The Rapid Refresh Forecast System Version 1

Ben Blake[1,2]

on behalf of the wider RRFS development team that includes many developers across EMC, GSL, NSSL, GFDL, NCAR, DTC, and our academic partners

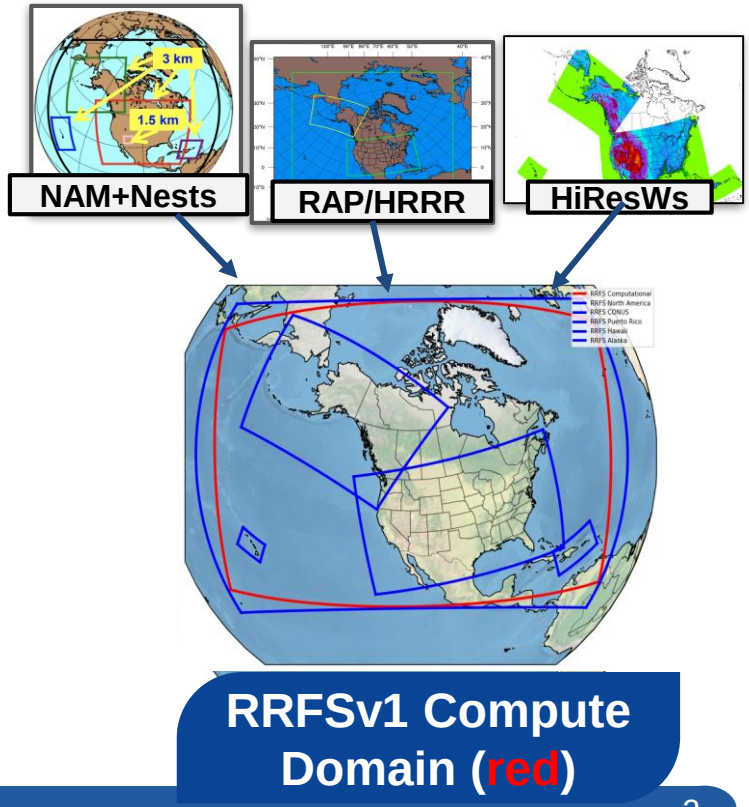
[1]SAIC
[2]NOAA/NWS/NCEP/EMC

Winter Weather Experiment Presentation
December 19, 2023

Rapid Refresh Forecast System (RRFS)

A UFS Application

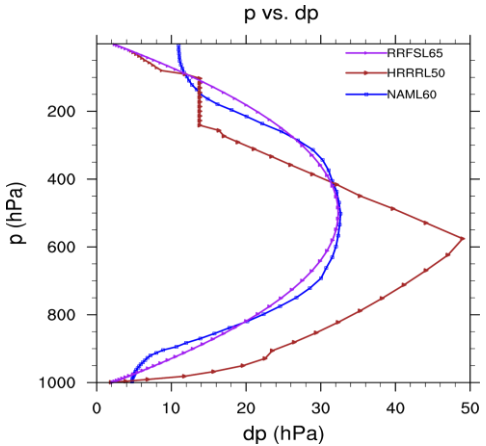
- **FV3 dynamical core Limited Area Model**
- **Hourly updated**
- **3 km grid spacing over North America**
- **65 vertical layers**
- **Hybrid 3DEnVar assimilation (30 members)**
- **Includes Smoke & Dust**
- **Deterministic forecasts to *at least* 18h every hour, 60h every 6 hours**
- **Ensemble forecasts to 60h every 6 hours, with membership decreasing after 42h**
  - 12 RRFS Members + 2 HRRR members (7 on-time + 7 t-6h)
- **Targeting a mid 2025 implementation**



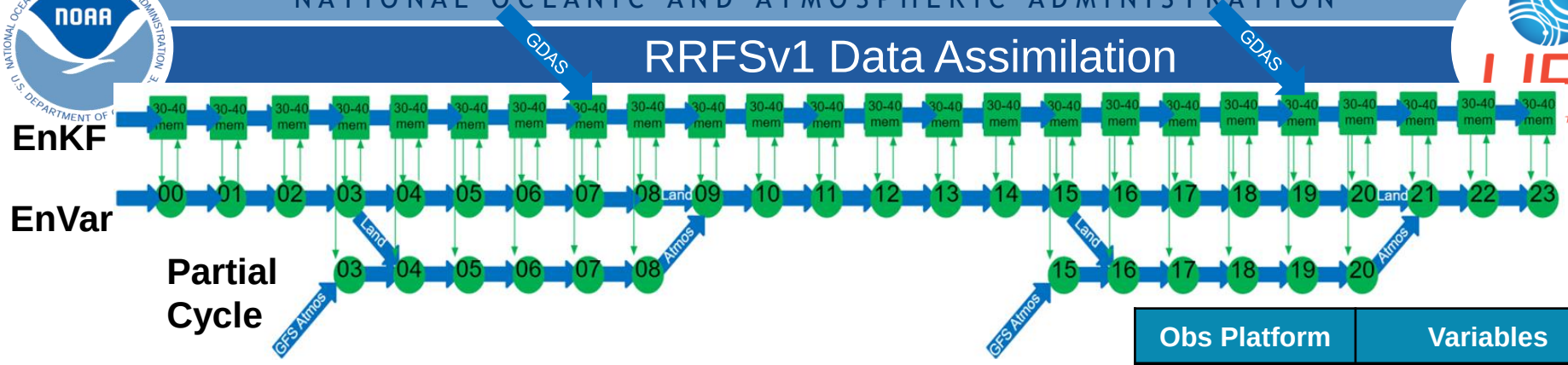
RRFS Physics and Vertical Resolution

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)

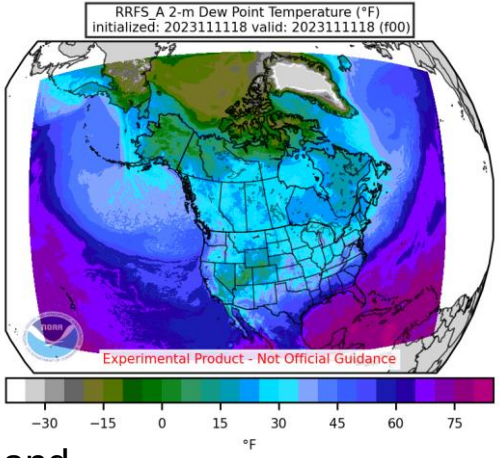
Parameter	RRFS	HRRRv4	NAMv4
Number of levels	65	50	60
Lowest level (m)	8	8	20
Top (hPa)	2	20	2



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



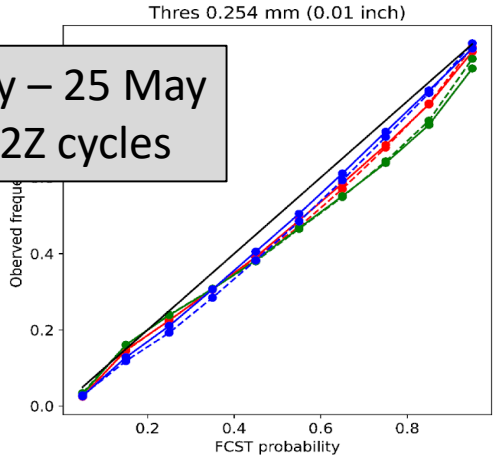
Obs Platform	Variables
METAR, Mesonet, Buoy, C-Man, Ship	T, moisture, W, ps, ceiling, vis
Rawinsonde	T, moisture, W
NEXRAD Radar	dBZ, rw, VAD W
Lightning	Flash Extent Density
Aircraft	T, moisture, W
GOES-16/18	ABI, AMVs, cloud top pres. & T
Polar Orbiters	Radiances (AMSUA, MHS, ATMS, CRIS, IASI, SSMIS)

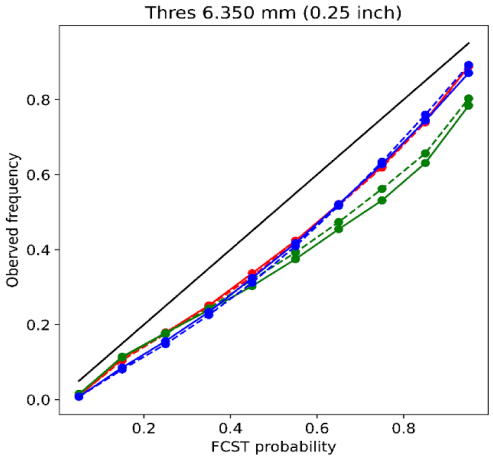
RRFSv1 Ensemble Design

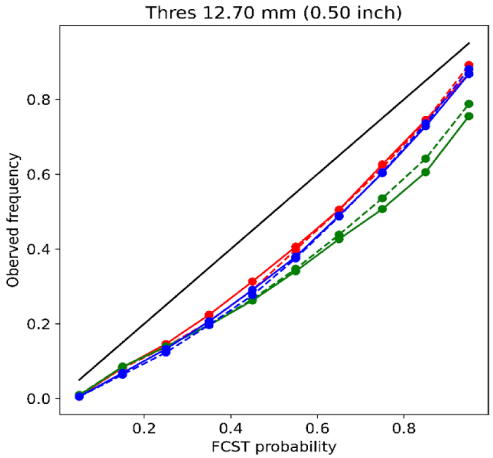
* SPP # fixed parameter pert	Microphysics	PBL	Sfc Layer	LSM	Convection	IC/LBC
mem1 (control)	Thompson	MYNN	MYNN	RUC	G-F deep	RRFS hybrid/GFS
mem2	Thompson*	TKE-EDMF	GFS	RUC*	G-F dp*+sh	RRFS enkf1/GEFSm1
mem3	Thompson*	MYNN*	MYNN*	RUC*	saSAS deep	RRFS enkf2/GEFSm2
mem4	NSSL#	MYNN*	MYNN*	RUC*	G-F deep*	RRFS enkf3/GEFSm3
mem5	NSSL#	TKE-EDMF	GFS	RUC*	G-F dp*+sh	RRFS enkf4/GEFSm4
mem6	NSSL#	MYNN*	MYNN*	RUC*	saSAS deep	RRFS enkf5/GEFSm5
mem7 (HRRR)	Thompson	MYNN	MYNN	RUC	None	RAP
mem8 (mem1-6h)						
mem9 (mem2-6h)						
mem10 (mem3-6h)						
mem11 (mem4-6h)						
mem12 (mem5-6h)						
mem13 (mem6-6h)						
mem14 (mem7-6h)						

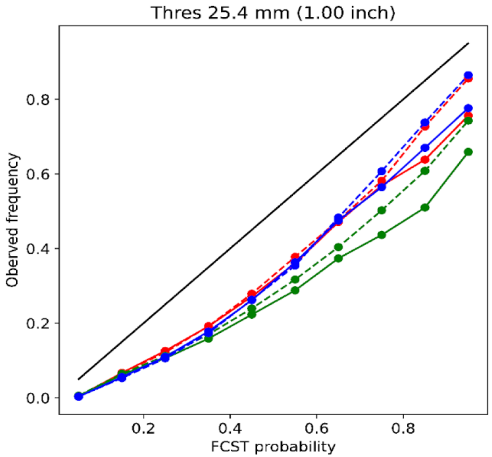
Reliability of 6hr precipitation with NMEP (averaged 6-36 hours every 6 hours)

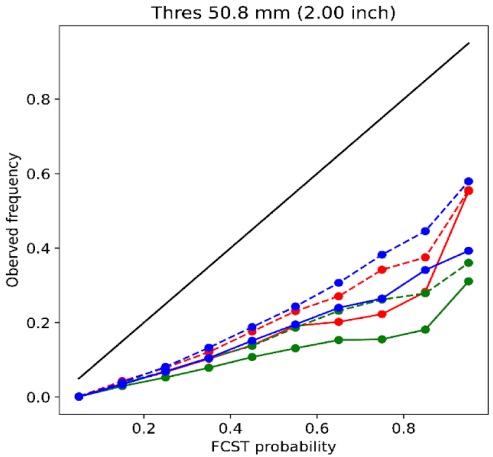
10 May – 25 May
00/12Z cycles











RRFSens

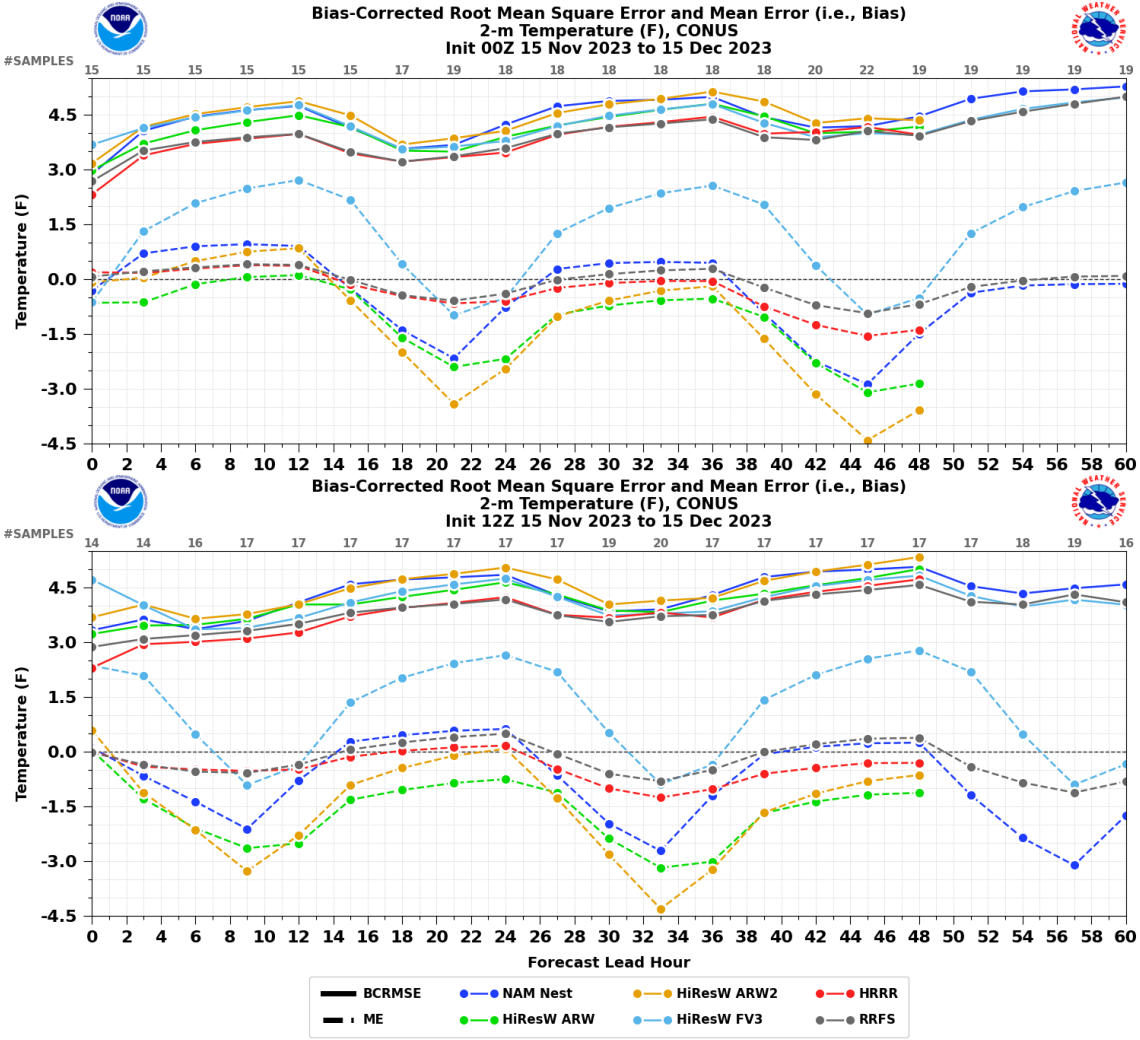
RRFSens (no HRRR)

