The Final Rapid Refresh and High-Resolution Rapid Refresh Operational Implementation and the Bridge to a Unified Forecast System

11 June 2019

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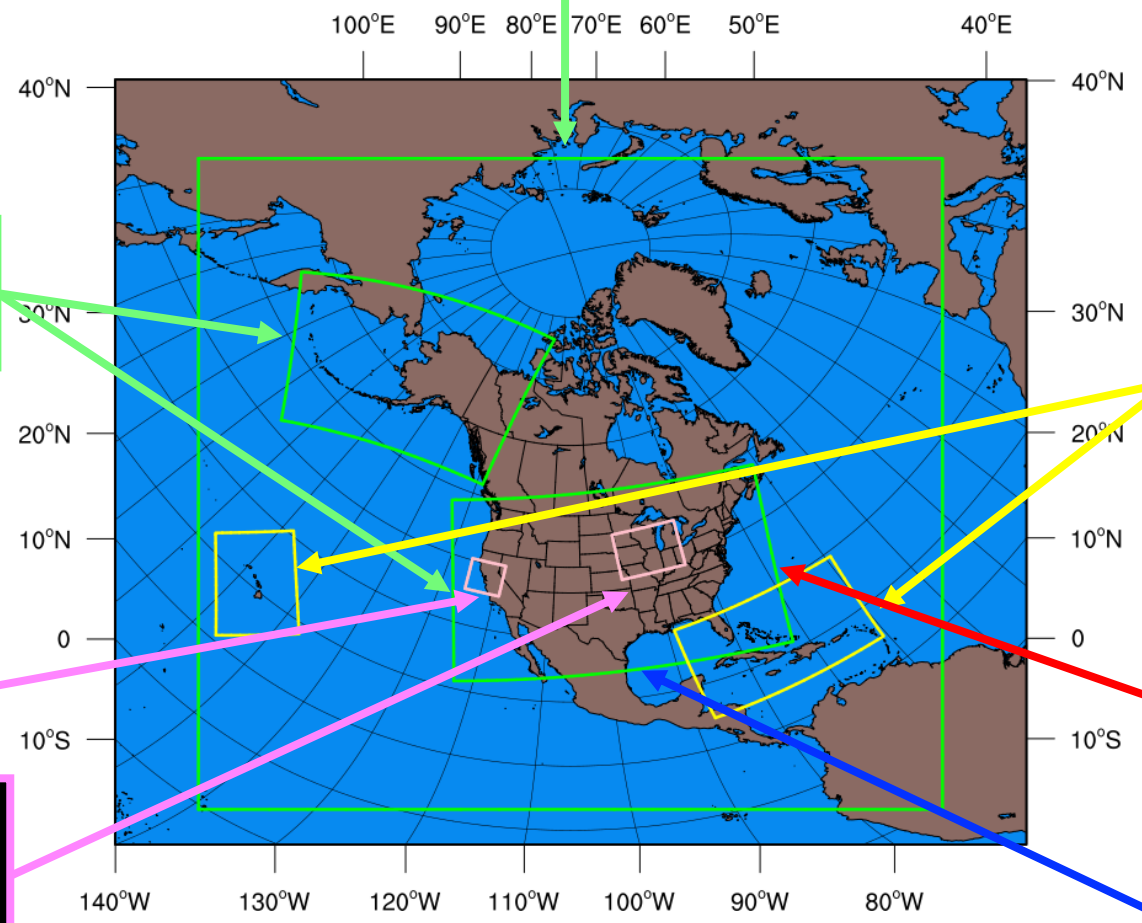
NOAA/ESRL/GLOBAL SYSTEMS DIVISION

RAP/HRRR Model Forecast Suite

13-km Rapid Refresh (RAPv4)

Initial & Lateral Boundary Conditions

Initial & Lateral Boundary Conditions



3-km High-Resolution Rapid Refresh (HRRRv3)

3-km HRRR-Smoke (VIIRS fire data)

Initial & Lateral Boundary Conditions

3-km High-Resolution Rapid Refresh Hawaii and Puerto Rico Testing (HRRR-HI, HRRR-PR) Experimental (ongoing)

3-km Storm-Scale Ensemble Analysis and Forecast (HRRRDAS/E) Experimental (ongoing)

1-km HRRRnest AWC/AQPI

1-km HRRRnest FAA/ICICLE

3-km RTMA-3D Experimental (ongoing)

RAP/HRRR Implementation History

Operational Implementations

01 May 2012
- RAPv1: Adoption of GSI, WRF-ARW and unified post
- Enabled use of community-developed software

25 Feb 2014
- RAPv2: Hybrid EnKF-3DVar data assimilation
- Significant improvement in upper-air forecasts

30 Sep 2014
- HRRRv1: 3-km Radar DA in WRF-ARW
- Significant improvement in convective forecasts

23 Aug 2016
- RAPv3/HRRRv2: Aerosol Thompson MP, improvements to MYNN PBL, RUC LSM, RRTMG Rad, Grell-Freitas cumulus
- Significant improvement in surface forecasts

12 Jul 2018
- RAPv4/HRRRv3: Hybrid Vertical Coordinate, Eddy Diffusivity Mass Flux PBL
- Reduction in short-lead biases and improved mesoscale environment
- Extended forecast lengths to 39/36 hrs
- HRRR-Alaska

Mar/Apr 2020
- RAPv5/HRRRv4: Storm-scale ensemble DA, Wildfire Smoke Prediction, Great Lakes Ice
- Reduction in longer-lead biases
- Extended forecast lengths to 51/48 hrs

2020 RAPv5/HRRRv4 Change Candidates

Model	Data Assimilation	Land-surface / post
WRF-ARWv3.9+ incl. phys changes ***Physics changes:*** MYNN PBL update – better sub-grid clouds, improved EDMF mixing - remove limit for subgrid qc/qi - decrease subgrid qc/qi radii RRTMG modifications for subgrid clouds Aerosols sources/sinks – fire/smoke, dust - Add smoke with VIIRS FRP Improved land-surface/snow model including better 2m T/Td diagnostics Latest Grell-Freitas conv (RAP only) Lake model for small lakes Enhanced gravity-wave drag ***Numerics changes:*** Reduced 6th order diffusion inc. hydrom Removal of mp_tend_lim Implicit-explicit vertical advection	**Merge with GSI trunk – 2019** ***New Observations for assimilation:*** GOES-16 radiances, CrIS/ATMS TC vitals for trop cyclone location/ strength Aircraft/raob moisture obs for p<300 hPa VIIRS/MODIS fire radiative power ***Assimilation Methods:*** HRRR - 3km ensemble DA (36 mems out to 1h) – HRRRDAS mean for HRRR IC and BEC	Switch to MODIS albedo (higher), replace 1-deg albedo. Add zenith-ang albedo adj 15” resolution land use data Fractional sea/lake ice concentration FVCOM data for Great Lakes lake temp/ice concentration VIIRS/MODIS/GOES fire radiative power HAILCAST diagnostic

RAPv4/HRRRv3 Summary of Changes

Operational RAPv4/HRRRv3

No Change in CONUS Domains

Newer Model Version
More Ensemble Weight
Advanced "Physics Suite"

Seasonal Vegetation Fraction/Leaf Area Index

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	953 x 834	13 km	50	Sigma-Isob Hybrid	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCO	CONUS	1799 x 1059	3 km	50	Sigma-Isob Hybrid	20 mb	RAP	Hourly (pre-forecast hour cycle)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.8.1+	GSI Hybrid Ensemble 0.85	13-km DFI, ½ Strength	RRTMG/ RRTMG	Thompson Aerosol v3.8.1	GF + Shallow	MYNN v3.8.1	RUC v3.8.1
HRRR	WRF-ARW v3.8.1+	GSI Hybrid Ensemble 0.85	3-km 15-min LH	RRTMG/ RRTMG	Thompson Aerosol v3.8.1	None	MYNN v3.8.1	RUC v3.8.1

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	Diffusion Option	6th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5th/5th	Positive-Definite	w-Rayleigh 0.2	Full (2)	Yes 0.12	20 min	MODIS Seasonal	0.01 K/s	60 s
HRRR	5th/5th	Positive-Definite	w-Rayleigh 0.2	Full (2)	Yes 0.25	15 min with SW-dt	MODIS Seasonal	0.07 K/s	20 s

RAPv4/HRRRv3 Summary of Changes

Upcoming RAPv5/HRRRv4

No Change in Domains

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	953 x 834	13 km	50	Sigma-Isob Hybrid	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCO	CONUS	1799 x 1059	3 km	50	Sigma-Isob Hybrid	20 mb	RAP	Hourly (pre-forecast hour cycle)

Newer Model Version
HRRRDAS Use
Advanced "Physics Suite"

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.9.1+	GSI Hybrid Ensemble 0.85	13-km DFI, ½ Strength	RRTMG/ RRTMG	Thompson Aerosol v3.8.1	GF + Shallow	MYNN v3.9.1+	RUC v3.9.1+
HRRR	WRF-ARW v3.9.1+	GSI Hybrid HRRRDAS Ensemble 0.85	3-km 15-min LH	RRTMG/ RRTMG	Thompson Aerosol v3.8.1	None	MYNN v3.9.1+	RUC v3.9.1+

CLM Lake Model
FVCOM Great Lakes

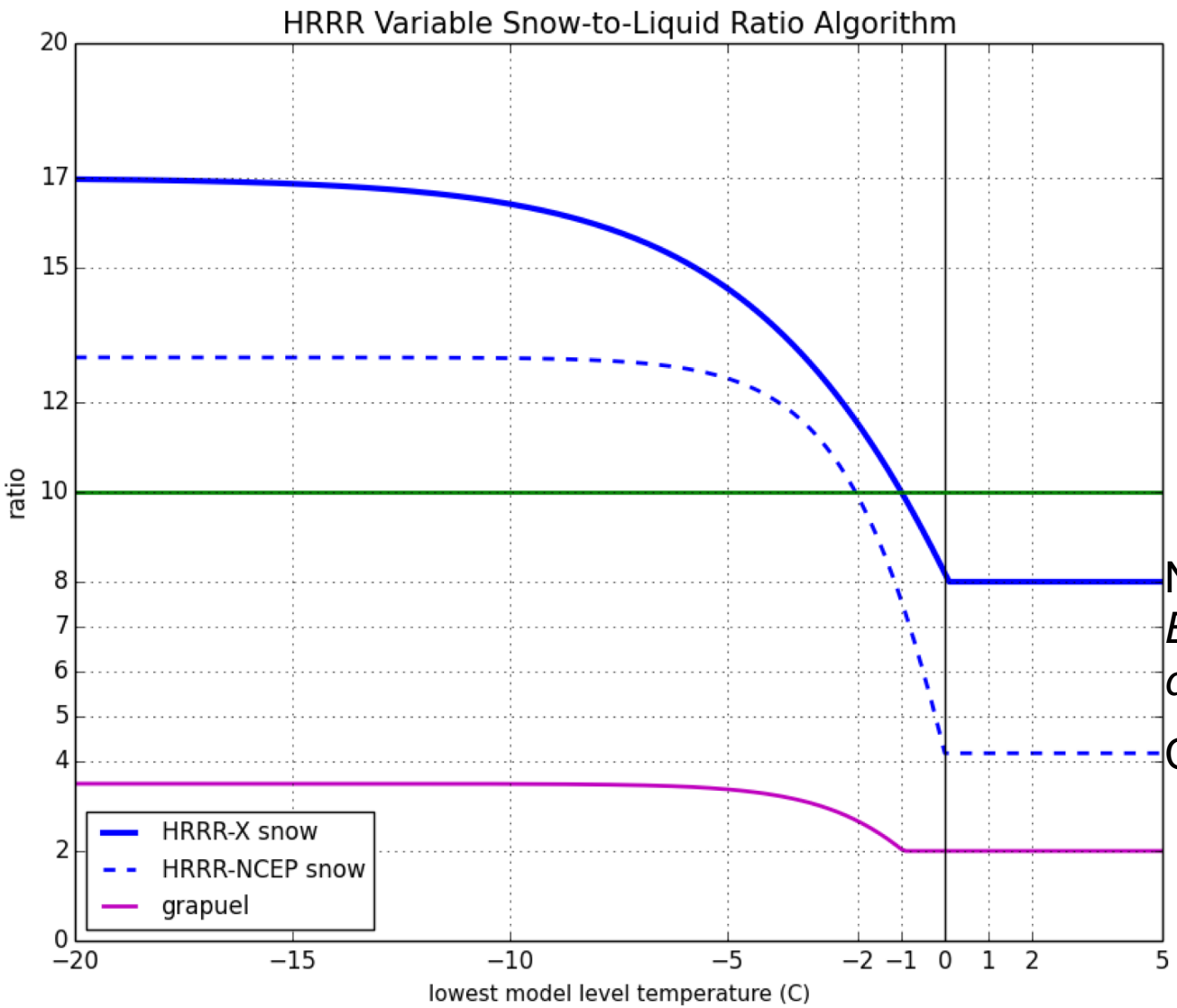
Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	Diffusion Option	6th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5th/5th	Positive-Definite	w-Rayleigh 0.2	Full (2)	Yes 0.12/0.04	20 min	MODIS Seasonal	None	60 s
HRRR	5th/5th	Positive-Definite	w-Rayleigh 0.2	Full (2)	Yes 0.12/0.04	15 min with SW-dt	MODIS Seasonal	None	20 s

RAPv5/HRRRv4 Transition to Operations

RAPv5/HRRRv4 What:	When:
GSD-EMC Package Briefing	25 Sept 2018
GSD-EMC Package Briefing	Nov-Dec 2017
GSD code hand-off to EMC	**04 June 2019 (underway)**
NCEP EE2 Meeting	Jul 2019
EMC 24x7 parallel	Jul 2019
EMC Evaluation Begins	15 Aug 2019
EMC Evaluation Ends	15 Oct 2019
EMC CCB Meeting	Late Oct 2019
NCEP Director Briefing	Late Oct 2019
EMC code hand-off to NCO	01 Nov 2019
NCO 24x7 parallel	Jan 2020
NCO 30-day start	10 Feb 2020
NCO Management Meeting	March 2020
NCEP Implementation	23 March 2020

RAP/HRRR/HRRRE “ASNOW” algorithm

SLR



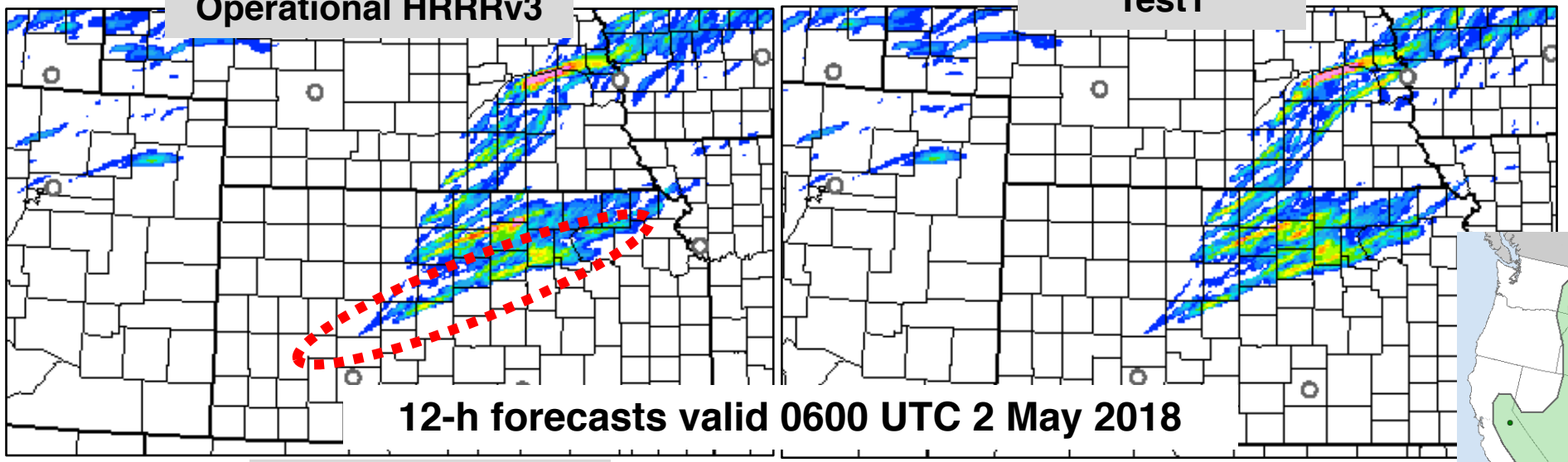
New prototype RAPv5/HRRRv4
Based on two years of development/testing/evaluation

