The High-Resolution Rapid Refresh (HRRR) Numerical Weather Prediction Model

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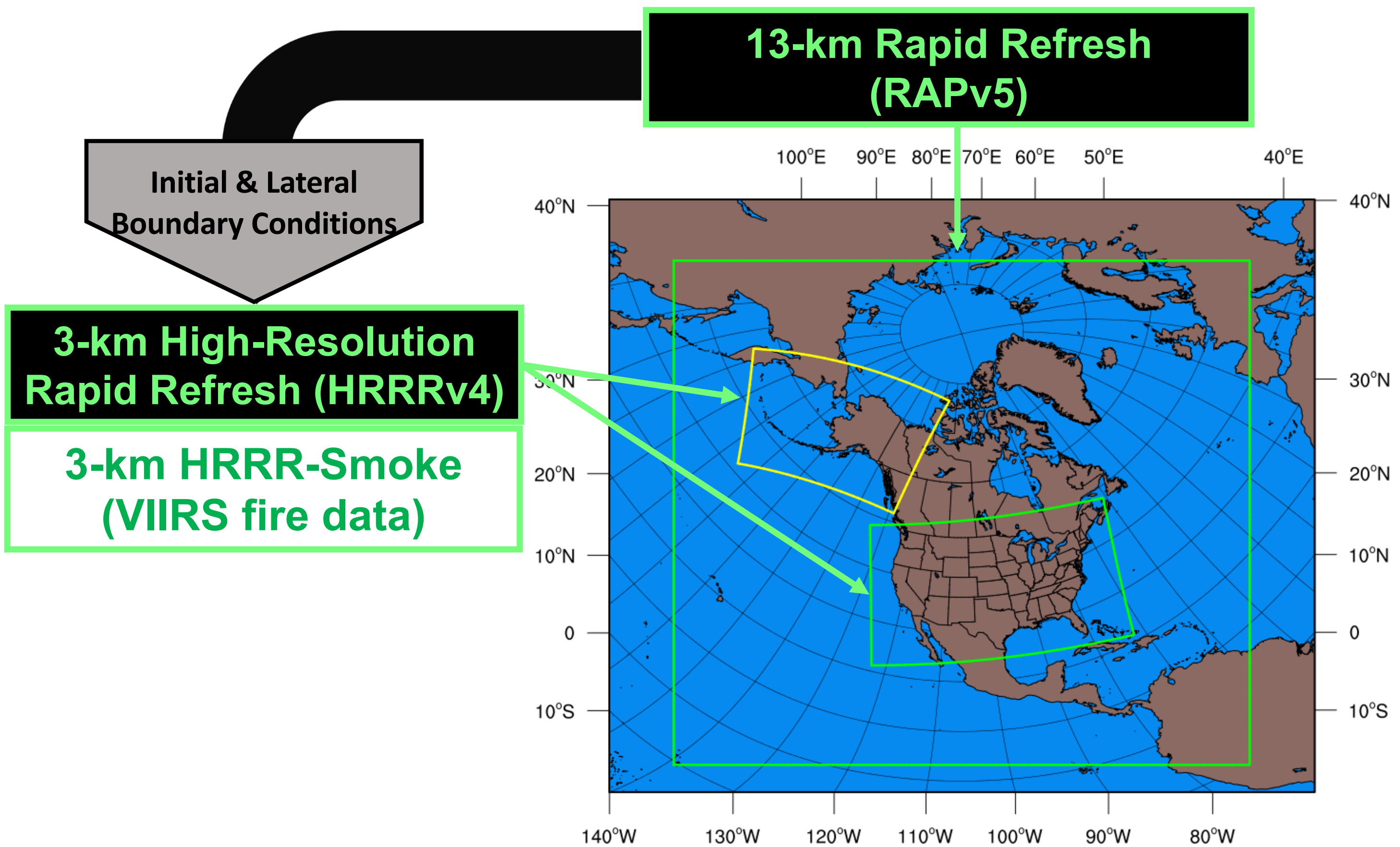
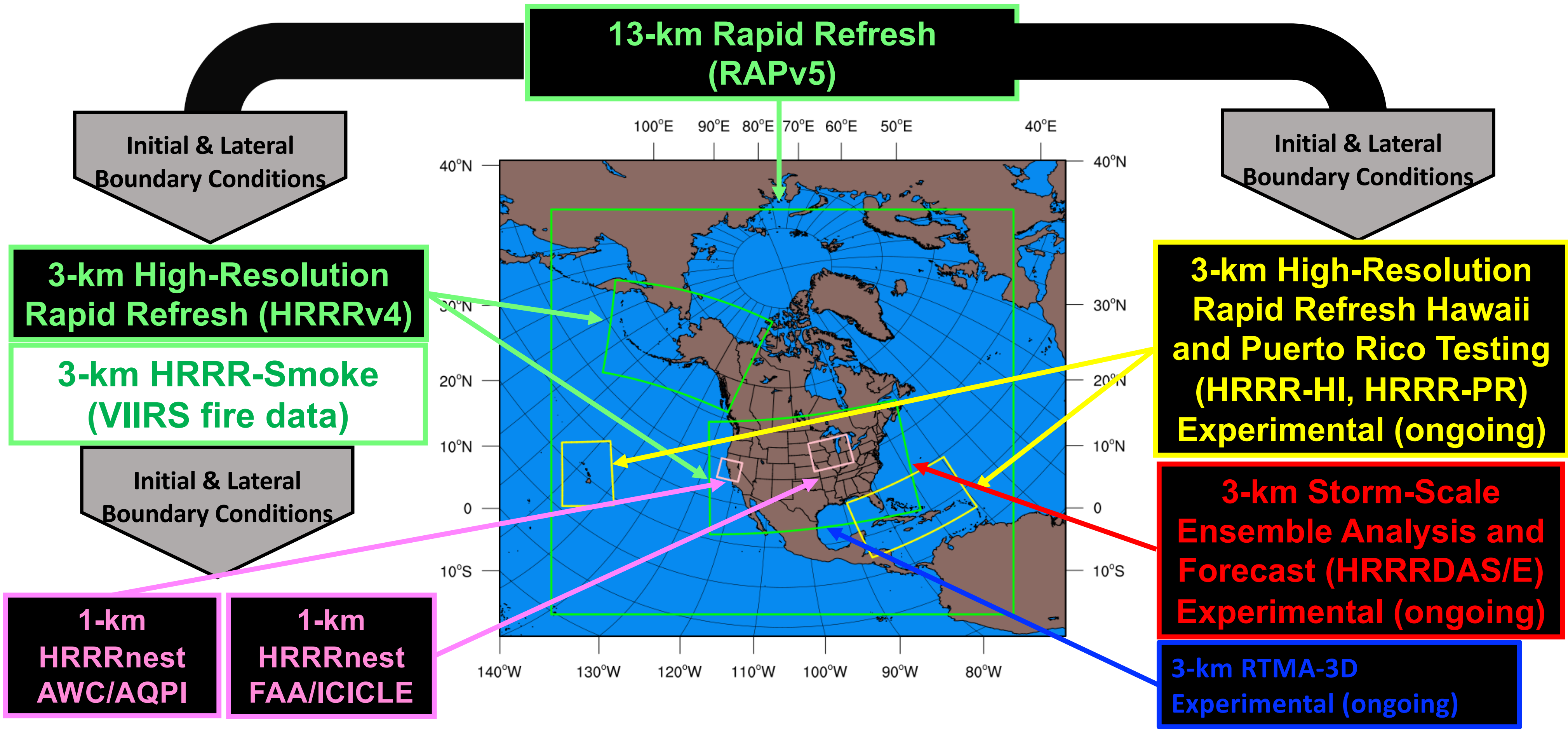
NOAA/ESRL/GLOBAL SYSTEMS LABORATORY

RAP/HRRR Model Forecast Suite



RAP/HRRR Model Forecast Suite



RAP/HRRR Observations Assimilated

	Hourly Observation Type	Variables Observed	Obs Count / Hour
Profiles	Rawinsonde	Temperature, Humidity, Wind, Pressure	120 (most @00z/12z)
	Profiler – 915 MHz	Wind, Virtual Temperature	20-30
	Radar – VAD	Wind	125
	Radar	Radial Velocity	125 radars
"Radar"	Radar reflectivity – CONUS	3-d refl ➔Rain, Snow, Graupel	1,500,000
	Lightning	(proxy reflectivity)	NLDN
Aircraft	Aircraft (AMDAR, TAMDAR)	Wind, Temperature	2,000 -26,000
	Aircraft – WVSS, TAMDAR	Humidity	100 - 3500
	Surface/METAR	Temperature, Moisture, Wind, Pressure, Clouds, Visibility, Weather	2800 - 3200
Surface	Surface/Mesonet	Temperature, Moisture, Wind	~12K (~10K monitored)
	Buoys/ships	Wind, Pressure	200 – 400 (every 3h)
	GOES AMVs (atmos motion vectors)	Wind	2000 - 4000
	AMSU/HIRS/MHS/ATMS/CrIS (RARS)	Radiances	1K-10K
Satellite	GOES	Radiances	large
	GOES cloud-top press/temp	Cloud Top Height	100,000
	GPS – Precipitable water	Humidity	350-400
	WindSat Scatterometer	Winds	2,000 – 10,000

RAP/HRRR Implementation History

Operational Implementations

01 May 2012 ➢ RAPv1: Adoption of GSI, WRF-ARW and unified post ➢ Enabled use of community-developed software	**25 Feb 2014** ➢ RAPv2: Hybrid EnKF-3DVar data assimilation ➢ Significant improvement in upper-air forecasts
30 Sep 2014 ➢ HRRRv1: 3-km Radar DA in WRF-ARW ➢ Significant improvement in convective forecasts	**23 Aug 2016** ➢ RAPv3/HRRRv2: Aerosol Thompson MP, improvements to MYNN PBL, RUC LSM, RRTMG Rad, Grell-Freitas cumulus ➢ Significant improvement in surface forecasts
12 Jul 2018 ➢ RAPv4/HRRRv3: Hybrid Vertical Coordinate, Eddy Diffusivity Mass Flux PBL ➢ Reduction in short-lead biases and improved mesoscale environment ➢ Extended forecast lengths to 39/36 hrs ➢ HRRR-Alaska	**Mar/Apr 2020** ➢ RAPv5/HRRRv4: Storm-scale ensemble DA, Wildfire Smoke Prediction, Great Lakes Ice ➢ Reduction in longer-lead biases ➢ Extended forecast lengths to 51/48 hrs

HRRRv3 Shortcomings

Gap **How to address:**

- Doesn't cover Day-Ahead

- 36h forecasts every 6h HRRRv3 (July 2018), extension from previous 18 h
- **48h forecasts** every 6h in **HRRRv4 (upcoming @NCEP)**

- **Problems with 2-6h conv storm prediction**

- More accurate storms w/3km ens data assimilation **(HRRRv4)**

- Daytime warm bias, excessive low-cloud erosion, diurnal cycle

- breakthrough **– far better subgrid-scale cloud in HRRRv4/RAPv5**

- Guidance on smoke?

