FV3 LAM Testing

19 November 2020

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Content contributions from EMC, NSSL, SPC and WPC

NOAA/GLOBAL SYSTEMS LABORATORY

NOAA Model Operational Implementation Timeline to FY24

NPS Modeling System	Current Version	Q3 FY 20	Q4 FY 20	Q1 FY 21	Q2 FY 21	Q3FY21 - Q2FY22 MORATORIUM	Q3 FY 22	Q4 FY 22	Q1 FY 23	Q2 FY 23	Q3 FY 23	Q4 FY 23	Q1 FY 24	Q2 FY 24	Q3 FY 24	Q4 FY 24	UFS Application
Global Weather & Global Analysis	GFS/ GDASv15				GFSv16									GFSv17/ GEFSv13			UFS Medium Range & Sub-Seasonal
Global Waves	GWMv3																
Global Weather Ensembles	GEFSv11		GEFSv12														
Global Wave Ensembles	GWESv3																
Global Aerosols	NGAC v2																
Short-Range Regional Ensembles	SREFv7																
Global Ocean & Sea-Ice	RTOFSv1.2			RTOFSv2					RTOFSv3								UFS Marine & Cryosphere
Global Ocean Analysis	GODASv2								GODASv3								
Seasonal Climate	CDAS/CFSv2															SFSv1	UFS Seasonal
Regional Hurricane 1	HWRFv12		HWRFv13				HAFSv1				HAFSv2				HAFSv3		UFS Hurricane
Regional Hurricane 2	HMONv2	HMONv3															
Regional High Resolution CAM 1	HiRes Window v7			HIRESWv8						RRFSv1				RRFSv2			UFS Short-Range Regional HiRes CAM & Regional Air Quality
Regional High Resolution CAM 2	NAM nests/ Fire Wxv4																
Regional High Resolution CAM 3	RAPv4/ HRRRv3			RAPv5/ HRRRv4													
Regional HiRes CAM Ensemble	HREFv2			HREFv3													
Regional Mesoscale Weather	NAMv4																
Regional Air Quality	CMAQv5						CMAQv6										
Regional Surface Weather Analysis	RTMA/ URMA v2.7		RTMA/ URMA v2.8								3DRTMA/ URMAv3						
Atmospheric Transport & Dispersion	HySPLITv7						HySPLITv8								HySPLITv9		UFS Air Quality & Dispersion
Coastal & Regional Waves	NWPSv1.2			NWPS v1.3			NWPS v1.4						RWPSv1				UFS Coastal
Great Lakes	GLWUv3.4						GLWUv4								GLWUv5		UFS Lakes
Regional Hydrology	NWMv2			NWMv3							NWMv4						UFS Hydrology
Space Weather 1	WAM/IPEv1															WAMv2	UFS Space Weather
Space Weather 2	ENLILv1																

Unified Forecast System (UFS) Applications

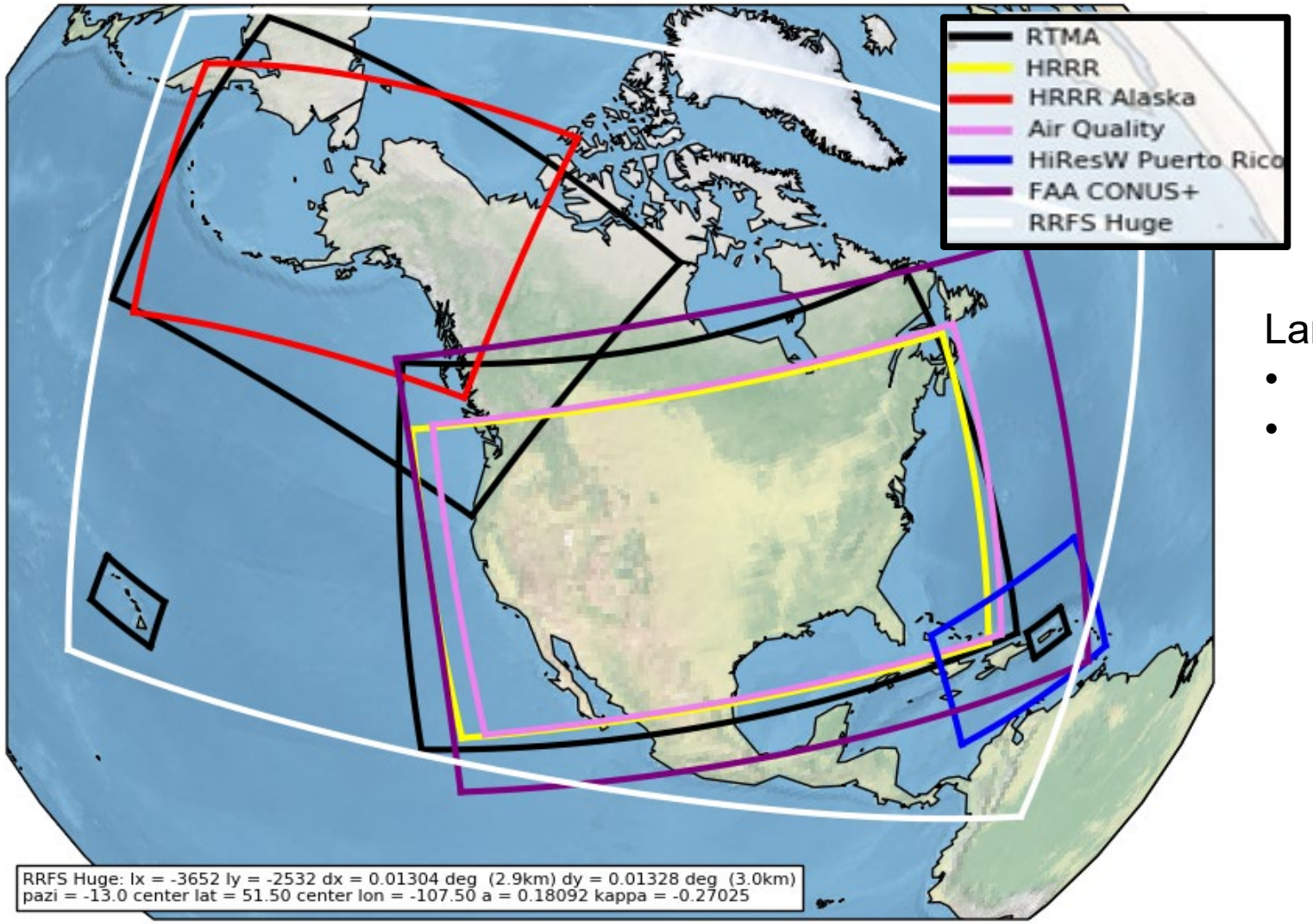
Global Systems
~10-13 km grid spacings

Regional Systems
~1-3 km grid spacings

Rapid Refresh Forecast System (RRFS)

- Consolidation of regional models NAM/RAP/HRRR/HREF
- Carry forward data assimilation and physics research and development

RRFS Domain Development



Current Generation: HRRR domain (yellow)
Next Generation: RRFS draft domain (white)

Larger 3-km domain of coverage

- More observation-sparse oceanic regions
- More reliance upon satellite observations

RRFS Domain Development

Experimental Real-Time Integration/Output:

CONUS: 3-km, 1800x1060 (approx), 65 levels, 20 mb top (1,908,000 grid cells)
Alaska: 3-km, 1440x1080 (approx), 65 levels, 20 mb top (1,555,200 grid cells)
NA: 13-km, 953x834 (approx), 65 levels, 15 mb top (794,802 grid cells)

Operational Candidate:

North America (NA): 3-km, 3000x3000 (approx), 65 levels (minimum), 2 mb top
Approximately 9,172,000 grid cells compared to 3,538,944 grid cells in GFS (2.5X more)

RRFS Design Options:

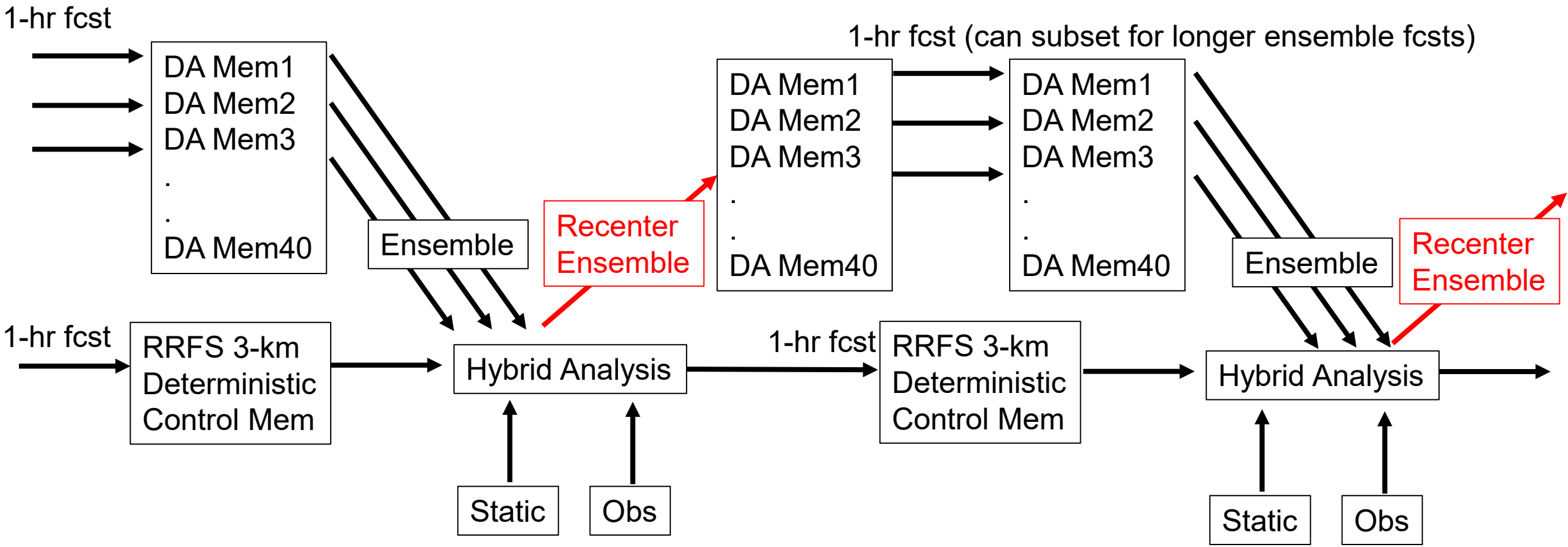
(1) 13-km (ish) GFS and 3-km RRFS NA domains

- GFS would supply lateral boundary and partial cycled initial conditions directly to RRFS
- Eliminates the complexity and resources of a three-tiered model system (global, meso regional, CAM)
- Requires more accurate meso environment from GFS through data assimilation and physics improvements
- Scale-separation with data assimilation may still be needed along with “cleaner” LBC perturbation method

(2) 13-km (ish) GFS and 13-km and 3-km RRFS NA domains

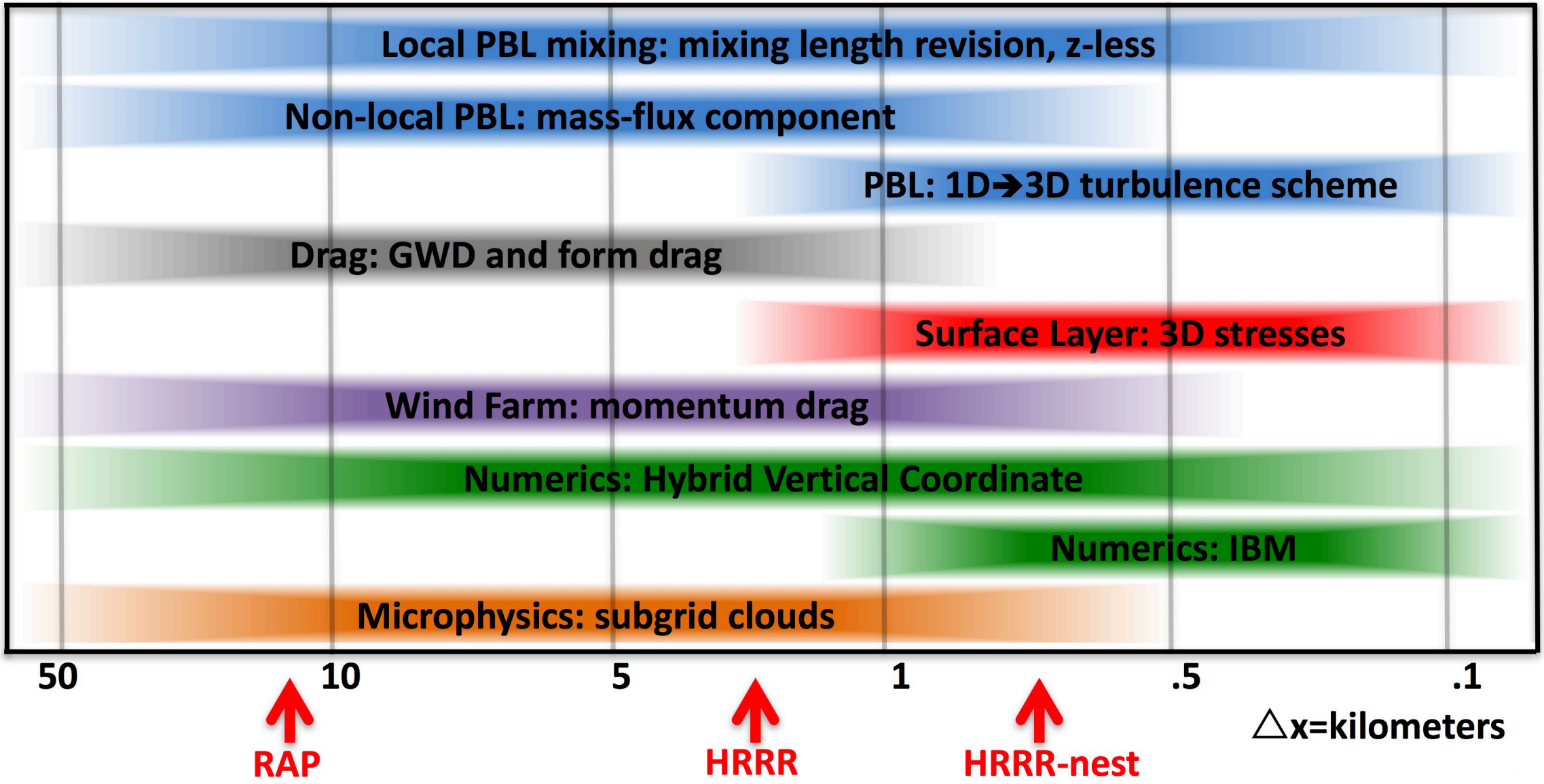
- 12-km RRFS would supply lateral boundary and partial cycled initial conditions directly to RRFS
- Retains the complexity and resources of a three-tiered model system (global, meso regional, CAM)
- Provides intervening layer for meso environment limiting the impact of GFS inputs

RRFS Design Development



- Two-way coupled deterministic and ensemble forecast system
- Deterministic analysis benefits from ensemble “flow-dependent” covariance information
- Ensemble benefits from hybrid analysis through recentering of ensemble mean

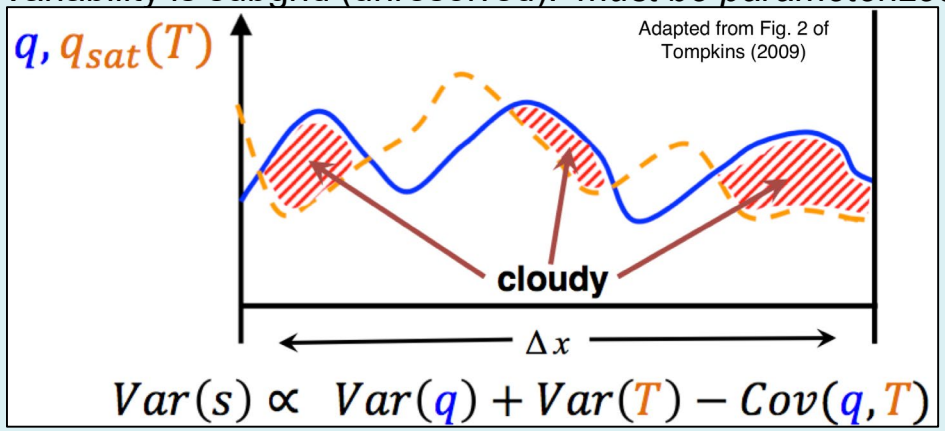
CAM Physics Development: Estimated Scales of Impact

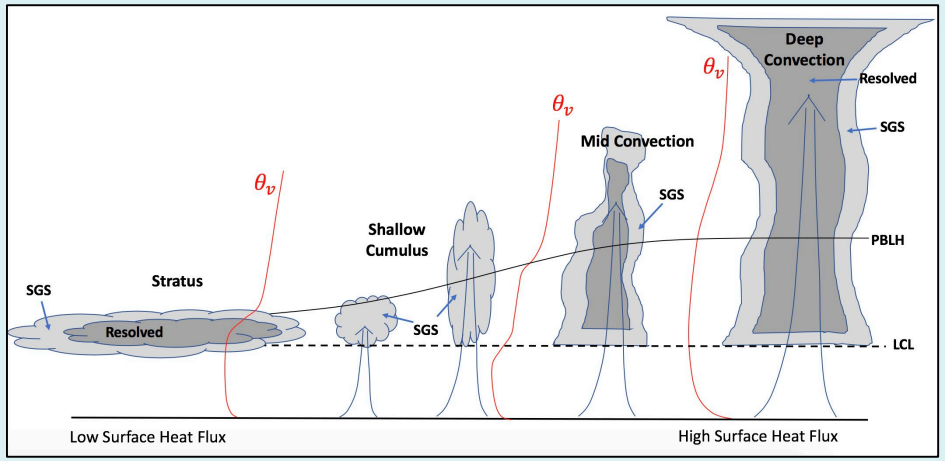


Improved Subgrid-Scale Cloud Representation

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*





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)