Current Operational RAPv4/HRRRv3

Implicit-Explicit Vertical Advection in HRRR (NSSL-GSD collaboration)

Operational HRRRv3

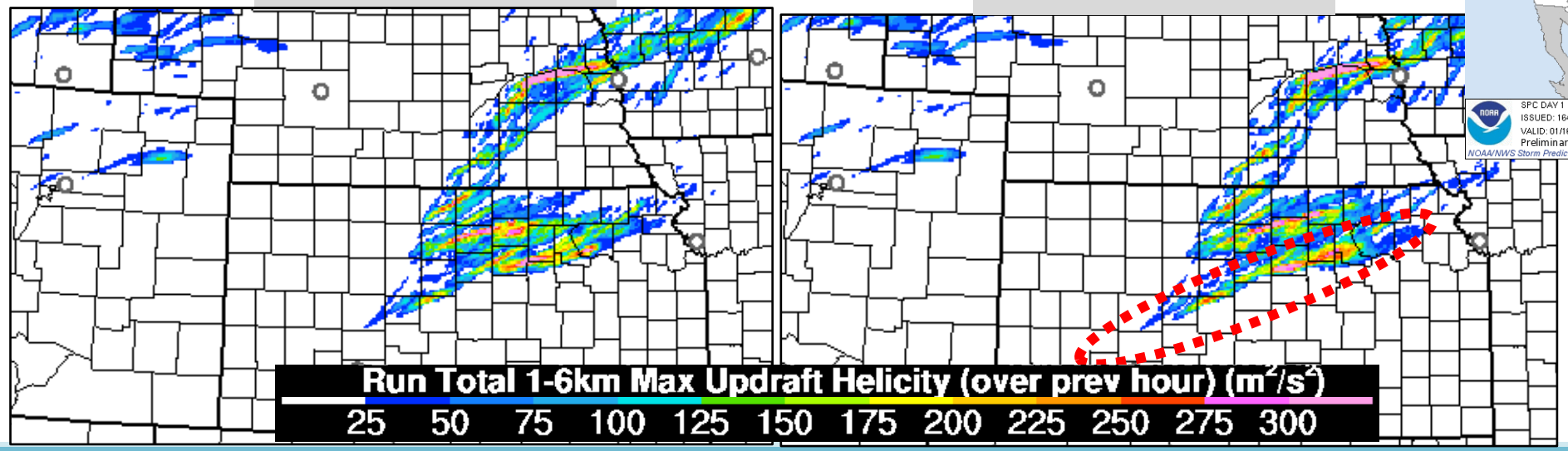
Test1

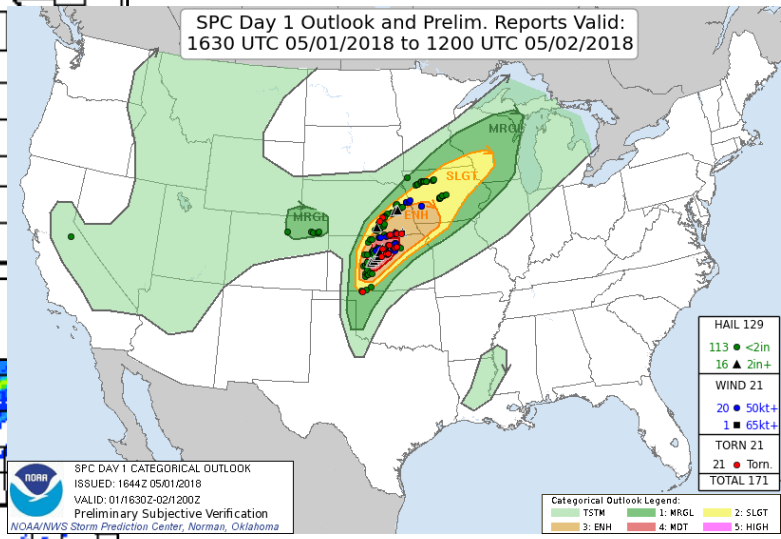


12-h forecasts valid 0600 UTC 2 May 2018

Test2

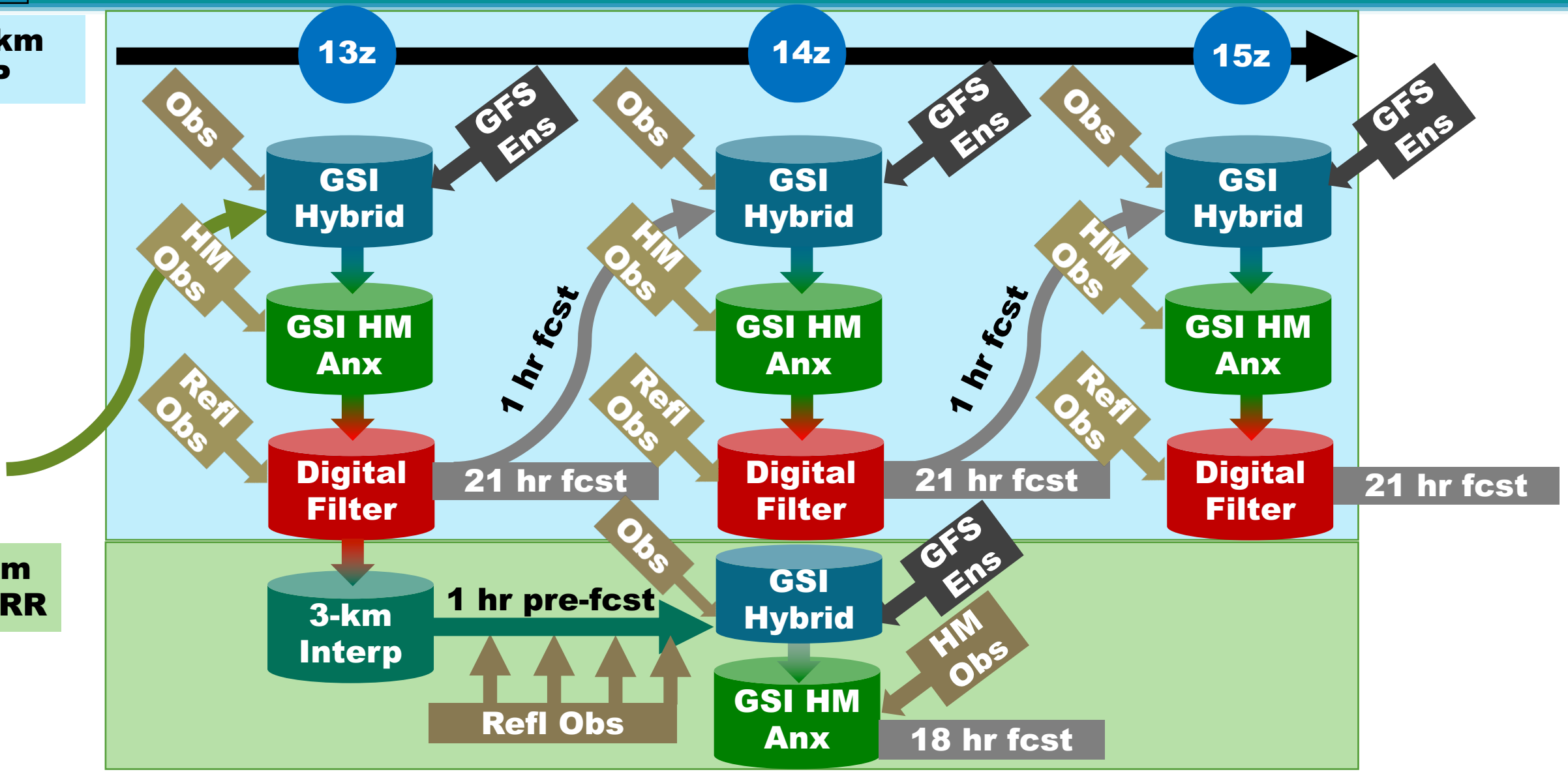
Candidate HRRRv4



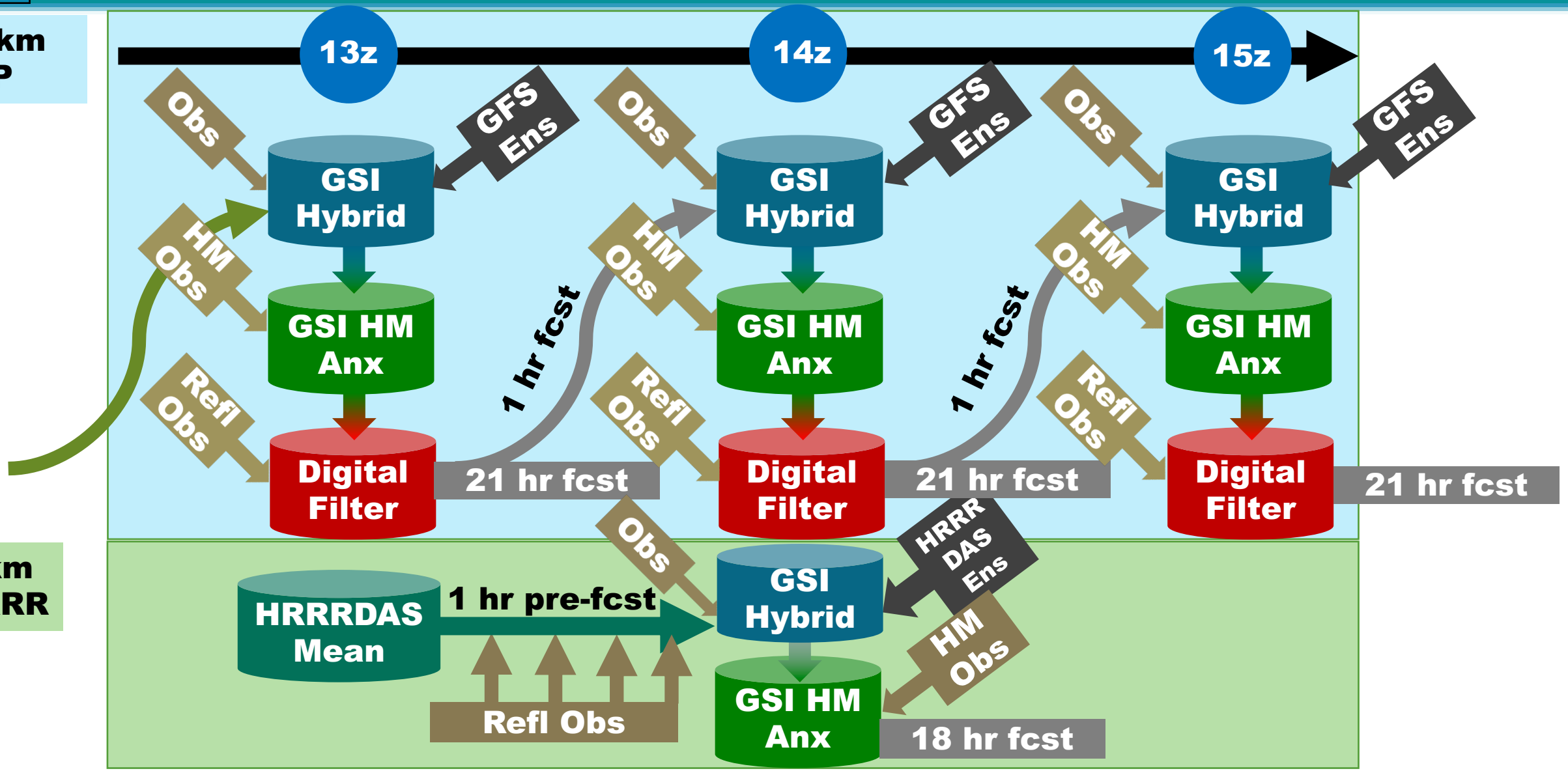


More intense updraft helicities without limiter on UVVs while maintaining larger time step

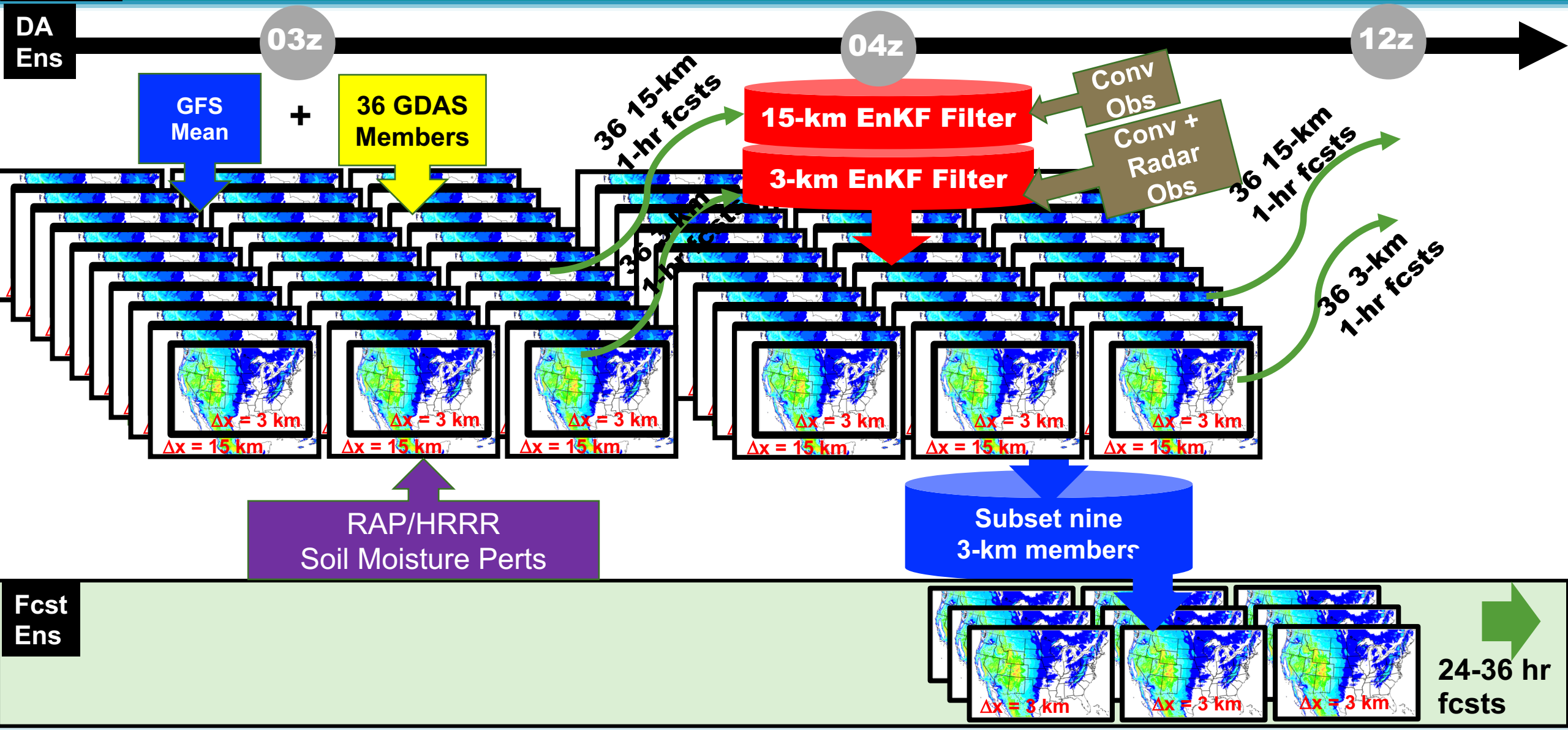
HRRRv3 Initialization from RAPv4



Proposed HRRRv4 Initialization



HRRRDAS/E Design



2019 HRRRDAS (Ensemble Analysis System)

Nested CONUS 15-km and 3-km domains with new R&D HPC resources (Jet augmentation)

