Current Status of the Rapid Refresh Forecast System

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on behalf of the wider RRFS team

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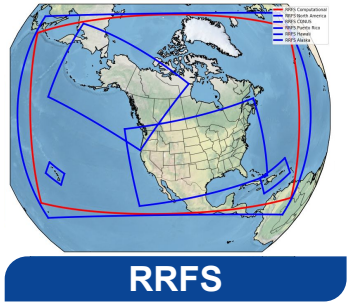


UFS
UNIFIED FORECAST SYSTEM

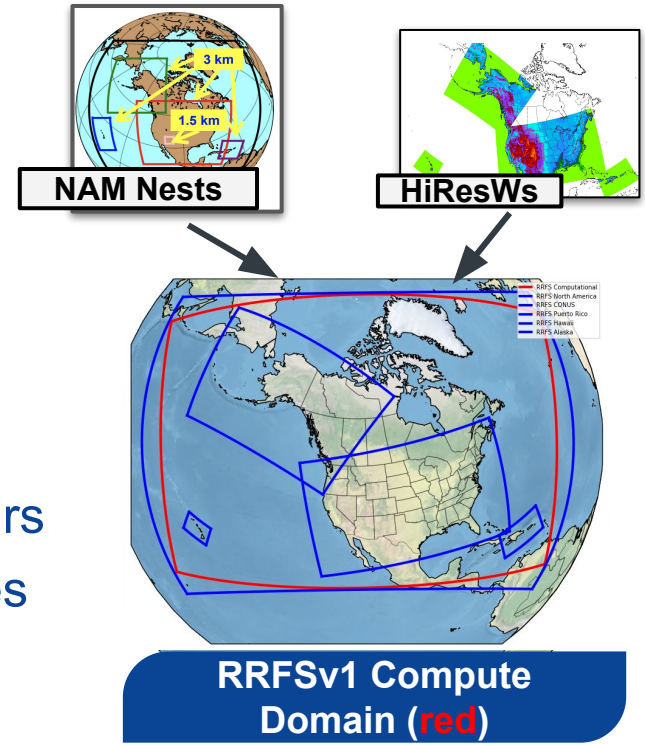
A potentially large pivot ahead for RRFSv1

- The RRFS development team pushed over the last year to optimize overall system performance ahead of a code freeze in late March this year.
- RRFS subsequently had issues with missed severe storms during the Hazardous Weather Testbed in May 2024
  - Subjective and objective skill of RRFS (particularly POD) lagged well behind top performing CAMs.
  - RRFS was relatively worse this year from SPC perspective than the 2023 version of RRFS.
- Recently, decision was made to delay RRFSv1, pulling back from the implementation process to explore alternative options.

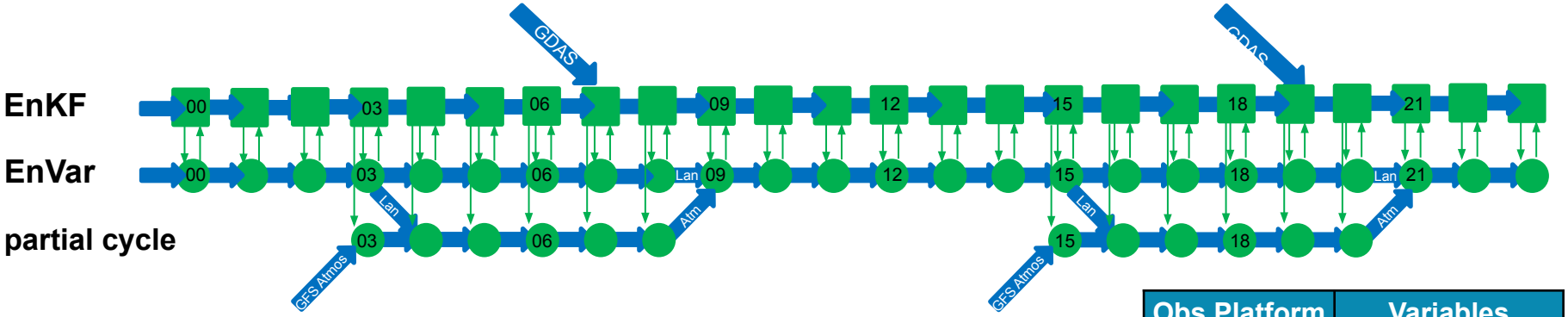
Current Rapid Refresh Forecast System (RRFS)

A UFS Application

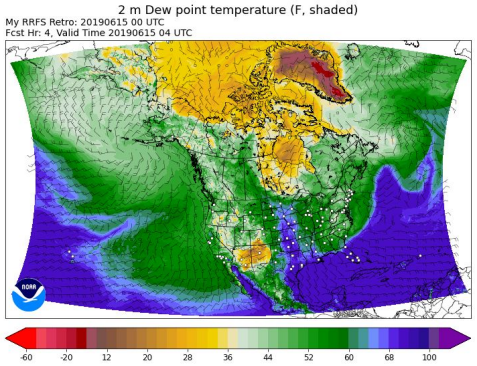
- 3 km grid spacing over North America
- FV3 dynamical core
- Hourly updated
- 65 vertical layers
- Hybrid 3DEnVar assimilation (30 members)
- Includes Smoke & Dust
- Det. & Ensemble forecasts to 60 h, every 6 hours
- Deterministic forecasts only to 18 h, other cycles



