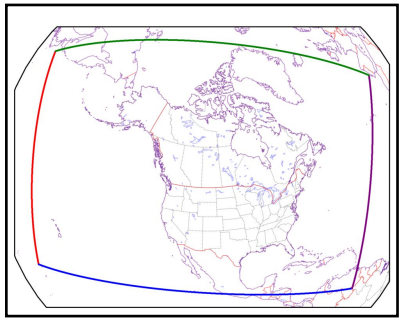
NOAA's Rapid Refresh Forecast System

Matthew Pyle[1] on behalf of the wider development team, which spans EMC, GSL, NSSL, GFDL, NCAR/DTC, and our academic partners

[1]NOAA/NCEP/EMC

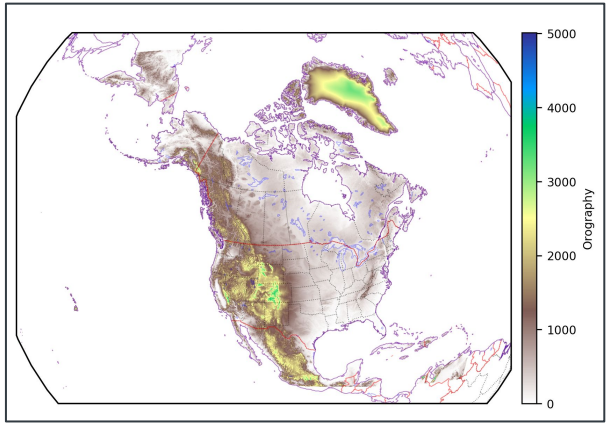


UNIFIED FORECAST SYSTEM

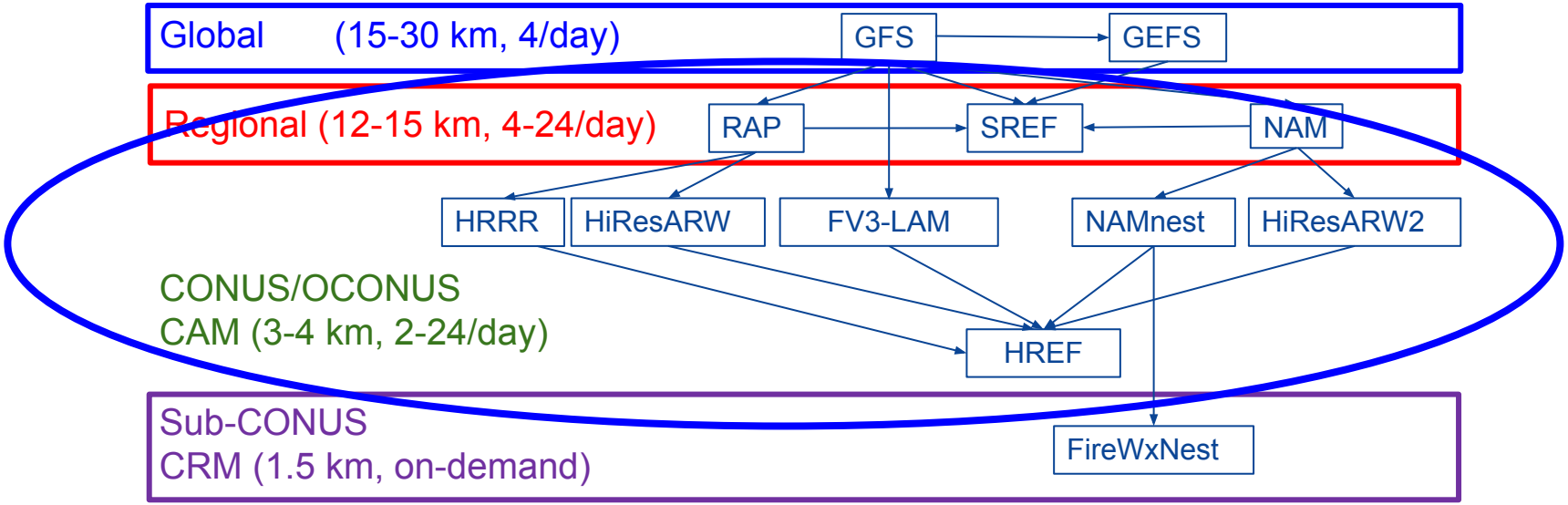
Rapid Refresh Forecast System (RRFS)

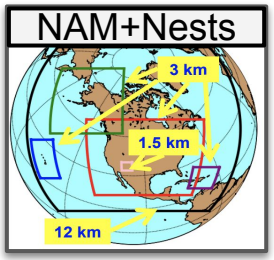
A UFS Application

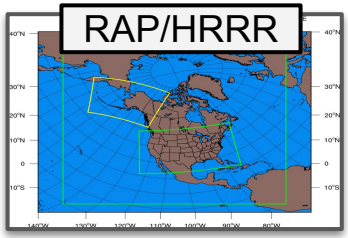
- Based on the FV3 dynamical core Limited Area Model (LAM) capability
  - Black et al. (*JAMES*, 2021)
- Hourly updated
- Convection-allowing (~3 km)
- 65 vertical layers
- Hybrid 3DEnVar assimilation (30 members)
- Ensemble forecasts (~~9~~ *5* members *augmented with TL members*)
  - Stochastic and multiphysics suite
  - 60h every 6 hours

