State of FV3 CAM Development

4 November 2018

Curtis Alexander and team

NOAA/ESRL/GLOBAL SYSTEMS DIVISION

UFS CAM Working Group

Contributions from NSSL/EMC

UFS CAM WG Membership

- *Curtis Alexander ESRL/GSD ***
- *Jack Kain EMC ***
- *Lou Wicker NSSL***
- *Lucas Harris GFDL***

- Eric Rogers EMC
- Jacob Carley EMC
- Geoff DiMego EMC
- Adam Clark NSSL
- Israel Jirak SPC
- SJ Lin GFDL
- Stan Benjamin ESRL/GSD
- Sundararaman Gopalakrishnan AOML
- Andy Hazelton AOML

- Dave Stensrud PSU
- Ming Xue OU/CAPS
- Xuguang Wang OU/SoM
- Jaime Wolff NCAR/DTC
- Glen Romine NCAR/MMM
- Bill Putman NASA/GMAO
- Gary Lackmann NC State
- Vittorio Gensini NIU

*Co-Chair ***

Project Summary Overview

Development of NGGPS/UFS Programmatic Planning Documents

- CAM Strategic Implementation Plan (SIP) Annex
- CAM Verification Metrics
- CAM Test Plan
- CAM User Support

Development of Stand Alone Regional (SAR) FV3 Software

- Regional mesoscale and storm-scale (CAM) applications
- Pre-processing of externally-provided initial and boundary conditions
- Integration and output of SAR FV3 on “mimicked” operational regional mesoscale and storm-scale grids
- Use of operational CAM physics packages through CCPP
- Post-processing of SAR FV3 output including GRIB2 grids and graphics
- MET verification of SAR FV3 output
- End-to-end SAR FV3 workflow/scripts and documentation
- Evaluation of SAR FV3 forecasts including one-off case studies, retrospective periods and real-time comparisons
- Baseline for evaluation using operational regional mesoscale and CAM forecasts (e.g. RAP and HRRR)
- Conduct early-developer SAR FV3 workshop

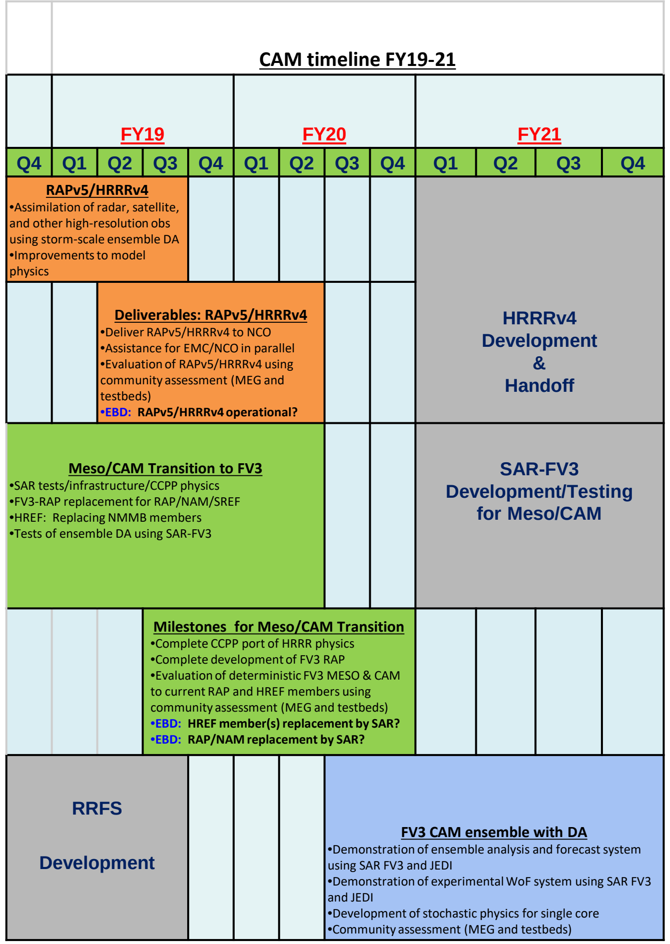
Development of UFS CAM SIP

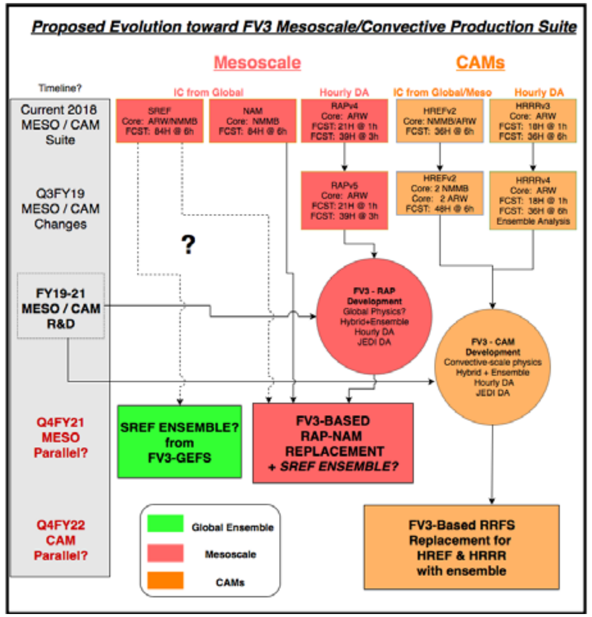
CAM SIP FY19-21

Project 7.1: Implementation of the RAPv5/HRRRv4 CAM ensemble analysis and hybrid deterministic HRRR forecast system

Project 7.2: Development of a SAR FV3 Meso/CAM replacement systems for NAM/RAP/HREF-Member

Project 7.3: Developing a full CAM-scale ensemble DA and prediction system based on the SAR FV3 system





Target FY22 for Rapid-Refresh Forecast System (RRFS) based on SAR FV3 and JEDI to replace NAM/RAP/HRRR/HREF

Draft UFS CAM Verification Metrics (1 August 2018)

Vertical Temporal Attributes

Validation Source

Priority and Readiness Rankings

Scores and Stratifications (scales, times, thresholds)

Forecast Field	Application	Vertical Attribute	Temporal Attribute	Validation Source	Priority/Importance	Maturity/Readiness	Deterministic Methodology	Deterministic Scores	Deterministic Stratifications	Ensemble Methodology	Ensemble Scores	Ensemble Stratifications
Downward Shortwave Radiation	Air Quality/Energy Land Surface	Surface	Instantaneous/Average	ARM, Surfrad (Oak ridge, ameriflux), USCRN	3	1	Grid-to-Point	RMSE, BIAS	sub-regions, Need to average in time			
Ceiling	Aviation	Column	Instantaneous	METARs	1	1	Grid-to-Point	CSI, BIAS, FSS, POD, FAR, AUR, Performance Diagram	Forecast Length [0-36 hr], Threshold [500, 1000, 3000, 5000, 10000 ft], Domain [W and E CONUS]	Point probability, HIRA? (see MET documentation for neighborhood around ob points)	Briar Score, Briar Skill Score (other ensemble reference), Reliability, Sharpness, CRPS, CRPSS (other ensemble reference)	Smoothing [? km], Probabilities [0, 5, 10, ...100]
Echo Top Height	Aviation	Column	Instantaneous	MRMS Echo Top	2	1	Grid-to-Grid	CSI, BIAS, FSS, POD, FAR, AUR, Performance Diagram	Forecast Length [0-36 hr], Threshold [20,25,30,35,40 kft], Scale [03, 40 km], Domain [W and E CONUS]	Neighborhood probability	Briar Score, Briar Skill Score (other ensemble reference), Reliability, Sharpness, CRPS, CRPSS (other ensemble reference)	Neighborhoods [10, 20, 40, 80 km], Smoothing [? km], Probabilities [0, 5, 10, ...100]
Visibility	Aviation	Surface	Instantaneous	METARs	1	1	Grid-to-Point	CSI, BIAS, FSS, POD, FAR, AUR, Performance Diagram	Forecast Length [0-36 hr], Threshold [0.5, 1.0, 3.0, 5.0, 10.0 mi], Domain [W and E CONUS]	Point probability, HIRA? (see MET documentation for neighborhood around ob points)	Briar Score, Briar Skill Score (other ensemble reference), Reliability, Sharpness, CRPS, CRPSS (other ensemble reference)	Smoothing [? km], Probabilities [0, 5, 10, ...100]
CAPE/CIN	Environmental	Mixed, Most-Unstable, Surface-Based	Instantaneous	RAOB	2	1	Grid-to-Point	RMSE, BIAS	Forecast Length [0-36 hr], Diurnal [00,12 Z], Domain [W and E CONUS]	Ensemble arithmetic mean, standard deviation of ensemble members vs mean (ensemble spread), ob error, ensemble spread + ob error (total spread), standard deviation of ensemble mean vs obs (ensemble error), bias of ensemble mean vs obs (ensemble bias), RMSE and BIAS of each member (ensemble design)	Spread-skill ratio, rank histogram?	

Pre-implementation decision making is initial emphasis

Holistic set of CAM forecast fields/applications: Environmental, Severe, Precip/Winter, Aviation, Energy, Air Quality

Total of thirty CAM forecast fields identified

Eleven high-priority and high-readiness CAM fields identified

Development of UFS CAM Programmatic Planning Documents

Draft UFS CAM Test Plan
(1 August 2018)

Pre-implementation decision making is target application

Relatively immature document

CAM Working Group will resume development in the coming month(s)

UFS CAM User Support

CAM Working Group discussing many fundamental questions…

Test Plan for Evaluating a Stand Alone CAM Configuration for the UFS

- Contacts: Curtis Alexander (curtis.alexander@noaa.gov),
- Date of plan: Drafted July 30, 2018
- Introduction
  - Background: As part of the NWS commitment to move towards a Unified Forecast System (UFS), NCEP's Regional/Mesoscale Modeling Suite will transition to use a high-resolution (CAM) version of the FV3 dynamic core, both for the modeling and data assimilation components. A Stand Alone Regional (SAR) FV3 capability will be matured to facilitate low-observation-latency frequently-updating data assimilation cycles for components of the regional modeling suite.
  - Motivation: Development of the NAM modeling system, including its high-resolution nests and the NMMB dynamic core, has been discontinued at NCEP. Similarly, the RAP, including its nested HRRR system and its ARW dynamic core, will be frozen at NCEP by the end of FY2019. However, operational execution of these modeling and associated DA systems will continue until comparable FV3-based systems are able to give similar performance.
  - Goals: Any decisions to sunset legacy modeling systems and/or implement new modeling systems will be based on the following criteria:
    - Do they provide similar or improved forecast guidance relative to current operational products and contribute to a more unified production suite? Group discussion about how to quantify "similar or improved" model performance, since some variables can improve and others do not? Group consensus is that we should focus on the best possible way to capture the most relevant/important metrics to inform the decision makers.
    - Are they afcan they be implemented from available HPC resources? If they are more expensive, are the forecast benefit(s) worth the added cost? There was some group discussion regarding whether one agency could handle all of the CPU for the FV3-CAM. Perhaps some HPC/workload can be allocated among different agencies (EMC, ESRL, etc.)
    - Can the forecast products meet operational delivery times?
    - Don't forget all end users, such as local WFOs, regional centers, national centers, private customers, air force, etc.
- Experiment design
  - Source codes (list code repositories and name of branches; when available, add tag names):