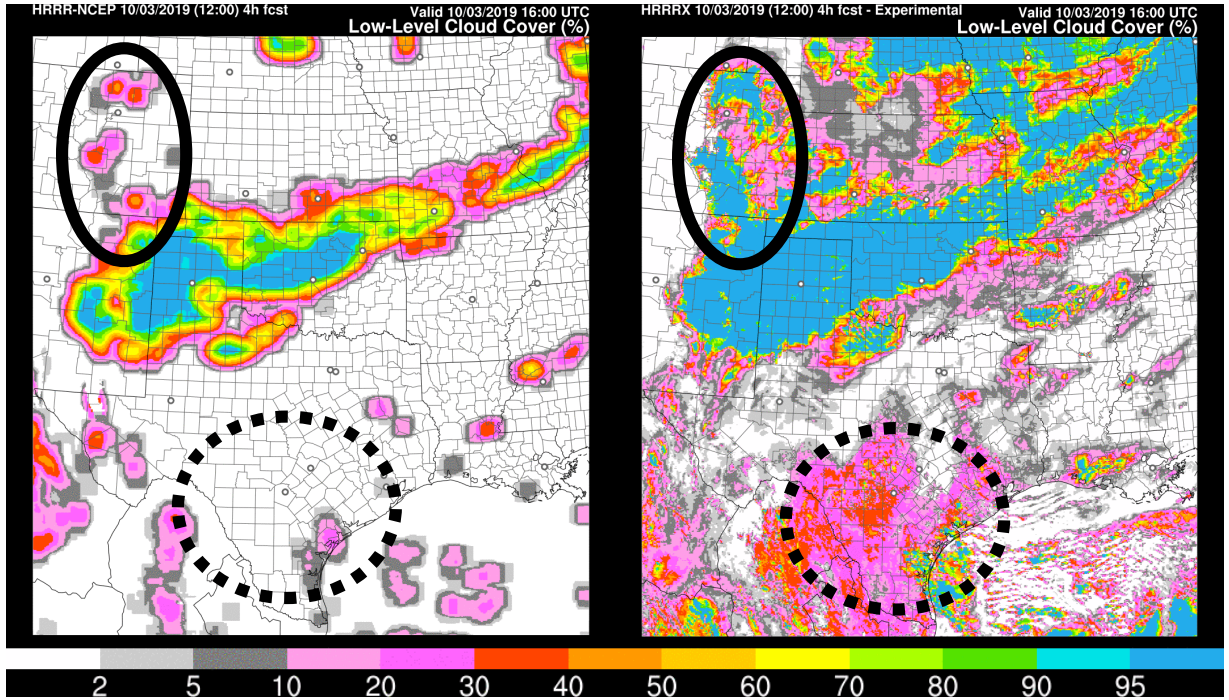
From binary to continuous cloud fraction – next DA step

4-h HRRR Forecast
Init: 1200 UTC 3 Oct 2019
Valid: 1600 UTC 3 Oct 2019

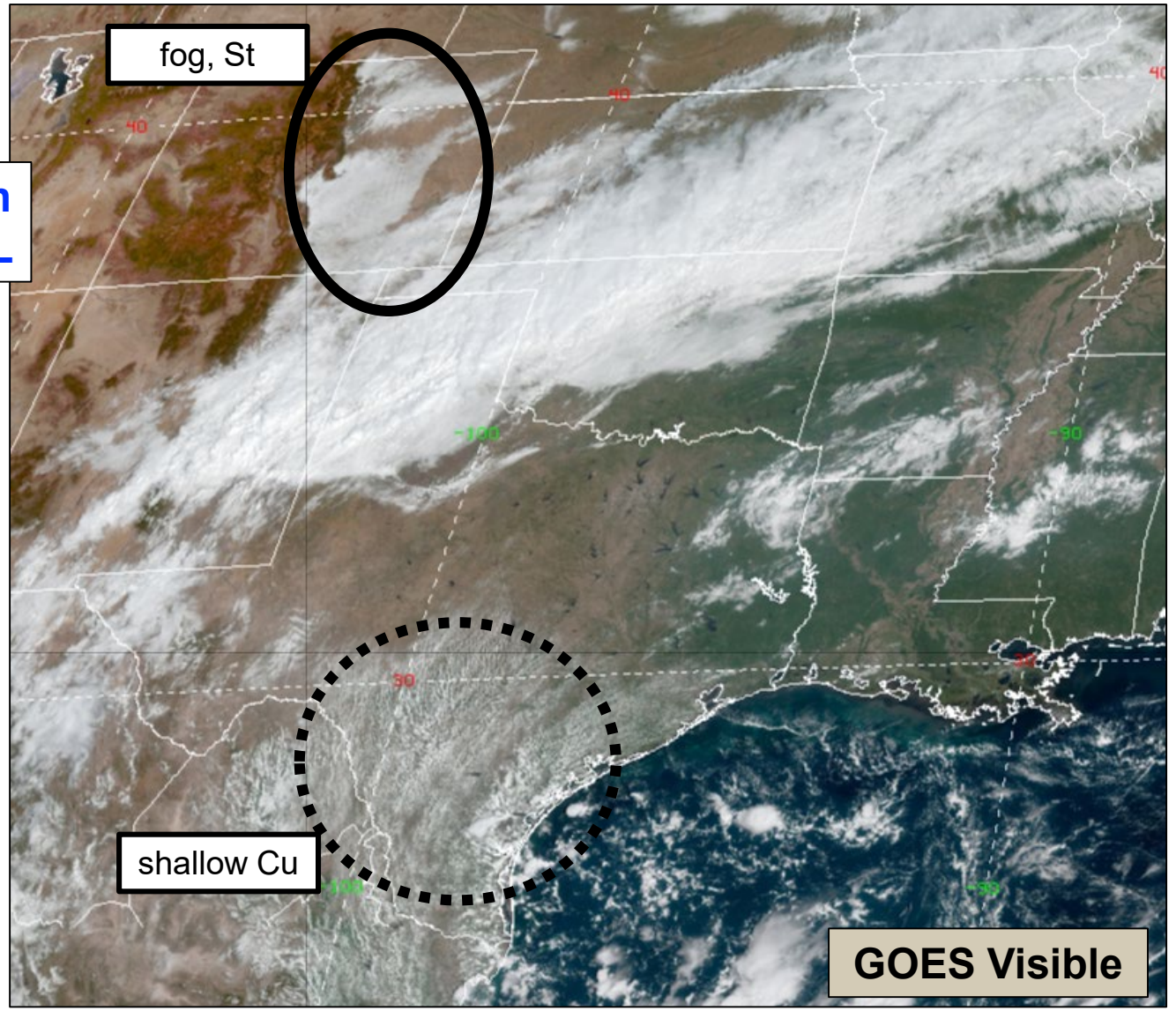
Low-Level Cloud Cover (%)

Old method – smoothed explicit (qc/qi>0) cloud

New method – quasi-progn cloud fraction – MYNN PBL



HRRR cloud-etage definitions:
low: below 642 hPa (~12 kft MSL)

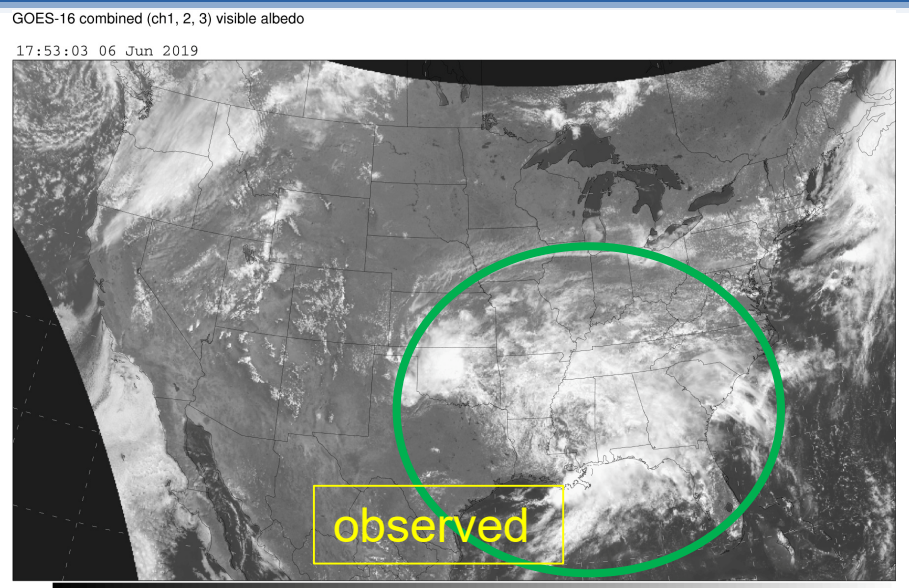


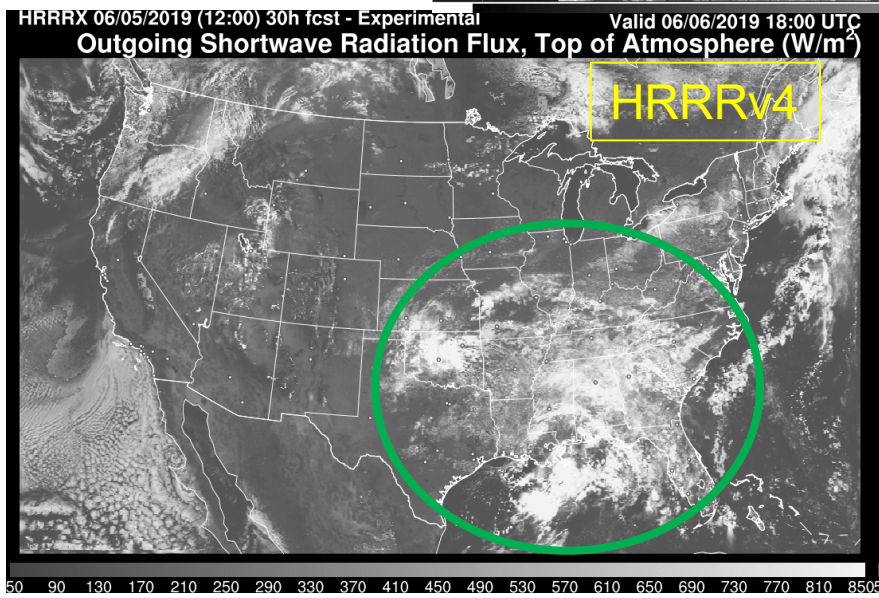
From binary to continuous cloud fraction – next DA step

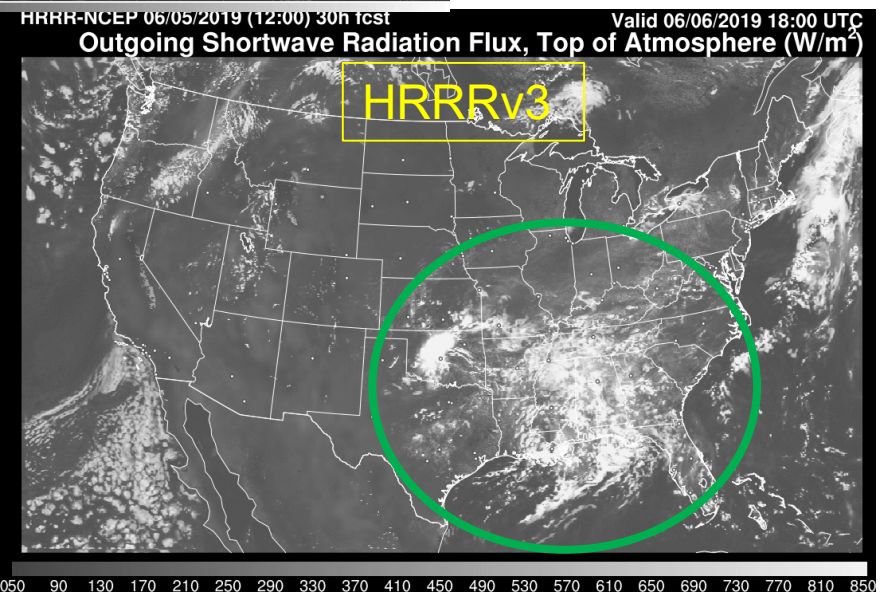
Comparison of SW-up at top of atmosphere

18 UTC 06 June 2019

Initialized 12 UTC 05 June
Fcst hr 30:

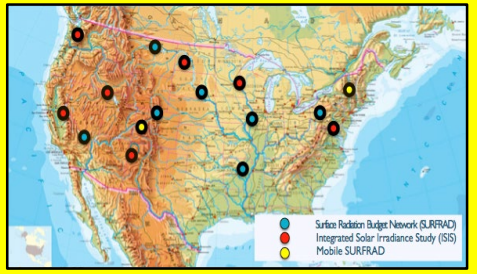




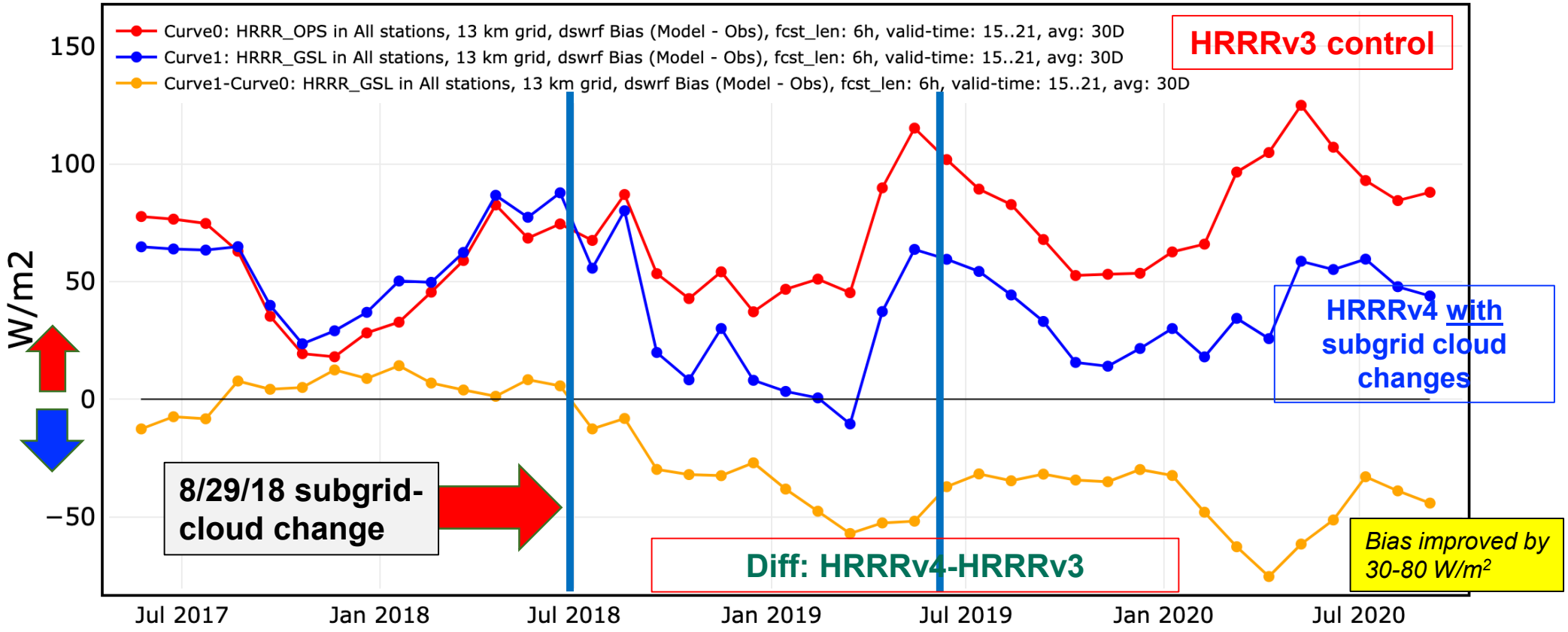


Improved short wave radiation forecasts

3km HRRR model – 6h forecast
Downward shortwave radiation **bias** vs.
NOAA SURFRAD radiation network. (daytime 15z-21z)



Experimental HRRR worse / better



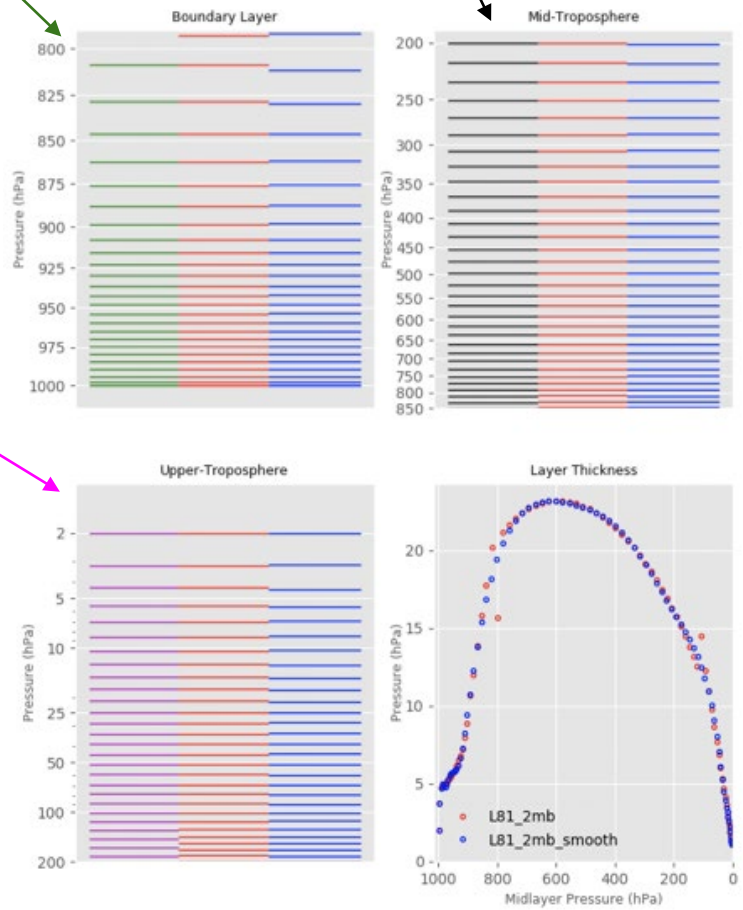
Prototyping Grid Configurations for 12-km/3-km FV3 LAM DA

