UFS Webinar Series

The Unified Forecast System Short-Range Weather Application for Convection Allowing Model Forecasts

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NOAA/GLOBAL SYSTEMS LABORATORY

NOAA/NCEP/EMC

NCAR/DTC

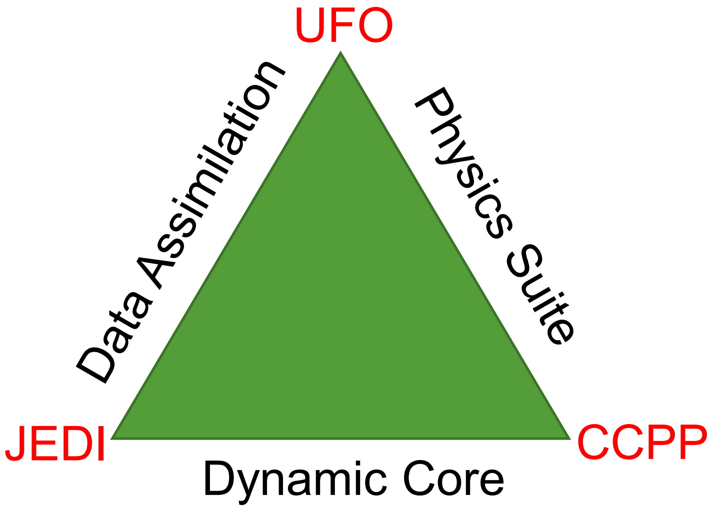
NOAA/NSSL

UFS What is it?

https://ufscommunity.org/

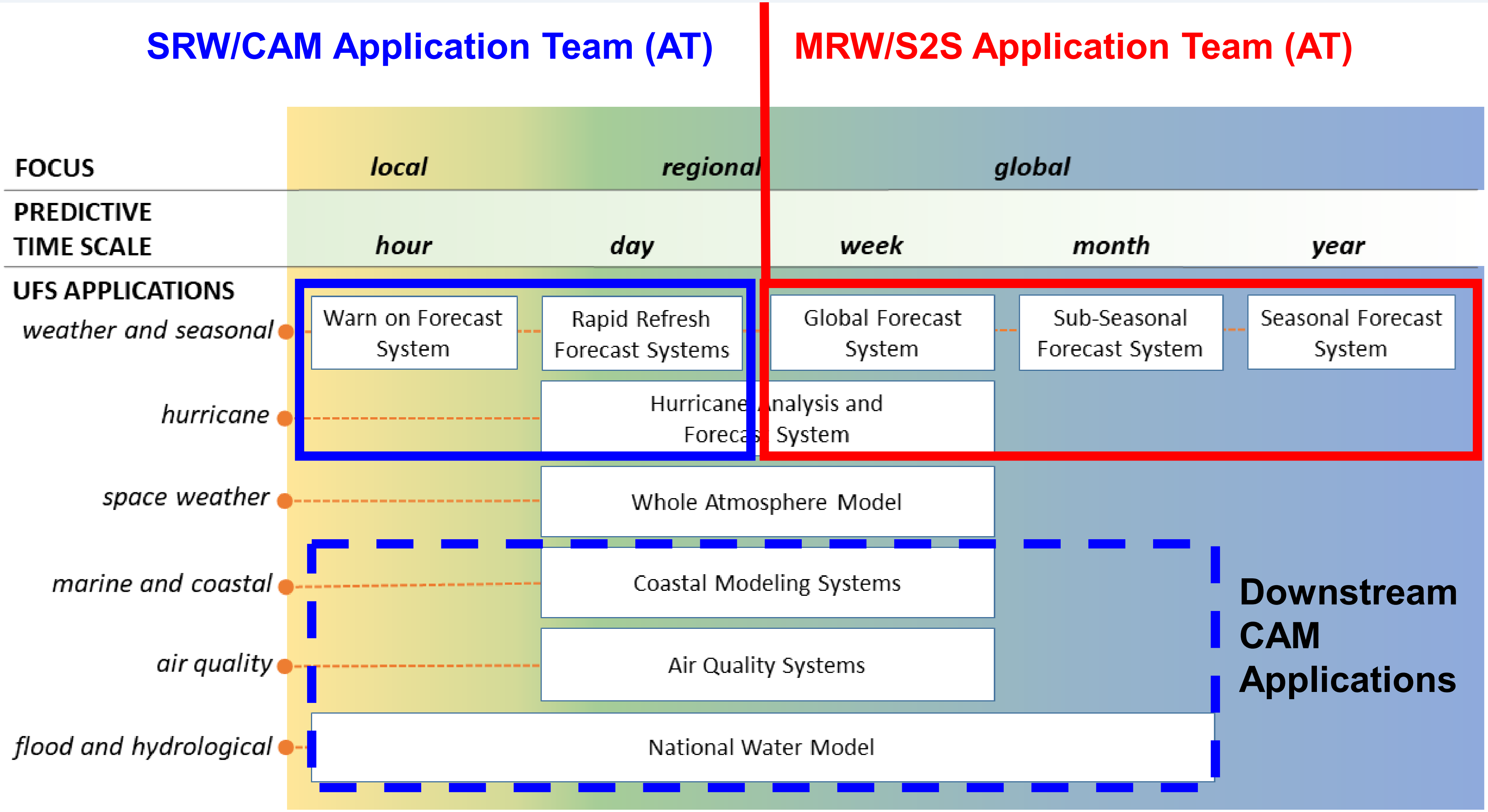
The Unified Forecast System (UFS) is a:

- community-based, coupled, comprehensive Earth modeling system
- numerical applications span local to global domains
- predictive time scales from sub-hourly analyses to seasonal predictions
- designed to support the Weather Enterprise
- the source system for NOAA's operational numerical weather prediction applications



Increasingly modular components
Agnostic interactions through enabling software technologies like CCPP
UFS applications may differ in one or more components, but goals:
Data Assimilation → Joint Effort for Data assimilation Integration (JEDI)
Physics Suite → Scale-awareness for local to global
Dynamic Core → FV3

UFS Applications

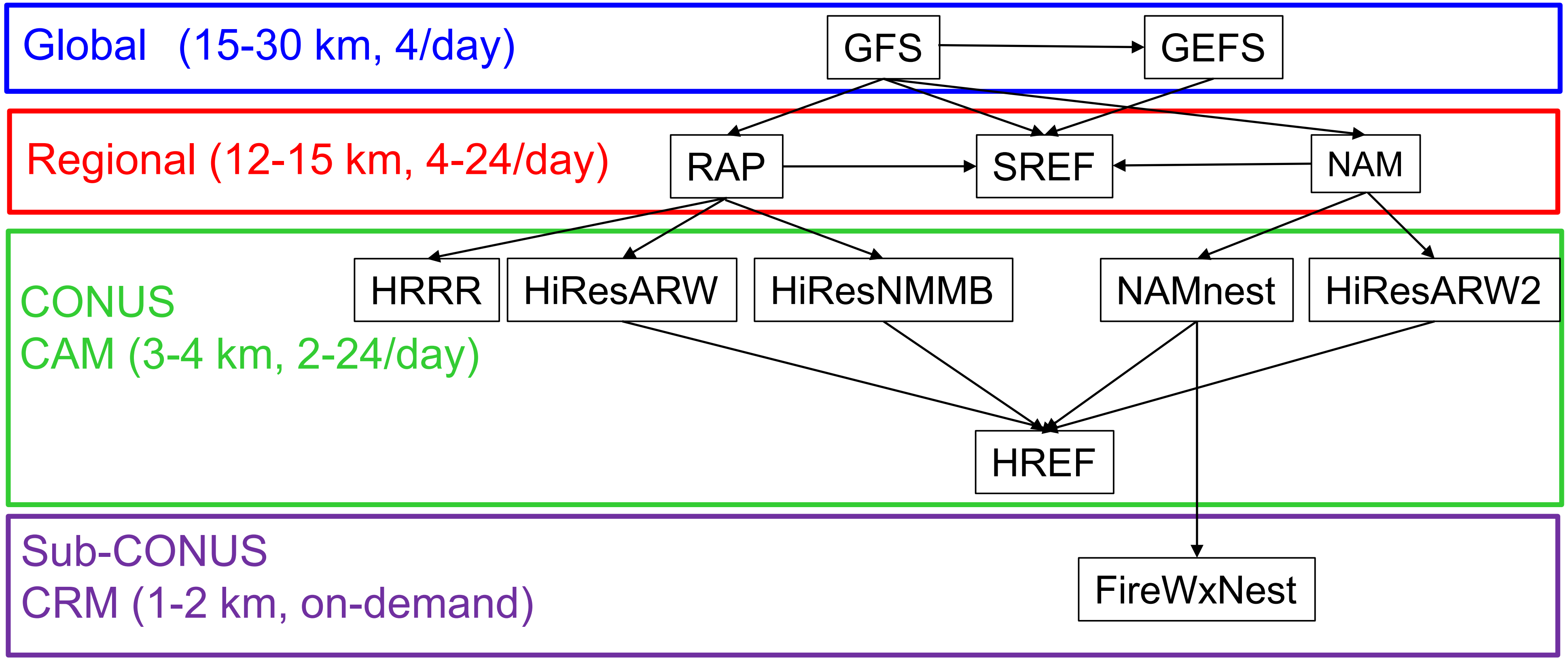


CAM Regional Forecast Systems (Sub-Projects)

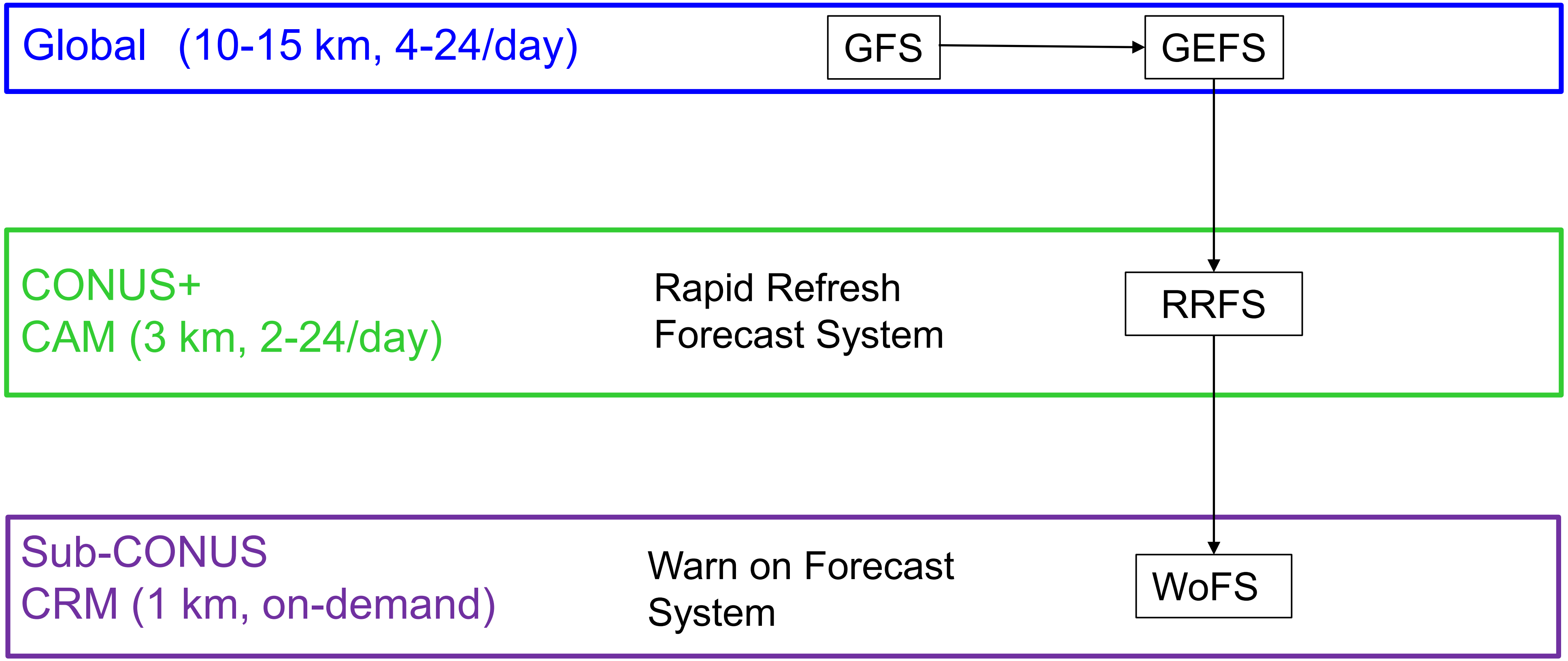
System Name	RTMA/URMA-3D	WoFS	RRFS	HAFS
Predictive Time Scale	Now	Next few hours	Next few days	Next week
Grid Spacing	2.5 km	1 km	3 km	1-3 km
Cadence Update	15 min	30 min (on-demand)	Hourly	Six hourly
Domain	CONUS	Sub-CONUS	CONUS	Oceanic Basins
Operational Legacy System Replacements	RTMA-2D URMA-2D	Fire Wx Nest	NAMnests/HRRR/HiResWindows/HREF	HWRF/HMON
Model Core	SAR FV3	SAR FV3	SAR FV3	SAR FV3 or Global FV3 Nest
Analysis System	GSI to JEDI	GSI to JEDI	GSI to JEDI	GSI to JEDI
First Implementation	Q3FY23	FY24-25	Q2FY23	Q3FY22

- Rapid Refresh Forecast System (RRFS)
  - Based on the FV3-Stand Alone Regional (SAR)
  - Rapidly updated
  - Convection-allowing (~3 km)
  - Ensemble data assimilation (est. 30 or 40 members)
  - Ensemble forecasts (est. 10 members)
    - 18h+ hourly
    - 36-60h every 6 to 12 hours
- When? ~FY23
- Facilitate replacement of several current regional systems
  - e.g., NAM+nests, RAP +HRRR, HiRes Windows, HREF

FY20 (now)


Global (15-30 km, 4/day)
GFS
GEFS
Regional (12-15 km, 4-24/day)
RAP
SREF
NAM
CONUS
CAM (3-4 km, 2-24/day)
HRRR
HiResARW
HiResNMMB
NAMnest
HiResARW2
HREF
Sub-CONUS
CRM (1-2 km, on-demand)
FireWxNest

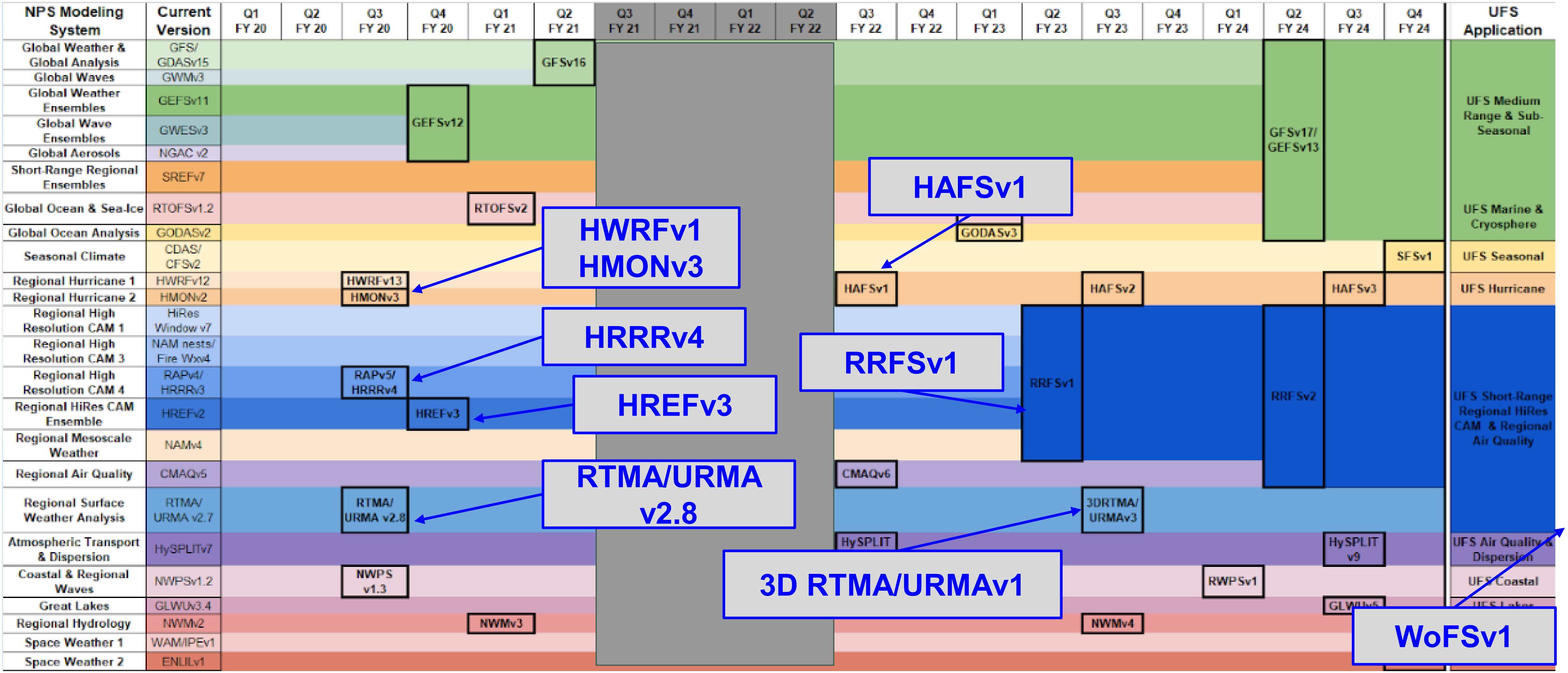
FY2??



GFS/GEFS
needs to subsume
RAP/NAM/SREF

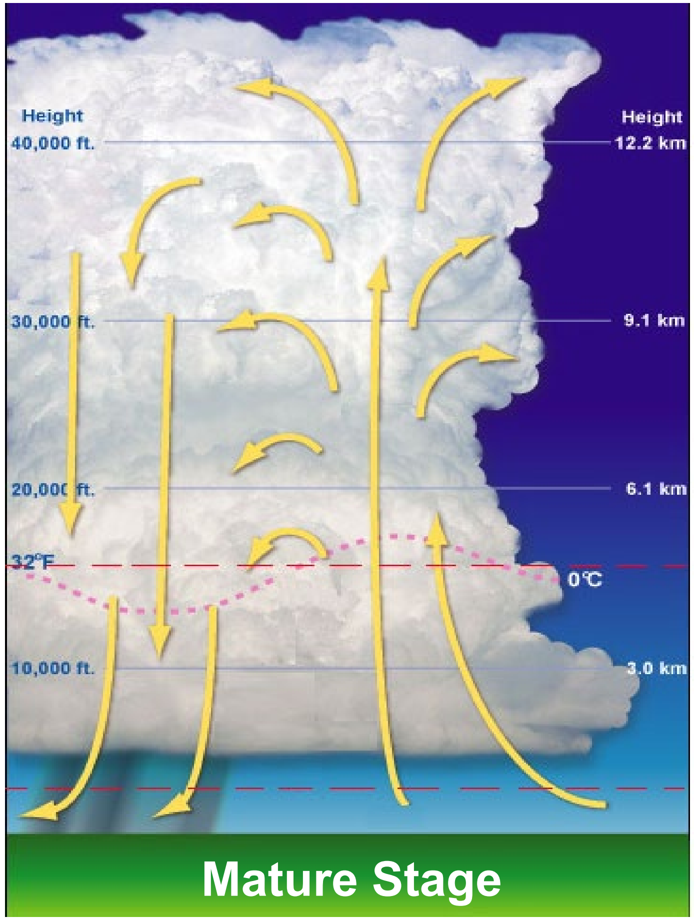
RRFS
needs to subsume
HRRR/NAMnest/HREF

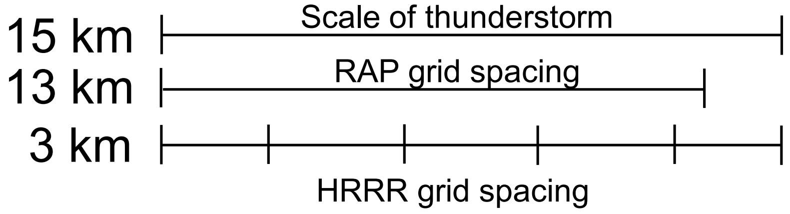
Hypothetical Implementation Timeline to FY24



Explicit Deep Convection

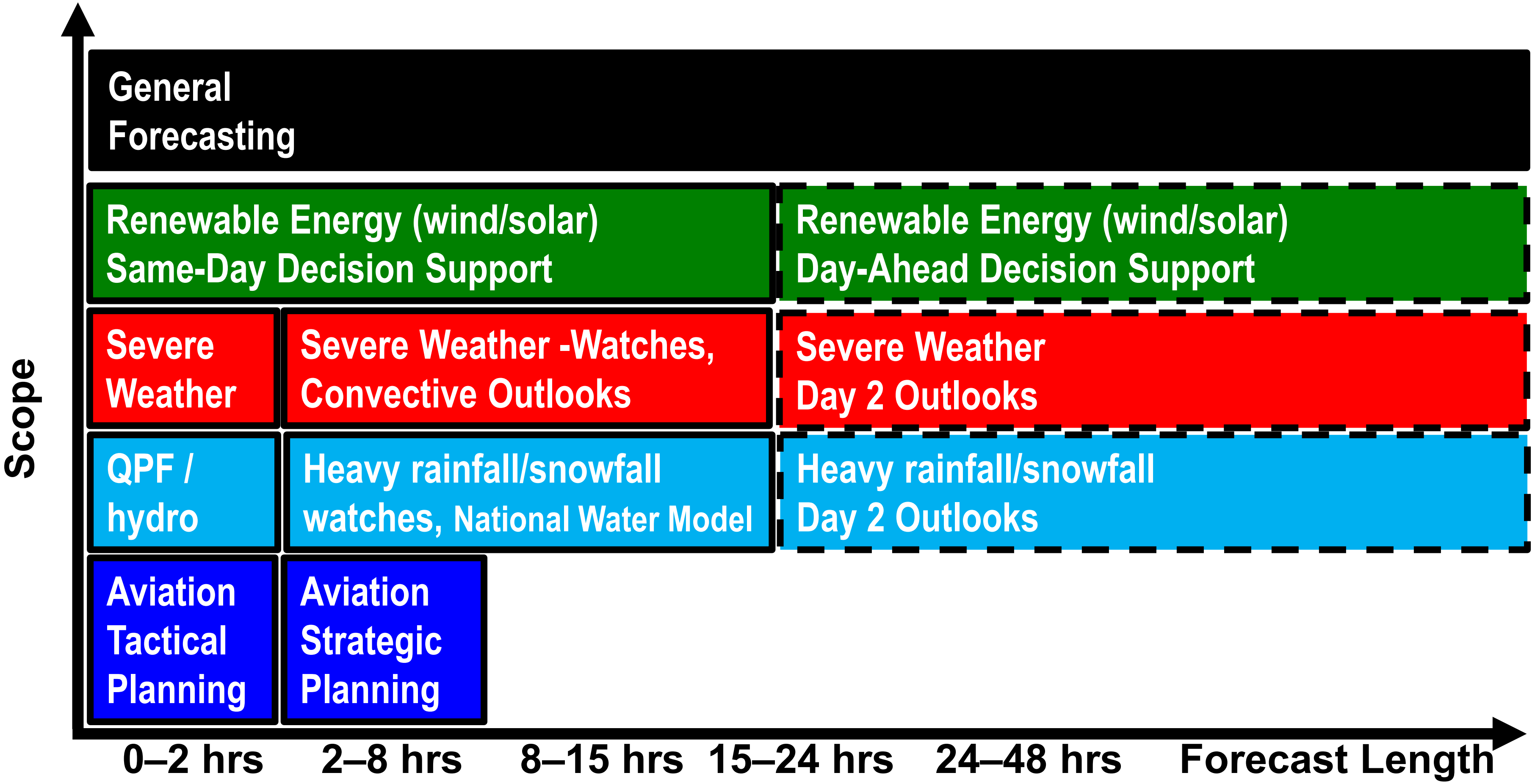
- Models such as the HRRR with a horizontal grid spacing of 3 km can develop many convective circulations explicitly.
- Deep convective parameterization is not needed for these models.
- This configuration allows for improved prediction of convective mode and structure.



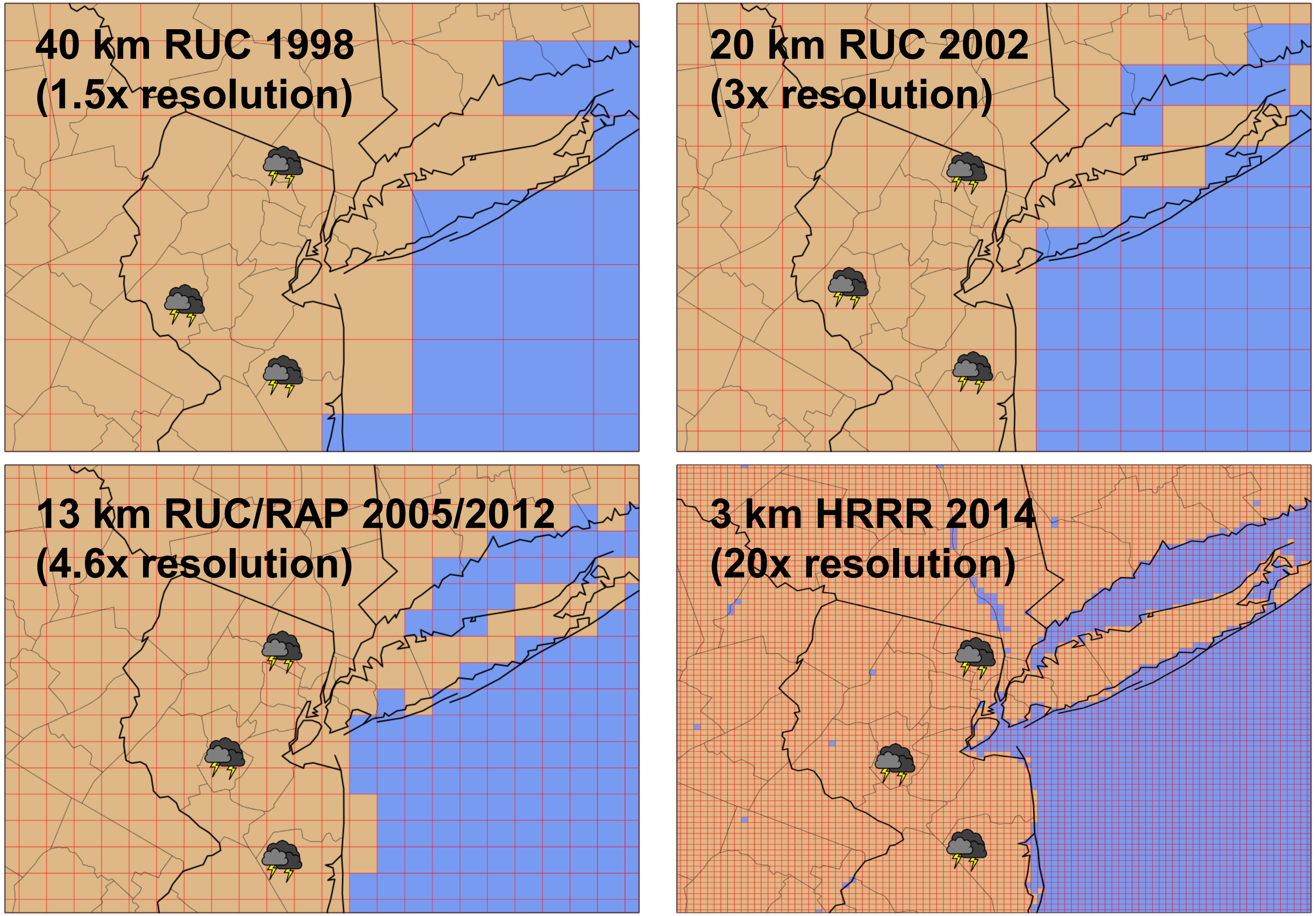


RAP/HRRR: Hourly-Updating Weather Forecast Suite

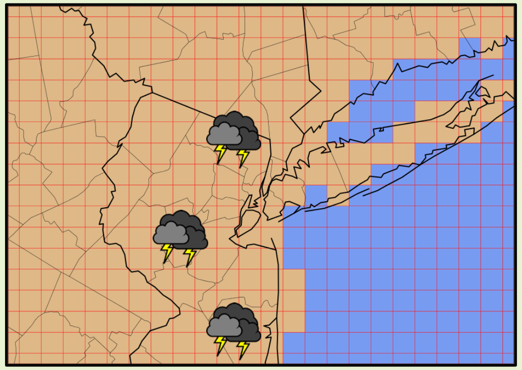
Example: National Weather Service including SPC, WPC, and AWC
FAA Command Center
NSSL, ARL, NCAR, and LL (Lincoln Laboratory)



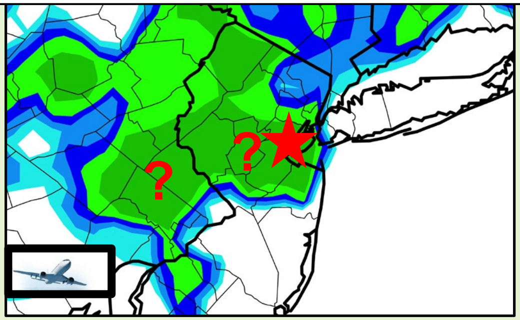
Finer Spatial Resolution
More Accurate Structure of Convection
(Thunderstorms)



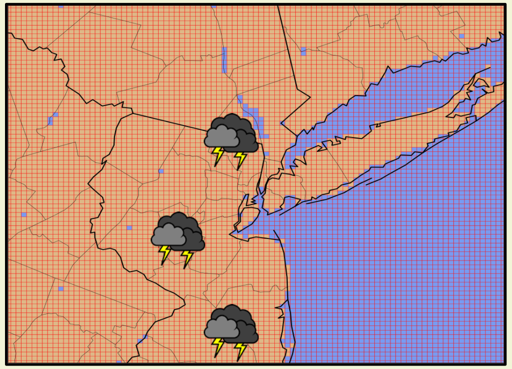
Older Generation
"Standard Definition" Computer Forecast



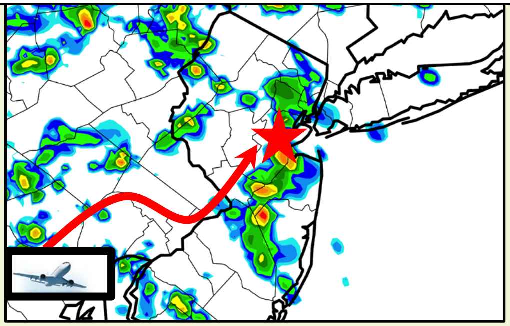
6 hr Thunderstorm Forecast



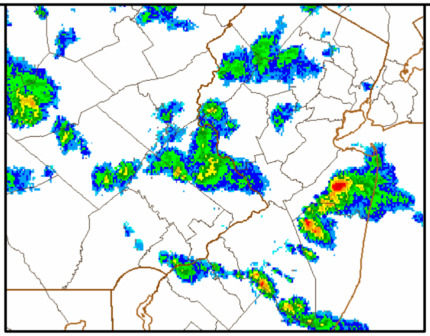
Next Generation (HRRR)
"High Definition" Computer Forecast