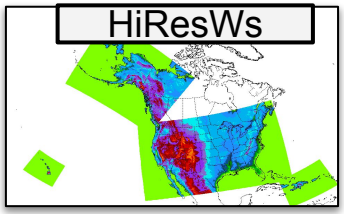


Near Current Snapshot of Regional Model Suite

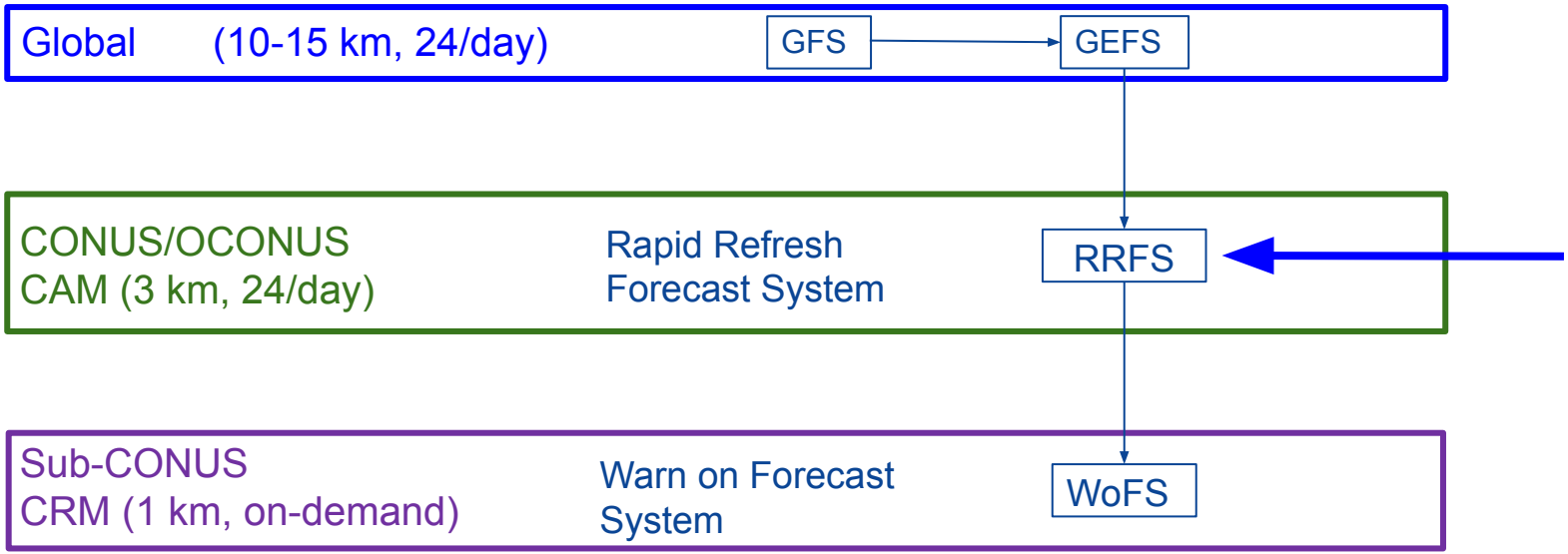






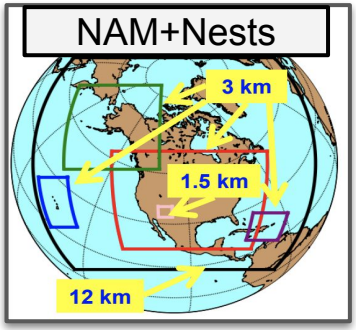


Unification of the Regional Model Production Suite

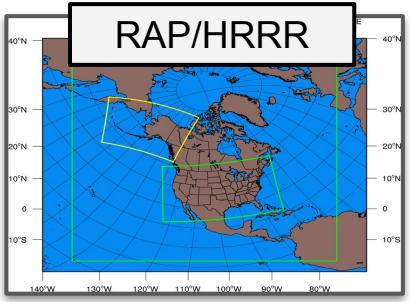


Unifying Regional Domains

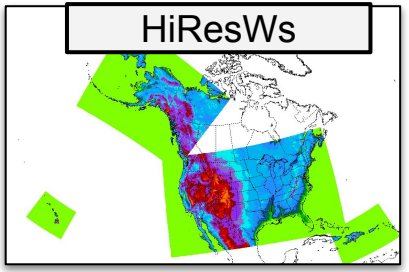
NAM+Nests

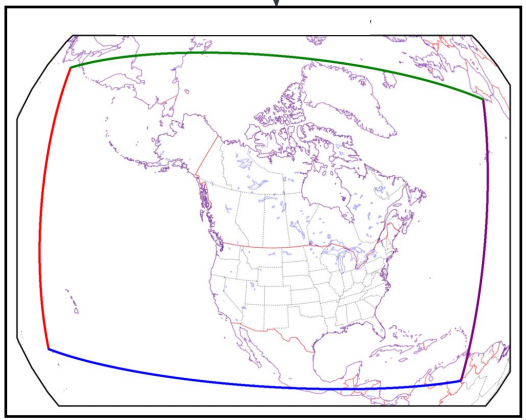


RAP/HRRR



HiResWs

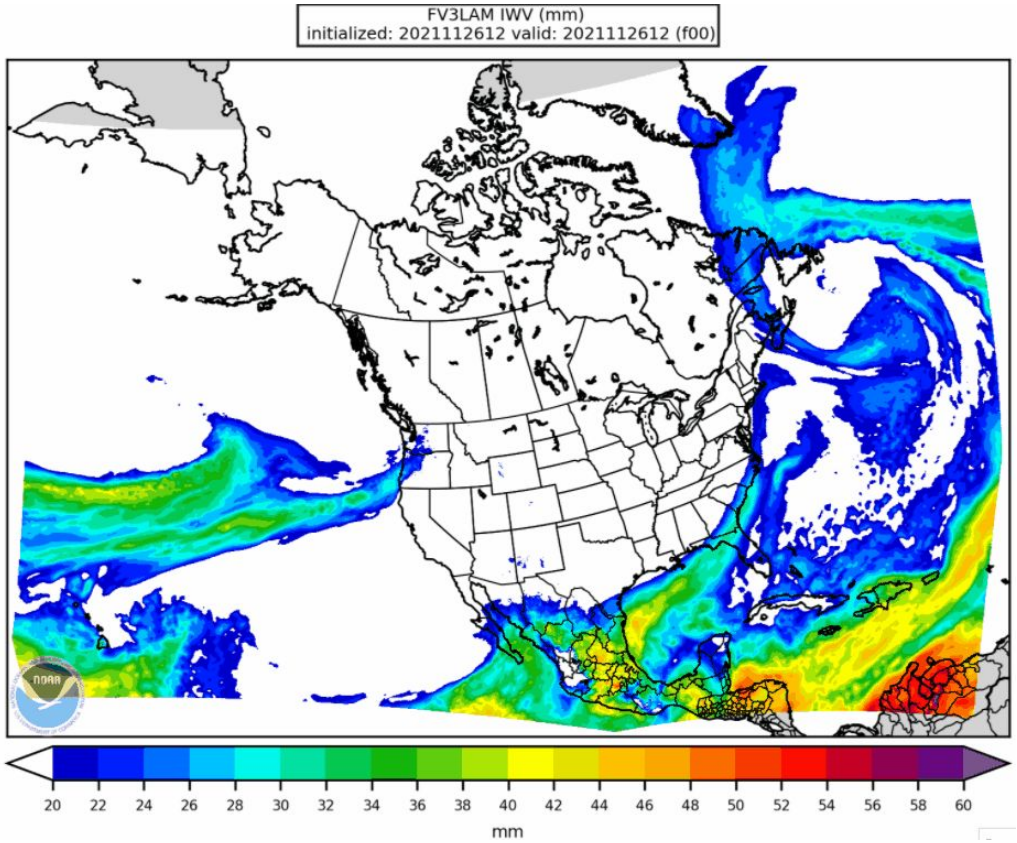




~10.7 million cells per layer

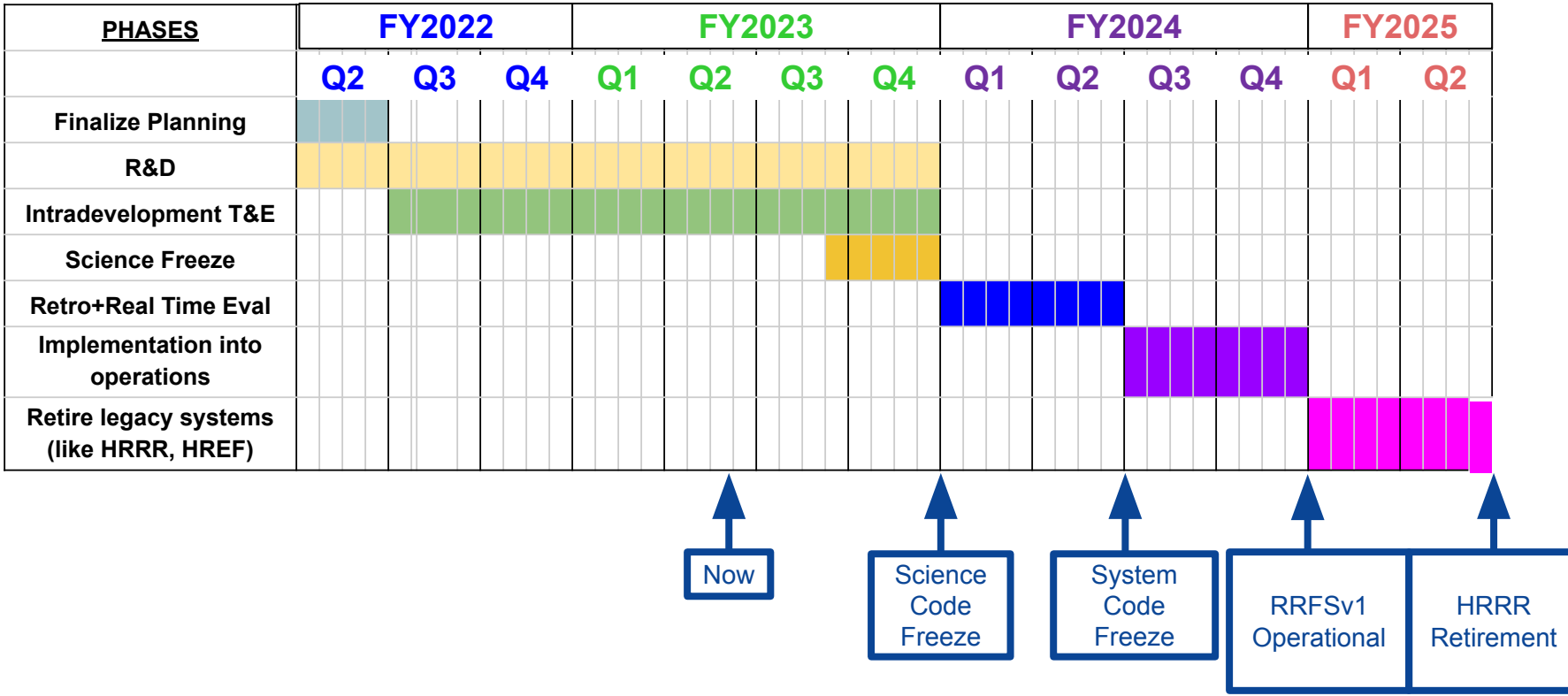
3 km RRFS North American domain

Larger - High Resolution Domain



Example from an older, smaller NA domain prototype

[notional] RRFS Implementation Timeline - targeting Q4FY24



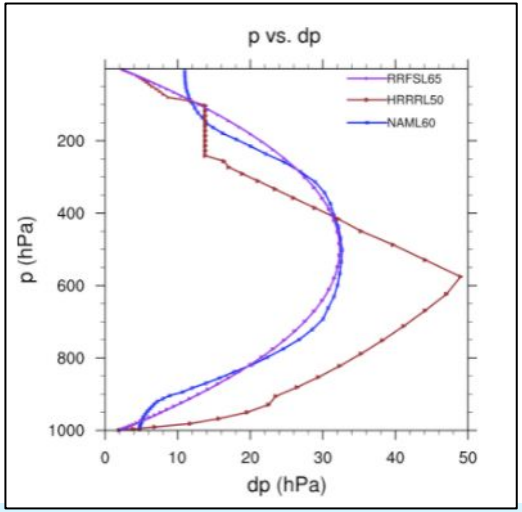
RRFS Physics and Vertical Resolution

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)
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 (not yet in place)	Subin et al. (2012), Mallard et al. (2015), Benjamin et al. (2022)
Near-Surface Sea Temperature	NSST	Fairall et al. (1996), Derber and Li (2018)

