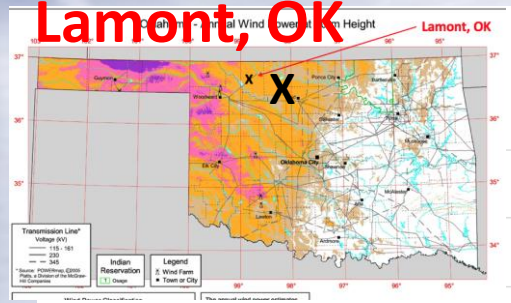
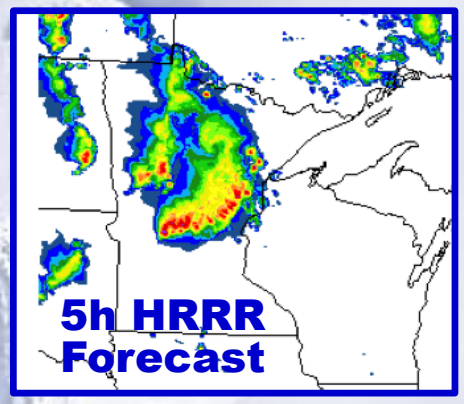







# Better wind/solar forecasts in the 2019-20 NOAA HRRR weather model

**Stan Benjamin**

*Senior Scientist for Advanced Modeling Systems*

*Joseph Olson, Curtis Alexander, Eric James, Jaymes Kenyon, Terra Ladwig, Dave Turner*

*NOAA Earth System Research Laboratory*

*Boulder, CO USA*

*ESIG Meteorology & Market Design for Grid Services Workshop*

***5 June 2019, Denver, CO USA***

# RAP/HRRR: NOAA Hourly-Updating Weather Forecast Models

## - July 2018 NOAA/NCEP upgrade

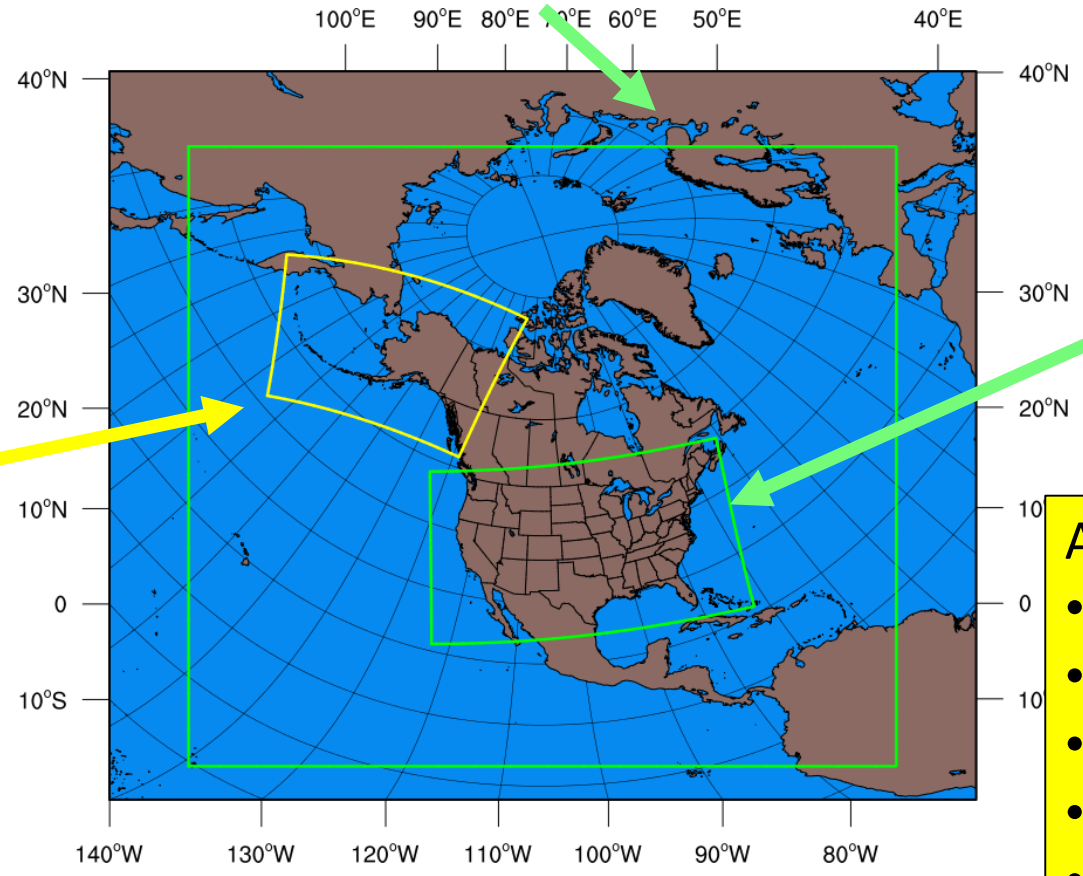
**13-km Rapid Refresh (RAPv4) – to 39h (July 2018)**

Initial & Lateral Boundary Conditions

Initial & Lateral Boundary Conditions

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

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




Applications
- Severe weather
- Aviation/transportation
- Energy
- Hydrology/ Nat. Water Model
- Situational awareness for decision making

# HRRR gaps for energy industry application

| Gap | How to address: |
| --- | --- |
| **- doesn't cover Day-Ahead** | **- 36h forecasts every 6h** in NOAA operational HRRRv3 (starting July 2018), extension from current 18 h<br>**- 48h forecasts** every 6h in **HRRRv4 (start May 2020 @NCEP)** |
| - too many convective outflows | - better in **HRRRv3** via reduced too much convection for 1-6h environment,<br>- More accurate storms w/3km ens data assimilation (HRRRv4) |
| - too much 10m wind at night | - improvements (MYNN boundary layer)) in **HRRRv3 / HRRRv4** |
| - still inadequate clouds | - **breakthrough- sub-gridscale cloud in HRRRv4/RAPv5**<br>**- smoke forecasts added– improved aerosols (HRRRv4 – 2020)** |

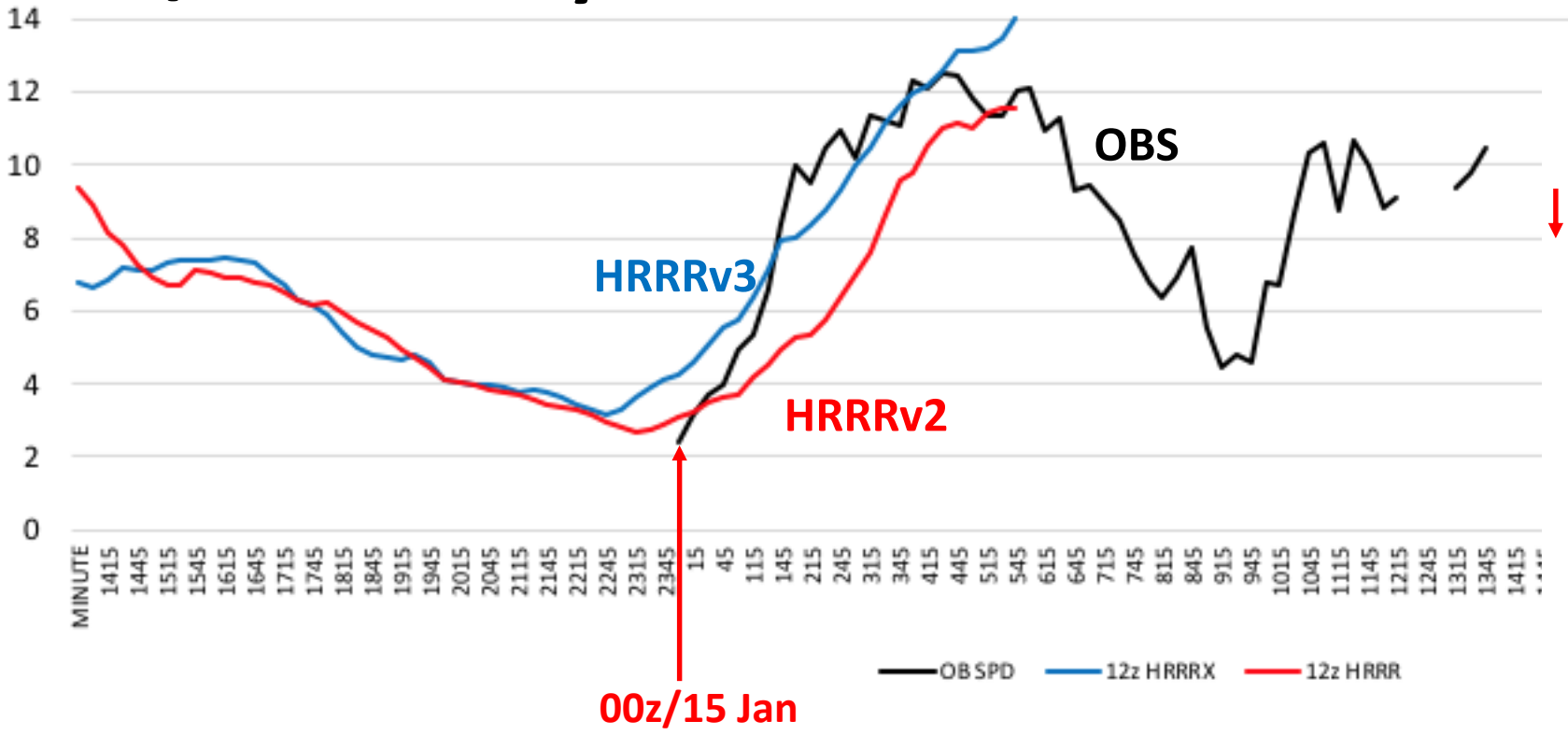
OBS SPD  12z HRRRX  12z HRRR

**HRRRv2 - NOAA operational**

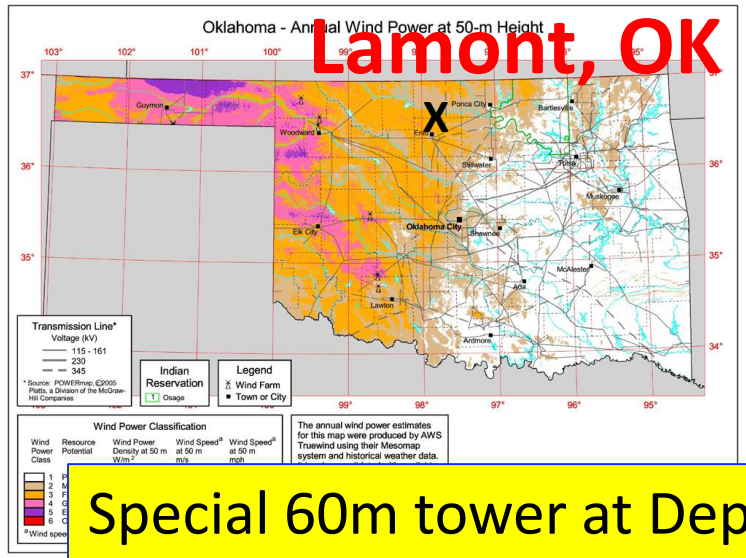
**HRRRv3 – new version July 18**

60m Wind Tower obs vs. 80m HRRR forecasts
Wind Speed (m/s) at LAMONT, OK
14-15 Jan 2018

