



AMS 100th Annual Meeting
30th Conference on Weather Analysis and Forecasting (WAF)
26th Conference on Numerical Weather Prediction (NWP)



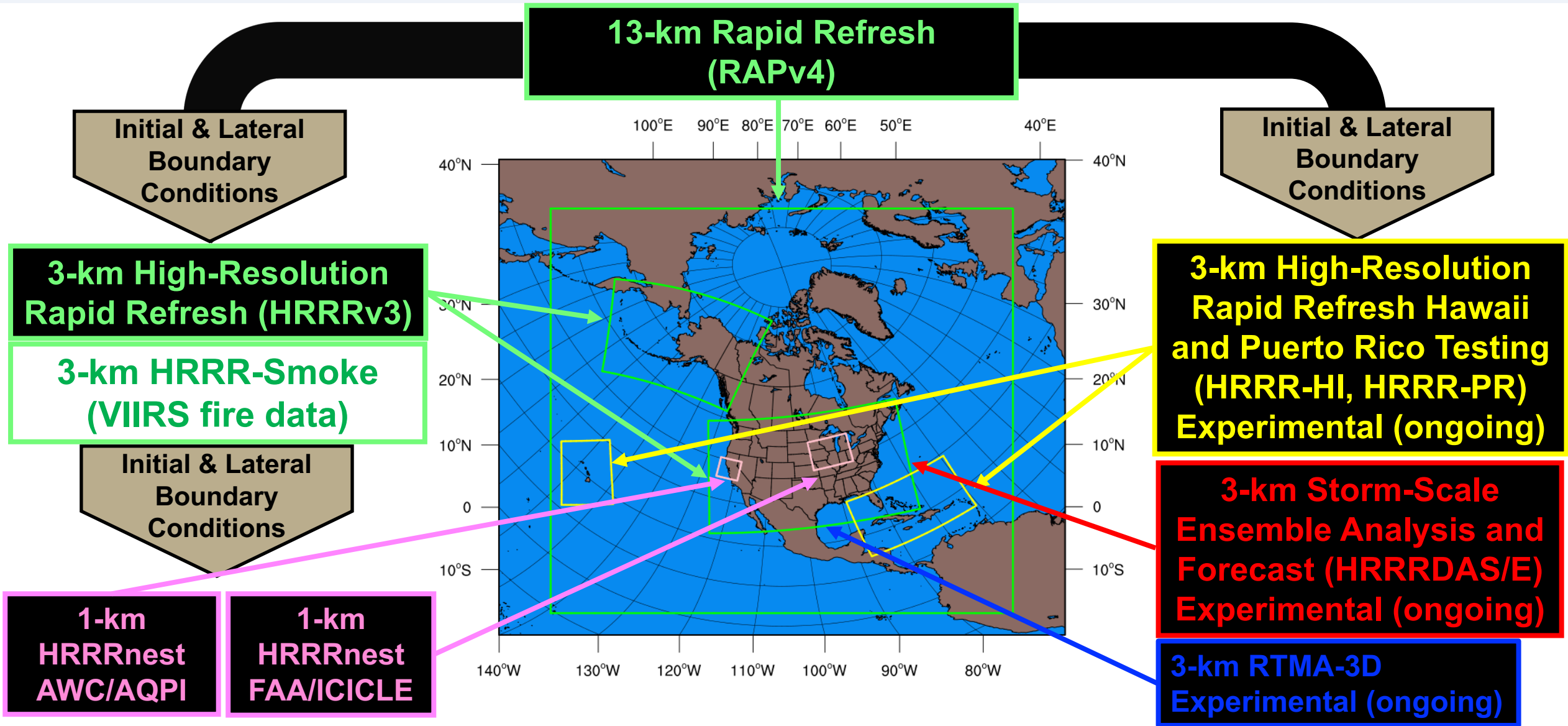
Rapid Refresh (RAP) and High Resolution Rapid Refresh (HRRR) Model Development

15 Jan 2020

Curtis Alexander, David Dowell, Ming Hu, Joseph Olson, Tanya Smirnova, Terra Ladwig, Steve Weygandt, Jaymes Kenyon, Eric James, Haidao Lin, Georg Grell, Guoqing Ge, Trevor Alcott, Stan Benjamin, John Brown, Michael Toy, Ravan Ahmadv, Amanda Back, Jeffrey Duda, Molly Smith, Jeff Hamilton, Brian Jamison, Isidora Jankov, David Turner

NOAA/ESRL/GLOBAL SYSTEMS DIVISION

RAP/HRRR Model Forecast Suite

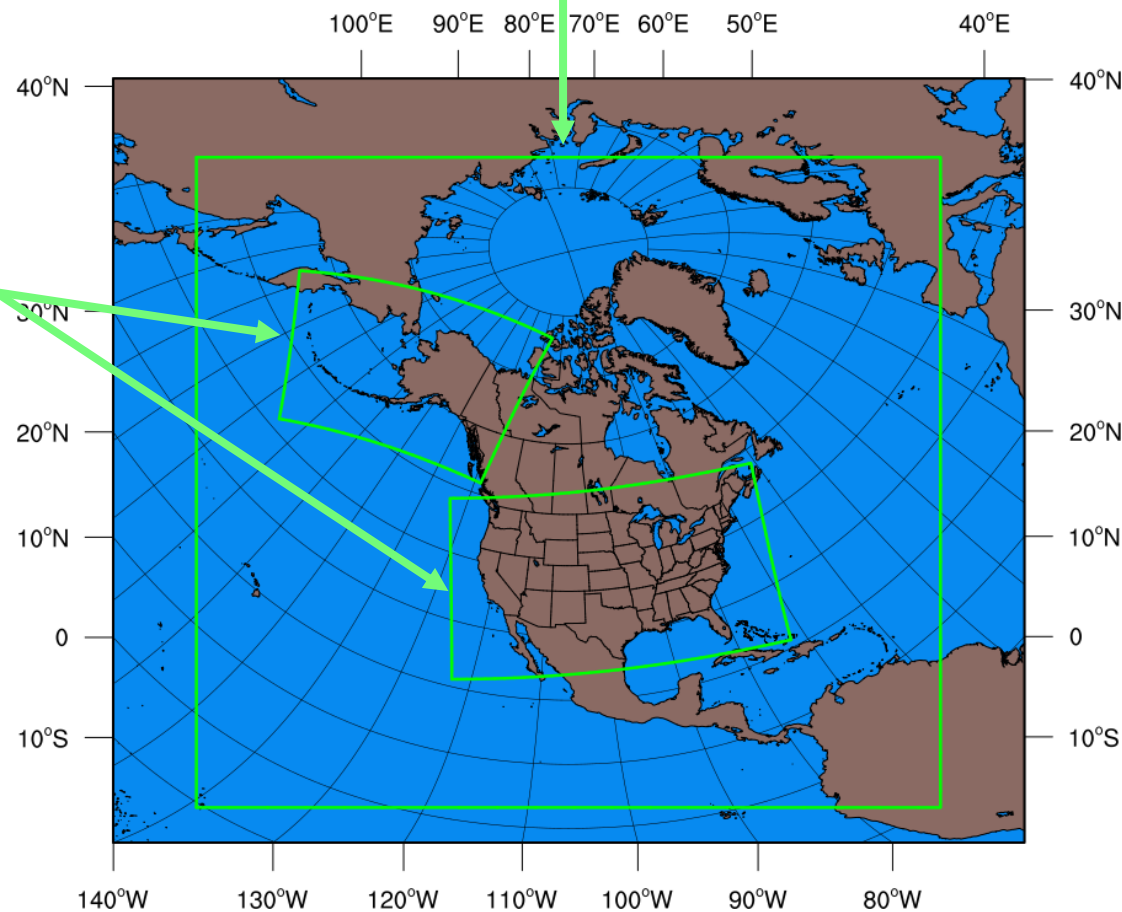


RAP/HRRR Model Forecast Suite

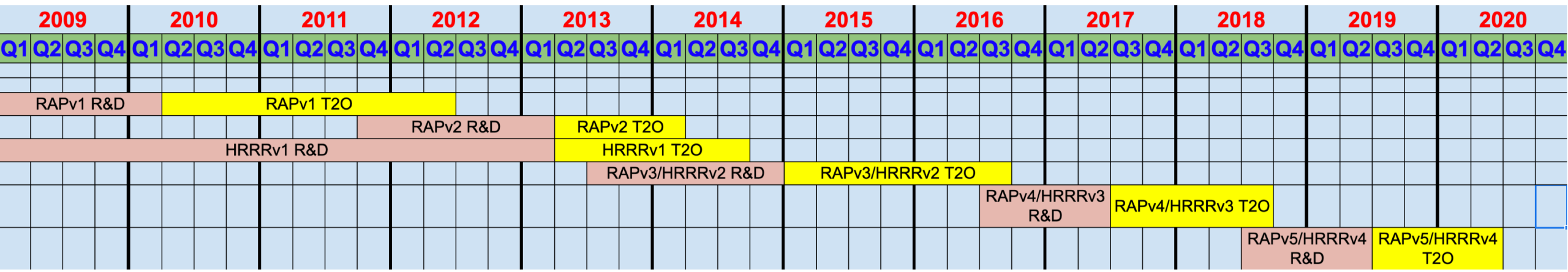
**13-km Rapid Refresh
(RAPv5)**

**Initial & Lateral
Boundary
Conditions**

**3-km High-Resolution
Rapid Refresh (HRRRv4)**



RAP/HRRR Implementation History



NWS NCEP and WFOs – Feedback “O2R” and Implementations “R2O”

Aviation (FAA, NCAR, MIT/LL, AWC) – CoSPA Project – SIP/FIP/GTG/etc... – 15 min output

Severe (SPC, NSSL) – Vortex II/SE Projects – WoF – Hourly Maximum Fields

Energy (DOE) – WFIP 1/2, SFIP Projects – Averaged Direct/Diffuse Rad/Wind

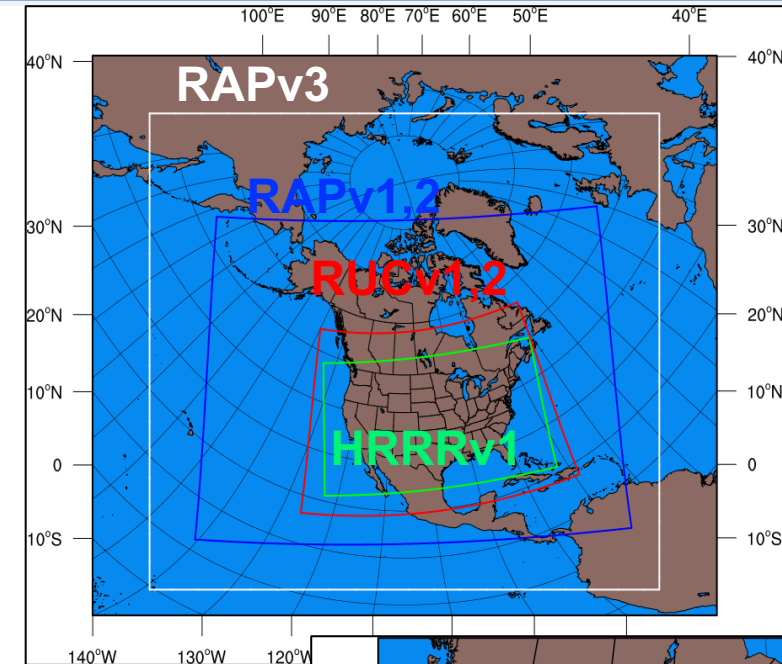
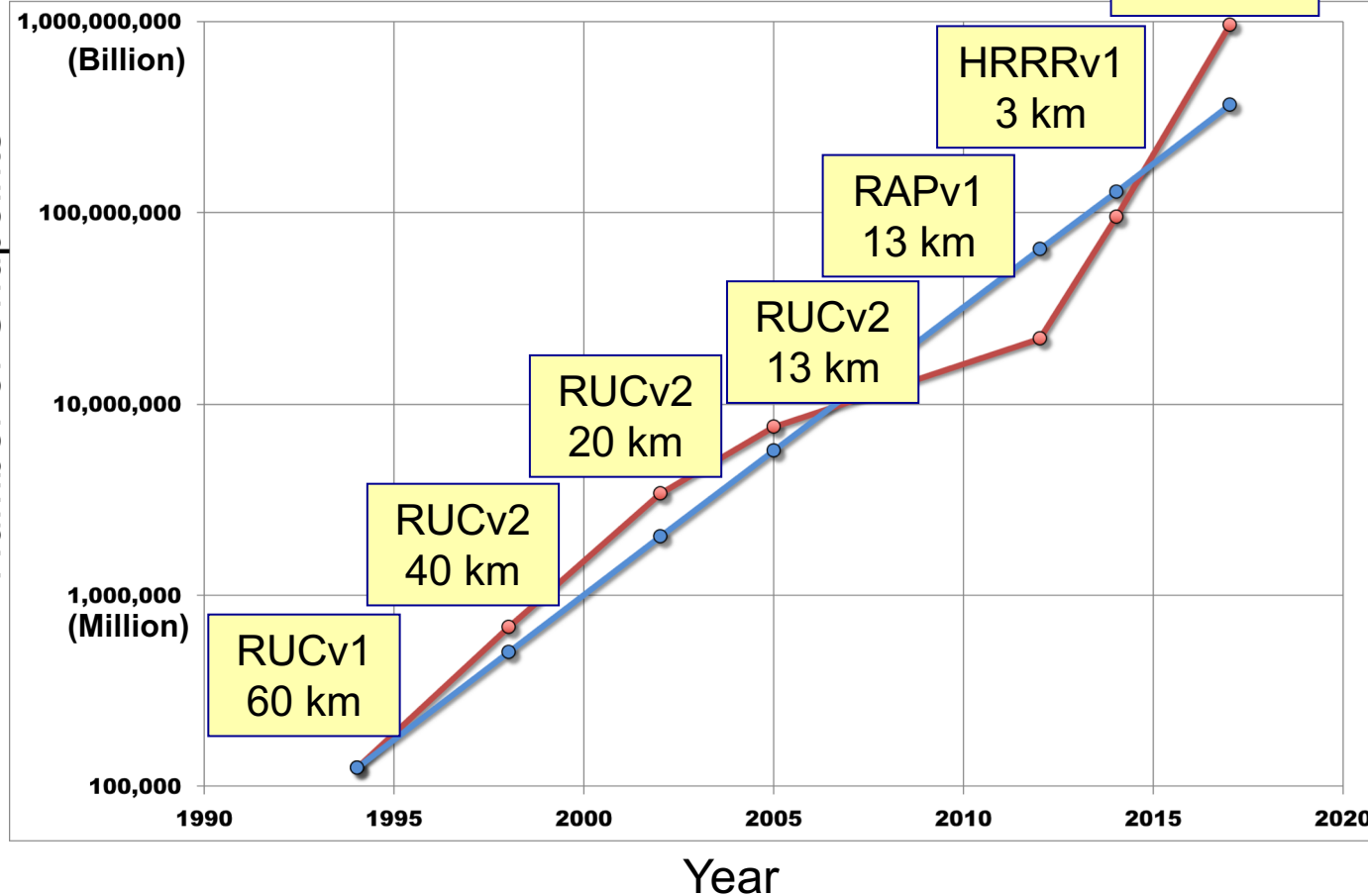
Hydrology (WPC, OWP) – AQPI, NWM Projs, PQPF/Ptype

Air Quality (WFOs) – FRP, Smoke, Feedbacks

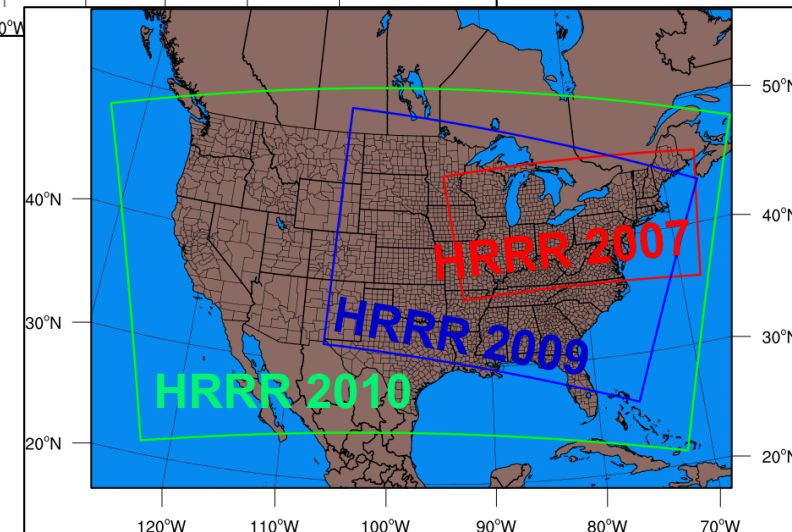
Coupling – FVCOM, Lakes

High Impact Weather Prediction Needs: HPC

Growth rate
Similar To
Moore's Law



Larger
Forecast
Domains



2020 RAPv5/HRRRv4 Changes

Model	Data Assimilation	Land-surface / post
<p>WRF-ARWv3.9+ incl. phys changes</p> <p><u>Physics changes:</u> MYNN PBL update – better sub-grid clouds, improved EDMF mixing - remove limit for subgrid qc/qi - decrease subgrid qc/qi radii</p> <p>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</p> <p><u>Numerics changes:</u> Reduced 6th order diffusion inc. hydrom Removal of mp_tend_lim Implicit-explicit vertical advection (IEVA)</p>	<p>Merge with GSI trunk – 2019</p> <p><u>New Observations for assimilation:</u> GOES-16 ABI radiances N20 CrIS-FSR/ATMS (with direct readout) GOES-16 AMVs TC vitals for trop cyclone location/strength Aircraft/raob moisture obs for p<300 hPa VIIRS/MODIS fire radiative power</p> <p><u>Assimilation Methods:</u> HRRR - 3km ensemble DA (36 mems out to 1h) – HRRRDAS mean for HRRR IC and BEC</p> <p>Extend 03/09/15/21z RAP to f51 Extend 00/06/12/18z HRRRs to f48</p>	<p>Switch to MODIS albedo (higher), replace 1-deg albedo.</p> <p>Add zenith-ang albedo adj</p> <p>15” resolution land use data</p> <p>Fractional sea/lake ice concentration</p> <p>FVCOM data for Great Lakes lake temp/ice concentration (HRRR only)</p> <p>VIIRS/MODIS fire radiative power</p> <p>HAILCAST diagnostic</p> <p>Smoke (2.5 pm) products</p>

