# RAPID REFRESH (RAP)
# Upgrade V4.0.0
# HIGH-RESOLUTION RAPID REFRESH (HRRR)
# Upgrade V3.0.0

## EMC Change Configuration Board

**January 26, 2018**

**Presented by: Geoff Manikin**
**Collaborators: Ben Blake, Corey Guastini, Curtis Alexander, Stan Benjamin, Steve Weygandt, David Dowell, Ming Hu, Tanya Smirnova, Joseph Olson, James Kenyon, Georg Grell, Eric James, Haidao Lin, Terra Ladwig, John Brown, Trevor Alcott, and Isidora Jankov**

# Quick Overview of Changes

- Updated versions of WRF-ARW model (3.8.1), GSI, and post
- Introduce HRRR-Alaska
- Extend 4 RAP and 4 HRRR cycles each day
- Change to hybrid vertical coordinate
- Improved convective scheme (RAP only), microphysics, LSM, and PBL scheme
- Refined roughness lengths over various land use types
- Give more ensemble weight to hybrid DA
- Assimilate AMVs over land and TAMDAR
- New radiances assimilated in RAP; lightning and radar radial velocities assimilated in HRRR
- METAR and GOES cloud building made consistent

**http://www.emc.ncep.noaa.gov/mmb/bblake/rap_hrrr/**

# RAPv4/HRRRv3 Change Highlights

| Data Assimilation | Model | Land-surface/post |
|---|---|---|
| Merge with GSI trunk – Mar 2017<br><br>***New Observations for assimilation:***<br>Add AMVs over land and TAMDAR<br>NCEP new VAD wind retrievals<br>Add IASI, CrIS, SEVIRI radiances<br>Use direct readout radiances (larger volume)<br><br>***Assimilation Methods:***<br>Revised PBL pseudo-obs –better winds/RH<br>More ens weight in hybrid DA (0.85/0.15)<br>Cloud building – smaller qc/qi, cloud CCN now specified, GOES/METAR build <1200m<br><br>Radar reflectivity assimilation<br>- Latent heating reduced by 50% - RAP only<br>- also affects HRRR – reduces too much convection | WRF-ARW v3.8.1+ incl. phys changes<br><br>***Physics changes:***<br>Thompson microphysics – improved ice clouds (not excessive)<br><br>MYNN PBL update – better sub-grid clouds, EDMF (local/deep) mixing<br><br>Land-sfc model update – mosaic snow, 2m temp diagnostic<br><br>Revised Grell-Freitas cumulus (RAP)<br>Eclipse-ready short-wave radiation<br><br>***Numerics changes:***<br>Hybrid vertical coordinate from NCAR<br>Low-level subgrid wind drag<br>Diffusion – horiz only, not on slopes | MODIS higher-res 15” land-use data<br><br>VIIRS real-time greenness veg fraction<br><br>Revised roughness length<br><br>10m wind (not ~8m)<br><br>Wind gust diag fixed (stronger at night)<br><br>Visibility diag improved |

# 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) |

**Parallel RAPv4/HRRRv3**

| 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) |

# RAPv4/HRRRv3 Summary of Changes

**Operational RAPv3/HRRRv2**

| 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 |

**Parallel RAPv4/HRRRv3**

| 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 |

# RAPv4/HRRRv3 Summary of Changes

**Operational RAPv3/HRRRv2**

| Model | Horiz/Vert Advection | Scalar Advection | Upper-Level Damping | Diffusion Option | 6th Order Diffusion | SW Radiation Update | Land Use | MP Tend Limit | Time-Step |
|---|---|---|---|---|---|---|---|---|---|
| **RAP** | 5th/5th | Positive-Definite | w-Rayleigh 0.2 | Simple (1) | Yes 0.12 | 20 min | MODIS Seasonal | 0.01 K/s | 60 s |
| **HRRR** | 5th/5th | Positive-Definite | w-Rayleigh 0.2 | Simple (1) | Yes 0.25 | 15 min with SW-dt | MODIS Seasonal | 0.07 K/s | 20 s |

**Parallel RAPv4/HRRRv3**

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

# RAP/HRRR: Hourly-Updating Weather Forecast Suite

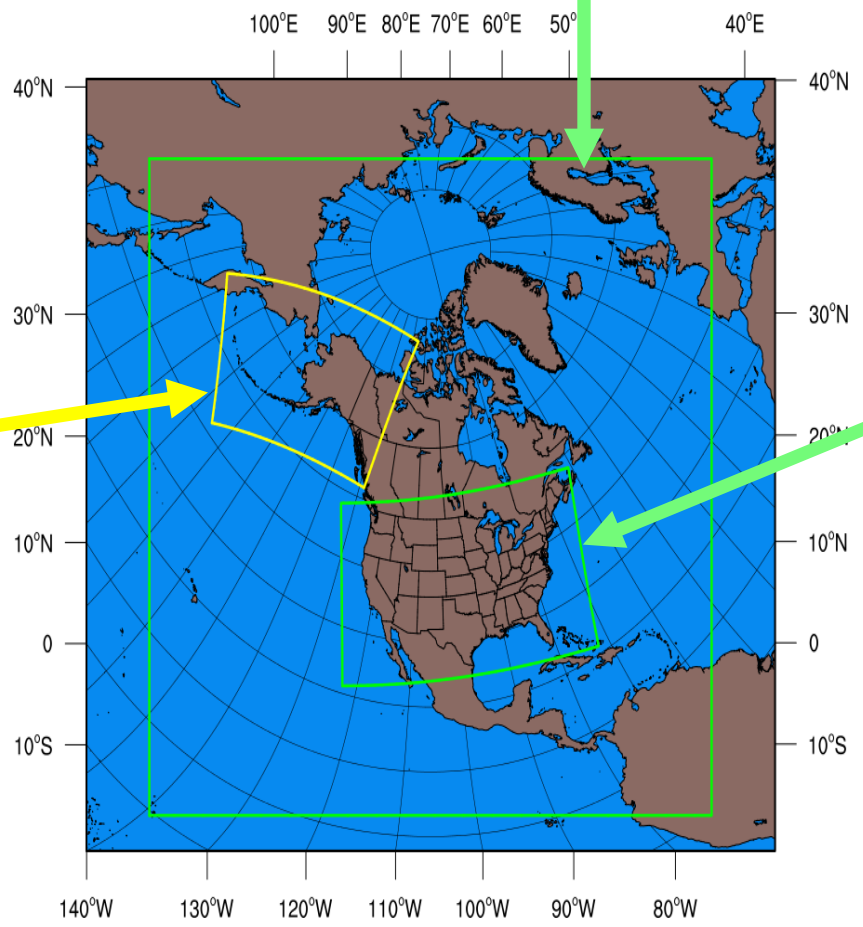
**13-km Rapid Refresh (RAPv4) – to 39h (May 2018)**

Initial & Lateral Boundary Conditions

Initial & Lateral Boundary Conditions

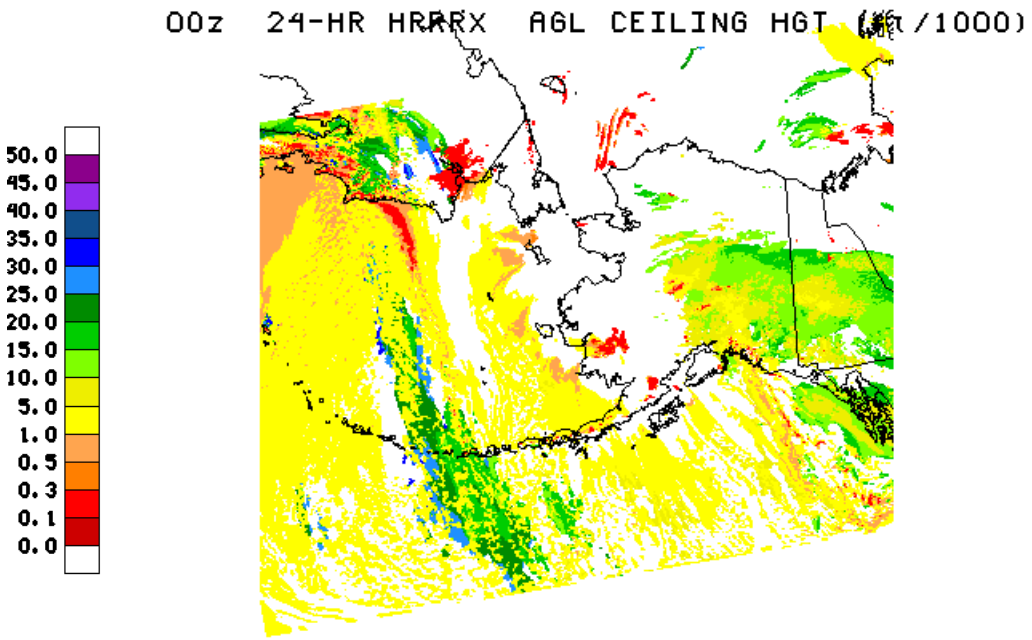
**3-km High-Resolution Rapid Refresh Alaska (HRRR-AK) 36 hr (May 2018)**

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



# HRRR-Alaska

- Run every third hour
- 03/09/15/21z forecasts to 18 hours; 00/06/12/18z cycles to 36 hours



# Expected Benefits of this Upgrade

- Extensions likely to help with day 2 forecasting efforts, and HRRR extension can be eventually added to HREF
- Improvements to cloud and visibility forecasts
- New hi-res guidance for Alaska
- Significant improvement to high reflectivity / precip bias in first few hours of forecast
- Improved wind/turbulence guidance over terrain

# Forecast Extensions

- RAP will be extended to 39 hours at 03/09/15/21z
- HRRR will be extended to 36 hours at 00/06/12/18z
- HRRR-AK will have same extensions
- potential inclusion of HRRR extensions in HREFv2.1 or v3.0

# RAP/HRRR DEPENDENCIES

**UPSTREAM:** GFS, Obsproc, EnKF, MRMS, RTGSST, IMS

**DOWNSTREAM-RAP:** SREF, RTMA/URMA, HRRR, HYSPLIT, NARRE, Verification, NOSOFS, NWM, NBM, HIRESW, GTG

**DOWNSTREAM-HRRR**: RTMA/URMA, Verification, NWM, GLMP, NMB, HYSPLIT

**Upstream dependencies require following enhancements:**

1. Obsproc_rap_v3.0.0 released in October

**Downstream dependencies require following enhancements:**

1. Verification gridtobs update v4.4.11 to be submitted by P. Shafran
2. Verification precip update v4.1.0 to be submitted by Y. Lin

# DEVELOPMENT TESTING

- **RAPv4/HRRRv3 developed/tested at GSD for 2+ years**
- **Code frozen Spring 2017**
- **Built at EMC in summer 2017**
- **Had many difficulties getting runs through the development machine**
- **Moved to white space on cray during fall**
- **Still some issues with disk space filling up, but runs have generally been reliable**
- **Using EMC parallel for cold season stats; using GSD parallel from last summer for warm season stats**
- **HRRRX is skipping 01/07/13/19z cycles**

# RESOURCES

- HRRRv2 has HWM ~115 nodes
- HRRRv3 has HWM ~135 nodes

- RAPv3 has HWM ~60 nodes
- RAPv4 has HWM ~65 nodes

- HRRR-AK has HWM ~90 nodes

System HWM > 400 nodes during overlapping

# STORAGE

- RAP ops uses 665 GB/day in /com2
- RAPX uses 818 GB/day

- HRRR ops uses 2.386 TB/day in /com2
- HRRRX uses 3.443 TB/day (includes extensions and Alaska)

# RAP PRODUCT CHANGES

**RAP currently generates:**

- 13, 20, and 40 km hourly output on pressure levels (grid covering CONUS+)
- 13, 20 km hourly output on native levels (CONUS+)
- 11 km hourly Alaska output
- 13 km hourly full domain output for both native and pressure levels
- 32 km hourly full domain output
- 16 km hourly Puerto Rico output
- smartinit output for CONUS, AK, PR
- station time series bufr data

**CHANGES**

- extra forecast hours
- some output files will have additional parameters
- smartinit output will be written directly in grib2
- cloud ice parameter (3D) identification changed
- hopefully send extensions to AWIPS

# HRRR PRODUCT CHANGES

**HRRR currently generates:**

- 3 km output on native and pressure levels and smaller file with sfc parameters
- 2.5 km NDFD/smartinit output
- 15 minute sub-hourly data (small subset of parameters)
- station time series bufr data

**CHANGES**

- some output files will have additional parameters
- extra forecast hours (no sub-hourly data for extensions)
- hopefully send extensions to AWIPS
- new set of HRRR-AK products, including AWIPS
- cloud ice parameter (3D) identification changed

# Summary of Evaluations

- MEG presentations on 8/17/17, 11/16/17, and 12/21/17
- Reviews presented at 1/25/18 MEG meeting
- ER, CR, WR, SR, AR all recommend implementation;  same for WPC, AWC, SPC
- Evaluations highlighted significant usefulness of forecast extensions
- Overall synoptic benefit was evaluated as either neutral or slightly positive
- Some improvement seen in cloud fields
- Clear improvement in first few hours of HRRR reflectivity/precip forecasts

# Comments on Extensions

- They meet aviation and other short term forecasting requirements **Eastern Region**
- Benefits of the extended forecasts include convective applications (timing, mode, coverage), aviation applications, precip type/intensity, and wind shift timing **Southern Region**
- They help with the day 2 forecasting efforts Central Region
- This will be a significant help to local office forecast operations and help the NBM **Western Region**
- They'll help very **much. Many of our wind/precip events are multi-day requiring warning products that span a few days.** Alaska Region

# Comments on Extensions cont.

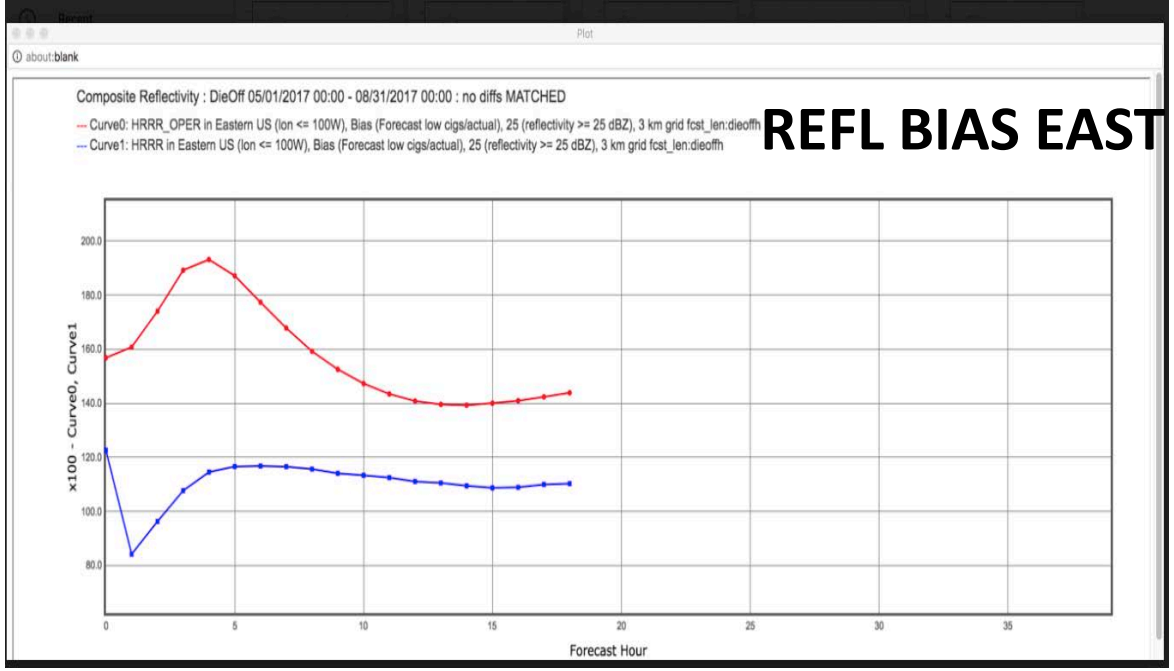
- The extensions  will be helpful for day 1 (e.g. forecasts initialized at 00z valid through the next convective day) and day 2 forecasts, especially when viewed from an ensemble perspective  **SPC**
- The extensions of the RAP/HRRR provide critical support to our Day 1-2 QPF and winter weather forecasts as well as our Day 1 and 2 Excessive Rainfall outlooks.  **WPC**
- The extensions allow us to extend the automated Traffic Flow Management Convective Forecast (TCF) beyond its current eight hour forecast times  **AWC**
- They will help the AWC/NAM staff in supporting the FAA PERTI effort in regards to planning for the next day **AWC/NAM**