HREF

——— nbr=45 km

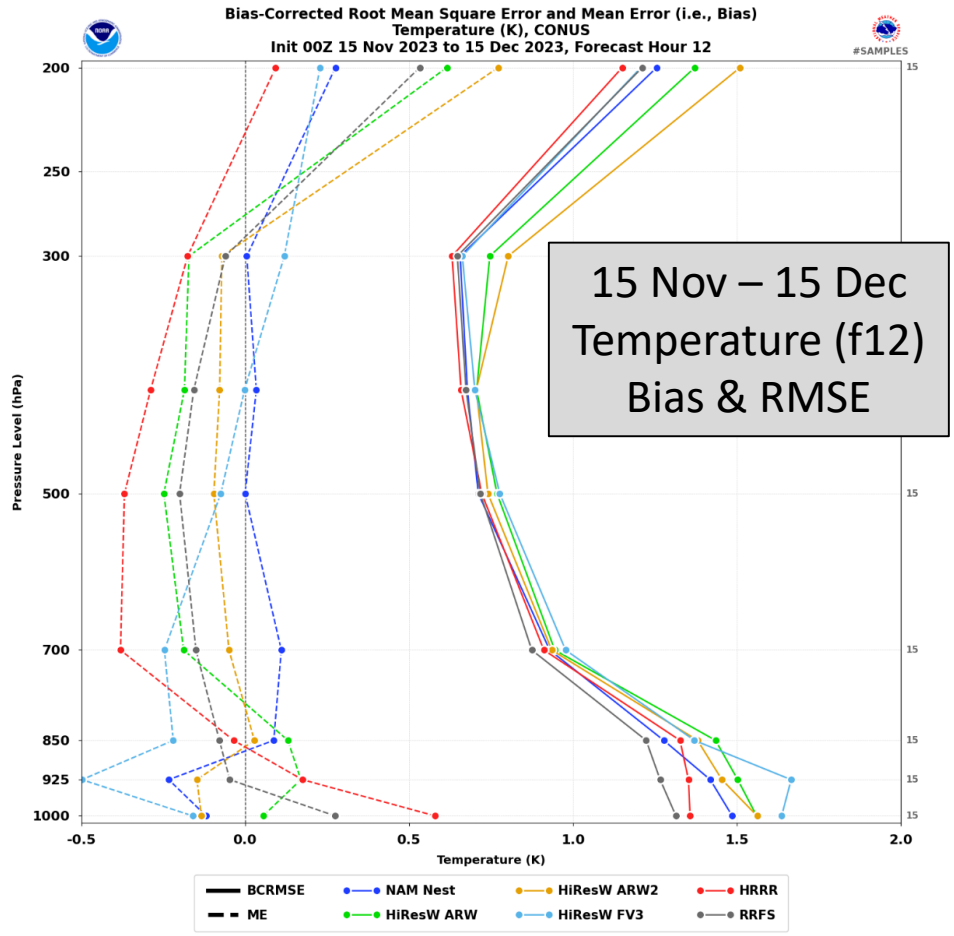
– – – nbr=85 km

*Thanks to Jili Dong (EMC) for this figure

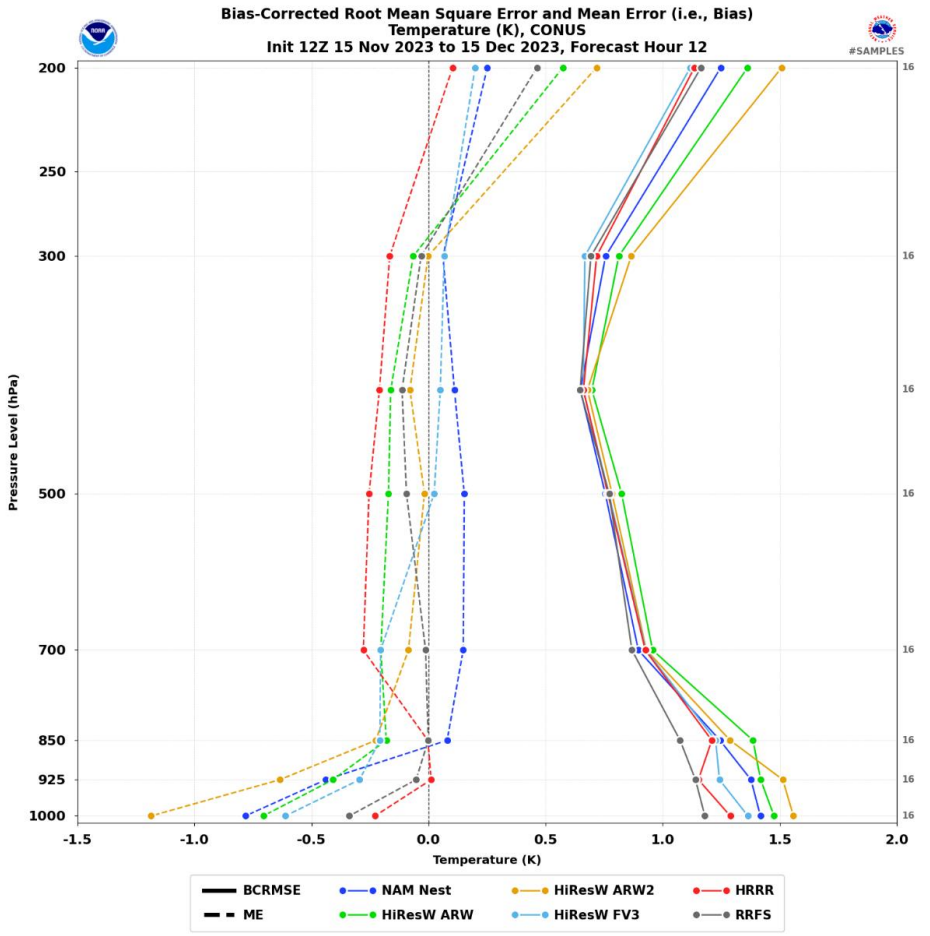


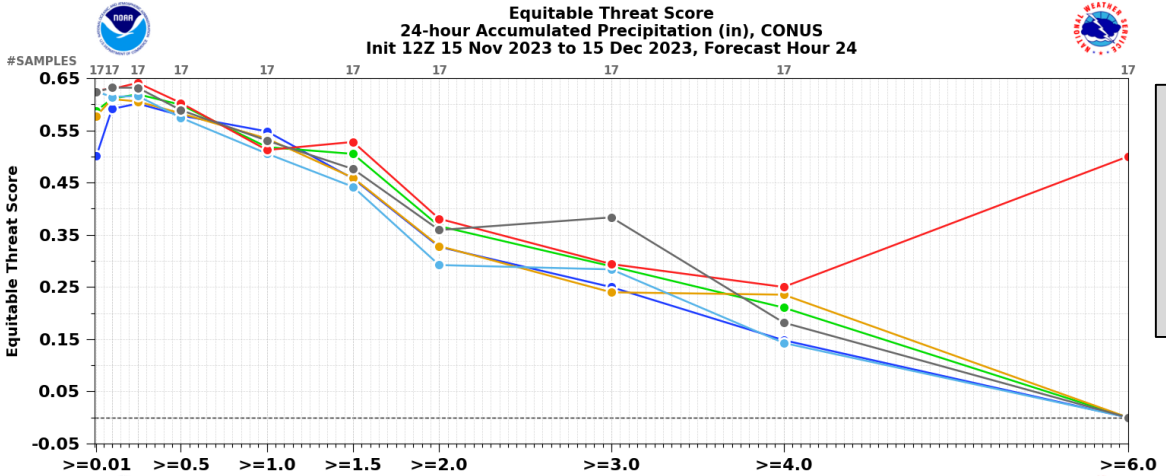
15 Nov – 15 Dec
2-m Temperature
Bias & RMSE

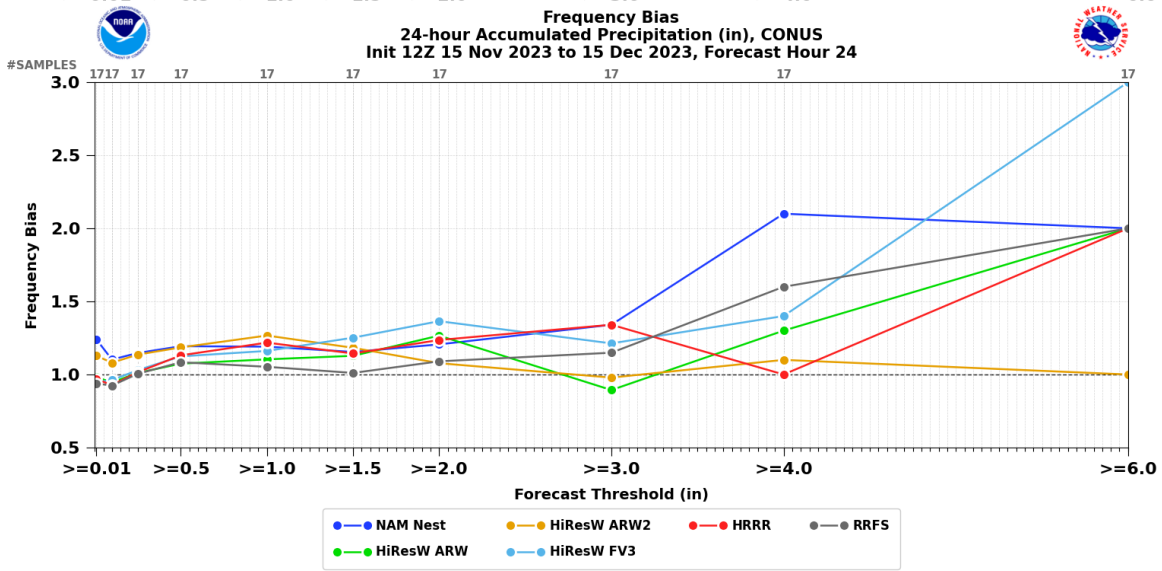
*Thanks to Marcel Caron (EMC) for the figures on this slide and following slides



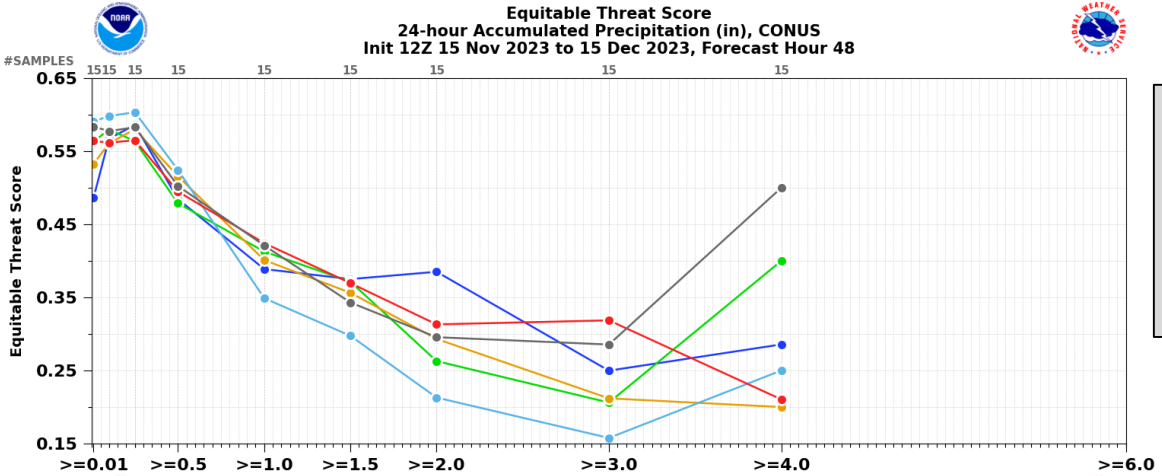
15 Nov – 15 Dec
Temperature (f12)
Bias & RMSE