2020 RAPv5/HRRRv4 Changes

Operational RAPv4/HRRRv3

No Change in CONUS
Domains

Newer Model Version
More Ensemble Weight
Advanced “**Physics Suite**”

Seasonal Vegetation
Fraction/Leaf Area Index

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	953 x 834	13 km	50	Sigma-Isob Hybrid	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCO	CONUS	1799 x 1059	3 km	50	Sigma-Isob Hybrid	20 mb	RAP	Hourly (pre-forecast hour cycle)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.8.1+	GSI Hybrid Ensemble 0.85	13-km DFI, ½ Strength	RRTMG/ RRTMG	Thompson Aerosol v3.8.1	GF + Shallow	MYNN v3.8.1	RUC v3.8.1
HRRR	WRF-ARW v3.8.1+	GSI Hybrid Ensemble 0.85	3-km 15-min LH	RRTMG/ RRTMG	Thompson Aerosol v3.8.1	None	MYNN v3.8.1	RUC v3.8.1

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	Diffusion Option	6 th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5 th /5 th	Positive-Definite	w-Rayleigh 0.2	Full (2)	Yes 0.12	20 min	MODIS Seasonal	0.01 K/s	60 s
HRRR	5 th /5 th	Positive-Definite	w-Rayleigh 0.2	Full (2)	Yes 0.25	15 min with SW-dt	MODIS Seasonal	0.07 K/s	20 s

2020 RAPv5/HRRRv4 Changes

Upcoming RAPv5/HRRRv4

No Change in Domains

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	953 x 834	13 km	50	Sigma-Isob Hybrid	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCO	CONUS	1799 x 1059	3 km	50	Sigma-Isob Hybrid	15 mb	RAP	Hourly (pre-forecast hour cycle)

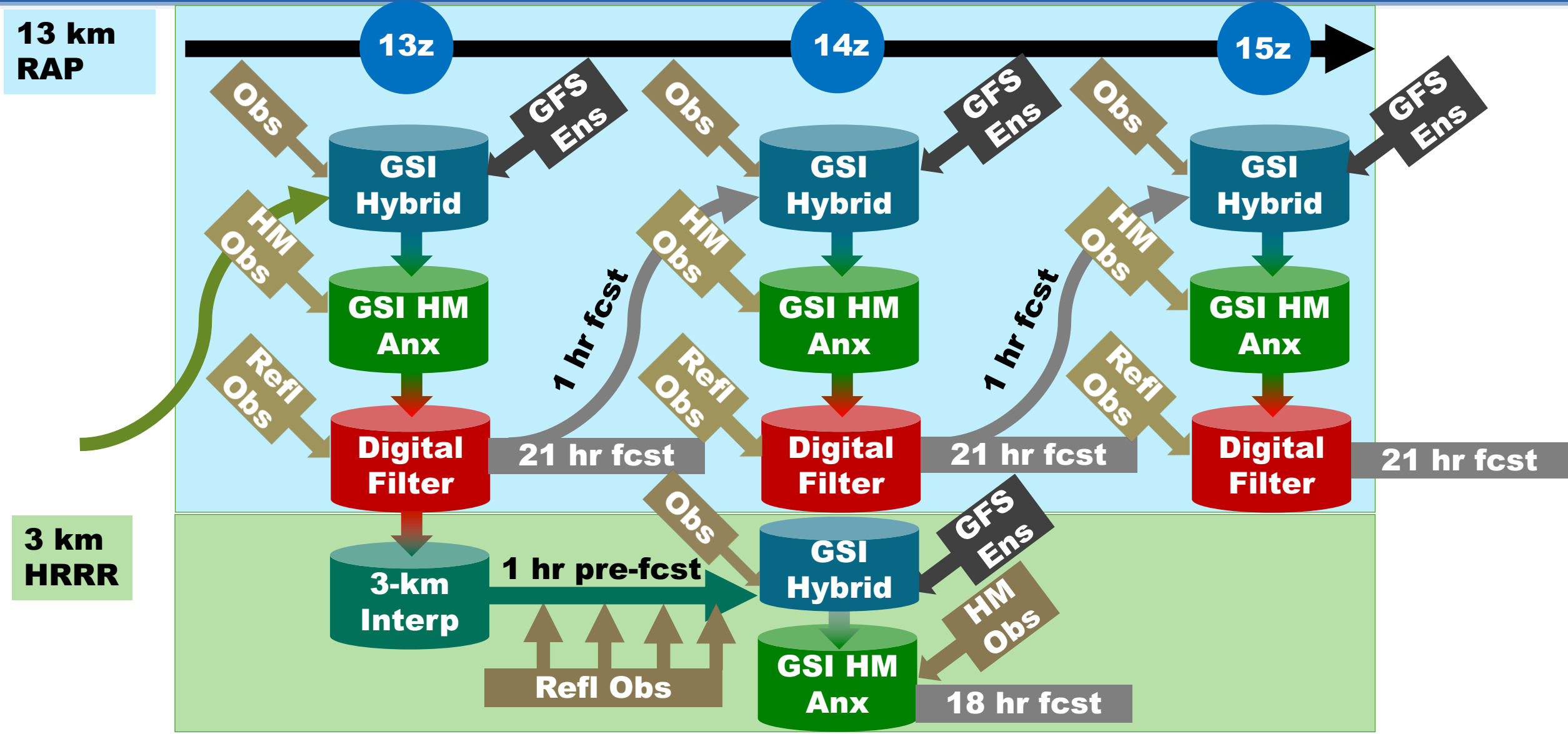
Newer Model Version
HRRRDAS Use
Advanced “Physics Suite”

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.9.1+	GSI Hybrid Ensemble 0.85	13-km DFI, ½ Strength	RRTMG/ RRTMG	Thompson Aerosol v3.8.1	GF + Shallow	MYNN v3.9.1+	RUC v3.9.1+
HRRR	WRF-ARW v3.9.1+	GSI Hybrid HRRRDAS Ensemble 0.85	3-km 15-min LH	RRTMG/ RRTMG	Thompson Aerosol v3.8.1	None	MYNN v3.9.1+	RUC v3.9.1+

CLM Lake Model
FVCOM Great Lakes

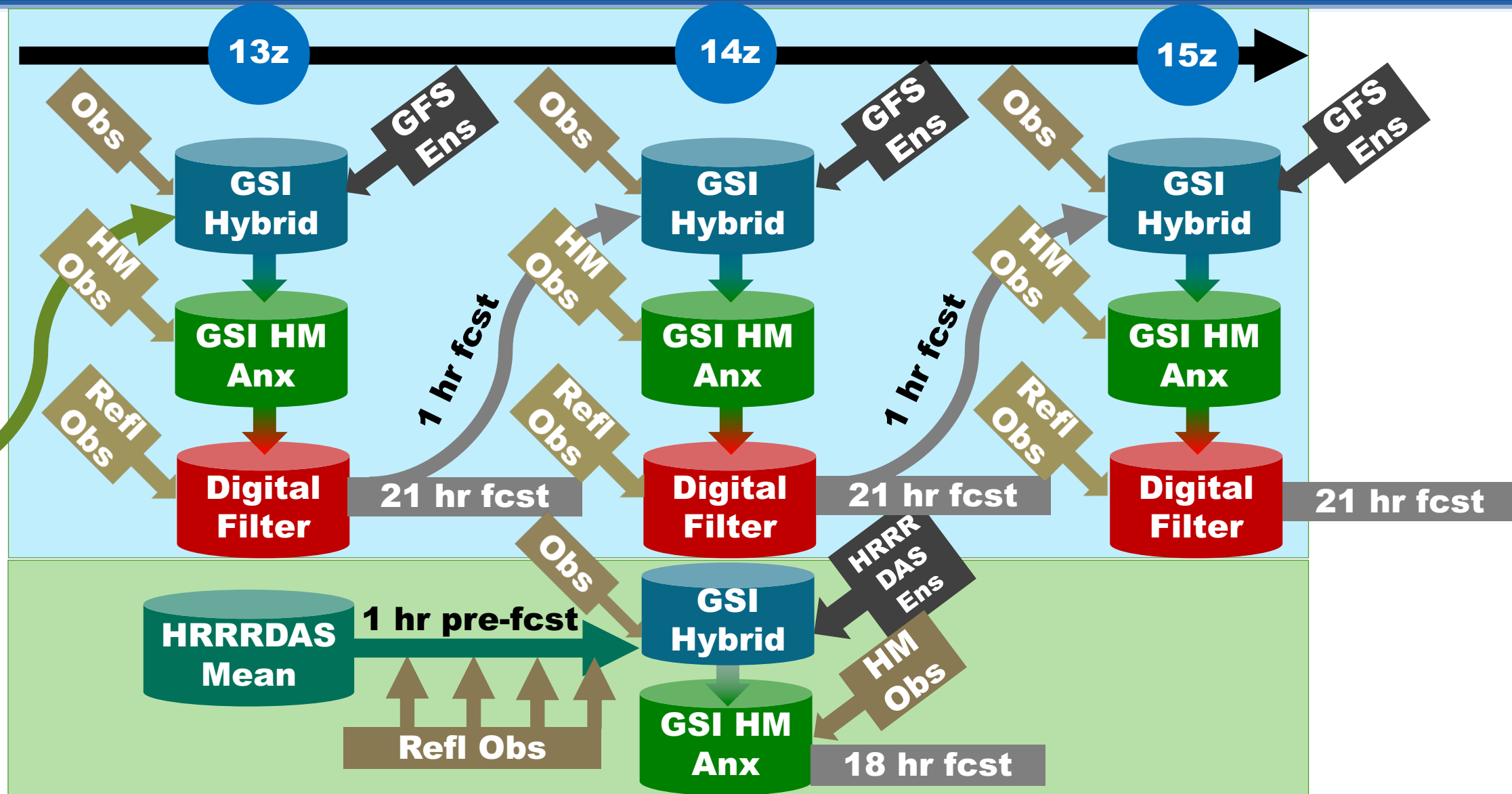
Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	Diffusion Option	6 th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5 th /5 th	Positive-Definite	w-Rayleigh 0.2	Full (2)	Yes 0.12/0.04	20 min	MODIS Seasonal	None	60 s
HRRR	5 th /5 th	Positive-Definite	w-Rayleigh 0.2	Full (2)	Yes 0.12/0.04	15 min with SW-dt	MODIS Seasonal	None	20 s

HRRRv3 Initialization from RAPv4



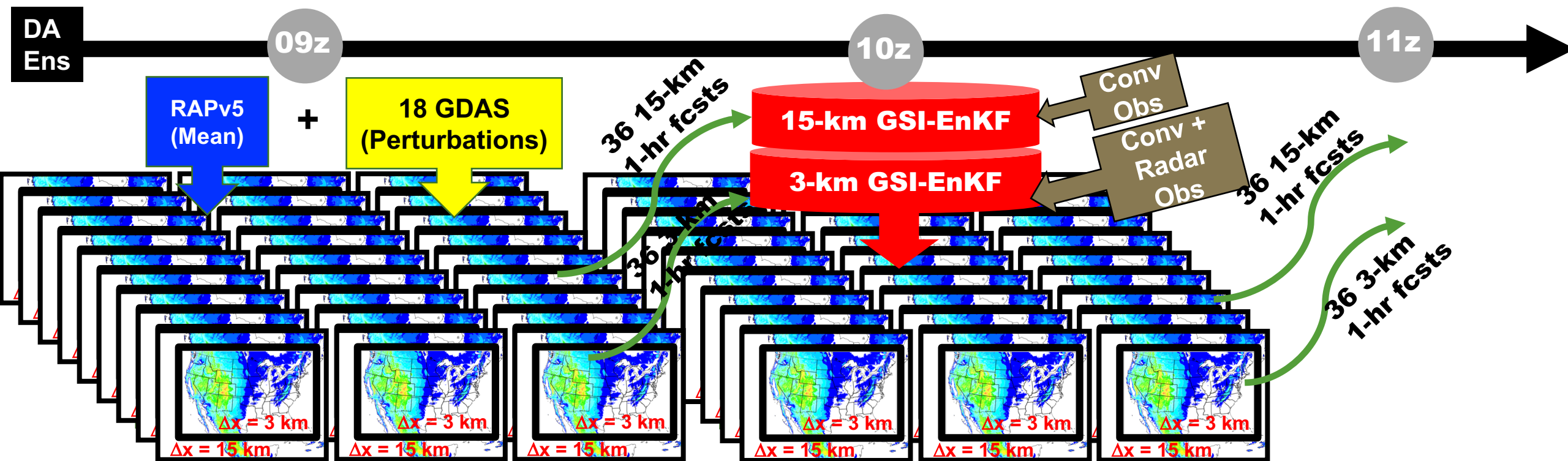
HRRRv4 Initialization

**13 km
RAP**



HRRR Data Assimilation System (HRRRDAS)

Collaboration from NSSL, EMC, NCAR and OU

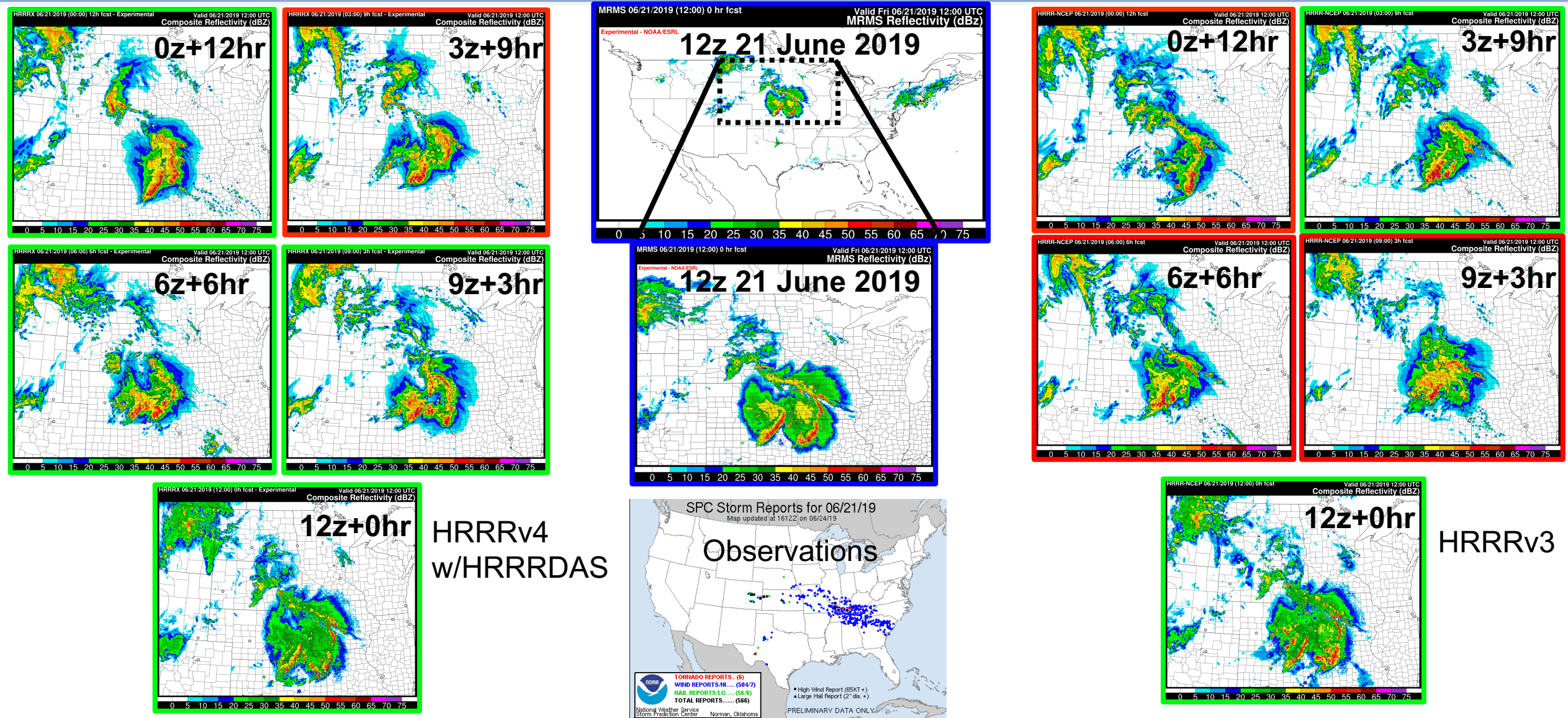


18 members re-initialized at 09z and inserted at 10z
 18 members re-initialized at 21z and inserted at 22z

Sources of Spread

- Hourly DA (posterior inflation)
- Lower boundary perturbations (soil moisture)
- Lateral boundary perturbations

HRRRDAS: Case Study 12 UTC 21 June 2019



Deterministic HRRR (FY20)

Initial conditions

Background error covariances

RTMA-3D (FY23)

Storm-scale
background error
covariances

Storm-scale
analysis uncertainty

HRRRDAS (FY20)

