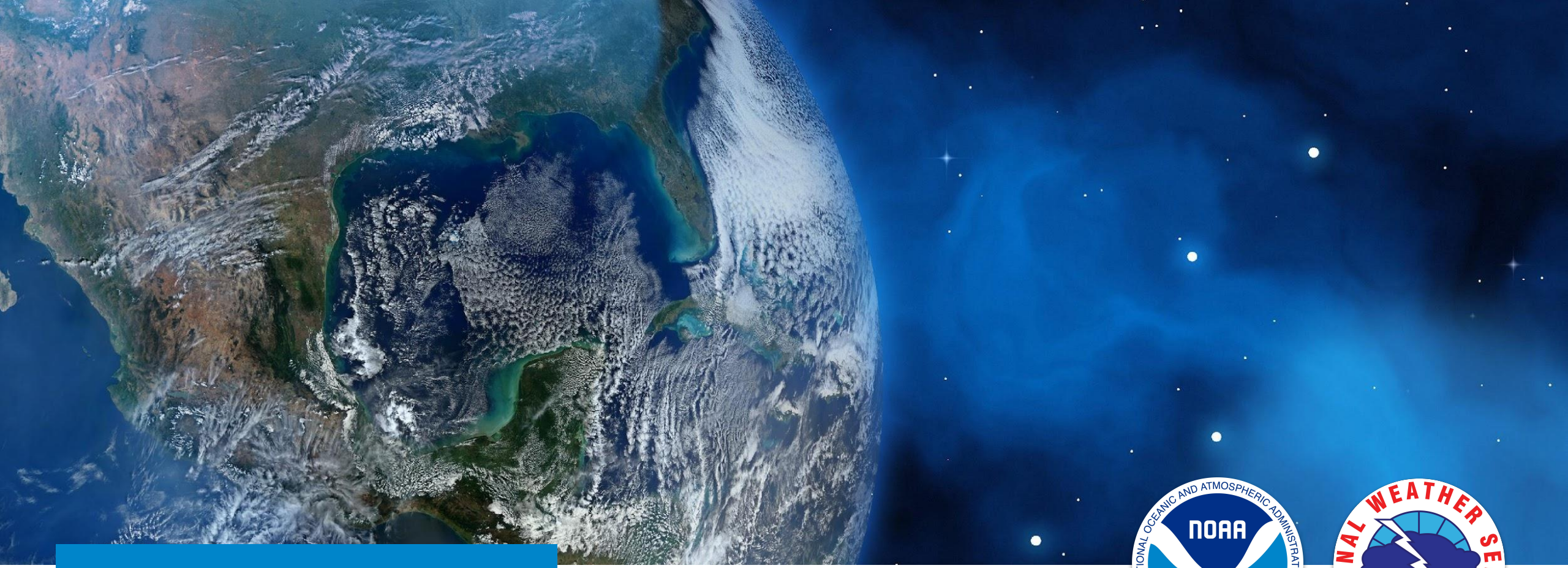


RRFS/REFS Webinar

Matthew Pyle, NWS/Office of Modeling and Development (OMD)

on behalf of the broader RRFS team

AI Disclaimer: “Google Gemini was used to assist with the creation of some of these slides. The content has been reviewed, edited, and validated by NWS staff.”

U.S. Department of Commerce

National Oceanic and Atmospheric Administration

National Weather Service

Collaboration on RRFS development

Development and evaluation of the RRFS has been a hugely collaborative effort between NWS/OMD, NOAA GSL, and ....

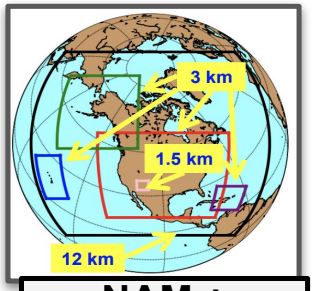
Webinar Outline

- What are RRFS & REFS?
- What is getting retired? What *isn't* getting retired?
- RRFS & REFS Products
- RRFS & REFS relative strengths and weaknesses
- Post-evaluation changes to RRFS (lake mask fix, 2 m Td change)
- Timeline for RRFSv1, and plans beyond this initial version

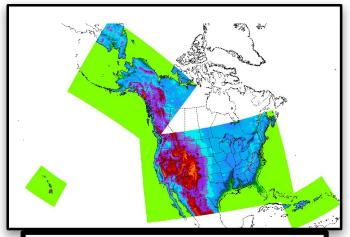
The Rapid Refresh Forecast System (RRFS) v1

A UFS Application

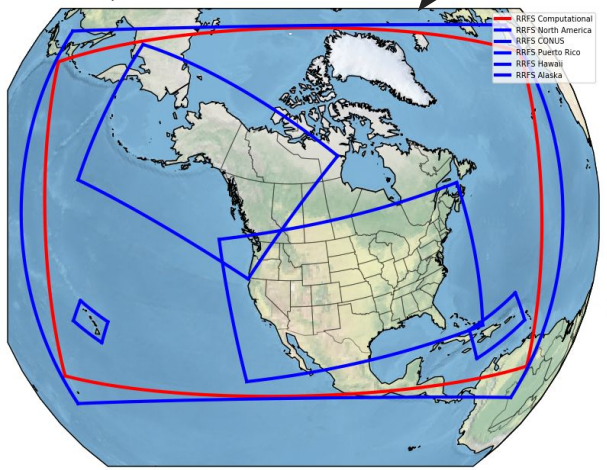
- 3-km grid spacing over North America
- FV3 dynamical core
- Hourly updated
- 65 vertical layers
- Hybrid 3DEnVar assimilation (30 members)
- Deterministic forecasts to 84 h, ensemble forecasts to 60 h, and a 1.5 km “firewx” domain to 36 h for 00/06/12/18Z cycles
- Deterministic forecasts only to 18 h, other cycles
- Deterministic runs include *smoke & dust*



NAM + NAM Nests

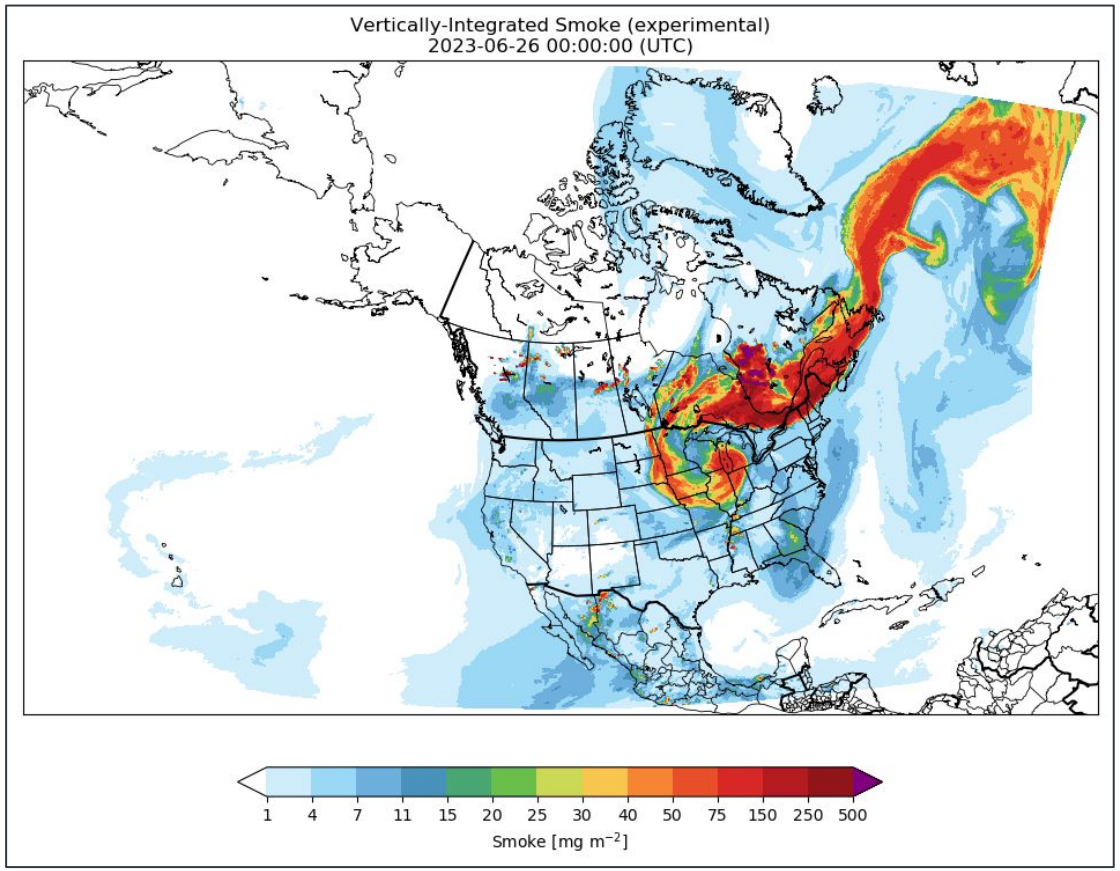


HiResW/ HREF



RRFSv1 Compute Domain (red)

Smoke and Dust



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 (now OMD), and P. Bhattacharjee (OMD) for material on this slide**

RRFS ensemble forecast design and membership

Ensemble spread from:

- ICs from different ensemble DA members
- Lateral boundaries from different GEFS members
- Multi physics
- Stochastic (*) and fixed (#) parameter perturbations
- Time lagging for ensemble product generation

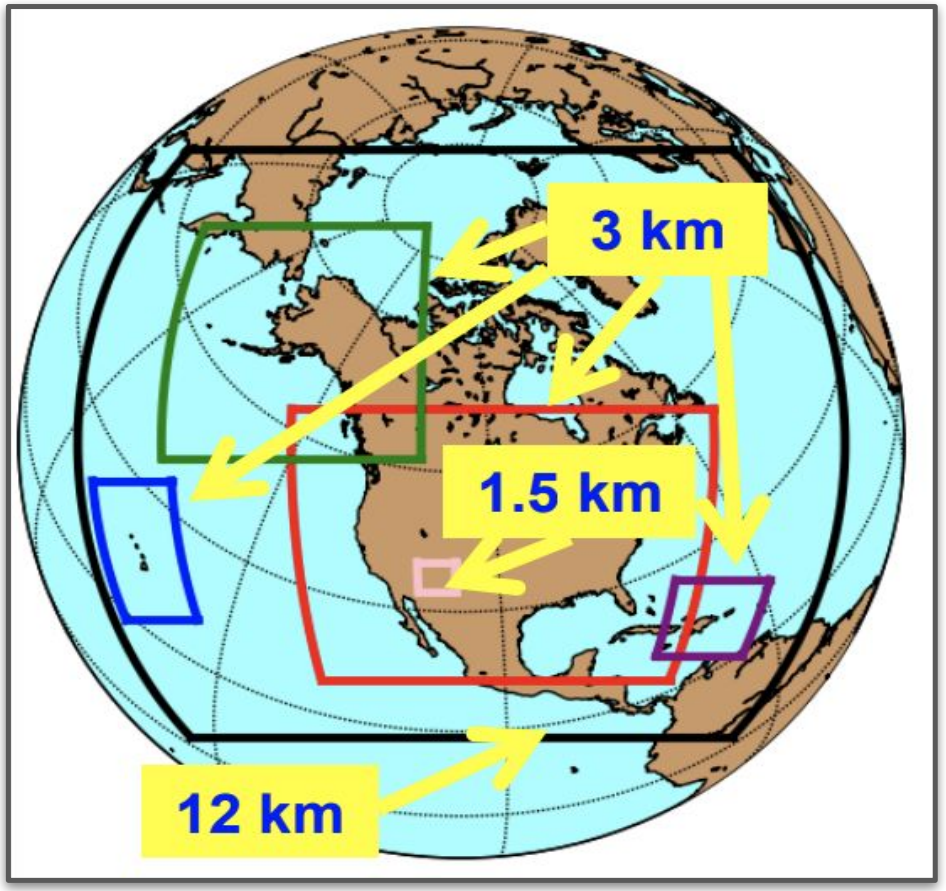
- Inclusion of HRRR for Alaska & CONUS domains

