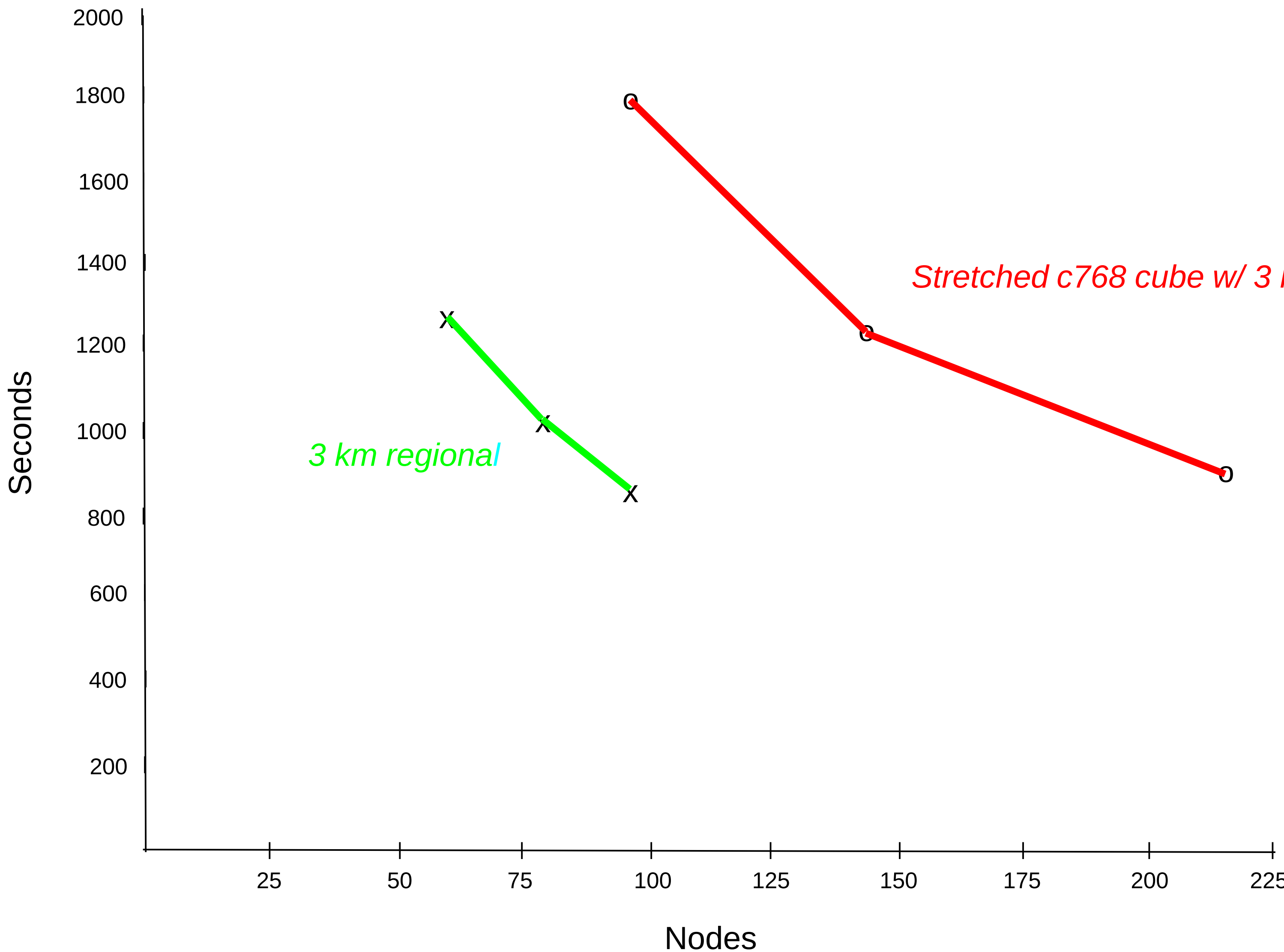
- Runs in about half the time of the nest/global for a given set of resources.

- Uses about half the resources of the nest/global for a given run time.