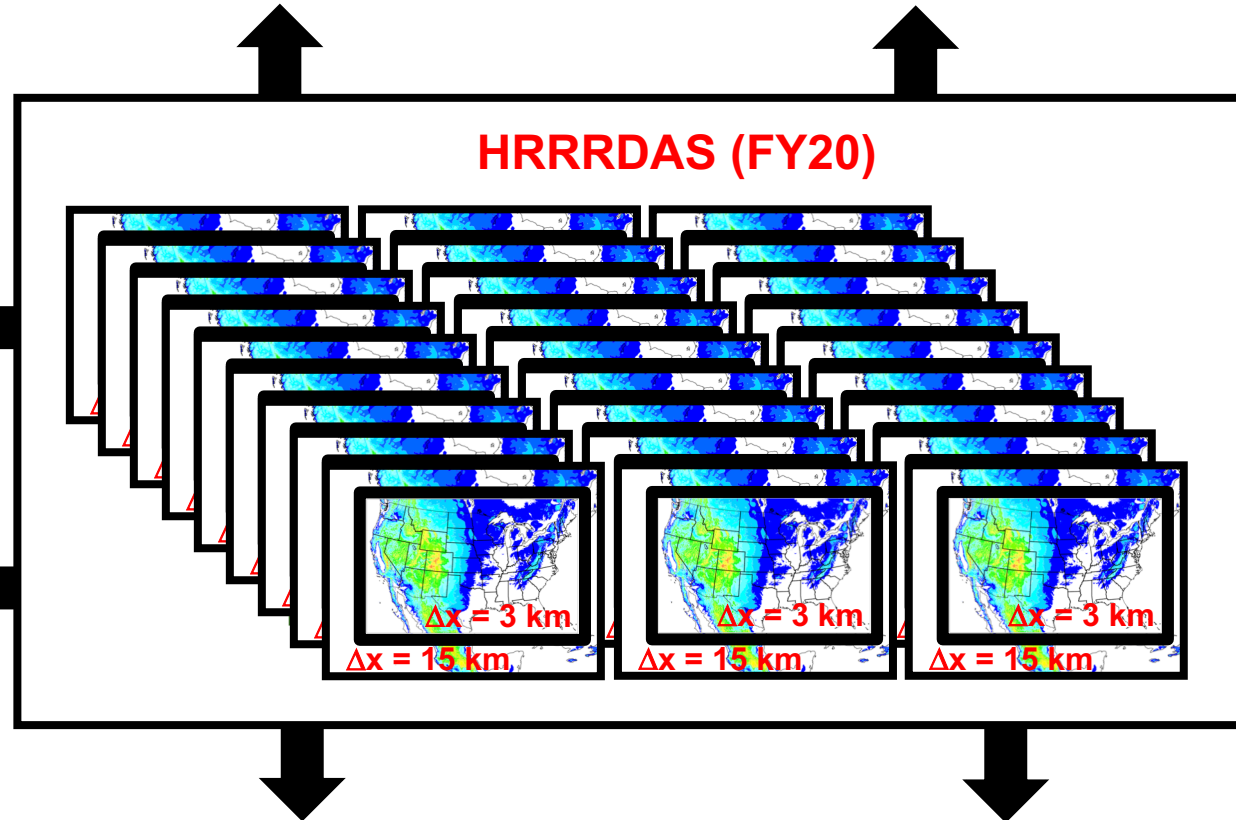
HRRRE (FY23 as part of RRFS)

Storm-scale
ensemble forecast

Warn-On-Forecast System (FY24-25+?)

Initial conditions

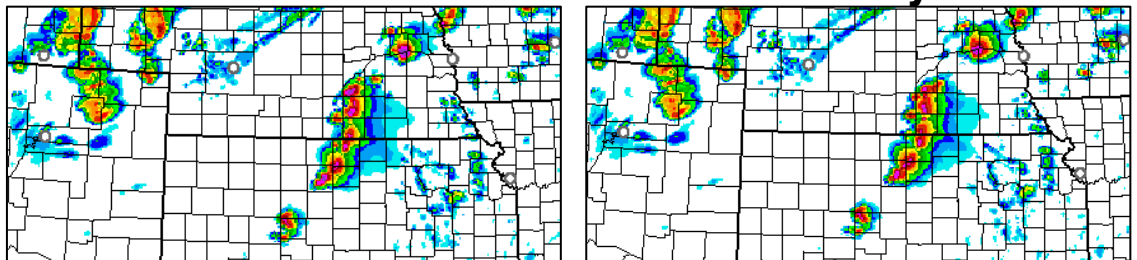
Boundary conditions



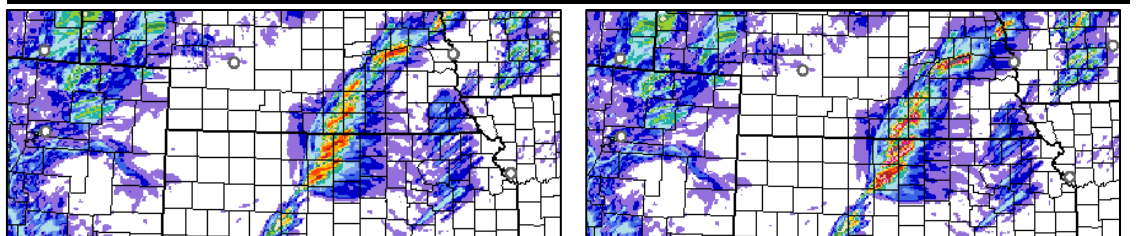
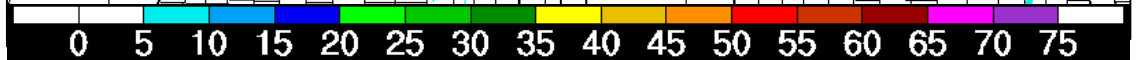
HRRRv3

HRRRv4

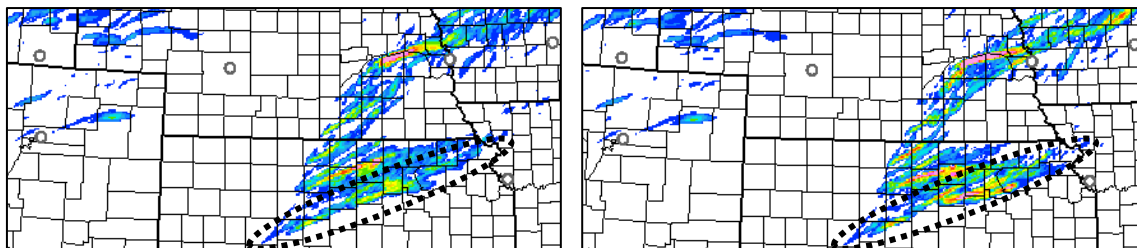
4-h forecasts valid 2200 UTC 1 May 2018



Composite Reflectivity (dBZ)



Max Updraft Velocity Sfc to 100mb (over prev hour) (m/s)



Run Total 1-6km Max Updraft Helicity (over prev hour) (m^2/s^2)

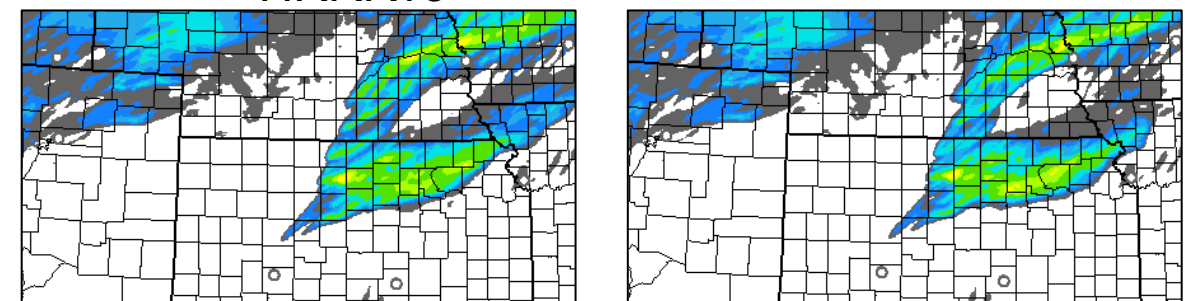


Use of Implicit-Explicit Vertical Advection (IEVA) allows for:

- Use of existing time-step (20s) while retaining stability
- Removal of microphysics latent heating rate limiter
- Prediction of more extreme vertical velocities in convection
- Higher values of updraft-helicity

HRRRv3

HRRRv4



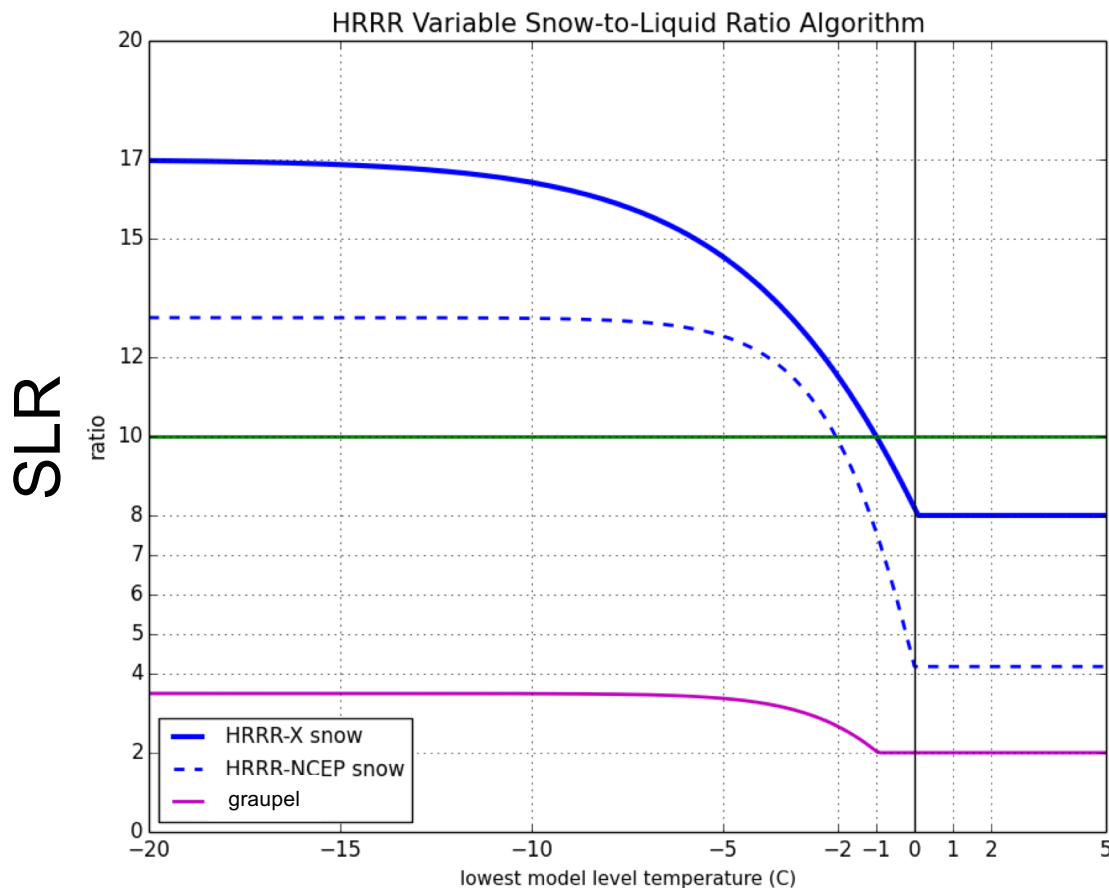
12h Total Precip (in)



12-h forecasts valid 0600 UTC 2 May 2018

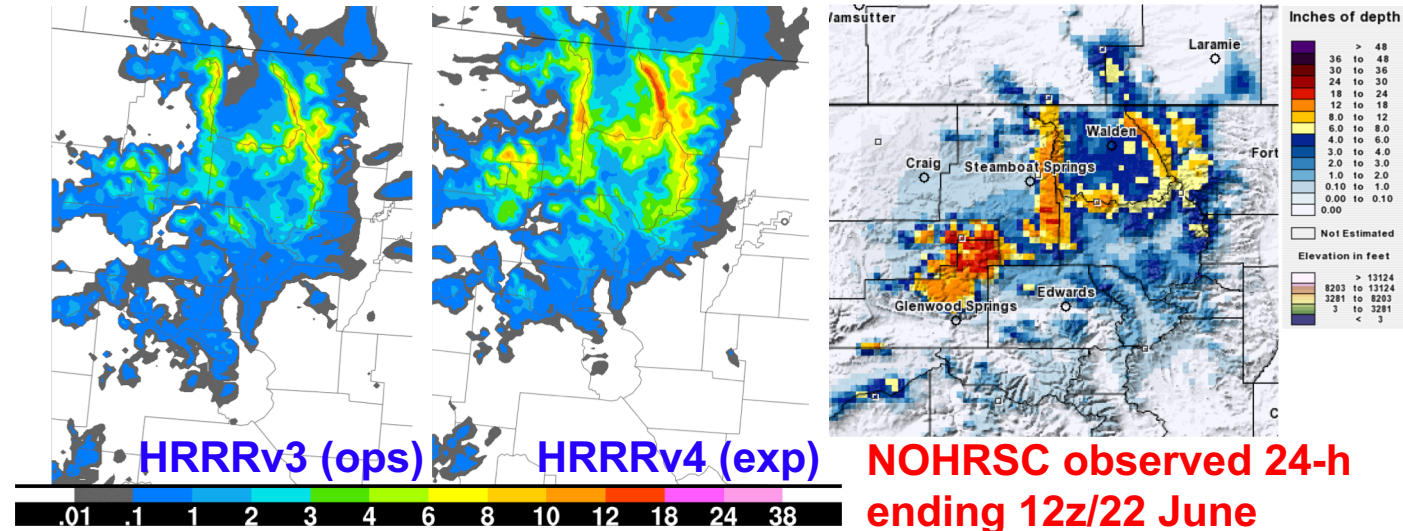
Slight change in precipitation

12z/21 June HRRR runs: snowfall forecasts for 24-h ending 12z/22 June using the variable snow method



New prototype RAPv5/HRRRv4 -- based on two years of development/testing/eval (WPC/WFOs)

Current Operational RAPv4/HRRRv3

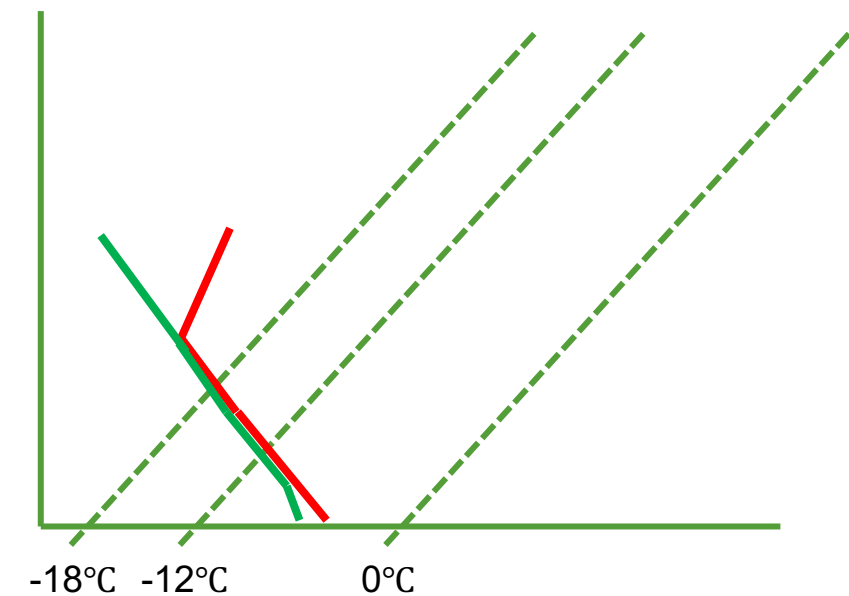


One size doesn't fit all...

Caveat #1: Lake effect, i.e., steep lapse rates

Lowest levels are fairly warm, BUT potentially a lot of depositional growth occurs in dendritic regime

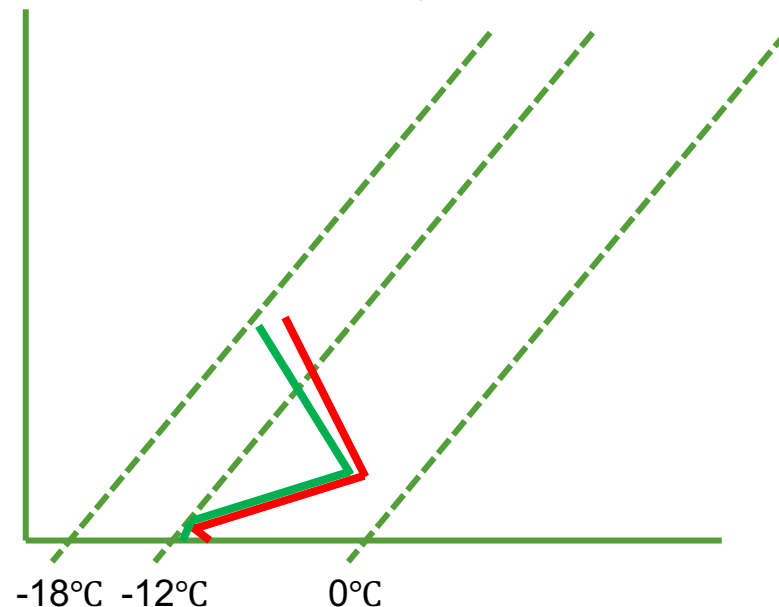
SLR already limited to 17:1, could be further **underestimated** in this scenario



Caveat #2: Overrunning events

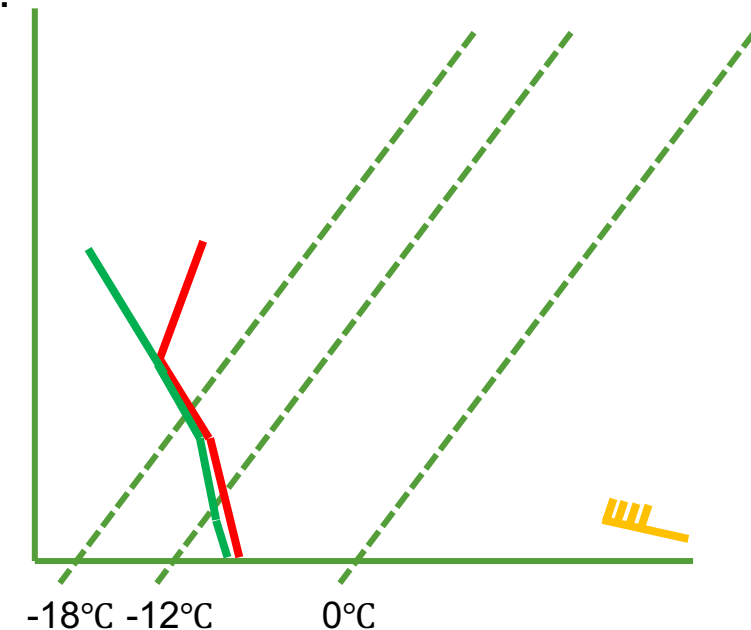
Lowest levels are cold, BUT depositional growth could be occurring outside the dendritic regime, plus accretion below

SLR of *snow* likely **overestimated**, but microphysics scheme might convert enough snow to graupel to compensate. Depends on forcing, moisture profile, etc.

