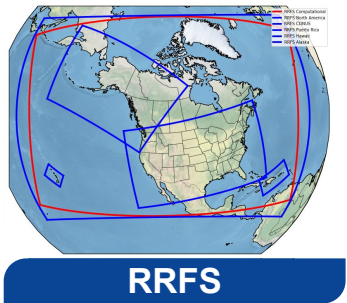


Development of the Rapid Refresh Forecast System Ensemble

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- ^b NOAA/Global Systems Laboratory, Boulder, CO
- ^c SAIC
- ^d CIRES





Global Weather, Waves & Global Analysis	GFS/GDAS v16.3								
Global Weather & Wave Ensembles, Aerosols	GEFS v12.3								Medium Range & Subseasonal Marine & Cryosphere Seasonal
Global Ocean Analysis	GODAS v2								
Short-Range Regional Ensembles	SREF v7.1								
Regional Weather (Parent Domain)	NAM v4.2								
Regional Weather (Parent Domain)	RAP v5.1								
Global Ocean & Sea-Ice	RTOFS v2.3								
Seasonal Climate	CDAS2 v1.2 / CFS v2.3								
Regional Hurricane 1	HWRF v13.2								
Regional Hurricane 2	HMON v3.2								
Regional High Resolution CAM 1	HiRes Window v8.1								
Regional High Resolution CAM 2	NAM nests / Fire Wx v4								
Regional High Resolution CAM 3	HRRR v4.1								
Regional HiRes CAM Ensemble	HREF v3.1								
Regional Air Quality	AQM v6.1								
Regional Surface Weather Analysis	RTMA / URMA v2.10								
Atmospheric Transport & Dispersion	HySPLIT v8.0								
Coastal & Regional Waves	NWPS v1.4								
Great Lakes	GLWU v2.0								
Regional Hydrology	NWM v2.1								
Space Weather 1 - WAM / IPE	WFS v1.0								Space Weather
Space Weather 2	ENLIL v1								
EMC Verification System	—								Verification