FV3GFS 24-hr Forecast Clocktimes

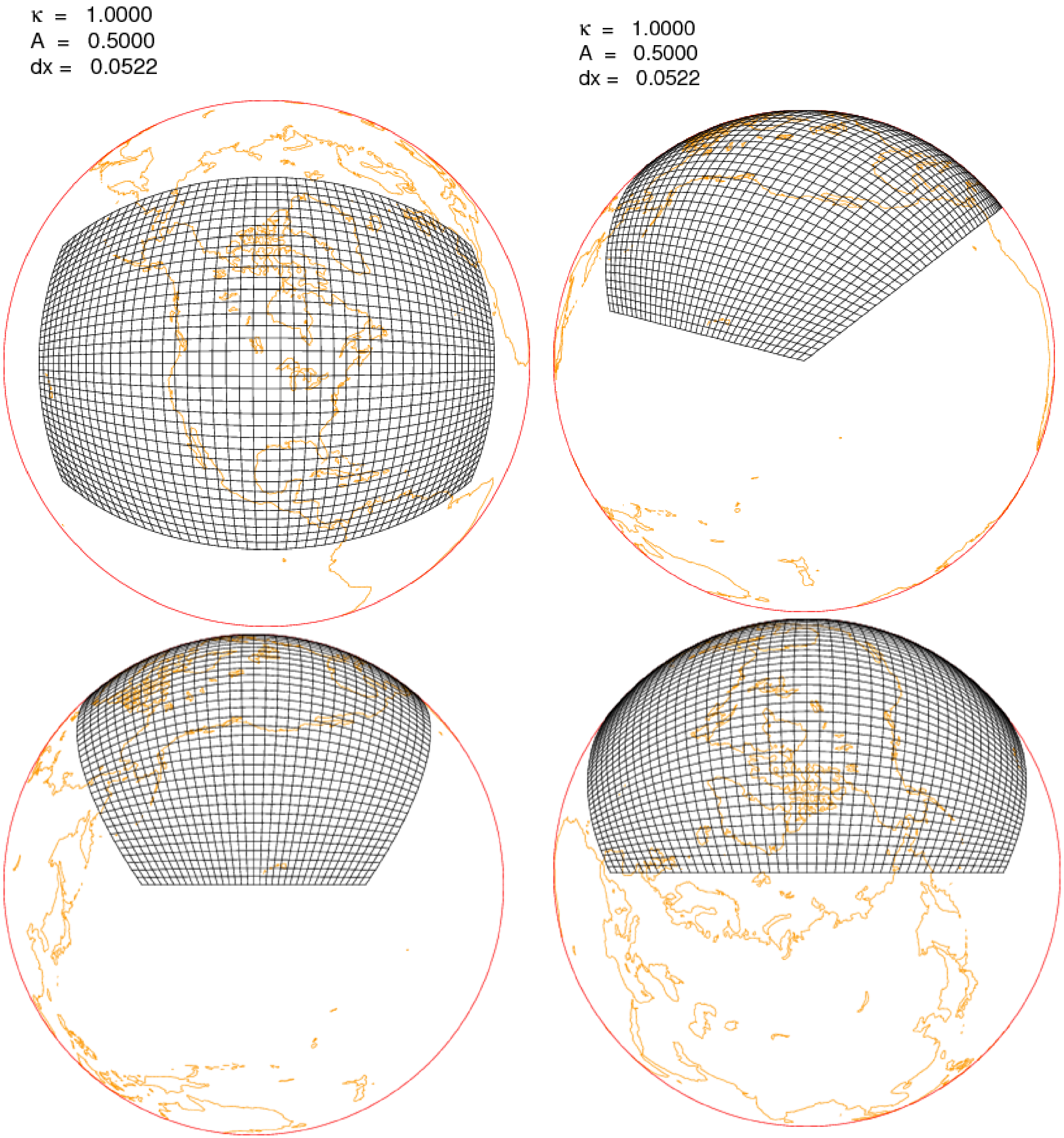
WCOSS Cray

No History Writes



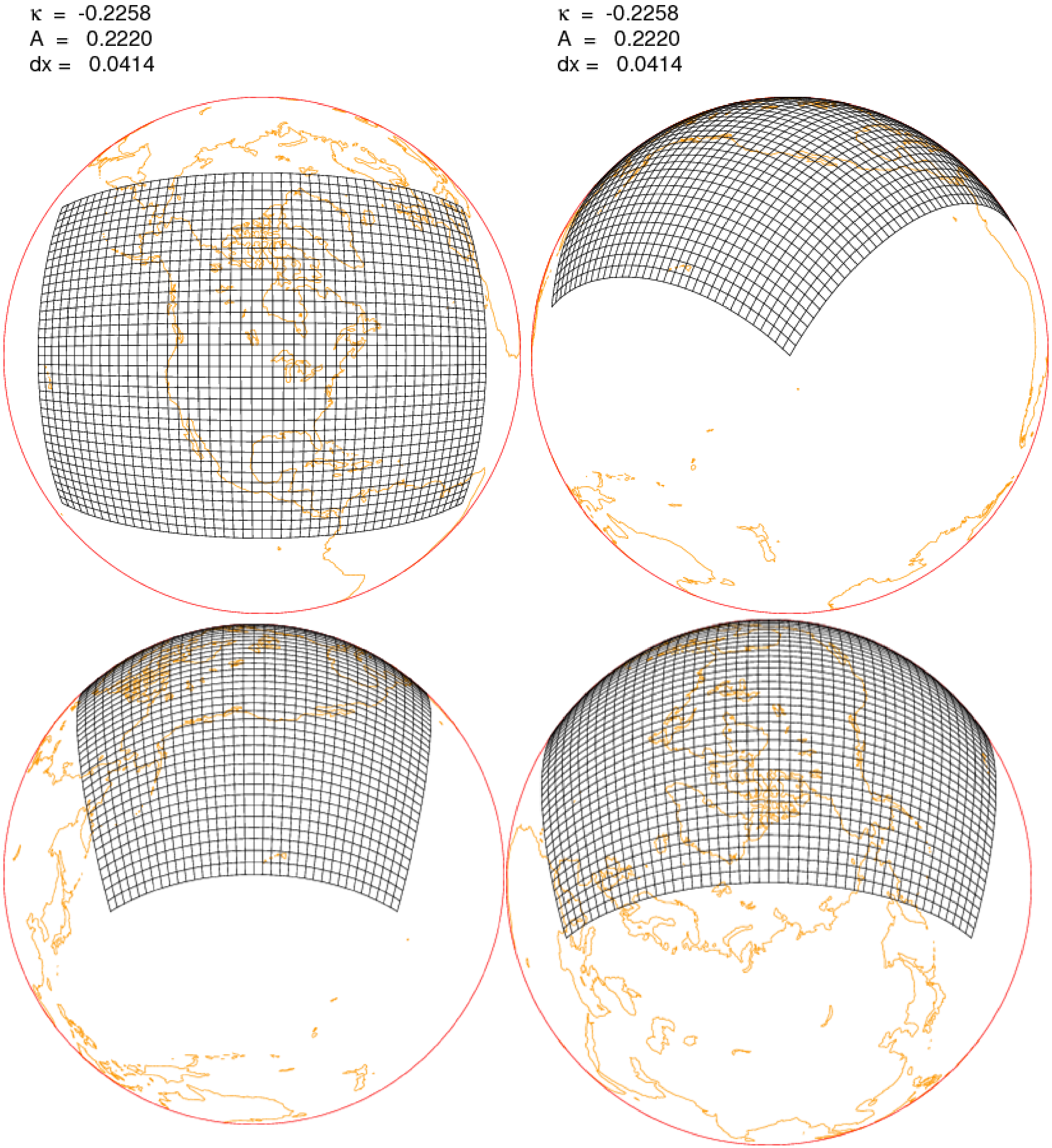
Variation in Grid Cell Area

- The regional FV3 domain was originally constructed to be similar to a nest without a global parent but still on the global gnomonic projection.
- For large domains the area of the grid cells can vary significantly between the center and edge of those domains due to the gnomonic projection of the global cube.
- A method has been devised to greatly reduce that variation in grid cell area on large regional domains. There is no association with the global cube's projection.



Views of a regional domain lying on the same projection as a parent cube, i.e., the same as a nest.