- **smoke forecasts added– improved aerosols (HRRRv4 / RAPv5)**

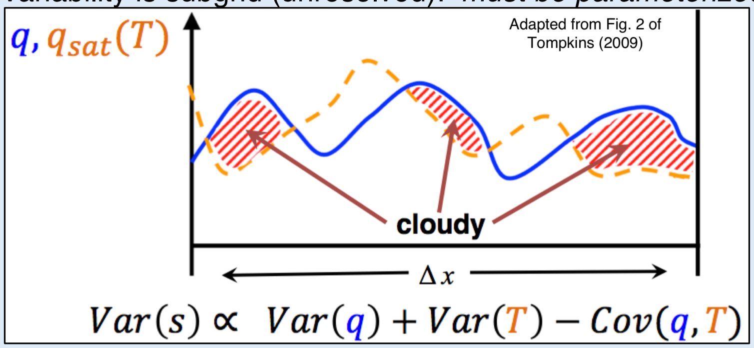
2020 RAPv5/HRRRv4 Primary Changes

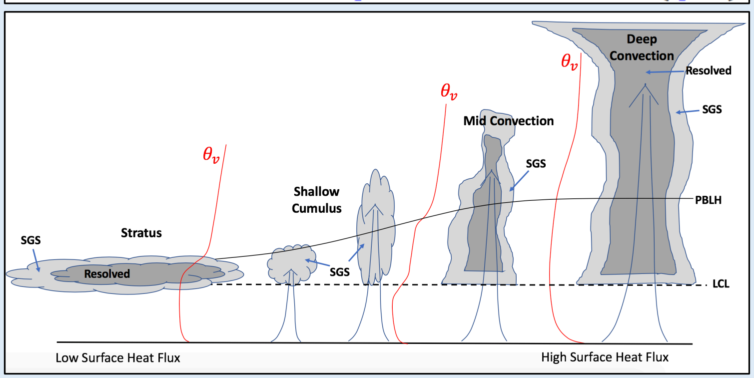
Model	Data Assimilation	Land-surface / post
WRF-ARWv3.9+ incl. phys changes *Physics changes:* MYNN PBL update – better sub-grid clouds, improved EDMF mixing - remove limit for subgrid qc/qi - decrease subgrid qc/qi radii RRTMG modifications for subgrid clouds Aerosols sources/sinks – fire/smoke, dust - Add smoke with VIIRS FRP Improved land-surface/snow model including better 2m T/Td diagnostics Latest Grell-Freitas conv (RAP only) Lake model for small lakes Enhanced gravity-wave drag *Numerics changes:* Reduced 6th order diffusion inc. hydrom Removal of mp_tend_lim Implicit-explicit vertical advection	Merge with GSI trunk – 2019 *New Observations for assimilation:* GOES-16 radiances, CrIS/ATMS TC vitals for trop cyclone location/ strength Aircraft/raob moisture obs for p<300 hPa VIIRS/MODIS fire radiative power *Assimilation Methods:* HRRR - 3km ensemble DA (36 mems out to 1h) – HRRRDAS mean for HRRR IC and BEC	Switch to MODIS albedo (higher), replace 1-deg albedo. Add zenith-ang albedo adj 15" resolution land use data Fractional sea/lake ice concentration FVCOM data for Great Lakes lake temp/ice concentration VIIRS/MODIS/GOES fire radiative power HAILCAST diagnostic

Improved Subgrid-Scale Cloud Representation

Subgrid-Scale (SGS) Clouds

- **Key Idea**: thermodynamic variability within a grid volume may produce small areas of saturation (*clouds*)
- Variability is subgrid (unresolved): *must be parameterized*

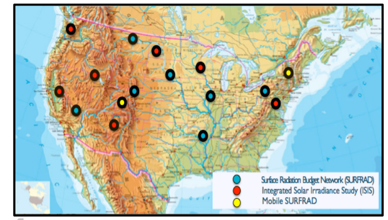




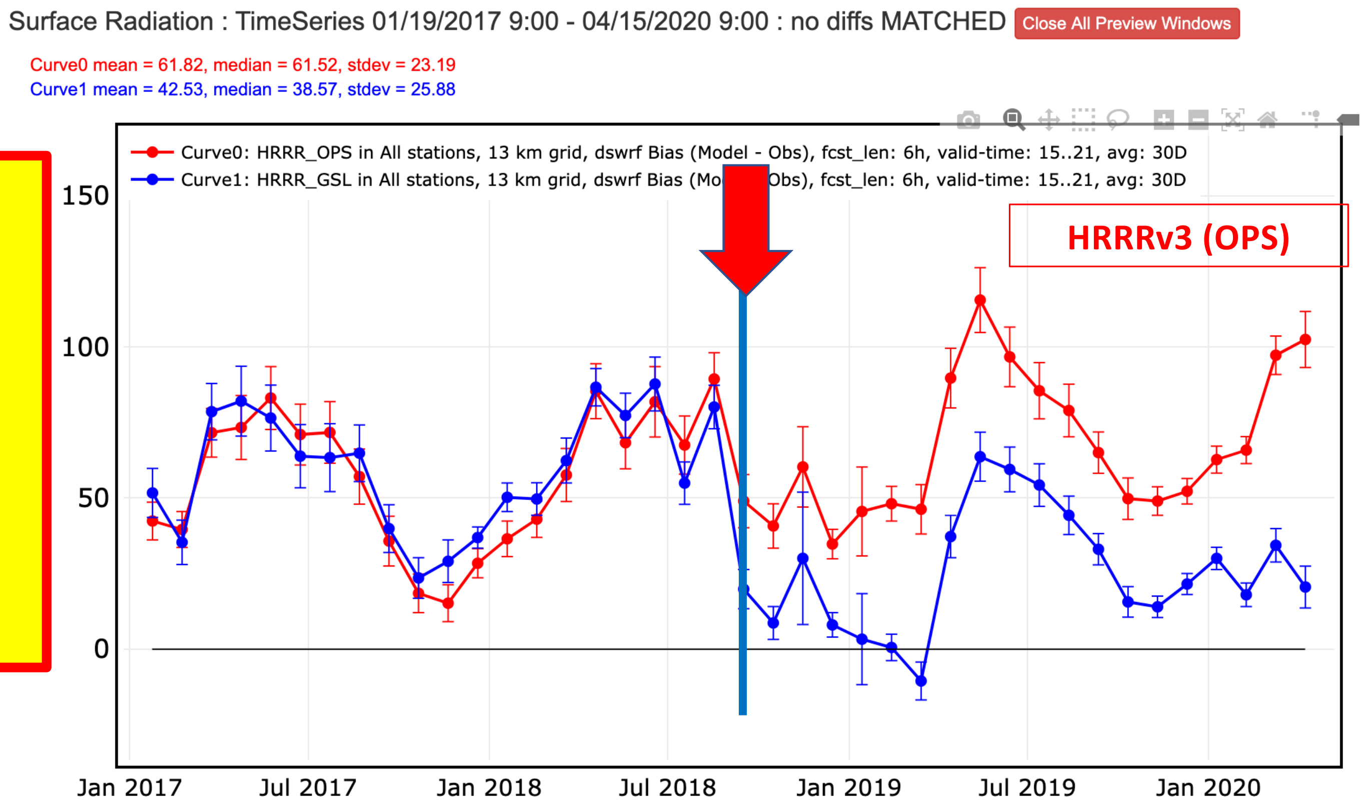
Key Changes for RAPv5 / HRRRv4:

- Mixing ratio (q_{cldwat} and q_{cldice}) of SGS clouds:
  - Removed constraints on q_x for stratiform SGS
  - Increased coverage of convective SGS via MYNN mass-flux approach
- Cloud fraction:
  - Stratiform: slightly reduced, except in high grid-scale RH
  - Use a modified Chaboreau and Bechtold (2002, 2005) scheme exclusively; discontinue use of Xu and Randall (1996)
- Effective radii (r_e) of SGS clouds:
  - Water: use Turner et al. (2007)
  - Ice: use Mishra et al. (2014)

Improved Subgrid-Scale Cloud Representation



8/29/18 subgrid-cloud change



Downward shortwave radiation bias vs. NOAA SURFRAD radiation network

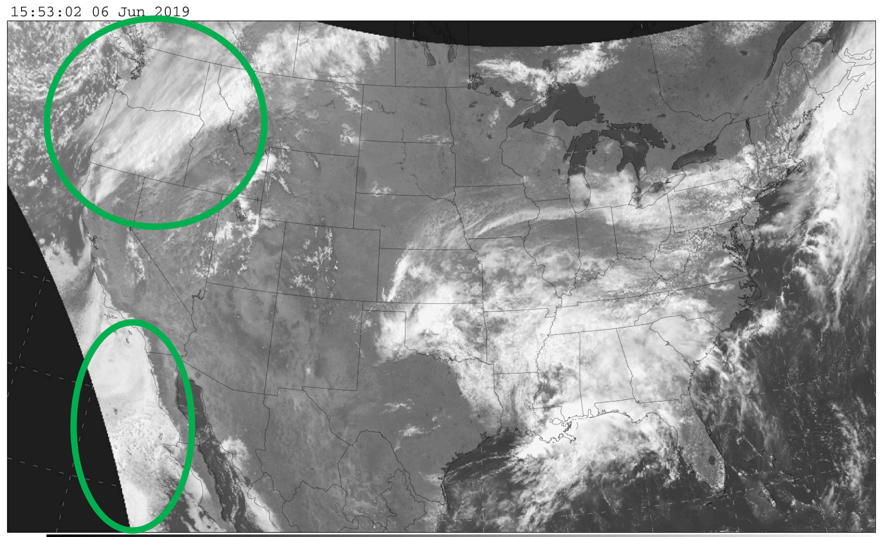
HRRRv4 with subgrid cloud changes

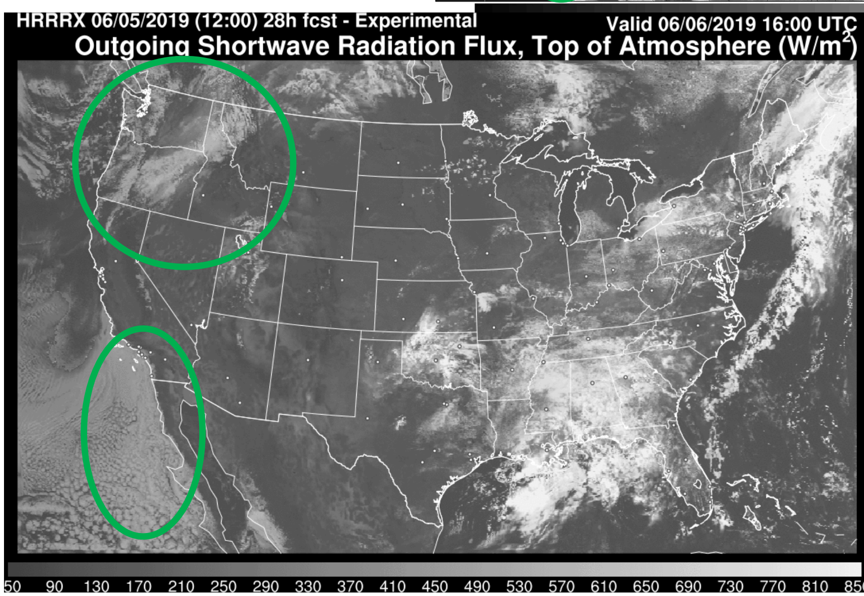
Comparison of SW-up at top of atmosphere

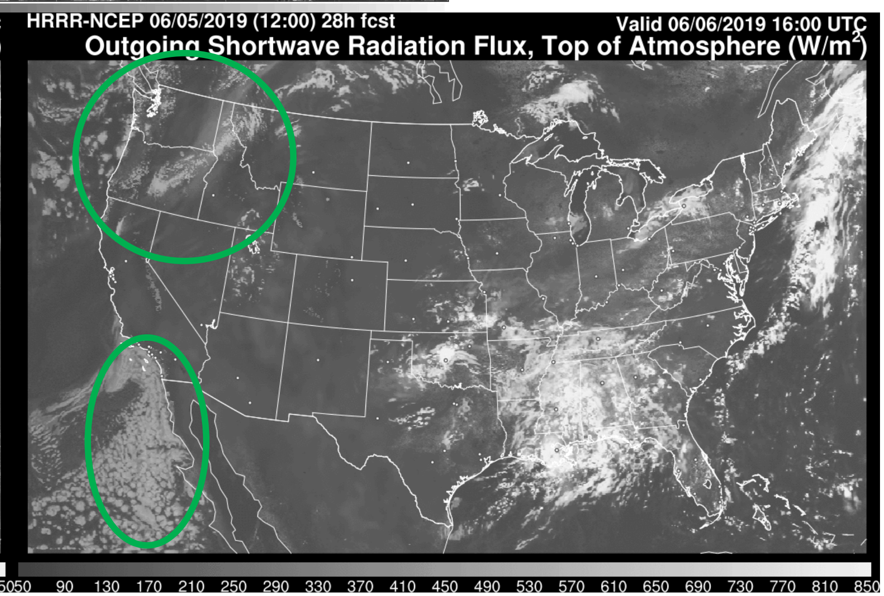
16 UTC 06 June 2019

Initialized 12 UTC 05 June
Fcst hr 28:

GOES-16 combined (ch1, 2, 3) visible albedo



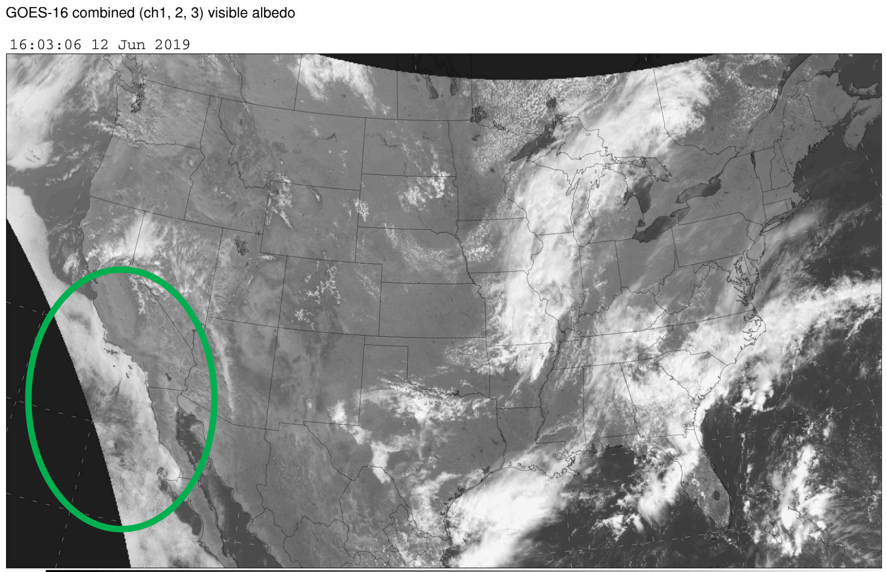


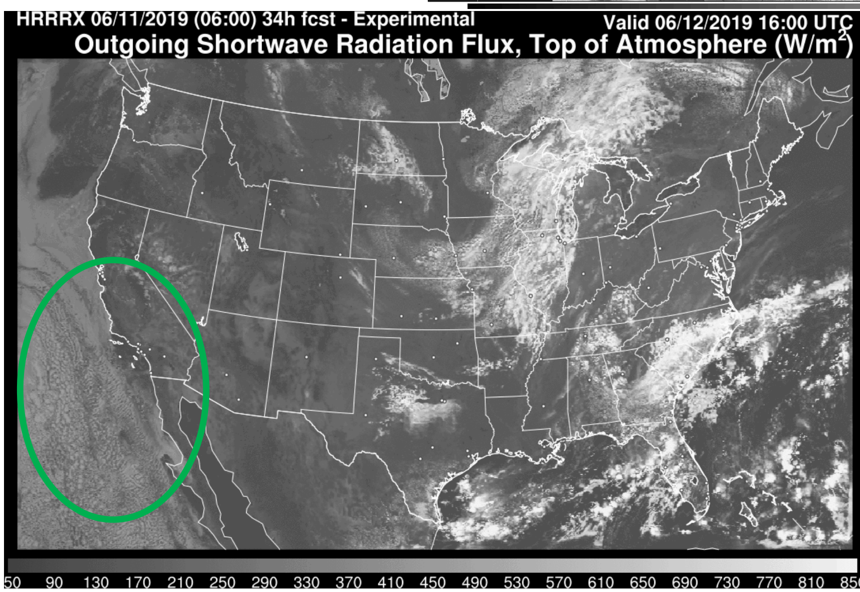


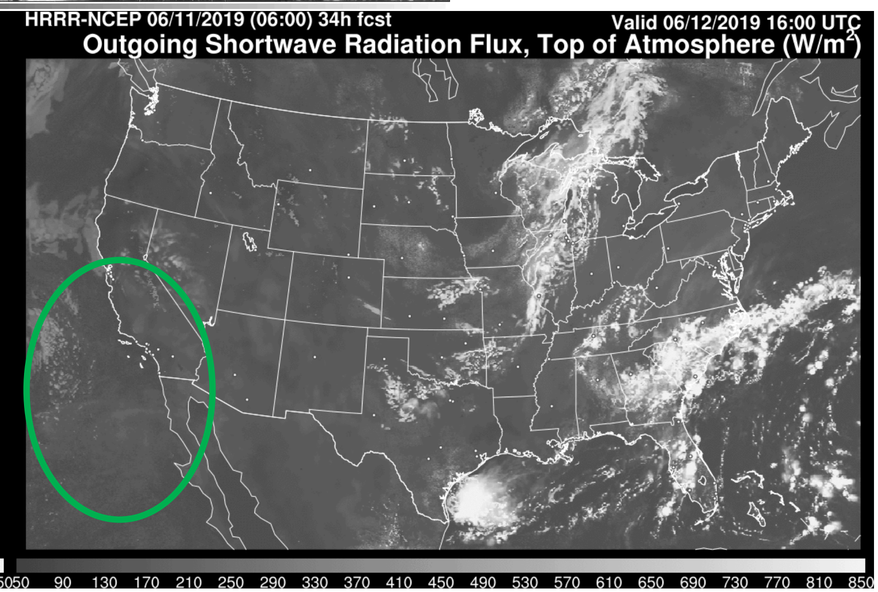
Comparison of SW-up at top of atmosphere

16 UTC 12 June 2019

Initialized 06 UTC 11 June
Fcst hr 34:



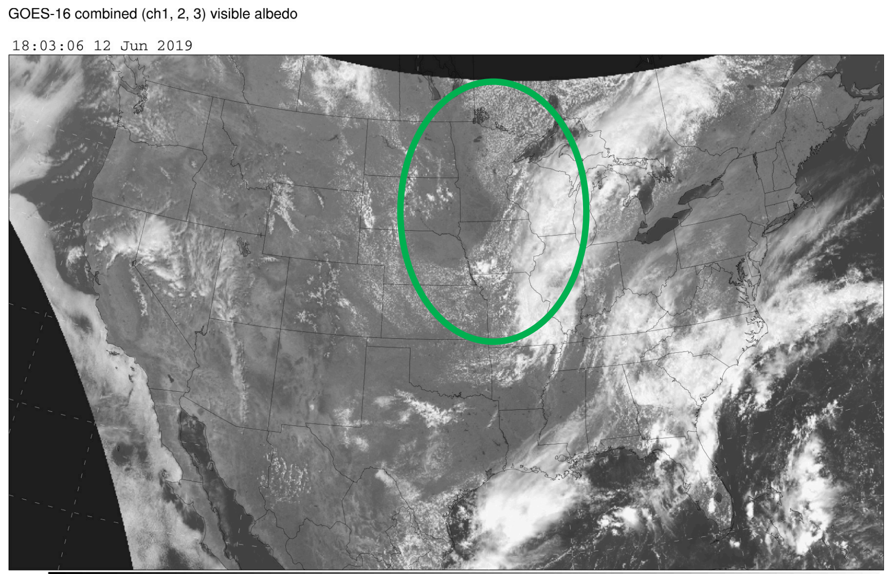


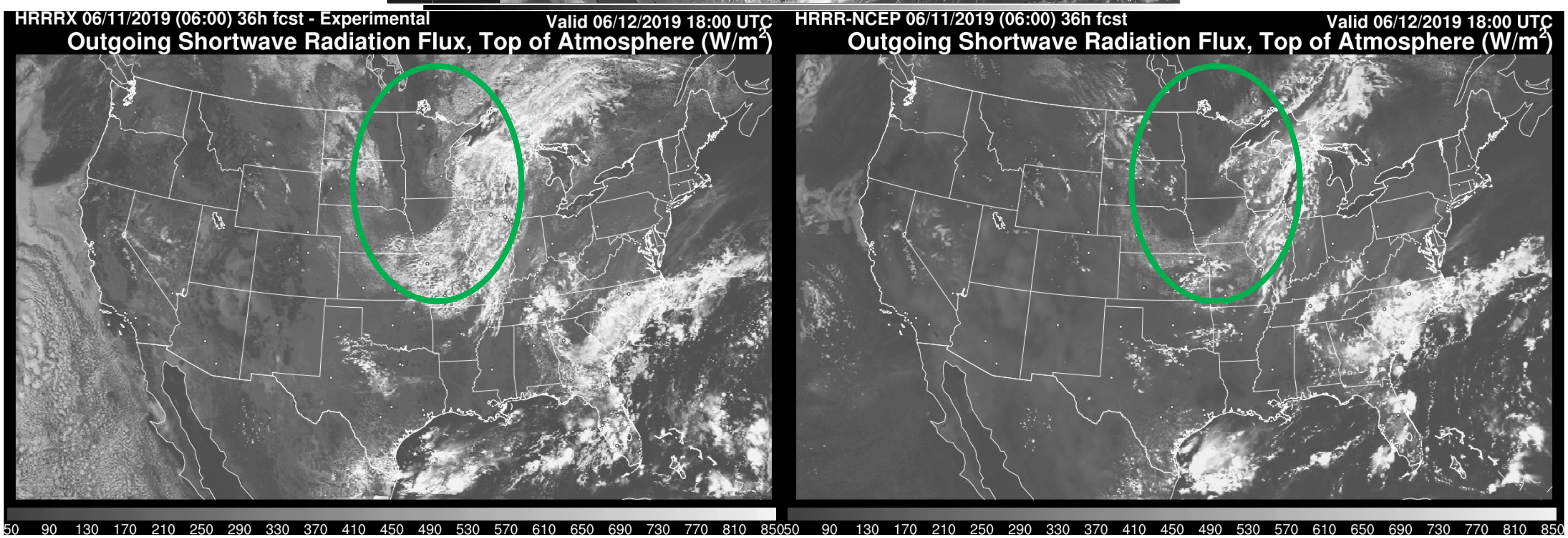


Comparison of SW-up at top of atmosphere

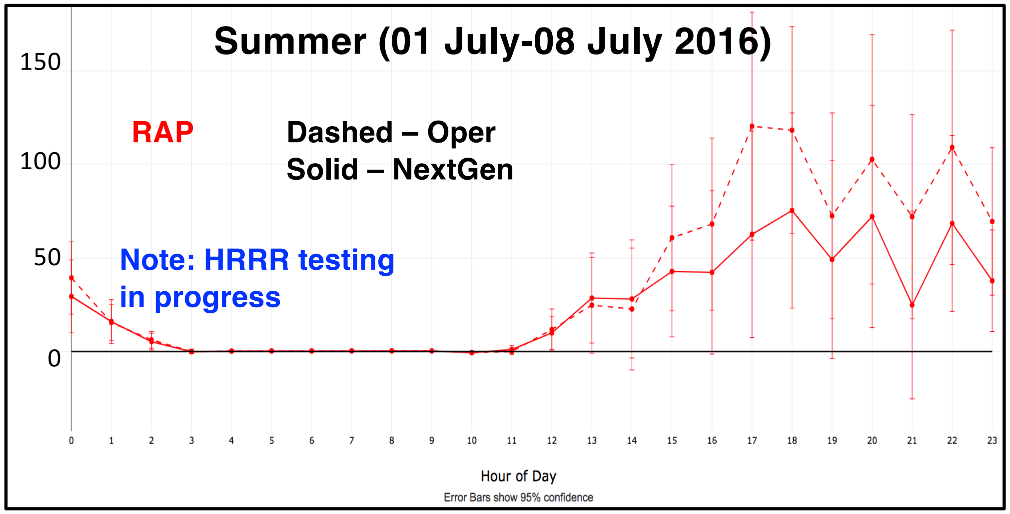
18 UTC 12 June 2019

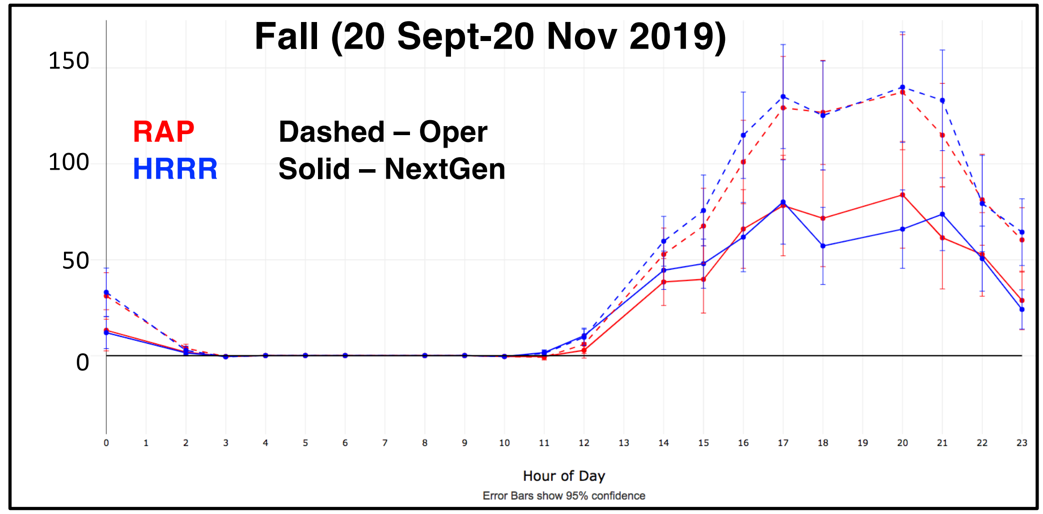
Initialized 06 UTC 11 June
Fcst hr 36:

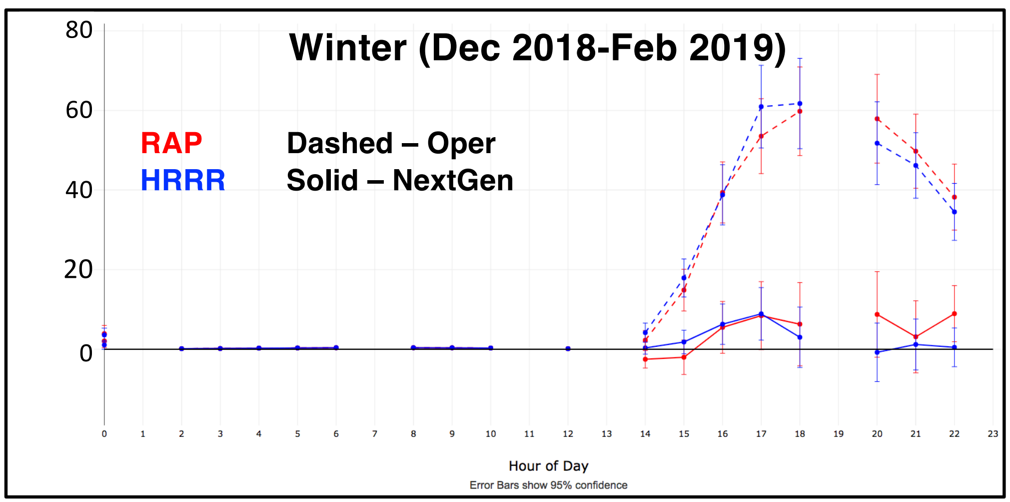


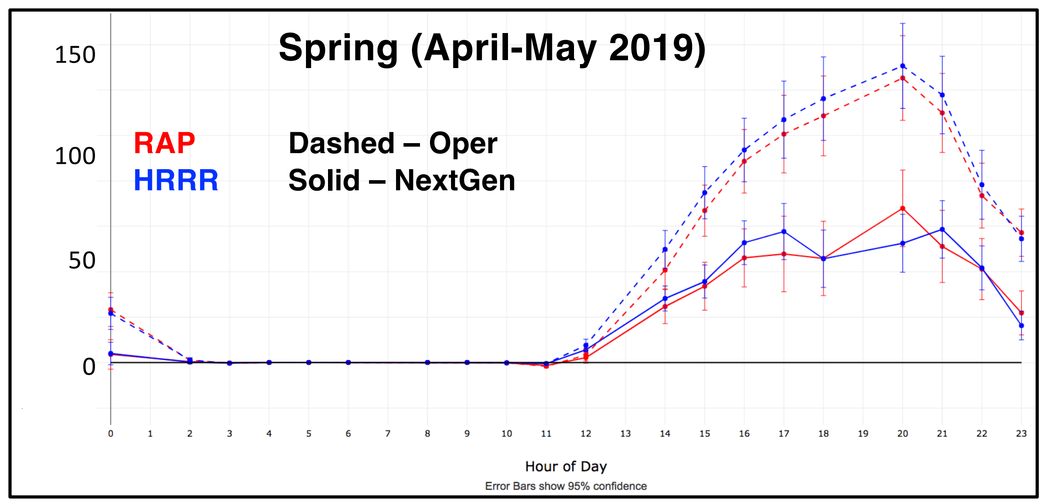


Diurnal Mean Surface GHI (W m^{-2}) | 12-h bias







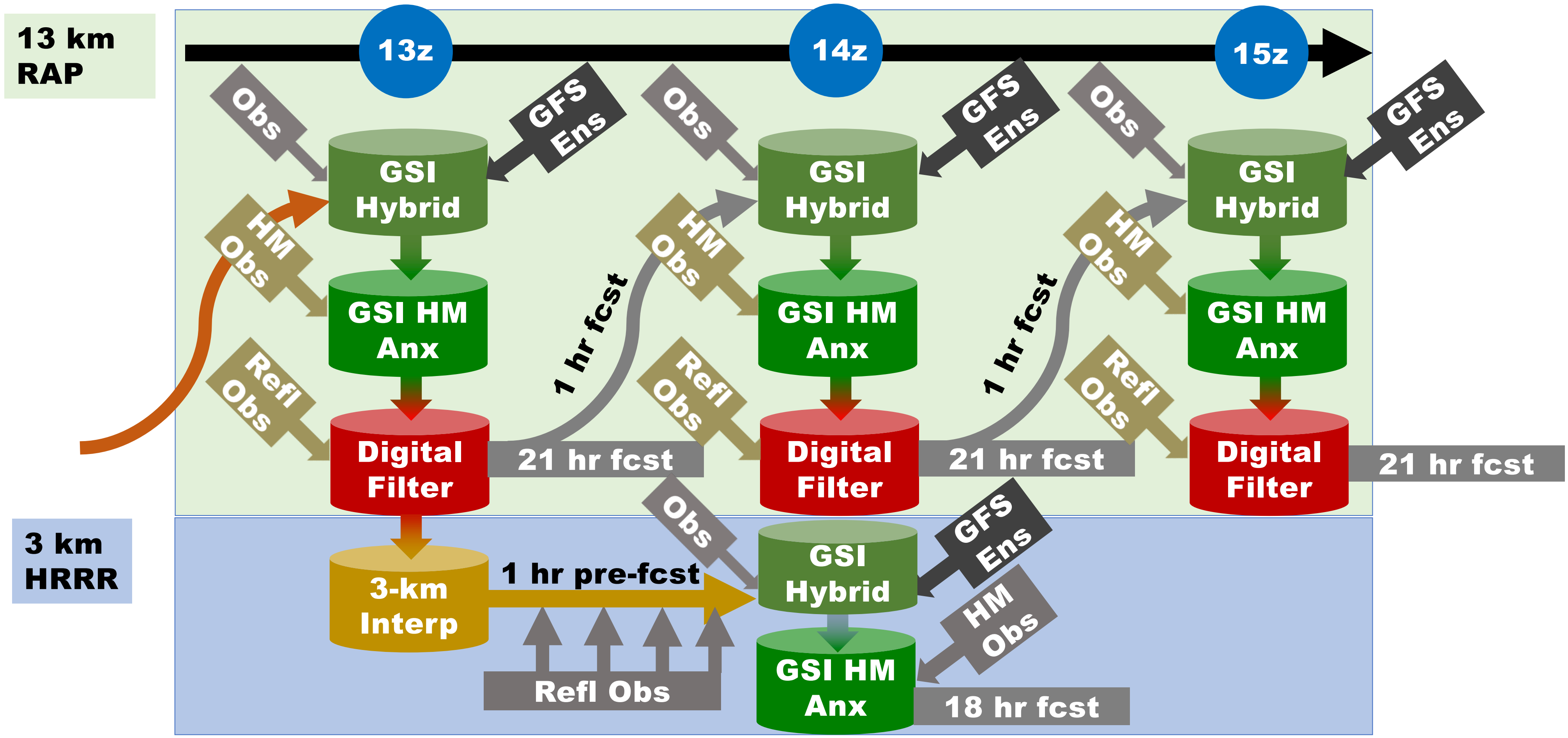


Changes to MYNN-EDMF to combat cold bias

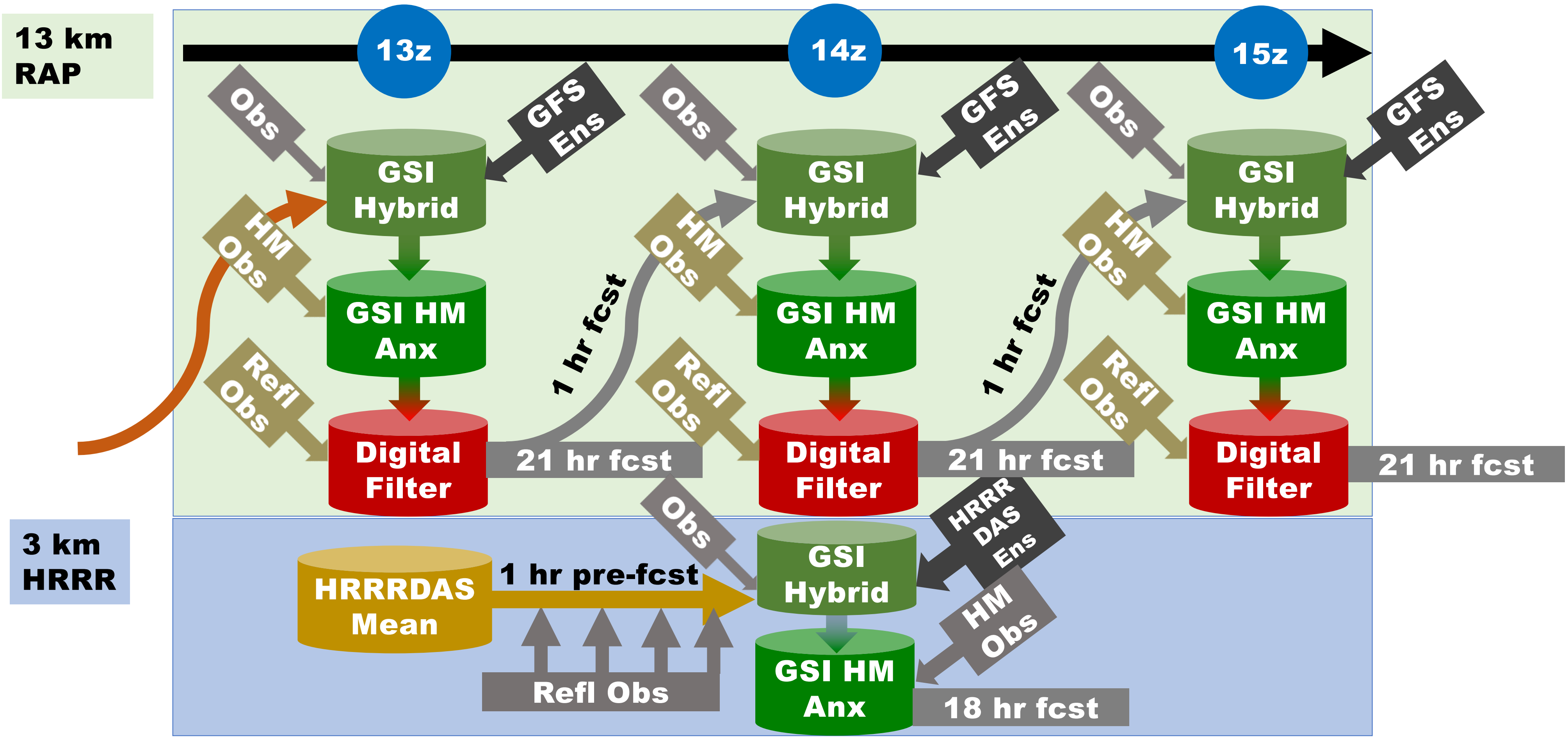
(All changed made for both RAP and HRRR)

	Approximate contribution to warming 12 hr fcst:
• **Mixing length:** • Increased the turbulent mixing	**~ +0.1 to +0.2 C (daytime only)**
• **Added TKE cycling:** • No longer re-spinning up the TKE every hour	**~ +0.1 C (in 0-3 hr fcst)**
• **Added dissipative heating (similar to Han and Bretherton 2019):**	**~ +0.1 C**
• **Added buoyancy flux functions (Bechtold and Siebesma 1998):**	**~+0.1 to +0.2 C (mostly over water)**
• **Surface layer scheme:** • Switched to exact calculation of z/L (from diagnostic mapping of $Ri_b \rightarrow z/L$) • Increased C_{zil} from 0.075 to 0.085	**~ +0.1 to +0.2 C (daytime only)**