GFS v17/
GDAS v17/
GEFS v13/
GODAS v3

Coupled Reanalysis & Seasonal Reforecast

GFS v18/
GEFS v14/
SFS v1

HAFS v1

HAFS v2

HAFS v3

HAFS v4

RRFS v1

RRFS v2/
WoFS v1

AQM v7

3DRTMA/URMA v1

3DRTMA/URMA v2

HySPLIT v9

HySPLIT v10

GLWU v3

GLWU v4

NWM v3

NWM v4

WFS v2

EVS v1

EVS v2

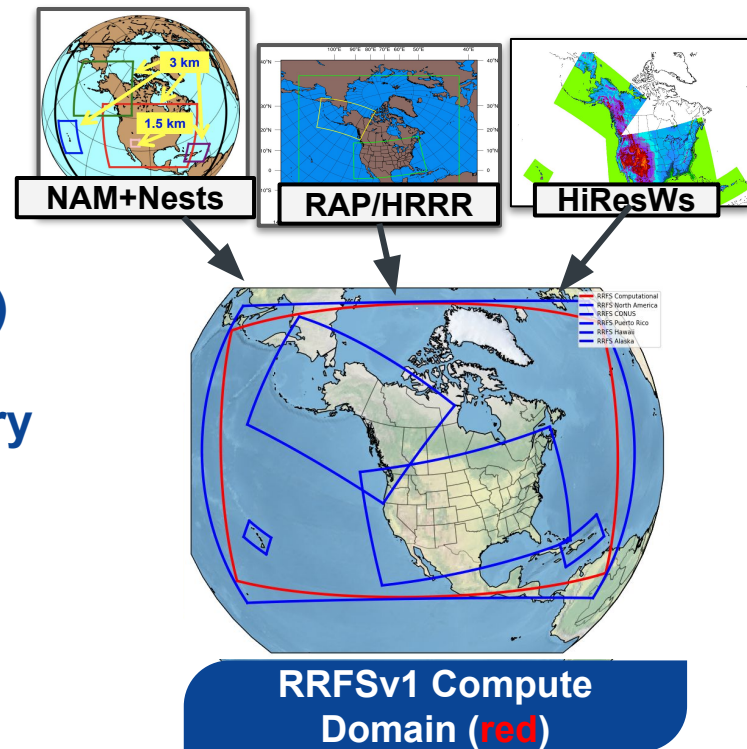
EVS v3



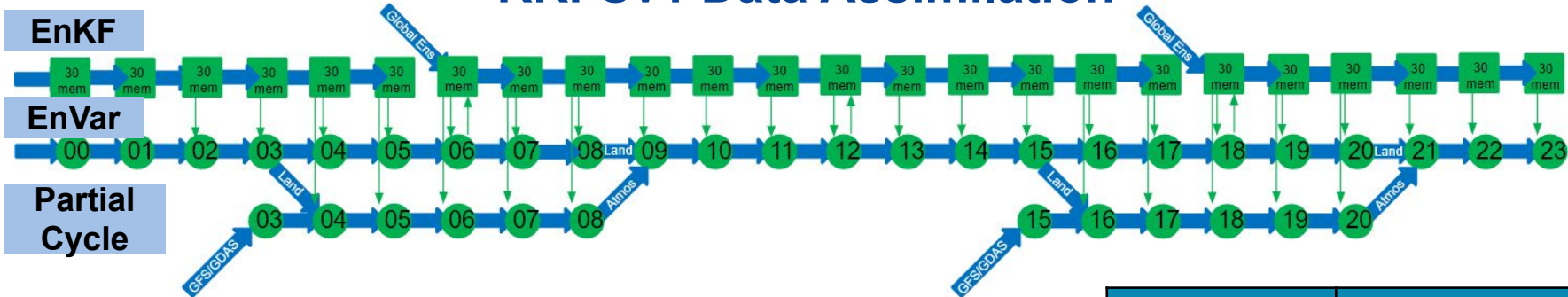
Rapid Refresh Forecast System (RRFS)

A UFS Application

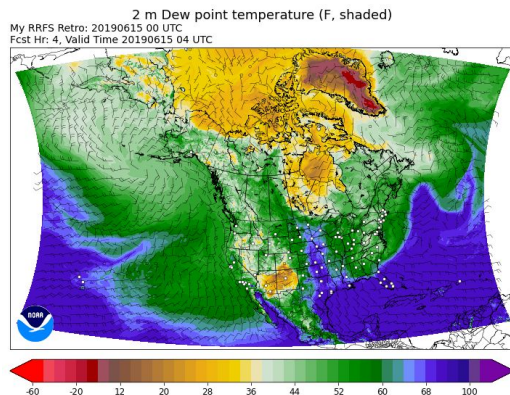
- FV3 dynamical core Limited Area Model
- Hourly updated
- 3 km grid spacing over North America
- 65 vertical layers
- Hybrid 3D EnVar assimilation (30 members)
- Built upon RAP/HRRR physics suite
- Deterministic forecasts to *at least* 18h every hour
- Deterministic & Ensemble forecasts to 60h every 6 hours



RRFSv1 Data Assimilation

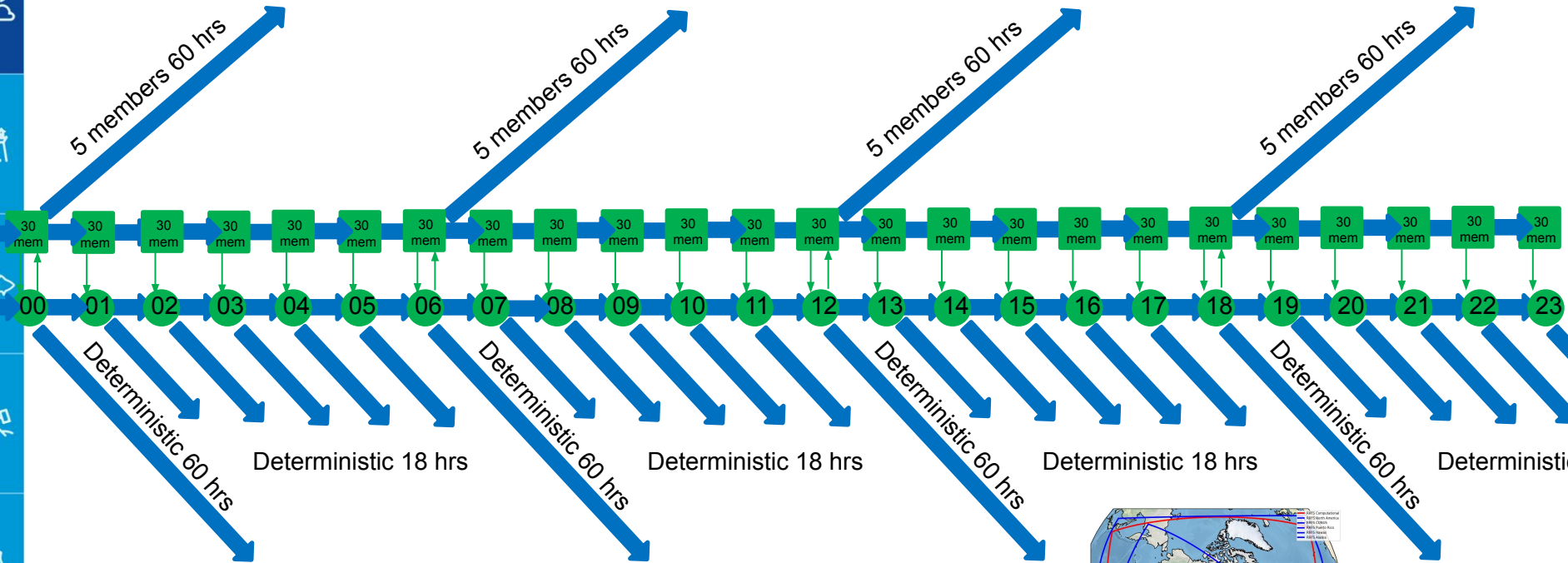


- Two-way interaction between 30 member 3-km DA ensemble (■) and 3-km deterministic RRFS hybrid 3DVar analysis (●)
- Partial cycle spin-up of atmosphere from GFS twice per day (RAP like), land states fully cyc'd
- All ensemble members (in square) and deterministic/control (circle) on 3-km NA grid