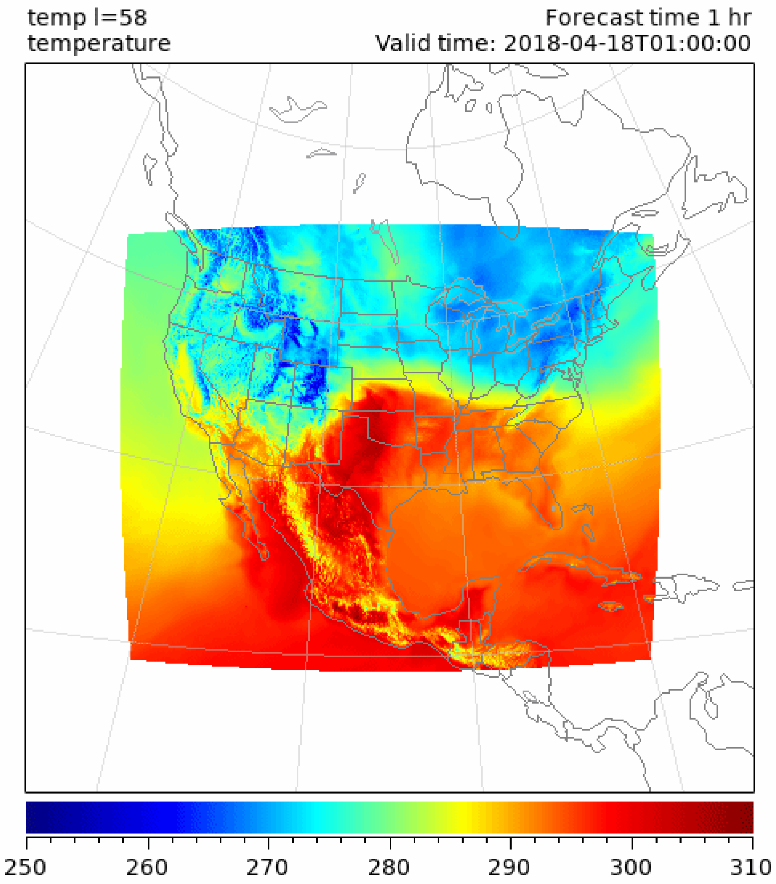
Development of Stand Alone Regional (SAR) FV3 Software

- Bi-weekly technical exchange meetings started in August including GSD, EMC, NSSL and GFDL
- Monthly in-person visits between GSD, EMC and NSSL personnel
- Initial SAR FV3 runs with GFS IC/BC executed
- FV3-SAR: Primary Modifications to FV3 Code (Material from Tom Black and Jim Abeles at EMC)
- The vast majority of changes to enable the regional capability have been placed in a single new module including:
  - 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
  - Restarting

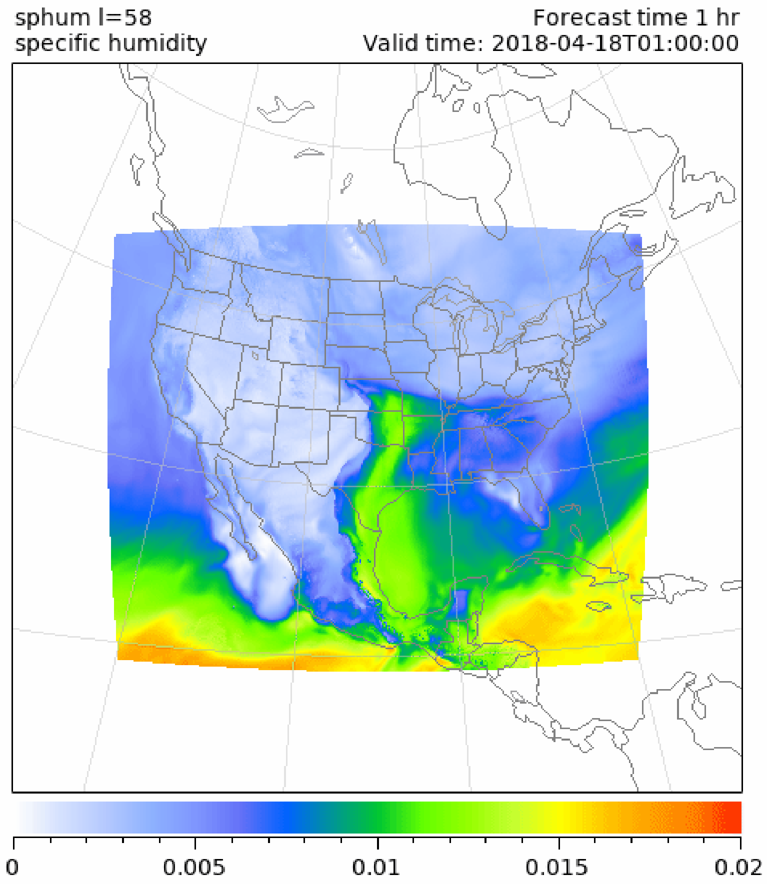
Development of Stand Alone Regional (SAR) FV3 Software

- Stand-alone regional FV3 test on NOAA Theia R&D HPC
- Nominal 3-km grid spacing
- 84-hr forecast
- 63 levels
- GFS initialization
- GFS physics
- Level 58 shown

Temperature



Specific Humidity



Forecast/graphics from Tom Black NOAA/NCEP/EMC

Development of Stand Alone Regional (SAR) FV3 Software

Development of external model pre-processor for SAR FV3 IC/BC using GRIB2 input

- Currently using existing WPS/NPS/NCL codes to transform GRIB2 model inputs to NetCDF IC/BC files
- NCL scripts initially developed to interpolate NetCDF IC/BC files from ARW/NMMB grid to SAR FV3 grid (GSD)
- Can also transform NetCDF files into nemsio files that chgres can use to map to SAR FV3 grid (NSSL)
- Need to bypass Ozone input field (not provided from models like RAP and HRRR)

Development of external model post-processor (UPP) for SAR FV3

- Currently using write component of FV3 to produce output on grids (RAP/NAM/HRRR) that UPP can process
- Need to develop UPP to read native gnomonic output grid and eliminate any difference between integration and output domains

Source code control

- Will use same repository and management structure as FV3GFS for model code: https://vlab.ncep.noaa.gov/redmine/projects/nemsfv3gfs
- End-to-end SAR FV3 workflow and scripts including pre-processing, integration and post-processing: https://vlab.ncep.noaa.gov/redmine/projects/fv3sar
- Utilities common to all instances of model usage to be placed into a UFS_UTIL repository
- Documentation and eventual user support being supplied through DTC (details TBD)

Operational RAPv4/HRRRv3 (12 July 2018)

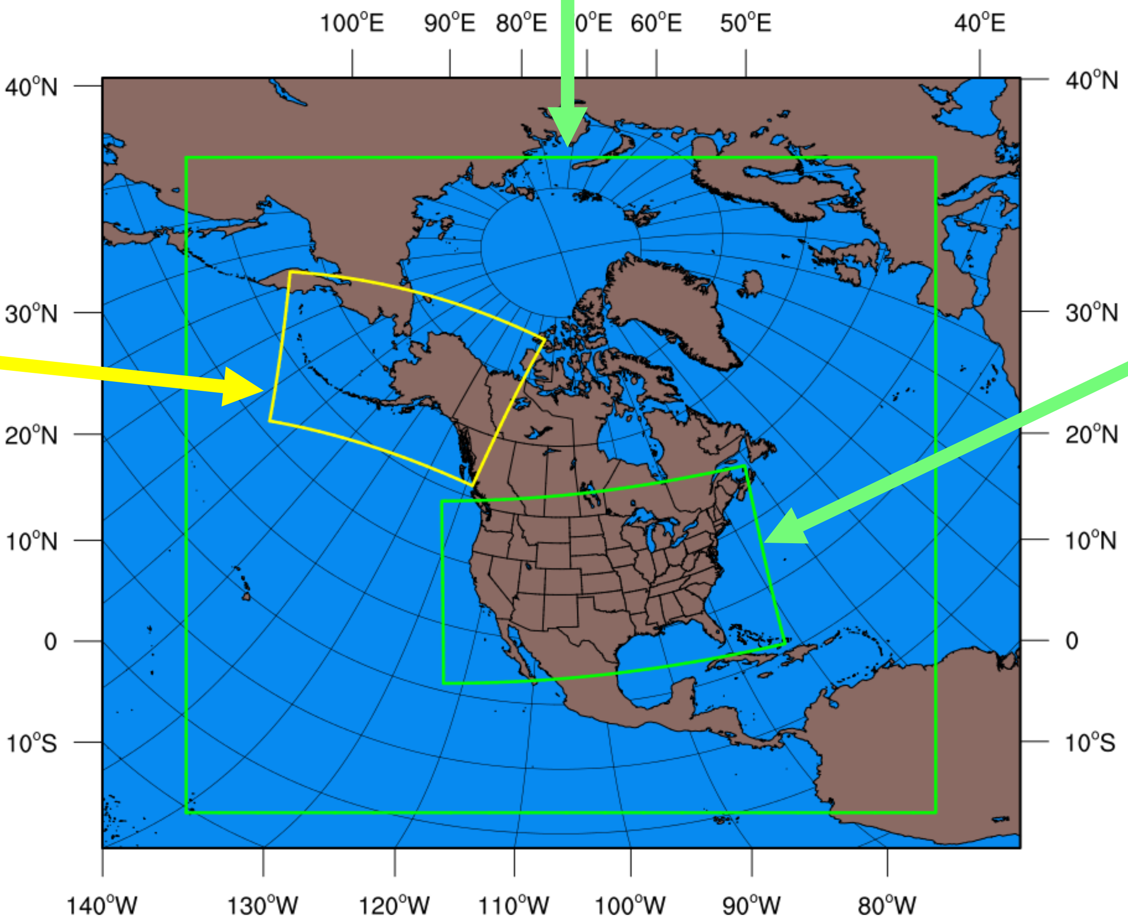
13-km Rapid Refresh (RAPv4) 21-39 hr

Initial & Lateral Boundary Conditions

Initial & Lateral Boundary Conditions

3-km High-Resolution Rapid Refresh Alaska (HRRR-AK) 18-36 hr

3-km High-Resolution Rapid Refresh (HRRRv3) 18-36 hr



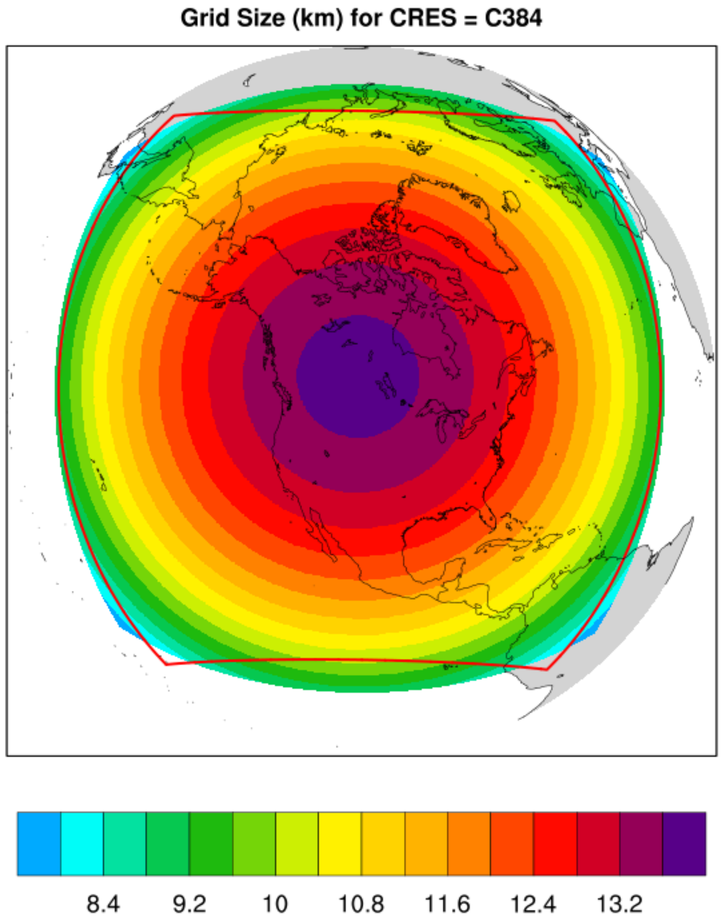
Development of Stand Alone Regional (SAR) FV3 Software