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

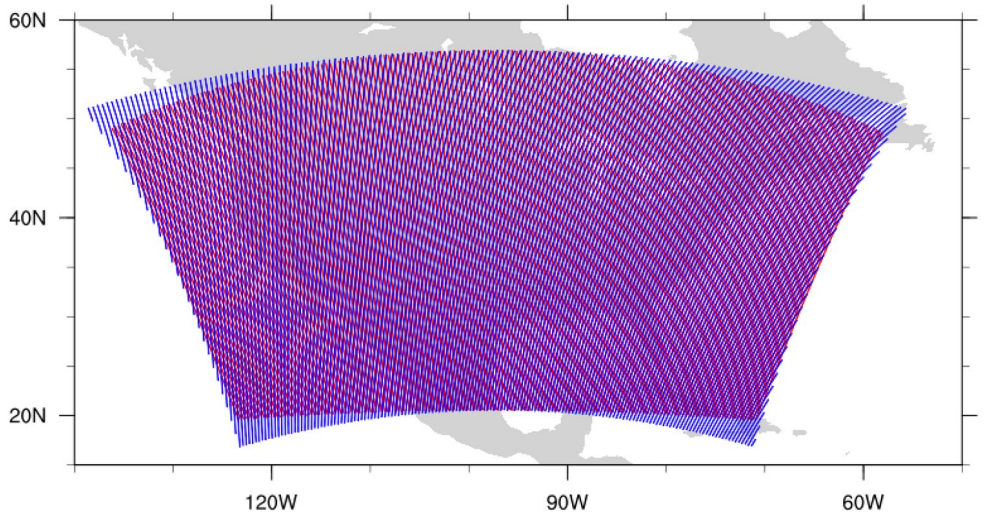
NAM

HRRR

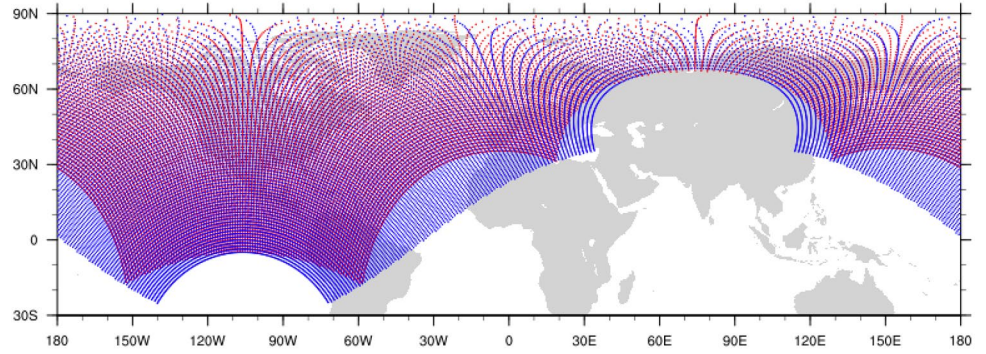
GFS



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



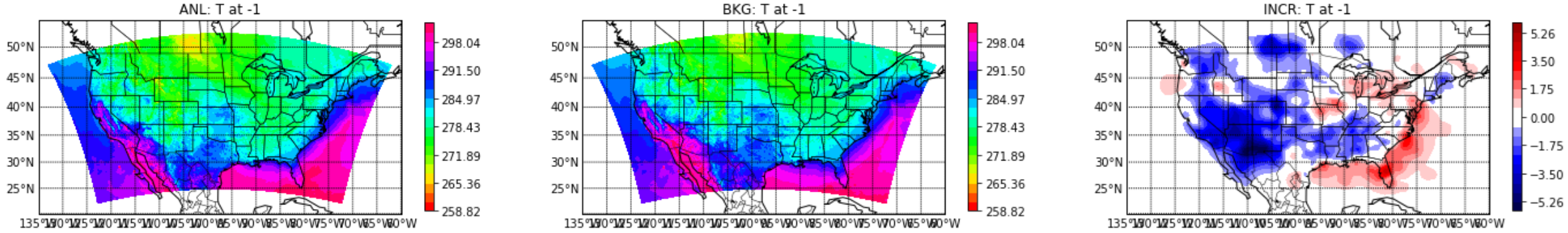
12-km FV3 LAM Forecast Grid
12-km GSI Analysis Grid



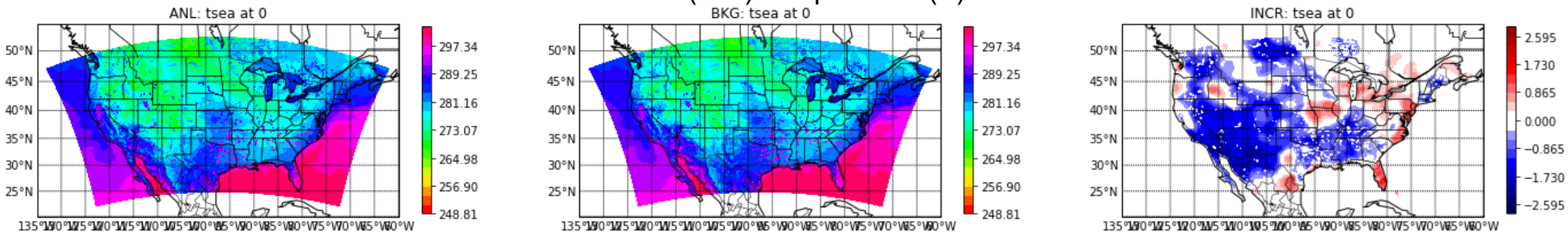
Interfacing Data Assimilation with the FV3 LAM

Analysis | Background | Difference

Lowest Atmospheric Level Temperature (K)



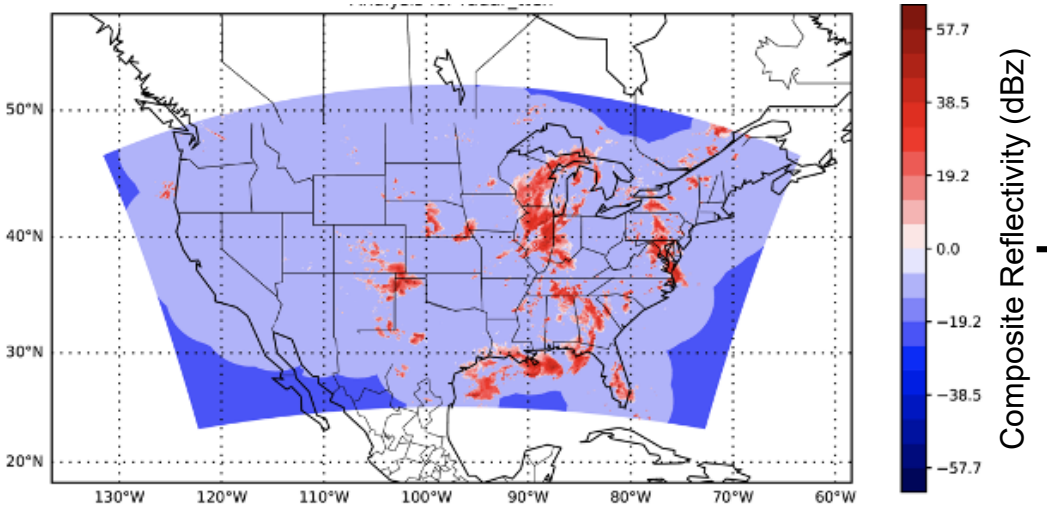
Skin (Soil) Temperature (K)



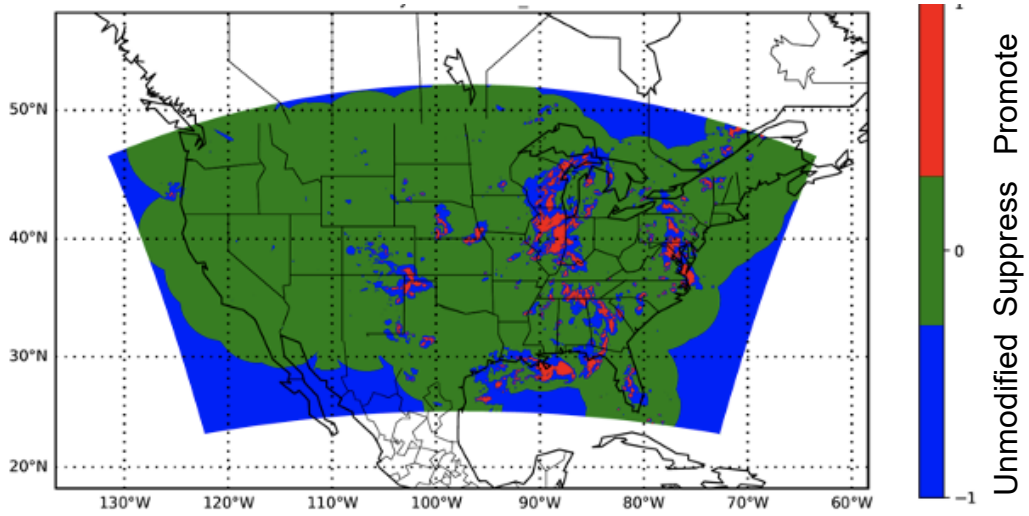
Soil temperature adjustments (lower right) in FV3 LAM derived from atmospheric analysis increments (upper right) through GSI

GSL: Testing of Latent Heat Forcing in the FV3 LAM

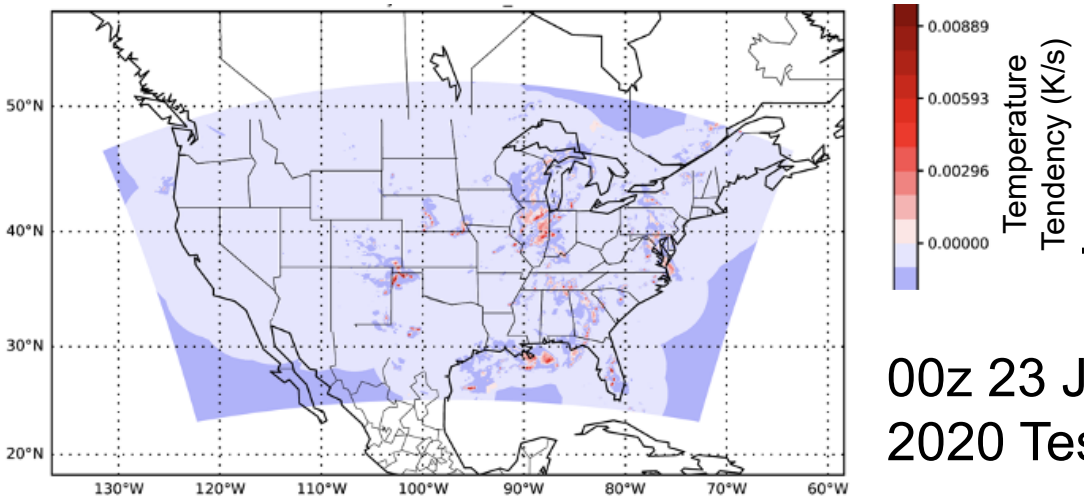
Observed MRMS Reflectivity Interpolated to FV3 LAM Analysis Grid



Reflectivity Transformed to Convective Promotion/Suppression Map

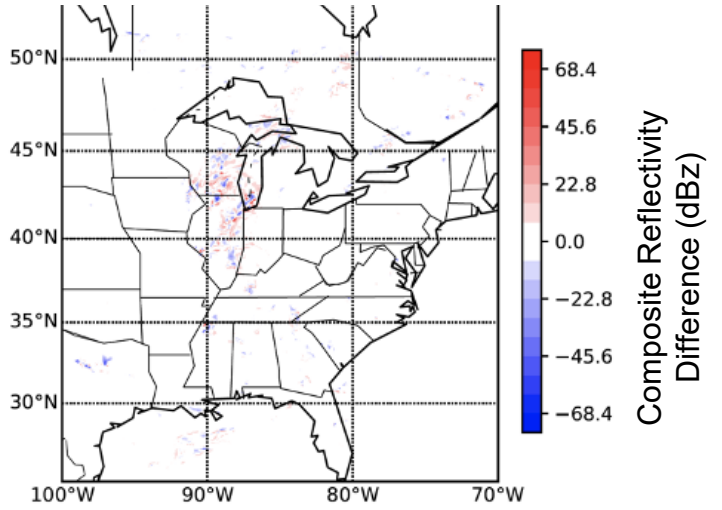


Column Maximum Temperature Tendency in FV3 LAM Analysis Grid



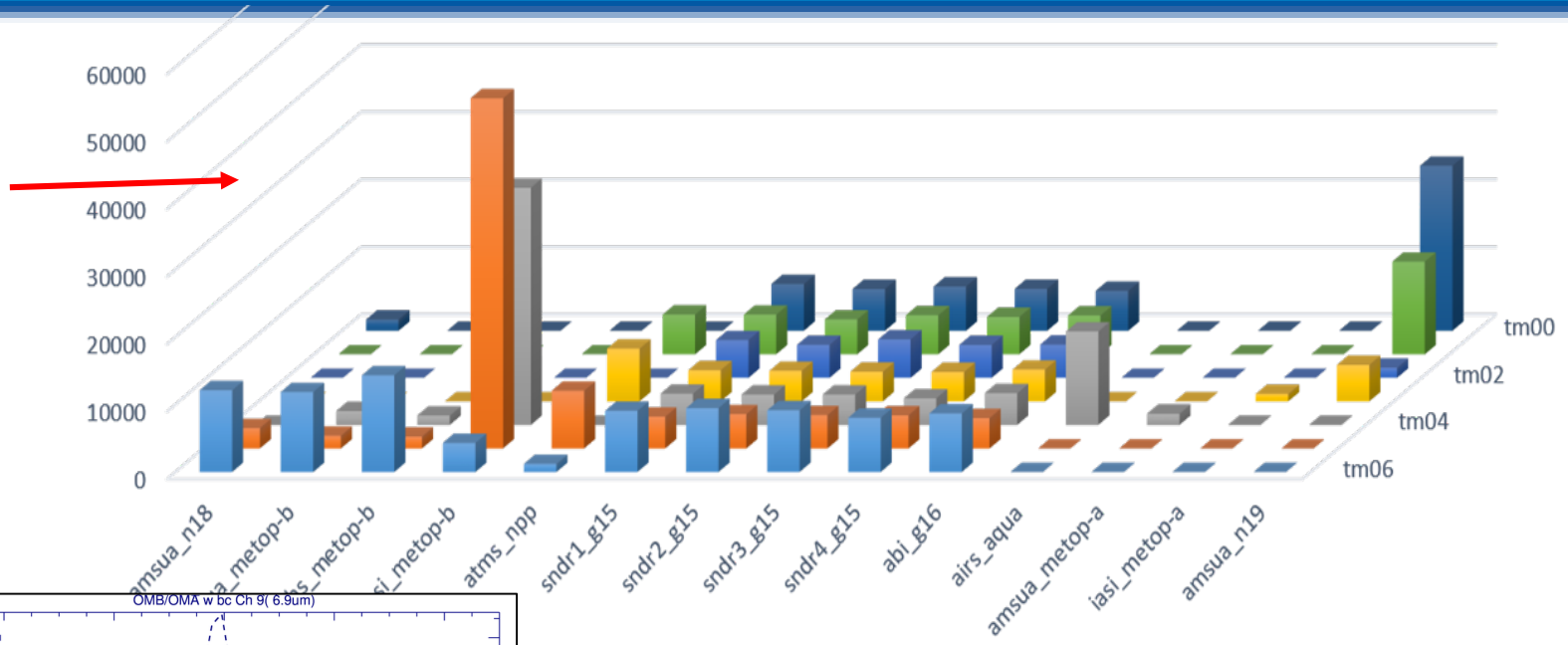
00z 23 June 2020 Test Case

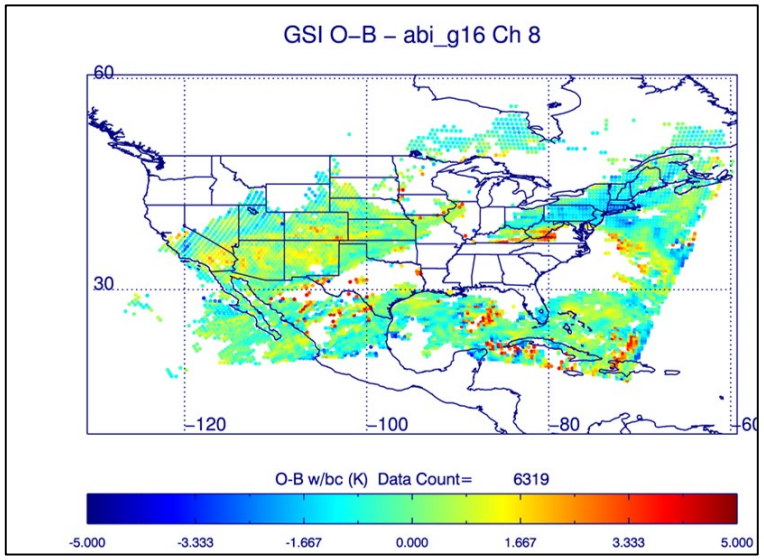
1-hr Forecast Difference (With Minus Without Temperature Tendency Specifications)