# STATS

# WARM SEASON STATS

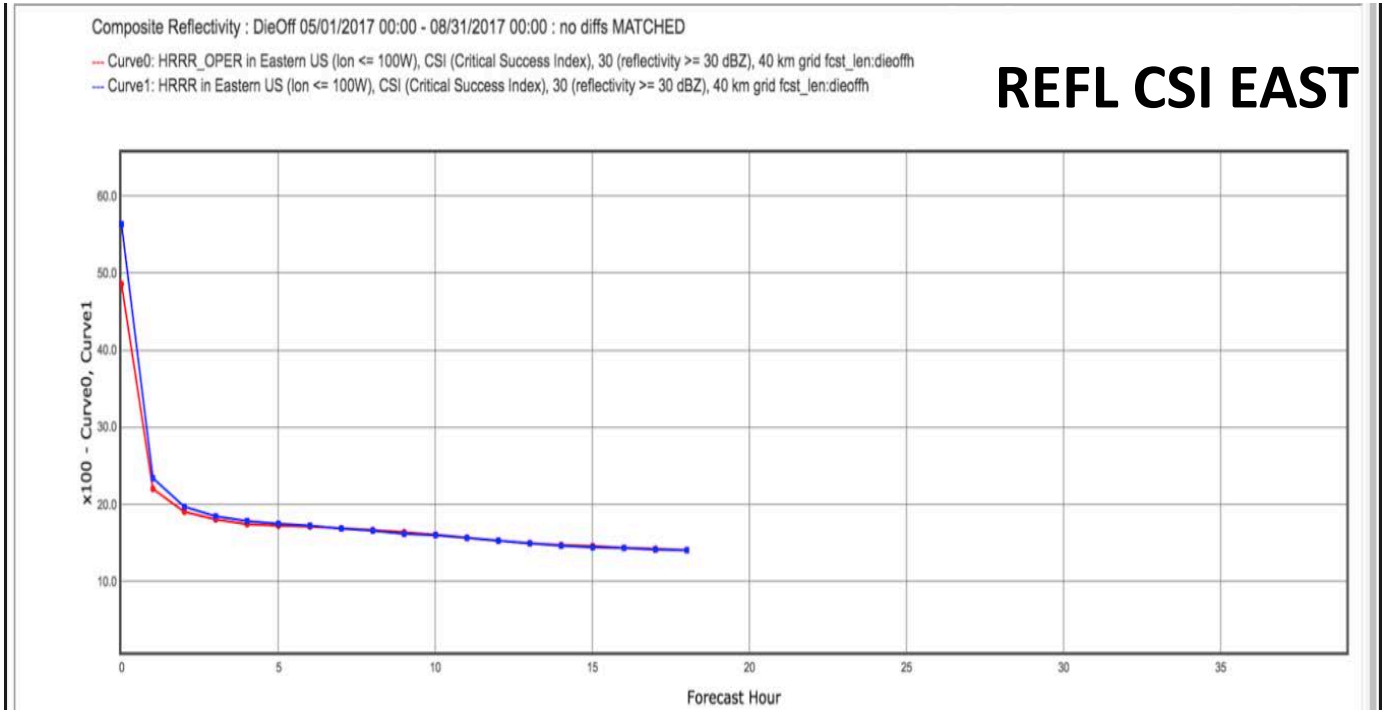
HRRR OPS (v2) or RAP OPS (v3)

HRRRX (v3) or RAPX (v4)




# REFL BIAS EAST

Large reduction in high reflectivity bias in first few hours

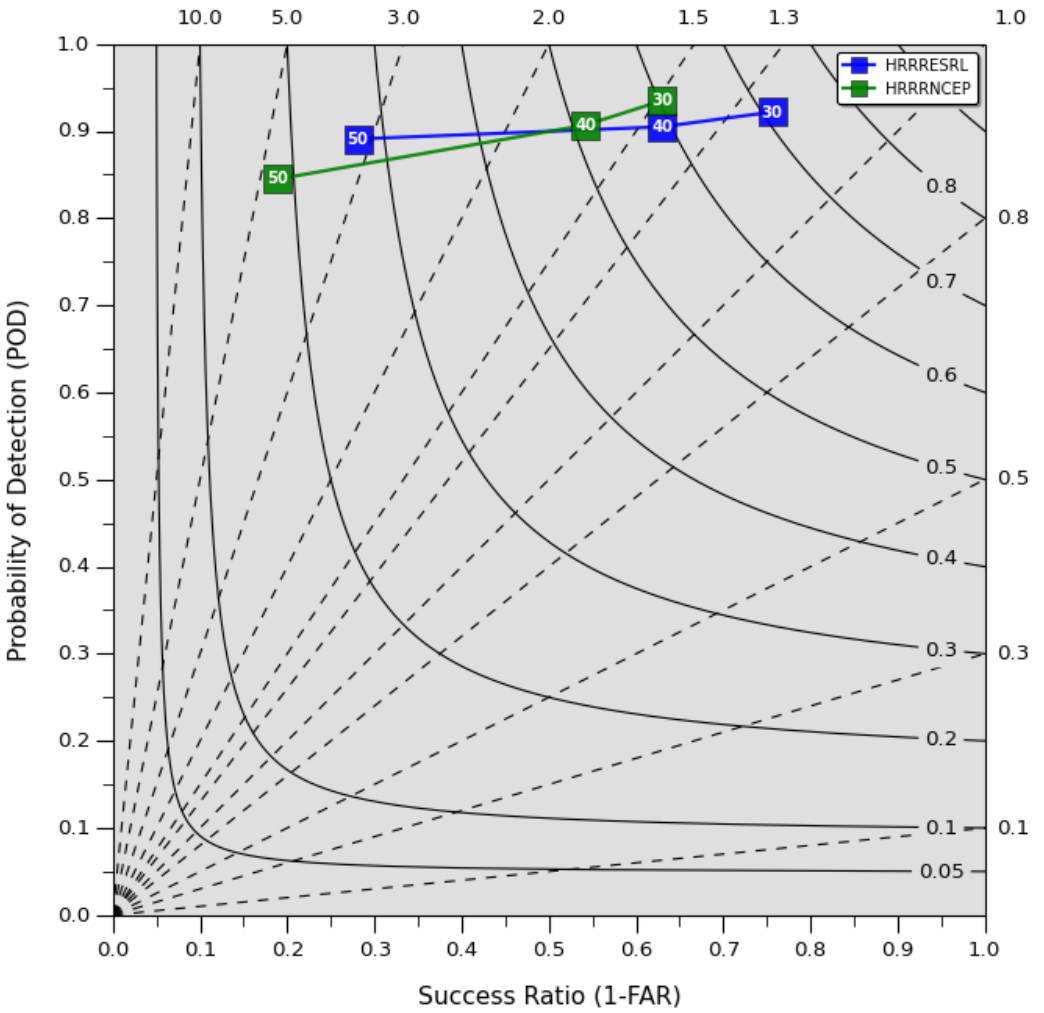



# REFL CSI EAST

# SPC HRRRv3 Evaluation
## 15Z HRRR: Performance Diagram

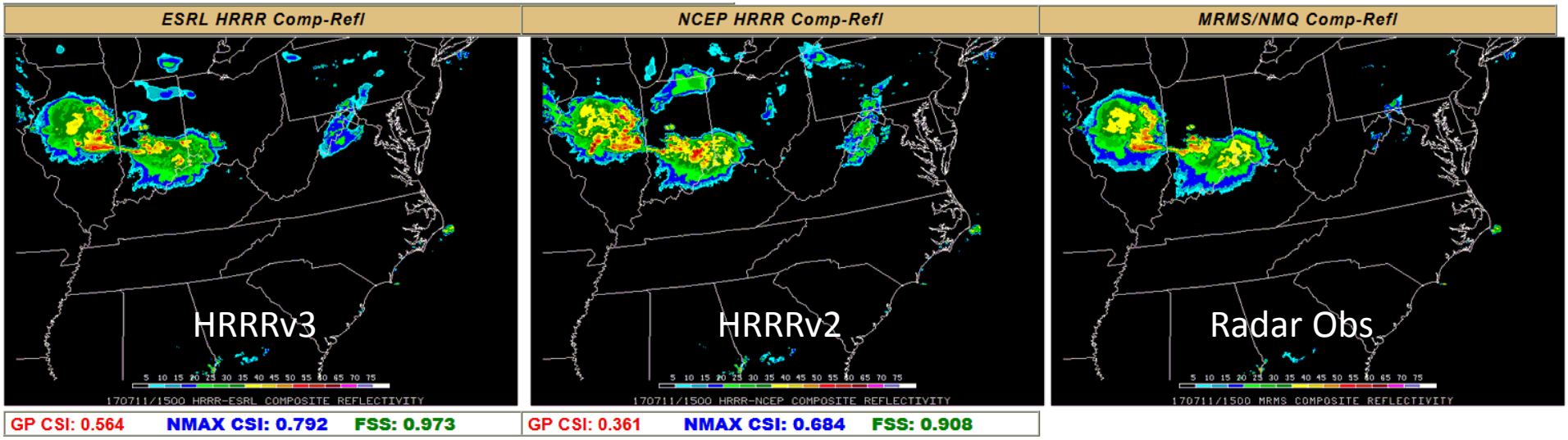
- For the **analysis (fh00) at 15Z** (similar to other times not shown), the HRRRv3 is better at matching observed radar characteristics.
- The HRRRv3 has similar POD with much reduced FAR and frequency bias at 30, 40, and 50 dBZ compared to the operational HRRRv2.

National Composite Reflectivity
**20170415-20170815**; 15Z cycle, fh00



# SPC HRRRv3 Evaluation
## 15Z HRRR: 00-h Analysis Example

- For the analysis (fh00) at 15Z, the HRRRv3 (left) is better at matching observed radar details (right) compared to HRRRv2 (center).
- This includes placement of high reflectivity core structures and a reduction in spurious low reflectivity regions.

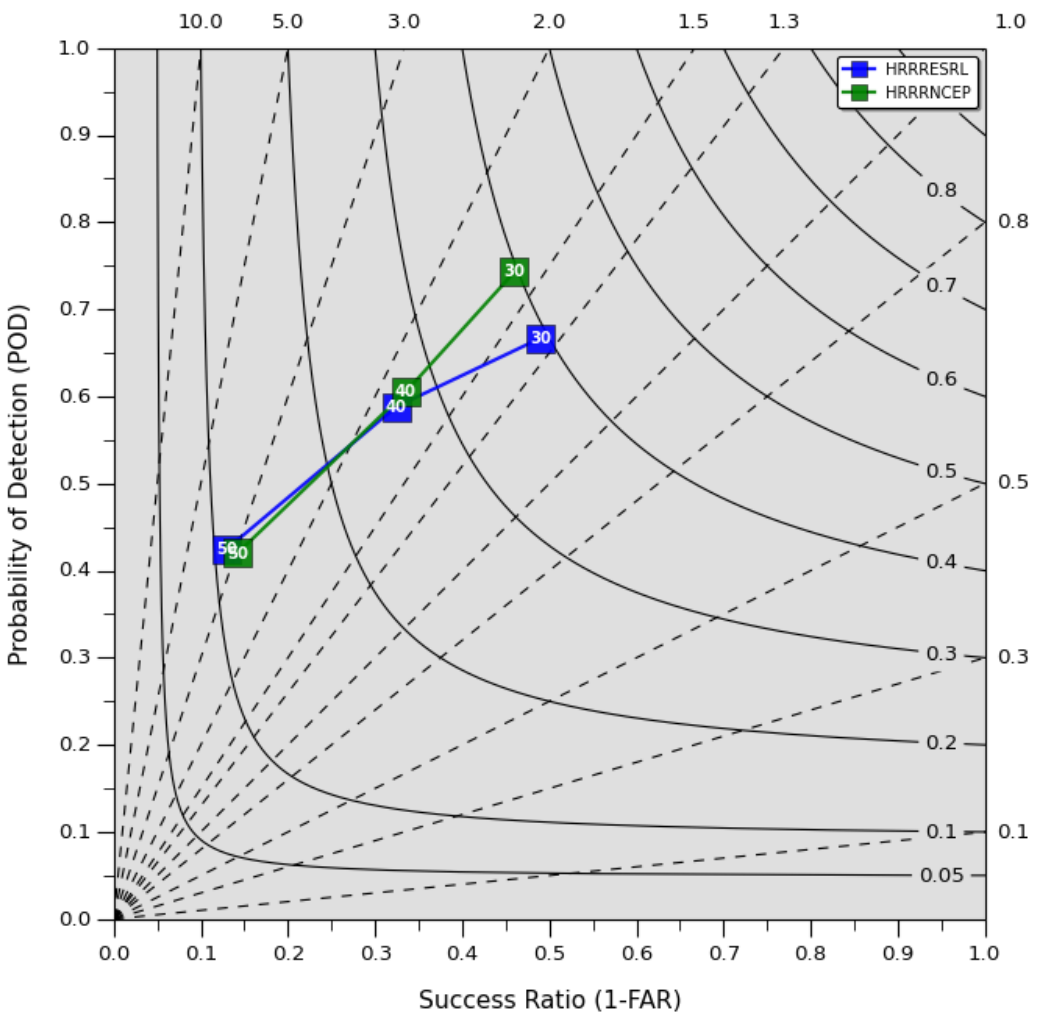



00-h Analyses of Composite Reflectivity
Valid 15Z on 11 July 2017

# SPC HRRRv3 Evaluation
## 15Z HRRR: Performance Diagram

- For slightly longer range forecasts (fh04-07) from 15Z, most of the statistical improvement in the HRRRv3 over the HRRRv2 has been lost.
- The most notable remaining benefit is the reduced frequency bias at 30 dBZ.

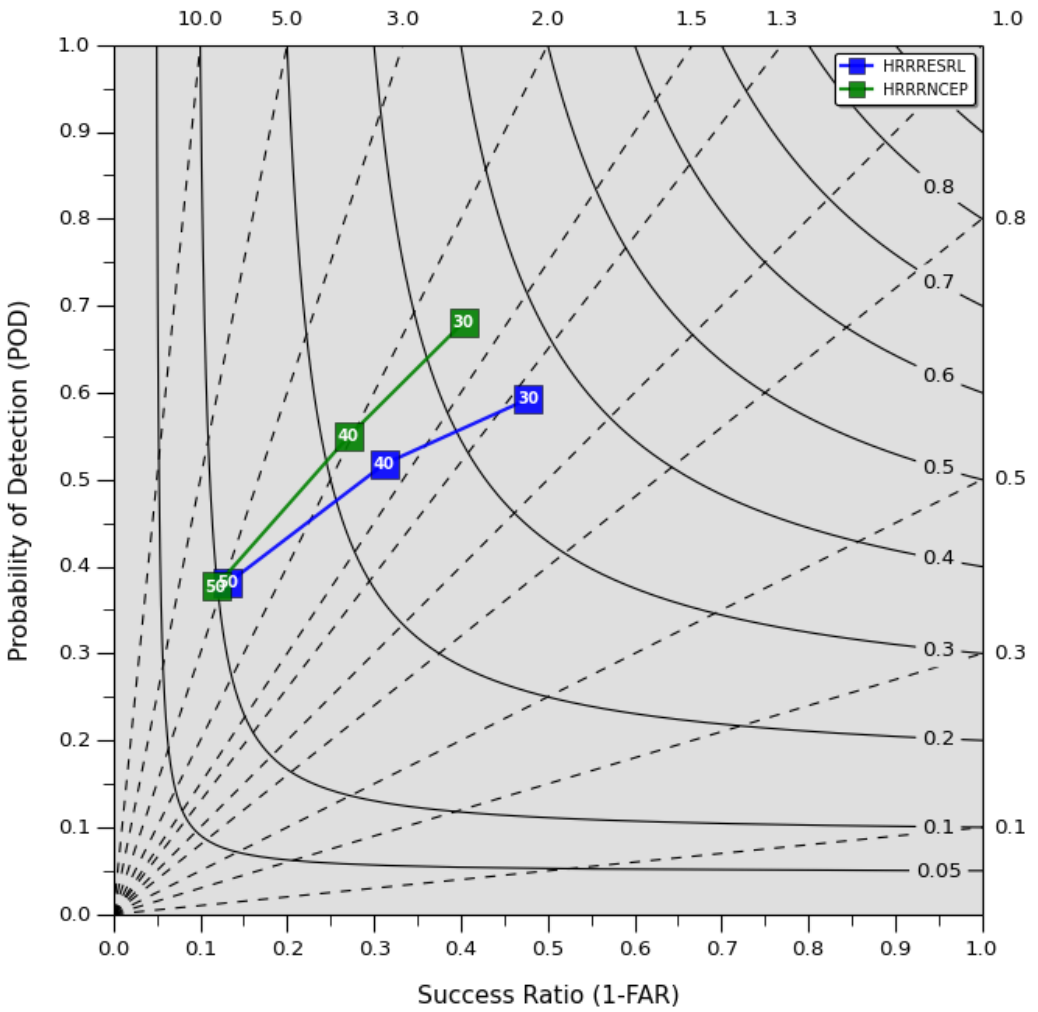
National Composite Reflectivity
**20170415-20170815**; 15Z cycle, fh04-07



