The Rapid Refresh Forecast System with an Emphasis on Winter Weather

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on behalf of the wider RRFS team

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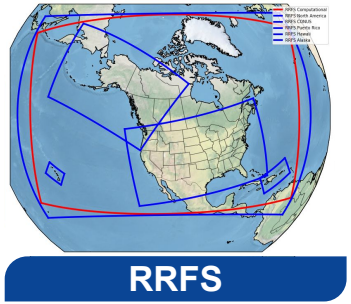
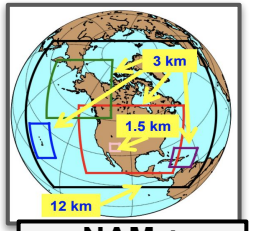


UFS
UNIFIED FORECAST SYSTEM

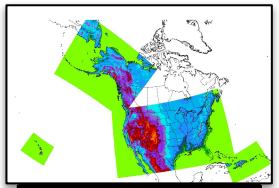
The Rapid Refresh Forecast System (RRFS)

A UFS Application

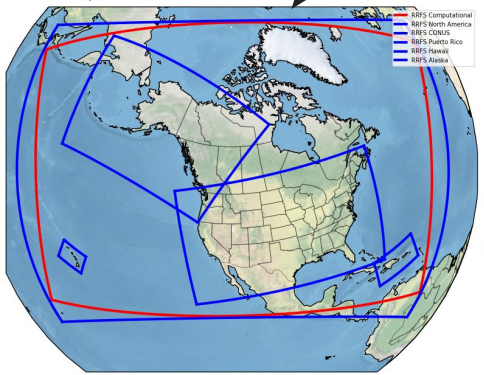
- 3 km grid spacing over North America
- FV3 dynamical core
- Hourly updated
- 65 vertical layers
- Hybrid 3DEnVar assimilation (30 mem)
- Includes Smoke & Dust
- Deterministic forecasts to 84 h & Ensemble forecasts to 60 h, every 6 h
- Deterministic forecasts only to 18 h, other cycles



NAM + NAM Nests



HiResW/ HREF

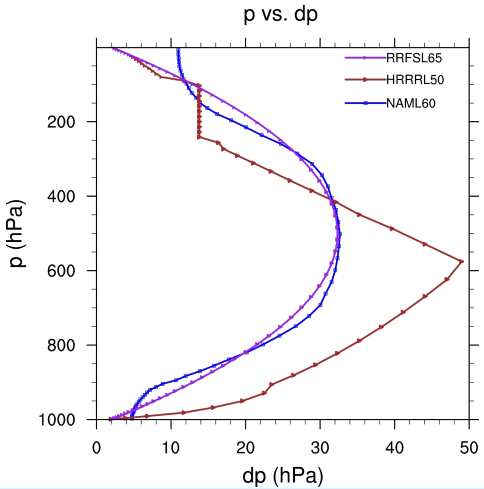


RRFSv1 Compute Domain (red)

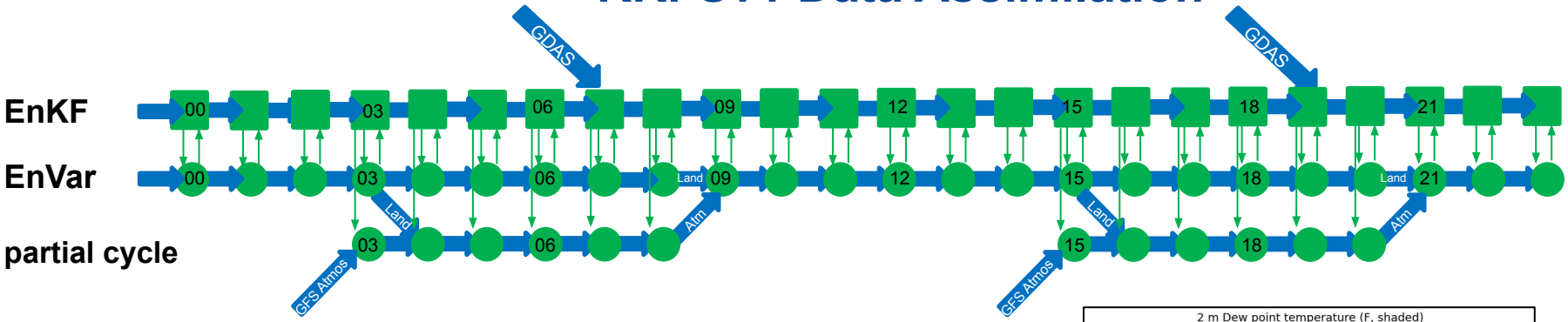
RRFS Physics and Vertical Resolution

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	saSAS	Han et al. (2017)
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)

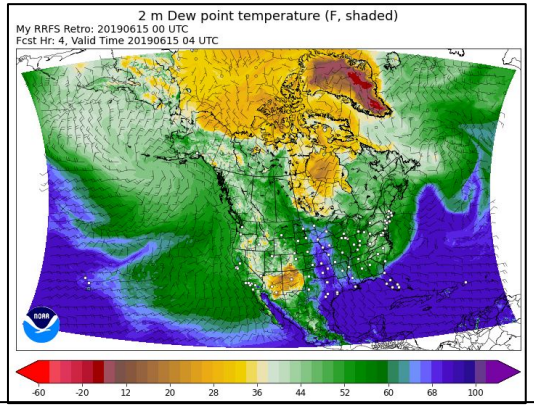
Parameter	RRFS	HRRRv4	NAMv4
Number of levels	65	50	60
Lowest level (m)	8	8	20
Top (hPa)	2	20	2



RRFSv1 Data Assimilation



- Two-way interaction between 30 member 3-km DA ensemble [■] and 3-km deterministic RRFS hybrid 3DEnVar analysis [●]
- Partial cycle spin-up of atmosphere from GFS twice per day (RAP like), land states fully cyc'd
- Large scale information from GDAS ensemble is blended into EnKF system twice per day.



All ensemble members (in square) and deterministic/control (circle) on 3-km NA grid

Ensemble forecast membership

60 h forecasts at 00/06/12/18 UTC

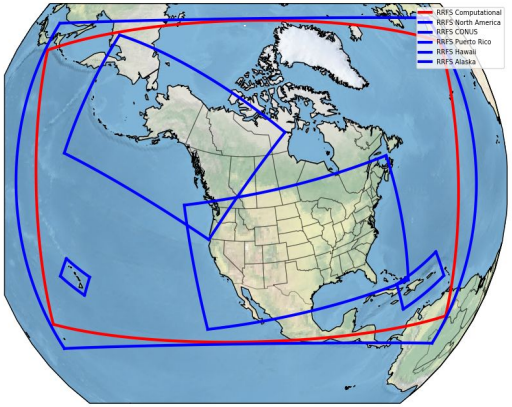
Sources of spread: EnKF ICs, GEFS LBCs, time-lagging, multi-physics, stochastic parameter perturbations(*), and fixed parameter perturbations (#)

	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)						

*Thanks to Jili Dong for this work

REFS Ensemble product generation relative to HREF

- **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



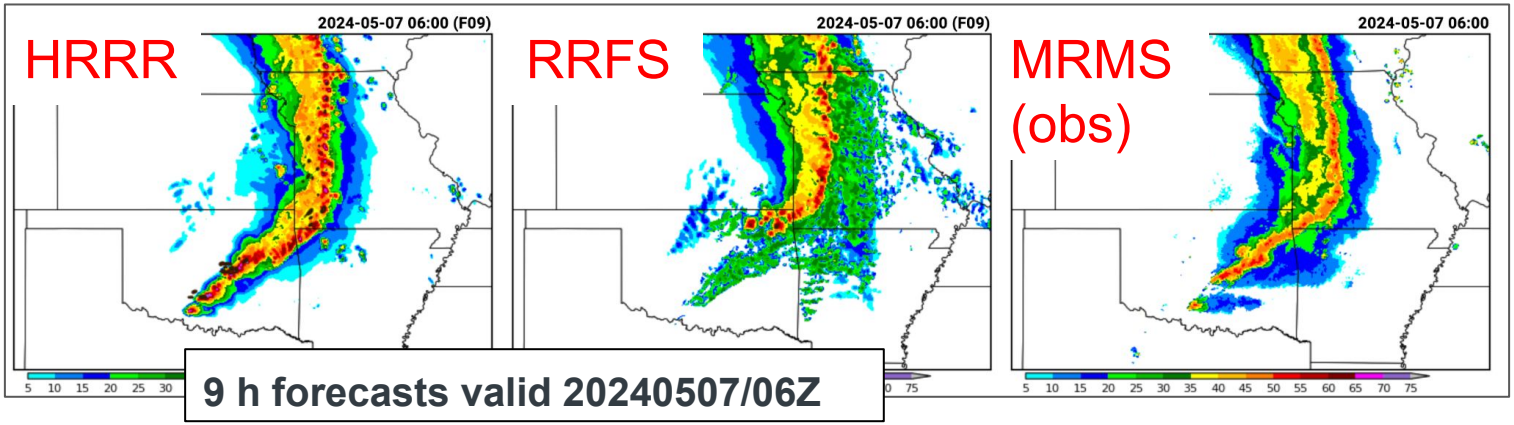
RRFSv1 Compute Domain (red)

Some recent RRFSv1 history

- Concerns about RRFS performance were raised in NOAA testbeds in 2023 and prior years about *overly heavy rainfall* and *overly intense convective storms*.
  - RRFS began running with parameterized convection in Aug 2023 to help mitigate these related issues.
  - FV3 dynamical core's inherent issues at 3 km were documented in a white paper - which recommends shifting to alternate dynamics (MPAS) beyond RRFSv1.
- RRFS Beta Evaluation (Jan-Mar 2024) - a period of iterative tuning based on real-time and retrospective results. Positive outcome from Beta led to an initial scientific code freeze.

Some recent RRFSv1 history (cont.)

- Post initial science freeze, RRFSv1 performed poorly in 2024 Hazardous Weather Testbed (May 2024)
  - Underdid some significant convective storms (low POD)
  - This deficiency created fresh impetus to explore options to improve RRFSv1 convective performance.



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

High POD for convective storms is a key SPC performance metric

RRFS did poorly relative to the operational HRRR and experimental MPAS runs by this measure

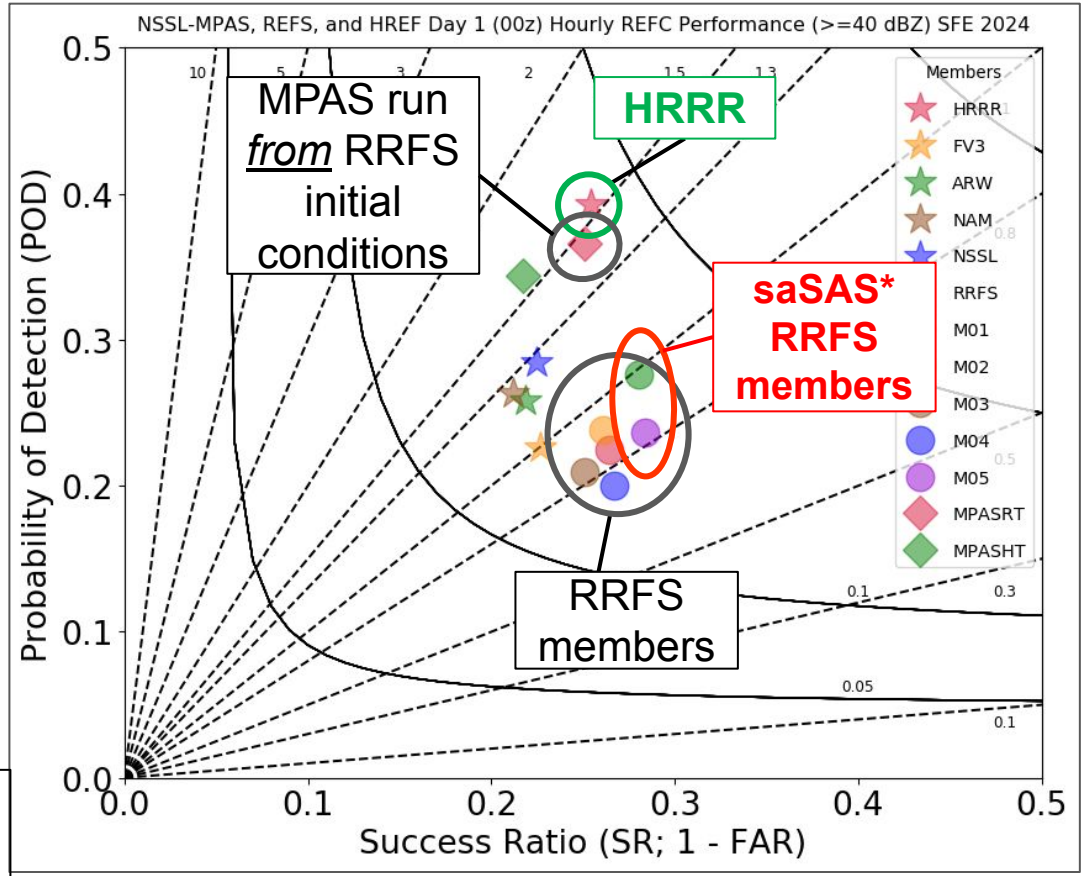


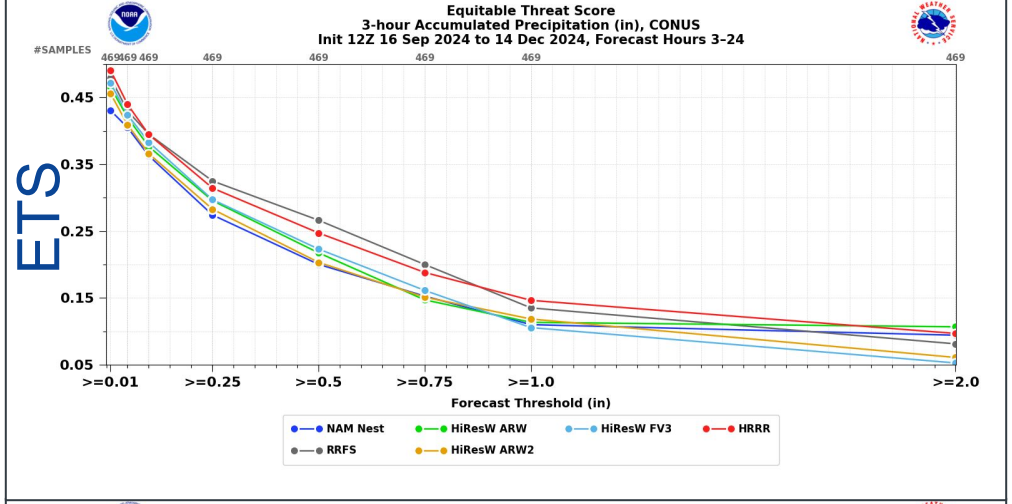
Image courtesy Jake Vancil (OU/CIWRO/SPC)