36 members hourly-cycled over full CONUS

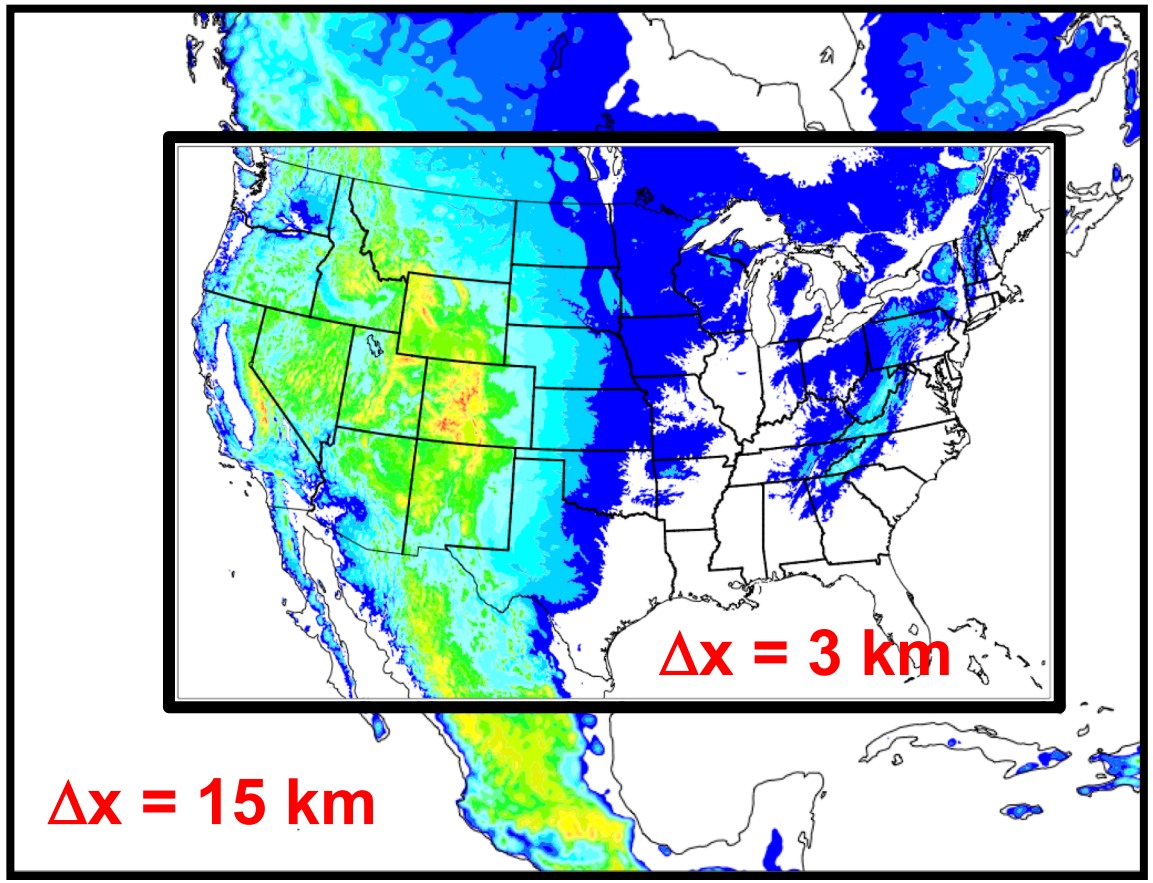
- Initial mean from GFS (atmos.) and RAP-HRRR (soil)
- Atmospheric perturbations from GFS ensemble (GDAS) to initialize HRRRDAS ensemble 1x per day
- Random soil-moisture perturbations

Hourly cycling with EnKF data assimilation

- Conventional observations both domains
- Reflectivity observations 3-km domain only
- Analysis variables: U, V, PH, T, MU, QVAPOR, QCLOUD, QICE, QRAIN, QSNOW, QGRAUPEL

Sources of Spread

- **Hourly DA (posterior inflation)**
- **Lower boundary perturbations (soil moisture)**
- **Lateral boundary perturbations**



HRRRDAS Foundation for Future Implementations

Deterministic HRRR (FY20)

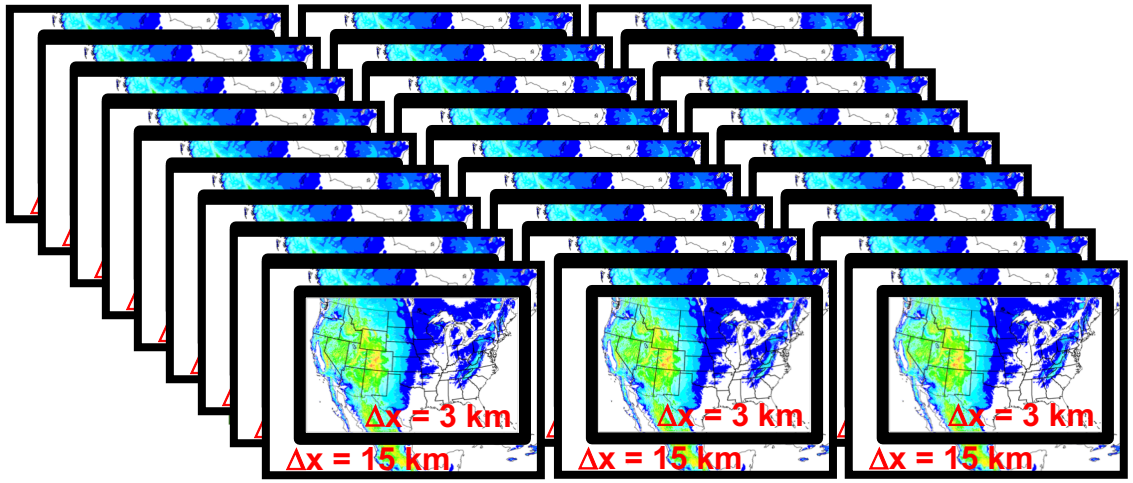
Initial conditions

Background error covariances

RTMA-3D (FY21)

Storm-scale background error covariances

Storm-scale analysis uncertainty



HRRRE (FY22? as part of RRFS)

Storm-scale ensemble forecast

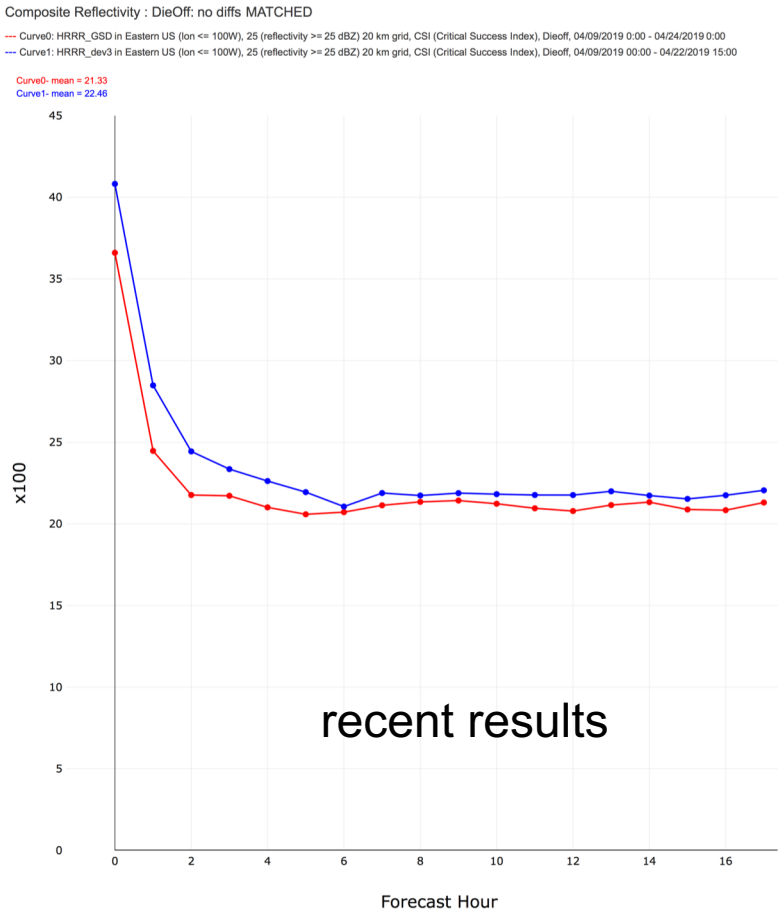
Warn-On-Forecast System (FY23-24+?)