RRFSv1 Deterministic Physics Suite - largely based on HRRR physics (using a proven suite for this scale reduced risk for RRFSv1)

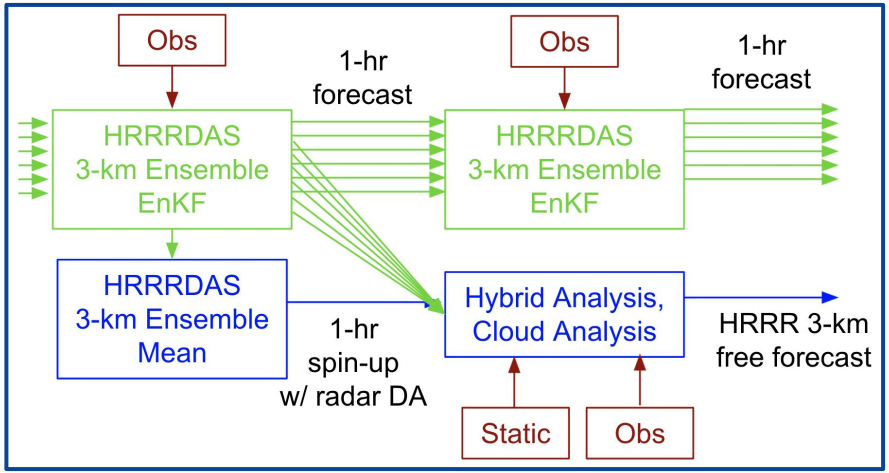
Tested L65 and L70 configurations for 30 cases

- Performance similar between L65 and L70
- Both improved over NAM's L60



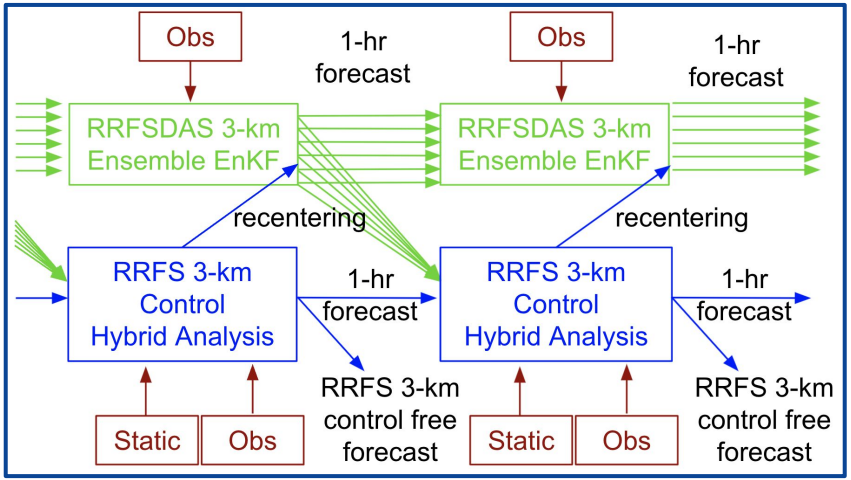
Active development: *Convective-scale Ensemble DA for RRFSv1*

Operational HRRR Storm-Scale Ensemble DA



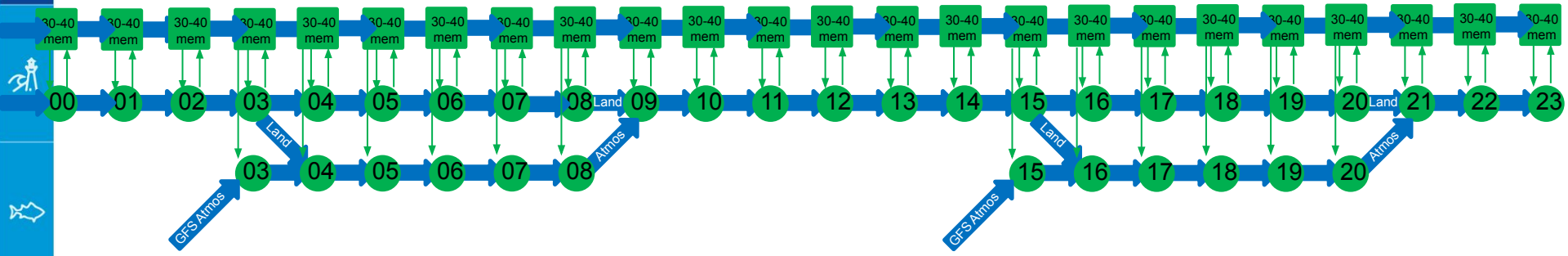
- Uses ensemble covariances in deterministic analysis
- Leverages ensemble mean for deterministic forecast
- One-way information from ensemble to deterministic forecast
- Deterministic atmospheric forecast not hourly cycled
- Deterministic forecast can fall outside ensemble solutions

RRFS Storm-Scale Ensemble DA

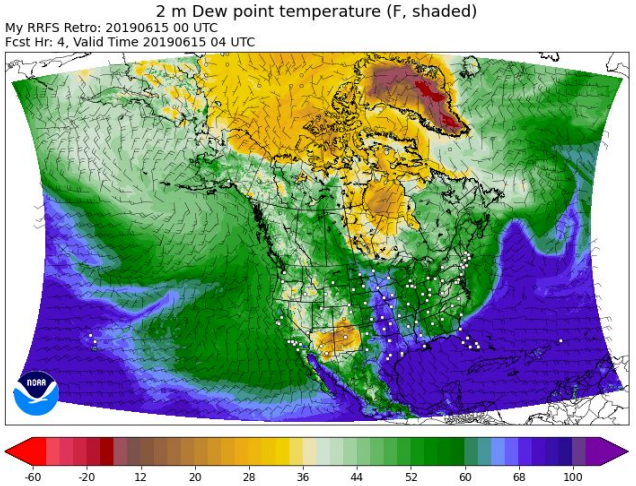


- Uses ensemble covariances in deterministic analysis
- Ensemble mean recentered from deterministic analysis (likely less frequently than originally planned)
- Two-way information between ensemble and control member
- Deterministic atmospheric forecast hourly cycled
- Deterministic/control forecast within ensemble solution space (if can restore hourly recentering)

RRFSv1 Data Assimilation Cycling



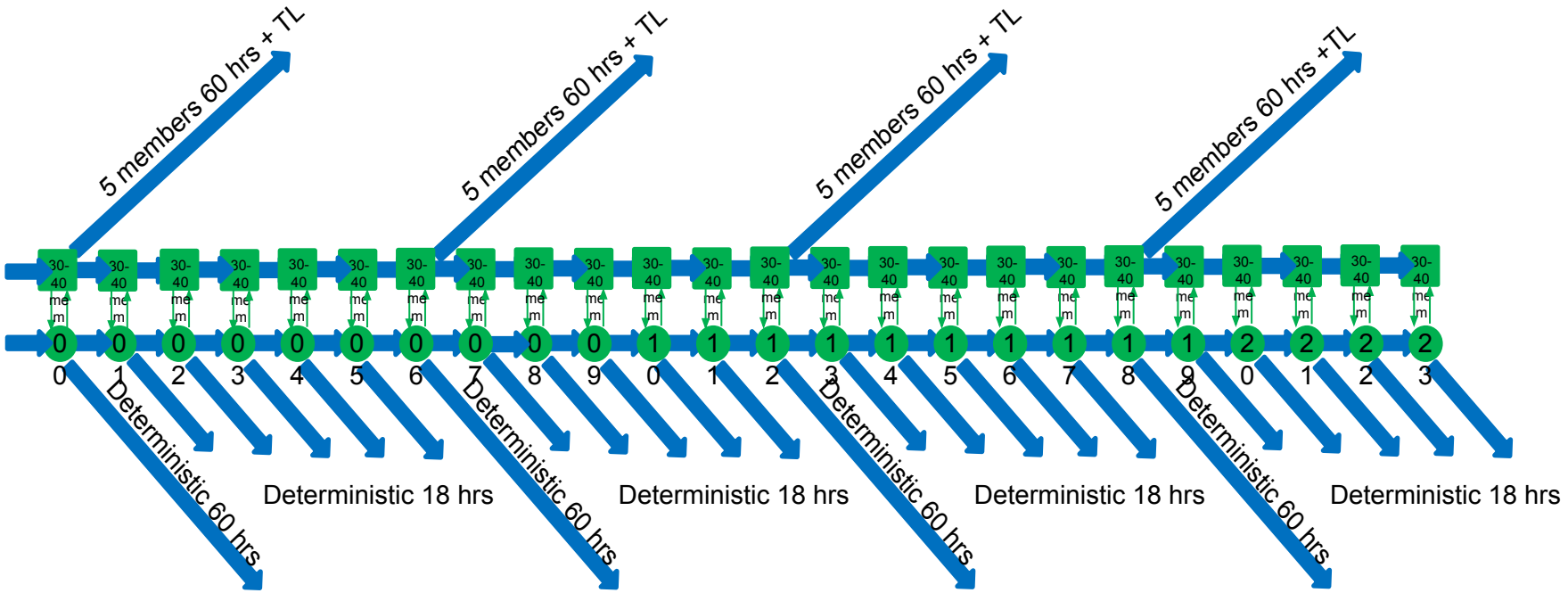
- Two-way interaction between 30 member 3-km DA ensemble ( ) and 3-km deterministic RRFS hybrid 3DEnVar analysis( )
- Partial cycle spin-up of atmosphere from GFS twice per day (RAP like), land states fully cyc'd
- All ensemble members (in square) and deterministic/control (circle) on 3-km NA grid