FV3 gnomonic projection in large regional domains yields large grid cell size differences between the center and edges

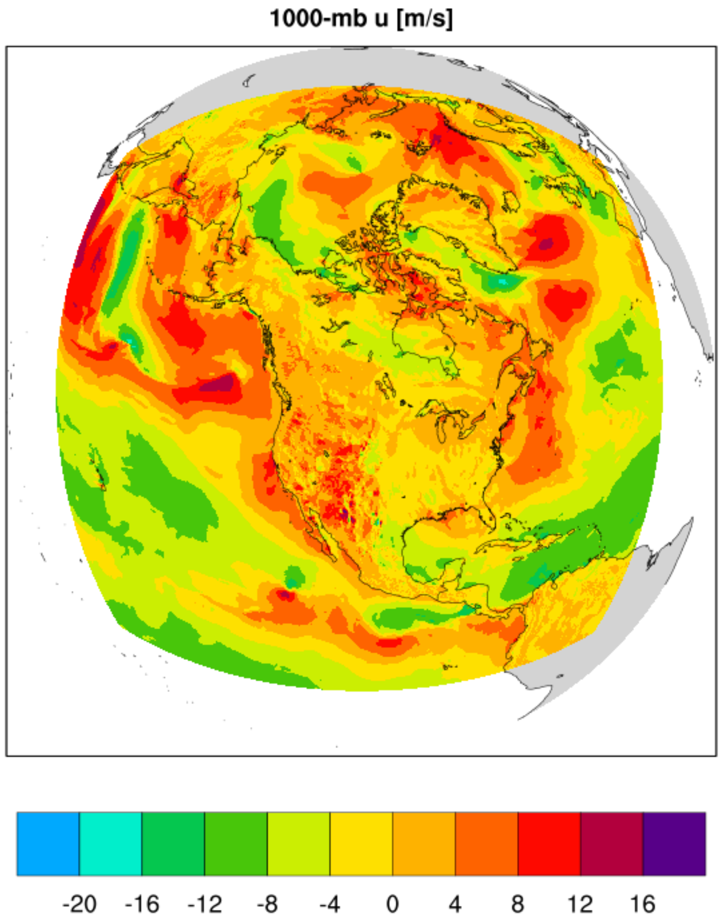
Cell size variance has ramifications for both model physics and time step required for numerical stability

Forecast/graphics from Gerard Ketefian and Jeff Beck (GSD)

RAP/NAM Domain



12-hr forecast plot of 1000 mb U-wind



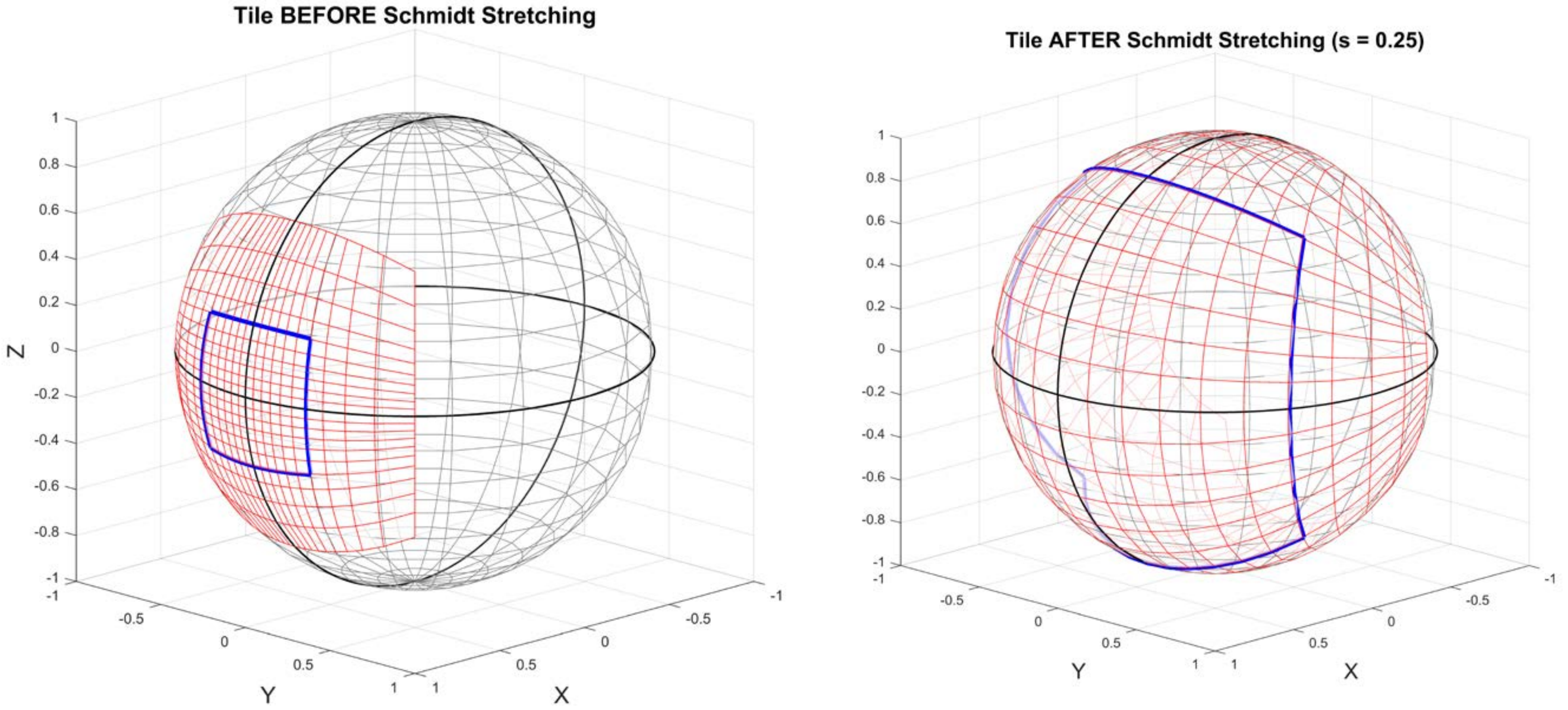
Development of Stand Alone Regional (SAR) FV3 Software

Idea from Jim Purser (EMC) to modify gnomonic projection for more uniformity being tested by Gerard Ketefian (GSD)

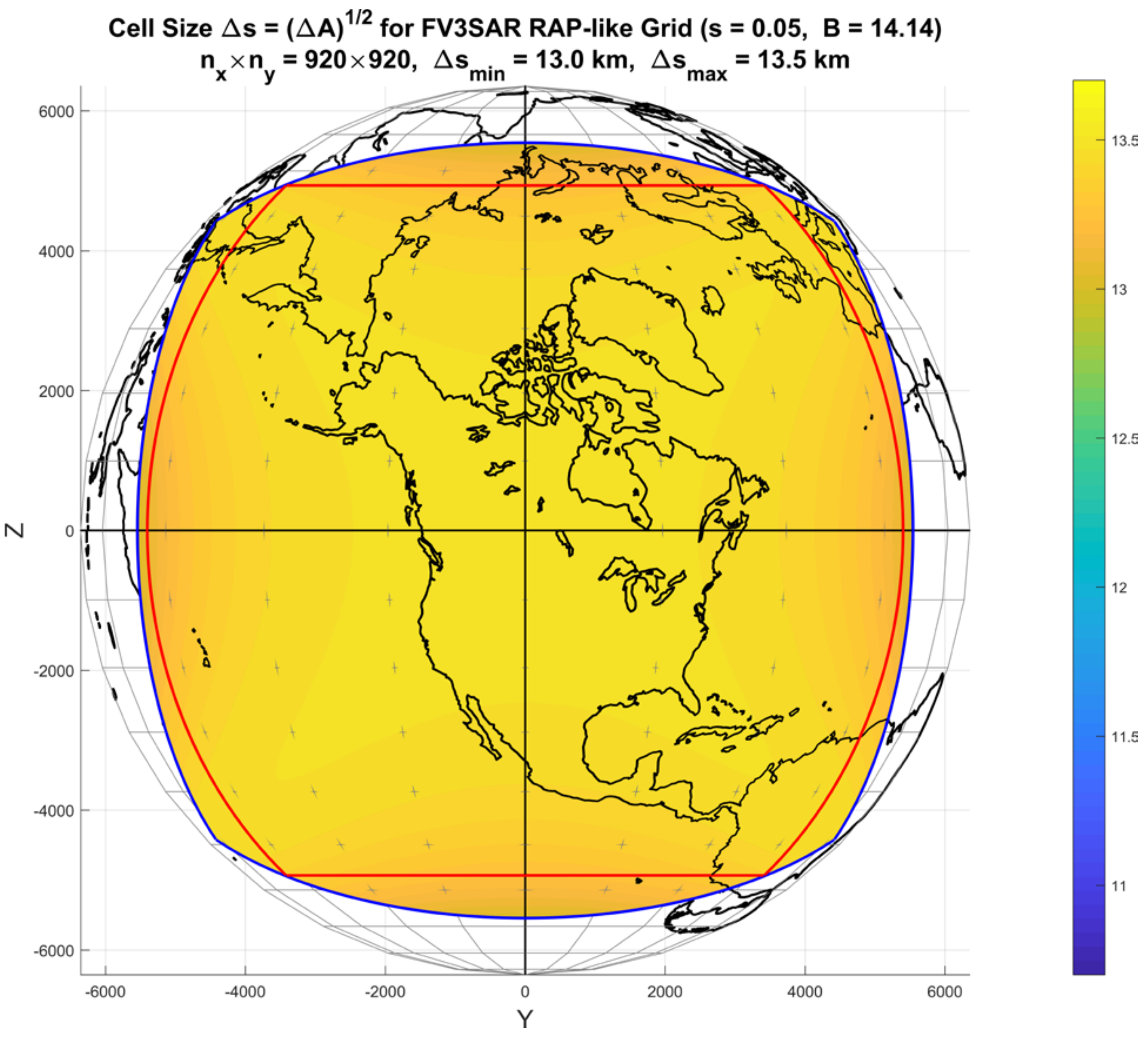
Idea: Make 6th tile (red) as large as possible so that regional domain (blue) is more uniform