Initial conditions

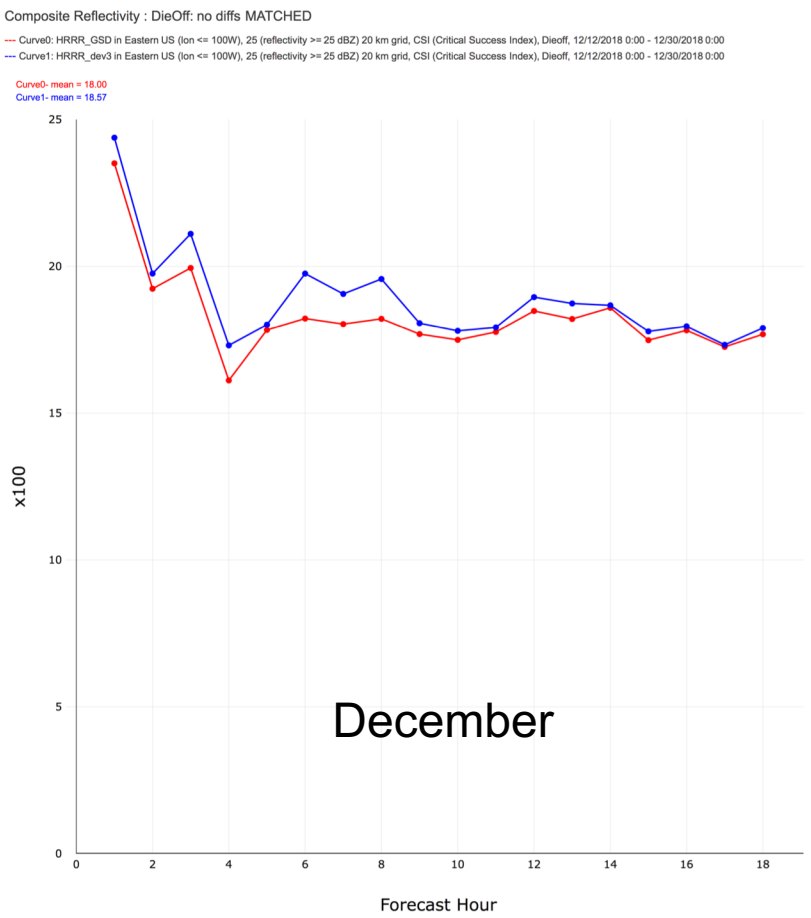
Boundary conditions

Reflectivity Verification CSI 25 dBZ, eastern US, 20-km scale

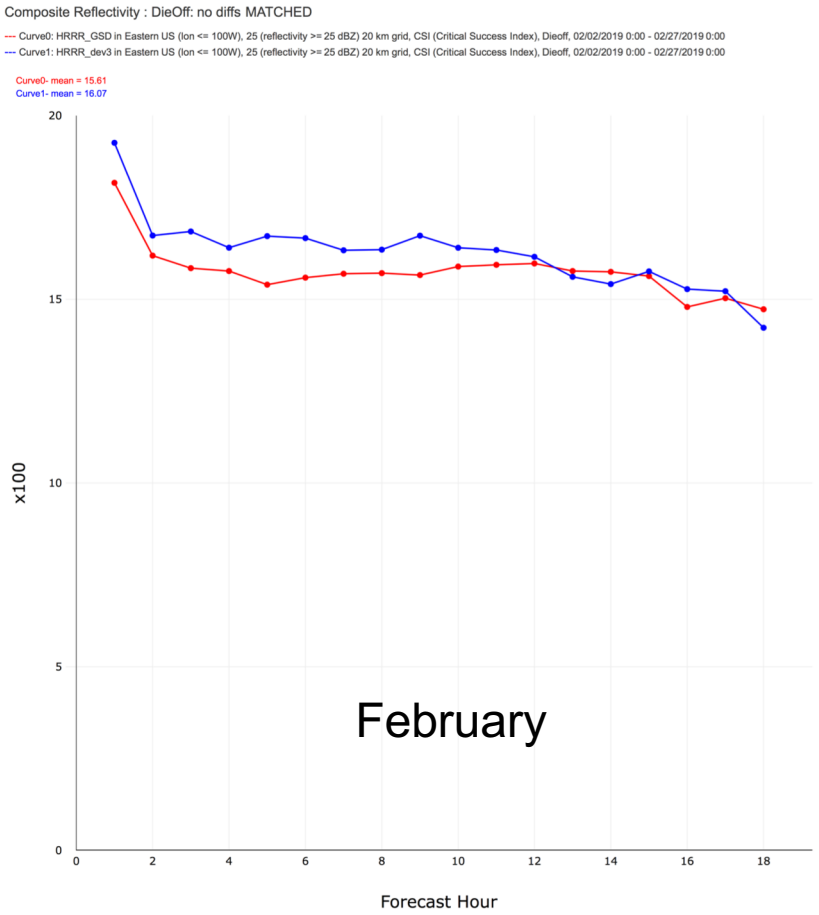
HRRRX **HRRRX using HRRRDAS**



HRRRDAS mean
GDAS ensemble



HRRRDAS mean
HRRRDAS ensemble

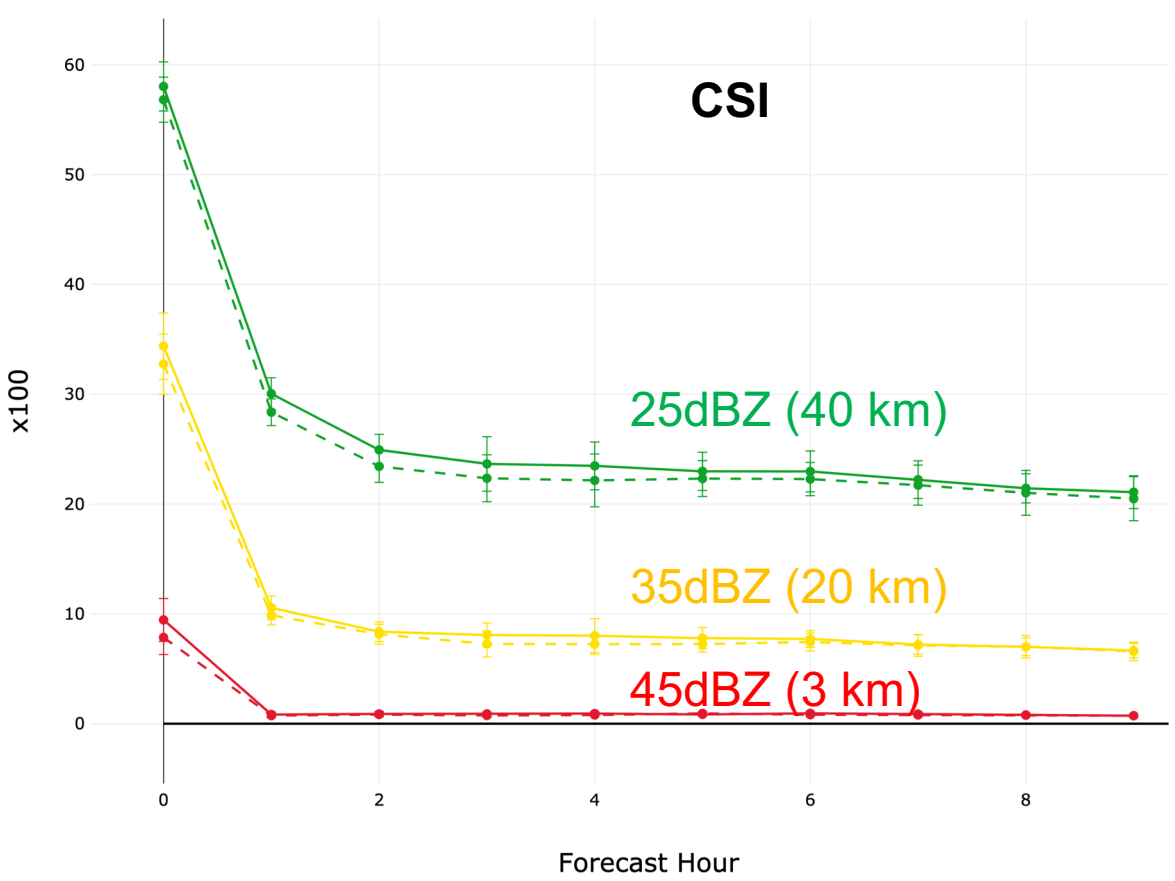


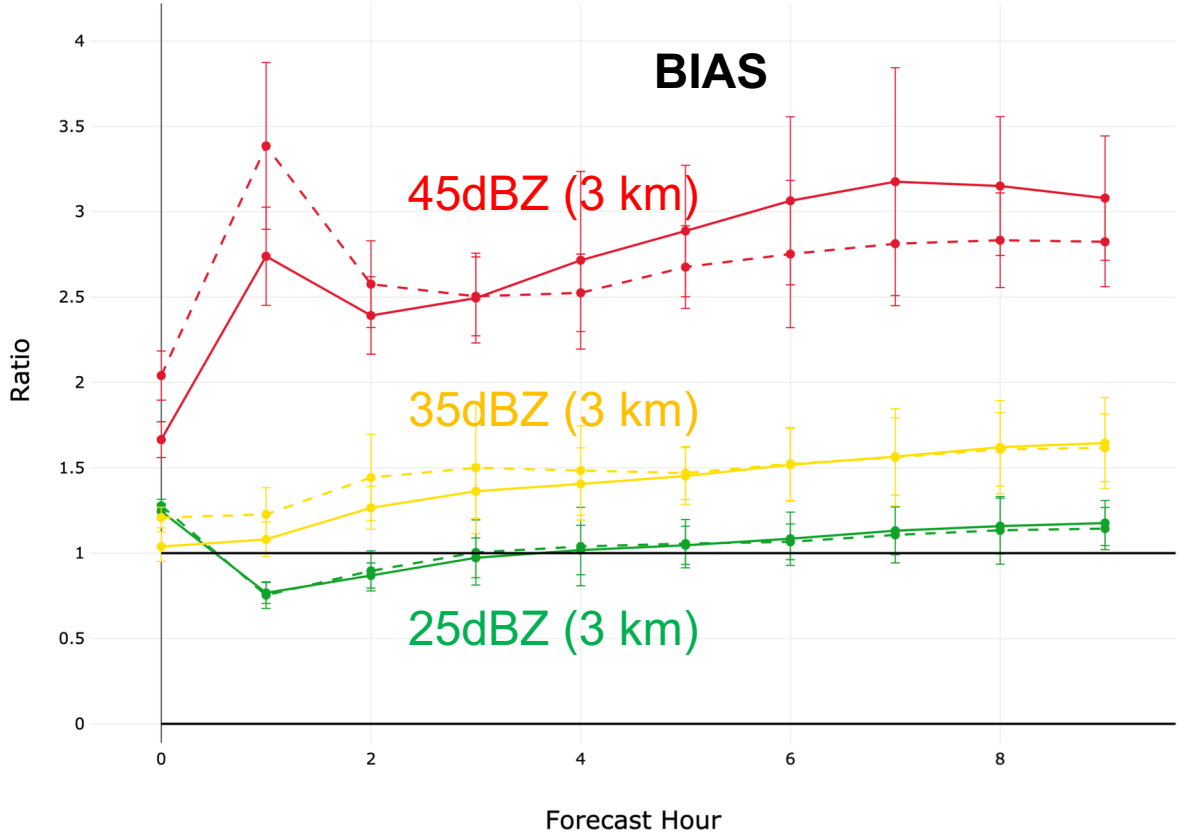
HRRRDAS mean
HRRRDAS ensemble

HRRR Composite Reflectivity Verification

HRRRv4 (exper)
HRRRv3 (oper)

Eastern US
5-11 June 2019



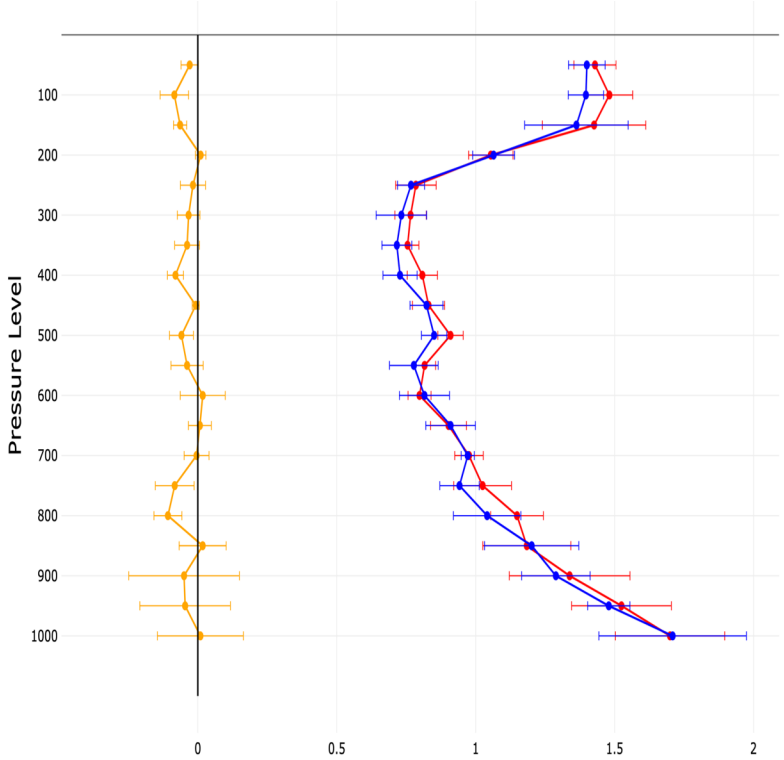


HRRR Upper-Level Verification

HRRRv4 (exper)
HRRRv3 (oper)

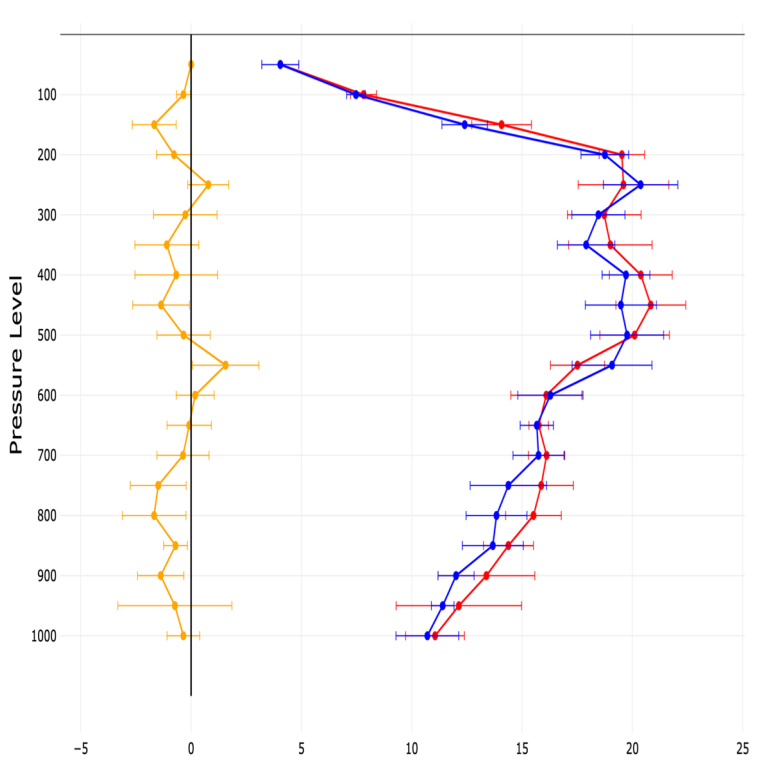
CONUS RAOB RMSE
12-hr forecasts
05-11 June 2019

Temperature



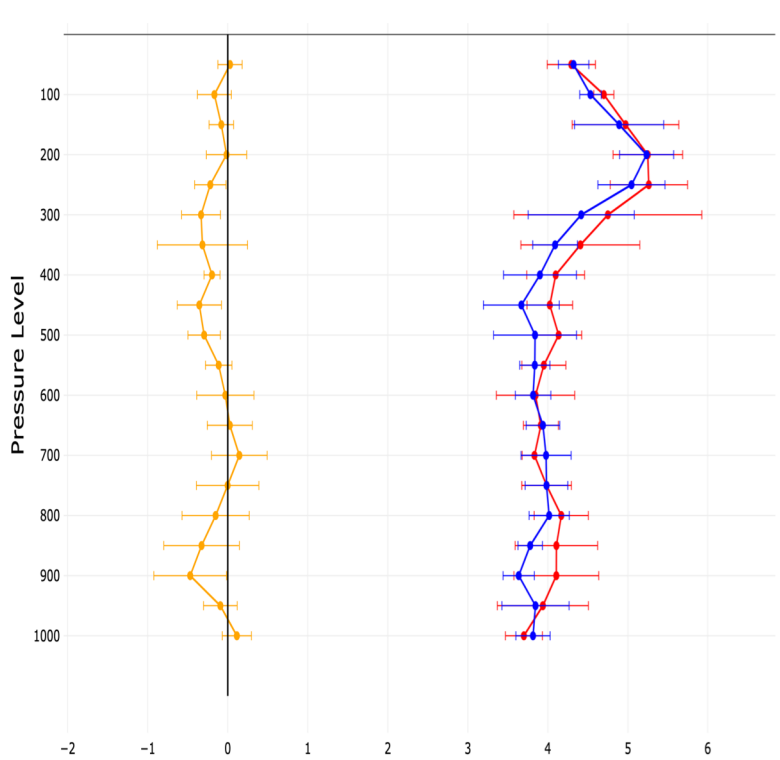
Less Error

RH



Less Error

Winds



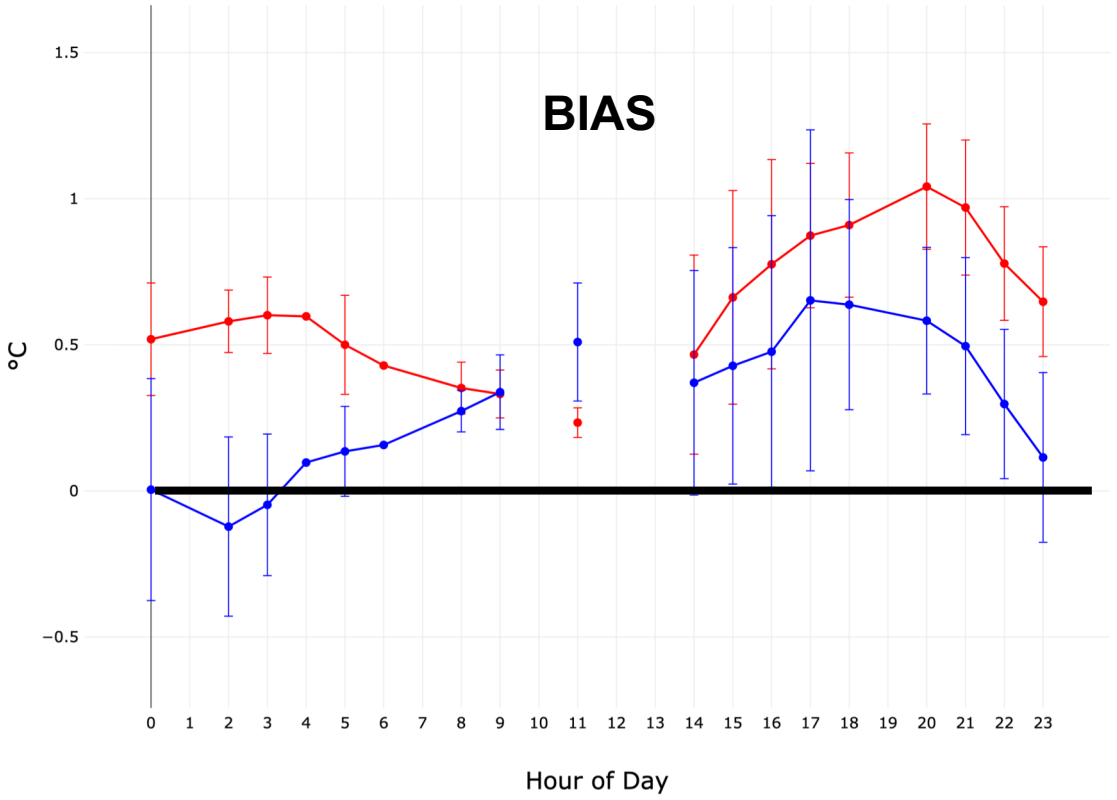
Less Error

2m Temperature Verification

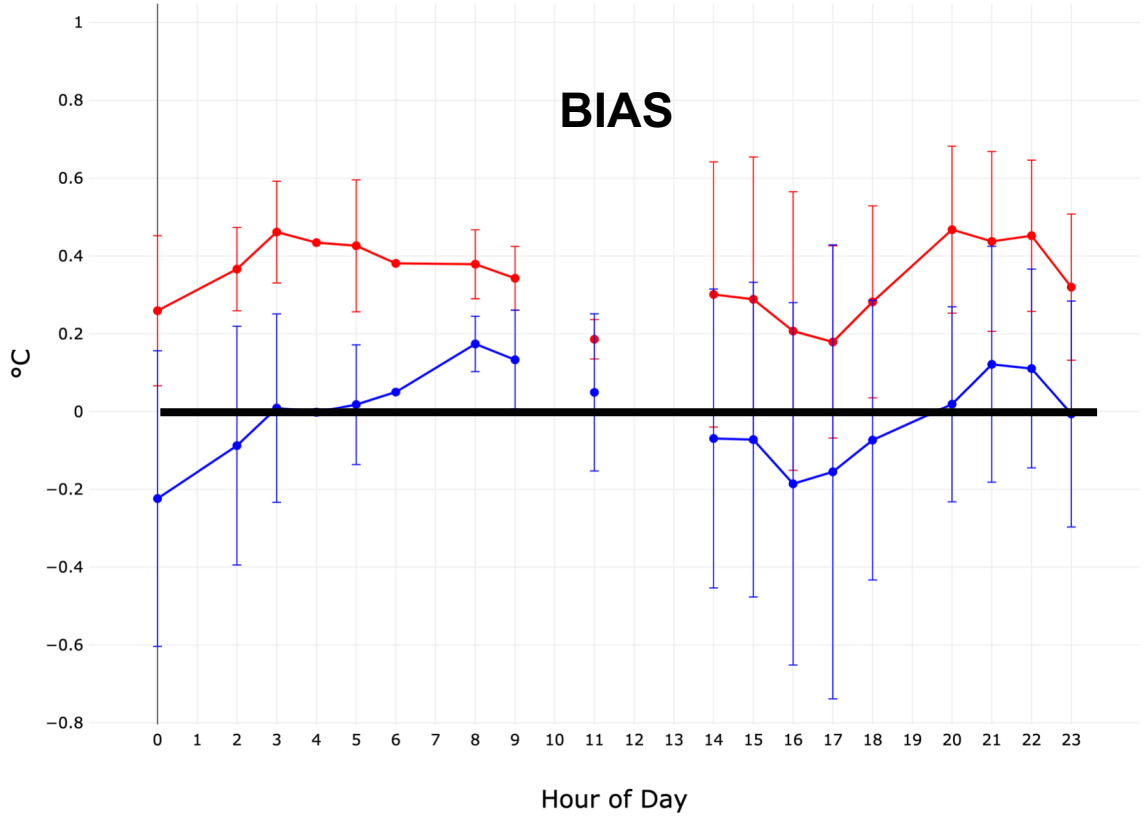
HRRRv4 (exper)
HRRRv3 (oper)