This membership feeds into the REFS ensemble product generation

	MP	PBL	sfc	lsm	Cu	IC/LBC
m1 (ctrl)	Thompson	MYNN	MYNN	RUC	saSAS 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)						

Retirements - NAM

- **NAM** (parent, nests, everything) + **NAM-MOS**

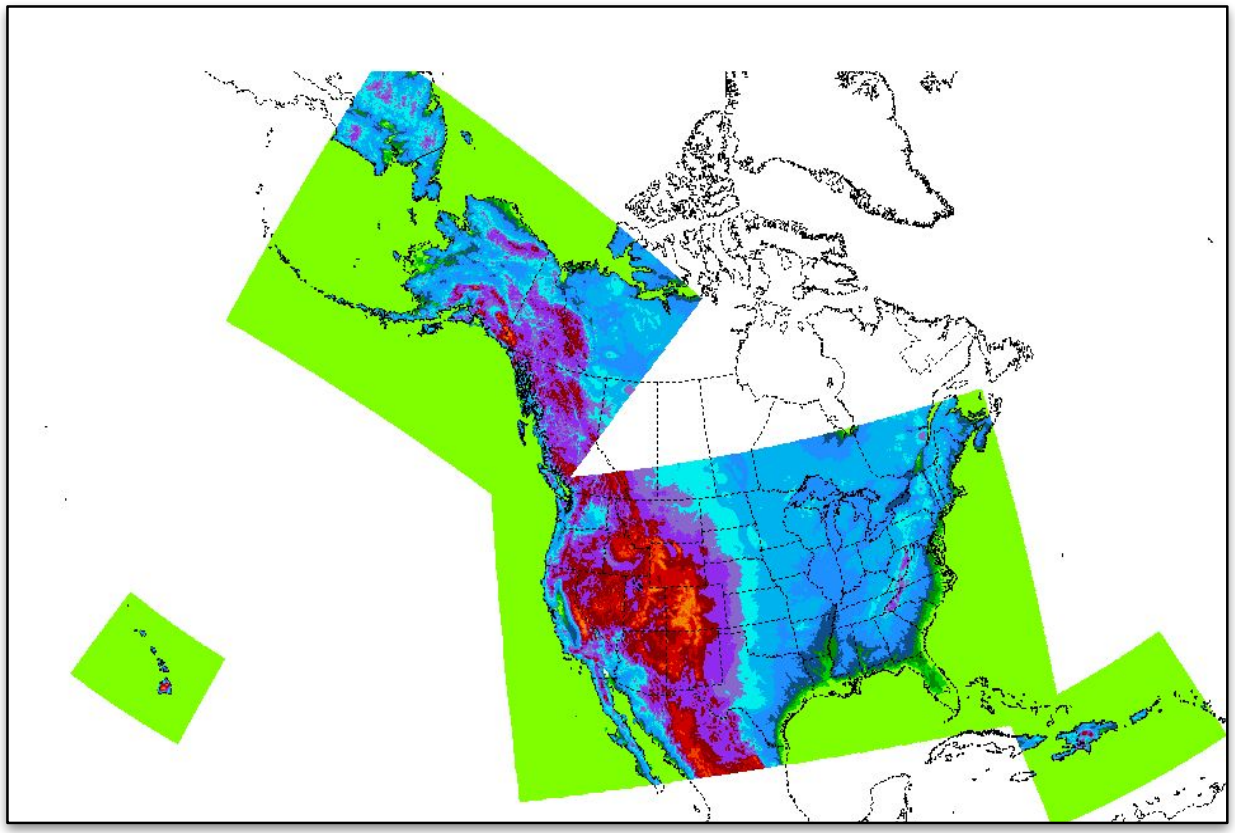


Last major upgrade of the NAM was in 2017

Retirements - HiresW and HREF

HiresW (except for Guam which is not covered by RRFS domain)

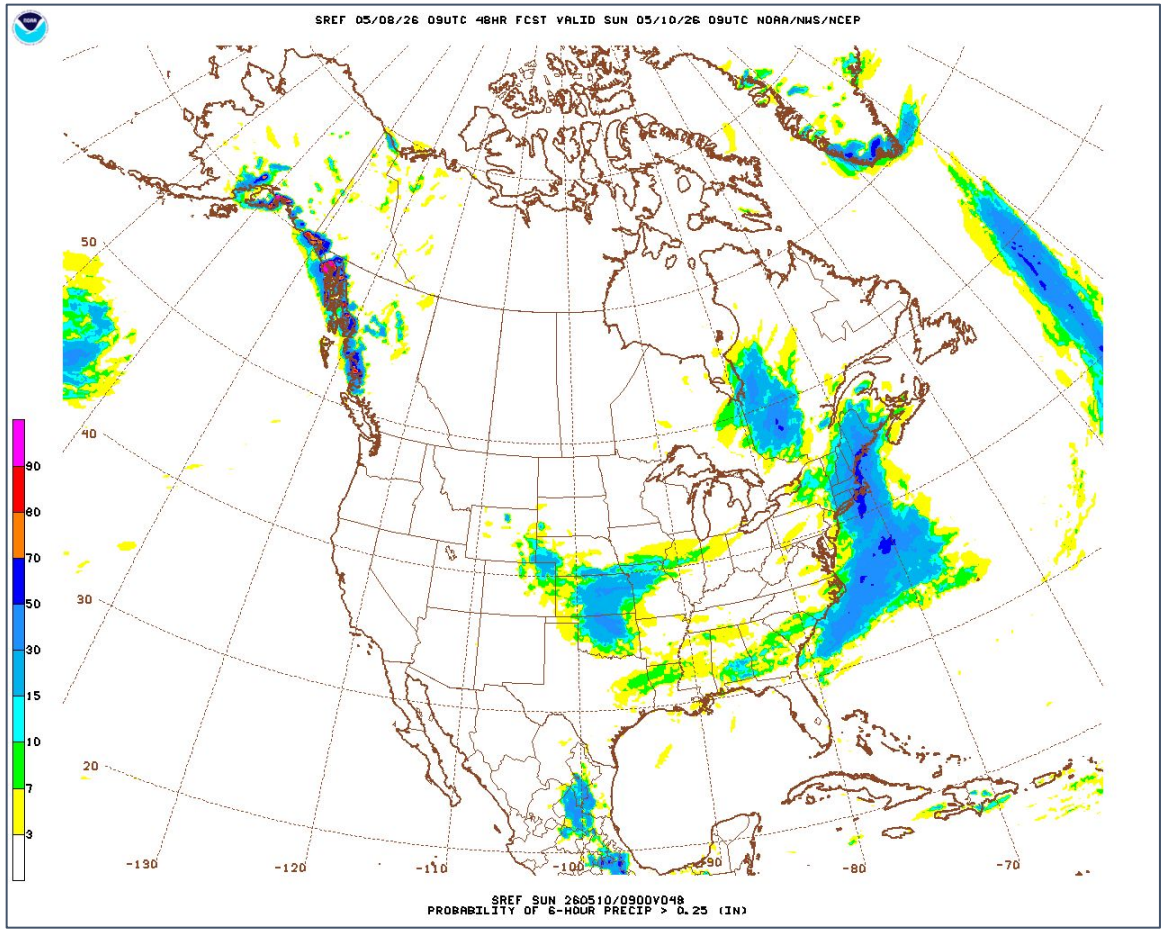
High Resolution Ensemble Forecast (**HREF**) (everything)



Last major upgrade of HiresW/HREF was in May 2021

Retirements - SREF

SREF (everything)



Last major upgrade of the SREF was in October 2015

Retirements - why?

The decision to retire multiple systems and simplify the operational modeling suite was made for several reasons

Redundancy

The NAM nests, HRRR, and HiresW all cover similar regions at roughly the same ~3 km grid spacing

Sustainability

The maintenance expense and technical debt generated by supporting multiple legacy systems is not sustainable, and hampers development.

Transitioning legacy systems to new computing platforms was a huge concern.