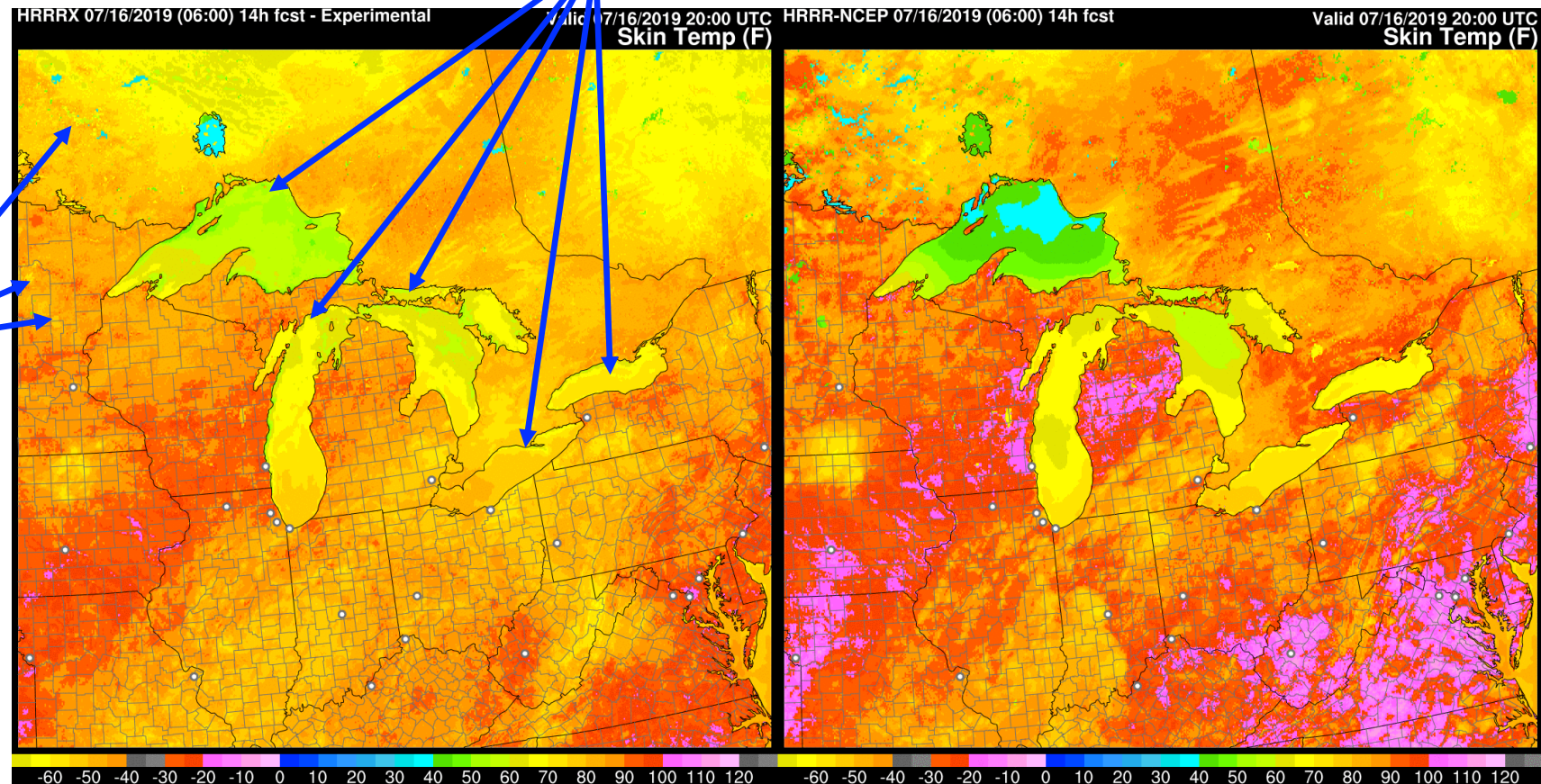


Caveat #3: Wind

Pure dendritic growth aloft but howling winds at the surface. Scheme does not account for surface wind speed, could **overestimate** SLR here.



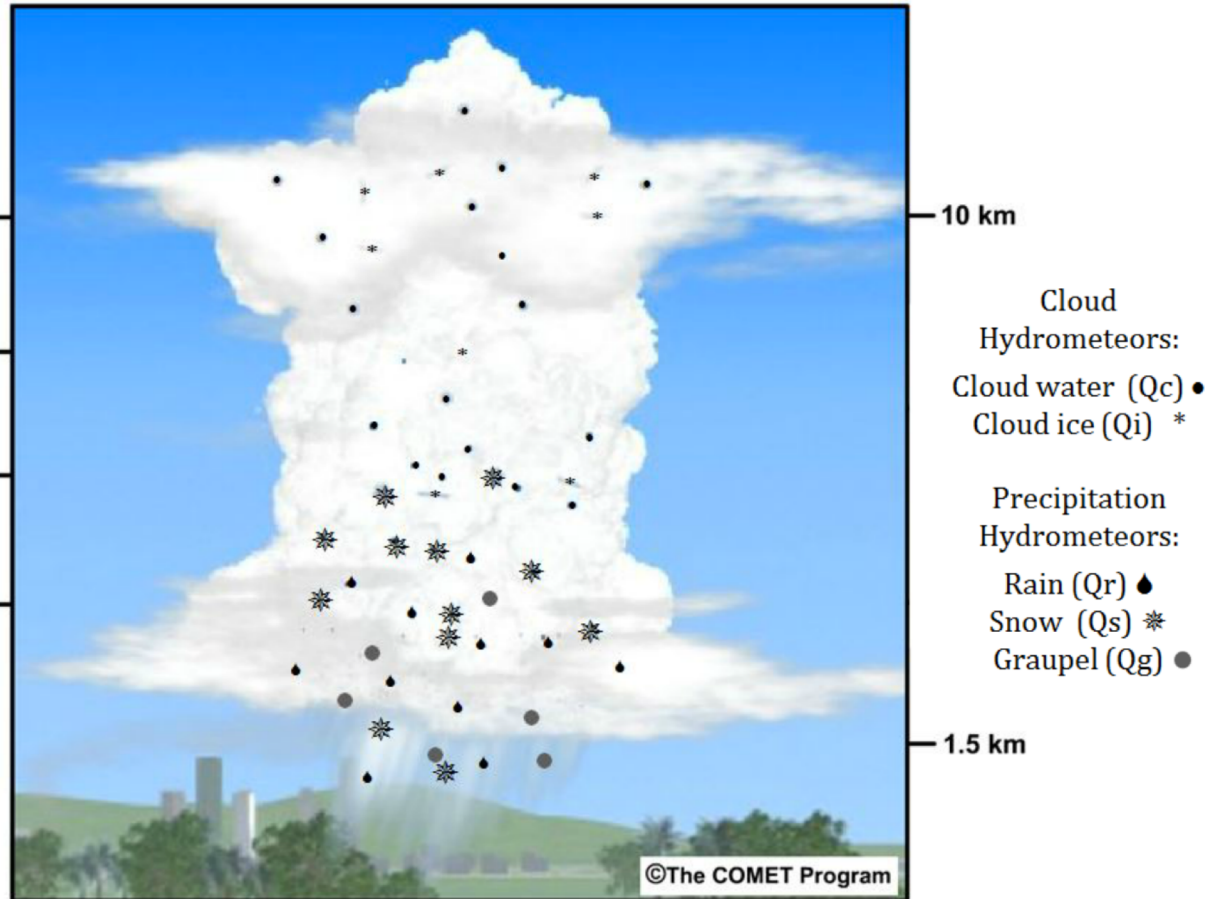
FVCOM lake temperatures (ESRL-GLERL collaboration)



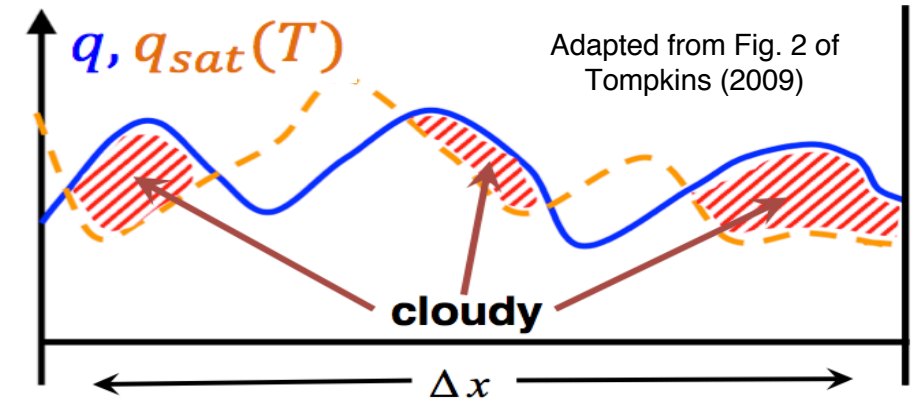
CLM Inland-Lake
Temperatures
(reduced cold bias
in warm season)

Explicit (Resolved) Clouds/Precipitation

RAP and HRRR use the Thompson microphysics scheme with 5 hydrometeor types



Sub-Grid (Unresolved) Clouds



$$Var(s) \propto Var(q) + Var(T) - Cov(q, T)$$

Assume a PDF of s
 (saturation ratio)

Retrieve Cloud Fraction,
 Cloud Condensate

Parameterize:
 assume subgrid PDFs for
 thermodynamic variables
 Chaboureaud and Bechtold (2002)

Improved Retention of Shallow Cold/Cloudy Airmasses

34-h ceiling forecasts

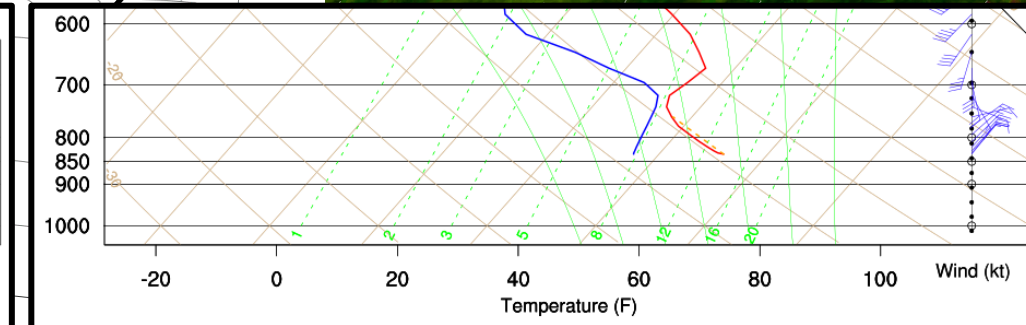
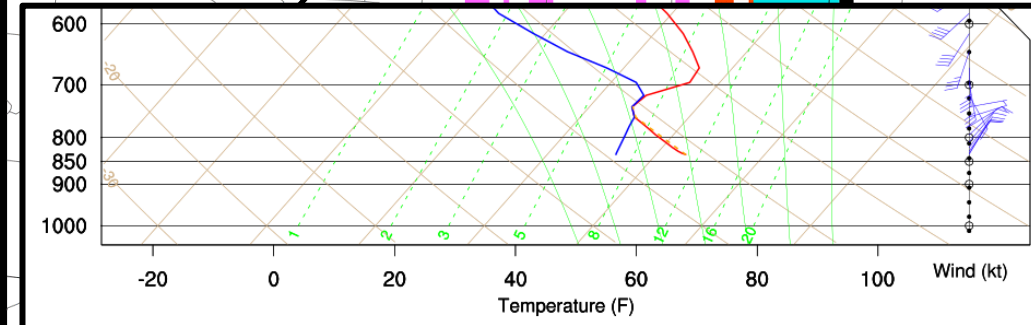
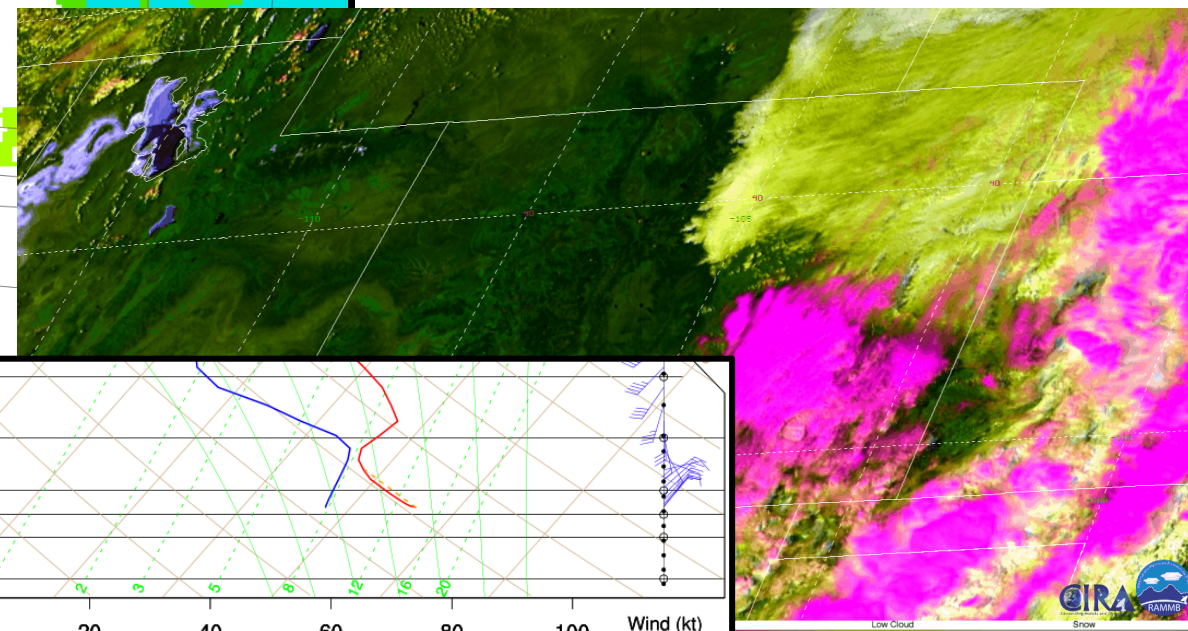
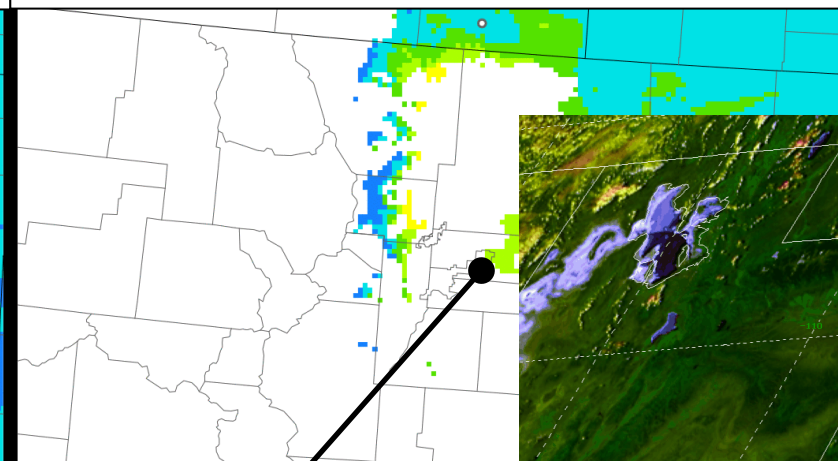
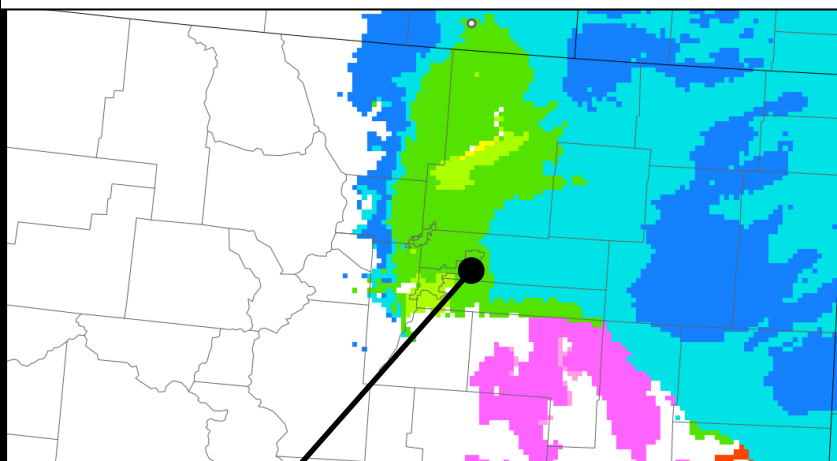
Init: 1200 UTC 30 Sep 2019