12 hr Forecasts

Western US
5-11 June 2019

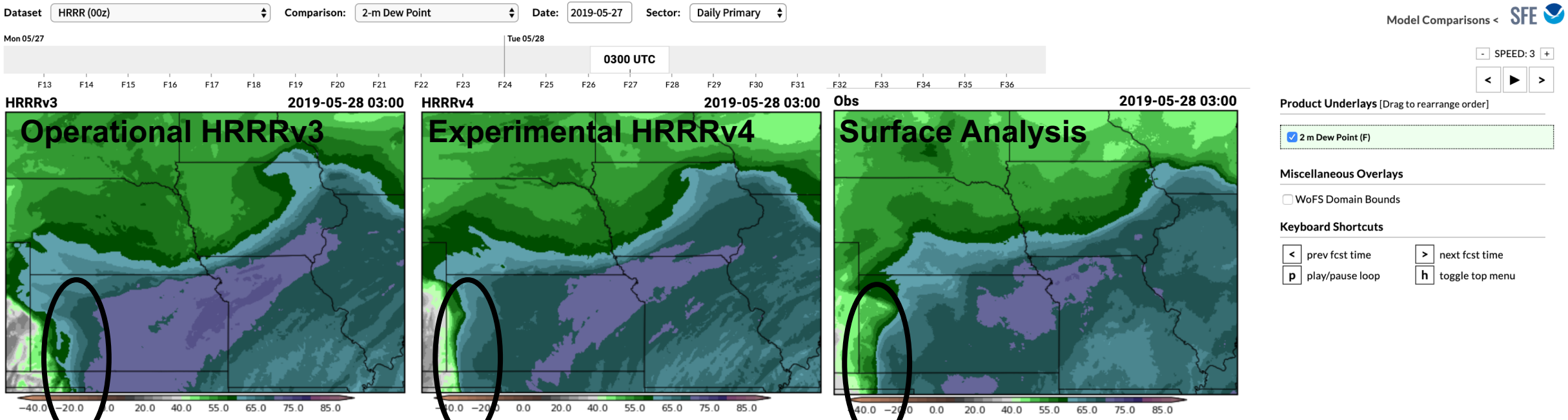


Eastern US
5-11 June 2019



2m Dewpoint Verification

27 hr Forecasts Valid
03 UTC 27 May 2019

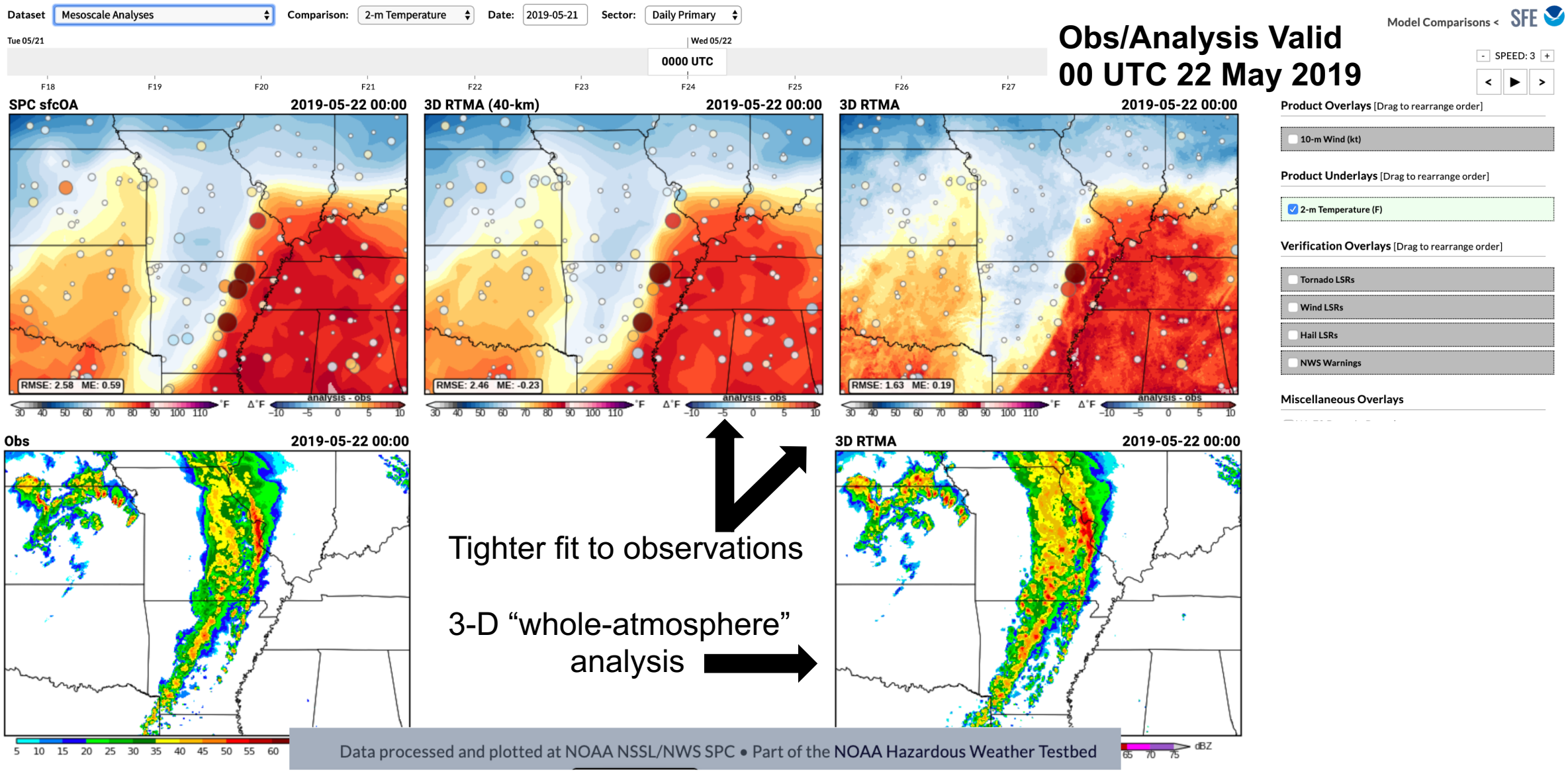


Dryline still mixing eastward

Dryline retreating westward

Data processed and plotted at NOAA NSSL/NWS SPC • Part of the NOAA Hazardous Weather Testbed

RTMA-3D: Meso-to-storm scale analysis



2019 HRRRE (Ensemble Forecast System)

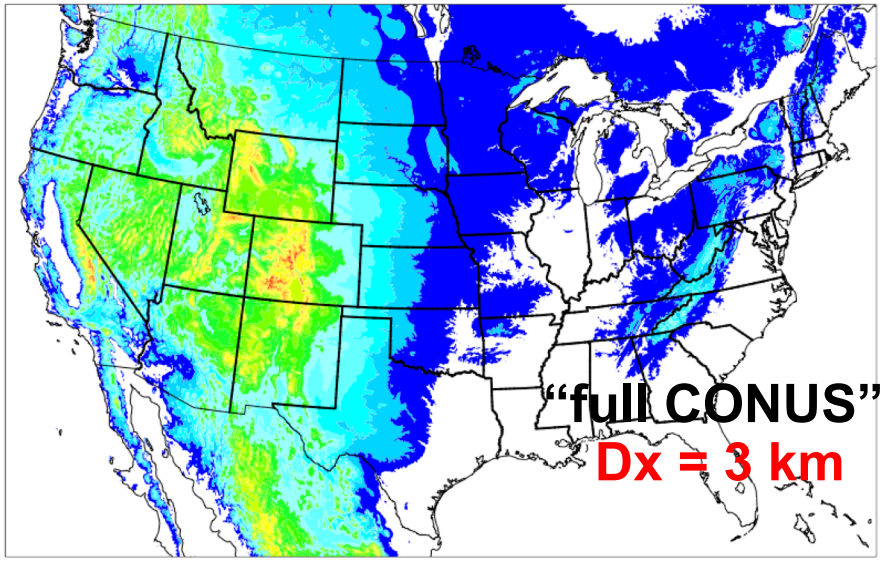
Full-CONUS 3-km forecasts initialized from 3-km analyses, 9-members + ens products

- 00 UTC: 0-36 hr forecast
- 12 UTC: 0-24 hr forecast
- 18 UTC: 0-24 hr forecast

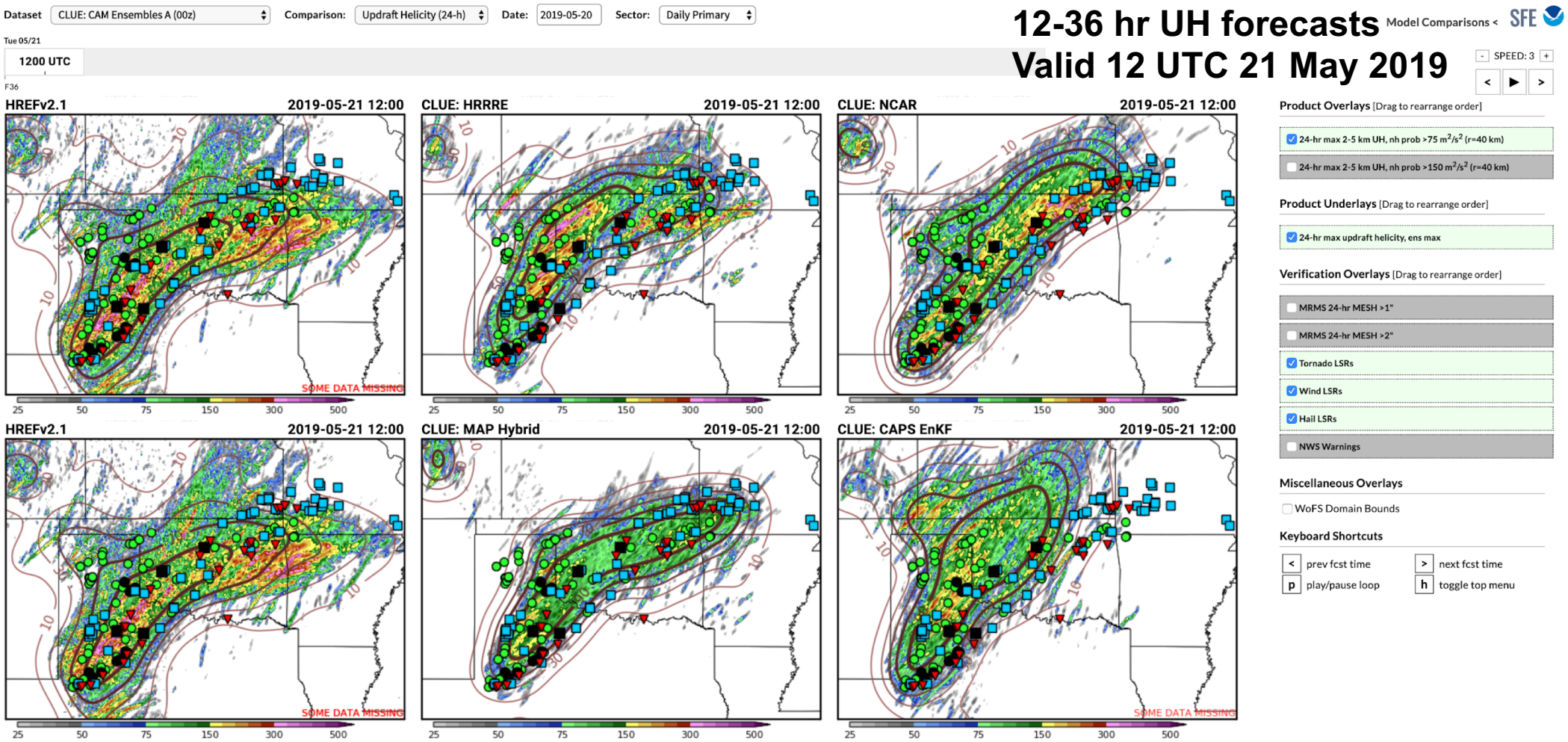
- Will be evaluated by NSSL/SPC/WPC/AWC in testbeds including CLUE
- Real-time experimental guidance available to NWS offices

Sources of Spread

- **Hourly DA (posterior inflation)**
- **Lower boundary perturbations (soil moisture)**
- **Lateral boundary perturbations**
- **Stochastic parameter perturbations across all of RAP/HRRR physics suite**



2019 HWT Spring Forecast Experiment: CAM Ensembles



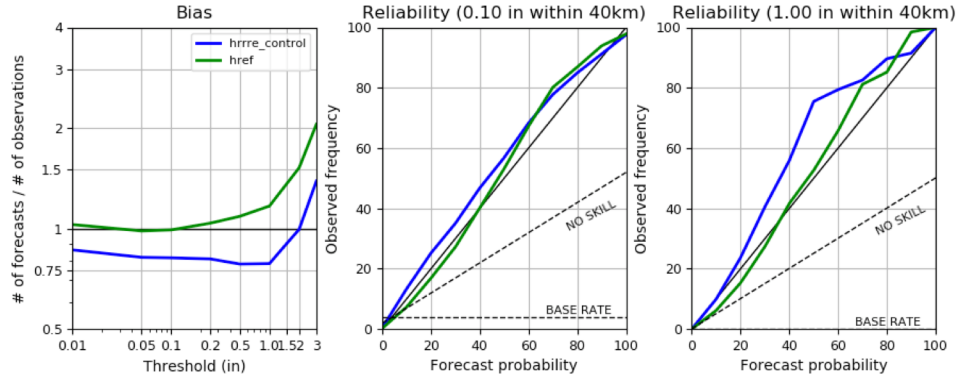
CAM Ensemble PQPF Verification: 09-21 May 2019

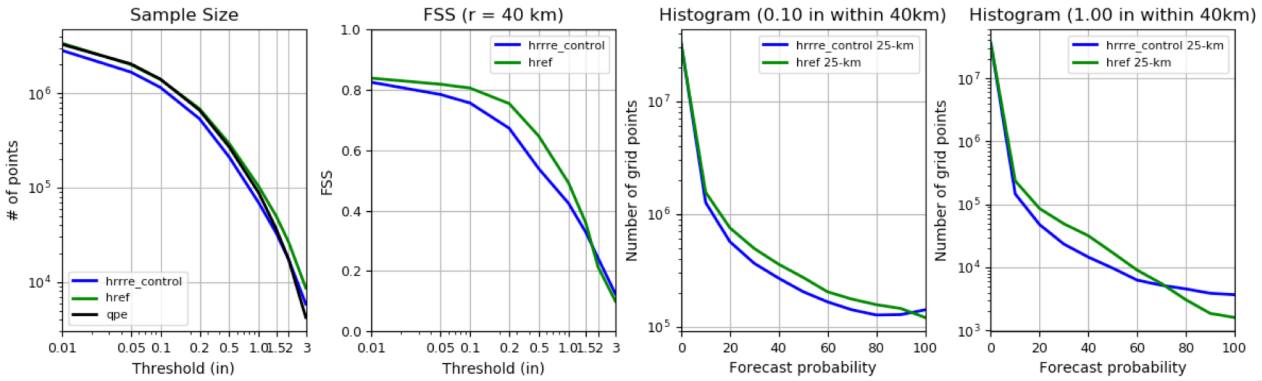
Ensemble PQPF Verification

0-6-h QPF vs Stage-IV QPE

2019-05-09 to 2019-05-21 (n=19)