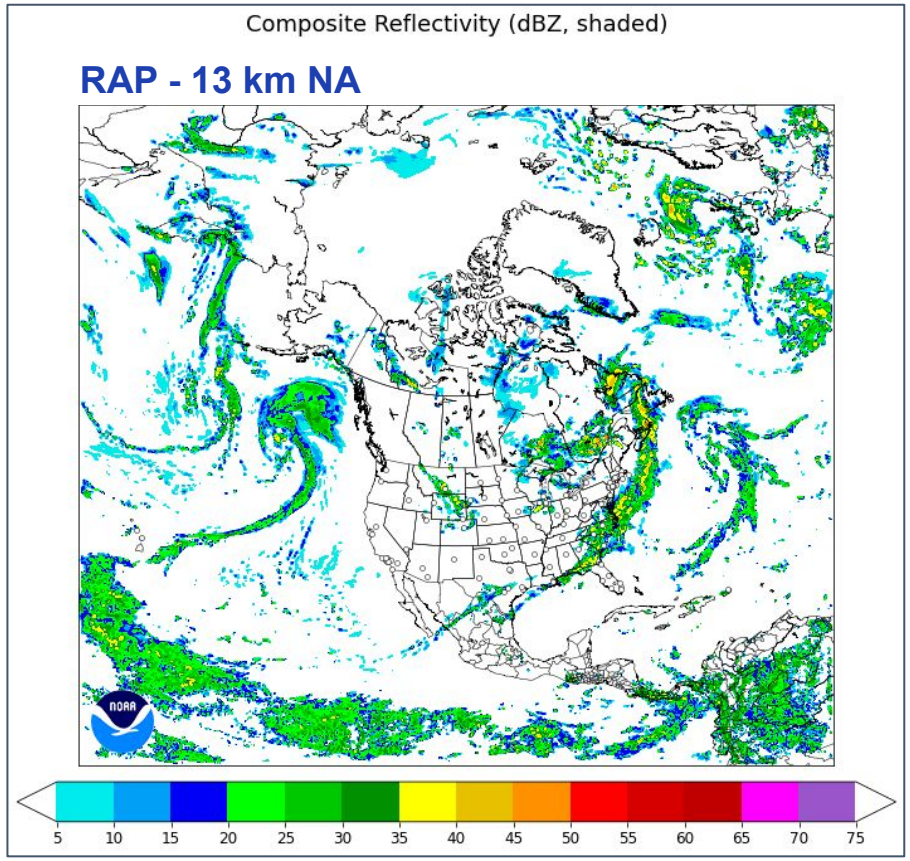
Computational constraints

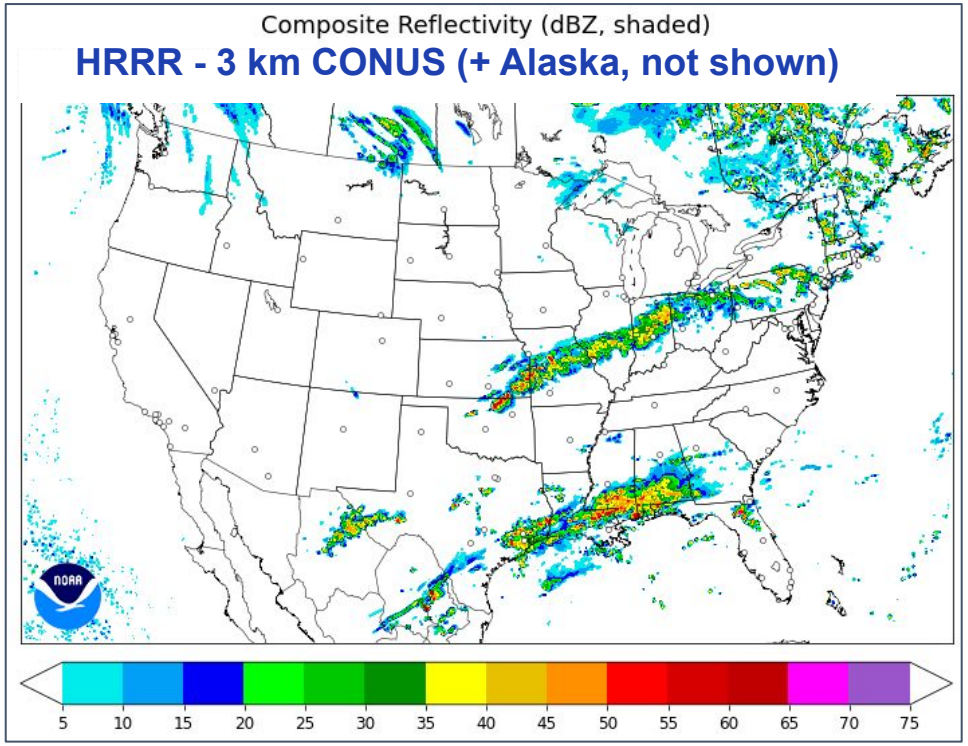
Retirement of legacy systems frees up resources (computing and network) to enable sharing of cutting edge model output.

NOT being retired (for now): RAP & HRRR

Original plans for RRFSv1 envisioned retiring these systems, but we pivoted away from this plan in 2023.

RAP/HRRR will remain frozen, with development focused on a future RRFS that *will* retire these models, possibly as soon as 2028.





last major upgrade in December 2020

RRFS Deterministic Products

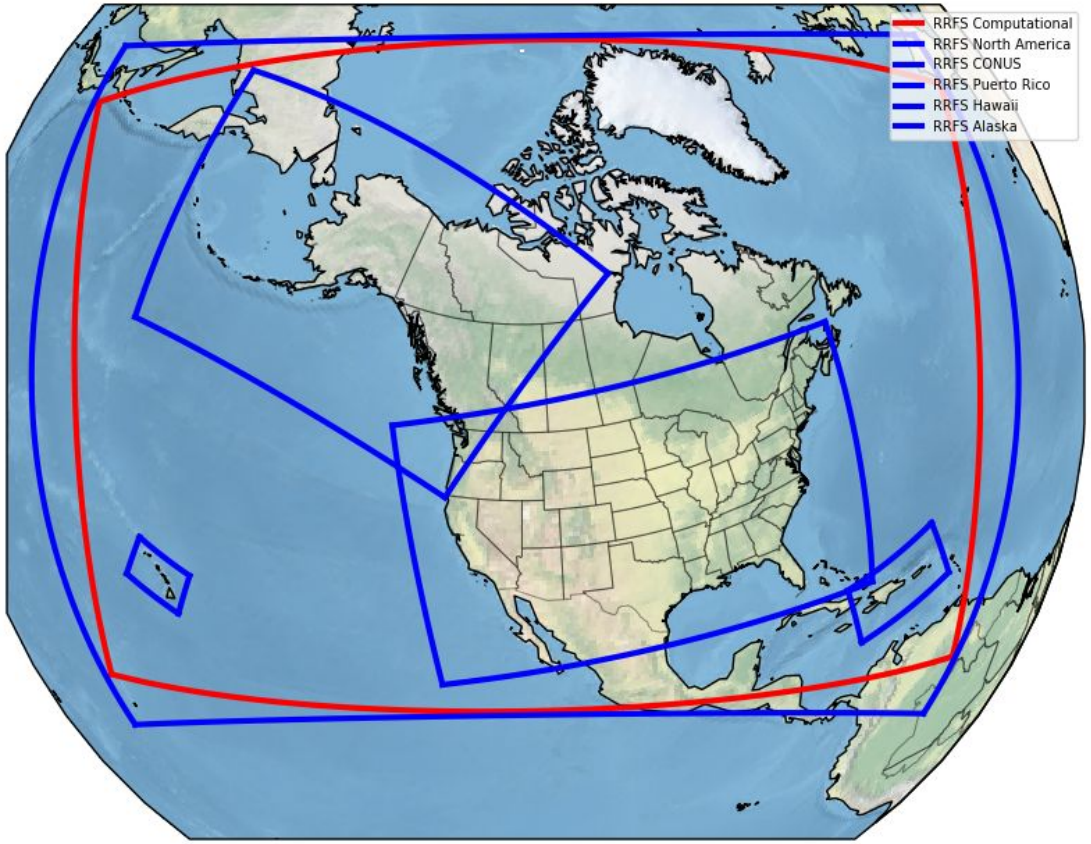
Regional "Cutout" Domains

RRFS runs as a single large 3-km domain. Distributed products are primarily on four output grid regions matching the NAM Nest grids:

- **CONUS** (3 km)
- **Alaska** (3 km)
- **Hawaii** (2.5 km)
- **Puerto Rico** (2.5 km)

Recent Addition

13-km North America grid for Satellite Broadcast Network (SBN) distribution of upper-level fields.



RRFS primary product domains (four smaller blue regions)

RRFS/REFS product distribution

A primary location for publicly available RRFS/REFS output will be on the NOMADS server:

- **Starting on July 7th (planned), pre-production parallel data will go to**
  - `https://nomads.ncep.noaa.gov/pub/data/nccf/com/rrfs/`**`para`**`/`
  - `https://nomads.ncep.noaa.gov/pub/data/nccf/com/refs/`**`para`**`/`
- **Starting on August 31st (planned), operational data will go to**
  - `https://nomads.ncep.noaa.gov/pub/data/nccf/com/rrfs/`**`prod`**`/`
  - `https://nomads.ncep.noaa.gov/pub/data/nccf/com/refs/`**`prod`**`/`

RRFS Deterministic Products

Products going to NOMADS (public distribution)

Isobaric (prslev) & Non-Isobaric (2dfld) Output

- **00/06/12/18 UTC cycles:** Hourly to 84 h for the four cutout domains [NAM/HiresW replacements]
- **03/09/15/21 UTC cycles:** Hourly to 18 h for the four cutout domains

Subhourly (subh) Output

- **All cycles**: Hourly files to 18 h with output every 15 minutes for the four cutout domains

1.5-km Fire Weather Domain

Isobaric (prslev) and non-isobaric (2dfld)

- **00/06/12/18 UTC cycles:** hourly to 36 h [NAM 1.5 km nest replacement]

BUFR Sounding Output

Point forecast output in BUFR format

- **00/06/12/18 UTC cycles:** hourly to 84 h [NAM/HiresW replacements]

REFS (ensemble products) Details

The RRFS Ensemble Forecast System (**REFS**) provides a direct replacement for the **HREF** system, and is quite similar in design. However, there are differences.

Ensemble composition

With timelagging and inclusion of the deterministic control member, all REFS domains include 12 RRFS members.

CONUS and AK add HRRR members to reach **14 total members**.

HREF Comparison: *6 members HI/PR, 8 member AK, 10 members CONUS*

Forecast length and product frequency

REFS products are **hourly to 60 h**, provided **4x/day** for all domains.

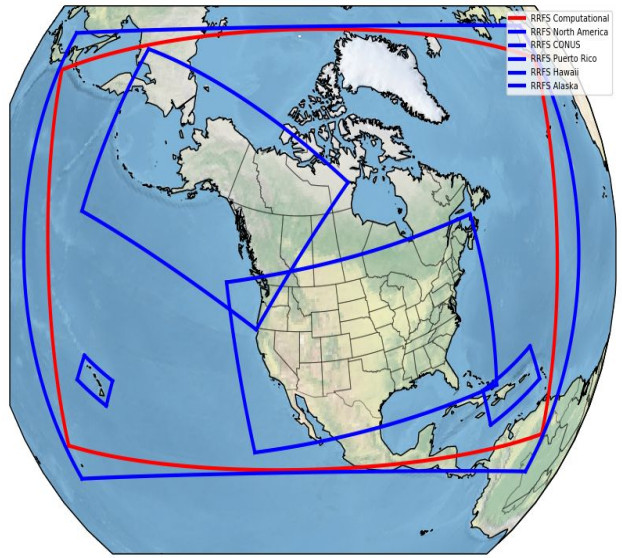
HREF Comparison: *Only to 48 h, and only 2x/day for non-CONUS domains*

Output grids & grid spacing

REFS product generation uses RRFS output grids: **3 km CONUS & Alaska; 2.5 km Puerto Rico & Hawaii**

HREF Comparison: *Uses 5 km output grids for all domains*

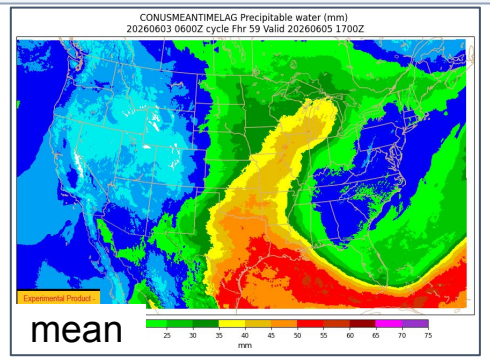
REFS product domains (four smaller blue regions)

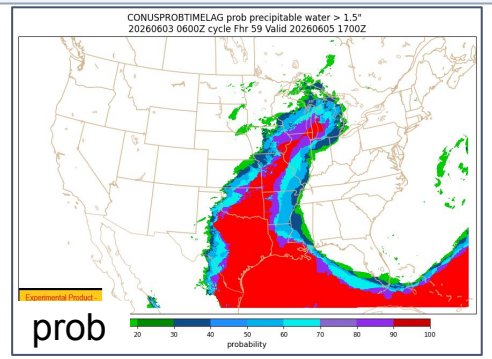


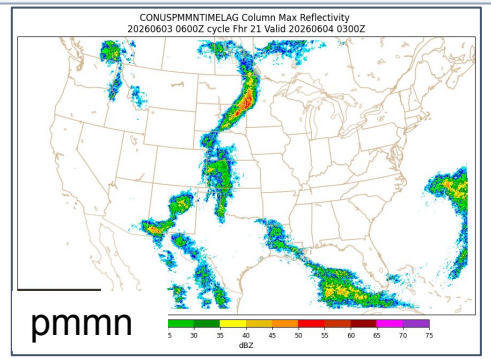
REFS ensemble product output

All REFS products (hourly to 60 h) will be sent to NOMADS

Product types in REFS match those of HREF (mean, prob, pmmn, ...)