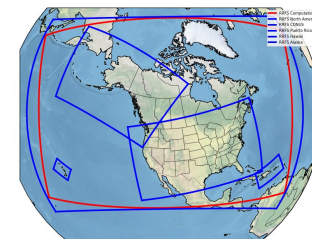


Obs Platform	Variables
METAR, Mesonet, Buoy, C-Man, Ship	T, moisture, W, ps, ceiling, vis
Rawinsonde	T, moisture, W
NEXRAD Radar	dBZ, rw, VAD W
Aircraft	T, moisture, W
GOES-16/18	ABI, AMVs, cloud top pres. & T
Polar Orbiters	Radiances (AMSUA, MHS, ATMS, CRIS, IASI, SSMIS)

RRFSv1 Initial Operational Capability for Forecasts

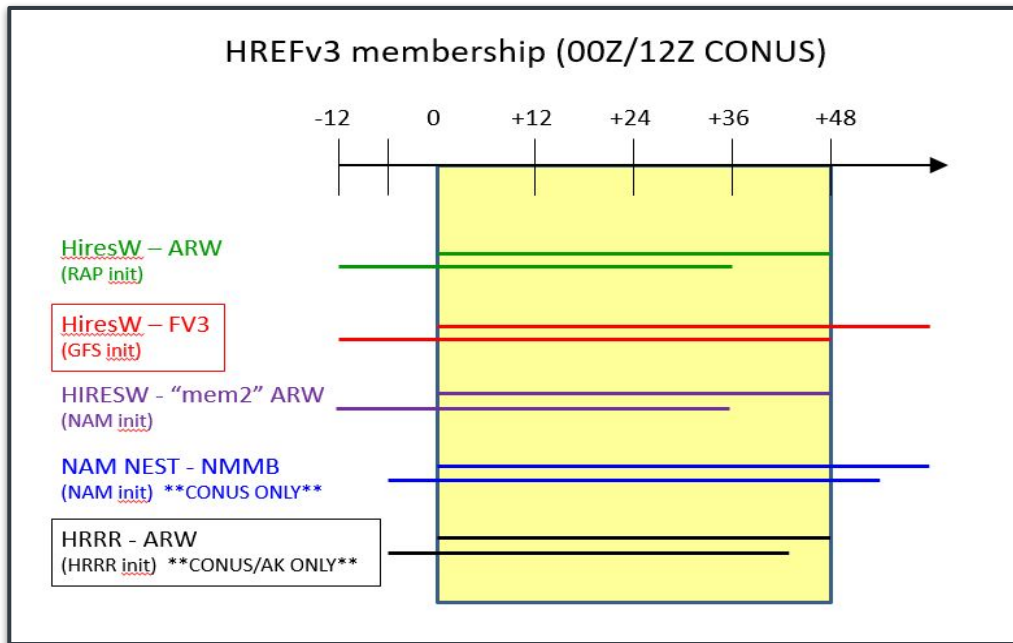


- We have enough compute to provide 5 members + 1 control every 6 hours out to 60 hours
 - Exploring available parameter-space for component design
- IC perturbations drawn from EnKF



RRFSv1 Compute Domain (red)

Let's Talk About the High Res Ensemble Forecast (HREF) System



A multi-dycore (3), multi-physics, time-lagged ensemble of deterministic forecast systems.

Initial conditions are drawn from control analyses from individual NWP systems

- RAP
- NAM
- NAM nest
- GFS

Forecast ensemble considerations for RRFS

- Single-physics, multi-physics configuration, ensemble size, etc.
 - Long term plan is to get to a single physics configuration, but possibly use multi-physics for RRFSv1 to enhance ensemble spread.
 - Availability of well-tuned physics suites is severely limited as we collectively focus on a small handful of physics suites.
 - Both single and multiphysics options, along with time lagging, were run for evaluation during the 2023 HWT/SFE period.
 - Decision still to be made for RRFSv1 - options show differences in skill/spread/reliability space (and neither unambiguously better).
 - Will include time lagging.
- Let's review some designs tested this Spring