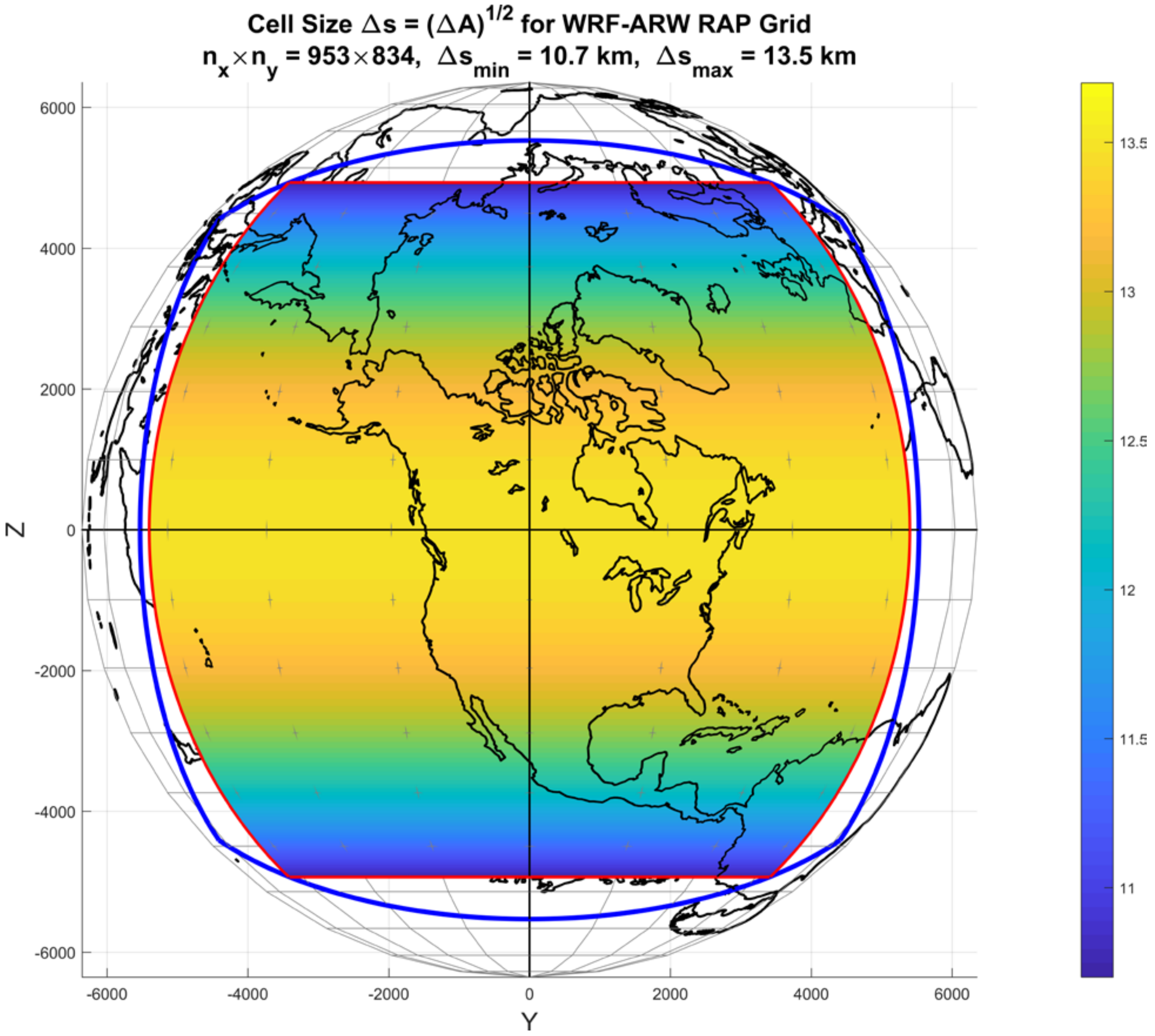
Introduce second parameter (s and B) that permits more grid cell uniformity and **SAR domains larger than a single cube-sphere face**

Incorporate changes back into FV3's horizontal grid generator utility (make_hgrid)

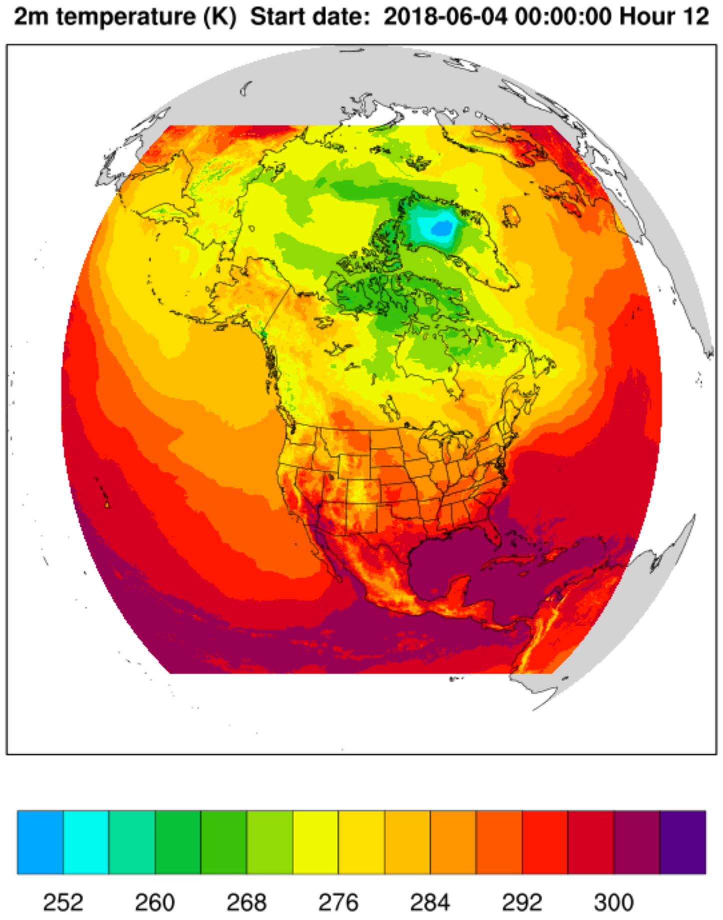


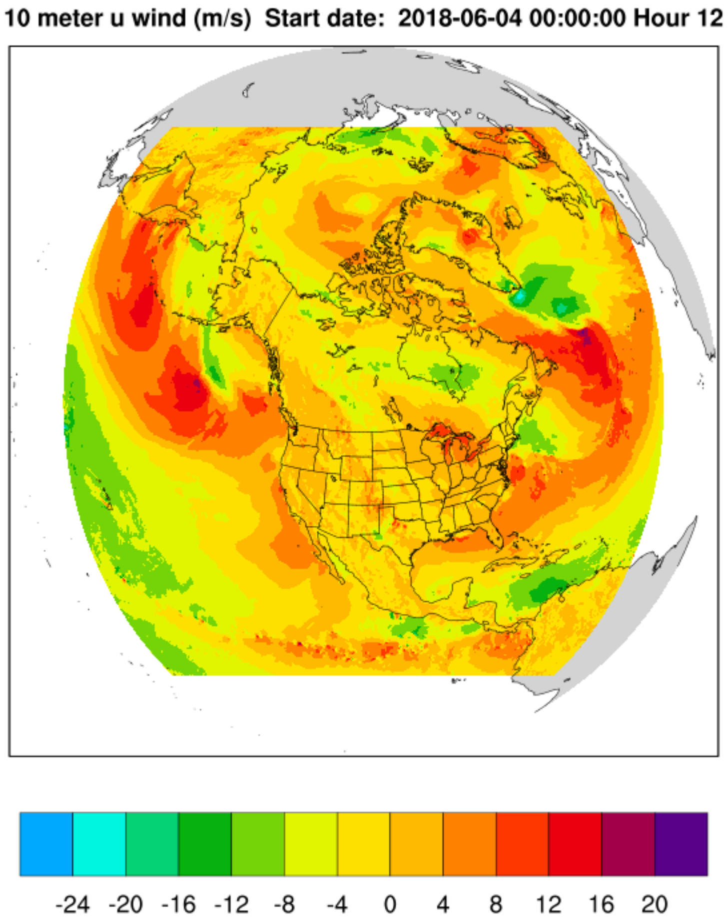
Development of Stand Alone Regional (SAR) FV3 System