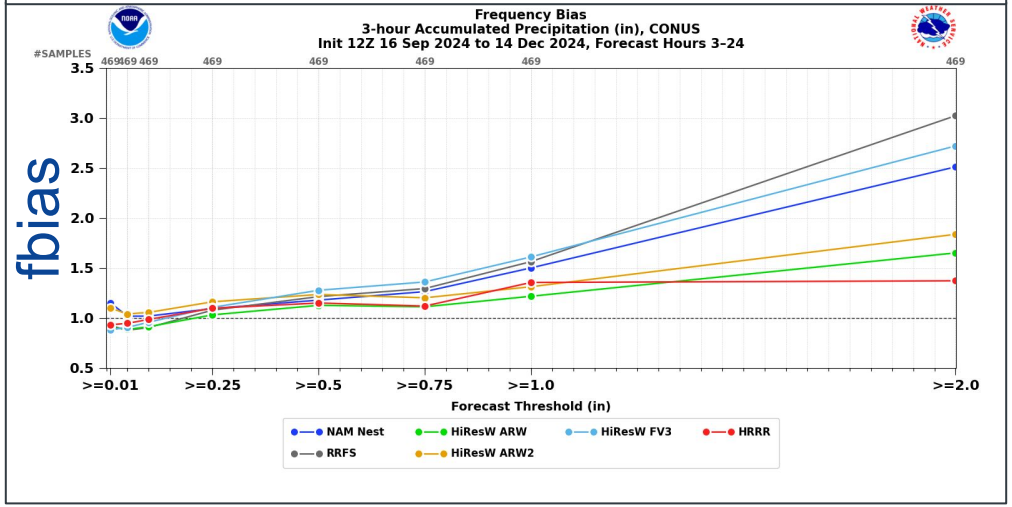
***saSAS =**

scale-aware Simplified Arakawa-Schubert (parameterized cnv)

A possible path forward for RRFSv1

- After seeing promising initial results for severe convection with an saSAS-based RRFS, more intensive reruns of the May 2024 period were made with it.
  - SPC viewed these saSAS reruns as a significant improvement over the original RRFS runs
- This spring convection testing was augmented with initial cold season retrospective saSAS testing - no red flags identified.
- *The real-time deterministic RRFS began running with saSAS convection in mid-August 2024*
- RRFSv1 code refrozen in late November 2024, and real-time RRFS shut down early December 2024 to enable retrospective experiments



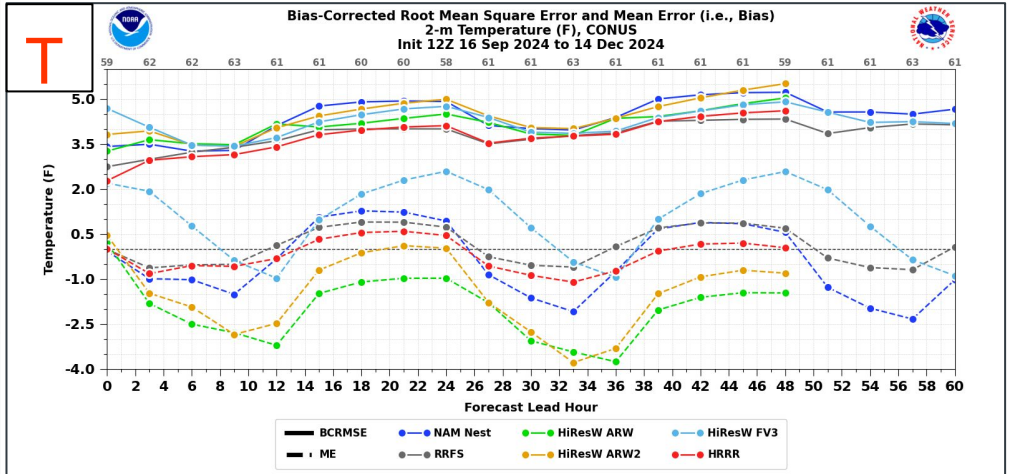


20240916 - ~20241203

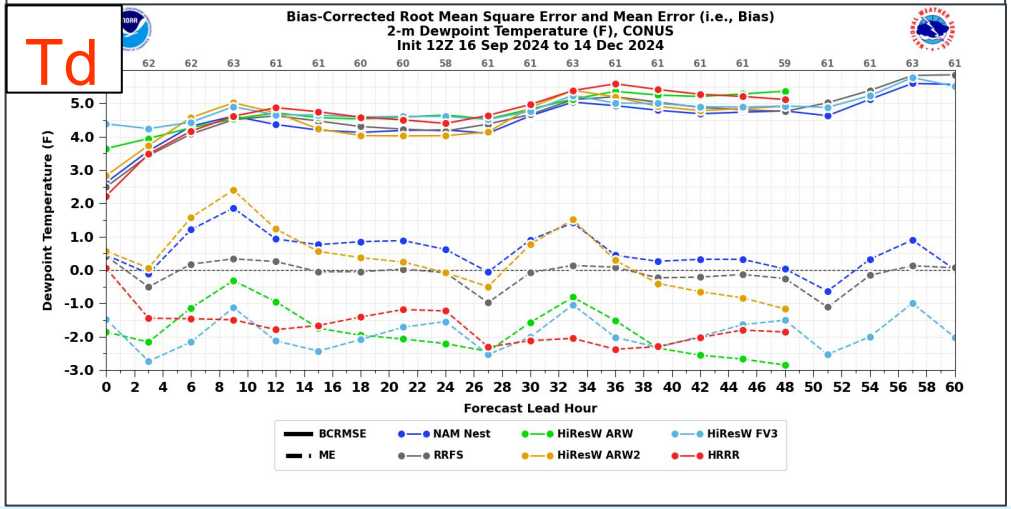
CONUS 3 h QPF, 12Z cycles
0-24 h forecasts

RRFS
HRRR
NAM Nest
HiresW ARW
HiresW ARW2
HiresW FV3

T



Td



20240916 - ~20241203

CONUS 2 m T/Td, 12Z cycles

RRFS

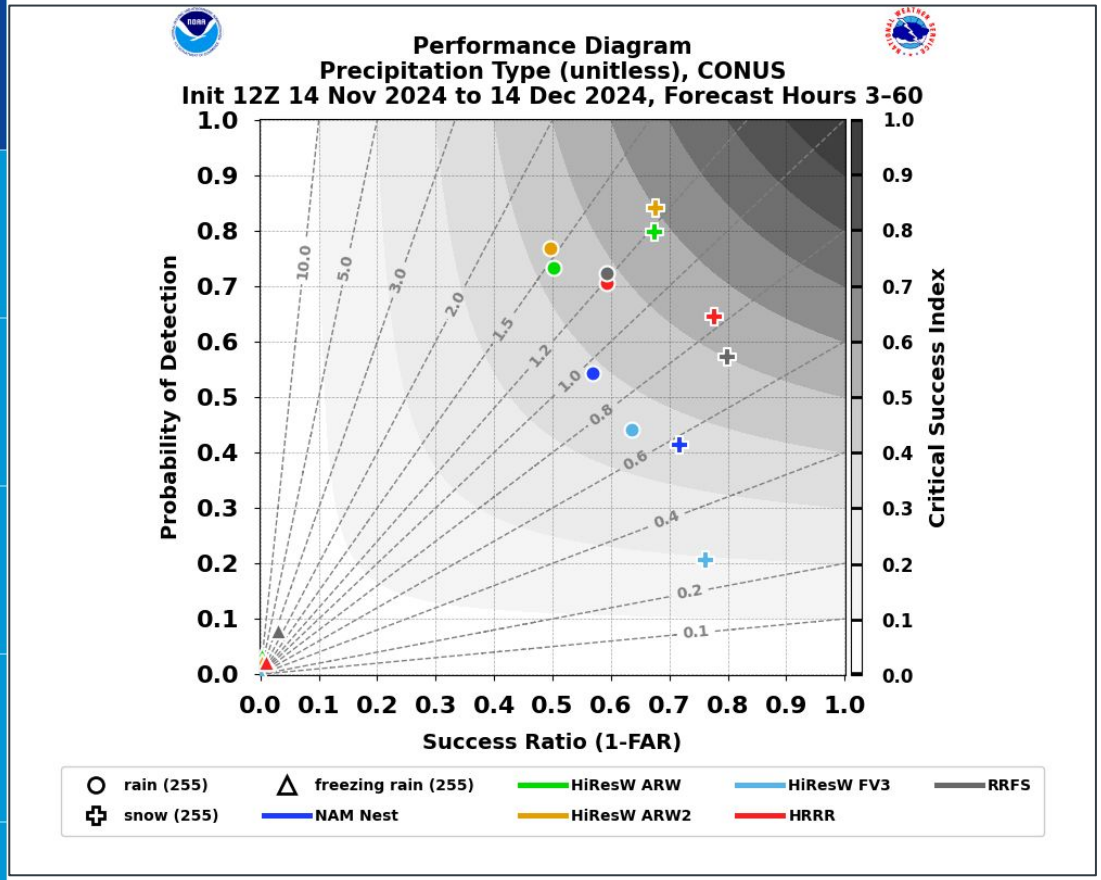
HRRR

NAM Nest

HiresW ARW

HiresW ARW2

HiresW FV3



20241114 - ~20241203

precipitation type perf diagram, 12Z cycles, f03-f60

RRFS

HRRR

NAM Nest

HiresW ARW

HiresW ARW2

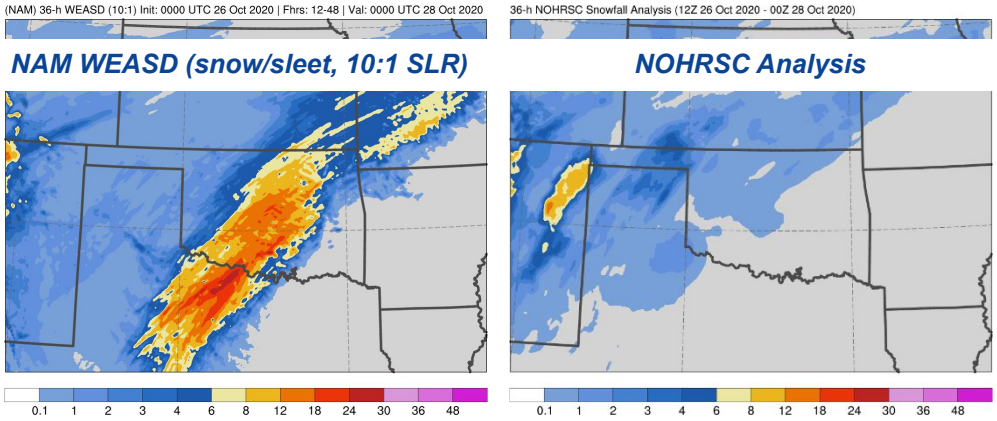
HiresW FV3

Now for some winter weather...

