

RAP/HRRR: Hourly-Updating Weather Forecast Suite

**13-km Rapid Refresh
(RAPv4) – to 39h (Feb 2018)**

Initial & Lateral
Boundary
Conditions

**3-km High-Resolution
Rapid Refresh (HRRRv3)
– to 36h (Feb 2018)**

Initial & Lateral
Boundary
Conditions

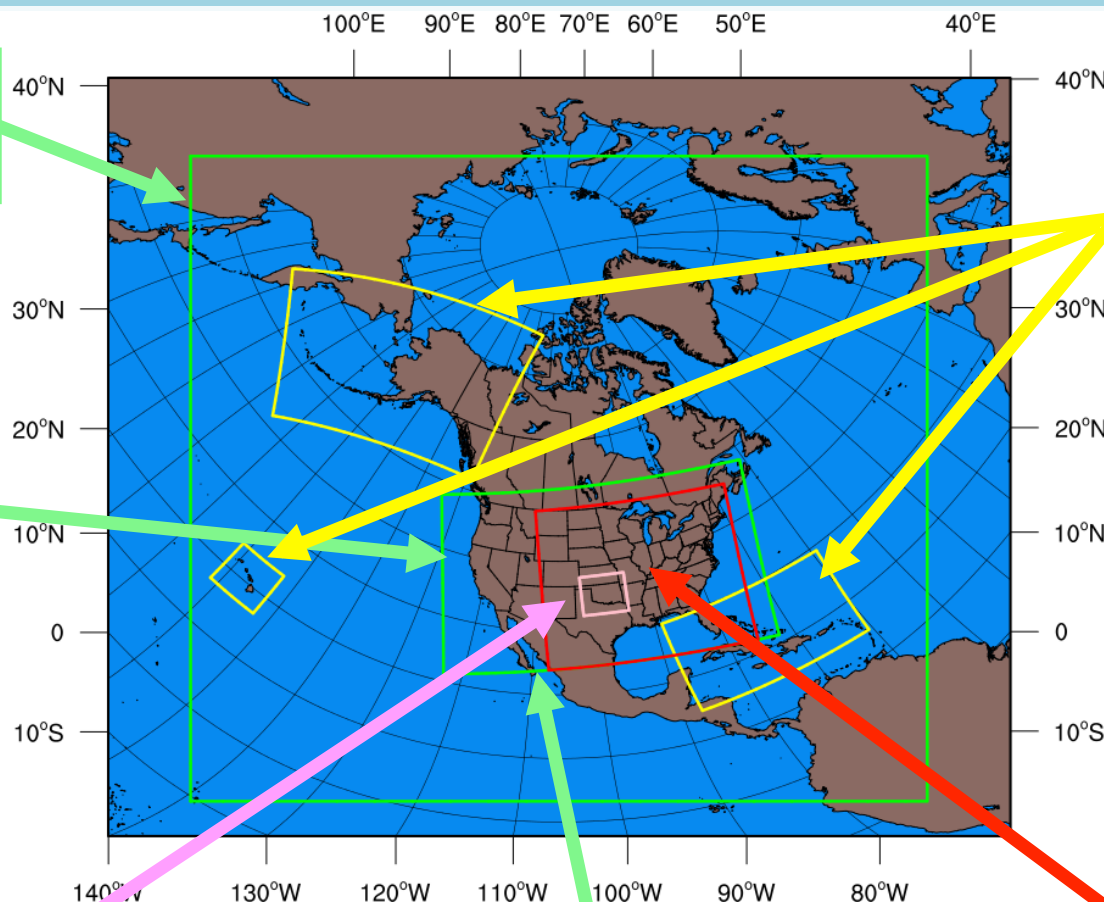
750-m HRRR nest
Scale-aware Physics
Testing (ongoing)

**3-km High-Resolution Time Lagged
Ensemble (HRRR-TLE)**

3-km HRRR-Smoke (VIIRS fire data)

**3-km High-Resolution
Rapid Refresh Alaska,
Hawaii and Puerto Rico
Testing (HRRR-AK,
HRRR-HI, HRRR-PR)
Experimental (ongoing)**

**3-km Storm-Scale
Ensemble Analysis and
Forecast (HRRRE)
55% CONUS HRRR
Experimental (ongoing)**



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**

13 Feb 2018

- RAPv4/HRRRv3: Hybrid Vertical Coordinate, Eddy Diffusivity Mass Flux PBL
- **Reduction in short-lead biases and improved mesoscale environment**

Extended Forecast Lengths

RAP: 03z, 09z, 15z, 21z 21 hrs → 39 hrs

RAP: All other hourly cycles remain 21 hrs

HRRR: 00z, 06z, 12z, 18z 18 hrs → 36 hrs

HRRR: All other hourly cycles remain 18 hrs

OCONUS Domains

HRRR-Alaska:

Every 3 hrs to 18 hrs

Every 6 hrs to 36 hrs

HRRR-Hawaii: ??

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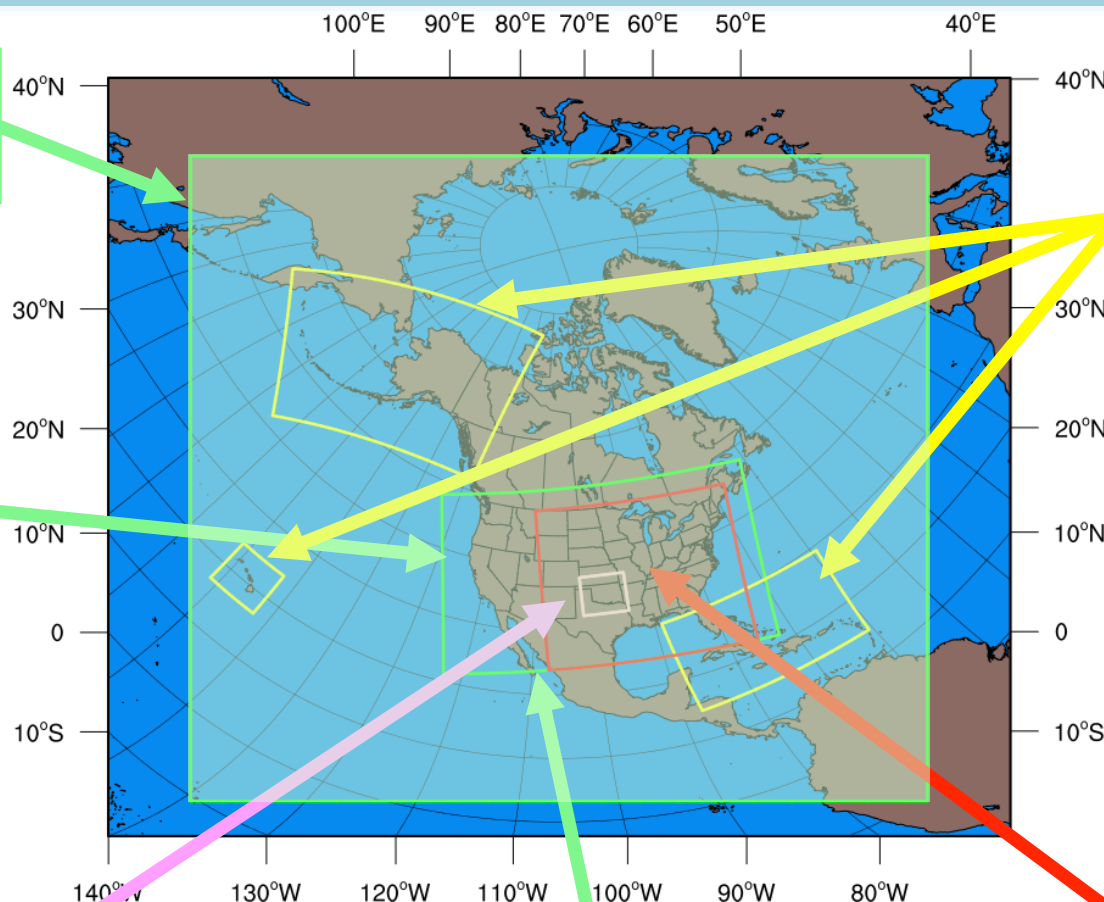
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RAPv4/HRRRv3 Change Highlights

	Model	Data Assimilation
RAPv4 (13 km)	WRF-ARW v3.8.1+ incl. physics changes <u>Physics changes (12 changes):</u> Thompson microphysics – improved upper-level clouds GF Convective update – more optimal precip bias MYNN PBL update – better sub-grid clouds, meso env LSM update – 15” MODIS data – better lower boundary Refined roughness lengths over various land use types <u>Numerics changes (3 changes):</u> Improved terrain (cell avg) – better winds /turbulence Hybrid vertical coordinate from NCAR – better meso env Full geometric diffusion – better winds/temp in terrain	Merge with GSI trunk – last updated in May 2017 <u>New Observations for assimilation (4 changes):</u> NCEP new VAD wind retrievals AMVs over land and TAMDAR Add IASI, CrIS, SEVIRI radiances <u>Assimilation Methods (9 changes):</u> Revised PBL pseudo-obs – reduce RH bias More ensemble weight in hybrid DA (0.85/0.15) METAR/GOES cloud consistent (<1200m AGL) Cloud building – smaller qc/qi – more retention Reduced latent heating – improved precip bias
HRRRv3 (3 km)	WRF-ARW v3.8.1+ incl. physics changes <u>Physics changes (12 changes):</u> Thompson microphysics – improved upper-level clouds MYNN PBL update – better sub-grid clouds, meso env LSM update – 15” MODIS data – better lower boundary Refined roughness lengths over various land use types Gravity wave drag (RAP and HRRR) – better winds <u>Numerics changes (2 changes):</u> Hybrid vertical coordinate from NCAR – better meso env Full geometric diffusion – better winds/temp in terrain	<u>New Observations for assimilation (5 changes):</u> NCEP new VAD wind retrievals AMVs over land and TAMDAR Radar radial velocity and lightning <u>Assimilation Methods (9 changes):</u> Revised PBL pseudo-obs – reduce RH bias More ensemble weight in hybrid DA (0.85/0.15) METAR and GOES cloud consistent (<1200 m AGL) Cloud building – smaller qc/qi – more retention

RAPv4/HRRRv3 Summary of Changes

Operational RAPv3/HRRRv2

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	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCO	CONUS	1799 x 1059	3 km	50	Sigma	20 mb	RAP	Hourly (pre-forecast hour cycle)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.6+	GSI Hybrid Ensemble to 0.75	13-km DFI	RRTMG/ RRTMG	Thompson Aerosol v3.6	GF + Shallow	MYNN v3.6	RUC v3.6
HRRR	WRF-ARW v3.6+	GSI Hybrid Ensemble to 0.75	3-km 15-min LH	RRTMG/ RRTMG	Thompson Aerosol v3.6	None	MYNN v3.6	RUC v3.6

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	Simple (1)	Yes 0.12	20 min	MODIS Seasonal	0.01 K/s	60 s
HRRR	5 th /5 th	Positive-Definite	w-Rayleigh 0.2	Simple (1)	Yes 0.25	15 min with SW-dt	MODIS Seasonal	0.07 K/s	20 s

RAPv4/HRRRv3 Summary of Changes

Upcoming 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)

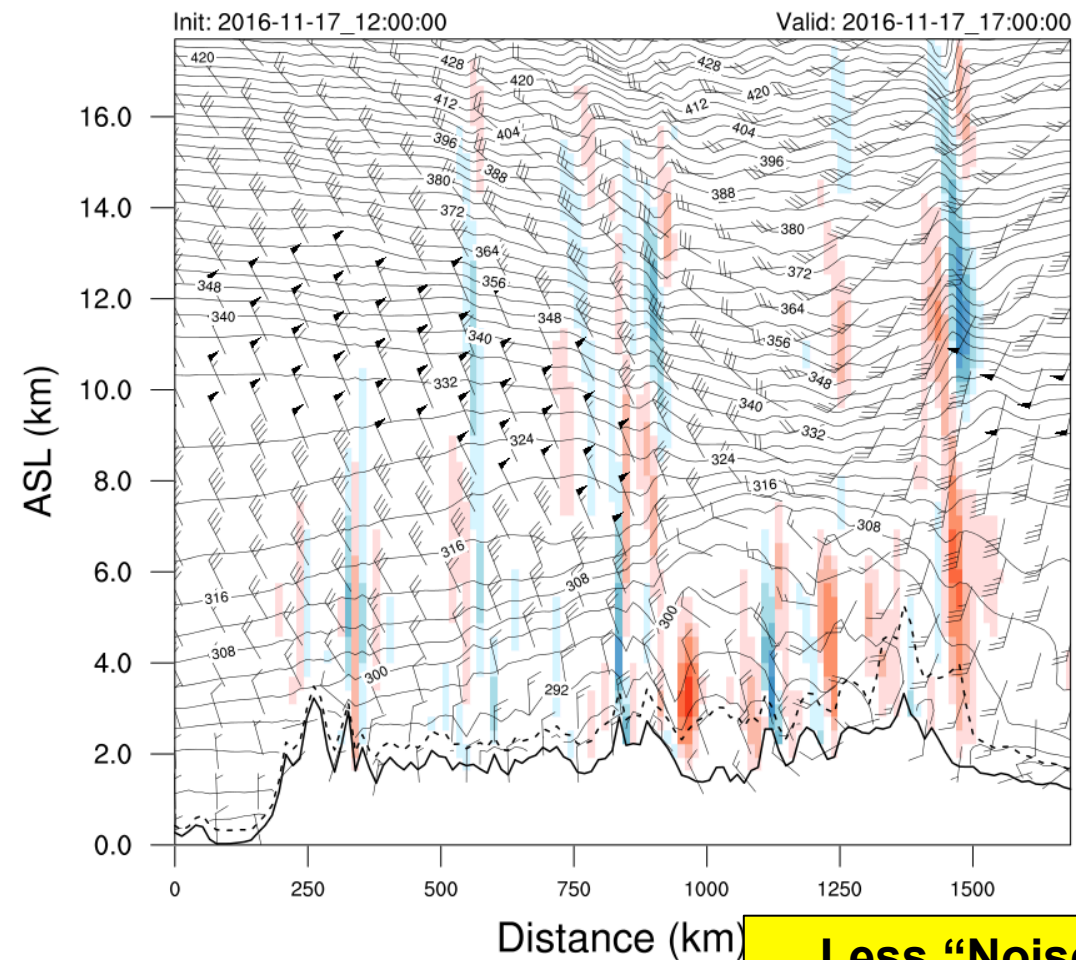
Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.8.1+	GSI Hybrid Ensemble to 0.85	13-km DFI, ½ Strength	RRTMG/ RRTMG	Thompson Aerosol v3.8.1	GF + Shallow	MYNN v3.8.1	RUC v3.8.1
HRRR	WRF-ARW v3.8.1+	GSI Hybrid Ensemble to 0.85	3-km 15-min LH	RRTMG/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

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New RAP/HRRR Vertical Coordinate

Hybrid coordinate

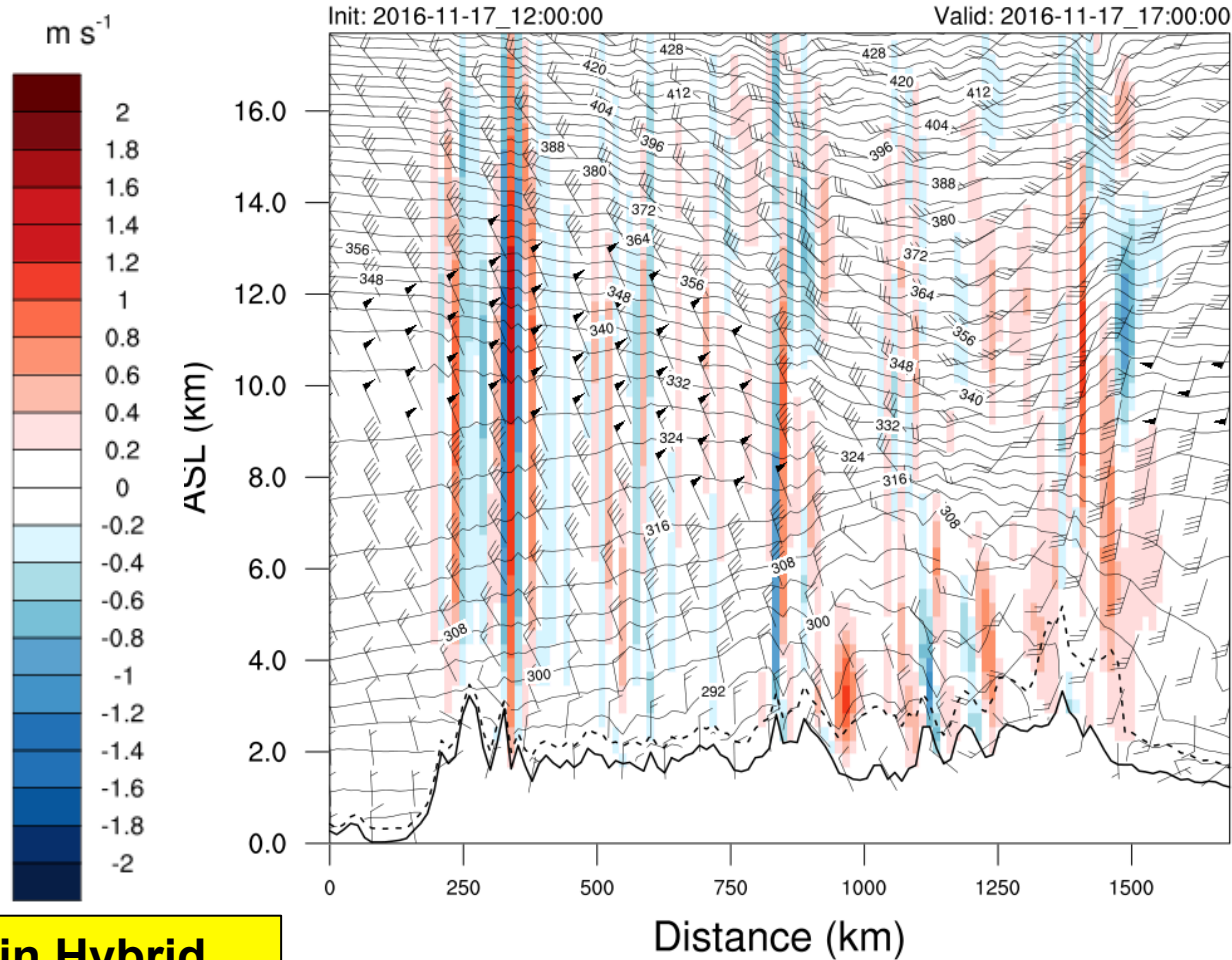
VVEL (fill), POTL TEMP (black), PBL TOP (dash)



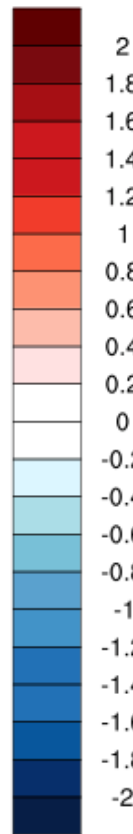
Less "Noise" in Hybrid

Terrain-following coordinate

VVEL (fill), POTL TEMP (black), PBL TOP (dash)



m s^{-1}



RAP RMSE Upper-Air Winter (Three Weeks Jan 2017)