Key Product Advancements vs. HREF

ASNOW products

Physical snow depth with variable snow-liquid ratio (SLR) products replace frozen precipitation accumulation (WEASD) products in HREF that used a fixed 10:1 SLR ratio.

Additional Fields

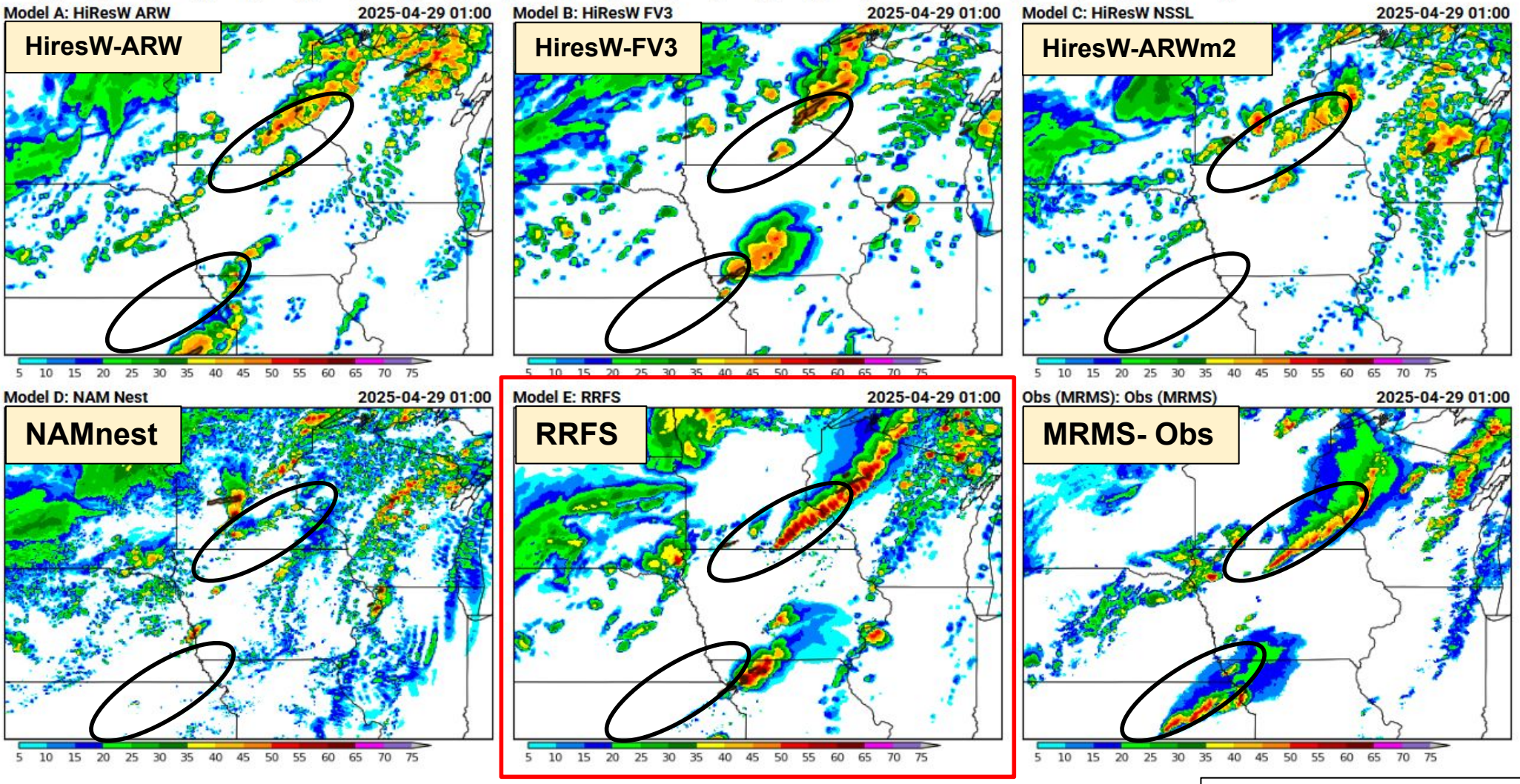
Adds numerous freezing rain probabilities, some higher threshold precipitation probabilities, and various other small additions relative to HREF.

RRFS strengths and weaknesses (from 2025 evaluation)

- Overall, the statistical performance of the RRFS/REFS was comparable to operational CAM models for most environmental fields
- RRFS demonstrated skill in the timing and placement of high-impact convective events, with the RRFS ensemble radar DA contributing to the usefulness of short-term forecasts
- RRFS/REFS has captured supercell convection structures well, with good representation of updraft tracks and reflectivity structures in some high-impact events
- RRFS has shown skill in identifying heavy rainfall events through Day 3
- RRFS has shown comparable skill to NAM and NAMnest for timing and placement of deep cold fronts and large-weather systems

slide courtesy Andrew Benjamin

April 2025 severe weather case - 13 h forecasts valid 0429/01Z



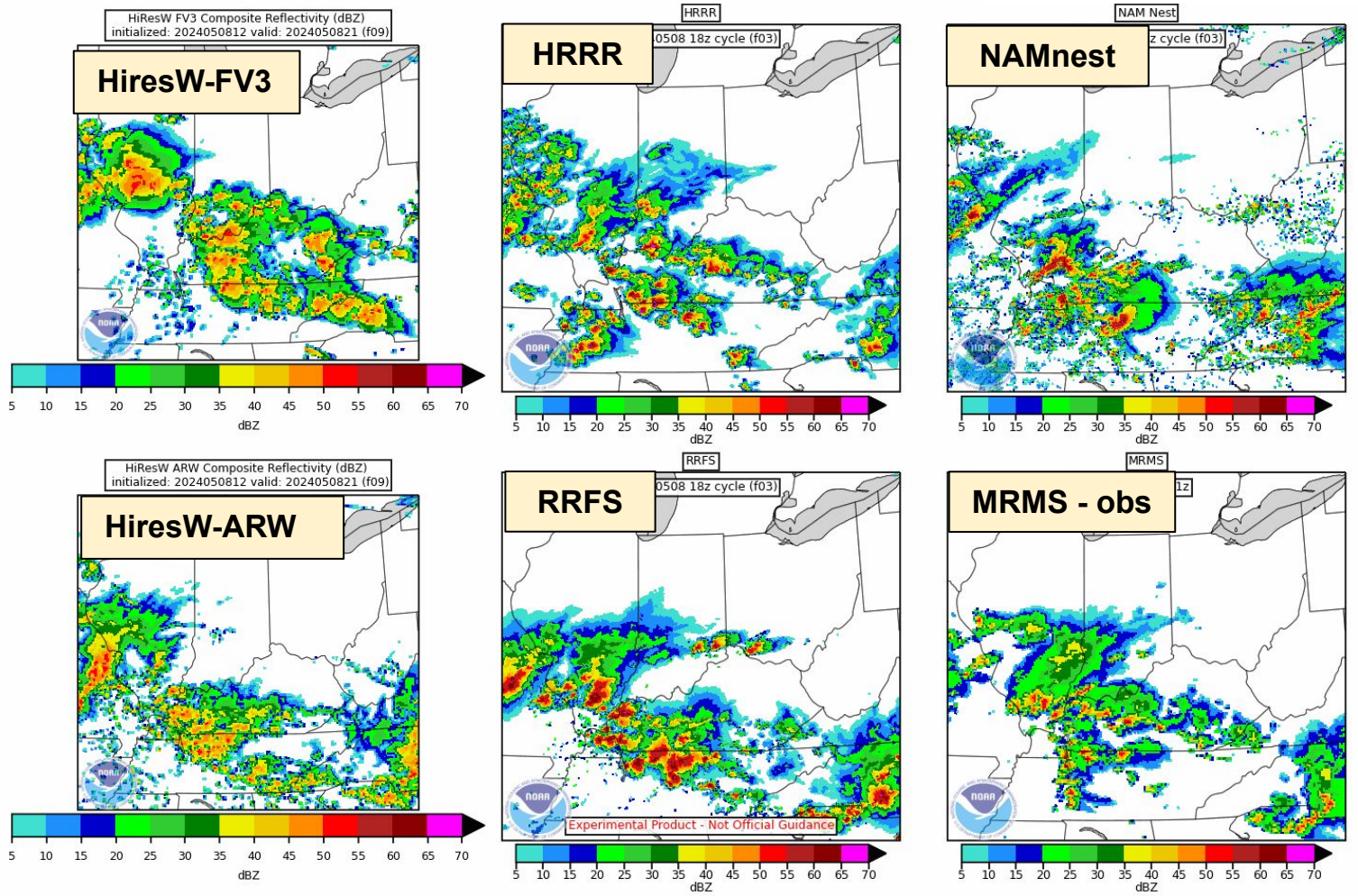
slide courtesy Andrew Benjamin

RRFS strengths and weaknesses (from 2025 evaluation)

- ~~**RRFS** often overestimated 2-m dewpoint, especially in the Western US and severe weather drylines~~
  (has been addressed, as we'll see on coming slides)
- **RRFS** has been shown at times to initiate convection that was too early and/or too intense, especially at long lead times
- **RRFS** has been shown to overpredict QPF during heavy precipitation events
- **RRFS/REFS** has struggled with low ceiling and visibility forecast, overestimating LIFR/IFR coverage and intensity
- **REFS** guidance for many fields tends to be more underdispersed compared to operational **HREF**

slide courtesy Andrew Benjamin

Overly strong RRFS convection from a 2024 retrospective case



- Forecasts initialized: 18z 8 May 2024 (F03) **ARW**, **FV3** (F09)
- **RRFS** composite reflectivity was too strong along the TN/KY border and southeast IL compared to MRMS analysis
- Despite overprediction, **RRFS** composite reflectivity extent is similar to MRMS observations, and an improvement over **HiResW ARW** and **HiResW FV3**