6 hr Thunderstorm Forecast



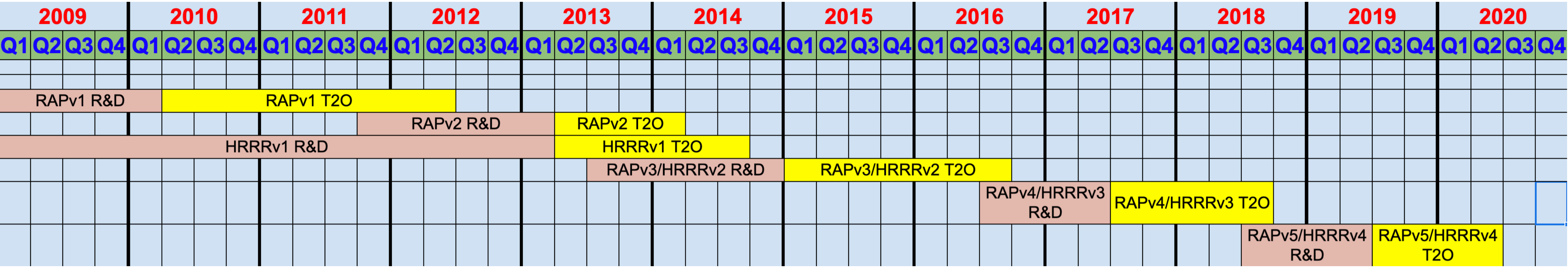
Actual Thunderstorms



Not enough information to help route aircraft on approach to Newark, NJ

Sufficient information to help route aircraft on approach to Newark, NJ

RAP/HRRR Implementation History



NWS NCEP and WFOs – Feedback "O2R" and Implementations "R2O"

Aviation (FAA, NCAR, MIT/LL, AWC) – CoSPA Project – SIP/FIP/GTG/etc… – 15 min output

Severe (SPC, NSSL) – Vortex II/SE Projects – WoF – Hourly Maximum Fields

Energy (DOE) – WFIP 1/2, SFIP Projects – Averaged Direct/Diffuse Rad/Wind

Hydrology (WPC, OWP) – AQPI, NWM Projs, PQPF/Ptype

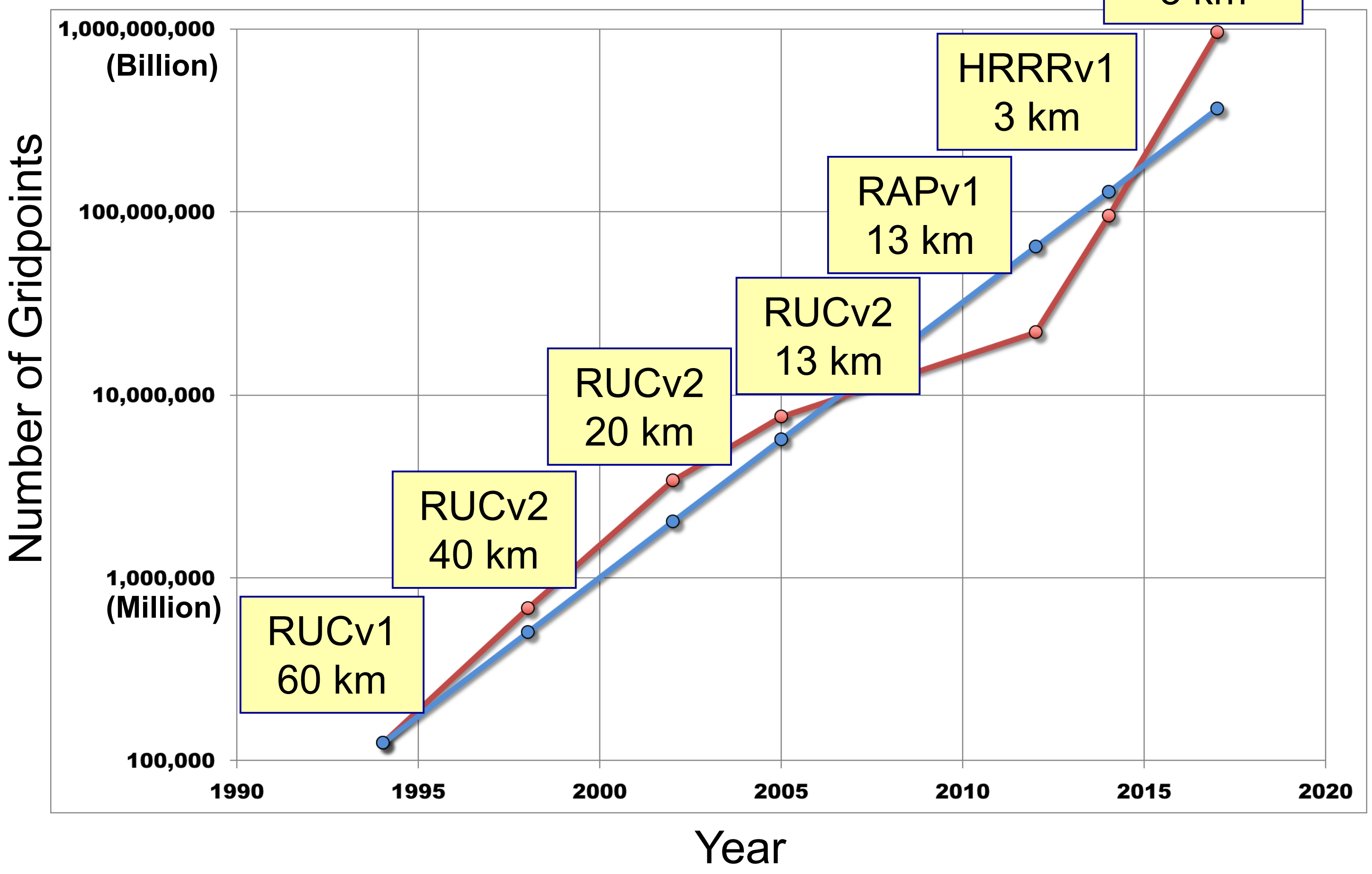
Air Quality (WFOs) – FRP, Smoke, Feedbacks

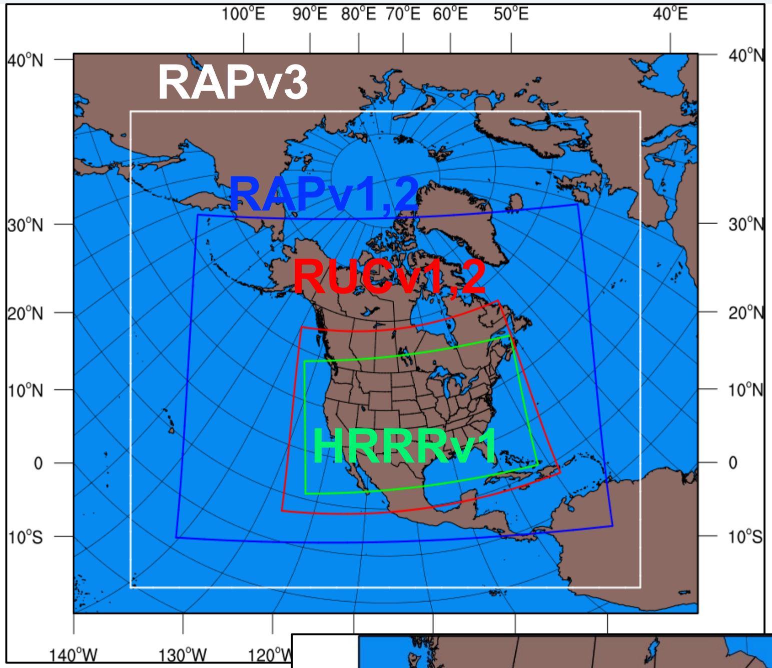
Coupling – FVCOM, Lakes

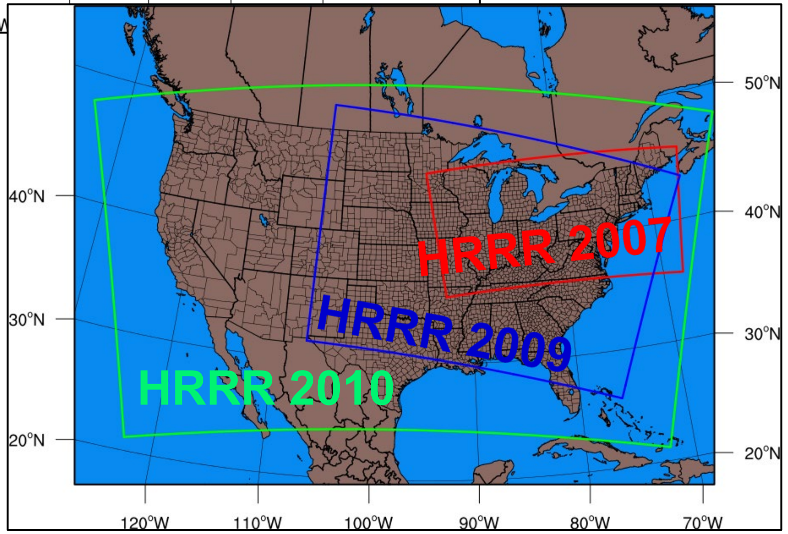
Summary of HRRRv4 Changes

Surface Characterization	Data Assimilation	Model Dynamics & Physics	Postprocessing Algorithms
Switch to MODIS albedo (higher), replace 1-deg albedo Adjust albedo for solar zenith angle 15” resolution land-use data Fractional sea/lake ice concentration FVCOM data for Great Lakes temps/ice fraction VIIRS/MODIS fire-radiative power (wildfire location, intensity)	GOES-16 ABI radiances N20 CrIS-FSR/ATMS (with direct readout) GOES-16 AMVs Use aircraft/raob moisture obs above 300 hPa TC vitals for tropical cyclone position/strength Use HRRR Data Assimilation System (HRRRDAS)	WRF–ARWv3.9+, including physics updates MYNN PBL update: - improved eddy-diffusion/mass-flux (EDMF) mixing Aerosol sources/sinks – fire/smoke, dust RUC land-surface: - improved representation of snow cover - better 2m T/T_d diagnostics - lake model for small lakes Enhanced orographic gravity-wave drag Reduced 6th-order diffusion, including hydrometeors Removal of microphysics latent-heating limit Use NSSL implicit–explicit vertical advection scheme	Major revisions to cloud-cover rendering Revisions to variable-density snowfall algorithm Add HAILCAST hail-size diagnostic

Growth rate Similar To Moore's Law

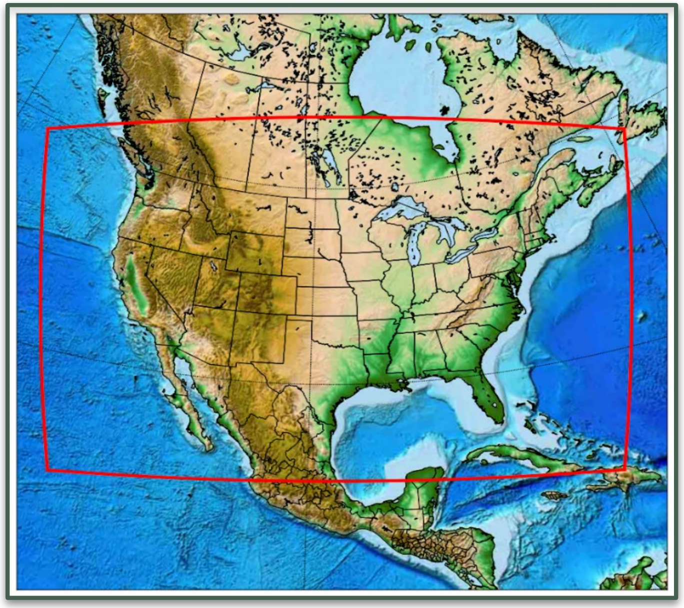


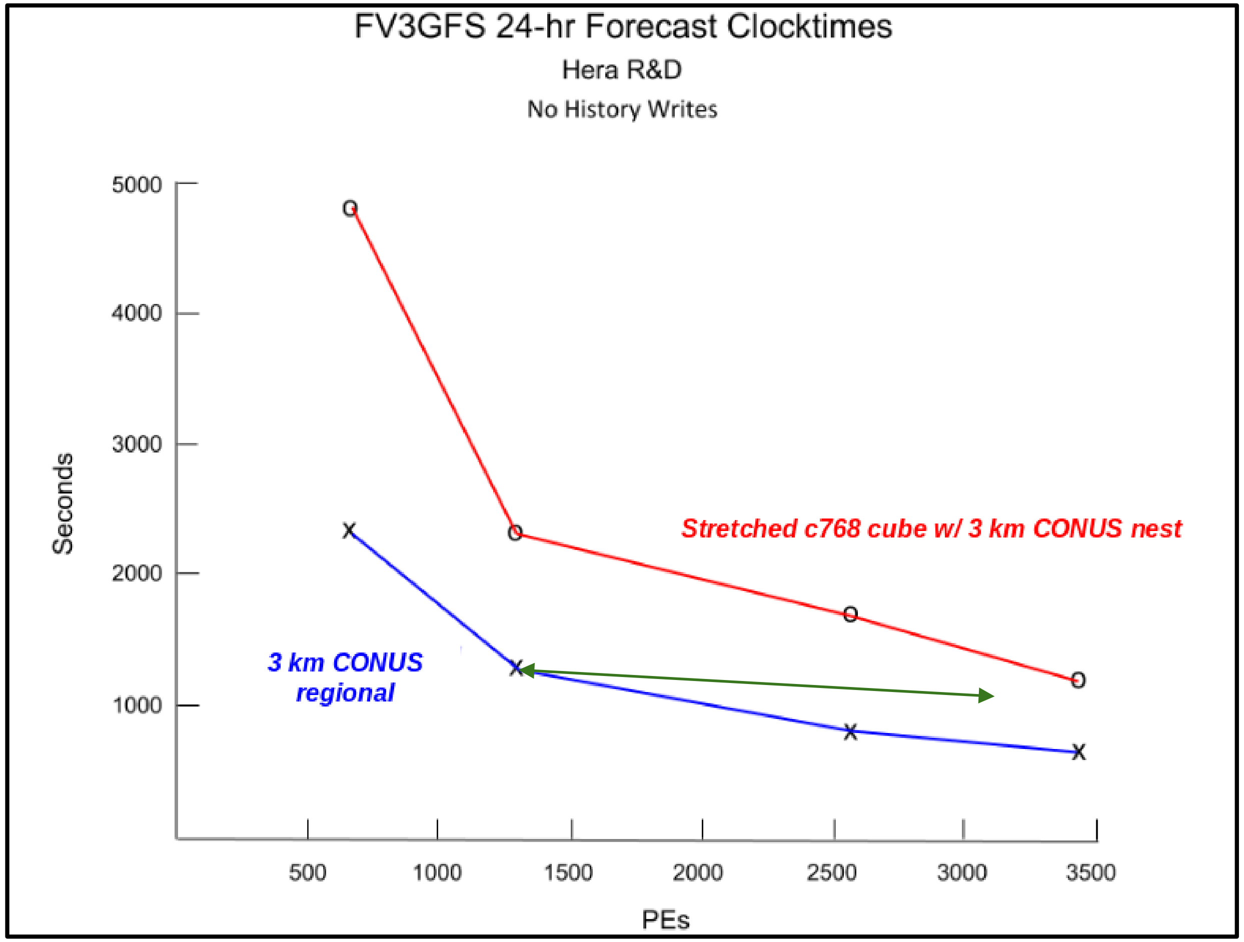




Larger Forecast Domains

- Running real time, continuously since May 2018
- 3 km Nest: May, 2018 - July 2019
- 3 km Stand Alone Regional (SAR): July, 2018 - Present





*Material courtesy of T. Black and J. Abeles

Limited area runs use less than half the tasks that the nest needs for completing in a given amount of time

Introducing and Testing Limited Area Capability of FV3

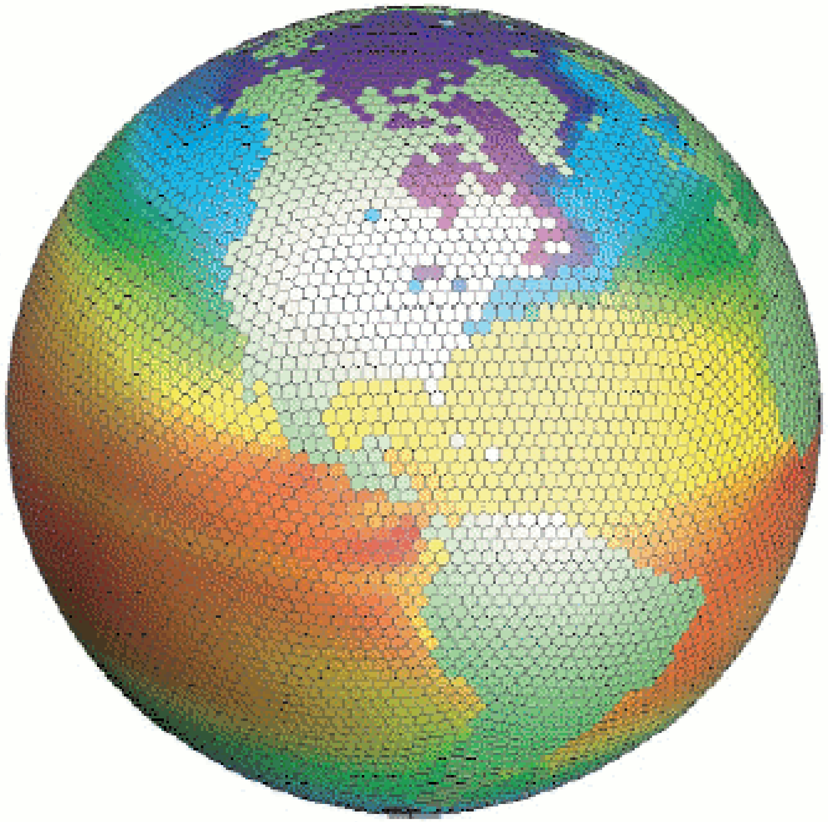
- Practical reasons underscore need for SAR (more efficient, focused development, flexibility, etc.)
- How do Nest and SAR compare in short lead times? ~60 hr forecast
  - ***No*** blending of LBCs (specified)
- FSS 6-h precip, June 2019: SAR vs NEST

▲	FV3SAR is better than FV3NEST at the 99% significance level
(green)	FV3SAR is better than FV3NEST at the 95% significance level
(grey)	No statistically significant difference between FV3SAR and FV3NEST
(pink)	FV3SAR is worse than FV3NEST at the 95% significance level
▼	FV3SAR is worse than FV3NEST at the 99% significance level
(blue)	Data missing
Statistic for symbols: DIFF_SIG , Statistic for values: DIFF	

			CONUS									
			F06	F12	F18	F24	F30	F36	F42	F48	F54	F60
FSS	6-h Precip. > 2 mm	< 5 km	▼ -0.002	0.000	-0.001	-0.005	0.002	0.000	0.015	0.007	0.010	0.002
		< 24 km	▼ -0.002	0.001	0.000	-0.006	0.003	0.001	0.017	0.008	0.013	0.003
		< 52 km	▼ -0.002	0.001	0.000	-0.005	0.005	0.003	0.018	0.010	0.014	0.003
		< 100 km	▼ -0.002	0.002	0.000	-0.004	0.006	0.004	0.017	0.010	0.015	0.004
		< 148 km	▼ -0.002	0.002	-0.001	-0.003	0.006	0.005	0.016	0.009	0.014	0.004
	6-h Precip. > 5 mm	< 5 km	▼ -0.003	-0.002	-0.003	-0.004	0.003	0.009	0.017	0.007	0.011	0.003
		< 24 km	▼ -0.004	-0.001	-0.003	-0.005	0.006	0.012	0.021	0.010	0.014	0.004
		< 52 km	▼ -0.004	0.001	-0.003	-0.003	0.008	0.015	0.023	0.013	0.015	0.005
		< 100 km	▼ -0.004	0.002	-0.003	-0.001	0.008	0.017	0.025	0.014	0.014	0.006
		< 148 km	▼ -0.004	0.002	-0.004	0.000	0.008	0.018	0.025	0.013	0.013	0.007
	6-h Precip. > 10 mm	< 5 km	-0.001	-0.001	-0.002	-0.007	0.010	0.016	0.012	0.009	0.018	0.000
		< 24 km	-0.001	-0.001	-0.004	-0.009	▲ 0.015	0.021	0.016	0.013	0.023	0.001
		< 52 km	-0.001	0.000	-0.005	-0.007	▲ 0.017	0.026	0.022	0.017	0.027	0.001
		< 100 km	-0.002	0.002	-0.005	-0.005	0.017	0.029	0.026	0.020	0.031	0.002
		< 148 km	-0.002	0.003	-0.006	-0.004	0.016	0.032	0.028	0.023	0.033	0.005

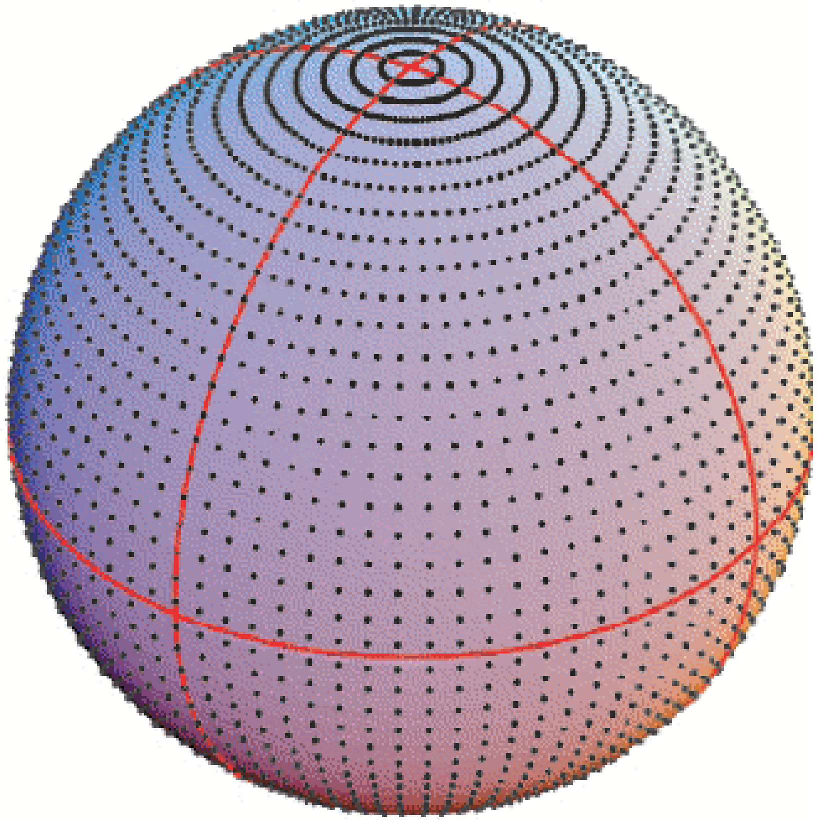
Global Discretization for NWP Models

Icosahedral grid



Nearly uniform grid size, including near poles

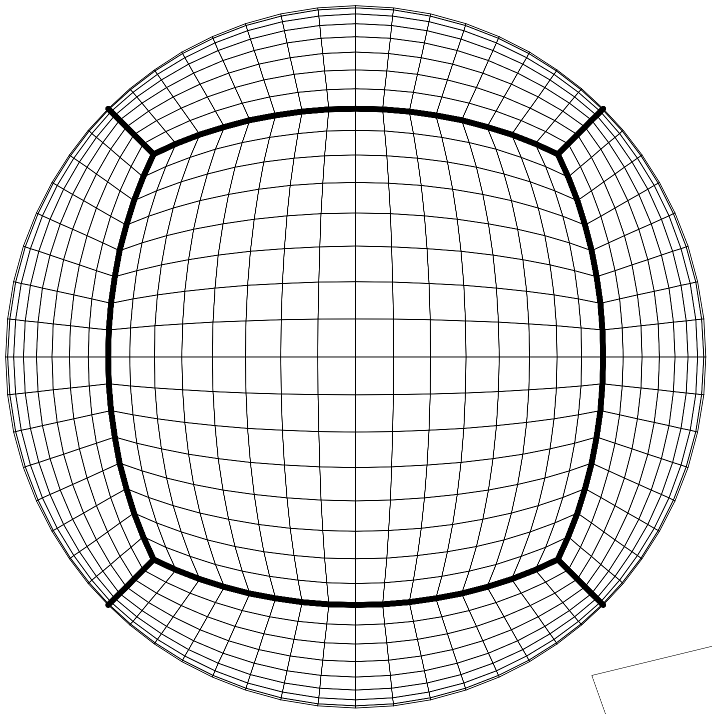
Lat-lon grid

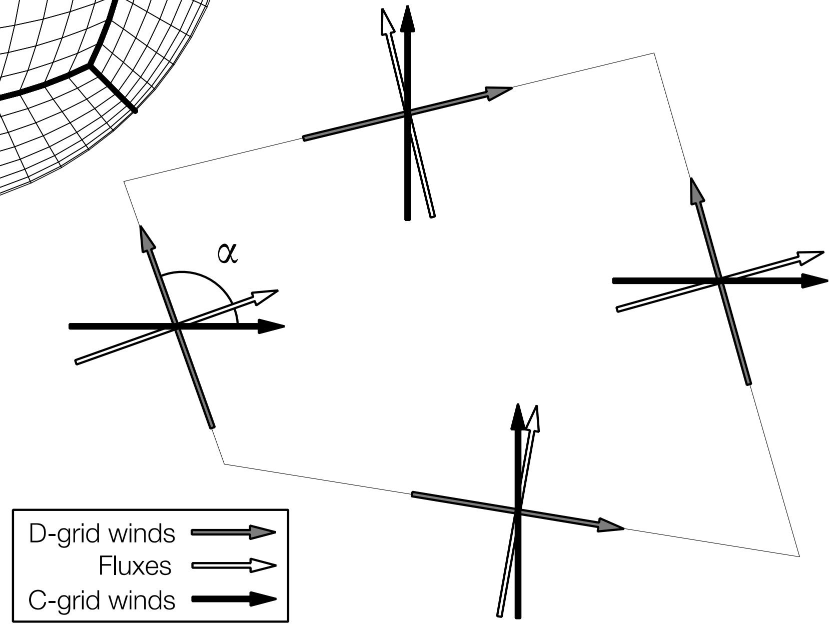


Numerical problems near poles

The FV3 Cubed Sphere:

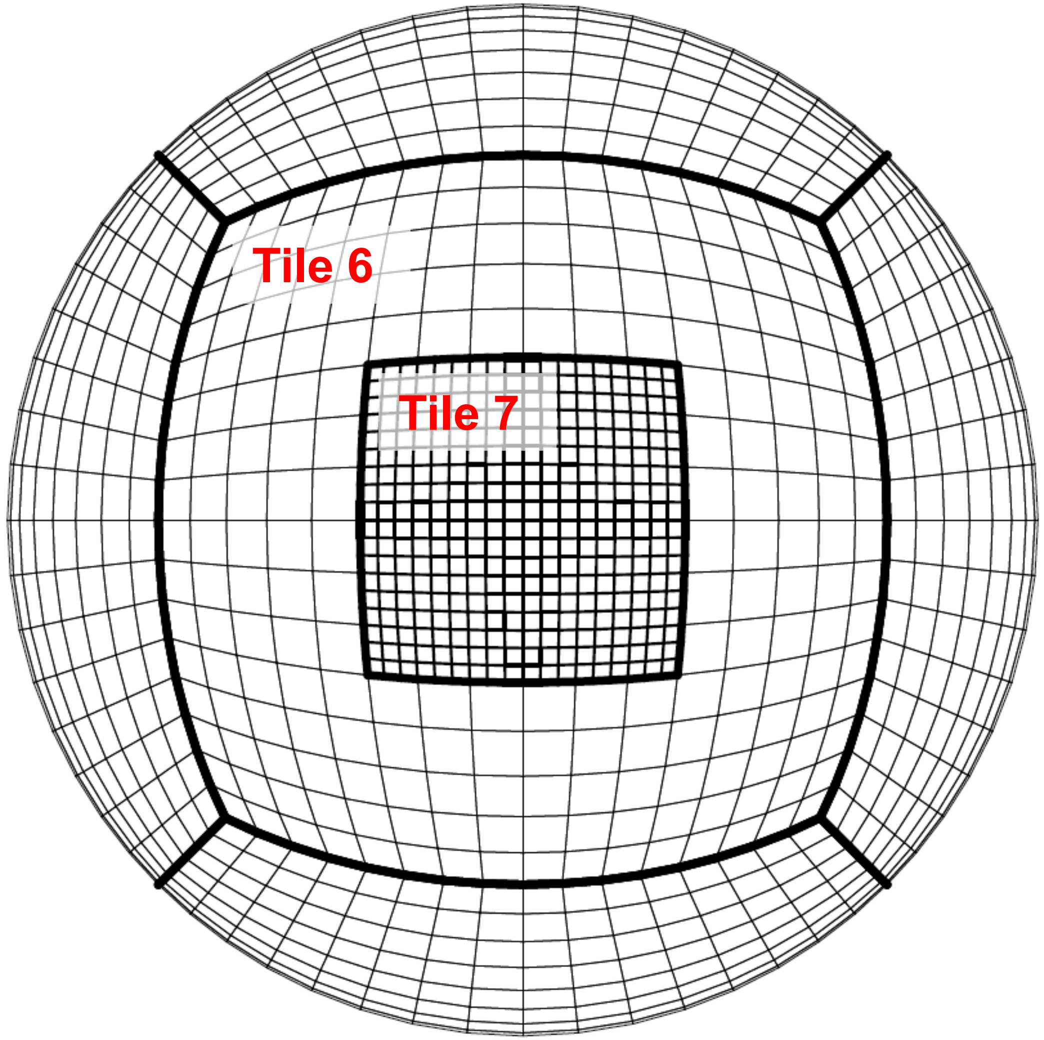
- Uses a gnomonic projection where great circles serve as model coordinates
- Global coverage consists of six tiles
- Offers good uniformity (widest cell only √2 wider than narrowest), **but only for standard six-tile global setup**
- Result is a non-orthogonal grid, requiring covariant and contravariant wind calculations
- Fluxes are orthogonal to model coordinates





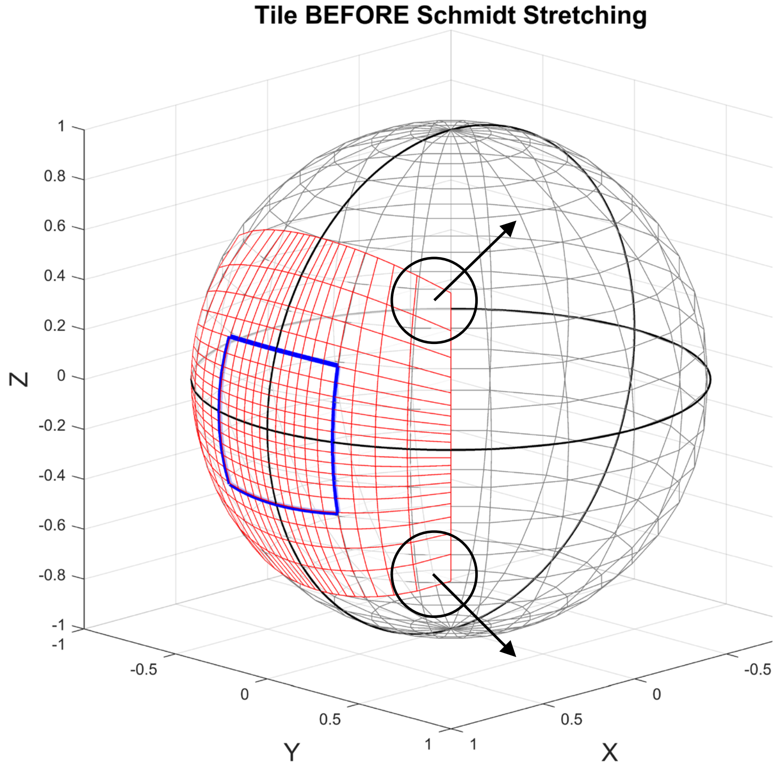
Initial SAR-FV3 code by EMC:

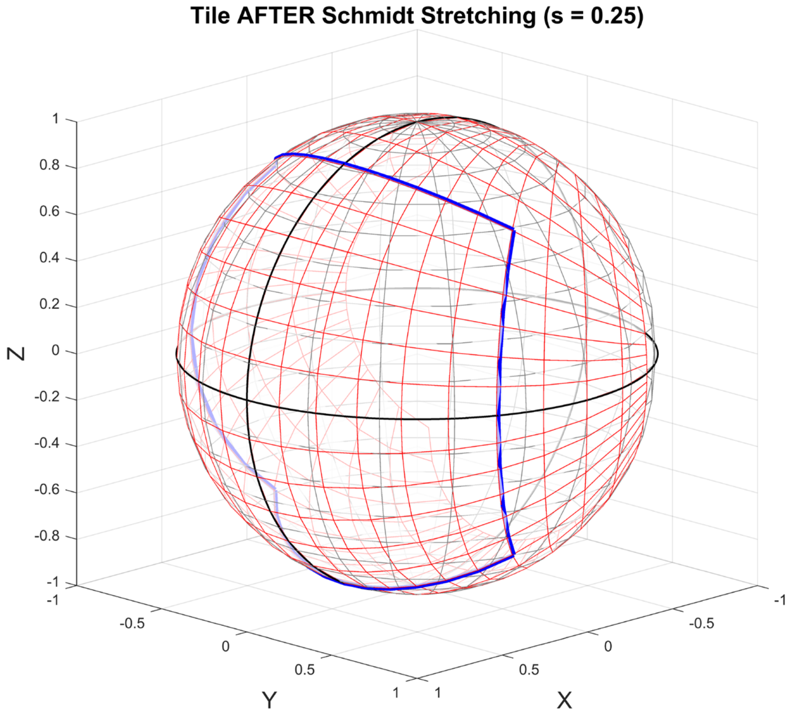
- Used the nesting capability (tile seven) in the FV3 to act as a regional domain, and remove tiles 1-5
- Still allows for Schmidt stretching of the gnomonic grid for flexible domain sizes
- Incorporated necessary modifications to FV3 code to include a halo around tile seven in which LBCs would be transferred to the regional domain
- Tile six is then discarded and all calculations are made on the regional domain with halo



Through collaboration with EMC (Jim Purser):

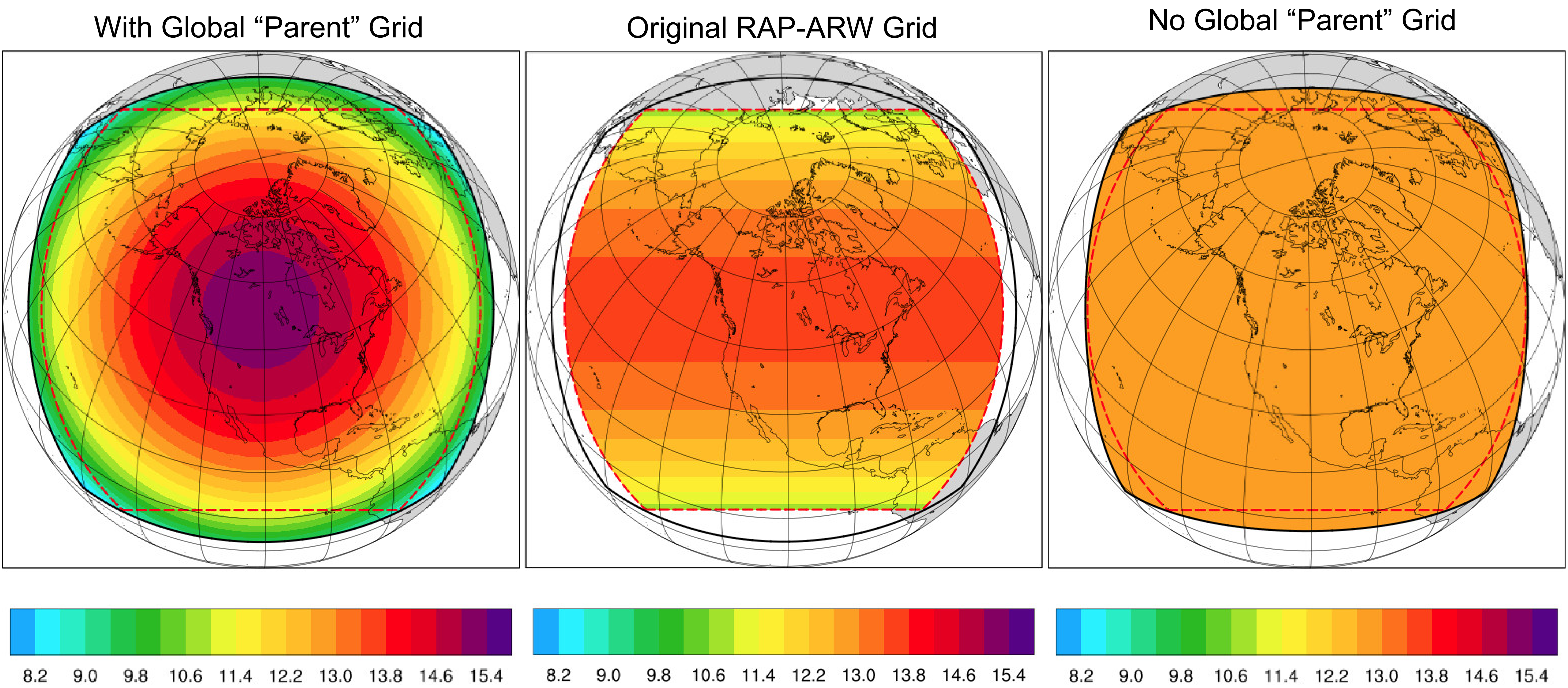
- Concentrate model coordinates (great circles) near center of tile six to improve uniformity after stretching
- Added two plotting parameters (alpha and kappa) to the generation of the gnomonic grid
- Flares the corners of the grid to reduce grid variability





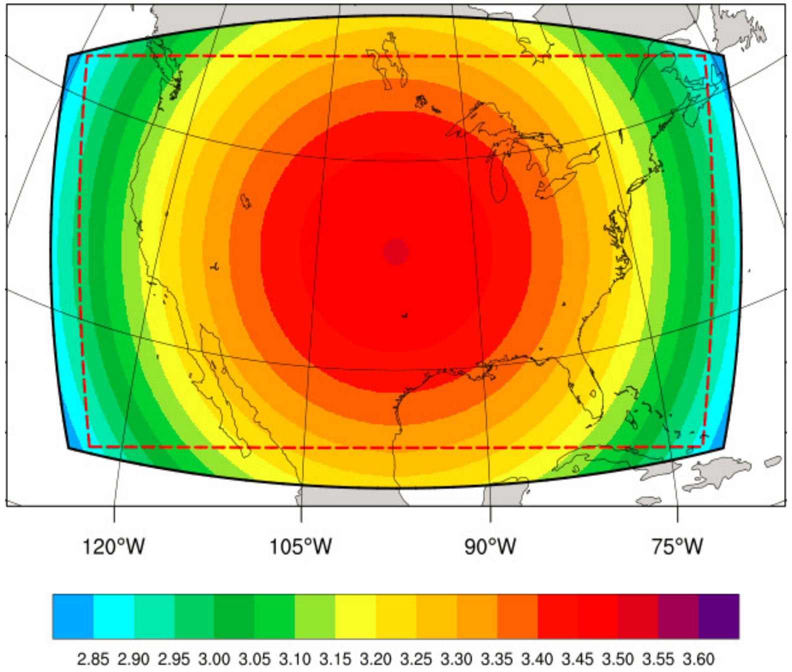
Blue represents the outline of the SAR grid (tile seven) with the sixth tile of the global FV3 in red

Comparison of RAP/RAP-equivalent Grids

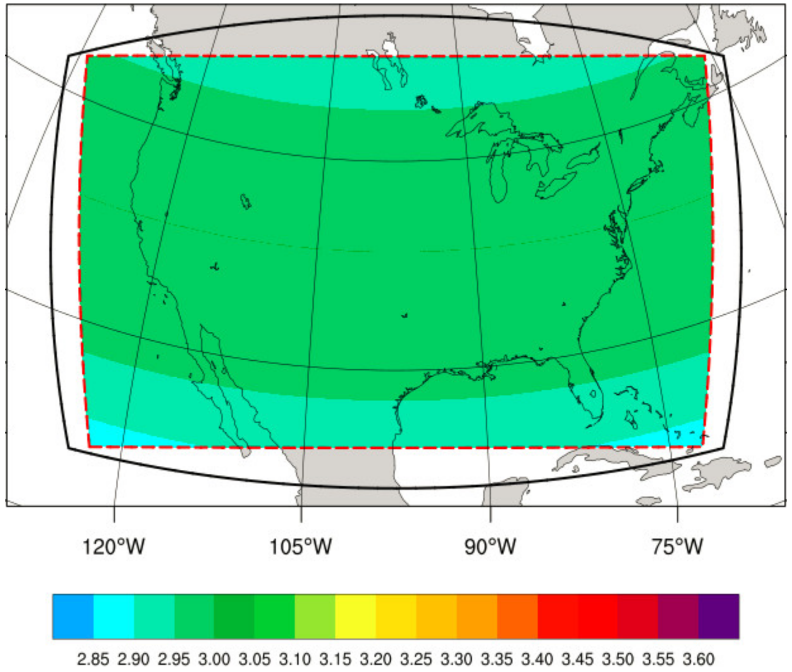


Comparison of HRRR/HRRR-equivalent Grids

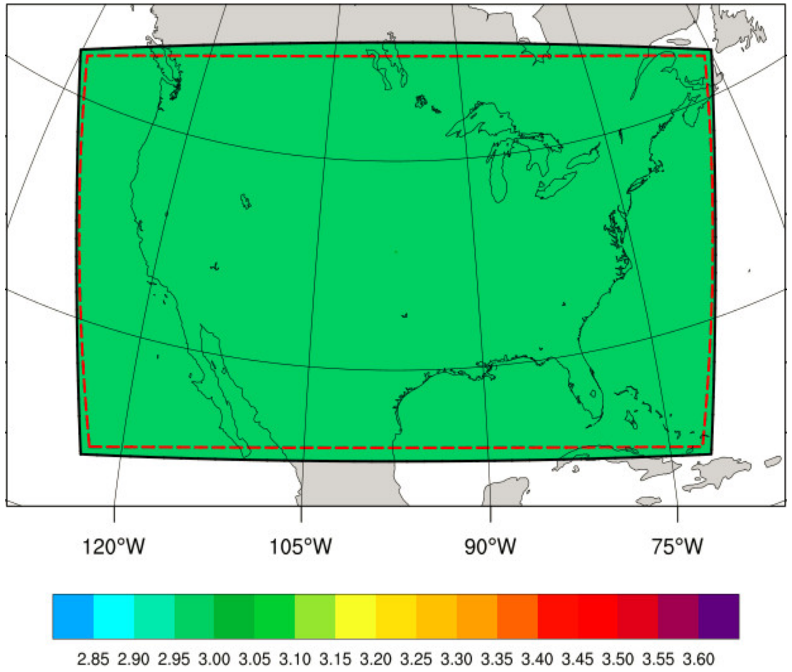
With Global “Parent” Grid



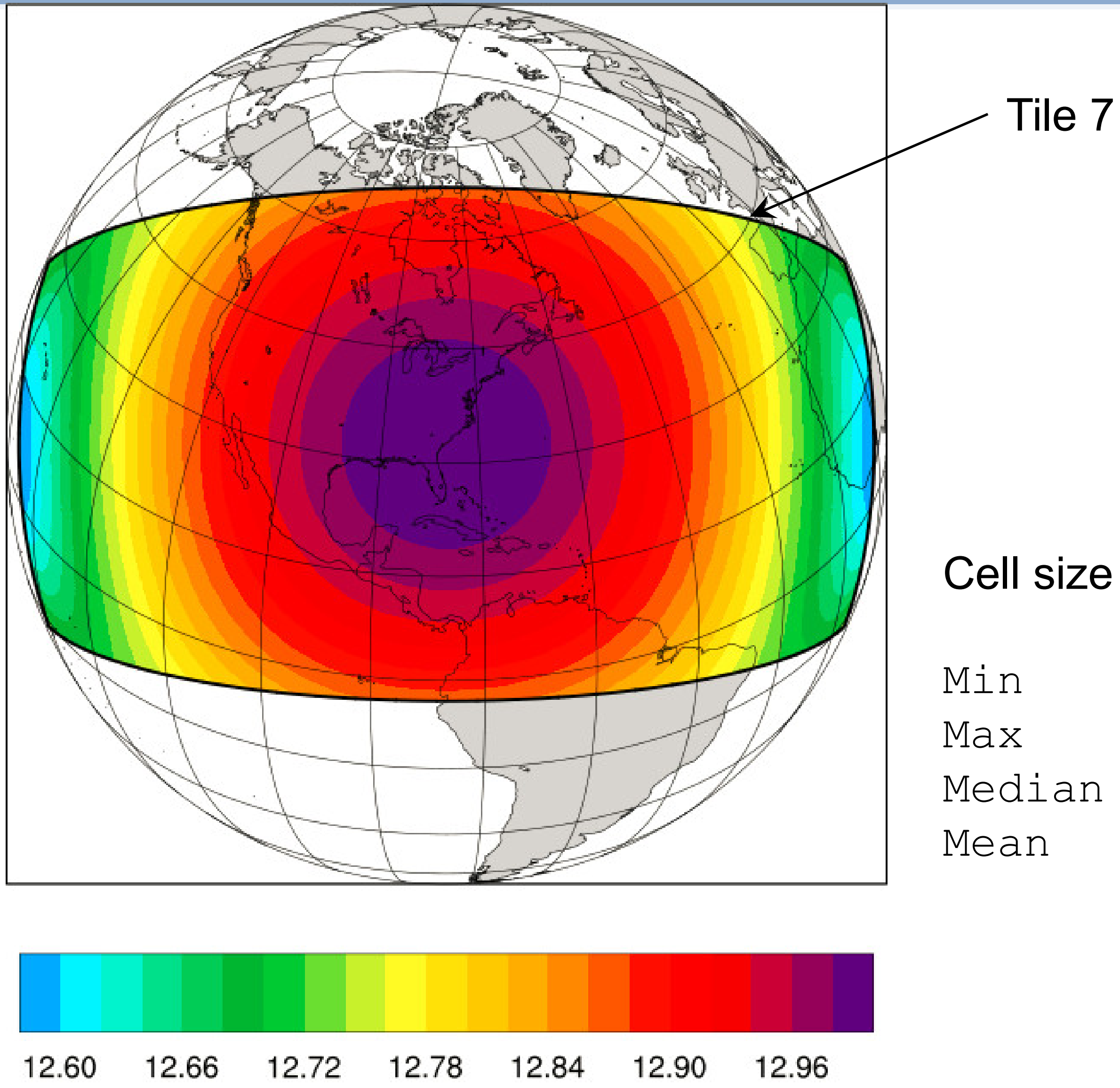
Original HRRR-ARW Grid



No Global “Parent” Grid



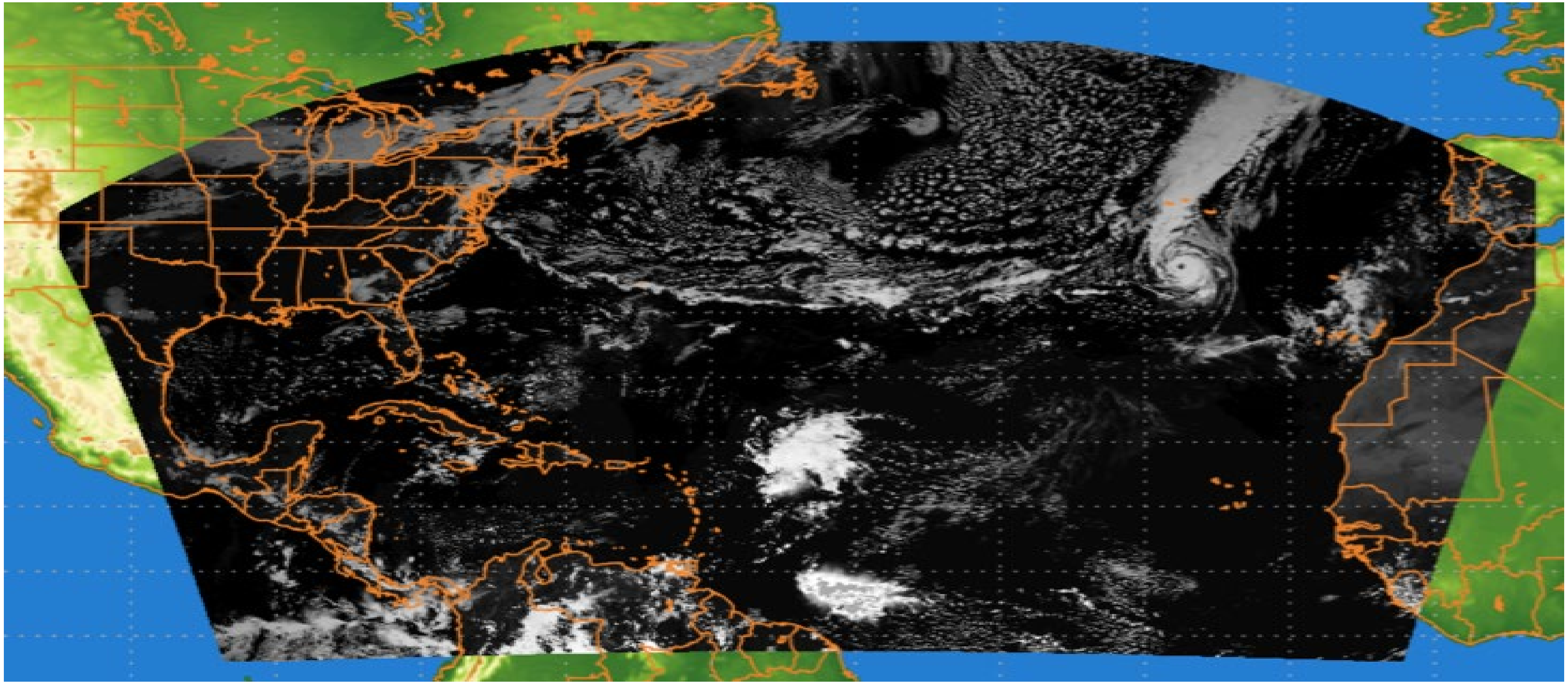
First Attempt at Double-Basin Hurricane Domain/Grid



Cell size stats:

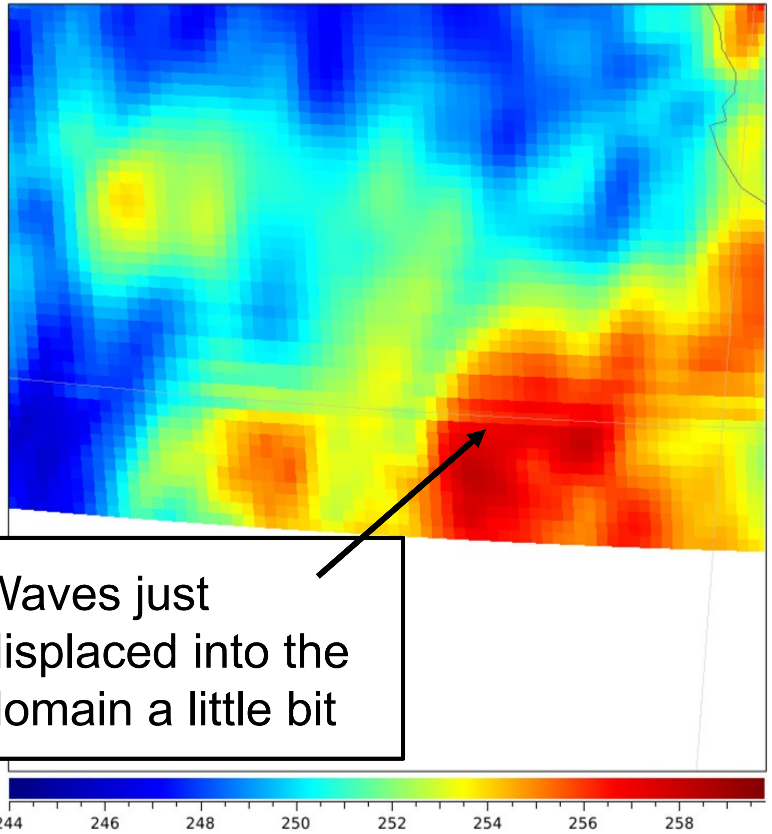
```
Min    = 12.58 km
Max    = 13.0  km
Median = 12.84 km
Mean   = 12.82 km
```

Nested 3-km FV3 GFS



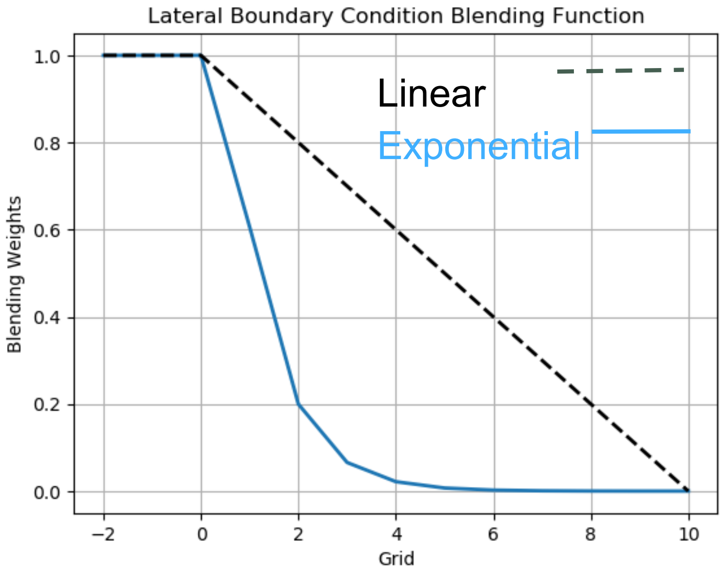
1. **HAFS v0.A** – A FV3 SAR configuration, analogous to the CAM FV3 SAR configuration, but for TC regions of interest. GFS physics and RAP/HRRR (continental CAM physics)
2. **HAFS v0.B** – A FV3 nest within the FV3 global model (as shown above)

Image courtesy of Andrew Hazelton (NOAA/AOML/HRD).



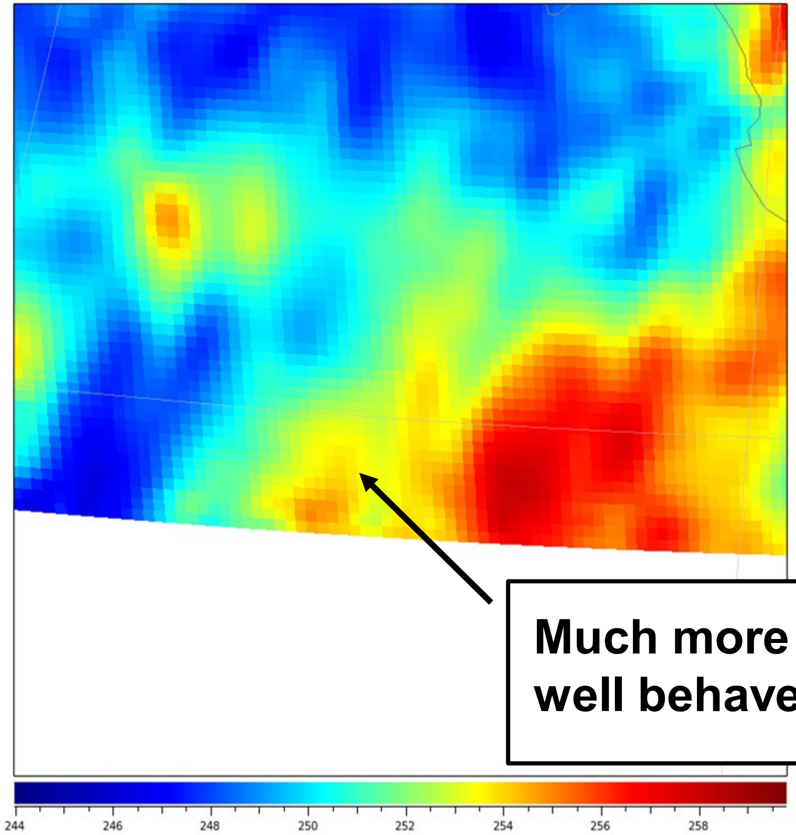
Waves just displaced into the domain a little bit

Linear Blending - 10 Rows



- Layer 4
- 6 Hour forecast
- ~23 km

*Material courtesy of T. Black (EMC)



Much more well behaved

Exponential Blending - 10 Rows

FV3-SAR Community Workflow Tasks

Run once per expt. (optional)

1. **`make_grid`** – Generates grid files (GFDL or JP format)
2. **`make_orog`** – Generates filtered orography files
3. **`make_sfc_climo`** – Generates surface climatology files (used if fields are not available in external model output)

Run once for each cycle

4. **`get_extrn_ics`** – Retrieves output files from the external model needed for generating ICs, surface fields, and the 0-th hour LBC
5. **`get_extrn_lbcs`** – Retrieves output files from the external model needed for generating LBCs
6. **`make_ics`** – Creates ICs on the native FV3-SAR grid (including surface fields and the 0-th hour LBC).
7. **`make_lbcs`** – Creates LBCs for each boundary condition interval on the FV3-SAR grid.
8. **`run_fcst`** – Runs a forecast (cycle) with the FV3-SAR
9. **`run_post`** – Processes write-component forecast output files through UPP to generate grib2 files