2023 real-time experiments for HWT and FFaIR

A time-lagged approach

* Stochastic parameter perturbations (SPP)
 # parameter perturbations
 All **mply** perturbed members have SPPT
 No SPPT for **sphy** in May due to instability

time-lagged members

Ensemble 1 single physics ensemble (sphy)

Ensemble 2 multi physics ensemble (mply)

	MP	PBL	sfc	Ism	IC/LBC
m1 (ctrl)	Thompson	MYNN	MYNN	RUC	RRFS hybrid/GFS
m2	Thompson*	MYNN*	MYNN*	RUC*	RRFS enkf1/GEFSm1
m3	Thompson*	MYNN*	MYNN*	RUC*	RRFS enkf4/GEFSm4
m4	Thompson*	MYNN*	MYNN*	RUC*	RRFS enkf5/GEFSm5
m5	Thompson*	MYNN*	MYNN*	RUC*	RRFS enkf6/GEFSm6
m6	Thompson*	MYNN*	MYNN*	RUC*	RRFS enkf7/GEFSm7
m7 (ctrl)	Thompson	MYNN	MYNN	RUC	RRFS hybrid/GFS-6h
m8	Thompson*	MYNN*	MYNN*	RUC*	RRFS enkf1/GEFSm1-6h
m9	Thompson*	MYNN*	MYNN*	RUC*	RRFS enkf4/GEFSm4-6h
m10	Thompson*	MYNN*	MYNN*	RUC*	RRFS enkf5/GEFSm5-6h
m11	Thompson*	MYNN*	MYNN*	RUC*	RRFS enkf6/GEFSm6-6h
m12	Thompson*	MYNN*	MYNN*	RUC*	RRFS enkf7/GEFSm7-6h

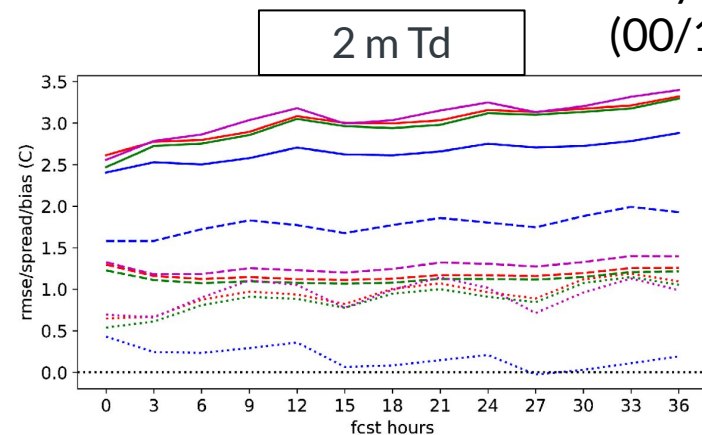
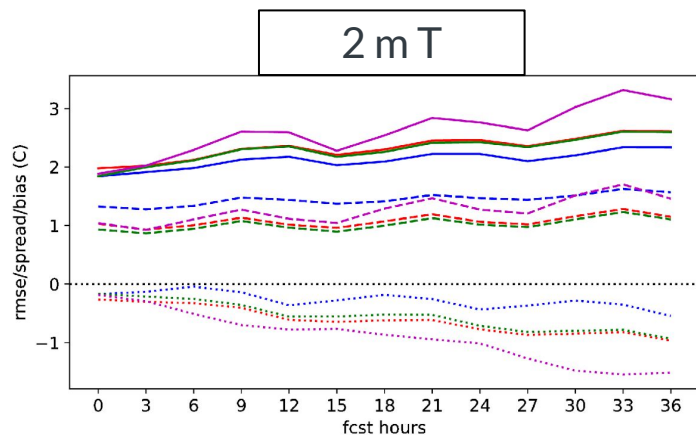
	MP	PBL	sfc	Ism	Cu	IC/LBC
m1 (ctrl)	Thompson	MYNN	MYNN	RUC	N/A	RRFS hybrid/GFS
m2	Thompson*	H-EDMF	GFS	RUC*	Shal	RRFS enkf1/GEFSm1
m3	Thompson*	TKE-EDMF	GFS	RUC*	Shal	RRFS enkf4/GEFSm4
m4	NSSL#	MYNN*	MYNN*	RUC*	N/A	RRFS enkf5/GEFSm5
m5	NSSL#	H-EDMF	GFS	RUC*	Shal	RRFS enkf6/GEFSm6
m6	NSSL#	TKE-EDMF	GFS	RUC*	Shal	RRFS enkf7/GEFSm7
m7 (ctrl)	Thompson	MYNN	MYNN	RUC	N/A	RRFS hybrid/GFS-6h
m8	Thompson*	H-EDMF	GFS	RUC*	Shal	RRFS enkf1/GEFSm1-6h
m9	Thompson*	TKE-EDMF	GFS	RUC*	Shal	RRFS enkf4/GEFSm4-6h
m10	NSSL#	MYNN*	MYNN*	RUC*	N/A	RRFS enkf5/GEFSm5-6h
m11	NSSL#	H-EDMF	GFS	RUC*	Shal	RRFS enkf6/GEFSm6-6h
m12	NSSL#	TKE-EDMF	GFS	RUC*	Shal	RRFS enkf7/GEFSm7-6h