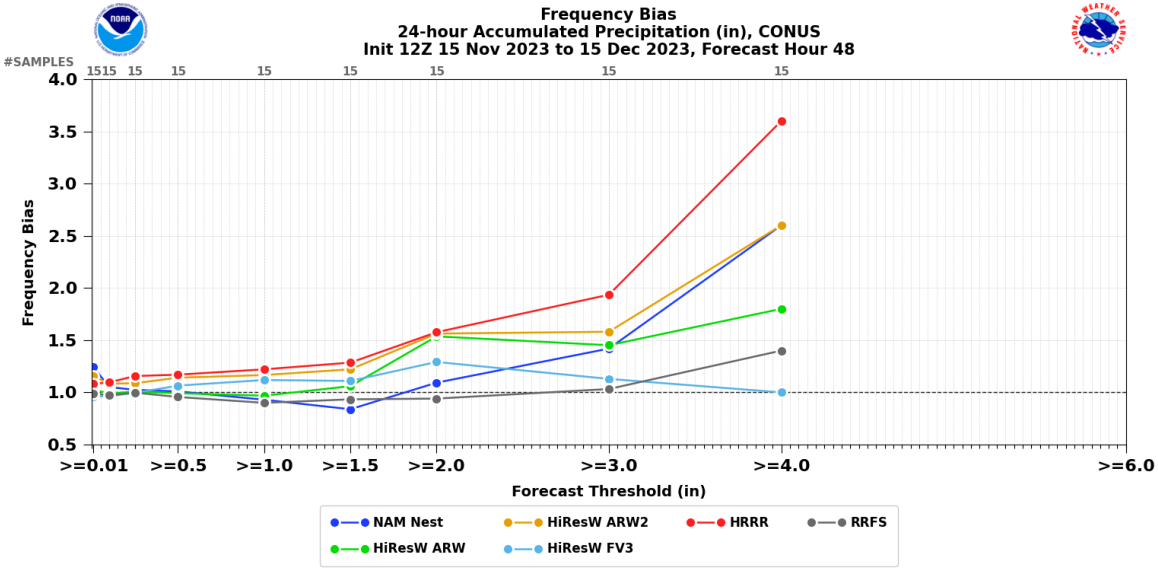




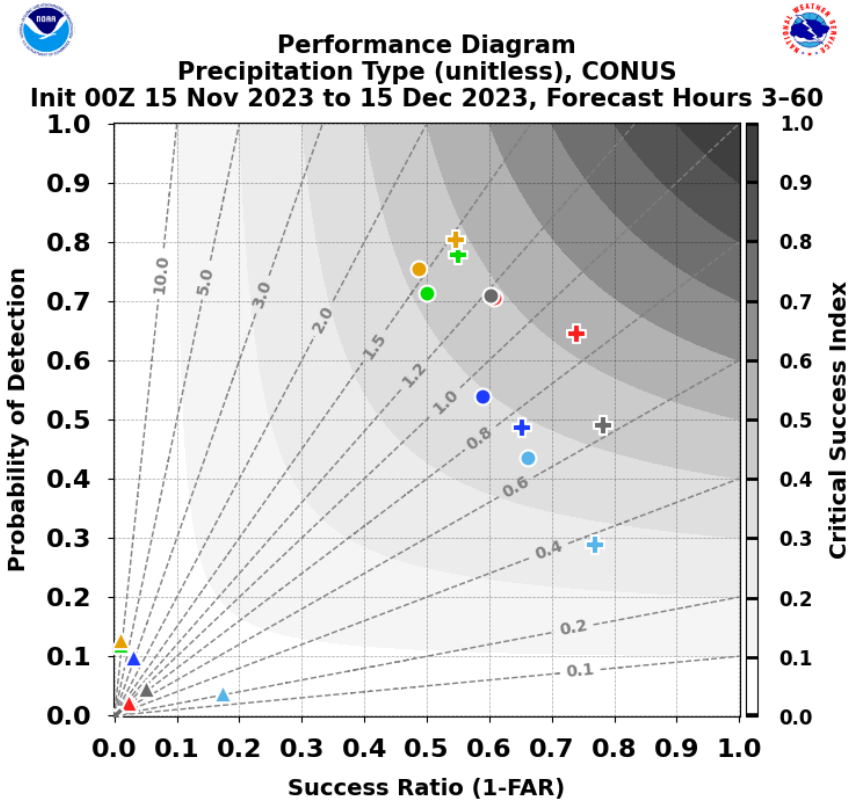


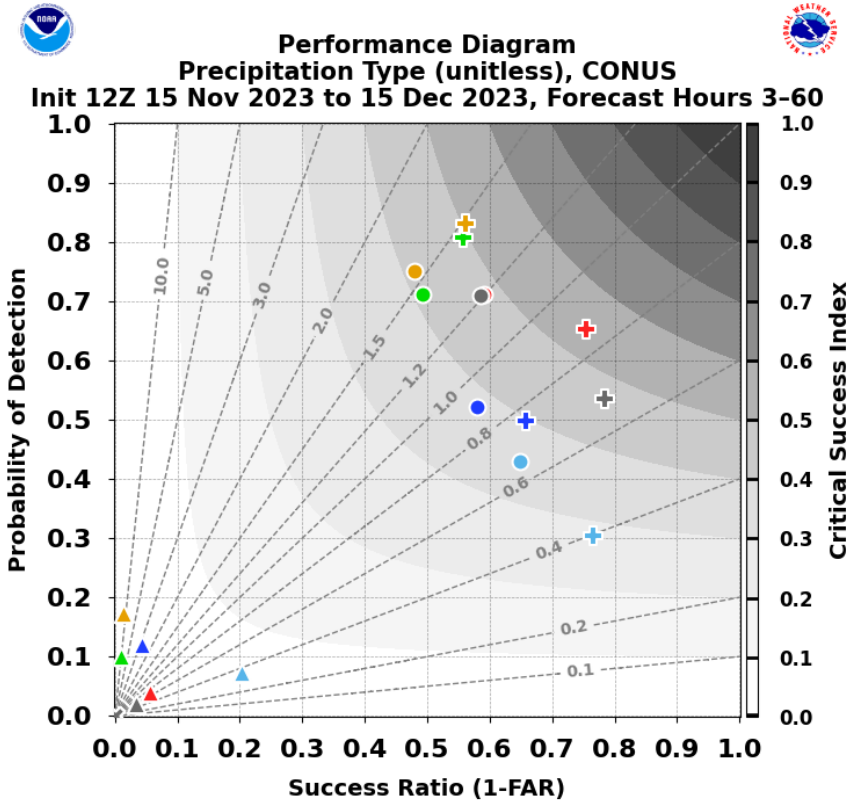
15 Nov – 15 Dec
24-hr Accum Precip
(f24)
ETS & FBias





15 Nov – 15 Dec
24-hr Accum Precip
(f48)
ETS & FBias


Performance Diagram
Precipitation Type (unitless), CONUS
Init 00Z 15 Nov 2023 to 15 Dec 2023, Forecast Hours 3-60
Probability of Detection
Success Ratio (1-FAR)
Critical Success Index
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
10.0
5.0
3.0
2.0
1.5
1.2
1.0
0.8
0.6
0.4
0.2
0.1


Performance Diagram
Precipitation Type (unitless), CONUS
Init 12Z 15 Nov 2023 to 15 Dec 2023, Forecast Hours 3-60
Probability of Detection
Success Ratio (1-FAR)
Critical Success Index
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
10.0
5.0
3.0
2.0
1.5
1.2
1.0
0.8
0.6
0.4
0.2
0.1

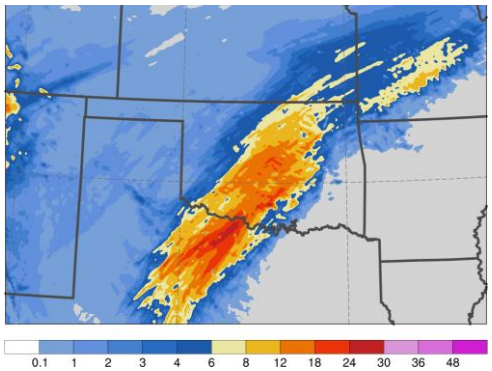

rain (260)
snow (260)
freezing rain (260)
ice pellets (260)
NAM Nest
HiResW ARW
HiResW ARW2
HiResW FV3
HRRR
RRFS

Now for some winter weather...

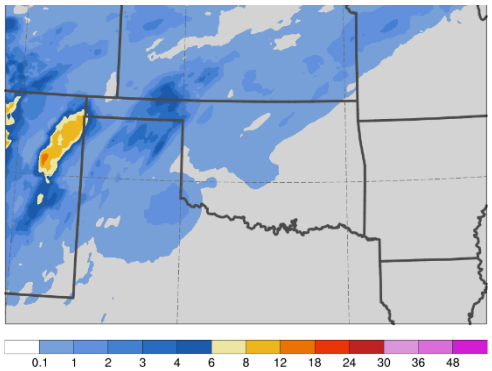
Winter Weather Parameters

- 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

NAM WEASD (snow/sleet, 10:1 SLR)



NOHRSC Analysis



*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
    - Accumulated SNOD works well, but can struggle in early/late season snow events with initially warmer soil (from Alicia Bentley, EMC)

- Note: There is a current issue with SNOD in RRFS being much too low. The RRFS development team is actively looking into it. Will show some recent material from Marc Chenard (WPC) at the end of this presentation.

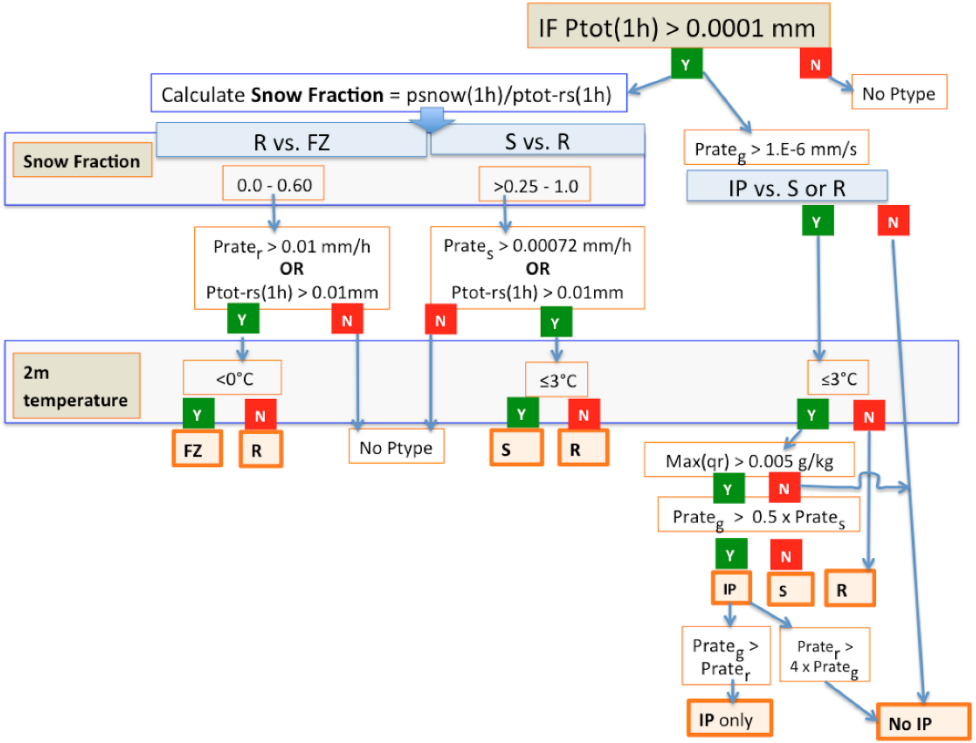
Winter Weather Parameters

- ASNOW (RRFS/HRRR) – accumulated snowfall (m)
  - Uses a variable/effective SLR – combines snow + sleet
  - Recommended field to look at for snowfall accumulation totals

- TSNOWP (RRFS only) – total snow precipitation accumulation (kg/m2) – water equivalent
- FRZR (RRFS/HRRR) – freezing rain accumulation (kg/m2) – water equivalent
- FROZR (RRFS/HRRR) – sleet accumulation (kg/m2) – water equivalent

- % of frozen precip – quantifies the % of hydrometeors reaching the surface as snow or sleet
  - Freezing rain has a % of frozen precip value of 0
  - High values indicate snow accumulation is favorable, low values indicate mixed precip is likely

Precipitation Type

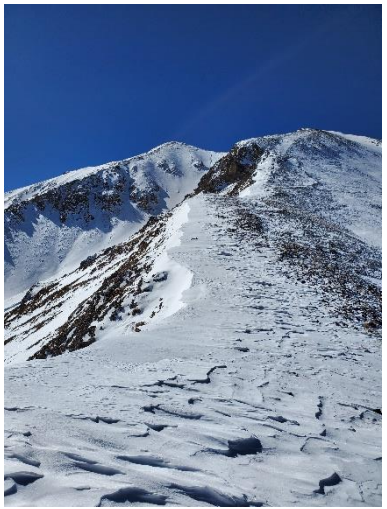


- RRFS utilizes the same method as the RAP/HRRR for calculating precipitation type
- Based on the explicit prediction of hydrometeors (snow, rain, graupel) reaching the surface from the Thompson microphysics
- Can get ‘yes’ answers for multiple types
- Computes snow fraction (fallen snow in past hour / 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)

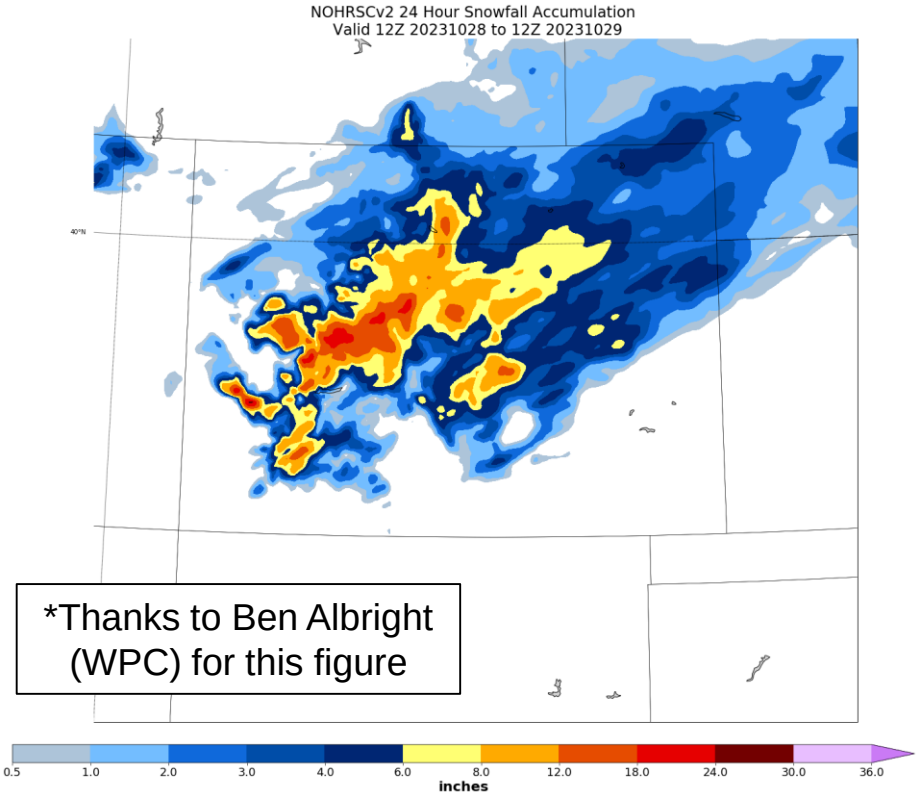
*Thanks to Geoff Manikin (MDL) for material on this slide