RRFSv1 Data Assimilation



- Two-way interaction between 30 member 3-km DA ensemble ( ) and 3-km deterministic RRFS hybrid 3DEnVar analysis( )
- *Twice daily, large scale GDAS information is blended into RRFS EnKF system*
- Partial cycle spin-up of atmosphere from GFS twice per day, land states fully cyc'd



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
Lightning	Flash Extent Density
Aircraft	T, moisture, W
GOES-16/18	ABI, AMVs, cloud top pres. & T
Polar Orbiters	Radiances (AMSUA, MHS, ATMS, CRIS, IASI, SSMIS)

Changes in RRFS parallels since last year's UIFCW (1/2)

- Real time runs shifted to running over full NA domain (late July 2023)
- Shift to 32-bit physics (mid Aug 2023)
- Inclusion of Grell-Freitas deep convection to help address warm season hyper QPF/convection issues (mid Aug 2023)
- Inclusion of CLM (small lakes) (Oct 2023)
- Shift from 30h GEFS to 7h GDAS to initialize RDAS-EnKF (Nov 2023)
- Shift from a single-physics to multi-physics ensemble (Dec 2023)

Changes in RRFS parallels since last year's UIFCW (2/2)

- Inclusion of scale- and variable-dependent localization (SDL/VDL) (end Jan 2024)
- Begin assimilating GOES lightning data (Feb-Mar 2024)
- Begin blending of RRFS EnKF and GDAS EnKF (Feb-Mar 2024)
- "Streak" fix - reduced strength of 2-dz filtering, but applied over depth of atmosphere (late Mar 2024)
- Countless physics bug fixes and tweaks
- Considerable output product work, including generation of 15 minute output

The multi-physics ensemble membership

Ensemble forecasts at 00/06/12/18 UTC

Sources of spread:

EnKF ICs,
GEFS LBCs,

multi-physics,
stochastic parameter perturbations(*),
fixed parameter perturbations (#),

time-lagging

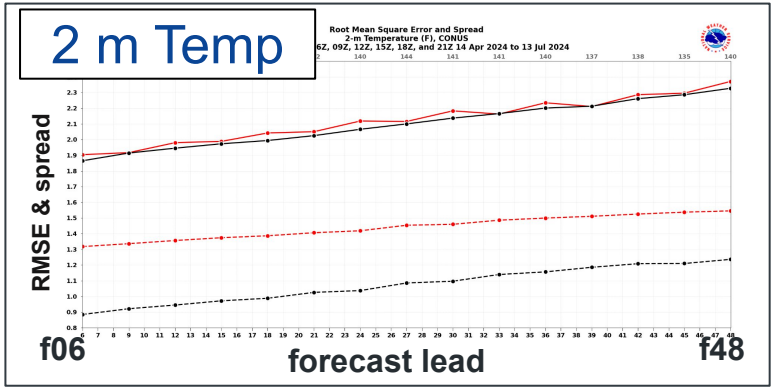
	MP	PBL	sfc	lsm	Cu	IC/LBC
m1 (ctrl)	Thompson	MYNN	MYNN	RUC	G-F deep	RRFS hybrid/GFS
m2	Thompson*	TKE-EDMF	GFS	RUC*	G-F dp*+sh	RRFS enkf1/GEFSm1
m3	Thompson*	MYNN*	MYNN*	RUC*	saSAS deep	RRFS enkf2/GEFSm2
m4	NSSL#	MYNN*	MYNN*	RUC*	G-F deep*	RRFS enkf3/GEFSm3
m5	NSSL#	TKE-EDMF	GFS	RUC*	G-F dp*+sh	RRFS enkf4/GEFSm4
m6	NSSL#	MYNN*	MYNN*	RUC*	saSAS deep	RRFS enkf5/GEFSm5
m7 (m1-6h)						
m8 (m2-6h)						
m9 (m3-6h)						
m10 (m4-6h)						
m11 (m5-6h)						
m12 (m6-6h)						
m13 (HRRR)	Thompson	MYNN	MYNN	RUC	None	HRRRDAS / RAP
m14 (m13-6h)						

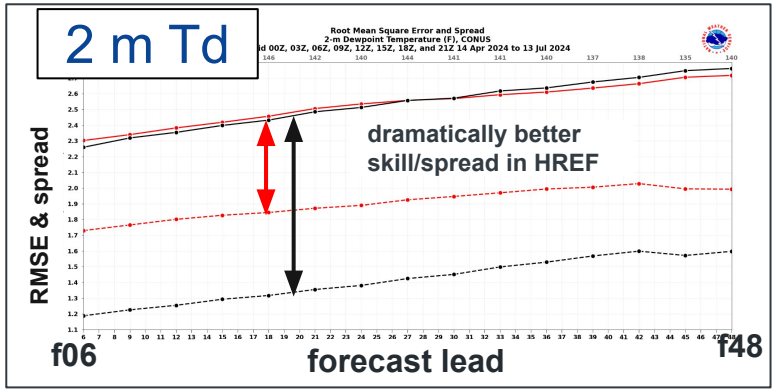
HRRR used in ensemble product gen for CONUS/AK