Winter Weather Parameters

WEASD – Water Equivalent of Accumulated Snow Depth (kg/m2)

- Apply a snow-to-liquid ratio (SLR) to get inches of snow
- A 10:1 SLR is not always representative – leads to the overprediction of snowfall totals during events with marginal temps, and the underprediction of snowfall totals during events with very cold temps
- Tallied by combining snow/sleet – for events where sleet (low SLR) is the primary precip type, 10:1 WEASD maps show erroneously large snow totals



*Thanks to Alicia Bentley (EMC) for material on this slide

Winter Weather Parameters

SNOD – instantaneous snow depth (m)

- Determined by the land surface model using a variable/effective SLR based on snow density
- Accounts for warm ground, compacting, melting, and sublimation processes
- EMC's MEG has advocated for users to look at accumulated SNOD (depth at fXX – depth at f00) as an alternative to 10:1 SLR WEASD
  - This approach generally works well, but can struggle in early/late season snow events with initially warmer soil (from Alicia Bentley, EMC)

Winter Weather Parameters

ASNOW (RRFS/HRRR) – accumulated snowfall (m)

- Uses a variable/effective SLR – combines snow + sleet
- *A good field to look at for snowfall accumulation totals*
- *Used in REFS for snow accumulation probabilities*

TSNOWP (RRFS only) – total snow precipitation accumulation (kg/m2) – water equivalent

FROZR (RRFS/HRRR) – sleet accumulation (kg/m2) – water equivalent

FRZR (RRFS/HRRR) – freezing rain accumulation (kg/m2) – water equivalent

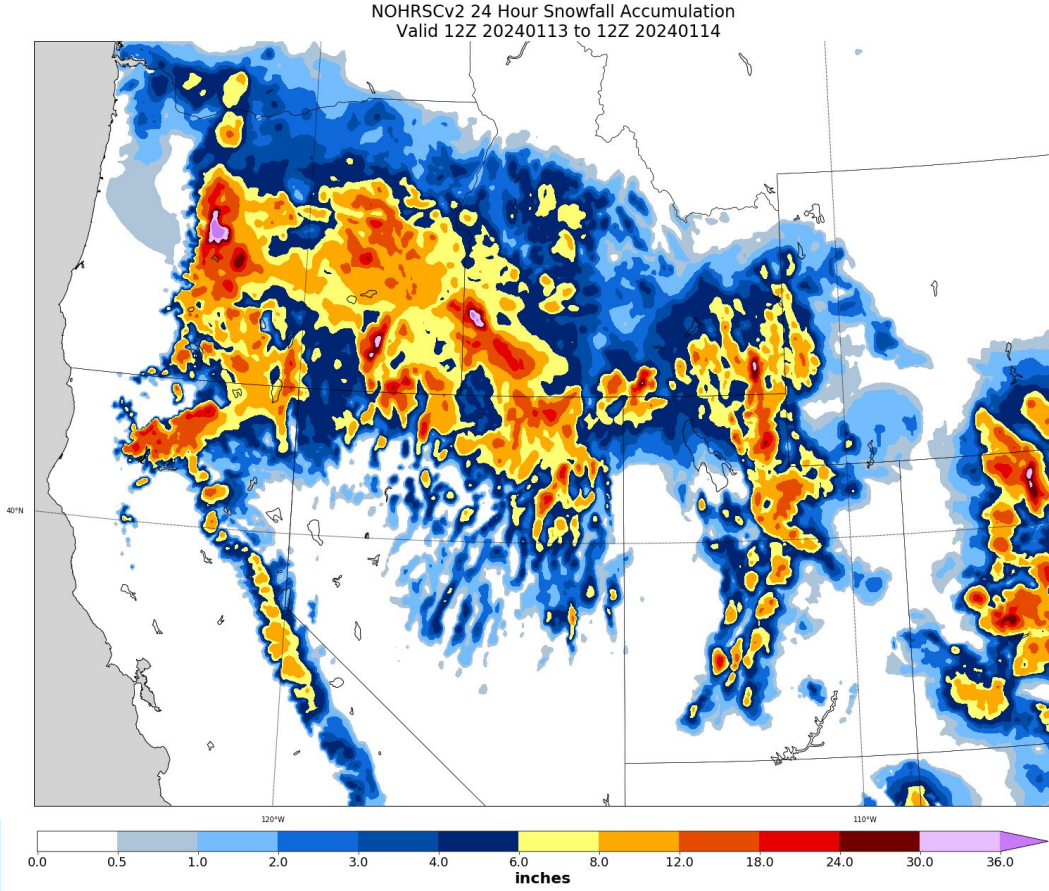
CPOFP – quantifies the % of hydrometeors reaching the surface as frozen precipitation (as snow/sleet)

- Freezing rain has a value of zero
- High values indicate snow accumulation is favorable, low values are indicative of mixed precip

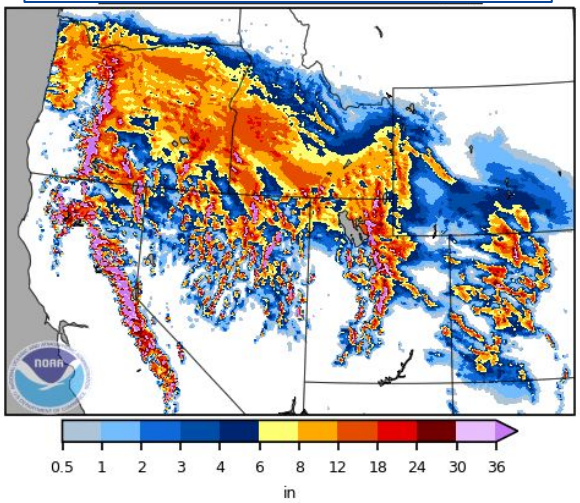
Western US Snowfall – 13-14 Jan 2024

- RRFS/HRRR – ASNOW (variable density)
- NAM nest – WEASD with a 10:1 SLR

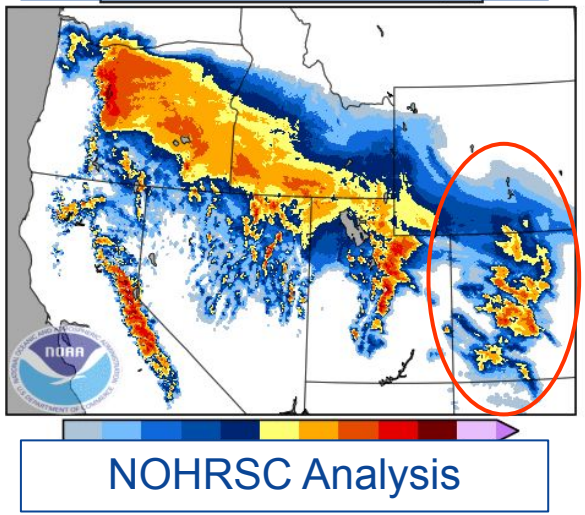
*Thanks to Ben Albright (WPC) for this figure



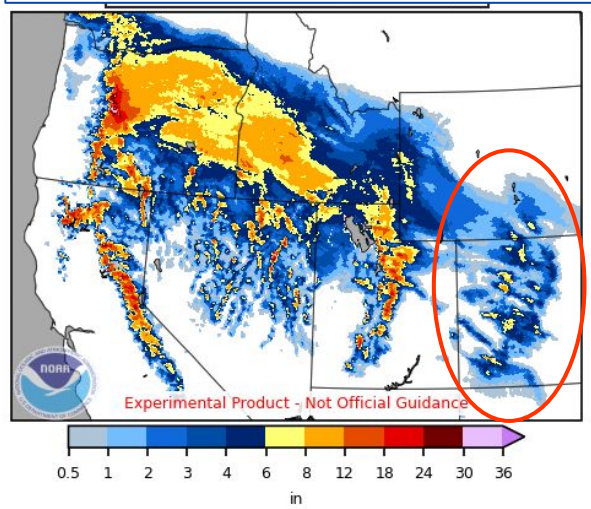
NAM Nest WEASD (10:1)



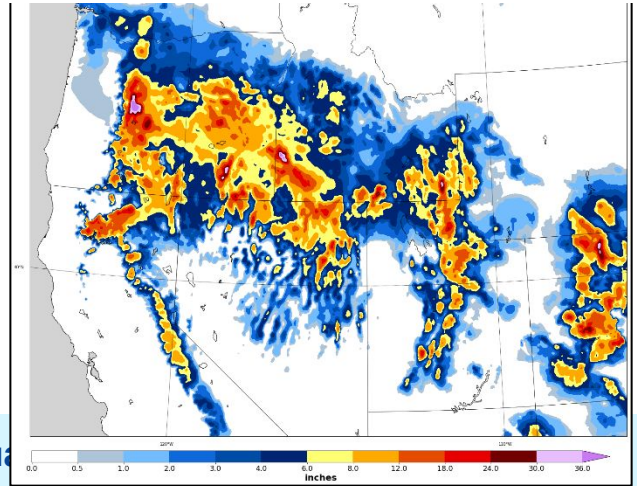
HRRR ASNOW (var den)



RRFS retro ASNOW (var den)



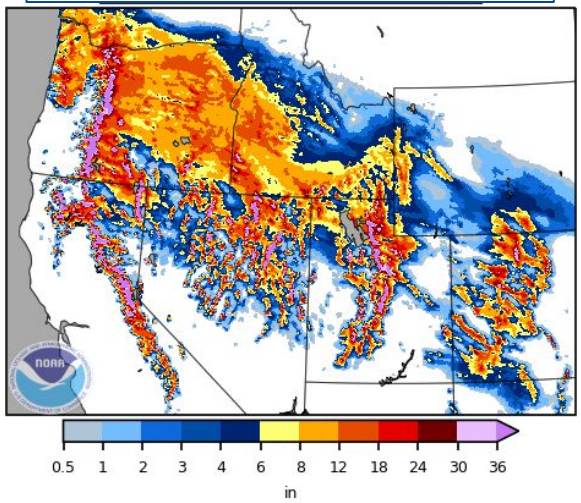
NOHRSC Analysis



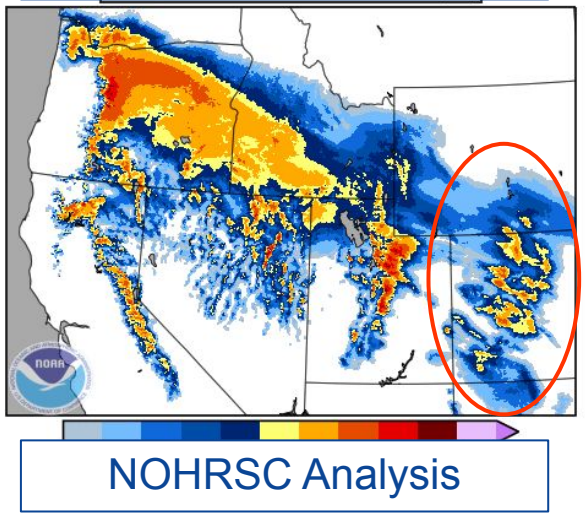
48-h forecasts from the 12 Jan 12Z cycle

24-h snowfall accumulation valid 13 Jan 12Z – 14 Jan 12Z

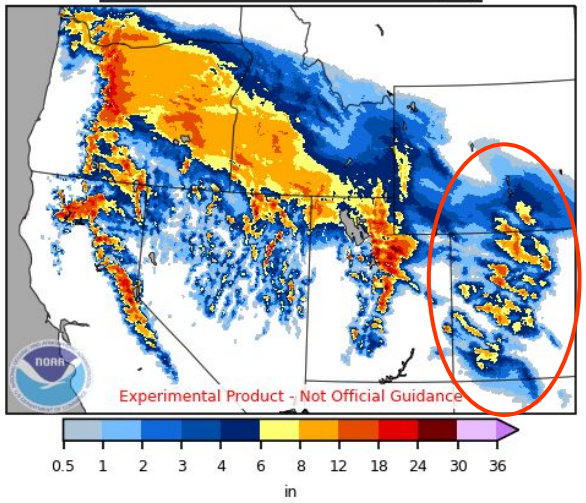
NAM Nest WEASD (10:1)



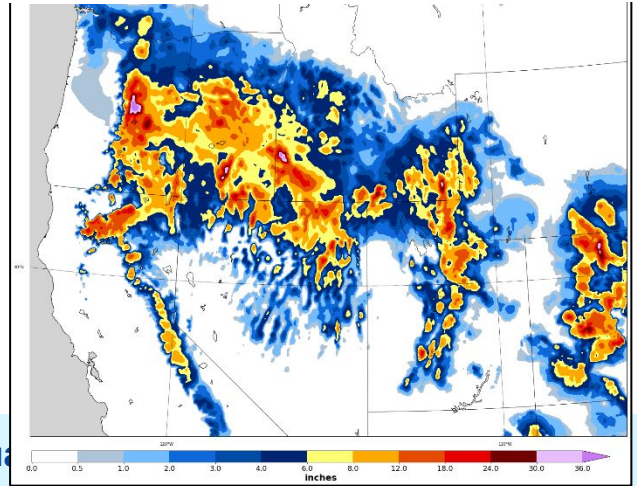
HRRR ASNOW (var den)



RRFS retro ASNOW (var den)



