Status and Opportunities with the Rapid Refresh Forecast System

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on behalf of the RRFS development team

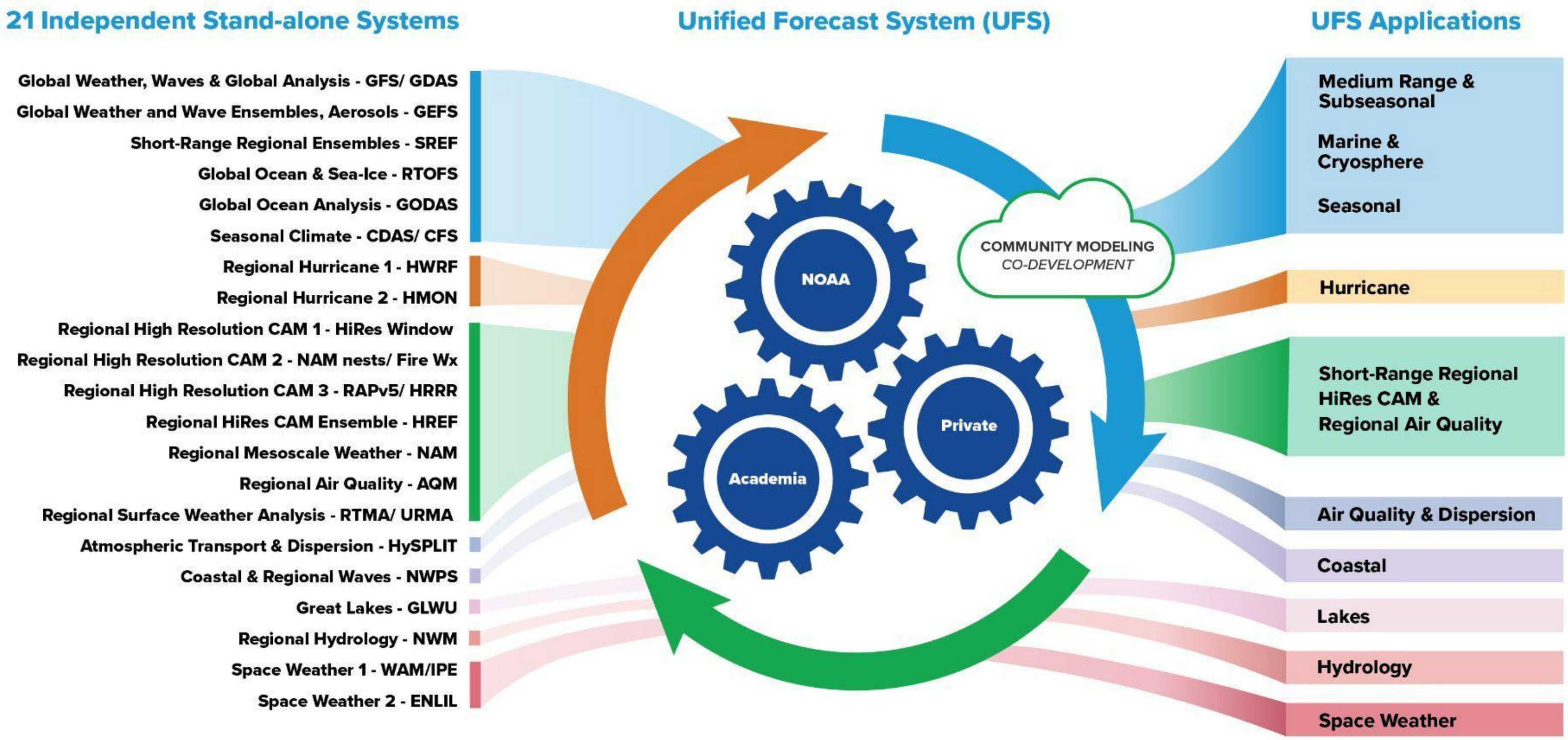
[1]NOAA/NWS/NCEP/EMC

[2]NOAA/OAR/GSL

July 20th, 2022

Simplifying NOAA's Operational Forecast Suite

Reducing the 21 Stand-alone Operational Forecast Systems into Eight Applications



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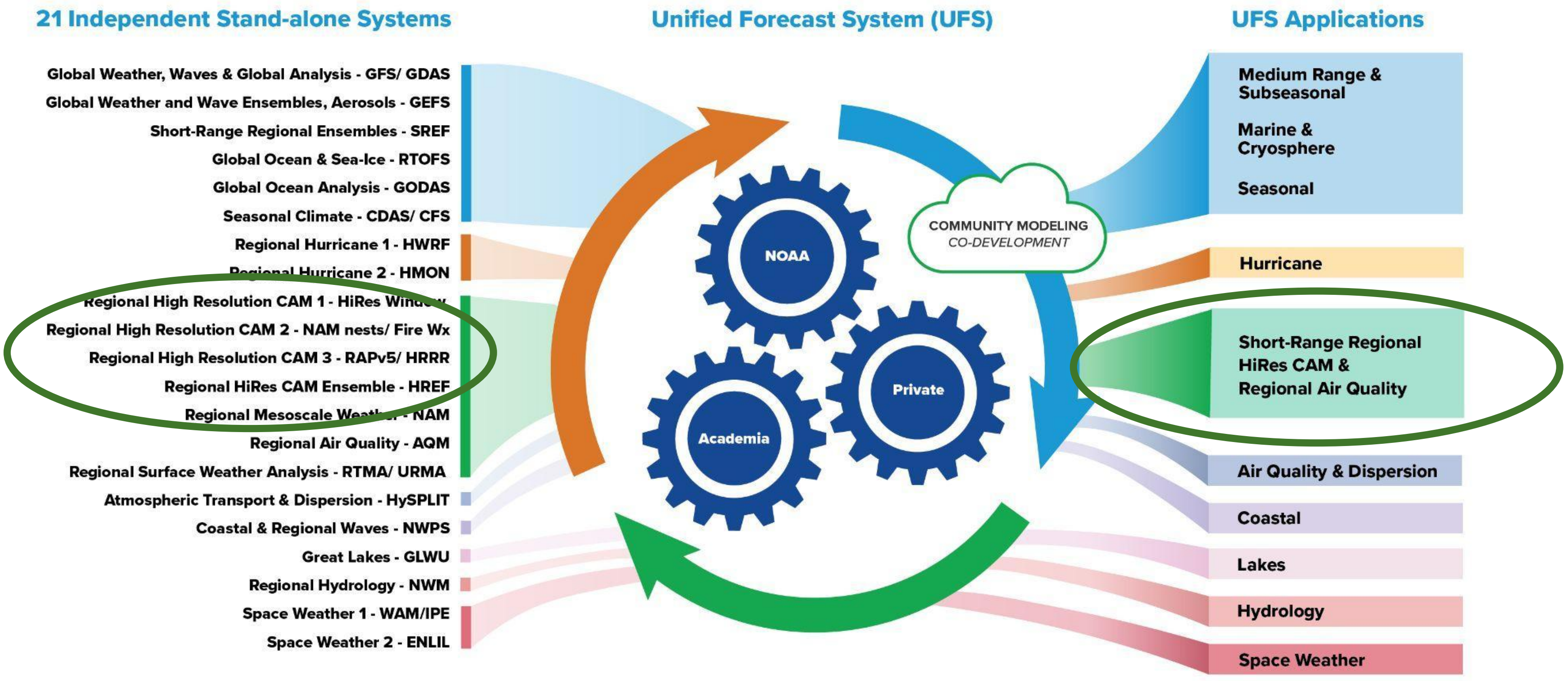
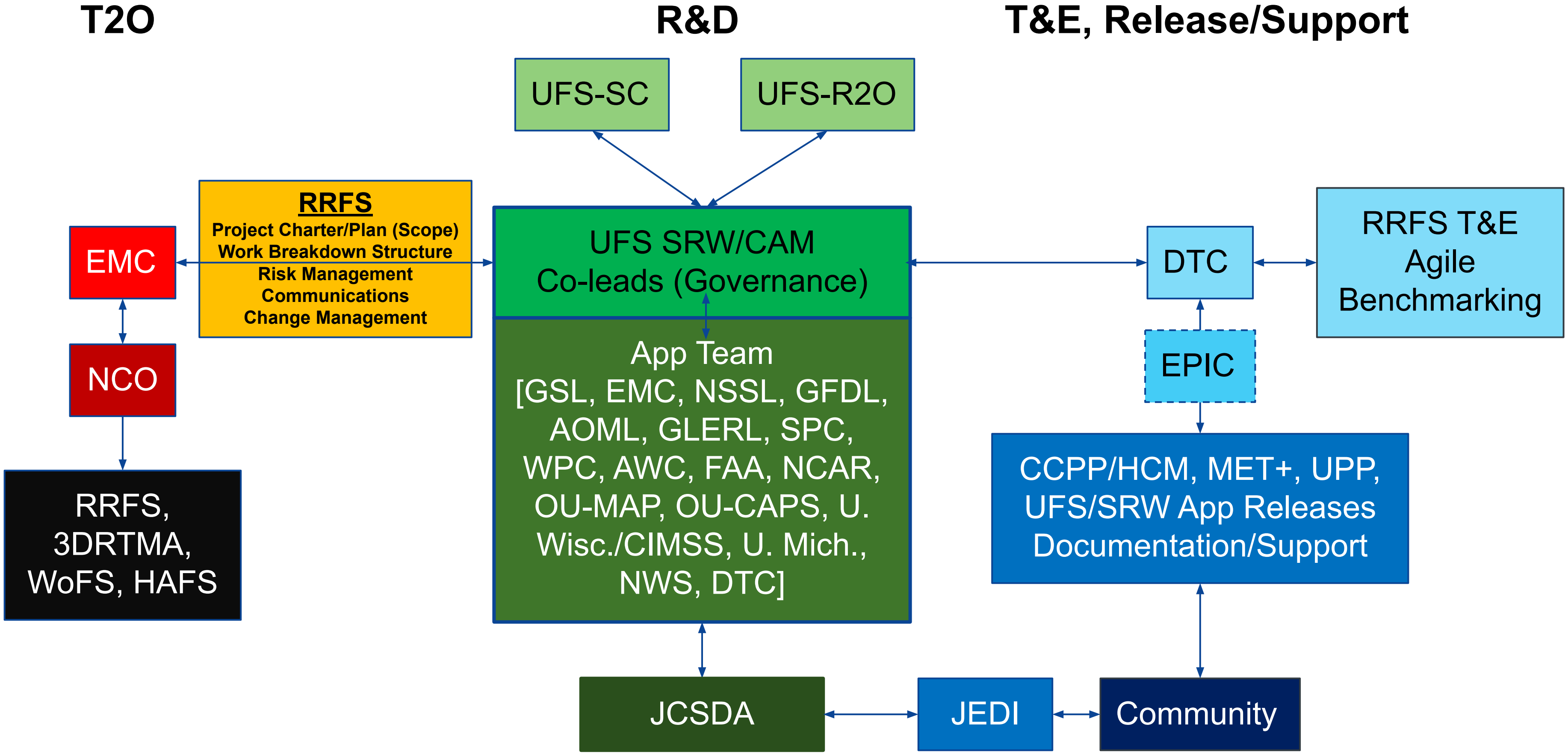