Courtesy of Jim Purser

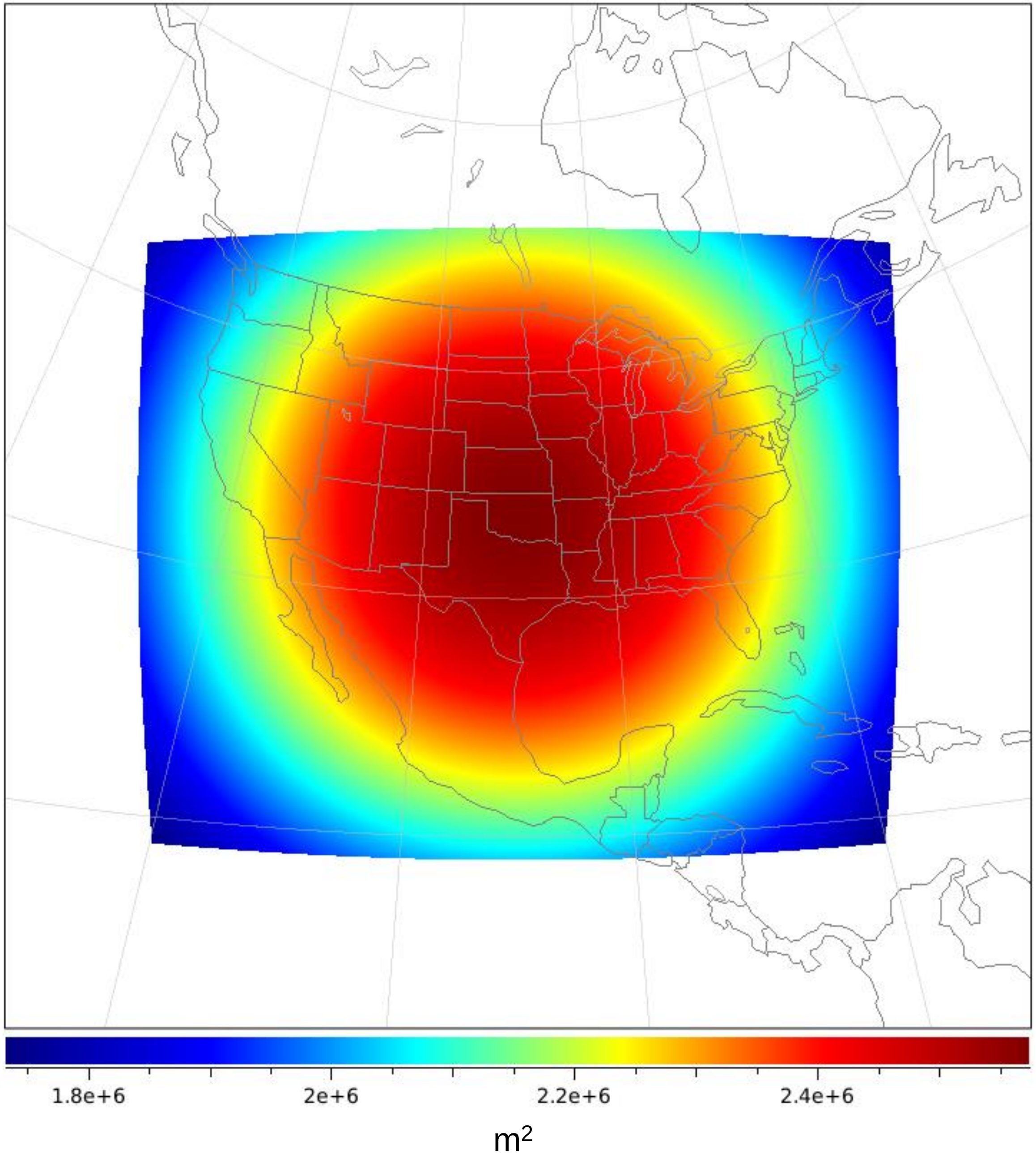


Views of a regional domain independent of a parent cube and modified to reduce grid cell area variation.

Courtesy of Jim Purser

Grid Cell Area on Parent-Oriented 3 km Regional FV3 Domain

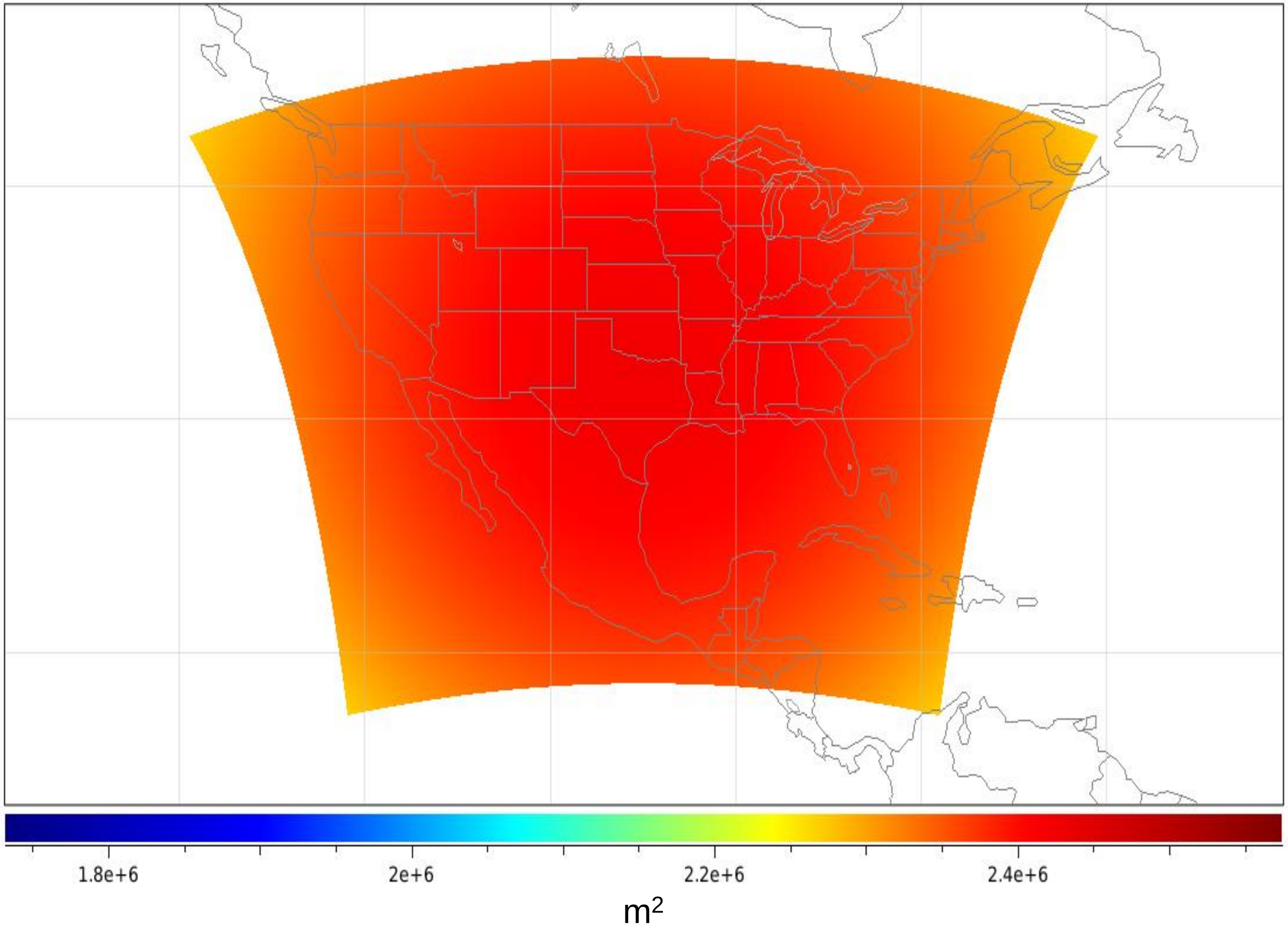
Uses stretched C768 cube projection.