RAPv4
RAPv3 (ops)
RAPv4-RAPv3

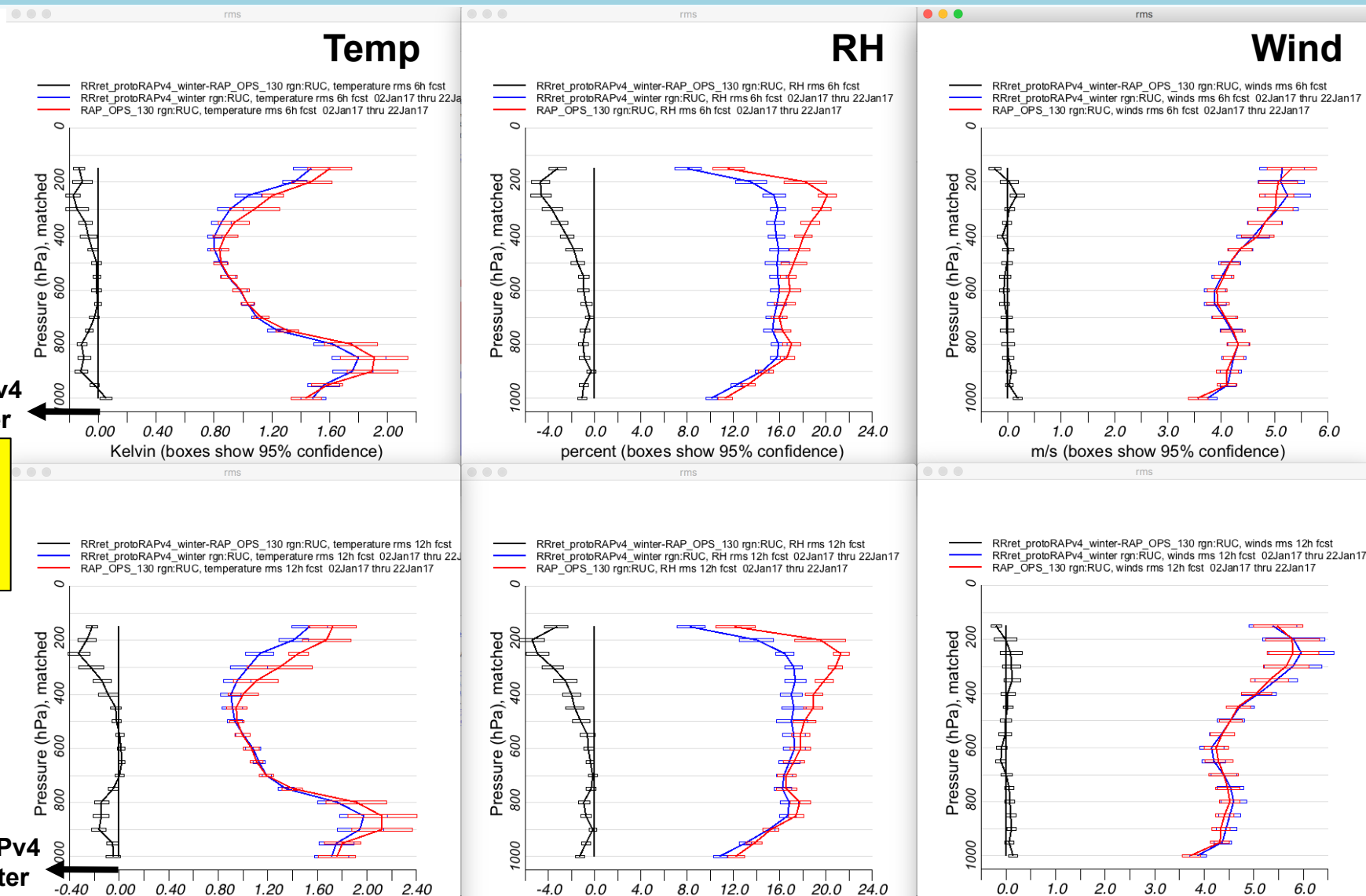
6 hr

**RAPv4
better**

**Full
Tropospheric
Improvements**

12 hr

**RAPv4
better**



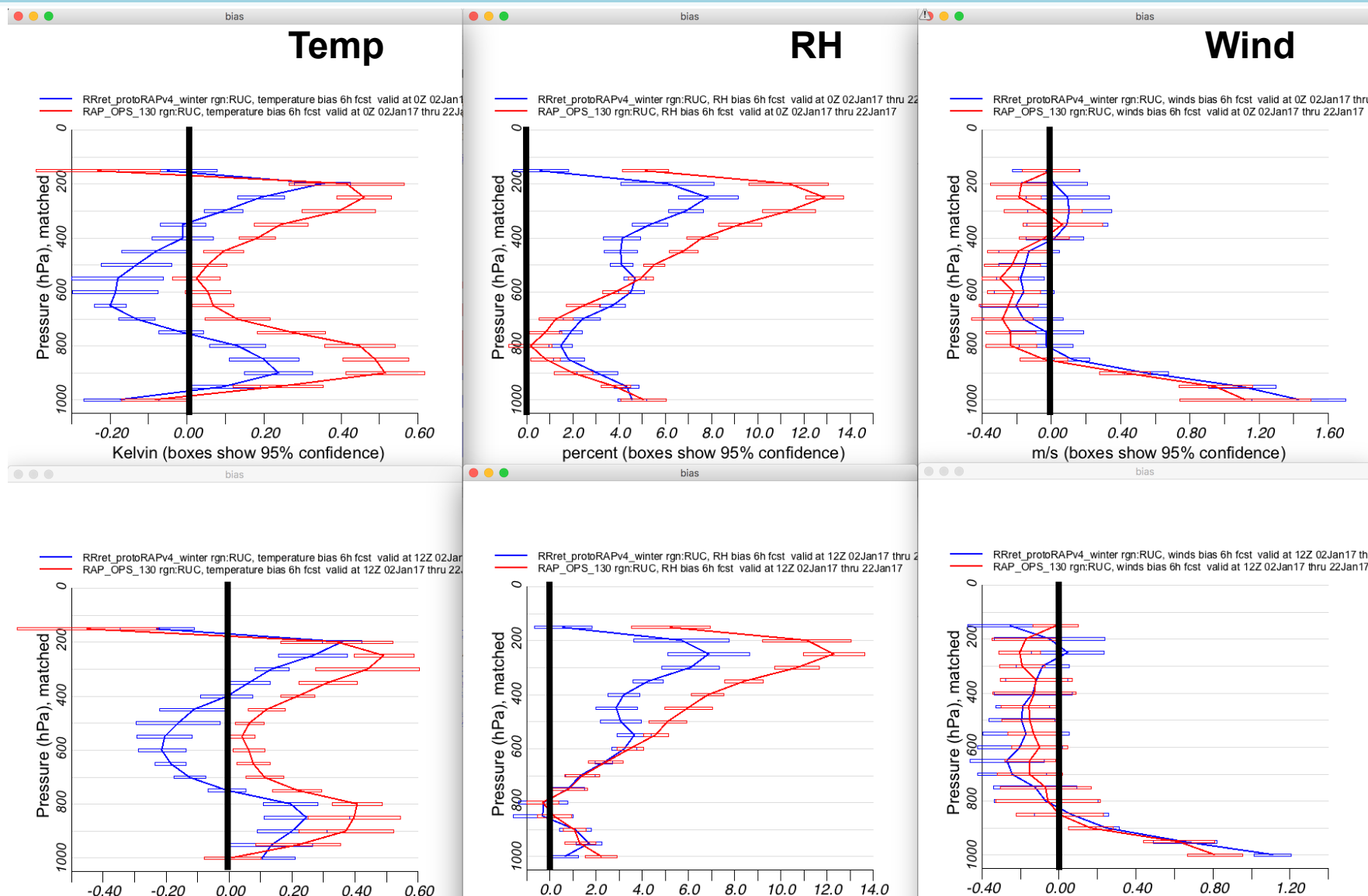
RAP BIAS Upper-Air Winter (Three Weeks Jan 2017)

RAPv4
RAPv3 (ops)
6 hr fcsts

00 UTC

**Reduced
 RH Bias
 Aloft**

12 UTC



RAP RMSE Upper-Air Summer (Three Weeks Jul 2016)

RAPv4
RAPv3 (ops)
RAPv4-RAPv3

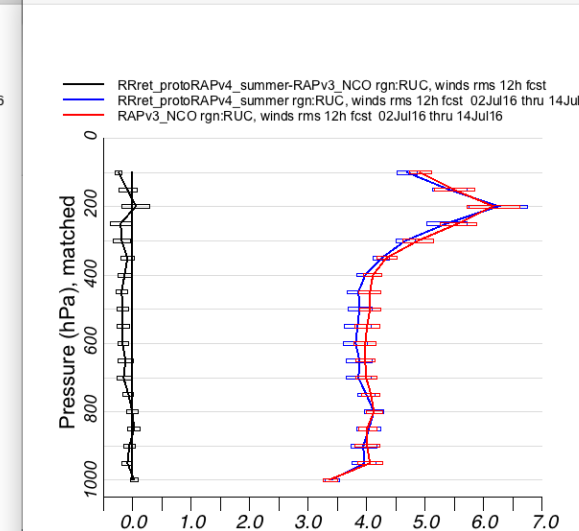
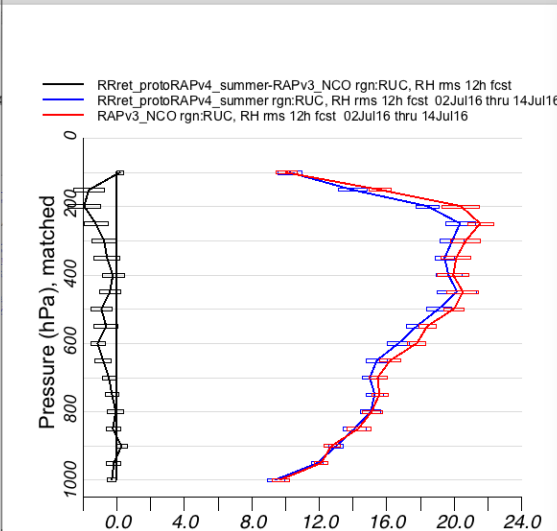
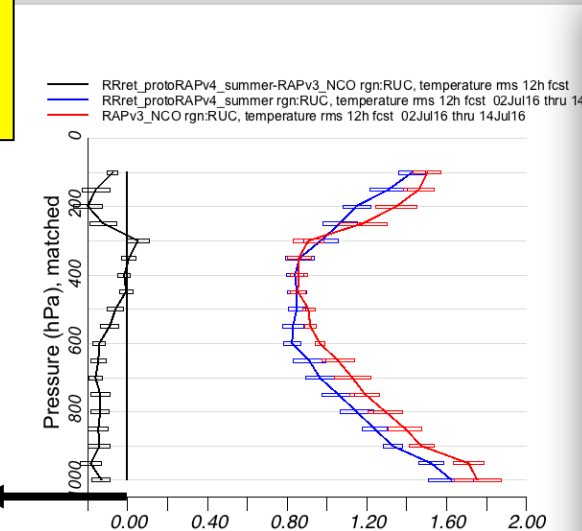
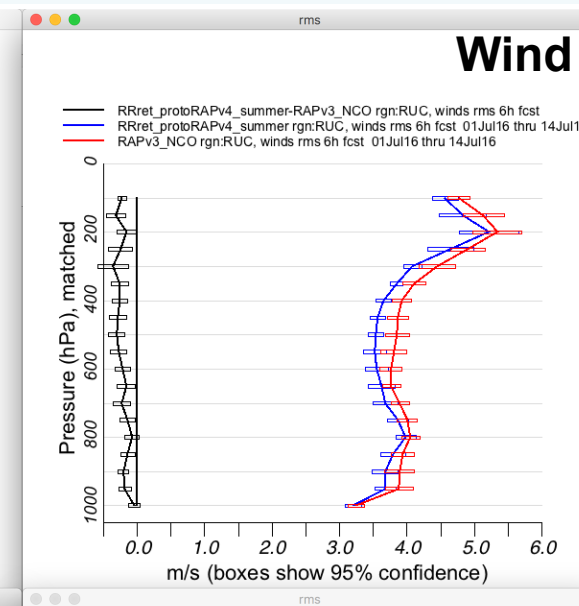
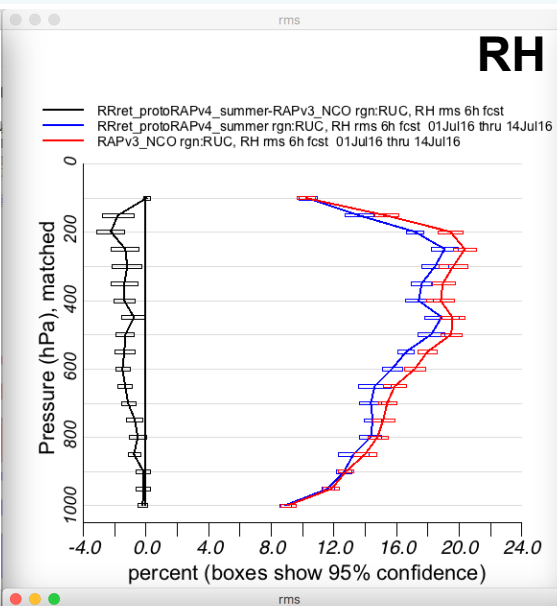
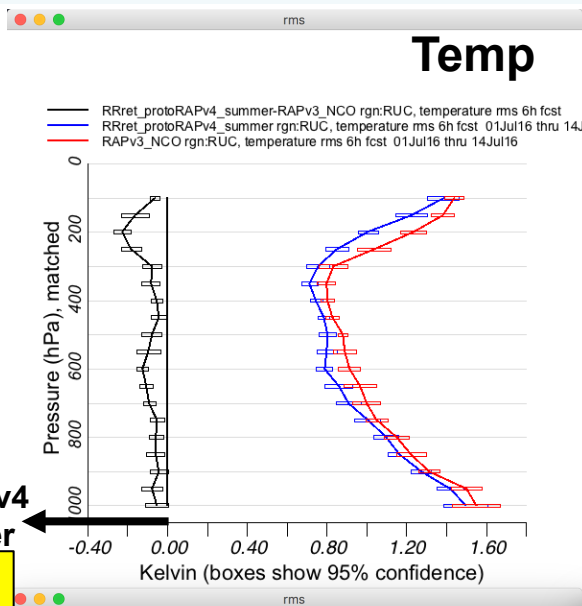
6 hr

RAPv4
better

**Full
Tropospheric
Improvements**

12 hr

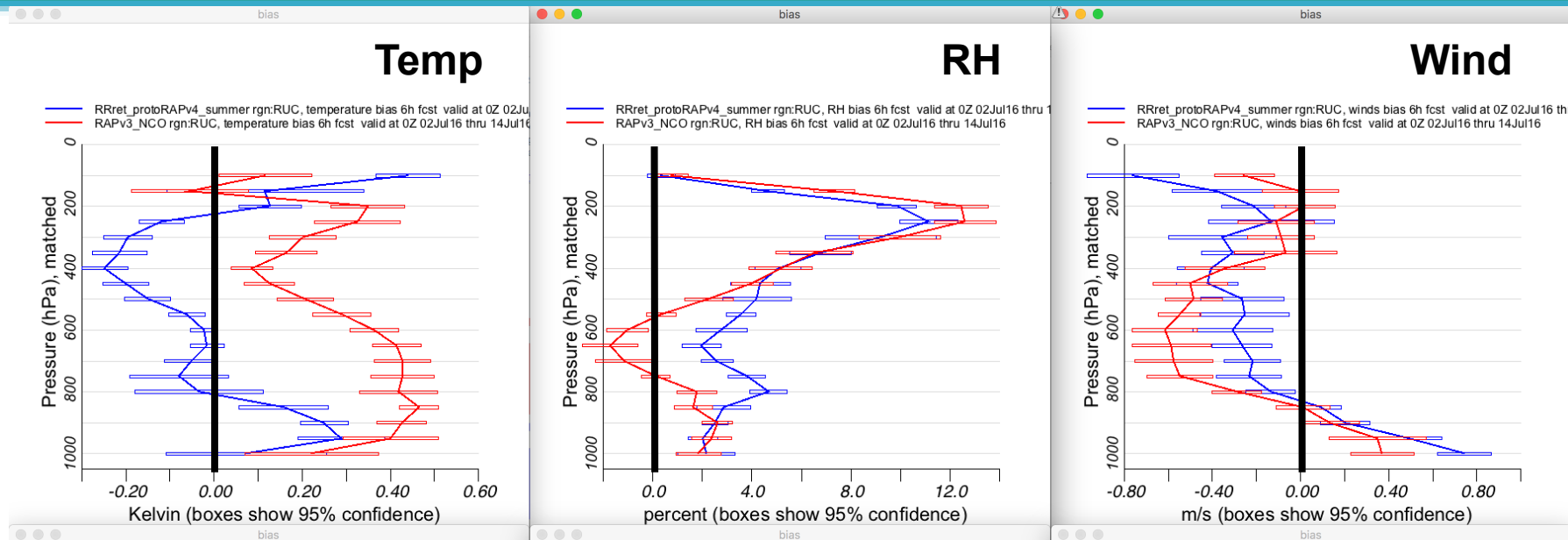
RAPv4
better



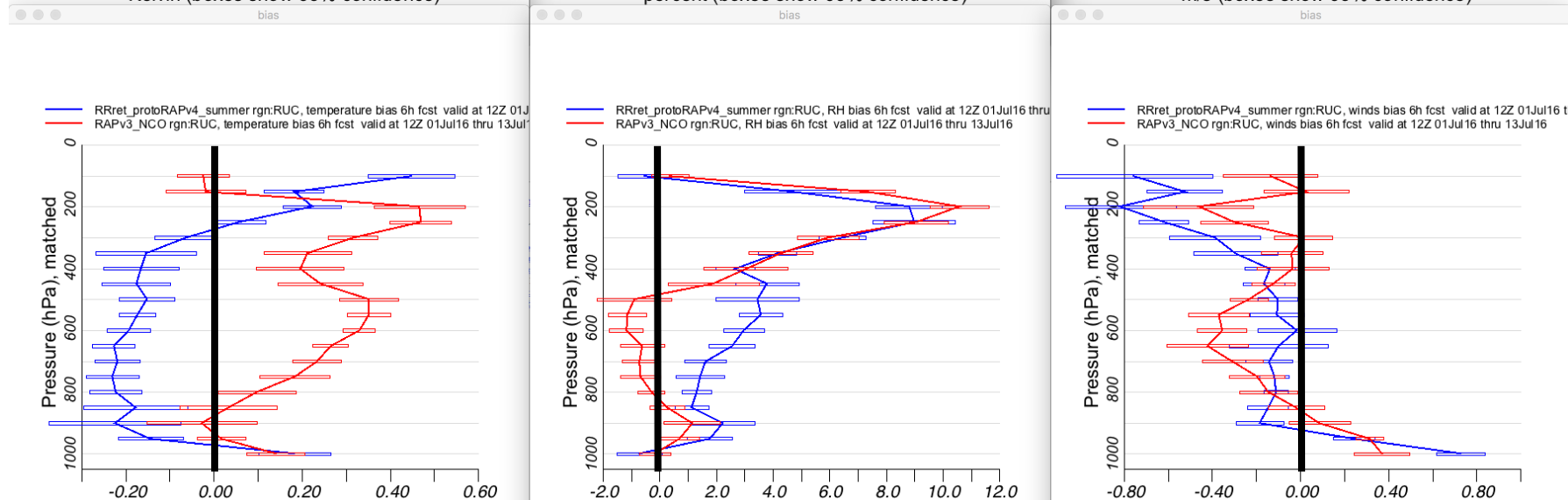
RAP BIAS Upper-Air Summer (Three Weeks Jul 2016)