Valid: 2300 UTC 1 Oct 2019

1 Oct 2019: shallow frontal-inversion stratus in weak upslope flow behind surface cold front

HRRRv4

HRRRv3 (OPS)

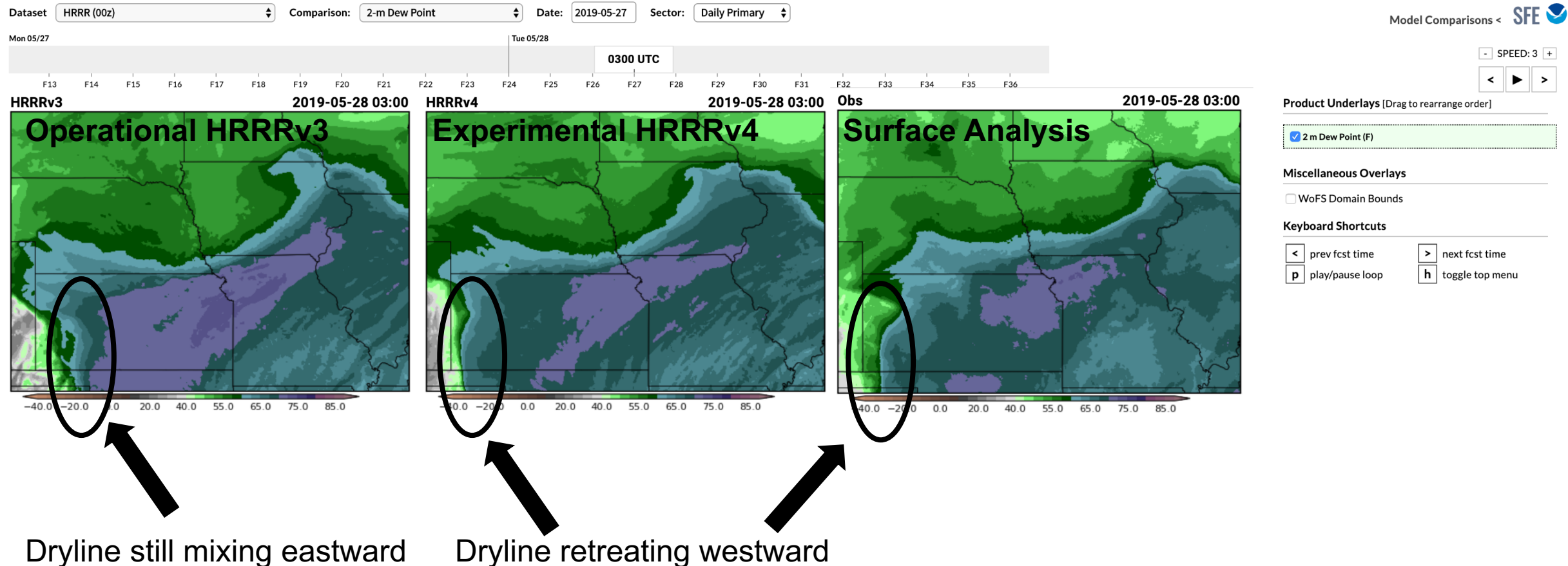


23 UTC 1 Oct



Dryline Position and Evolution

27 hr Forecasts Valid
03 UTC 27 May 2019



Data processed and plotted at NOAA NSSL/NWS SPC • Part of the NOAA Hazardous Weather Testbed

Product Underlays [Drag to rearrange order]

☒ 2 m Dew Point (F)

Miscellaneous Overlays

☐ WoFS Domain Bounds

Keyboard Shortcuts

< prev fcst time
p play/pause loop

> next fcst time
h toggle top menu

SPEED: 3



Dryline Position and Evolution

27 hr Forecasts Valid
03 UTC 27 May 2019

Dataset: HRRR (00z) Comparison: 2-m Dew Point Date: 2019-05-27 Sector: Daily Primary

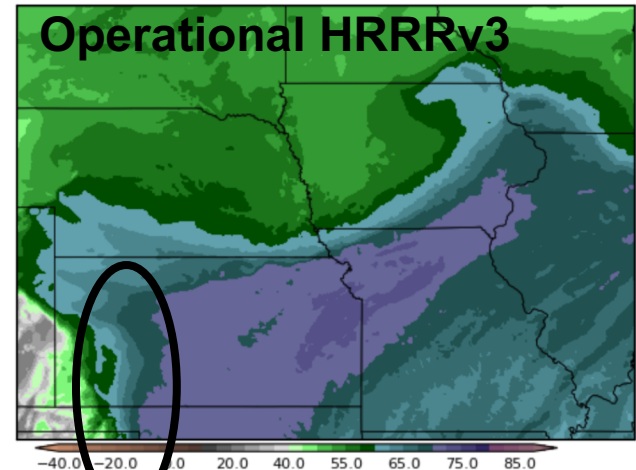
Mon 05/27

Tue 05/28

0300 UTC

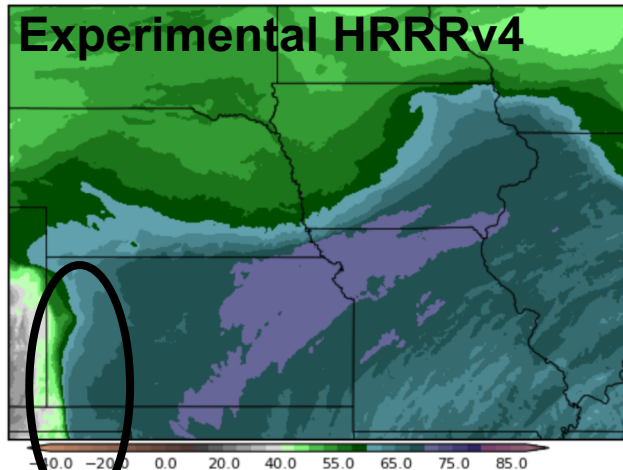
F13 F14 F15 F16 F17 F18 F19 F20 F21 F22 F23 F24 F25 F26 F27 F28 F29 F30 F31 F32 F33 F34 F35 F36

HRRRv3 2019-05-28 03:00



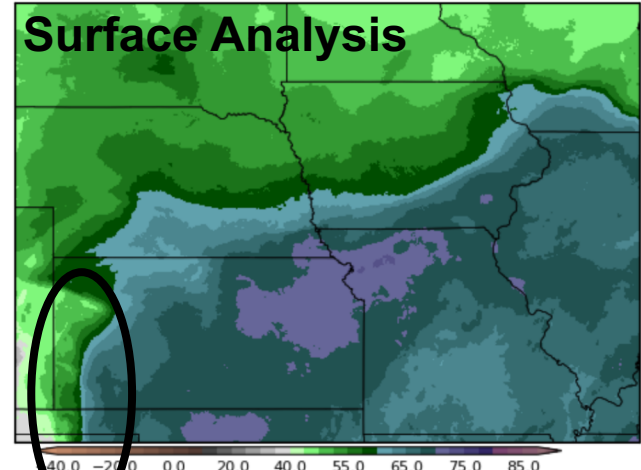
Dryline still mixing eastward

HRRRv4 2019-05-28 03:00



Dryline retreating westward

Obs 2019-05-28 03:00



Model Comparisons < SFE

SPEED: 3



Product Underlays [Drag to rearrange order]

☒ 2 m Dew Point (F)

Miscellaneous Overlays

☐ WoFS Domain Bounds

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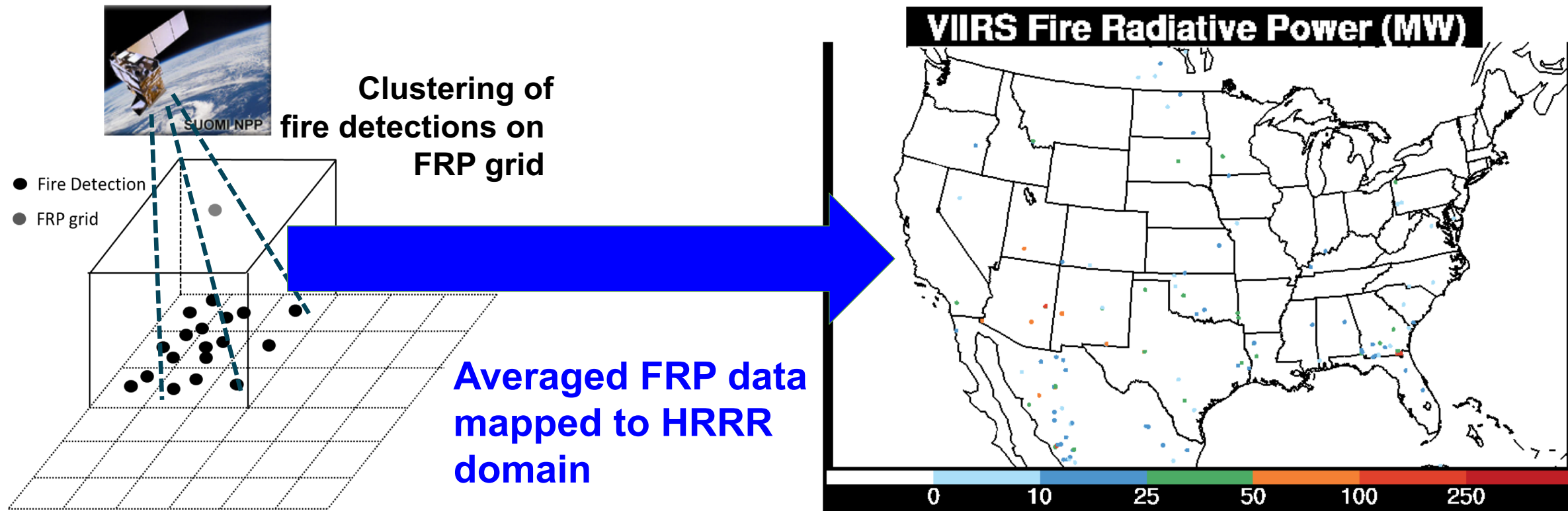
> next fcst time

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Data processed and plotted at NOAA NSSL/NWS SPC • Part of the NOAA Hazardous Weather Testbed

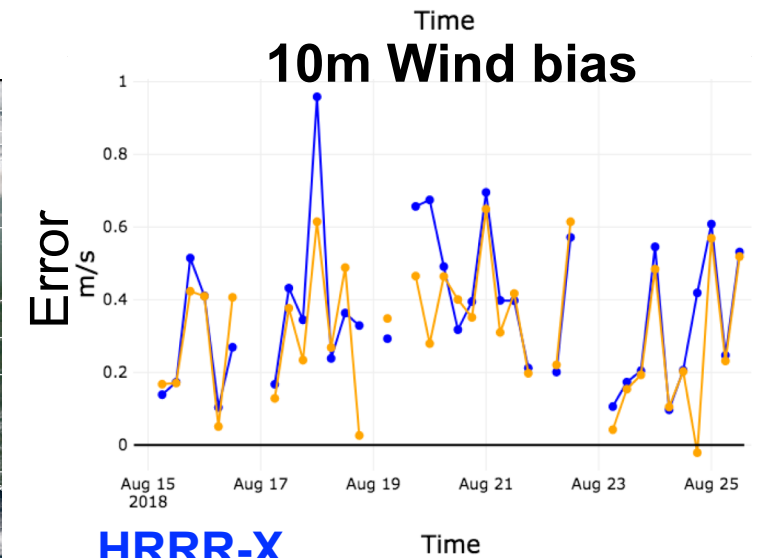
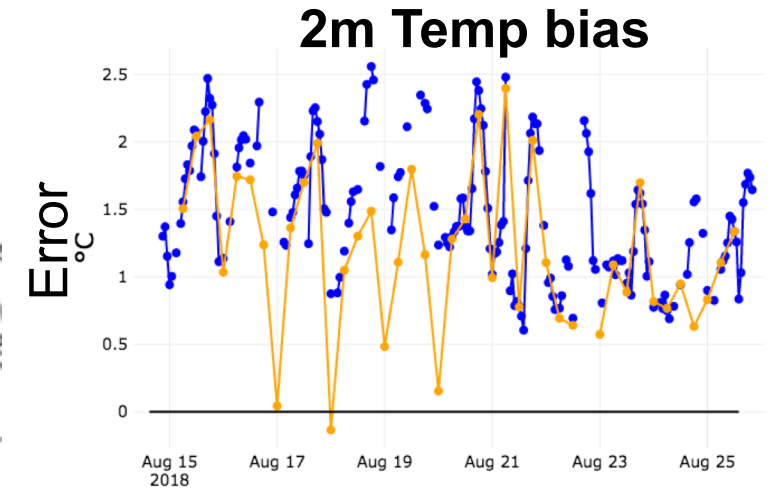
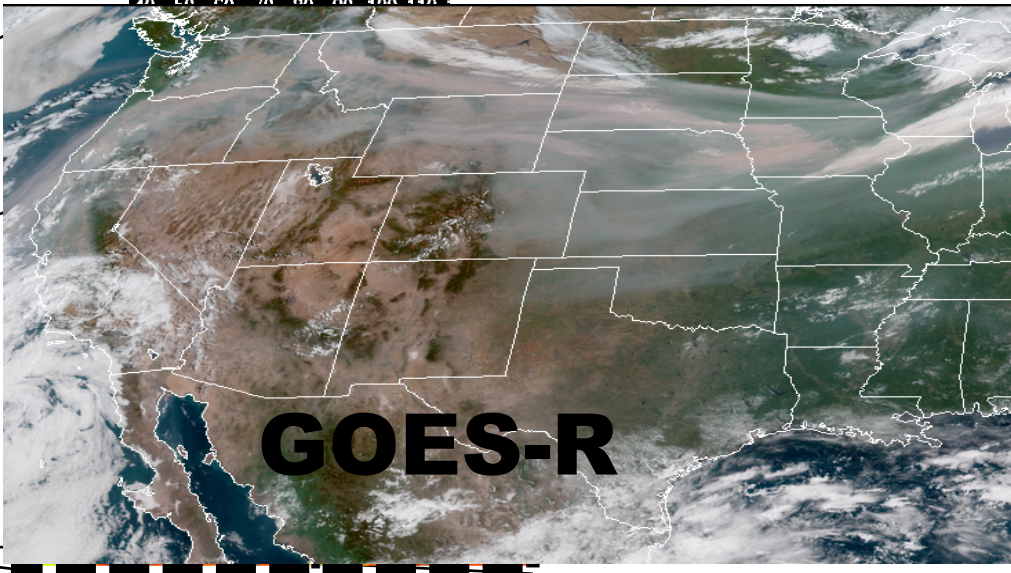
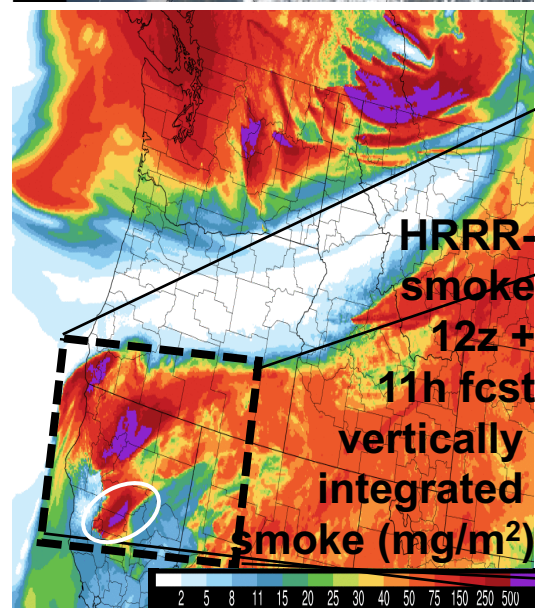
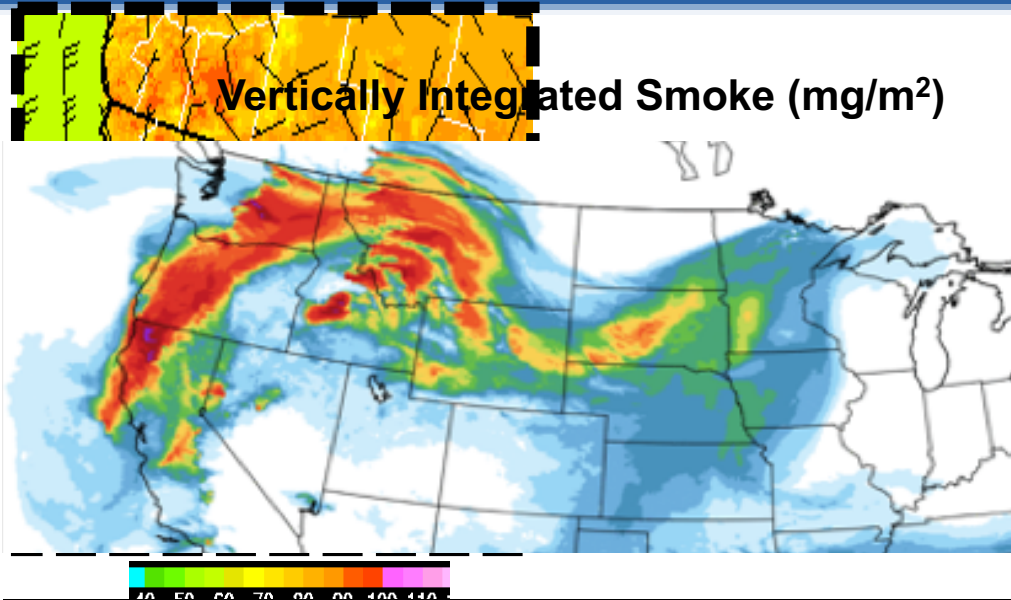
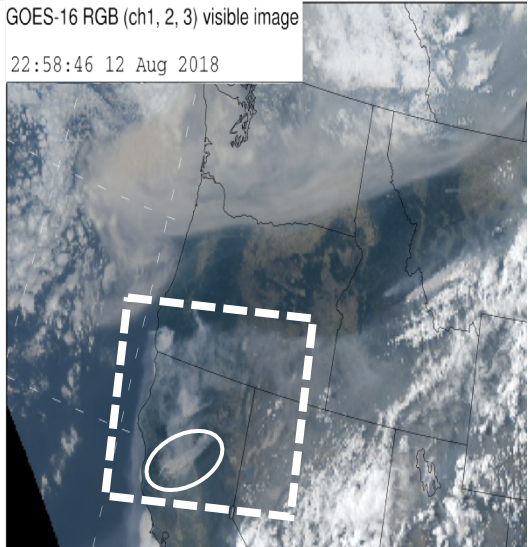
• Parallel RAP and HRRR runs