Thanks to Jili Dong for this work

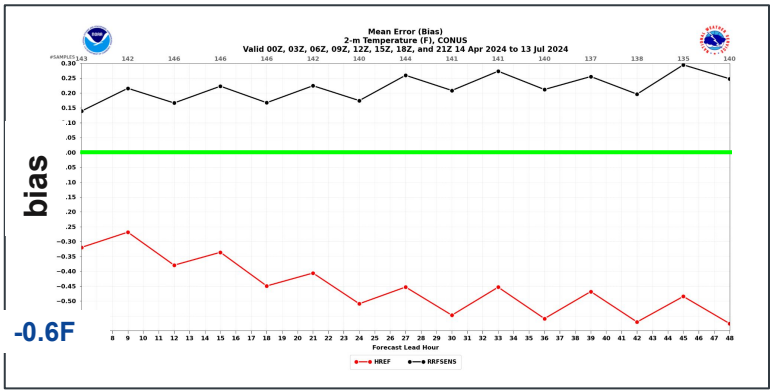
mid-Apr to mid-Jul 2024

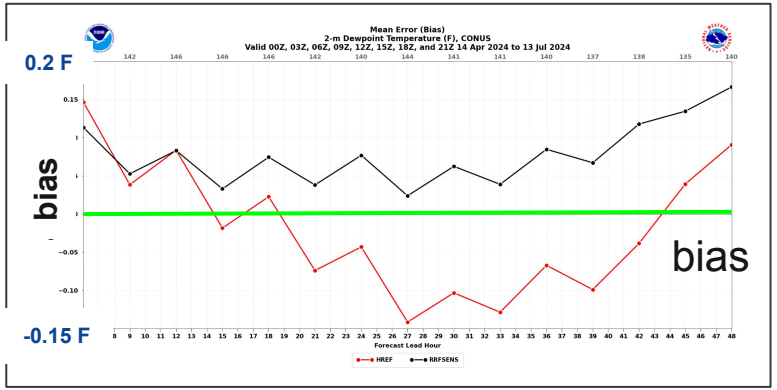
ensemble performance





REFS





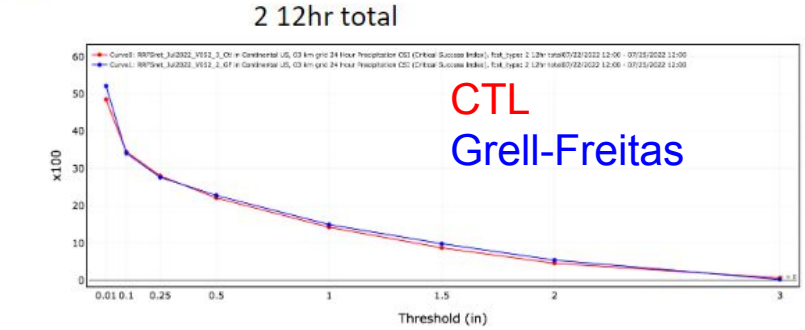
HREF

RRFS convective-storm intensity and coverage issue -

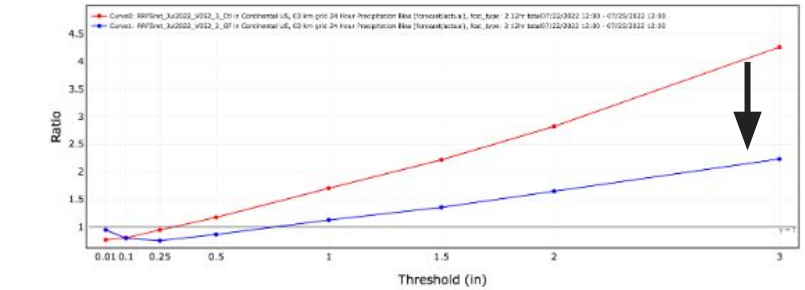
testing impact of GF convection

CSI

00Z July 20 ~ 23Z July 26, 2022

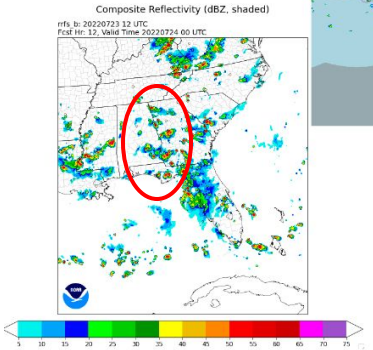


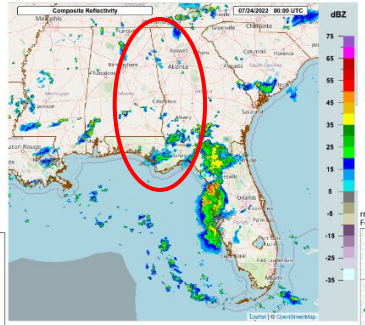
BIAS



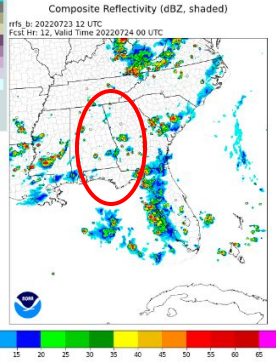
MRMS *20220724/00Z VT*

CTL





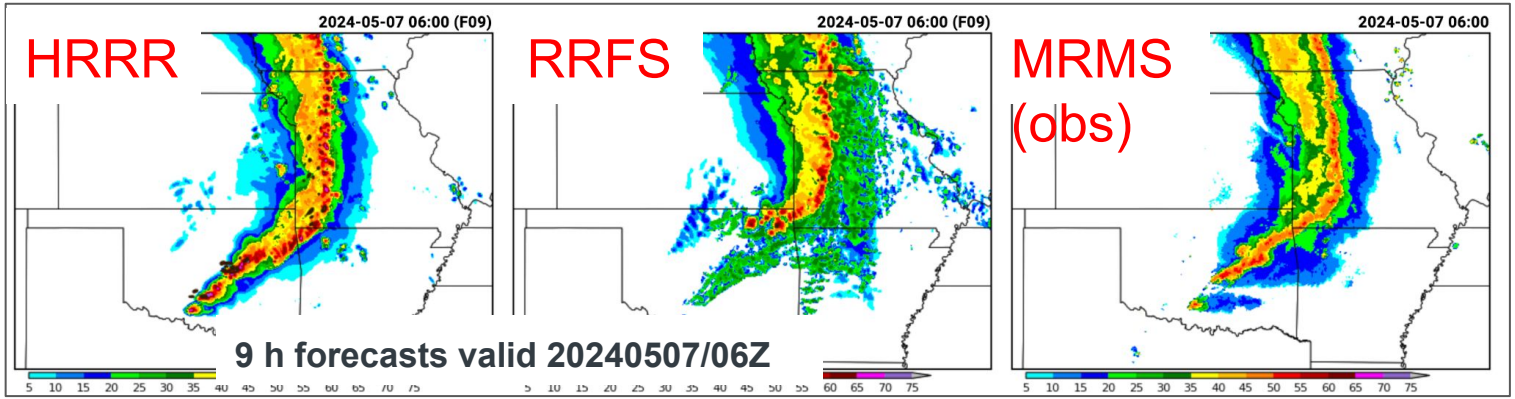
Grell-Freitas



*Thanks to Georg Grell and Haiqin Li for this work

RRFS challenges at HWT experiment

- In a tremendously active severe weather season during the 2024 HWT, the *deterministic* RRFS had numerous struggles in highlighting regions of severe weather.