Colorado Snowstorm – 28-29 Oct 2023

- 24-h snowfall accumulation valid 28 Oct 12Z – 29 Oct 12Z
  - RRFS/HRRR – ASNOW (variable density)
  - NAM nest – WEASD (10:1)

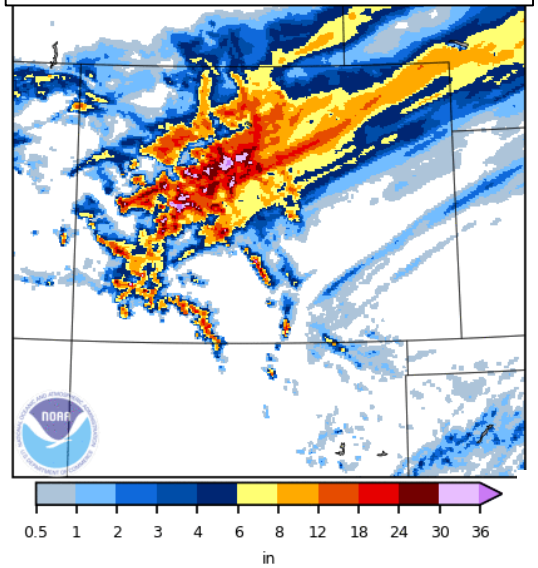


31 Oct: southwest Colorado at ~13,000 ft

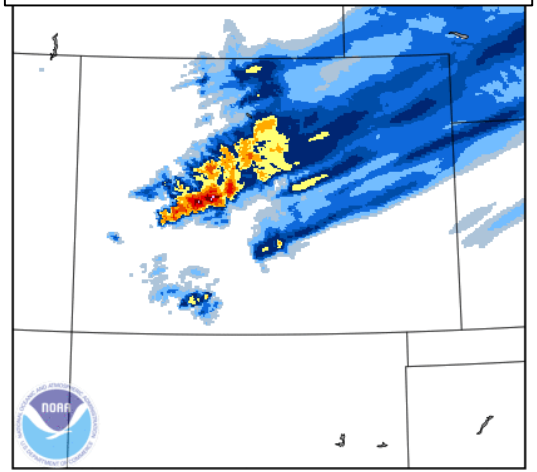


*Thanks to Ben Albright (WPC) for this figure

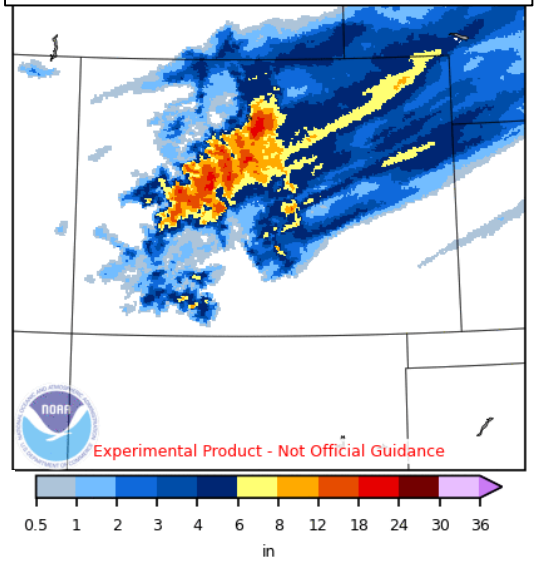
NAM Nest WEASD (10:1)



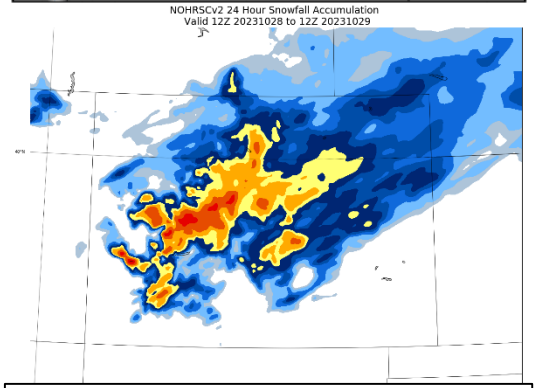
HRRR ASNOW (var den)



RRFS ASNOW (var den)



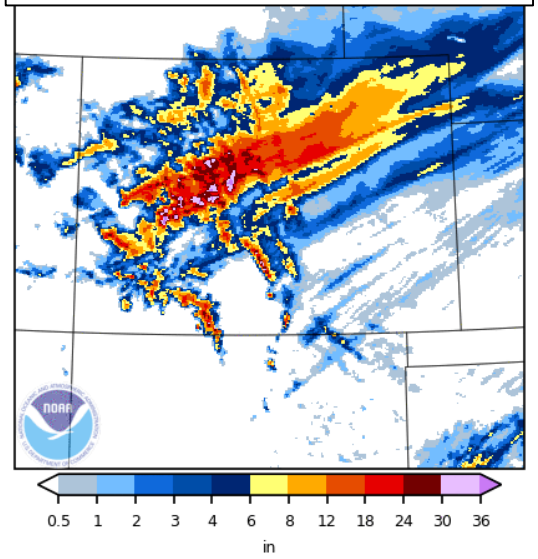
24-h snowfall accumulation valid 28 Oct 12Z – 29 Oct 12Z



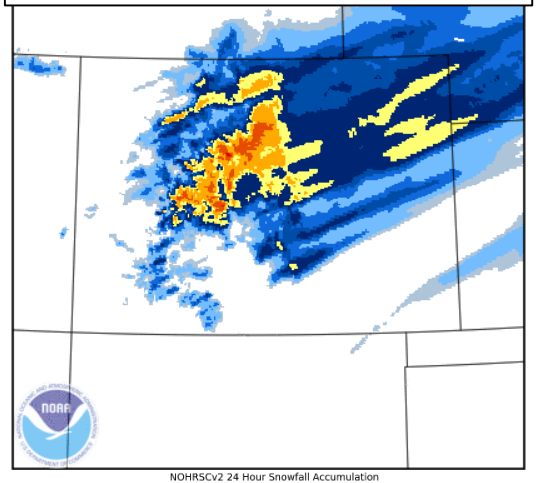
NOHRSC Analysis

48-h forecasts from the 27 Oct 12Z cycle

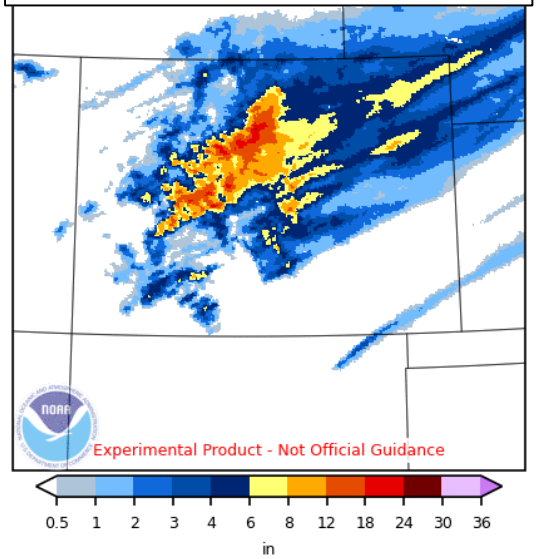
NAM Nest WEASD (10:1)



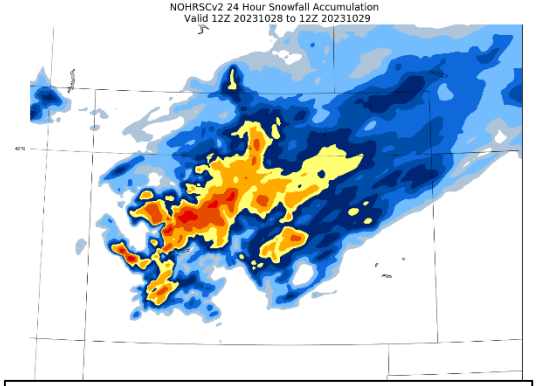
HRRR ASNOW (var den)



RRFS ASNOW (var den)



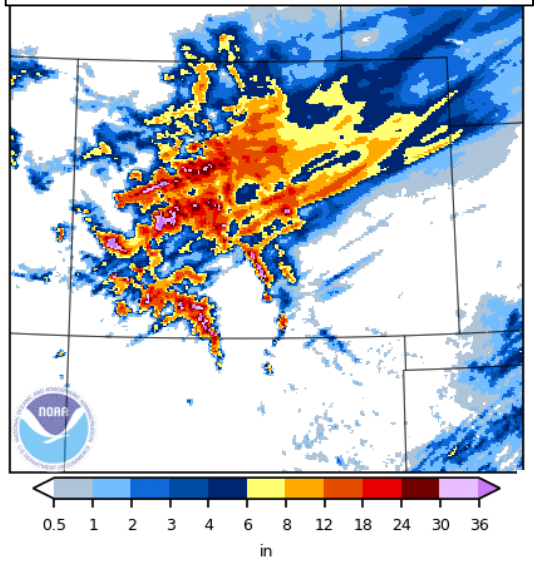
24-h snowfall accumulation valid 28 Oct 12Z – 29 Oct 12Z



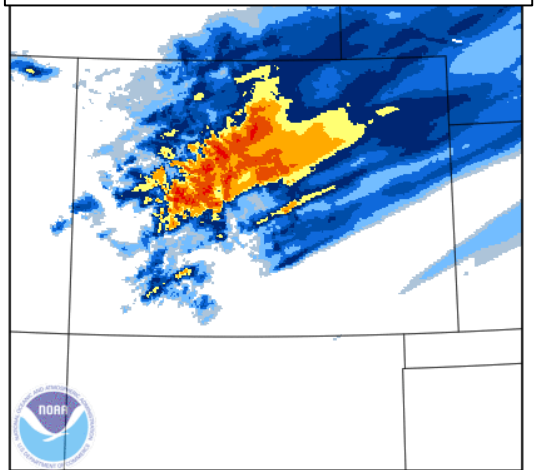
NOHRSC Analysis

36-h forecasts from the 28 Oct 00Z cycle

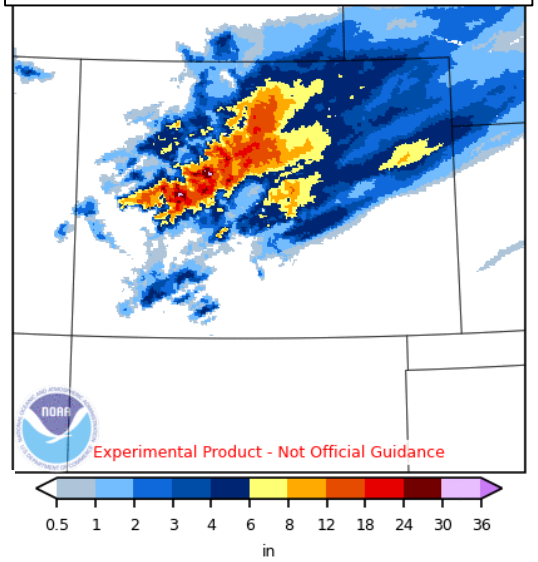
NAM Nest WEASD (10:1)



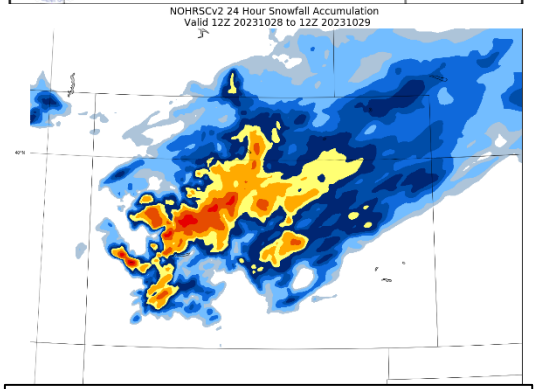
HRRR ASNOW (var den)



RRFS ASNOW (var den)