FV3-SAR Community Workflow Status and Details

- The workflow has been tested on multiple supercomputing platforms, including NOAA HPC in Boulder (Theia, Jet) and in DC (WCOSS), OU/NSSL (Stampede/Odin), and soon on NCAR's Cheyenne
- Supports FV3GFS, GSMGFS, RAP, HRRR, or NAM data for IC/BCs and can read in grib2, nemsio, and netcdf format for FV3GFS data
- Compatible with the Community Common Community Physics Package (CCPP) and supports either the GFS or GSD physics suites
- Users can generate their own domains, or select from pre-defined domains, including coarse- and high-resolution versions of the RAP, HRRR, HRRR-AK, EMC-CONUS, EMC-AK, and HAFSv0.A

```
…………

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Regional FV3 Testing in SPC/NSSL HWT SFE

GSL

Member: gsl-sarfv3	ICs	LBCs	Micro-physics	PBL	LSM	Radiation	Hord	Model
gsl-fv3sar01	HRRRv4	RAP	Thompson	MYNN	RUC	RRTMG	5	FV3
gsl-fv3sar02	HRRRv4	RAP	Thompson	MYNN	RUC	RRTMG	6	FV3
gsl-fv3sar03	GFS	GFS	Thompson	MYNN	RUC	RRTMG	5	FV3
gsl-fv3sar04	GFS	GFS	Thompson	MYNN	RUC	RRTMG	6	FV3

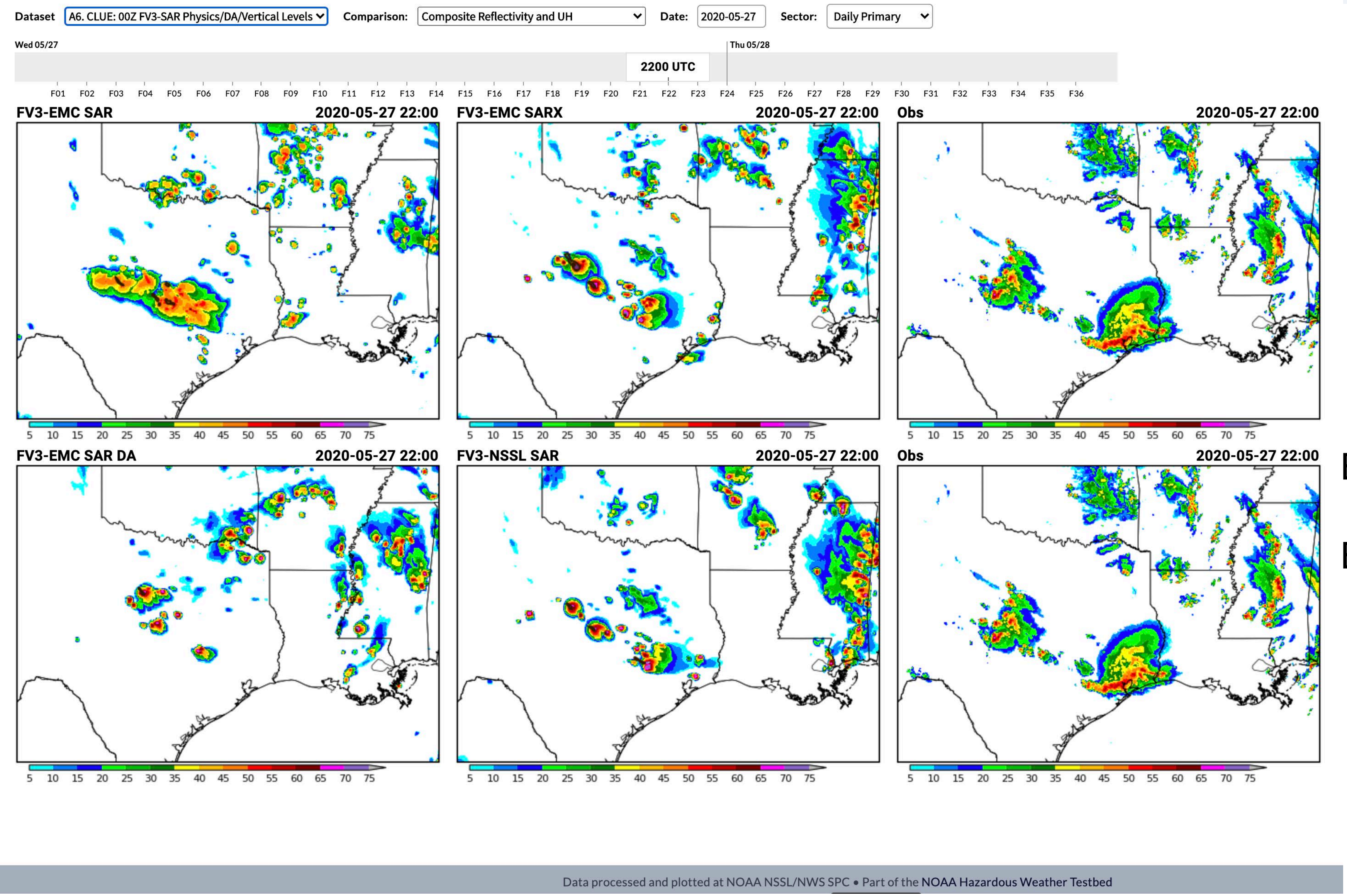
EMC

Members: emc-fv3sar	ICs	LBCs	Microphysics	PBL	LSM	Radiation	Model
emc-fv3sar	GFSv15	GFSv15f	GFDL	EDMF	NOAH	RRTMG	FV3
emc-fv3sarX	GFSv15	GFSv15f	Thompson	MYNN	NOAH	RRTMG	FV3
emc-fv3sarDA	GFSv15	GFSv15f	Thompson	MYNN	NOAH	RRTMG	FV3

NSSL

Members: nssl-glm	ICs	LBCs	Microphysics	PBL	LSM	Radiation	Model
sarfv3-ICs01	GFS	GFSf	Thompson	MYNN	NOAH	RRTMG	FV3
sarfv3-ICs02	UM	UMf	Thompson	MYNN	NOAH	RRTMG	FV3

Regional FV3 Testing in SPC/NSSL HWT SFE

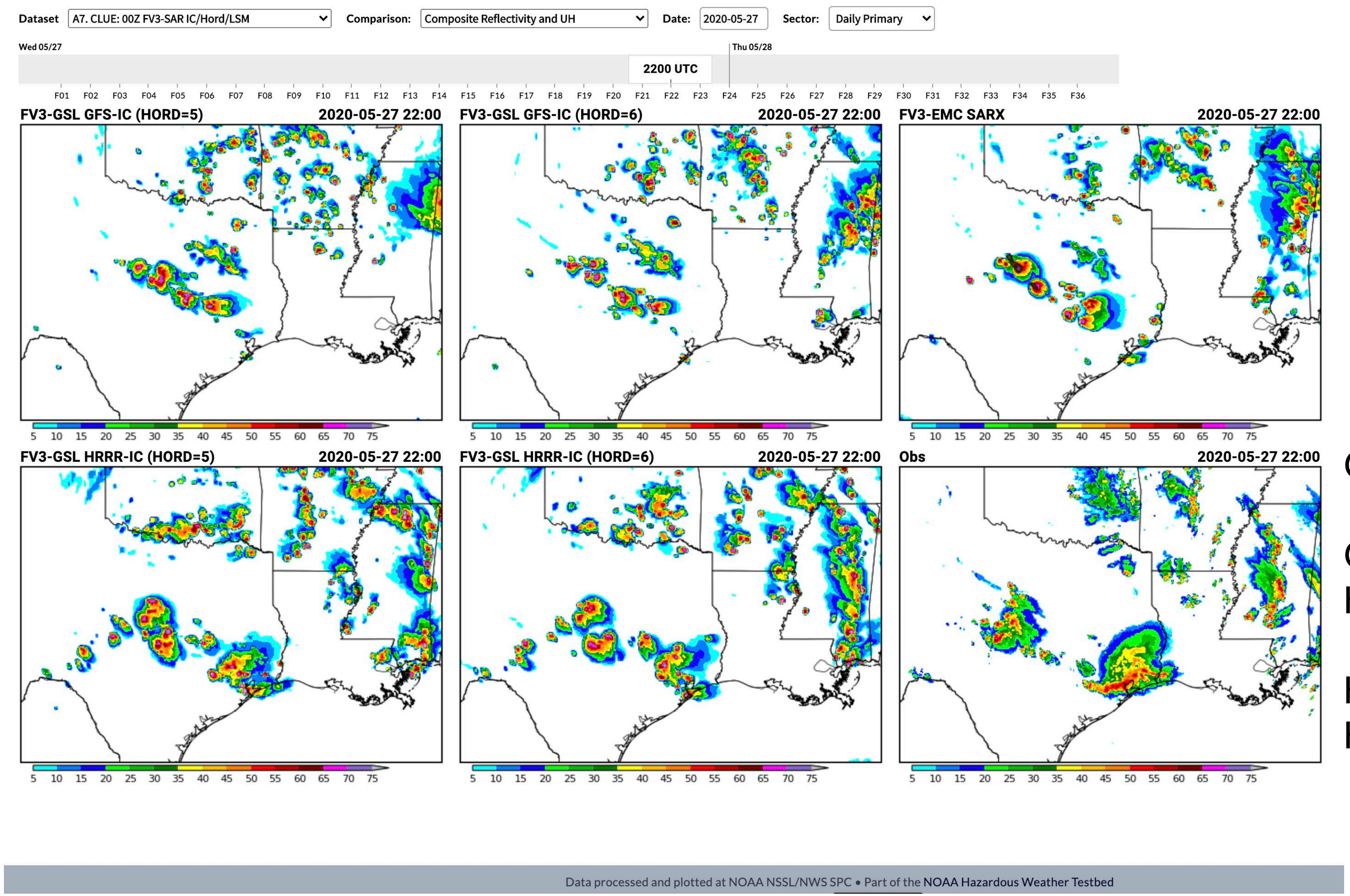


Hazardous Weather Testbed
2020 Spring Forecast Experiment

22 hr reflectivity forecasts
Valid 22z 27 May 2020

EMC, NSSL physics variations

EMC Data Assimilation



Hazardous Weather Testbed
2020 Spring Forecast Experiment

22 hr reflectivity forecasts
Valid 22z 27 May 2020

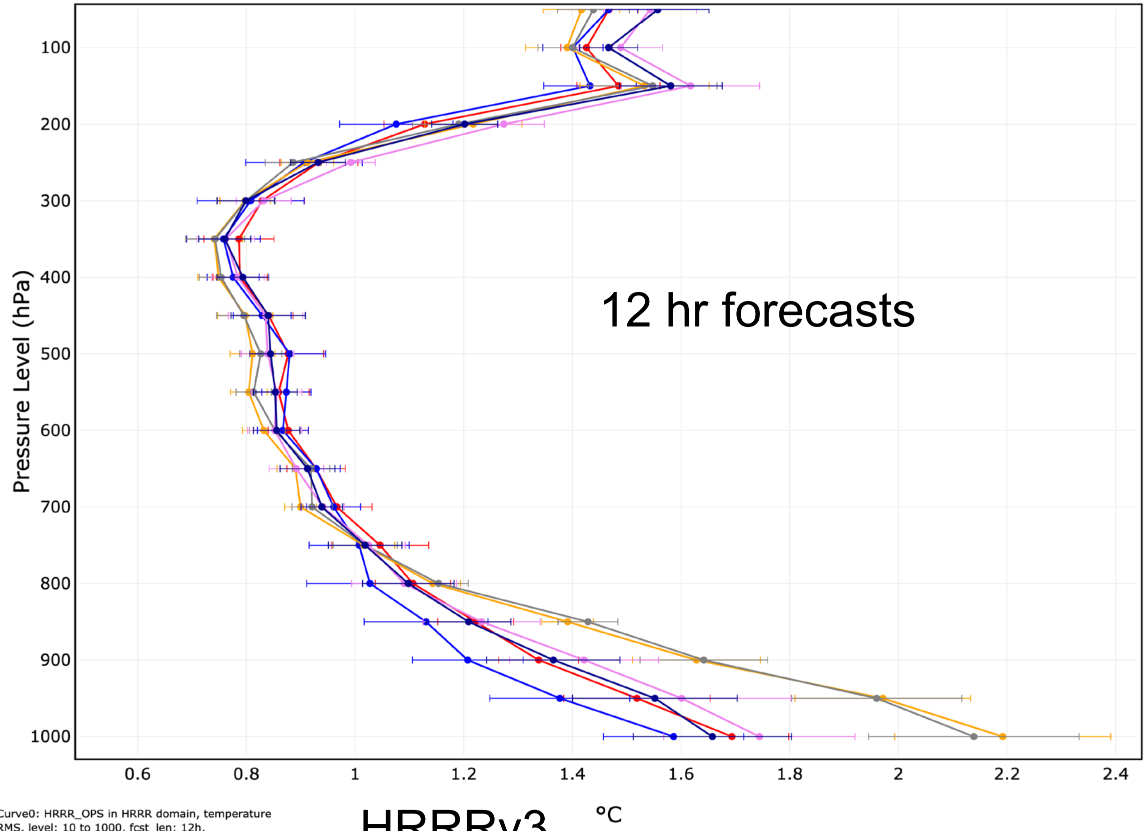
GSL Variations:

GFS initial conditions (top)
HRRRv4 initial conditions (bottom)

Horizontal advection option 5 (left)
Horizontal advection option 6 (center)

Regional FV3 Testing in SPC/NSSL HWT SFE

May 2020 CONUS RAOB Verification
Temperature RMSE



Curve0: HRRR_OPS in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/02/2020 11:30 - 06/01/2020 12:00 — HRRRv3

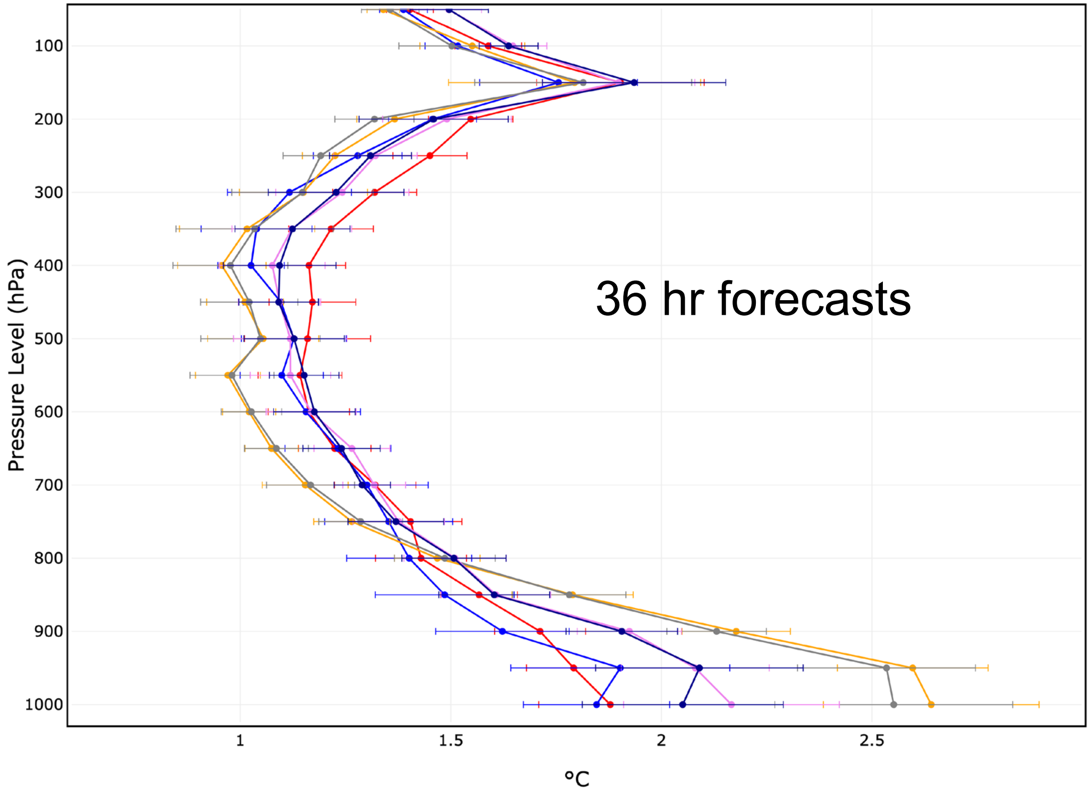
Curve1: HRRRv4_NCO in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 06/01/2020 12:00 — HRRRv4

Curve2: RRFS_dev1 in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 05/30/2020 12:00 — GFS IC (hord 5)

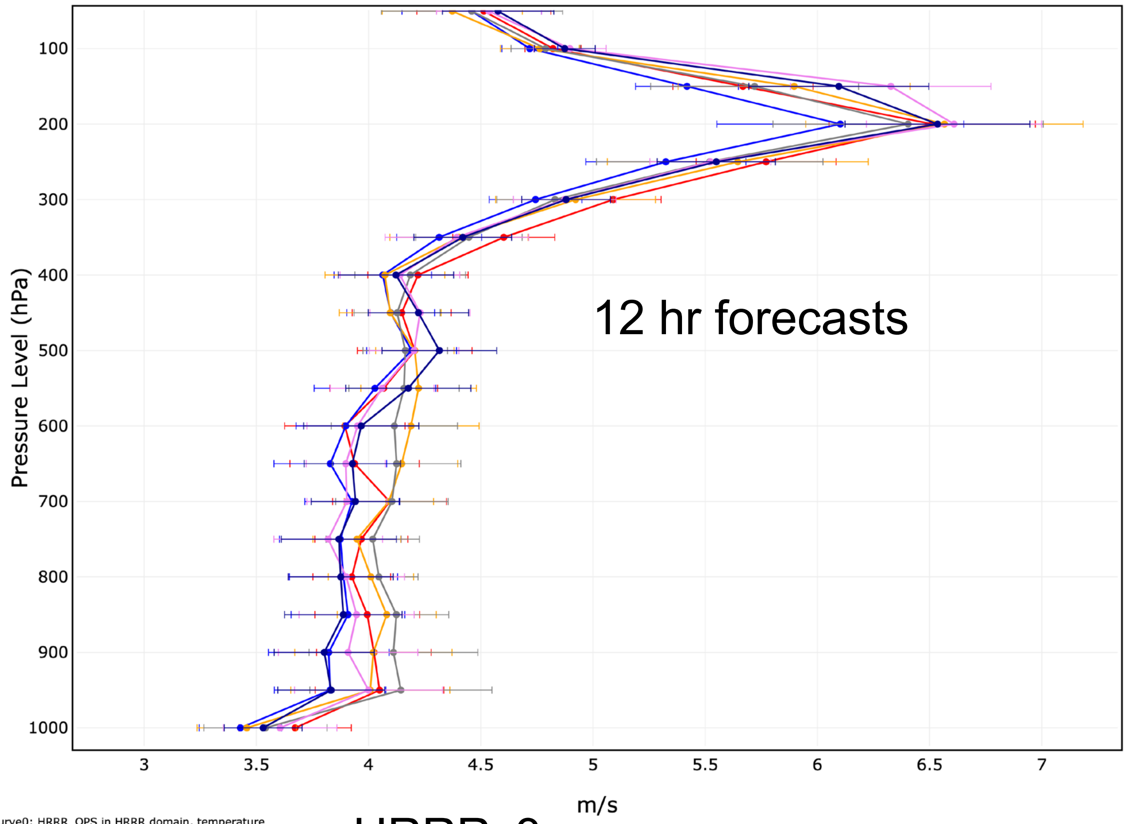
Curve3: RRFS_dev2 in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 05/30/2020 12:00 — GFS IC (hord 6)

Curve4: RRFS_dev3 in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 05/30/2020 12:00 — HRRR IC (hord 5)

Curve5: RRFS_dev4 in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 05/30/2020 12:00 — HRRR IC (hord 6)



Regional FV3 Testing in SPC/NSSL HWT SFE



Curve0: HRRR_OPS in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/02/2020 11:30 - 06/01/2020 12:00 — HRRRv3

Curve1: HRRRv4_NCO in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 06/01/2020 12:00 — HRRRv4

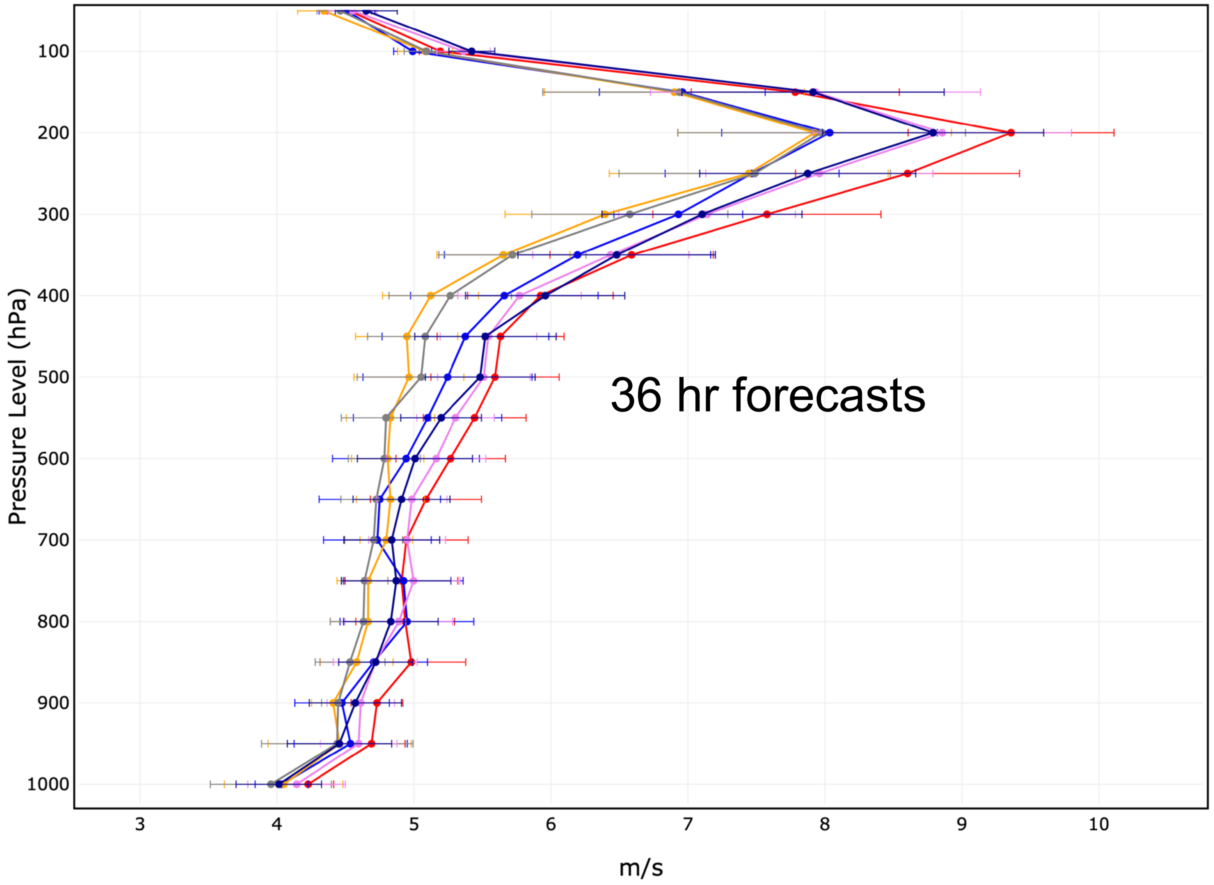
Curve2: RRFS_dev1 in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 05/30/2020 12:00 — GFS IC (hord 5)

Curve3: RRFS_dev2 in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 05/30/2020 12:00 — GFS IC (hord 6)

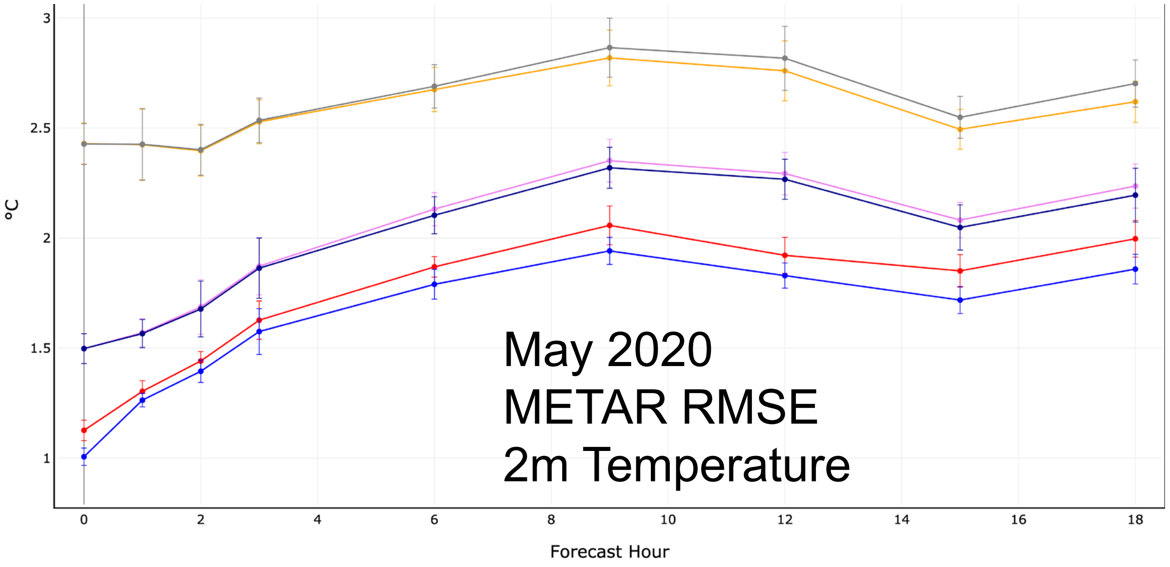
Curve4: RRFS_dev3 in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 05/30/2020 12:00 — HRRR IC (hord 5)

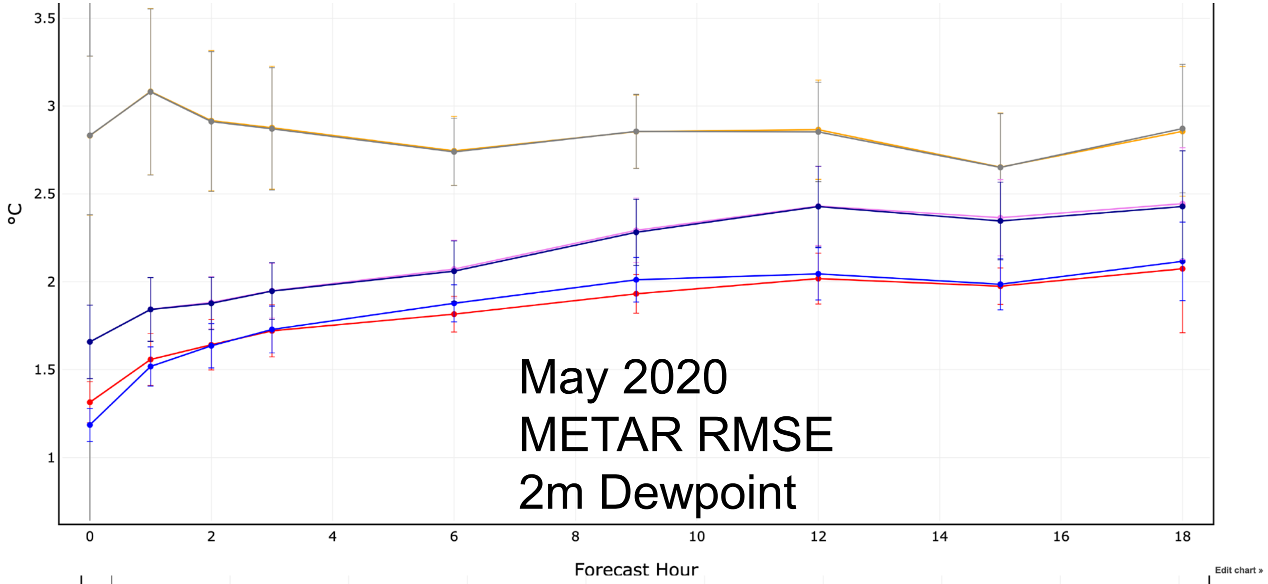
Curve5: RRFS_dev4 in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 05/30/2020 12:00 — HRRR IC (hord 6)

May 2020 CONUS RAOB Verification
Wind RMSE



Regional FV3 Testing in SPC/NSSL HWT SFE





Curve0: HRRR_OPS in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/02/2020 11:30 - 06/01/2020 12:00 — HRRRv3

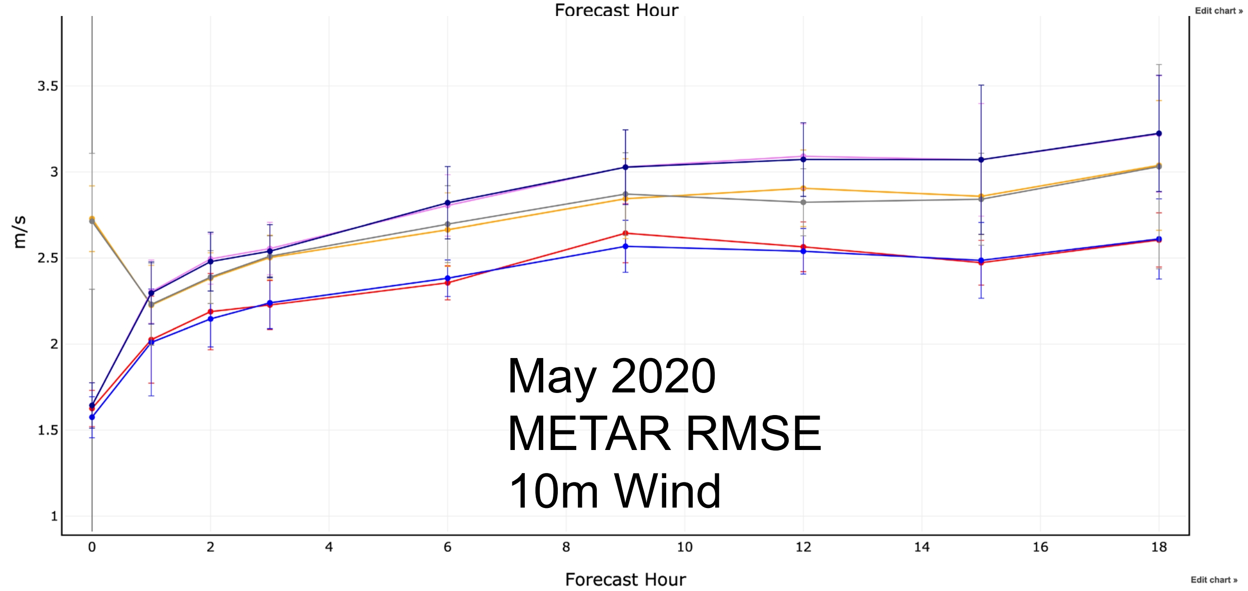
Curve1: HRRRv4_NCO in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 06/01/2020 12:00 — HRRRv4

Curve2: RRFS_dev1 in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 05/30/2020 12:00 — GFS IC (hord 5)