0-6 hr fcsts





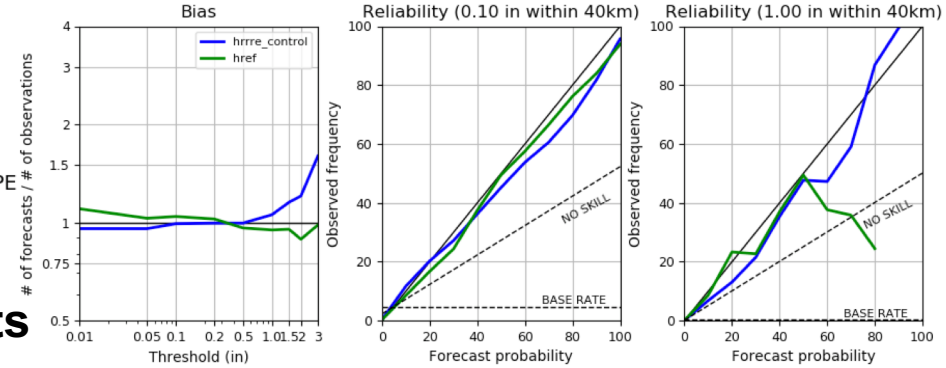
HRRRE
HREF

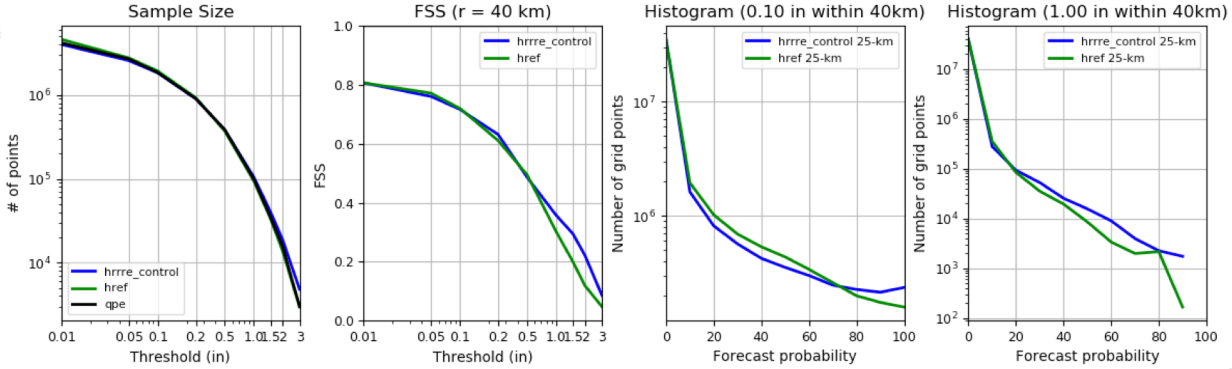
Ensemble PQPF Verification

18-24-h QPF vs Stage-IV QPE

2019-05-08 to 2019-05-21 (n=21)

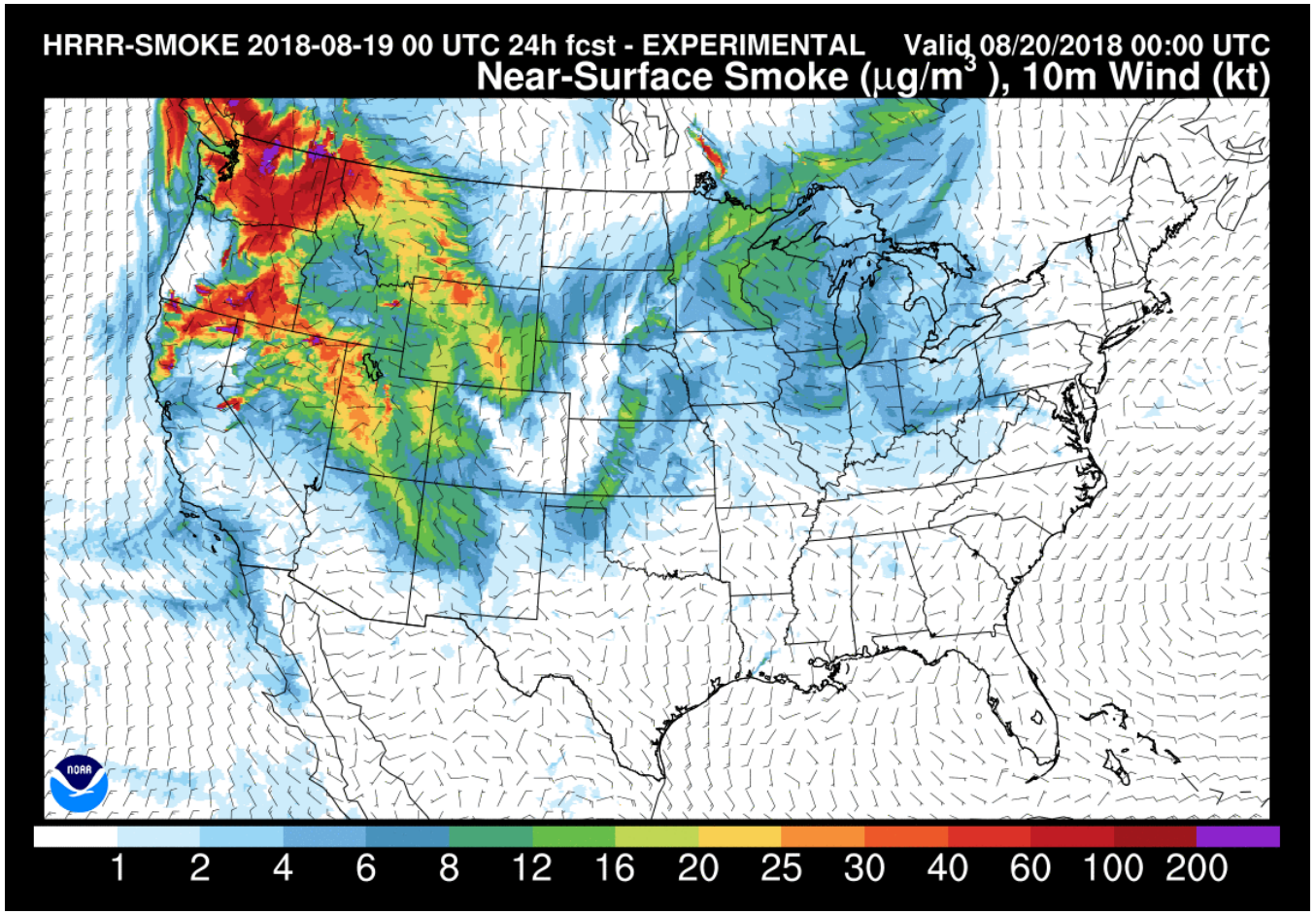
18-24 hr fcsts

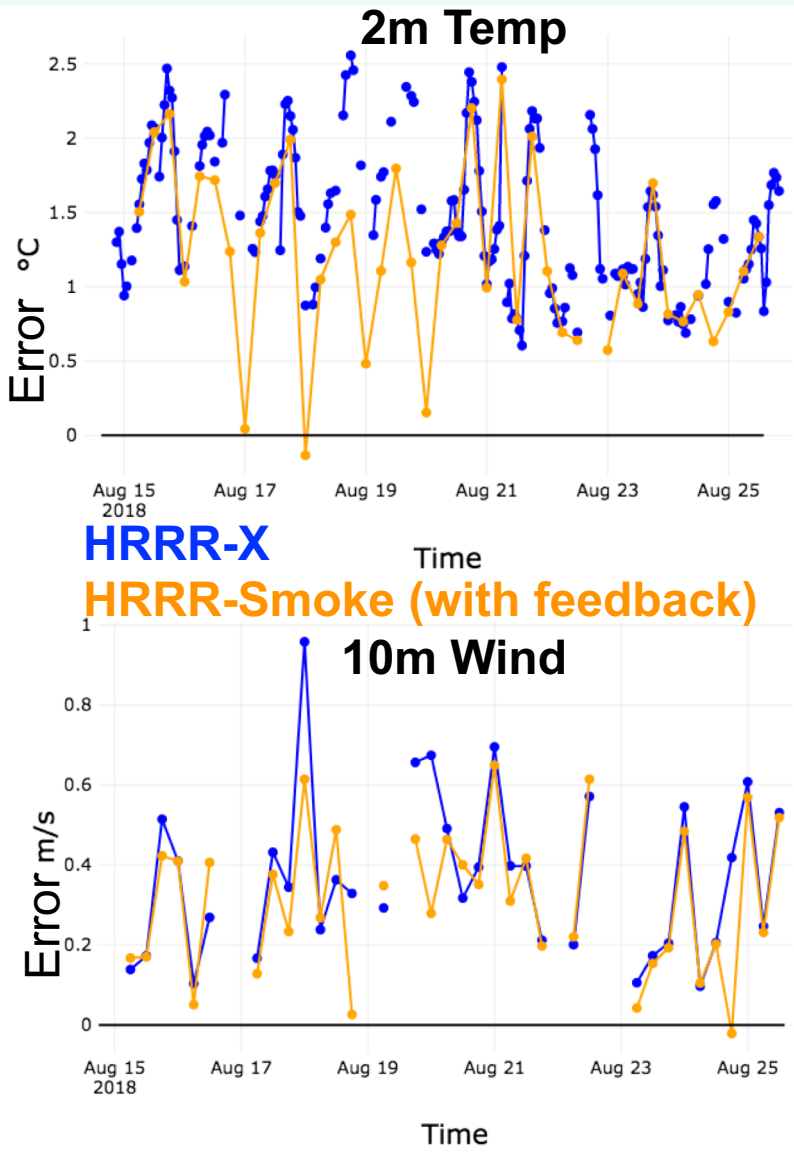




HRRRE comparable PQPF reliability with HREF
HRRRE has low(er) bias compared to HREF

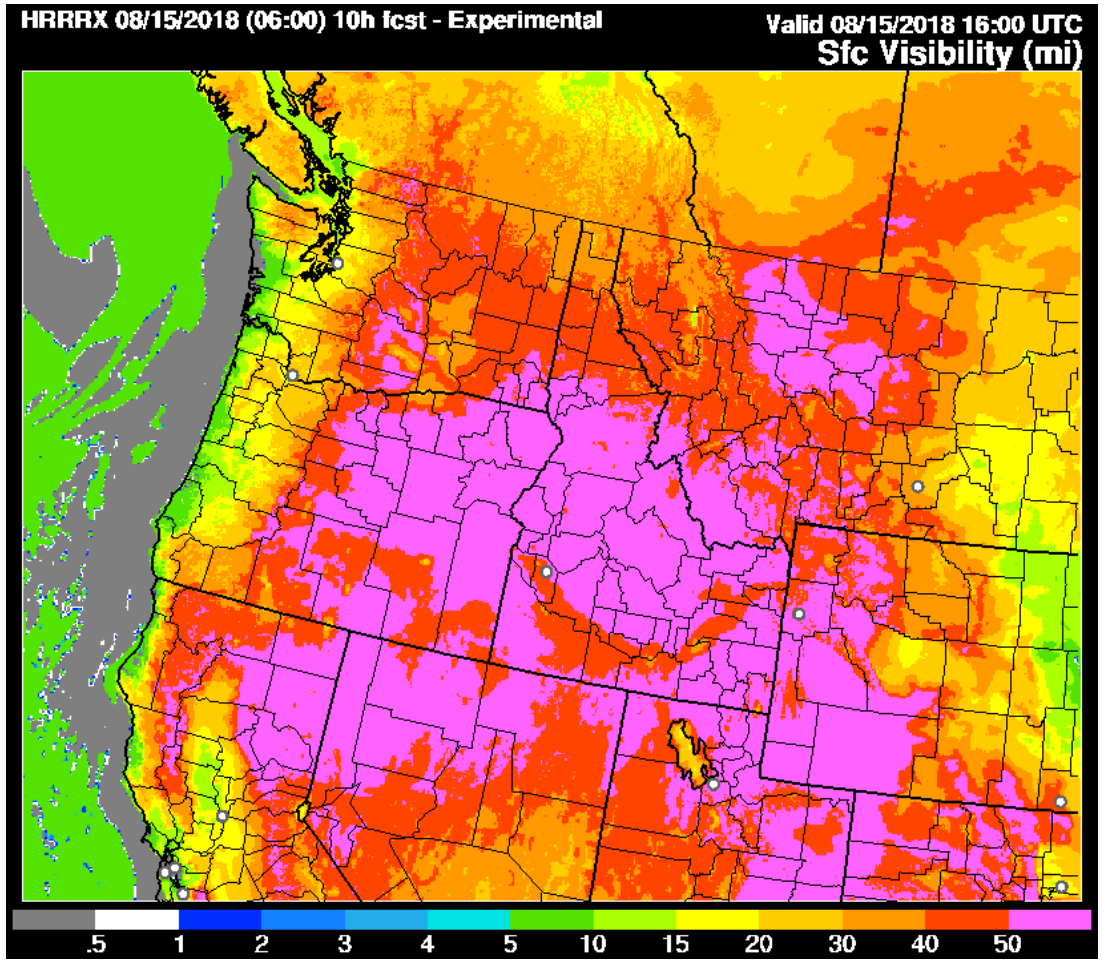
RAP/HRRR Smoke Capability



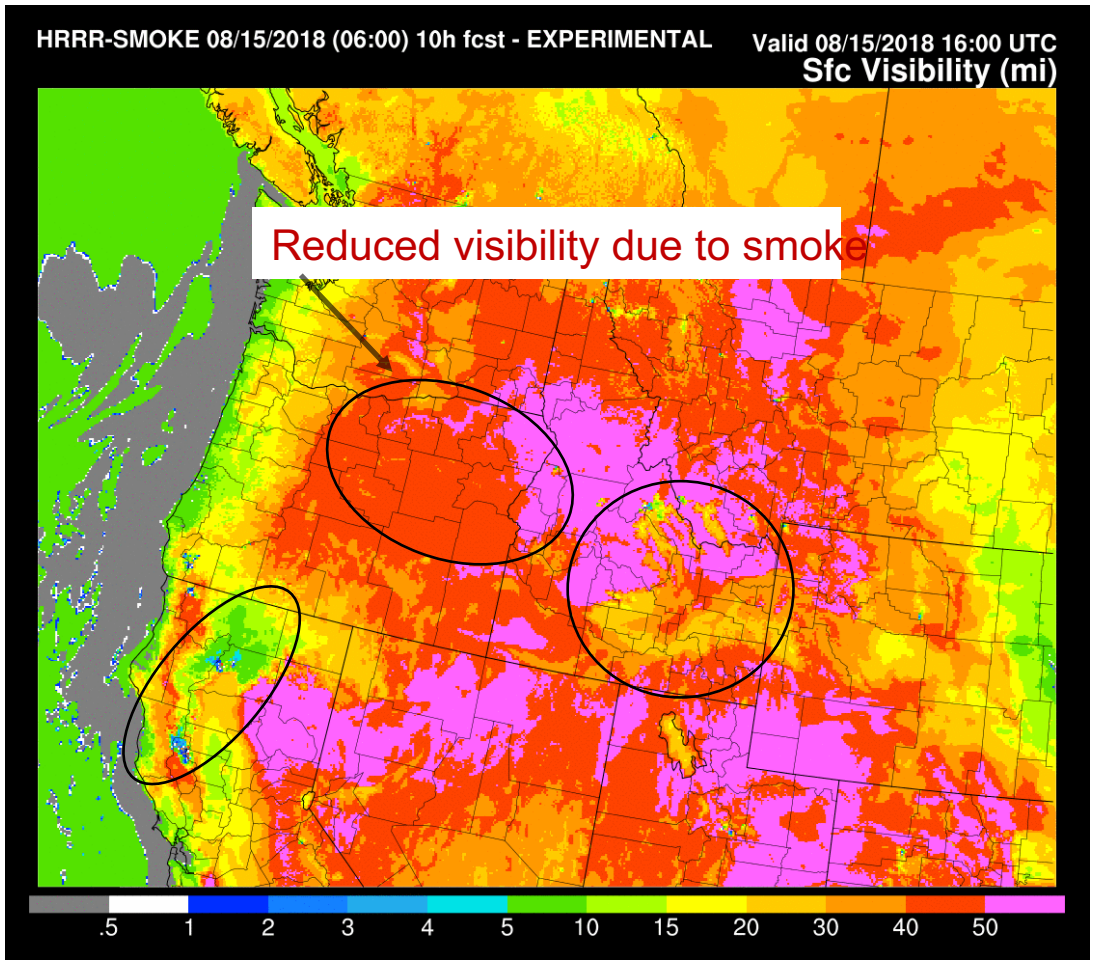


RAP/HRRR Smoke Capability

Surface visibility forecasts for 15 Aug 2018



Numerical Weather Prediction system w/o smoke (HRRR)