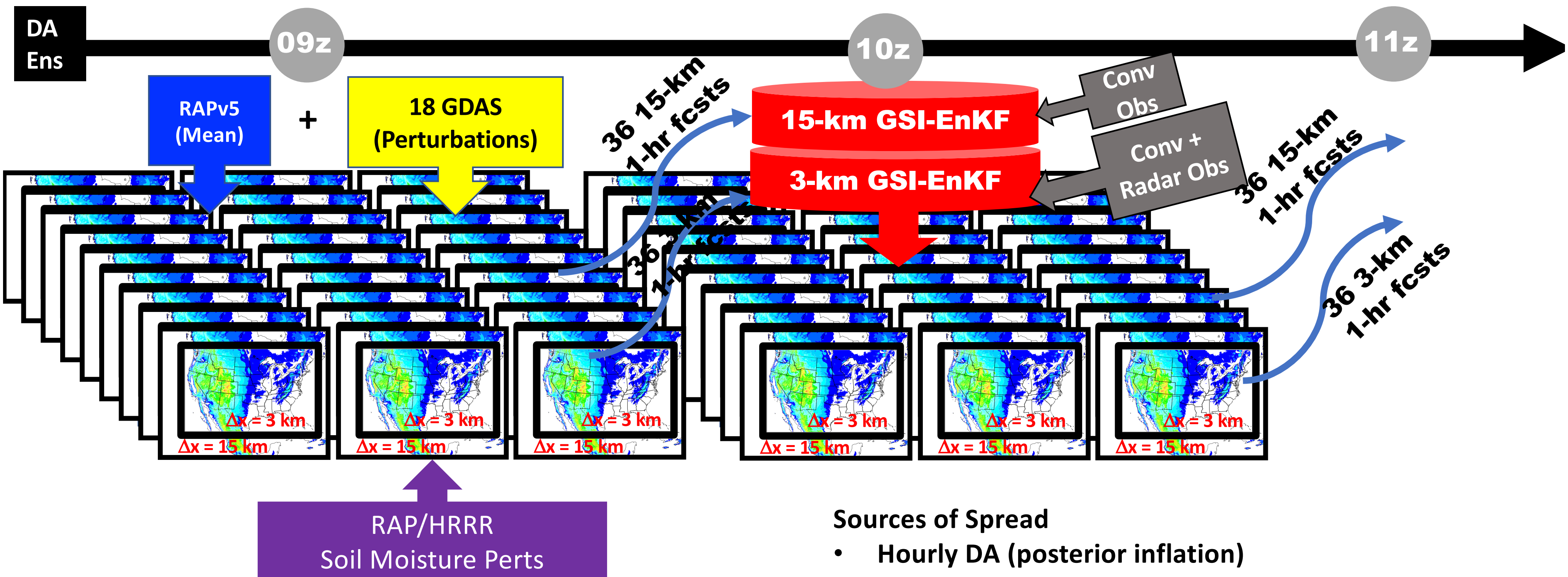
HRRRv3 Initialization from RAPv4



HRRRv4 Initialization from HRRRDAS



HRRR Data Assimilation System (HRRRDAS)

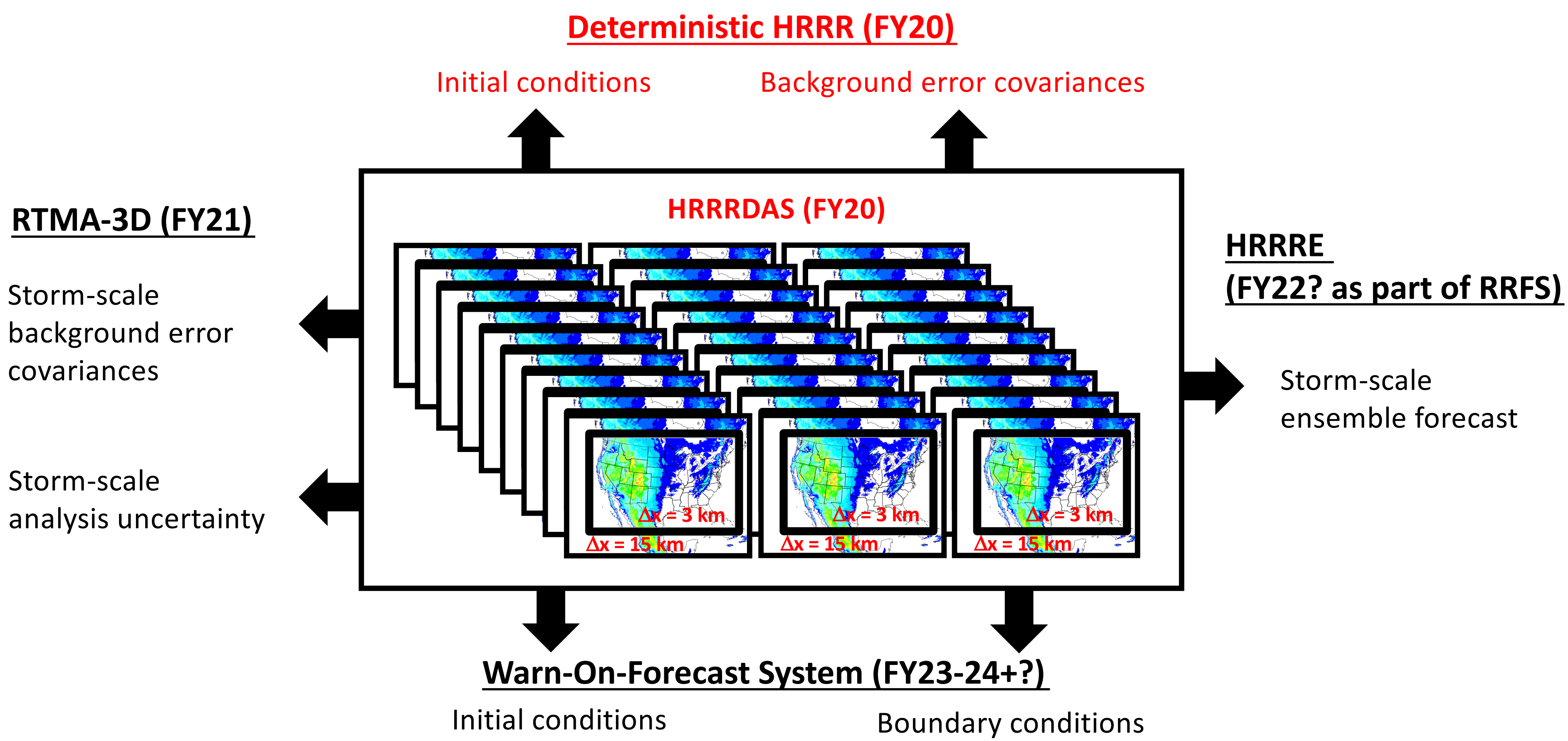


18 members re-initialized at 09z and inserted at 10z
18 members re-initialized at 21z and inserted at 22z

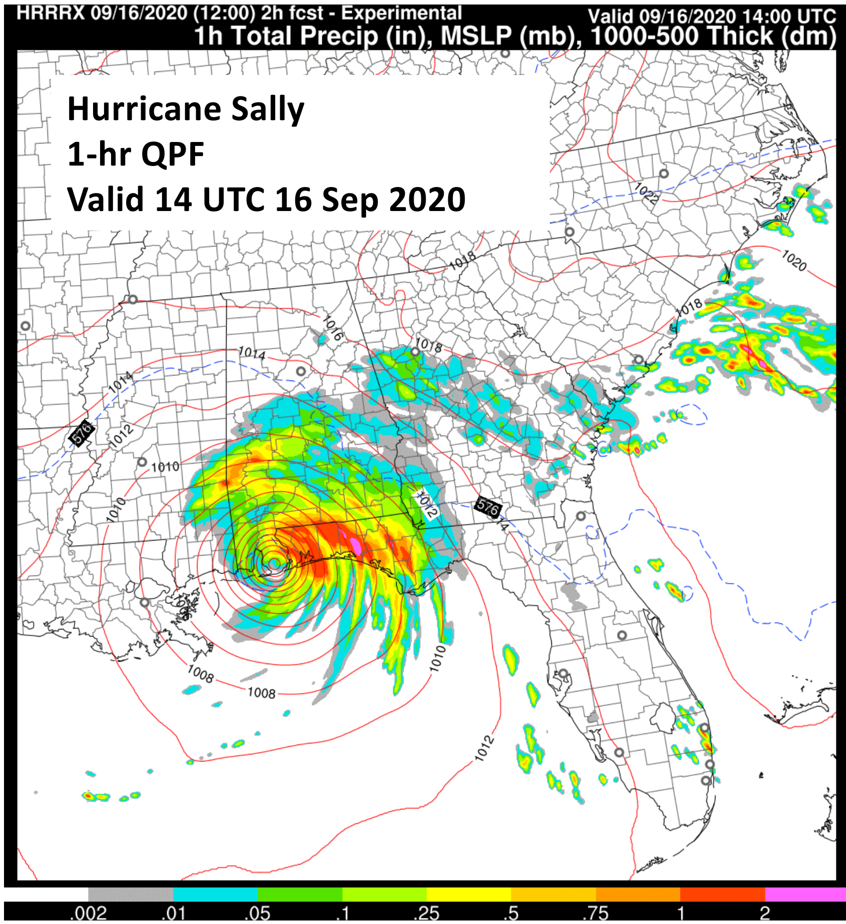
Sources of Spread

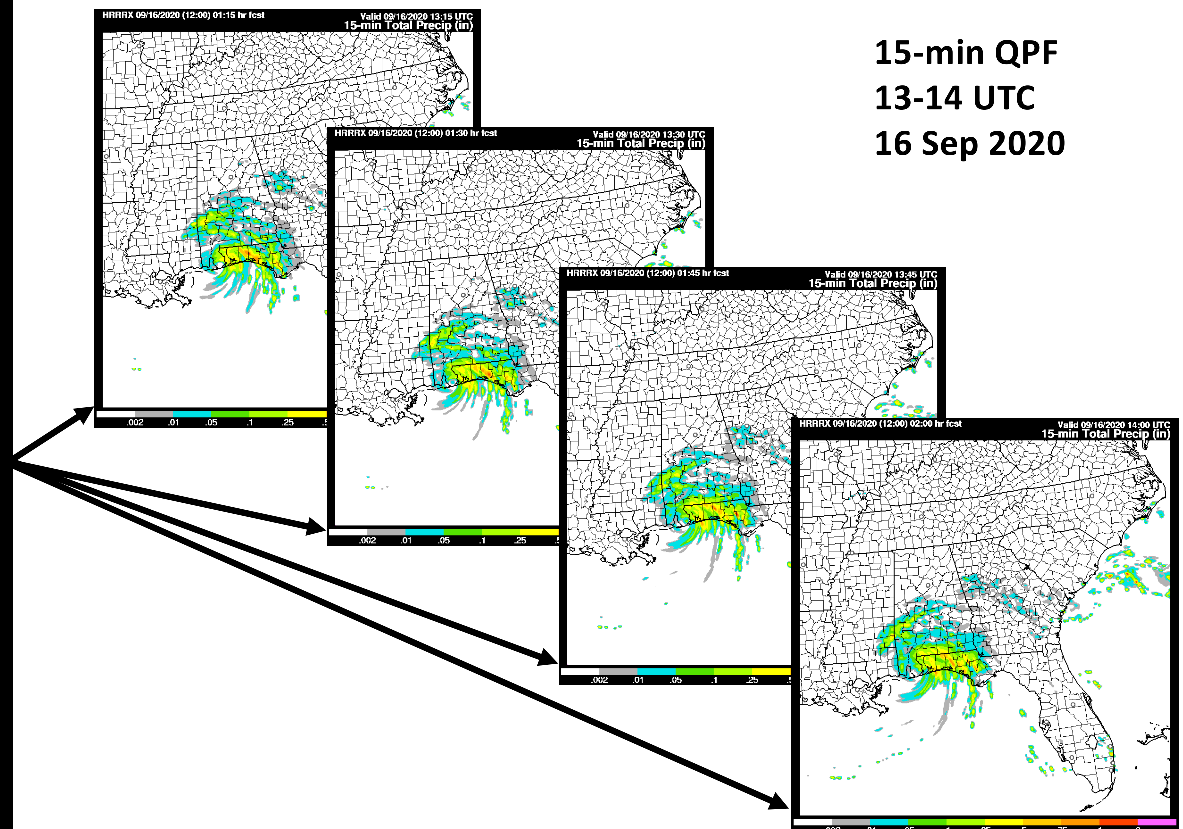
- **Hourly DA (posterior inflation)**
- **Lateral boundary perturbations**