- Specification of smoke from **VIIRS fire radiative power (FRP)**
- **3D transport** of smoke, interaction with physics (**radiation, wet deposition**)
- Only slightly greater computational cost than standard runs for RAPv5/HRRRv4



GOES-16 RGB (ch1, 2, 3) visible image

22:58:46 12 Aug 2018



HRRR-X

HRRR-Smoke (with feedback)

NCEP/EMC: RAPv5 Verification Summary

Evaluation Metric	CONUS – East	CONUS – West	Alaska
Upper Air Temperature	Neutral		
Upper Air RH	Neutral		
Upper Air Winds	Mostly Improved		
2-m Temperature	Degraded	Neutral	Insufficient Alaska-specific stats to make a judgment
2-m Dewpoint	Neutral	Neutral	
10-m Winds	Improved	Neutral	
Ceiling	Somewhat Improved		
Visibility	Somewhat Improved	Somewhat Improved	
Cloud Cover	Improved		Improved
QPF	Neutral	Somewhat Degraded	N/A

NCEP/EMC: HRRRv4 Verification Summary

Evaluation Metric	CONUS – East	CONUS – West	Alaska
Upper Air Temperature	Mostly Improved		Improved
Upper Air RH	Mostly Improved		Improved
Upper Air Winds	Mostly Improved		Neutral
2-m Temperature	Somewhat Improved	Improved	Mostly Improved
2-m Dewpoint	Improved	Improved	Mostly Improved
10-m Winds	Somewhat Degraded	Improved	Neutral
Ceiling	Somewhat Improved	Somewhat Improved	Somewhat Improved
Visibility	Somewhat Improved	Somewhat Improved	Somewhat Improved
Cloud Cover	Improved		Improved
QPF	Somewhat Improved	Somewhat Degraded	N/A

HRRR-OPS
HRRRv4

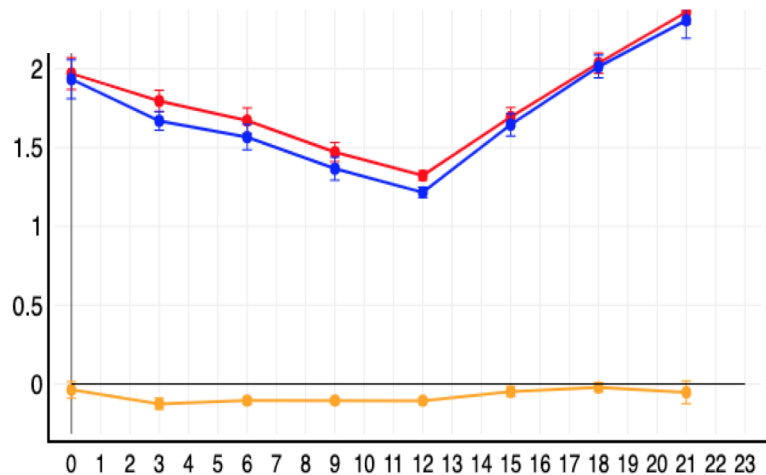
6-h fcst

12-h fcst

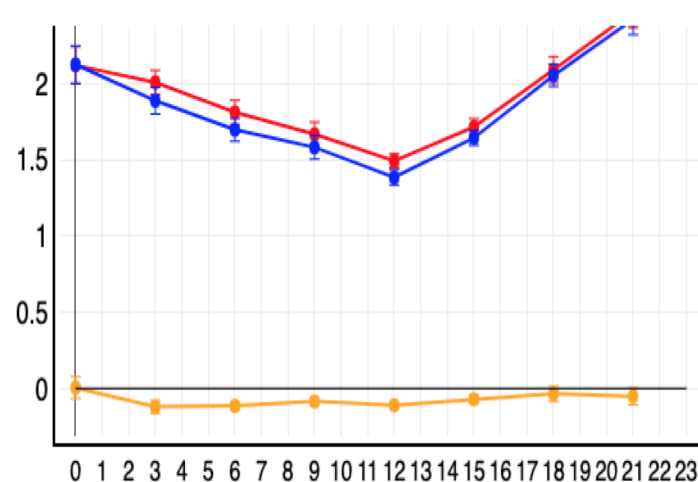
18-h fcst

RMSE

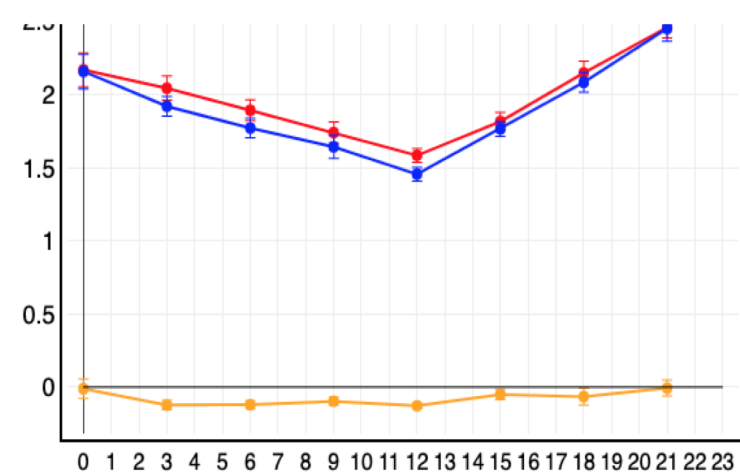
°C



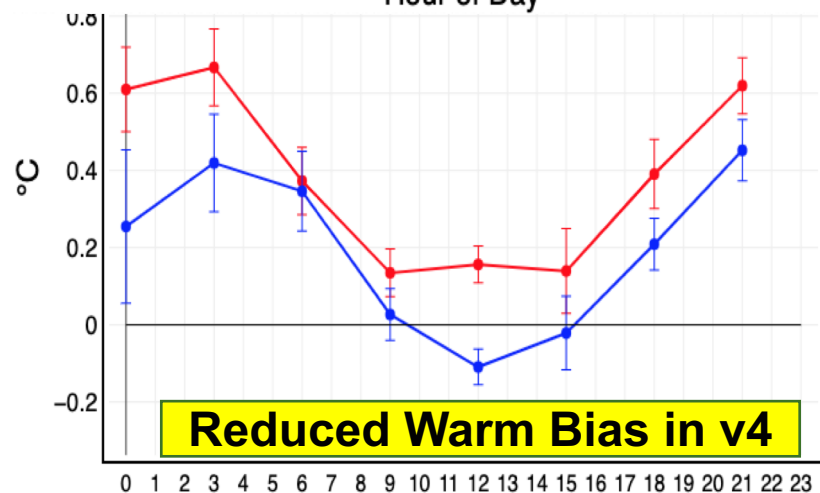
°C



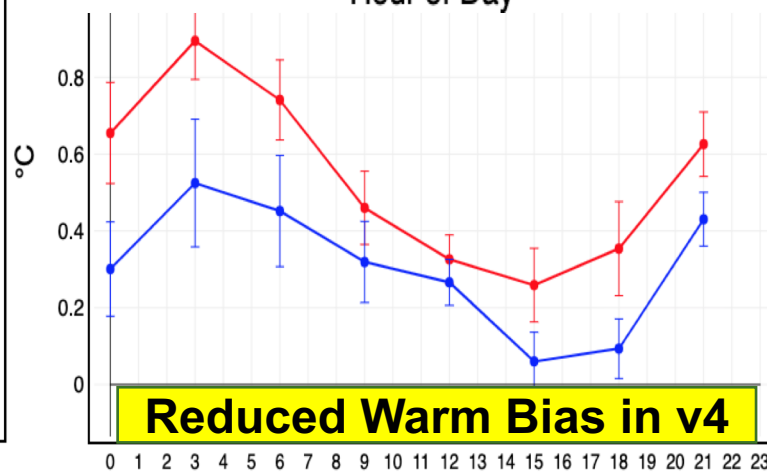
°C



Hour of Day

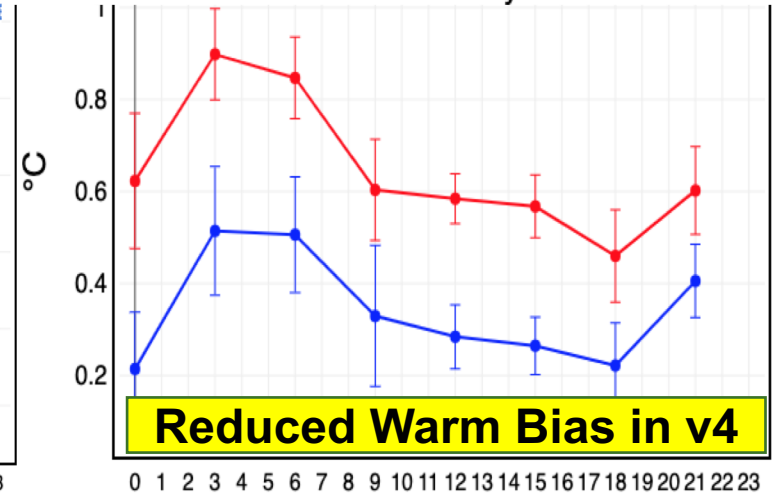


Hour of Day



Hour of Day

Hour of Day



Hour of Day

HRRR Retrospective Verification: 2mT East CONUS 1-28 Feb 2019

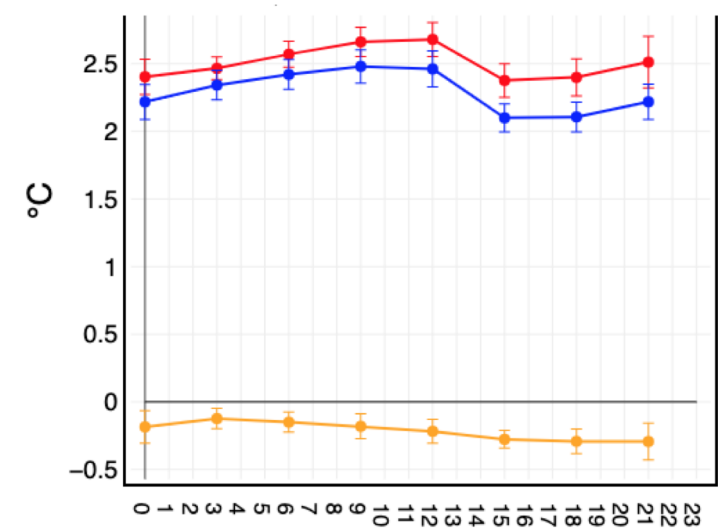
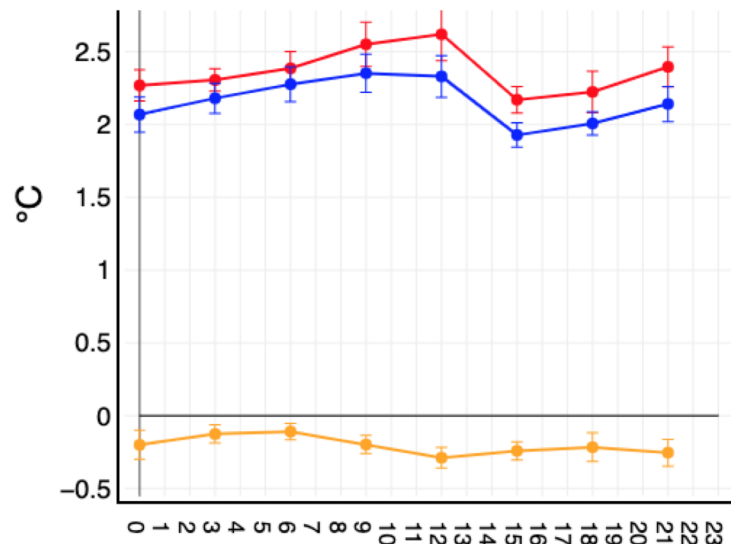
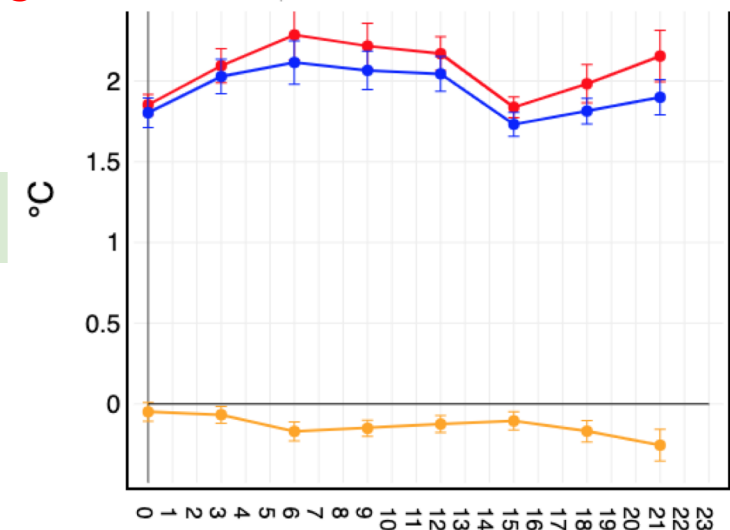
HRRR-OPS
HRRRv4

RMSE

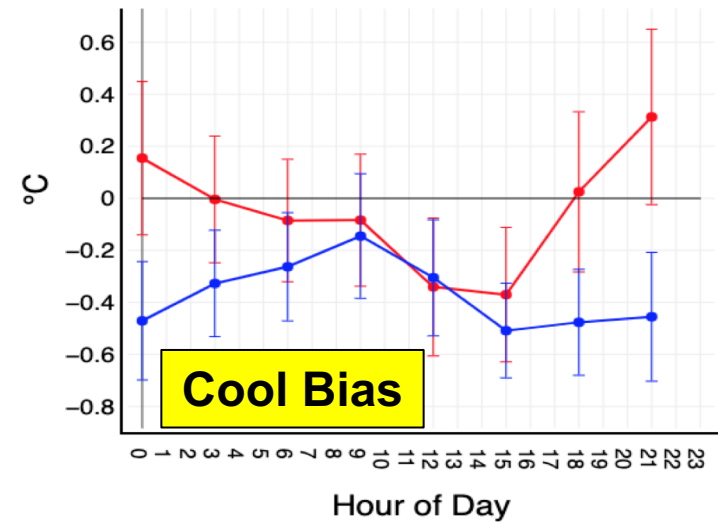
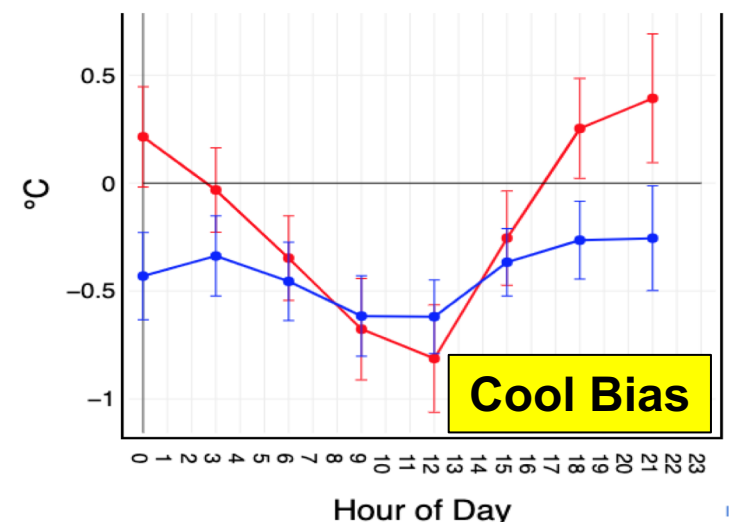
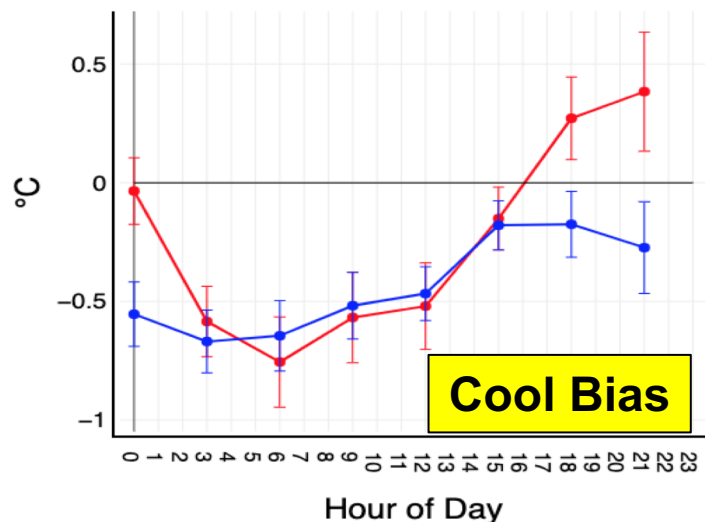
6-h fcst