RAPv4
RAPv3 (ops)
6 hr fcsts

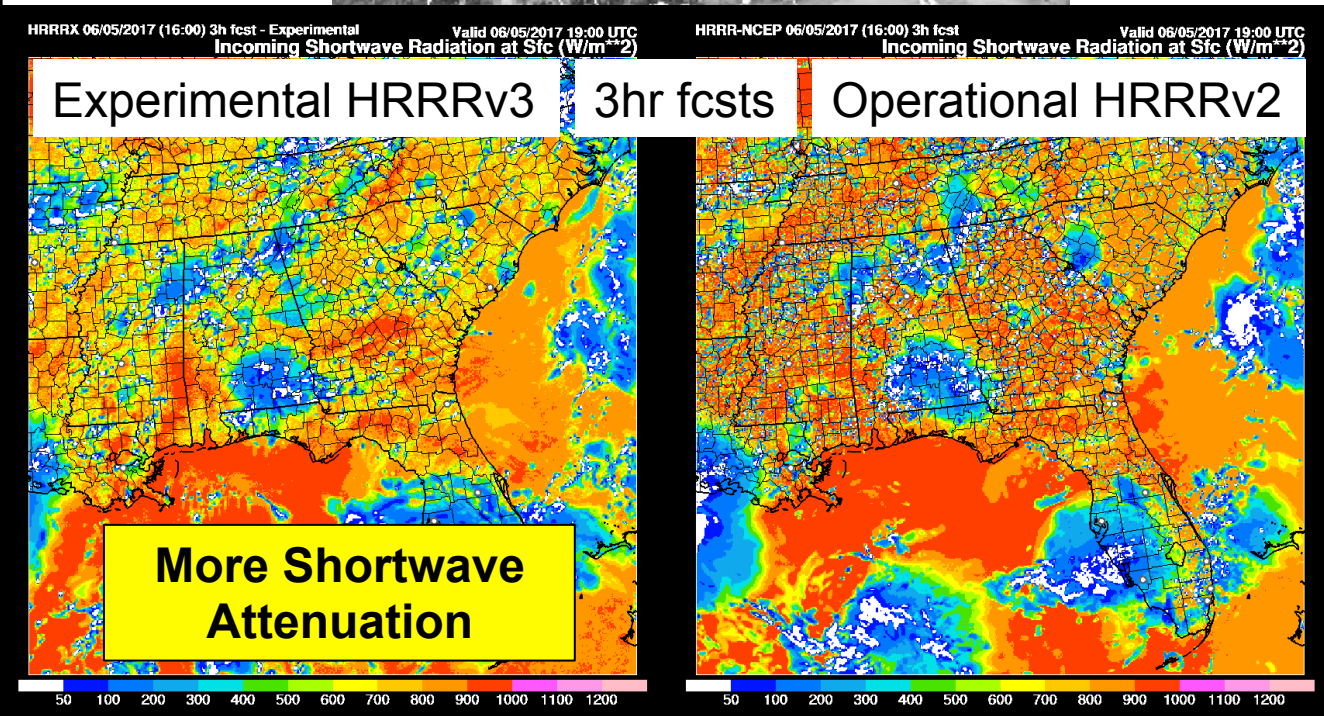
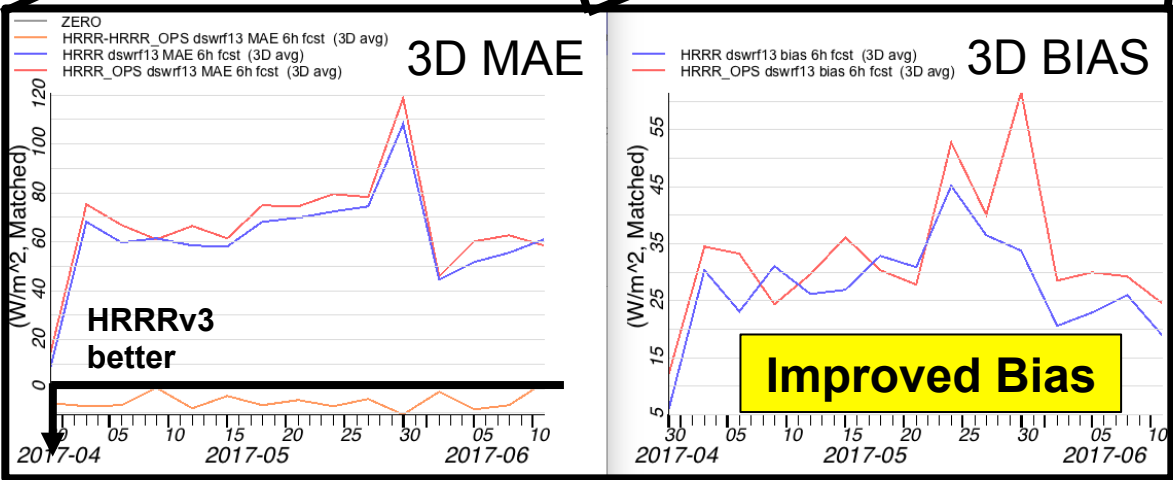
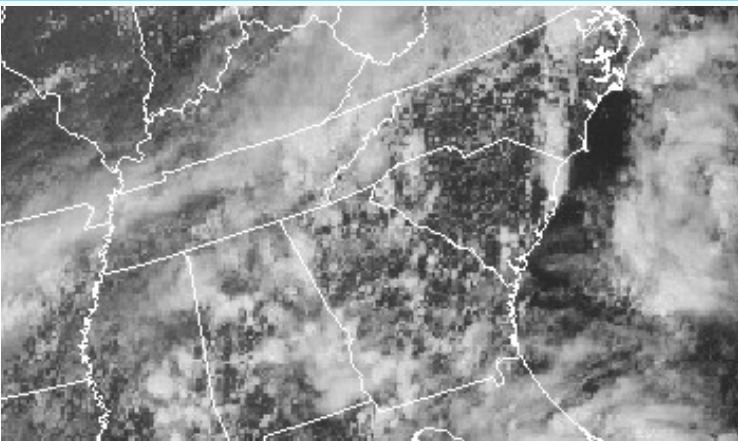
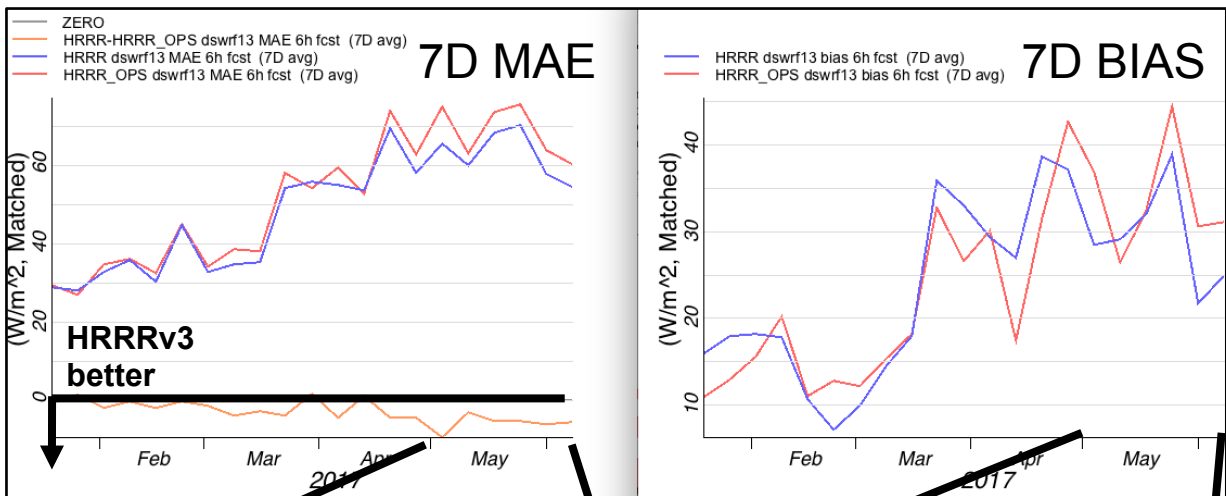
00 UTC



12 UTC



SURFAD/ISIS DSWRF 6hr Fcst Verification



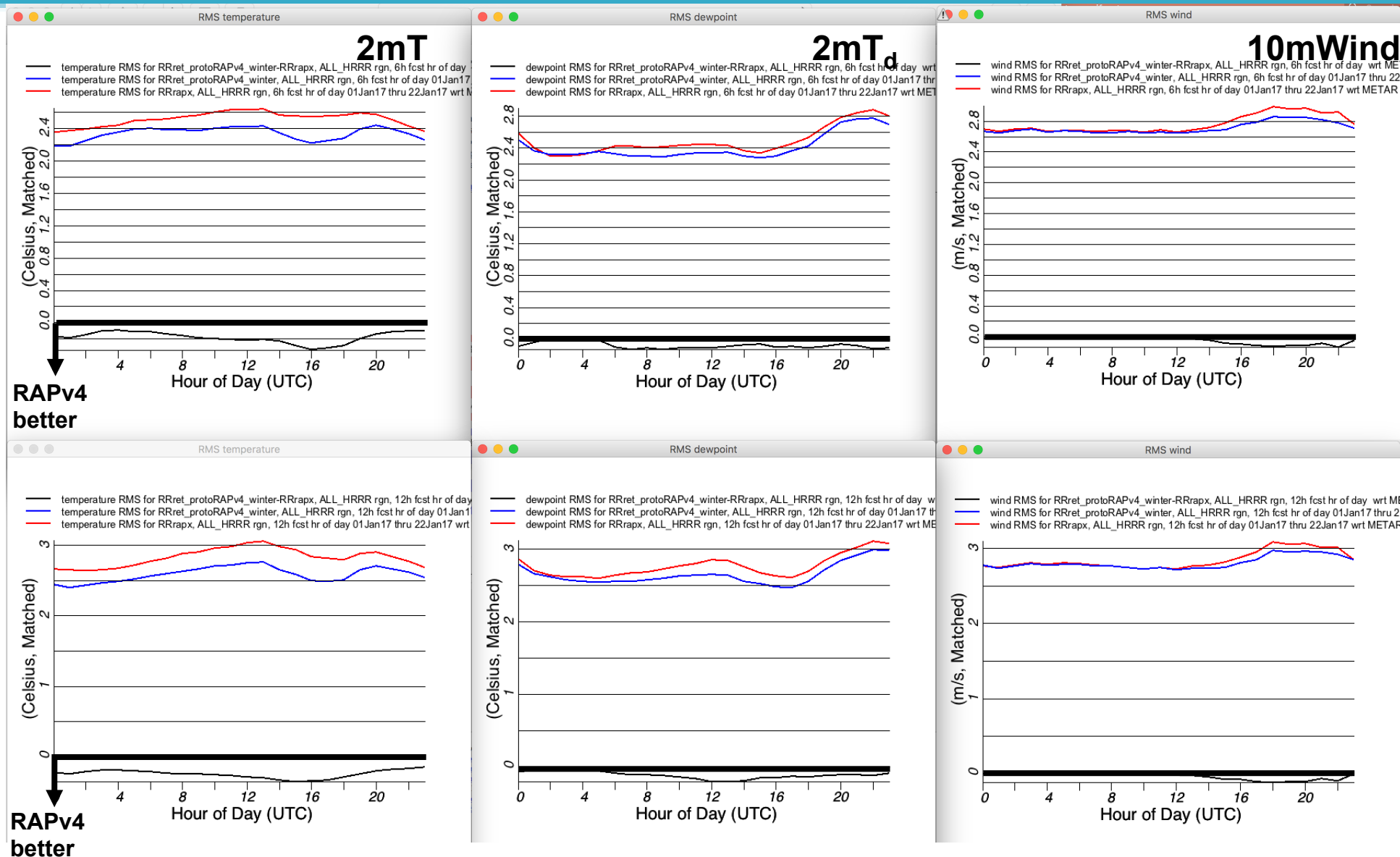
RAP RMSE Surface Winter (Three Weeks Jan 2017)

RAPv4
RAPv3 (ops)
RAPv4-RAPv3

6 hr

Improved
 Diurnal T/
 T_d

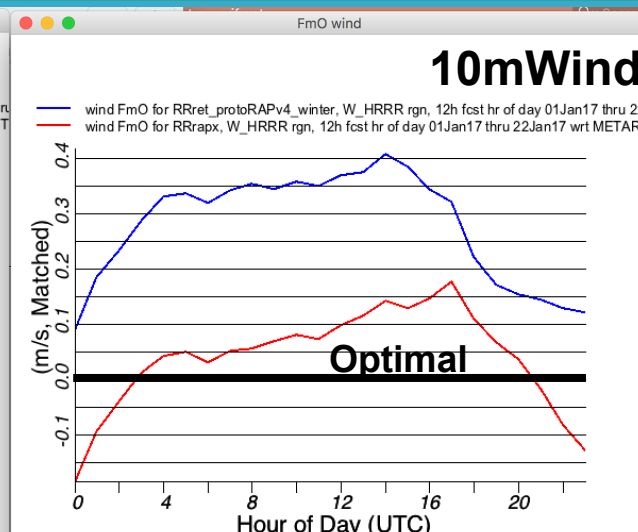
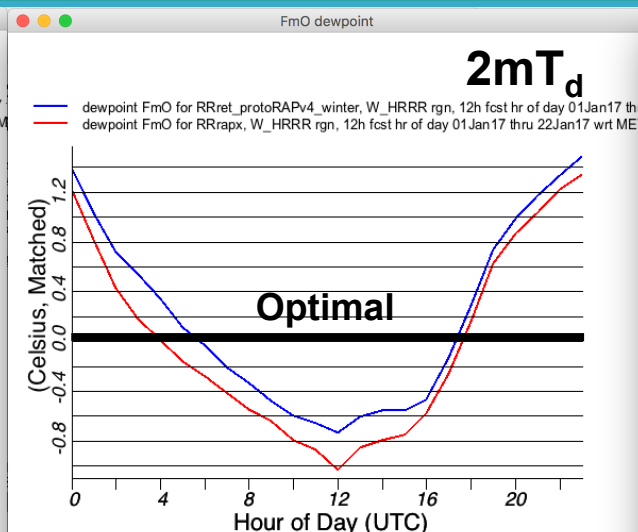
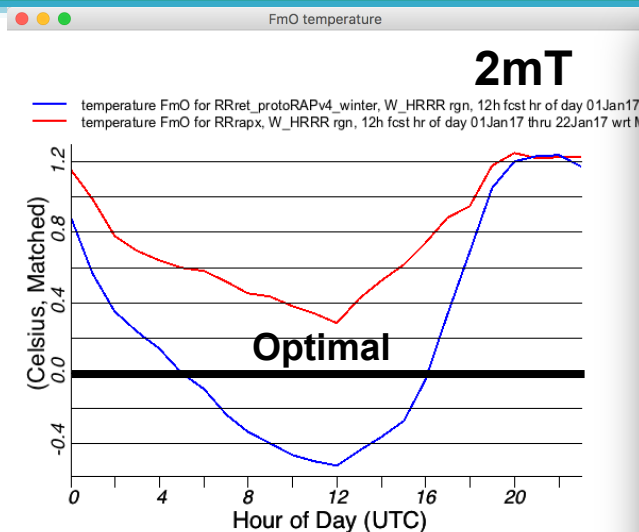
12 hr



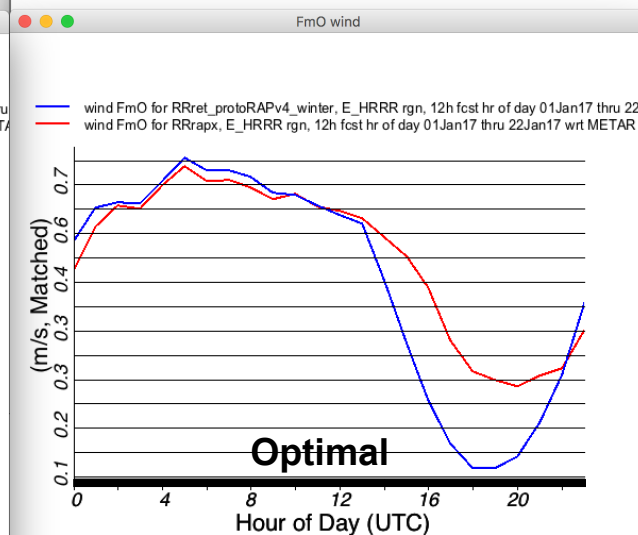
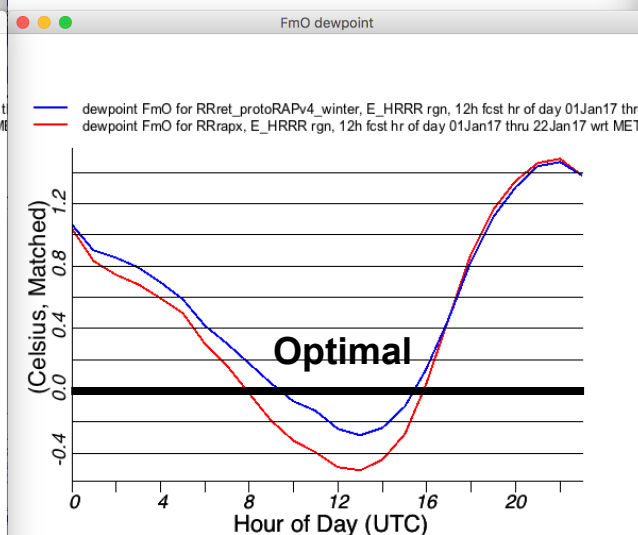
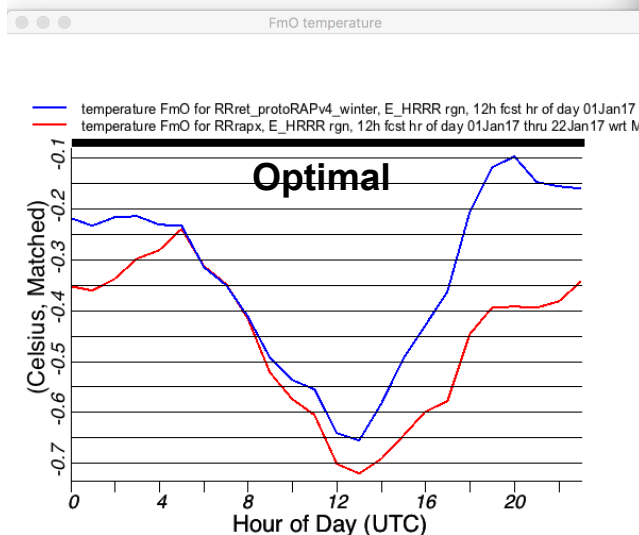
RAP BIAS Surface Winter (Three Weeks Jan 2017)