24-h snowfall accumulation valid 28 Oct 12Z – 29 Oct 12Z



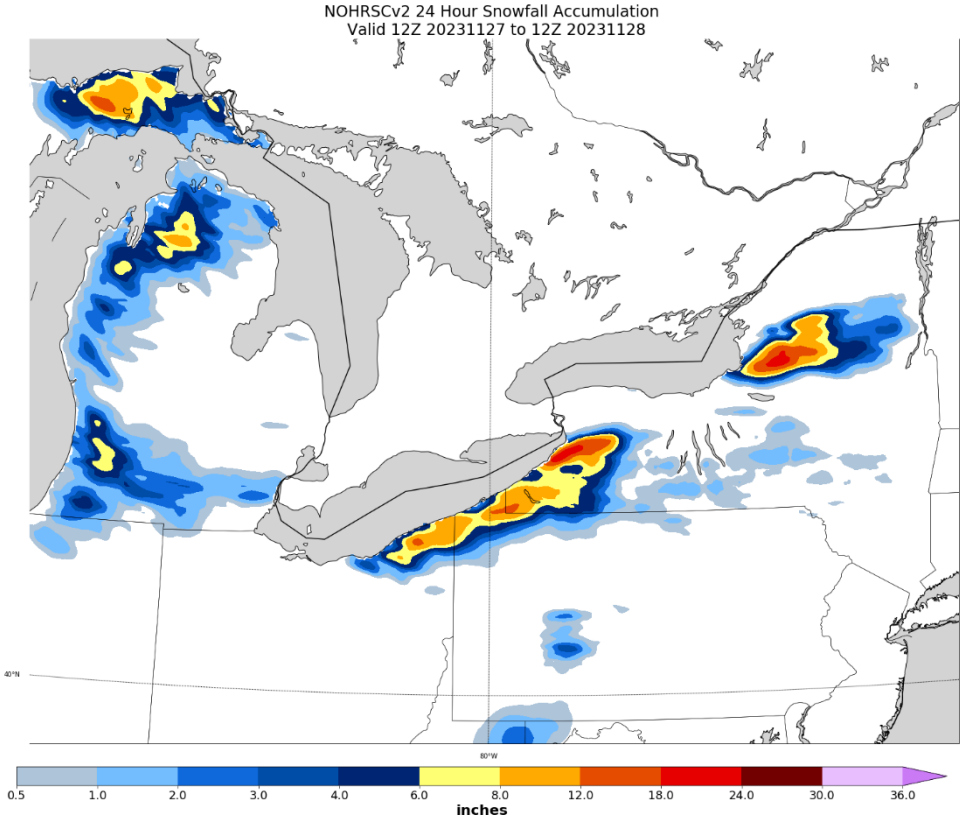
NOHRSC Analysis

24-h forecasts from the 28 Oct 12Z cycle

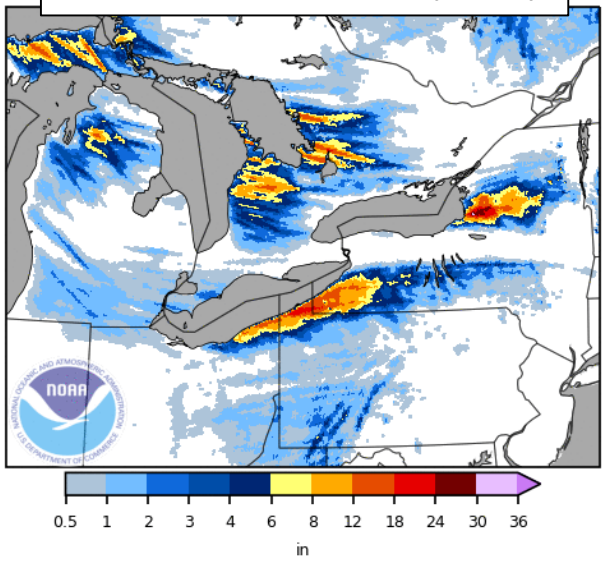
Lake Effect snow – 27-28 Nov 2023

- 24-h snowfall accumulation valid 27 Nov 12Z – 28 Nov 12Z
- Note: NOHRSC only covers CONUS, so ignore the snowfall over Canada
- RRFS uses FVCOM Great Lakes data – check out Christiane Jablonowski's (Univ. of Michigan) WWE seminar on 8 Feb for more information!

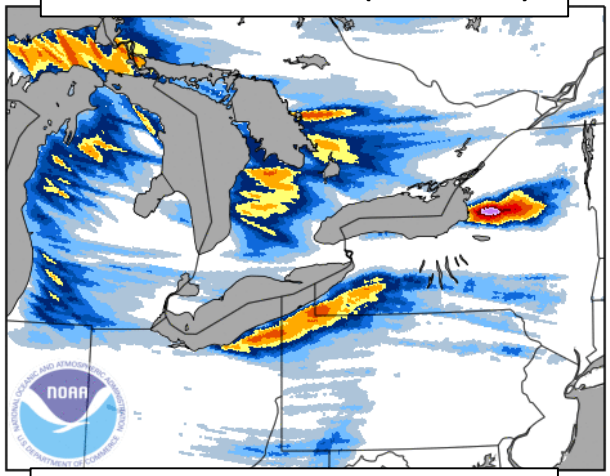
*Thanks to Ben Albright (WPC) for this figure



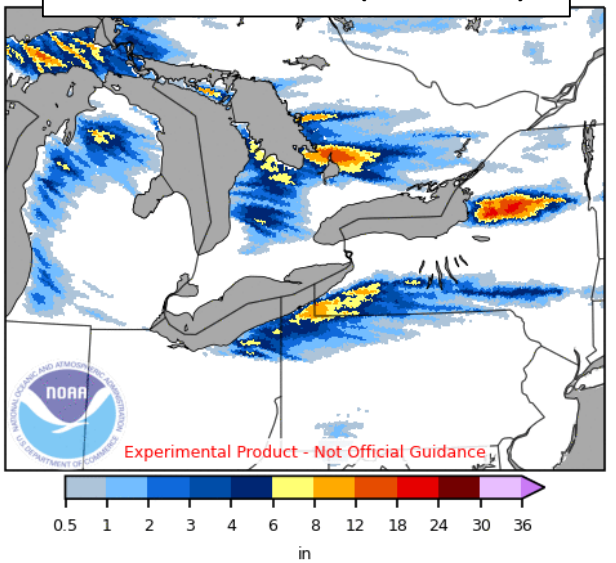
NAM Nest WEASD (10:1)



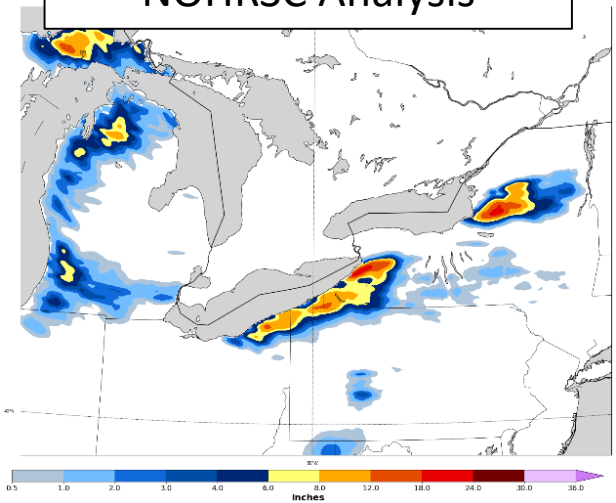
HRRR ASNOW (var den)



RRFS ASNOW (var den)



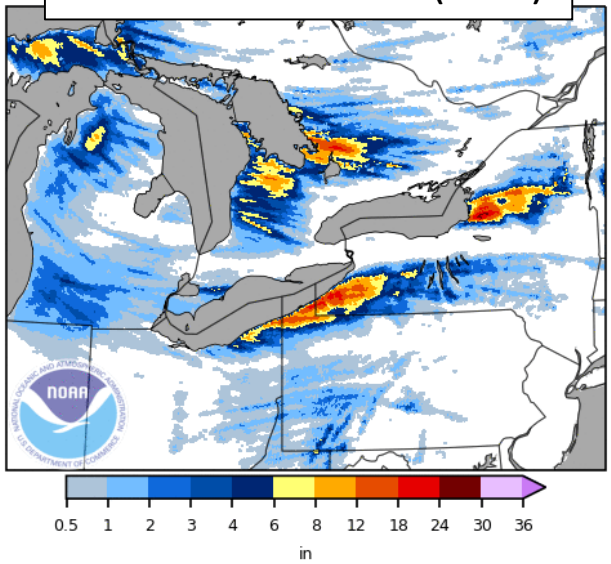
NOHRSC Analysis



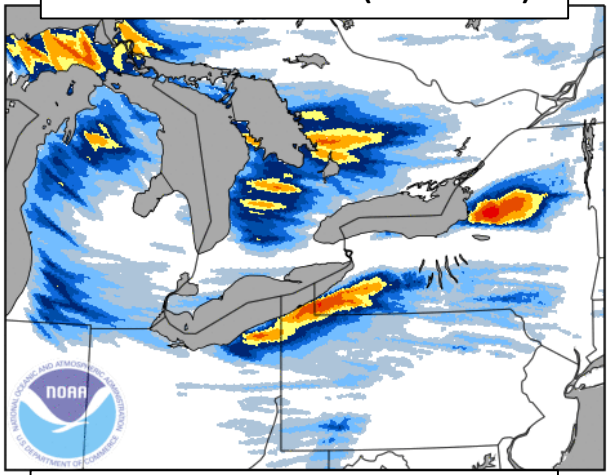
24-h snowfall accumulation valid 27 Nov 12Z – 28 Nov 12Z

36-h forecasts from the 27 Nov 00Z cycle

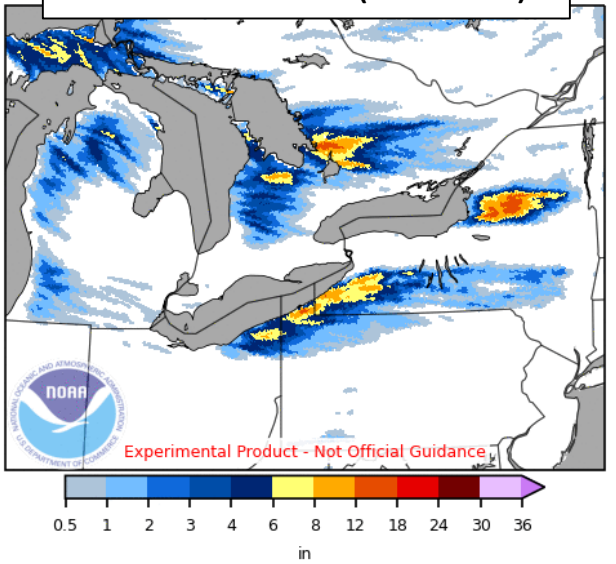
NAM Nest WEASD (10:1)



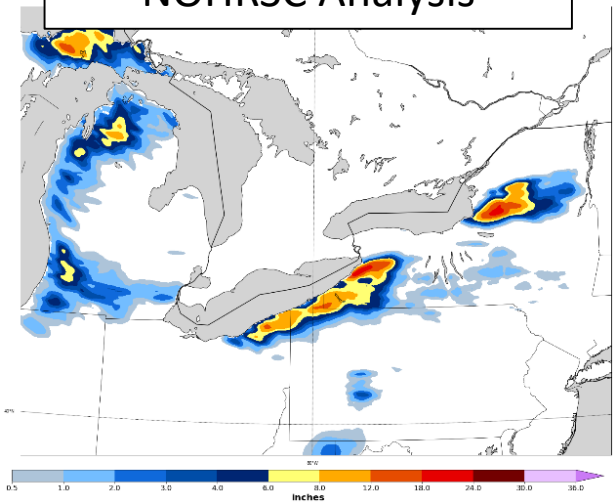
HRRR ASNOW (var den)



RRFS ASNOW (var den)