NOHRSC Analysis



24-h forecasts from the 13 Jan 12Z cycle

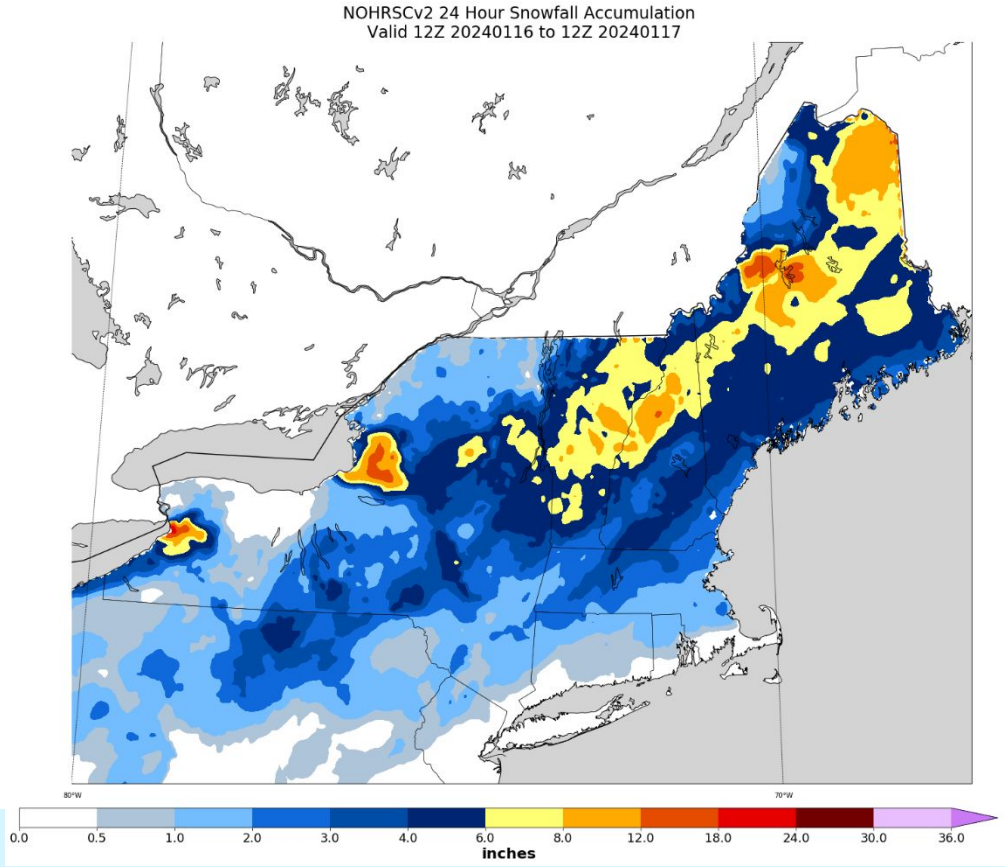
24-h snowfall accumulation valid 13 Jan 12Z – 14 Jan 12Z

Northeast US Snowfall – 16-17 Jan 2024

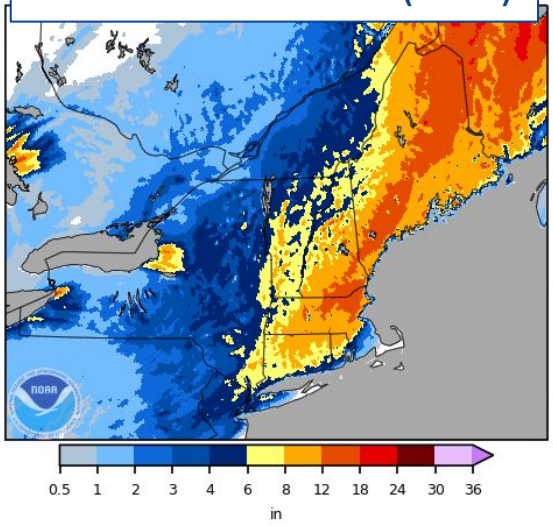
- Note: NOHRSC only covers CONUS, so ignore the (lack of) observed snowfall over Canada

- RRFS uses FVCOM Great Lakes data (as does HRRR)

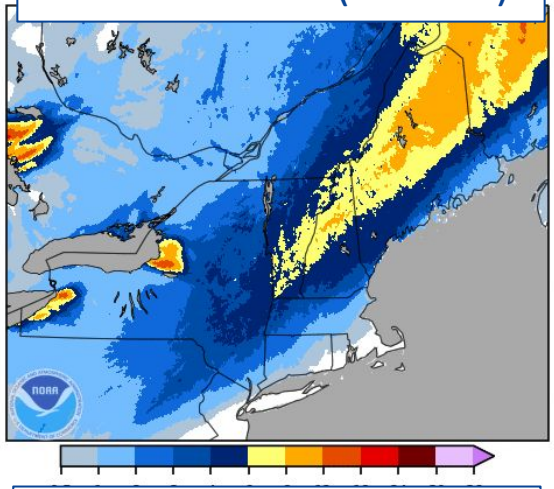
*Thanks to Ben Albright (WPC) for this figure



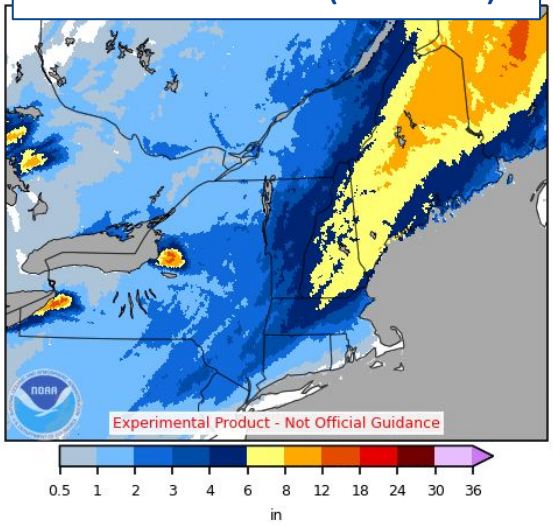
NAM Nest WEASD (10:1)



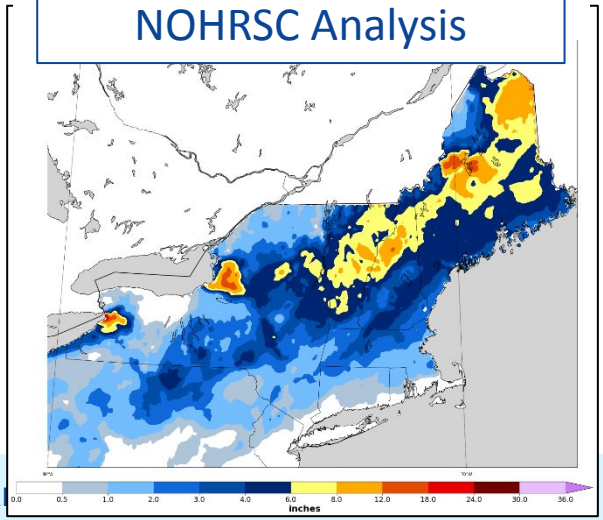
HRRR ASNOW (var den)



RRFS ASNOW (var den)



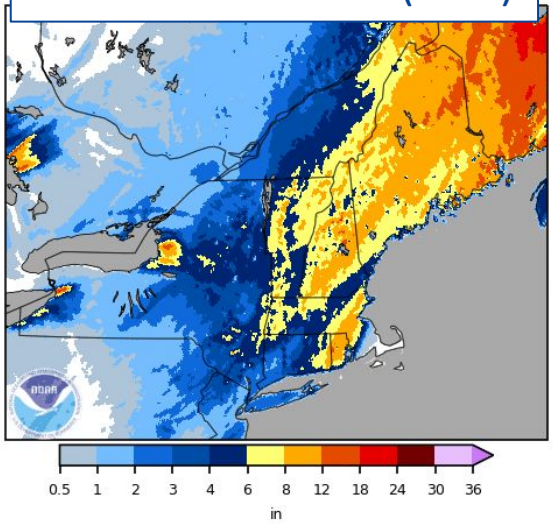
NOHRSC Analysis



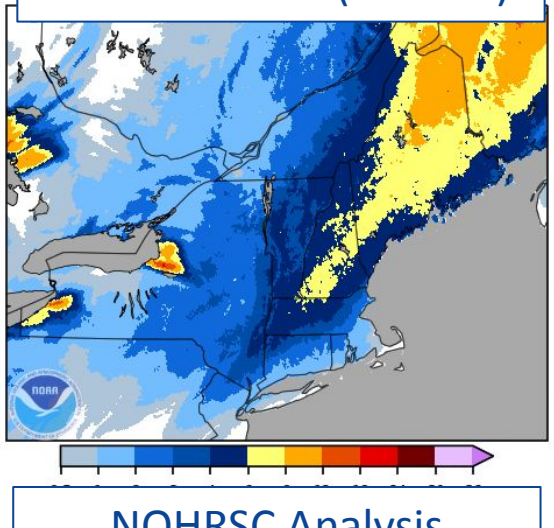
36-h forecasts from the 16 Jan 00Z cycle

24-h snowfall accumulation valid 16 Jan 12Z – 17 Jan 12Z

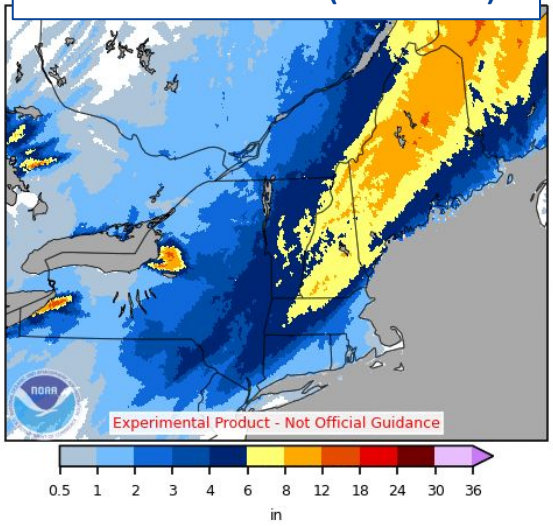
NAM Nest WEASD (10:1)



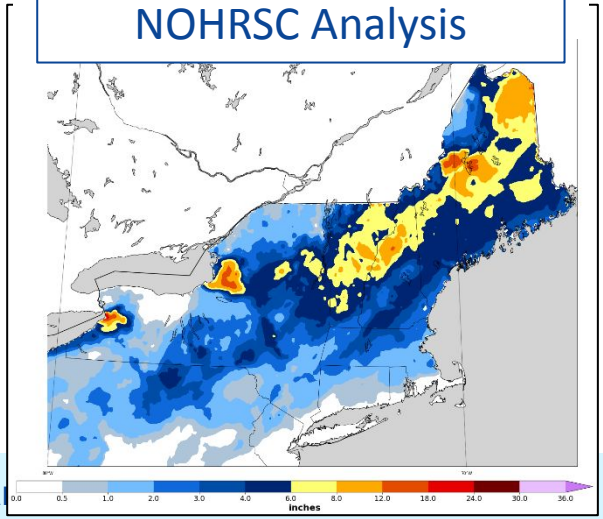
HRRR ASNOW (var den)



RRFS ASNOW (var den)