Variation is ~45%

Grid Cell Area on Modified Regional 3 km FV3 Domain

Independent of C768 cube projection.



Variation is ~7%

Same color range as in previous slide.

Summary of Ongoing and Planned Regional FV3 Work

- Daily runs continue of the 3 km regional FV3 with an identical domain to nest runs.

  http://www.emc.ncep.noaa.gov/mmb/bblake/fv3/

  Soon testing will begin of regional runs using the modified domains to reduce grid cell area variation.

- Test inclusion of boundary rows in the data assimilation to remove imbalance seen in the early hours of the regional forecast.

- Add blending between the boundary and the outermost rows of the integration.

- Past cases are being investigated with particular scrutiny of microphysics and boundary layers schemes at mesoscale resolutions.

- Collaborating with other groups on testing regional FV3 for Convective Allowing Model forecasts.

Jim Purser's Description of Regional Grid Modification to Reduce Variation of Grid Cell Area

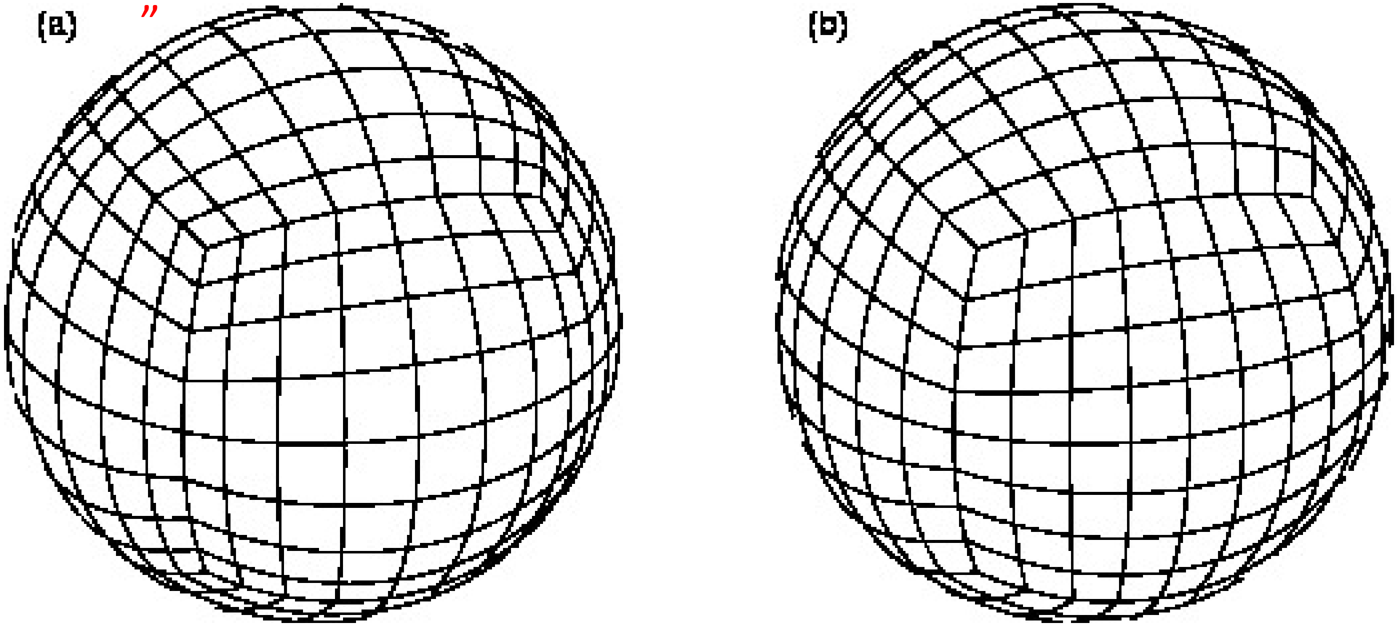
Parameterizing grids on the sphere derived by Schmidt transforms of gnomonic grids.

The family of grids that are of interest to us are rectangular subdomains, uniformly discretized, and transformed to the surface of the sphere via simple transformations defined by just two nontrivial continuous parameters.

One of these parameters can best be thought of as determining the variation in the spacing between grid lines of each of the intersecting pair of families.

The second parameter can be thought to "stretch" the grid on the sphere, often to give preferential resolution to a region of interest, or, as in our case, to help to minimize the overall pattern of distortions in the grid that are an inevitable consequence of placing any discrete grid on a spherically curved surface.

“EQUIDISTANT ” “EQUIANGULAR”

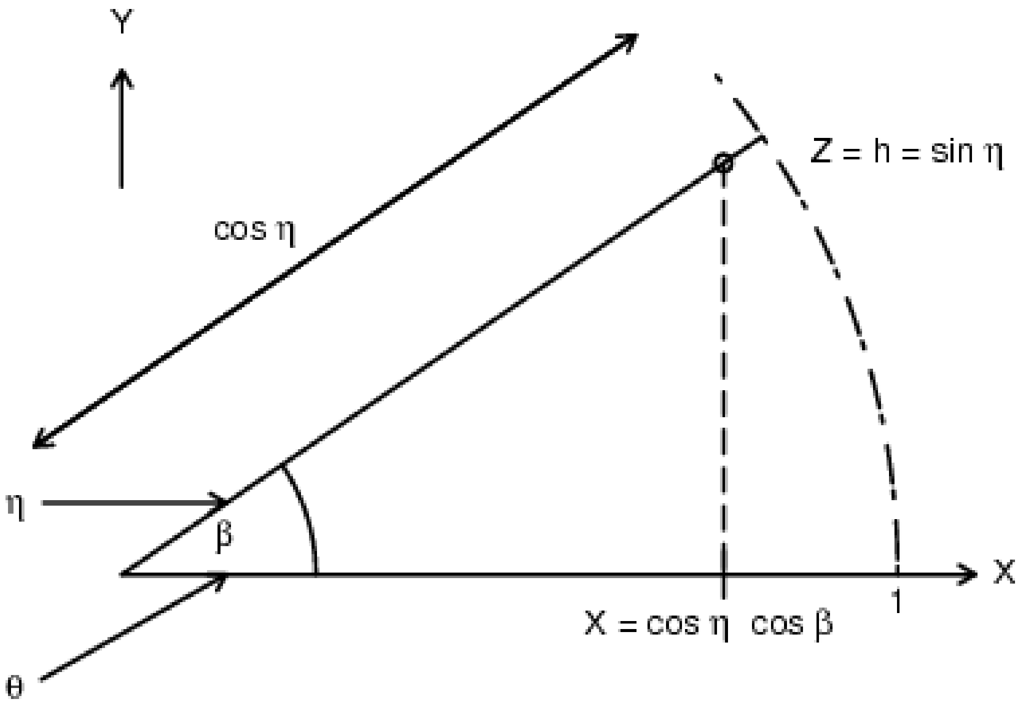


For purely cubic grids (without stretching, so that the cubic symmetry is preserved) the common gnomonic grids include the “equidistant” form (a) whose projected lines on the surface of the tangent cube are spaced equidistantly, and the “equiangular” form (b) whose fan of planes through the center of the Earth subtend angles there that change by equal increments.