NOHRSC Analysis

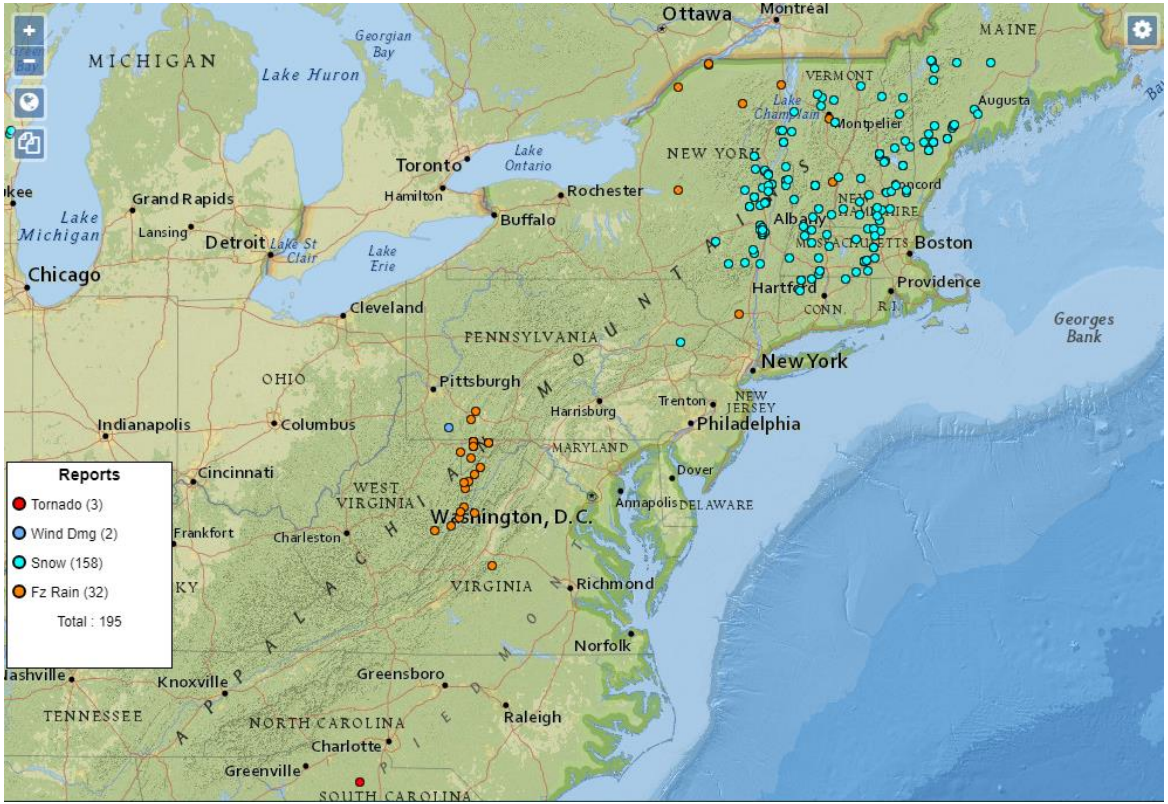


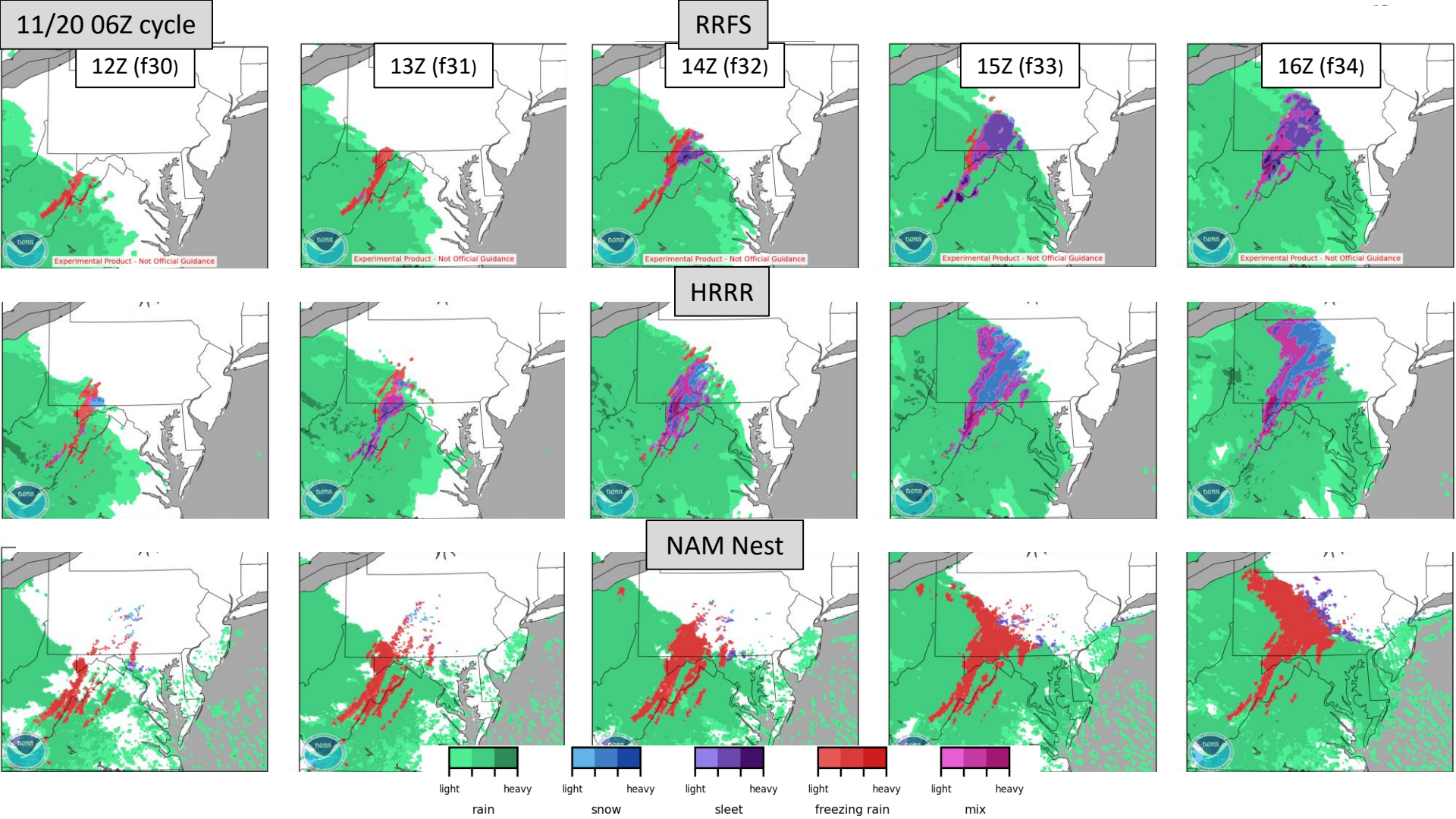
24-h snowfall accumulation valid 27 Nov 12Z – 28 Nov 12Z

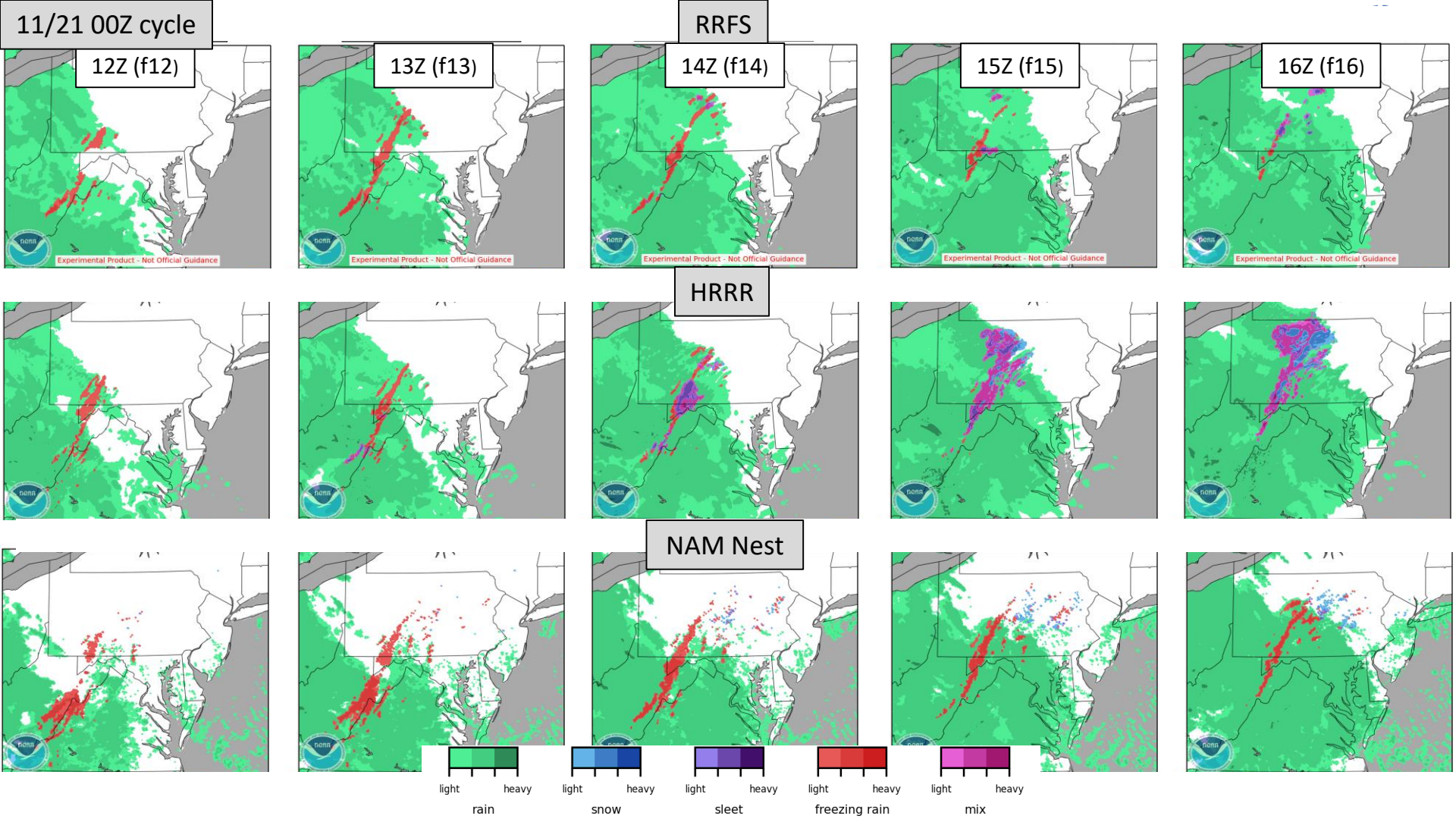
24-h forecasts from the 27 Nov 12Z cycle

West Virginia/Maryland Freezing Rain – 21 Nov

- 23 freezing rain reports in WV/MD occurred between 1230Z and 17Z
- No reports of sleet
- Precip type – RRFS, HRRR, NAM nest
  - Note: NAM nest uses the NCEP dominant method; no mixed precip
- RRFS ensemble products
  - Mean dominant ptype
  - Prob 2-m T < 0ºC
  - Probs for 1-h/6-h freezing rain

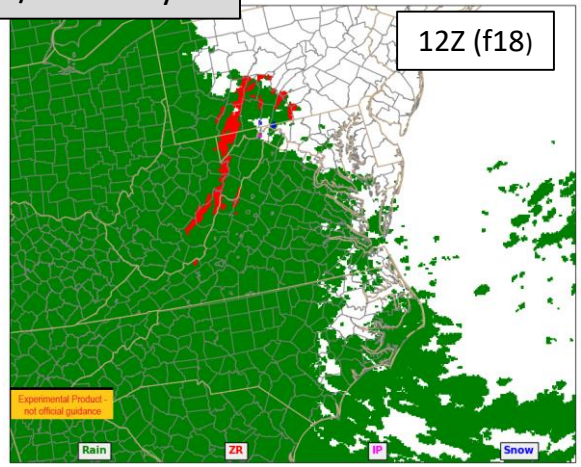


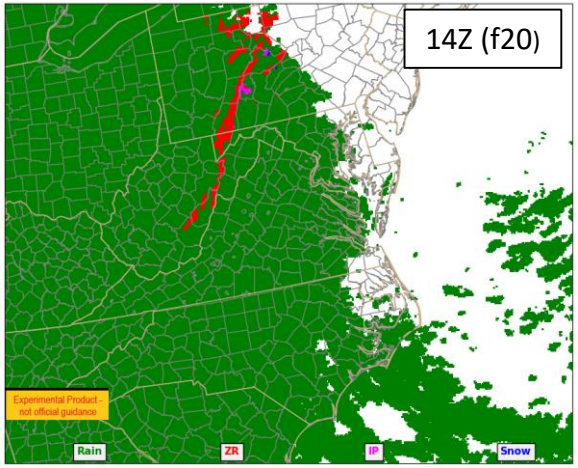

11/20 06Z cycle
RRFS
12Z (f30)
13Z (f31)
14Z (f32)
15Z (f33)
16Z (f34)
Experimental Product - Not Official Guidance
HRRR
NAM Nest
light
heavy
rain
snow
sleet
freezing rain
mix

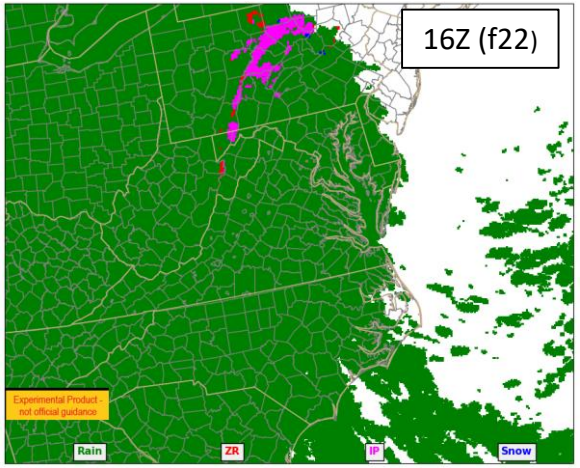

11/21 00Z cycle
RRFS
12Z (f12)
13Z (f13)
14Z (f14)
15Z (f15)
16Z (f16)
Experimental Product - Not Official Guidance
HRRR
NAM Nest
light
heavy
rain
snow
sleet
freezing rain
mix