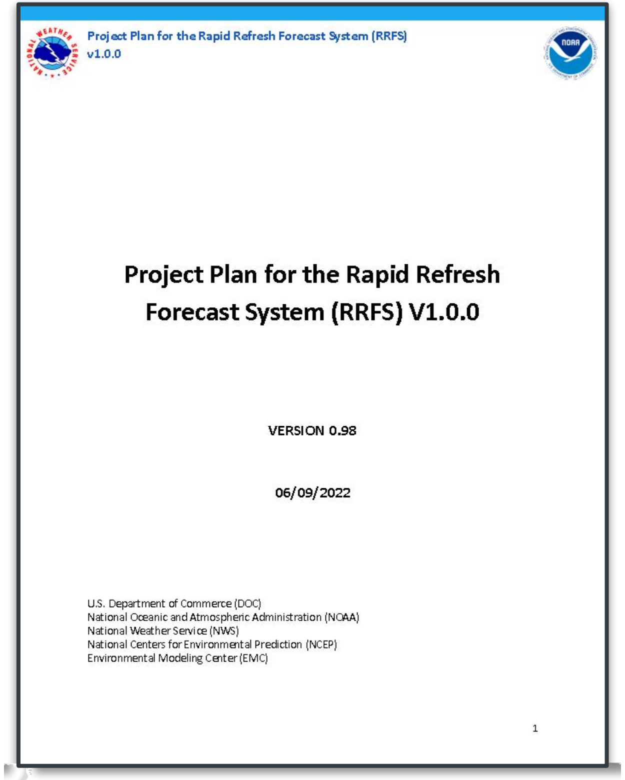
UFS Era


T2O
R&D
T&E, Release/Support
UFS-SC
UFS-R2O
RRFS
Project Charter/Plan (Scope)
Work Breakdown Structure
Risk Management
Communications
Change Management
EMC
NCO
RRFS, 3DRTMA, WoFS, HAFS
UFS SRW/CAM Co-leads (Governance)
App Team [GSL, EMC, NSSL, GFDL, AOML, GLERL, SPC, WPC, AWC, FAA, NCAR, OU-MAP, OU-CAPS, U. Wisc./CIMSS, U. Mich., NWS, DTC]
DTC
RRFS T&E Agile Benchmarking
EPIC
CCPP/HCM, MET+, UPP, UFS/SRW App Releases Documentation/Support
JCSDA
JEDI
Community

RRFSv1 Project Plan

Informed by Stakeholder Feedback and Requirements

1. HRRRv4 Implementation & Evaluation (2020)
2. HREFv3 Implementation & Evaluation (2021)
3. UFS Forecaster priority workshops (2020-2021)
4. UFS Metrics Workshops (2021)
5. NOAA Testbed reports from HWT and HMT (2020, 2021)
6. CaRDS 21-012
7. CaRDS CAM Ensemble (draft)


Project Plan for the Rapid Refresh Forecast System (RRFS)
v1.0.0

Project Plan for the Rapid Refresh Forecast System (RRFS) V1.0.0

VERSION 0.98

06/09/2022

U.S. Department of Commerce (DOC)
National Oceanic and Atmospheric Administration (NOAA)
National Weather Service (NWS)
National Centers for Environmental Prediction (NCEP)
Environmental Modeling Center (EMC)

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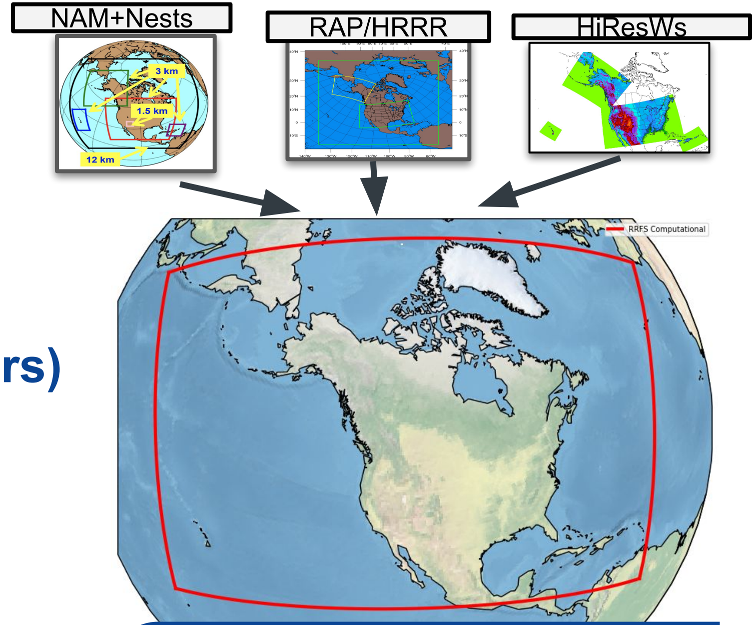
Rapid Refresh Forecast System (RRFS)