  - Several cases were noted with muted convective initiation (CI) or poor retention of strong convection overnight. Use of parameterized convection likely playing a role, but running w/o parameterized Cu proved problematic for FV3 at 3 km spacing.



Day 1 00Z Composite Reflectivity (> 40 dBZ) 2024 HWT

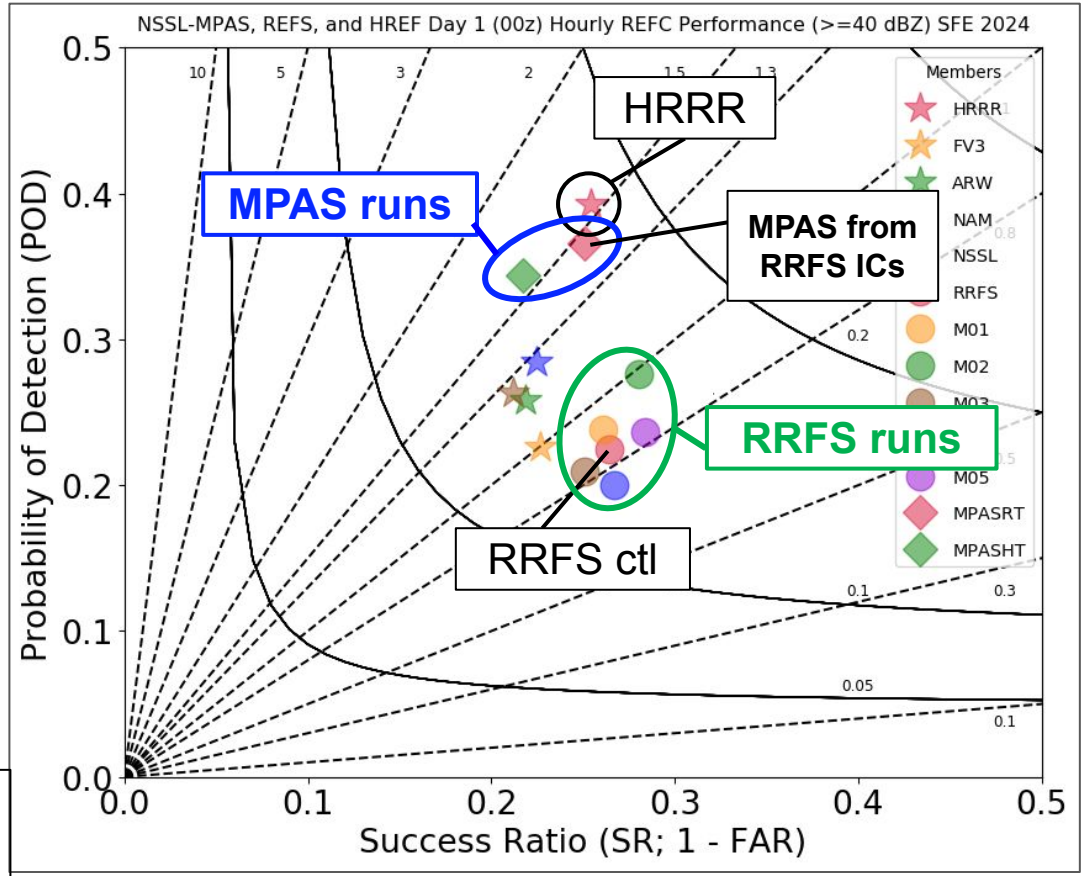


Image courtesy Jake Vancil (OU/CIWRO/SPC)

Repurposed retrospective RRFS tests

- Three months (Feb 2022, June & July 2023) of deterministic forecasts over full NA domain, using ICs from full RRFS DA system
  - Initially slated to be the final RRFS retrospectives for evaluation ahead of an operational implementation
  - With change in RRFS implementation plans, they are being repurposed to provide a benchmark of current RRFSv1 for comparison against a potential next generation RRFS prototype
  - We also have RRFS ICs saved from the 2024 HWT period - another period to explore with future retrospectives.