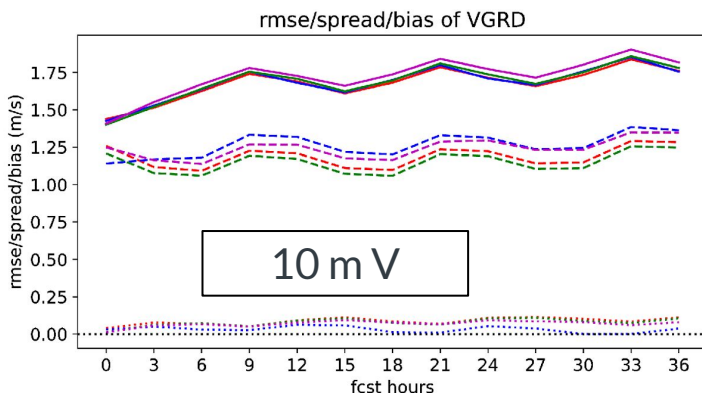
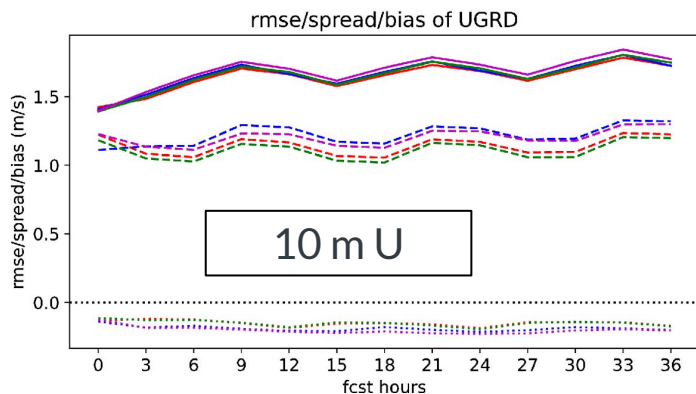
RRFS single/multi-physics ensemble comparison

- sensible weather

May 10 - May 25
(00/12Z 31 cycles)



- SPHY TL30
- SPHY TL12
- MPHY TL12
- HREF
- rmse
- spread
- bias



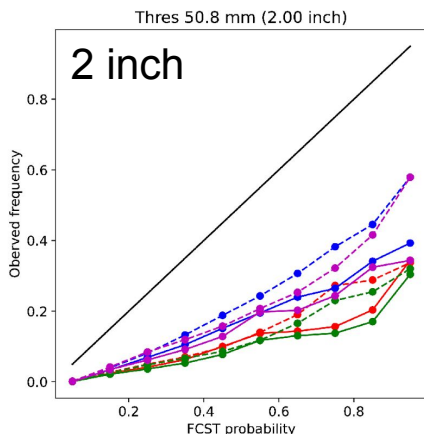
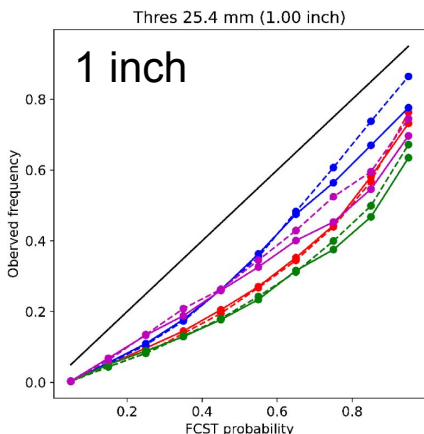
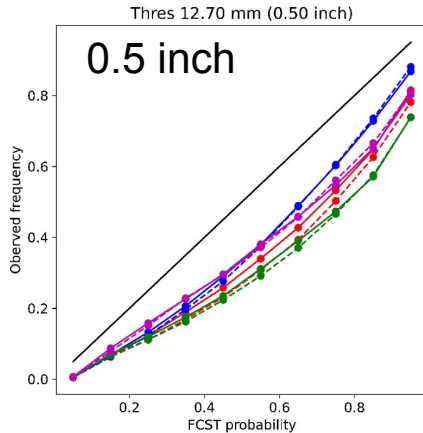
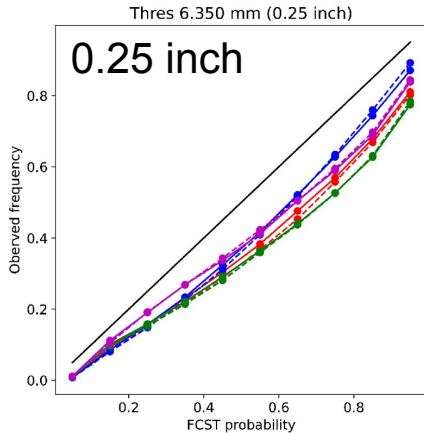
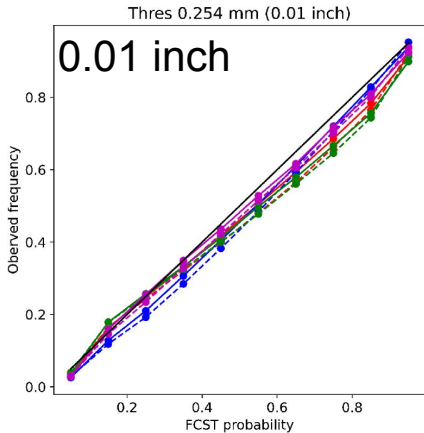
TL with 30 members from 3 consecutive cycles tested to see impact on spread/error