HRRRDAS Foundation for Future Implementations



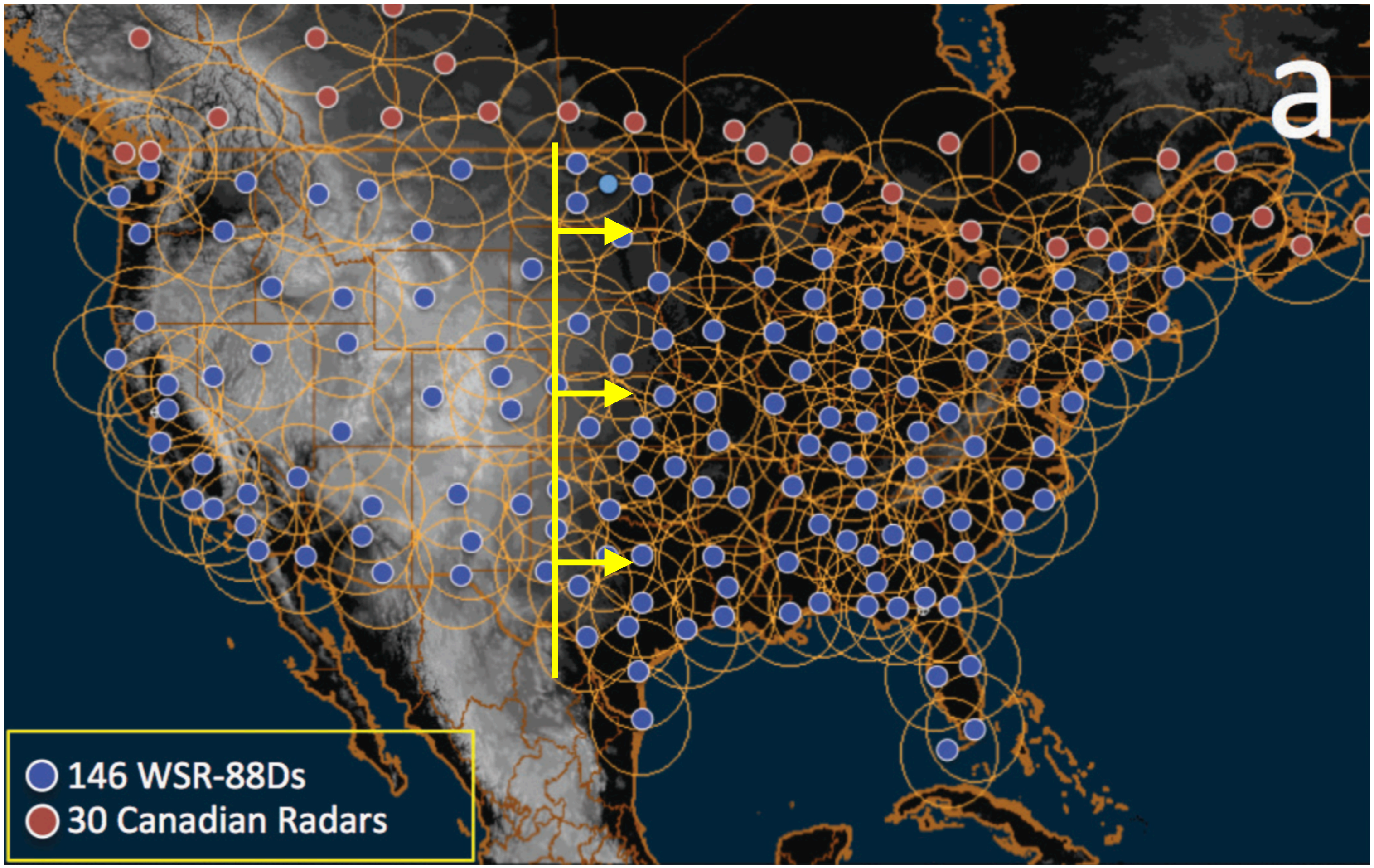
HRRRv4 QPF Output





15-min QPF
13-14 UTC
16 Sep 2020

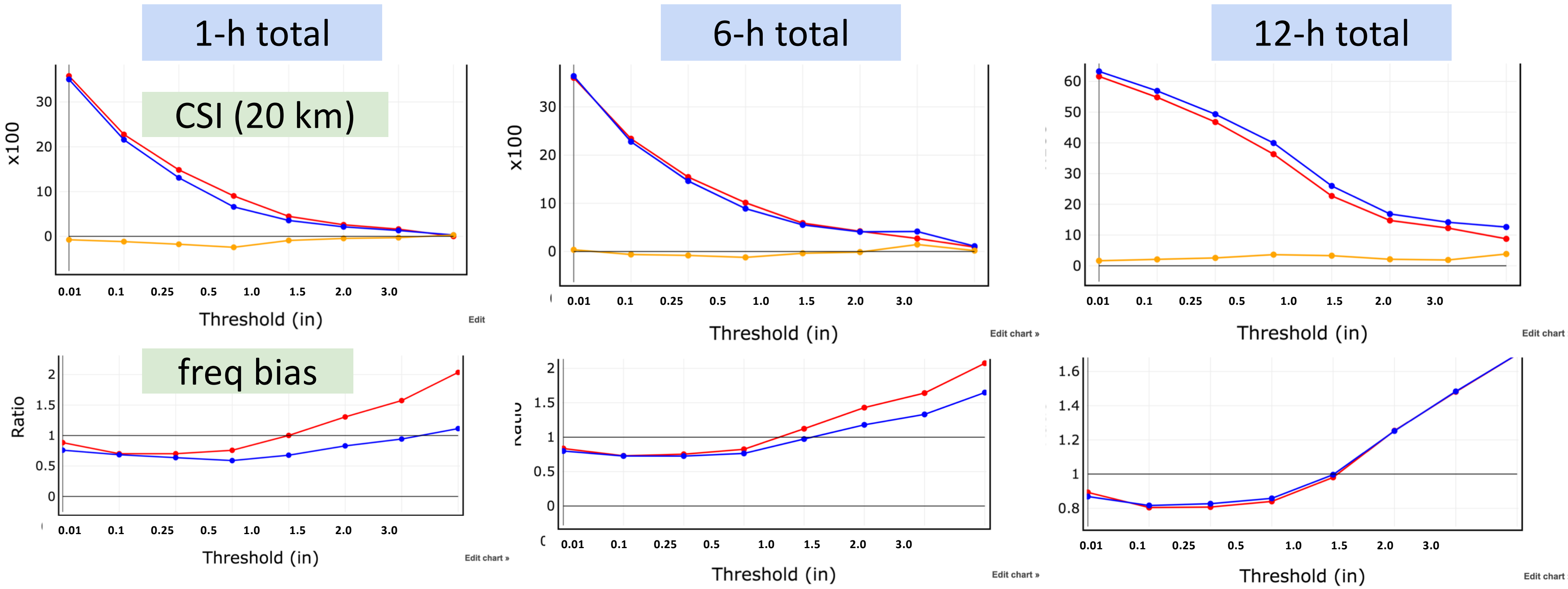
Multi-Radar, Multi-Sensor (MRMS) Radar Mosaic



HRRR QPF Verification ECONUS May 2019

Grid-to-Grid Comparison with Stage-IV Precip Product

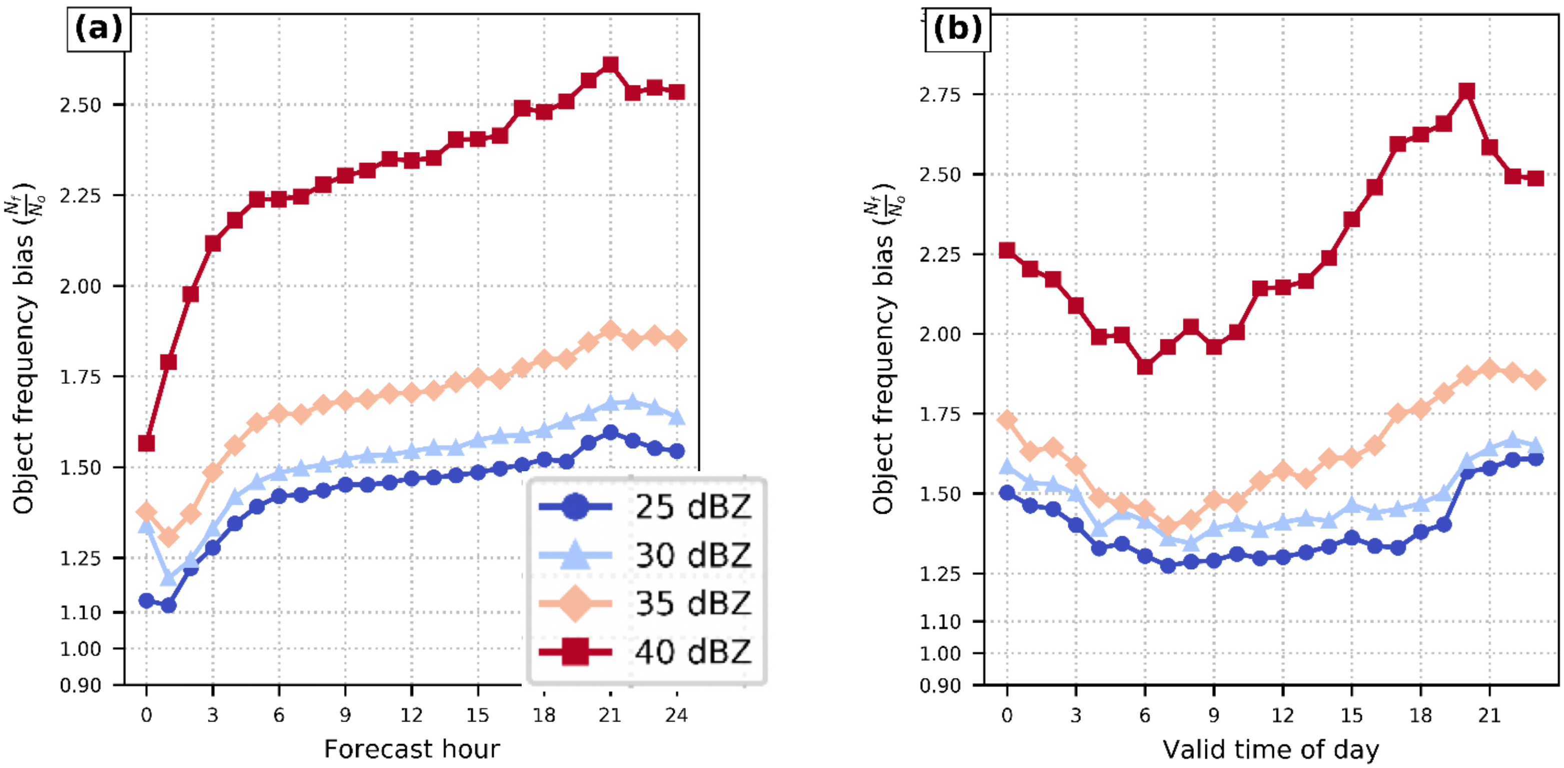
HRRR-OPS
HRRRv4



HRRR Reflectivity Verification ECONUS

Verifying using reflectivity "objects" (MODE in MET)

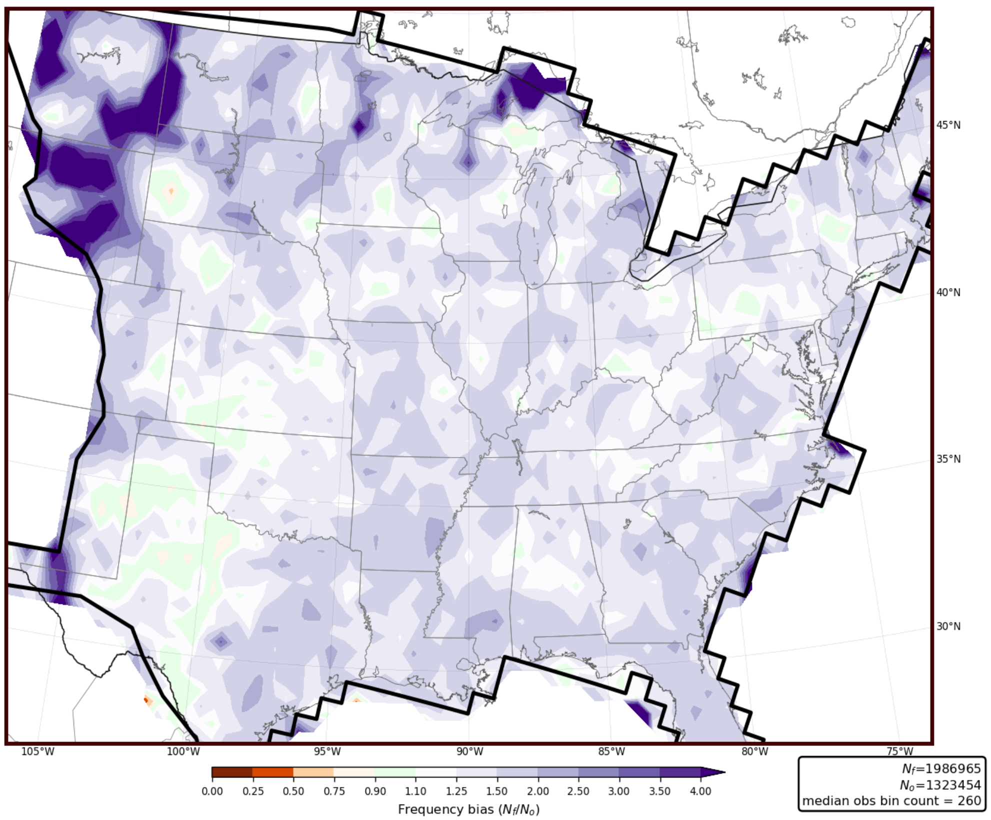
Object Frequency Bias



HRRR Reflectivity Verification ECONUS

Verifying using reflectivity "objects" (MODE in MET)