It is convenient to include both cases within a single family, continuously parameterized by a real number, B. For the case (a), the parameter is B=0, and for case (b), B=1, but other values of B are also allowed; for example, the FV3 global model presently uses B=1/2.

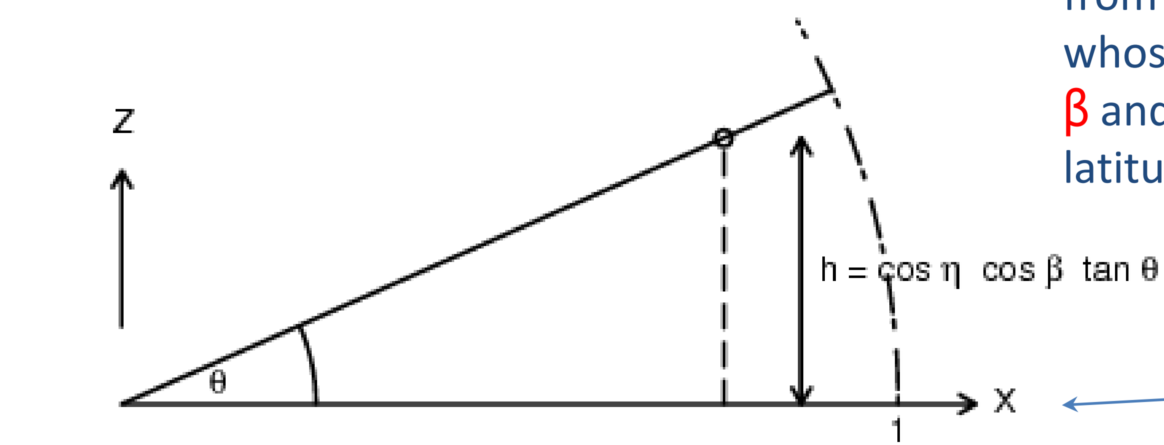
As a visual comparison of the panels of the figure suggests, this B governs the profile of spacing between the grid lines between the middle and edge of each tile.

Geometrical interpretation of gnomonic grid-spacing parameter $B=[\cos(\beta)]^{1/2}$:



Polar view of cube's tile (face) centered at **X=1, Y=Z=0** (earth-centered Cartesians).

The longitude, β, relative to the tile center, is the great-circle arc along which the grid points are uniformly spaced (equal angles of their latitudes, η, there). If β**=0**, hence **B=1**, then this corresponds to the "equiangular" case.



The same configuration viewed from the (west) side. The grid line whose latitude is η at longitudes β and $-\beta$, attains it maximum latitude, θ, at the tile median.

Equator

The algebraic relationship connecting the coordinate, **y**, of a grid line to the angle, θ, in the case where the range of **y** is scaled to go from -1 to +1 between the edges of the cube, can be deduced directly from the Euclidean geometrical picture of the previous slide:

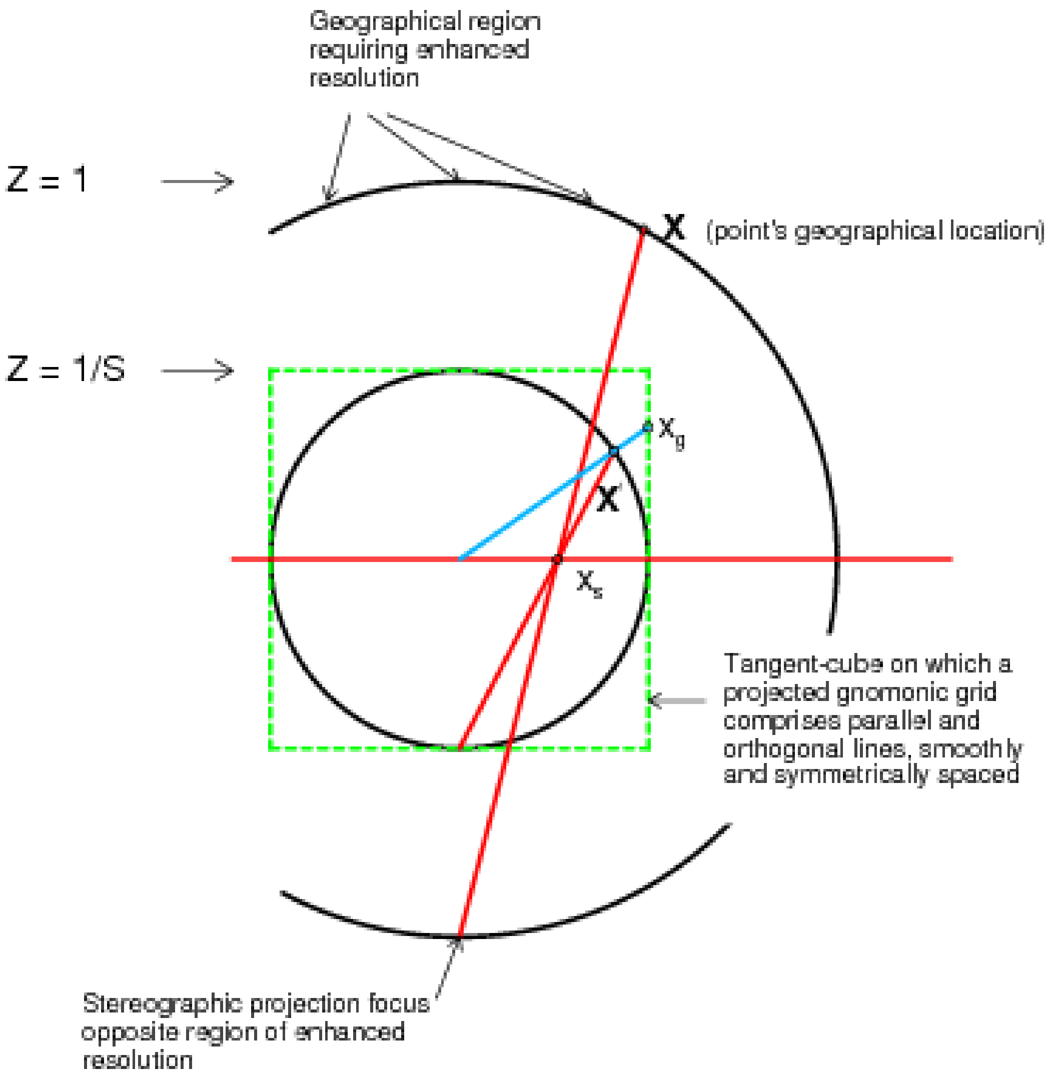
$$\tan(\theta) = \tan[\arctan(B^{1/2})\, y]/B^{1/2}$$