NOHRSC Analysis

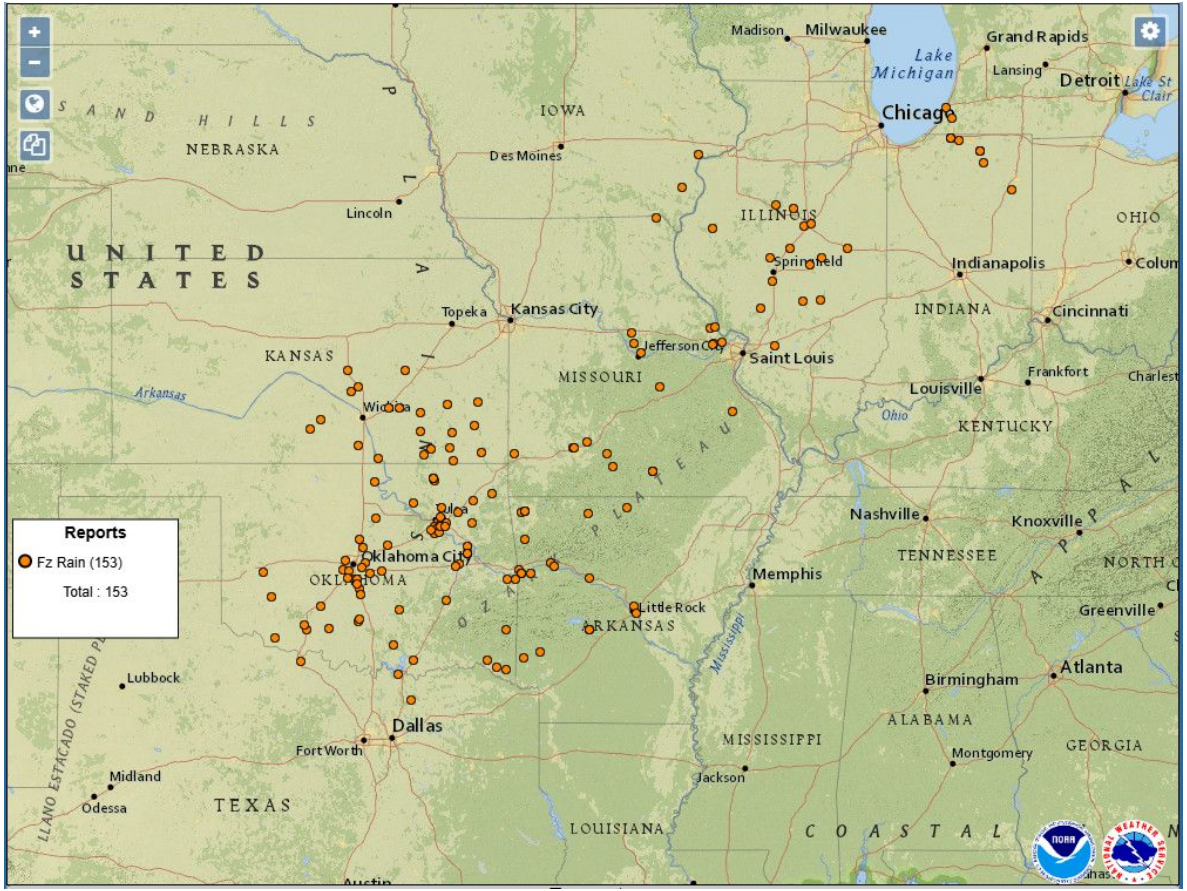


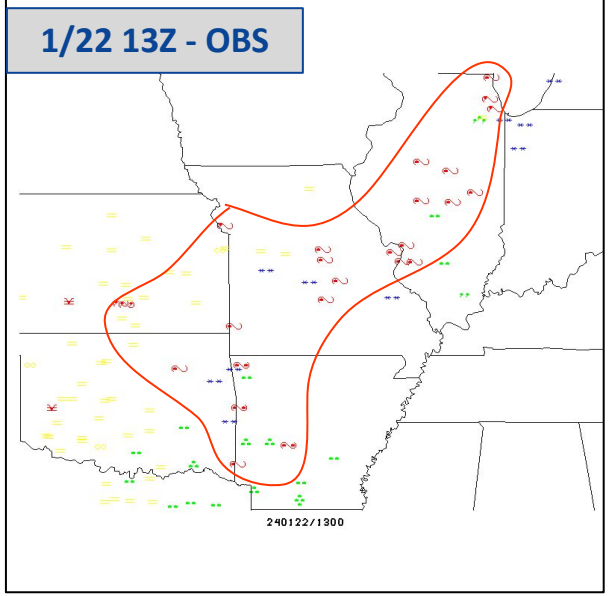
24-h forecasts from the 16 Jan 12Z cycle

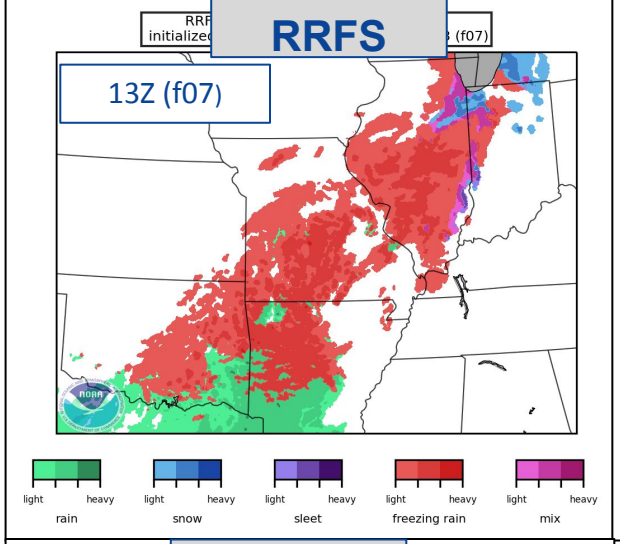
24-h snowfall accumulation valid 16 Jan 12Z – 17 Jan 12Z

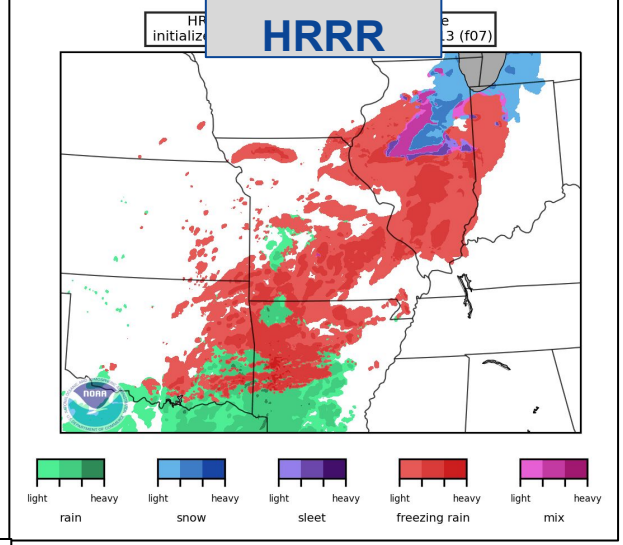
Central US Freezing Rain – 22 Jan 2024

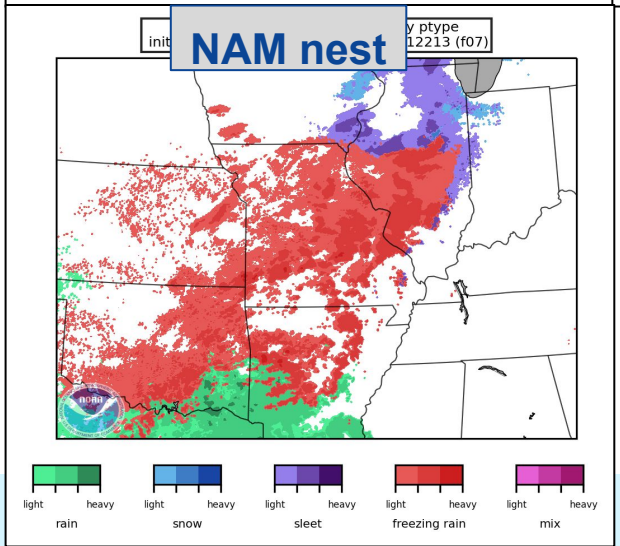
- 148 freezing rain reports occurred between 12Z and 00Z, no sleet reports
- A somewhat long duration freezing rain event w/ multiple waves of freezing precip
- Precip type – RRFS, HRRR, NAM nest
  - Note: NAM nest uses the NCEP dominant method; no mixed precip

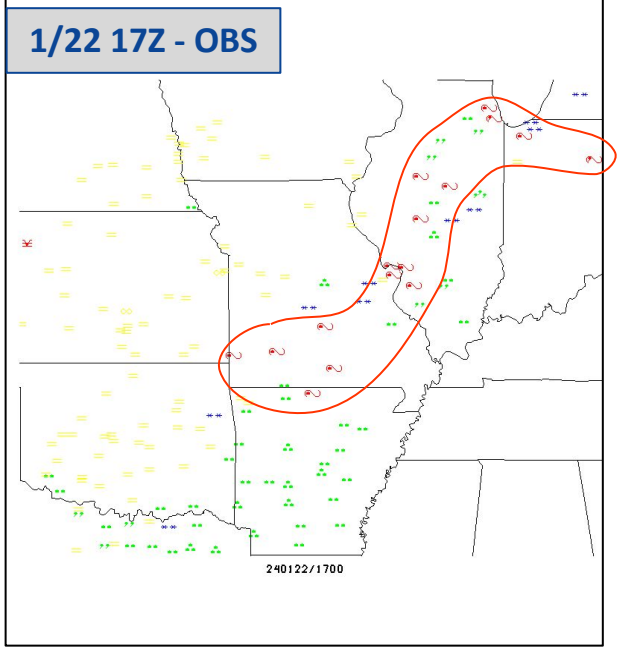


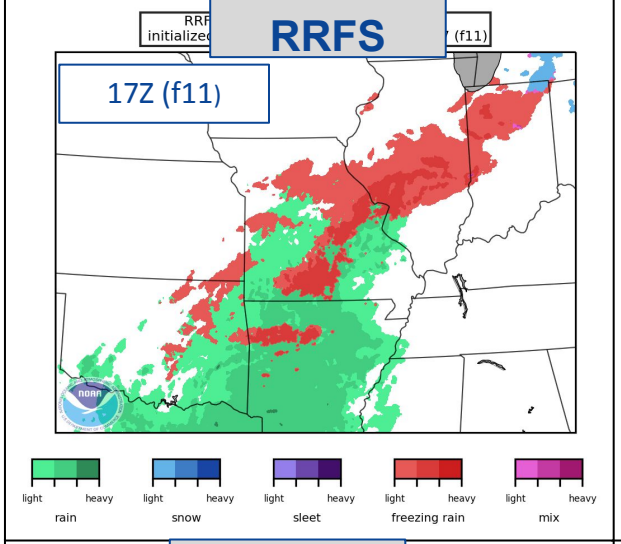

1/22 13Z - OBS
240122/1300

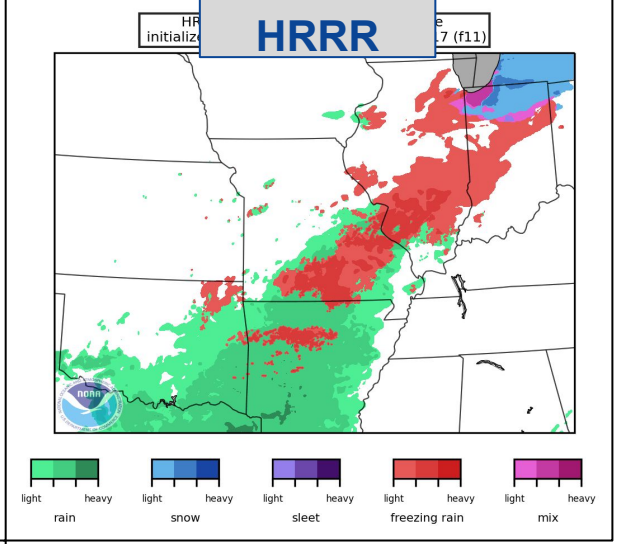

RRFS
13Z (f07)
light
heavy
rain
snow
sleet
freezing rain
mix

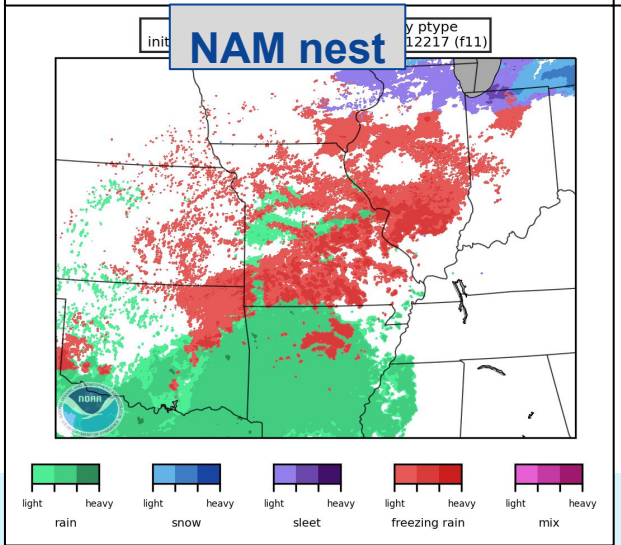

HRRR
rain
snow
sleet
freezing rain
mix


NAM nest
rain
snow
sleet
freezing rain
mix


1/22 17Z - OBS
240122/1700


RRFS
17Z (f11)
light
heavy
rain
snow
sleet
freezing rain
mix


HRRR
light
heavy
rain
snow
sleet
freezing rain
mix


NAM nest
light
heavy
rain
snow
sleet
freezing rain
mix

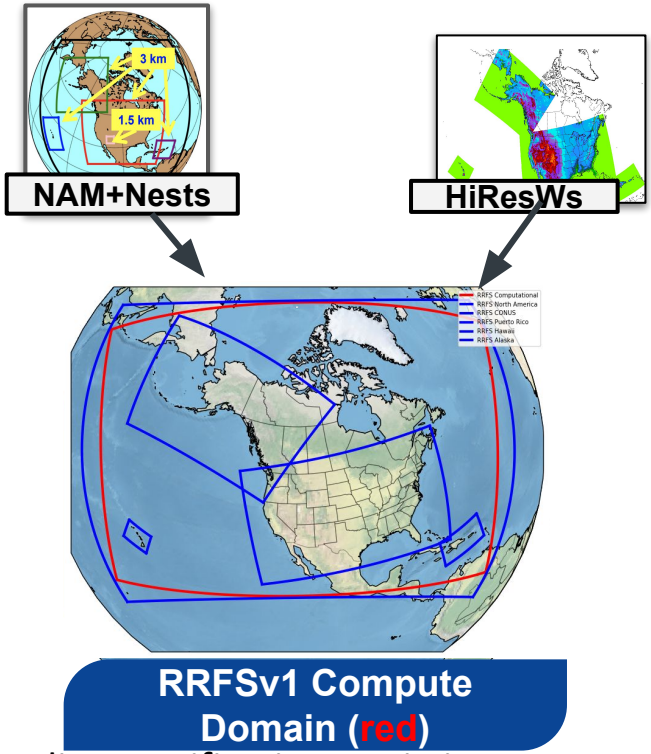
Next steps for RRFS

- RRFS recently finished* running the deterministic aspect of final retrospective testing (with full DA system, over North America):
  - Jan 8 to Feb 8, 2024 (winter retro)
  - July 2023 (summer retro)
  - *May 2024 (spring/severe retro) - Discovered last week that improper initial soil states were used in spinning up this retro. In the process of being rerun.
- Also hoping to run the REFS forecast ensemble for a limited number (~30 cycles) of cases
- Once retros have been analyzed, a final eval by NWS forecasters and other stakeholders (planned for 4/1 to 6/15) will inform an NCEP decision on whether to go forward with RRFSv1 or not.