RAPv4
RAPv3 (ops)
12 hr fcsts

West US



East US



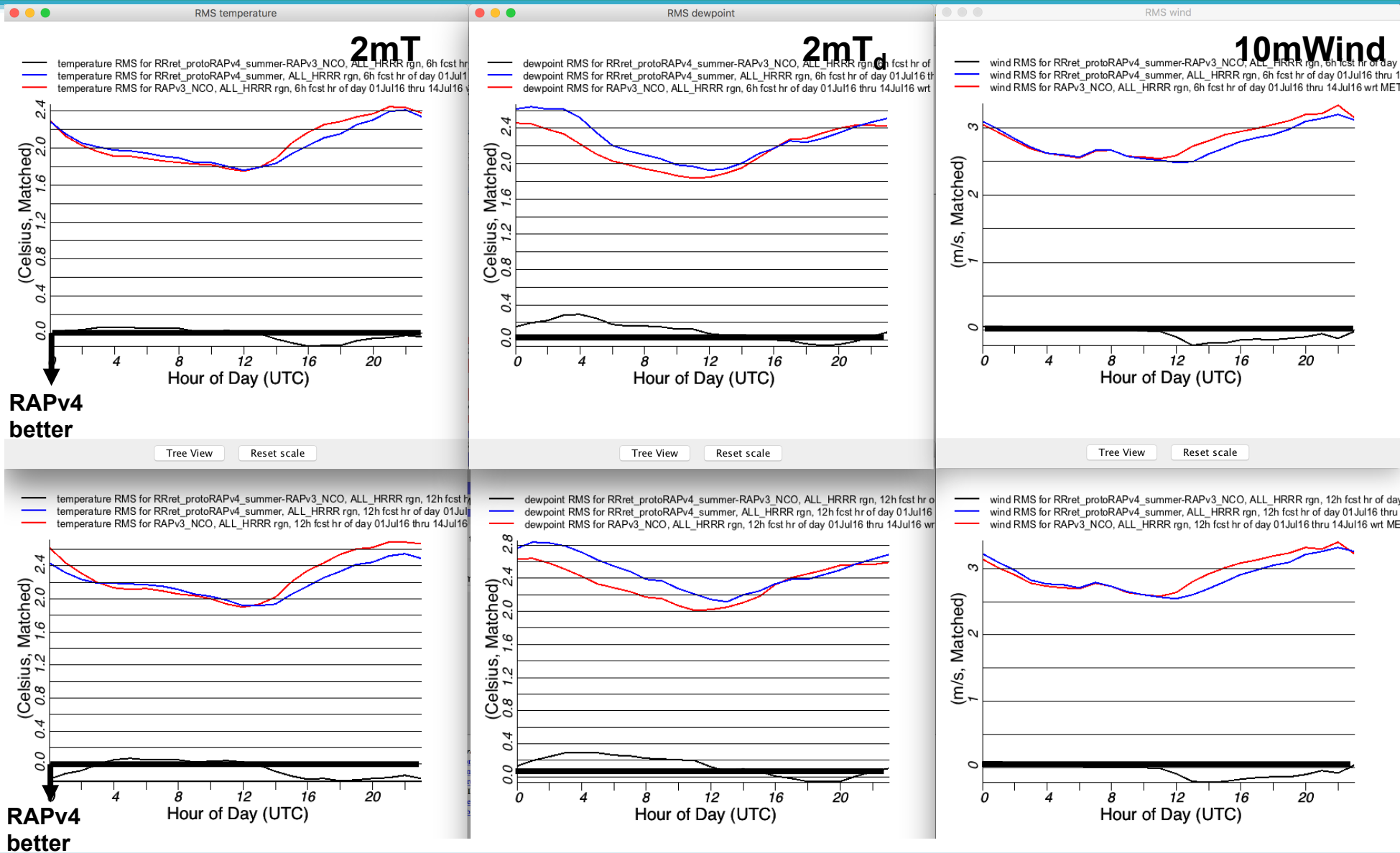
RAP RMSE Surface Summer (Three Weeks Jul 2016)

RAPv4
RAPv3 (ops)
RAPv4-RAPv3

6 hr

Improved
 Daytime T/
 T_d/Wind

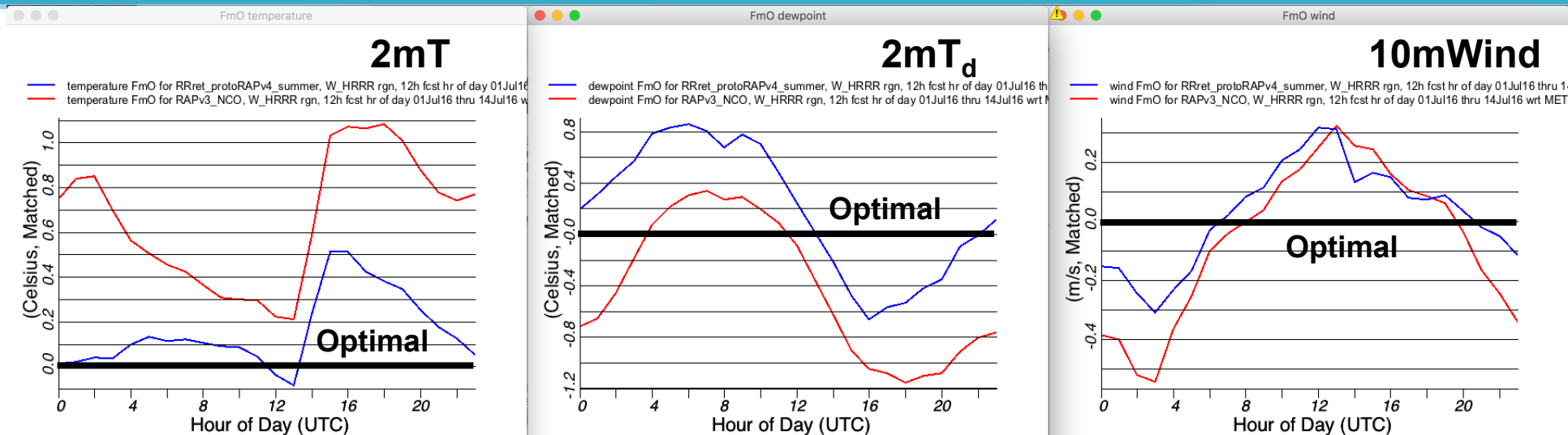
12 hr



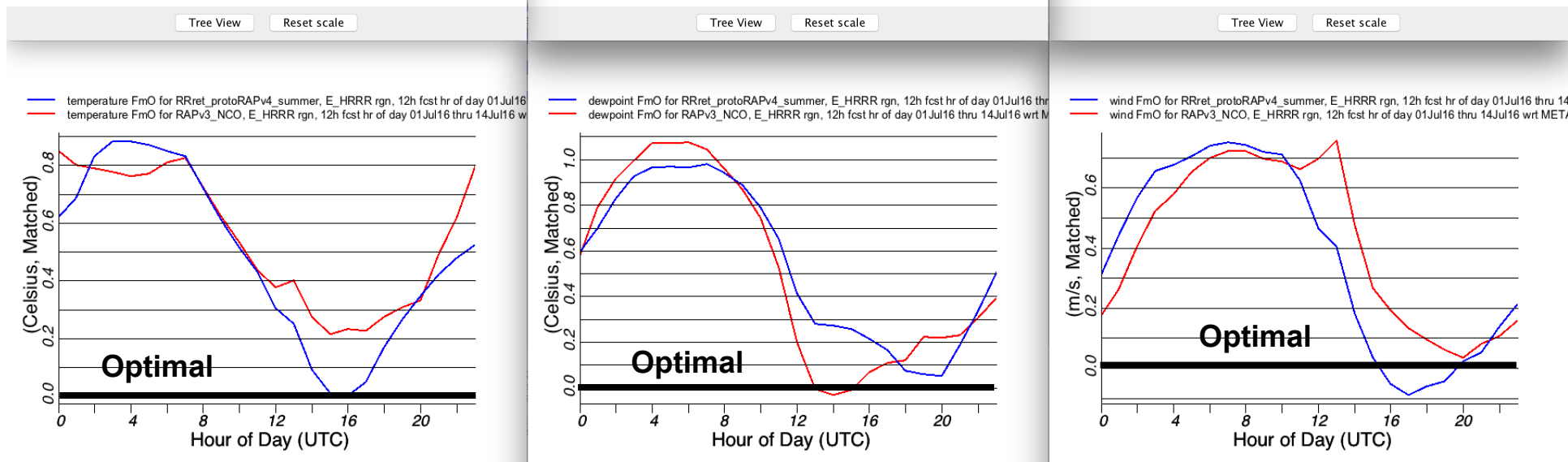
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12 hr fcsts

West US

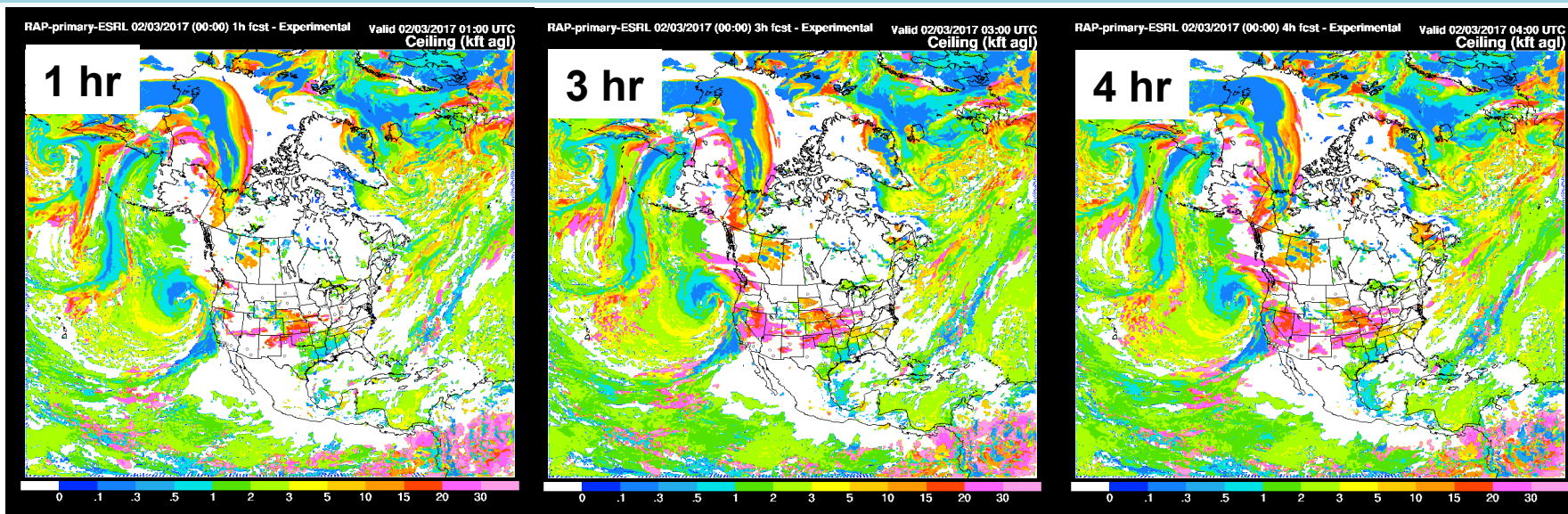


East US

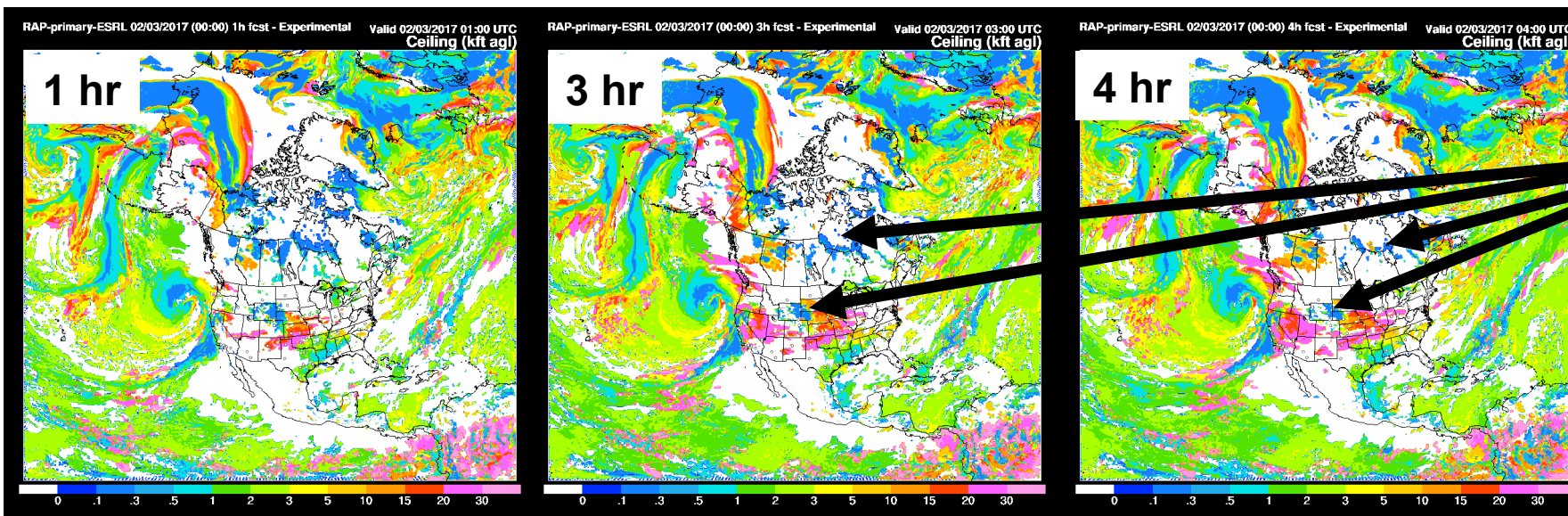


RAP/HRRR Cloud Building w/Smaller Size Distribution

No
qnr/qni
specified



qnr/qni
specified
at large
values
(small
sizes)



More
low
clouds
retained

RAP TSS Ceiling Winter (Three Weeks Jan 2017)

RAPv4
RAPv3 (ops)
RAPv4-RAPv3

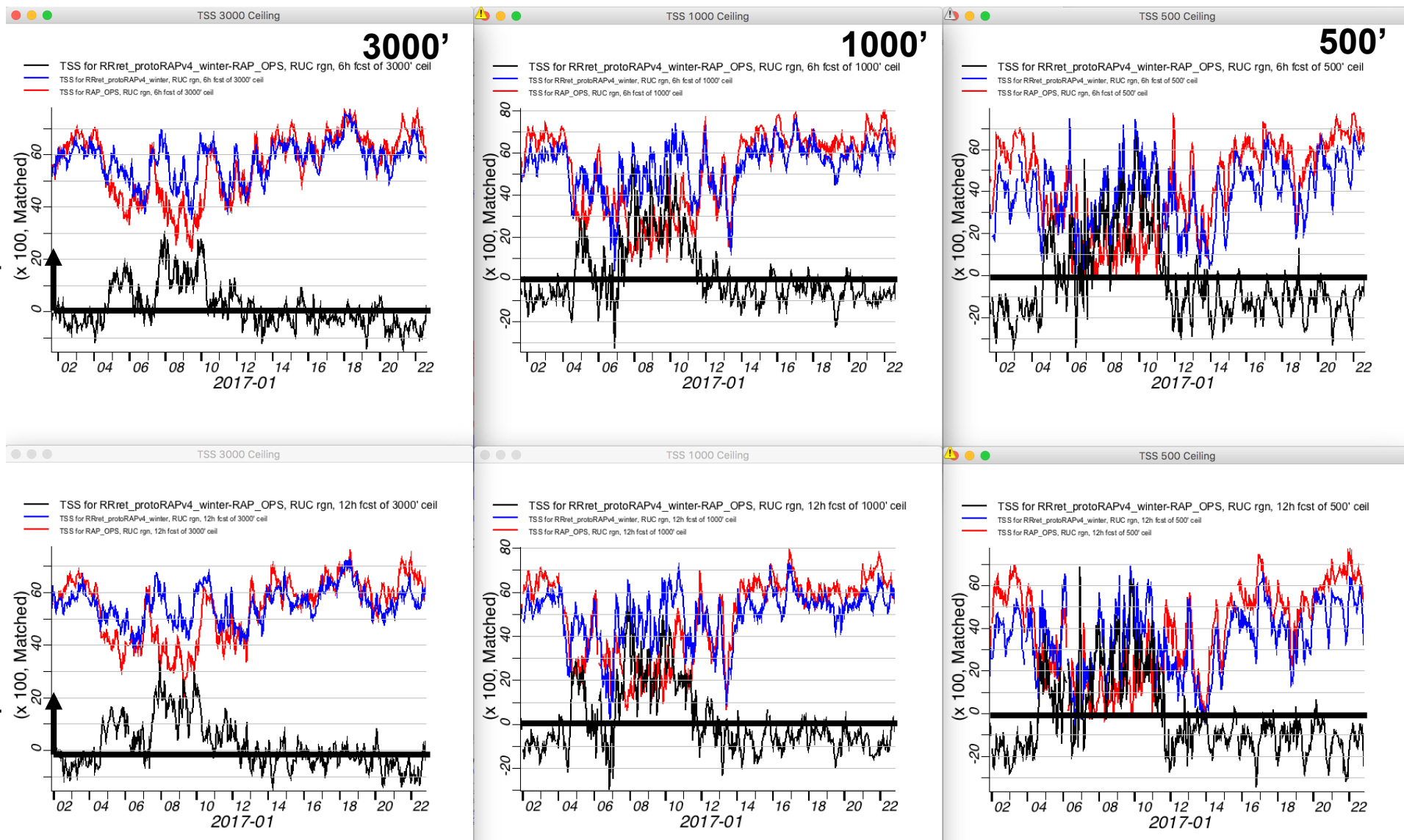
6 hr

**More Skill
 During Cold/
 Cloudy
 Outbreak
 6-11 Jan**

12 hr

**RAPv4
 better**

**RAPv4
 better**

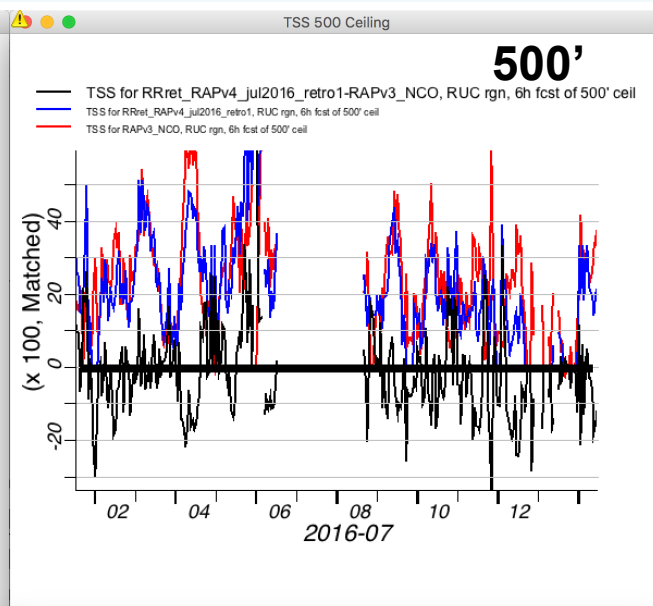
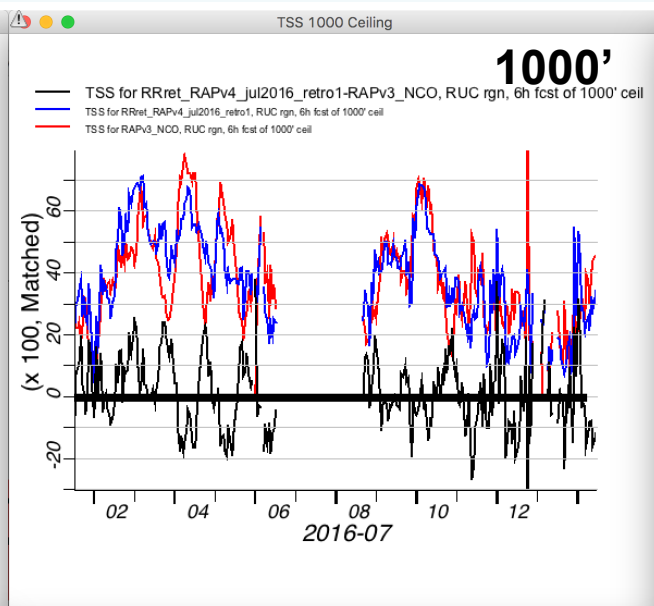
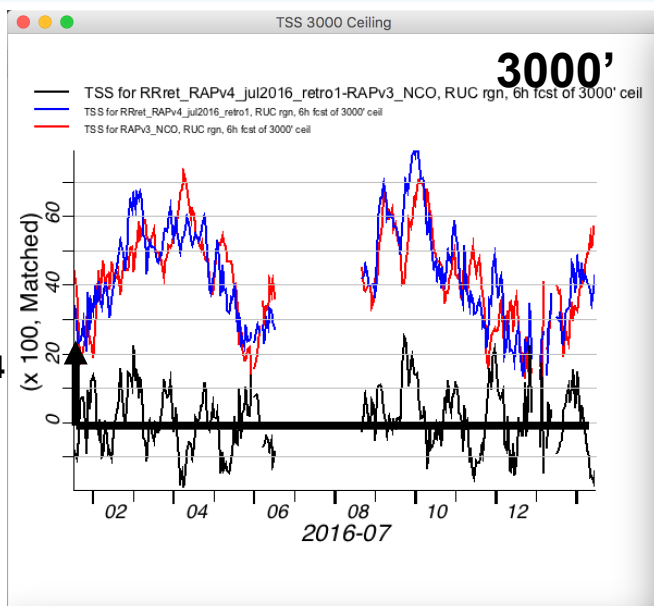