Evolving RRFSv1 plans

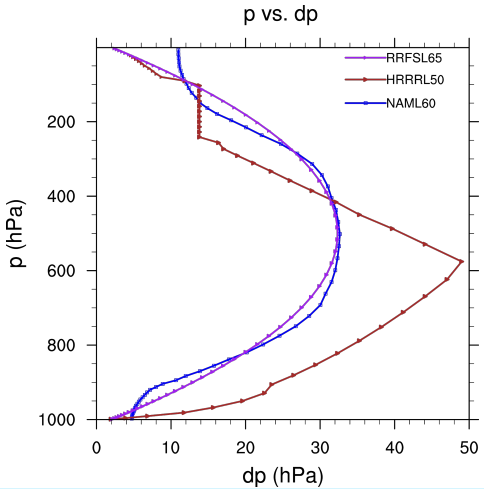
- Results from the 2024 Hazardous Weather Testbed recently led to a decision to delay the implementation of RRFSv1.
- Currently exploring ways forward with NWS leadership, including possibly shifting certain aspects of RRFS to use MPAS.
- Take home message: *we are unlikely to implement the current RRFS.*

Backup Slides

RRFS Physics and Vertical Resolution

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)
Deep Convection	Grell-Freitas	Grell and Freitas (2014)
Gravity Wave Physics	Small Scale and Turbulent Orographic Gravity-Wave & Form Drag	Beljaars et al. (2004) Tsiringakis et al. (2017) Toy et al. (2021)
Land Model	RUC LSM	Smirnova et al. (1997, 2000, 2016)
Large Lakes	FVCOM	Fujisaki-Manome et al. (2020)
Small Lakes	CLM Lake	Subin et al. (2012), Mallard et al. (2015), Benjamin et al. (2022)
Long and Short Wave Radiation	RRTMG	Iacono et al. (2008), Mlawer (1997)

Parameter	RRFS	HRRRv4	NAMv4
Number of levels	65	50	60
Lowest level (m)	8	8	20
Top (hPa)	2	20	2

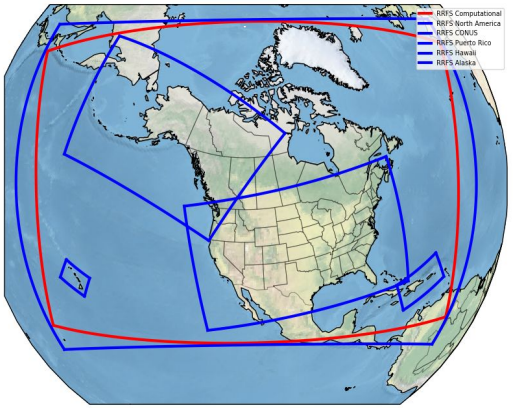


Shift to 32-bit physics

- Existing ops NWS models based on the FV3 dycore (e.g., GFS, GEFS, HAFS, ...) use 32-bit dynamics and 64-bit physics
- The historical norm for short-range regional forecast systems has been 32-bit physics (NAM, HRRR, ...)
- Shifting the RRFS from 64- to 32-bit physics:
  - reduced total restart file volume by about 1/3 (179 GB to 120.5 GB)
  - sped up forecasts by ~10-15%
  - showed minimal forecast impact

REFS Ensemble product generation

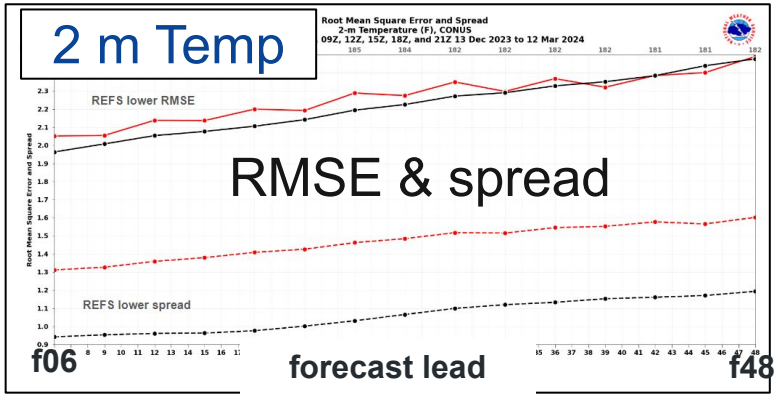
- **Membership**
  - All REFS domains include 12 RRFS members, CONUS and AK add 2 HRRR members to push to 14 total members
  - HREF membership sizes: CONUS (10), AK (8), HI/PR (6)
- **Forecast length and frequency**
  - REFS goes to 60 h, 4x/day for all domains
  - HREF goes to 48 h, 2x/day most domains
- **Output grids**
  - REFS uses output grids of RRFS (NAM nest regions) - 3 km CONUS & AK; 2.5 km PR & HI
  - HREF is processed on 5 km HiresW output grids