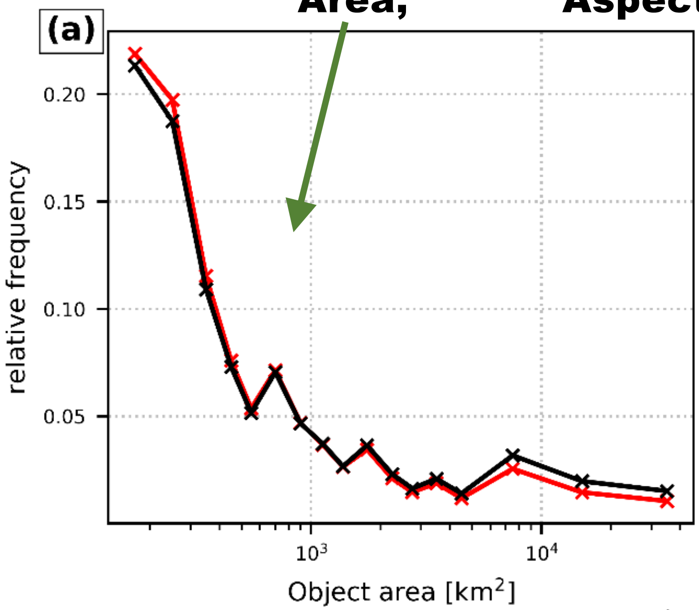
Spatial Distribution of Object Frequency Bias when object reflectivity > 30 dBZ

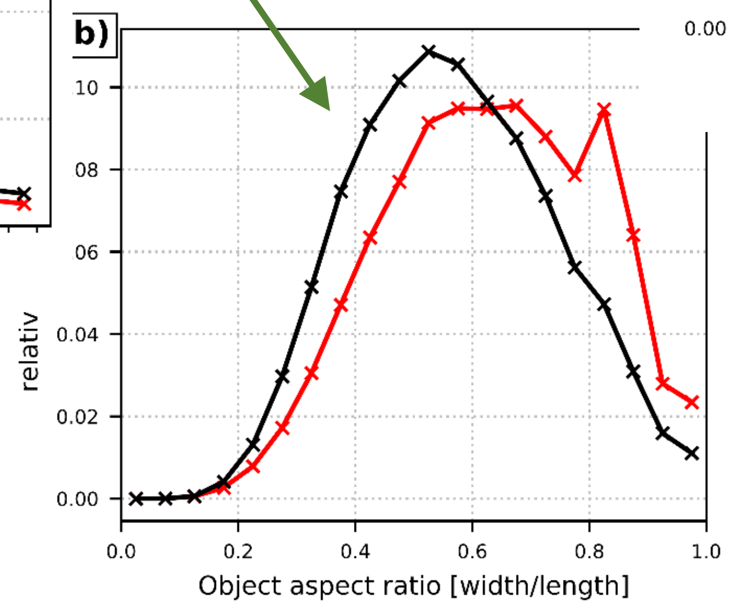


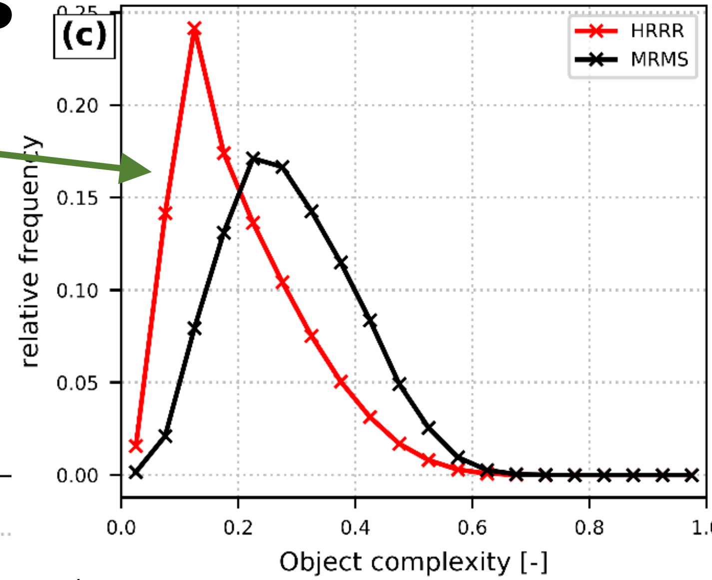
HRRR Reflectivity Vx over ECONUS

Verifying using reflectivity “objects” (MODE in MET)

Area, Aspect Ratio, Complexity





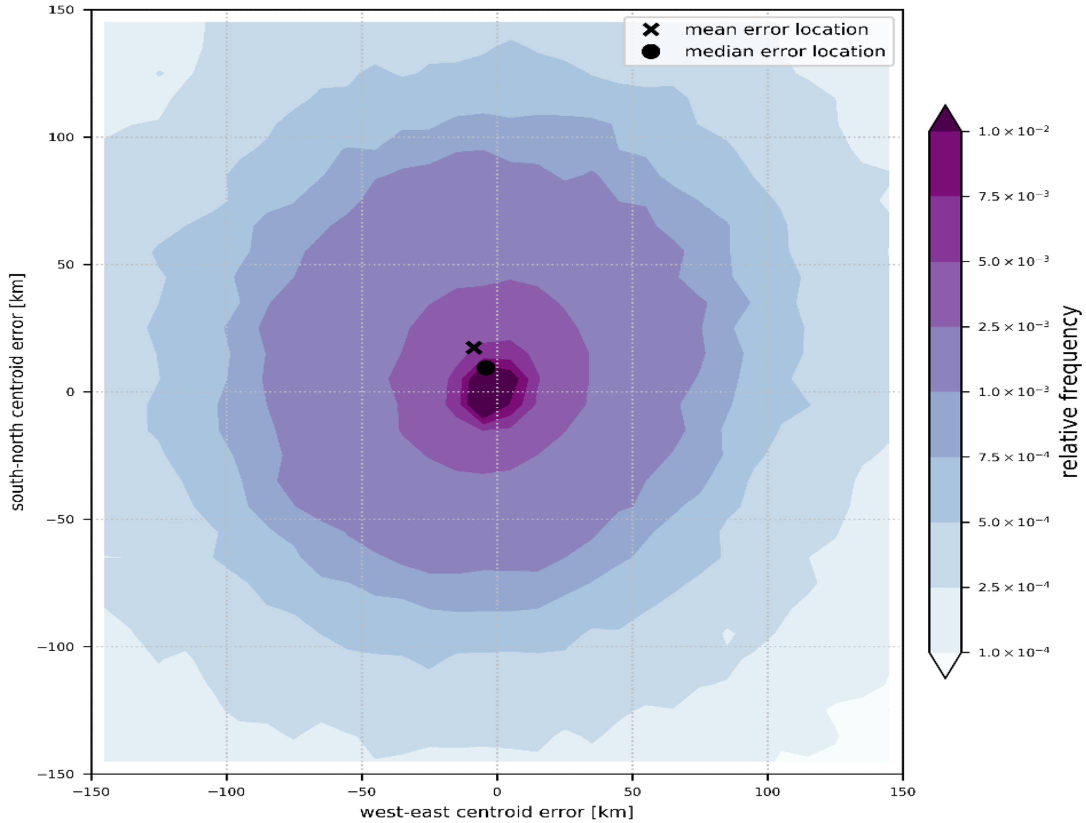


HRRR Reflectivity Verification ECONUS

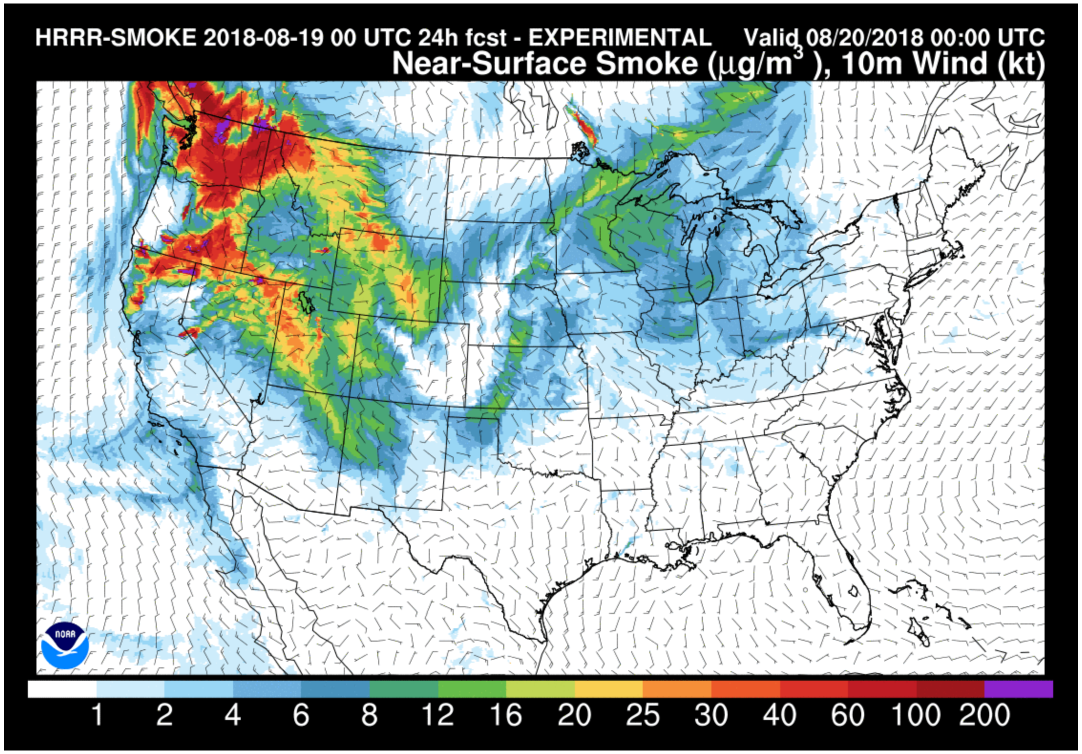
Verifying using reflectivity "objects" (MODE in MET)

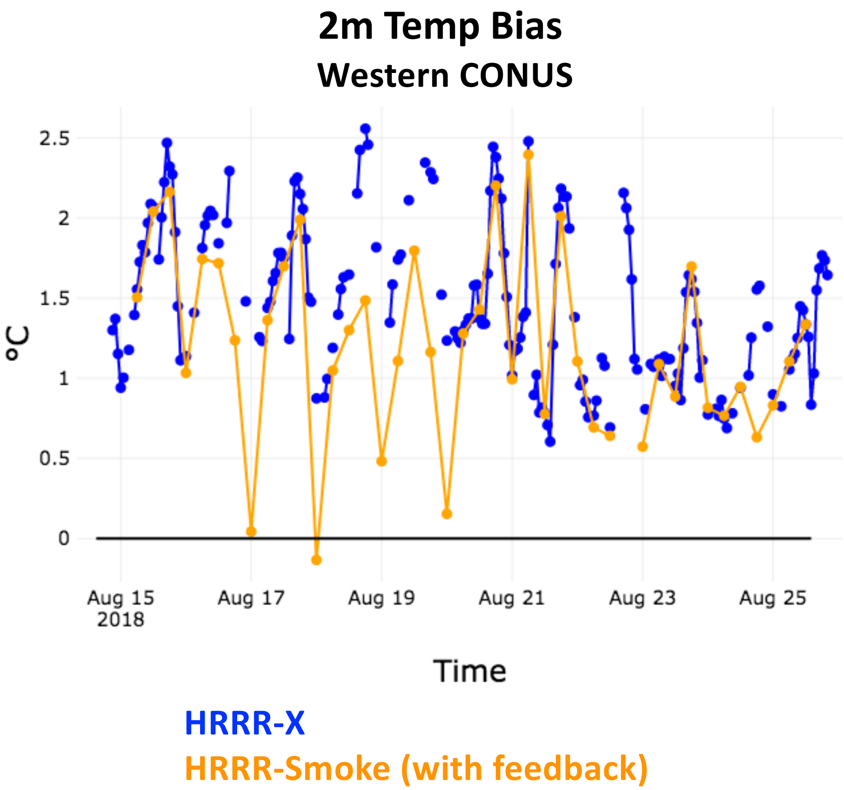
Displacement errors for object reflectivity > 40 dBZ