slide courtesy Andrew Benjamin

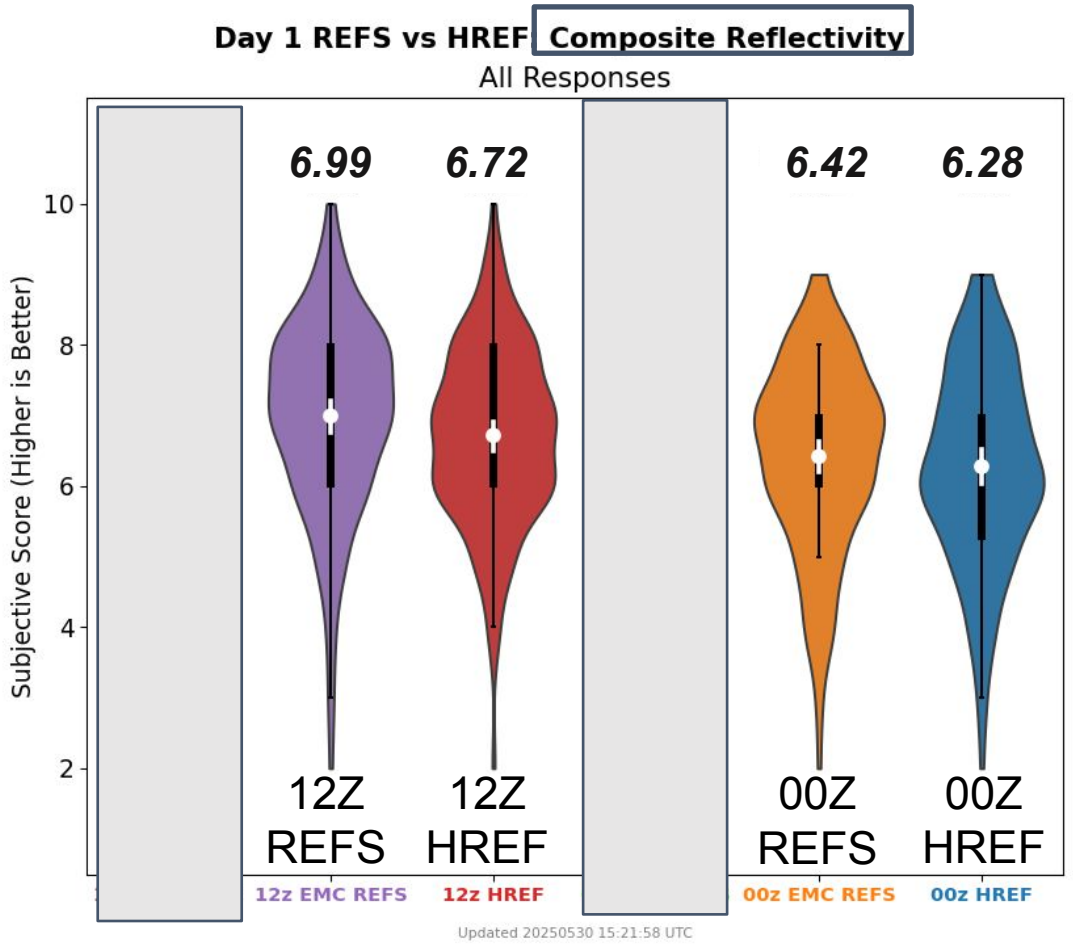
REFS performance relative to HREF for severe weather

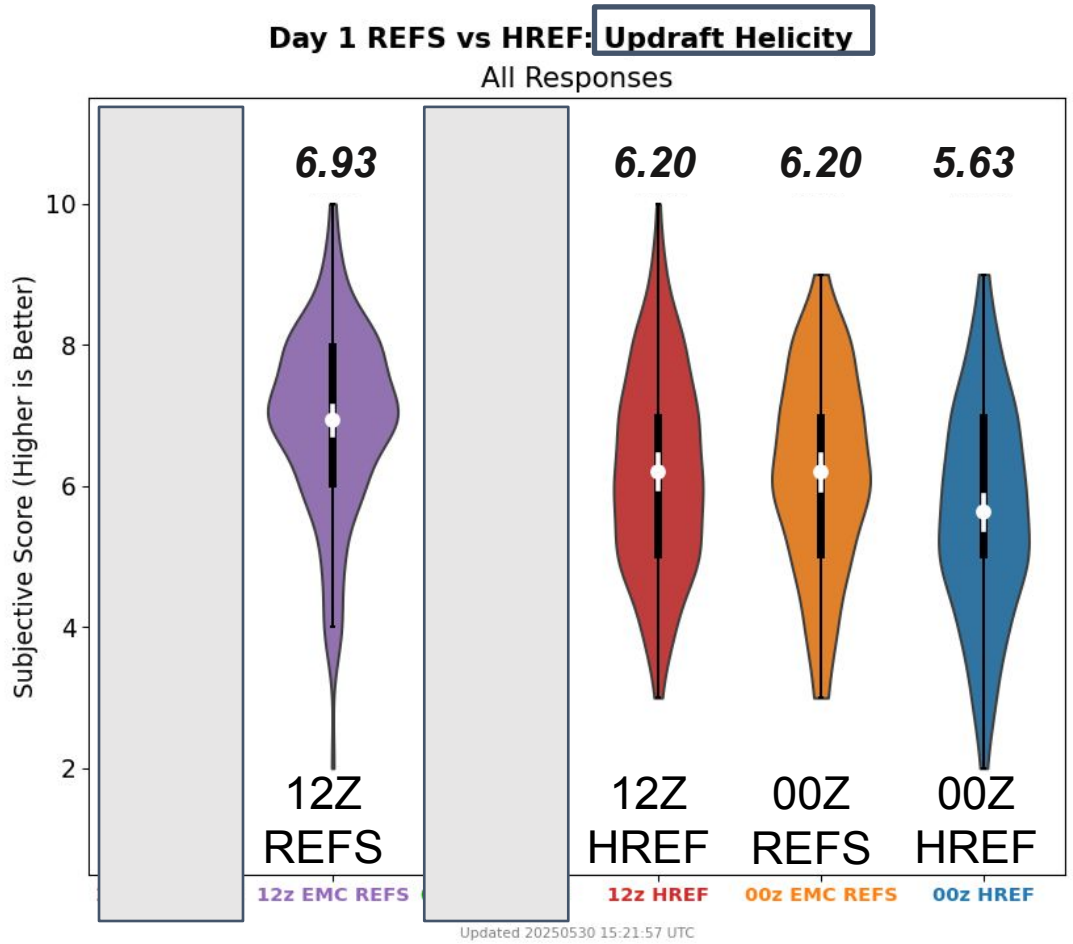
- The next two slides show summary ensemble performance over the length of the SPC/NSSL Hazardous Weather Testbed (Spring Forecasting Experiment) from the last two years

- These results are based on blinded subjective evaluations from participants, who independently rate each forecast on a 1-10 scale for a targeted “region of interest” for a given day. Plots summarize all scores given over the five week experiment.

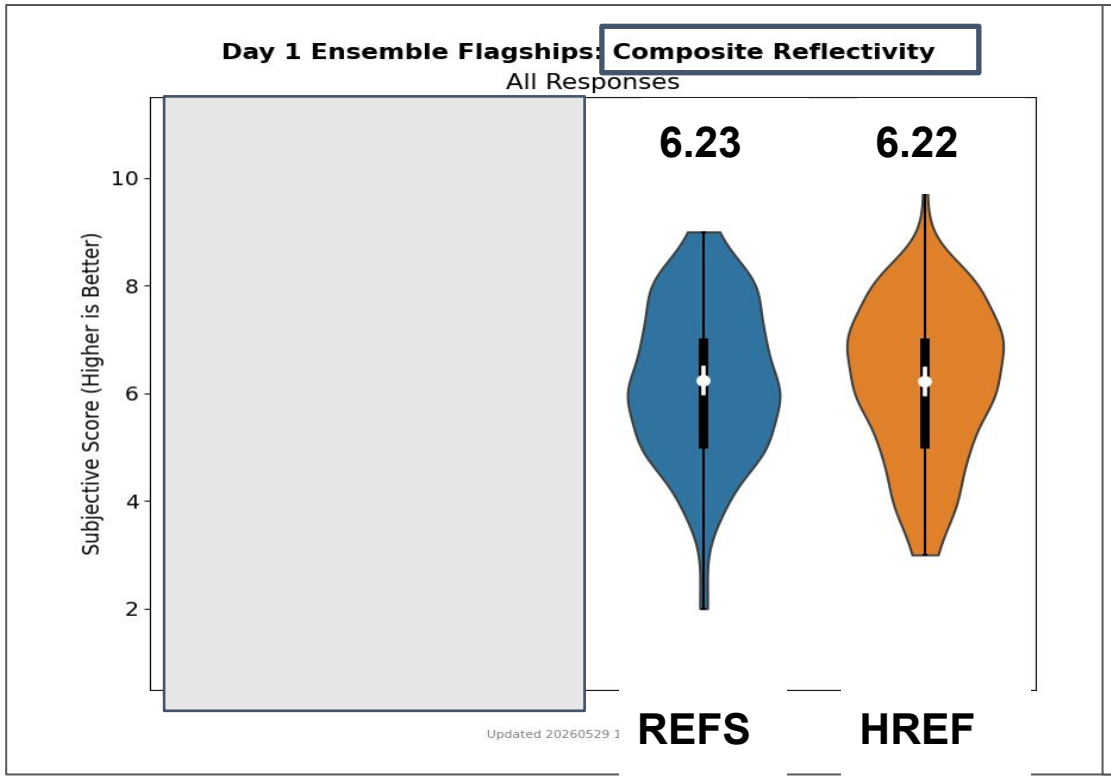
- This comparison is purposely limited to comparing the operational HREF and the parallel REFS systems (thus some alternate ensemble configurations on the original slides are blocked out)

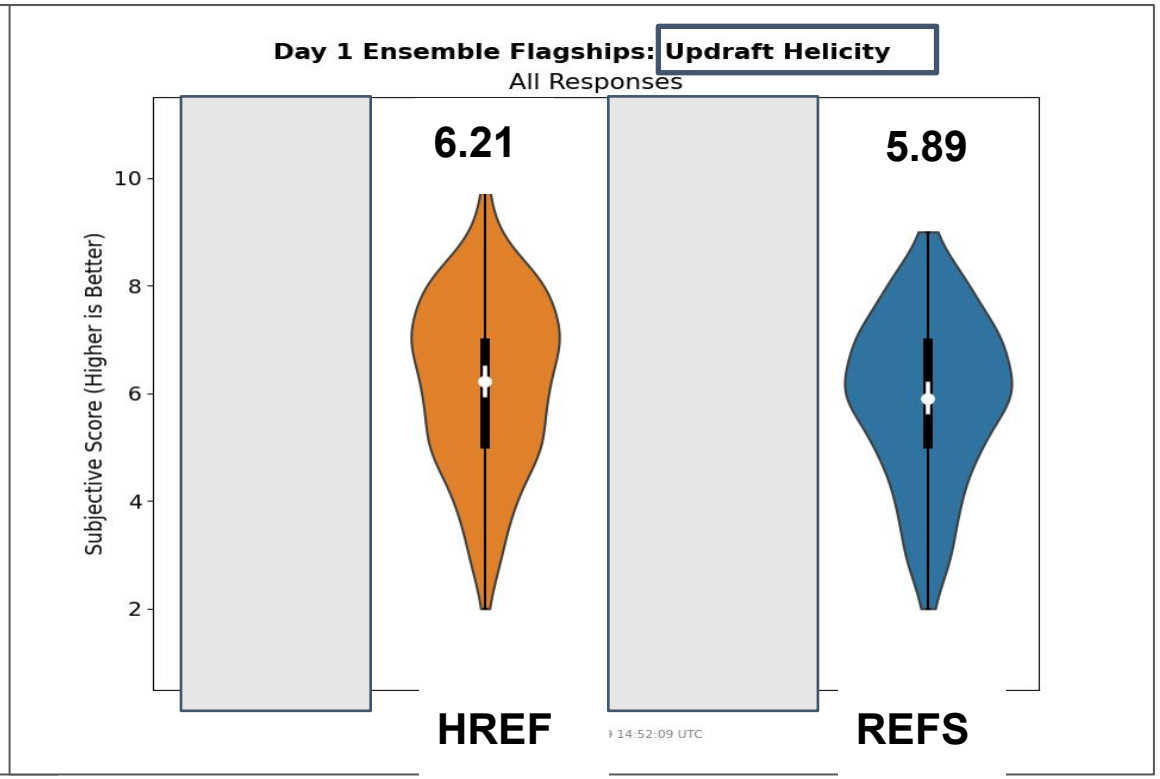
2025 HWT SFE Subjective Rating Distributions
Day 1 00Z & 12Z REFS vs. HREF