RAP TSS Ceiling Summer (Three Weeks Jul 2016)

RAPv4
RAPv3 (ops)
RAPv4-RAPv3

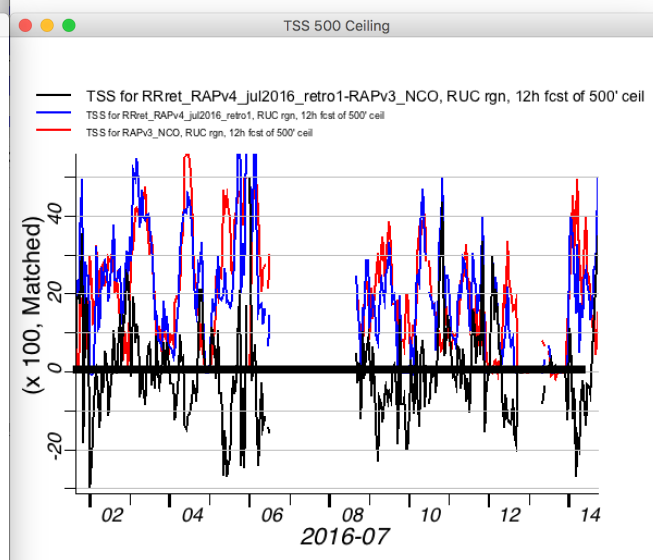
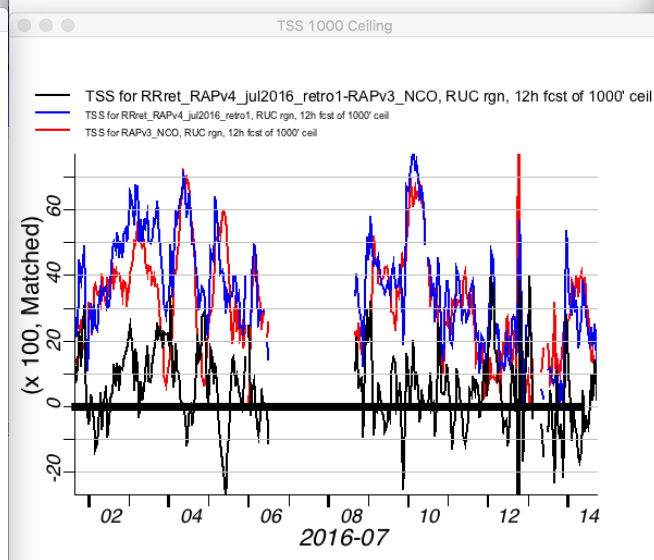
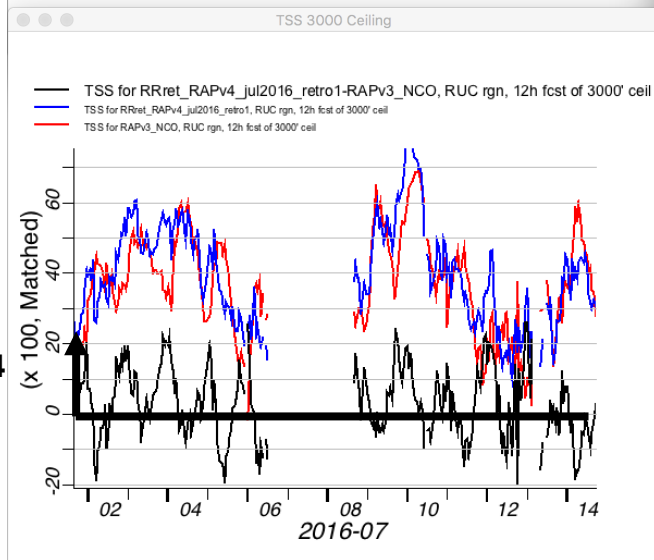
6 hr

**RAPv4
better**



12 hr

**RAPv4
better**



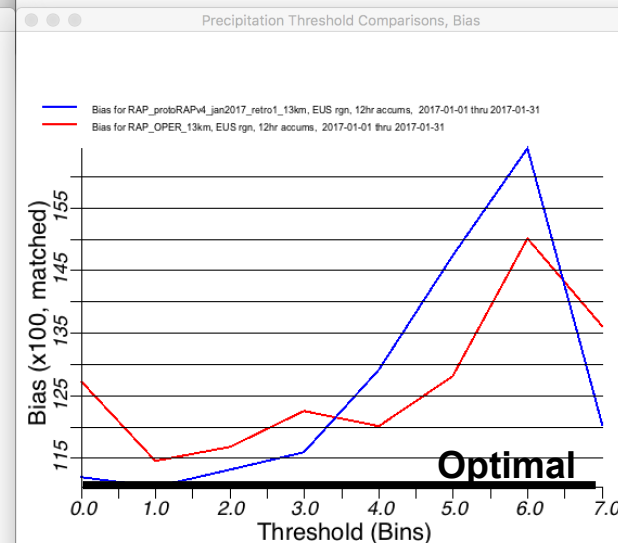
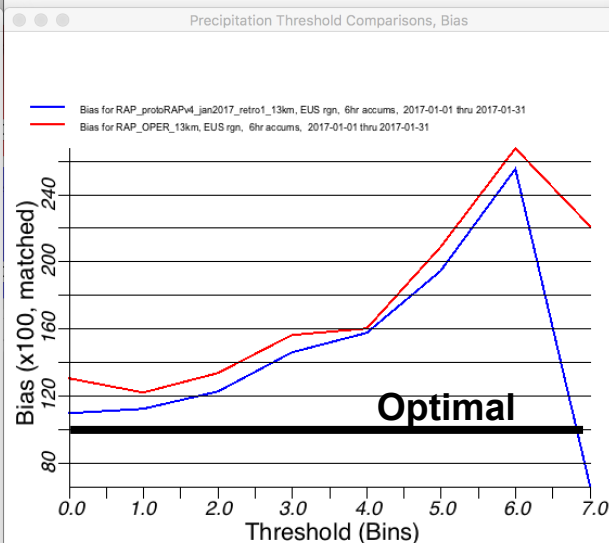
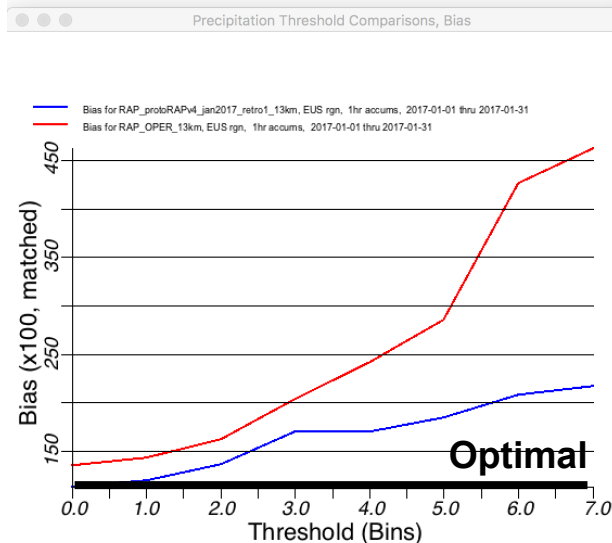
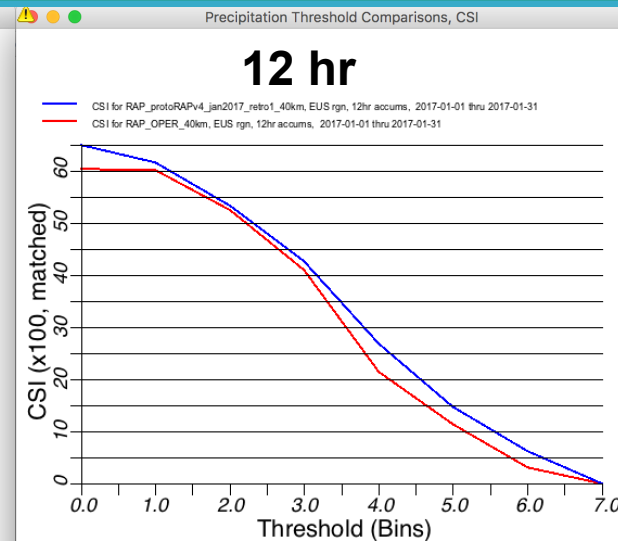
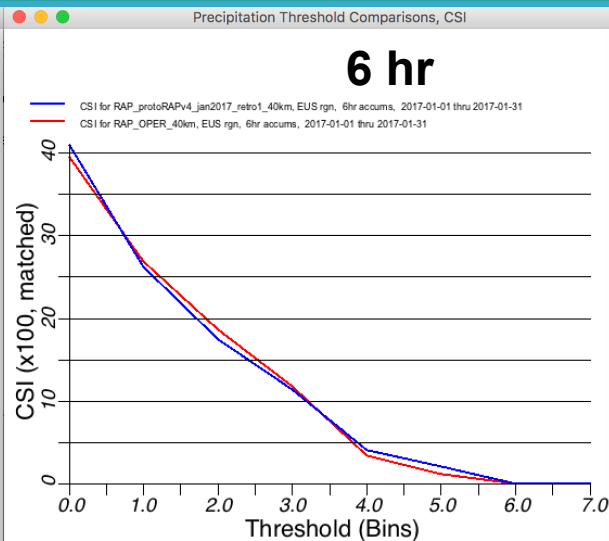
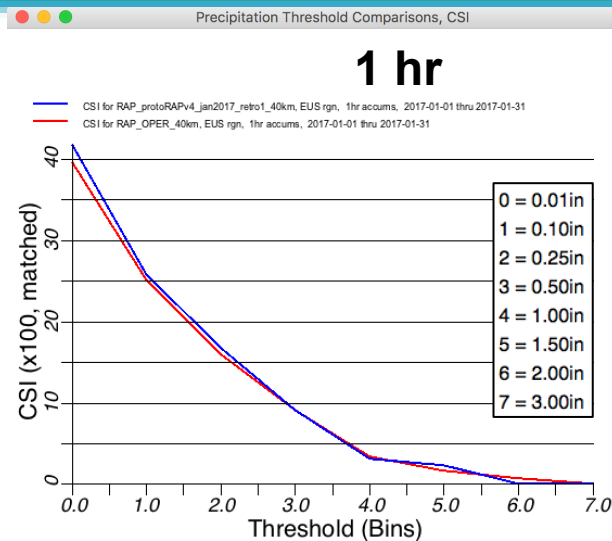
RAP CSI/BIAS Precipitation Winter (Three Weeks Jan 2017)

RAPv4
RAPv3 (ops)

CSI
40 km

BIAS
13 km

More
Optimal
Bias



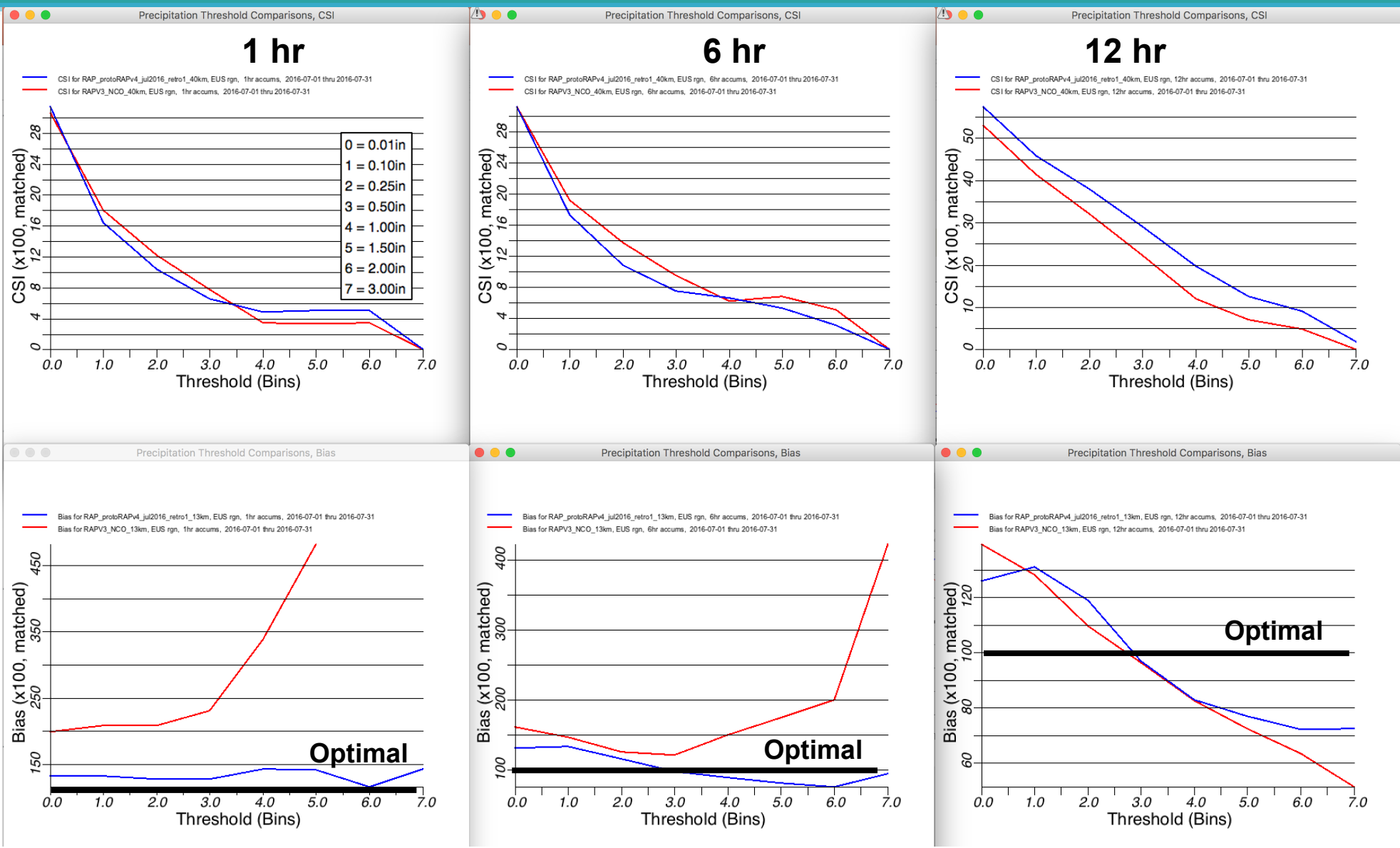
RAP CSI/BIAS Precipitation Summer (Three Weeks Jul 2016)

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RAPv3 (ops)

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BIAS
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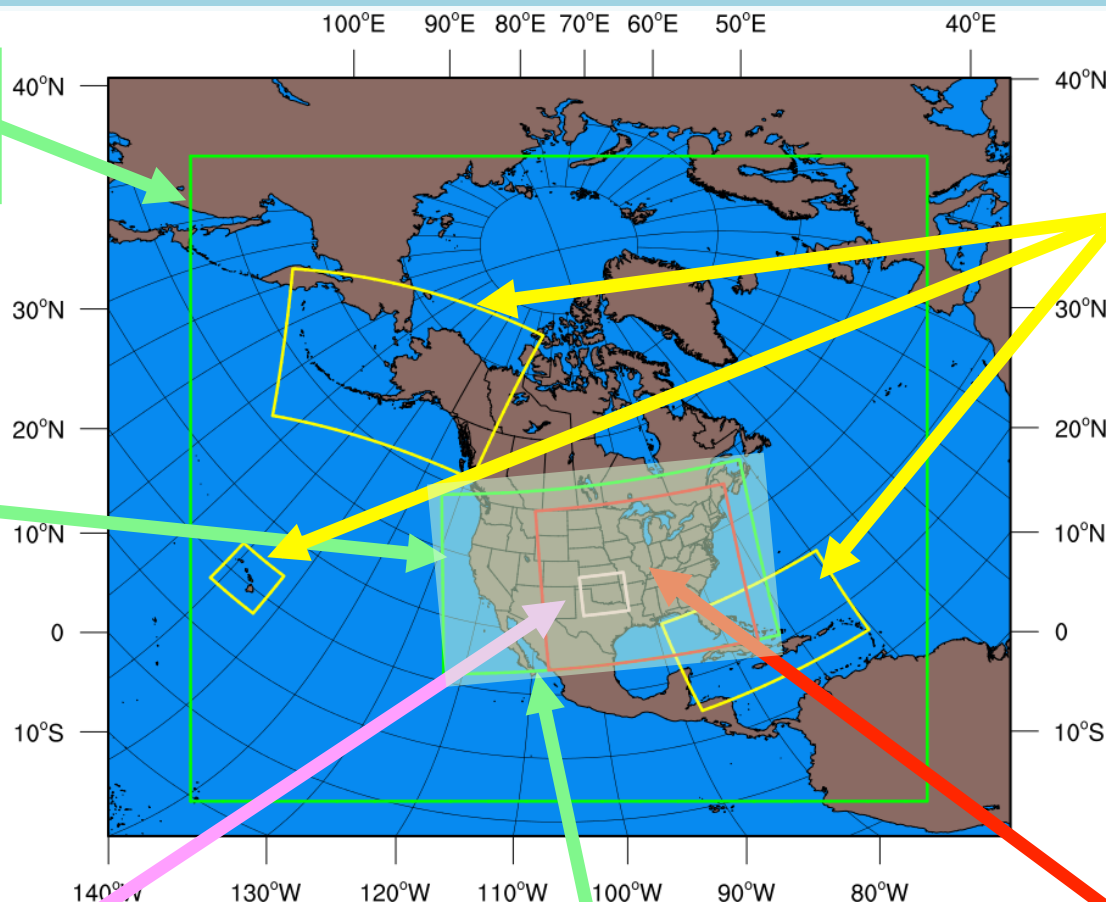
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3-km HRRR-Smoke (VIIRS fire data)