Summary

- RRFS will be a *major* change
  - Consolidating a large fraction of operational CAM guidance with a single, unified 3-km system covering North America
- Much work remains to be done (and approvals need to be given) if it is to be implemented about one year from now.

Thanks for listening!



Email: Matthew.Pyle@noaa.gov

Website for comparison graphics, experiment change log, model namelists, verification statistics: https://www.emc.ncep.noaa.gov/users/emc.campara/rrfs

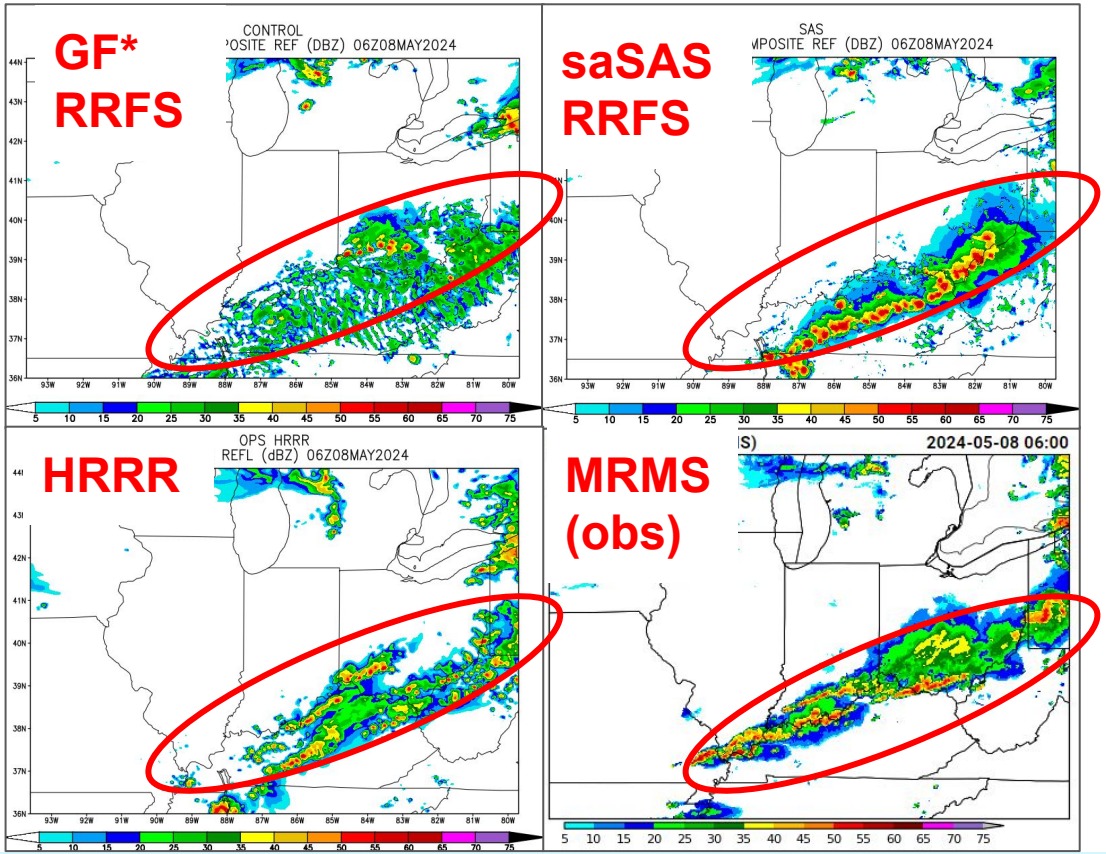
Supplemental Slides

RRFSv1 Implementation Status and complicating factors

- RRFS currently is targeting an early calendar 2026 implementation, but many hurdles remain, including getting scientific and technical approval of the package
- Factors complicating the RRFS implementation timeline:
  - **Implementation moratorium** (currently scheduled to cover a year starting in Aug 2026 to allow NCEP production suite to be ported to new machine)
  - **GFS/GEFS implementations** - big systems also targeting the pre-moratorium timeframe. RRFS is coordinating with GFS/GEFS teams to avoid targeting the same time

12 h forecasts of composite reflectivity

valid 06Z 8 May 2024



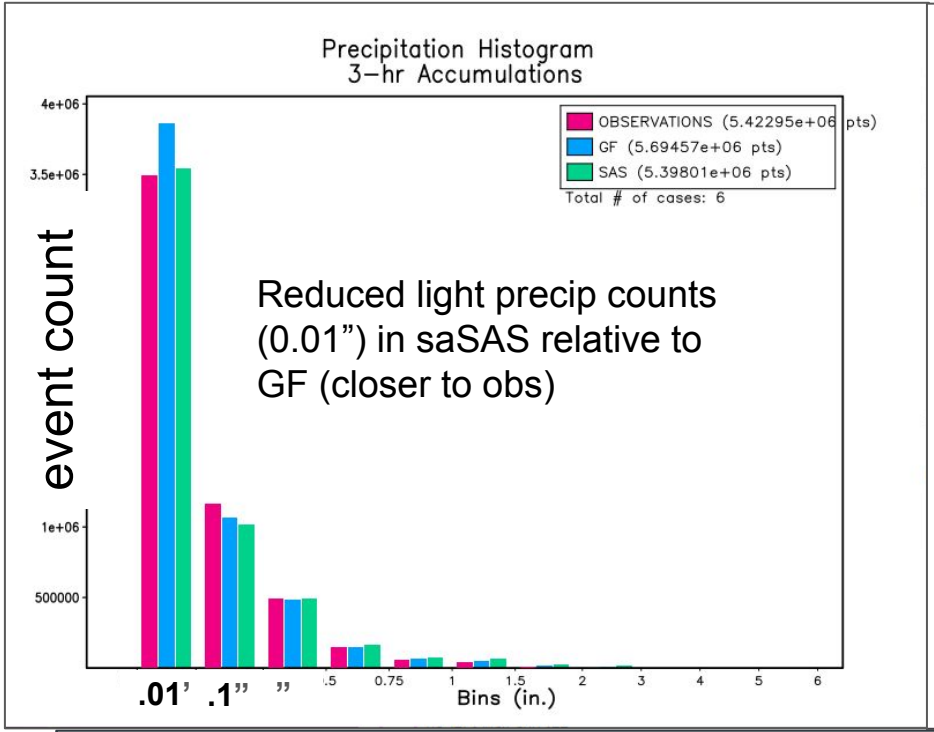
***GF =**

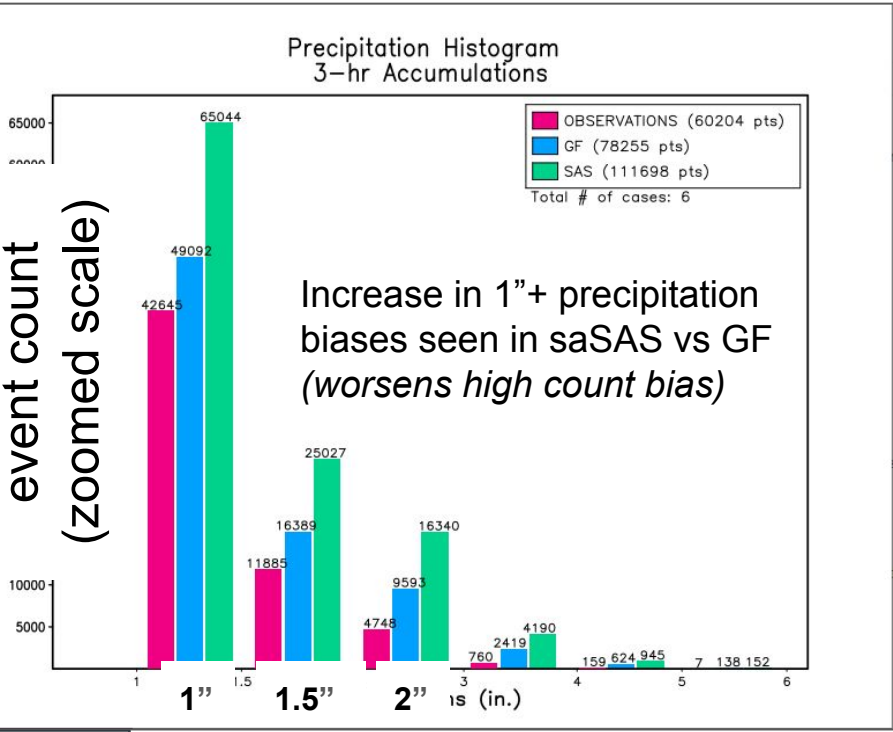
Grell-Freitas (parameterized cnv) - what was running in RRFS at time of HWT

Comparison provided by Eric Aligo

Composite 3 h Precipitation Histograms

total counts from six cases (May 2024)