Projected RRFSv1 Ensemble Forecast Design

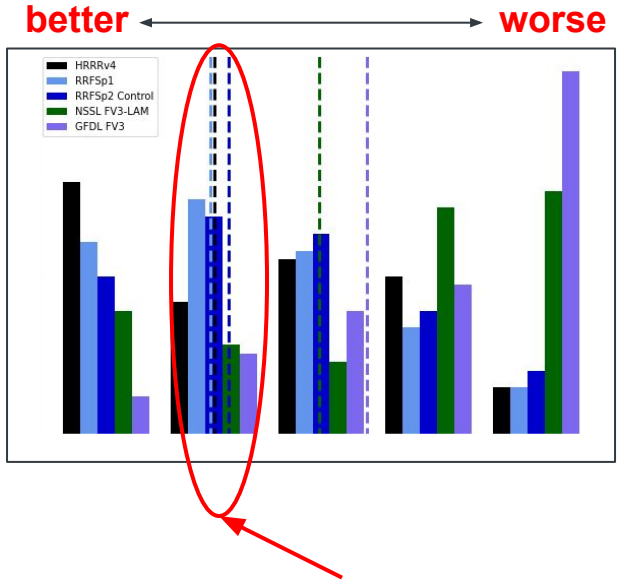
- **Current cycle** (5 ens members + deterministic control run)
  + **6 h old cycle** (4 TL ens members)
  = a 10 member forecast ensemble for product generation
- Sources of uncertainty/spread
  - Initial conditions from the EnKF DA system
  - LBC perturbations from GEFS
  - Model error:
    - Stochastic physics (SPP, SPPT, SHUM, SKEBS, etc.)
    - Multiple physics packages
- Why multiphysics?
  - Single physics CAM ensembles tend to be under-dispersive (*for now*)
- Design based on operational experience, testbeds, and ongoing JTTI/NGGPS/UFS-R2O collaborative projects

RRFSv1 Initial Operational Capability for Forecasts



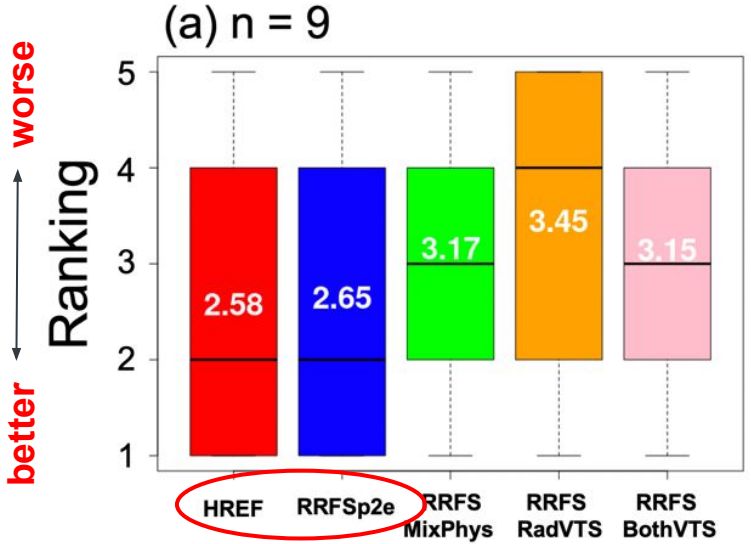
Real-time experimental RRFS subjective (participant) evaluations from 2022 HWT SFE

Deterministic Comparisons (reflectivity and UH):



ops HRRR and two RRFS prototypes tightly clustered in average rating (vertical dashes)

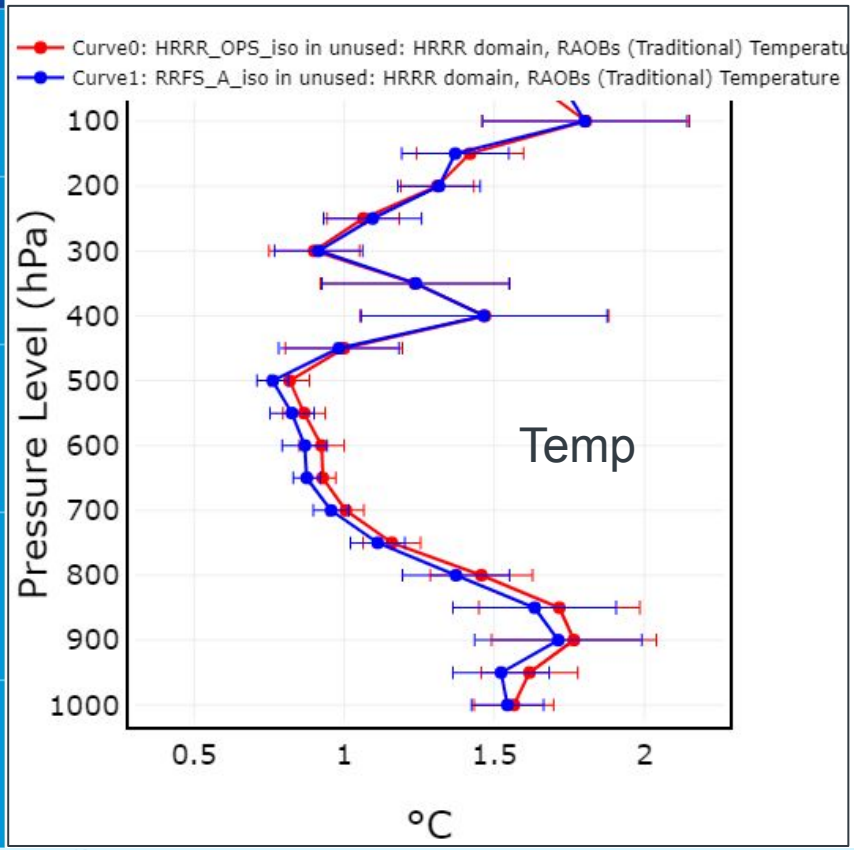
Ensemble Comparisons (for severe weather forecasting; lower = better):



ops HREF and RRFS ensemble rated similarly high

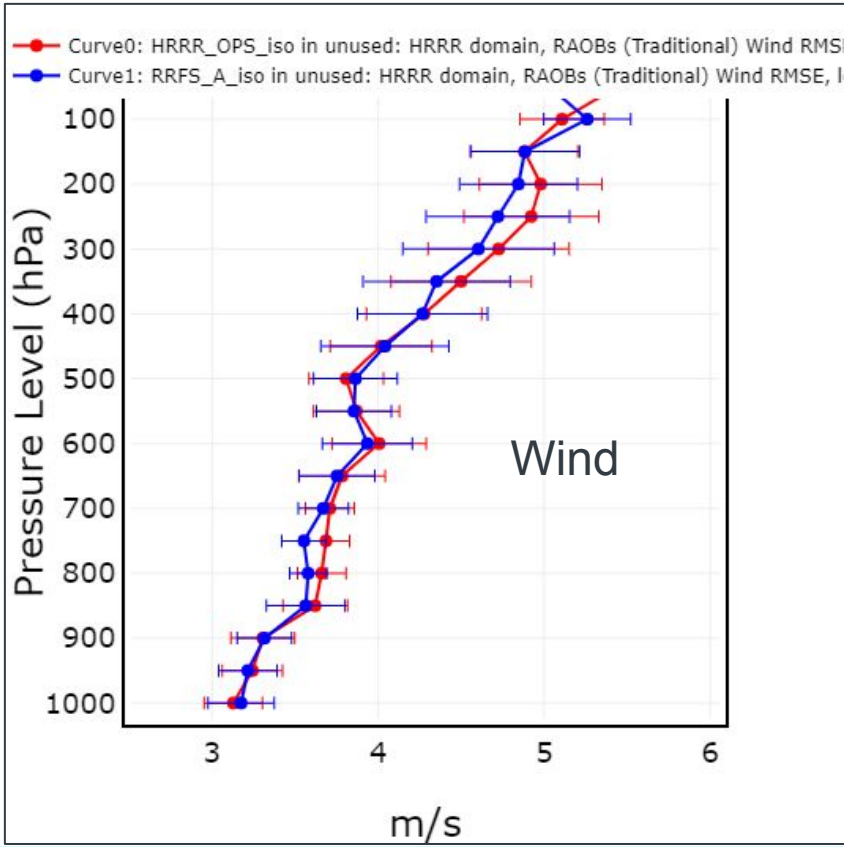
Figures courtesy of SPC/NSSL at: https://hwt.nssl.noaa.gov/sfe/2022/docs/HWT_SFE_2022_Prelim_Findings_FINAL.pdf