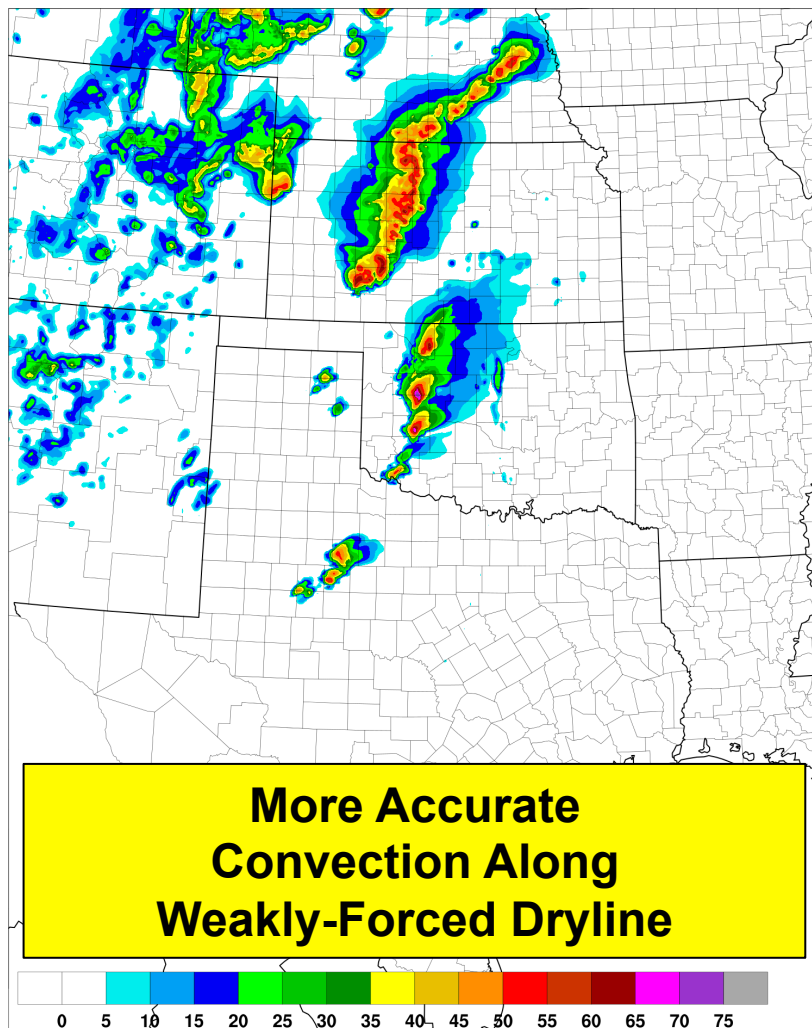
3-km High-Resolution Rapid Refresh Alaska, Hawaii and Puerto Rico Testing (HRRR-AK, HRRR-HI, HRRR-PR) Experimental (ongoing)

3-km Storm-Scale Ensemble Analysis and Forecast (HRRRE) 55% CONUS HRRR Experimental (ongoing)

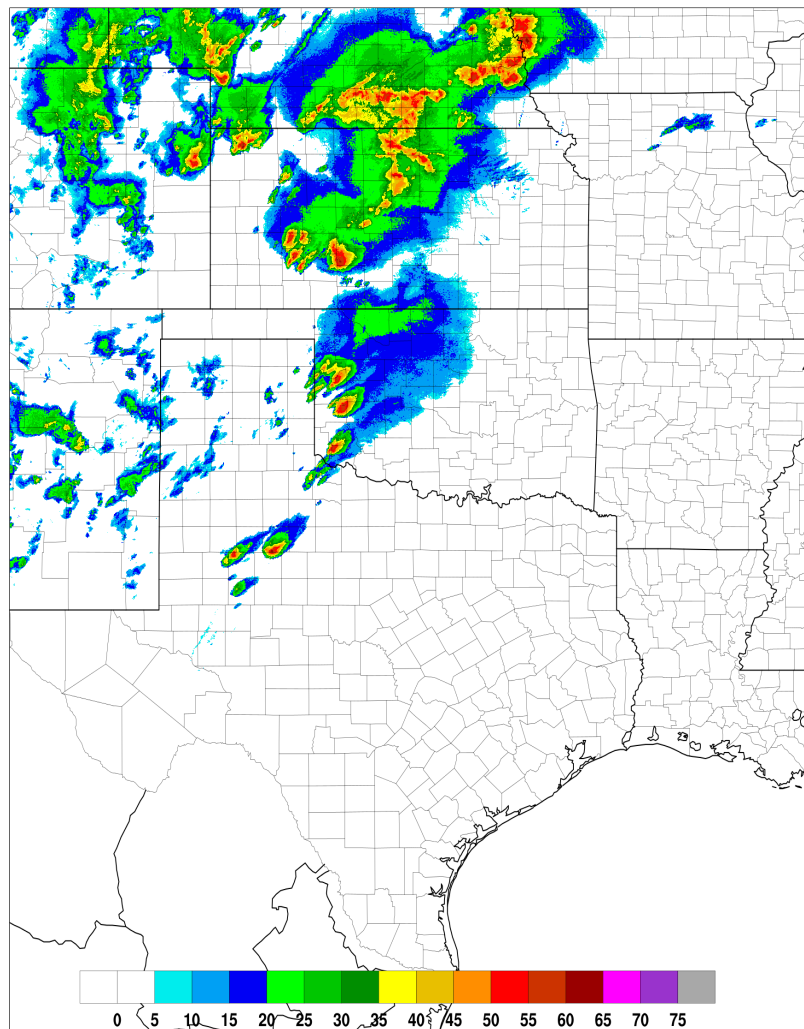


HRRR Improved Convective Forecasts

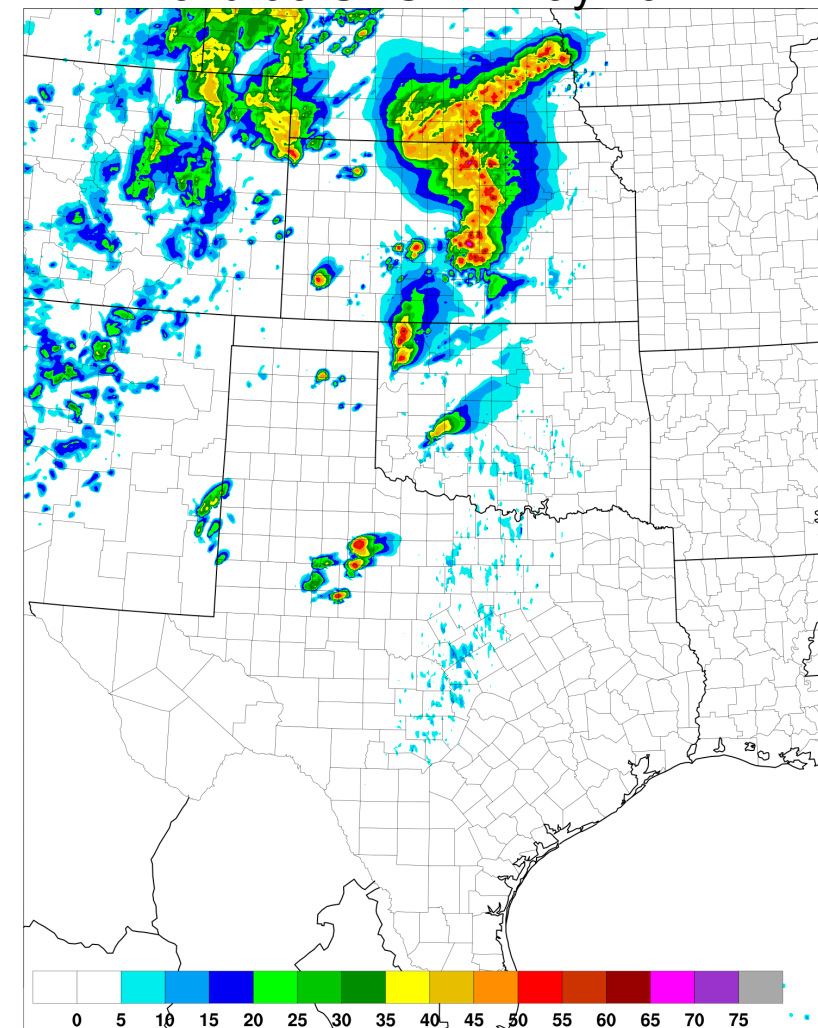
Experimental HRRRv3 13 hr fcst
Valid 00 UTC 17 May 2017



Composite Reflectivity Observations
00 UTC 17 May 2017



Operational HRRRv2 13 hr fcst
Valid 00 UTC 17 May 2017



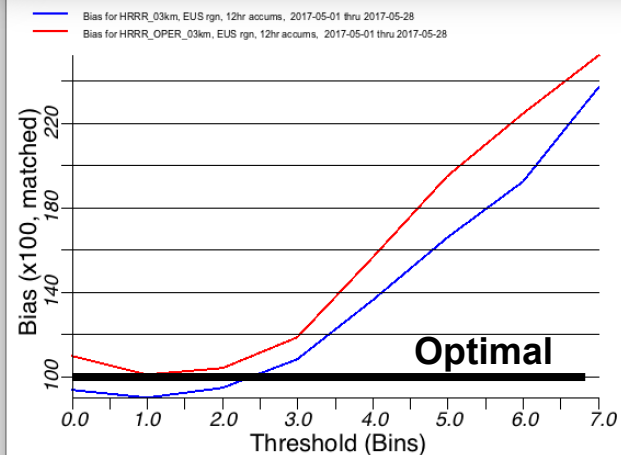
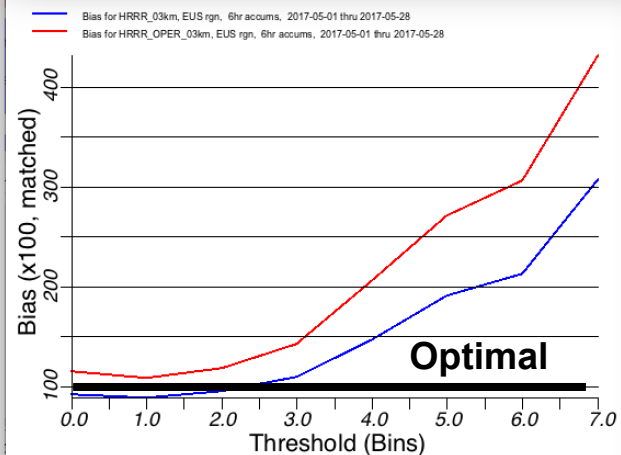
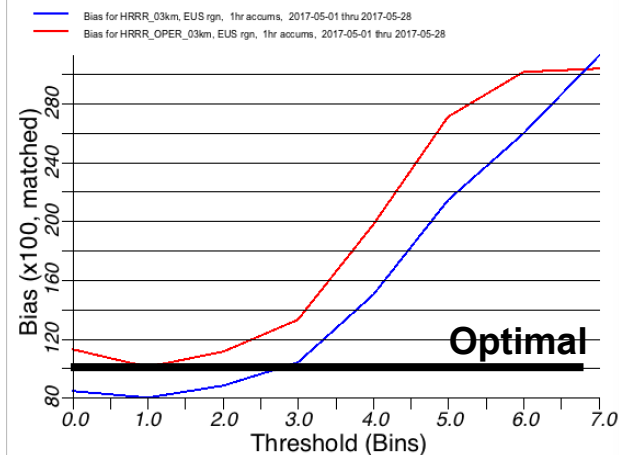
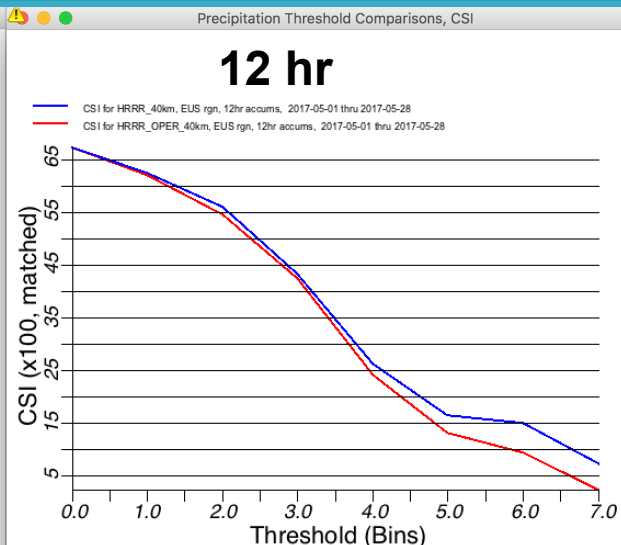
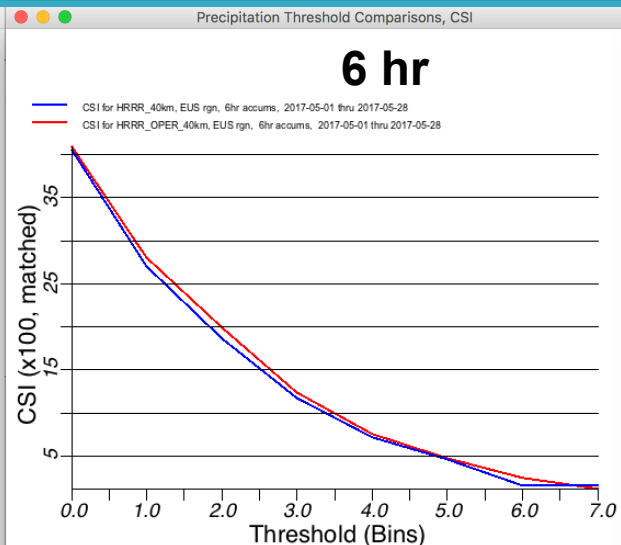
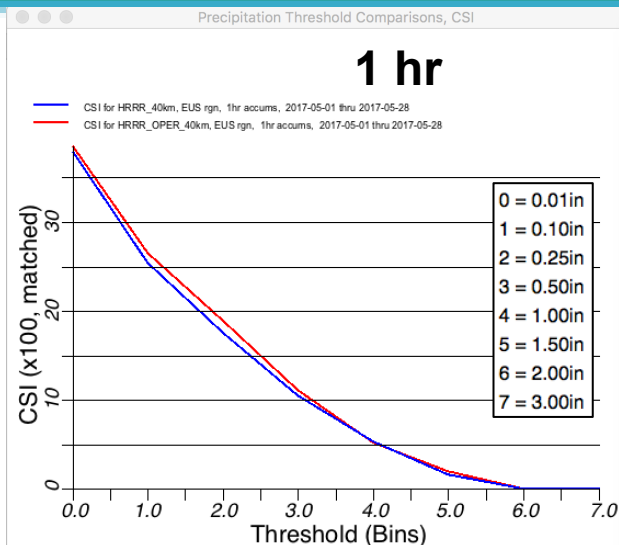
HRRR CSI/BIAS Precipitation Spring (Three Weeks May 2017)

HRRRv3
HRRRv2 (ops)

CSI
40 km

BIAS
3 km

More
Optimal
Bias



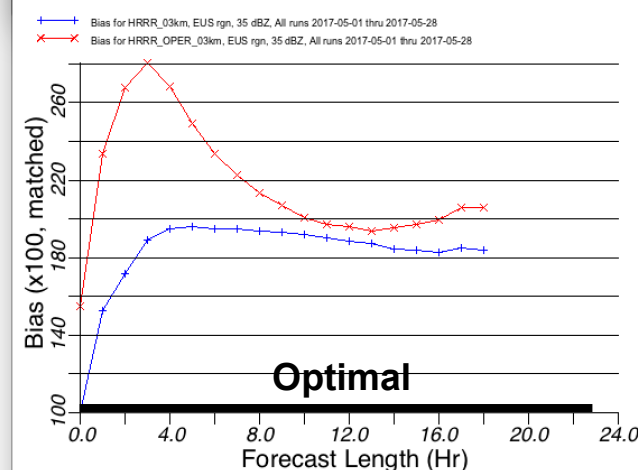
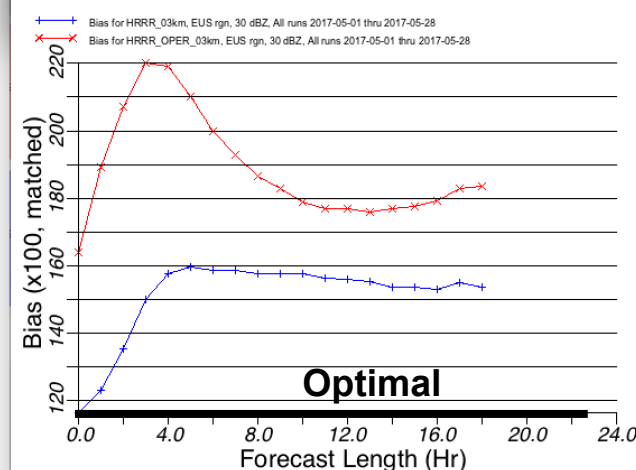
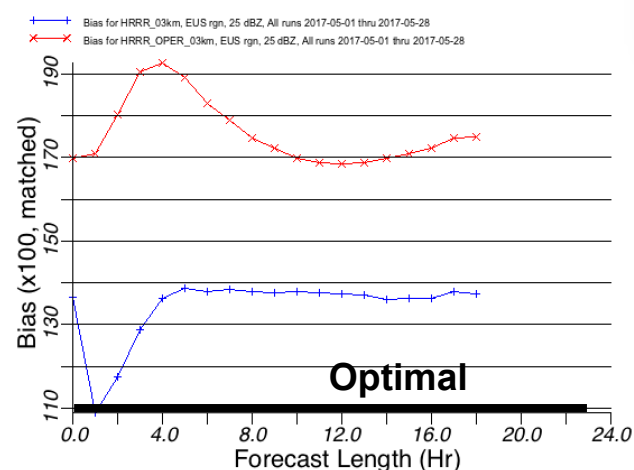
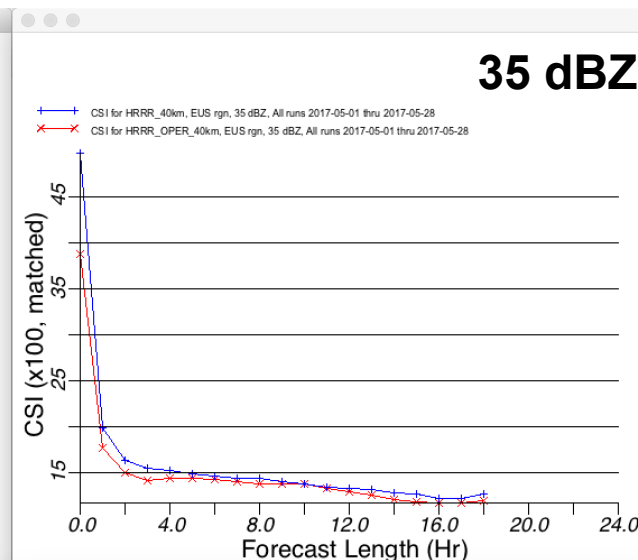
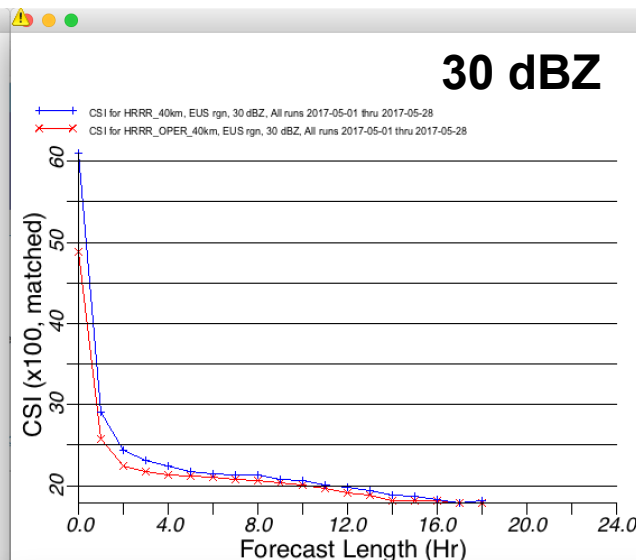
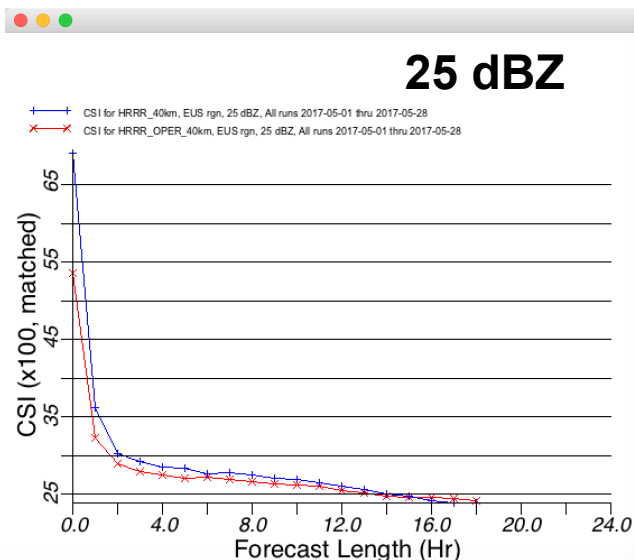
HRRR CSI/BIAS Reflectivity Spring (Three Weeks May 2017)