RRFS single/multi-physics ensemble comparison: Precip Reliability

- May 10 - May 25
- 6HR QPF
- Averaged over all forecast hours (6-36) every 6 hours
- (00/12Z 31 cycles)

TL with 30 members from 3 consecutive cycles tested to see impact on spread/error



- SPHY TL30
- SPHY TL12
- MPHYS TL12
- HREF
- nbr=45 km
- - - nbr=85 km



What Next?

- A clear gap remains between these RRFS designs and HREF
- Is our intent to implement a sweeping change too much at once?
 - Intending to subsume all of the following deterministic systems, which are HREF components: HRRR, NAM nest, HiResW ARW, HiResW “mem2” ARW, HiResW FV3LAM
- What if we assume the system which most recently upgraded and best matches RRFS design is maintained and folded into the RRFS ensemble?
- Let's re-visit our HWT dataset and see

Multi-model RRFs ensemble (HRRR+RRFS)

mm_sphy_t114

	MP	PBL/sfc
HRRR	Thompson	MYNN
m1 (ctrl)	Thompson	MYNN
m3	Thompson*	MYNN*
m4	Thompson*	MYNN*
m6	Thompson*	MYNN*
m8	Thompson*	MYNN*
m9	Thompson*	MYNN*
HRRR (t-6h)	Thompson	MYNN
m1 (ctrl) (t-6h)	Thompson	MYNN
m3 (t-6h)	Thompson*	MYNN*
m4 (t-6h)	Thompson*	MYNN*
m6 (t-6h)	Thompson*	MYNN*
m8 (t-6h)	Thompson*	MYNN*
m9 (t-6h)	Thompson*	MYNN*

mm_mphy_t114

	MP	PBL/sfc
HRRR	Thompson	MYNN
m1 (ctrl)	Thompson	MYNN
m3	Thompson*	TKE-EDMF/GFS
m4	Thompson*	MYNN*
m6	NSSL#	MYNN*
m8	NSSL#	TKE-EDMF/GFS
m9	NSSL#	MYNN*
HRRR (t-6h)	Thompson	MYNN
m1 (ctrl) (t-6h)	Thompson	MYNN
m3 (t-6h)	Thompson*	TKE-EDMF/GFS
m4 (t-6h)	Thompson*	MYNN*
m6 (t-6h)	NSSL#	MYNN*
m8 (t-6h)	NSSL#	TKE-EDMF/GFS
m9 (t-6h)	NSSL#	MYNN*

mm_sphy_t110

	MP	PBL/sfc
HRRR	Thompson	MYNN
m1 (ctrl)	Thompson	MYNN
m4	Thompson*	MYNN*
m6	Thompson*	MYNN*
m9	Thompson*	MYNN*
HRRR (t-6h)	Thompson	MYNN
m1 (ctrl) (t-6h)	Thompson	MYNN
m4 (t-6h)	Thompson*	MYNN*
m6 (t-6h)	Thompson*	MYNN*
m9 (t-6h)	Thompson*	MYNN*