2026 HWT SFE Subjective Rating Distributions
Day 1 00Z REFS vs. HREF





Late (post-2025 evaluation) changes made to RRFSv1

The evaluation process that led to the approval of RRFS for implementation identified two important issues to correct:

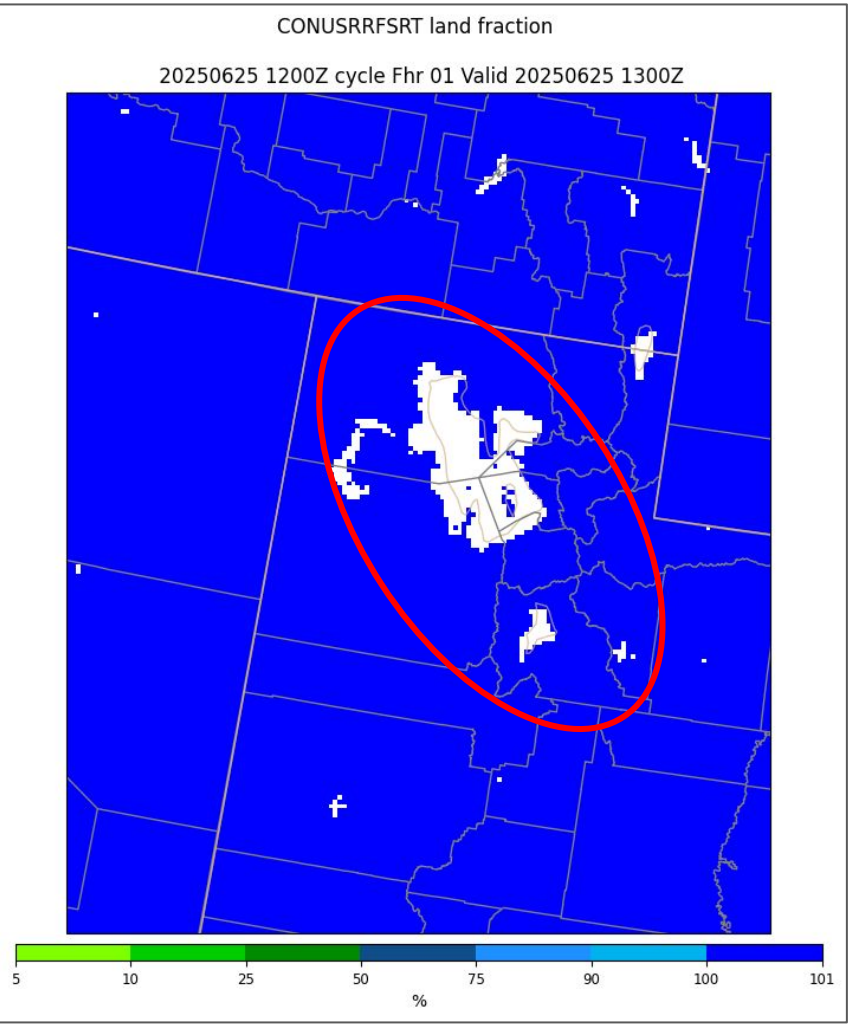
- **Lake Mask Discrepancy:** The Great Salt Lake and other western lakes were larger in RRFS than in reality.
- **Dew Point Bias:** 2 m dew points exhibited a significant high (moist) bias in very arid environments - problematic for fire weather forecasting.

Proactive fixes ahead of implementation

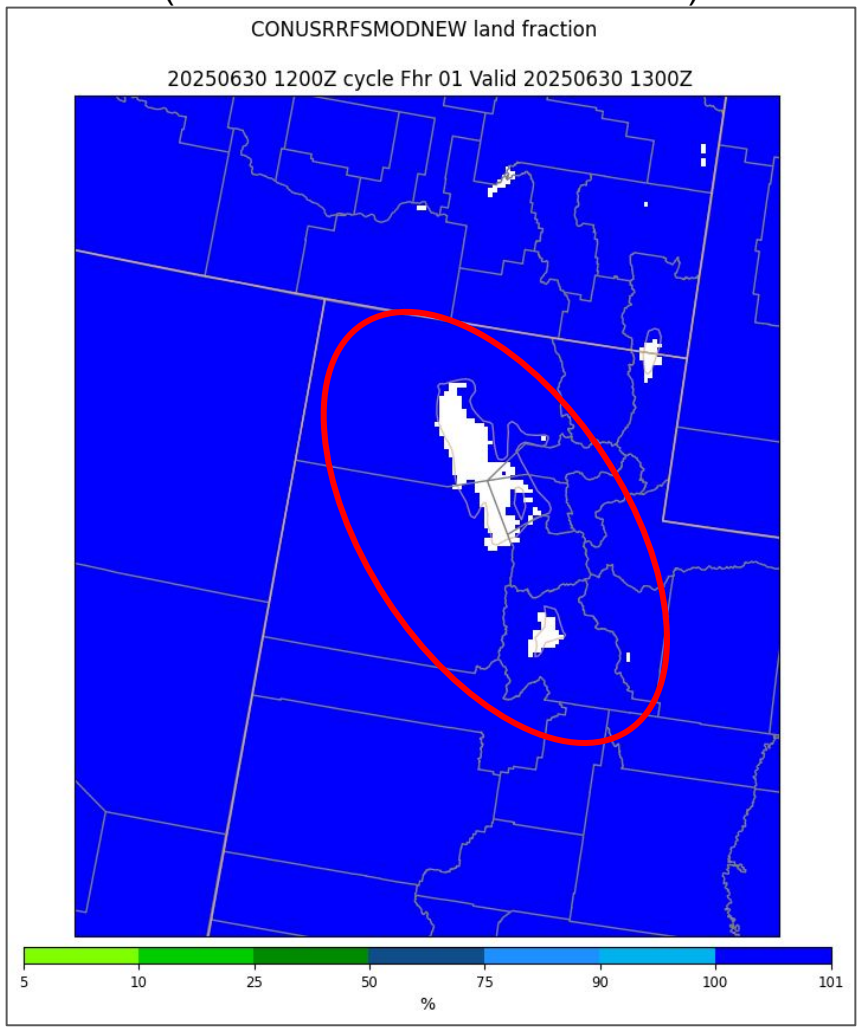
Leveraging implementation delays, we have successfully addressed both problems for the initial version of RRFS.

Late (post-2025 evaluation) changes made to RRFSv1

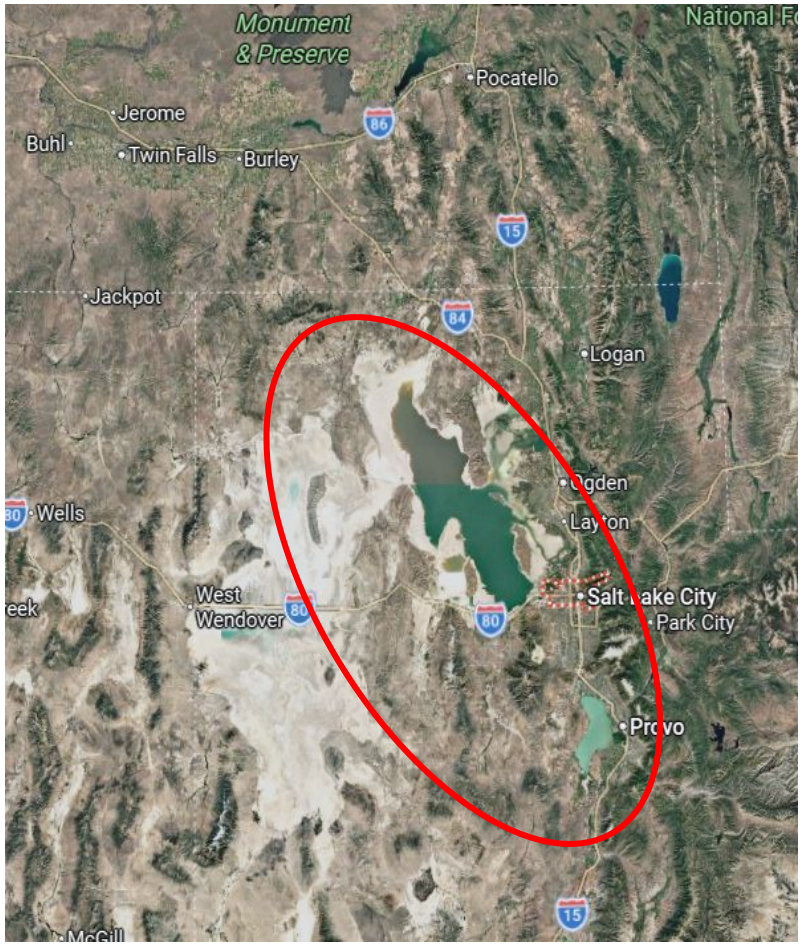
Pre-update lake mask



Updated lake mask
(tuned toward HRRR lake mask)