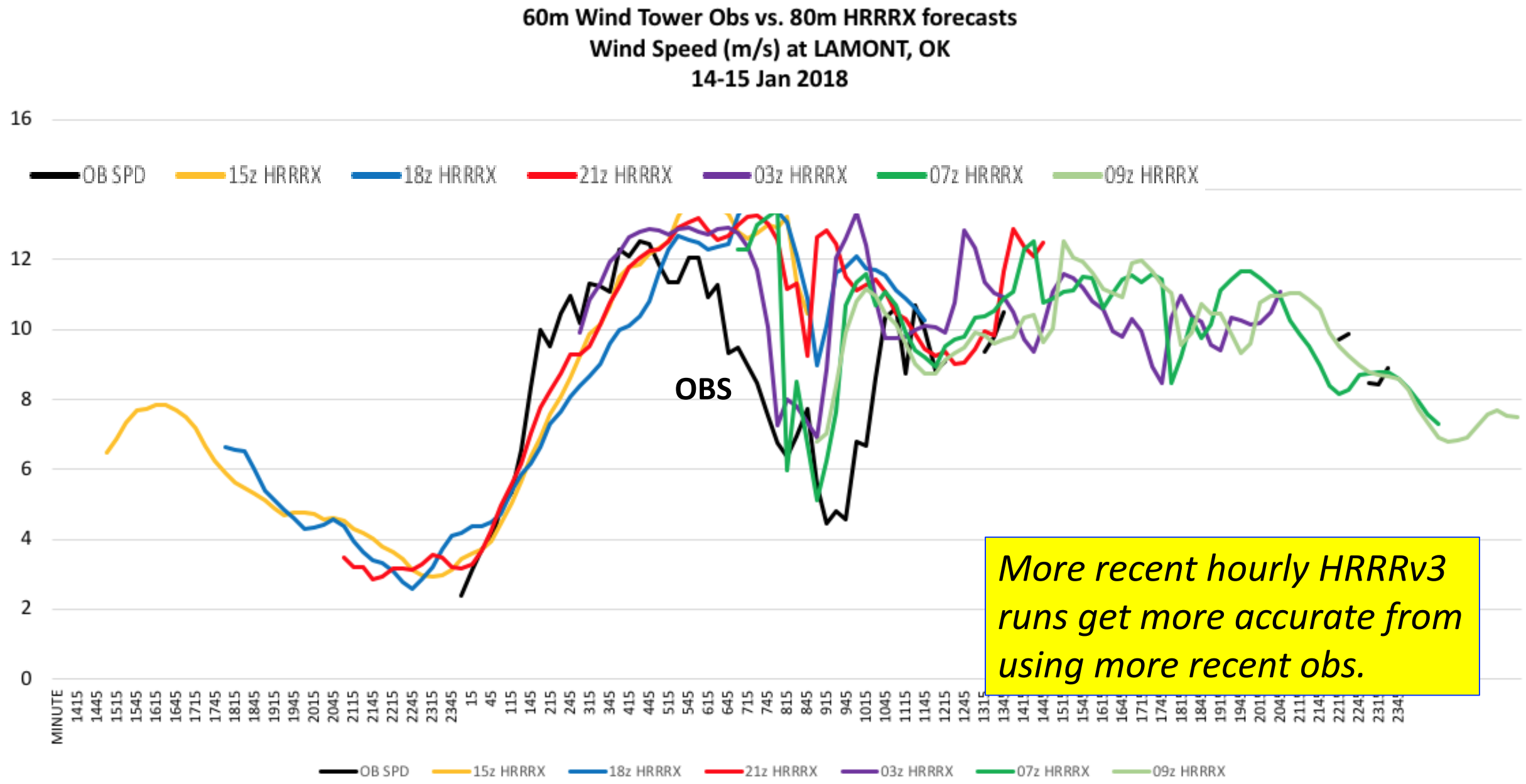
# 12z/14 January 2018 HRRR runs



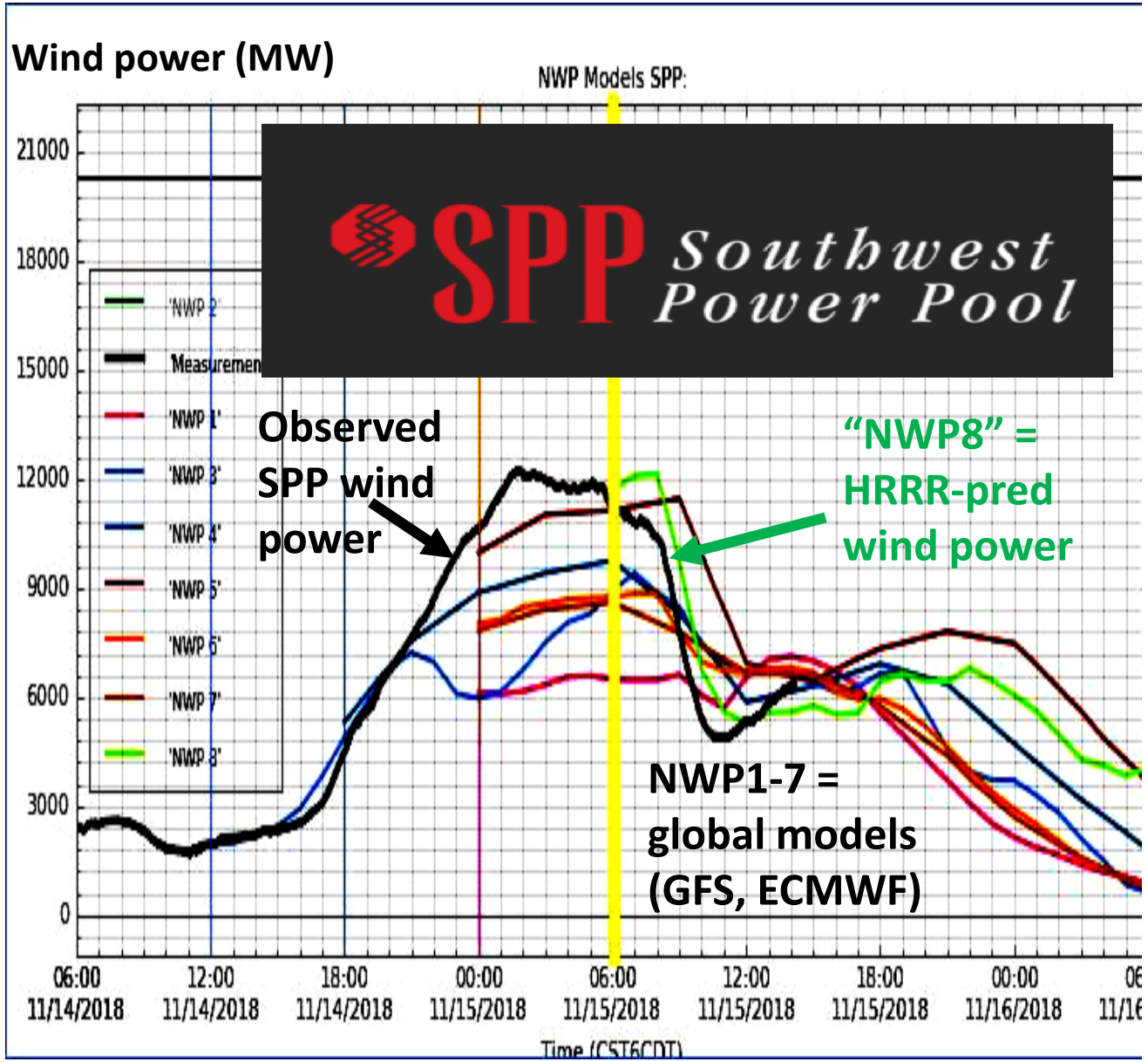

*HRRRv3 more accurate than HRRRv2*




Special 60m tower at Dept. of Energy observation site at Lamont, Oklahoma

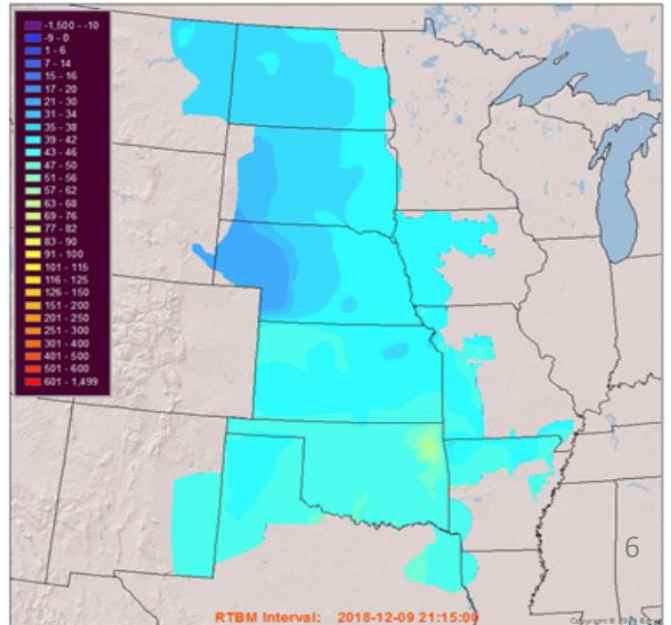

60m Wind Tower Obs vs. 80m HRRRX forecasts
Wind Speed (m/s) at LAMONT, OK
14-15 Jan 2018
OB SPD
15z HRRRX
18z HRRRX
21z HRRRX
03z HRRRX
07z HRRRX
09z HRRRX
OBS
More recent hourly HRRRv3 runs get more accurate from using more recent obs.
MINUTE

# Case #1 – 15 Nov 2018 – HRRR for SPP via E&M

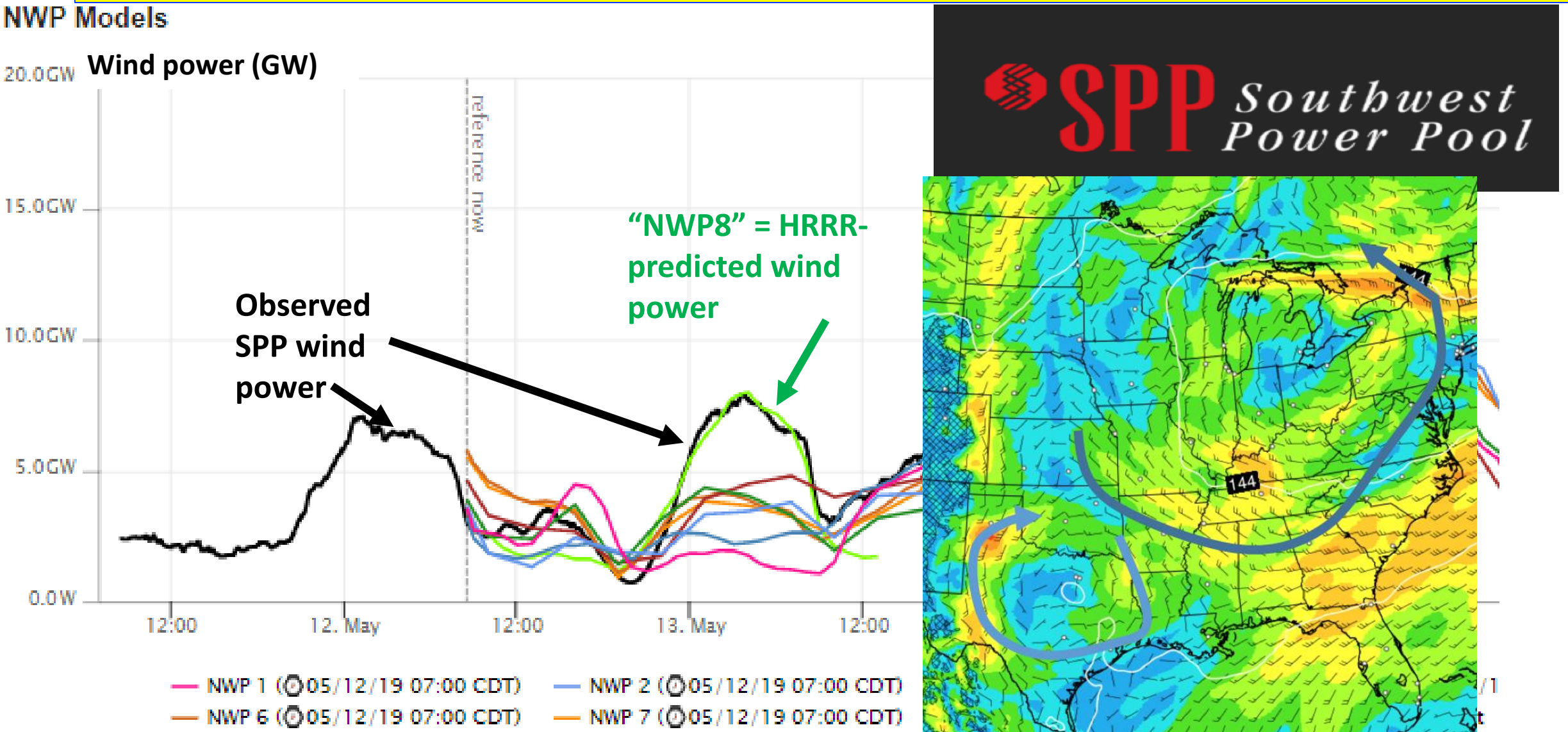



**29 Nov 2018 – "SPP switched short-term forecast to the HRRR today.** It is now the main weight for forecasting our 21,000MW of wind power in the Midwest! SPP went from not using HRRR in July 2018 to full weight implementation in 4 months because it performed so well, especially on morning and afternoon dips or ramps. "

- Gunnar Shaffer – Southwest Power Pool, Little Rock, AR. 25 million customers.



# Another case – 12 May 2019




Observed SPP wind power

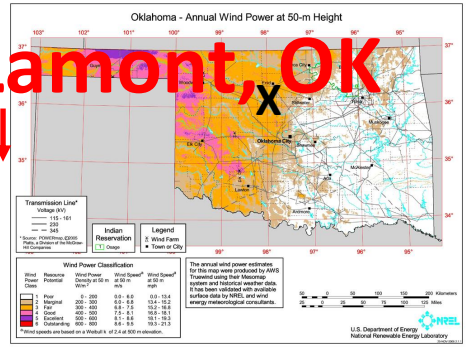
"NWP8" = HRRR-predicted wind power

**NWP1-7 = global models (GFS, ECMWF, etc.)**

SPP Southwest Power Pool




E&M now using HRRR for SPP, MISO, ERCOT, PJM



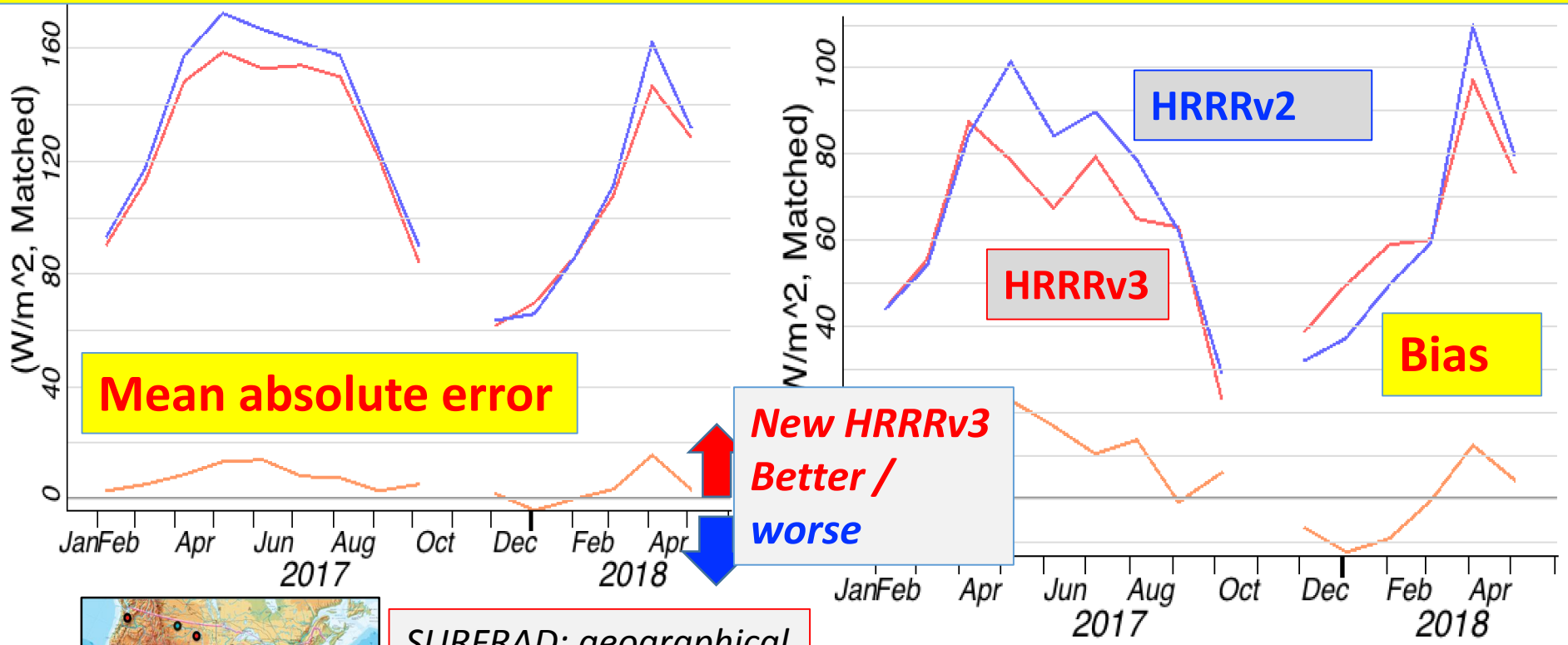


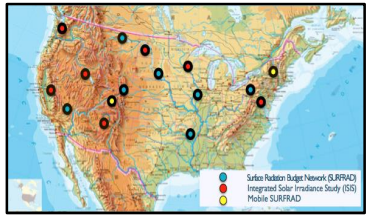


*May 2019 case - hourly **HRRRv4** runs get more accurate from using more recent obs.*