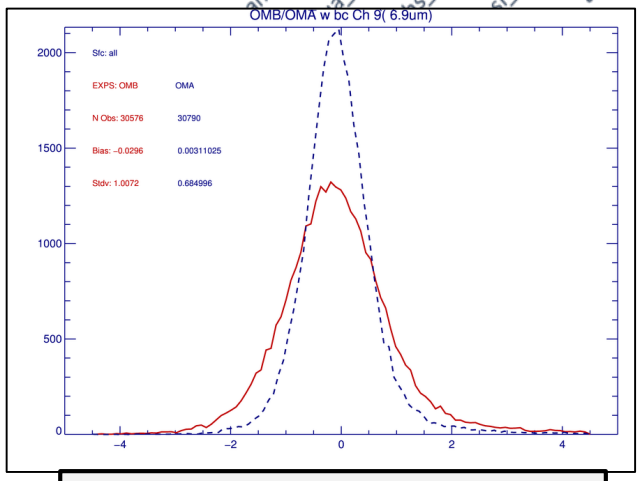
EMC: Ongoing Radiance DA Development

- *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

tm06 tm05 tm04 tm03 tm02 tm01 tm00

Coldstart from GFS

60 hr 3 km forecast

6 hour forecast at 3 km

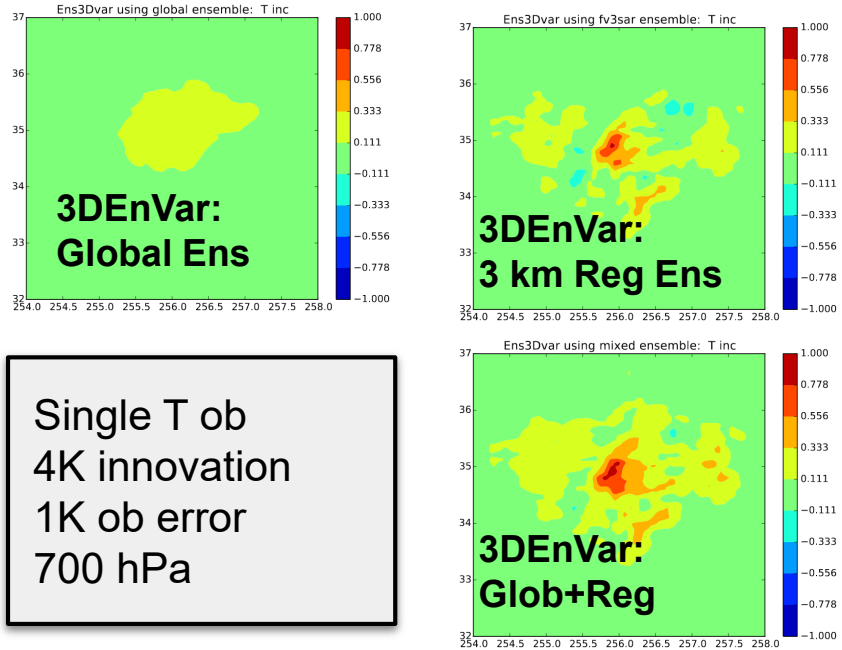
Hourly hybrid 3DEnVar assimilation

- Using global EnKF members

*Material courtesy of X. Zhang

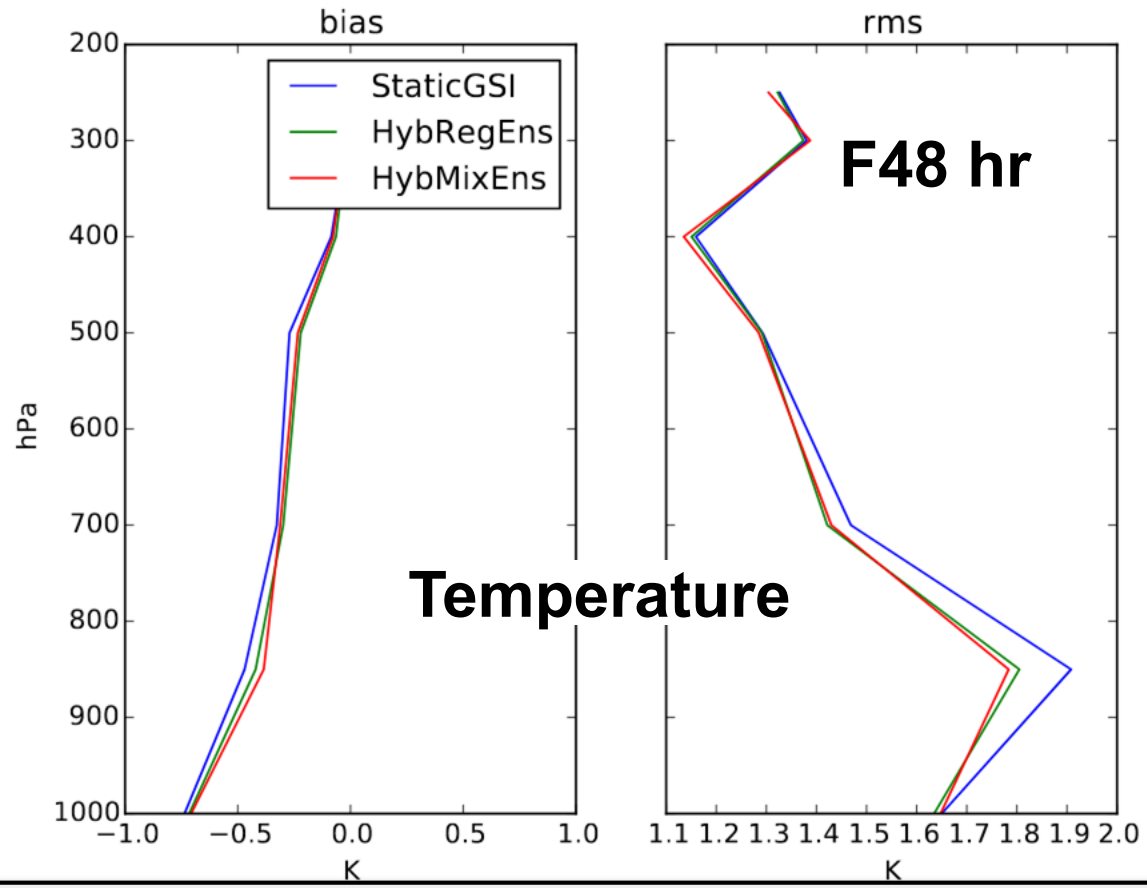
EMC: RRFS DA Algorithm Development

- 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



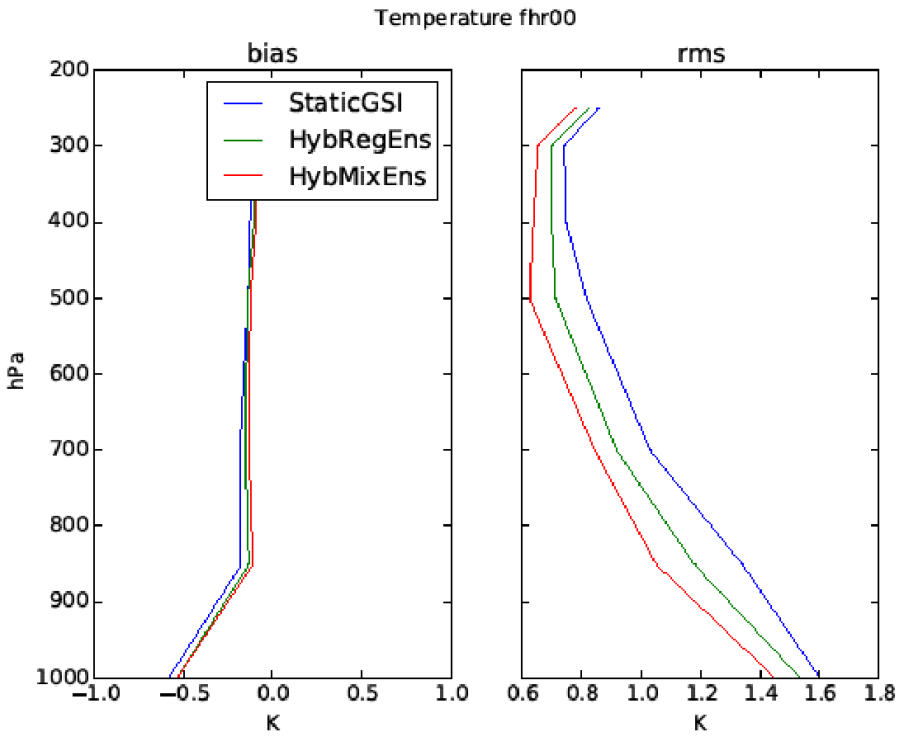
StaticGSI: 3DVar

*Hyb uses 0.25 static **B***

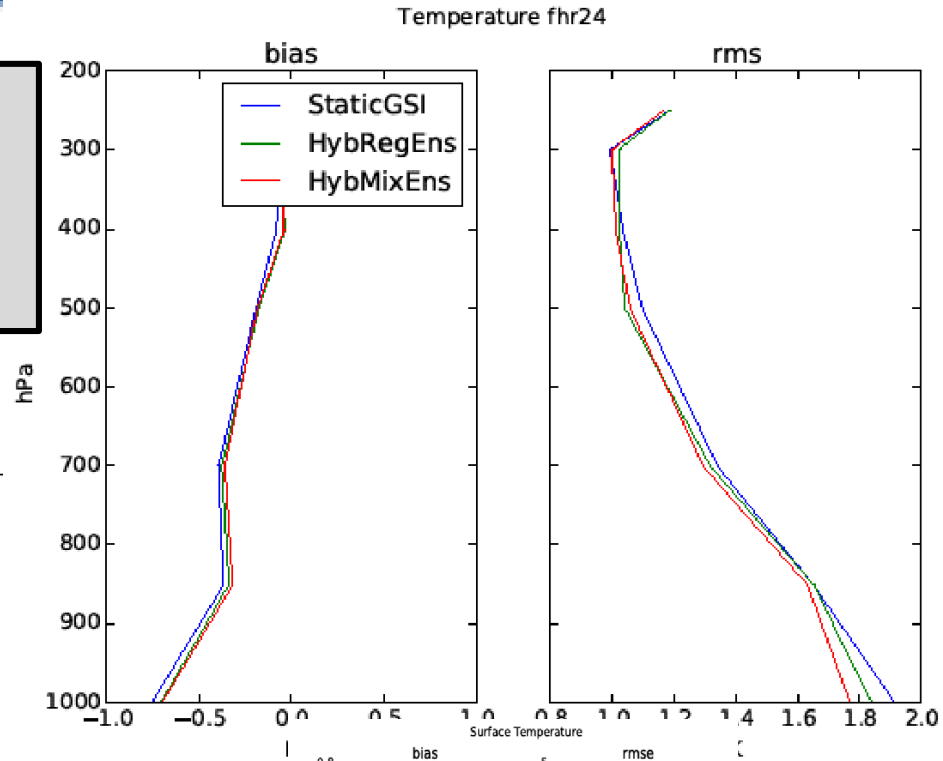
HybRegEns: 20, 3-km members

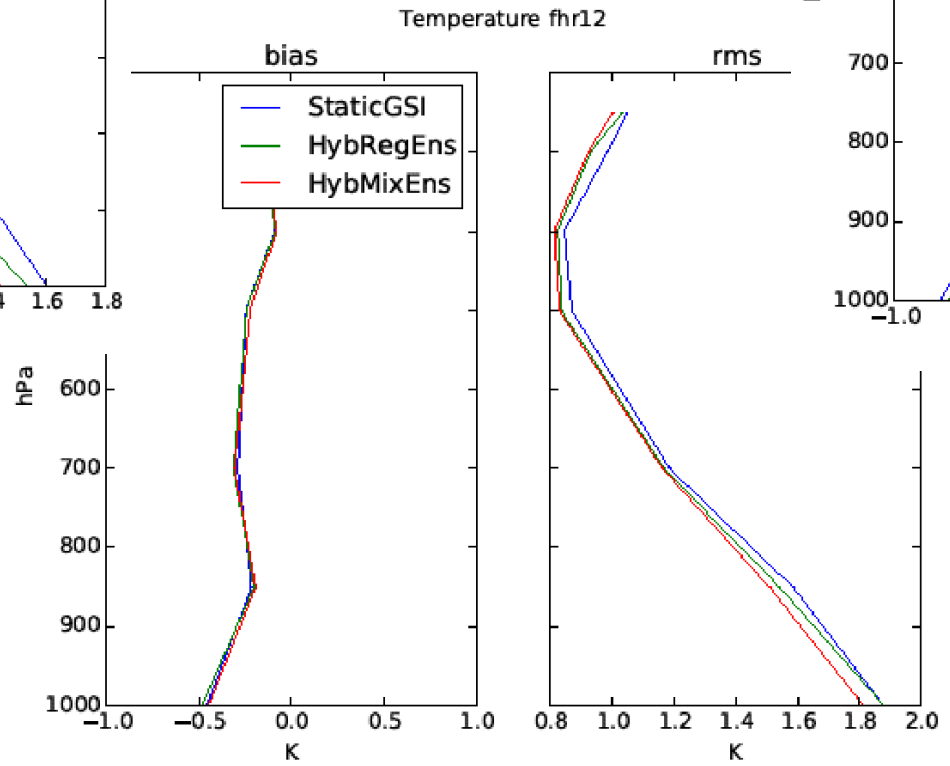
HybMixEns: 20, 3-km members + 80 global members

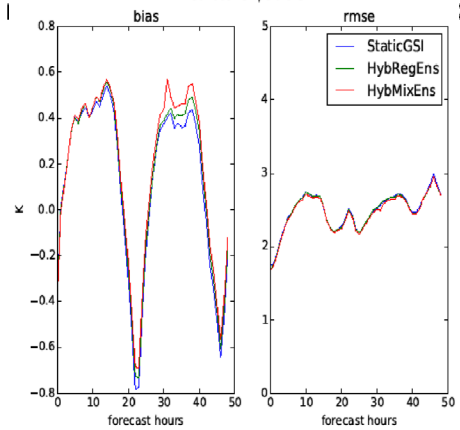
EMC: Ongoing Radiance DA Development



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);

FV3 LAM 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

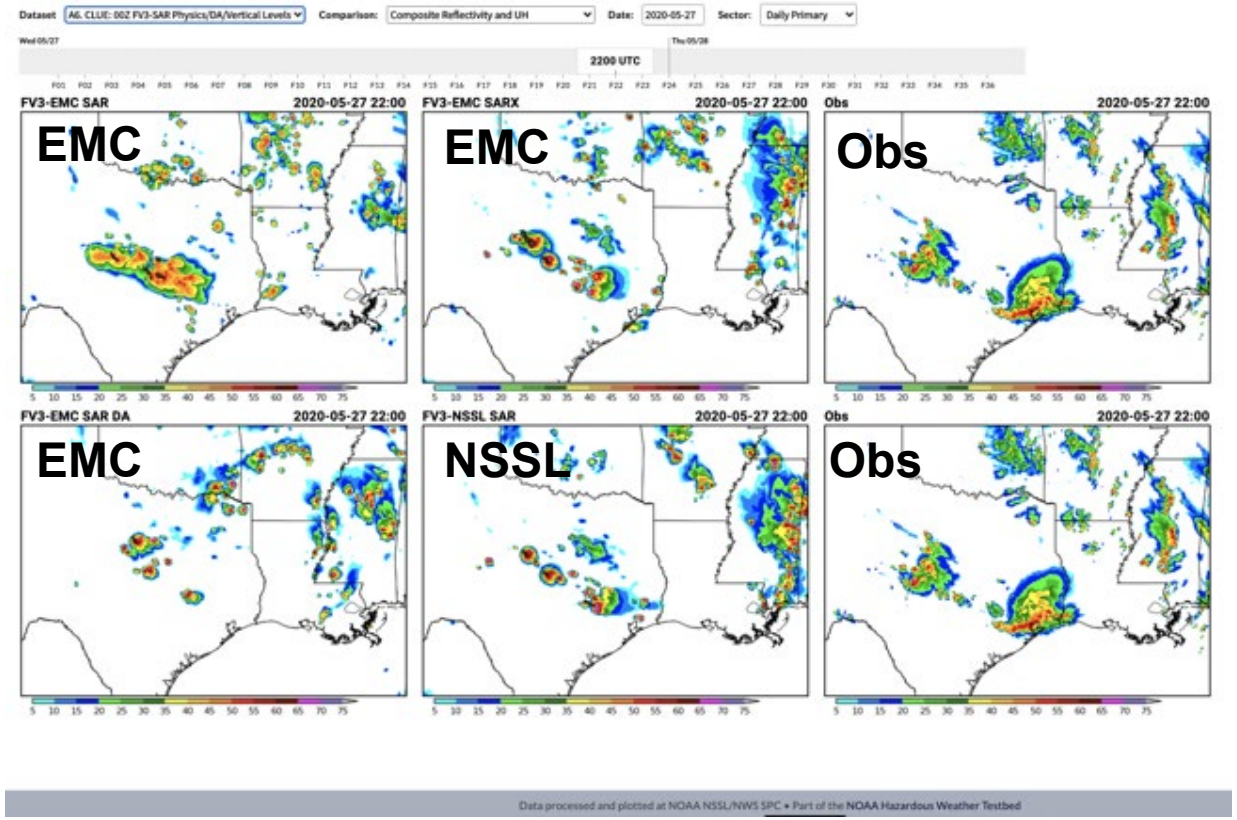
Members: emc-fv3sar	ICs	LBCs	Microphysics	PBL	LSM	Radiation	Model
emc-fv3sar	GFSv15	GFSv15f	GFDL	EDMF	NOAH	RRTMG	FV3
emc-fv3sarX	GFSv15	GFSv15f	Thompson	MYNN	NOAH	RRTMG	FV3
emc-fv3sarDA	GFSv15	GFSv15f	Thompson	MYNN	NOAH	RRTMG	FV3