# SPC HRRRv3 Evaluation
## 03Z HRRR: Performance Diagram

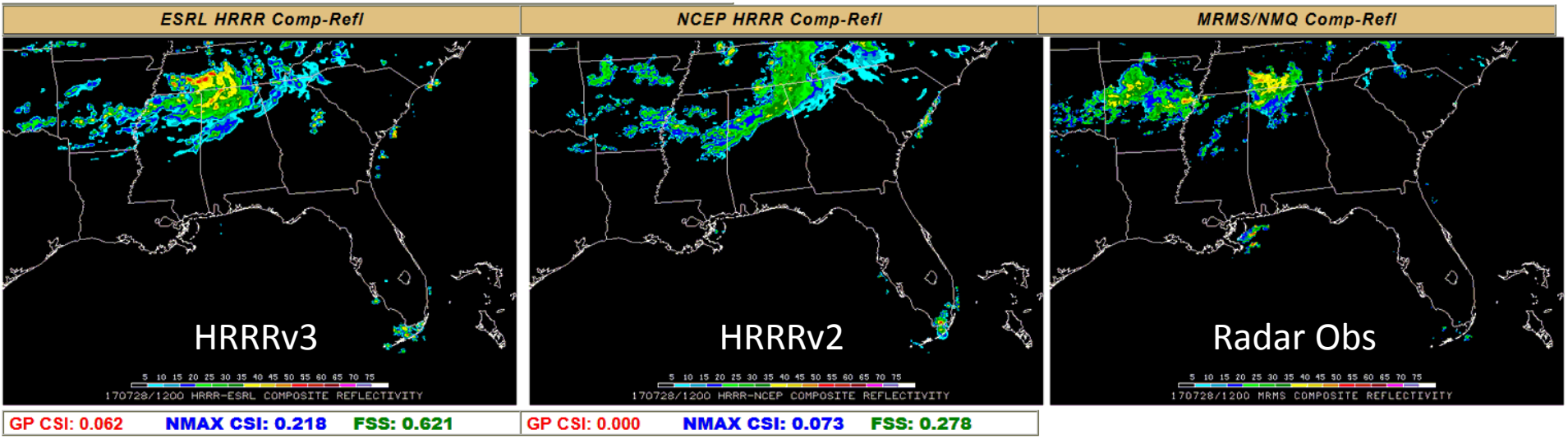
- For the initial SPC Convective Outlook issued at 0600Z, one key challenge for SPC forecasters is determining the evolution of overnight storms.
- The 03Z cycle 9-h forecast valid at 1200Z shows improved CSI, FAR, and frequency bias for the HRRRv3 despite having a lower POD at 30 and 40 dBZ.

National Composite Reflectivity
**20170415-20170815**; 03Z cycle, fh09



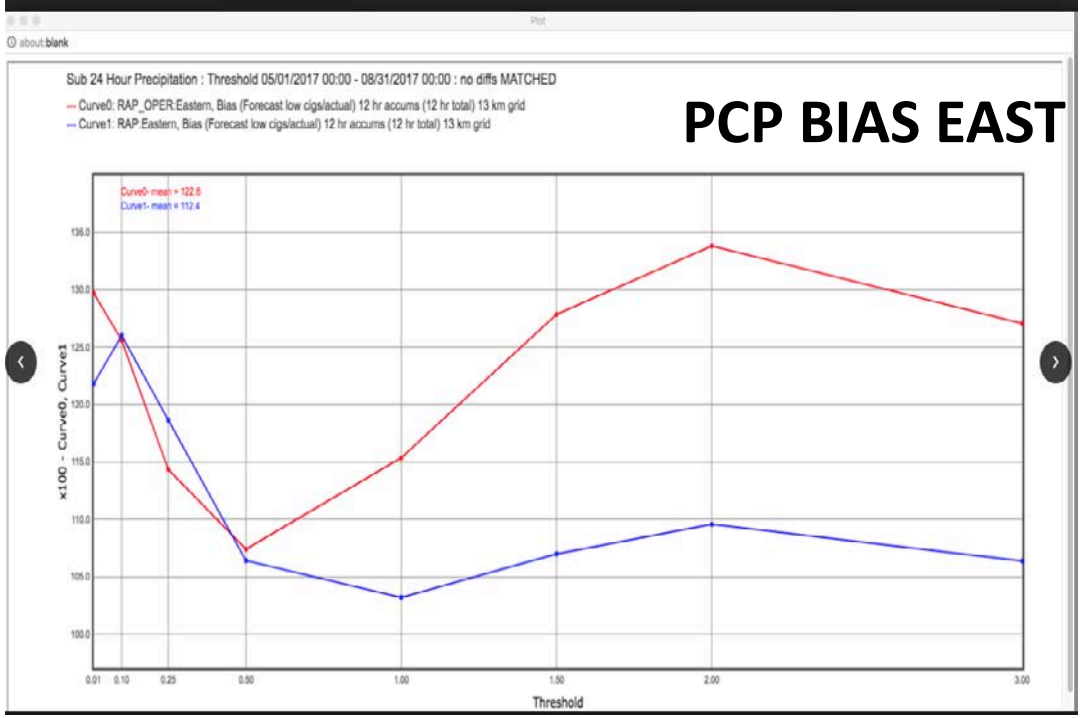
# SPC HRRRv3 Evaluation
## 03Z HRRR: Overnight Example

- The HRRRv3 (left) maintained a small MCS moving over the Tennessee Valley, while the HRRRv2 (center) weakened it too quickly.
- While overnight convective forecasts are not always better in HRRRv3 compared to HRRRv2, this example shows the type of improvement indicated in the longer-term statistics