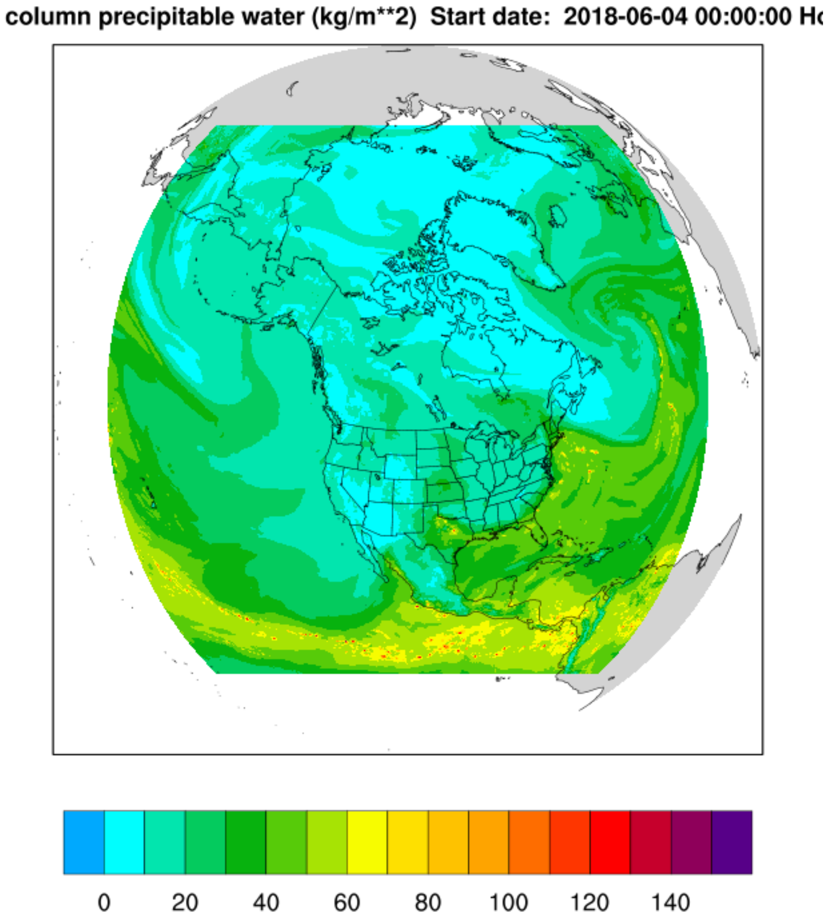




12 Hour RAP Forecast (GFS physics) from Jeff Beck (GSD)

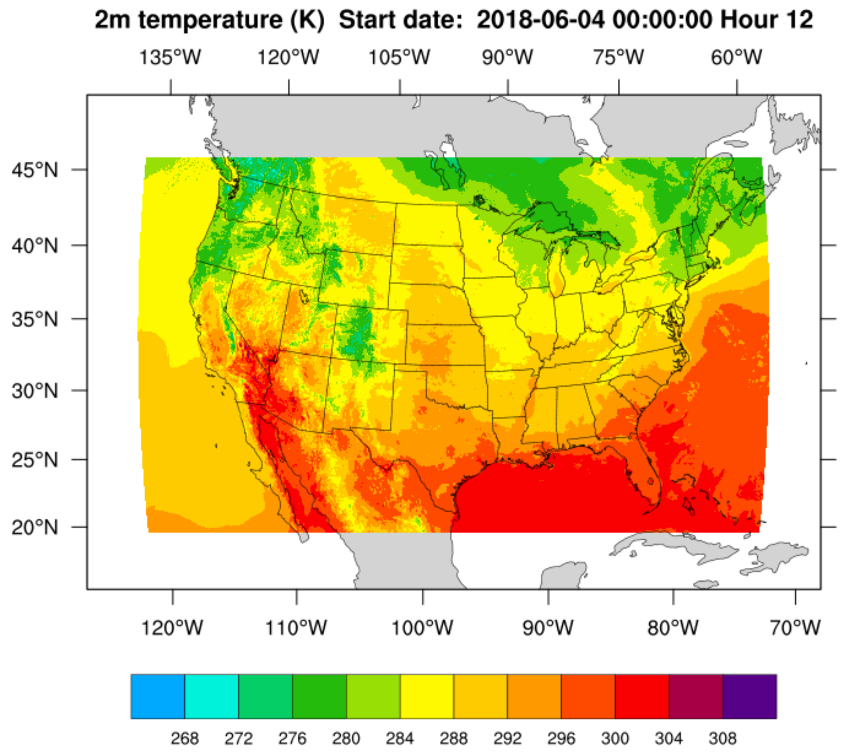


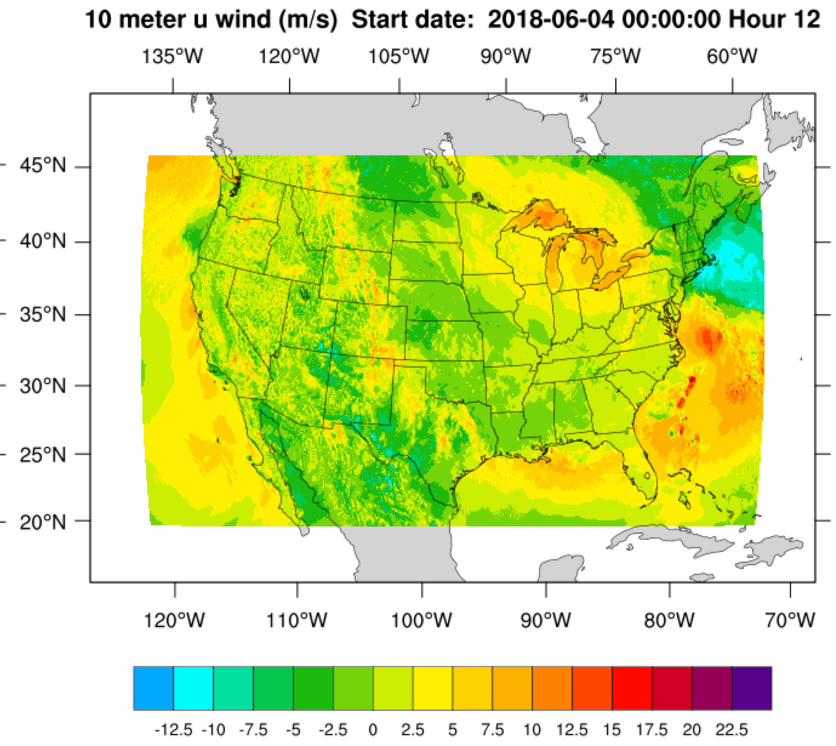


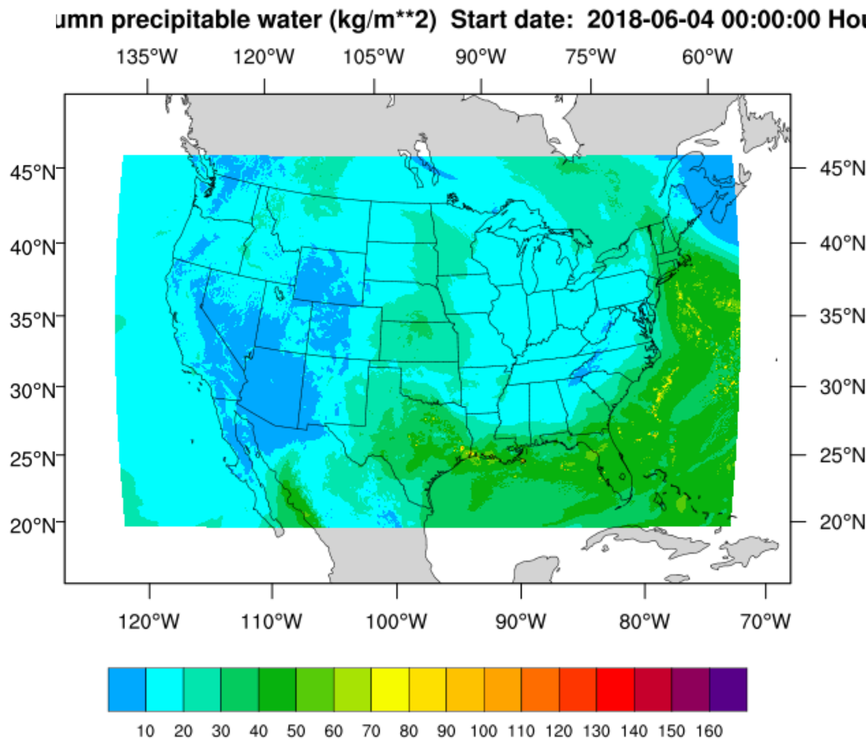


Development of Stand Alone Regional (SAR) FV3 Software