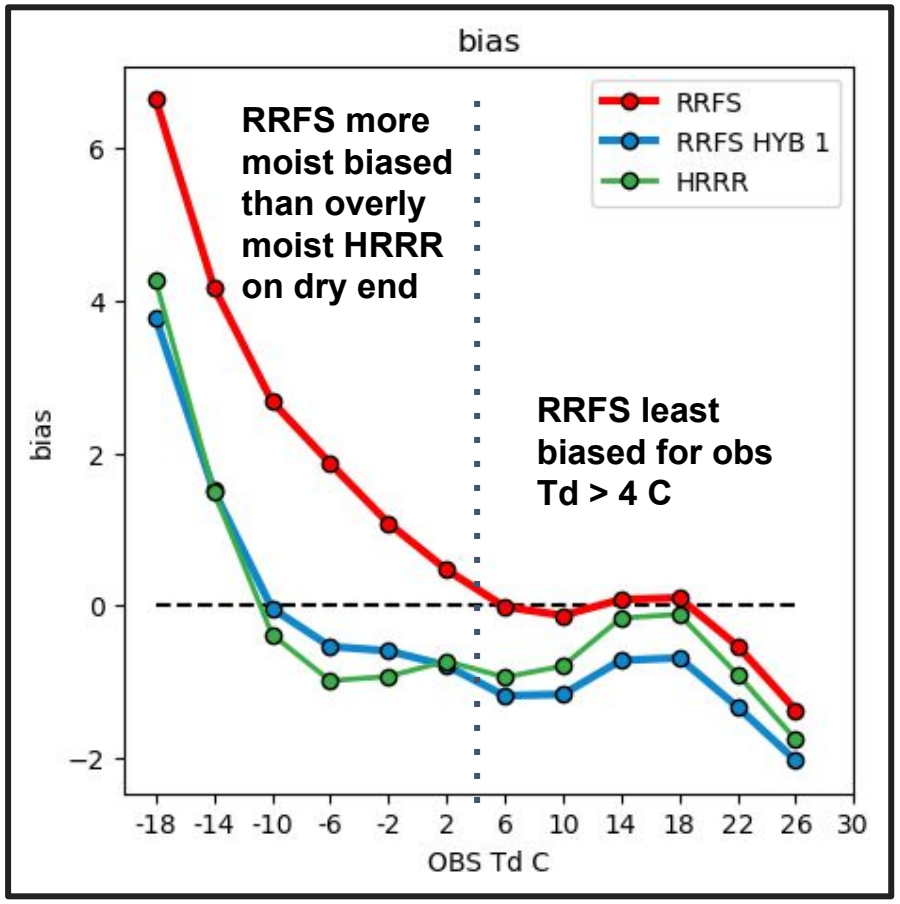


Google Maps terrain depiction



Late (post-2025 evaluation) changes made to RRFSv1

Numerous complaints about overly moist 2 m Td in western US - most evident in very arid regions. Of concern for fire weather forecasting



May 12-18, 2025
00/06/12/18Z cycles
forecast hours 3-48

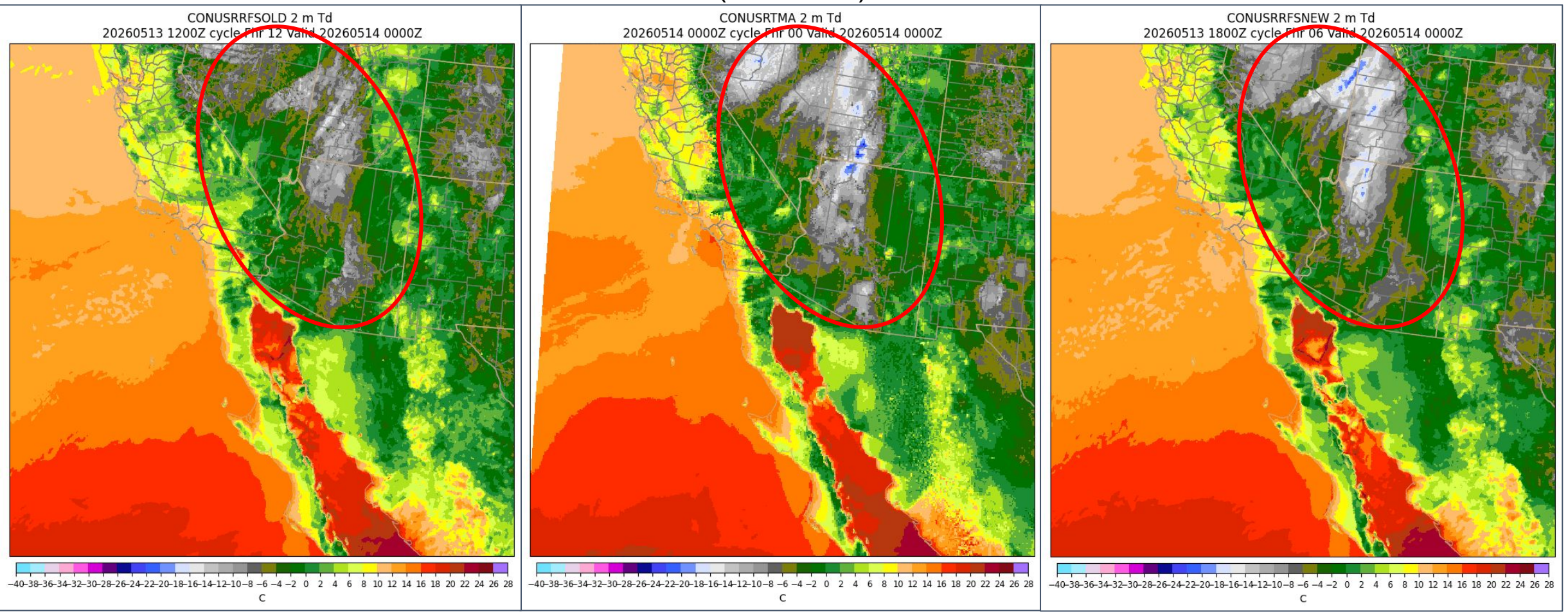
Courtesy Mike Baldwin/ Nick Nauslar, SPC

Late (post-2025 evaluation) changes made to RRFSv1

12 h forecast from 0513/12Z
(old Td diagnostic - 0514/00Z valid)

RTMA 2 m Td analysis
(0514/00Z)

6 h forecast from 0513/18Z
(new Td diagnostic - 0514/00Z valid)



Next steps for RRFS/REFS v1

- As mentioned earlier, we are nearing the start of the official “eval” parallel for RRFS/REFS (which will include public distribution of RRFS/REFS data)
- This parallel currently is scheduled to start on July 7th, but that date is subject to change
- The implementation date for RRFS currently is listed as August 31st

Future plans for RRFS (beyond v1)

- The plan to improve RRFS, particularly the related issues of overly intense convective storms and excessive heavy precipitation, centers around a transition to the Model for Prediction Across Scales (MPAS).
- Development of a future RRFS using MPAS and the Joint Effort for Data-assimilation Integration (JEDI) system is ongoing across NOAA, with initial prototypes being tested internally.
- Early results with MPAS-based RRFS prototypes are encouraging
- How the operational transition from RRFSv1 to a fully MPAS+JEDI-based RRFS occurs is still being refined, but with a desire to implement at least some of it in 2028.

https://repository.library.noaa.gov/view/noaa/56514 provides some justification for this planned change in dynamical core.

details courtesy of Clark Evans (NOAA/GSL)