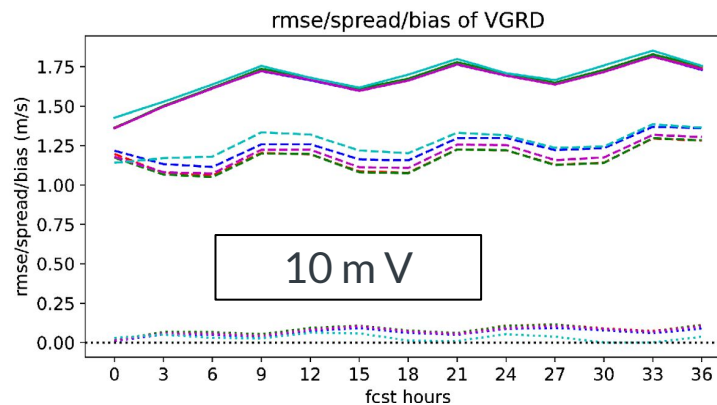
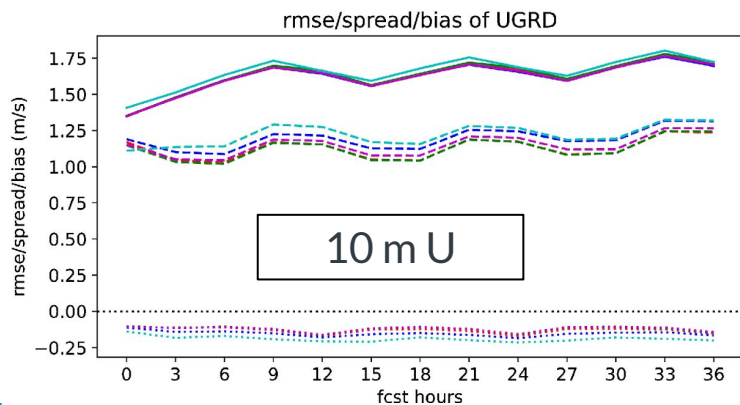
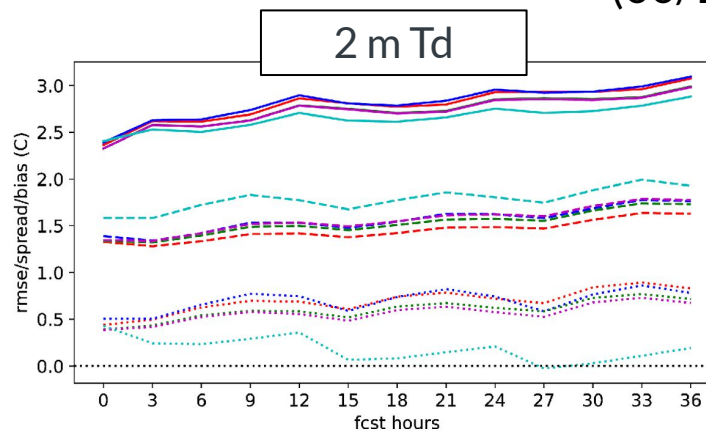
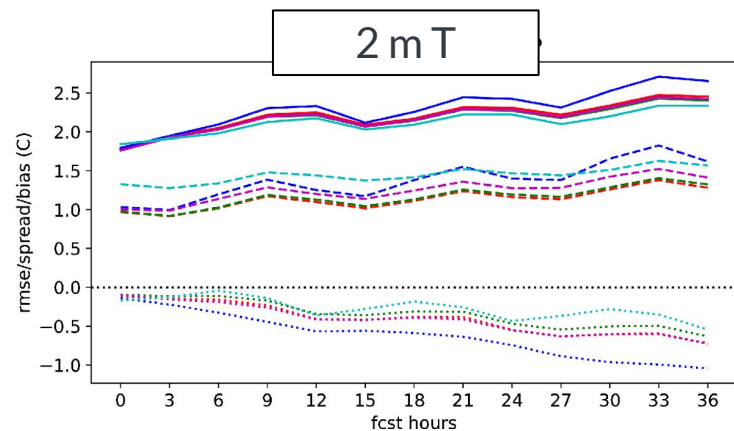
mm_mphy_t110

	MP	PBL/sfc
HRRR	Thompson	MYNN
m1 (ctrl)	Thompson	MYNN
m4	Thompson*	MYNN*
m6	NSSL#	MYNN*
m9	NSSL#	MYNN*
HRRR (t-6h)	Thompson	MYNN
m1 (ctrl) (t-6h)	Thompson	MYNN
m4 (t-6h)	Thompson*	MYNN*
m6 (t-6h)	NSSL#	MYNN*
m9 (t-6h)	NSSL#	MYNN*



HRRR TL + RRFS Ensemble Comparison - Sensible Weather

May 10 - May 25
(00/12Z 31 cycles)