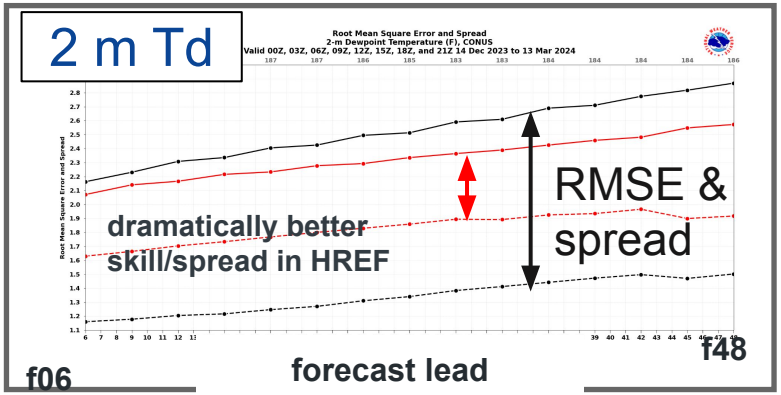


RRFSv1 Compute Domain (red)

mid-Dec 2023 to mid-Mar 2024

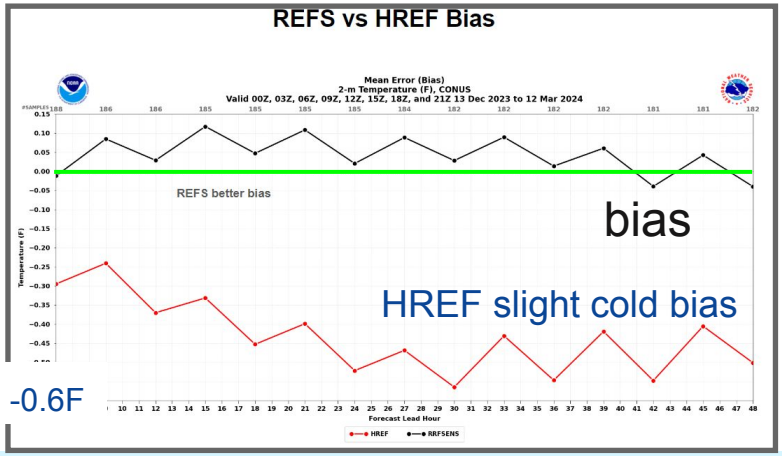
ensemble performance

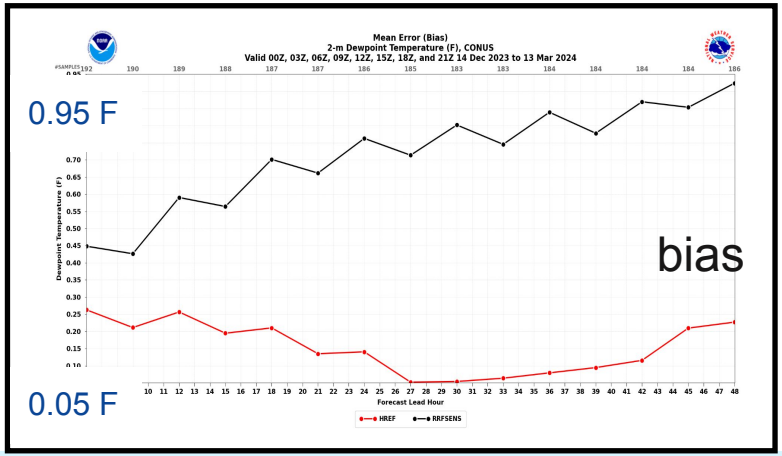




REFS

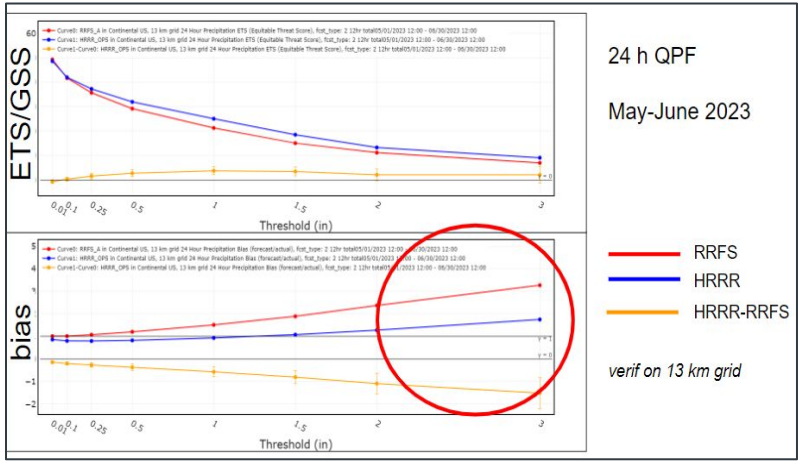
HREF





RRFS convective-storm intensity and coverage issue

- Testbeds (like FFaIR), and objective verification, have shown that RRFS prototypes have long had a high bias for heavy precipitation in the warm season
- *Grell-Freitas (GF) parameterized convection was added to RRFS (mid-Aug 2023) to help mitigate this issue, with additional follow on tuning:*