11/20 18Z cycle

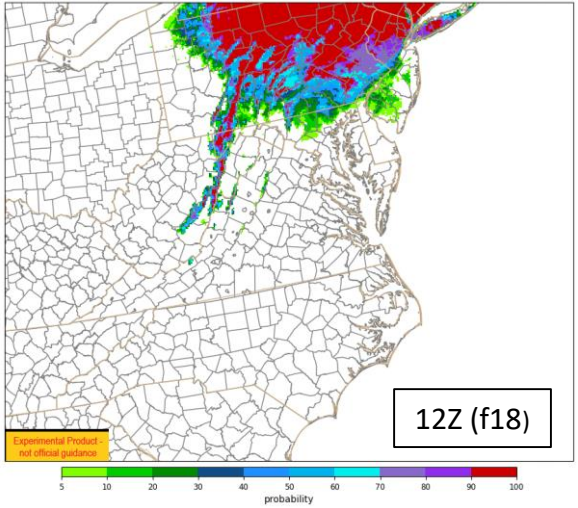
Mean Dominant Precipitation Type

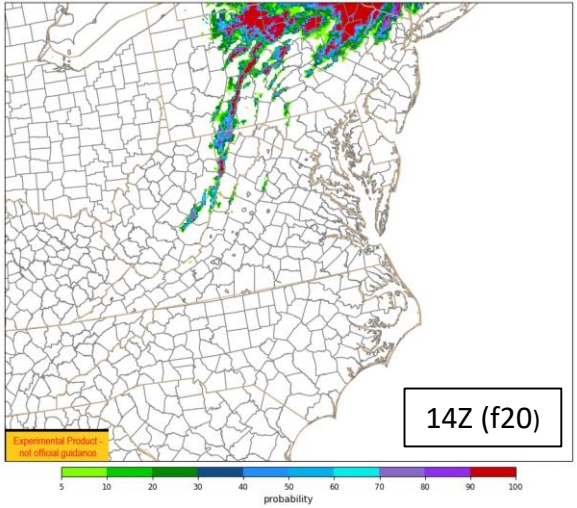


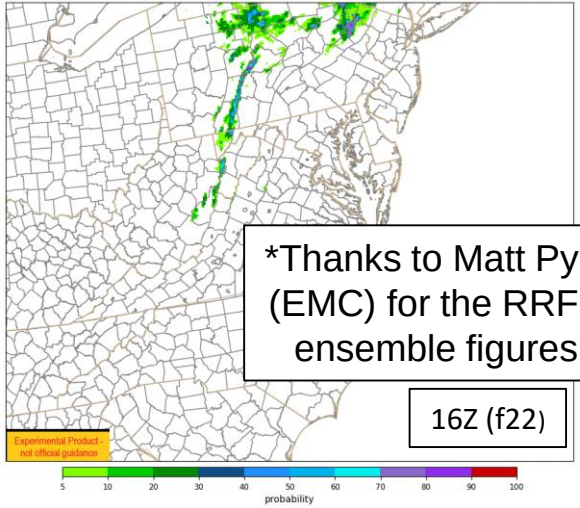




Probability of 2-m T < 0°C



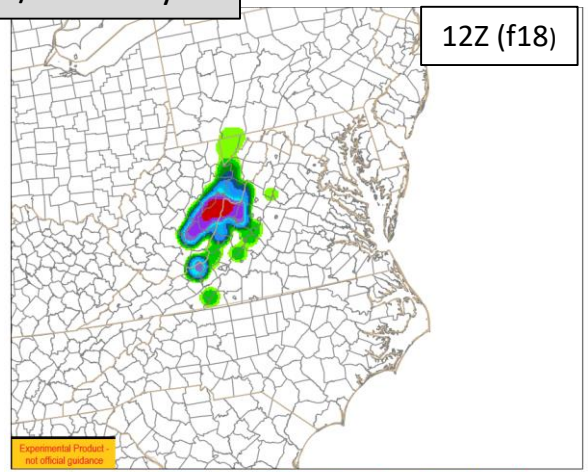


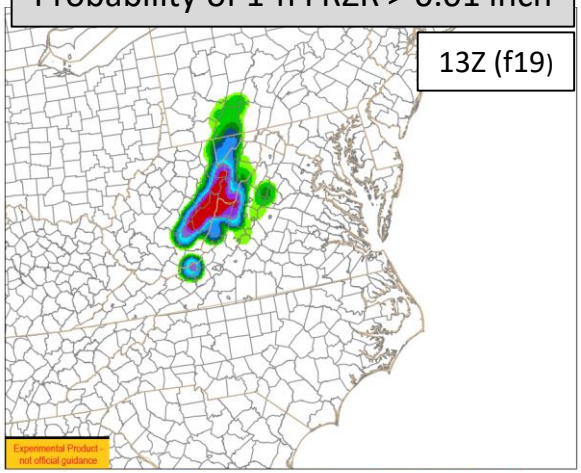


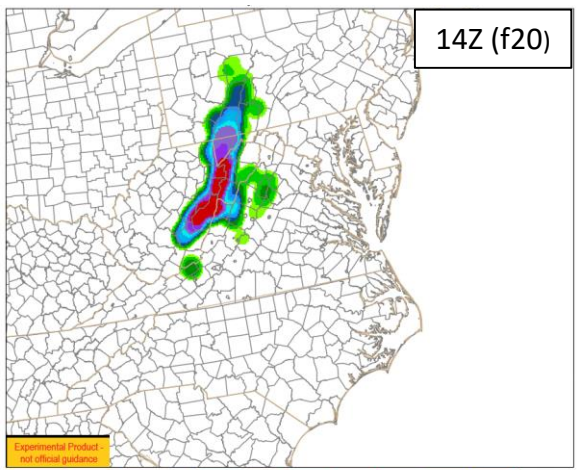
*Thanks to Matt Pyle (EMC) for the RRFS ensemble figures

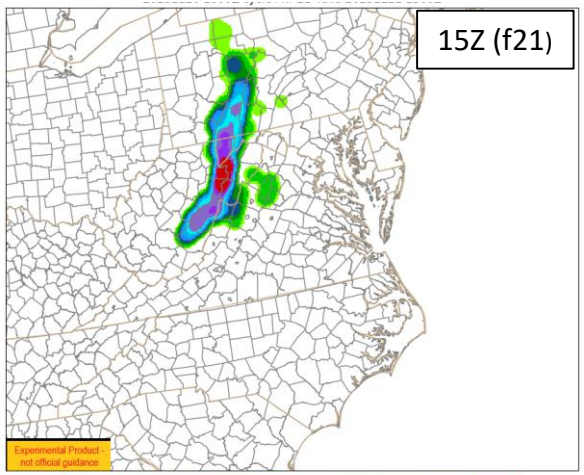
11/20 18Z cycle

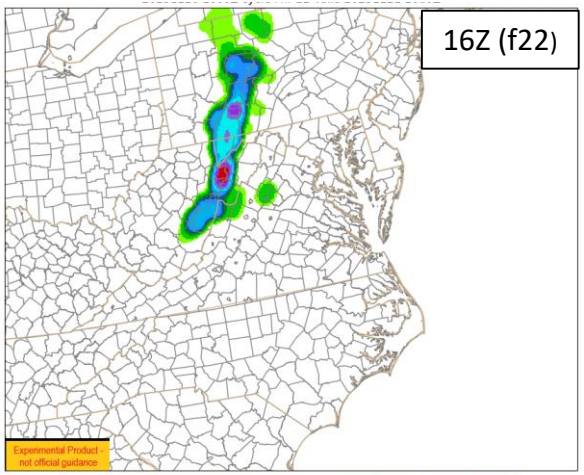
Probability of 1-h FRZR > 0.01 inch

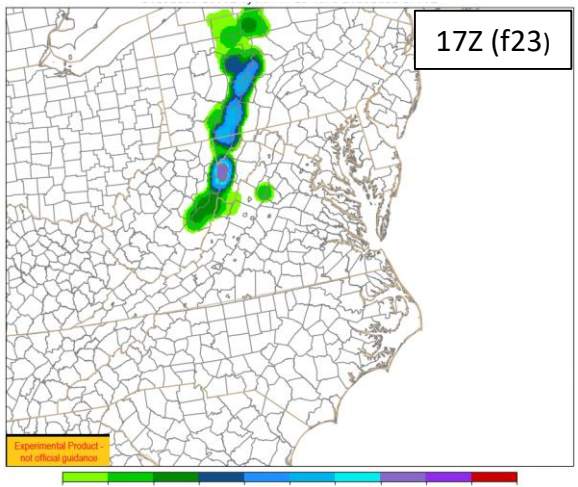








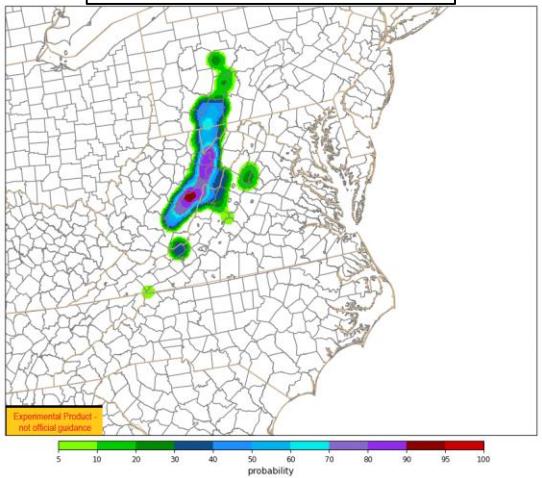




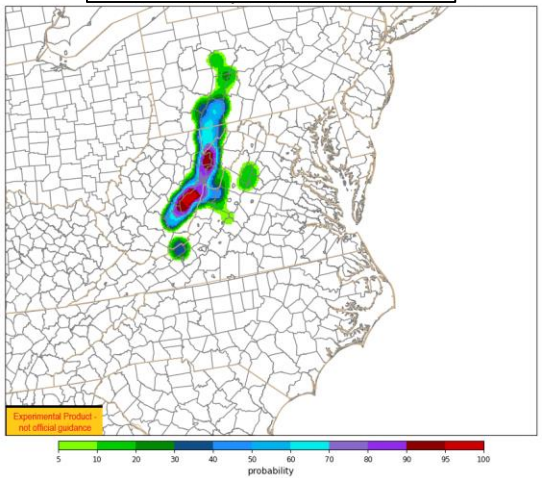
Probability of 6-h FRZR > 0.1 inch

Valid 11/21 12Z - 18Z

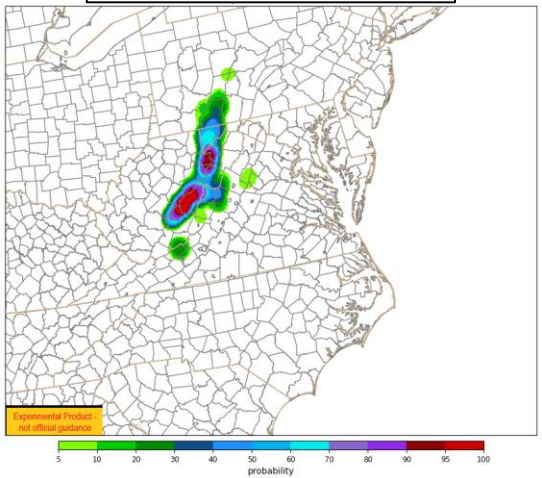
11/20 12Z cycle (f24-f30)



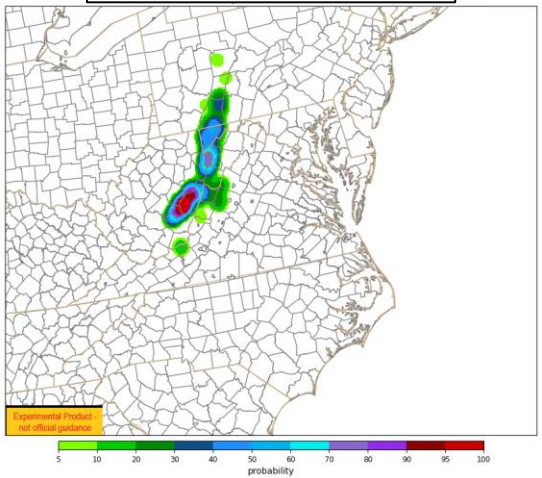
11/20 18Z cycle (f18-f24)



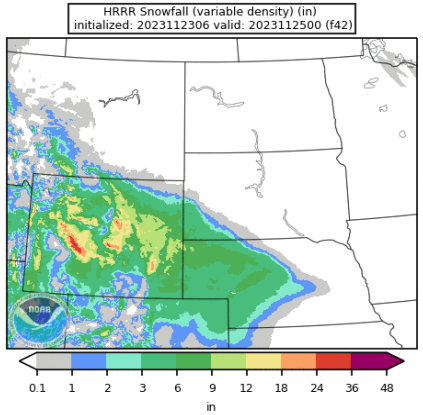
11/21 00Z cycle (f12-f18)

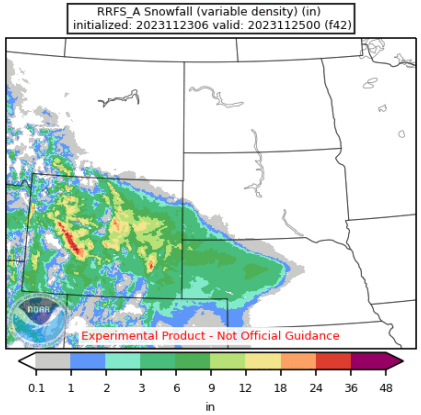


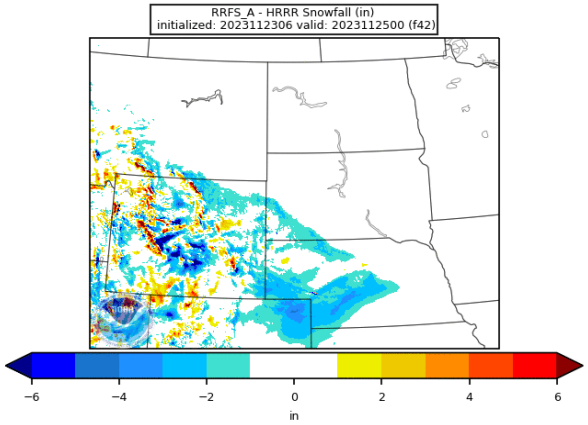
11/21 06Z cycle (f06-f12)



Snow Depth (SNOD) Issue in RRFS







ASNOW (Variable Density)

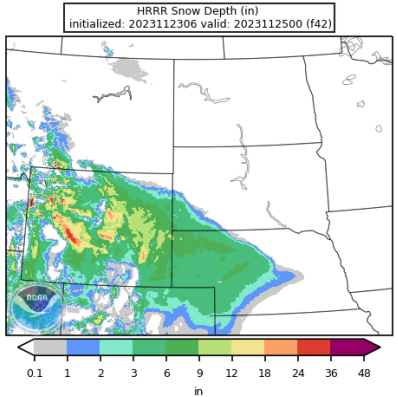
RRFS vs HRRR

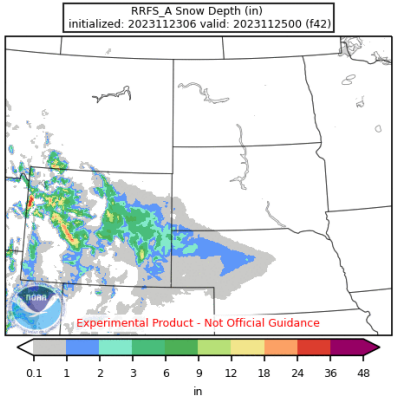
- Similar snowfall accumulation forecasts from the HRRR and RRFS

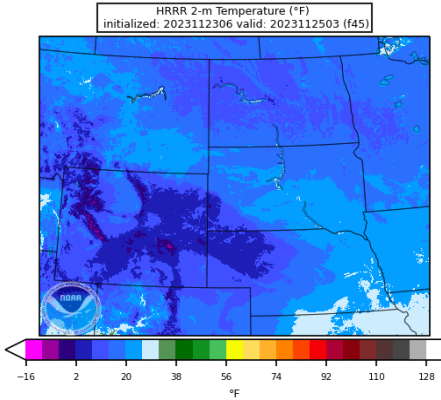
*Thanks to Marc Chenard (WPC) for material on this slide and the next 4 slides

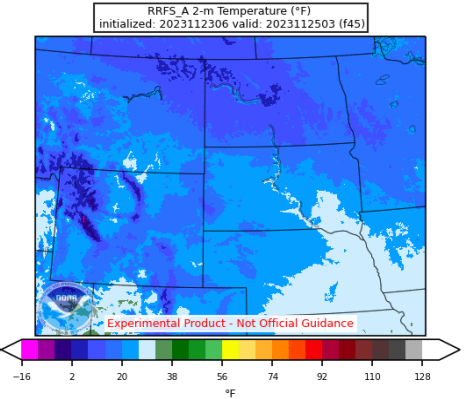
Snow Depth (left) and 2m Temperatures (right)