12 Hour HRRR Forecast (GFS physics) from Jeff Beck (GSD)

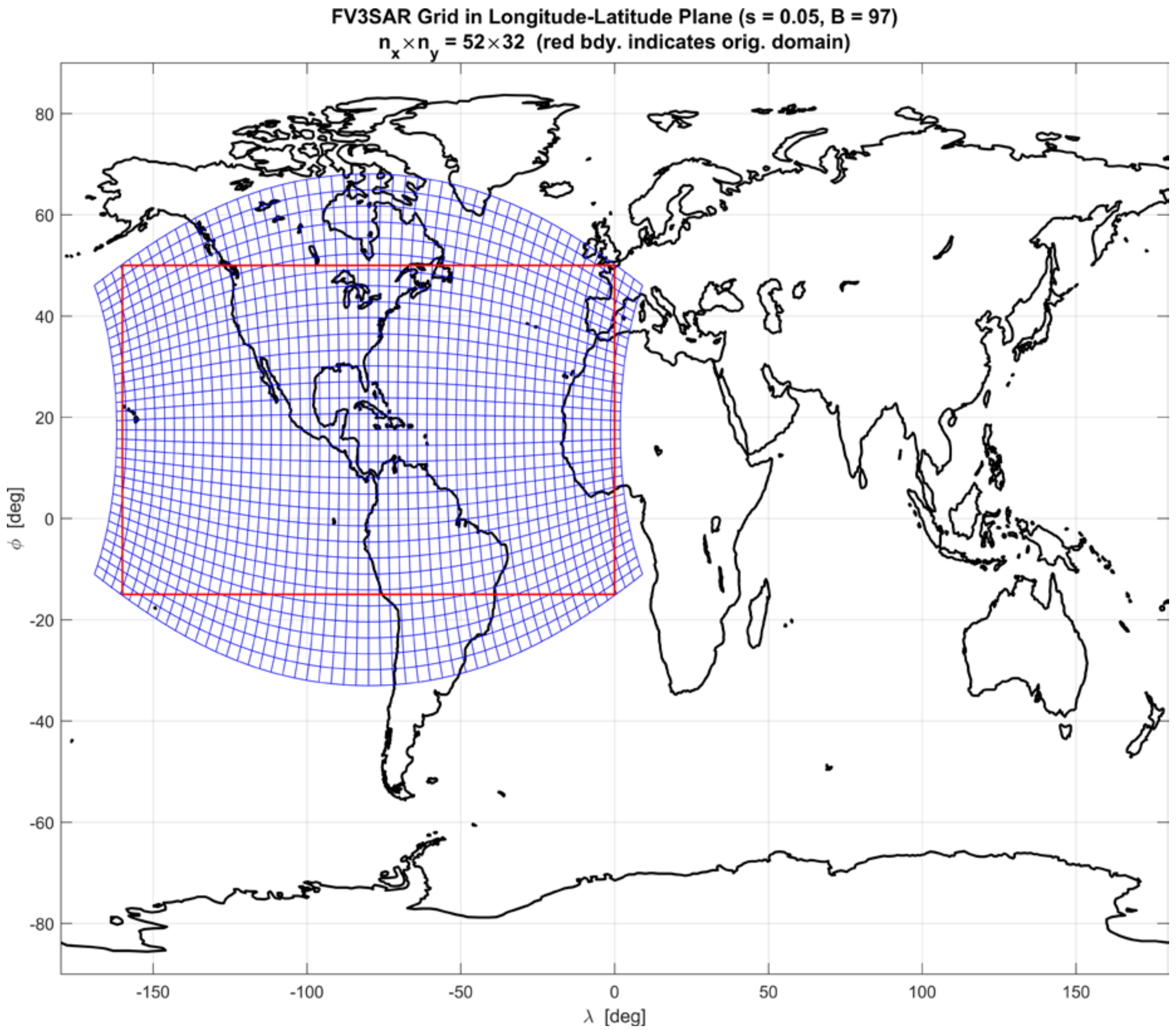


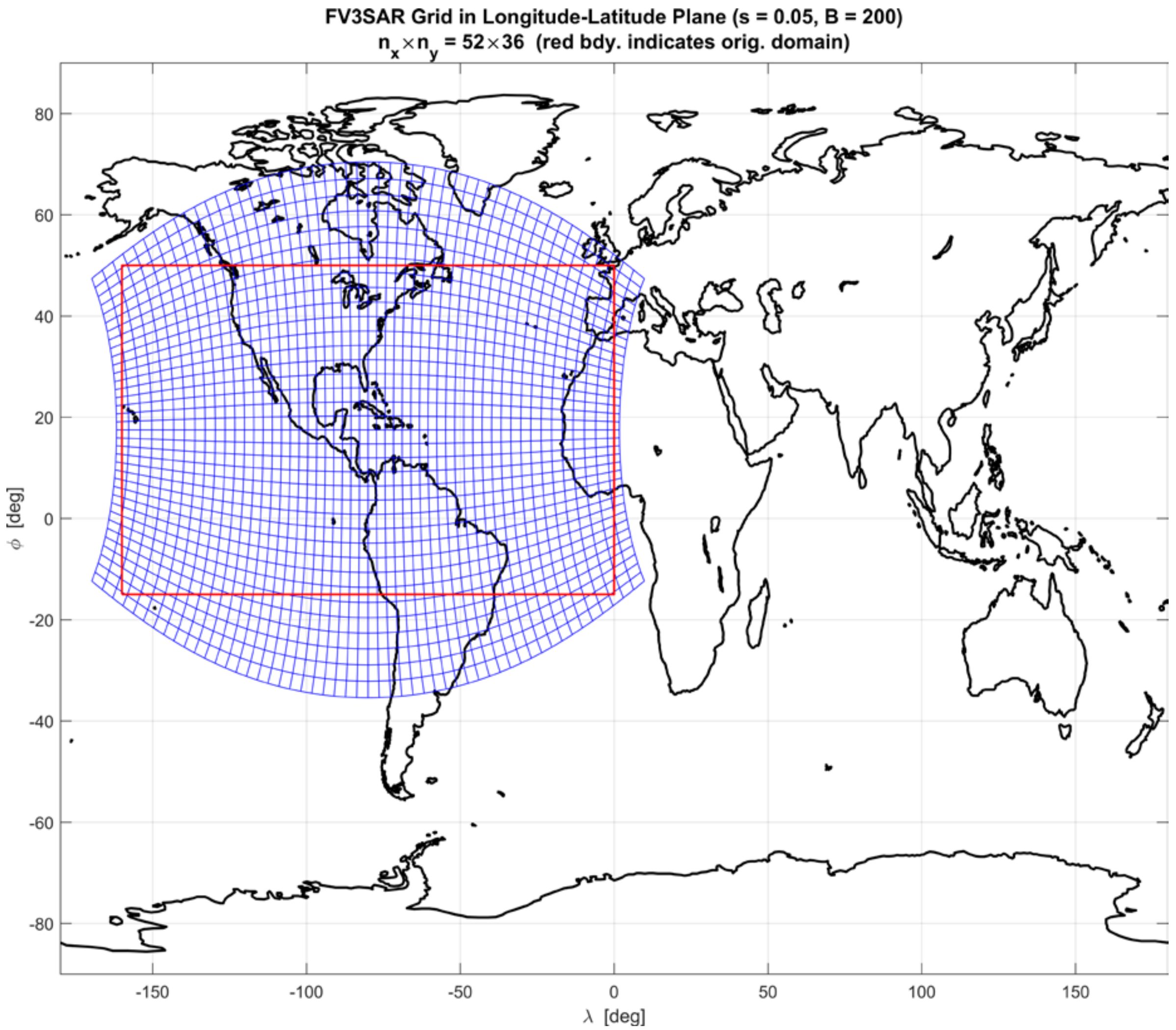




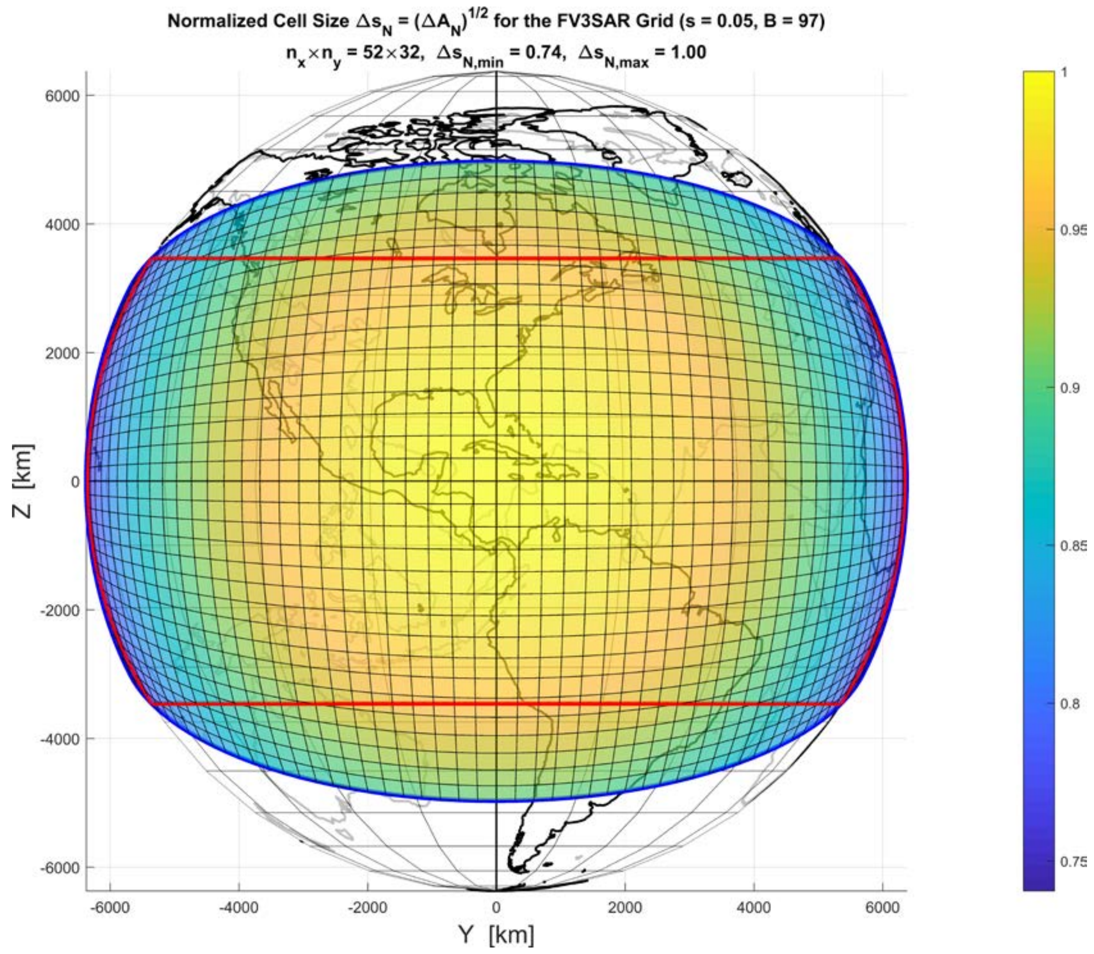
Development of Stand Alone Regional (SAR) FV3 System

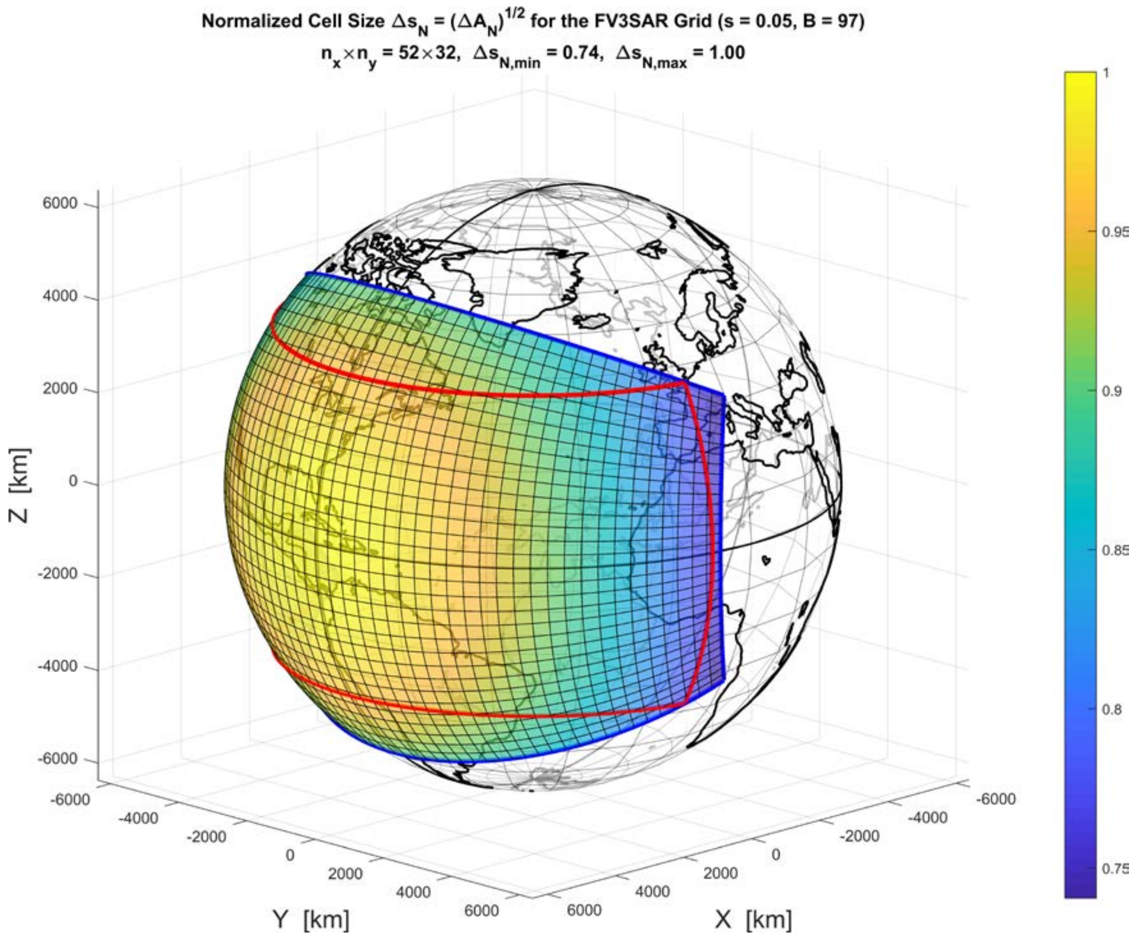
Mockup of two-basin domains with SAR FV3