We need not restrict the validity of this formula only to “geometrical” cases where **B** is the square of the cosine of an angle – the algebraic consistency persists even when **B>1**. It is less obvious, but nevertheless true, that the algebraic consistency is maintained even when **B<0** (although we must have **B> -1**). But, in order to avoid having to deal with imaginary numbers, it is then more convenient to rewrite the formula, when **B<0**, as the equivalent:

$$\tan(\theta) = \tanh[\operatorname{arctanh}((-B)^{1/2})\, y] /(-B)^{1/2}$$

A second parameter, conventionally referred to as the Schmidt enhancement factor, **S**, controls the degree of grid stretching of the global configuration so that a selected region can be endowed with an enhancement of the grid resolution (at the expense of the antipodal region).

Geometrical interpretation of conventional Schmidt (1977) transformation with enhancement factor S



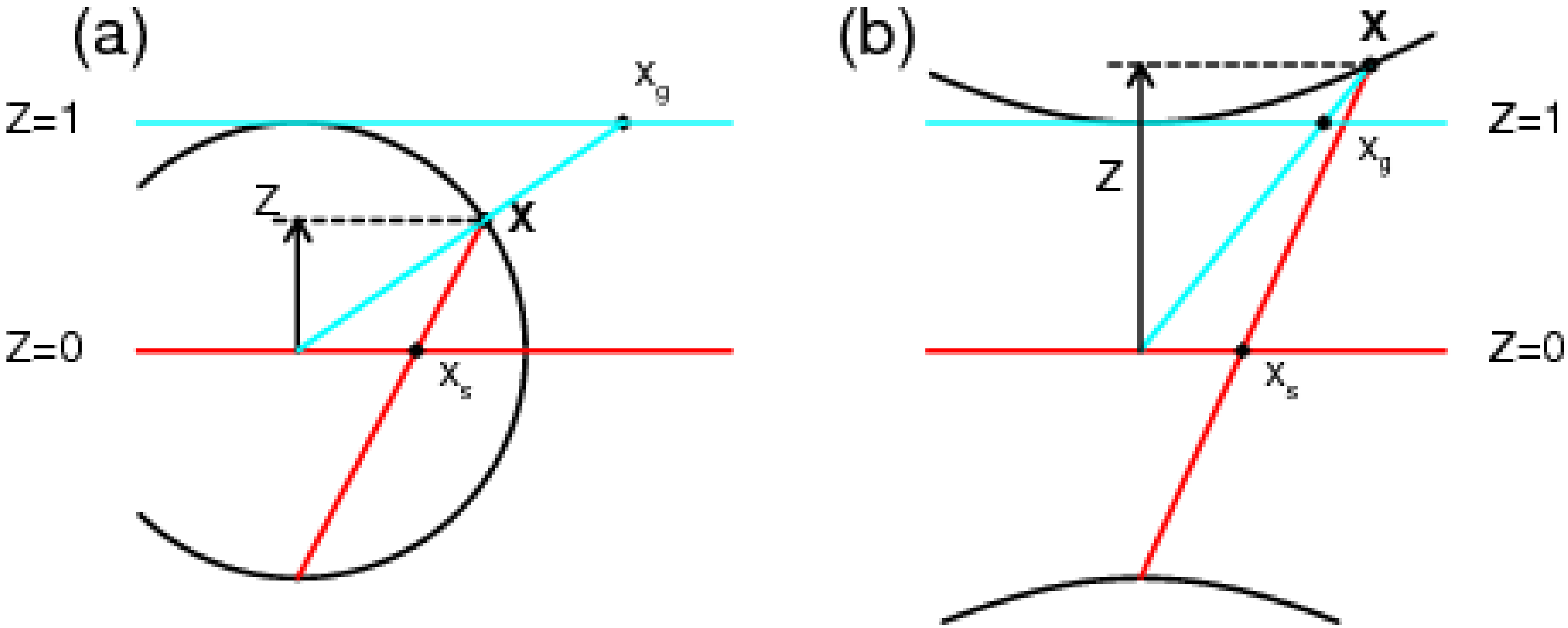
A stereographic projection of a point, **X**, on the unit-radius Earth to $\mathbf{x_s}$ on the stereographic (equatorial) plane is followed by an inverse-stereographic mapping to **X'** on a sphere reduced in size by the Schmidt factor, **S**. Assume the discretization is of a symmetrical and approximately uniform kind on this smaller sphere . E.g., a gnomonic (central) projection connects **X'** to a point, $\mathbf{x_g}$, on the surface of the tangent-cube. On this cube, a grid of smoothly-spaced parallel and orthogonal lines, would implicitly discretize the original sphere ("Earth"), via these transformations , so as to enhance the resolution by a factor **S** in the geographical region indicated.

Schmidt, F., 1977: Variable fine mesh in spectral global models. *Beitrage zur Physik der Atmosphare*, **50,** 211—217.

Unconstrained by the topological restrictions of the global domain, there is no impediment to generalizing the Schmidt transform to include the case where the gnomonic grid on the pseudo-sphere (of an appropriate "radius") is first stereographically-projected to the common equatorial plane, then back-projected by an ordinary inverse-stereographic mapping to the Earth. This combined maneuver is mathematically equivalent to the case where the Schmidt enhancement factor becomes **imaginary**!

Keeping parameters conveniently real, we replace that factor, S, by its square, κ – equal to the constant **Gaussian curvature** (relative to that of the Earth) of whichever surface (sphere or pseudo-sphere) was chosen to define the construction of the gnomonic grid framework. For the cases where $\kappa = S^2 > 0$, the gnomonic grid lines correspond to geodesic great-circles on the image sphere of radius **1/S**. For $\kappa<0$, the gnomonic grid lines are also geodesics, but now of the pseudo-sphere with this negative Gaussian curvature. The intermediate case, $\kappa=0$, corresponds to an orthogonal grid of straight line geodesics on the stereographic plane itself.

In order for our parameter space to not exhibit singular behavior as our new parameter, κ, passes through zero, it is desirable to simultaneously replace the grid-spacing parameter, B, by the new parameter, $A = \kappa * B$.