A UFS Application

- **Based on the FV3 dynamical core <u>L</u>imited <u>A</u>rea <u>M</u>odel (LAM) capability**
  - Black et al. (*JAMES*, 2021)
- **Rapidly updated**
- **Convection-allowing (~3 km grid spacing)**
- **65 vertical layers**
- **Hybrid 3DEnVar assimilation (30-40 members)**
- **Deterministic forecasts to 18h every hour**
- **Ensemble forecasts to 60h every 6 hours**
  - 9 members (+1 deterministic control)
  - IC perturbations, stochastic, & multiphysics



RRFSv1 Computational Domain

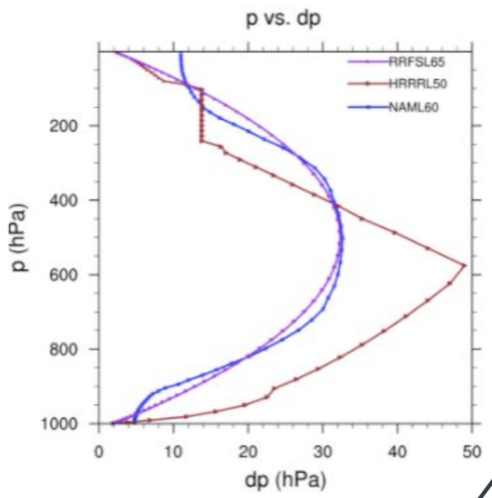
RRFS Development Status & Progress

	Model Infrastructure	Dynamics/Physics	Data Assimilation	Testing/Eval/T2O
2018-19	• FV3LAM established • ESG grid • GFS IC/LBC option	• CCPP ready	• GSI FV3LAM interface	
2020	• RAP/HRRR IC/LBC option • Initial dynamics options	• RRFSv1 alpha suite • Thompson/RRTMG • UGW/MYNN/GFS SL	• Conventional DA	• SFE/FFaIR/WWE • RAPv5/HRRRv4
2021	• SRWv1.0 app release • N. America domain • Cloud HPC deployment • 65 vertical layers set • VGF/IMS snow/ice updating	• MYNN SL • RUC/Noah LSM • SPPT • SPP • Smoke	• Partial cycling design • Soil temp/moisture adj • Radar reflectivity LH DA • Satellite clear radiances	• SFE/FFaIR/WWE • HREFv3 • DTC benchmark • MEG Alpha Eval
2022	• FVCOM Great Lakes • Ensemble ICs • UPP read ESG grid	• 8th order damping • Ensemble physics • FLAKE/CLM Lake • NoahMP LSM	• Soil temp/moisture adj • EnKF ensemble • Cloud analysis • Stoch phys in EnKF mems • EnKF recentering/coupling	• SFE/FFaIR/AWT/WWE • Agile prototyping

• Tested in real-time experiment • Some testing • More development needed

RRFSv1 Physics and Vertical Resolution

- Tested L65 and L70 configurations for 30 cases
  - Performance between L65 and L70 is very similar
  - Both improved over NAM's L60
- 1.2% increase in HPC per vertical level
  - L70 is ~%6 more expensive than L65



RRFS vertical resolution along with two historical configurations for reference.

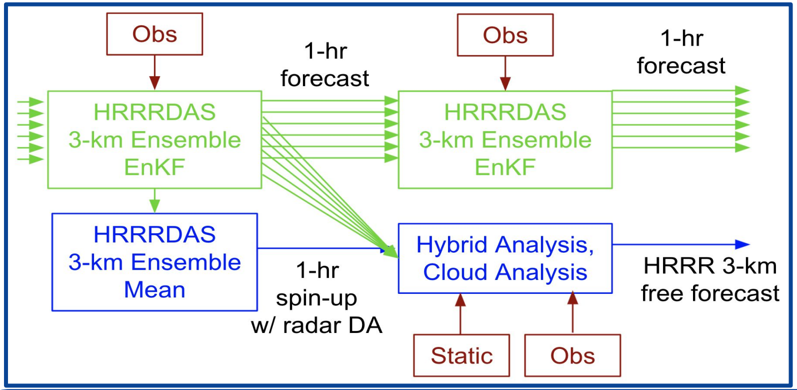
Parameter	RRFS	HRRRv4	NAMv4
Number of levels	65	50	60
Lowest level (m)	8	8	20
Top (hPa)	2	20	2
Transition to pure pressure (hPa)	45	200	300

- RRFSv1 physics suite (CCPP)
- Origin largely in HRRR physics
- Change to community LSM

Physical parameterization schemes for the RRFS.

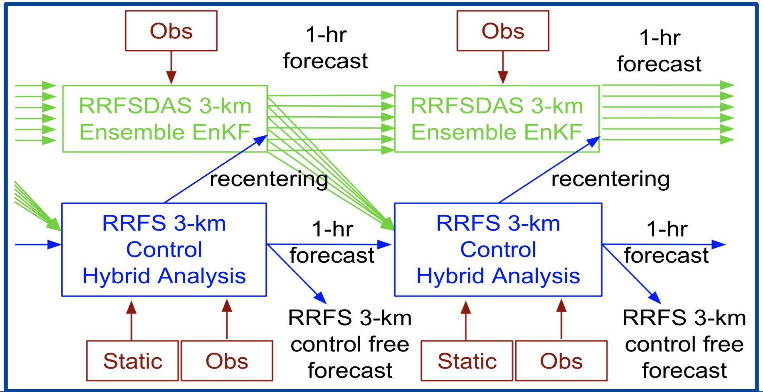
Physics	SCHEME	REFERENCE
PBL/Turbulence	MYNN-EDMF	Olson et al. (2019)
Surface Layer	MYNN	Olson et al. (2021)
Microphysics	Thompson-Eidhammer	Thompson and Eidhammer (2014)
Climatological Aerosols	Thompson-Eidhammer	Thompson and Eidhammer (2014)
Smoke and Dust	RAVE fire data, FENGSA scheme for dust	Ahmadov et al., Freitas et al., 2010
Shallow Convection	MYNN-EDMF	Olson et al. (2019) Angevine et al. (2020)
Gravity Wave Physics	Small Scale and Turbulent Orographic Form Drag	Beljaars et al. (2004) Tsiringakis et al. (2017) Toy et al. (2021)
Land Model	Noah-MP	Niu et al. (2011)
Large Lakes	FVCOM	Fujisaki-Manome et al. (2020)
Small Lakes	FLake/CLM Lake	Mironov (2008)/Subin et al. (2012), Mallard et al. (2015)
Near-Surface Sea Temperature	NSST	Fairall et al. (1996), Derber and Li (2018)
Long and Short Wave Radiation	RRTMG[3]	Iacono et al. (2008), Mlawer (1997)

RRFSv1 Data Assimilation



Operational HRRRv4 HiRes Ensemble DA

- Ensemble covariances in deterministic analysis
- Leverages ensemble mean for deterministic forecast
- *One-way* information from ensemble to deterministic forecast
- Deterministic atmospheric forecast *not* hourly cycled
- *Non*-var/*non*-hybrid cloud/radar DA in deterministic HRRR
- Deterministic forecast can fall *outside* ensemble solutions