Curve3: RRFS_dev2 in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 05/30/2020 12:00 — GFS IC (hord 6)

Curve4: RRFS_dev3 in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 05/30/2020 12:00 — HRRR IC (hord 5)

Curve5: RRFS_dev4 in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 05/30/2020 12:00 — HRRR IC (hord 6)



Interfacing Data Assimilation Updates with the SAR LBCs

Old Method

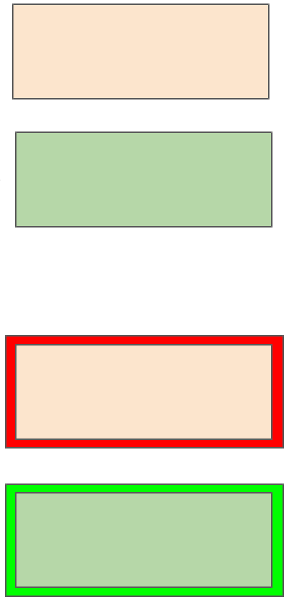
Model writes fields into restart files ***without the boundary***:

GSI updates the integration domain:

New Method

Model writes fields into restart files ***with the boundary***:

GSI updates the entire domain ***including the boundary***:

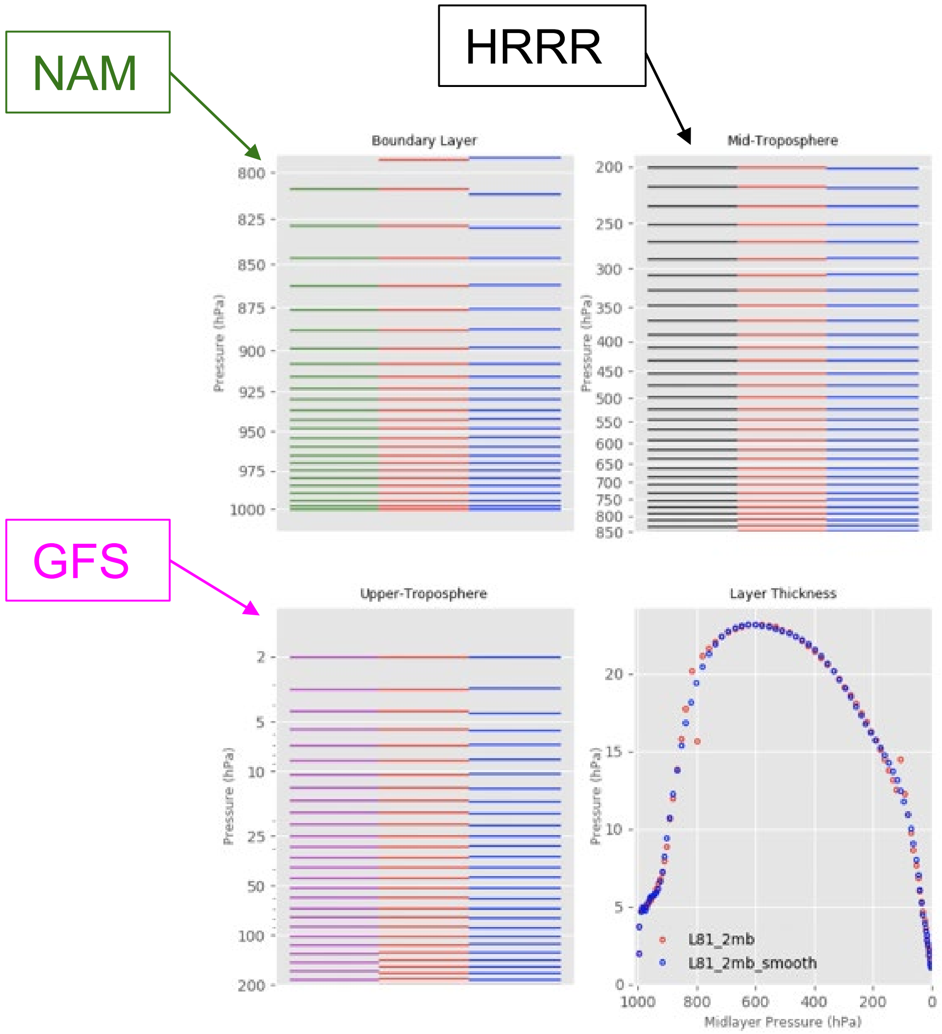


New lateral boundary condition update capability to provide consistency between the lateral boundaries and internal, computational grid following the data assimilation step.

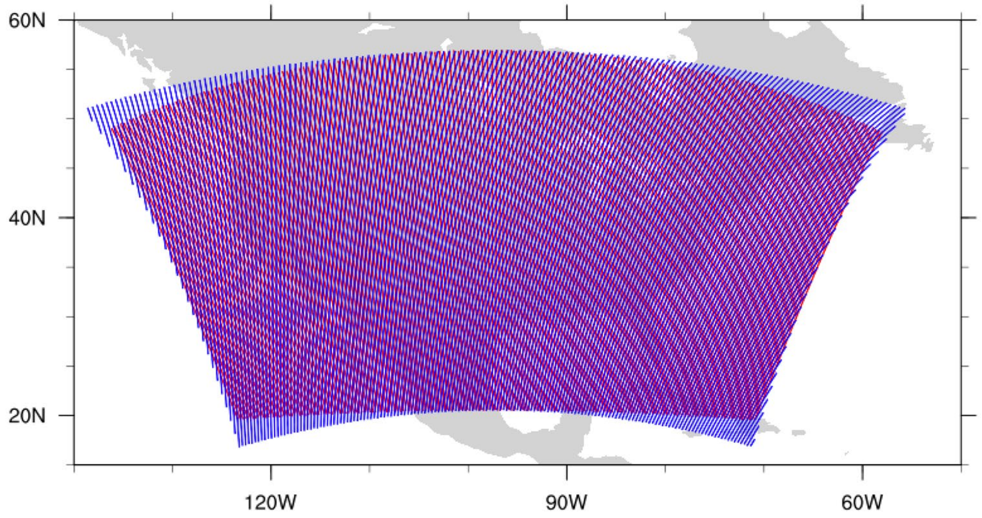
*Material courtesy of (EMC)

Prototyping Grid Configurations for 12-km/3-km SAR FV3 DA

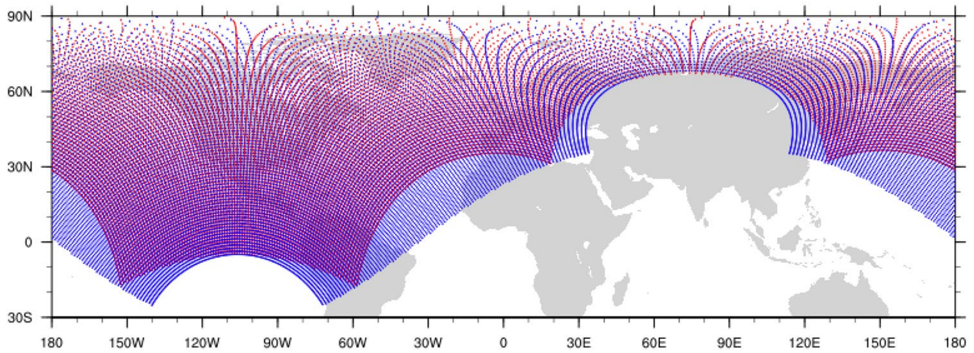
SAR FV3 (81 combined vertical levels)
SAR FV3 (81 smoothed vertical levels)



3-km SAR FV3 Forecast Grid
3-km GSI Analysis Grid

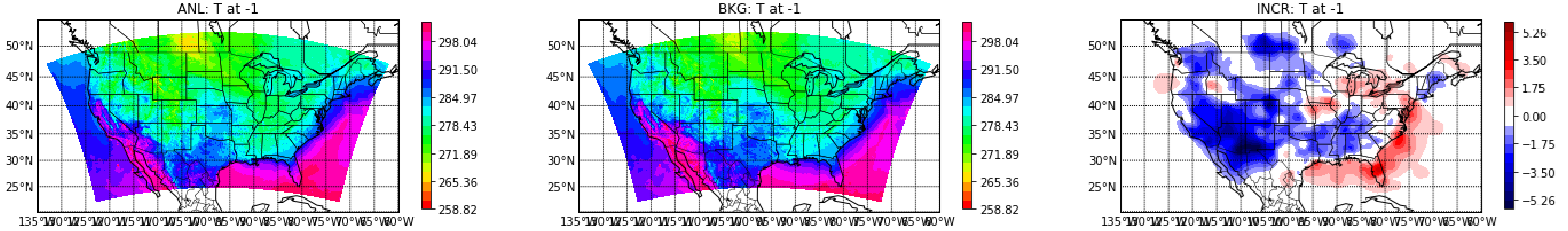


12-km SAR FV3 Forecast Grid
12-km GSI Analysis Grid

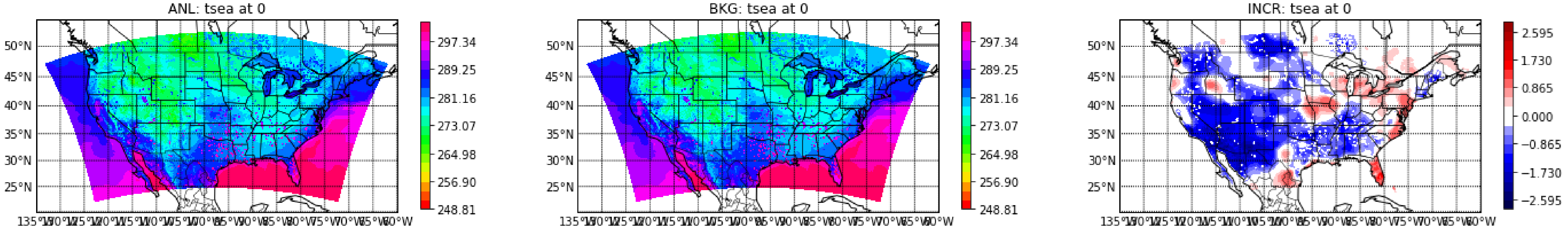


Analysis | Background | Difference

Lowest Atmospheric Level Temperature (K)

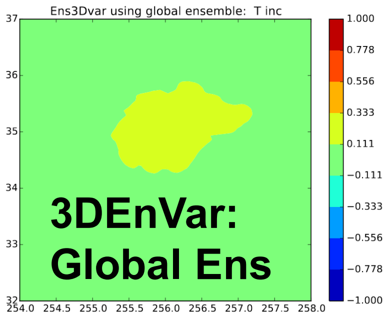


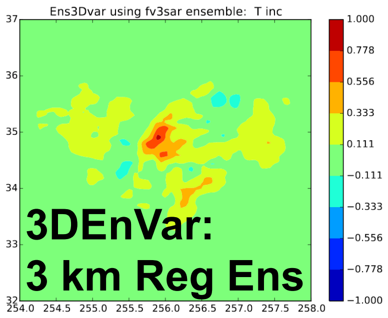
Skin (Soil) Temperature (K)

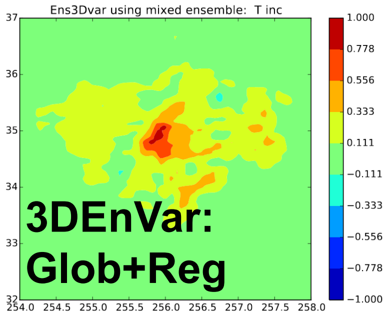


Soil temperature adjustments (lower right) in SAR FV3 derived from atmospheric analysis increments (upper right) through GSI

- Advancing ensemble methods, including (hybrid) EnVar
- Evaluating combining regional + global members in the ensemble **B**

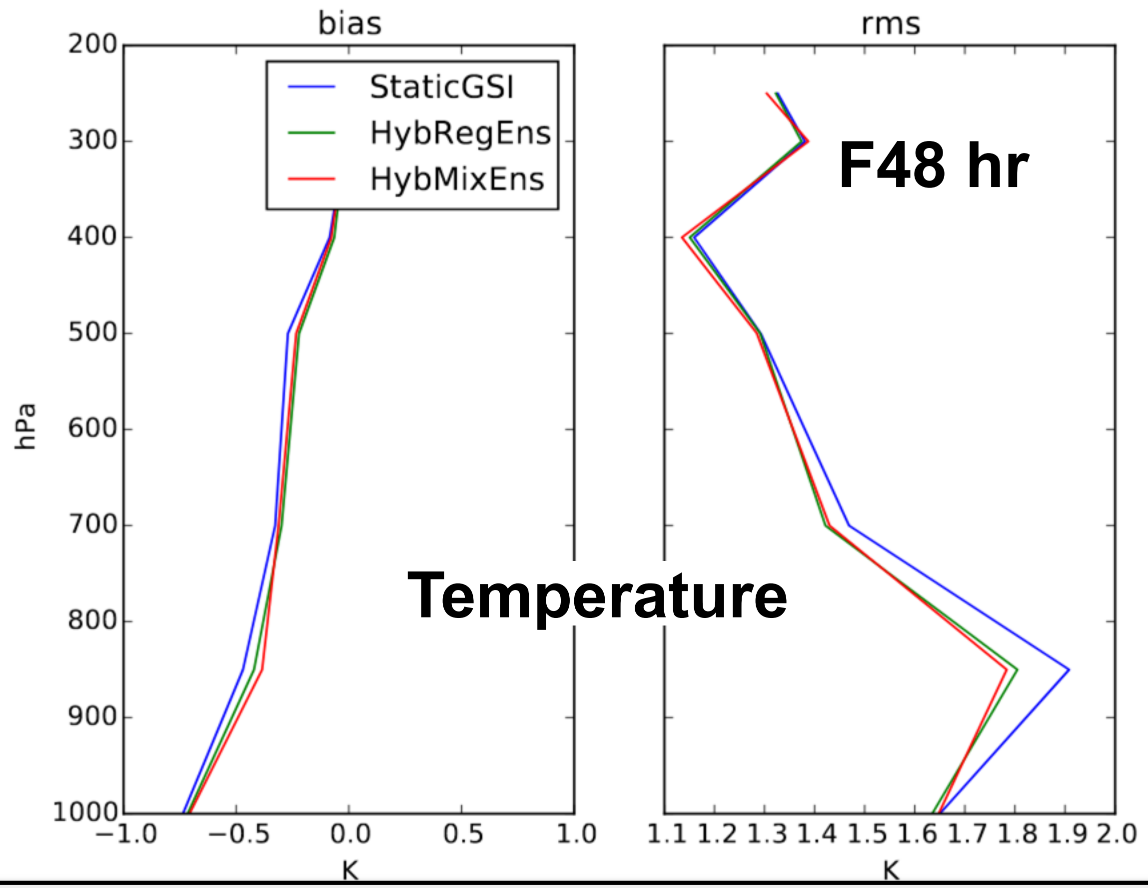






Single T ob
4K innovation
1K ob error
700 hPa

*Material courtesy of T. Lei



StaticGSI: 3DVar

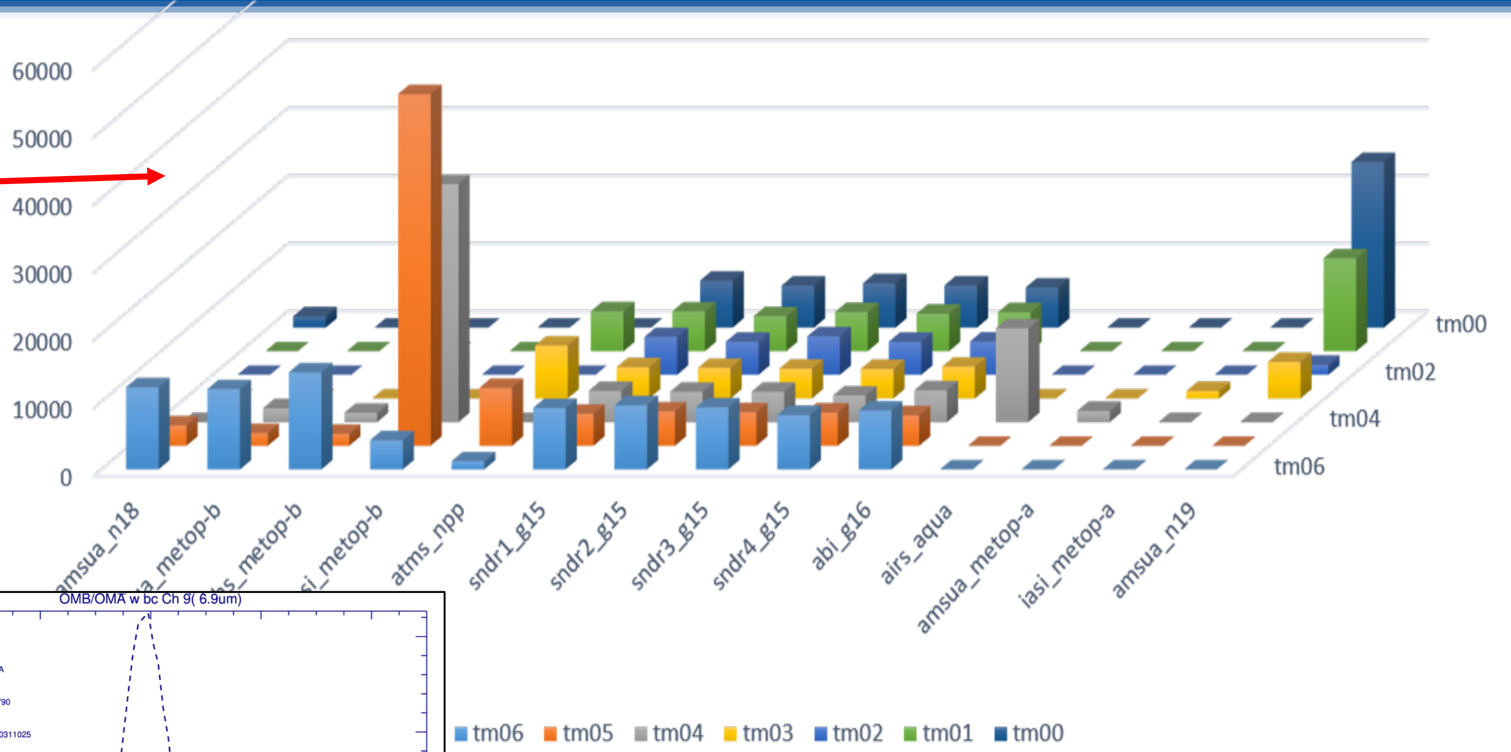
HybRegEns: 20, 3-km members

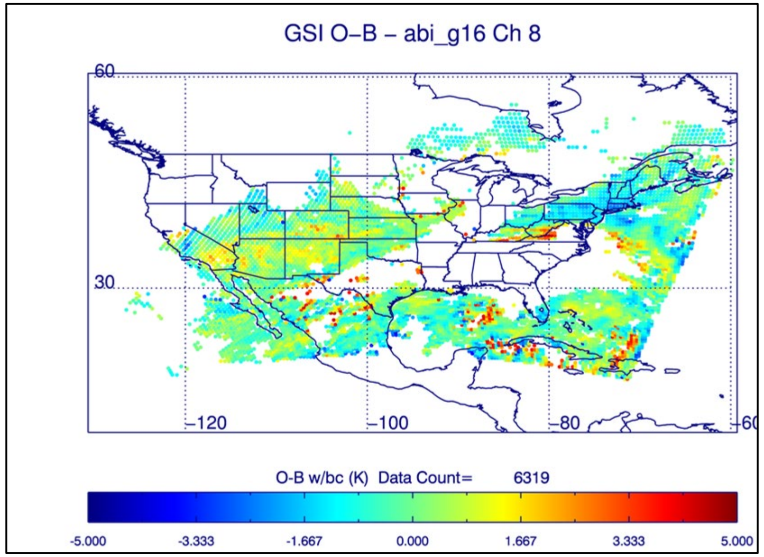
HybMixEns: 20, 3-km members + 80 global members

*Hyb uses 0.25 static **B***

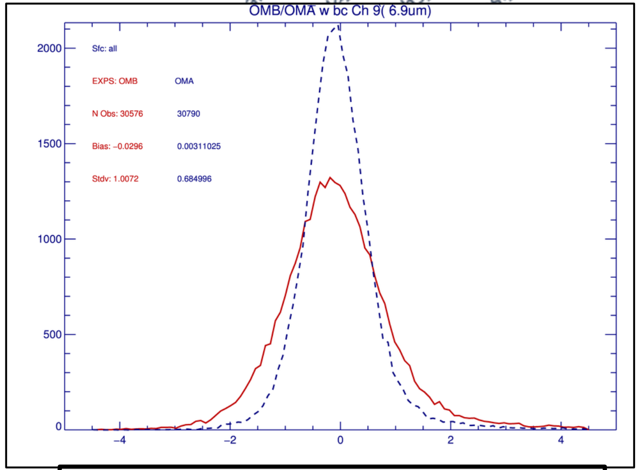
Ongoing Radiance DA Development

- *Hourly* assimilation of radiances
  - Same data as GFS
- Using radiance data through Regional ATOVS Retransmission Service (RARS) to reduce the data latency
- Bias corrections for all satellite instruments are estimated within the regional system

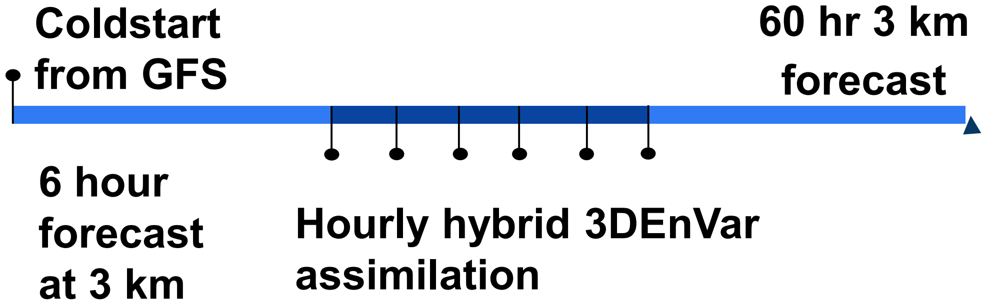




GOES-16 O-Bs



GOES-16 O-Bs and O-As *with* bias correction



- Using global EnKF members

*Material courtesy of X. Zhang

Preliminary evaluation from limited samples

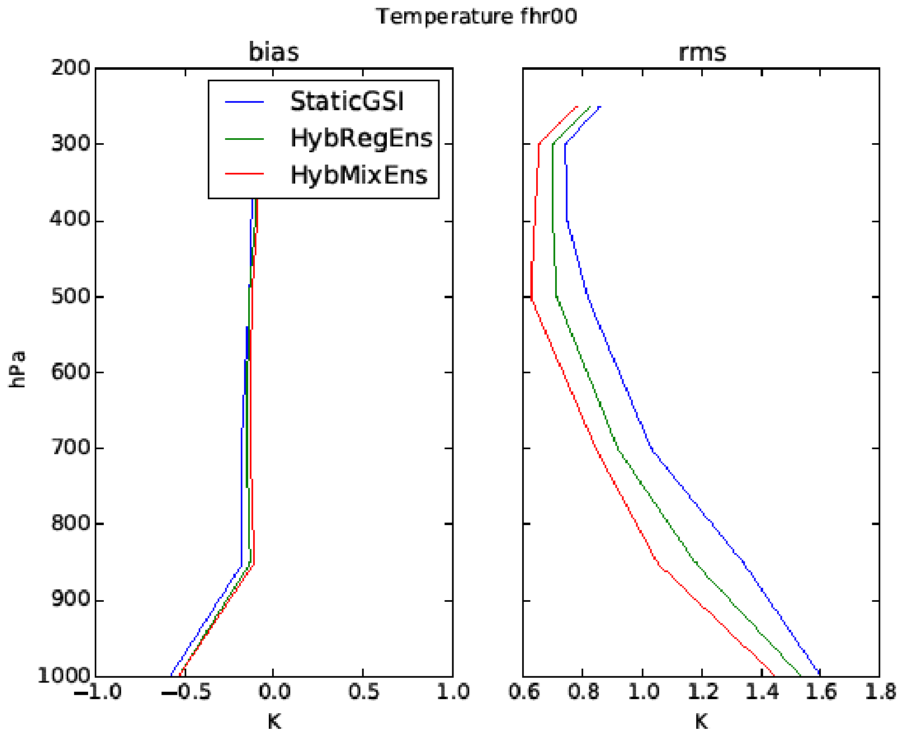
5 days with one 6 hour DA cycles (00z or 12z) each days in Dec 2019

- **StaticGSI**: 3DVar (static background error only)
- **HybRegEns**: Hybrid DA with 0.25 weight for static part, 20 (3 km) cycled FV3SAR ensembles (two way, re-centered ensemble).
- **HybMixEns**: Using 3 km ensembles from **HybRegens** and pre-set global ensembles from GFS/GDAS system.

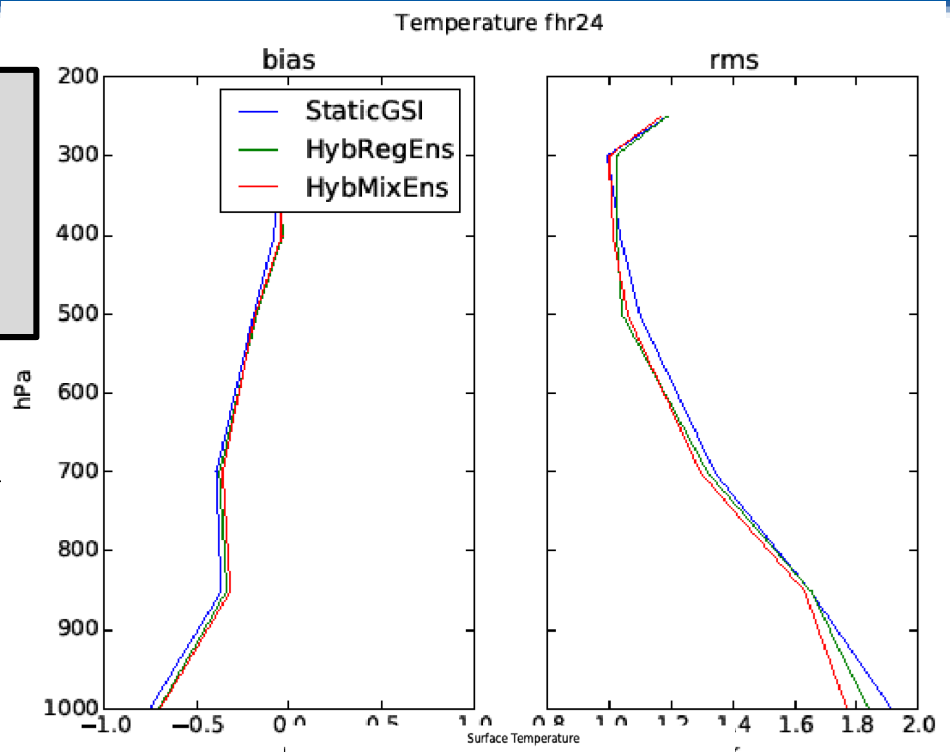
Conventional and satellite data are assimilated

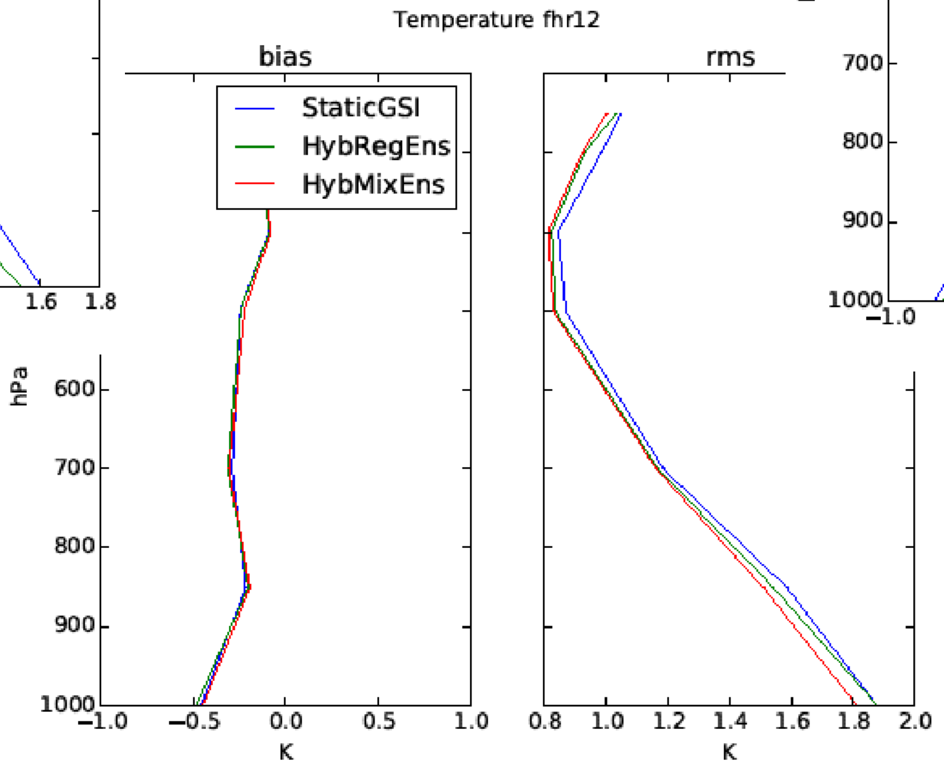
Control variables: stream function, velocity potential, surface pressure, temperature, and normalized humidity

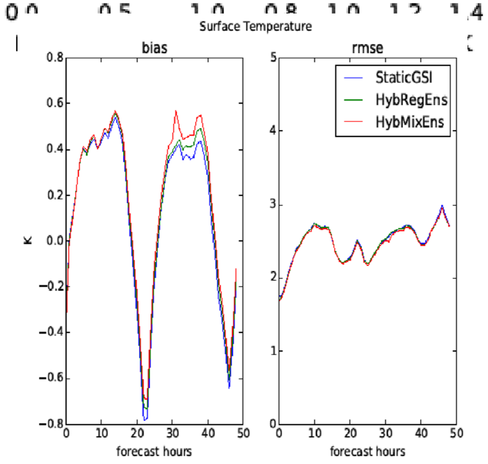
Ongoing Radiance DA Development



Verification against ADPUPA (upper level obs) and surface observation with METplus





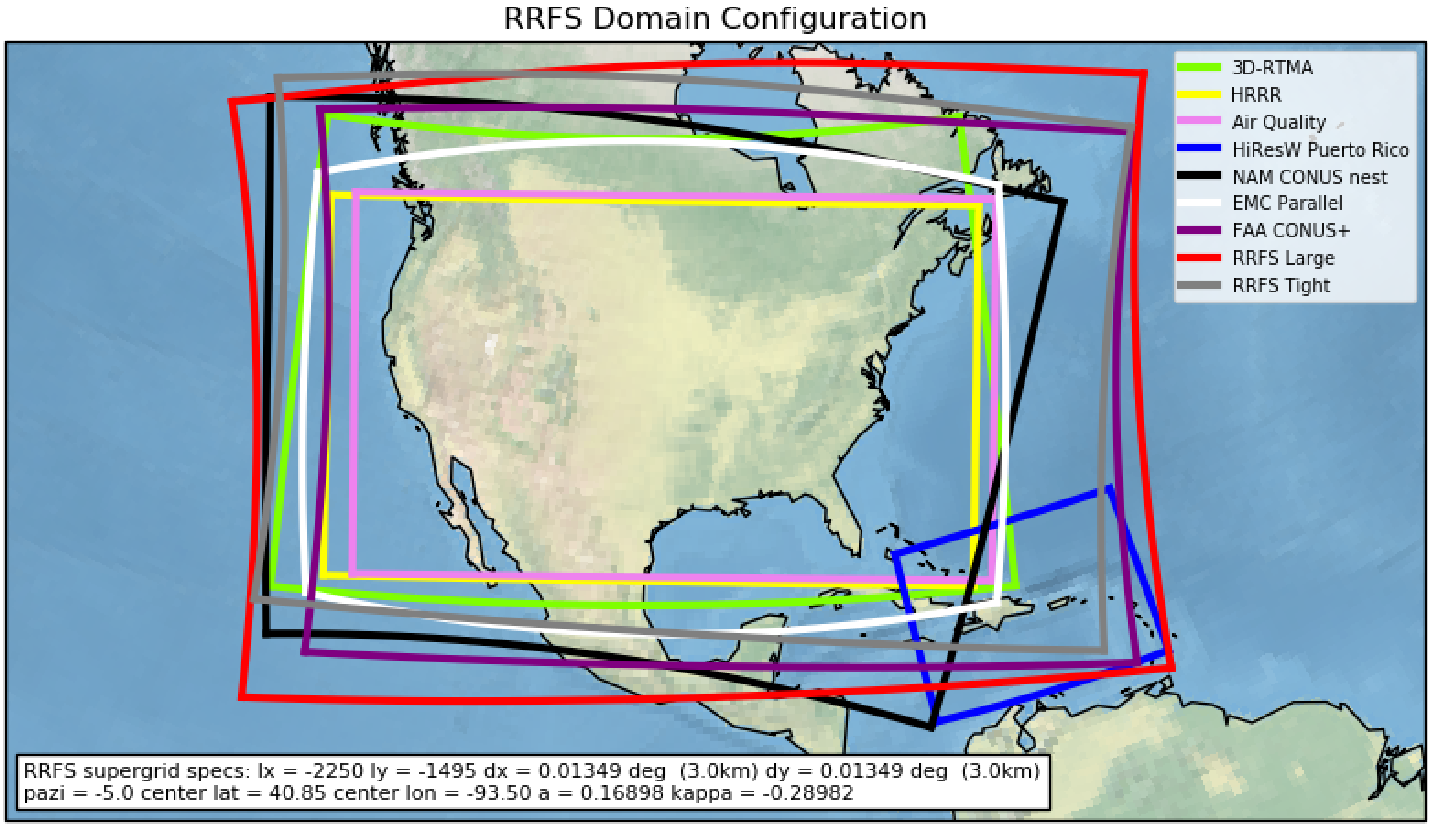


The benefit of HybMixEns over HybRegEns through 12 hours for temperature; No improvement found for wind forecast (at this time);

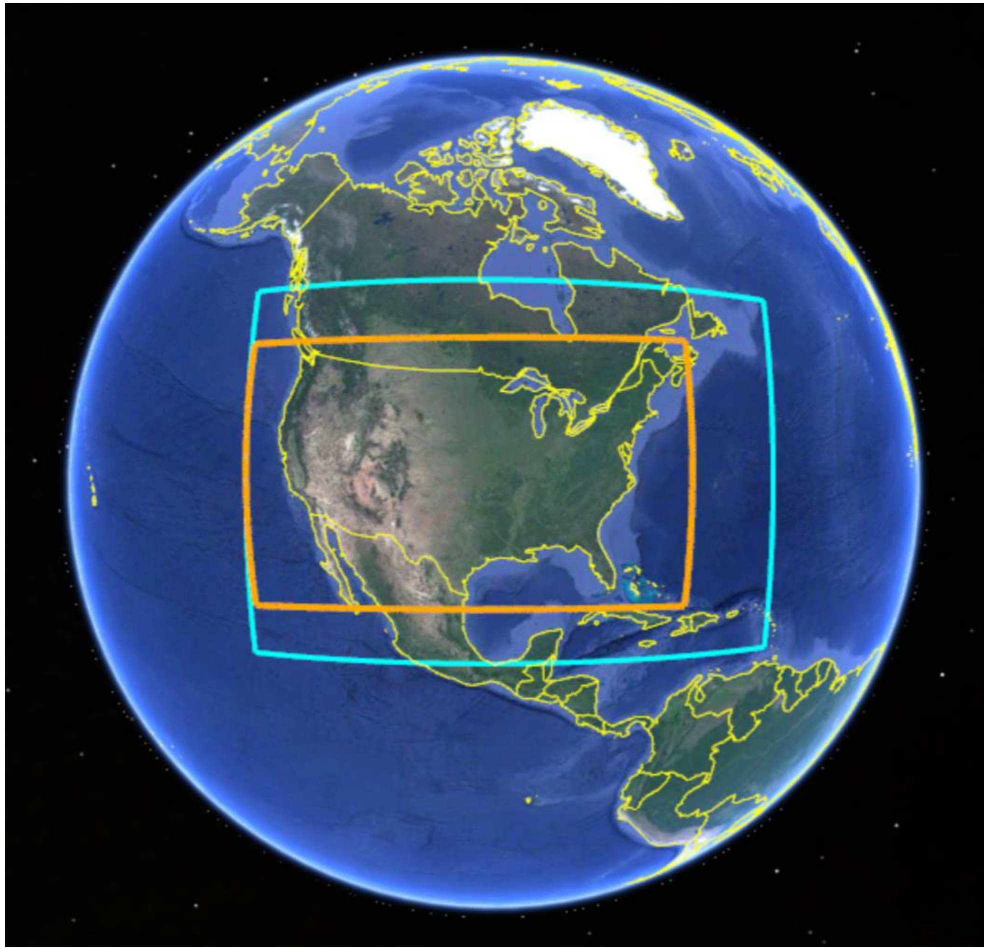
Parameterization	RAP/HRRR Suite	FV3CAM (RRFS) Baseline Physics
Microphysics	Aerosol-aware, radiation-coupled Thompson	Aerosol-aware, radiation-coupled Thompson
Surface/Boundary Layer (PBL)	Scale-aware MYNN	Scale-aware MYNN
Short/Longwave Radiation	RRTMG	RRTMG
Land Surface Model (LSM)	RUC (9 level)	Noah-MP (contingent upon RUC-like modifications including increased levels)
Cumulus	Scale-aware Grell/Freitas (GF)	N/A