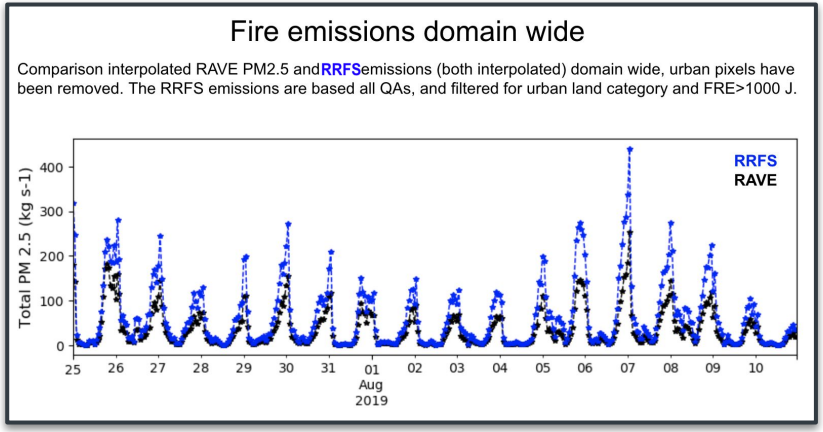
  - GF is not called if the boundary layer scheme's (MYNN) shallow convection scheme is active
  - Disabled congestus convection, but slightly *decreased* the characteristic cloud size for deep convection
  - Apply scale-aware scaling of GF deep *only* when the microphysics scheme is *not* active
  - Convective cloud condensate from GF is coupled to radiation via subgrid scale cloud fractions
  - Radar reflectivity from GF is included in the total reflectivity output from the model

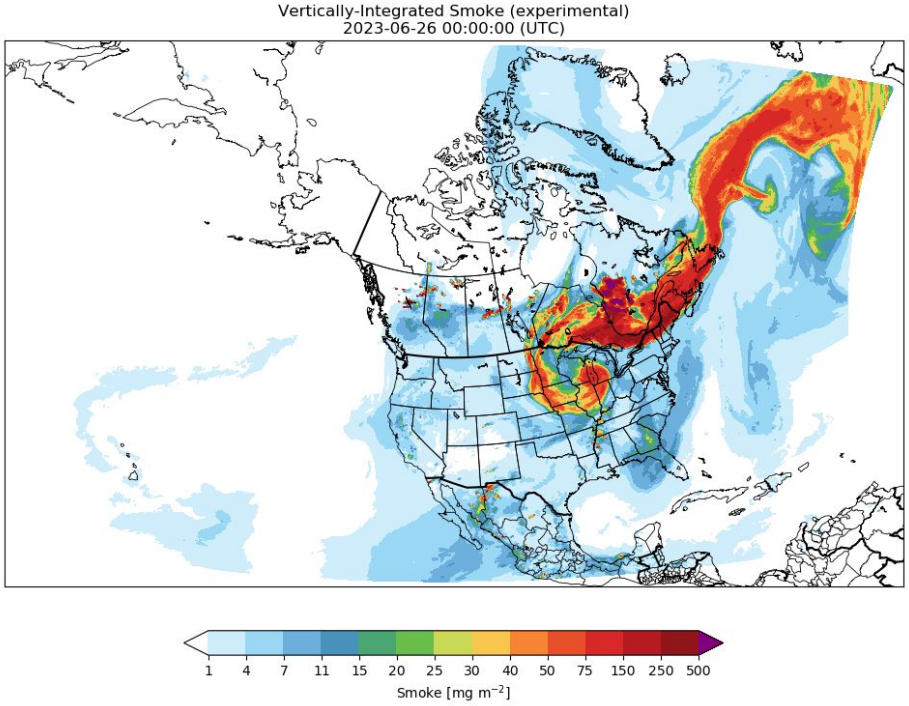
*Thanks to Georg Grell and Haiqin Li for this work

Smoke and Dust

- Included in 3-km RRFS over North America
- Input data: RAVE Emissions
  - Fire Radiative Power → plume rise
  - Fire Radiative Energy → estimate emissions

RAVE → Regional Hourly Advanced Baseline Imager (ABI) and Visible Infrared Imaging Radiometer Suite (VIIRS) Emissions