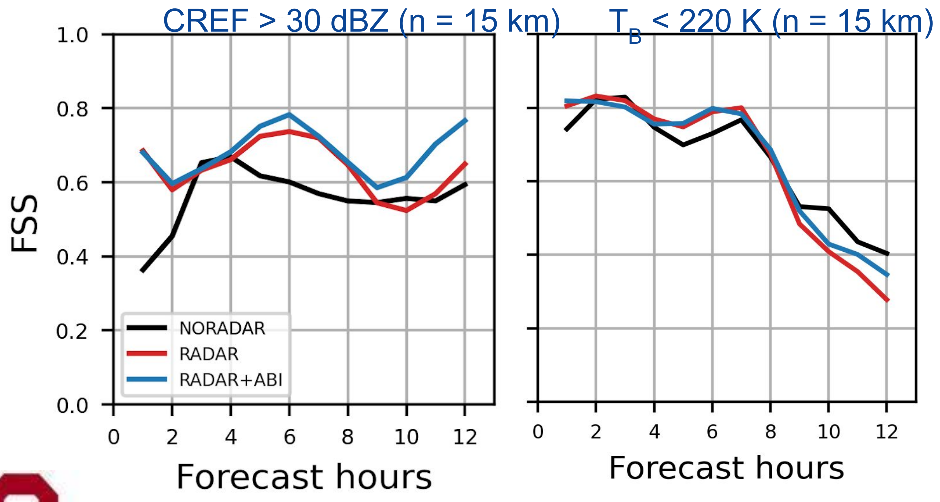
RRFSv1 HiRes Ensemble DA

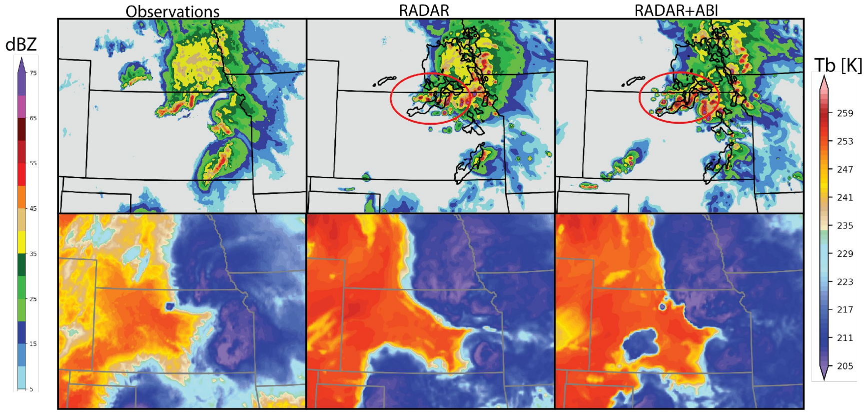
- Ensemble covariances in deterministic analysis
- Ensemble mean recentered from deterministic analysis
- *Two-way* information between ensemble and control member
- Deterministic atmospheric forecast *hourly* cycled
- Hybrid cloud/radar DA in deterministic RRFS
- Deterministic/control forecast *within* ensemble solution space

RRFS: Collaboration with OU/MAP

Impacts of assimilating GOES ABI obs. on forecasts

- Benefits from assimilating ABI observations continue into the forecast period, esp. for localized convection
- Impacts are smaller for T_b as all experiments produce too cold anvils that are larger than the obs