Additional microphysics and boundary layer schemes will be used in multi-physics configurations

Draft RRFS Domains – NOT Finalized



NWP CONUS Plus Domain (blue)
HRRR Domain (orange)

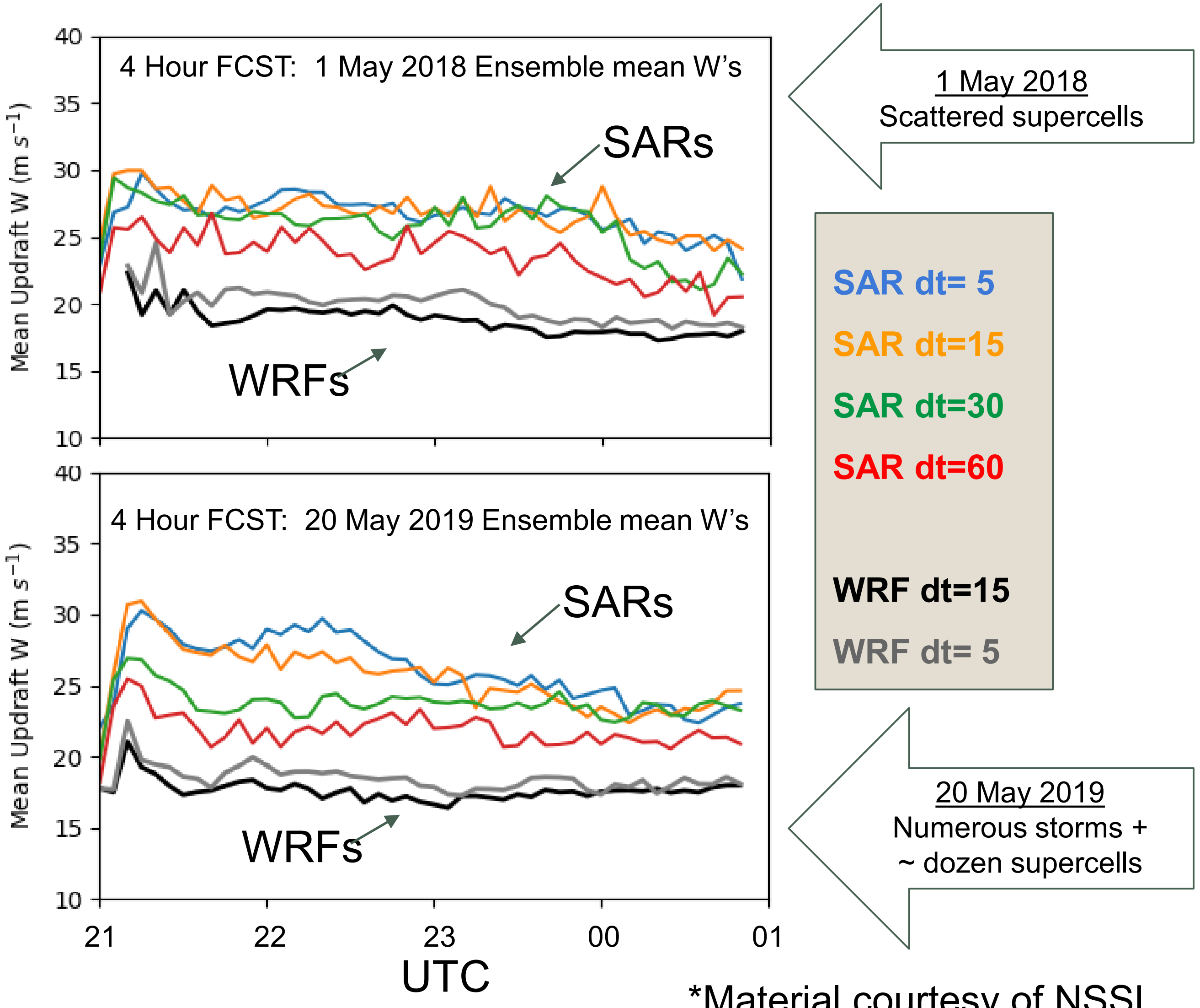


CAM Attributes and Verification Metrics

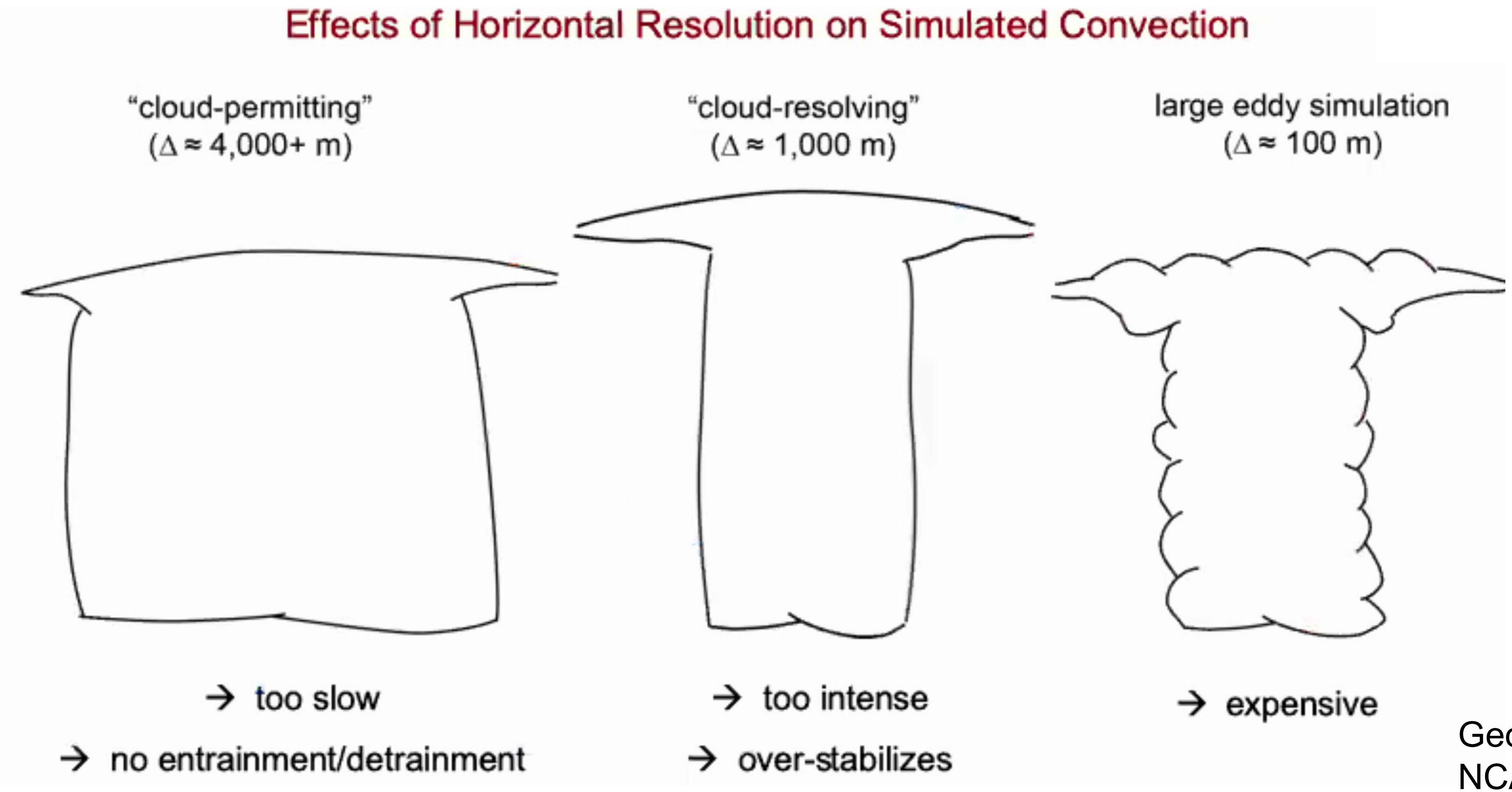
Forecast Field	Application	Vertical Attribute	Temporal Attribute	Validation Source	Skill Scores
Temperature	Environmental	Column	Instantaneous	RAOBs	RMSE, BIAS
Specific Humidity	Environmental	Column	Instantaneous		RMSE, BIAS
Wind	Environmental	Column	Instantaneous		RMSE, BIAS
CAPE/CIN	Environmental	Mixed, Most-Unstable, Surface-Based	Instantaneous		RMSE, BIAS
Storm Relative Helicity	Environmental	0-1, 0-3 km AGL	Instantaneous		RMSE, BIAS
Temperature	Environmental	2-m	Instantaneous	METARs	RMSE, BIAS
Dewpoint	Environmental	2-m	Instantaneous		RMSE, BIAS
Wind	Environmental	10-m	Instantaneous		RMSE, BIAS
Downward Shortwave Radiation	Air Quality/Energy Land Surface	Surface	Instantaneous/Average	ARM, Surfrad (Oak ridge, ameriflux), USCRN	RMSE, BIAS
Ceiling	Aviation	Column	Instantaneous	METARs	CSI, BIAS, FSS, POD, FAR, AUR, Performance Diagram
Visibility	Aviation	Surface	Instantaneous		
Echo Top Height	Aviation	Column	Instantaneous	MRMS Echo Top	
Simulated Reflectivity	Severe	Composite	Instantaneous	MRMS Mosaic Composite	
Updraft Helicity	Severe	2-5, 0-3 km AGL	Hourly Maximum	Storm Reports	
Precipitation	Precip	Surface	1-hr, 6-hr, 24-hr Totals	Stage IV 1-hr, 6-hr, 24-hr Precip	

Will be using METplus verification for pre-operational decision making
Test plan under development

- SAR has many tunable parameters
- Part of challenge is that SAR solutions appear fairly sensitive to parameter changes - more than current CAMS.
- **Example of Sensitivity: Two Warn on Forecast cases**
- Take hourly DA generated analyses from WRF-ARW WoFS and initialize the SAR with those analyses.
- Run 4 hour forecasts with 18 members for both models
- Use “same” physics in both ensembles-> HRRR suite
- Simple test: Change the SAR time step
  - WoFs runs using dt=5 and 15 sec
  - SAR runs with 5, 15, 30, 60 sec time step
  - Mean values are generated from obj-based storm identification and represent the average W over 27 pts.
- *SAR updrafts are sensitive to choice in* ***time step....***
- *Why are SAR updrafts 50-75% larger than current operational CAM with same mesoscale environment and same time step?*



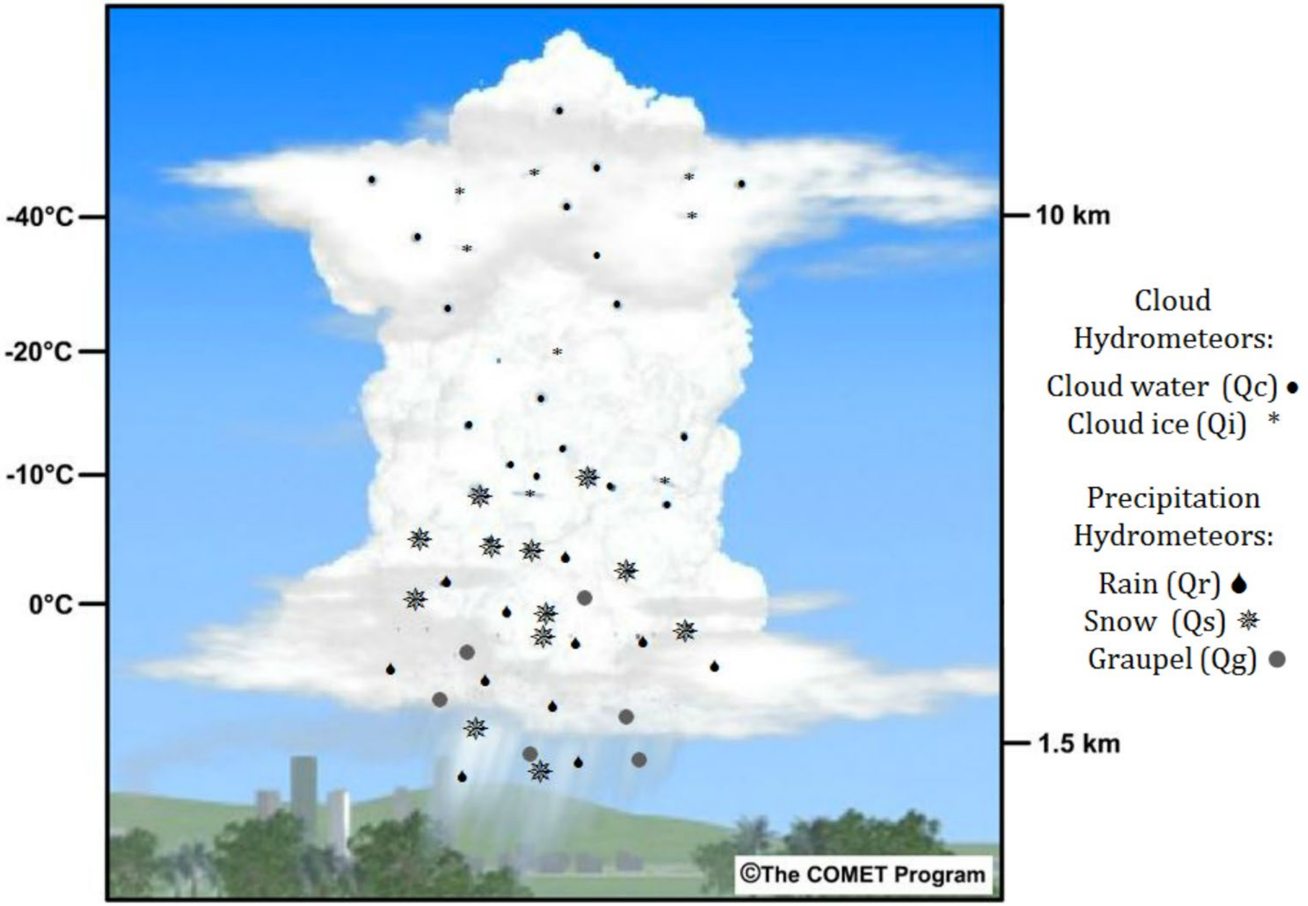
*Material courtesy of NSSL



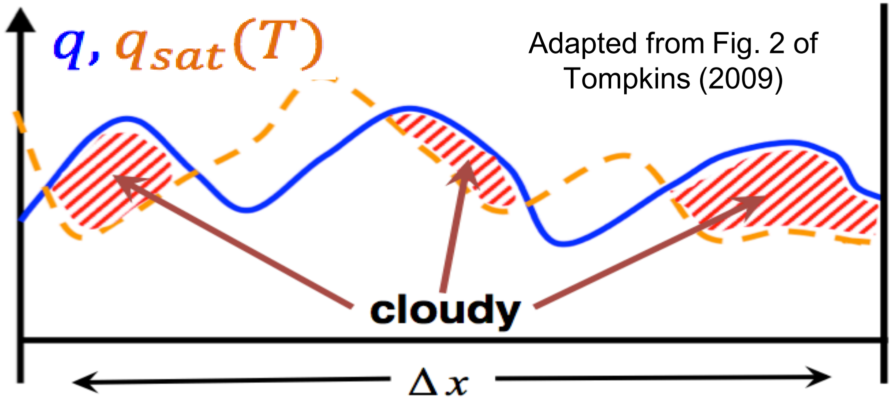
George Bryan
NCAR

Explicit (Resolved) Clouds/Precipitation

RAP and HRRR use the Thompson microphysics scheme with 5 hydrometeor types



Sub-Grid (Unresolved) Clouds



$$Var(s) \propto Var(q) + Var(T) - Cov(q,T)$$

Assume a PDF of *s* *(saturation ratio)*

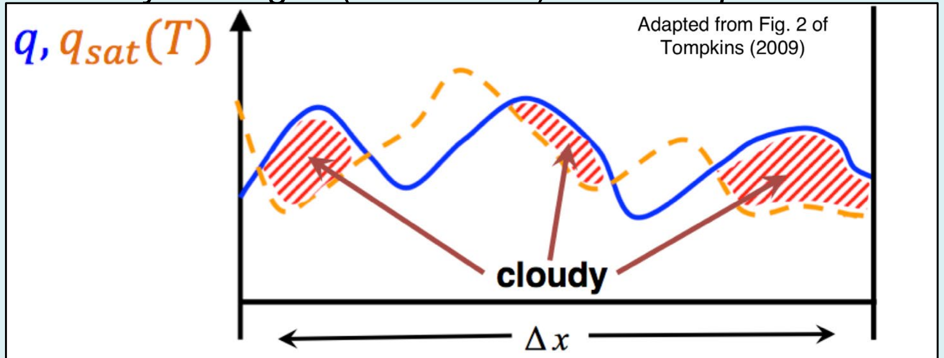
Retrieve Cloud Fraction, Cloud Condensate

Parameterize: *assume* subgrid PDFs for thermodynamic variables
Chaboureau and Bechtold (2002)

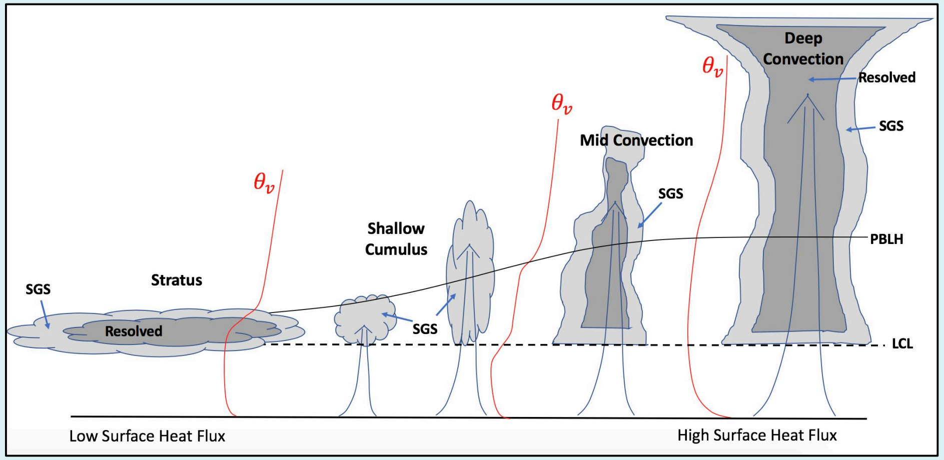
Improved Subgrid-Scale Cloud Representation

Subgrid-Scale (SGS) Clouds

- **Key Idea**: thermodynamic variability within a grid volume may produce small areas of saturation (*clouds*)
- Variability is subgrid (unresolved): *must be parameterized*



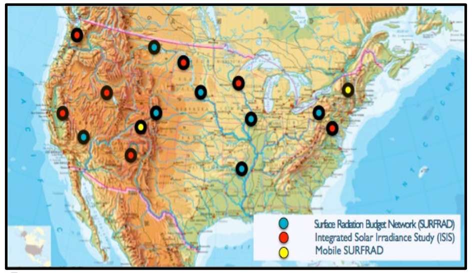
$$Var(s) \propto Var(q) + Var(T) - Cov(q, T)$$



Key Changes for RAPv5 / HRRRv4:

- Mixing ratio (q_{cldwat} and q_{cldice}) of SGS clouds:
  - Removed constraints on q_x for stratiform SGS
  - Increased coverage of convective SGS via MYNN mass-flux approach
- Cloud fraction:
  - Stratiform: slightly reduced, except in high grid-scale RH
  - Use a modified Chaboreau and Bechtold (2002, 2005) scheme exclusively; discontinue use of Xu and Randall (1996)
- Effective radii (r_e) of SGS clouds:
  - Water: use Turner et al. (2007)
  - Ice: use Mishra et al. (2014)

Improved Subgrid-Scale Cloud Representation

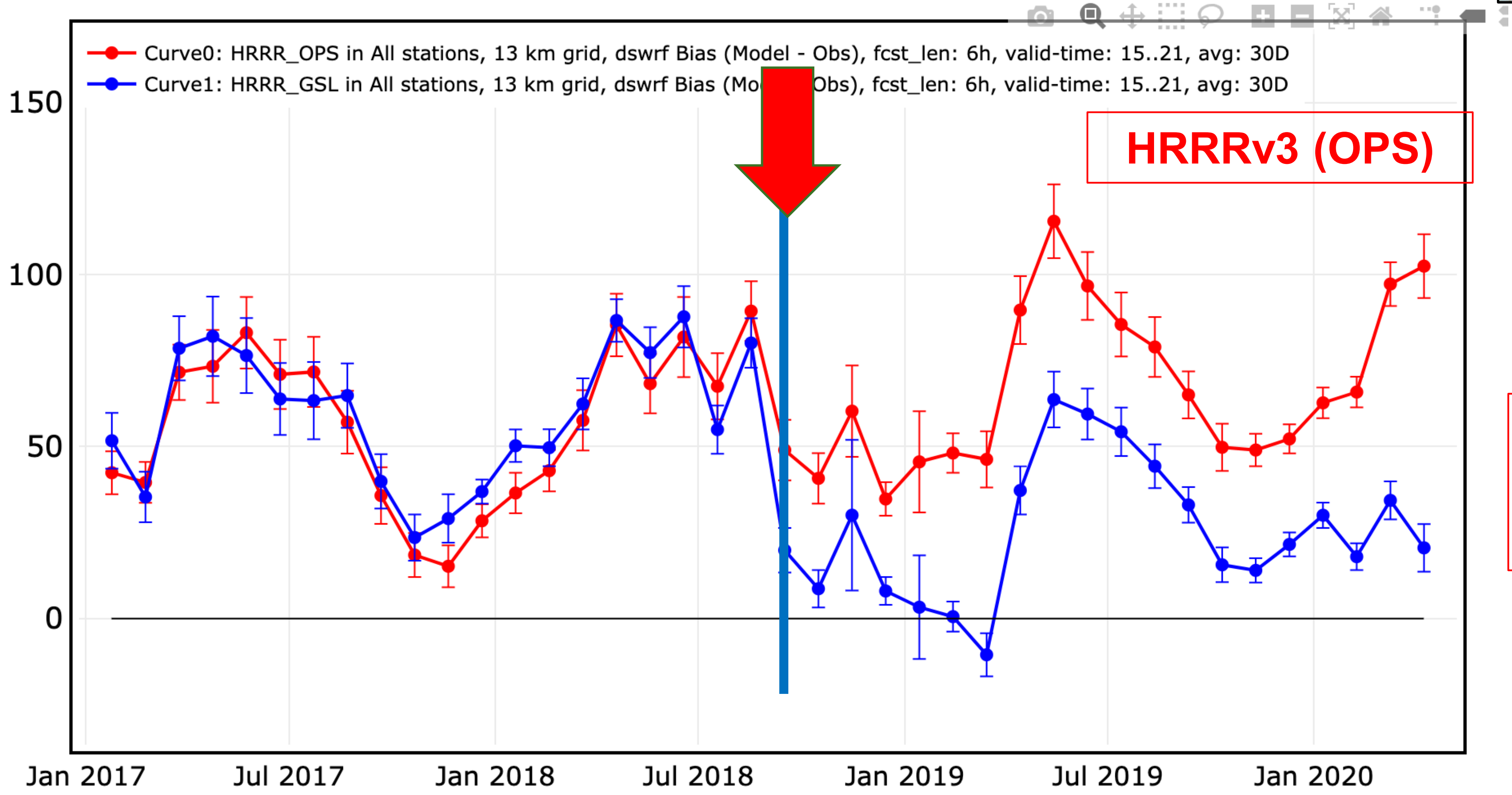


8/29/18 subgrid-cloud change

Surface Radiation : TimeSeries 01/19/2017 9:00 - 04/15/2020 9:00 : no diffs MATCHED Close All Preview Windows

Curve0 mean = 61.82, median = 61.52, stdev = 23.19