# A remaining problem in HRRRv3 – high downward SW bias

## 12h HRRR v2/v3 downward SW rad vs. SURFRAD – Mean daytime (15-21z)



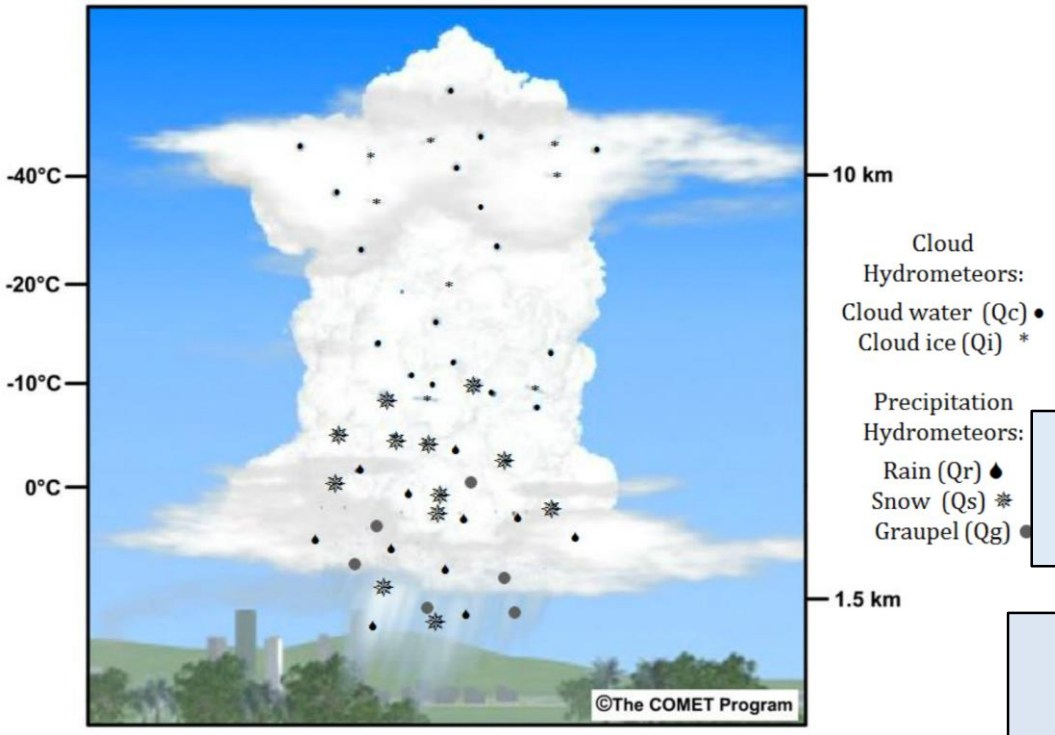
*SURFRAD: geographical diversity critical for model evaluation*

*July 18 – HRRRv3 better for MAE/bias but much more needed.*
*Sept 18 – (later in this talk). Much better.*

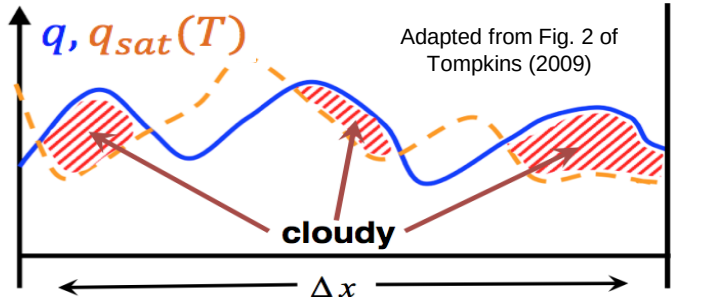
# Physics Development Emphasis: Sub-Grid Clouds – MYNN boundary layer

## 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 PDF of *s (saturation ratio)***

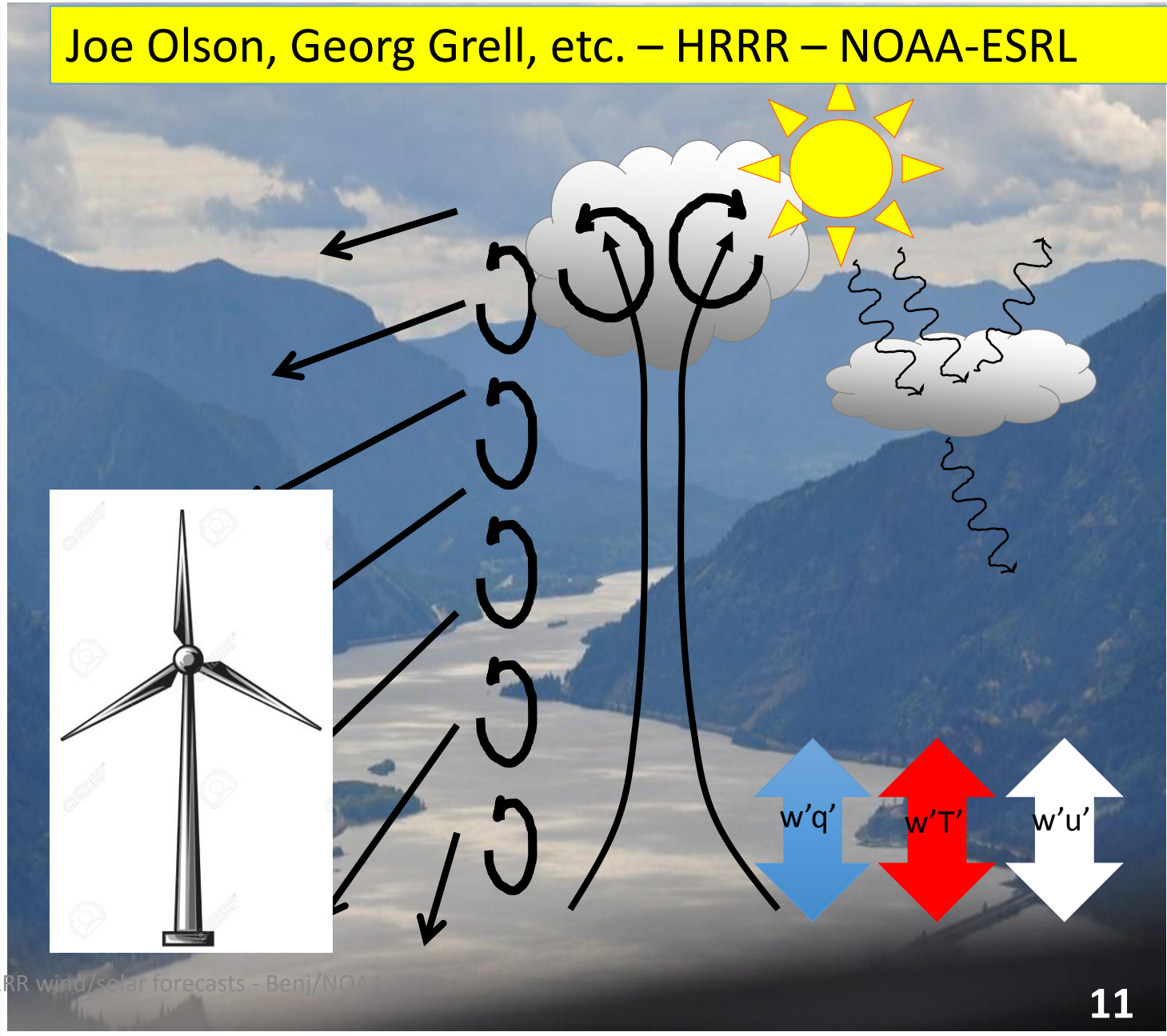
**Parameterize: *assume* subgrid PDFs for thermodynamic variables**
**Chaboureau-Bechtold (2002)**

**Retrieve Cloud Fraction, Cloud Condensate**

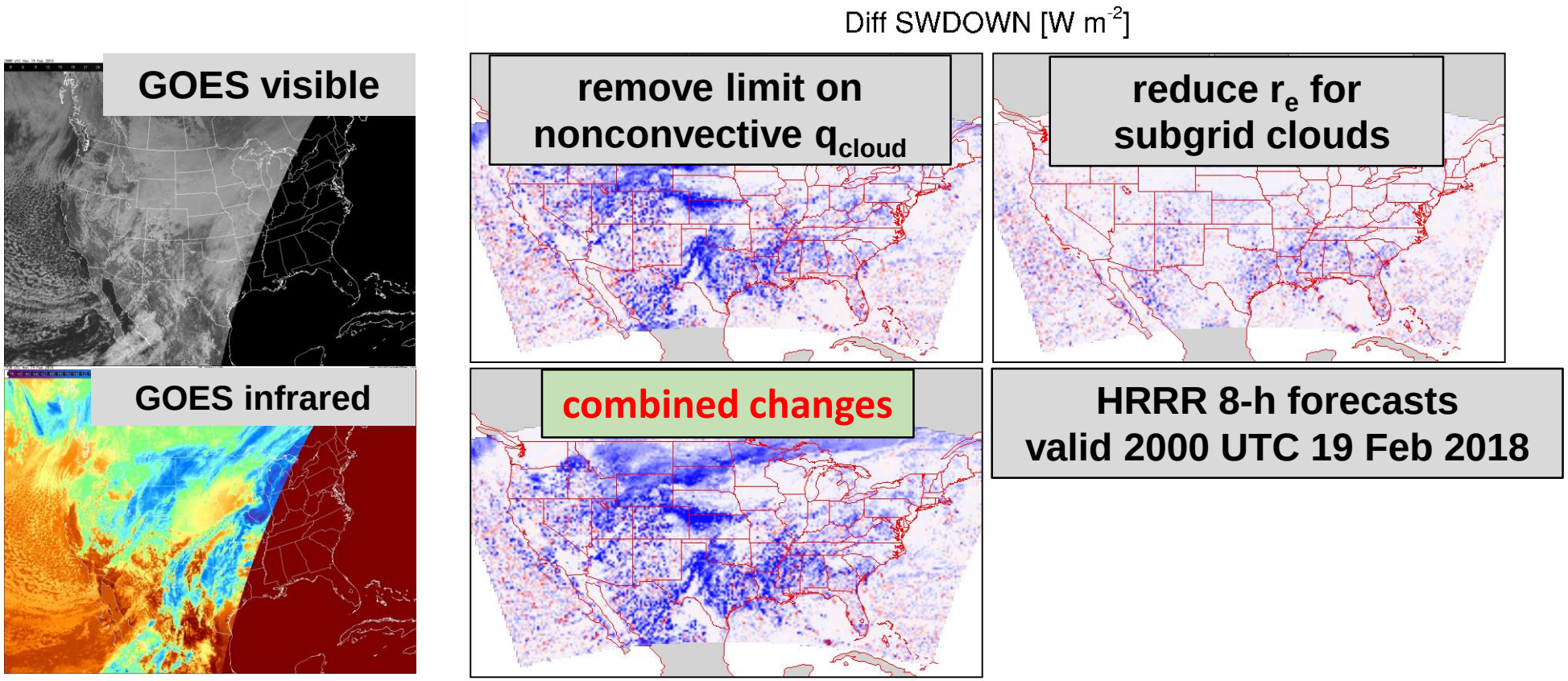
*Joseph Olson*
*NOAA/ESRL/GSD*

# Physical Processes and Their Representations

| Process | Model Component | Change/Addition |
|---|---|---|
| Turbulent Diffusion | MYNN PBL/ 3d-Blended TKE | • Mixing length<br>○ Scale-aware<br>○ Z-less<br>• 1D → 3D as $f(\Delta x) \rightarrow 0$ |
| Non-local Turbulent Transport | MYNN Mass-flux | • Multi-plume<br>• TKE transport<br>• Momentum transport<br>• Scale-aware |
| Surface Fluxes | RUC LSM/ MYNN Sfc Layer | • Scalar roughness<br>• M-O alternatives<br>• 3D surface stress |
| **Clouds** | Thompson/Aerosol/ Chaboureau-Bechtold | • Subgrid scale clouds<br>• Coupled to radiation<br>• prognostic |
| Numerics/ Dynamics | Vertical Coordinate, Advection | • Hybrid Vertical Coordinate |
| Turbine Drag | Wind Farm Parameterization | • Wind direction effects<br>• Power calculation |



# Cloud/radiation experiments w/ 3km HRRR – downward SW rad




1. Reduce cloud-droplet effective radius for subgrid clouds:
- land: reduce 7.5 -> 5.4 μm, water: reduce 10.5-> 9.6 μm (Miles et al 2000)
2. Remove 0.5% sat vap pressure constraint on $q_{cloud}$ for subgrid clouds (MYNN)

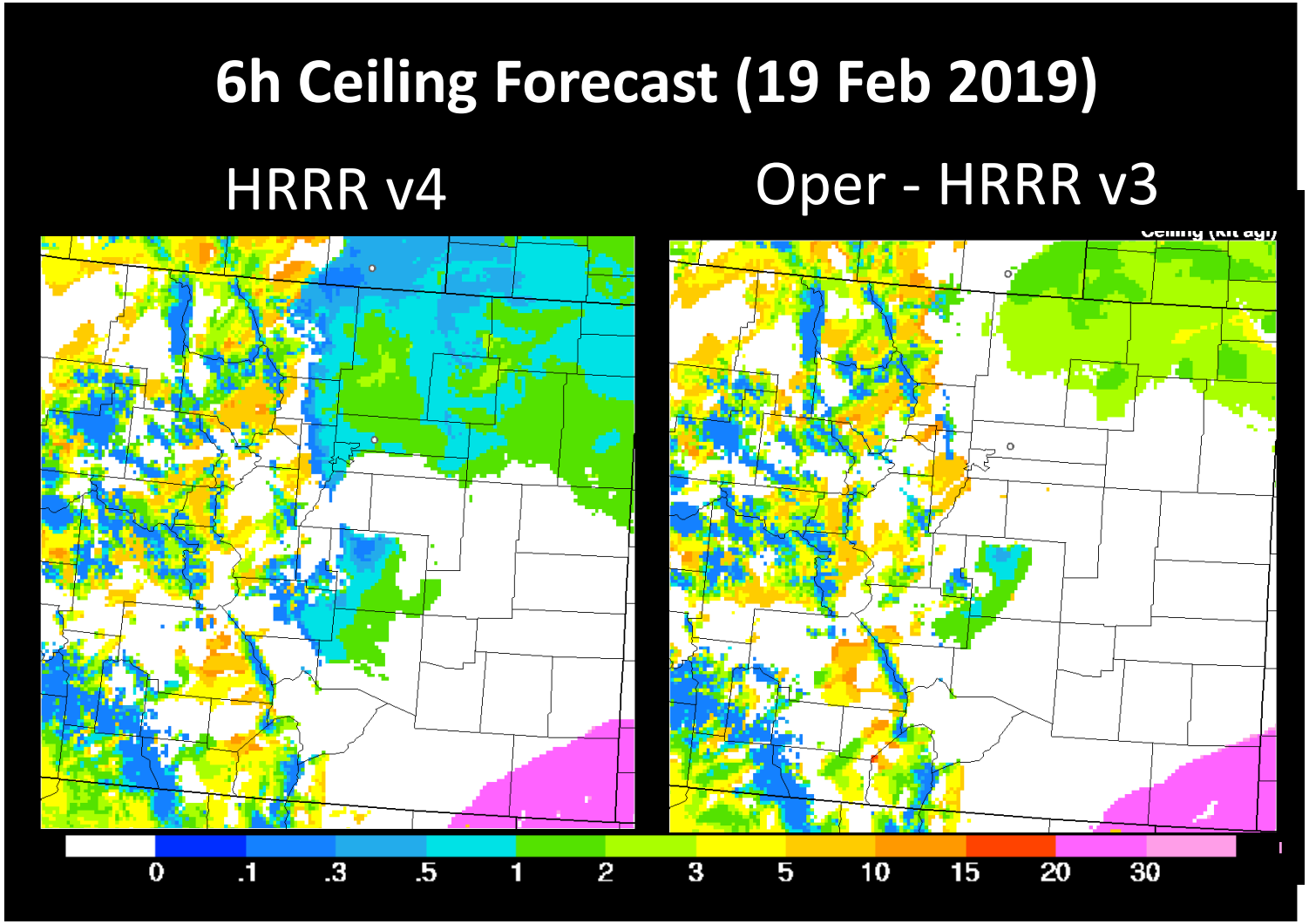
# Improved low stratus retention

Boundary-layer improvements via MYNN PBL scheme

- better sub-grid clouds
- improved EDMF (eddy diff/ mass flux) mixing length
- Remove limit to subgrid-scale cloud water
- change in subgrid cloud radii for radiation (RRTMG)