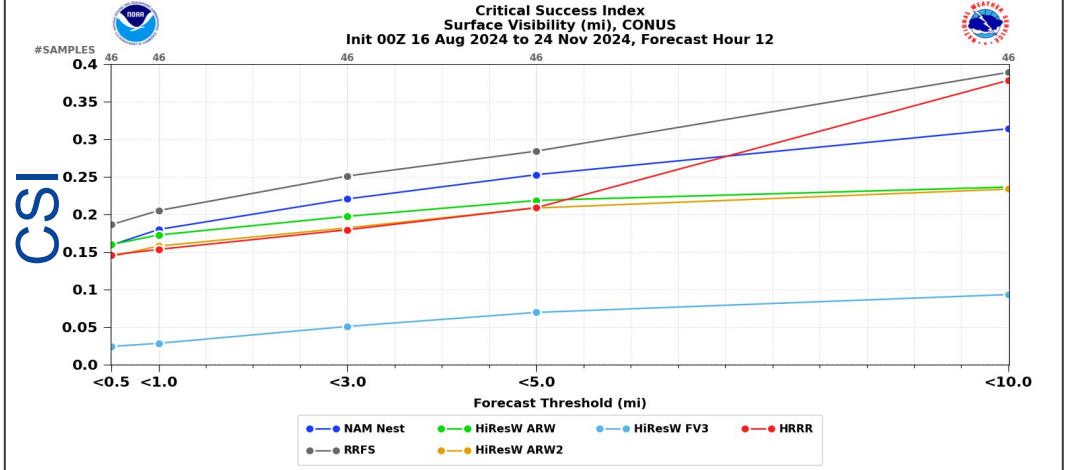


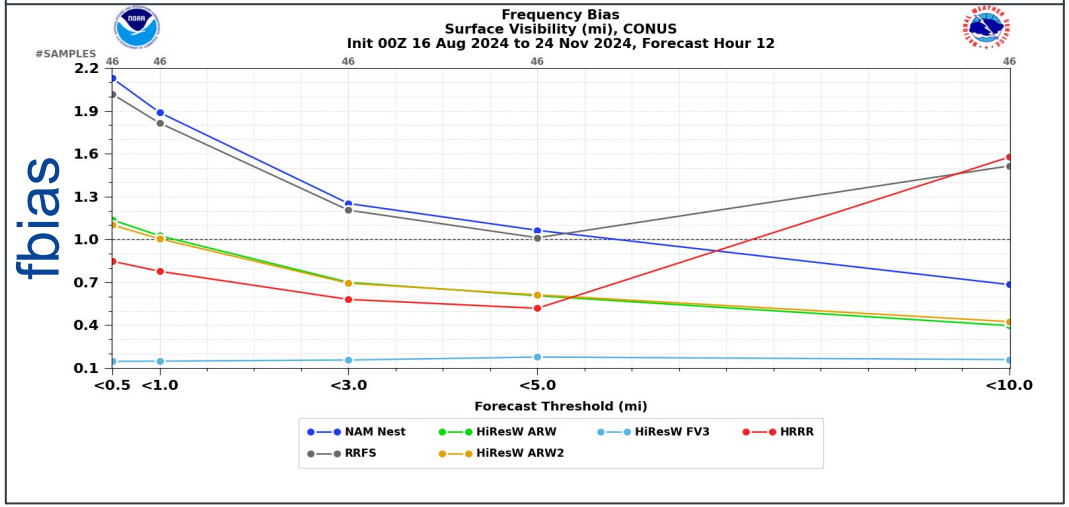
obs

GF-based RRFS

saSAS-based RRFS

Comparison provided by Eric Aligo





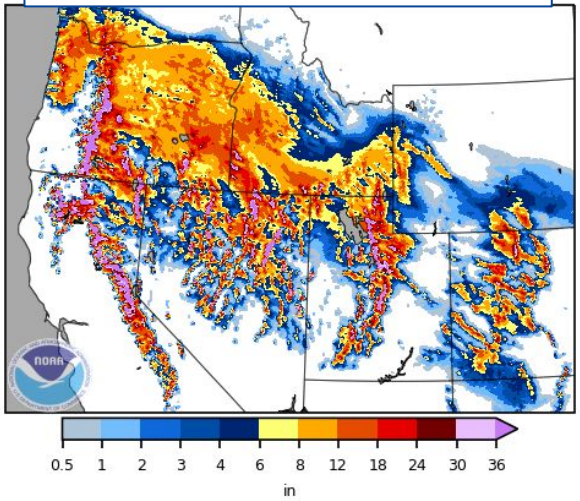
20240816 - 20241124

CONUS surface visibility

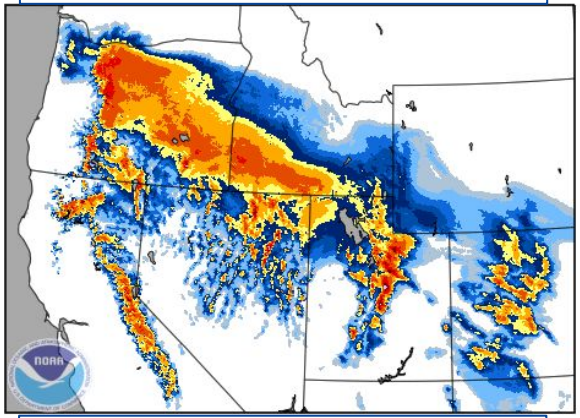
12 h forecasts valid 12Z

RRFS
HRRR
NAM Nest
HiresW ARW
HiresW ARW2
HiresW FV3

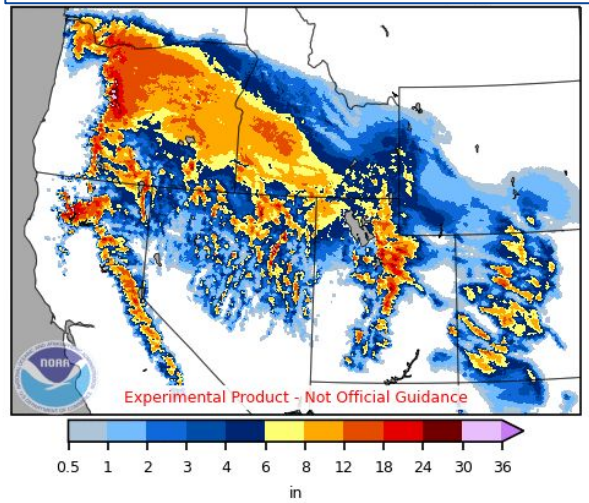
NAM Nest WEASD (10:1)



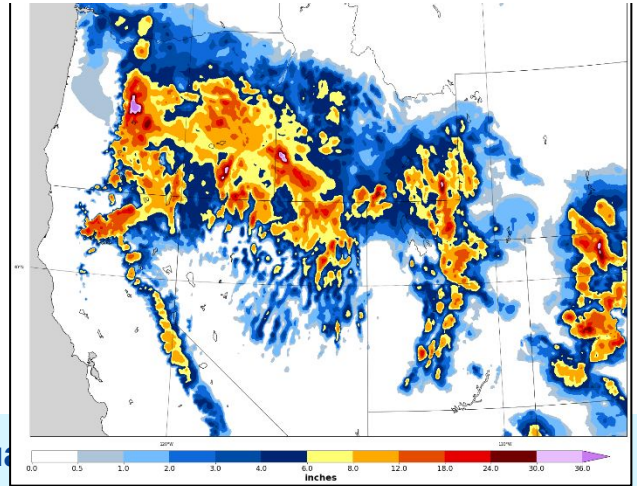
HRRR ASNOW (var den)



RRFS retro ASNOW (var den)



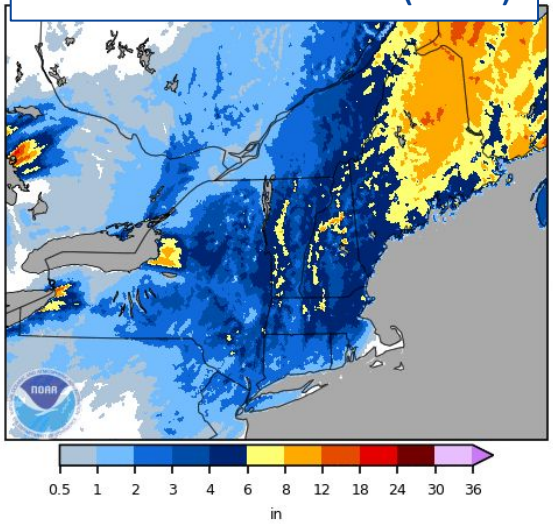
NOHRSC Analysis



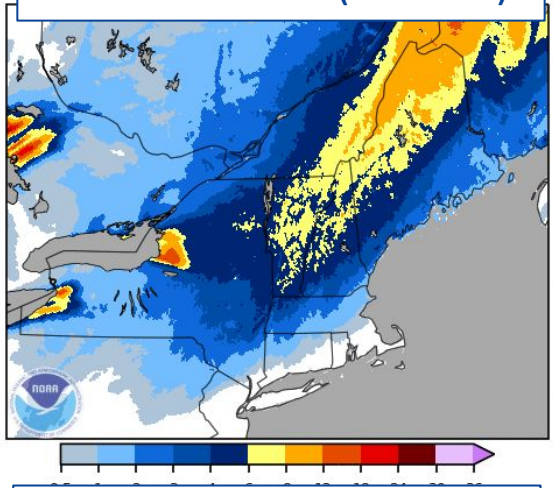
24-h snowfall accumulation valid 13 Jan 12Z – 14 Jan 12Z

36-h forecasts from the 13 Jan 00Z cycle

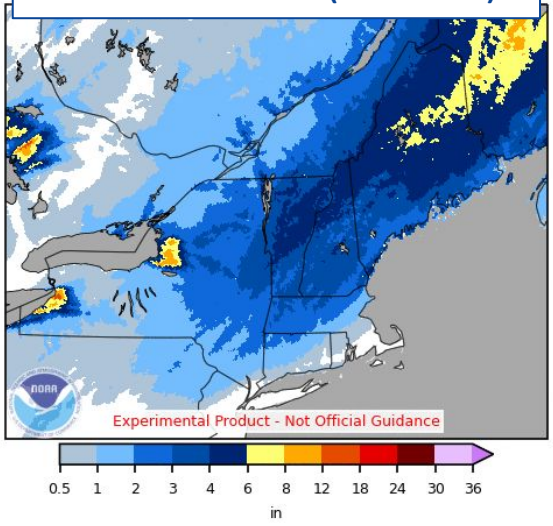
NAM Nest WEASD (10:1)



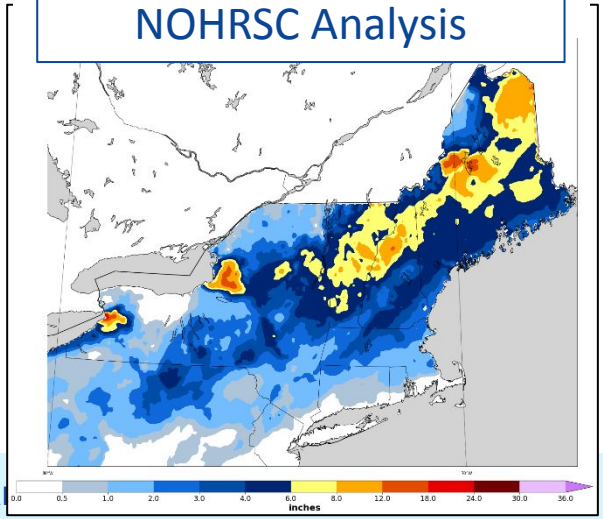
HRRR ASNOW (var den)



RRFS ASNOW (var den)



NOHRSC Analysis

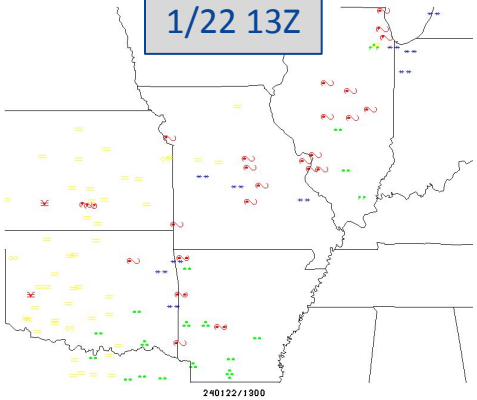


48-h forecasts from the 15 Jan 12Z cycle

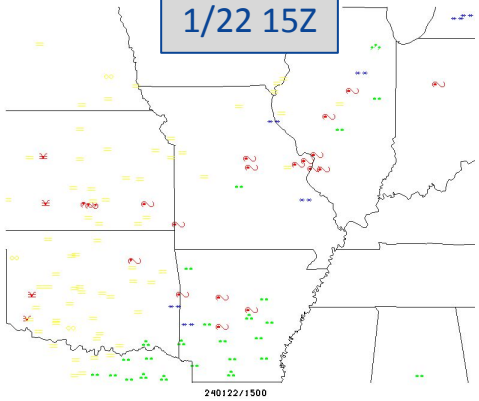
24-h snowfall accumulation valid 16 Jan 12Z – 17 Jan 12Z