Curve1 mean = 42.53, median = 38.57, stdev = 25.88

Downward shortwave radiation bias vs. NOAA SURFRAD radiation network

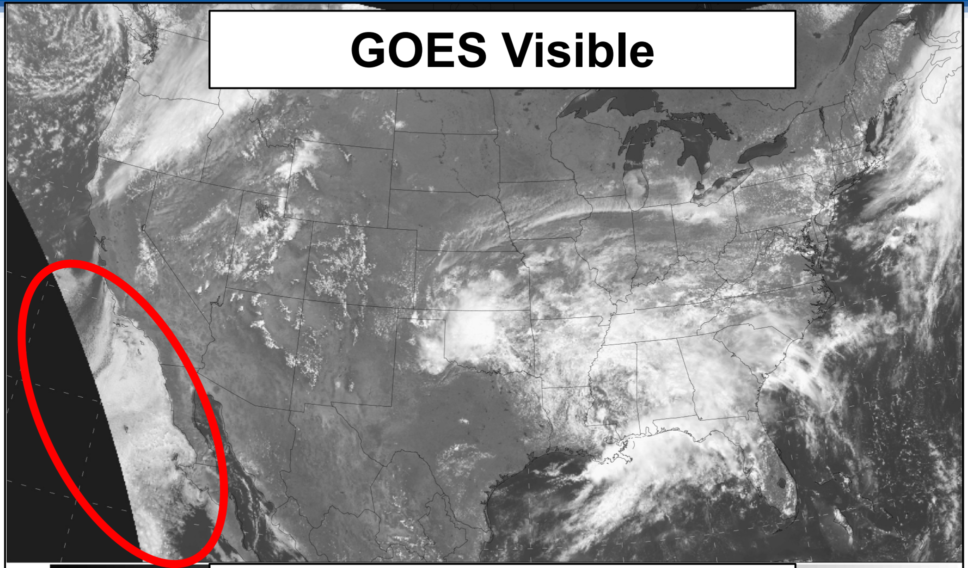


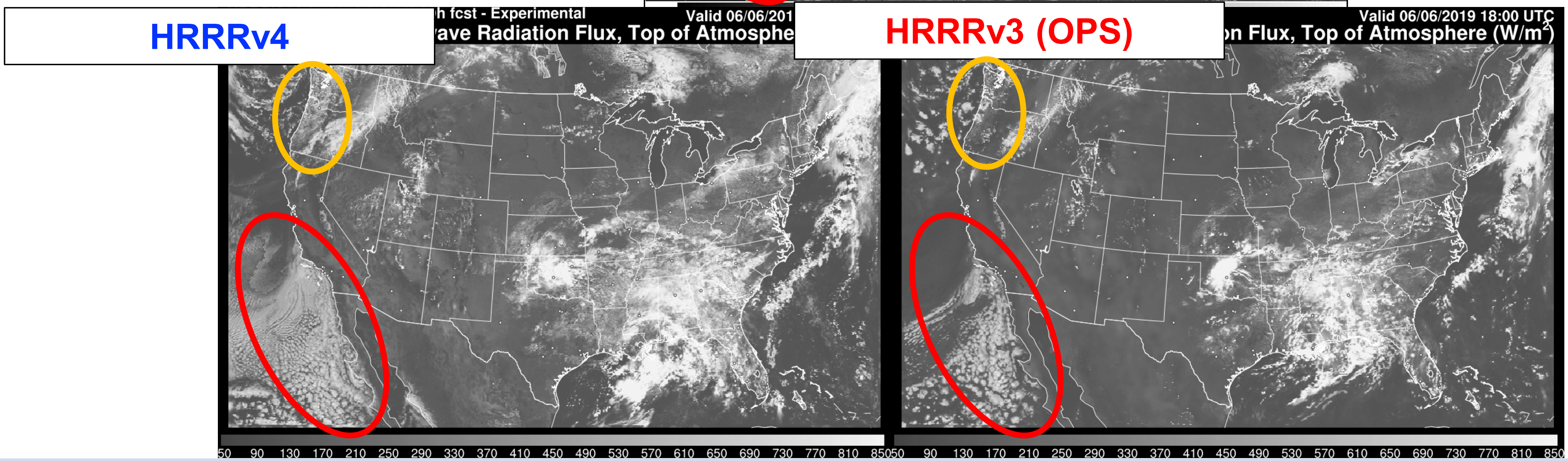
HRRRv4 with subgrid cloud changes

Improved Subgrid-Scale Cloud Representation

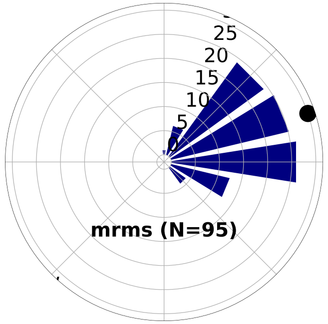
HRRR 30-h forecasts of upwelling shortwave at TOA

Init: 1200 UTC 05 Jun 2019
Valid: 1800 UTC 06 Jun 2019





CAM Storm Motion Biases



Storm Motion Biases

Courtesy of
Corey Potvin
NOAA/NSSL

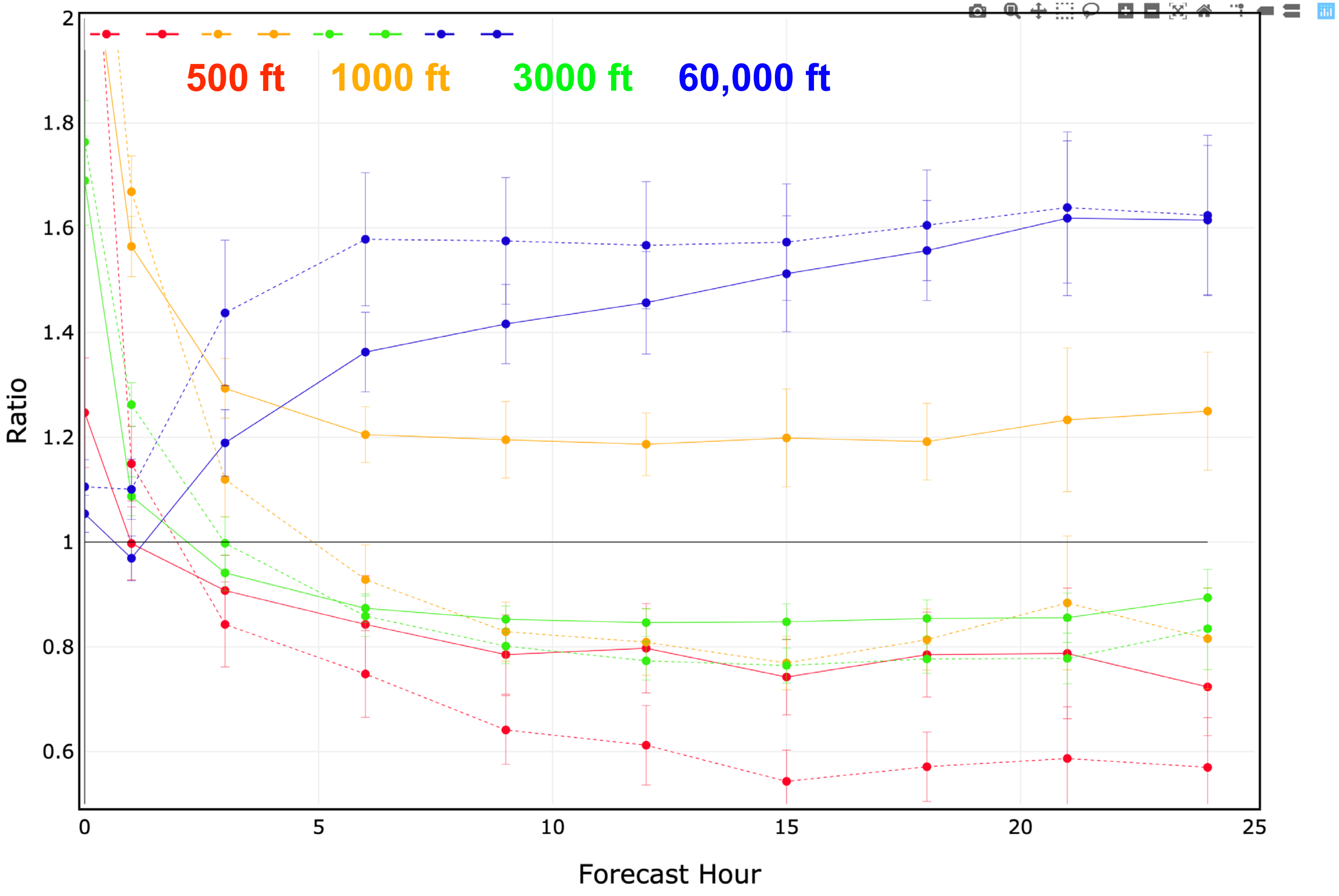
Relative to MRMS radar observations (upper left)
Modeled storms move too quickly in sheared environments
Modeled storms don’t deviate rightward (enough) from mean shear vector

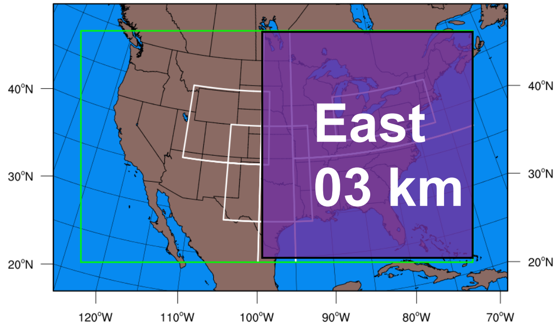
nam3km (N=202)

CAM Forecast Retention of Clouds

HRRRv4
HRRRv3

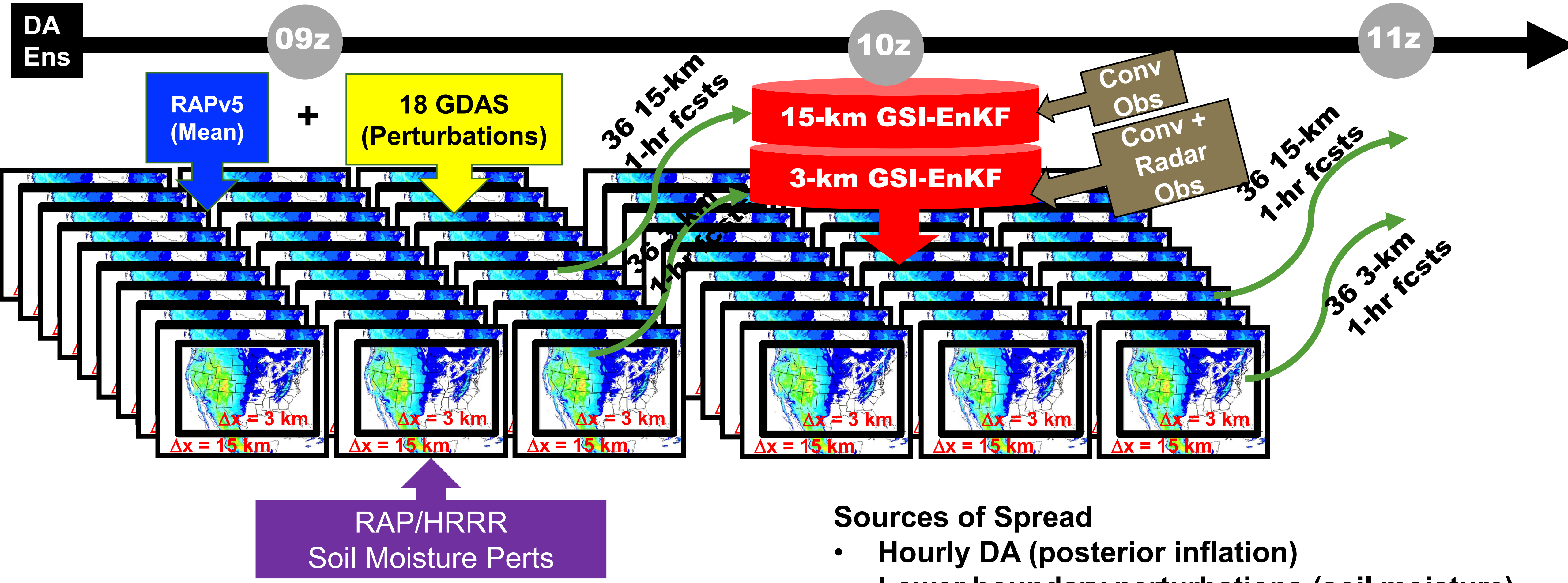
HRRR Ceiling Bias
6 June – 5 July 2019





Rapid loss of cloud mass remains a challenge for balance/retention of these features

HRRR Data Assimilation System (HRRRDAS) Collaboration from NSSL, EMC, NCAR and OU



18 members re-initialized at 09z and inserted at 10z
18 members re-initialized at 21z and inserted at 22z

Sources of Spread

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

Deterministic HRRR (FY20)

Initial conditions

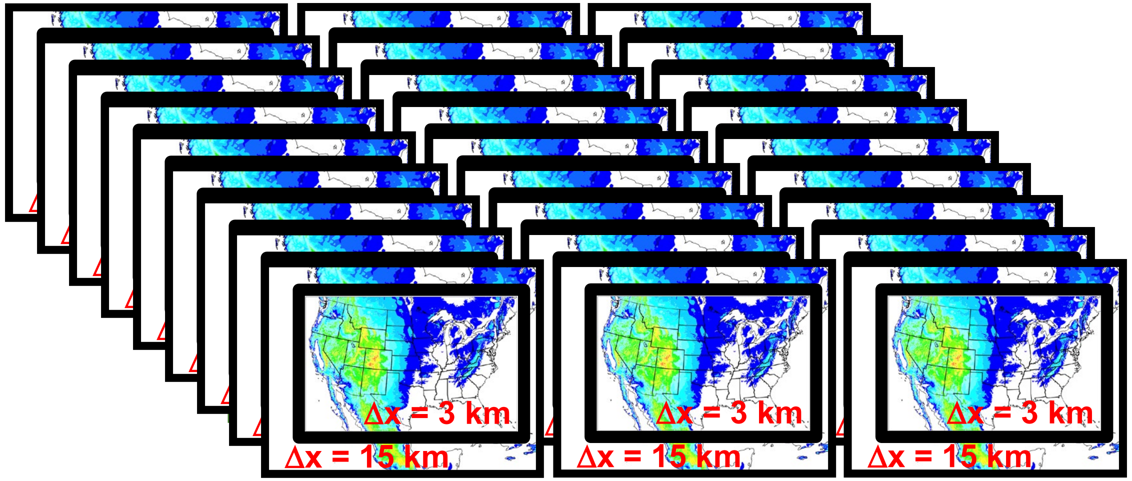
Background error covariances

RTMA-3D (FY23)

Storm-scale background error covariances

Storm-scale analysis uncertainty

HRRRDAS (FY20)



HRRRE (FY23 as part of RRFS)

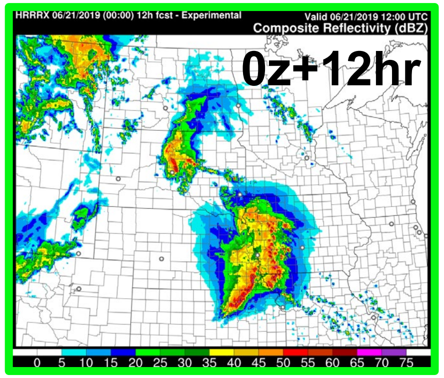
Storm-scale ensemble forecast

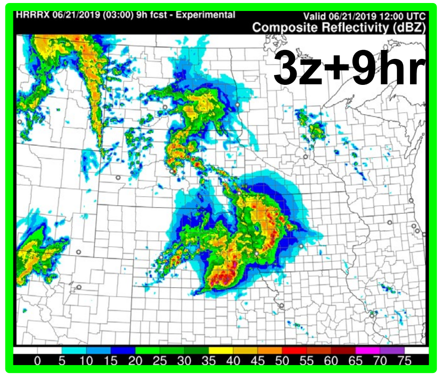
Warn-On-Forecast System (FY24-25+?)

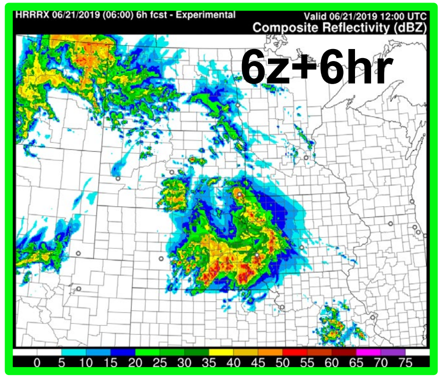
Initial conditions

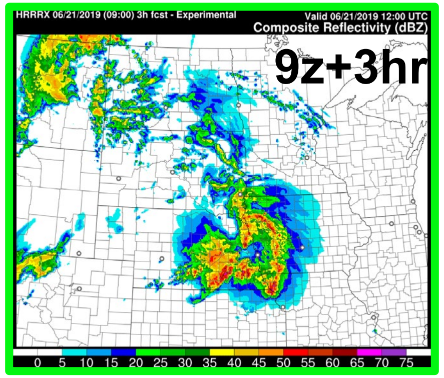
Boundary conditions

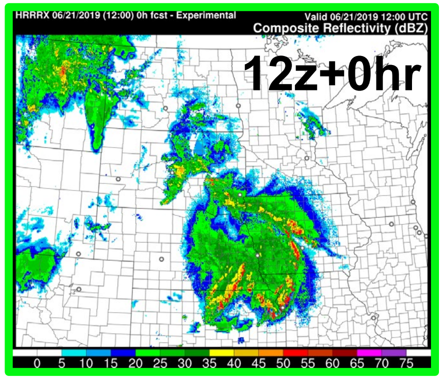
HRRRDAS: Case Study 12 UTC 21 June 2019



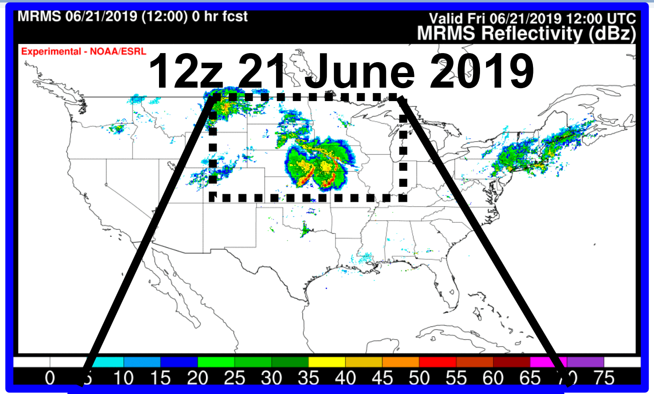


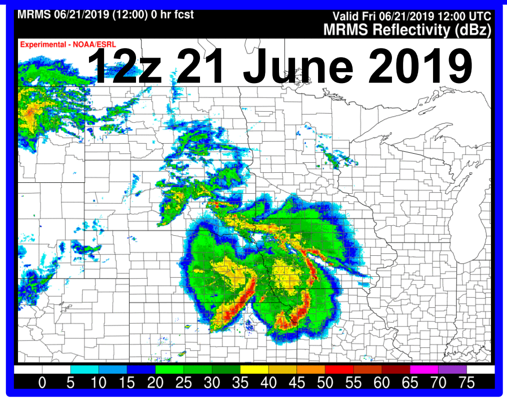


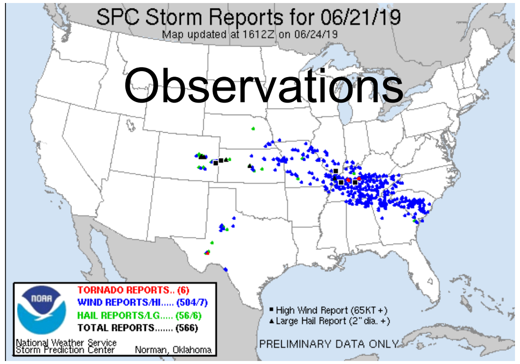


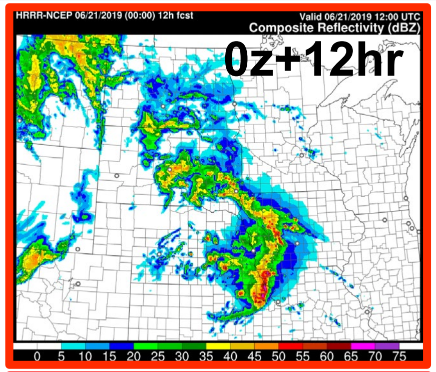


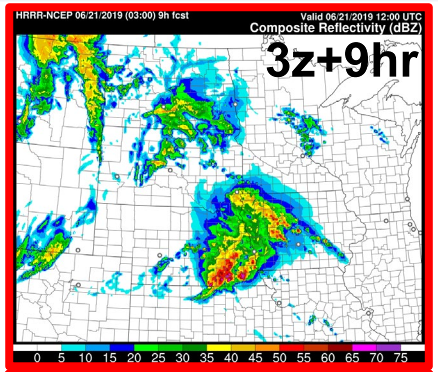
HRRRv4 w/HRRRDAS

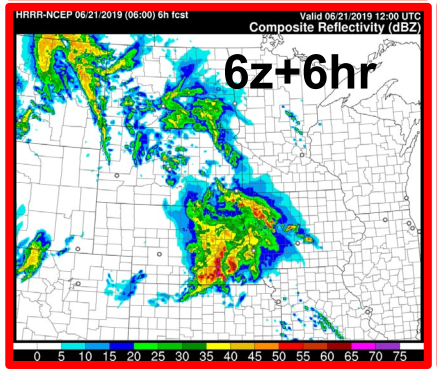


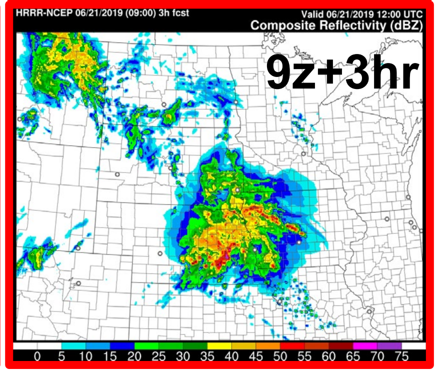


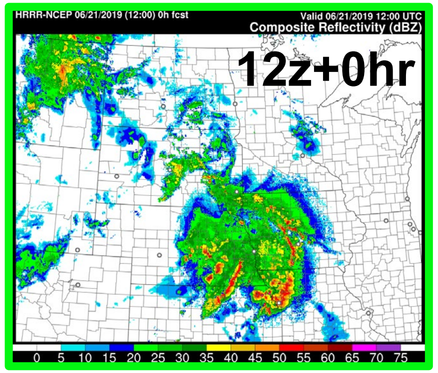












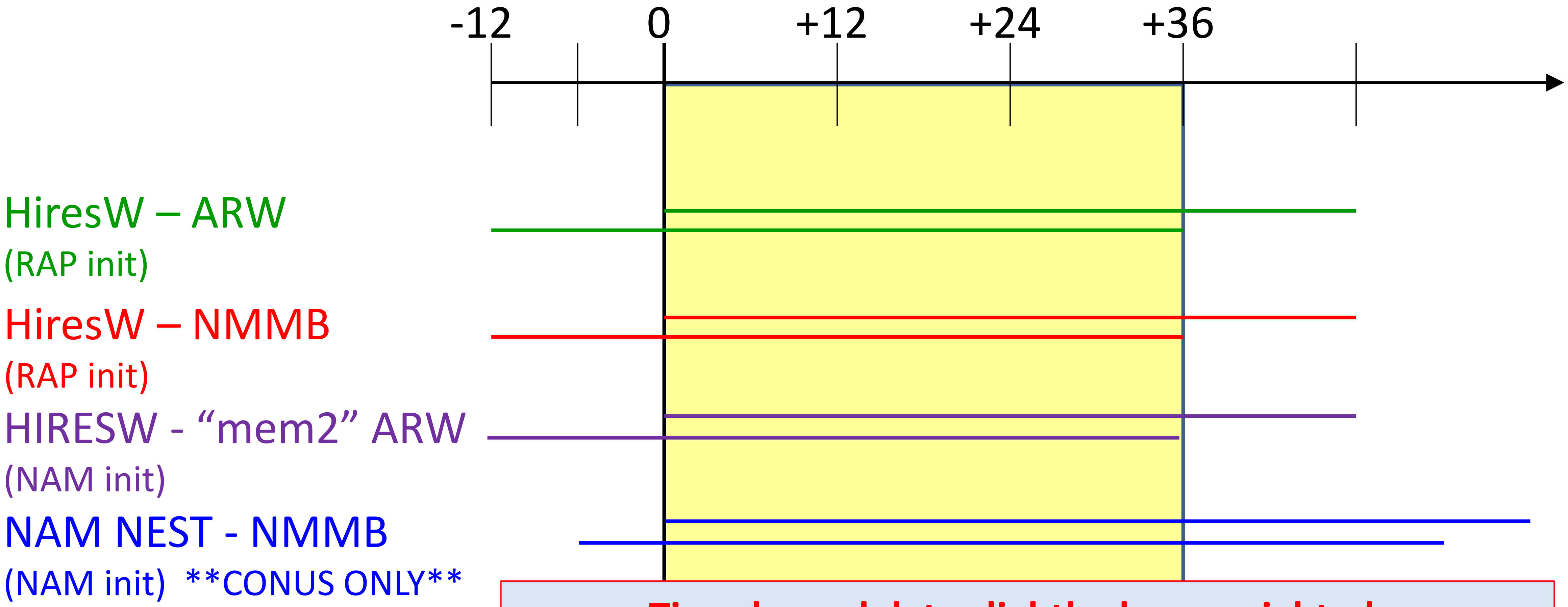
HRRRv3

High-Resolution Ensemble Forecast (HREF)

- Only high-resolution (~3 km) ensemble in NCEP operations
- 8 members combine time-lagging, varying initial condition sources, and mixed-physics approaches
- 00 and 12 UTC runs with 36-h forecast length
- Future update will include HRRR members, quantile-mapping bias correction and variable smoothing

Member	ICs/LBCs	Microphysics	PBL	Grid spacing	Vert. levels	Time step
HRW NSSL	NAM/NAM -6h	WSM6	MYJ	3.2 km	40	19.1 s
HRW NSSL -12h	NAM/NAM -6h	WSM6	MYJ	3.2 km	40	19.1 s
HRW ARW	RAP/GFS -6h	WSM6	YSU	3.2 km	50	18.9 s
HRW ARW -12h	RAP/GFS -6h	WSM6	YSU	3.2 km	50	18.9 s
HRW NMMB	RAP/GFS -6h	Ferrier-Aligo	MYJ	3.2 km	50	6.6 s
HRW NMMB -12h	RAP/GFS -6h	Ferrier-Aligo	MYJ	3.2 km	50	6.6 s
NAM CONUS Nest	NAM/NAM	Ferrier-Aligo	MYJ	3 km	60	6.25 s
NAM CONUS Nest -12h	NAM/NAM	Ferrier-Aligo	MYJ	3 km	60	6.25 s

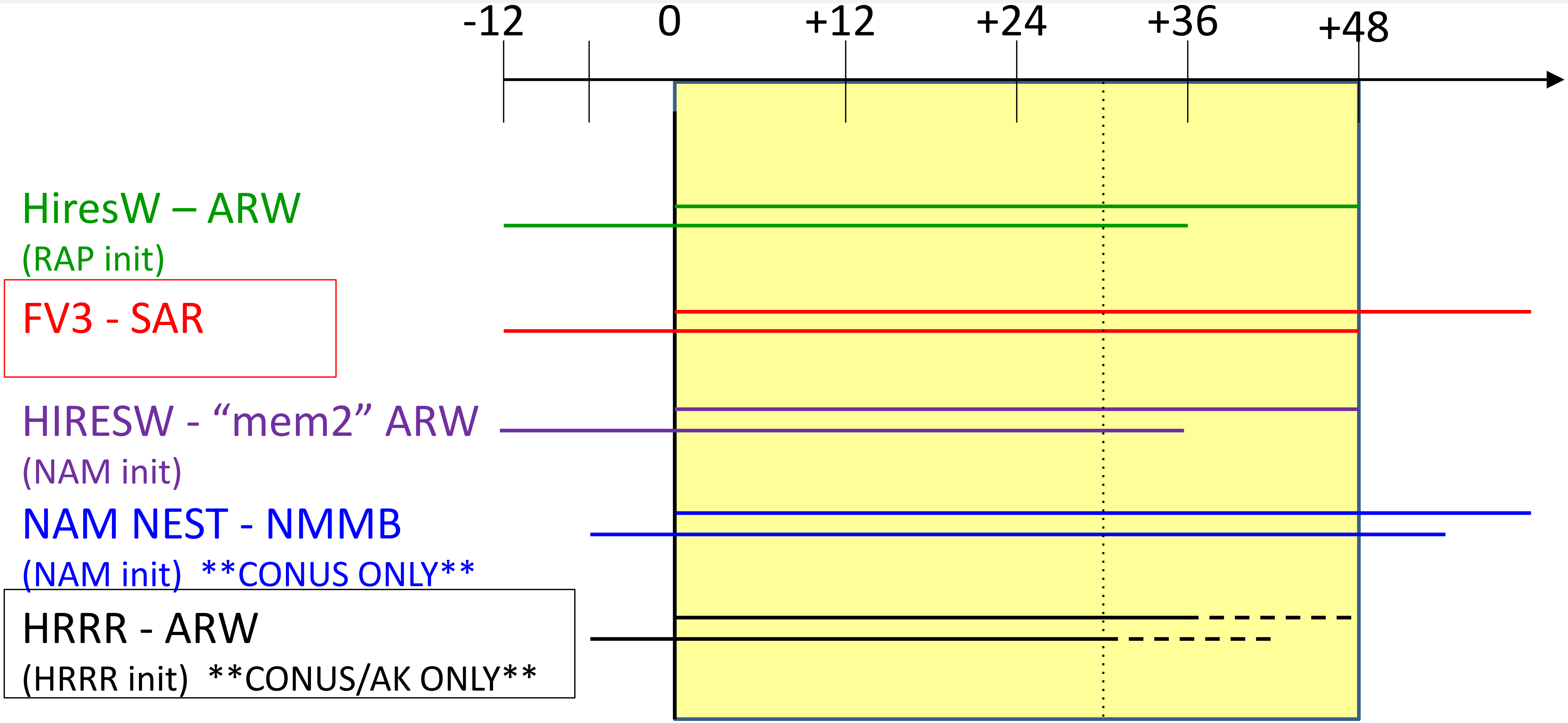
HREFv2 CONUS membership



Time-lagged data slightly downweighted –
12 h old cycle given 75% weighting in mean fields

Courtesy of Matt Pyle’s MEG HREFv3 MEG presentation from Sept. 26th, 2019

48 h HREFv3 membership (00/12Z CONUS)



Courtesy of Matt Pyle’s MEG HREFv3 MEG presentation from Sept. 26th, 2019

Plans for HREFv3

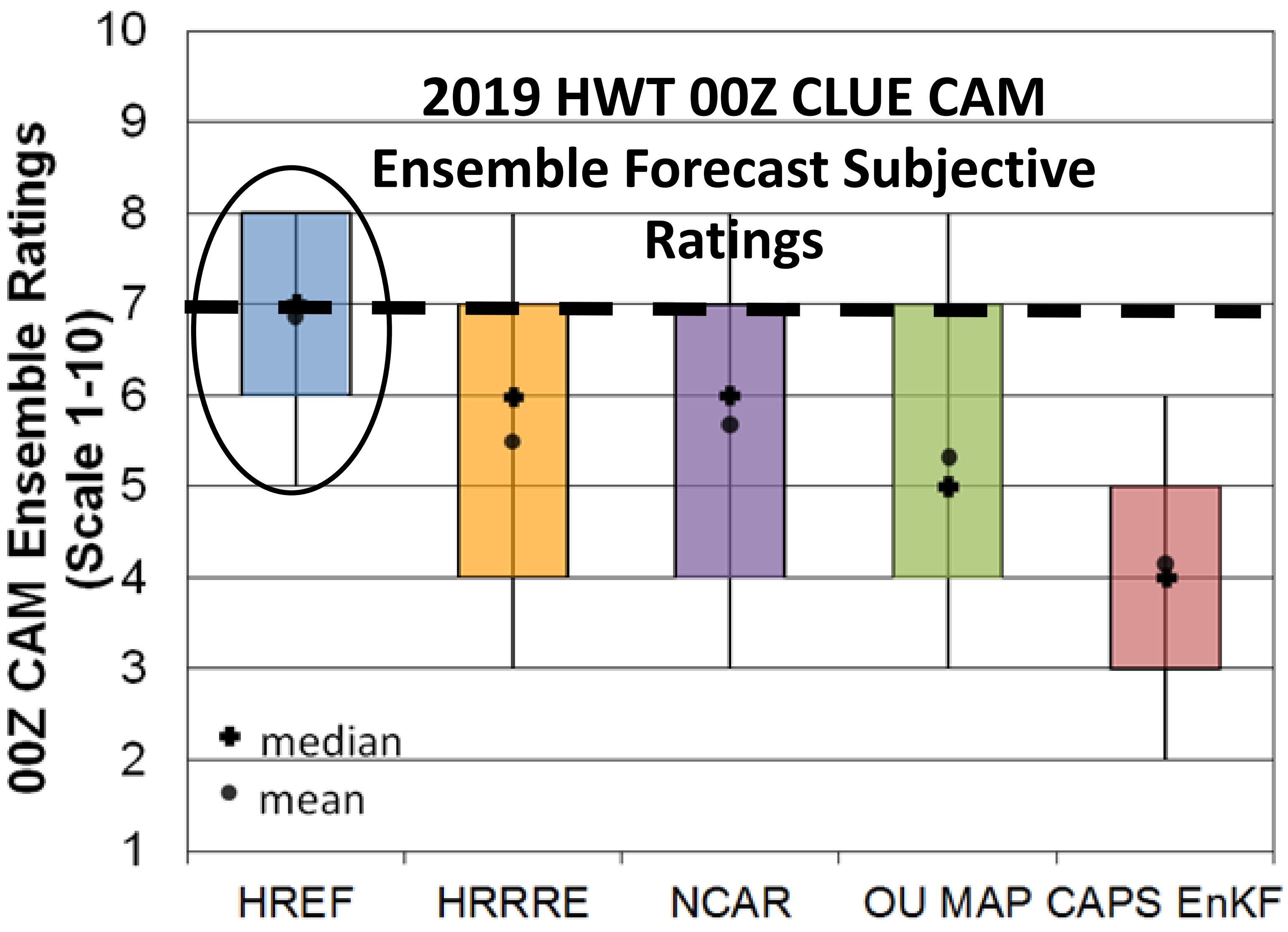
- **Add** regional 3 km *FV3* and *HRRR* runs as new members (with time-lagged members of each), and **eliminate** the *HiresW-NMMB* members.
- Likely product additions and modifications:
  - The Ensemble Agreement Scale (EAS) probability type will be introduced for select PQPF and snow products
  - Probabilities of QPF exceeding Average Recurrence Intervals (e.g., a 100 year event) and FFG (1 h, 3 h, and 6 h periods)
  - Local Probability Mean (LPM) for QPF
  - Extend forecast range from 36 h to 48 h

Courtesy of Matt Pyle's MEG HREFv3 MEG presentation from Sept. 26th, 2019