Removed diffusion of hydrometeors

Goal: retaining stable layers

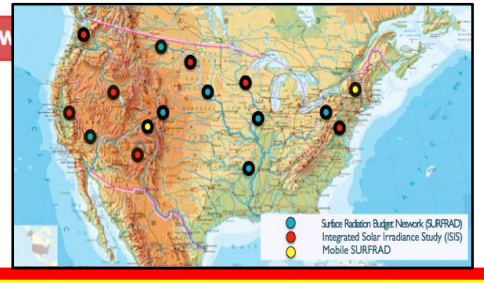


Surface Radiation : TimeSeries 06/04/2018 11:00 - 06/04/2019 11:00 : show matching diffs UNMATCHED Close All Preview

--- Curve0: HRRR_OPS in All stations, 13 km grid, dswrf Bias (Model - Obs), fcst_len: 6h, valid-time: 15..21, avg: 7D hide curve hide points show annotation

--- Curve1: HRRR_GSD in All stations, 13 km grid, dswrf Bias (Model - Obs), fcst_len: 6h, valid-time: 15..21, avg: 7D hide curve hide points show annotation

--- Curve1-Curve0: Difference hide curve hide points show annotation




# Downward SW radiation bias (vs. SURFRAD) decreased by ~50 W/m$^2$

**8/29/18 subgrid-cloud change**

**HRRRv3 control**

**HRRRv4 with subgrid cloud changes**

W/m2

150
100
50
0
−50

New worse

New better

**HRRRv4 minus HRRRv3**

July Sept Nov Jan Mar

2018 2019

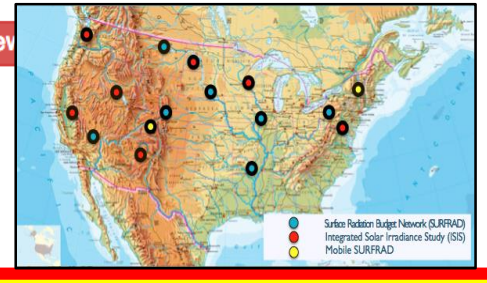
Jul 2018 Sep 2018 Nov 2018 Jan 2019 Mar 2019 May 2019

Surface Radiation : TimeSeries 06/04/2018 11:00 - 06/04/2019 11:00 : show matching diffs UNMATCHED Close All Previe

--- Curve0: HRRR_OPS in All stations, 13 km grid, dswrf MAE, fcst_len: 6h, valid-time: 15..21, avg: 7D hide curve hide points show annotation

--- Curve1: HRRR_GSD in All stations, 13 km grid, dswrf MAE, fcst_len: 6h, valid-time: 15..21, avg: 7D hide curve hide points show annotation

--- Curve1-Curve0: Difference hide curve hide points show annotation




# Downward SW radiation mean abs error (vs. SURFRAD) decreased by 10-30 W/m$^2$

**8/29/18 subgrid-cloud change**

W/m2

250
200
150
100
50
0
−50

HRRRv4 minus HRRRv3

New worse

New better

HRRRv3 control

HRRRv4 with subgrid cloud changes

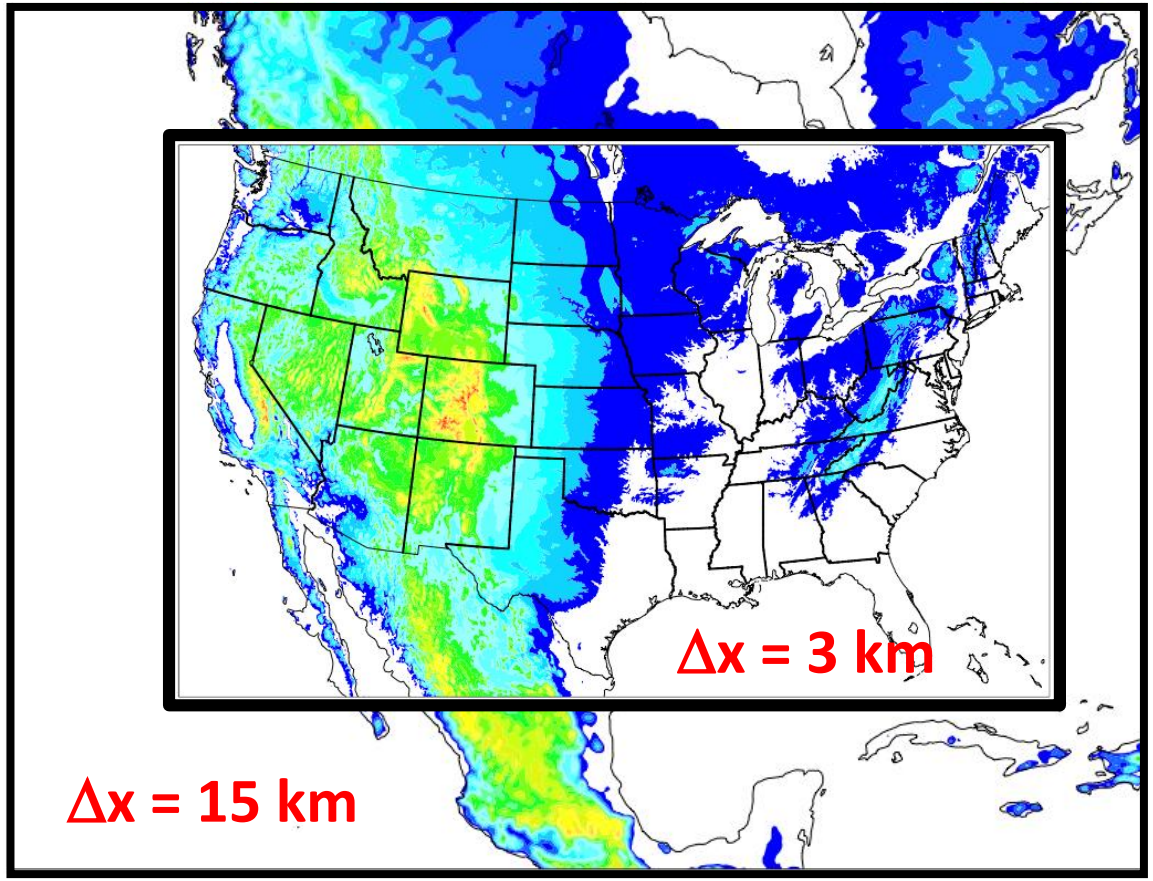
July Sept Nov Jan Mar

2018 2019

Jul 2018 Sep 2018 Nov 2018 Jan 2019 Mar 2019 May 2019

# 2019 HRRRE Analysis System

**Nested CONUS 15-km and 3-km domains with new R&D HPC resources (Jet augmentation)**




**36 members hourly-cycled over full CONUS**

- Initial mean from GFS (atmos.) and RAP-HRRR (soil)
- Atmospheric perturbations from GFS ensemble (GDAS) to initialize HRRRDAS ensemble
- Random soil-moisture perturbations

**Hourly cycling with EnKF data assimilation**

- Conventional observations both domains
- Reflectivity observations 3-km domain only
- Analysis variables: U, V, PH, T, MU, QVAPOR, QCLOUD, QICE, QRAIN, QSNOW

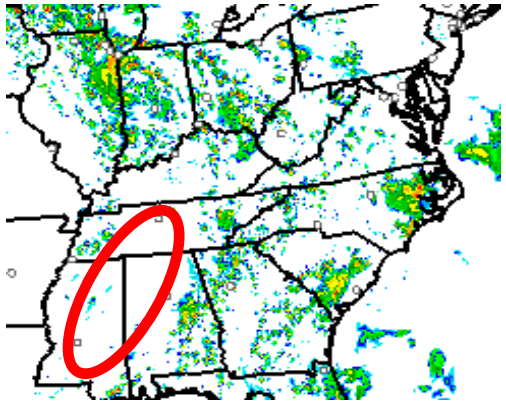
**Sources of Spread**

- **Hourly DA (posterior inflation)**
- **Lower boundary perturbations (soil moisture)**
- **Lateral boundary perturbations**
- **Stochastic parameter perturbations across most/all of RAP/HRRR physics suite**

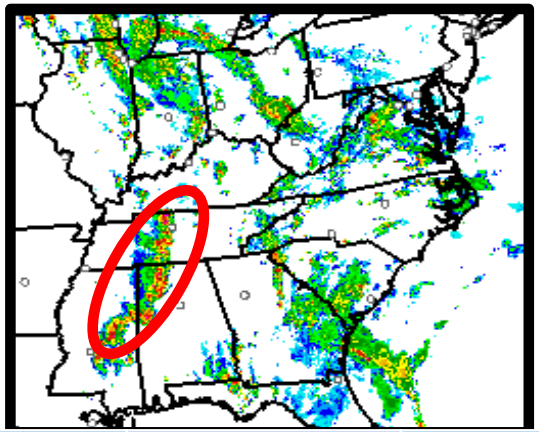
# Benefits of HRRRE information for energy/aviation

Four of nine HRRRE ensemble members captured a squall-line (with high aviation impact) that was COMPLETELY MISSED by the single deterministic HRRR run