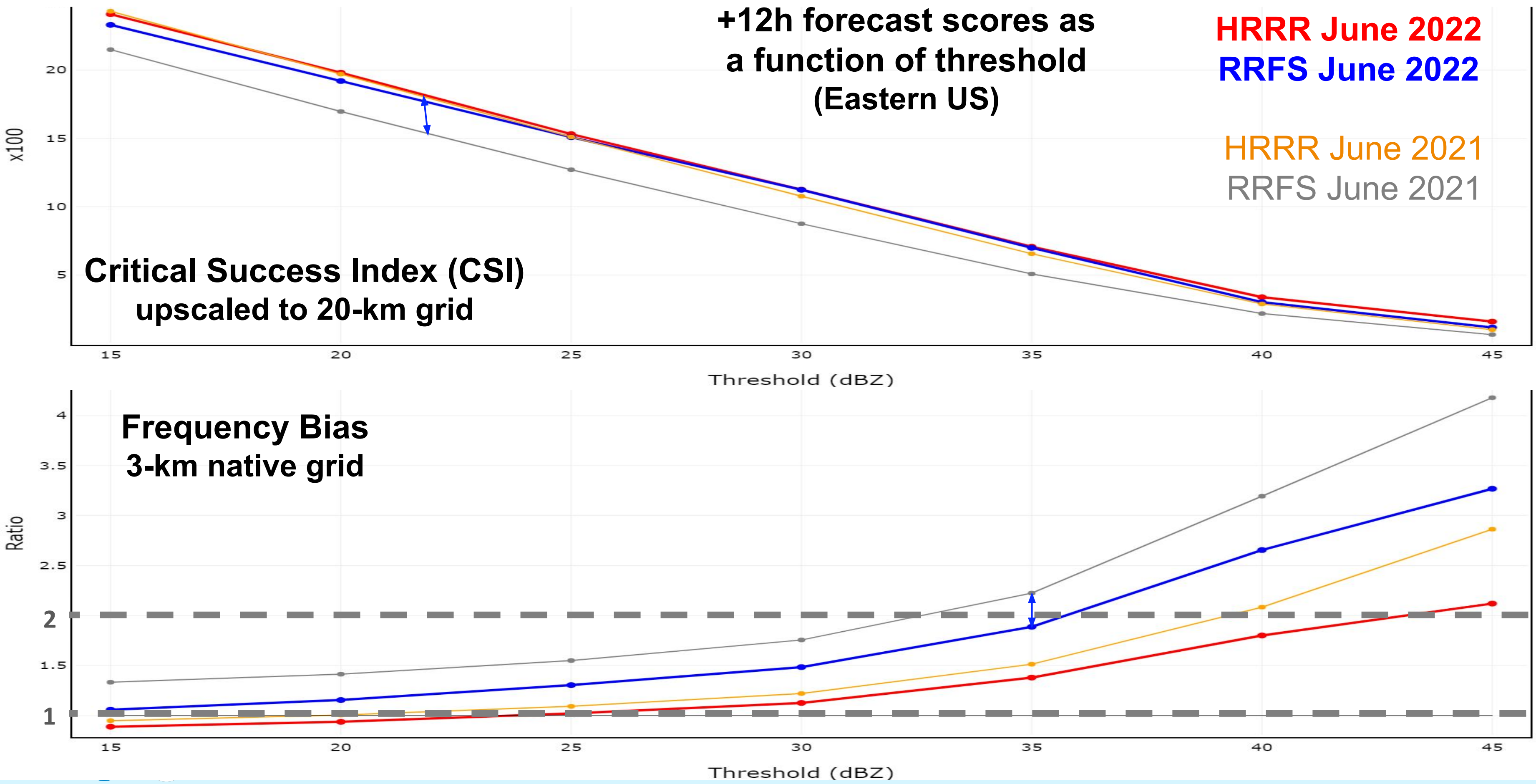




Acknowledgement to OU/MAP group

RRFS reflectivity skill closing gap compared to HRRR

control member

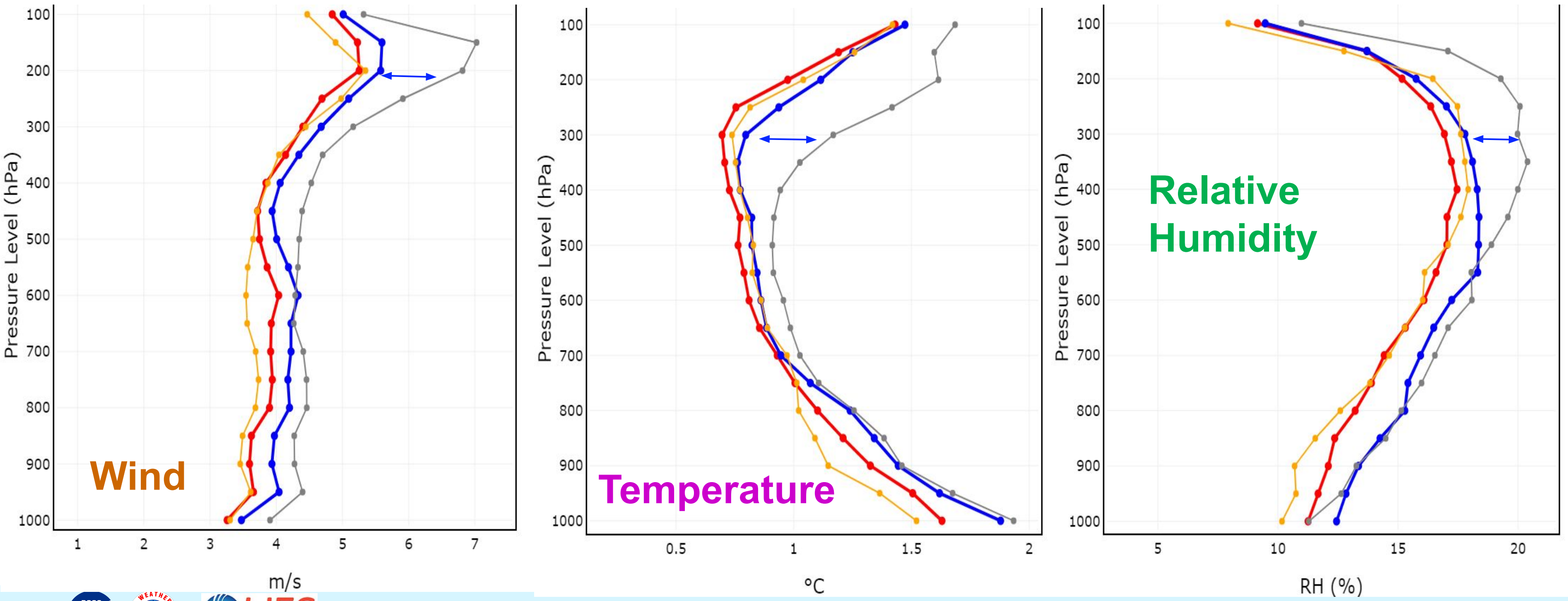


RRFS upper-air skill closing gap compared to HRRR

control member

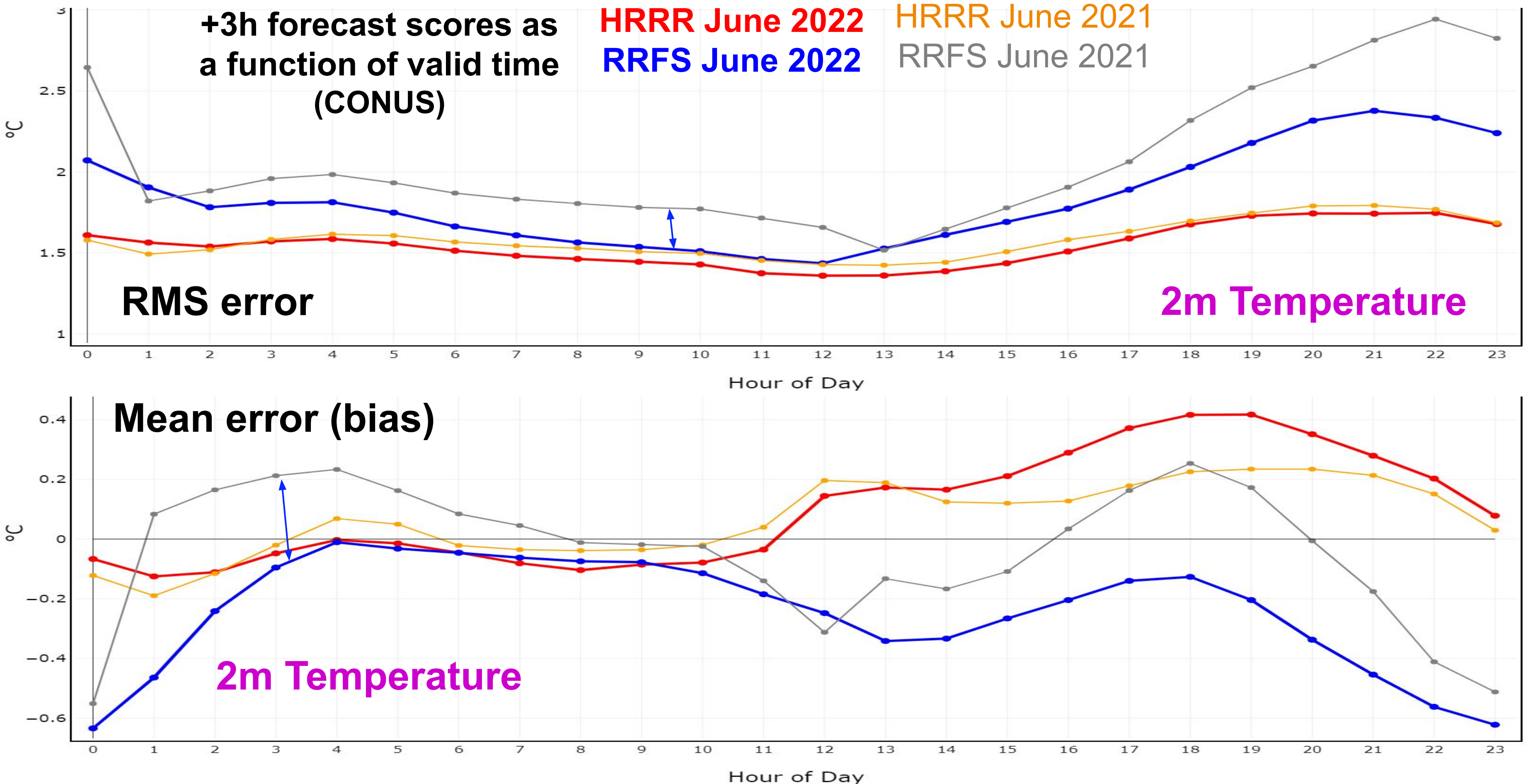
+12h forecast RMS errors

HRRR June 2022 HRRR June 2021
RRFS June 2022 RRFS June 2021



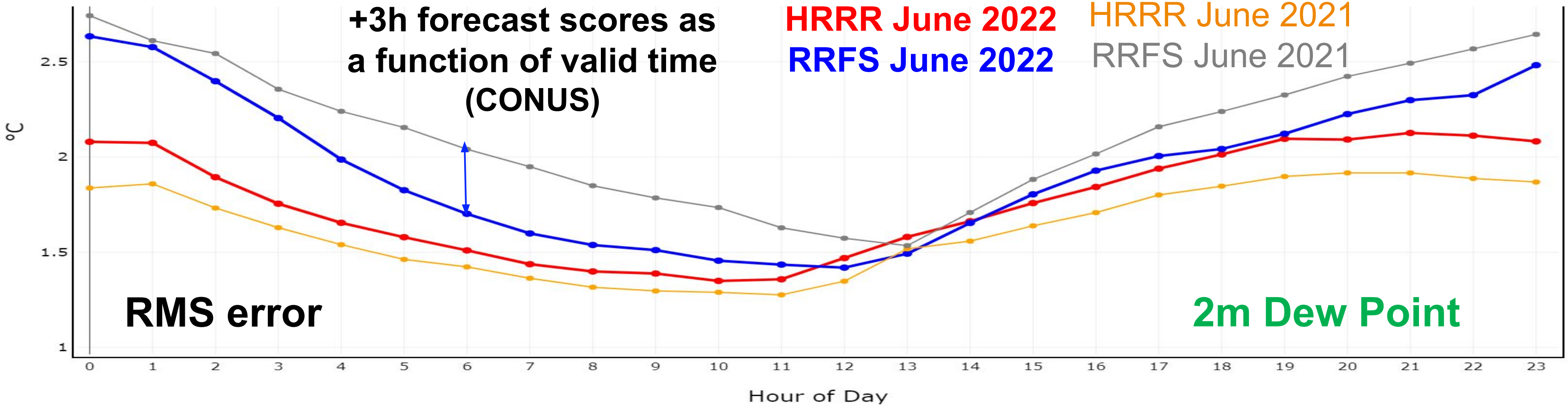
RRFS surface skill closing gap compared to HRRR