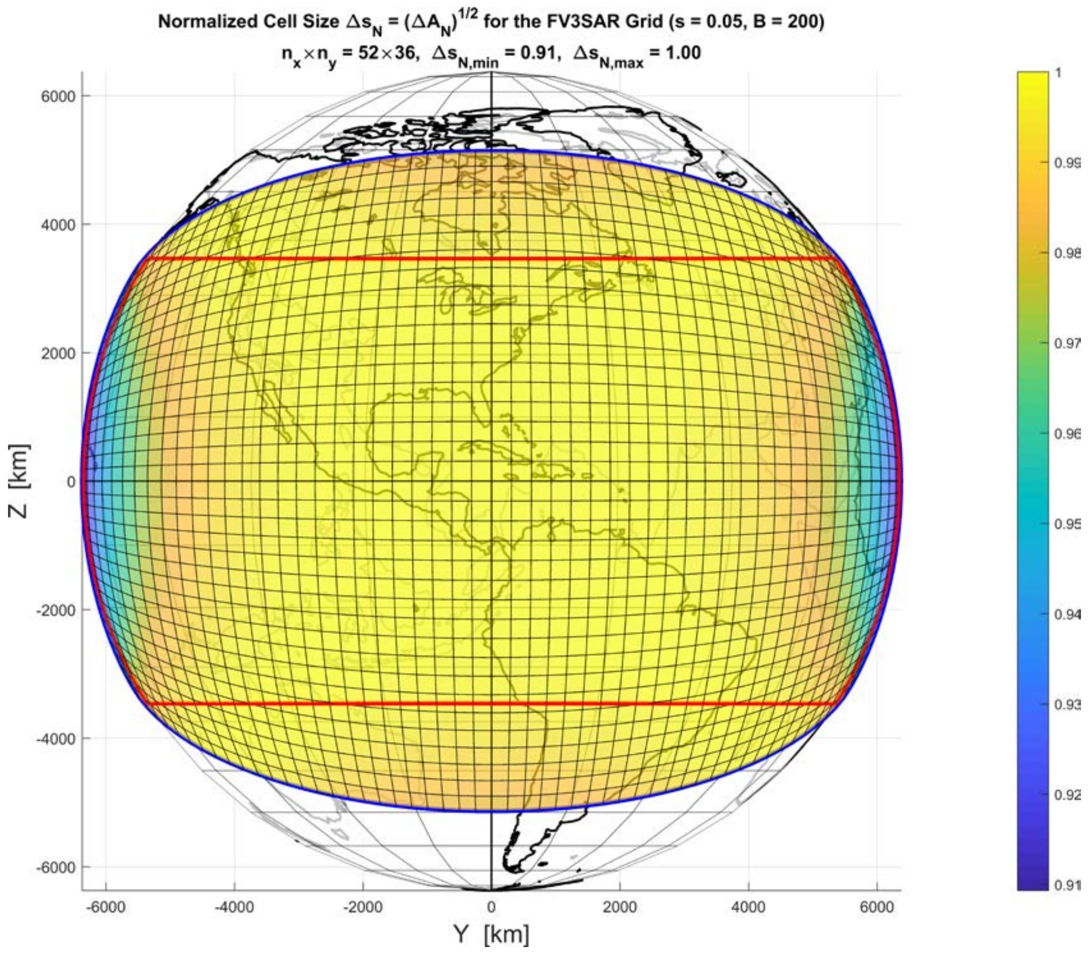


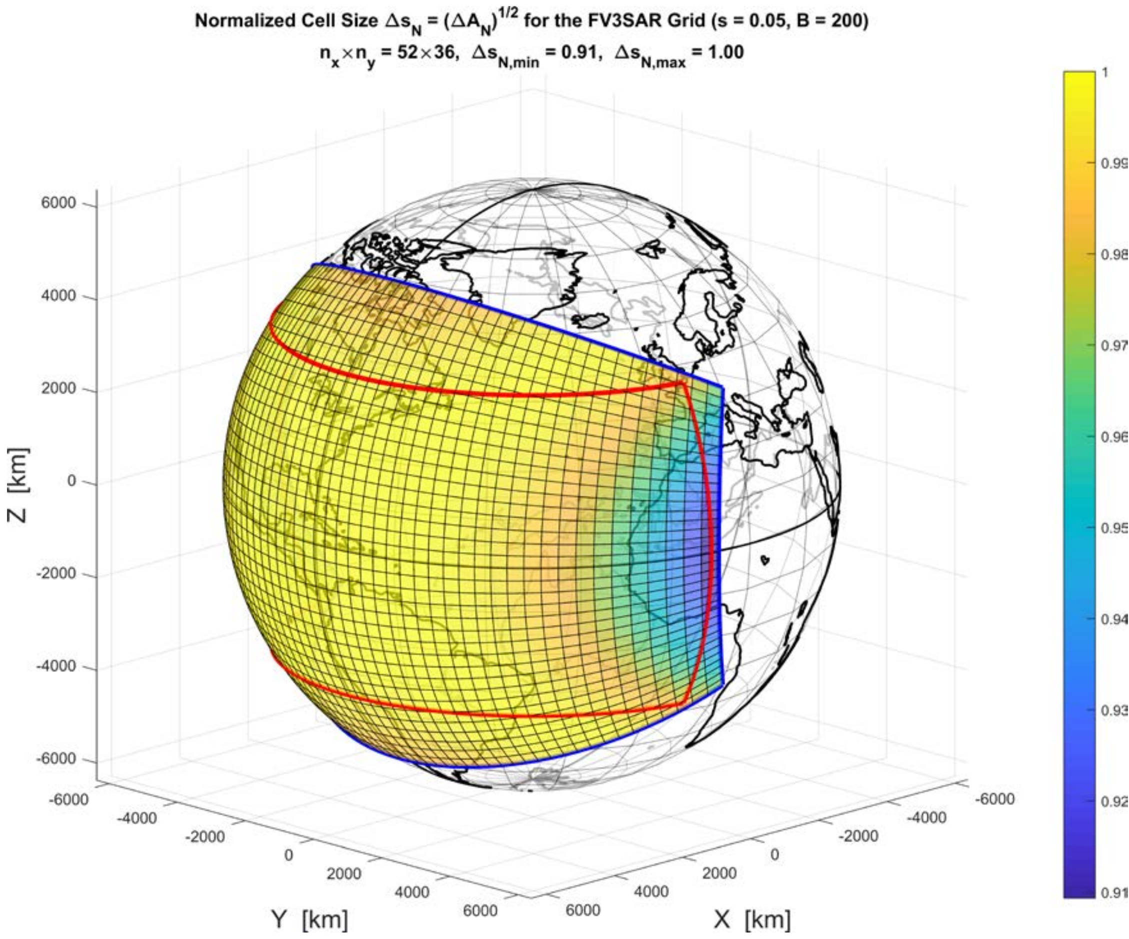
Example 50 gridpoint configuration that minimizes grid-cell aspect ratio differences





Example 50 gridpoint configuration that minimizes grid-cell area variance

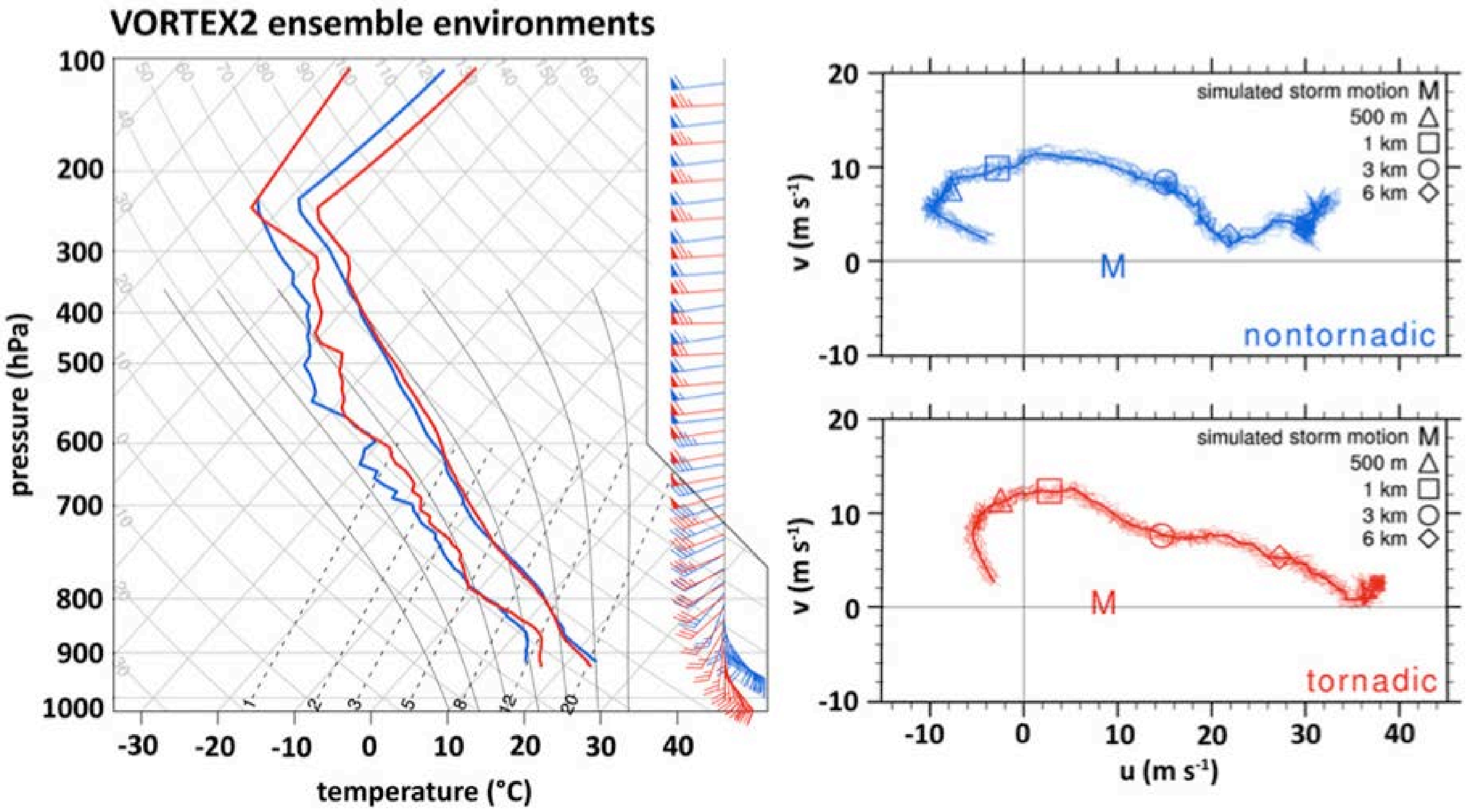




Is 3 km grid sufficient to resolve storm-scale processes that differentiate between the T and NT environments?

HPC resource trade-off between increased resolution and need for ensemble prediction systems at CAM scales to quantify forecast uncertainty

Bottom Line: Is 3 km good enough for now to prioritize CAM ensemble prediction R2O?



	0 - 500 m SRH	0 – 1 km SRH
Non-Tornadic (NT)	80	151
Tornadic (T)	159	224

Lou Wicker
(NSSL)

NSSL Experimental Design

- Reproduce the Coffer *et al.* experiments at NSSL
- Decrease the horizontal resolution while holding the vertical resolution constant: Δx = 0.5, 1, 2, and 3 km ($\Delta z_{max/min}$ = 20, 300 m)
  - repeat Coffer and Parker (2017b) sensitivity runs using the 15 snds
  - determine resolutions where the storms' low-level rotation character becomes indistinguishable
- Repeat the above runs, but reduce the number of vertical levels in half from 115 to 64 vertical levels ($\Delta z_{max/min}$ = 40, 600 m)