12 h forecasts valid 12Z
Mid Nov 2022 to Mid Feb 2023

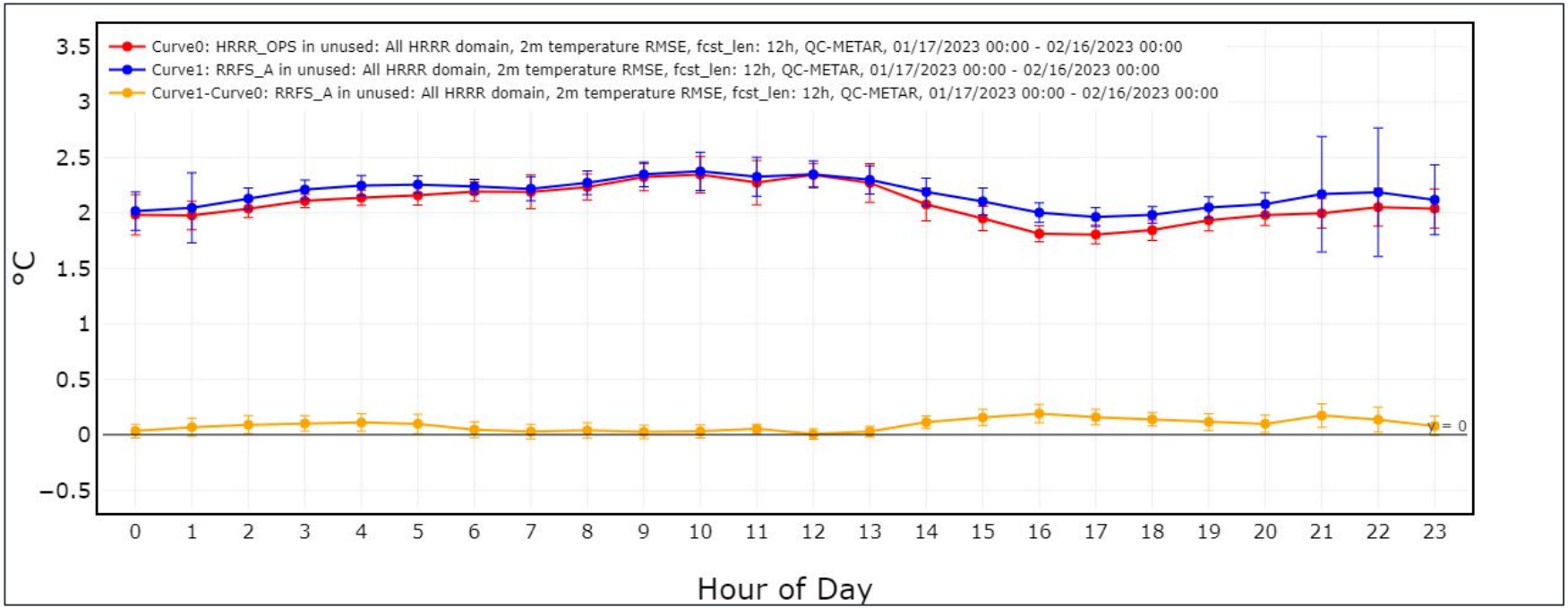


RRFS

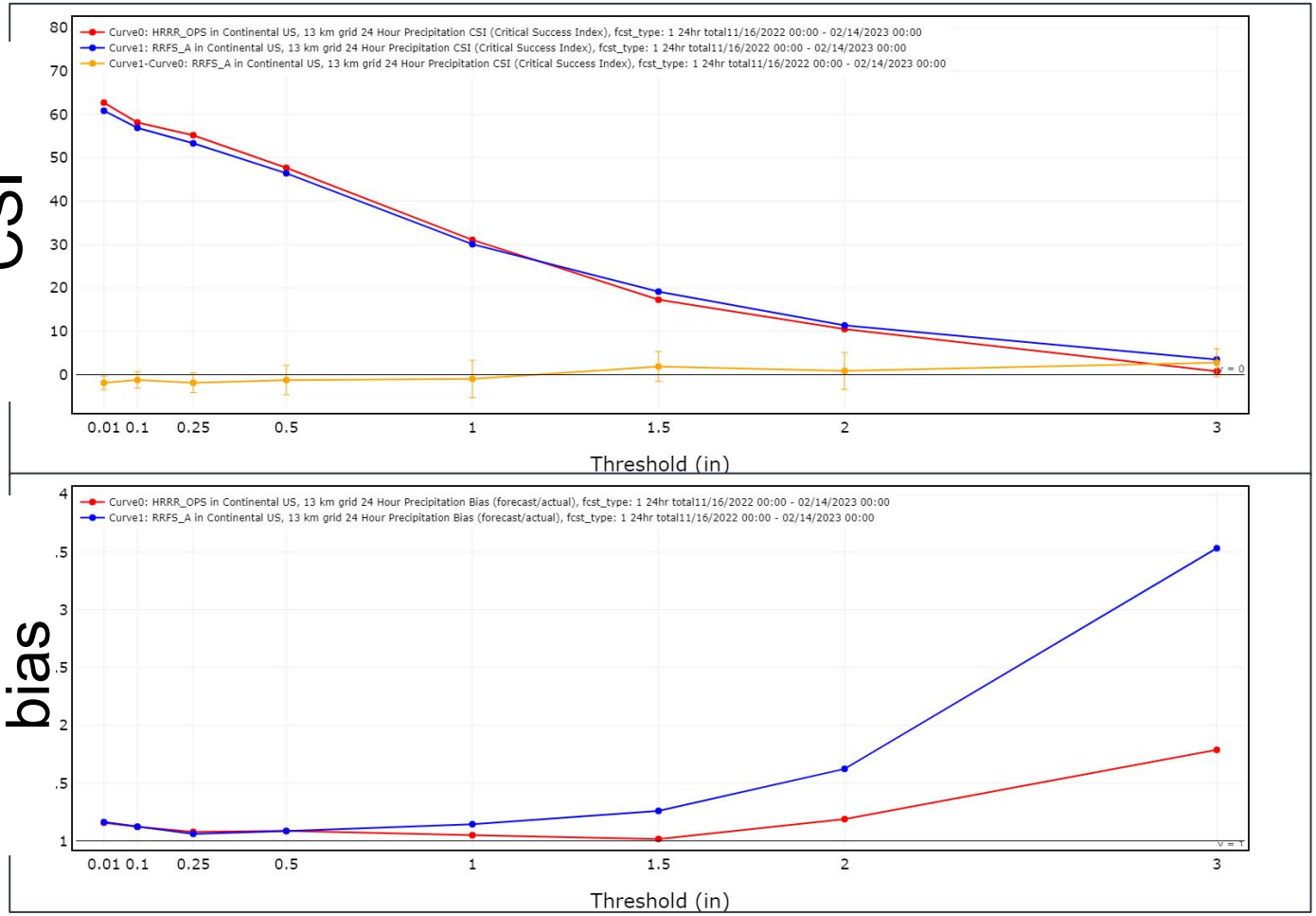
HRRR



12 h, 2 m temperature RMS
mid Jan - mid Feb 2023



RRFS HRRR

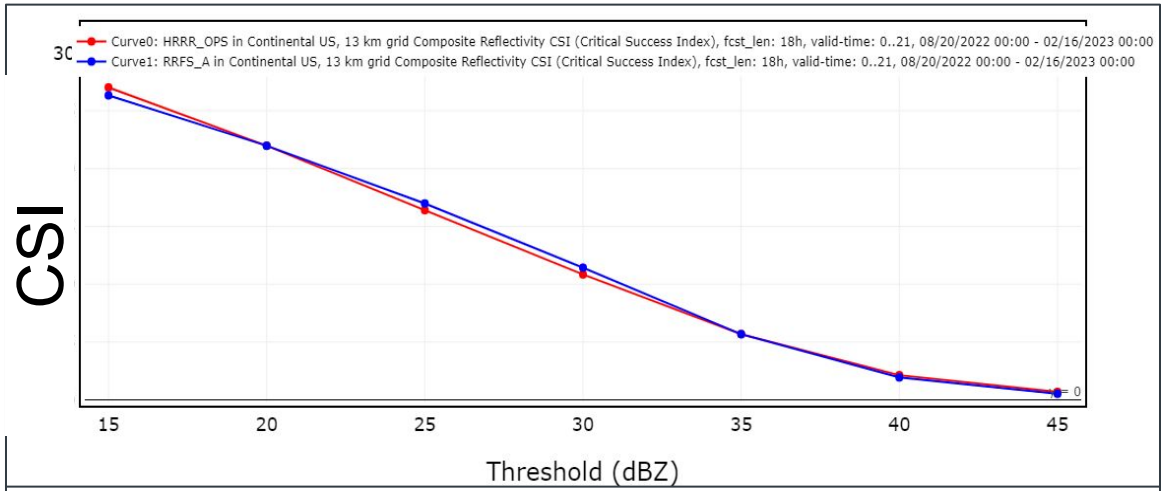


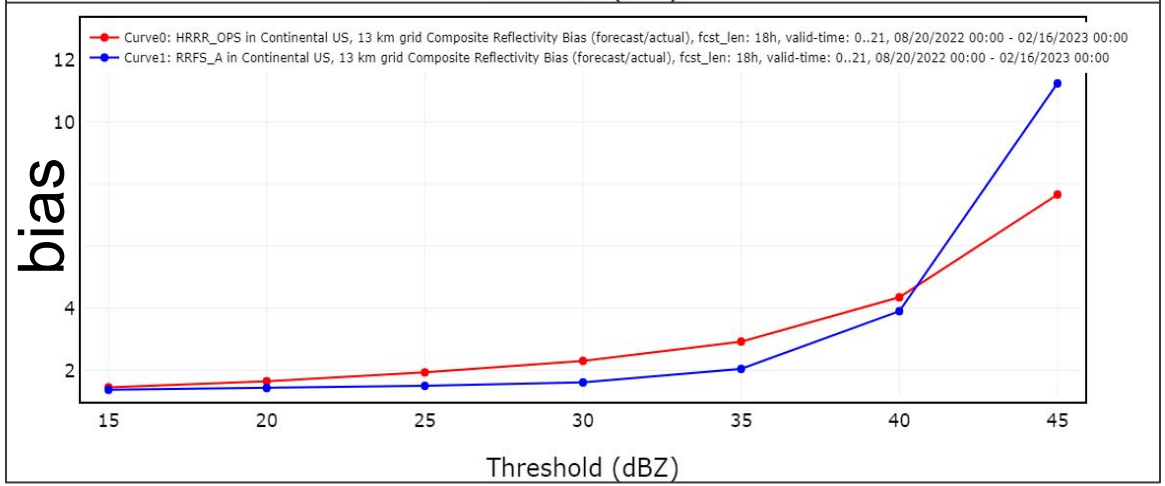
24 h QPF

mid Nov 2022 - mid Feb 2023

RRFS

HRRR





REFC 18 h forecast

18/21/00Z VTs

Mid Aug 2022 to Mid Feb 2023

RRFS

HRRR

Heavy precipitation issue

- A high bias in heavy precipitation is a long-standing RRFS/FV3 issue, particularly in the warm season (as highlighted in FFaIR experiments). Also manifests as a high bias at higher reflectivity thresholds
- An R2O Transition Plan between GFDL, GSL, and EMC is looking for solutions to this issue for RRFSv1
  - Most promising option identified thus far is to dampen the condensational heating within the microphysics