Probability density function of two-dimensional centroid displacement error at 40 dBZ aggregated over all forecast hours



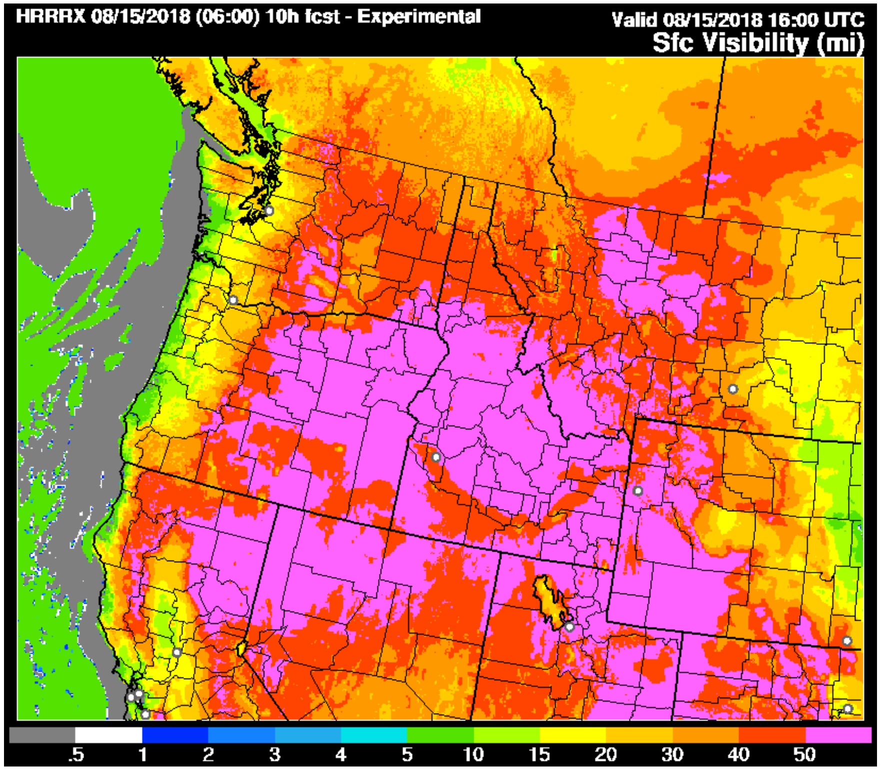
RAP/HRRR Smoke Capability



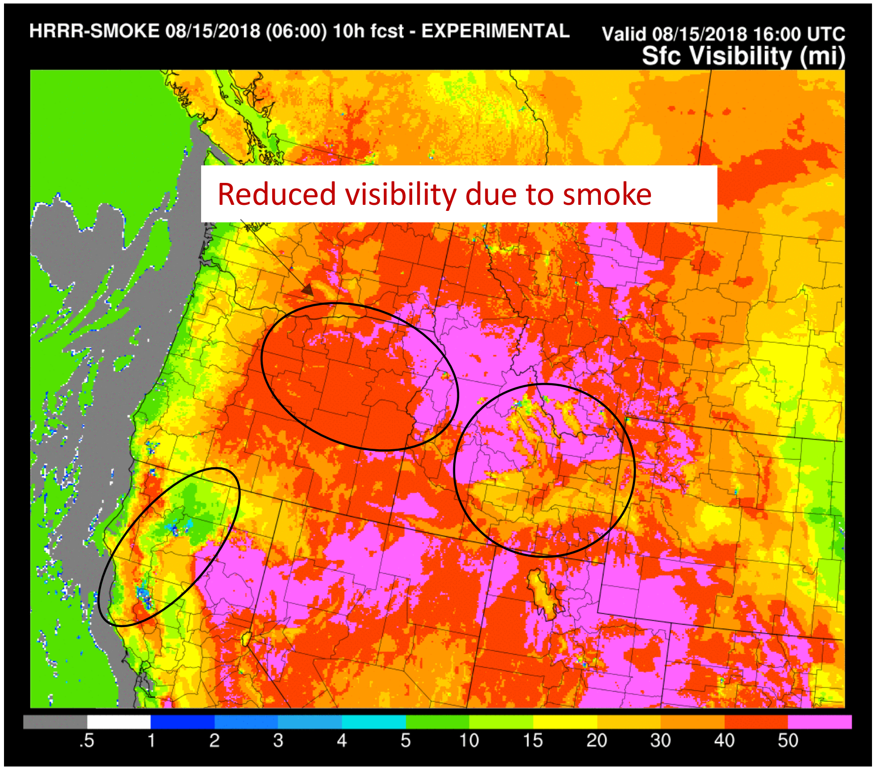


RAP/HRRR Smoke Capability

Surface visibility forecasts for 15 Aug 2018



Numerical Weather Prediction system w/o smoke (HRRR)

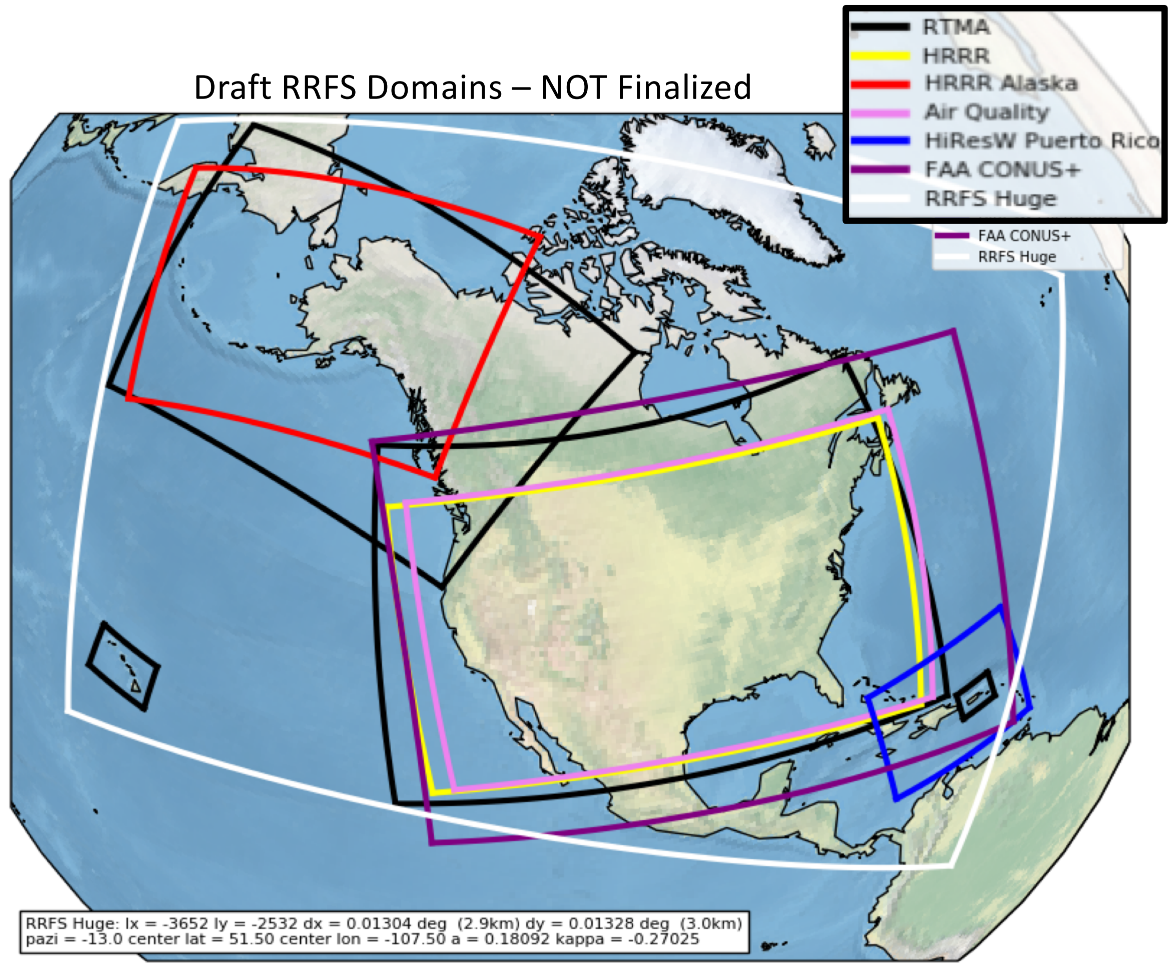


NWP model with smoke (HRRR-Smoke)

RRFS Development

- NOAA is moving towards a Unified Forecast System (UFS) for weather prediction at all scales
  - Global Forecast System
  - Rapid Refresh Forecast System (RRFS)
- Same dynamic core, same physics schemes, same DA method for both
- GFS already part of UFS (summer 2019), and RRFS should be operational by 2023
  - New dynamic core (FV3) being tested at storm-scale resolution
- Codes available to community

Draft RRFS Domains – NOT Finalized



FV3-CAM Timeline → Rapid Refresh Forecast System

NPS Modeling System	Current Version	Q1 FY 20	Q2 FY 20	Q3 FY 20	Q4 FY 20	Q1 FY 21	Q2 FY 21	Q3 FY 21	Q4 FY 21	Q1 FY 22	Q2 FY 22	Q3 FY 22	Q4 FY 22	Q1 FY 23	Q2 FY 23	Q3 FY 23	Q4 FY 23	Q1 FY 24	Q2 FY 24	Q3 FY 24	Q4 FY 24	UFS Application
Global Weather & Global Analysis	GFS/ GDASv15						GFSv16												GFSv17/ GEFSv13			UFS Medium Range & Sub-Seasonal
Global Waves	GWMv3																					
Global Weather Ensembles	GEFSv11				GEFSv12																	
Global Wave Ensembles	GWESv3																					
Global Aerosols	NGAC v2																					
Short-Range Regional Ensembles	SREFv7																					
Global Ocean & Sea-Ice	RTOFSv1.2					RTOFSv2								RTOFSv3								UFS Marine & Cryosphere
Global Ocean Analysis	GODASv2													GODASv3								
Seasonal Climate	CDAS/ CFSv2																				SFSv1	UFS Seasonal
Regional Hurricane 1	HWRFv12			HWRFv13								HAFSv1				HAFSv2				HAFSv3		UFS Hurricane
Regional Hurricane 2	HMONv2			HMONv3																		
Regional High Resolution CAM 1	HiRes Window v7														RRFSv1				RRFSv2			UFS Short-Range Regional HiRes CAM & Regional Air Quality
Regional High Resolution CAM 3	NAM nests/ Fire Wxv4																					
Regional High Resolution CAM 4	RAPv4/ HRRRv3			RAPv5/ HRRRv4																		
Regional HiRes CAM Ensemble	HREFv2				HREFv3																	
Regional Mesoscale Weather	NAMv4																					
Regional Air Quality	CMAQv5											CMAQv6										
Regional Surface Weather Analysis	RTMA/ URMA v2.7			RTMA/ URMA v2.8												3DRTMA/ URMAv3						
Atmospheric Transport & Dispersion	HySPLITv7											HySPLIT v8								HySPLIT v9		UFS Air Quality & Dispersion
Coastal & Regional Waves	NWPSv1.2			NWPS v1.3								NWPS v1.4						RWPSv1				UFS Coastal
Great Lakes	GLWUv3.4											GLWUv4								GLWUv5		UFS Lakes
Regional Hydrology	NWMv2					NWMv3										NWMv4						UFS Hydrology
Space Weather 1	WAM/IPEv1																				WAMv2	UFS Space Weather
Space Weather 2	ENLILv1																					

Summary

- RAP / HRRR is a significant part of the operational NWP suite
- RAPv5 / HRRRv4 in process of being released to operations
  - Updated physics (esp wrt subgrid-scale clouds)
  - Updated to storm-scale DA
  - Implementation in December 2020
- NWS / NOAA moving towards a unified forecasting system
  - Simplify the operational NWP modeling suite
  - Want to make this more of a community resource (EPIC)
  - Global forecast system already using this new dycore (FV3) with original GFS physics
  - Are moving current RAP/HRRR physics into new dycore for storm-scale NWP
  - Ultimately UFS will have single physics package for all scales
  - New DA system to replace GSI (JEDI)
- New customers for the HRRR
  - Traditional customers are convective weather community and aviation
  - New ones are hydrometeorology and renewable energy