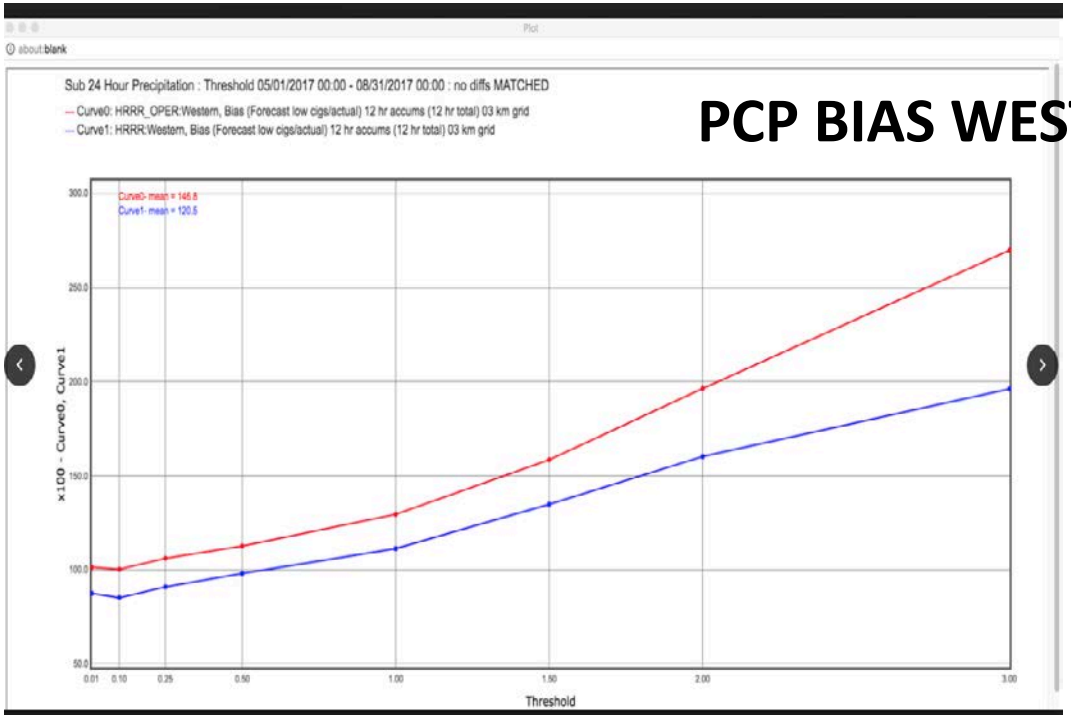


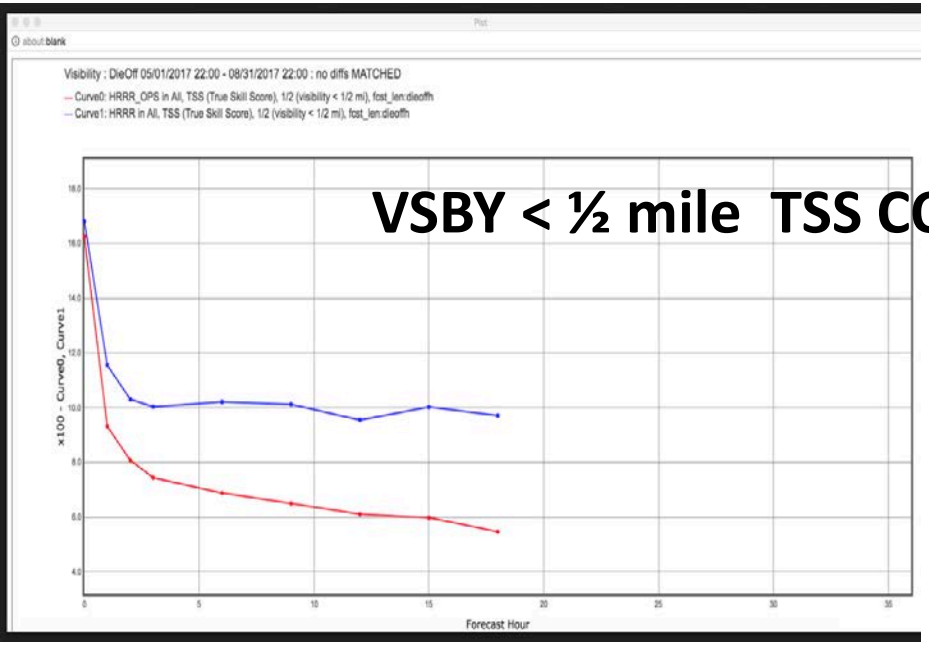

09-h Forecasts of Composite Reflectivity
Valid 12Z on 28 July 2017

# PCP BIAS EAST



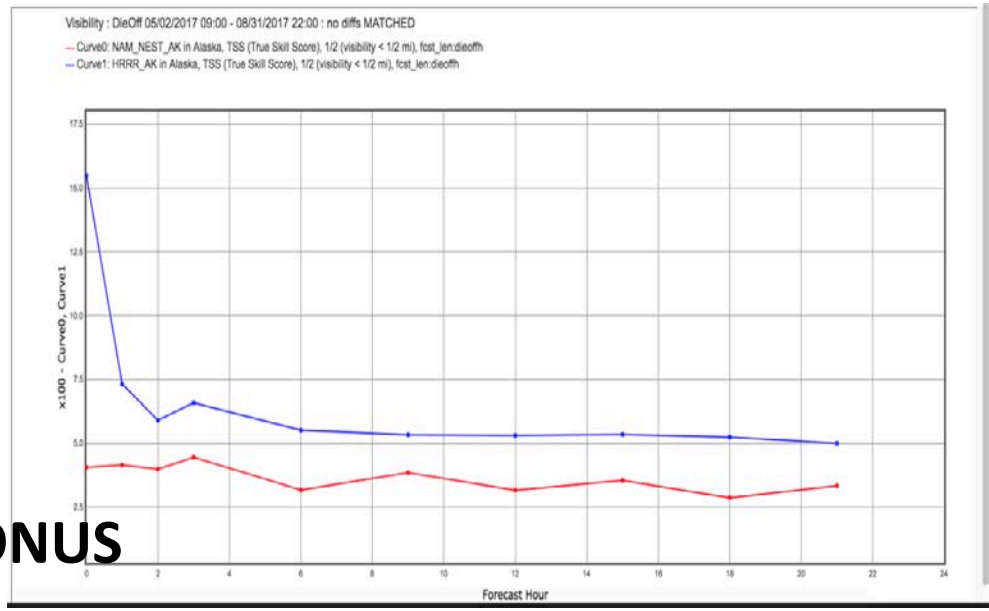

# PCP BIAS WEST

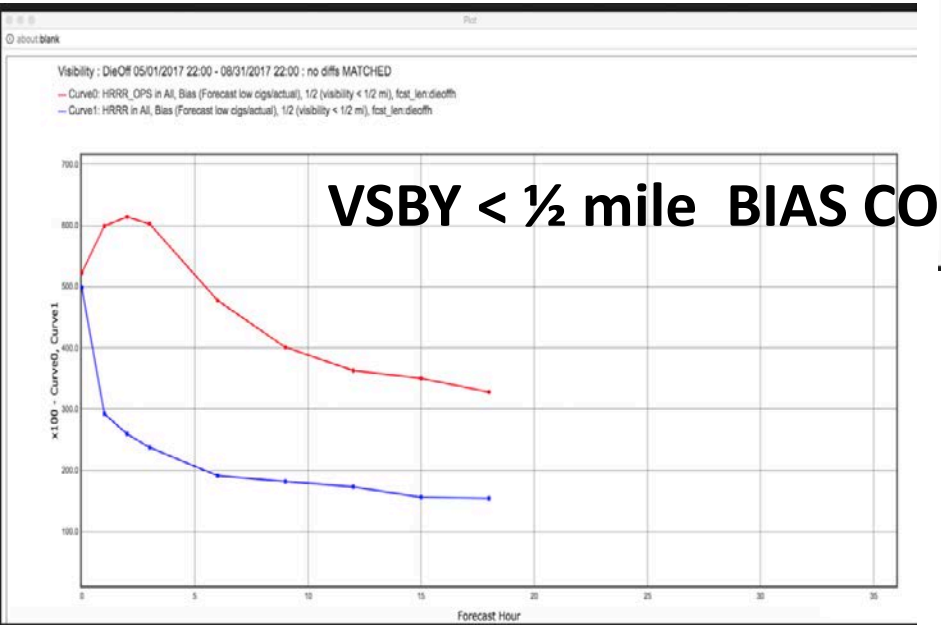





## VSBY < ½ mile TSS CONUS

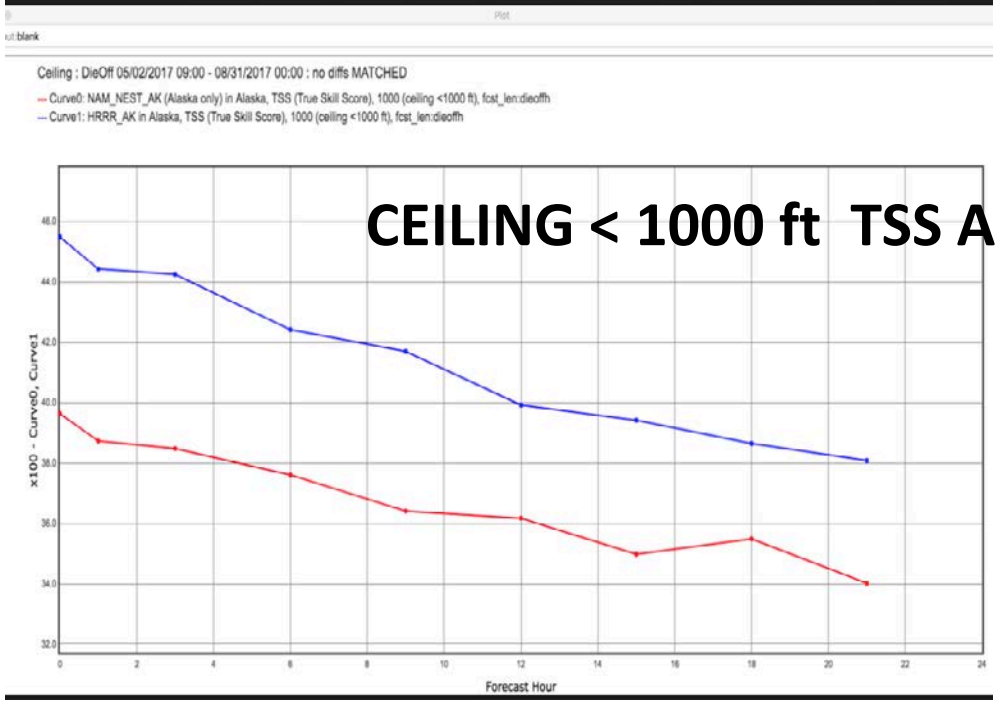
## VSBY < ½ mile TSS AL



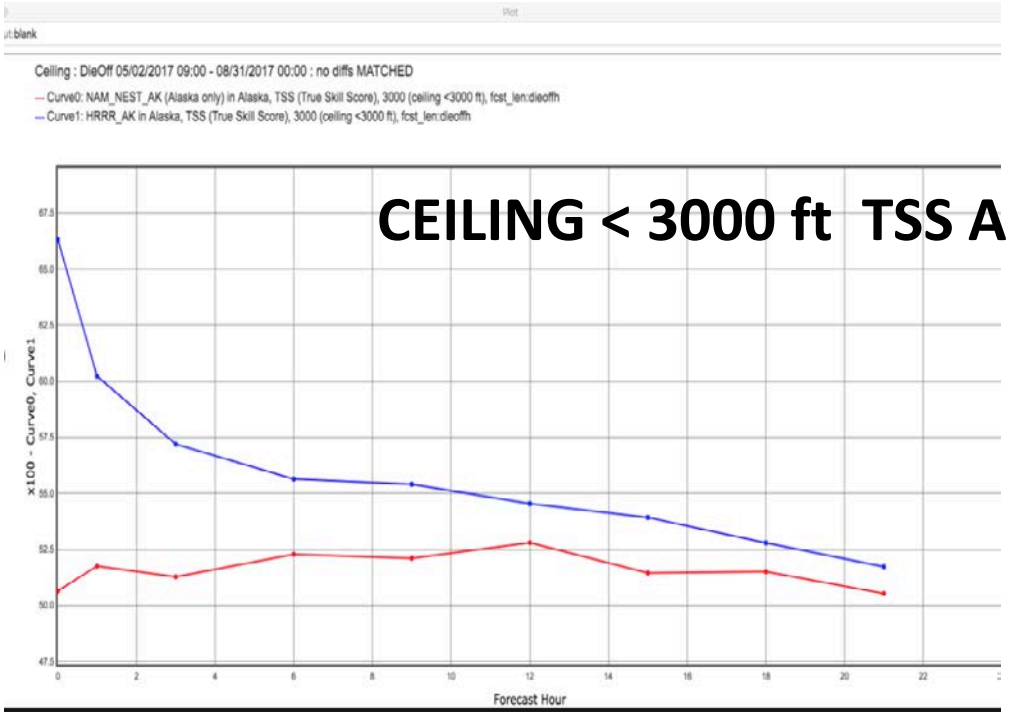




## VSBY < ½ mile BIAS CONUS

RED is NAM NEST on these images

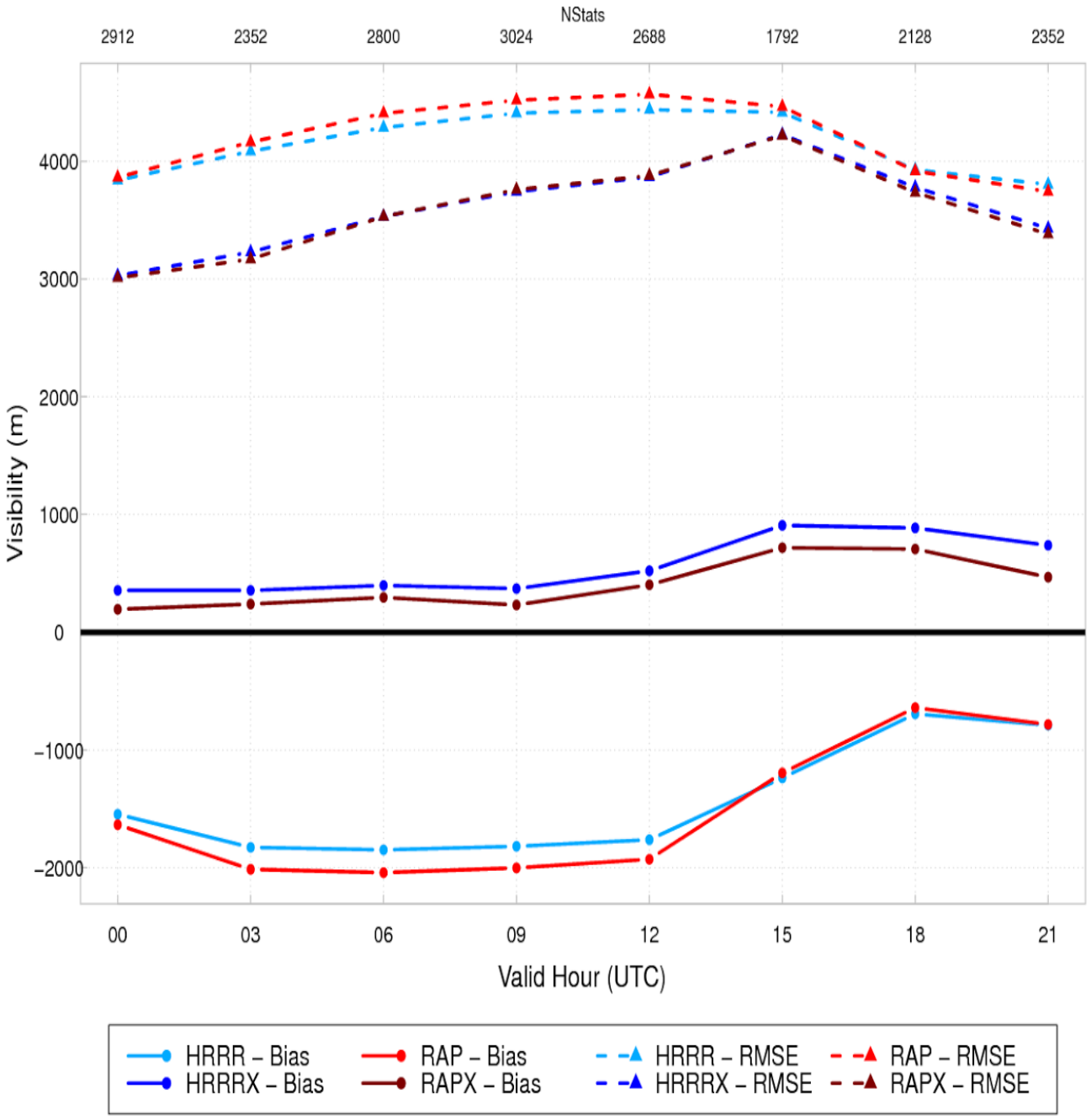


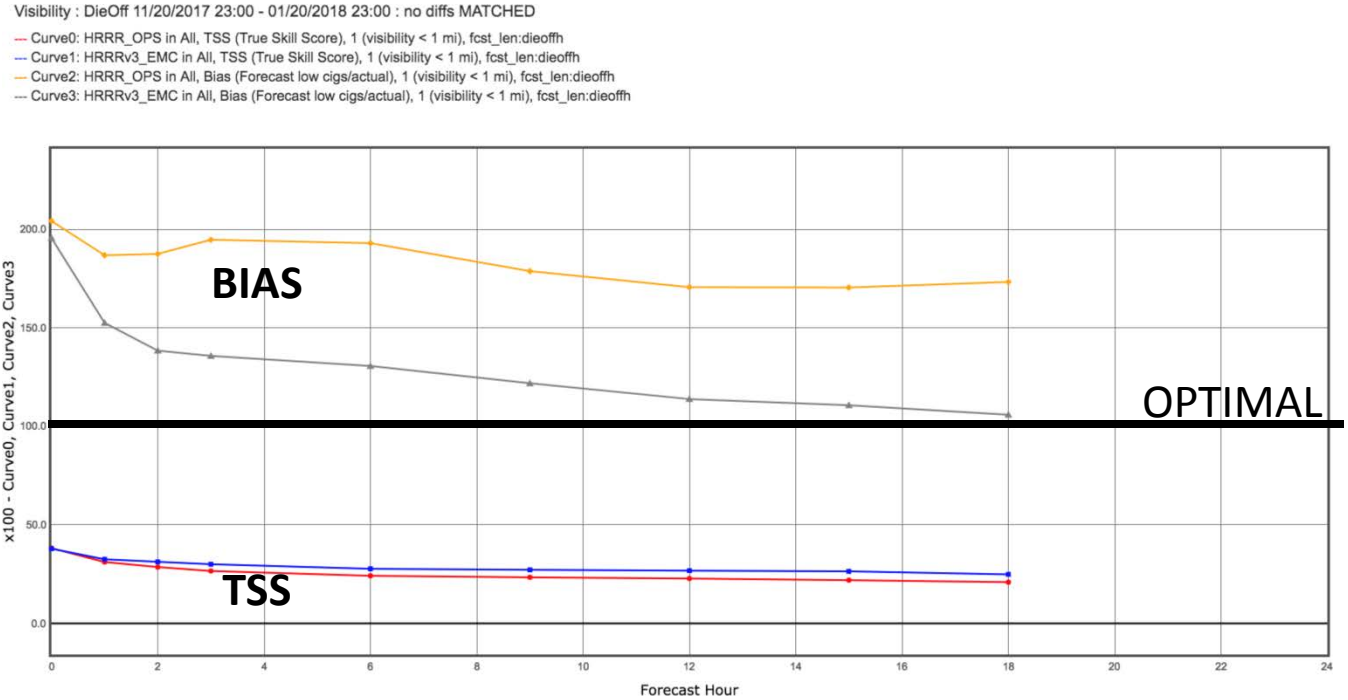

**CEILING < 1000 ft TSS ALASKA**



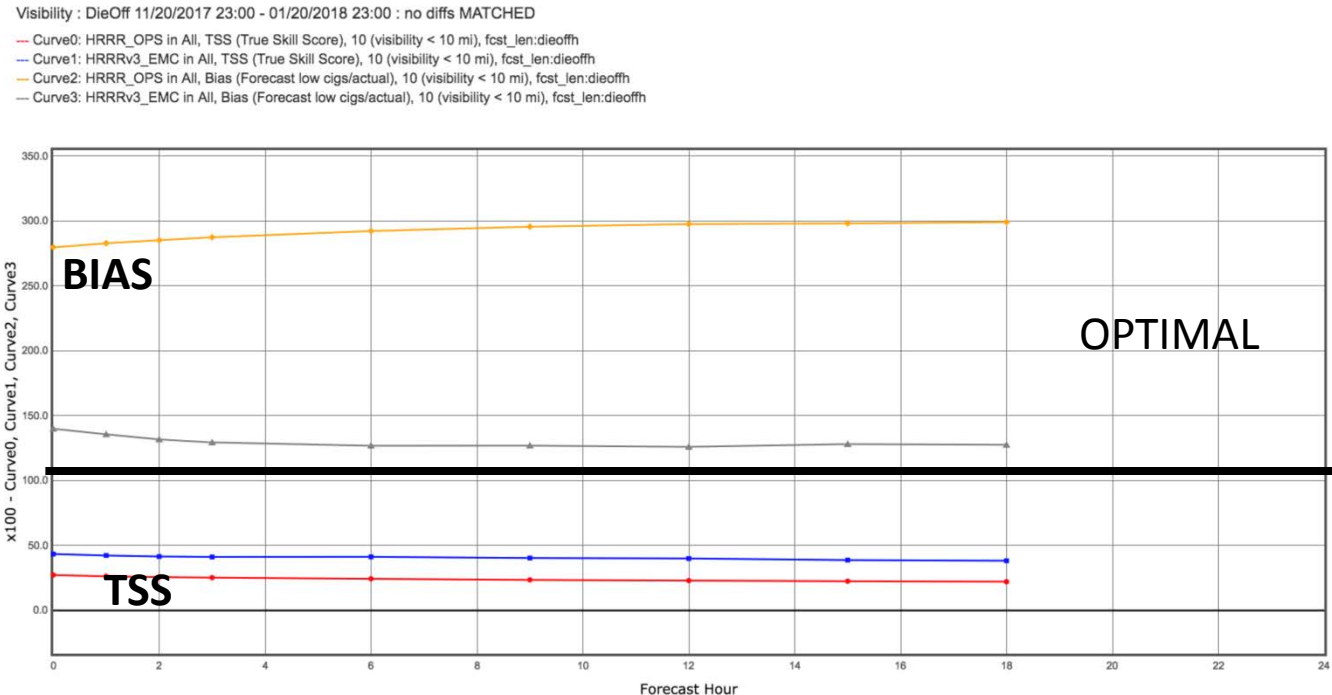

**CEILING < 3000 ft TSS ALASKA**

# COOL SEASON STATS

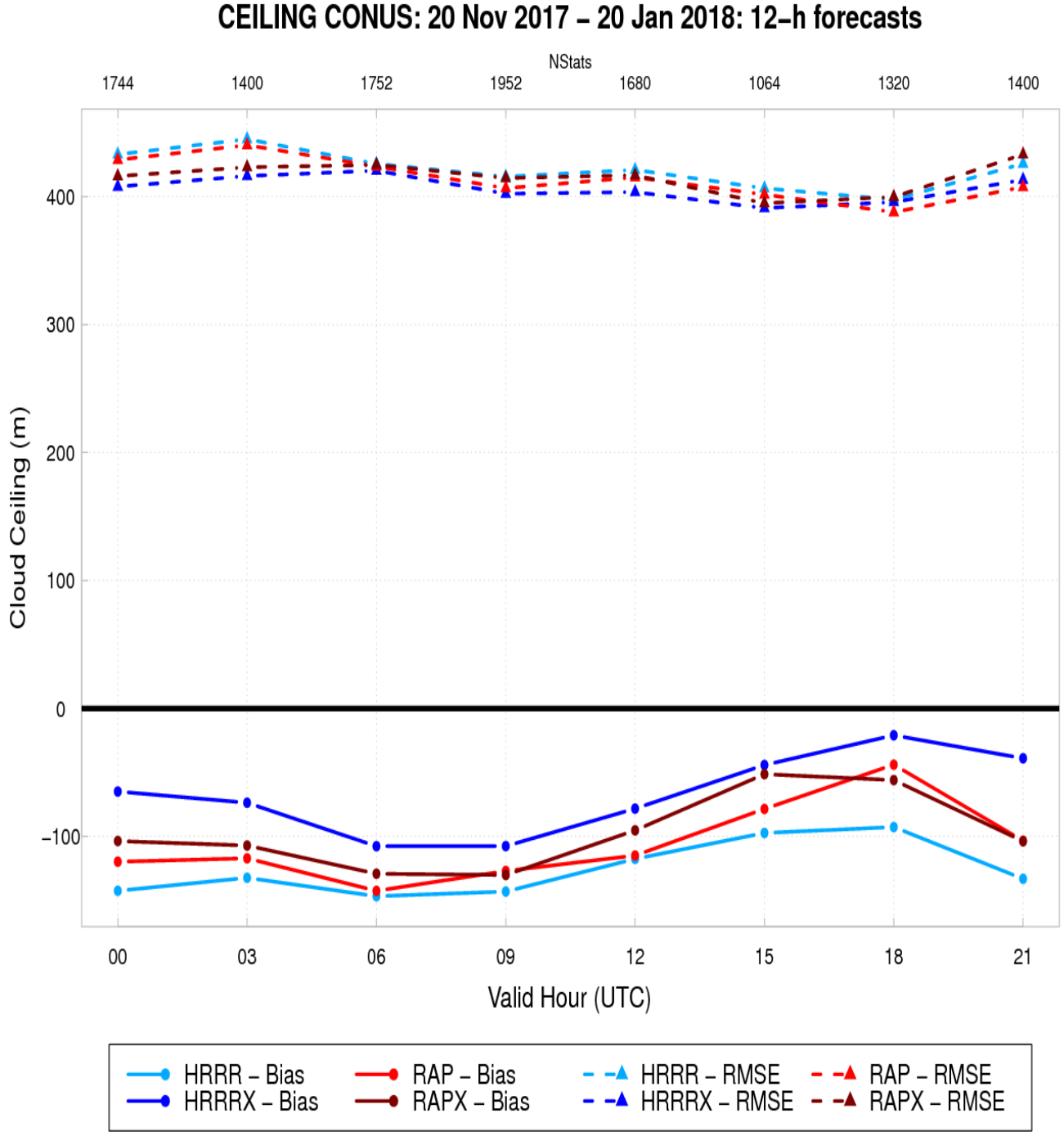

VIS CONUS: 20 Nov 2017 – 20 Jan 2018: 12–h forecasts
NStats
2912
2352
2800
3024
2688
1792
2128
2352
4000
3000
2000
1000
0
−1000
−2000
Visibility (m)
00
03
06
09
12
15
18
21
Valid Hour (UTC)
HRRR – Bias
HRRRX – Bias
RAP – Bias
RAPX – Bias
HRRR – RMSE
HRRRX – RMSE
RAP – RMSE
RAPX – RMSE