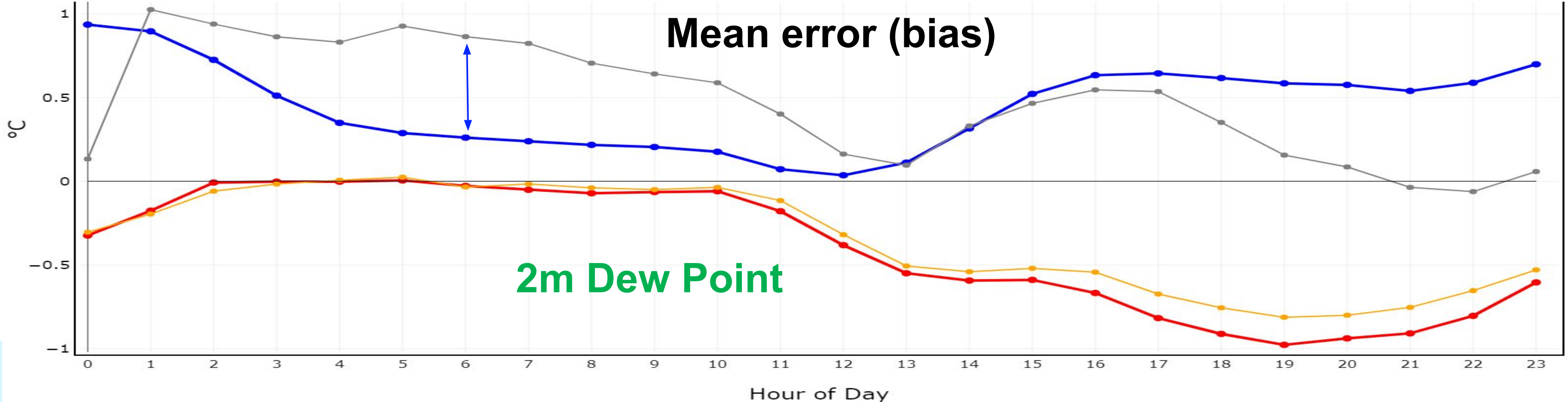
control member



RRFS surface skill closing gap compared to HRRR

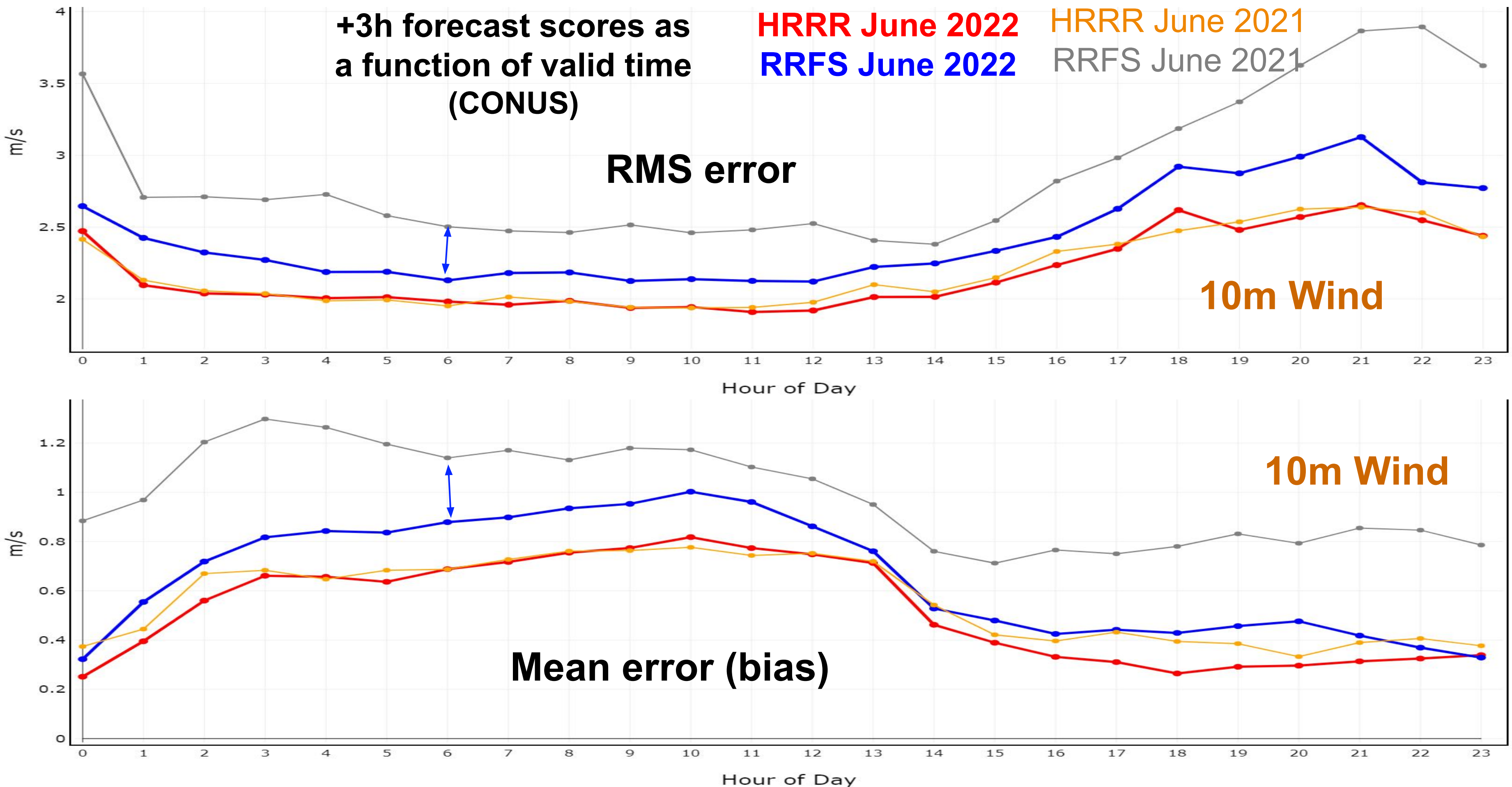
control member



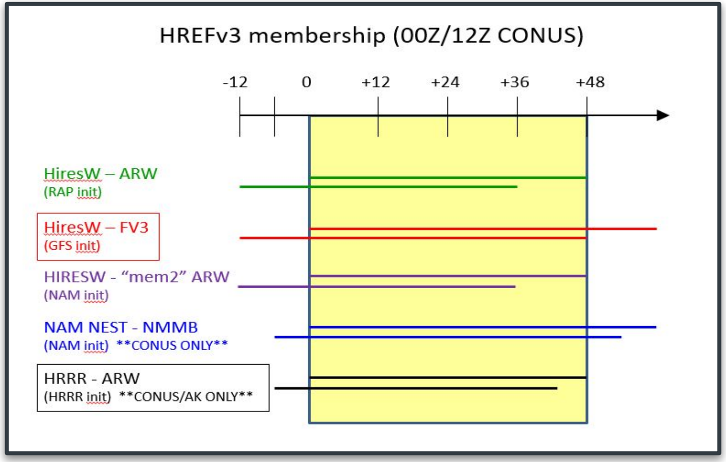


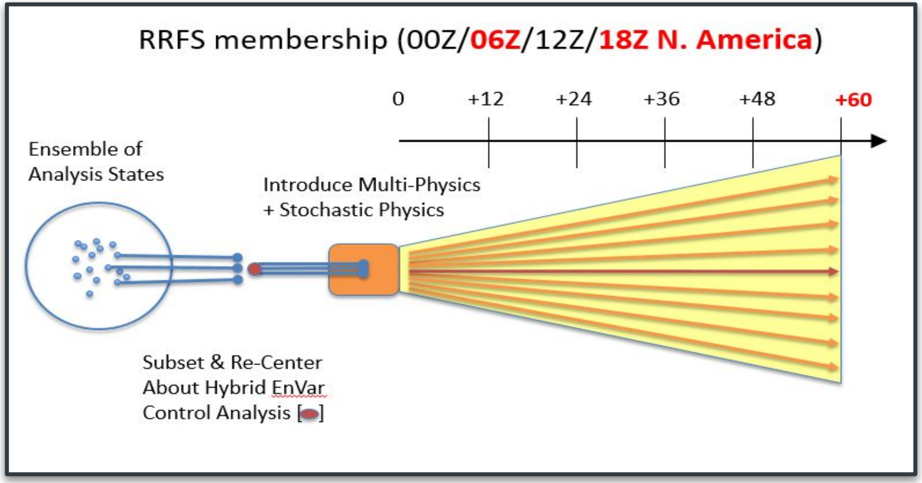
RRFS surface skill closing gap compared to HRRR

control member



RRFSv1 Forecast Ensemble Design





- 5 on time members + 5 time lagged
- 48H forecast length 2x per day
- Multi-dycore (3)
- ICs from NAM + nests, RAP, HRRR, GFS
- Multiphysics