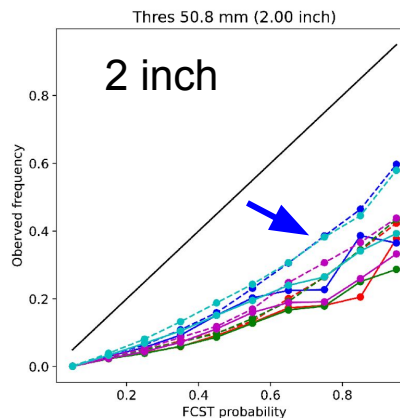
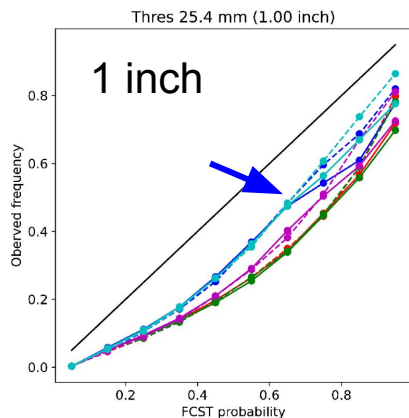
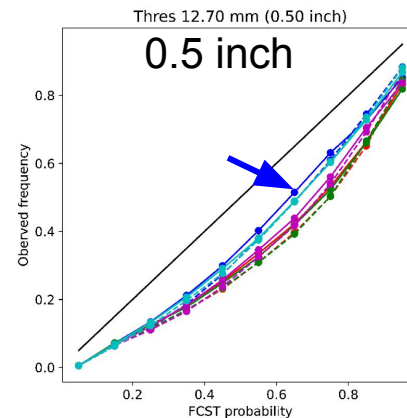
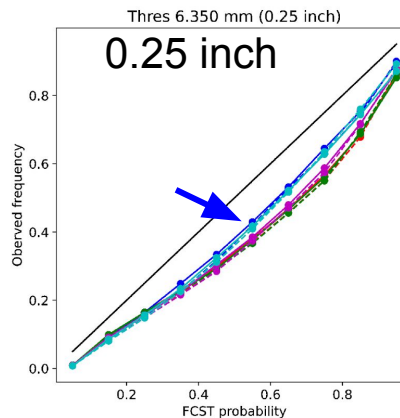
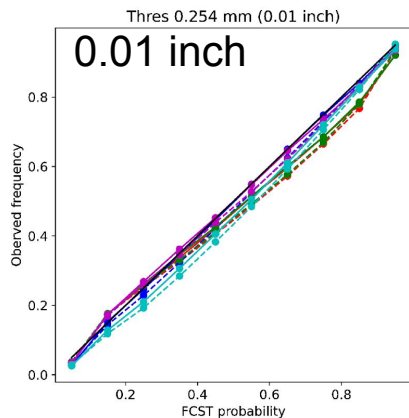


- MM_SPHY_TL14
- MM_MPHY_TL14
- MM_SPHY_TL10
- MM_MPHY_TL10
- HREF
- rmse
- spread
- bias



HRRR TL + RRFS Ensemble Comparison - Precip Reliability

- May 10 - May 25
- 6HR QPF
- Averaged over all forecast hours (6-36) every 6 hours
- (00/12Z 31 cycles)



- MM_SPHY_TL14
- MM_MPHY_TL14
- MM_SPHY_TL10
- MM_MPHY_TL10
- HREF

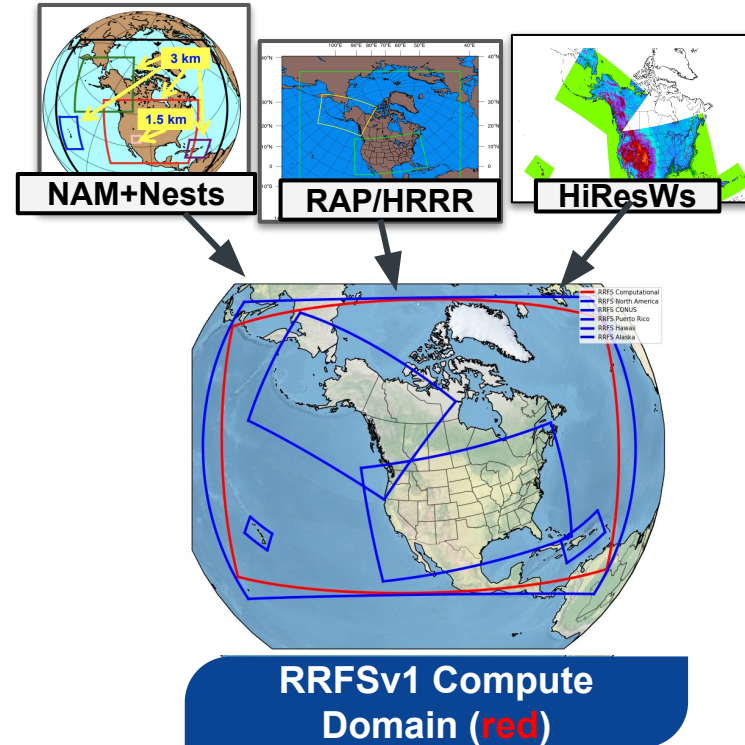
- nbr=45 km
- - - nbr=85 km





Summary

- More work to be done on ensemble design
 - SPPT stability issues
 - The HRRR+RRFS initially appears promising but....
 - Multi-modality, various bias characteristics, inclusion of control members in the ensemble, etc...
- RRFS will be a *major* change
 - Consolidating wide swath of operational CAM guidance with a single, unified 3-km system covering North America
- Targeting a science freeze in 6-8 months
 - Implementation planned to follow 9-12 months thereafter



Thank you! Questions?