HRRRv3
HRRRv2 (ops)

CSI
40 km

BIAS
3 km

More
Optimal
Bias



RAP/HRRR: Hourly-Updating Weather Forecast Suite

**13-km Rapid Refresh
(RAPv4) – to 39h (Feb 2018)**

Initial & Lateral
Boundary
Conditions

**3-km High-Resolution
Rapid Refresh (HRRRv3)
– to 36h (Feb 2018)**

Initial & Lateral
Boundary
Conditions

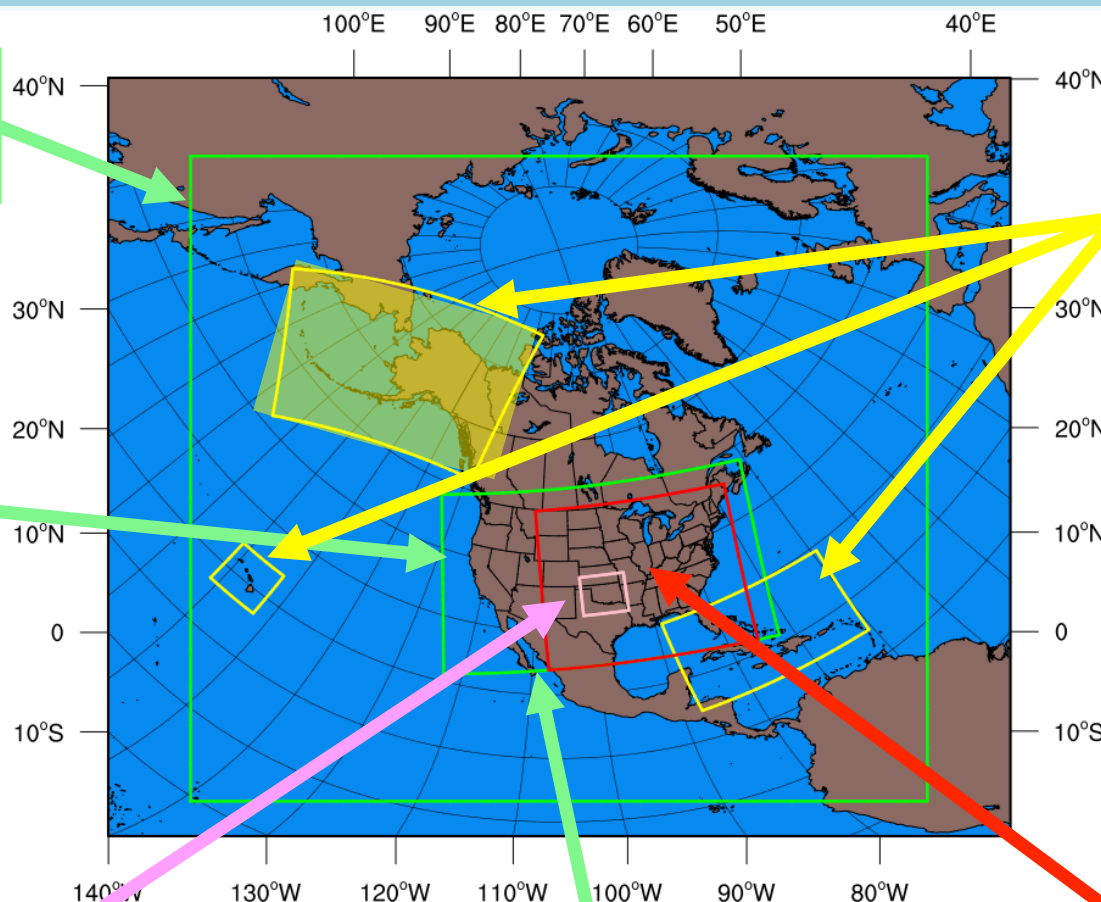
750-m HRRR nest
Scale-aware Physics
Testing (ongoing)

**3-km High-Resolution Time Lagged
Ensemble (HRRR-TLE)**

3-km HRRR-Smoke (VIIRS fire data)

**3-km High-Resolution
Rapid Refresh Alaska,
Hawaii and Puerto Rico
Testing (HRRR-AK,
HRRR-HI, HRRR-PR)
Experimental (ongoing)**

**3-km Storm-Scale
Ensemble Analysis and
Forecast (HRRRE)
55% CONUS HRRR
Experimental (ongoing)**



Ceiling (True Skill Score) HRRR-AK vs NAM-NEST-AK (two weeks)

NAM-AK
HRRR-AK
NAM-HRRR

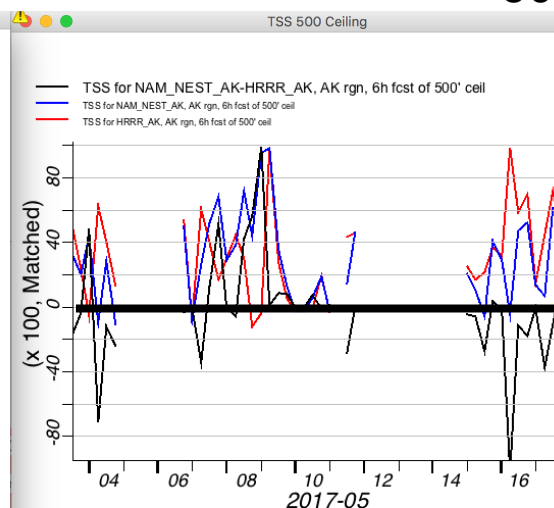
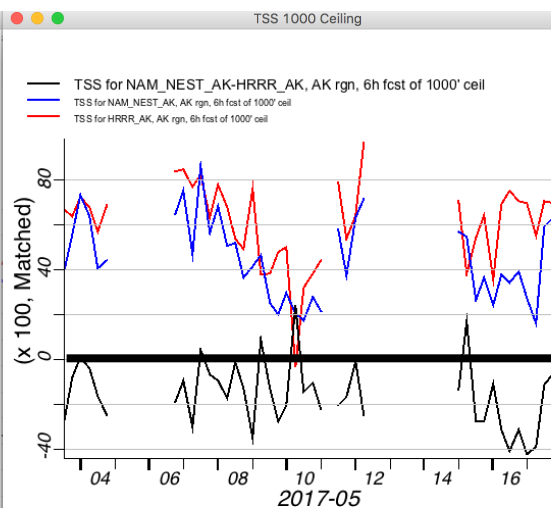
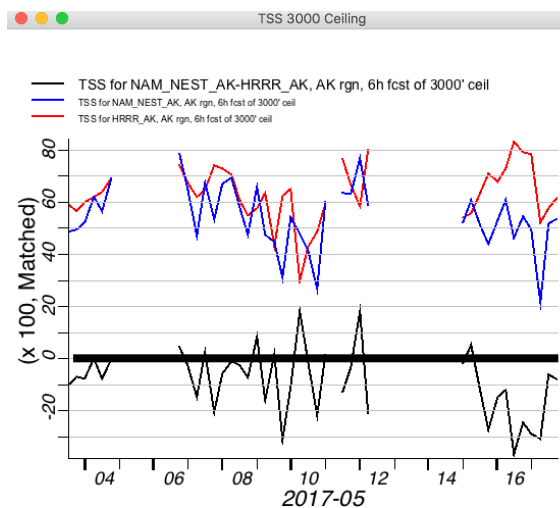
6 hr

HRRR
better
↓

3000'

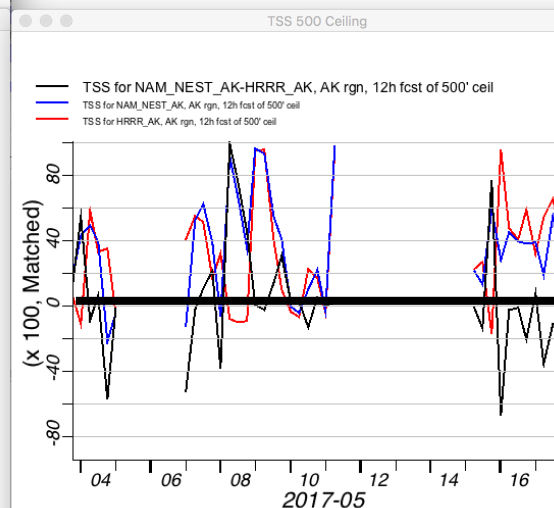
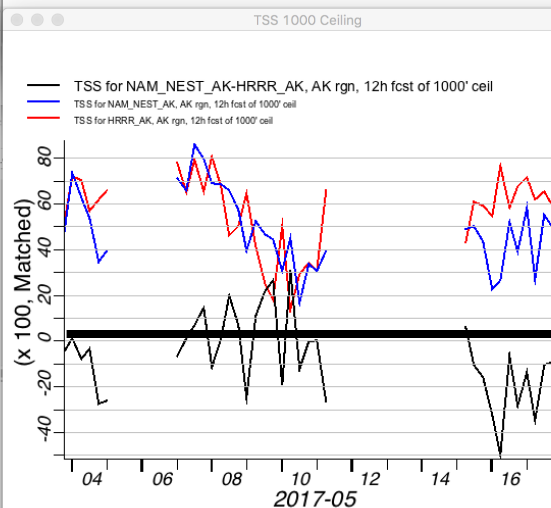
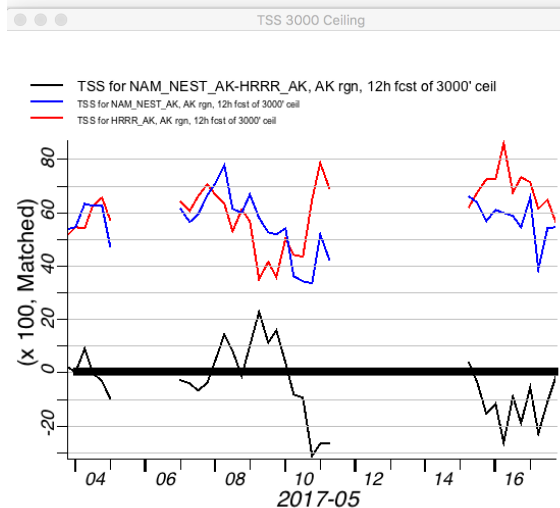
1000'

500' (rare)



12 hr

HRRR
better
↓



Visibility (True Skill Score) HRRR-AK vs NAM-NEST-AK (two weeks)

NAM-AK
HRRR-AK
NAM-HRRR

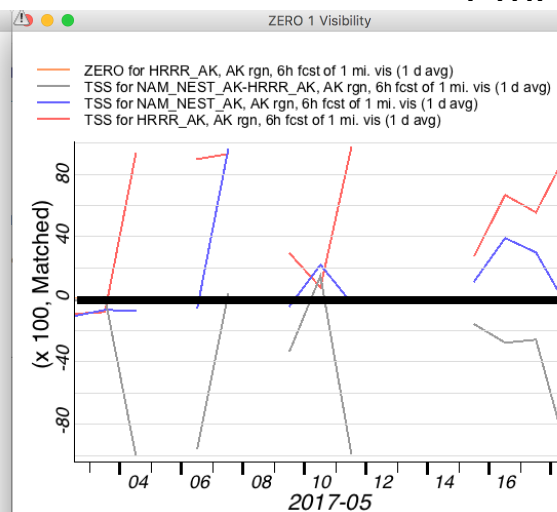
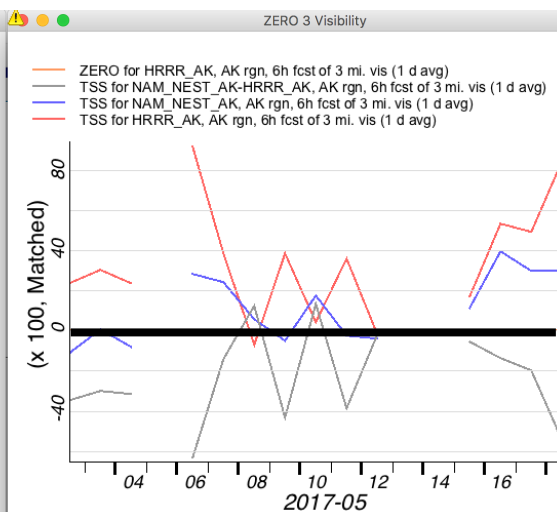
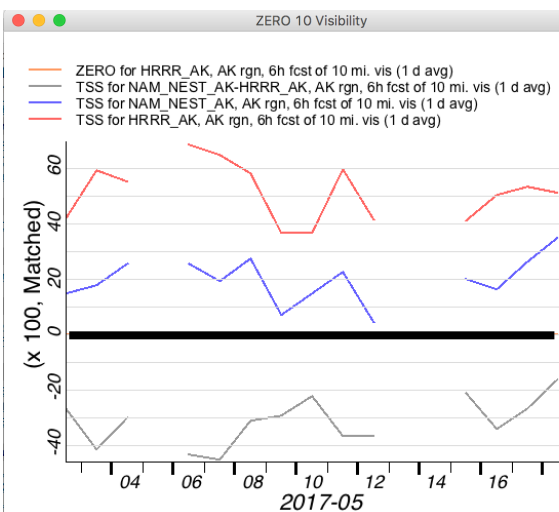
6 hr

HRRR
better
↓

10 mi

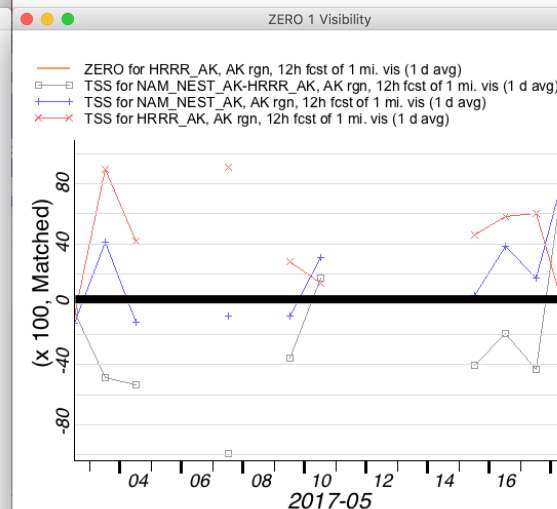
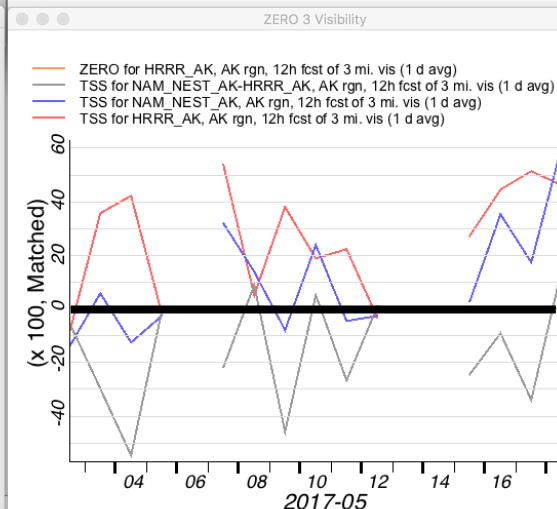
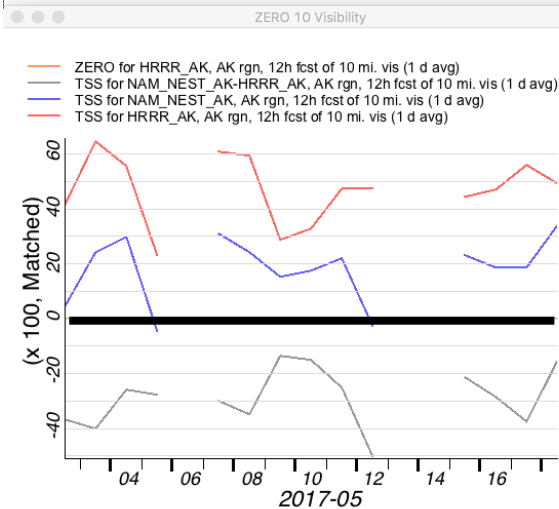
3 mi

1 mi (rare)



12 hr

HRRR
better
↓



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Rapid Refresh (HRRRv3)
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Initial & Lateral
Boundary
Conditions

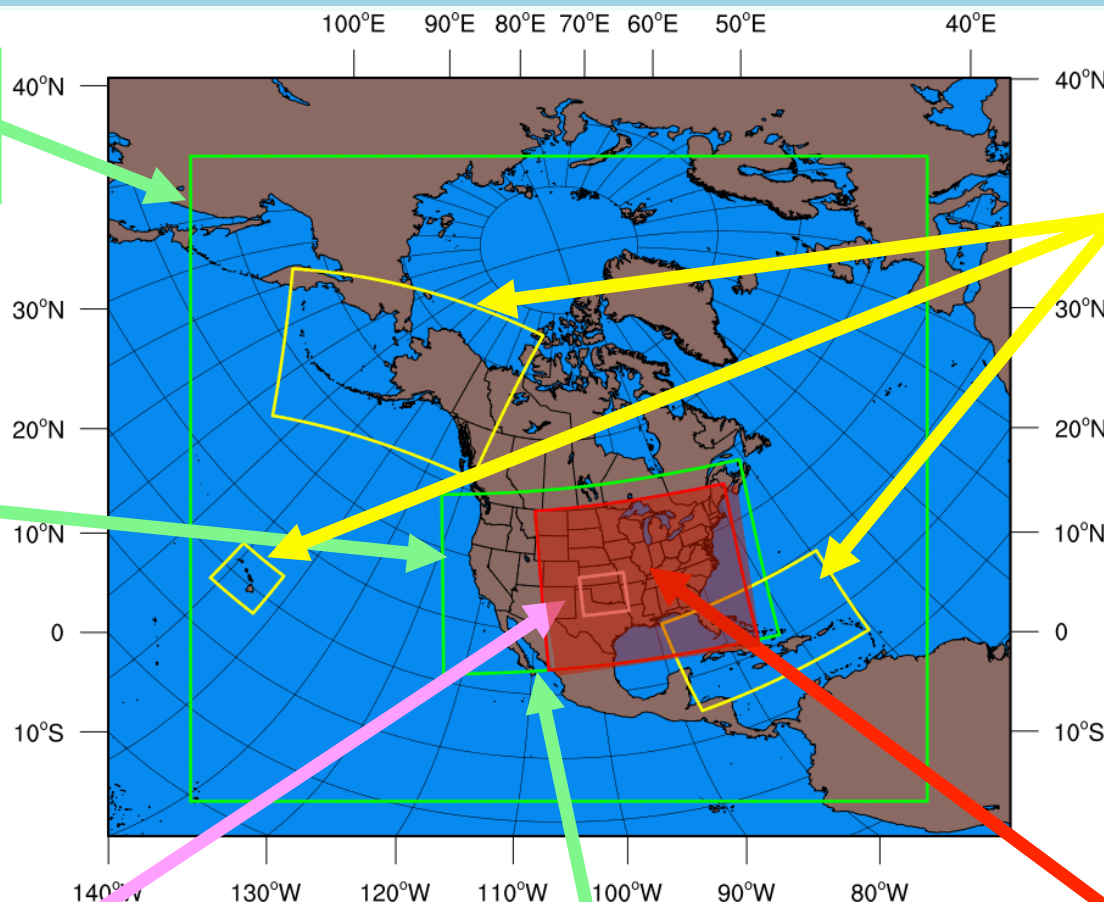
750-m HRRR nest
Scale-aware Physics
Testing (ongoing)