    - In early testing, this approach reduces frequency of very high precipitation rates and high simulated reflectivity
    - Needs more evaluation before going into wider parallel testing

Some winter weather items (at last!)

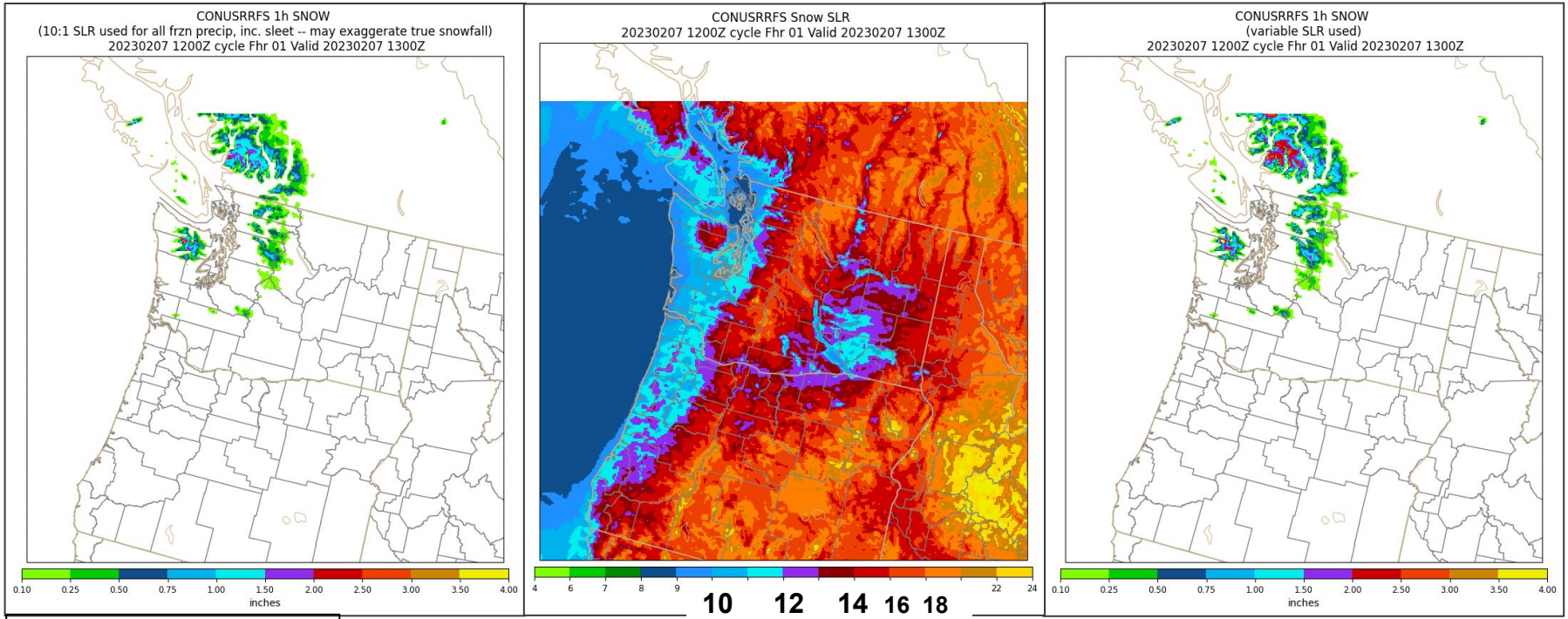
- Development team has been adding a number of functionalities relevant to winter weather that exist in the HRRR into the RRFS prototype system:
  - Variable snow density output product
  - Accumulation products for FRZR, sleet, etc.
  - FVCOM (Great Lakes model)

1 h snowfall (converted from model WEASD)

10:1 SLR applied

Roebber-type SLR (1000/SDEN) product - UPP generated

variable SLR applied



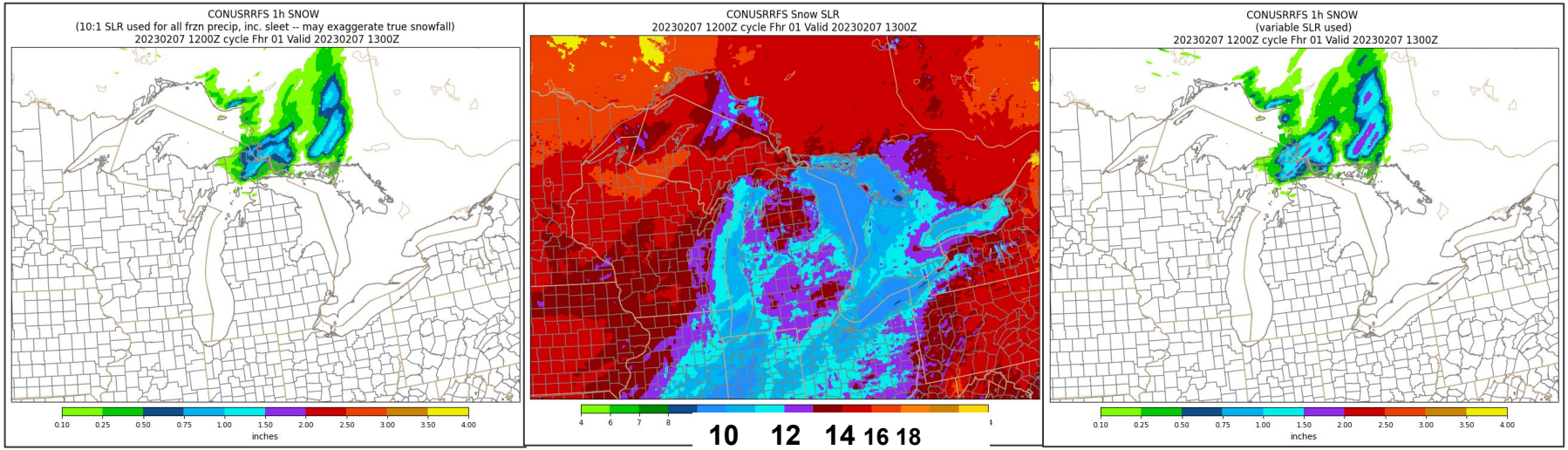
20230212/15Z cycle

1 h snowfall (converted from model WEASD)