NSSL

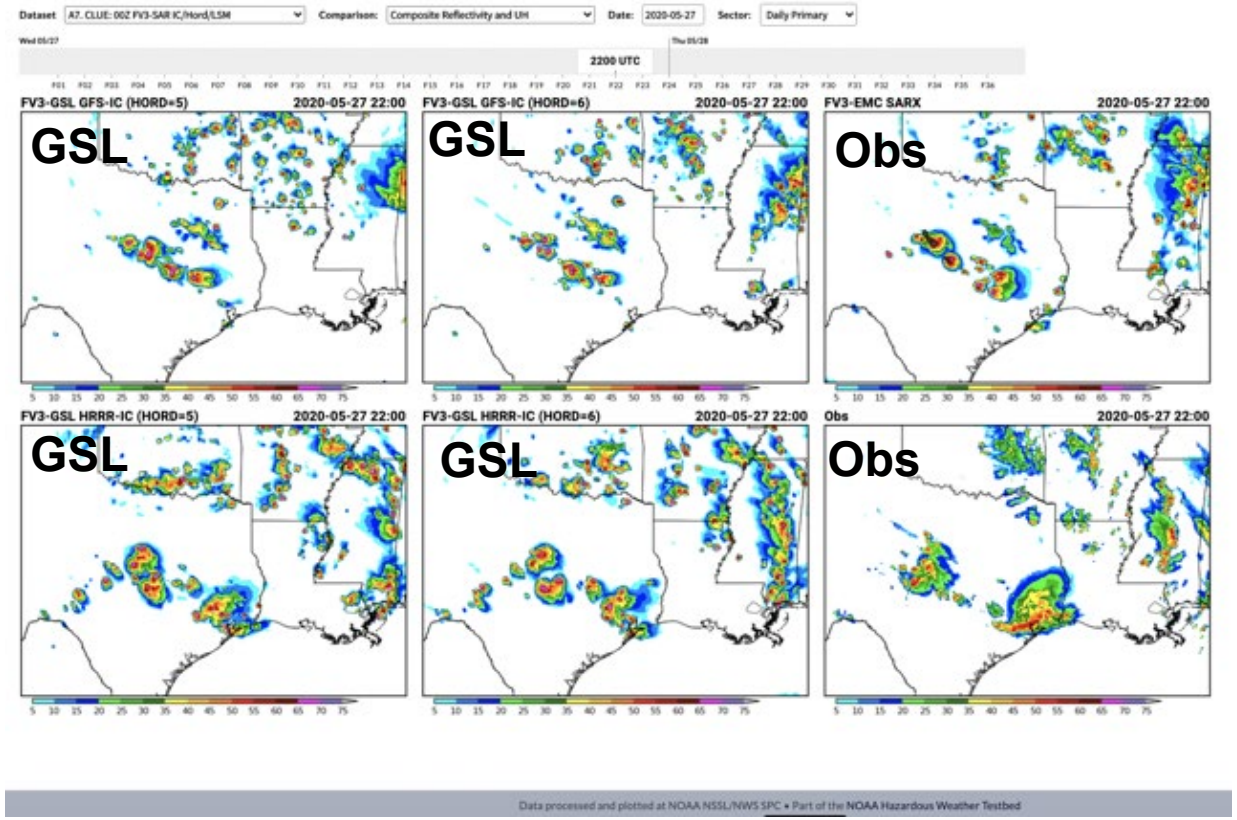
Members: nssl-glm	ICs	LBCs	Microphysics	PBL	LSM	Radiation	Model
sarfv3-ICs01	GFS	GFSf	Thompson	MYNN	NOAH	RRTMG	FV3
sarfv3-ICs02	UM	UMf	Thompson	MYNN	NOAH	RRTMG	FV3

EMC, GSL, NSSL: Real-Time Demonstration of FV3 LAM in SPC/NSSL Hazardous Weather Testbed

FV3 LAM 22hr Forecasts of Composite Reflectivity from 00z 27 May 2020
Valid 22z 27 May 2020 (obs in right columns)

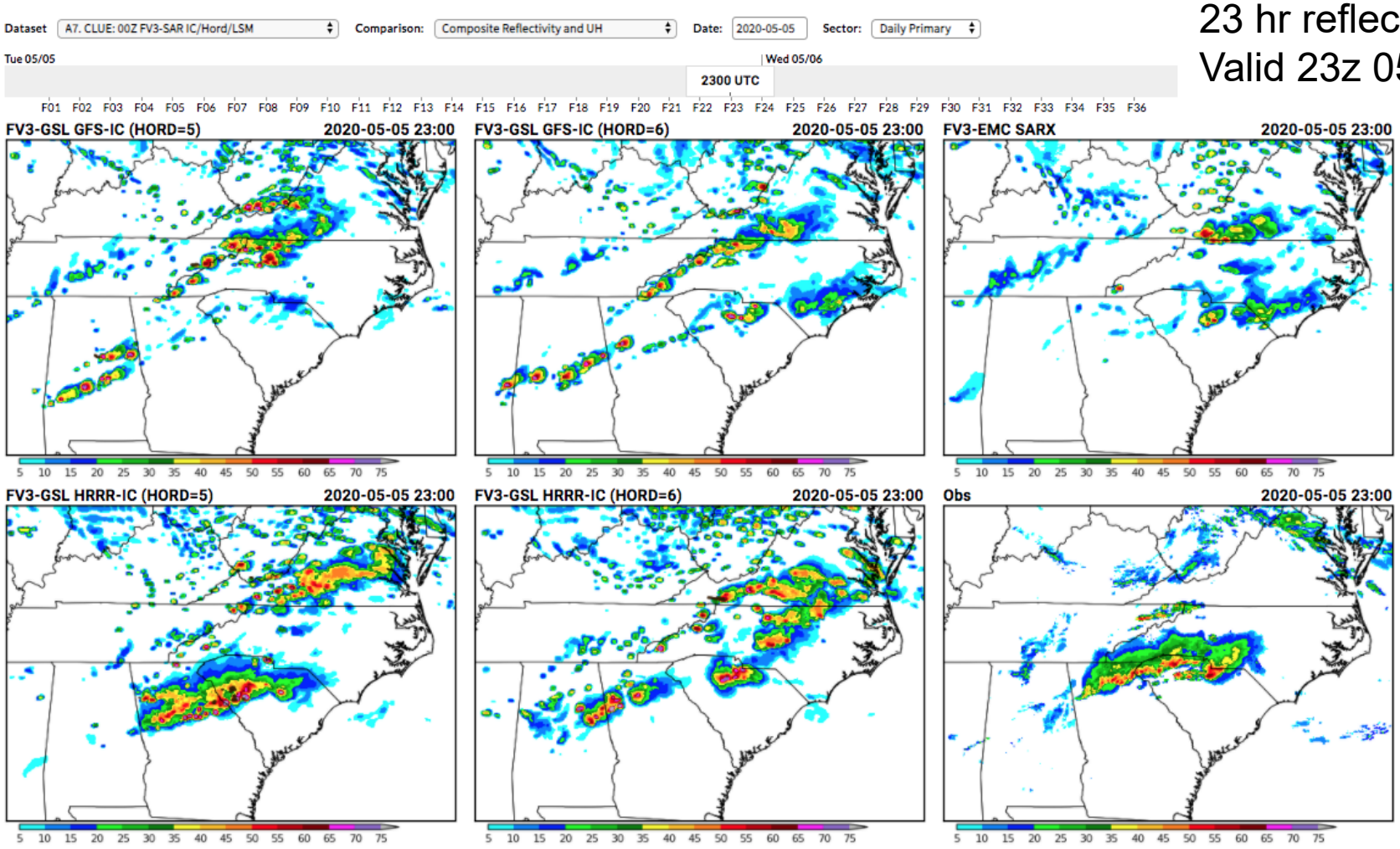


EMC and NSSL demonstrating FV3 LAM forecast sensitivity to differences in physics and use of data assimilation



GSL demonstrating FV3 LAM forecast sensitivity to differences in initial/boundary conditions and use of different horizontal advection options

Regional FV3 Testing in SPC/NSSL HWT SFE



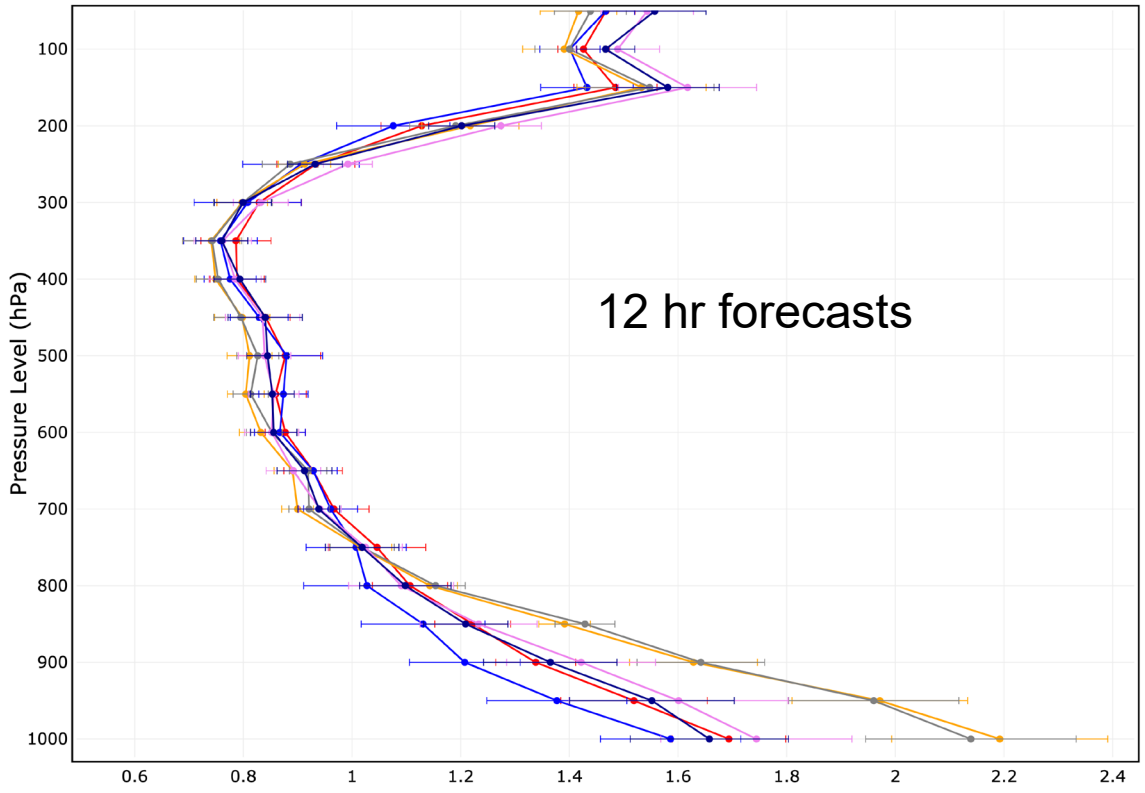
23 hr reflectivity forecasts
Valid 23z 05 May 2020

"Hord 5" dynamics suite options seem to produce improved storm-structure, but results very preliminary and sample size is small

Initial conditions appear to have the largest influence

Graphics courtesy of NSSL/SPC

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

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

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

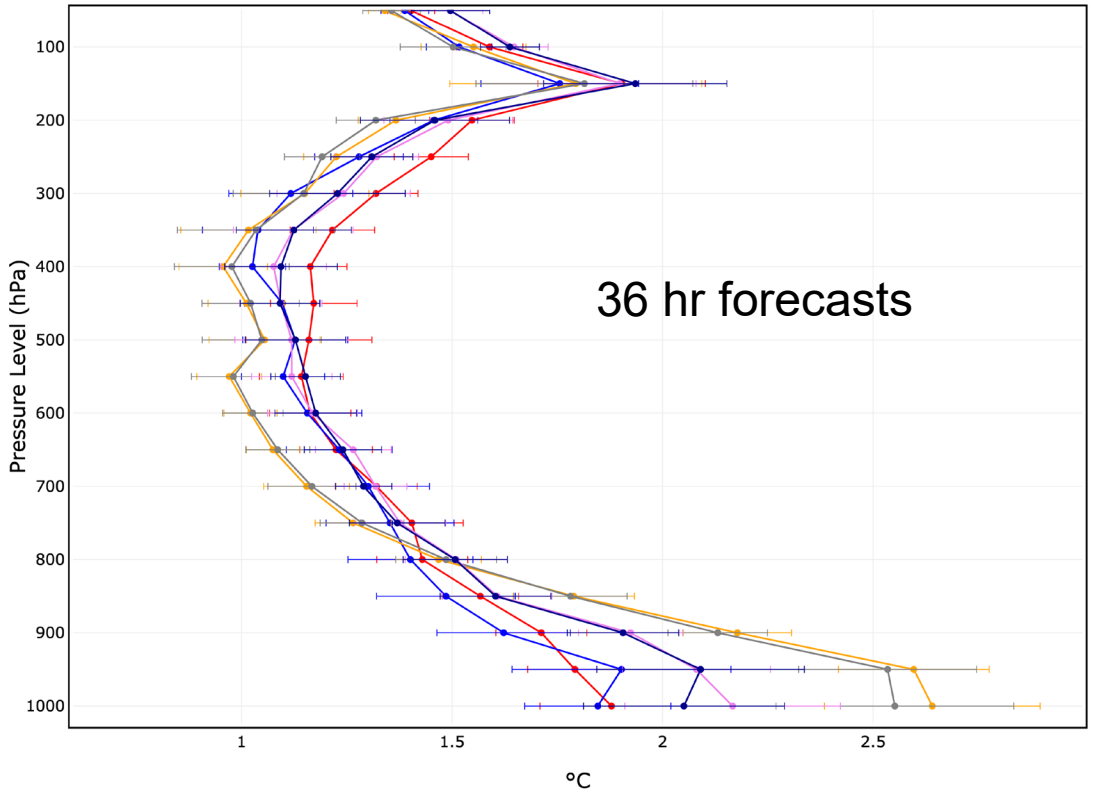
Curve3: RRFS_dev2 in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 05/30/2020 12:00

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

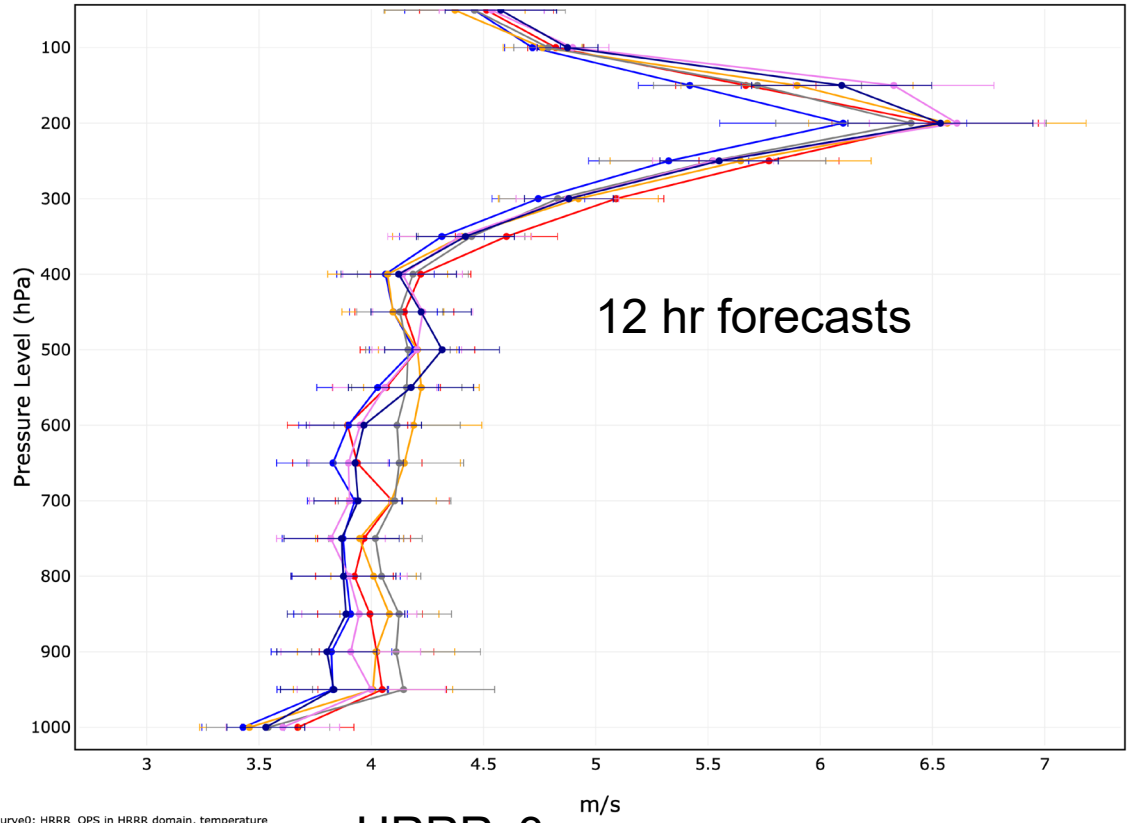
Curve5: RRFS_dev4 in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 05/30/2020 12:00

HRRRv3
HRRRv4
GFS IC (hord 5)
GFS IC (hord 6)
HRRR IC (hord 5)
HRRR IC (hord 6)

May 2020 CONUS RAOB Verification
Temperature 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