- 9 members + control member (complete N. America coverage)
- 60H forecast length 4x per day
- Single dycore
- IC perturbations subset from 30-40 member EnKF
- Multiphysics+stochastic physics

- Single core & physics CAM ensembles designed *to date* have typically been under-dispersive vs. HREF
- RRFSv1 ensemble design leveraging HRRRE development and HIWT, DSUP, UFS-R2O projects to incorporate methods of representing uncertainty (multiphysics, SPP, etc.)
- Goal: Skillful spread & error relationship.
    - RRFSv2+ converge toward single physics to facilitate fundamental reductions in forecast error

RRFS ensemble development in AWS cloud (2021 HWT)

**Synergy with FY19 Disaster Supplemental IFHFW Project*

2021/05/03-2021/06/04 00Z cycles to 36 hours

First Real Time Prototype Test of RRFS Ensemble

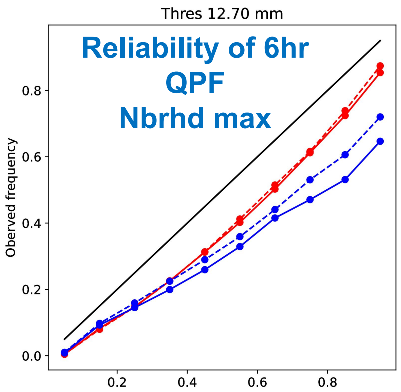
Made possible with cloud HPC

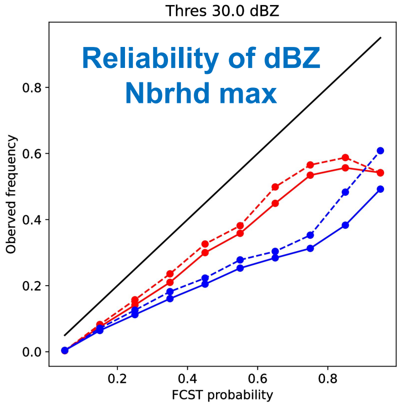
- 9 member ensemble
- 3-km North American domain
- Run in real time on AWS Cloud HPC for ***2021*** Testbeds

	IC/LBC (init from 6hr fcst)	physics	Stochastic physics
Mem1	GFS	MYNN PBL/sfc+Thompson MP	NA
Mem2	GEFS mem1	(RRFS suite)	SPPT
Mem3	GEFS mem2		SPPT/SHUM/SKEB
Mem4	GFS	TKE EDMF+GFS sfc+GFDL MP	NA
Mem5	GEFS mem1	(GFS suite)	SPPT
Mem6	GEFS mem2		SPPT/SHUM/SKEB
Mem7	GFS	Hybrid EDMF+GFS sfc+NSSL MP	NA
Mem8	GEFS mem1		SPPT
Mem9	GEFS mem2		SPPT/SHUM/SKEB

SPPT: Stochastically Perturbed Parameterization Tendencies
SHUM: Stochastically-Perturbed boundary-layer Humidity
SKEB: Stochastic Kinetic Energy Backscatter

Thanks to Ted Mansell and Larissa Reames of NSSL, Tim Supinie of OU/CAPS for their help on NSSL MP

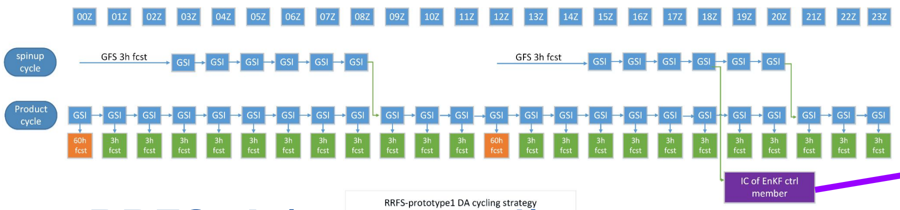




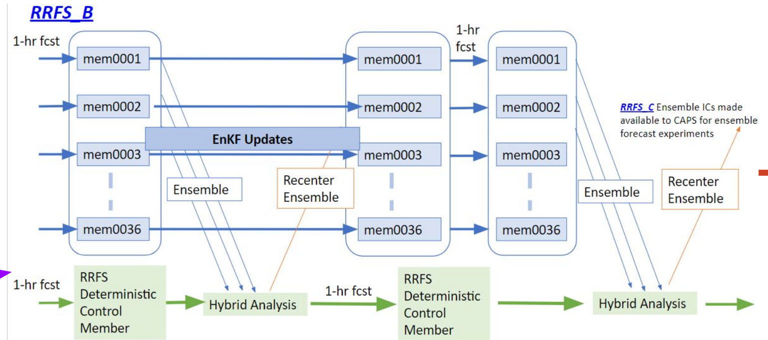
RRFS NMEP with NBR size=40 and 80 km

HREF NMEP with NBR size=40 and 80 km

Coordinated Testing and Development in NOAA Testbeds



RRFS-prototype1 DA cycling strategy



- **RRFS_A (prototype1):**
  - Running on WCOSS
  - Hourly cycling
  - Full land cycling, 2x per day partial cycle
  - Semi-coupled land DA from RAP/HRRR
  - Non-variational cloud analysis
  - Global EnKF members in hybrid

- **RRFS_B (prototype 2):**
  - Running on Jet
  - Pulls central state from RRFS_A
  - 3km, 36 member EnKF + 3DEnVar
  - Hourly cycle from 18Z to 00Z
  - Forecast to 36HR+

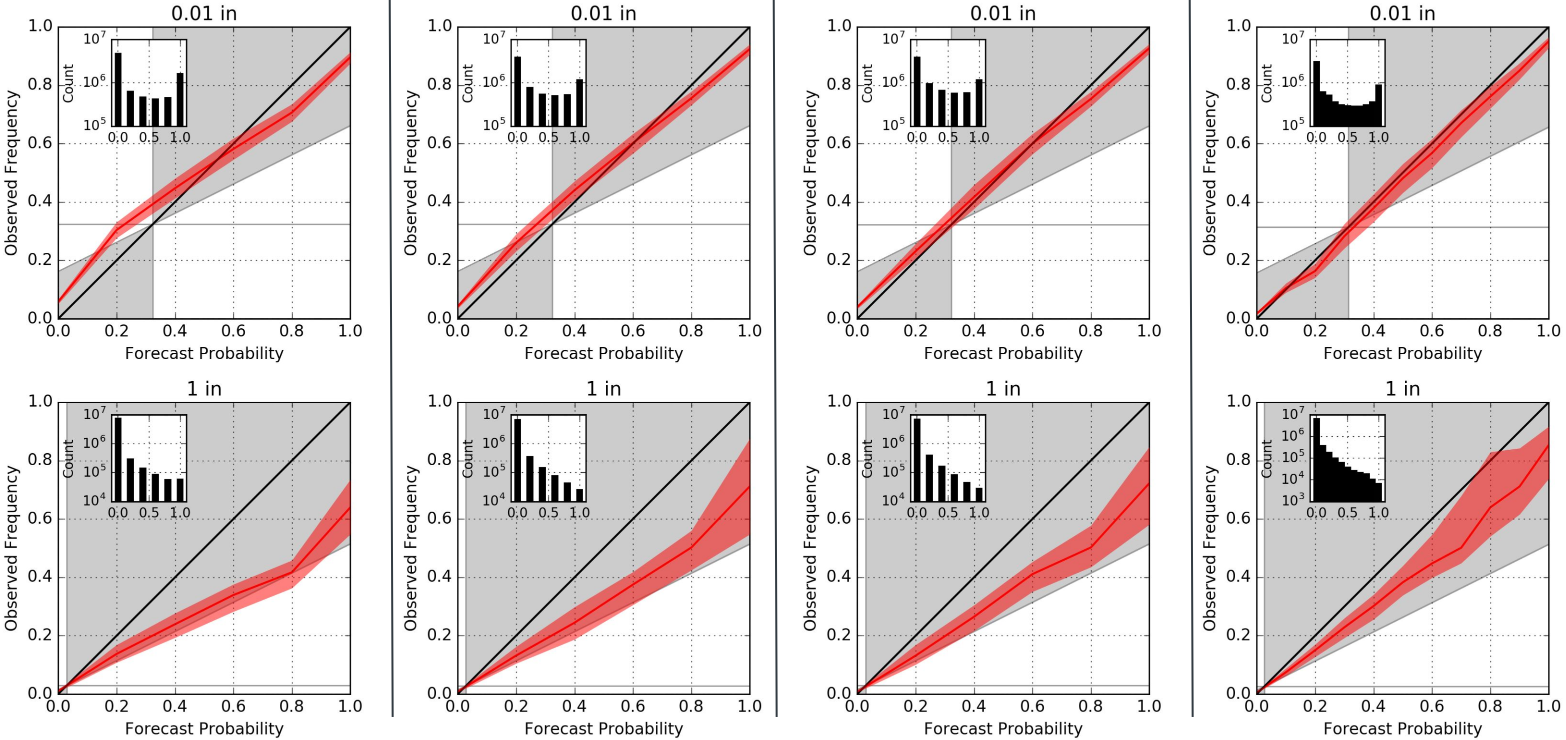
- RRFS_C (CAPS prototypes 3+):
  - Leverage ensemble of HiRes ICs from RRFS_B to conduct ensemble forecast design experiments