Observed Precipitation Type

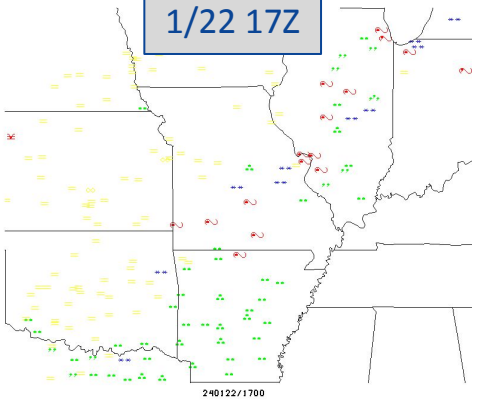
1/22 13Z



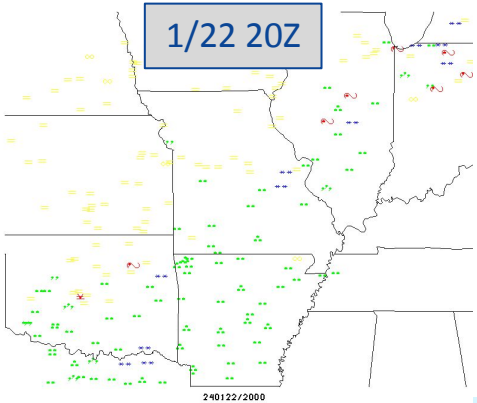
1/22 15Z



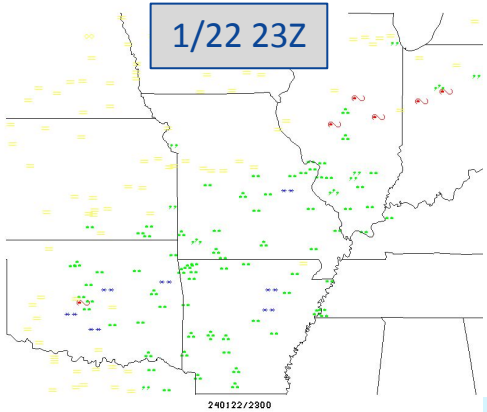
1/22 17Z



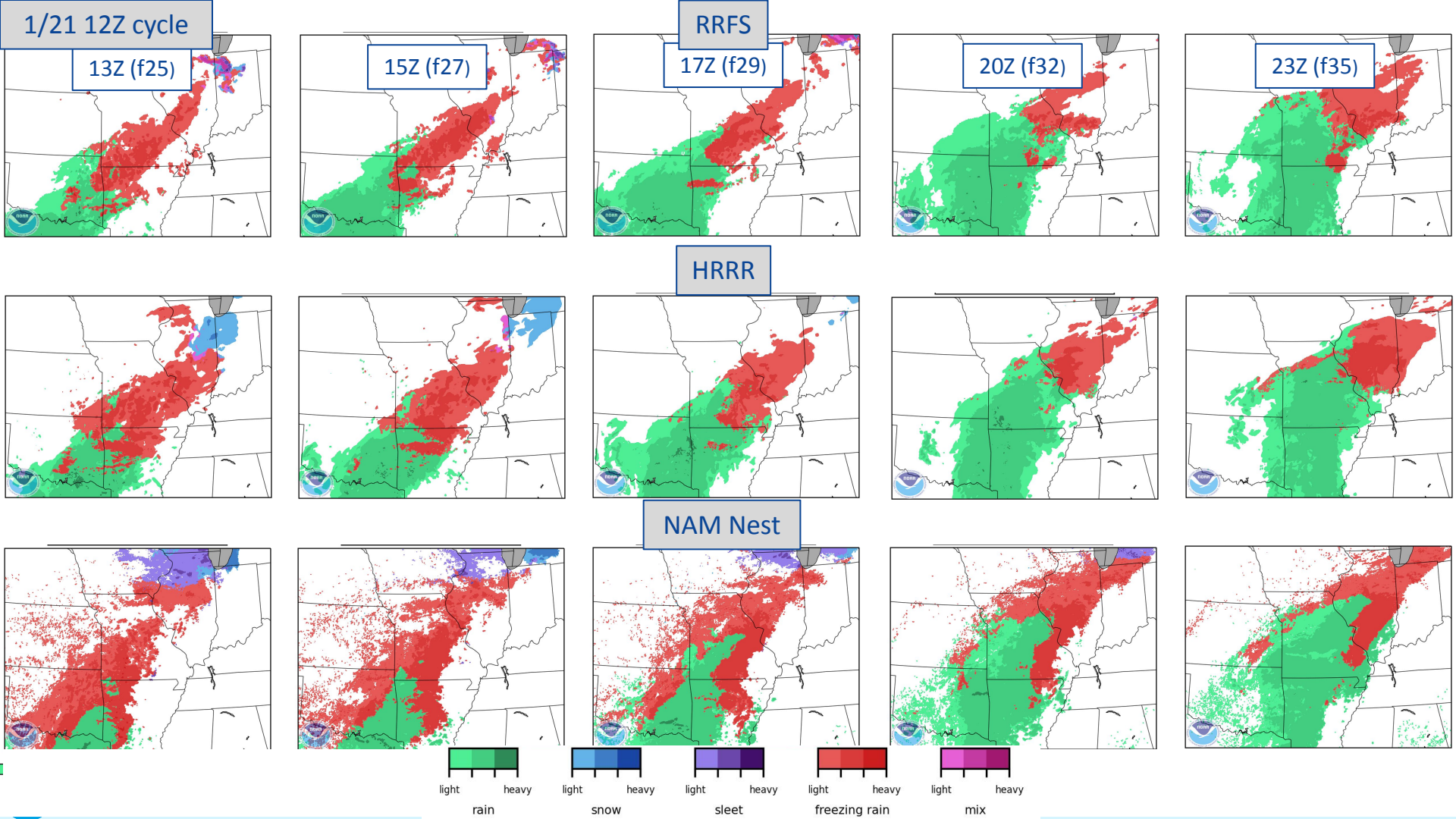
1/22 20Z

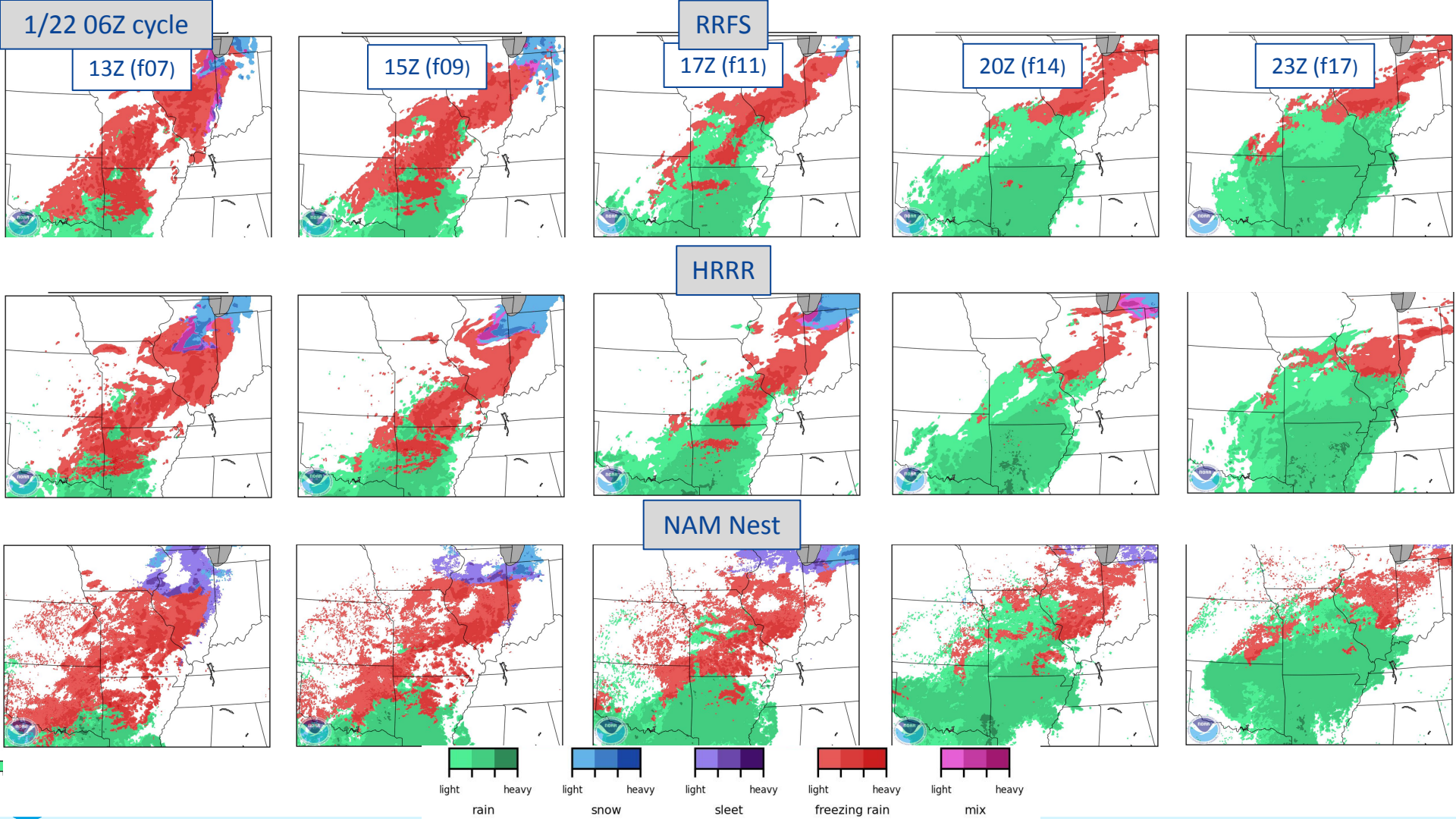


1/22 23Z

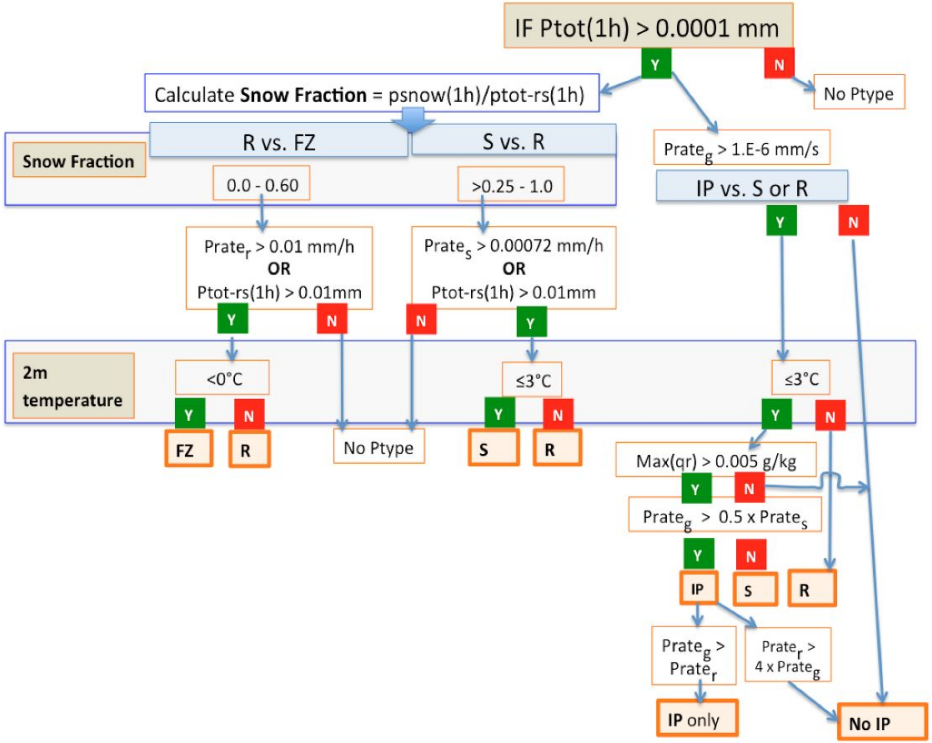


RRFS status for W


1/21 12Z cycle
13Z (f25)
15Z (f27)
RRFS
17Z (f29)
20Z (f32)
23Z (f35)
HRRR
NAM Nest
light
heavy
rain
snow
sleet
freezing rain
mix


1/22 06Z cycle
13Z (f07)
15Z (f09)
RRFS
17Z (f11)
20Z (f14)
23Z (f17)
HRRR
NAM Nest
light
heavy
rain
snow
sleet
freezing rain
mix

Precipitation Type



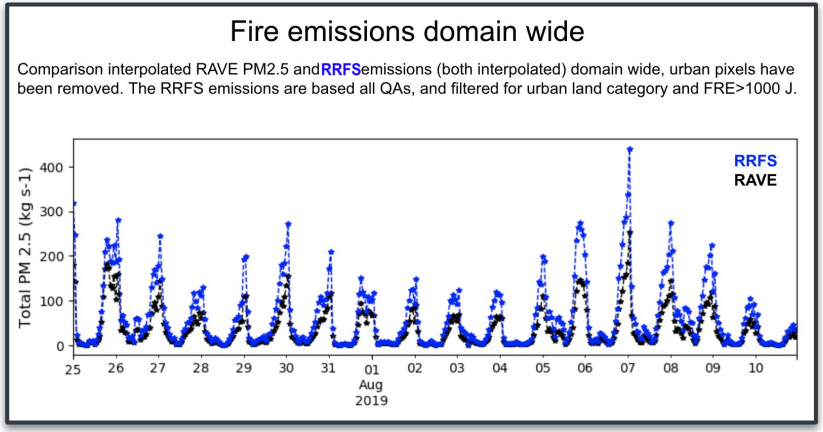
- RRFS utilizes the same method as the RAP/HRRR for calculating precipitation type
- Based on the explicit prediction of hydrometeors (snow, rain, graupel) reaching the surface from the Thompson microphysics
- Can get ‘yes’ answers for multiple types
- Computes snow fraction (fallen snow in past hour / total snow + rain over past hour) to determine potential for snow/rain/freezing rain
- Also checks fall rate for graupel to determine potential for sleet (IP)

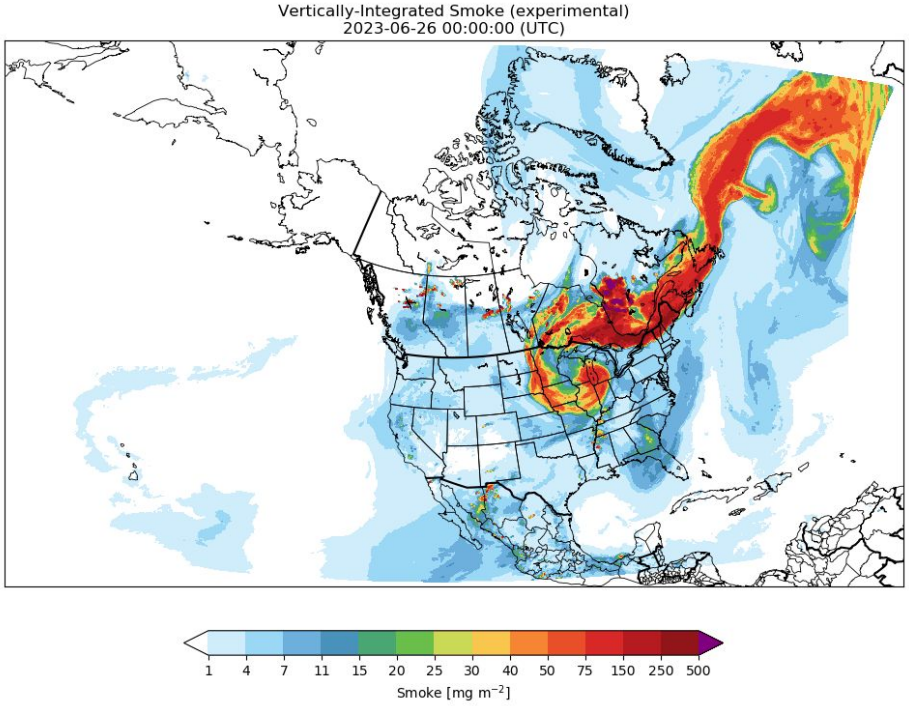
*Thanks to Geoff Manikin (MDL) for material on this slide

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