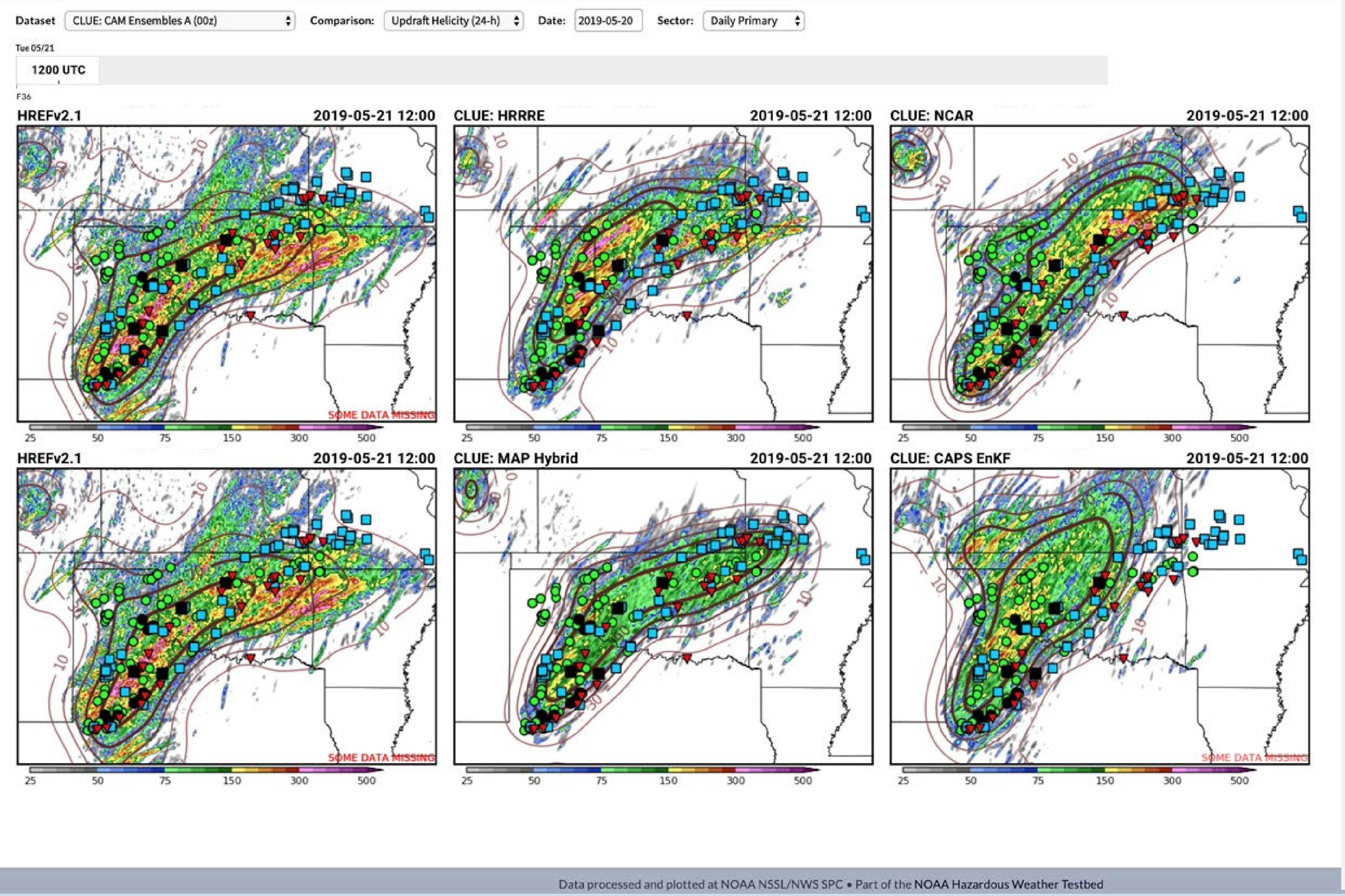
00Z CAM Ensemble Performance

- During the five-week 2019 HWT Spring Forecasting Experiment (SFE), experimental 0000 UTC CAM ensembles were subjectively compared to the HREFv2.1 (with HRRR)
- The HREF was consistently rated higher than other CAM ensembles for severe weather guidance in subjective evaluations (i.e., highest mean,
- median, and mode ratings)

Courtesy of Israel Jirak and HWT collaborators from SPC and NSSL



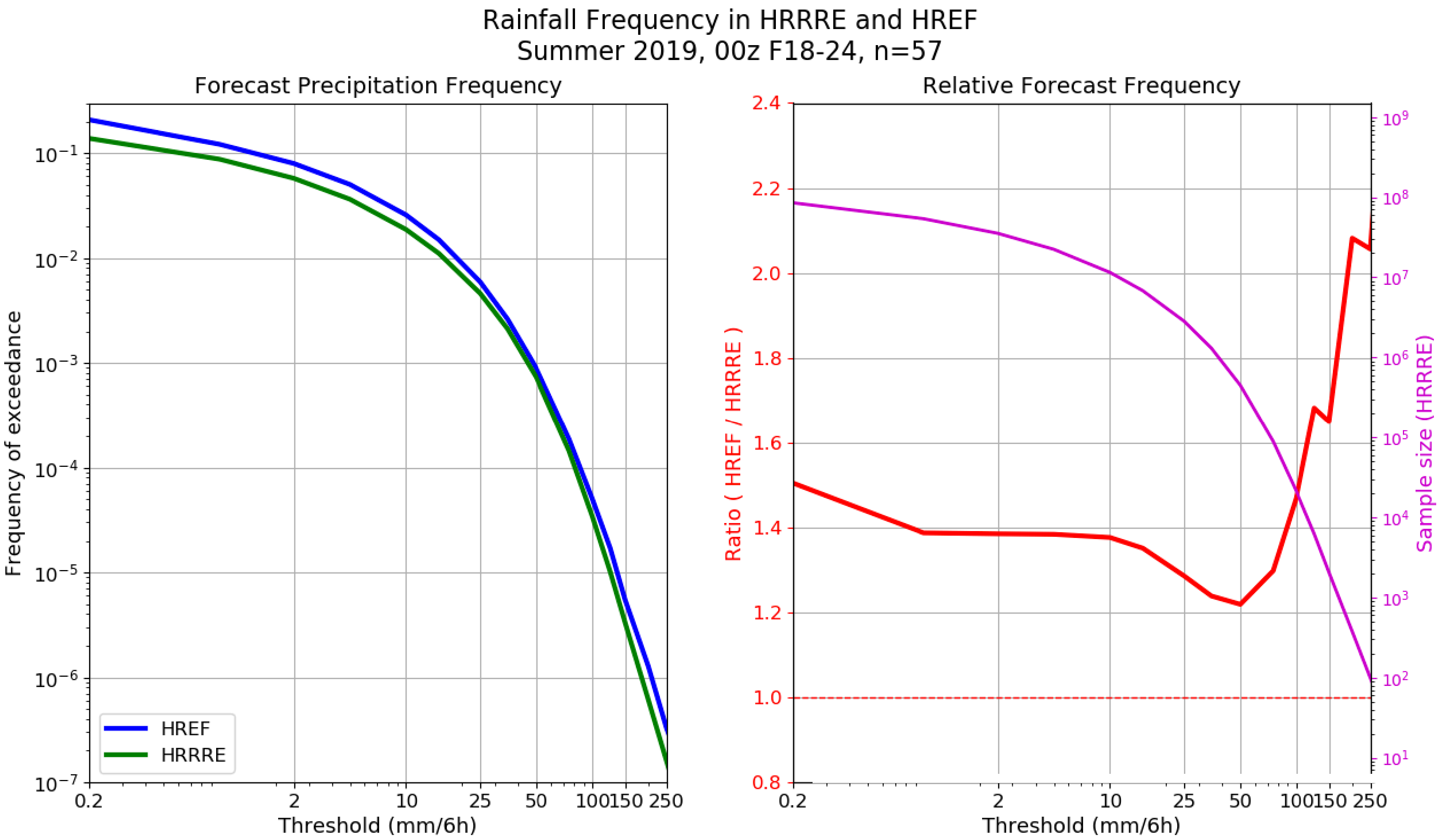
HRRRE and HREF 2019 Evaluation



Goal: Produce real-time, 9-member ensemble forecasts initialized from HRRRDAS during testbeds, for the purposes of getting community feedback and initializing WoFS.

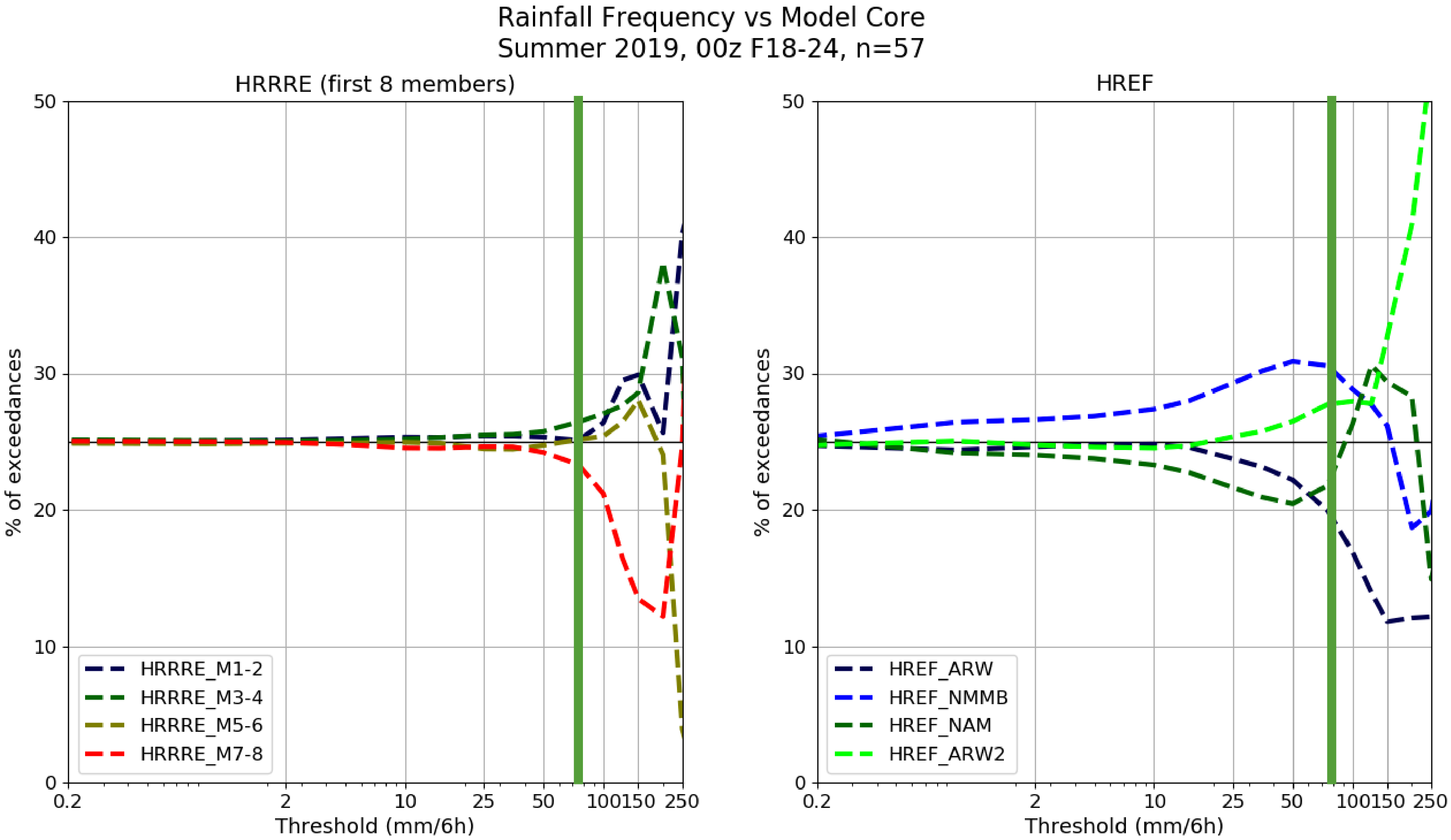
- Real-time 9-member single-dycore HRRR ensemble (HRRRE) 0-36 hr probabilistic forecasts using stochastic physics parameter perturbations as shown in the HWT evaluation (top-middle panel) for a high-impact severe weather period on 20-21 May 2019
- Overlaid storm-reports of tornadoes (red), high-winds (blue) and hail (green)
- Operational baseline CAM ensemble (HREFv2.1) shown in the left column

HRRRE and HREF 2019 QPF Evaluation



Courtesy of
Trevor Alcott
NOAA/GSL

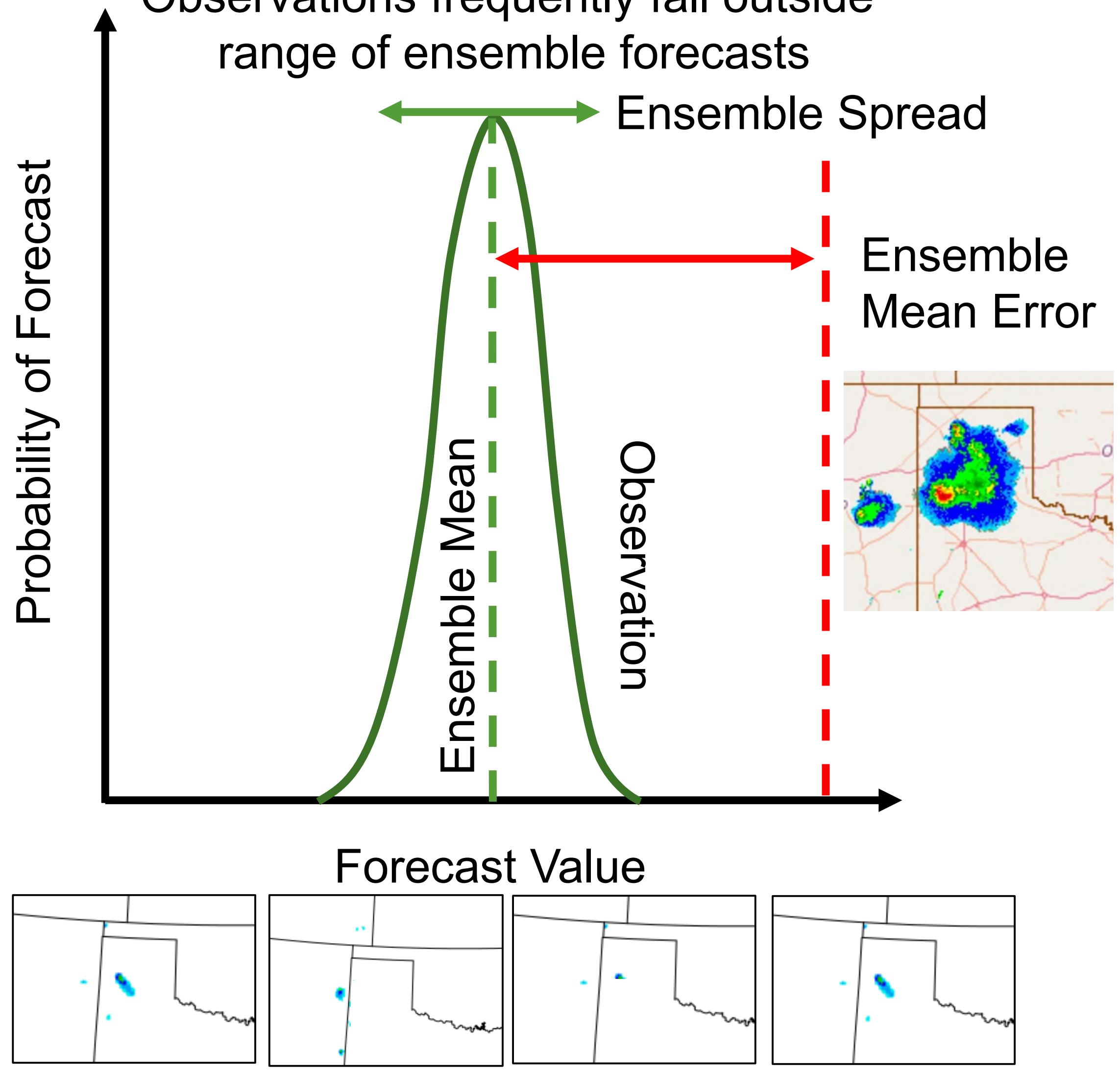
HRRRE and HREF 2019 QPF Evaluation



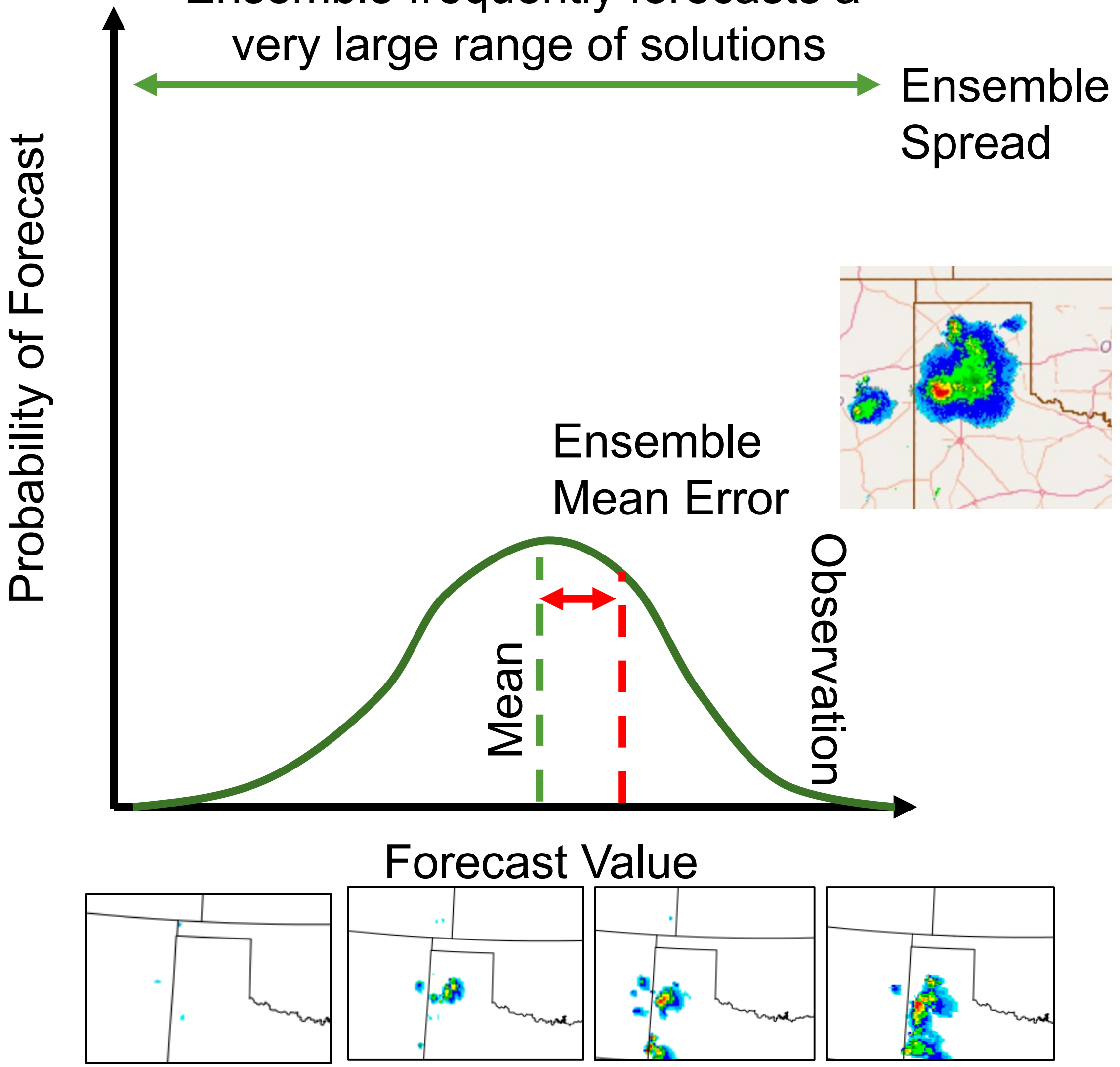
Courtesy of
Trevor Alcott
NOAA/GSL

Ensemble Forecast Challenge: Spread vs Error

Underdispersive:
Observations frequently fall outside range of ensemble forecasts

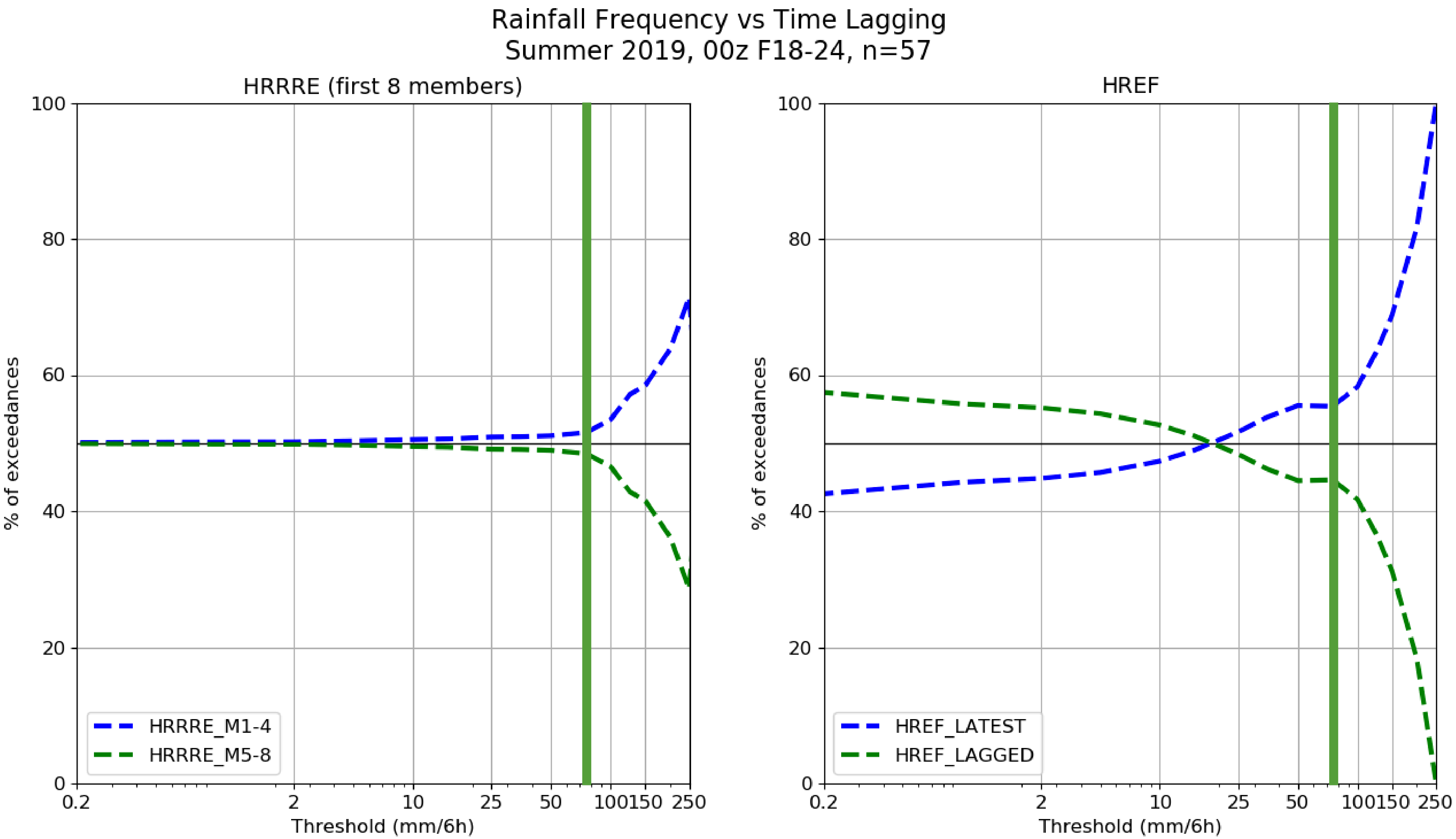


Overdispersive:
Ensemble frequently forecasts a very large range of solutions



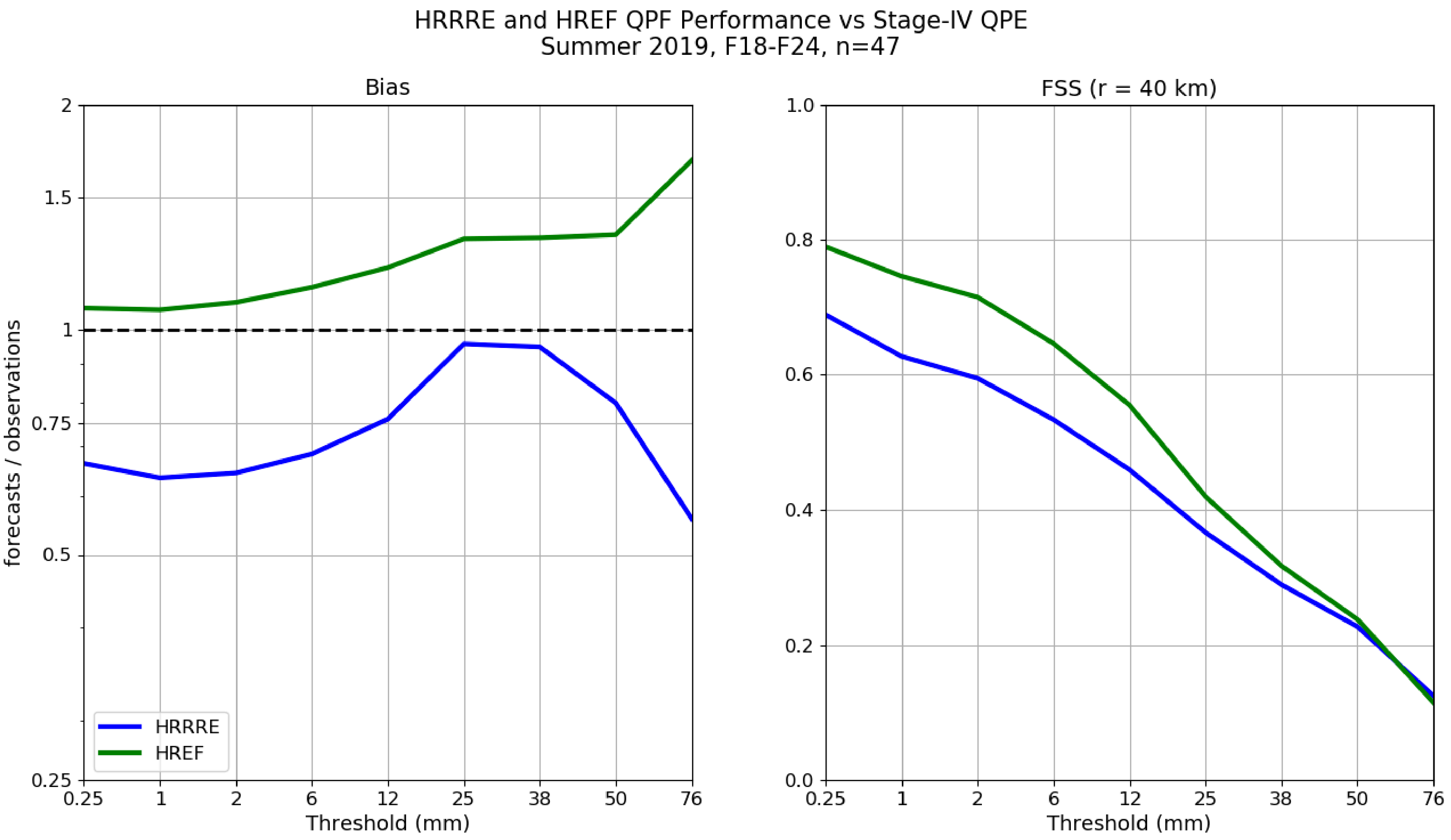
HRRRE and HREF 2019 QPF Evaluation

Courtesy of
Trevor Alcott
NOAA/GSL

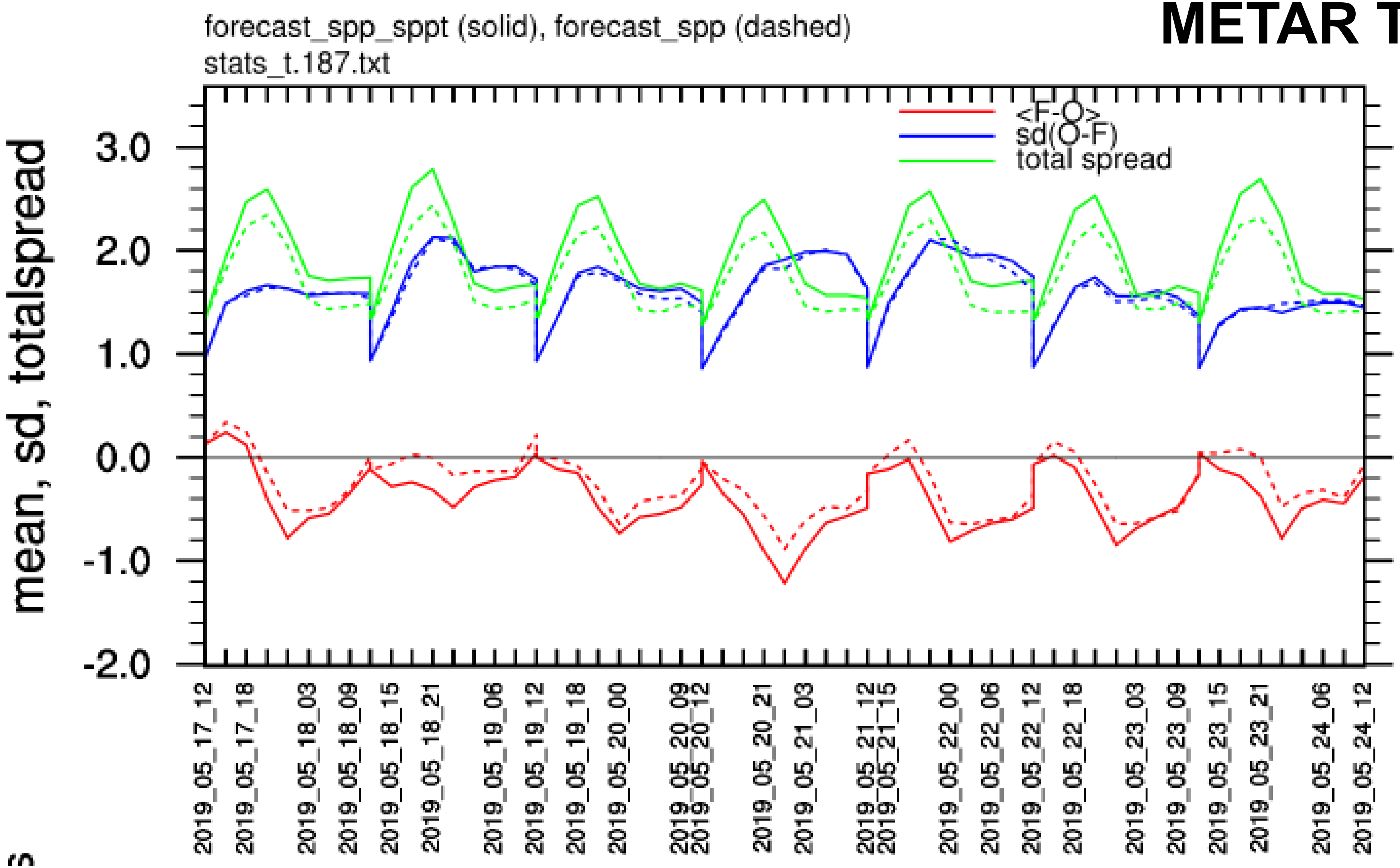


HRRRE and HREF 2019 QPF Evaluation

Courtesy of
Trevor Alcott
NOAA/GSL



METAR Temperature



SPP (dotted)

SPP + SPPT (solid)

Courtesy of
David Dowell
NOAA/GSL

7 forecasts (0-24 h)

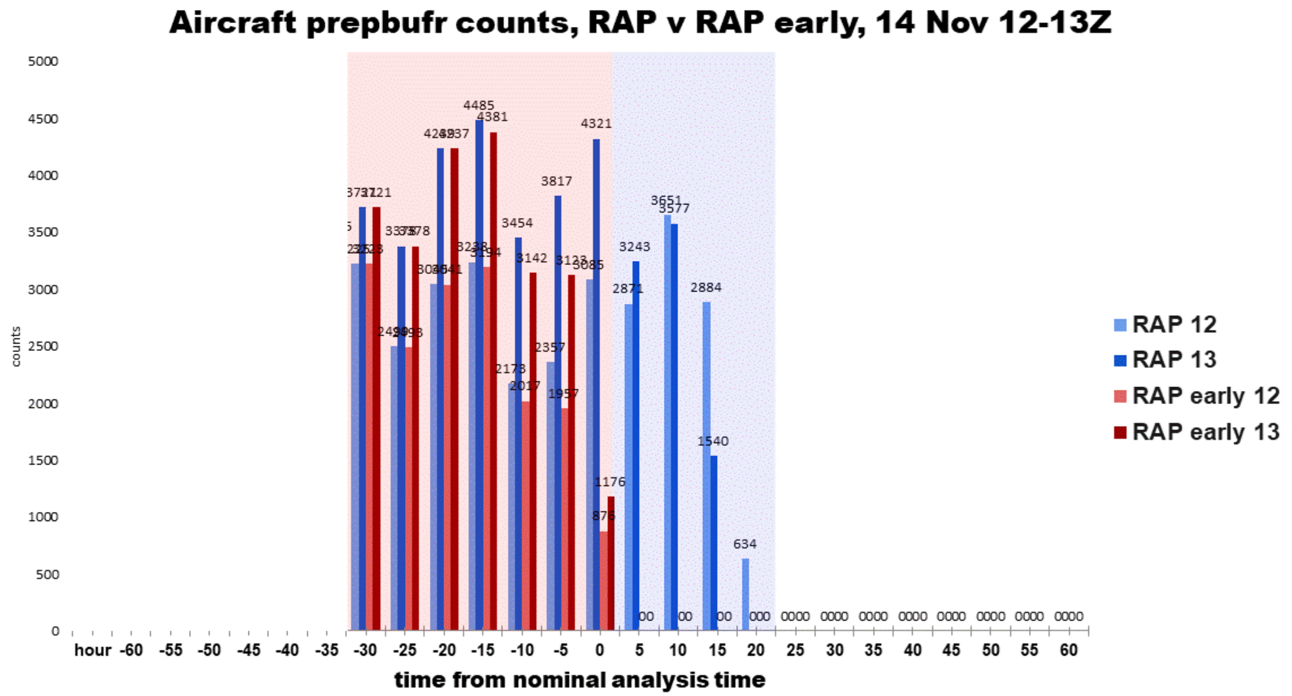


Fig. 1: Observation counts for aircraft as a function of 5 minutes observation time bins for the regular RAP observation files (blue, dump time at +26 mins.) and the early RAP observation files (red, dump time at +5 mins.) for 2 successive hours (12z and 14z, 13 November 2019).

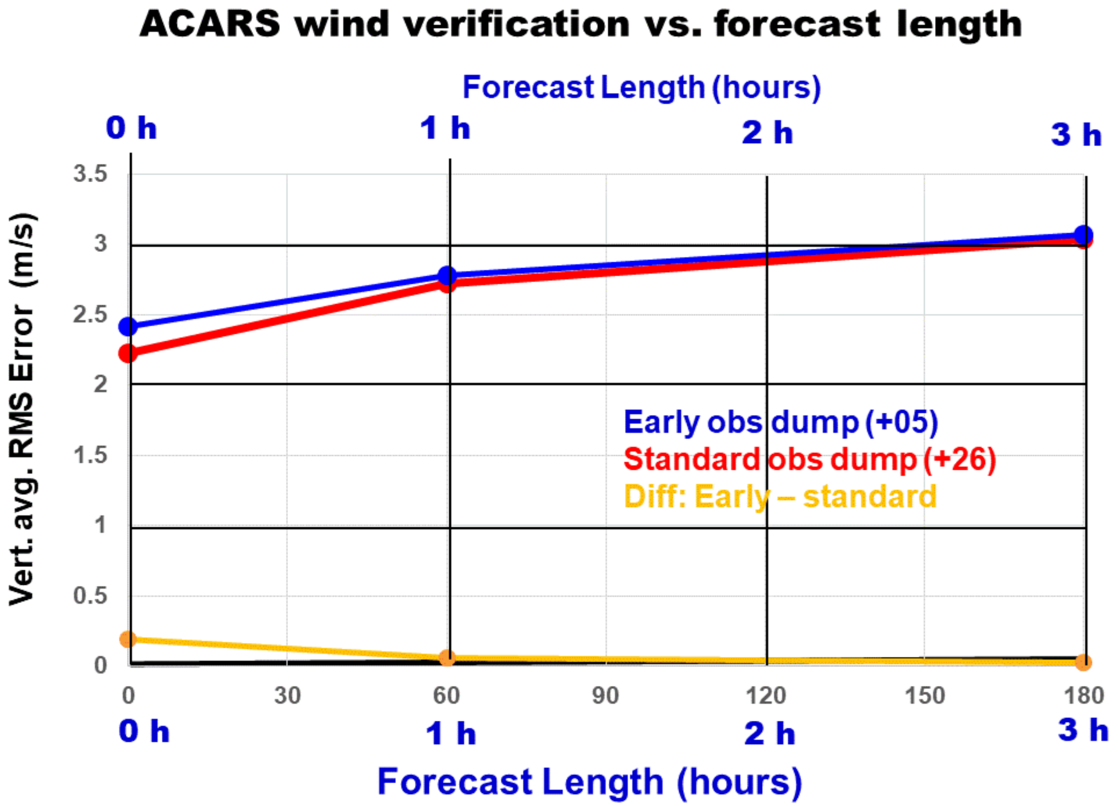


Fig. 2: Vertically averaged upper-air wind RMS errors (relative to ACARS data) for HRRR forecasts using the standard observation file dump (red curve, +26 mins.) vs. the early observation file dump (blue curve, +5 mins.) for the final analysis. Hourly forecasts from 4-16 November 2019 included in this comparison.

UFS Short Range Weather (SRW) Application Public Release

- **Stand-Alone Regional (SAR) FV3 Capability**
- **No Data Assimilation**
- **Extended Schmidt Gnomonic (ESG) Grid**
- **3-km, 12-km, 25-km configurations**
- **GFS/NAM/RAP/HRRR GRIB2 Initializations**
- **Physics Suites:**
  - **RRFS baseline (Thompson microphysics, MYNN turbulence and surface layer, Noah-MP land surface scheme, and RRTMG for longwave and shortwave radiation)**
  - **GFSv15**

28 August 2020: Code slush for preliminary pre-release testing
30 September 2020: Code freeze for final testing
16 October 2020: Documentation finalized
30 October 2020: Target release ready
2 November 2020: Announce release to public

https://cires-ufs.atlassian.net/wiki/spaces/CAMAT/overview
https://github.com/ufs-community/ufs-srweather-app
https://forums.ufscommunity.org/forum/short-range-weatherconvection-allowing-application

FV3-CAM Timeline → Rapid Refresh Forecast System

RAPv5/HRRRv4
Implementation
Freeze all non-FV3
CAM systems

CAM Development Continues
Demonstration FV3-CAM ensemble DA +
forecast system - evaluate against HREF.
Continue physics testing/advancement.

Development underway
standalone/regional, nesting,
DA, physics, etc.

HREFv3
Replace poorly performing
members with FV3-CAM if
justified via objective stats

RRFSv1
Implement RRFSv1
pending favorable
evaluation

Rapid Refresh Forecast System → To replace HREF, HRRR, NAM + nests, HiResWs

Timeline may be revised as development matures/progresses