**3-km High-Resolution Time Lagged
Ensemble (HRRR-TLE)**

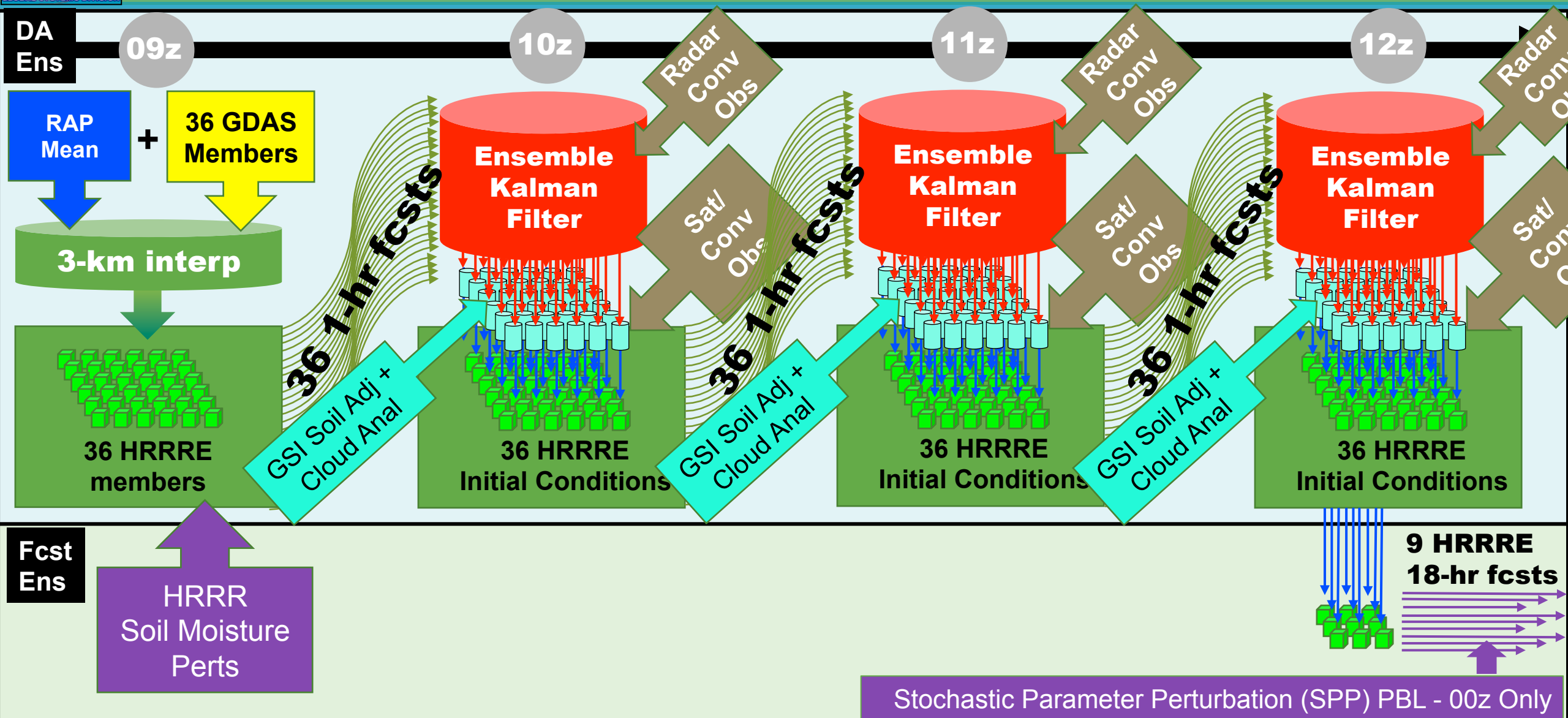
3-km HRRR-Smoke (VIIRS fire data)

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Rapid Refresh Alaska,
Hawaii and Puerto Rico
Testing (HRRR-AK,
HRRR-HI, HRRR-PR)
Experimental (ongoing)**

**3-km Storm-Scale
Ensemble Analysis and
Forecast (HRRRE)
55% CONUS HRRR
Experimental (ongoing)**

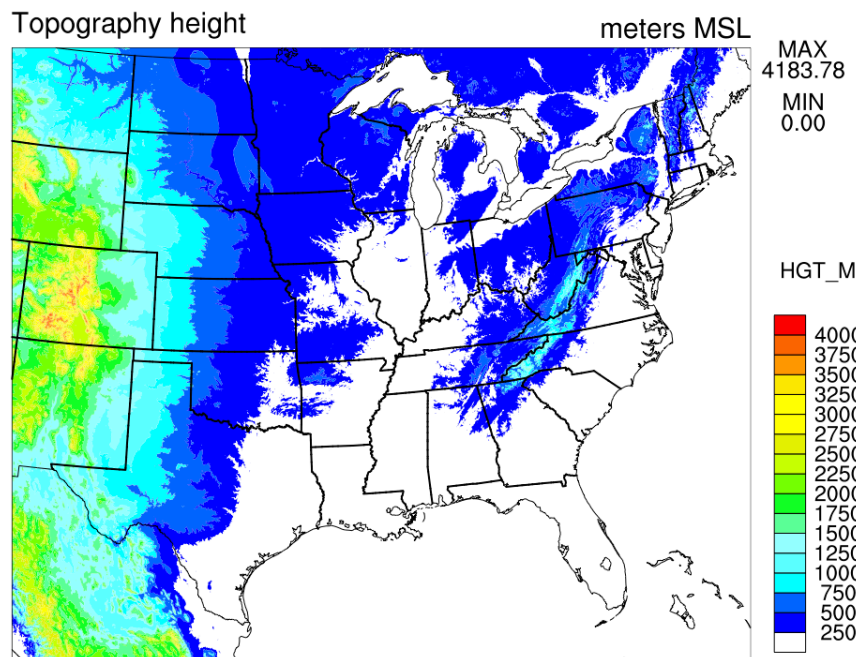


HRRRE 2017 Design



HRRRE 2017 (01 March – 30 June 2017)

55% CONUS HRRR



Real-Time Web Graphics

<https://rapidrefresh.noaa.gov/hrrr/HRRRE>

- Single core (ARW)
- Ensemble DA (DART and GSI-EnKF)
- RAP mean + GDAS perturbations w/more inflation
- Conventional observations
- Radar reflectivity observations
- Stochastic physics
- Cloud analysis
- Soil adjustments
- HRRR-TLE post-processing

Assimilation

36 members

1 hr cycling

15 fcsts / day

Start 09z day one

End 00z day two

Forecast

12z – Nine members to 18 hrs

15z – Nine members to 18 hrs

18z – Nine members to 18 hrs

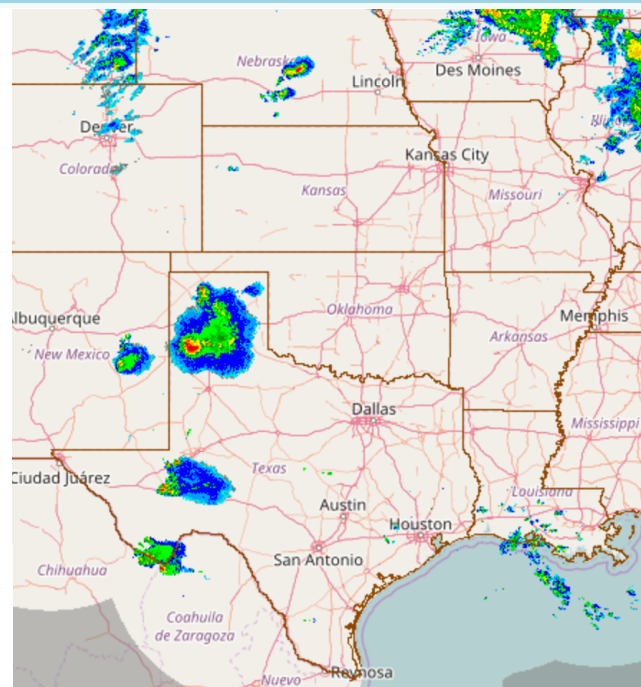
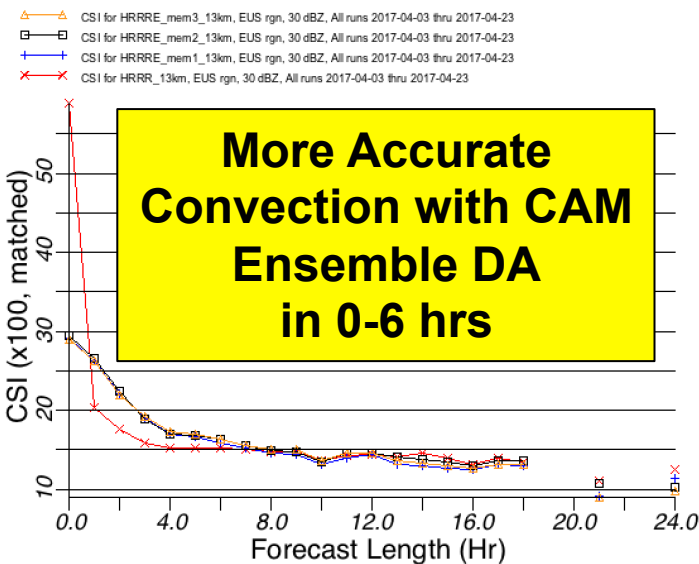
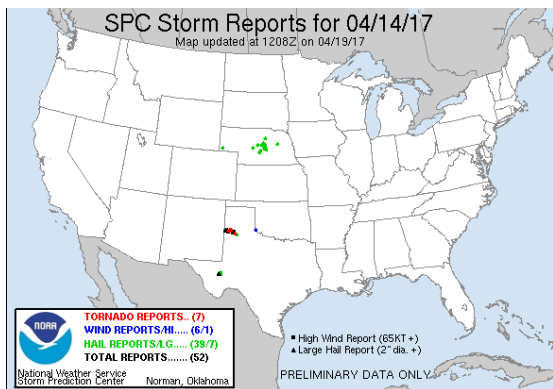
21z – Nine members to 18 hrs

00z – Nine members to 36 hrs

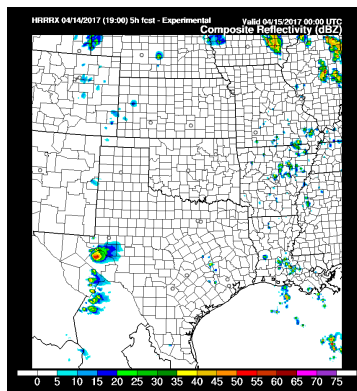
Proof-of-concept
Real-time demonstration
With NSSL Experimental
WoF System for ensembles
“NEWS-e”

Ensemble Forecast Challenge: Spread vs Error

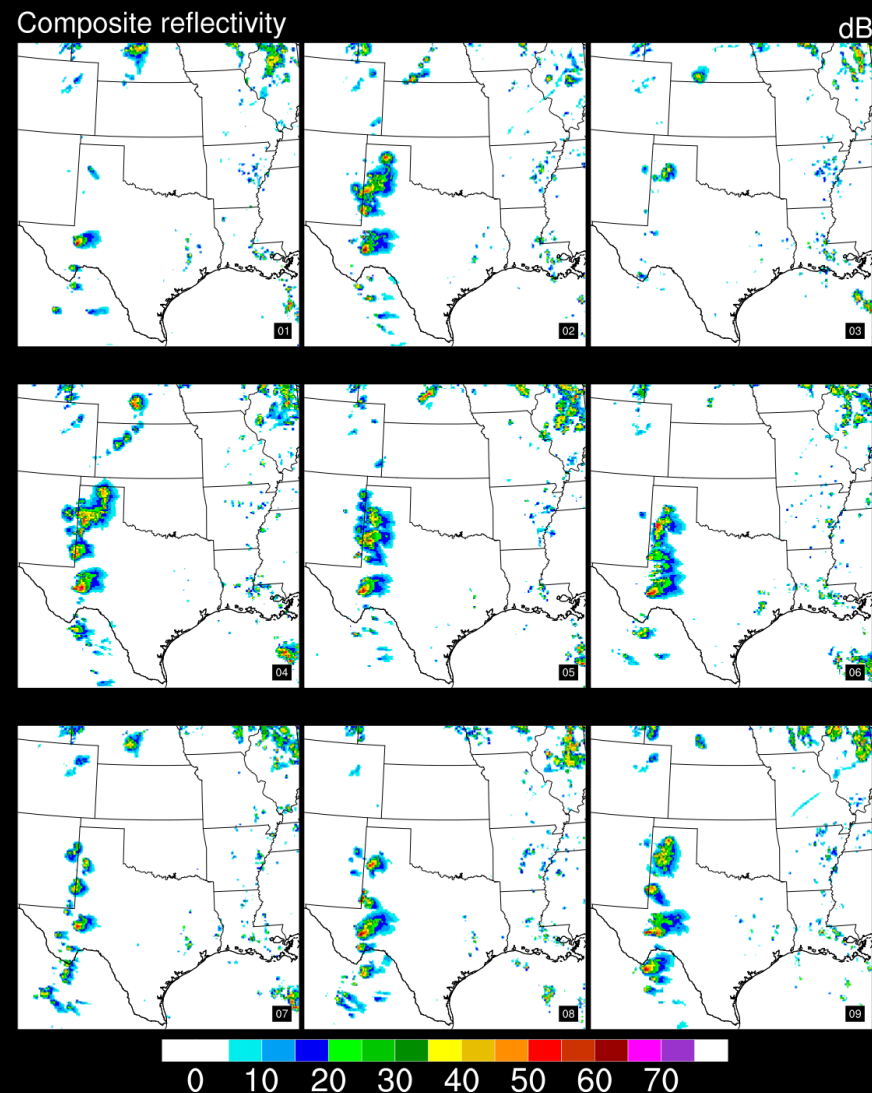
Isolated Supercell 00z 15 April 2017



Deterministic
HRRR 6-hr
Forecast



HRRRE 04/14/2017 (18:00) 6h fcst - Experimental Valid 04/15/2017 00:00 UTC



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Boundary
Conditions

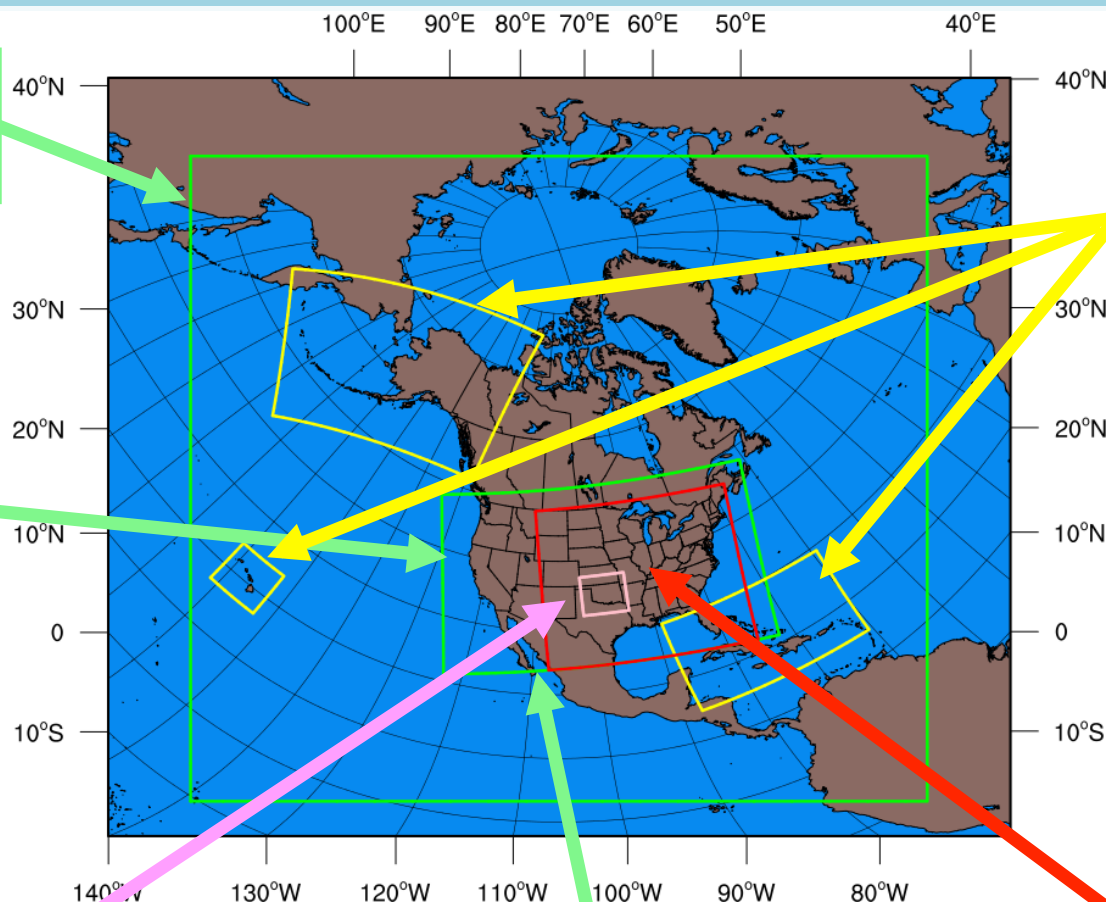
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3-km Storm-Scale Ensemble Analysis and Forecast (HRRRE) 55% CONUS HRRR Experimental (ongoing)





RAP/HRRR ESRL/GSD Development Talks

6.1	Wed 10:30	Georg Grell	New developments and applications using the scale and aerosol aware Grell-Freitas convection parameterization
P11 Testing	Wed 2-5	Isidora Jankov	Stochastic Approaches Within a High Resolution Rapid Refresh Ensemble- Part I: Sensitivity
P12	Wed 2-5	Jeff Beck	An Evaluation of 3D- and 4D-EnVar Sub-Hourly Data Assimilation in the HRRR
P34	Wed 2-5	Jaymes Kenyon	The MYNN Turbulence Parameterization: Recent Development and Current Capabilities
8.1	Thu 10:30	Jeff Beck	An evaluation of the new hybrid vertical coordinate in the RAP and HRRR
8.6	Thu 11:45	Joseph Olson	Addressing systematic biases in RAP/HRRR physics for WFIP2