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

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

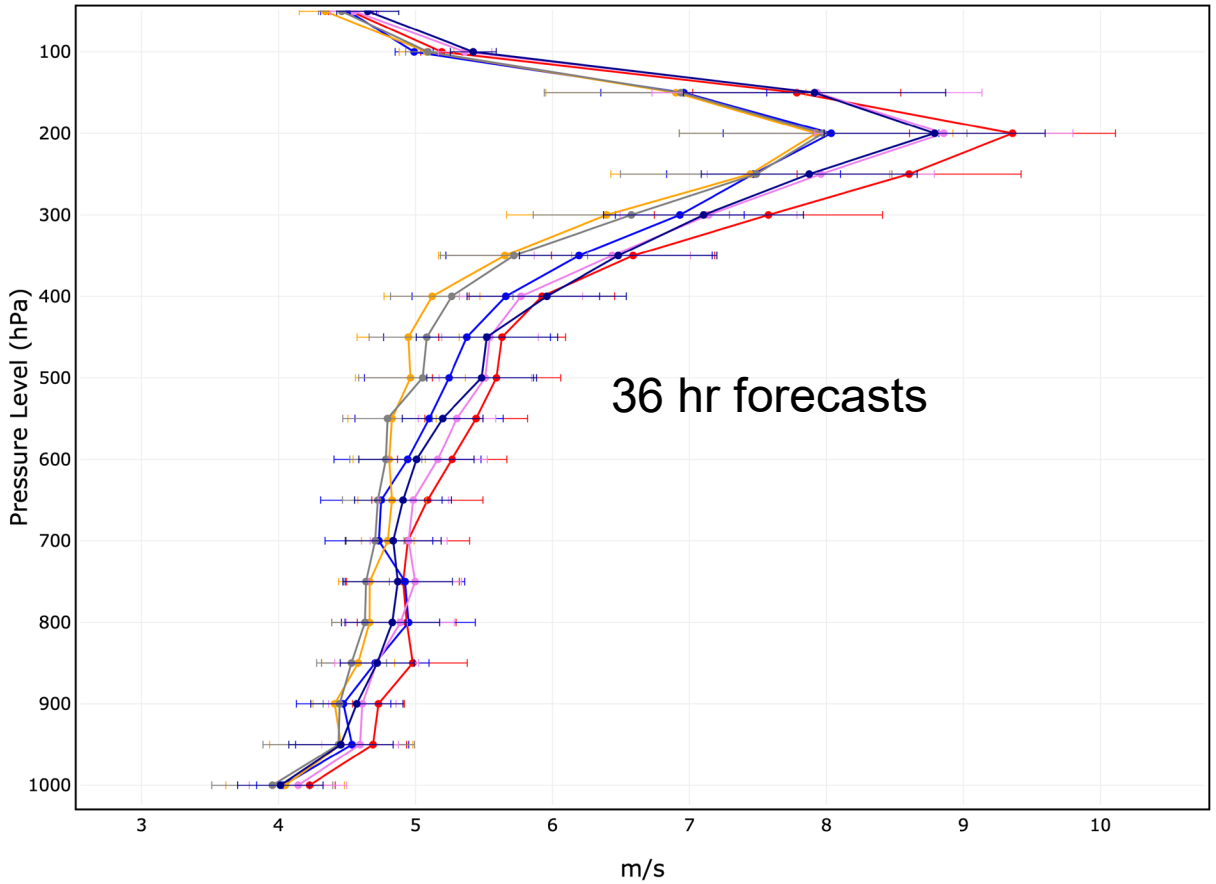
Curve3: RRFS_dev2 in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 05/30/2020 12:00

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

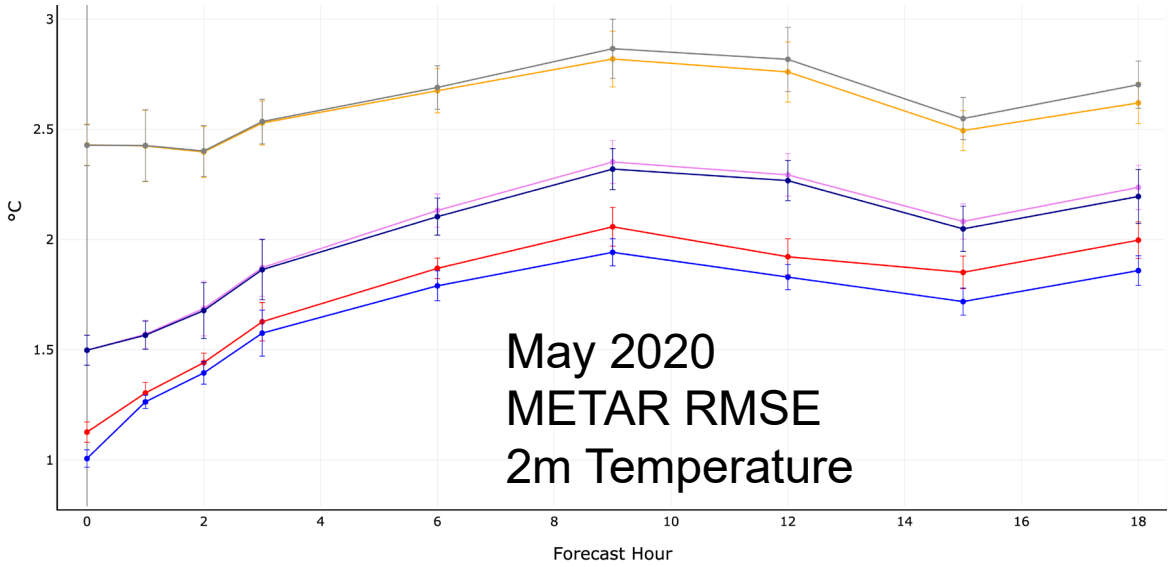
Curve5: RRFS_dev4 in HRRR domain, temperature RMS, level: 10 to 1000, fcst_len: 12h, valid-time: both, 05/08/2020 00:00 - 05/30/2020 12:00

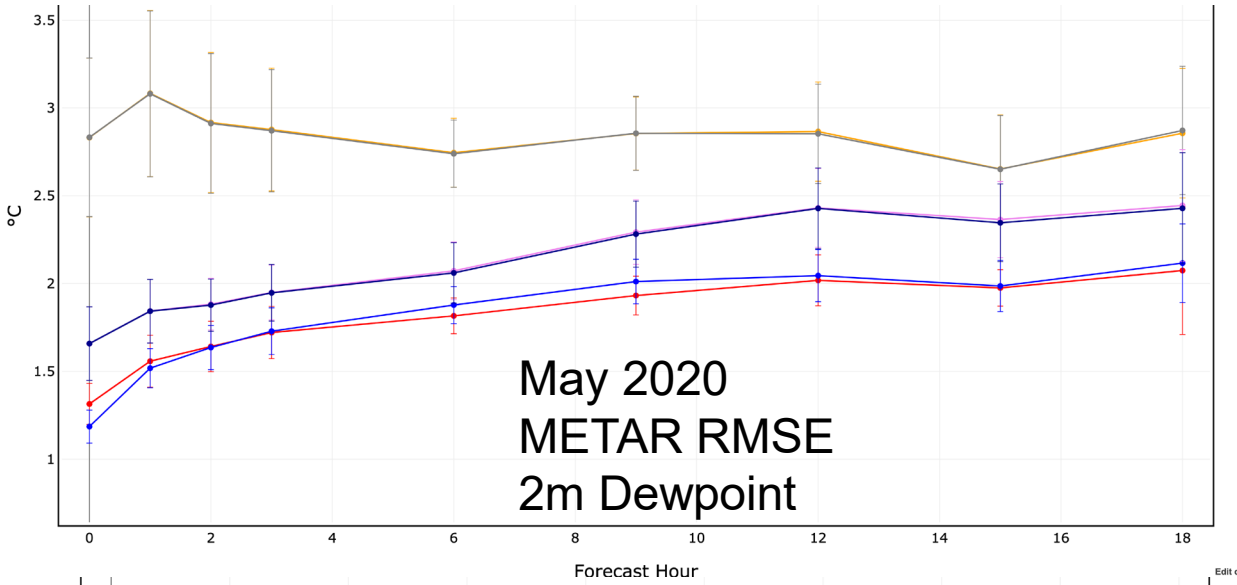
HRRRv3
HRRRv4
GFS IC (hord 5)
GFS IC (hord 6)
HRRR IC (hord 5)
HRRR IC (hord 6)

May 2020 CONUS RAOB Verification
Wind RMSE



Regional FV3 Testing in SPC/NSSL HWT SFE





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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

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HRRRv3
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GFS IC (hord 5)
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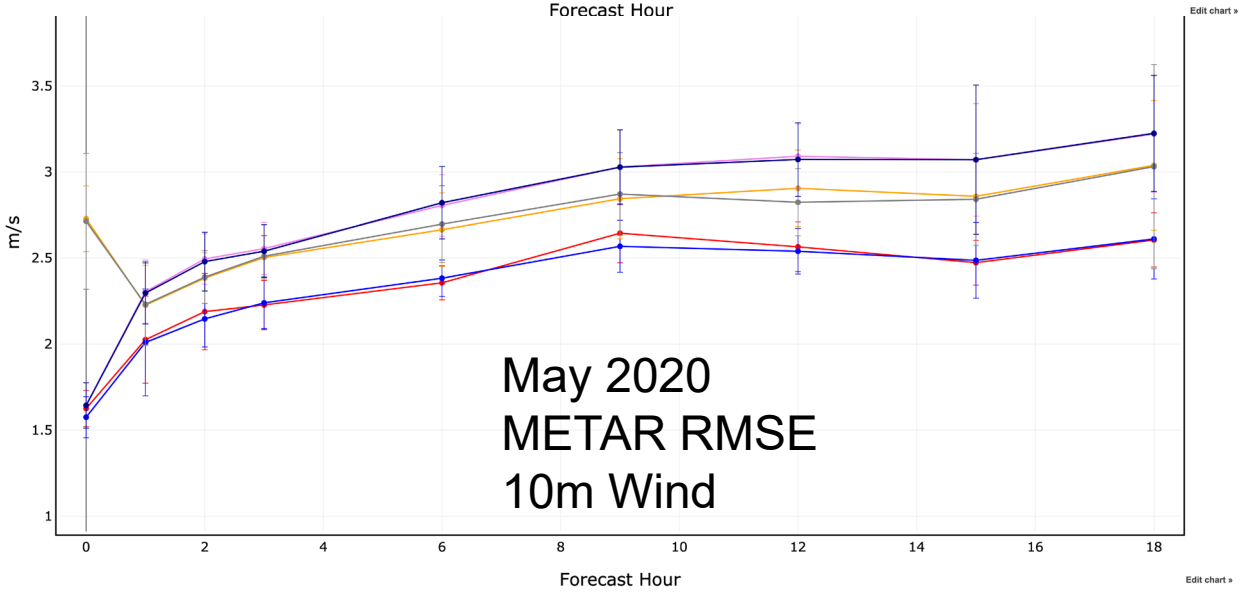
HRRR IC (hord 5)
HRRR IC (hord 6)



FV3 LAM Testing Diagrams in WPC FFaIR 24 h QPF

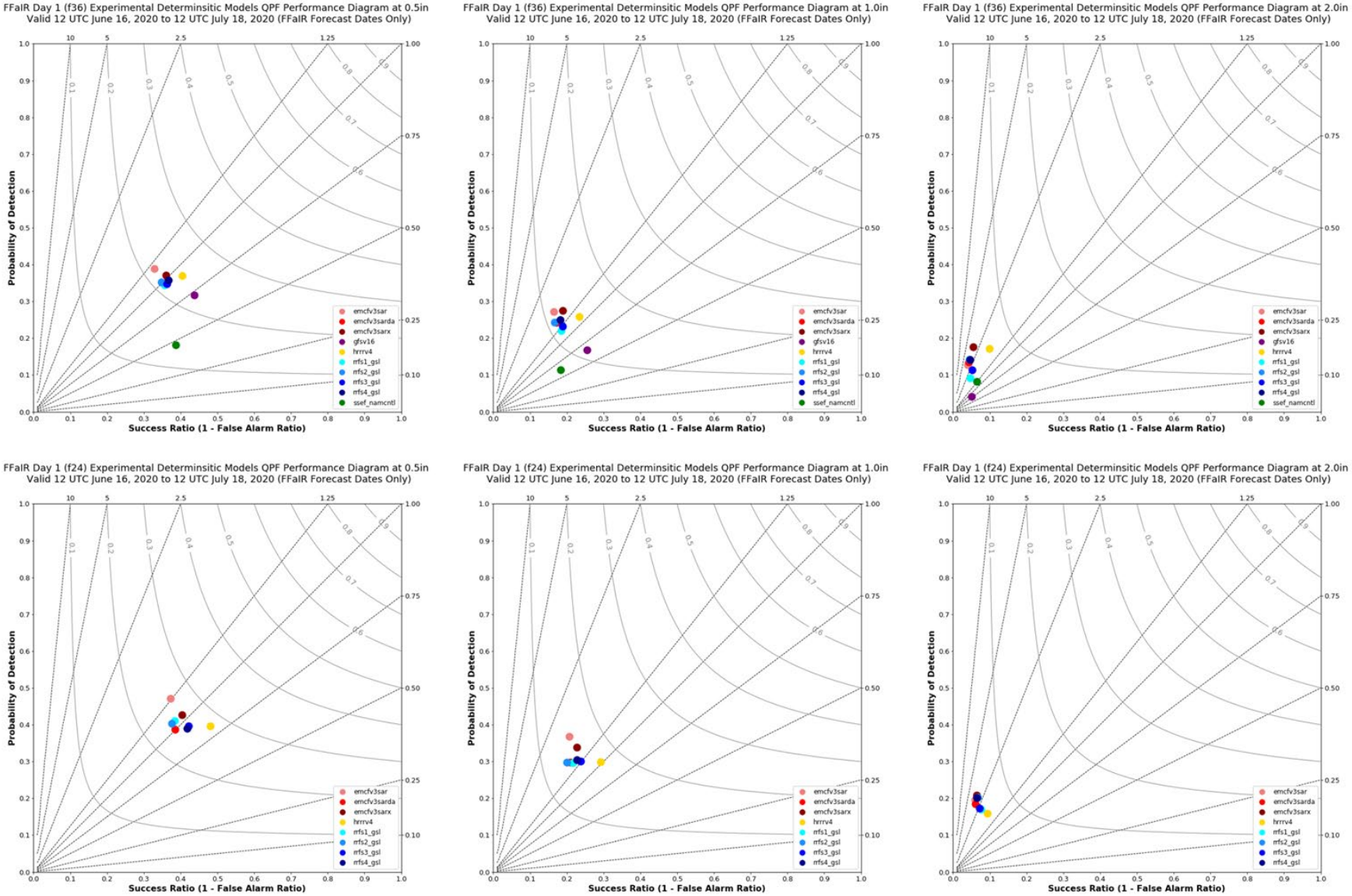
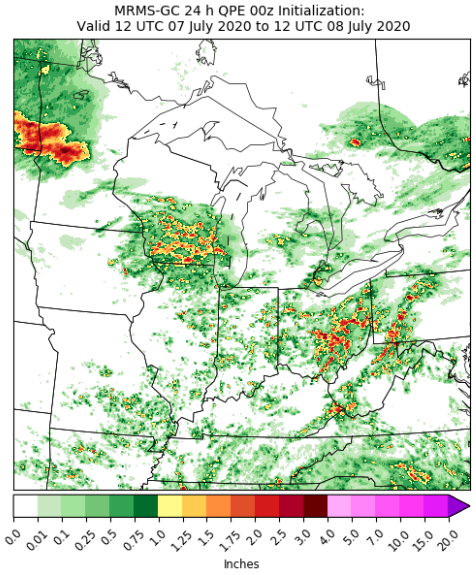
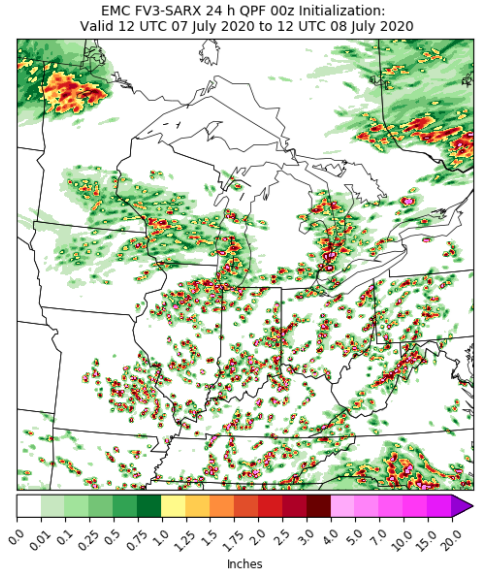


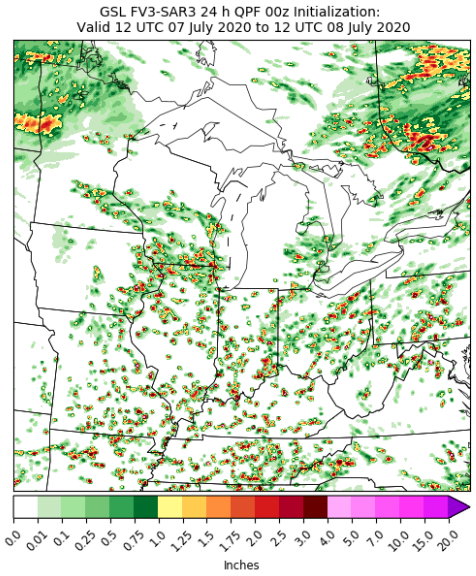
Figure courtesy of NCEP/WPC

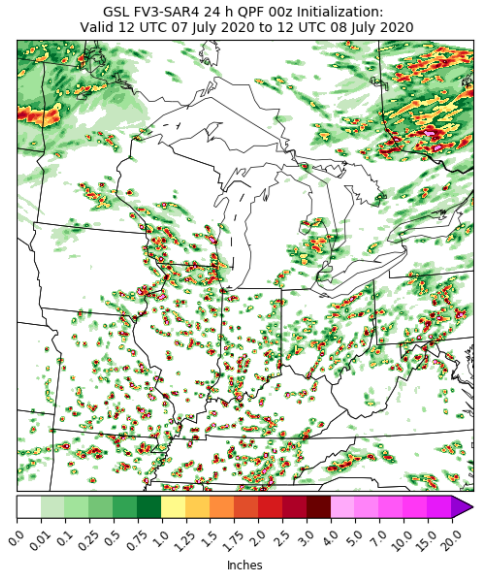
- The GSL LAMs are generally clustered together
- LAM3 and LAM4 typically have a higher CSI than LAM1 and LAM2
- LAM3 and LAM4 have similar CSI but LAM3 almost always has a bias closer to 1 than LAM4 has