10:1 SLR applied

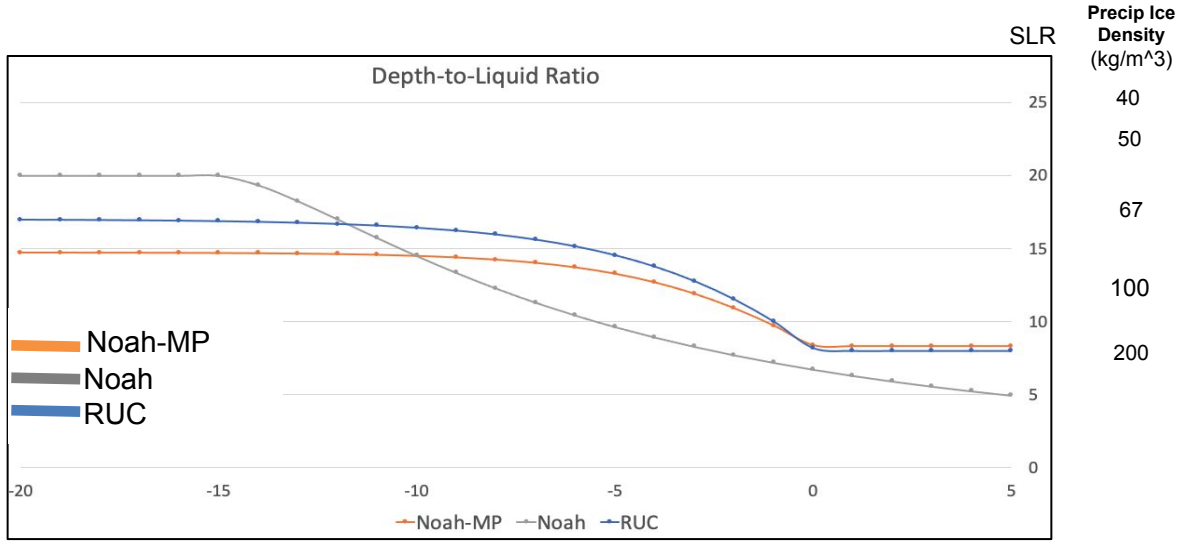
Roebber-type SLR (1000/SDEN) product - UPP generated

variable SLR applied



Variable Precipitation Ice Density (in progress)

- While previous examples showed a UPP (post processor) SDEN product, this describes something similar to be applied to snow accumulation within the model.
- Variable Precipitation Ice Density calculation was moved out of the RUC LSM in order to make it available to the RUC, NOAH and NOAH MP LSMs.
- The RUC LSM will be used in the first implementation of RRFS, and the NOAH MP LSM will be used in later upgrades.

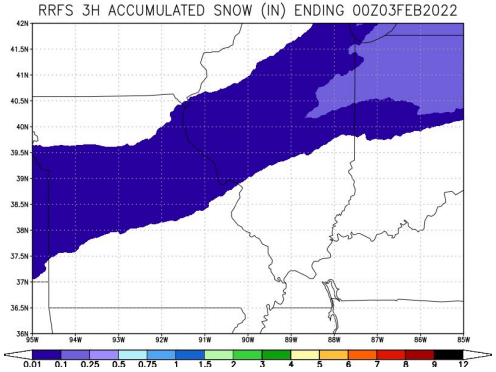


courtesy Eric Aligo

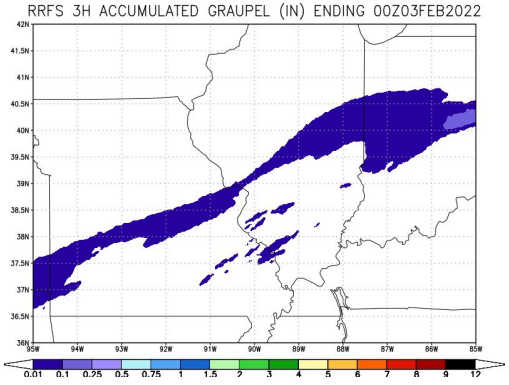
New Winter Weather Diagnostics (in progress)

- Six new winter weather diagnostics are being added to RRFS and GFS to mimic what is present in the operational HRRR output.
- Run-time accumulated as well as bucket values of snowfall (TSNOWP), graupel/sleet (FROZR) and freezing rain (FRZR) will be available in GRIB2 output.
- Snow water equivalent for snowfall and graupel/sleet (no SLR applied).

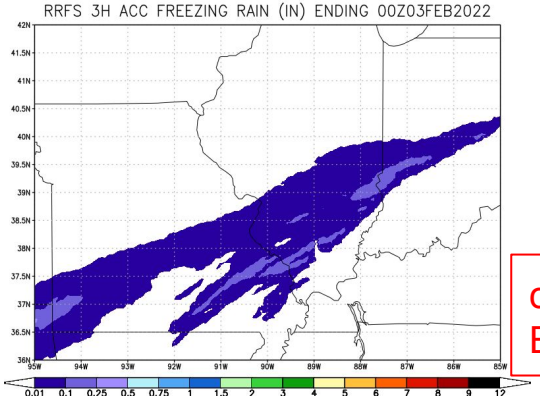
SNOWFALL



GRAUPEL/SLEET

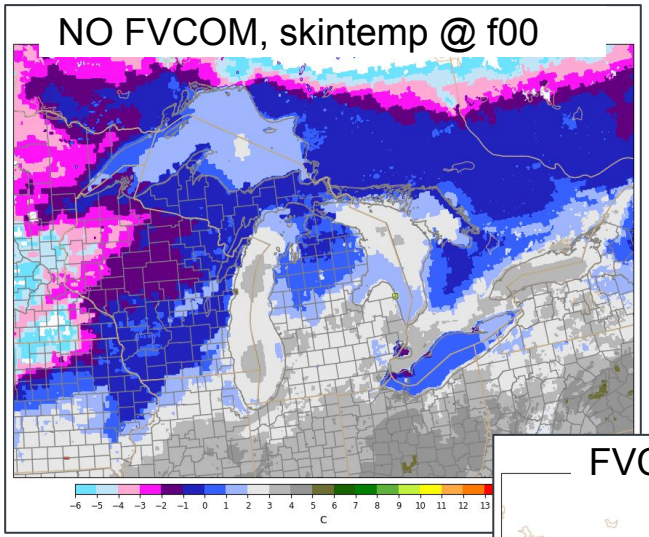


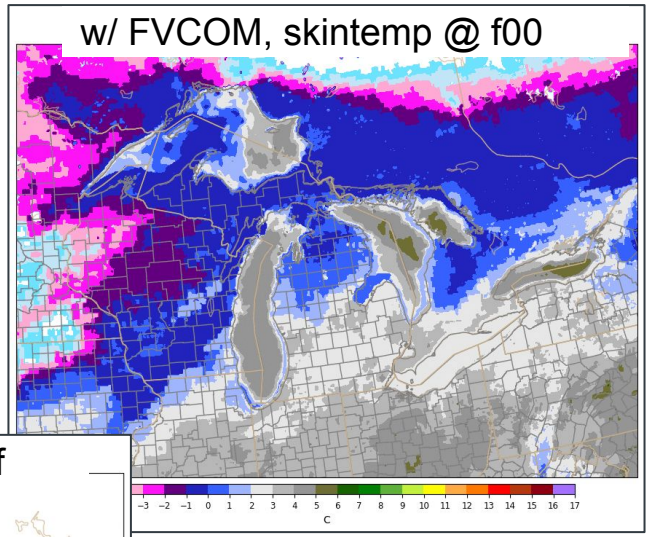
FREEZING RAIN

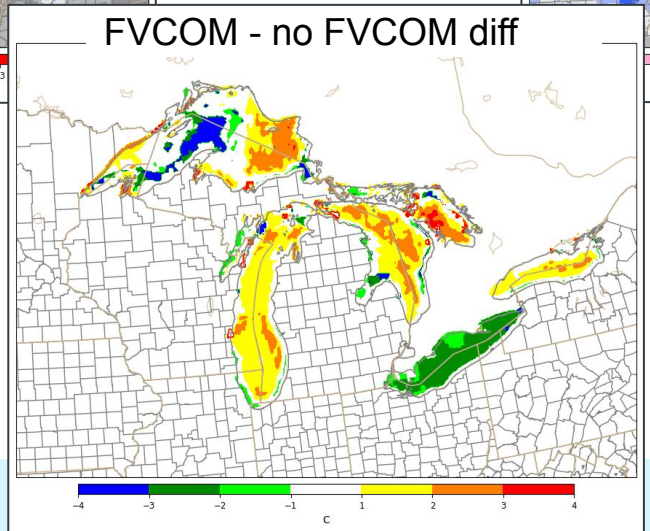


courtesy Eric Aligo

Inclusion of the Finite Volume Community Ocean Model (FVCOM) output over Great Lakes