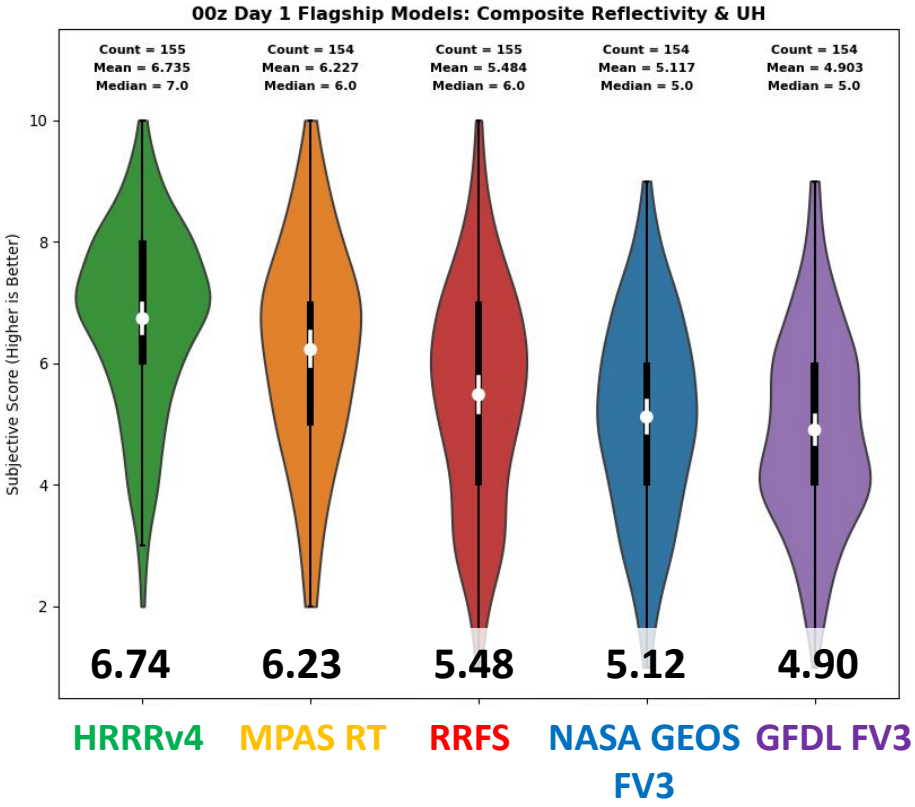




3 km vertically integrated smoke forecast from 26 June 2023 depicting impact from Canadian wildfires

*Thanks to J. Romero-Alvarez (GSL), R. Ahmadov (GSL), B. Baker (ARL), and P. Bhattacharjee (EMC) for material on this slide

2024 Day 1 Deterministic Flagships: Composite Reflectivity & UH



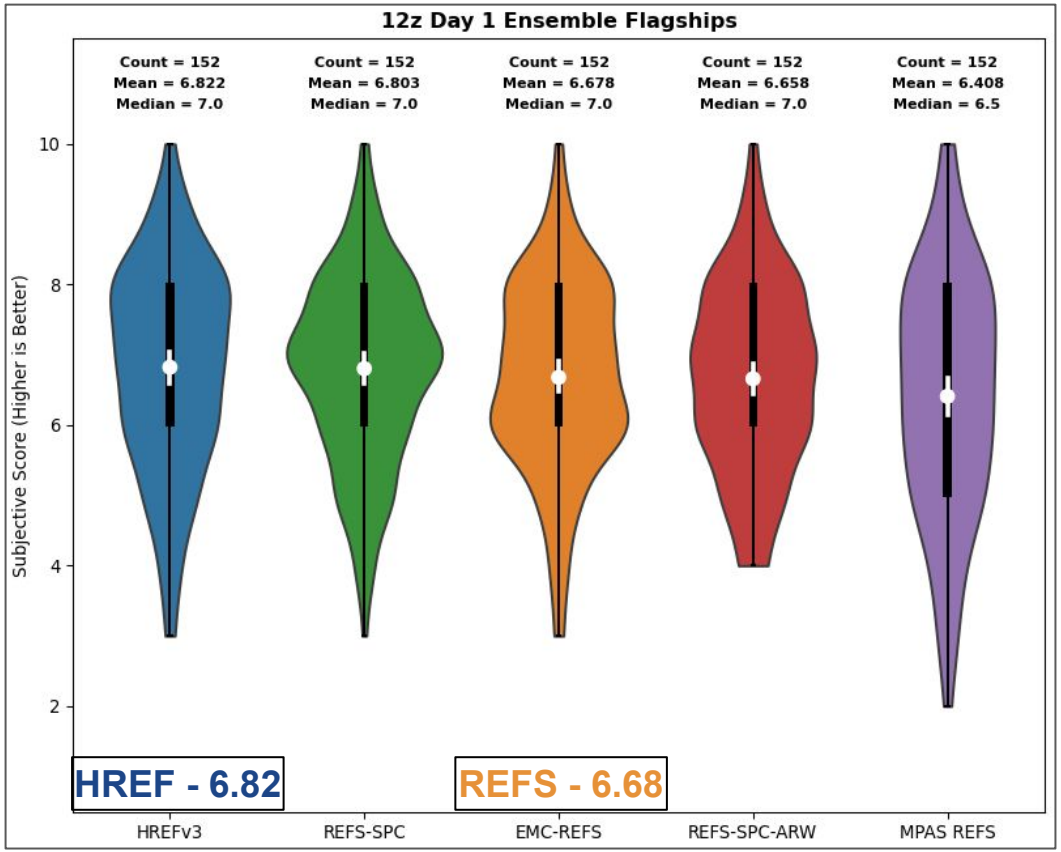
Change in mean subjective ratings relative to 2023.

	2024	2023
HRRR ↑	6.74	6.45
MPAS ↑	6.23	6.14
RRFS ↓	5.48	5.68
NASA-GEOS ↑	5.12	4.15
C-SHiELD ↓	4.90	5.23

- HRRRv4 was clear top performer & differences in average ratings were significant (paired student's t-test).
- MPAS RT was clear runner-up & differences w.r.t lower rated models were significant (including RRFS).
- Order of ratings was same as last year, except NASA-GEOS and GFDL FV3 (C-SHiELD) have switched places.
- HRRR, MPAS, and NASA-GEOS ratings went up this year, while RRFS and C-SHiELD went down.

slide courtesy Israel Jirak/Adam Clark

12Z HWT Ensemble Comparison (Day 1): Storm Attributes



plot courtesy Israel Jirak/ Adam Clark

Based on subjective evaluations, REFS was fairly competitive with HREF (surprising given deterministic RRFS performance).

REFS best in this comparison for Day 2 (not shown), dramatically different than 2023 HWT where Day 2 REFS performance was a concern.

“Streak” case in North Pacific, 20231205/18Z cycle