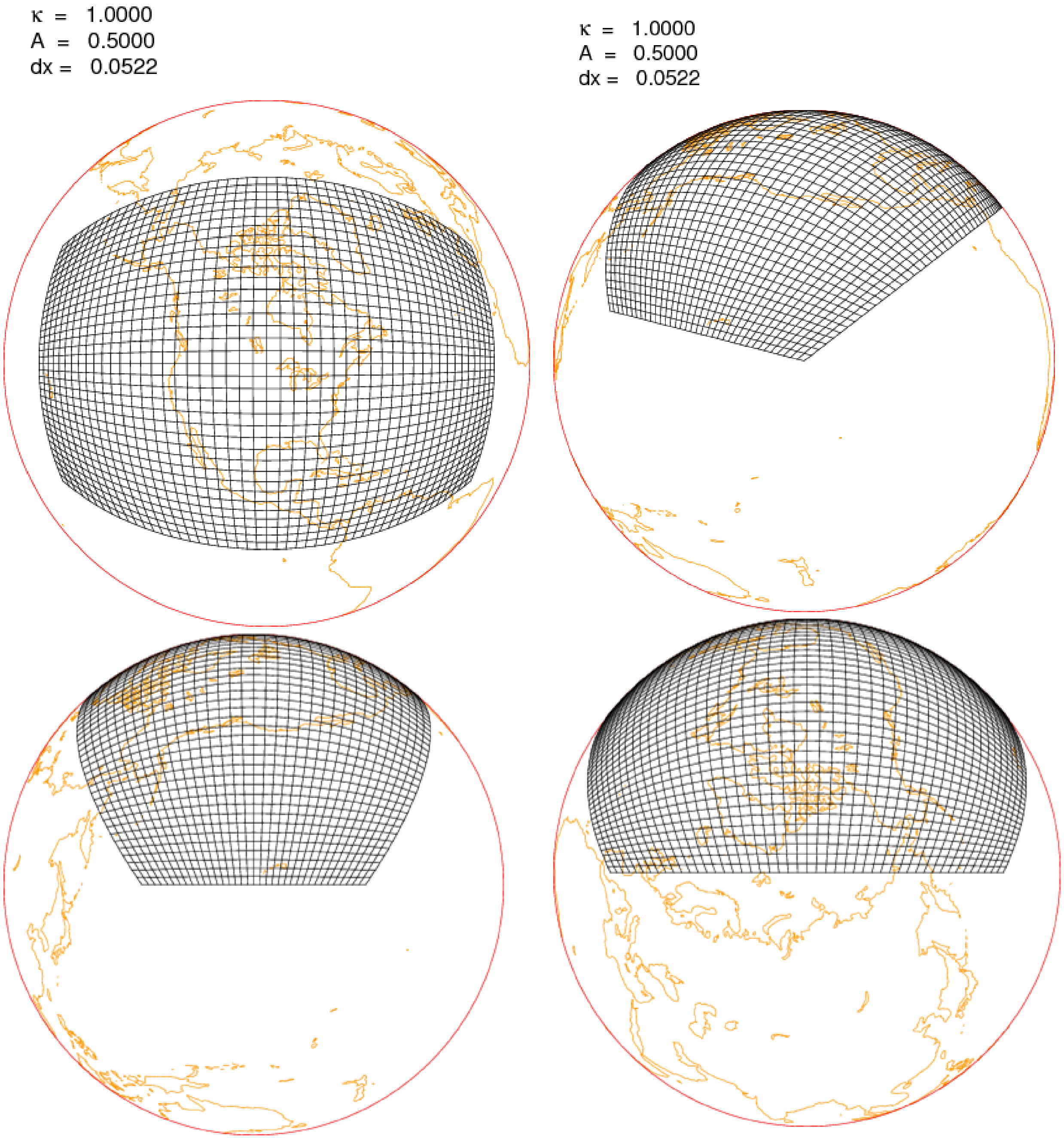


For the unit sphere, a point **X** stereographically projects as shown onto an image $\mathbf{x_s}$ on the equatorial ("stereographic") plane, or, by a change of the projection focus to the center, to an image, $\mathbf{x_g}$, on the gnomonic mapping plane **Z=1**. The conventional spherical case, for a sphere of unit radius, is shown in panel (a).

But exact analogues of both these projective mappings (**stereographic** and **gnomonic**) exist also for the pseudo-sphere. A simple geometrical model of this surface of constant **negative** curvature, illustrated for the case of unit "radius" in panel (b), is the hyperboloid of two sheets endowed with the pseudo-Euclidean metric,