NWP model with smoke (HRRR-Smoke)

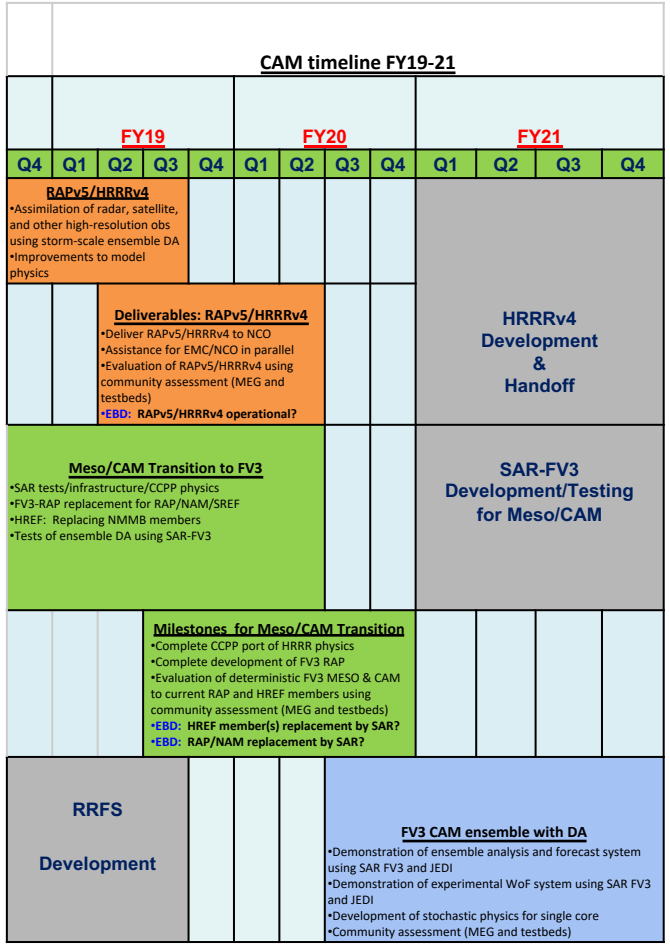
Unified Forecast System (UFS) CAM Strategic Implementation Plan (SIP)

CAM SIP FY19-21

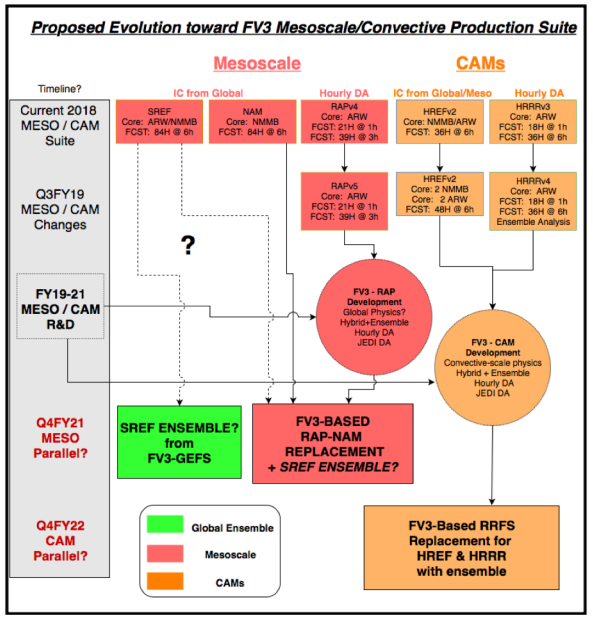
Project 7.1: Implementation of the RAPv5/HRRRv4 CAM ensemble analysis and hybrid deterministic HRRR forecast system

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



[ARW, NMMB] → FV3
[GSI, GSI-EnKF] → JEDI
[UPP] → UPP Refactored

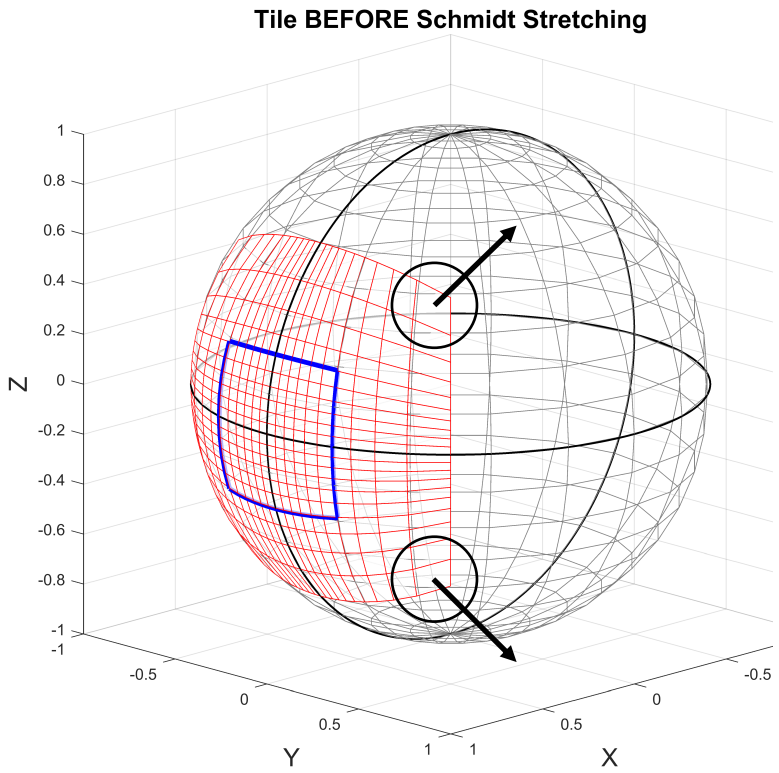


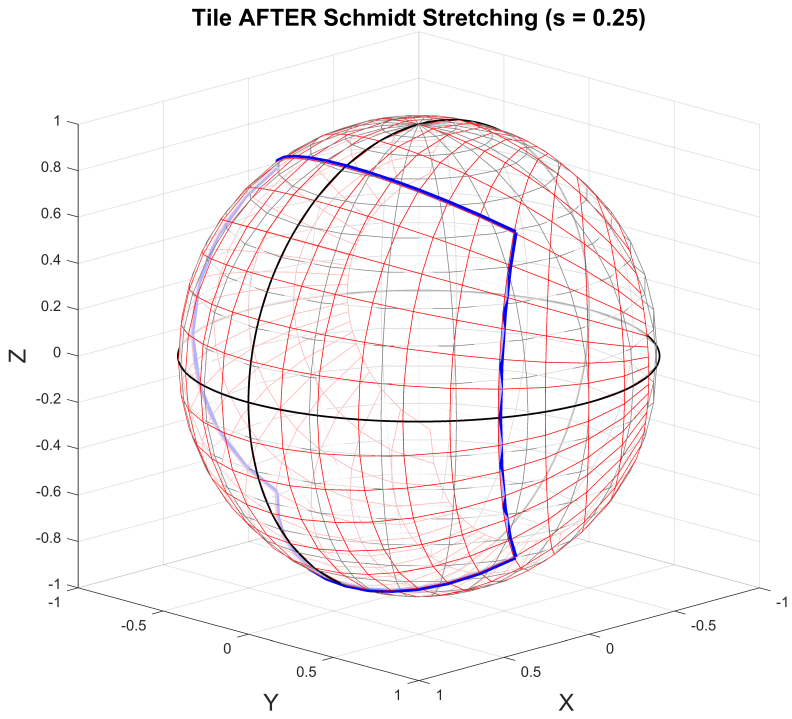
Target FY22 for Rapid-Refresh Forecast System (RRFS) based on SAR FV3 and JEDI to replace NAM/RAP/HRRR/HREF

Gnomonic Grid for Stand Alone Regional (SAR) FV3

Through collaboration with EMC (Jim Purser):

- Concentrate model coordinates (great circles) near center of tile six to improve uniformity after stretching
- Added two plotting parameters (alpha and kappa) to the generation of the gnomonic grid
- Flares the corners of the grid to reduce grid variability

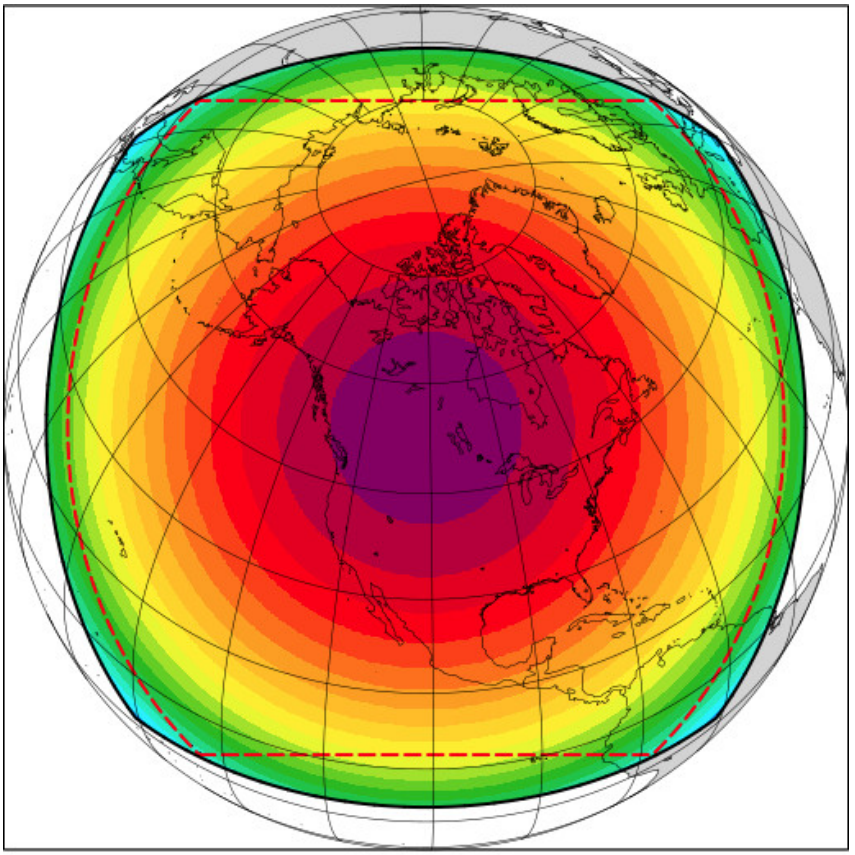




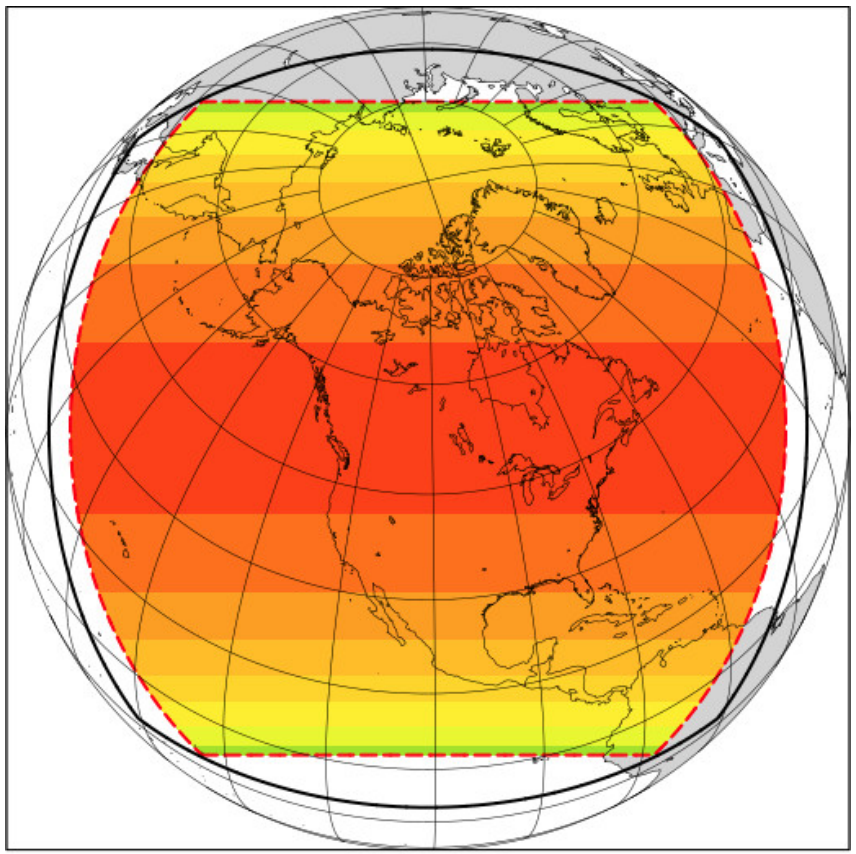
Blue represents the outline of the SAR grid (tile seven) with the sixth tile of the global FV3 in red