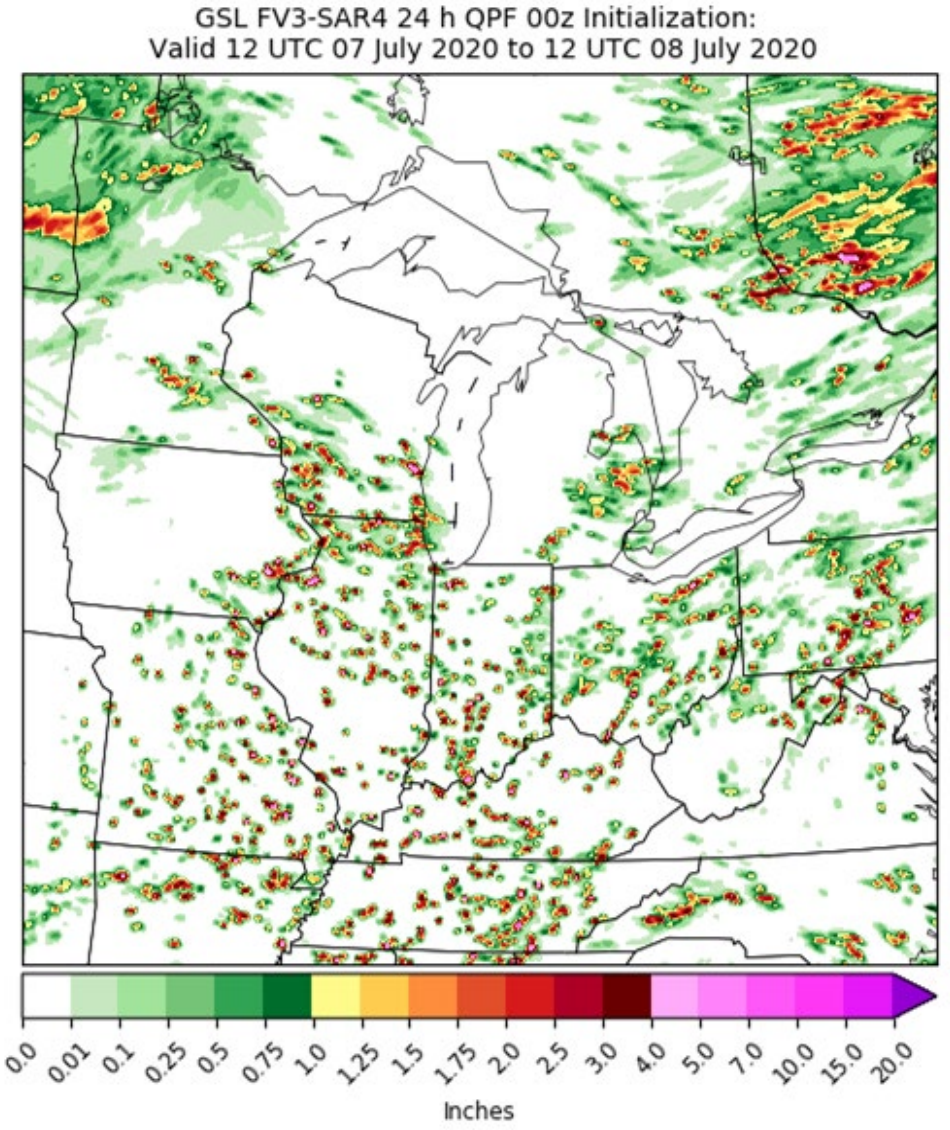
FV3 LAM Testing Diagrams in WPC FFaIR 24 h QPF











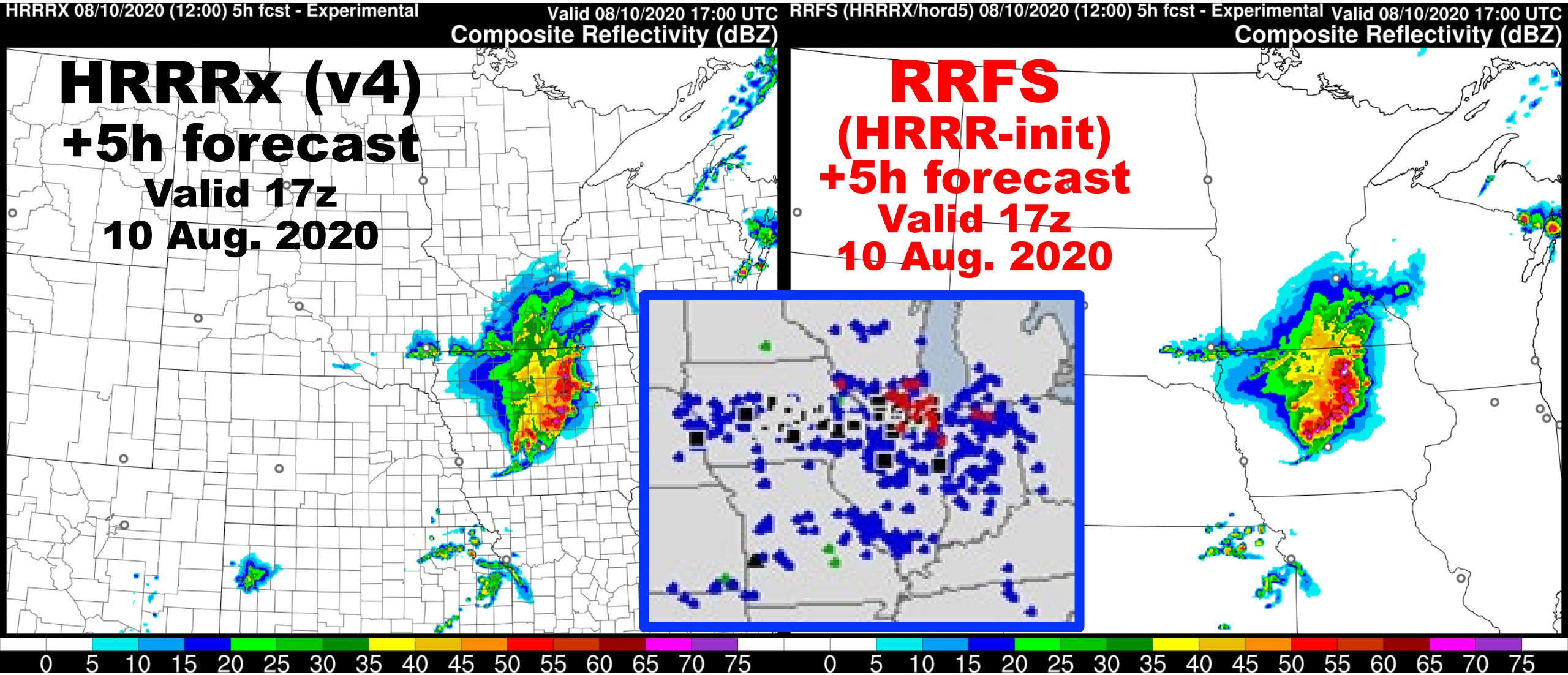
Noted high QPF bias

High reflectivity bias at higher thresholds (not shown) also observed

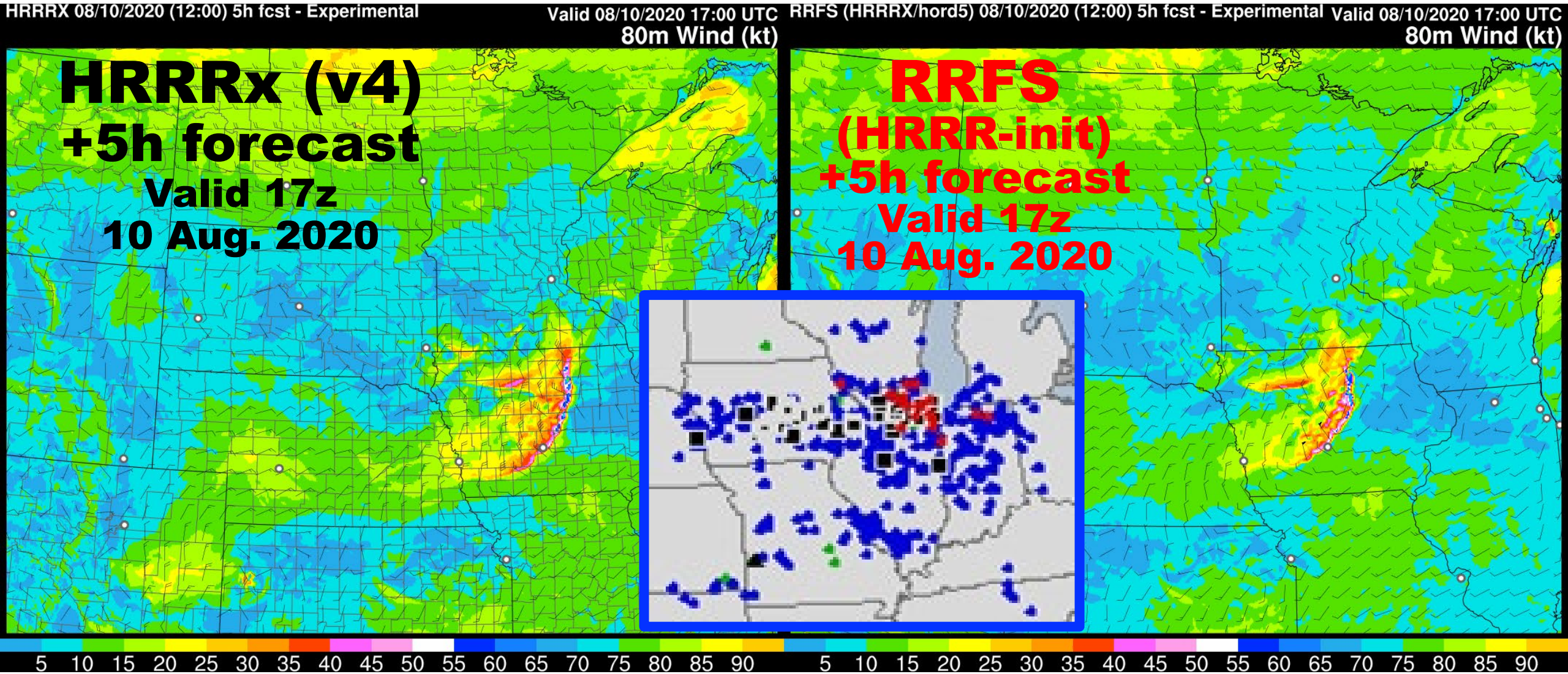
Related to large/deep UVVs in 3-km FV3 LAM?

Figures courtesy of NCEP/WPC

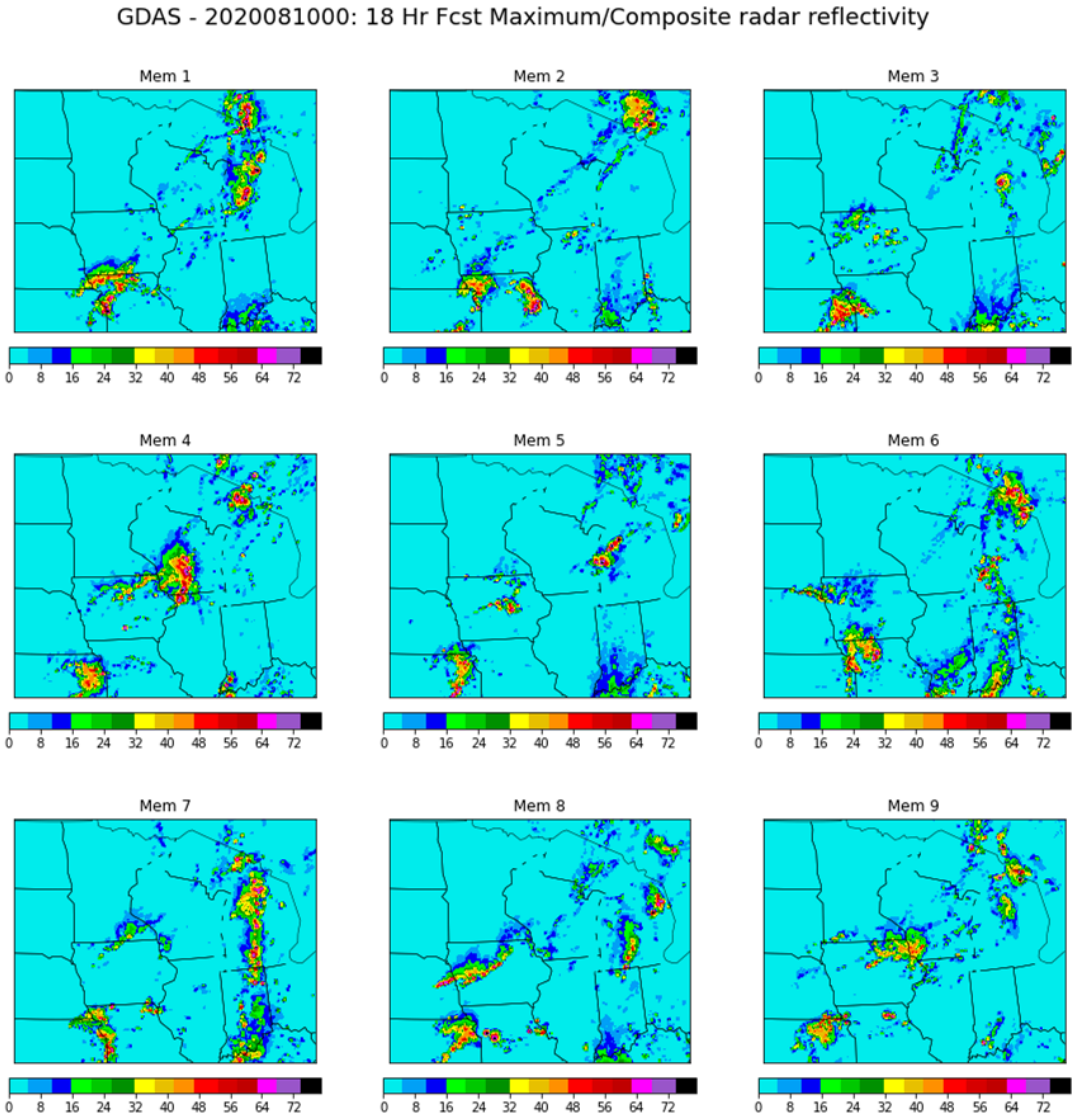
Comparison of HRRRv4 and RRFS (HRRR init)

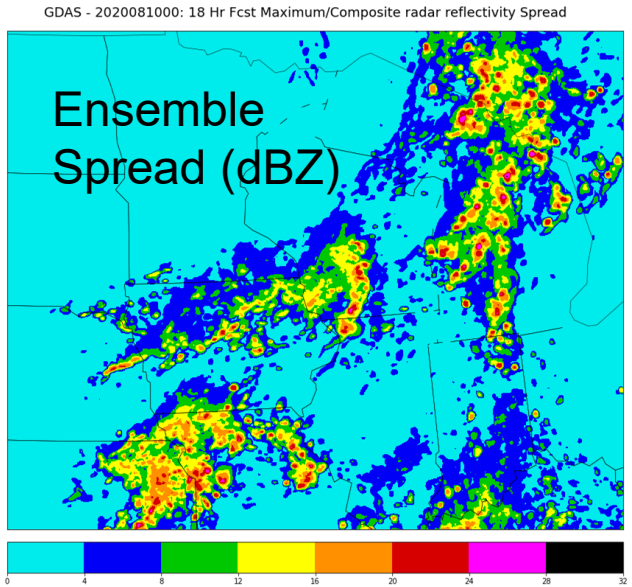


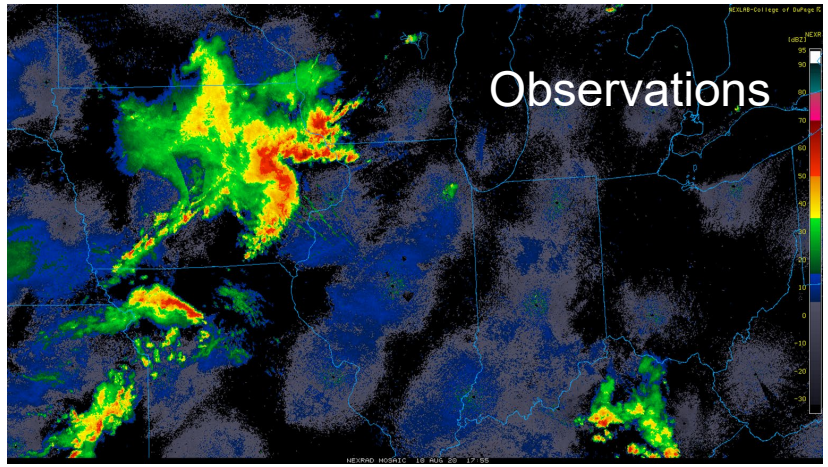
Comparison of HRRRv4 and RRFS (HRRR init)