12-h fcst

18-h fcst



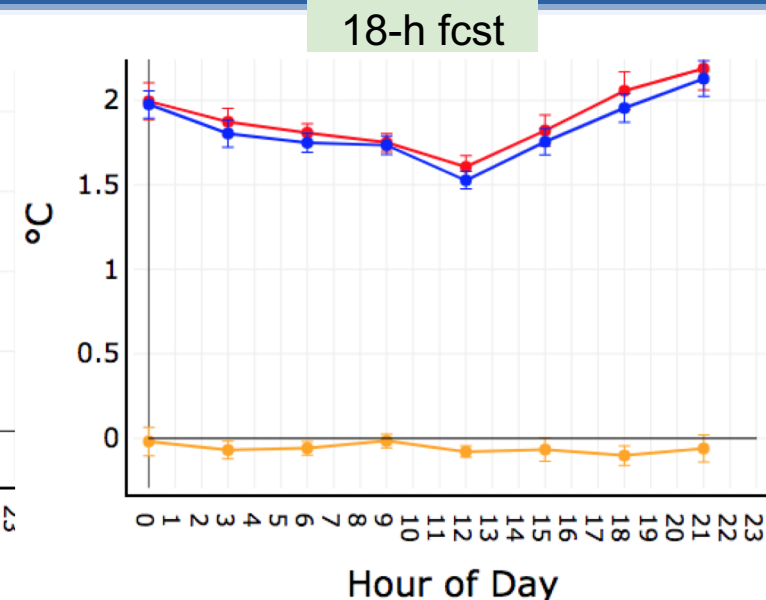
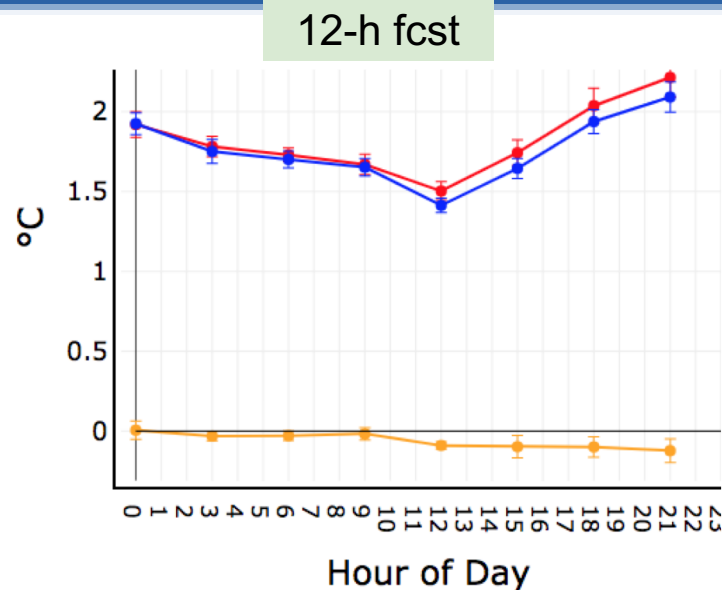
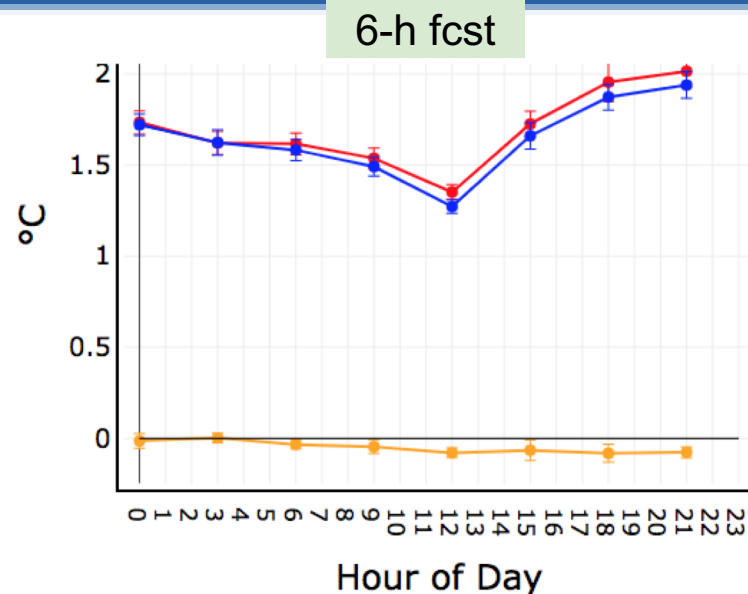
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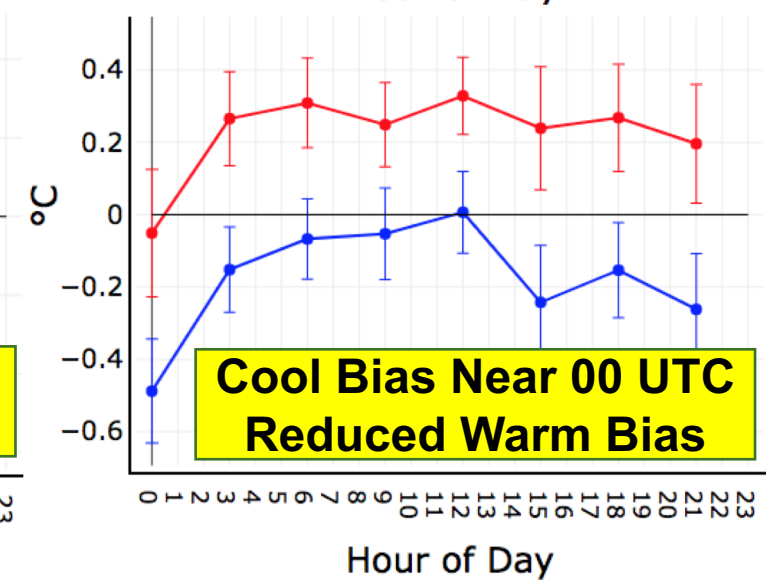
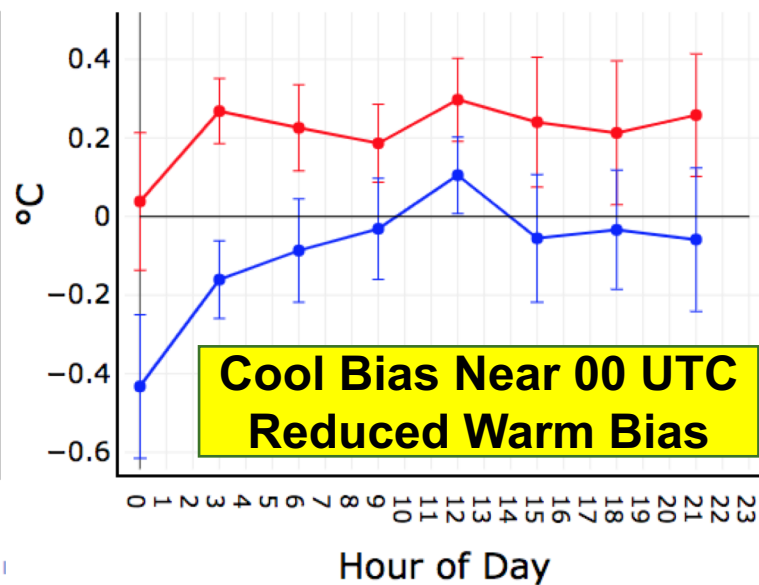
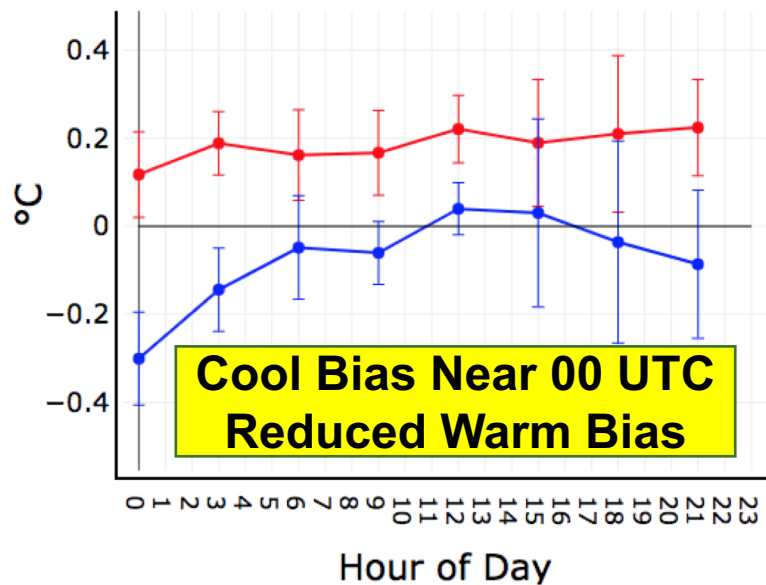
HRRR Retrospective Verification: 2mT East CONUS 1-31 May 2019

HRRR-OPS
HRRRv4

RMSE



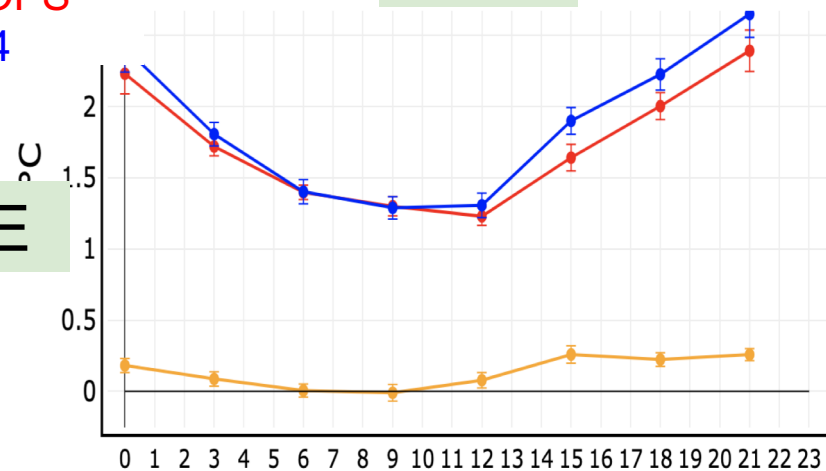
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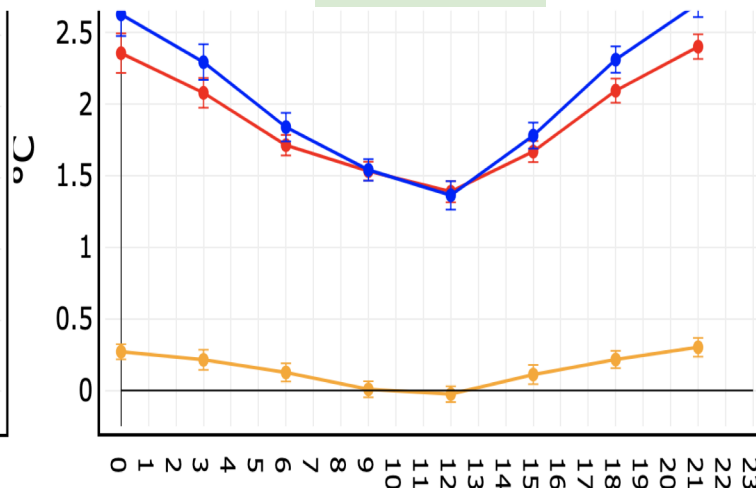
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HRRRv4

RMSE

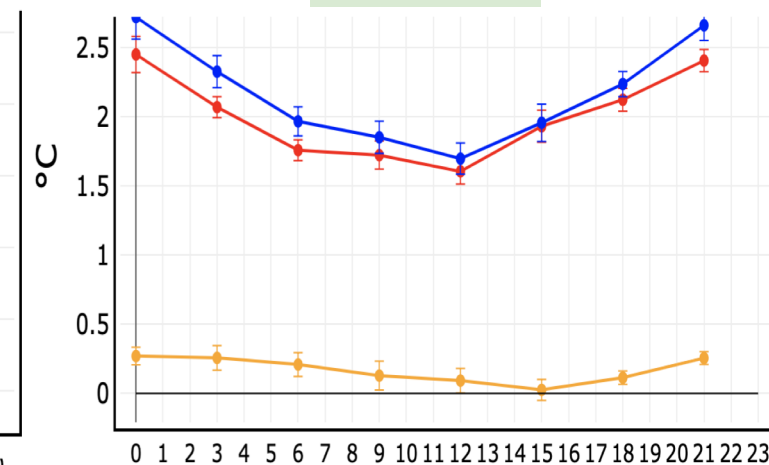
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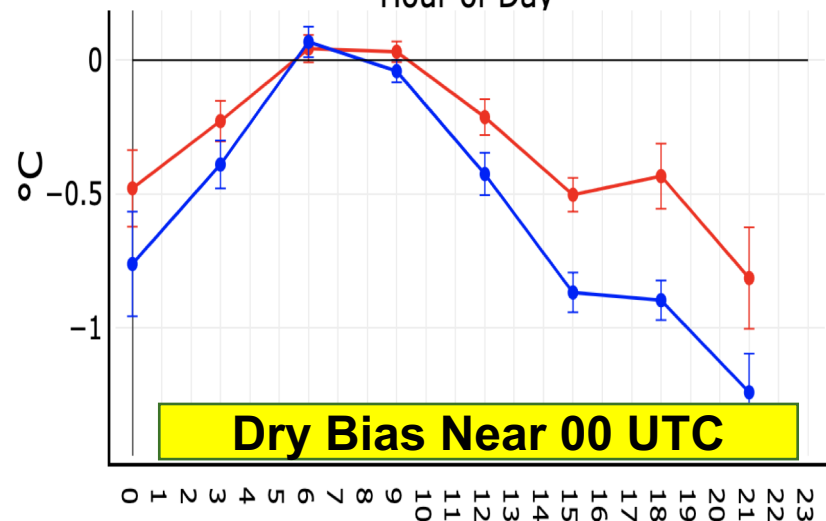


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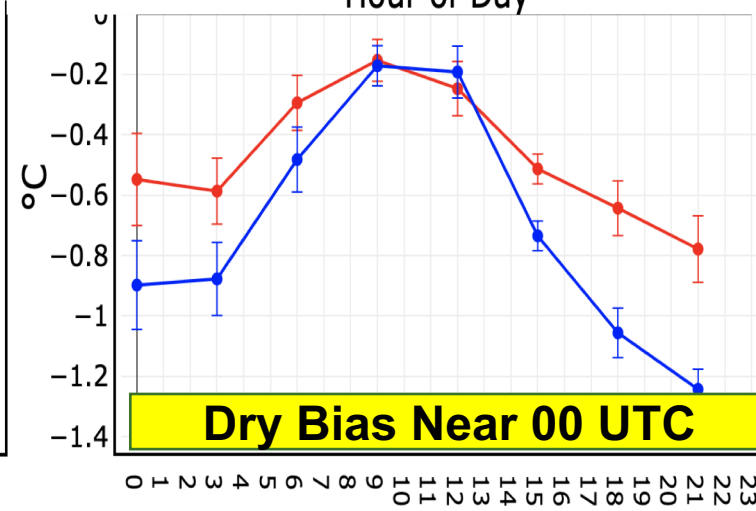


bias

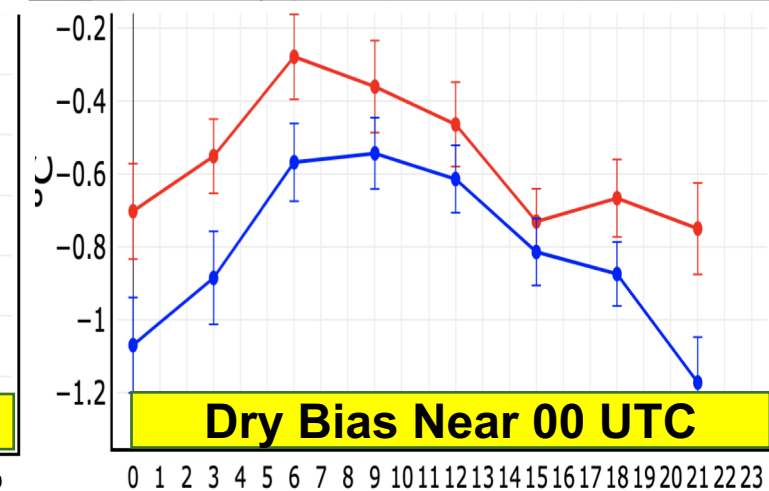
Hour of Day



Hour of Day



Hour of Day



Hour of Day

Hour of Day

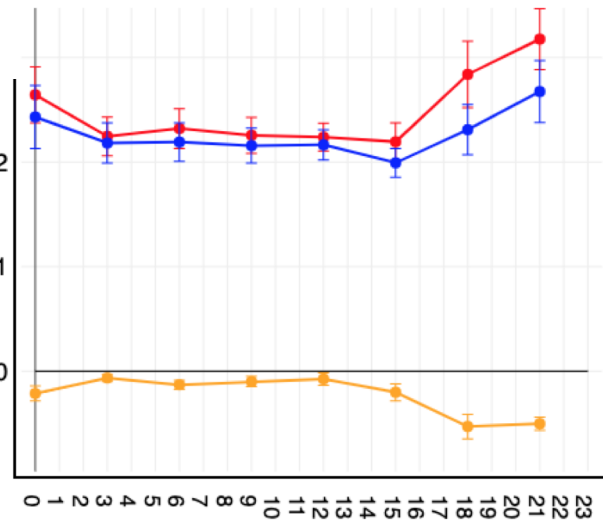
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HRRR Retrospective Verification: 2mT_d East CONUS 1-28 Feb 2019