Comparison of RAP/RAP-equivalent Grids

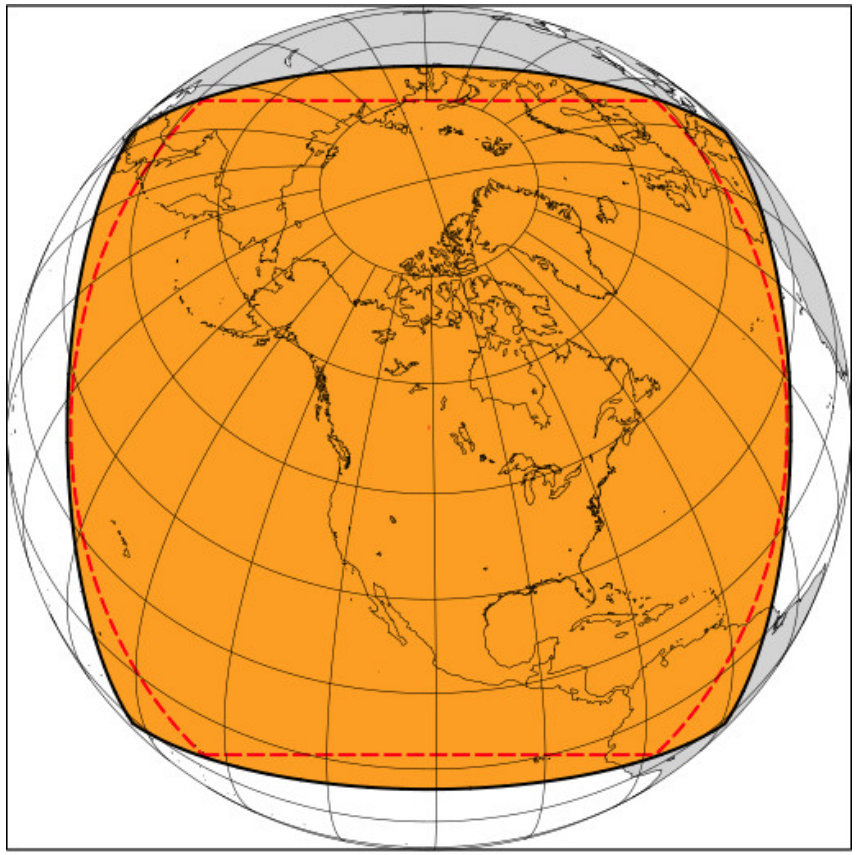
With Global “Parent” Grid

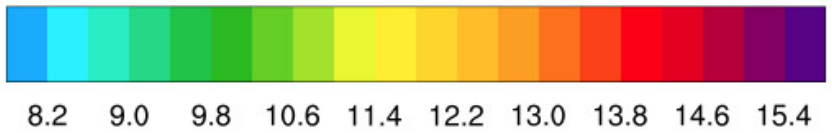


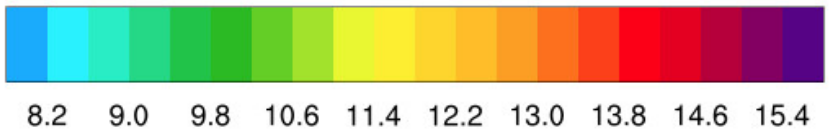
Original RAP-ARW Grid

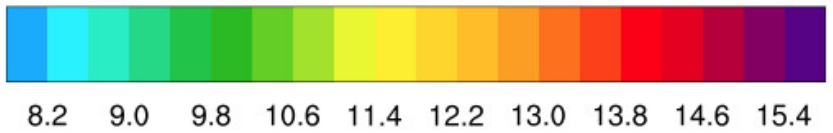


No Global “Parent” Grid



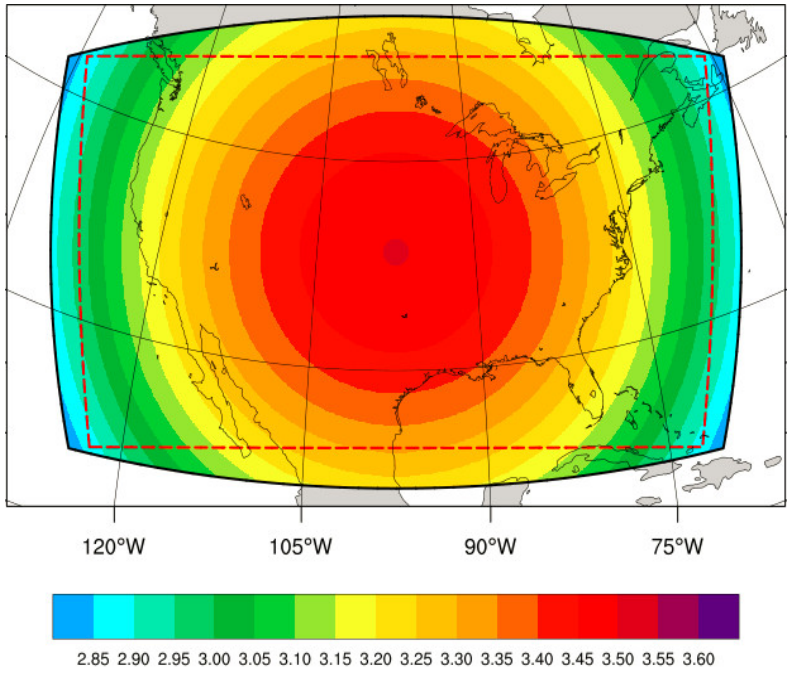




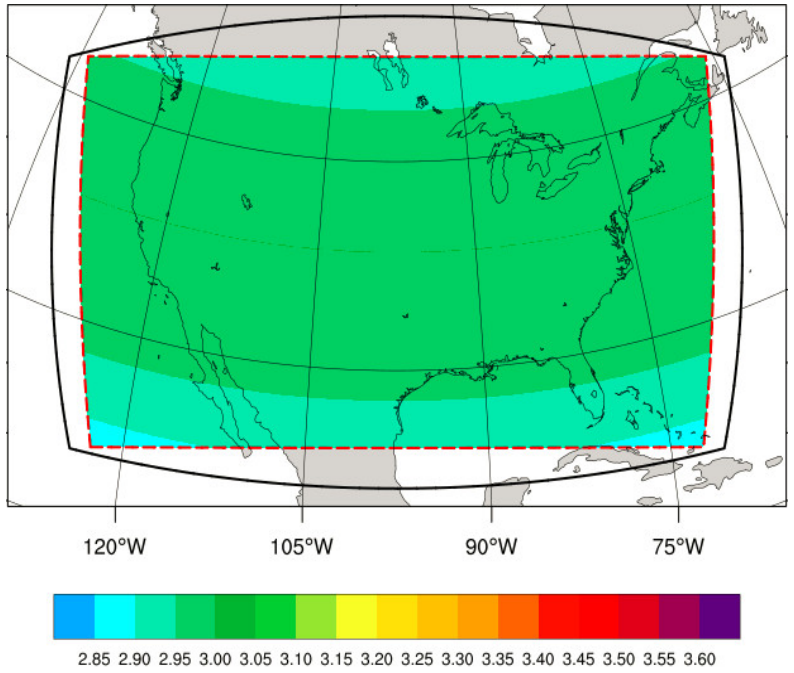


Comparison of HRRR/HRRR-equivalent Grids

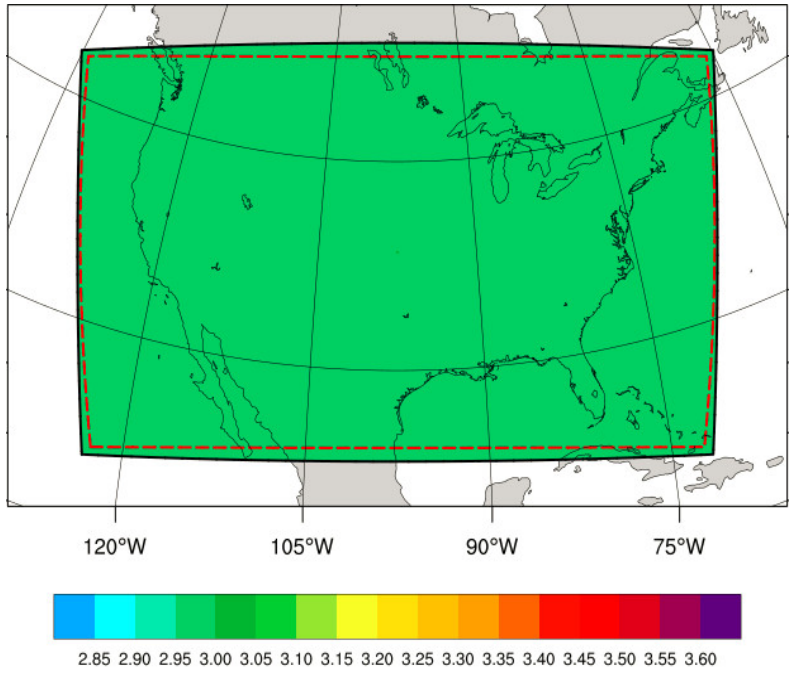
With Global “Parent” Grid



Original HRRR-ARW Grid



No Global “Parent” Grid

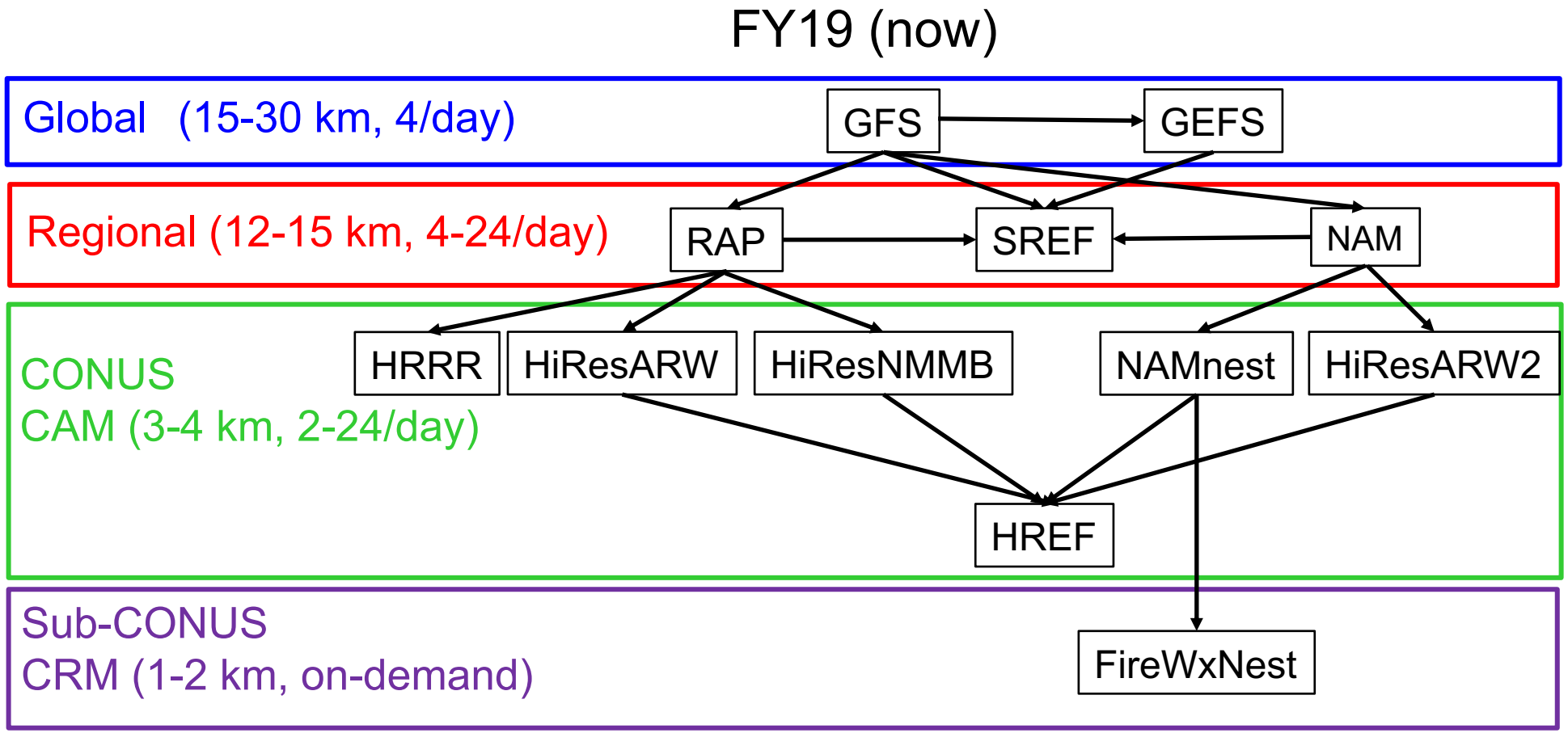


RAP/HRRR physics suite now using CCPP interface

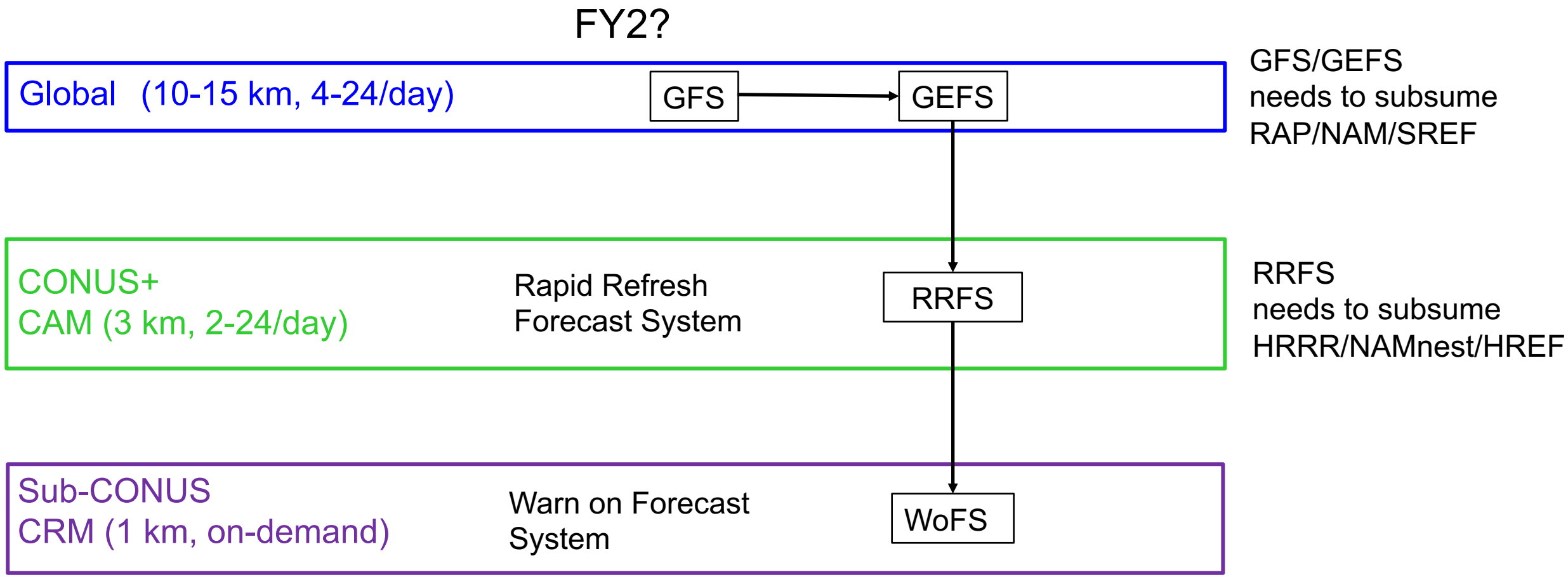
HRRR-FV3 runs starting using RAPv5 LBCs and HRRRv4 ICs along with RAPv5/HRRRv4 physics this month

Note: We are transferring all RAP/HRRR data assimilation and model physics capabilities to the (SAR) FV3

UFS: Simplification of Regional Model Production Suite



UFS CAM Application(s): The RRFS/WoFS



RAP/HRRR/CCPP ESRL/GSD Development Talks

P25	Wed 1:30	Jaymes Kenyon	Recent development of the MYNN turbulence parameterization for RAPv5 / HRRRv4
P27	Wed 1:30	Ligia Bernardet	Facilitating development of physical parameterizations for NOAA's Unified Forecast System
P58	Wed 1:30	Evan Kalina	Evaluation of the MYNN planetary boundary layer scheme in the Hurricane Weather Research and Forecast (HWRF) system
9.2	Thu 10:45	Joseph Olson	Improving cloud and solar radiation forecasts in the RAP/HRRR forecast systems
9.5	Thu 11:30	Michael Toy	Evaluating and tuning the orographic gravity wave drag scheme in the RAP model
10.6	Thu 2:45	Dom Heinzeller	The Common Community Physics Package CCPP: Unifying physics across NOAA and NCAR models using a common software framework