GSL: Development and Testing of 3-km FV3 LAM Ensemble

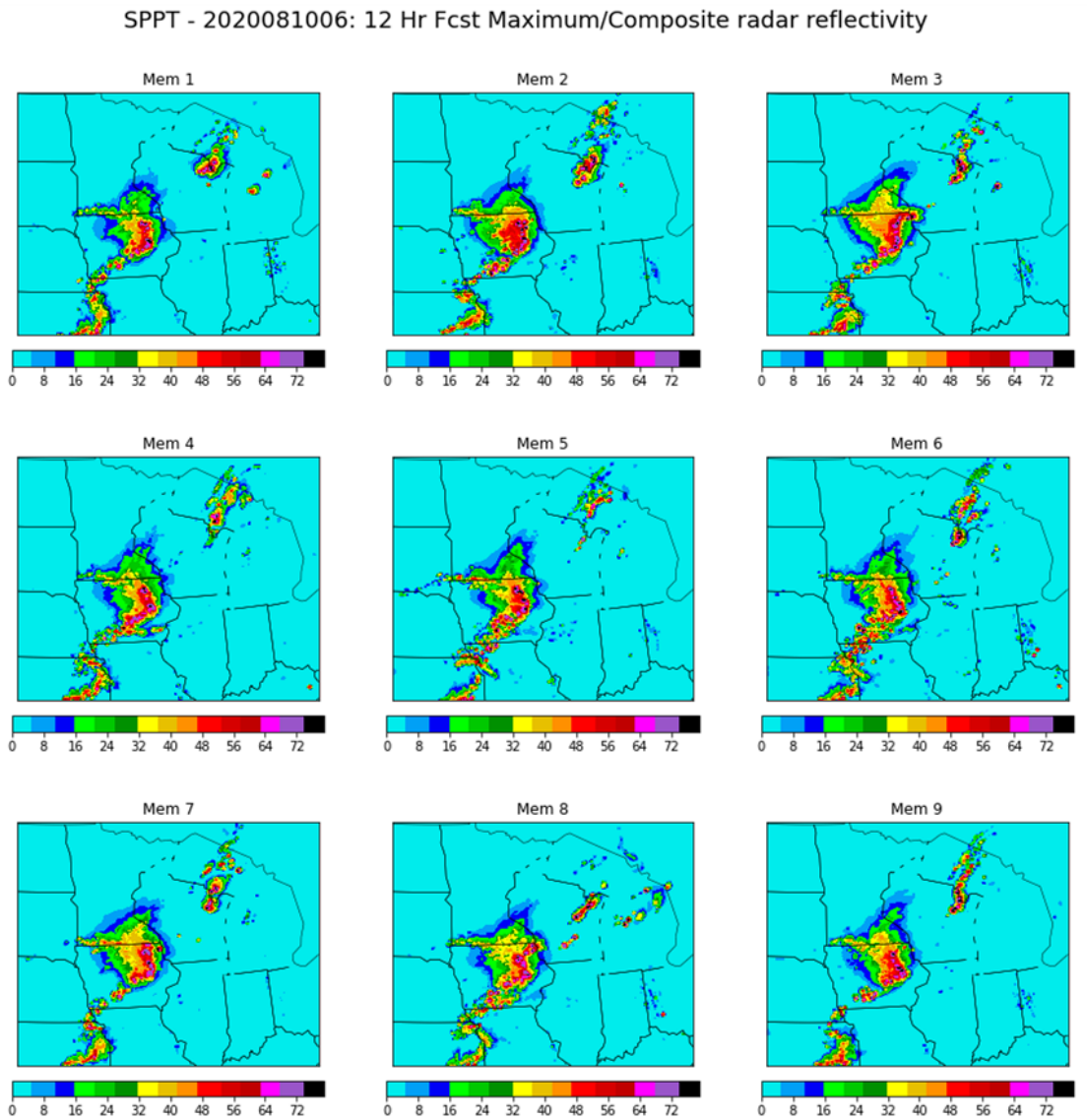


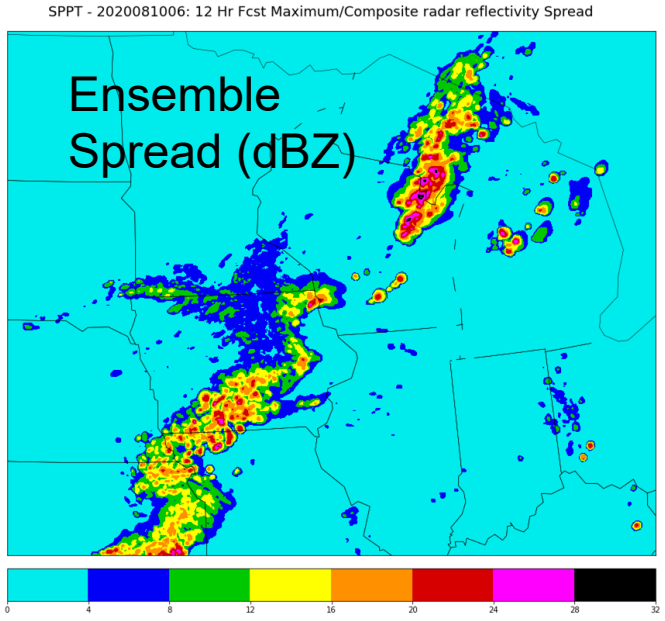


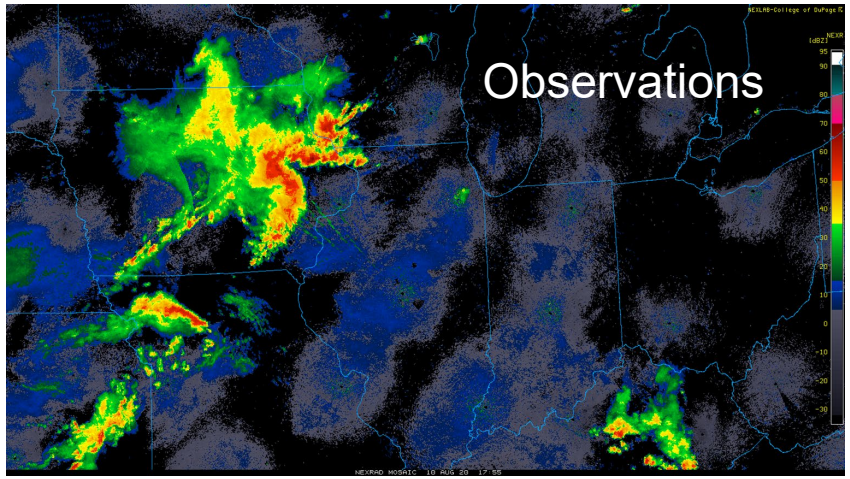


9-member 18-hr forecast valid 18z 10 Aug 2020 from initial condition perturbations (GDAS)

GSL: Development and Testing of 3-km FV3 LAM Ensemble



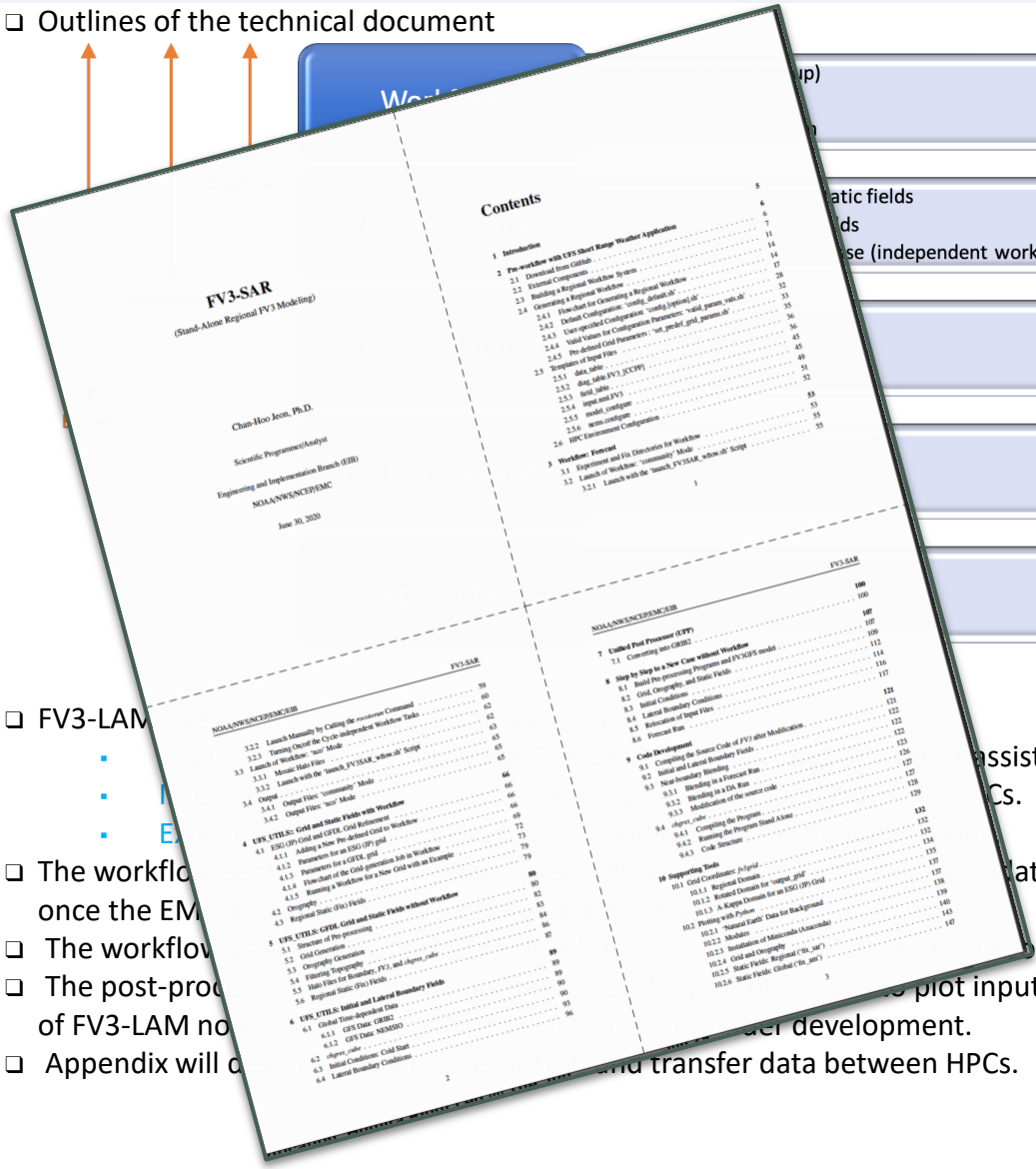




9-member 12-hr forecast valid 18z 10 Aug 2020 from stochastically perturbed physics tendencies (SPPT)

EMC: Technical documentation for FV3 LAM

- Outlines of the technical document



- FV3-LAM
  -
  -
  -
- The workflo
  once the EM
- The workflow
- The post-proc
  of FV3-LAM no
- Appendix will c

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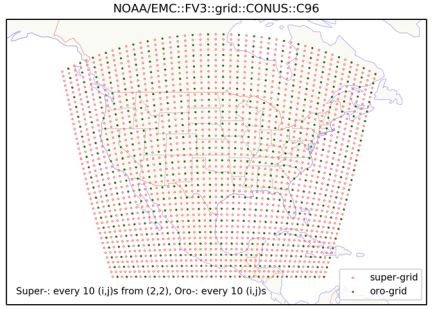
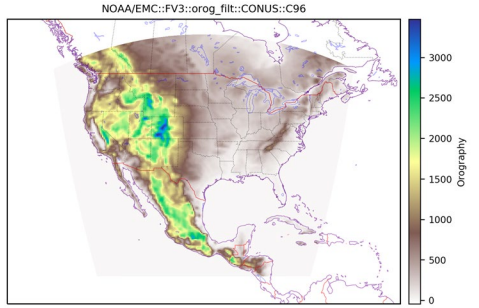
nd transfer data between HPCs.

EMC: Development of post-processing tools

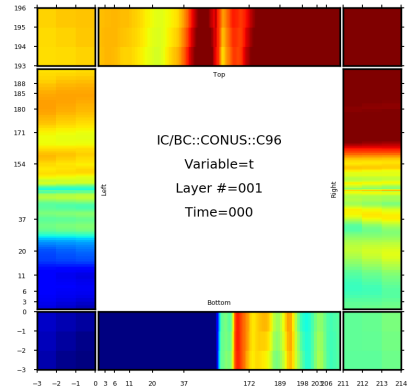
- Grid: FV3 super-grid / orography grid



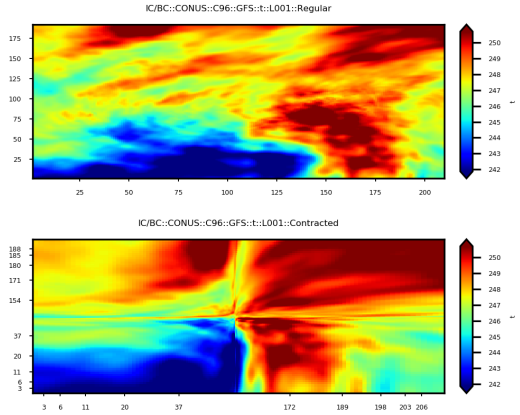
- Orography variables: filtered, mask etc.



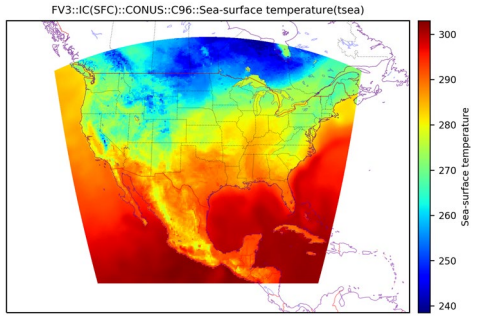
- LBCs: pressure, velocity, etc.



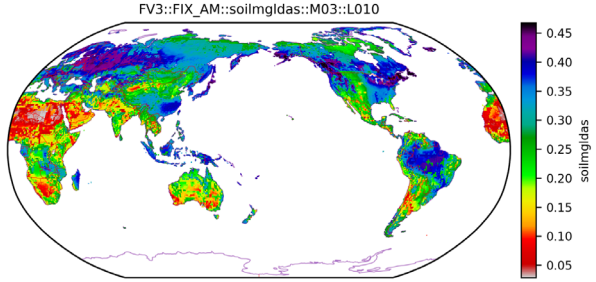
- Initial fields on regular/contracted coord.



- Surface climatology fields



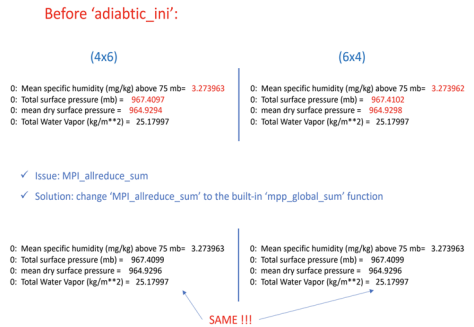
- Other global static fields



Goal to have regression test suite for LAM → Reproducibility issues found!

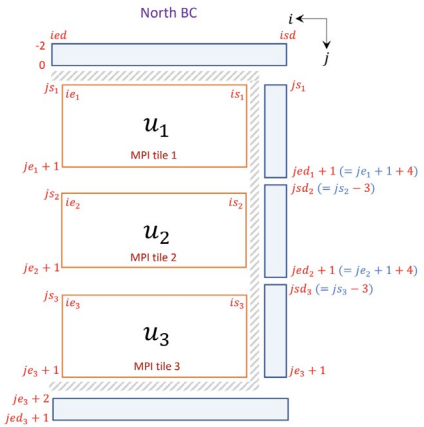
Ensuring reproducibility (1): Diagnostics

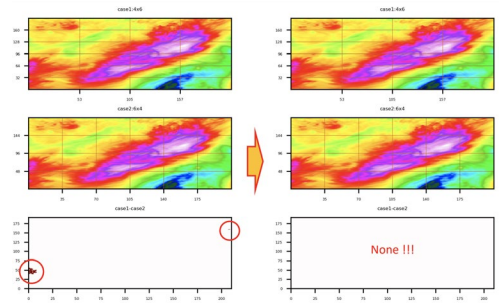
- Some diagnostic prints are done in a way that produces different results depending on the MPI layout
- *Not* a model issue - but may give the false appearance of one to a developer
- Fixed by using more appropriate MPI routines



Ensuring reproducibility (2): Dynamics and LBCs

- Look into model dynamics
- Examination of MPI tasks and tiles + interaction with LBCs
- Issue discovered at corner grid points of a few MPI tiles
- Updated code to correct missing boundary halo exchange → fixed!





Ensuring reproducibility (3): Physics

- Results are now bit reproducible when using GFS v15 physics suite in LAM!
- However - when testing with RRFS beta suite we encounter non-reproducible results with varying task counts
- Isolated to interface between model physics and dynamics
- Once complete, and assuming there are no further issues, this will translate into: Fixed code in UFS model repo, new regression suite for LAM, and reduced likelihood of this kind of future issue(s)

UFS Short Range Weather (SRW/CAM) Application Release

- **Limited Area Model (LAM) FV3 Capability**
- **No Data Assimilation**
- **Extended Schmidt Gnomonic (ESG) Grid**
- **3-km, 13-km, 25-km CONUS-type configurations**
- **GFS/NAM/RAP/HRRR GRIB2 Initializations**
- **Regional Workflow**
- **Physics Suite Definitions (SDFs):**
  - **RRFSv1alpha (RRTMG radiation, Thompson MP, MYNN PBL, GFS GWD/SL, NoahMP LSM)**
  - **GFSv15**

09 Oct 2020:	Code slush for preliminary pre-release testing
30 Nov 2020:	Code freeze for final testing
Dec 2020:	Documentation finalized
Dec/Jan 20/21:	Target release ready
Dec/Jan 20/21:	Announce release to public