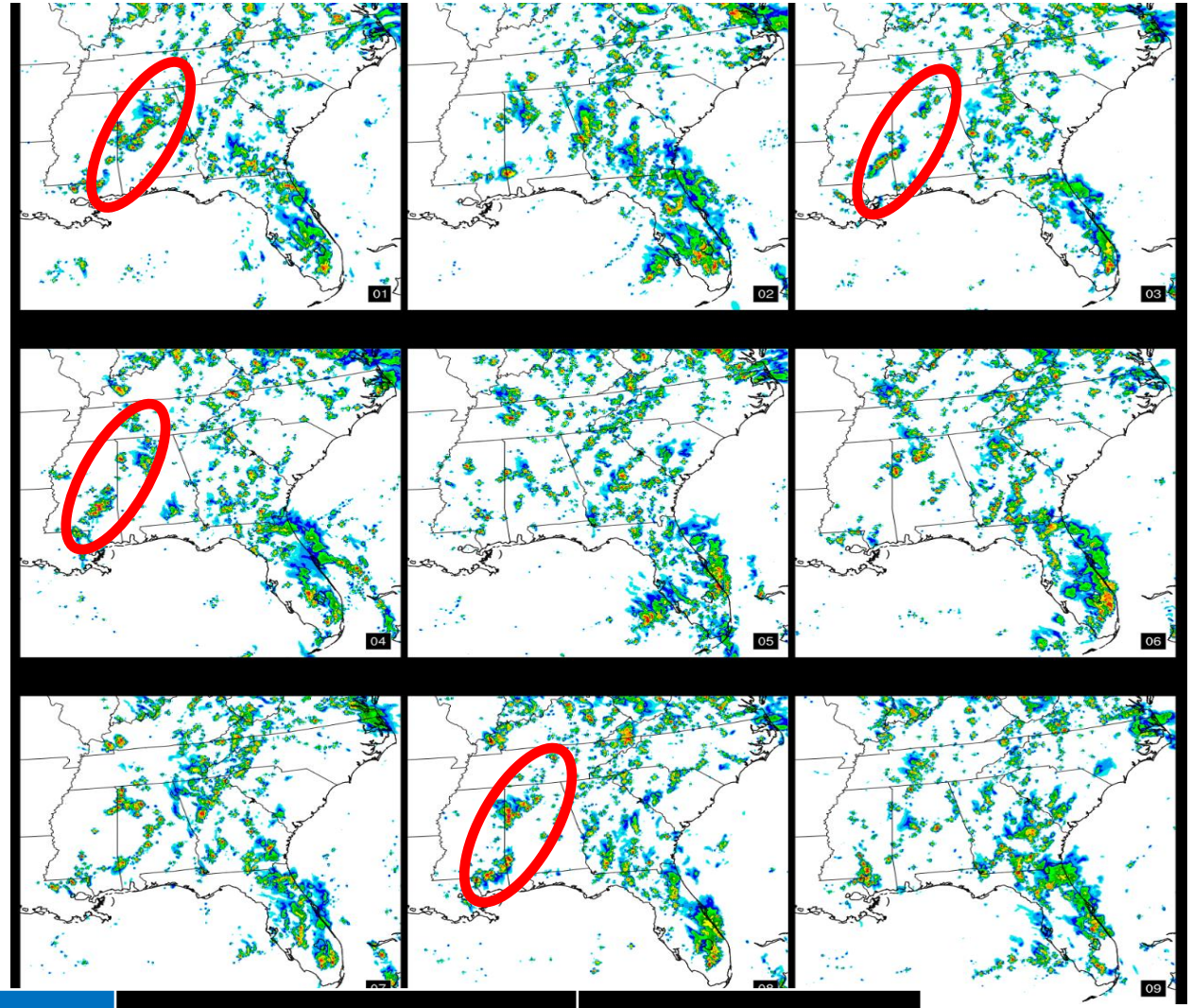
**11z+12h HRRR**



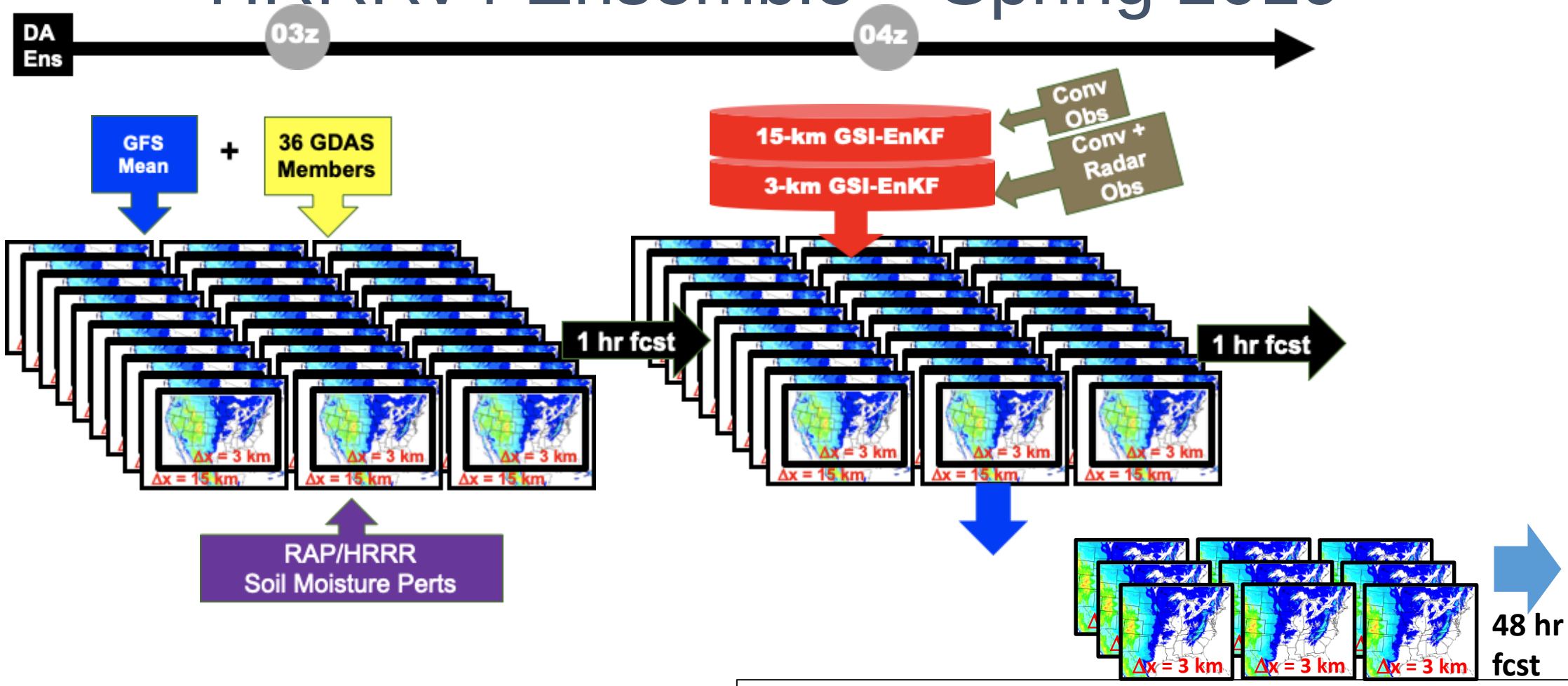
**23z anx**



**12z+11h HRRR Ensemble forecasts**

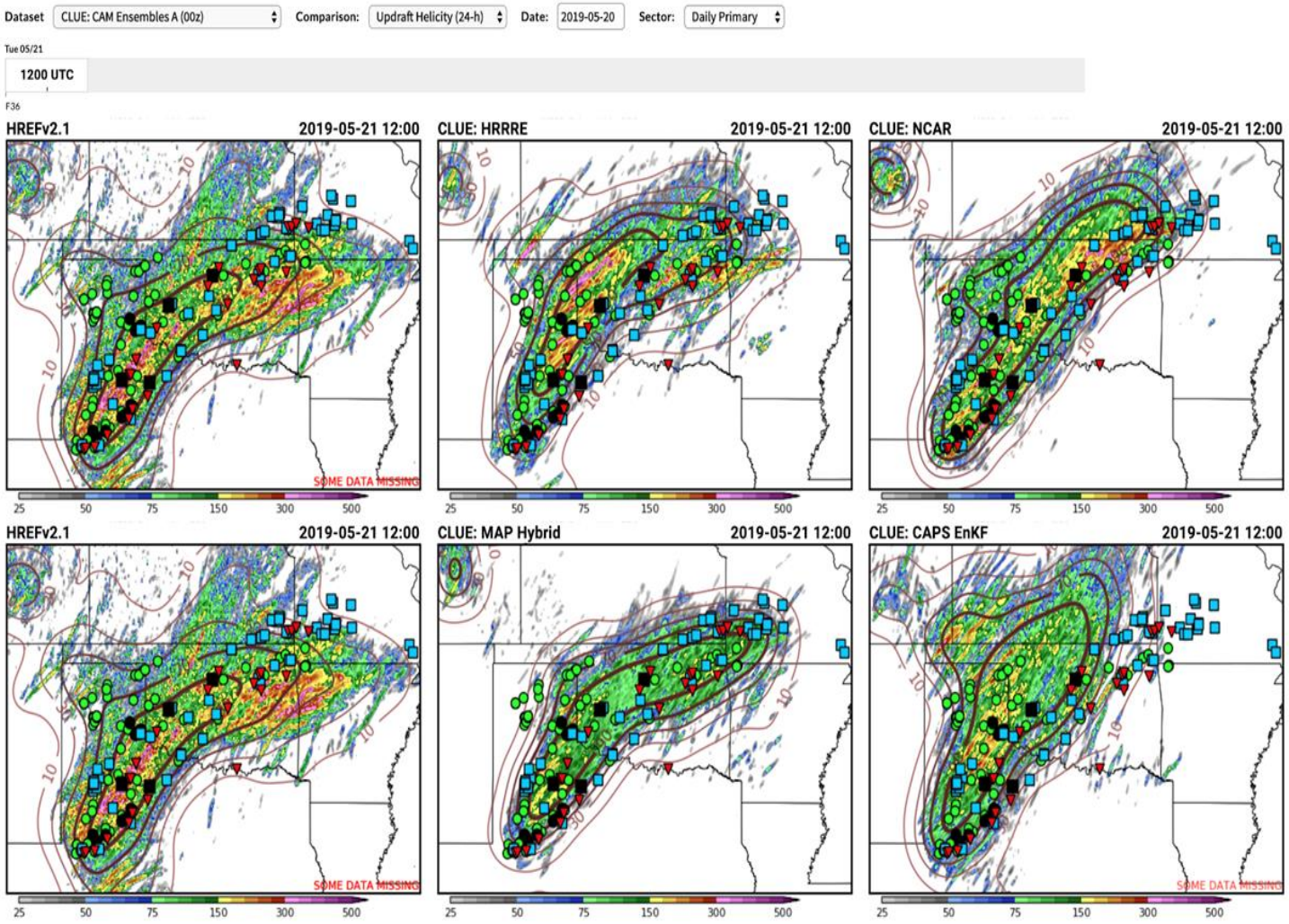


# HRRRv4 Ensemble – Spring 2019




- 36-member ensemble mean → HRRRv4 deterministic initial condition
- 36-member background error covariance → HRRRv4 deterministic hybrid analysis
- 9-member HRRRE ensemble forecast (0-36hrs)

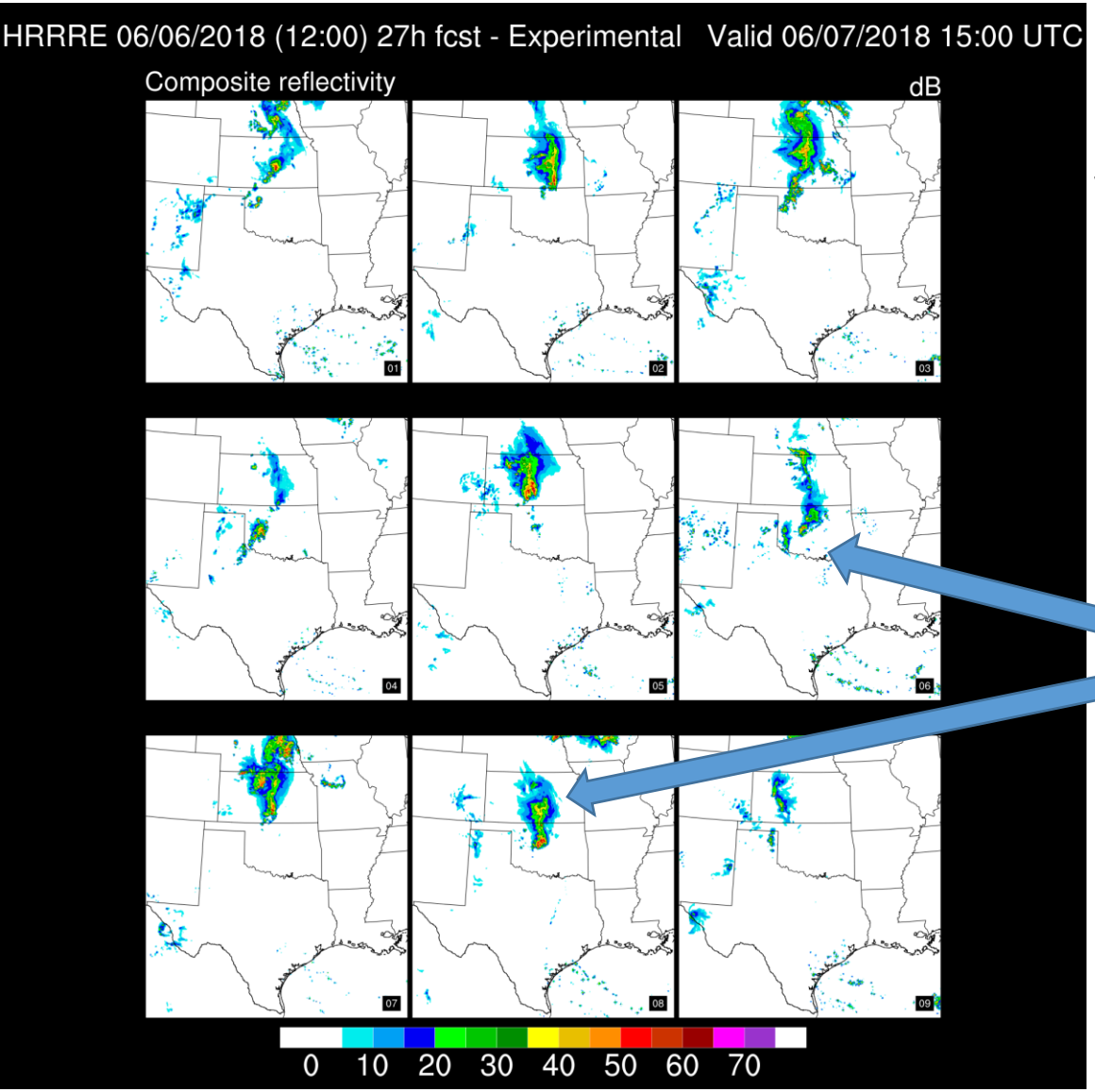
# CAM Ensemble - HRRRE – Spring 2019



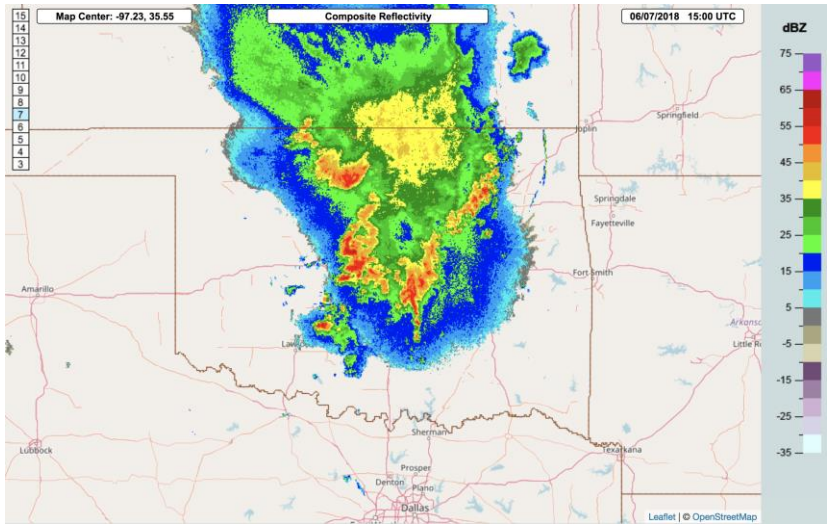

**Goal: Produce real-time, 9-member ensemble forecasts initialized from HRRRDAS during testbeds, for the purposes of getting community feedback and initializing WoFS.**

- GSD is producing
- real-time 9-member single-dycore HRRR ensemble (HRRRE) 0-36 hr probabilistic forecasts using stochastic physics parameter perturbations as shown in the HWT evaluation (top-middle panel) for a high-impact severe weather period on 20-21 May 2019 with
- overlaid storm-reports of tornadoes (red), high-winds (blue) and hail (green).
- Operational baseline CAM ensemble (HREFv2.1) shown in the left column.