VISIBILITY
CONUS
11/20/17-
01/20/18




- HRRR OPS
- HRRR OPS
- HRRR PARA
- HRRR PARA


CEILING CONUS: 20 Nov 2017 – 20 Jan 2018: 12–h forecasts
NStats
1744
1400
1752
1952
1680
1064
1320
1400
400
300
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−100
Cloud Ceiling (m)
00
03
06
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12
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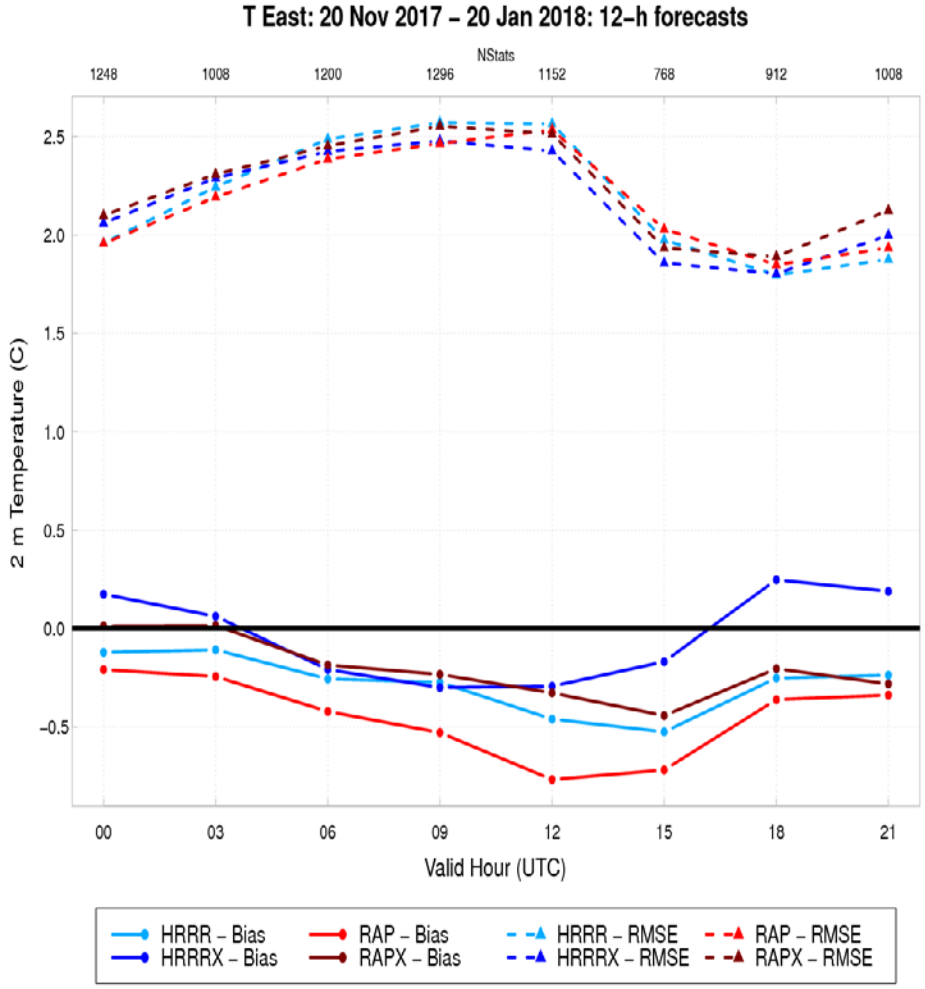
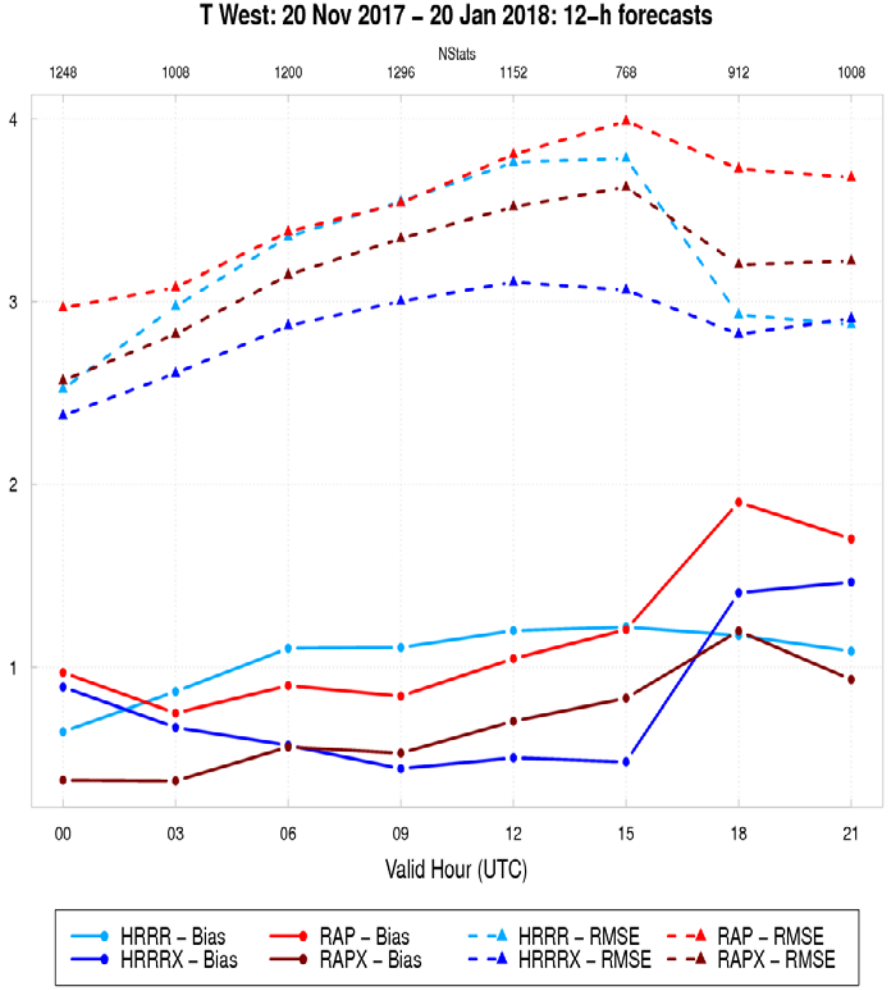
18
21
Valid Hour (UTC)
HRRR – Bias
HRRRX – Bias
RAP – Bias
RAPX – Bias
HRRR – RMSE
HRRRX – RMSE
RAP – RMSE
RAPX – RMSE


T East: 20 Nov 2017 – 20 Jan 2018: 12–h forecasts
NStats
1248
1008
1200
1296
1152
768
912
1008
2 m Temperature (C)
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
00
03
06
09
12
15
18
21
Valid Hour (UTC)
HRRR – Bias
HRRRX – Bias
RAP – Bias
RAPX – Bias
HRRR – RMSE
HRRRX – RMSE
RAP – RMSE
RAPX – RMSE


T West: 20 Nov 2017 – 20 Jan 2018: 12–h forecasts
NStats
1248
1008
1200
1296
1152
768
912
1008
4
3
2
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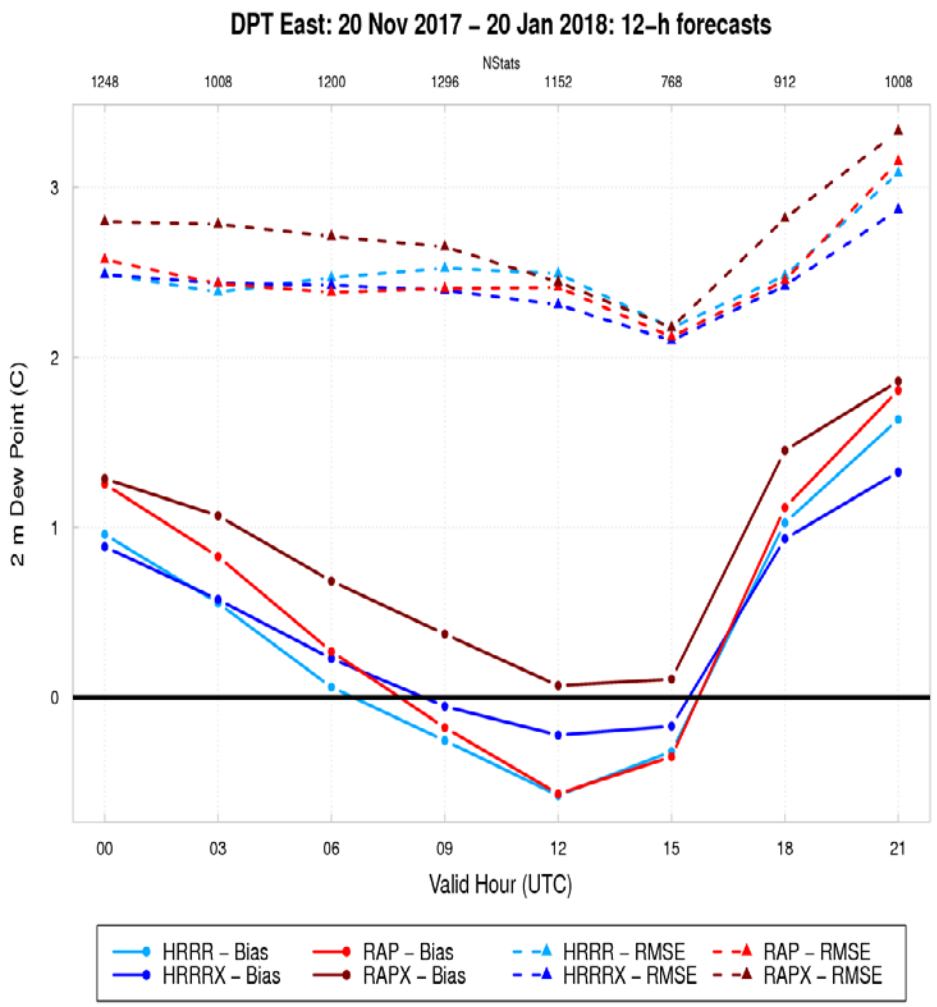
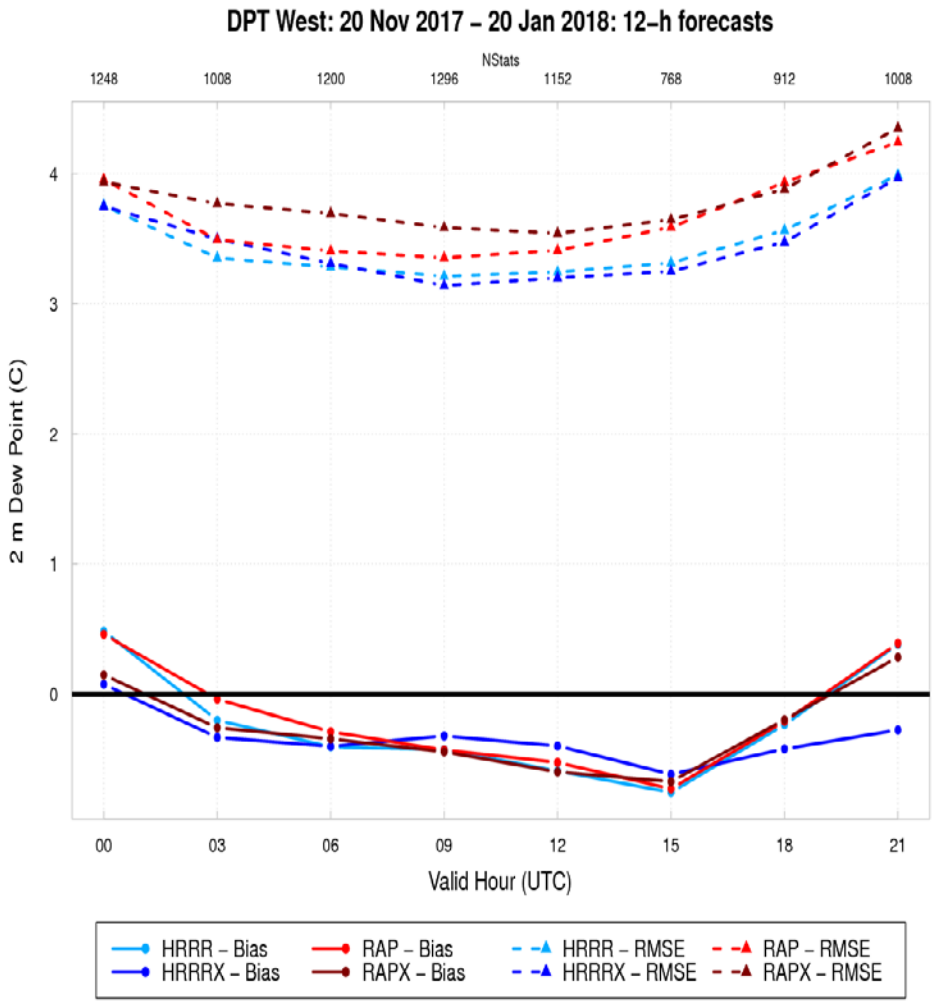
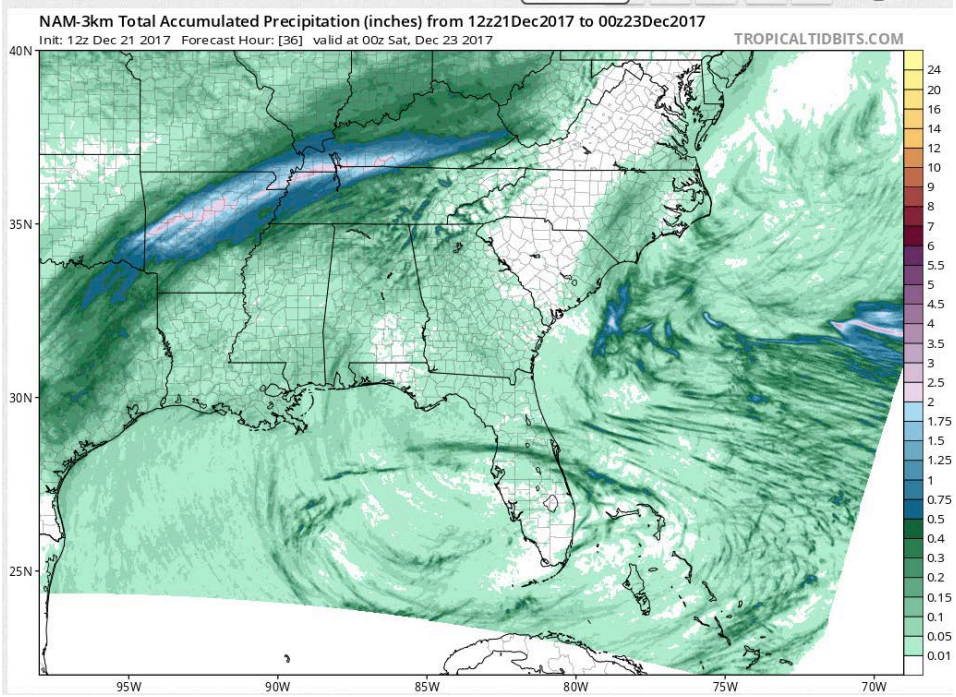
03
06
09
12
15
18
21
Valid Hour (UTC)
HRRR – Bias
HRRRX – Bias
RAP – Bias
RAPX – Bias
HRRR – RMSE
HRRRX – RMSE
RAP – RMSE
RAPX – RMSE