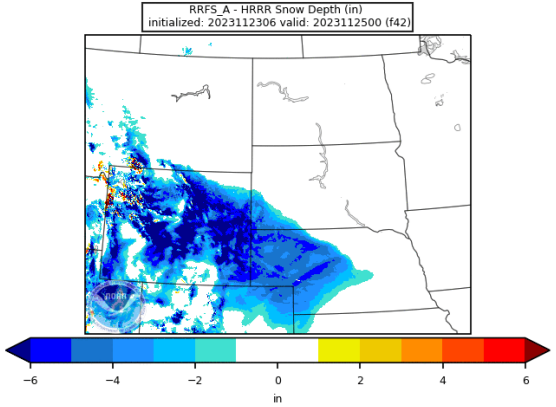
RRFS vs HRRR



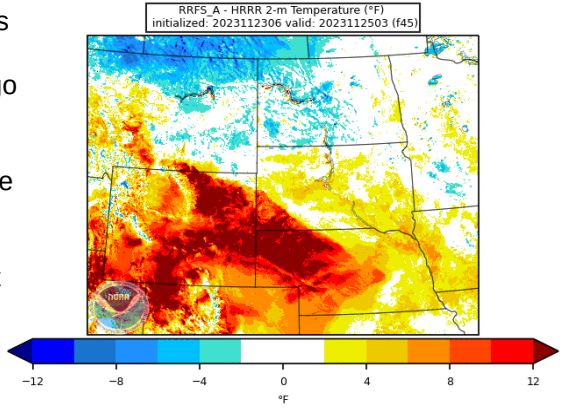






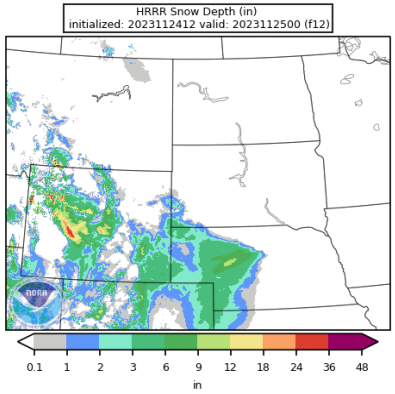


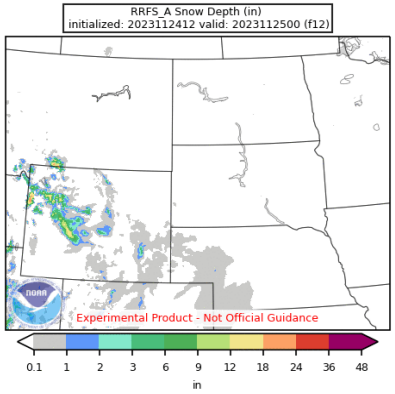
- Much larger snow depth differences between HRRR and RRFS
- Where did the accumulated snow go in WY/CO/NE?
- Results in big temperature differences as well. HRRR has more snow depth, thus much colder surface temperatures.
- Truth was probably in between, but RRFS definitely too warm

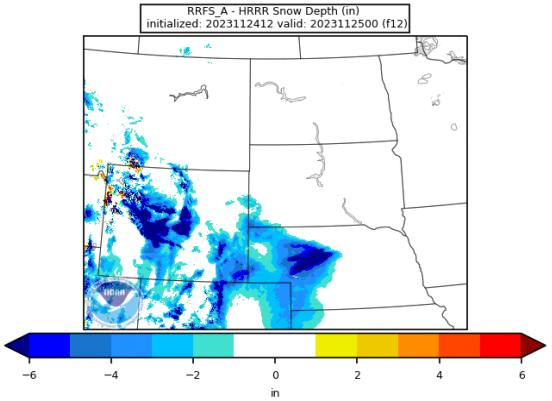


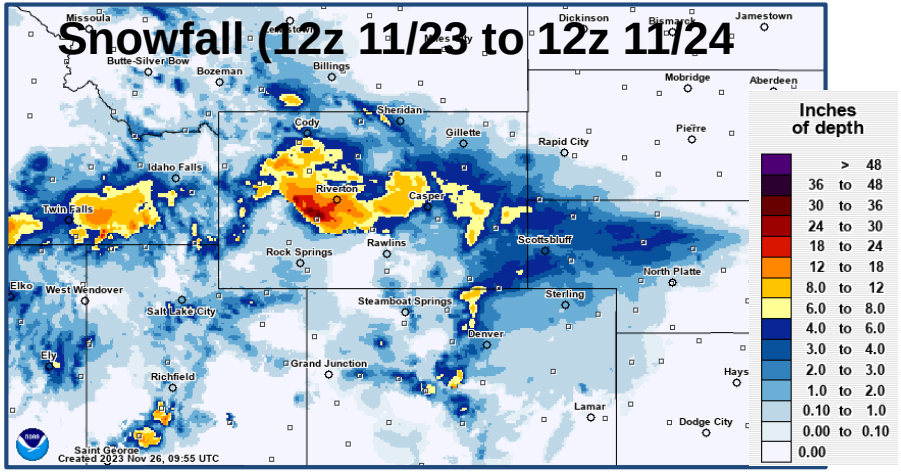
Snow Depth

RRFS vs HRRR



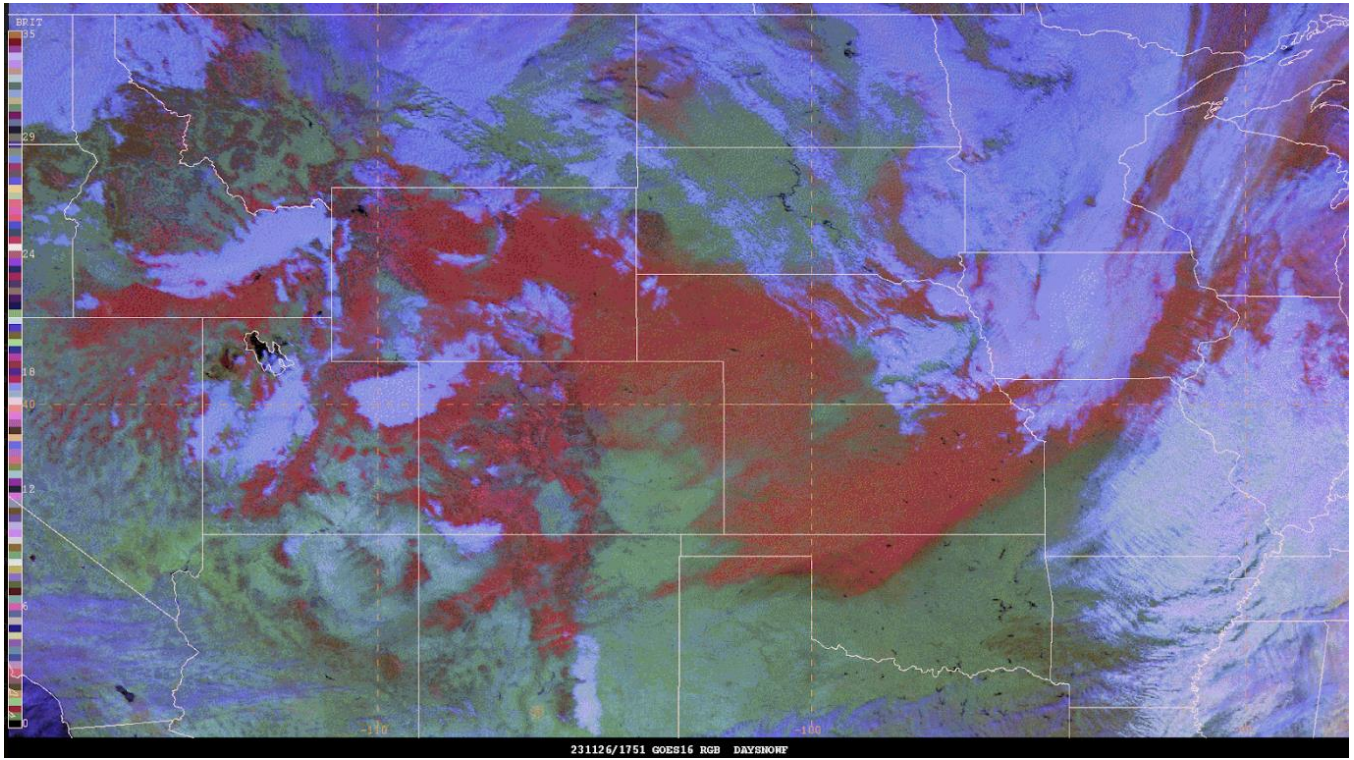




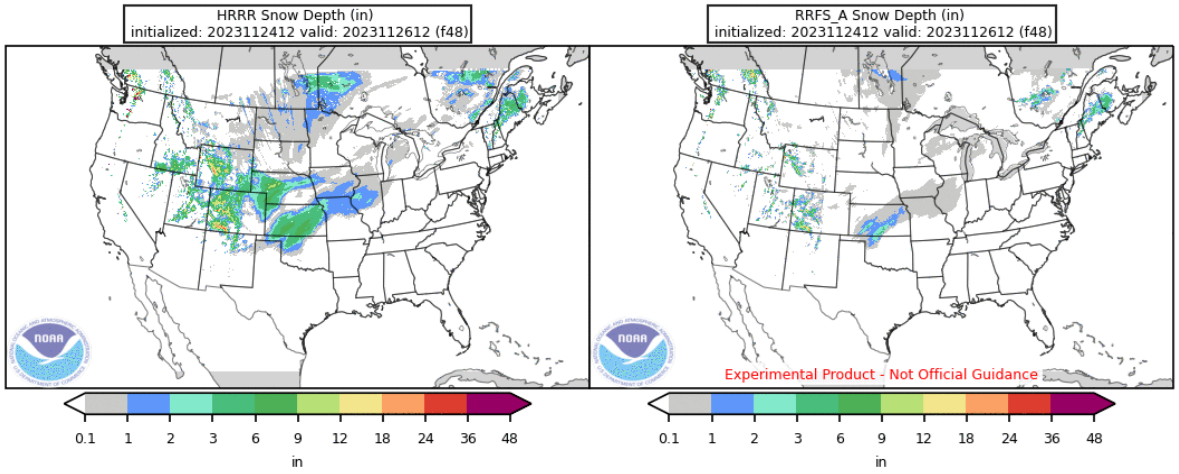


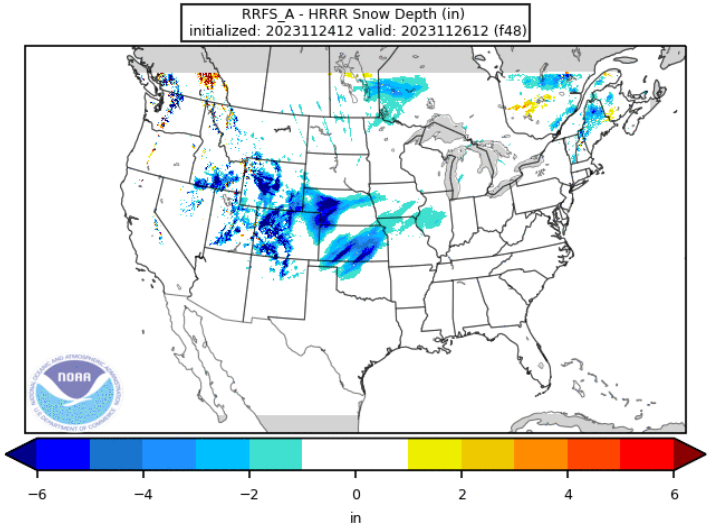
- Same valid time as previous slide. This is a 12 hr forecast and the previous slide a 42 hr.
- HRRR snow depth is lower than its 42 hr forecast, indicating it was probably initially overdone.
- RRFS seems way underdone with its snow depth when looking at past 24 hrs observed snowfall ending 12z on the 24th. Its 42 hr forecast was better (previous slide).

Satellite Snow Cover



- Red is snow
- Can’t really judge magnitude of snow depth from this image
- However can tell that the RRFS SNOD coverage is too low (see next slide)





RRFS vs HRRR snow depth valid near time of satellite image

Differences in snow accumulation not big, thus most differences coming from handling of accumulating snow depth from falling snow

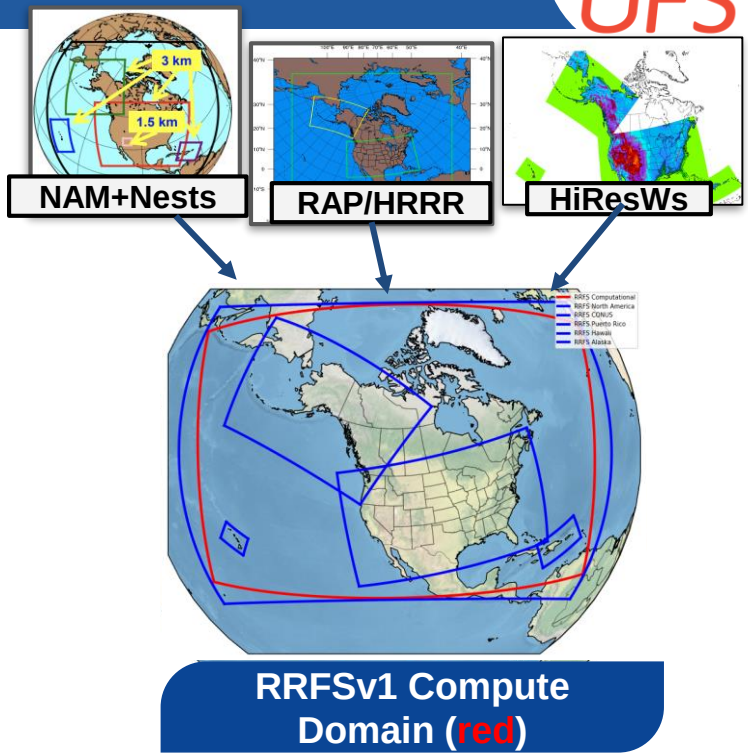
Snow Depth (SNOD) Issue in RRFS – Summary

- RRFS snow depth runs much lower than the HRRR and Nam Nest (not shown here)
  - Both initialized snow depth and snow depth accumulated over the model run
- RRFS snow accumulation is in the ballpark of the HRRR and Nam Nest
  - Suggests snow depth differences are coming from how the model is accumulating snow depth from the falling snow and not an issue with snowfall forecasts
- 2m Temperatures are warmer in the RRFS due to the lower snow depth
- Verification is a bit tricky but would suggest…
  - RRFS snow depth coverage and magnitudes are too low, but HRRR snow depth might be a bit too high. Somewhere in between seems closest to obs.
  - RRFS 2m temperatures too warm over areas that have snow (likely because RRFS has too little or no snow cover). HRRR might be too cold. Reality again somewhere in between

- The RRFS development team is actively looking into this. Upcoming bug fix.

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
- Targeting a science freeze at the end of March 2024 followed by a mid 2025 implementation



Thanks for listening!

Email: Benjamin.Blake@noaa.gov

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