# HRRRE Init 12 UTC 06 June 2018: 27 hr forecasts




HRRRE - 9 Members
27 hr forecasts
Valid 15 UTC 07 June 2018




MRMS reflectivity obs 15 UTC 07 June 2018. Major flooding occurred in Oklahoma City

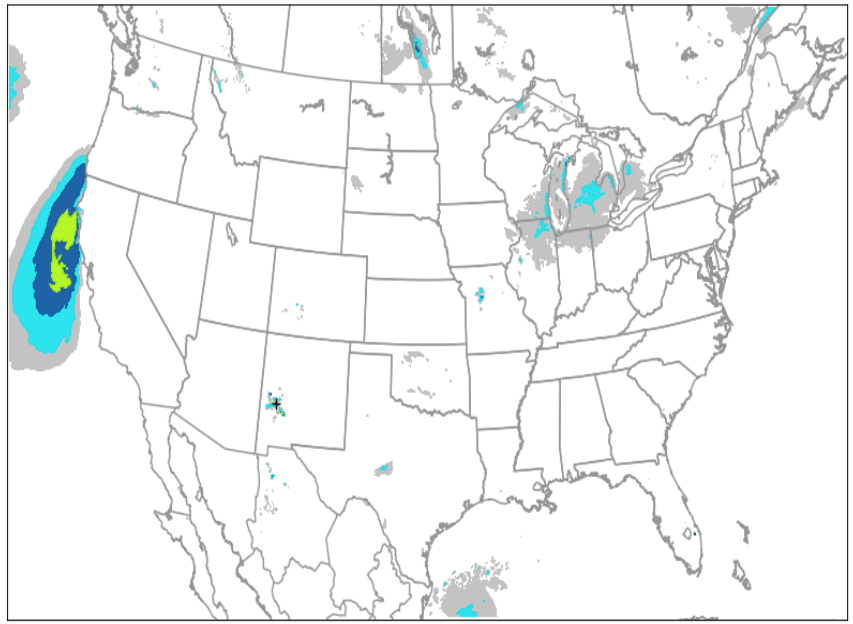
**A few members depicted a scenario with sustained convection in OK**

**Achievement**

***Ensemble*** **prediction of severe flooding conditions.**

| Intro | HRRRv3 to 36h | Wind cases | Better clouds | HRRRv4 to 48h +ens+smoke | Benj-RE-HRRR |
|---|---|---|---|---|---|

# HRRR Ensemble projects
# Likelihood of events within 40km for 50kt wind gust, tornado

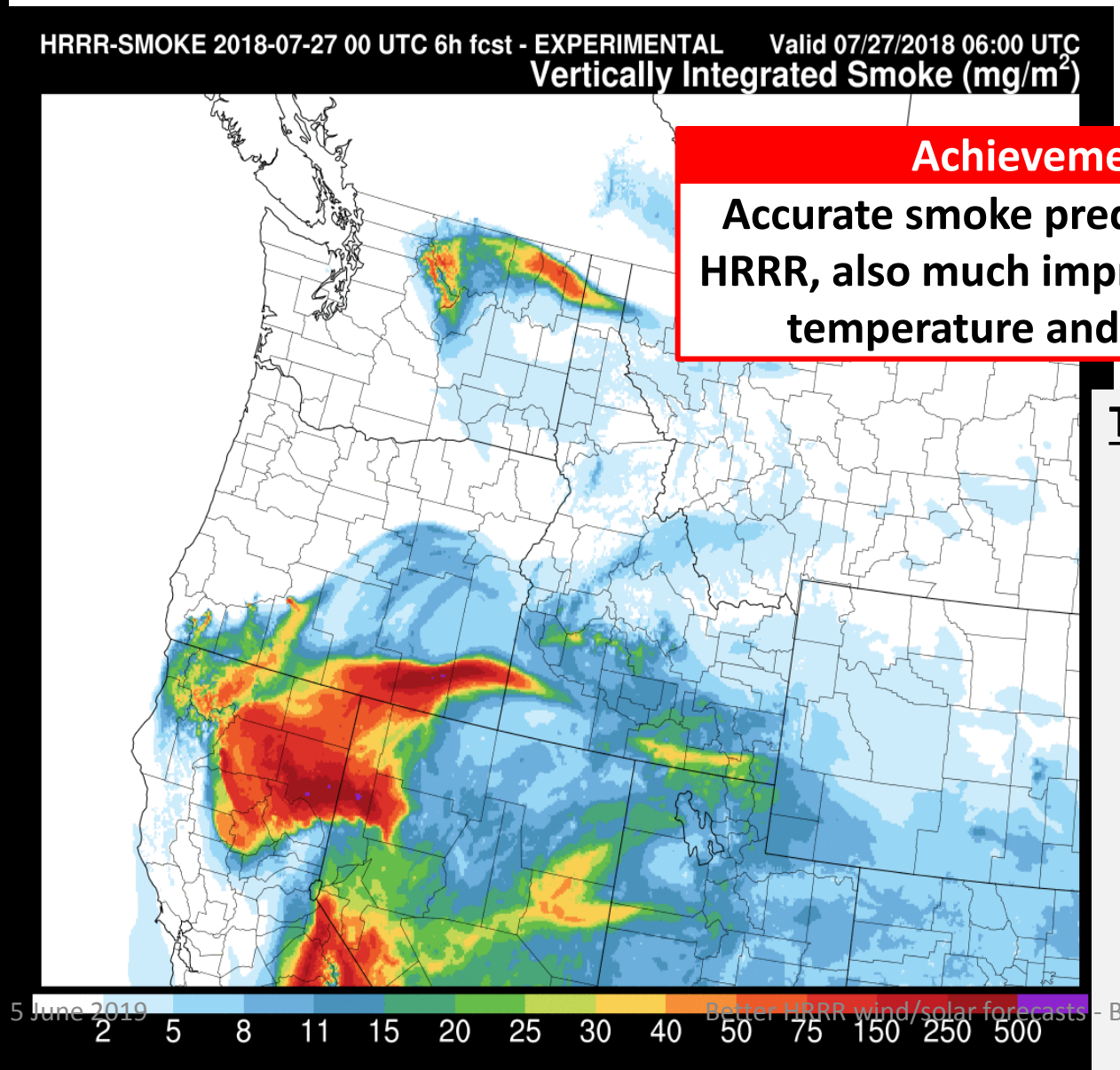





# additional products
# - Icing, lightning

High-Impact Event Prediction

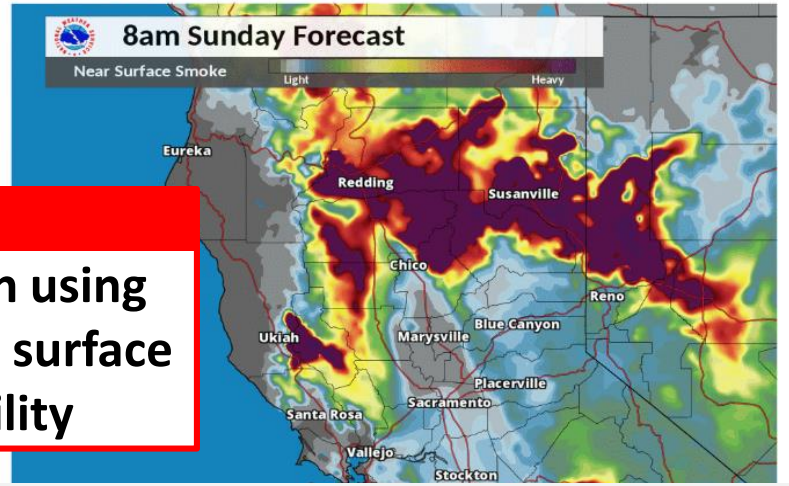
# Smoke forecast for the Carr Fire/other fires from the 00z/27 Jul 2018 run of the HRRR-Smoke model




**Achievement**

**Accurate smoke prediction using HRRR, also much improved surface temperature and visibility**

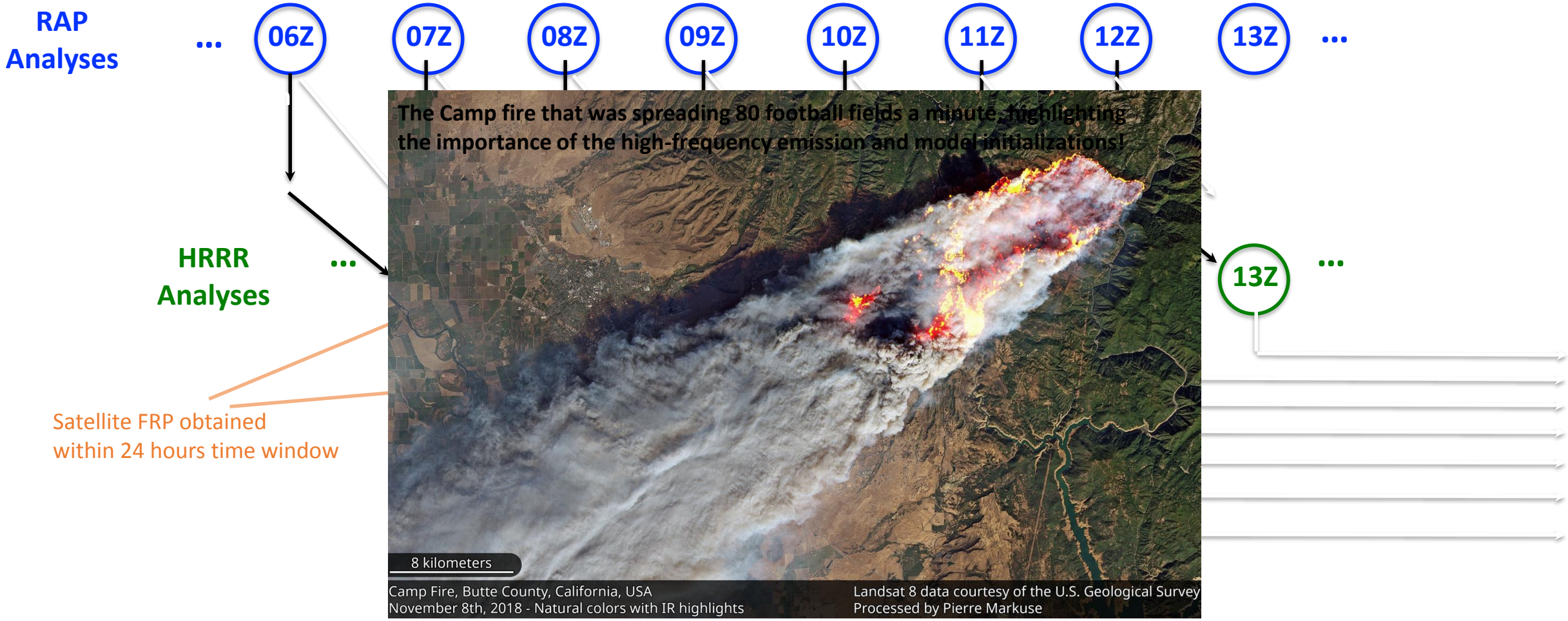
Output disseminated to the public is shown from the Sacramento WFO from 29 July.




## The HRRR-Smoke modeling system

- Single tracer (smoke) (minimal CPU cost)
- Will be merged within HRRRv4 – NCEP in 2020.
- Full coupling between meteorology and smoke; feedback of smoke on predicted radiation, clouds, and precipitation
- Biomass-burning emissions and inline plume rise parameterization based on satellite FRP
- Forecast goes out to 36 hours 4x/day
- HRRR-Smoke does NOT replace NCEP's existing air-quality models such as NAM-CMAQ or offline HYSPLIT; rather, it complements them.

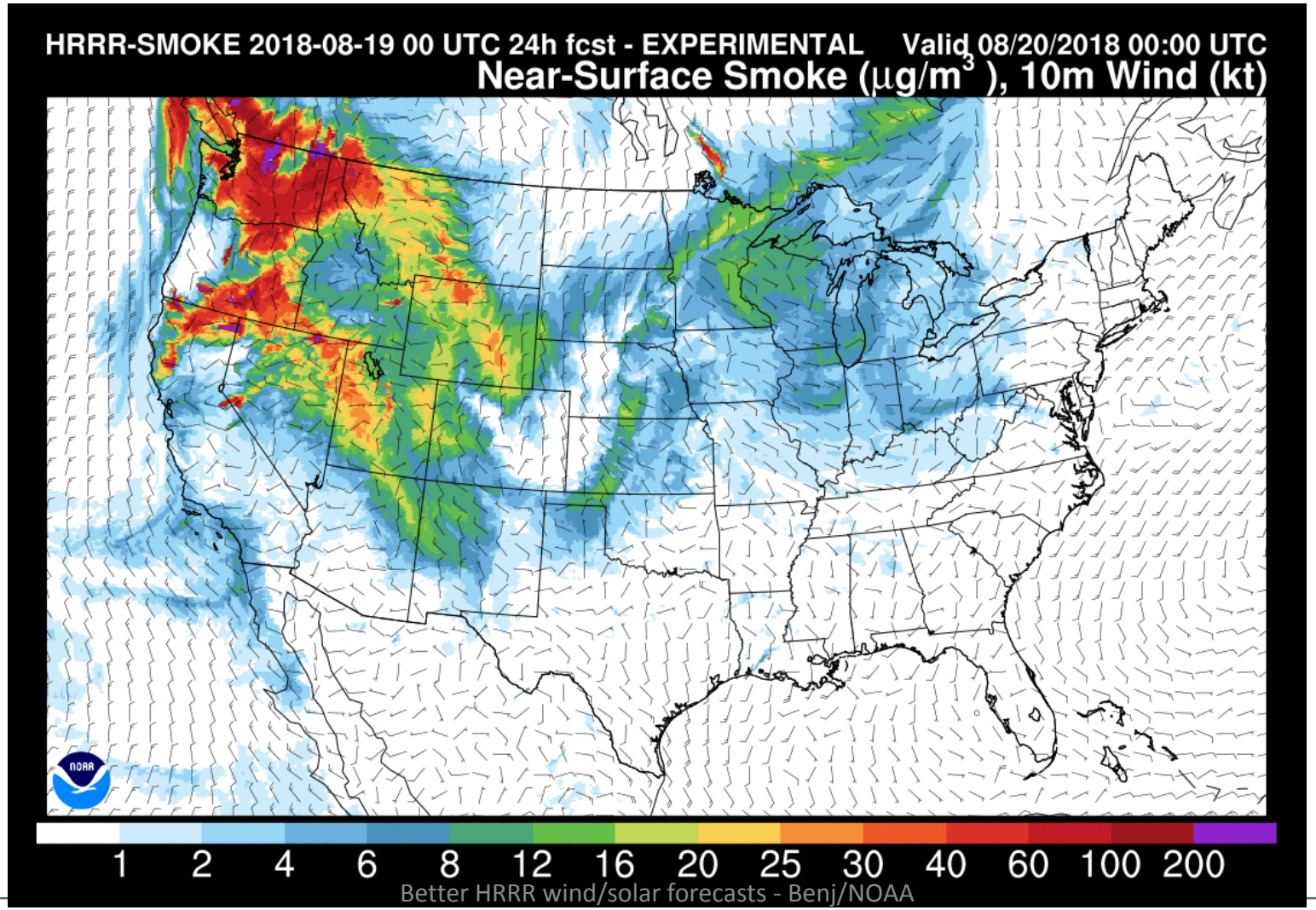
# Hourly cycle of HRRR: 1-h spin-up for each forecast
# New weather and smoke forecasts are produced 24 times a day




- Starting in March 2018 smoke emissions are simulated every hour for input to HRRR-Smoke. Simulated 3D smoke fields are cycled between the consecutive HRRR-Smoke forecasts.

# Near-surface smoke forecast for August 19, 2018 (rapidrefresh.noaa.gov/hrrr/HRRRsmoke/)

This plot shows simulated fine particulate matter (PM2.5 or fire smoke) concentrations and wind at the first model level (~8m above ground). This is the forecast of the near-surface fire smoke for August 19, 6pm EDT over the CONUS. This forecast is based on the model simulation of 24 hours from the model initialization time, which is 6pm EDT, August 18, 2018.