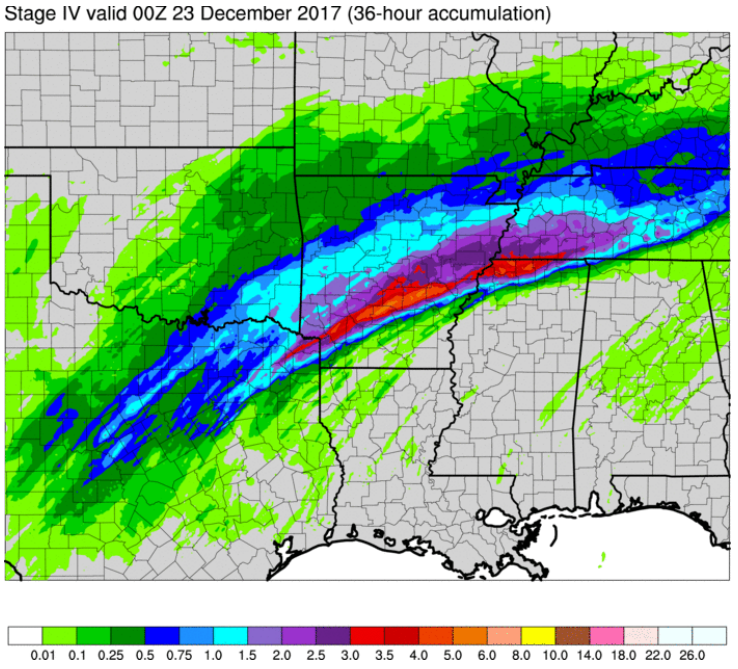

DPT East: 20 Nov 2017 – 20 Jan 2018: 12–h forecasts
NStats
1248 1008 1200 1296 1152 768 912 1008
2 m Dew Point (C)
0 1 2 3
00 03 06 09 12 15 18 21
Valid Hour (UTC)
HRRR – Bias
HRRRX – Bias
RAP – Bias
RAPX – Bias
HRRR – RMSE
HRRRX – RMSE
RAP – RMSE
RAPX – RMSE

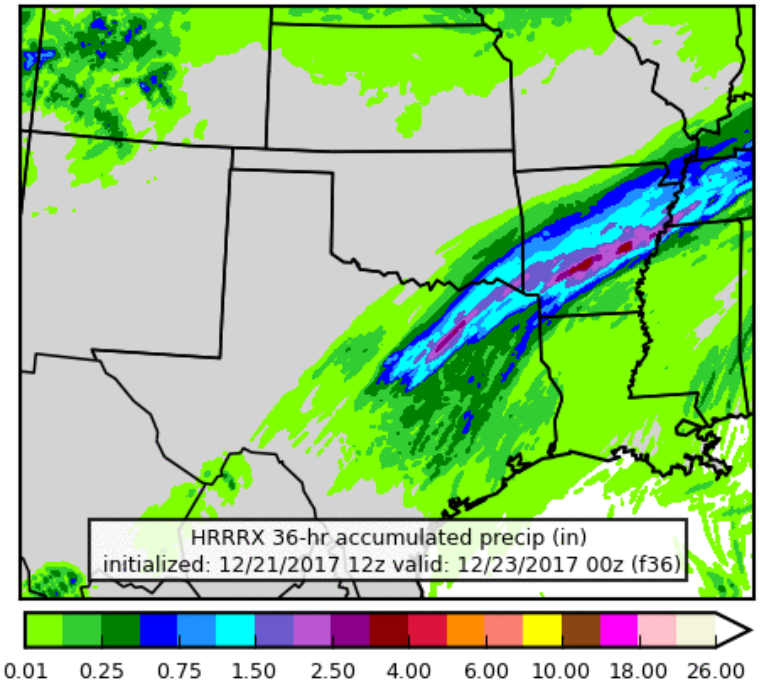

DPT West: 20 Nov 2017 – 20 Jan 2018: 12–h forecasts
NStats
1248 1008 1200 1296 1152 768 912 1008
2 m Dew Point (C)
0 1 2 3 4
00 03 06 09 12 15 18 21
Valid Hour (UTC)
HRRR – Bias
HRRRX – Bias
RAP – Bias
RAPX – Bias
HRRR – RMSE
HRRRX – RMSE
RAP – RMSE
RAPX – RMSE

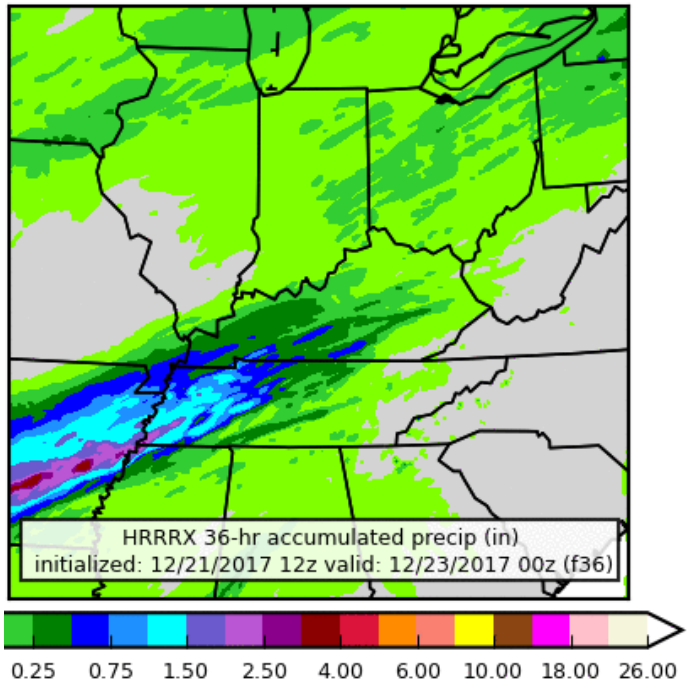
# Some Case Highlights

- Several provided by MEG
- STI SOO-based CAM evaluation team examined HRRRX performance on a set of diverse, high-impact cases in different parts of the country
- HRRRX performance was generally as good or better than HRRR, but a few slightly worse performances were noted