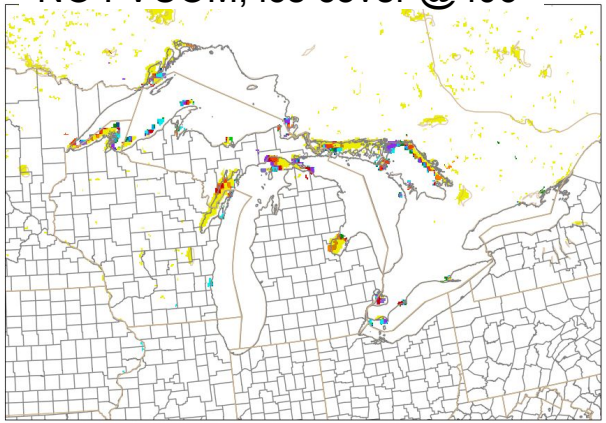


Great Lakes generally warmer with FVCOM in lake interiors for this case - with exception of Lake Erie (for reasons we'll soon see)

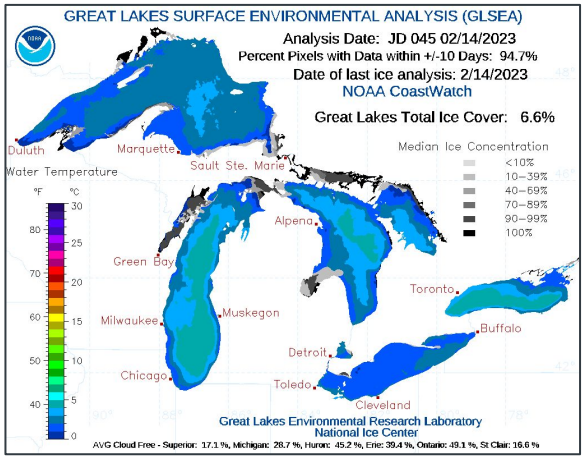
20230212/15Z cycle

Inclusion of the FVCOM output over Great Lakes

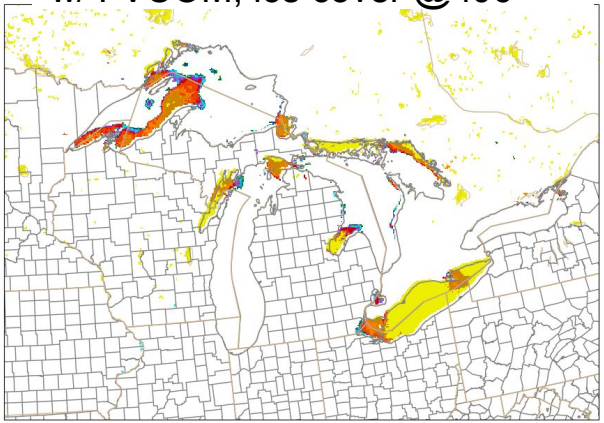
NO FVCOM, ice cover @ f06



GLERL analysis



w/ FVCOM, ice cover @ f06

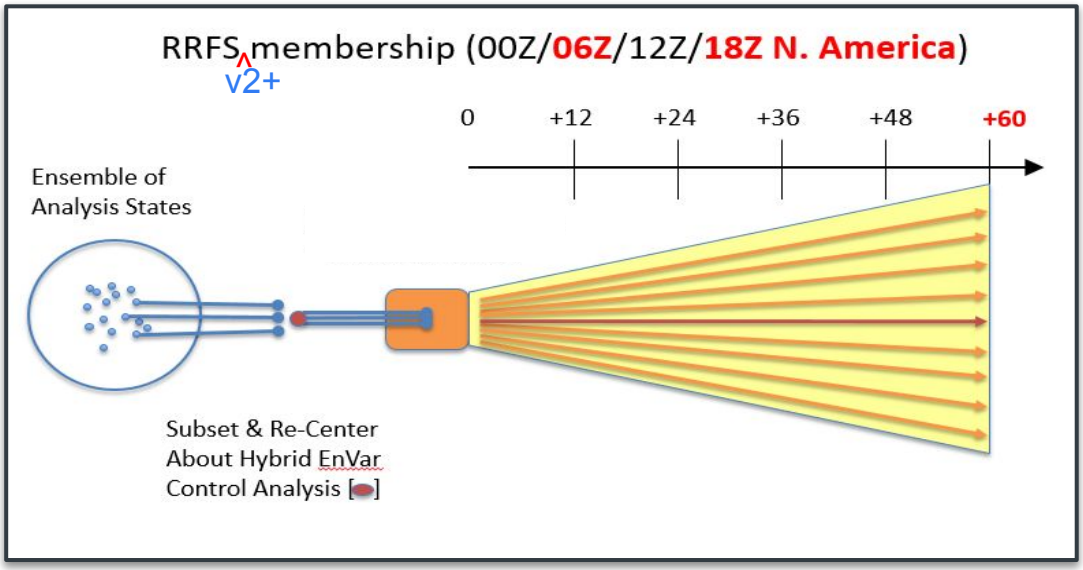


Generally ice free, aside from some bays and coastal regions (gray/black = ice)

Overdone ice cover Lake Erie and Superior with inclusion of FVCOM data

20230212/15Z cycle

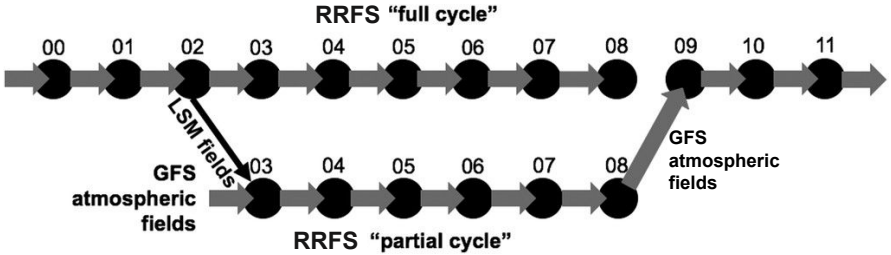
RRFSv2+ Ensemble Forecast System



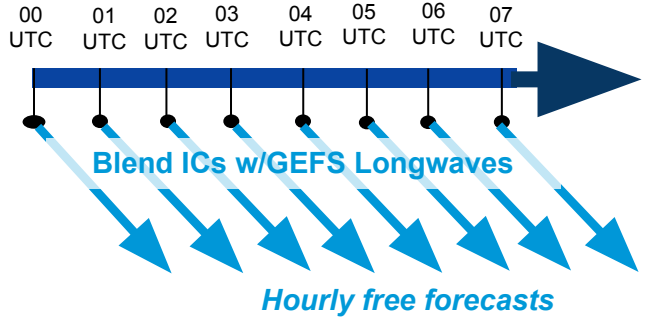
- Version 1's ***forecast*** ensemble is planned to be *multi-physics* + stochastic
- Version 2 → begin process toward single physics, evidence permitting
  - Members equally likely to be most skillful & developer+community focus on improving the single baseline system

Beyond RRFSv1 → Advances in Cycling

RRFSv1



RRFSv2+



RRFSv1 Partial Cycling

- Mitigates risk with familiar LAM cycling design (e.g. RAP)
- Ensures inclusion of longer wavelength information limiting drift
- Collects latent observations
- Partial cycling still more expensive than continuous cycling
- Workflow is more complex than continuous cycling

RRFSv2+ Full Cycling

- Blending GDAS/GEFS longwave perturbations into ICs
- Overlapping windows to collect latent observations
- Reduced computation cost compared to partial cycling
- Simplified workflow
- More development needed prior to operational transition

Schwartz, et al. , 2022: Comparing Partial and Continuously Cycling Ensemble Kalman Filter Data Assimilation Systems for Convection-Allowing Ensemble Forecast Initialization. *WAF*, **37**, 85-112.

Slivinski, wt al. , 2022: Overlapping Windows in a Global Hourly Data Assimilation System. *MWR*, https://doi.org/10.1175/MWR-D-21-0214.1.

Summary

- RRFS will be a *major* change:
  - Looking to replace wide swath of operational CAM guidance with a single, unified 3 km system covering North America
- Still have challenges to overcome, both scientific and technical, but shooting for a code freeze ~September 2023, and an implementation about a year later.