# 2020 RAPv5/HRRRv4 Change Candidates

## Most important for energy wind/solar forecasts

| Data Assimilation | Model | Land-surface / post |
|---|---|---|
| **Merged with GSI trunk – 2019**<br><br>***New Observations for assimilation:***<br>GOES-16 radiances,<br>new full-res channels for CrIS/ATMS<br>TC vitals for trop cyclone location/ strength<br>Aircraft/raob moisture obs for p<300 hPa<br>VIIRS/MODIS fire radiative power<br><br>***Assimilation Methods:***<br>HRRR - 3km ensemble DA (36 mems out to 1h)<br><br>HRRRDAS mean for HRRR initial conditions and boundaries | **WRF-ARWv3.9+ incl. phys changes**<br>***Physics changes:***<br>MYNN PBL update – better sub-grid clouds, improved EDMF mixing<br>- remove limit, decrease radii for subgrid qc/qi<br><br>Radiation modifications for subgrid clouds<br>Aerosols sources/sinks – fire/smoke,<br>dust - Add smoke with VIIRS/MODIS FRP<br>Improved land-surface/snow model<br>including better 2m T/Td diagnostics<br>Latest Grell-Freitas conv (RAP only)<br>Lake model for small lakes<br>Enhanced gravity-wave drag<br><br>***Numerics changes:***<br>Reduced 6th order diffusion inc. cloud hydrometeors<br>Removal of mp_tend_lim, exp-Implicit vert advect. | Switch to MODIS albedo (higher), replace 1-deg albedo.<br><br>Add zenith-ang albedo adjustment<br><br>15” resolution land-use data<br>Improved soil fields (BNU) and wilting point for some land-use<br><br>Fractional sea/lake ice concentration<br><br>FVCOM data for Great Lakes lake temp/ice concentration<br><br>VIIRS/MODIS/GOES fire radiative power<br><br>2018 – VIIRS greenness veg fraction added to HRRR and RAP |

# HRRR gaps for energy industry application

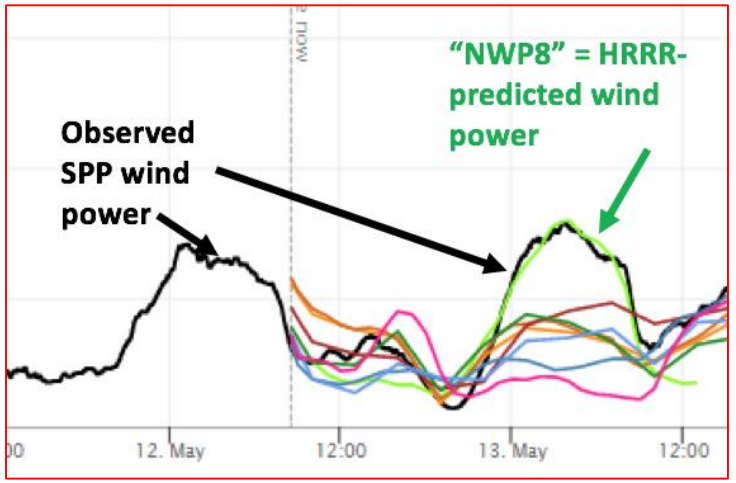
| Gap | How to address: |
| --- | --- |
| **- doesn't cover Day-Ahead** | **- 36h forecasts every 6h** in NOAA operational HRRRv3 (starting July 2018), extension from current 18 h<br>**- 48h forecasts** every 6h in **HRRRv4 (start May 2020 @NCEP)** |
| - too many convective outflows | - better in **HRRRv3** via reduced too much convection for 1-6h environment,<br>- More accurate storms w/3km ens data assimilation (HRRRv4) |
| - too much 10m wind at night | - improvements (MYNN boundary layer)) in **HRRRv3 / HRRRv4** |
| - still inadequate clouds | - **breakthrough- sub-gridscale cloud in HRRRv4/RAPv5**<br>**- smoke forecasts added– improved aerosols (HRRRv4 – 2020)** |

# Planned Evolution of Hourly Updating NOAA Models

## Expected Spring 2020:

## RAPv5 / HRRRv4

- Physics improvements and smoke prediction
  - Biggest improvement: cloud prediction
- HRRR-ensemble data assimilation – better radar/cloud
- Extension to 48h (from 36h for HRRRv3)




- Better short-range cloud and storm prediction (last WRF-ARW implementation)

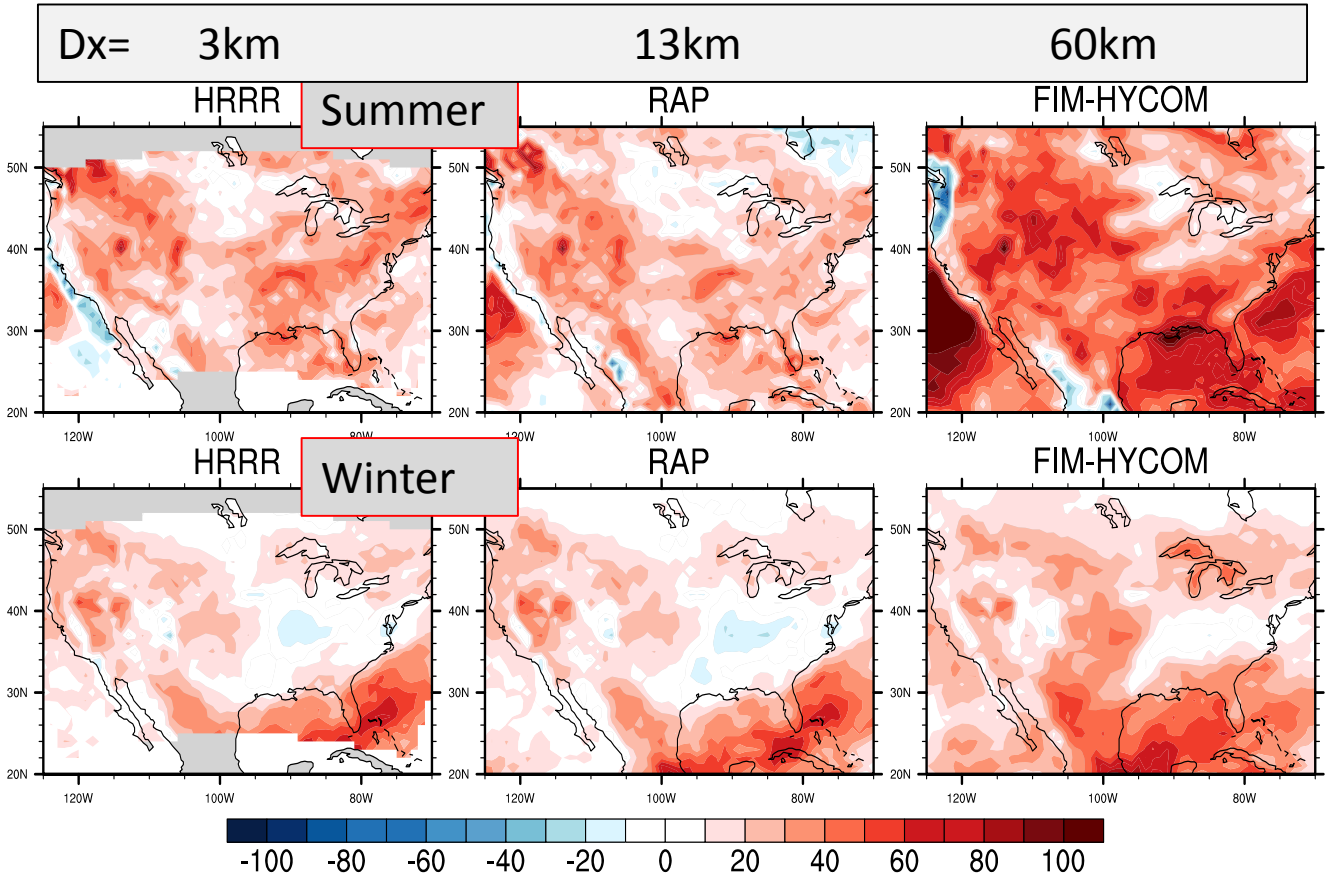
## Expected in 2022:

## Rapid Refresh Forecast System (RRFS)

- Full CAM ensemble assimilation (like HRRRv4). Now add ensemble prediction
- Use of NOAA Unified Forecast System (FV3 dynamic core, HRRR physics)

- Improved deterministic prediction
- Improved uncertainty / probability information

# Downward SW radiation error –
## Forecast minus CERES (W/m$^2$, NASA sat estimate)




July 2016 / Jan 2017 –
***General problem – excessive downward short-radiation, too little explicit and subgrid clouds***

- RAP – 13km - One-day forecasts over 31 days.
- HRRR – 3km – One-day forecasts over 31 days
- Global FIM/HYCOM – Single 31-day forecast
  - borrows from cumulus physics for RAP (Grell-Freitas convection)
  - Part of NOAA SubX subseasonal experiment

# Frequency of large error for 6h jet-level wind forecasts over US

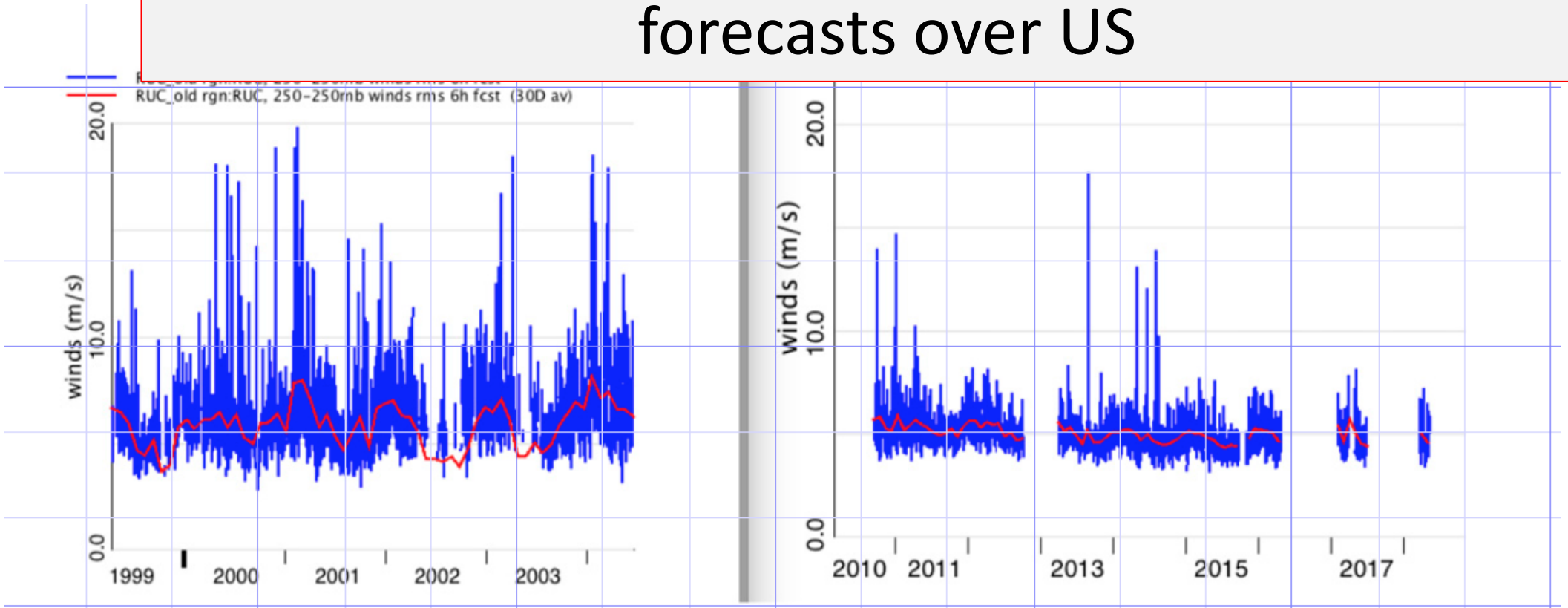



FIG. 13-20. The 250-hPa RMS vector error for 6-h wind forecasts against rawinsonde data over the the contiguous United States for NCEP hourly updated models: (left) RUC for 1999–2004 and (right) RAP for 2010–18. Blue shows all forecast valid times (0600 and 1800 UTC initial times, verified every 12 h), and red shows 30-day mean values.

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**Chapter 13**

**100 Years of Progress in Forecasting and NWP Applications**


STANLEY G. BENJAMIN AND JOHN M. BROWN

*NOAA/Office of Oceanic and Atmospheric Research/Earth System Research Laboratory*
*Global Systems Division, Boulder, Colorado*

# Frequency of large error for 5-day global 500-hPa height forecasts

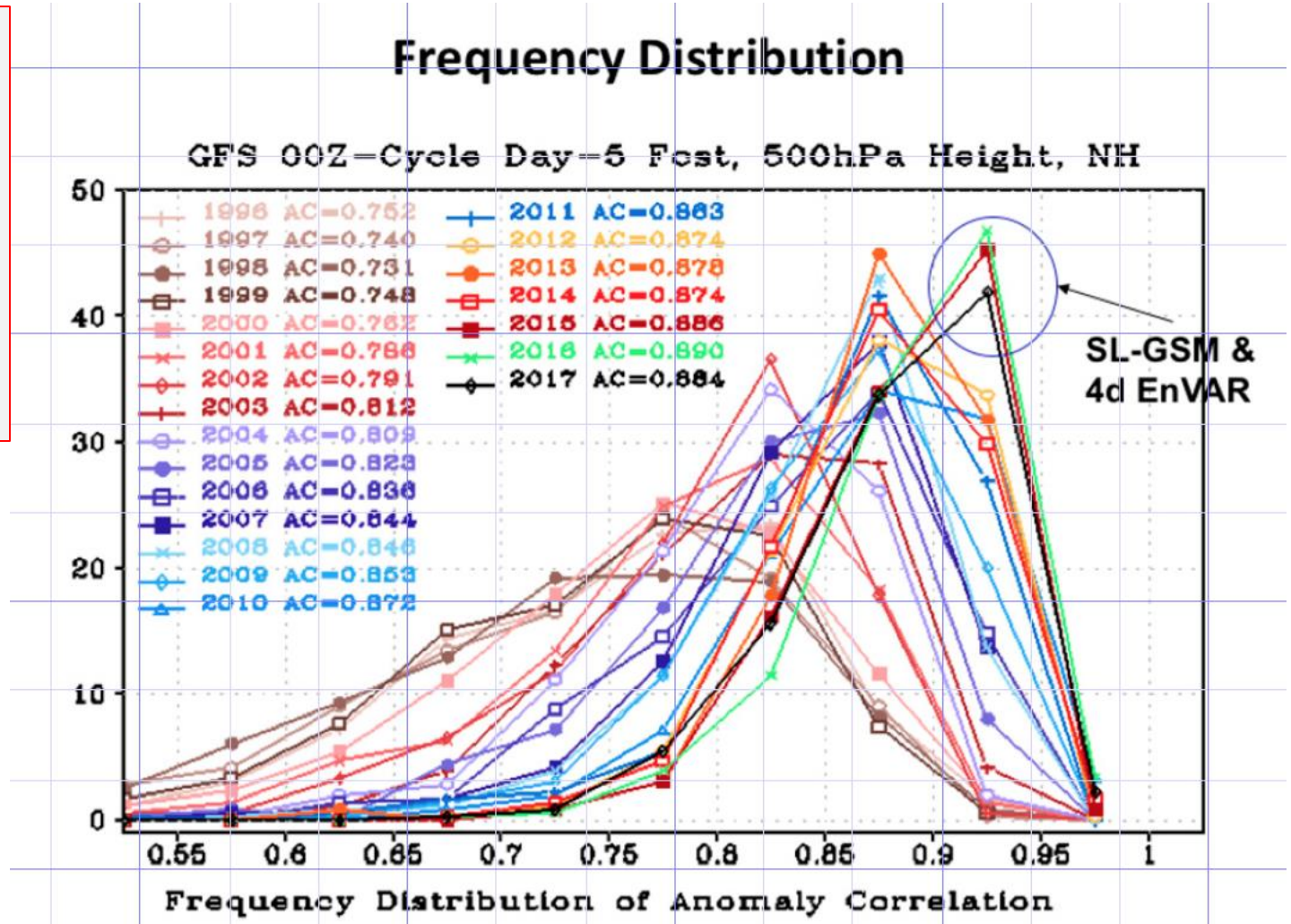


FIG. 13-19. Annual frequency distribution of U.S. GFS 500-hPa height 5-day anomaly correlation for the Northern Hemisphere for 1996–2017. Frequency values are shown for bins of 0.05 in width. SL-GSM refers to the semi-Lagrangian advection version of the global spectral model implemented in 2015–16 (Table 13-3). The figure is provided through the courtesy of F. Yang of NOAA/NCEP.