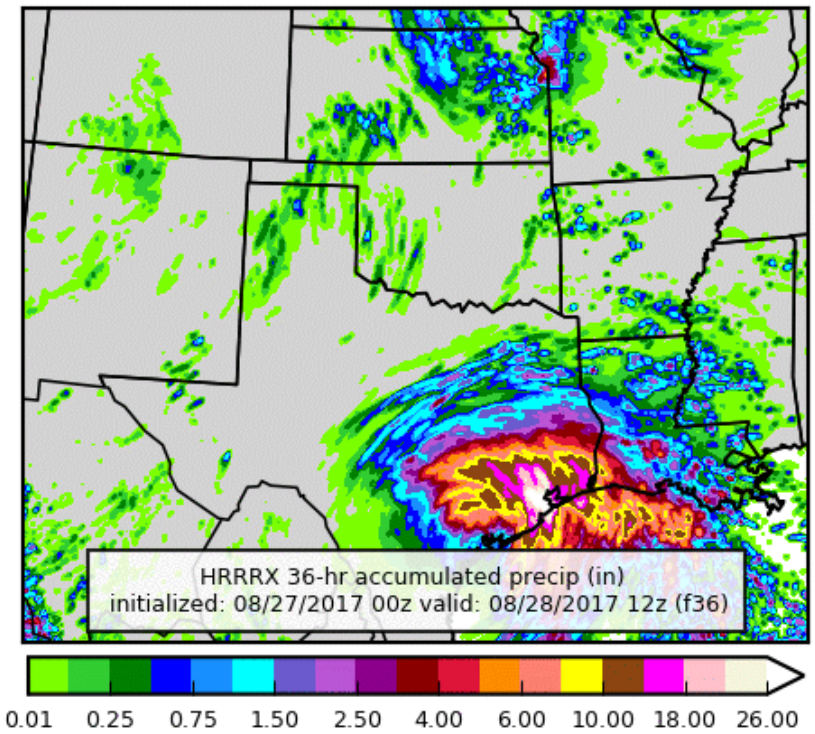


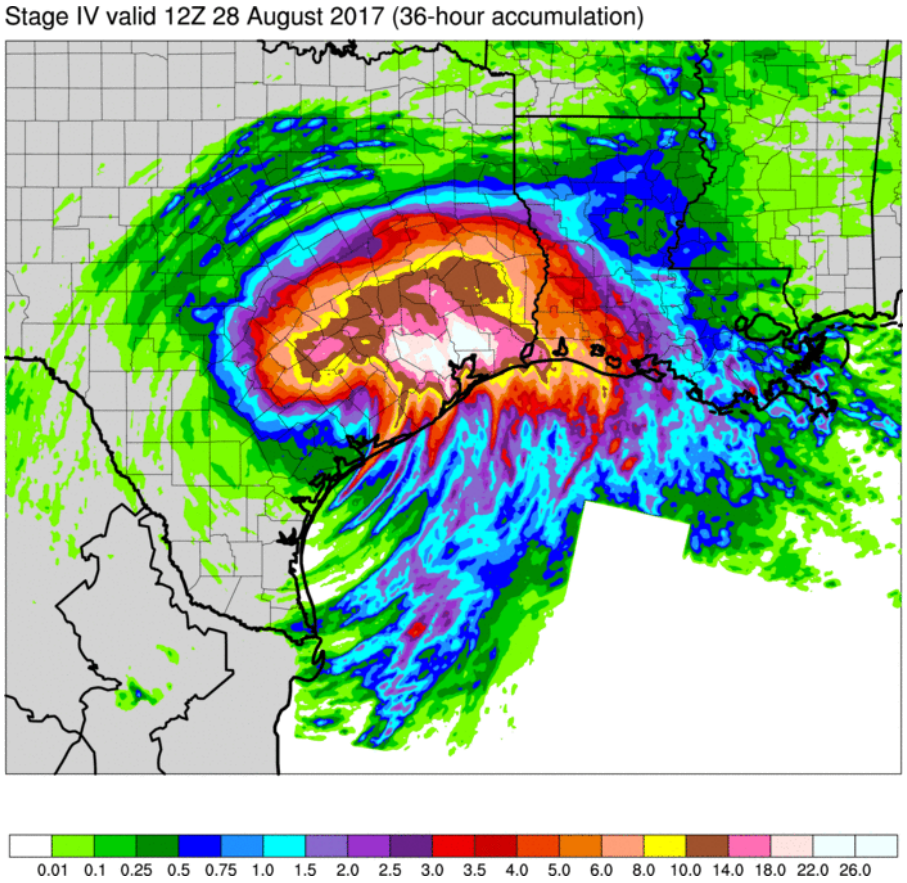



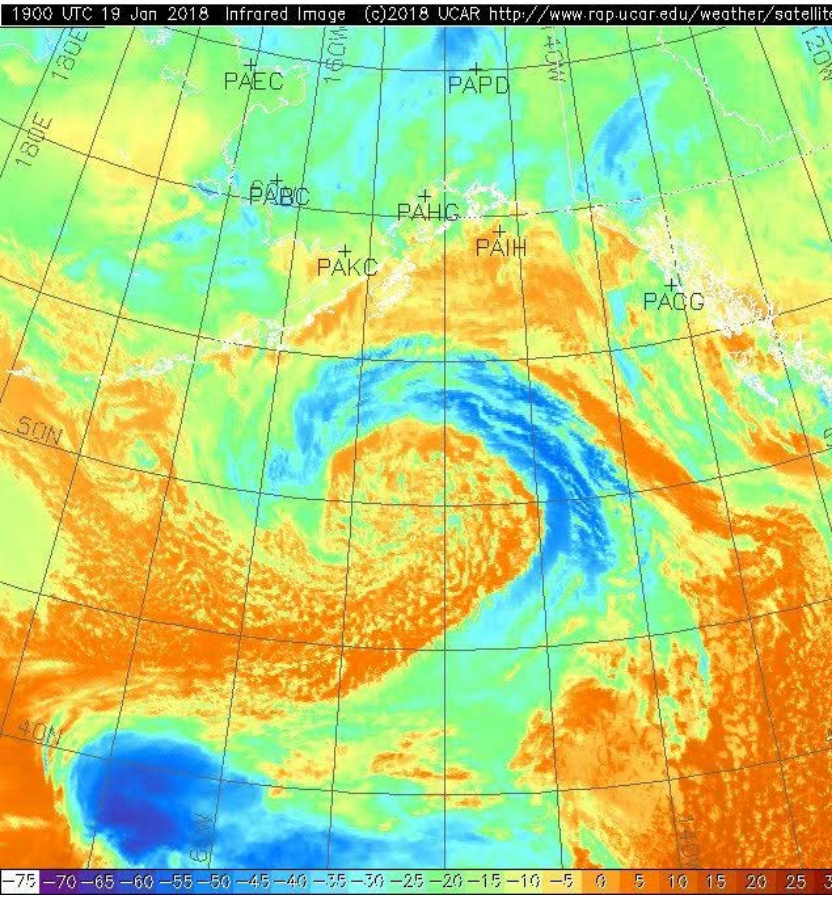



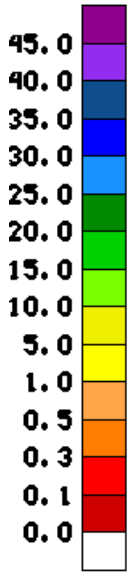

HRRRX correctly more south with heavy rain axis than NAM nest

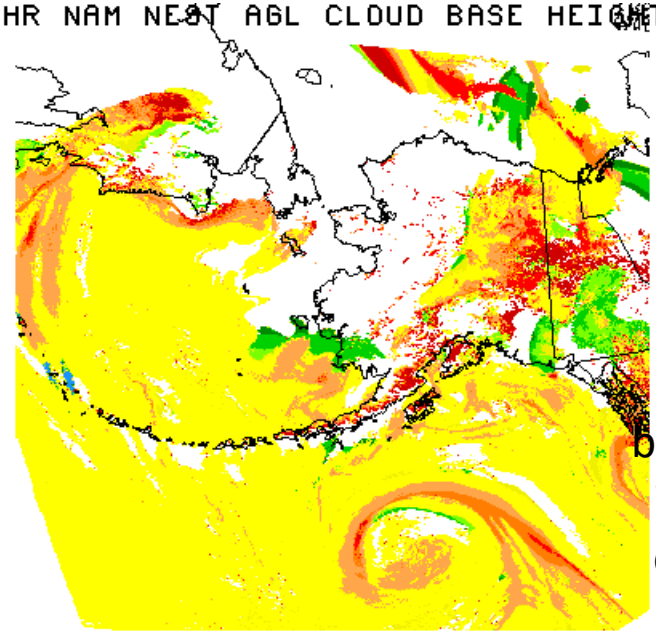


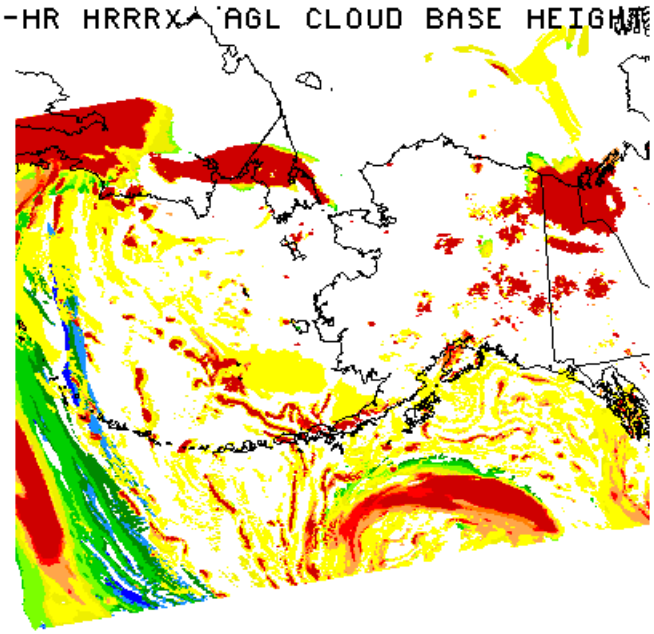

another example of a day 2
HRRRX application



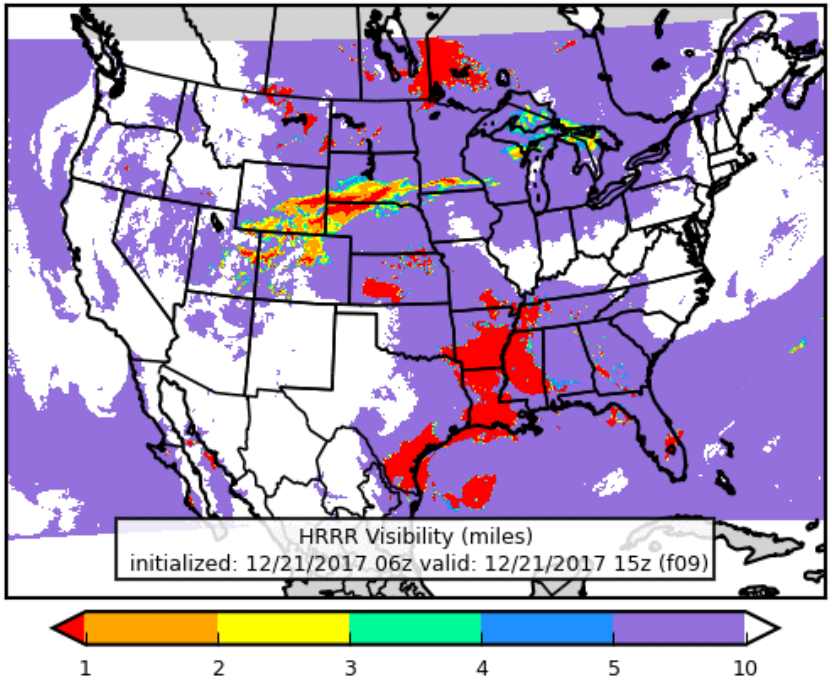



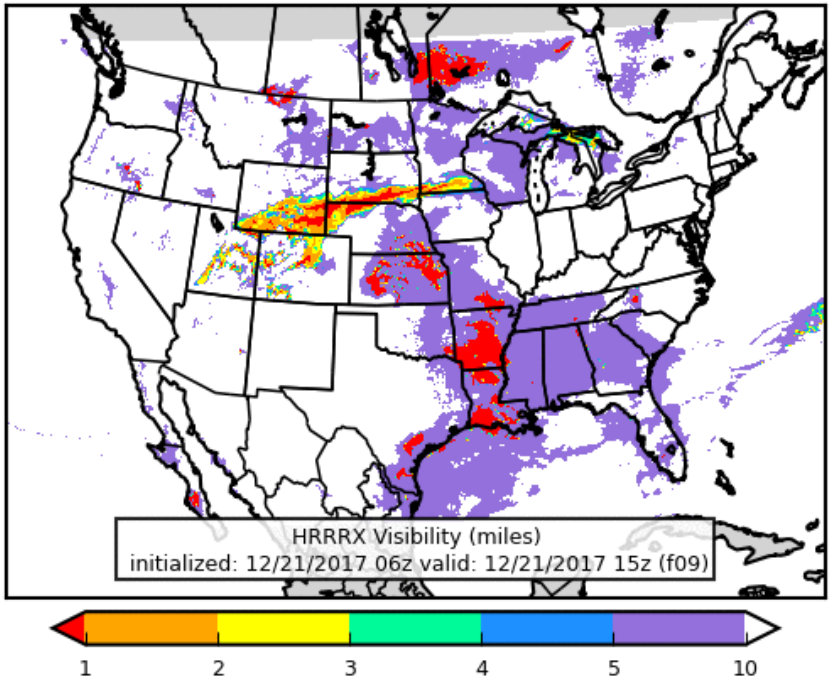



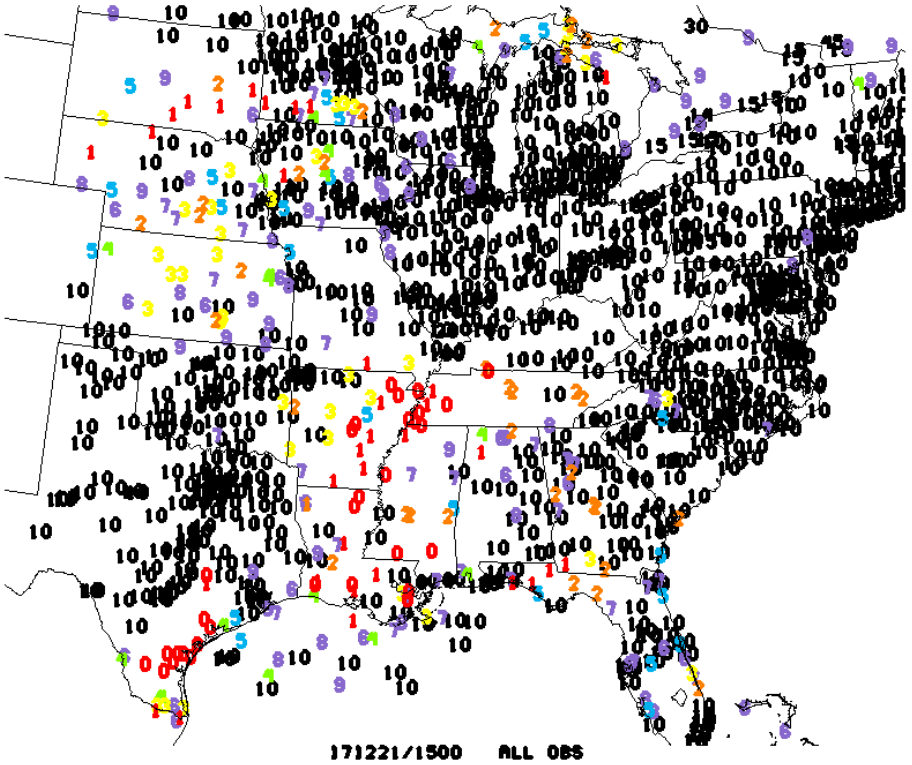

FCST MADE 18Z 01/19



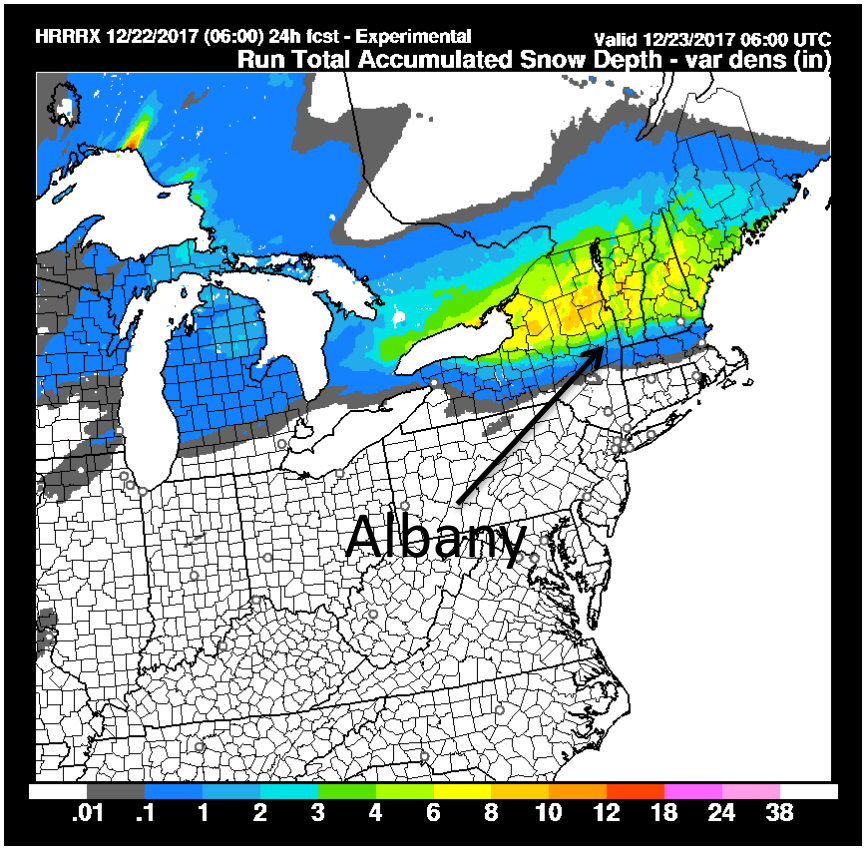

big differences in low-level cloud between HRRRX and NAM nest

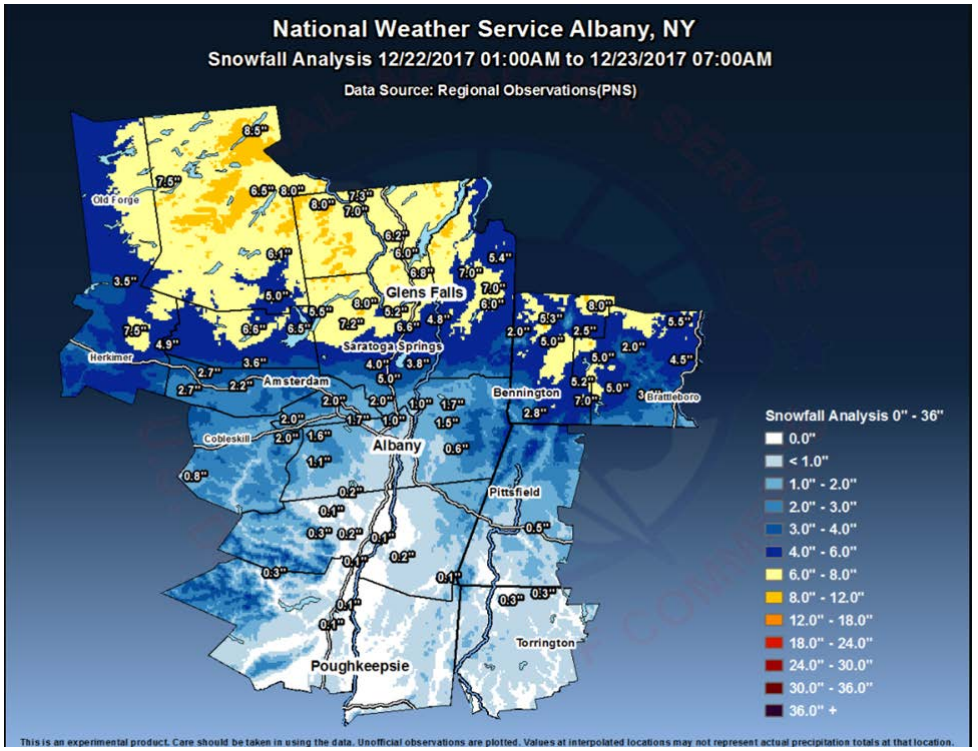

HRRR Visibility (miles)
initialized: 12/21/2017 06z valid: 12/21/2017 15z (f09)
1
2
3
4
5
10


HRRRX Visibility (miles)
initialized: 12/21/2017 06z valid: 12/21/2017 15z (f09)
1
2
3
4
5
10


171221/1500 ALL OBS

# HRRRX accumulated snow depth 12/22 6z cycle



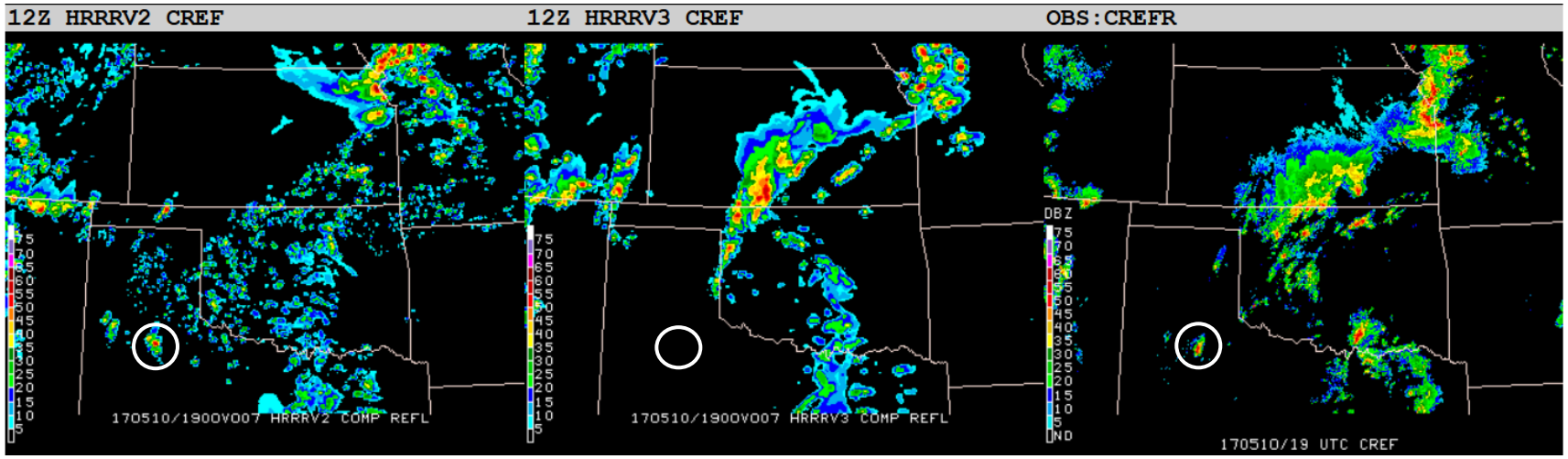



# SPC RAPv4/HRRRv3 Evaluation

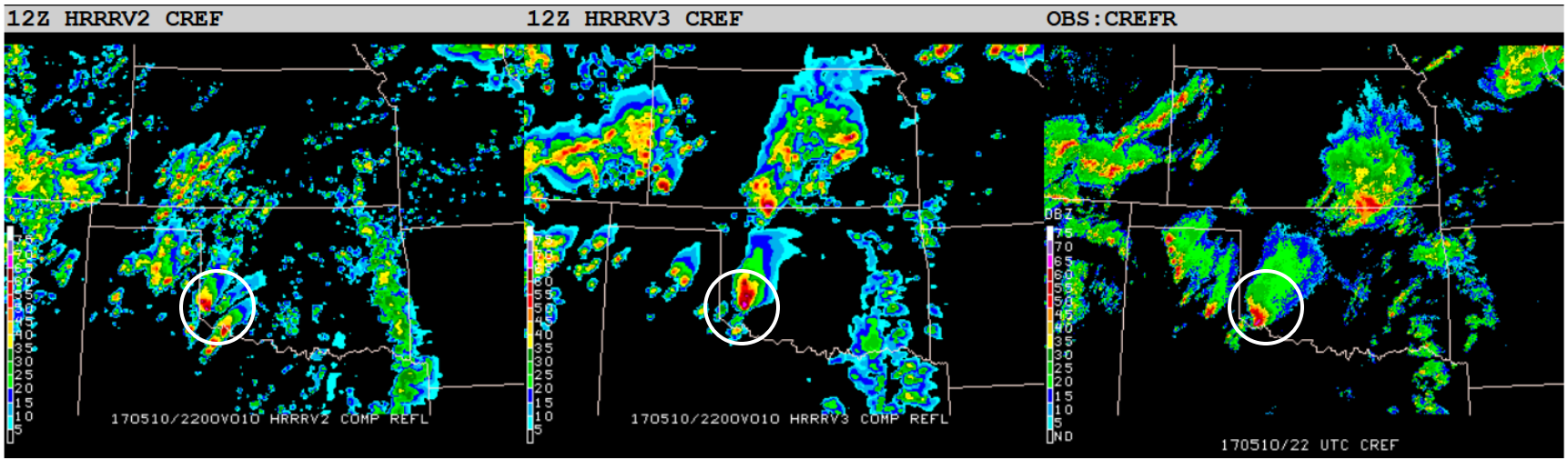
## 12Z HRRR: 10 May 2017 Case

- The HRRRv2 was earlier with convective initiation, but the HRRRv3 was better with evolution into dominant supercell