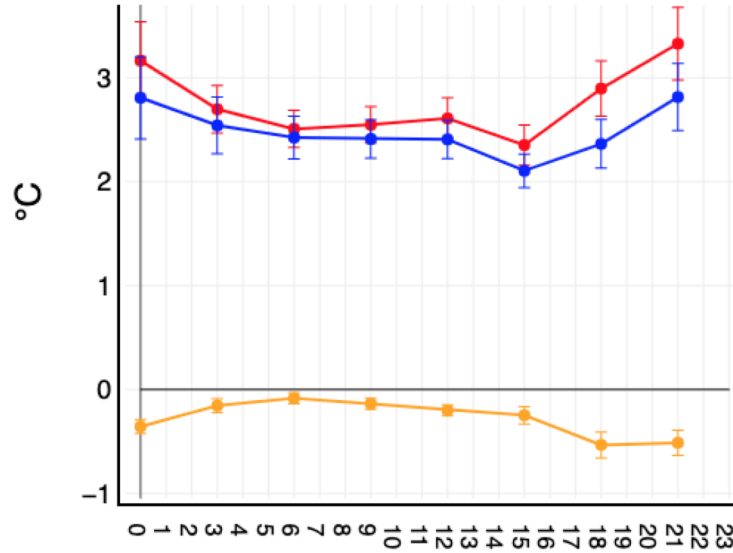
HRRR-OPS
HRRRv4

RMSE

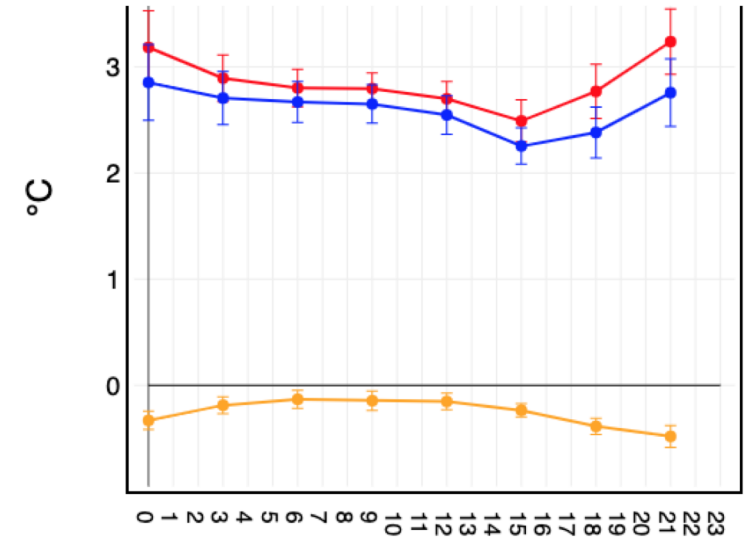
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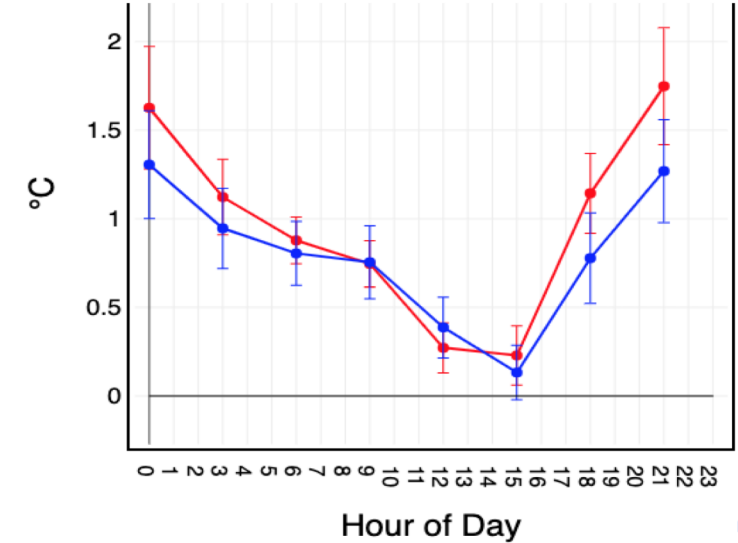
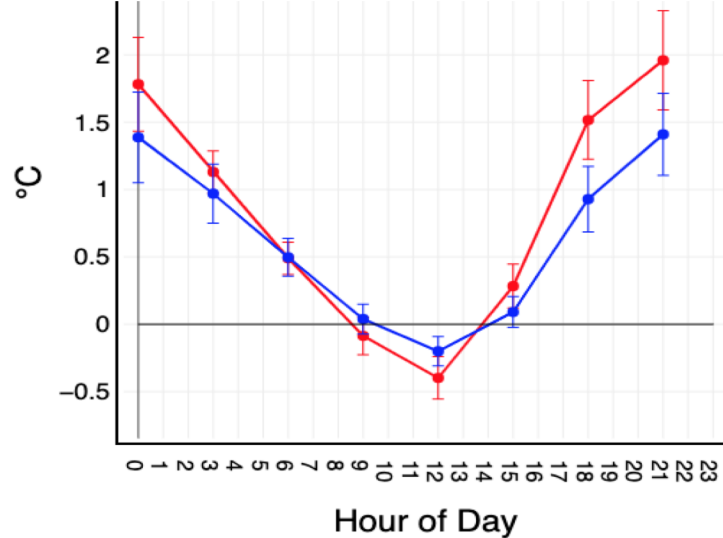
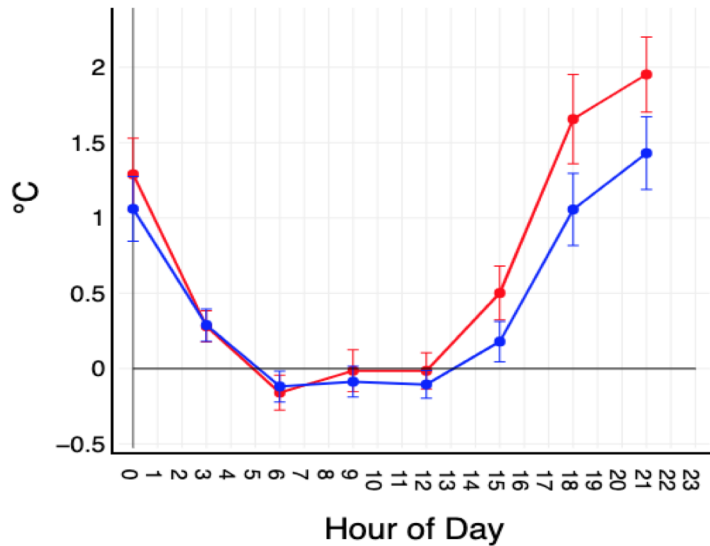
12-h fcst



18-h fcst



bias

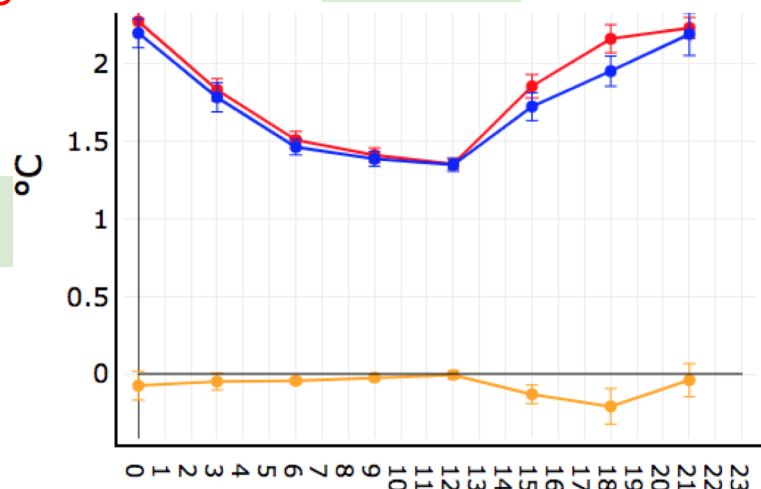


HRRR Retrospective Verification: 2mT_d East CONUS 1-31 May 2019

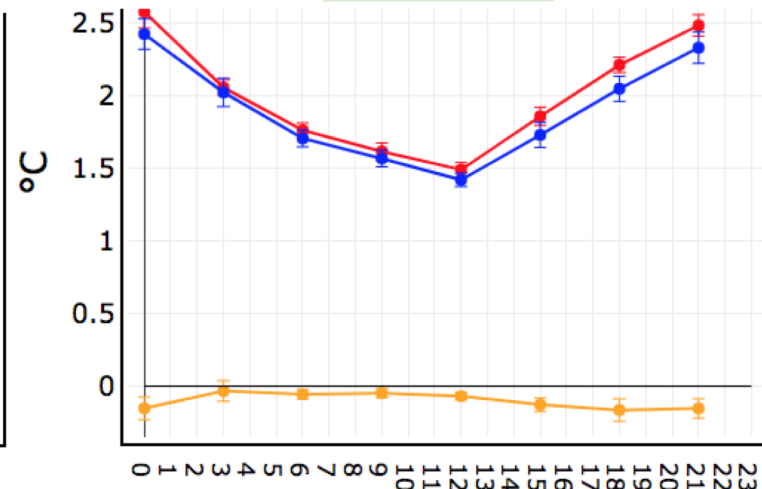
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HRRRv4

RMSE

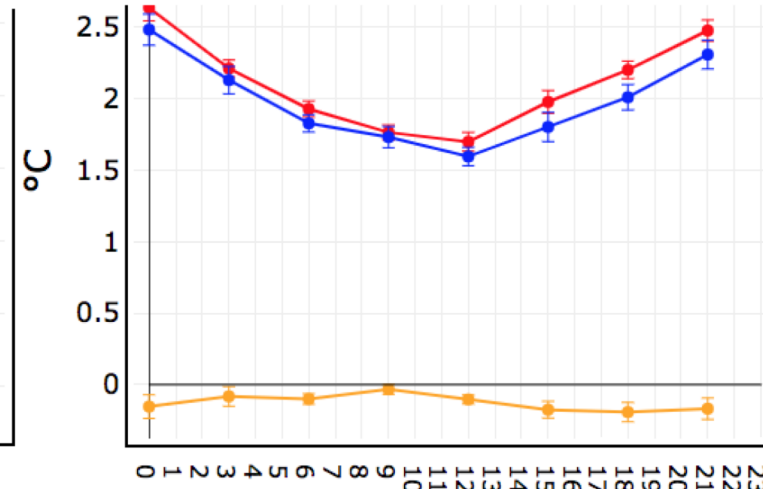
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12-h fcst



18-h fcst

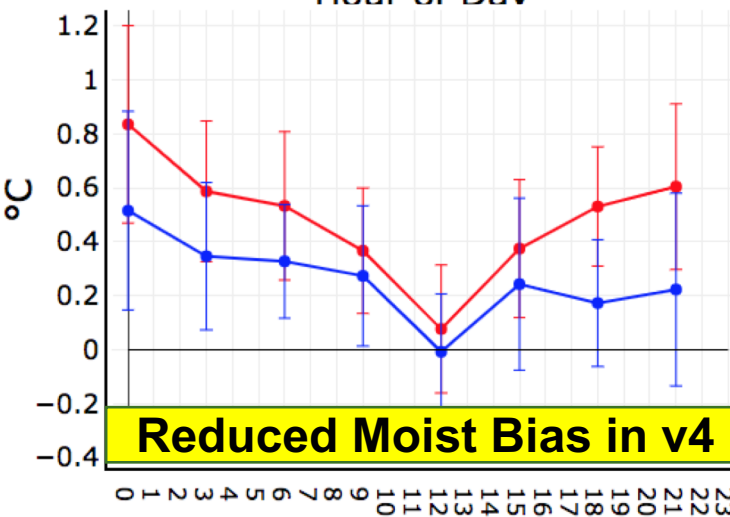
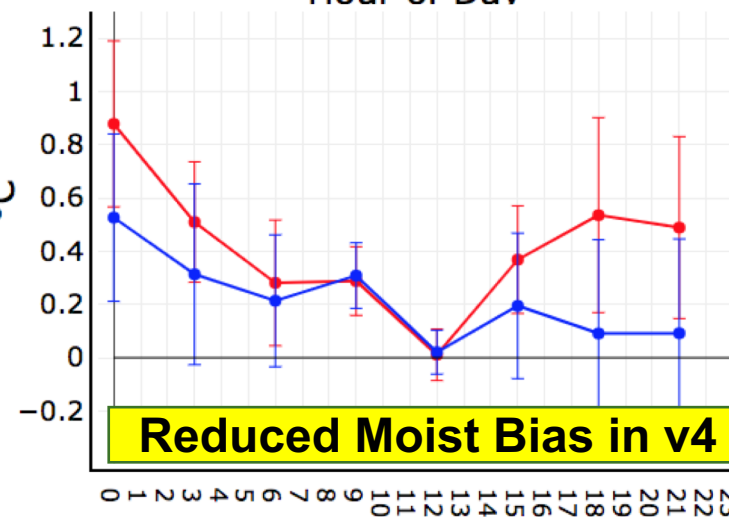
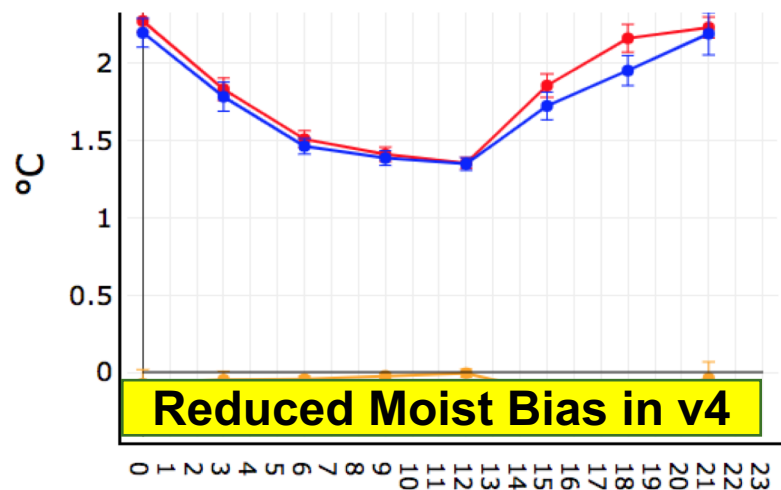


Hour of Day

Hour of Day

Hour of Day

bias



Hour of Day

Hour of Day

Hour of Day

Data Assimilation

Curtis Alexander, Amanda Back, Stan Benjamin, David Dowell, Jeff Duda, Guoqing Ge, Ming Hu, Eric James, Terra Ladwig, Haidao Lin, Steve Weygandt

Model Physics/Chemistry

Ravan Ahmadov, Hannah Barnes, Stan Benjamin, John Brown, Georg Grell, Siwei He, Jaymes Kenyon, Joe Olson, Tanya Smirnova, Mike Toy, Greg Thompson (NCAR)

Model Assessment/Verification

Trevor Alcott, Jason English, Venita Hagerty, Jeff Hamilton, Brian Jamison, Bill Moninger, Randy Pierce, Molly Smith, Bonny Strong, Ed Szoke, Dave Turner

Retrospectives Execution

Trevor Alcott, David Dowell, Jason English, Eric James, Jaymes Kenyon, Terra Ladwig

WCOS Parallel Maintenance and Support

David Dowell, Ming Hu, Sam Trahan

Management

Curtis Alexander, Melinda Marquis

EMC RAPv5/HRRRv4 Effort

Project Manager

Geoff Manikin

Code Manager

Ben Blake

EIB Compliance Check

Kate Howard

MEG

Geoff Manikin, Alicia Bentley, Logan Dawson, Shannon Shields

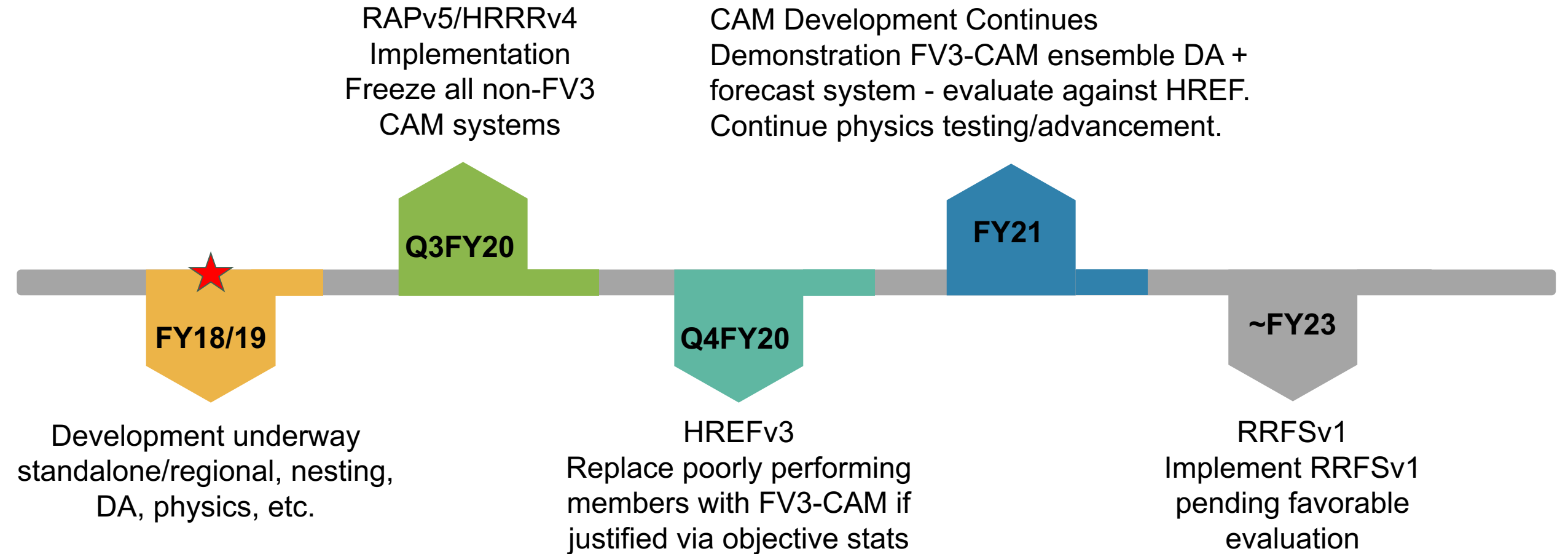
Verification

Logan Dawson, Perry Shafran, Ying Lin, Binbin Zhou

Management

Jason Levit, Vijay Tallapragada, Arun Chawla

FV3-CAM Timeline → Rapid Refresh Forecast System



Rapid Refresh Forecast System → To replace HREF, HRRR, NAM + nests, HiResWs

Timeline may be revised as development matures/progresses