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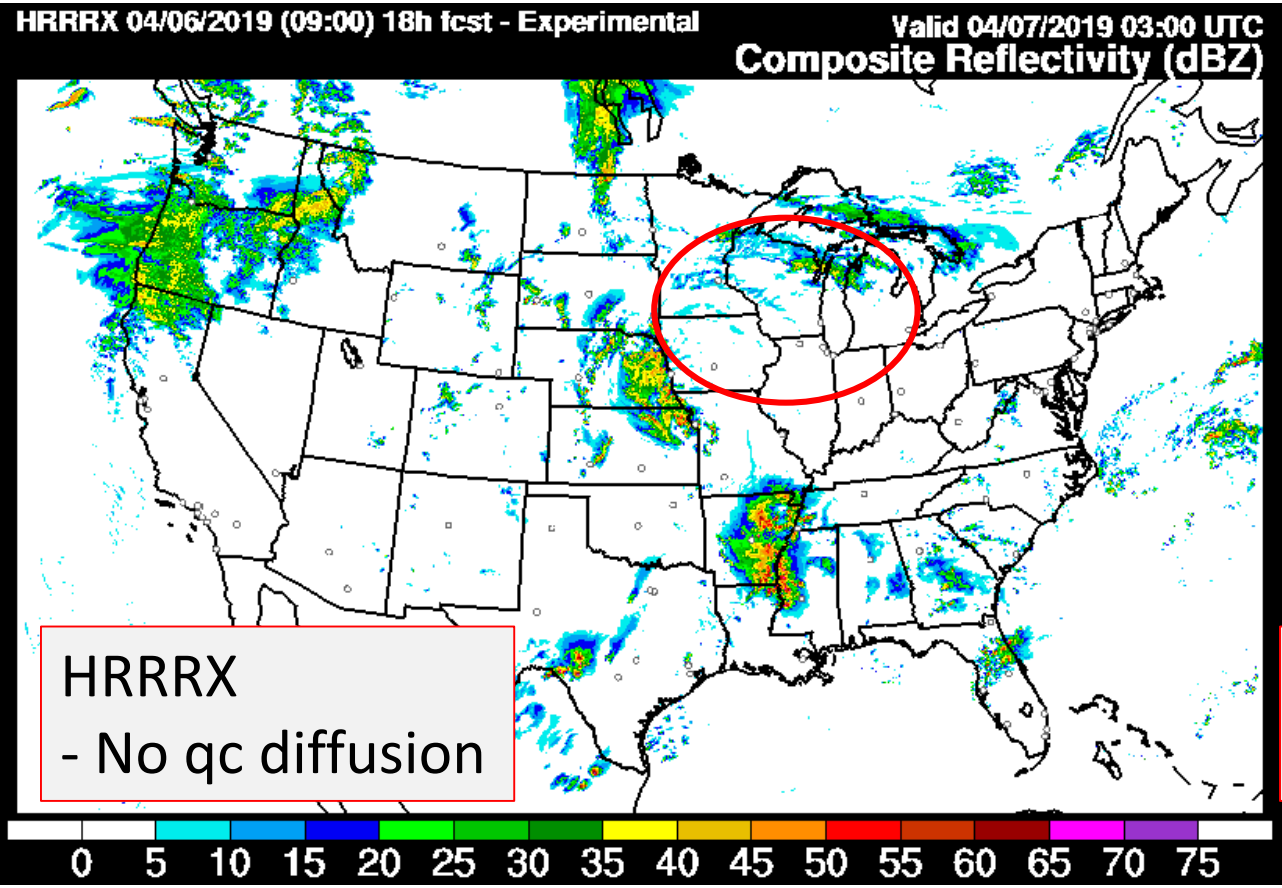
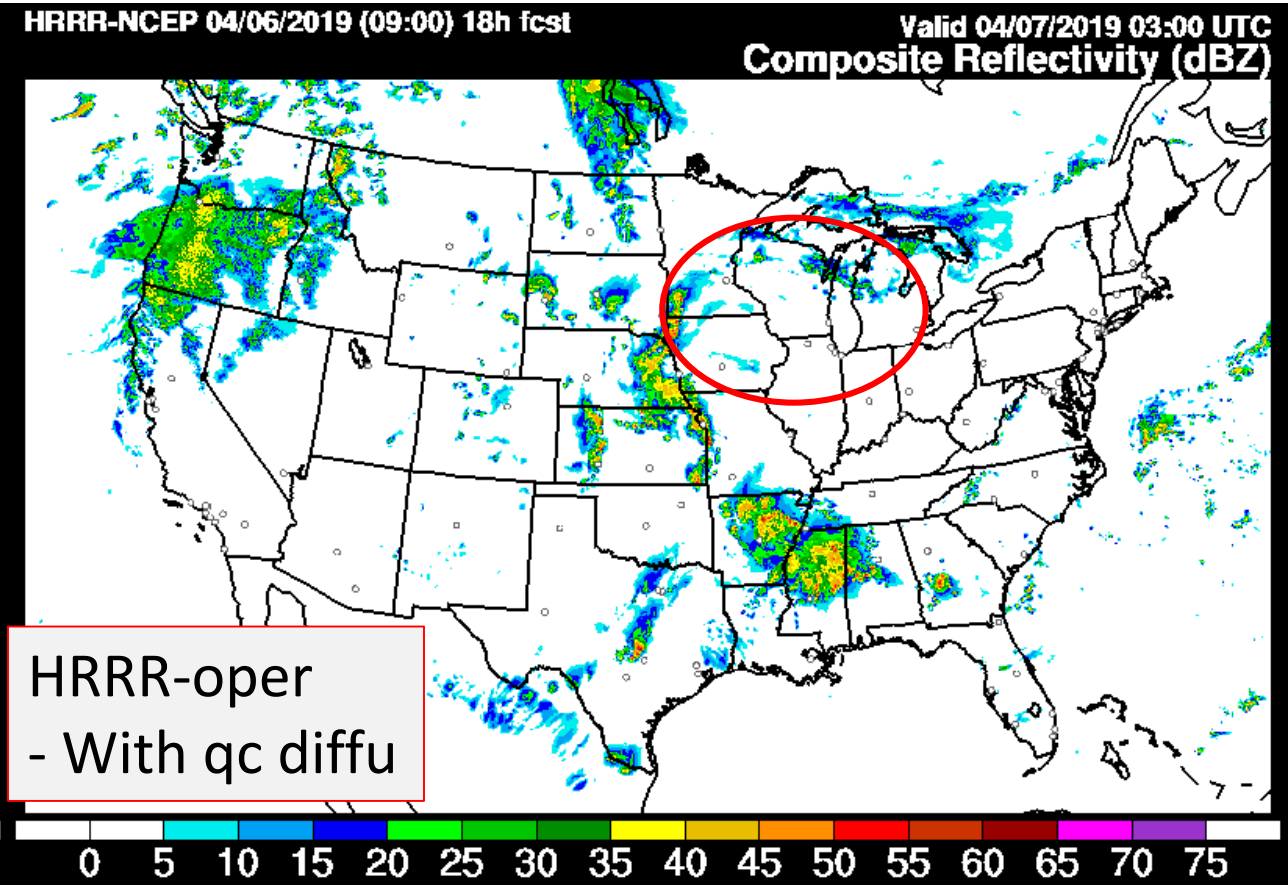
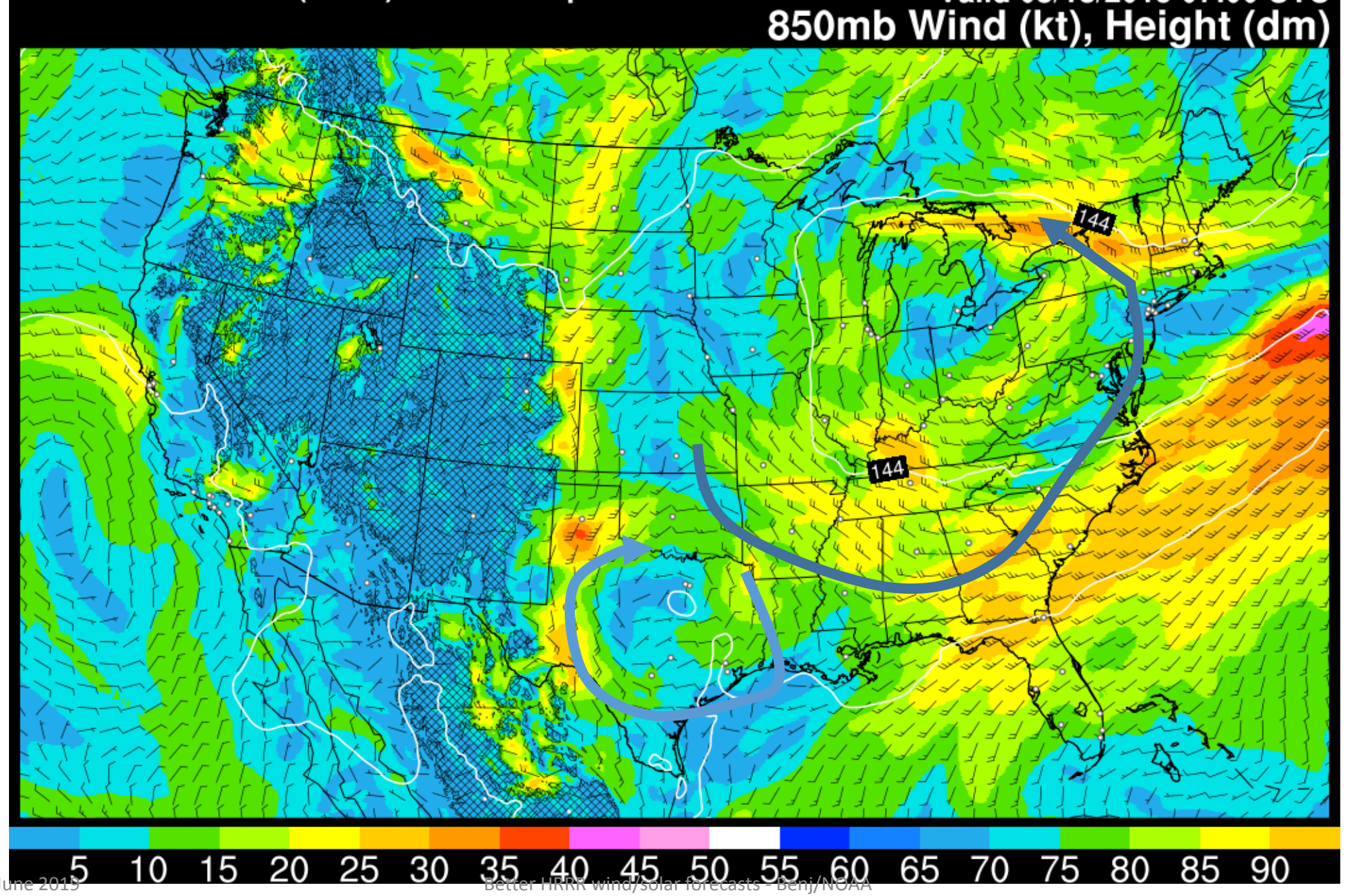
# 3. Effect of removing diffusion of hydrometeor fields

- more small clouds, smaller-scale cloud/precip bands




850mb Wind (kt), Height (dm)
144
144
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90

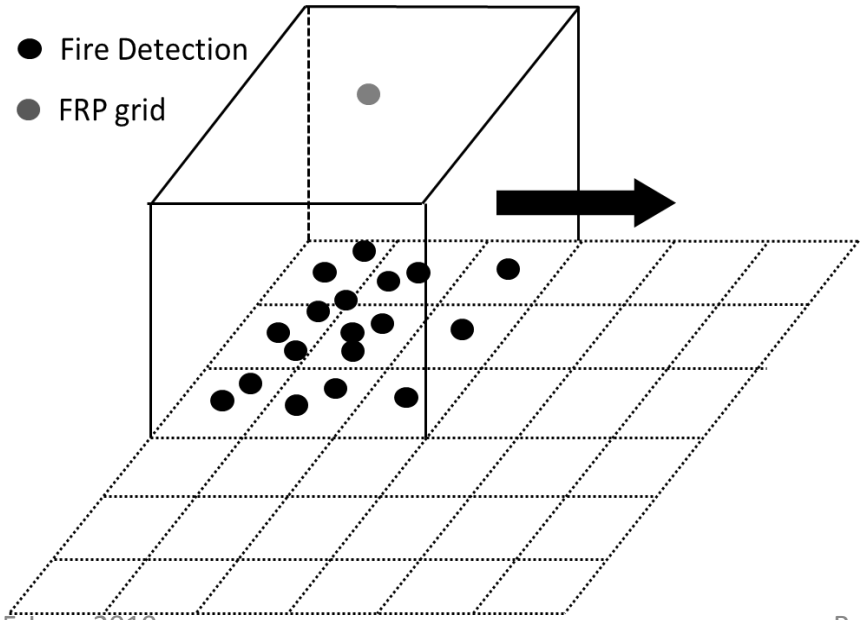
# Ingesting real-time VIIRS and MODIS FRP data to the HRRR-Smoke model

The clustering procedure performs a combination of all **fire radiative power** (**FRP**) data from **VIIRS** and **MODIS** according to the model spatial resolution and grid configuration.


Biomass burning emissions are estimated as follows:

*FRE= FRP x time (fire duration)*

$$M^{[\epsilon]} = FRE_{grid_{(lon,lat)}} \cdot \gamma . EF^{[\epsilon]}$$




Averaged satellite FRP data (24 hours) mapped over 3x3km HRRR CONUS grid pixels for August 19, 2018