Successfully run in HWT/SFE and now running in HMT/FFaIR

CAPS Multi-Phy. and Stochastic Phy. Ensembles with RRFS prototype EnKF ICs (all 5 members) run during 2022 HWT Spring Experiment

24-hr QPF Reliability Comparison with HREF

RRFS Multi-Phy | RRFS Multi-Phy+IC | RRFS M-Phy+IC+Stoch. | HREF



Microphysics
Thompson
NSSL

PBL
MYNN
TKE-EDMF

LSM
NOAH
NOAH-MP
RUC

Stochastic Pert:
SPPT+SKEB+
SHUM

IC Perturbations:
RRFS EnKF

EnKF IC+Multi-physics+Stochastic Perturbations is best but slightly lower reliability than HREF

Opportunities with the Rapid Refresh Forecast System

Opportunities with the Rapid Refresh Forecast System

UFS-Short Range Weather (SRW) Application Version 2 Public Release → Foundation for RRFS

Welcome to the UFS Short-Range Weather Application wiki!

For a guide to building and running the Short-Range Weather (SRW) Application, see the SRW App User's Guide.

This repository contains the model code and external links needed to build the UFS Short-Range Weather Application, which focuses on predictions of atmospheric behavior from less than an hour to several days. The application includes a user-friendly workflow, with pre-processing (preparation of inputs), a forecast model, and post-processing. The forecast model used in this application is the UFS Weather Model: https://github.com/ufs-community/ufs-weather-model/wiki

Getting Started

Before running the Short-Range Weather (SRW) Application, users should determine which of the four levels of support is applicable to their system. Generally, Level 1 & 2 systems are restricted to those with access through NOAA and its affiliates. These systems are named (e.g., Hera, Orion, Cheyenne). Levels 3 & 4 include some personal computers or non-NOAA-affiliated HPC systems.

The Quick Start Chapter provided in the User's Guide is an excellent place for new users to begin. It provides details on how to clone the SRW App, build it, and run a forecast. Users can access the documentation for the SRW App version that they plan to run.

Documentation and User Support

The UFS Short-Range Weather Application User's Guide has the most comprehensive information on the SRW App, including links to more thorough technical instructions.

Depending on what you are doing, you may need different versions of the Users Guide:

Version	Description
Develop Branch/Latest	Documentation for the head of the development branch. This may have gaps and errors.
Release v2.0.0	Documentation for the most recent release (v2.0.0).
Tag ufs-v1.0.1	Documentation for the v1.0.1 release.
Tag ufs-v1.0.0	Documentation for the v1.0.0 release.

GitHub Code and Wiki →

https://github.com/ufs-community/ufs-srweather-app/wiki/Getting-Started

UFS Short-Range Weather App Users Guide

release/public-v2

Search docs

	SRWv2			
Physics Suite Definition	**FV3_GFS_v16p8**	**FV3_RRFS_v1beta**	**FV3_WoFS**	**FV3_HRRR**
Radiation (SW/LW)	RRTMG	RRTMG	RRTMG	RRTMG
Microphysics (MP)	GFDL	Thompson Aerosol Aware	NSSL	Thompson Aerosol Aware
Boundary Layer (PBL)	TKE-EDMF	MYNN-EDMF	MYNN-EDMF	MYNN-EDMF
Surface Layer (SL)	GFS	MYNN	MYNN	MYNN
Gravity Wave Drag (GWD)	None	SSGWD/TOFD	SSGWD/TOFD	SSGWD/TOFD
Land Surface Model (LSM)	Noah	NoahMP	Noah	RUC
Deep Convection (DCU)	sa-SAS	None	None	None
Shallow Convection (SCU)	sa-MF	None	None	None
Lake Model (LM)	NSST	NSST	NSST	NSST

Supported Physics Suites

Users Guide →

https://ufs-srweather-app.readthedocs.io/en/release-public-v2/

*Acknowledge the EPIC, DTC, and NOAA teams for their tremendous effort!

Opportunities with the Rapid Refresh Forecast System

R&D Needs → Areas Welcome for Community Contributions [*not exhaustive!*]

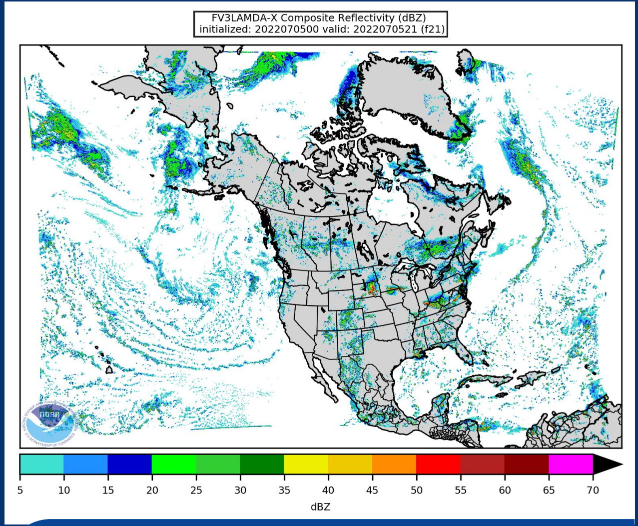
	Data Assimilation	Obs	Physics	Dynamics	Ensemble	Computing
Now (0-2 yrs)	• Multiscale/Blending • Earth System Coupling • New Forward Operators	• GOES AllSky • GLM GNSS (including ground based) • Radar	• CAM Parameterized Deep Convection (reduce high precip biases) • Higher Vertical Res Land/Lake Models	• Vertical Diffusion (reduce high convective VVs) • Physics-Dynamics Coupling	• Stochastic Physics • Ad-Hoc Schemes	• Cloud HPC
Next (2-5 yrs)	• Non-Gaussian, Non-Linear • Hybrid PFs	• UAVs • IoT • All sky • Small sats	• Improved Chem/Aer Interactions • Inline CMAQ	rban-Scale Nesting • Height-Based Vertical Coordinate	• Single Physics • AI/ML Post-Processing	• GPUs for parts of code • Domain Specific Language ports
Later (5-10+ yrs)	• AI/ML Emulator • Continuous In-Core	• All Surface • Phased array radar?	• AI/ML Emulators?	• Two-Way Nesting and couple to WoFS?	• More members	• Full code on GPUs • IPUs (1000s cores per node)

JEDI

Unify Physics Across UFS Apps

Closing

- RRFS is a major change
  - North American domain
  - 3 km ensemble
  - Rapid updates
- A community effort through the UFS
- RRFS will facilitate retirement and simplification of many longstanding systems
- Benchmark operational systems have decades of development
  - *<u>A high bar is a good thing</u>*
- RRFSv1 Implementation is planned for 2024
  - Targeting ~annual upgrade cadence thereafter



Experimental RRFS Forecast Column-Max Radar Reflectivity

Questions

Thank you!