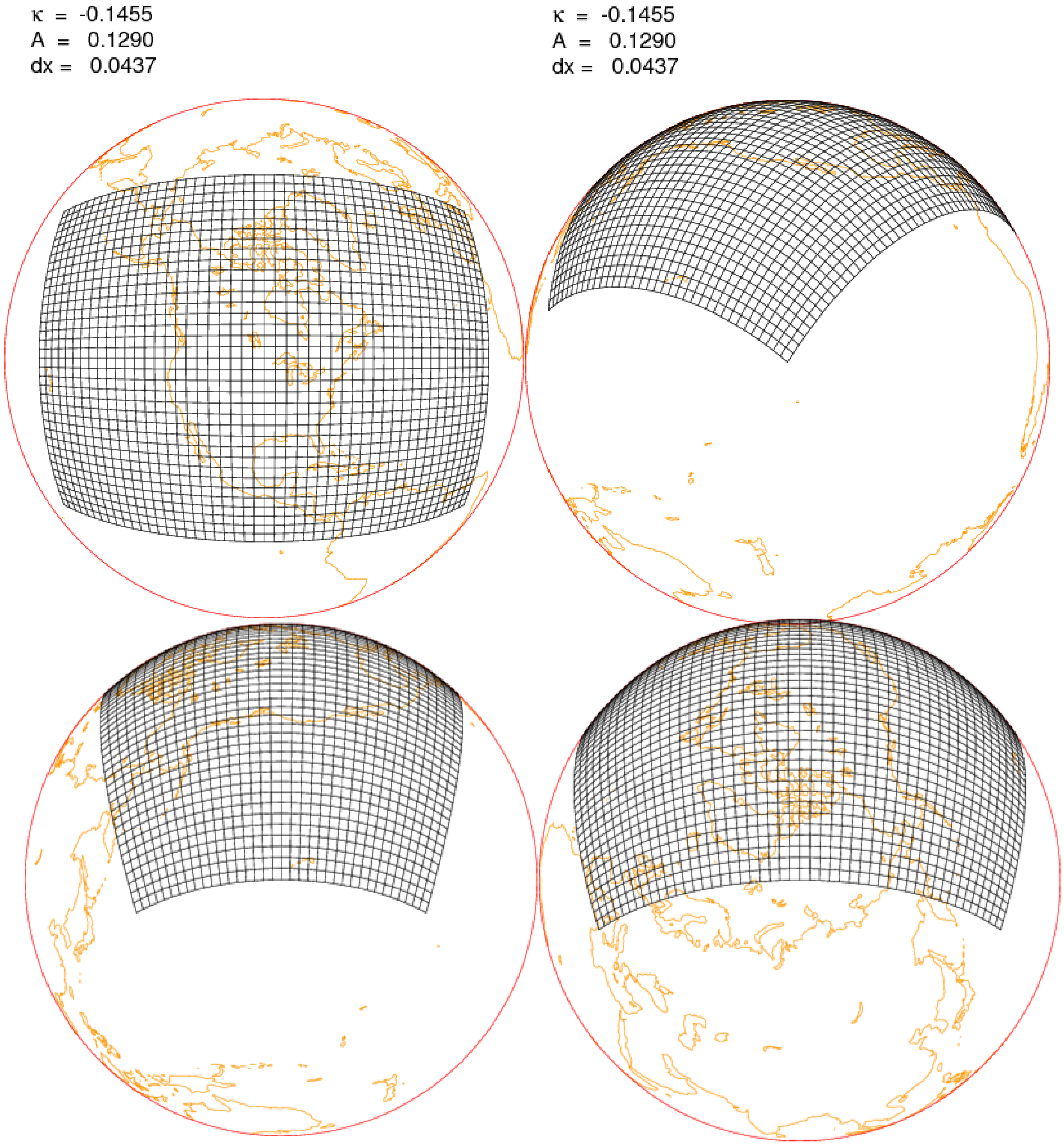
$$ds^2 = dX^2 + dY^2 - dZ^2.$$

Gnomonic grids centrally project to each tangent plane (here, at **Z=1**) as straight parallel and orthogonal lines.



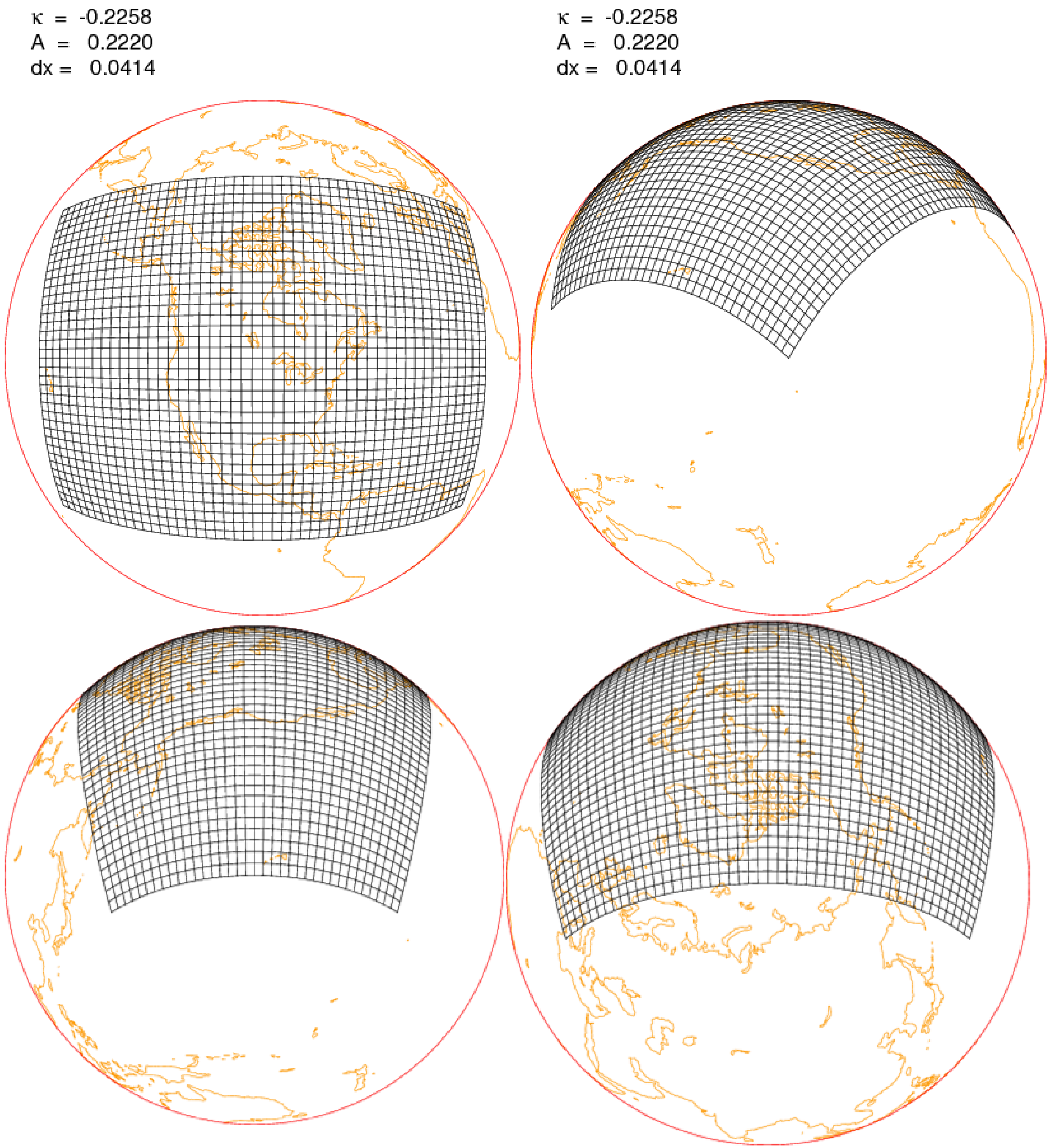
If the same projection used to construct the FV3 cubed sphere grid is naively adopted to create a large stand-alone rectangular domain, the distortions of the grid at the edges, and especially at the extremely obtuse-angled corners, become unacceptably severe.

(Recall that the new grid-spacing parameter is defined A = κ*B, which technically regularizes the new (A,κ) parameter space. Here, κ=1, so A=B, in this example.)



We can exploit the freedom to choose the gnomonic mapping parameters, **A** and κ, in the standalone rectangular domain, unconstrained by the need for tiles to "join" in a cube.

Using an objective criterion of optimality to reduce one measure of integrated grid distortion, the "best" grid has a small negative kappa, which gives the corners of the domain an acute angle and allows the edges to "flare" so as to reduce the pinching of grid lines there.



A slightly different criterion of grid optimality (that penalizes disparities of grid cell sizes more than the other components of grid distortion) leads to a small change in the "best" **A** and κ parameters, but a qualitatively similar appearance of the grid as a whole.