Questions?
rrfs.feedback@noaa.gov

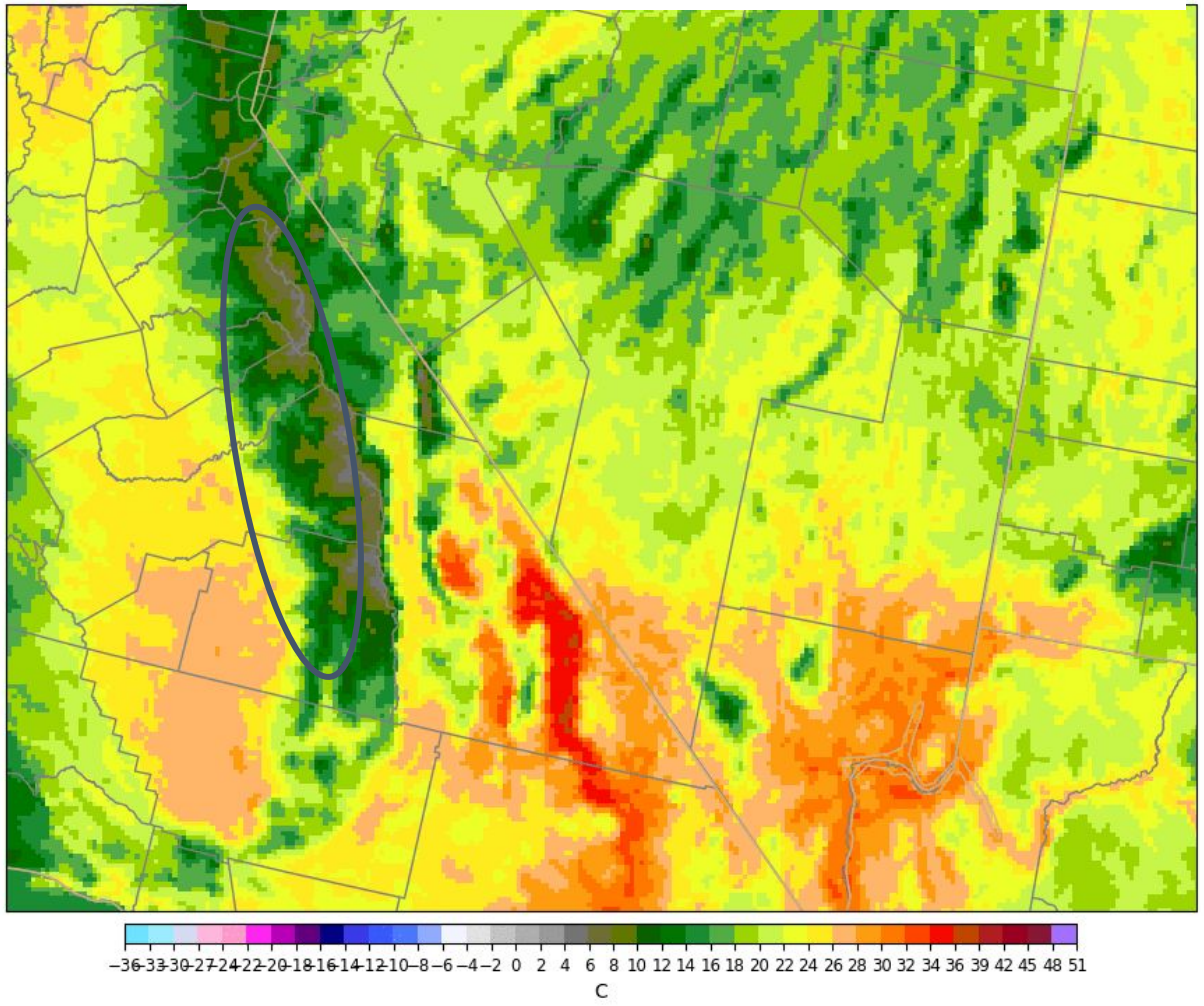
Backup material

RRFS and REFS products going to Satellite Broadcast

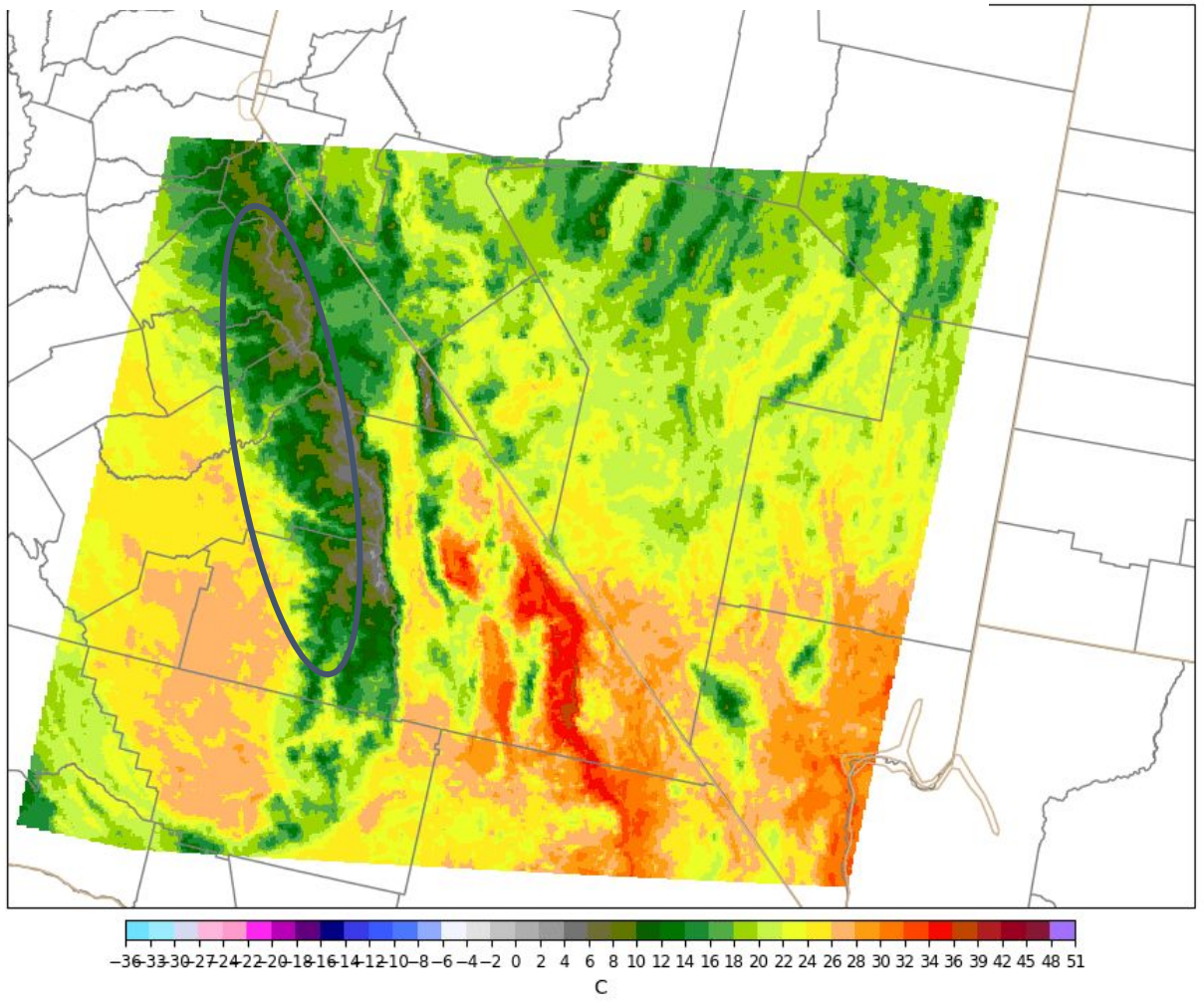
- Deterministic (RRFS) products:
  - 3 hourly to f60, then 6 hourly to f84
  - A limited set (~16 records) on the full North America 3 km grid
  - Limited amount of isobaric output (standard levels) over the full North America region, but at 13 km grid spacing.
- Ensemble (REFS) products:
  - 3 hourly to f48, then 6 hourly to f60
  - More limited set of products than is available on NOMADS
- 00/06/12/18 UTC cycles only,
- Sample headed products will be available in the parallel (on/after July 7th)
  - https://nomads.ncep.noaa.gov/pub/data/nccf/com/para/noaaport/rrfs/
  - https://nomads.ncep.noaa.gov/pub/data/nccf/com/para/noaaport/refs/

Backup material

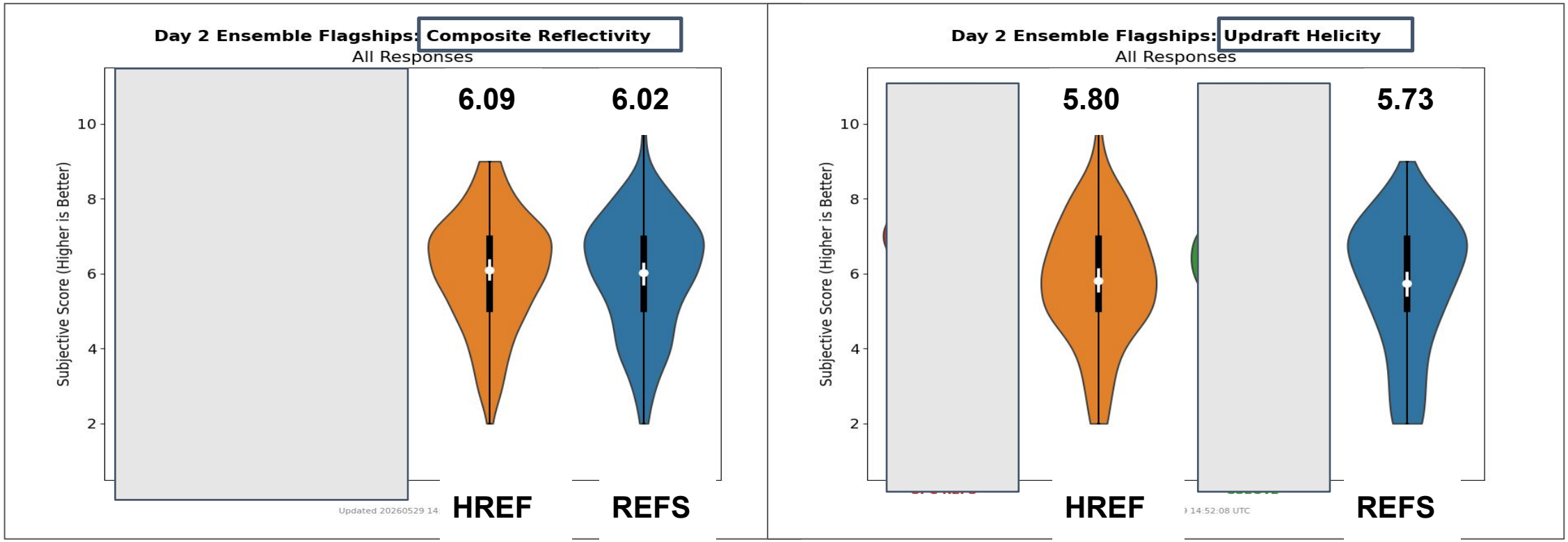
2 m Temperature, 3 km RRFS



2 m Temperature, 1.5 km RRFS fire weather domain



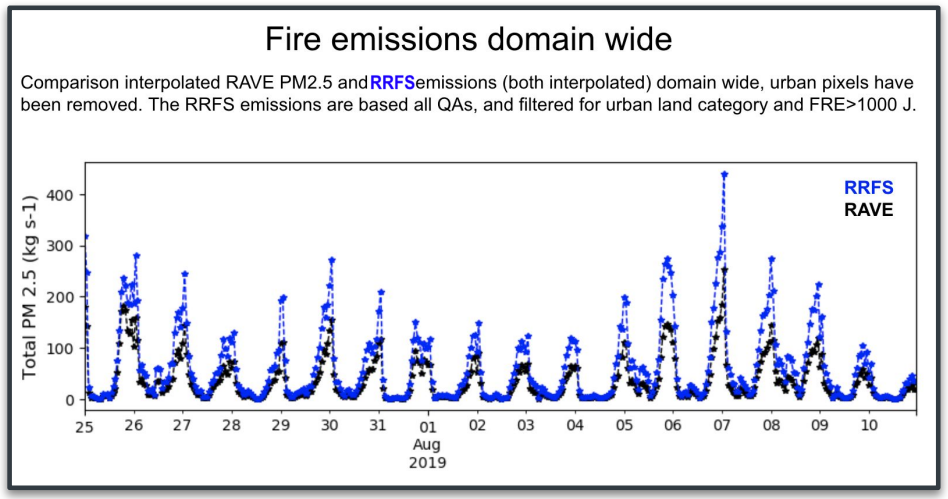
2026 HWT SFE Subjective Rating Distributions
Day 2 00Z REFS vs. HREF

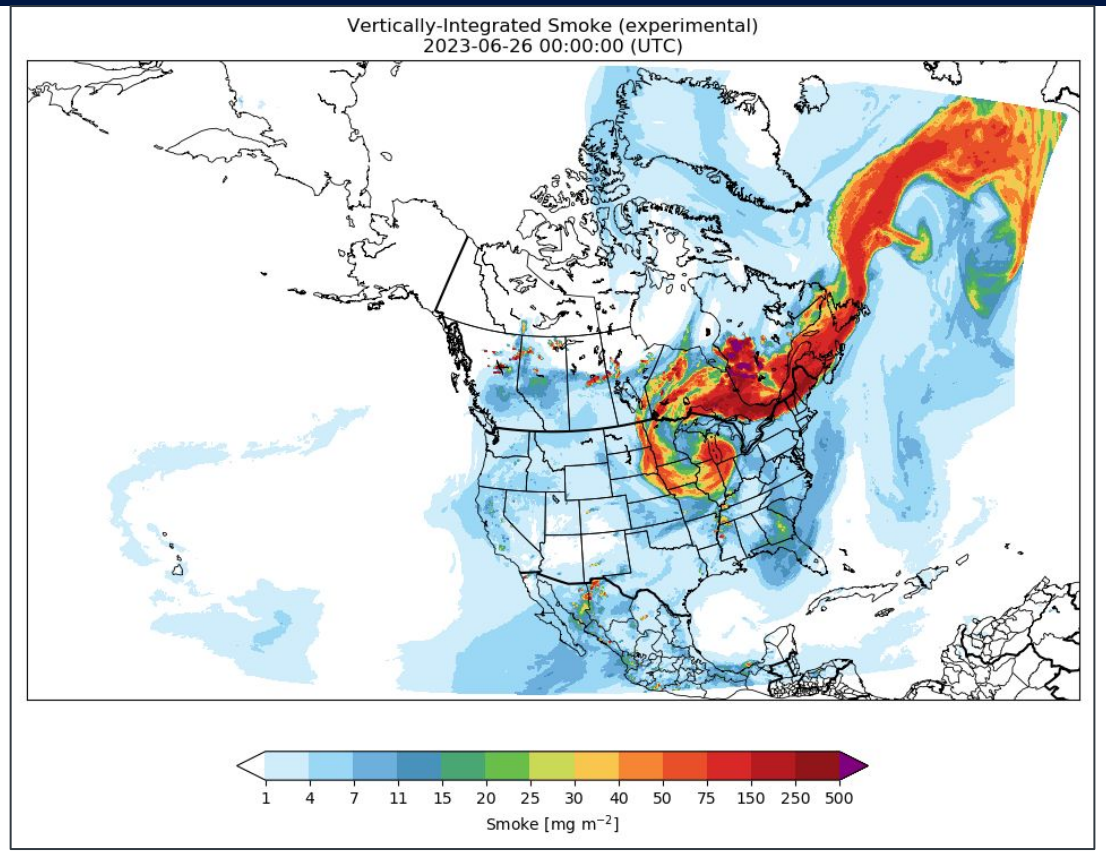


Smoke and Dust

- Included in 3-km deterministic 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 (now EMC), and P. Bhattacharjee (EMC) for material on this slide

Clark note: “However, the time-lagged HRRR + RRFS ensemble was rated very well throughout the experiment, better than Warn-on-Forecast, showing that there is value in the rapidly updating RRFS (alongside HRRR).”