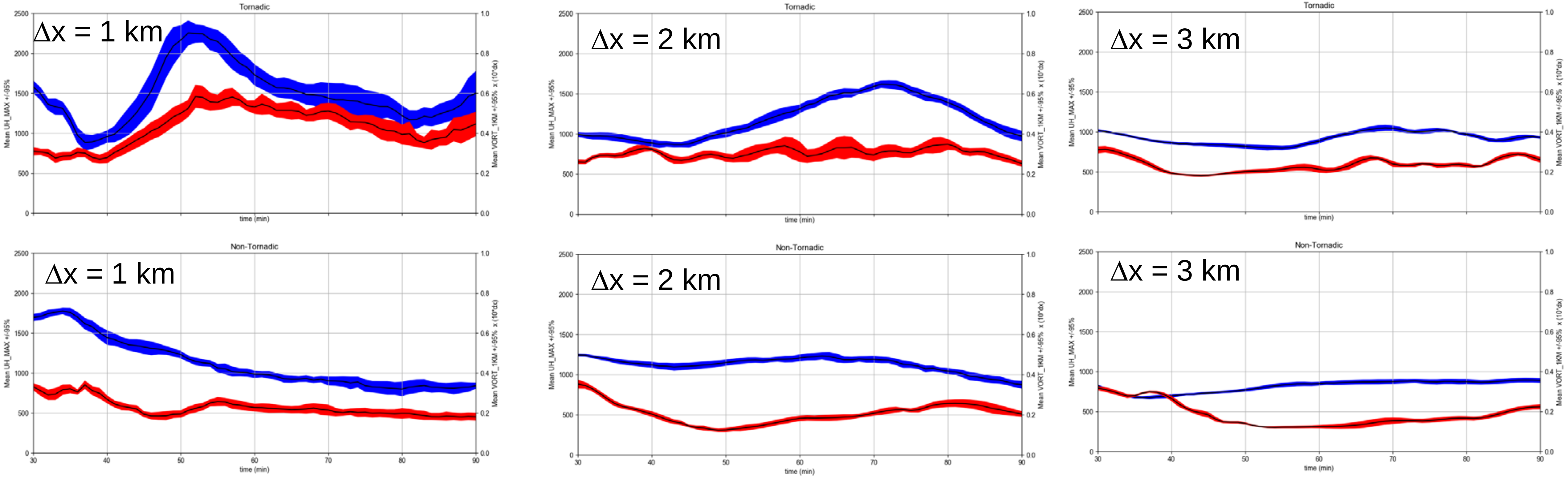
Lou Wicker
(NSSL)

NSSL Experimental Design

2-5km Updraft Helicity

1 km Vertical Vorticity

Tornadic snds



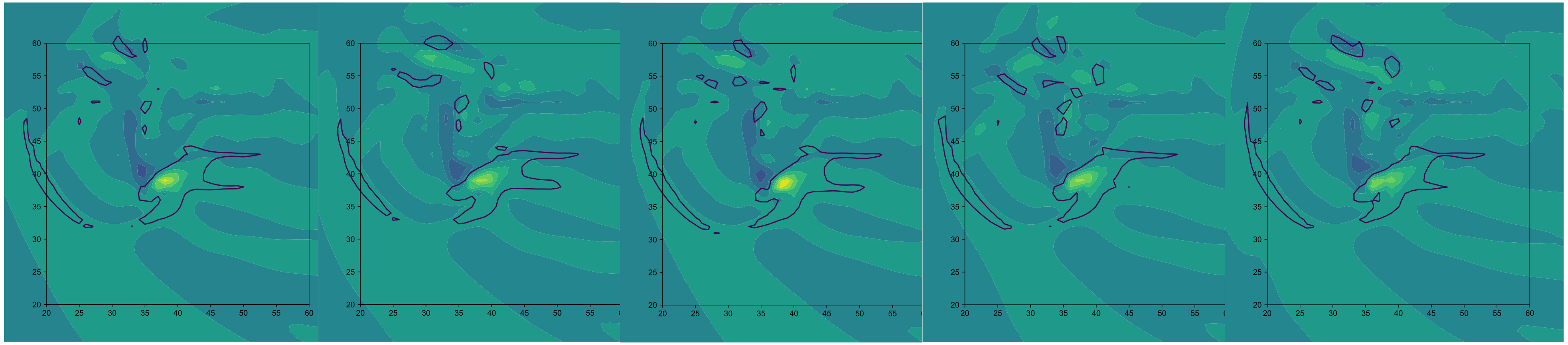
Lou Wicker (NSSL)

Non-tornadic snds

2 km Horizontal Cross sections Z = 1 km

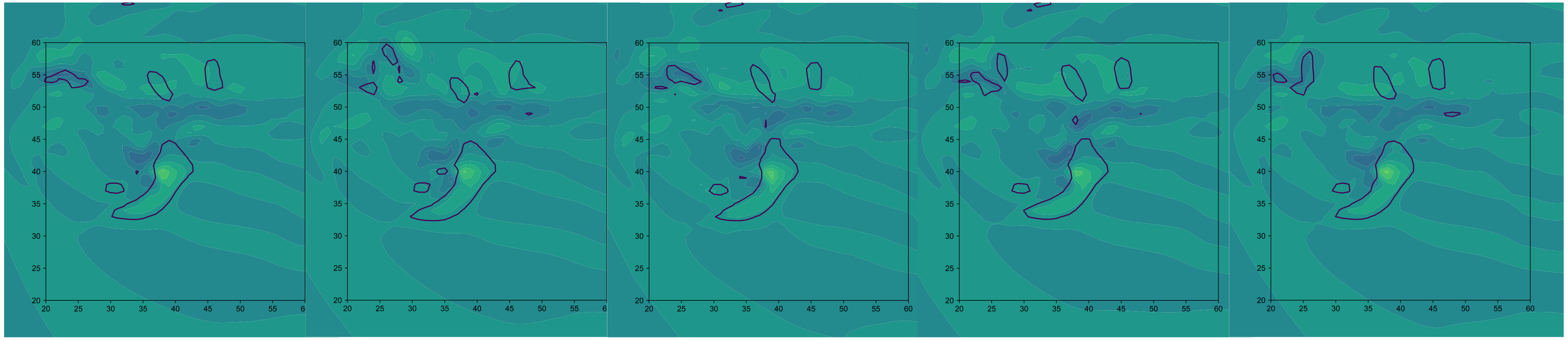
2 km Tornadic @ 58 min

W – contour (1 m/s)
ζ – shaded (-0.2, 0.2)



2 km Non-Tornadic @ 58 min

W – contour (1 m/s)
ζ – shaded (-0.2, 0.2)

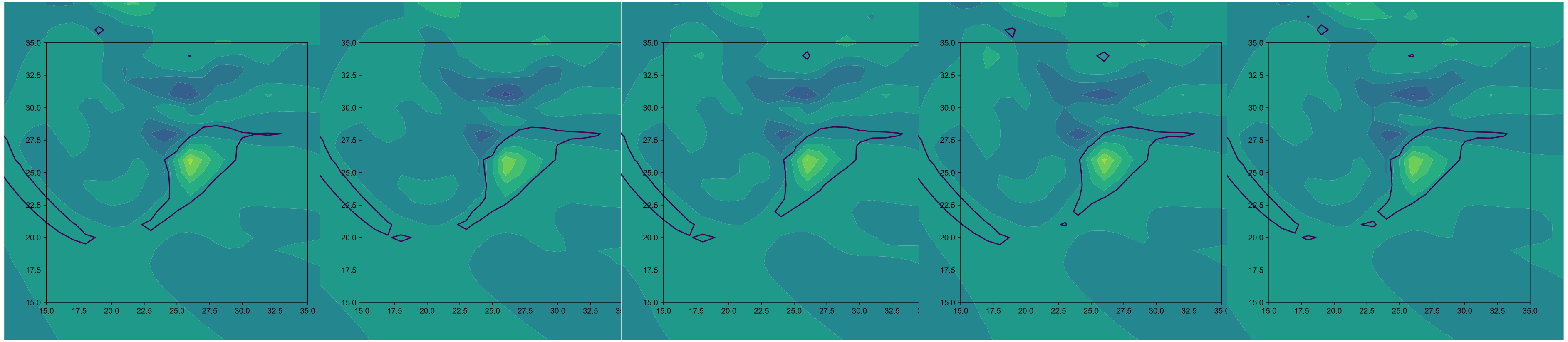


Lou Wicker
(NSSL)

3 km Horizontal Cross sections Z = 1 km

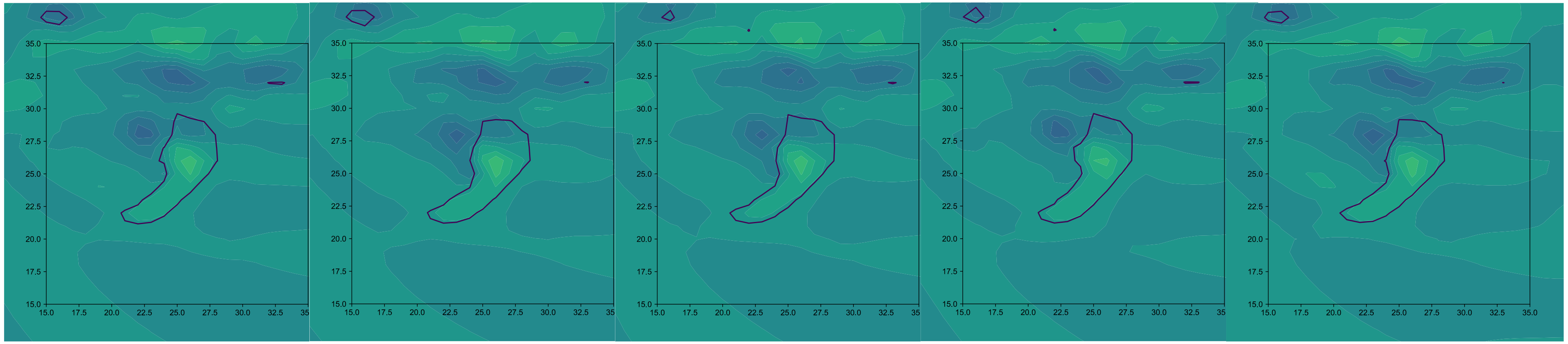
3 km Tornadic @ 58 min

W – contour (1 m/s)
ζ – shaded (-0.25, 0.25)



3 km Non-Tornadic @ 58 min

W – contour (1 m/s)
ζ – shaded (-0.25, 0.25)



Lou Wicker
(NSSL)

NSSL Experiment Summary

- Large sensitivity to both horizontal and vertical resolution
- Dx = 3 km **might be** able to resolve storm-scale processes that differentiate between the T and NT environments
- Dx = 1 km **is** sufficient to resolve storm-scale processes that differentiate between the T and NT environments
  - similar to Potvin and Flora (MWR, 2015)
  - the time of LL spin up across the ensemble varies (~10 min)
- Complex relationship between vertical resolution and vertical mixing parameterizations.
- Mixing has a large effect on structure of rotation and updraft.
- Lots more to understand!

Lou Wicker
(NSSL)

Stand-Alone Regional FV3 CAM Development

- August-September-October 2018 (GSD with collaboration/coordination from EMC and NSSL)
  - SAR FV3 configured for 3-km HRRR domain test
  - Complete RAP/HRRR physics suite installation in CCPP

- September-December 2018 (GSD with collaboration/coordination from EMC and NSSL)
  - Begin experiments using SAR FV3 with RAP/HRRR initial/boundary conditions and physics suite via CCPP
  - Evaluate one-off forecasts using CAM verification metrics
  - Begin rapid-cycling data assimilation installation in SAR FV3

- December 2018-March 2019 (GSD with collaboration/coordination from EMC and NSSL)
  - Execute retrospective SAR FV3 with RAP/HRRR initial/boundary conditions and physics suite via CCPP
  - Evaluate retrospective forecasts using CAM verification metrics
  - Begin real-time SAR FV3 forecasts on NOAA R&D HPC with verification using CAM verification metrics

- February-May 2019 (GSD with collaboration/coordination from EMC and NSSL)
  - Conduct early-developer/user workshop on SAR FV3 in February
  - Deliver final ARW-based version of RAP/HRRR to EMC for 2020 implementation
  - Continue rapid-cycling data assimilation installation/development in SAR FV3