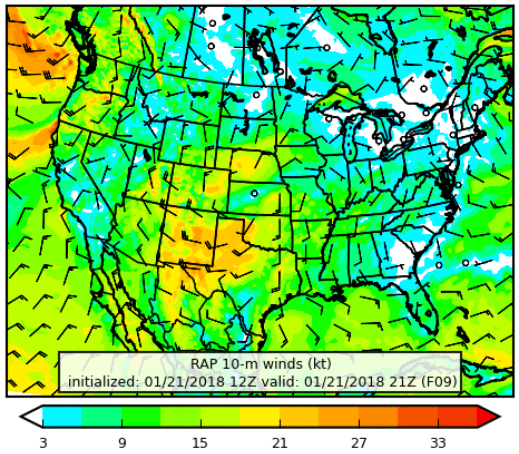
19Z 10 May 2017

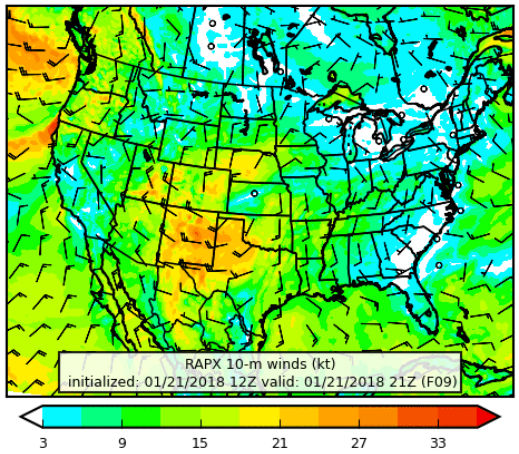


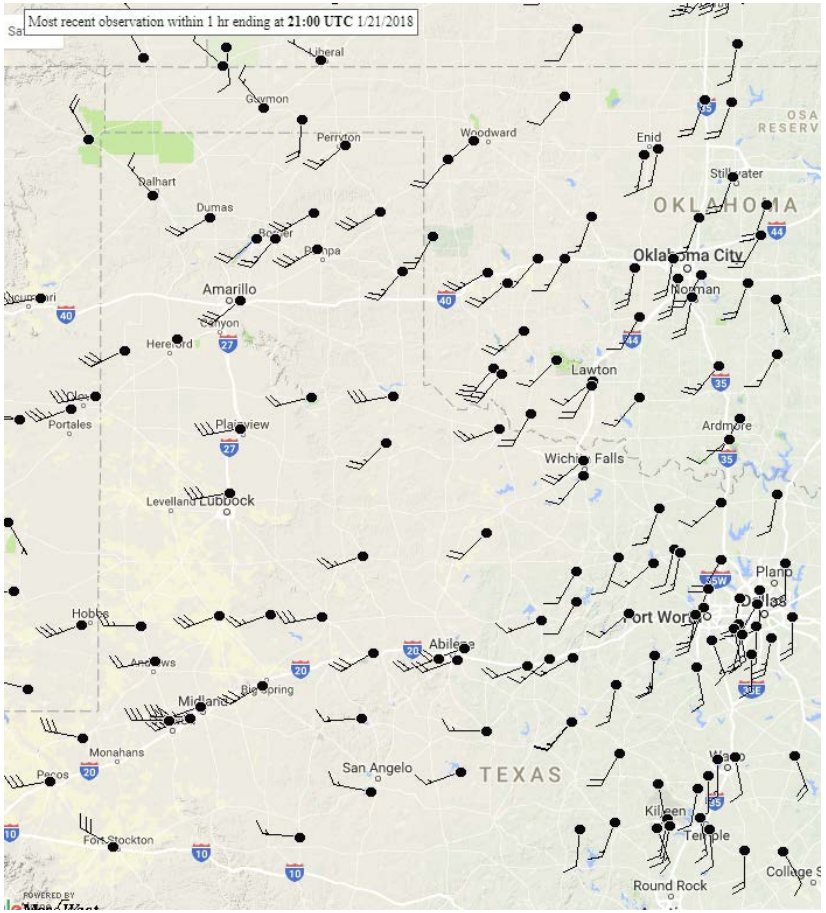

22Z 10 May 2017



# 10-m Winds (kts) from 1/21 12Z run
# 9 hour forecast RAPv4 vs operational RAP



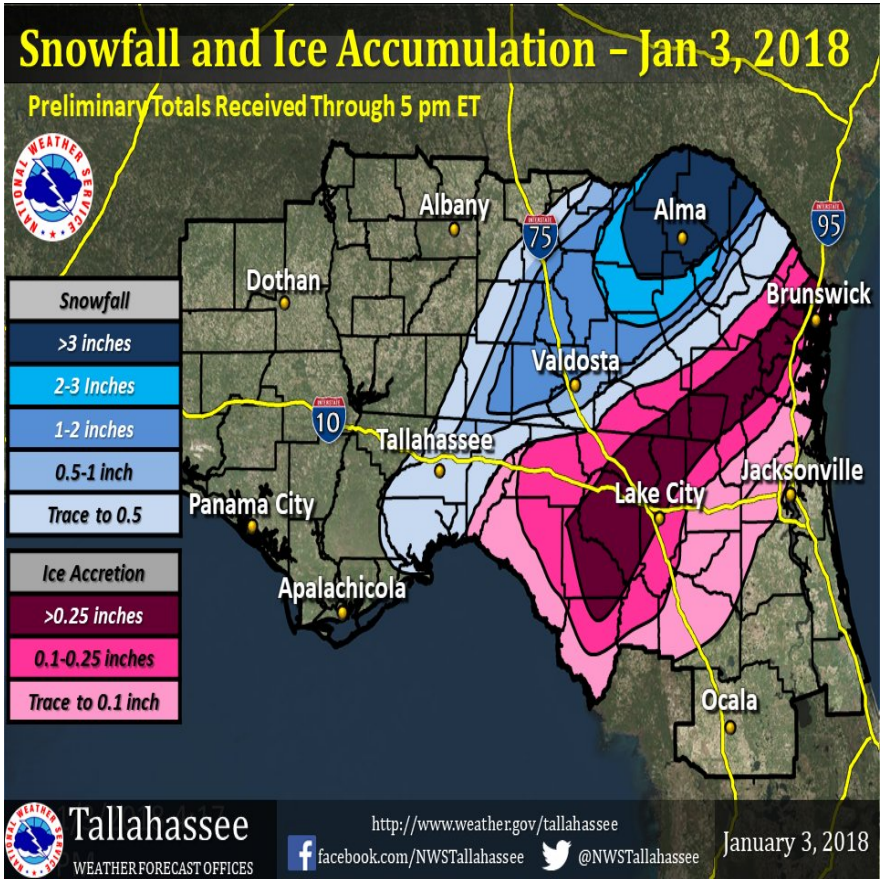



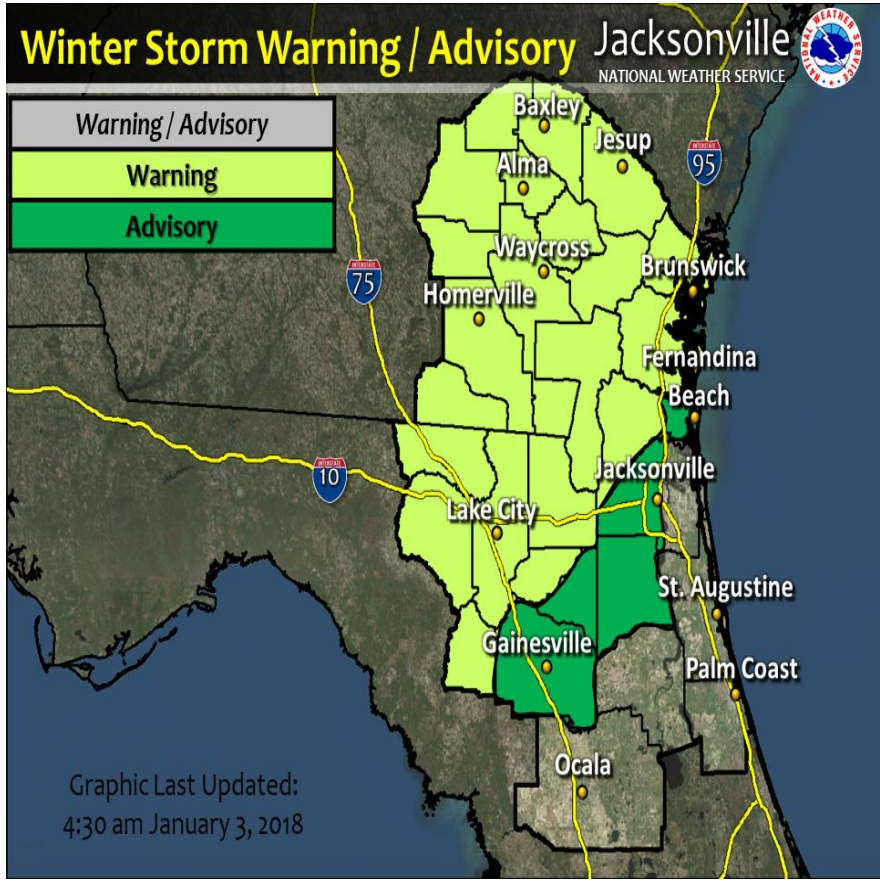

- 30-35 kt wind pronounces on southern High Plains @ 21Z.
- RAPX has stronger winds overall.
- Overall representation of winds was about 5-10 kts too light in strongest sustained wind corridors.

# What occurred….

A nearly perfect forecast, despite rarity of event and lack of understanding of model accura

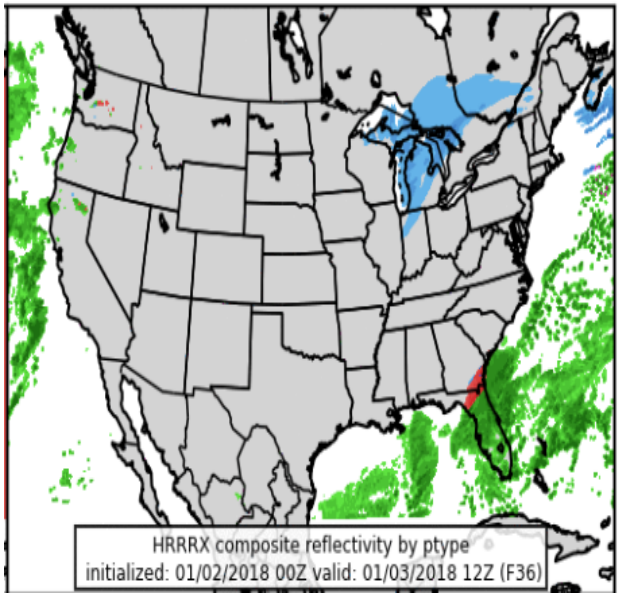



What occurred



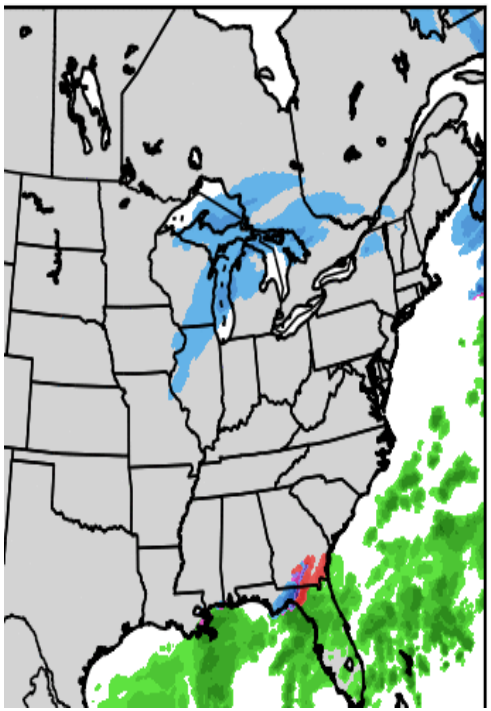

What was foreca

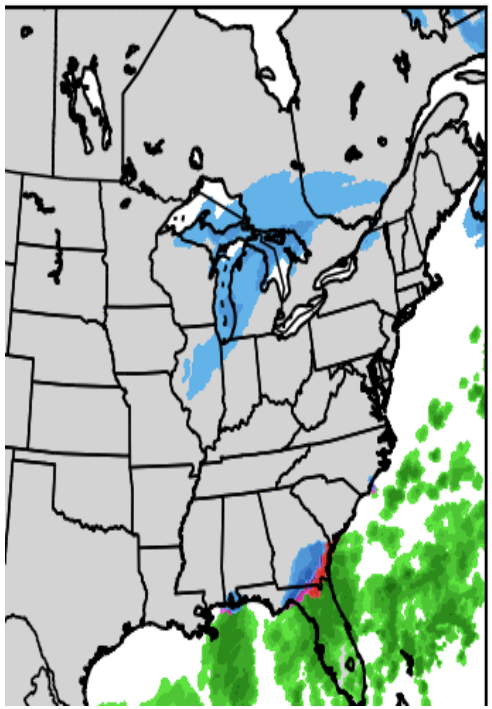
- 2-4” locally 6” snow Homerville to Waycros
- 0.25-.50 inch ice accumulation Lake City FL
- Minimal ice accumulation in advisory area.

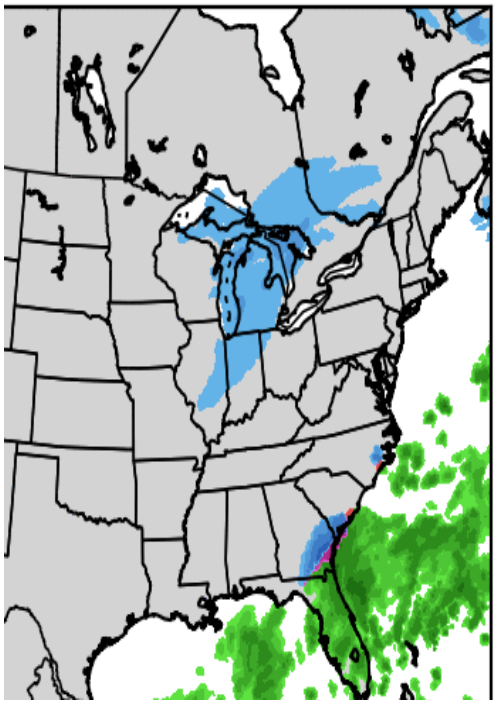



HRRRX 36hr forecast valid at start of ice event.

Similar for later run's 33hr forecast.







Accurate representation of transition toward snow (some heavy) 12-15z. Images are 30, 33, and 36hr forecast precip. type from 03z Jan 2 HRRRx

# RAPv4 HRRRv3
## Status as of 1/15/18

G

### Project Information & Highlights

**Leads:** G. Manikin (EMC), S. Earle (NCO)

**Scope:** Updated WRF-ARW3.8.1 code. Updates to microphysics, PBL scheme, data assimilation, and land-surface model. Extend four cycles/day to f39 (RAP)/f36 (HRRR). Add HRRR Alaska.

**Expected benefits:** Overall improved skill. Further reduce bias of overforecasting convection. Assist with day 2 forecasts. Improved and more frequent C & V guidance for Alaska.

**Dependencies:** Satisfactory external evaluation

G **Schedule**

| Milestones & Deliverables | Date | Status |
|---|---|---|
| Freeze system code | 10/9/2017 | Completed |
| Complete full retrospective/real time runs and evaluation | 1/20/2018 | On Track |
| Conduct CCB and deliver final system code to NCO | 1/26/2018 | On Track |
| Issue Service Change Notice | 3/27/2018 | On Track |
| Complete 30-day evaluation and IT testing | 4/26/2018 | On Track |
| Operational Implementation | 5/8/2018 | On Track |

EMC NCO Red text indicates change from previous quarter

G **Issues/Risks**

**Risk 1:** Running hourly EMC HRRR-CONUS and HRRR-AK parallels impossible on dev machine, even with devmax priority
**Resolution:** Running on cray production machine white space, although there have been some occasional disk space issues there; G. Vandenberghe performed I/O profile and helped to prepare systems to run safely on Cray
**Risk 2:** EMC does not have resources to run retrospective tests
**Resolution:** Those experiments have been run by ESRL, and we will use their statistics

G **Resources**

**Staff**: 0.5 Fed FTEs (G. Manikin) + 0.5 contractor FTEs (B. Blake)

**Funding Source**: STI, FAA

**Compute: EMC-DevCray: Parallels:** 320 nodes for 6-7 months; **Ops**: 320 nodes (2.5x)

**Archive: Parallels**: 50 GB; **Ops**: 2.5x (add Alaska HRRR and extended runs)

R **Management Attention Required** | Y **Potential Management Attention Needed** | G **On Target**

| Evaluation Starts | Evaluation Ends | NCEP Director Briefing | Code Handoff to NCO | 30 Day IT Test Starts | 30 Day IT Test Ends | Implementation |
|---|---|---|---|---|---|---|
| 11/20/2017 | 1/20/2018 | 2/2/2018 | 2/5/2018 | ~4/2/2018 | ~ 5/2/2018 | ~ 5/15/2018 |