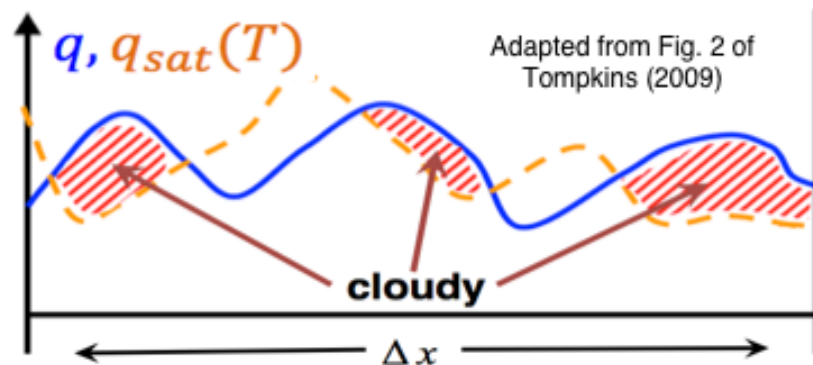


## Sub-Grid (Unresolved) Clouds



Use of radiation / cloud observations  
to reduce cloud-radiation model errors  
from 4-h to 4-week forecasts

*Stan Benjamin*

*Joseph Olson, Tanya Smirnova, Shan Sun, Allison McComiskey,  
Kathy Lantz, Chuck Long, Curtis Alexander, Georg Grell*

*NOAA Earth System Research Laboratory, Boulder, CO USA*



2018 GMAC  
Boulder, CO  
GMD, GSD

# RAP/HRRR: Hourly-Updating Weather Forecast Suite

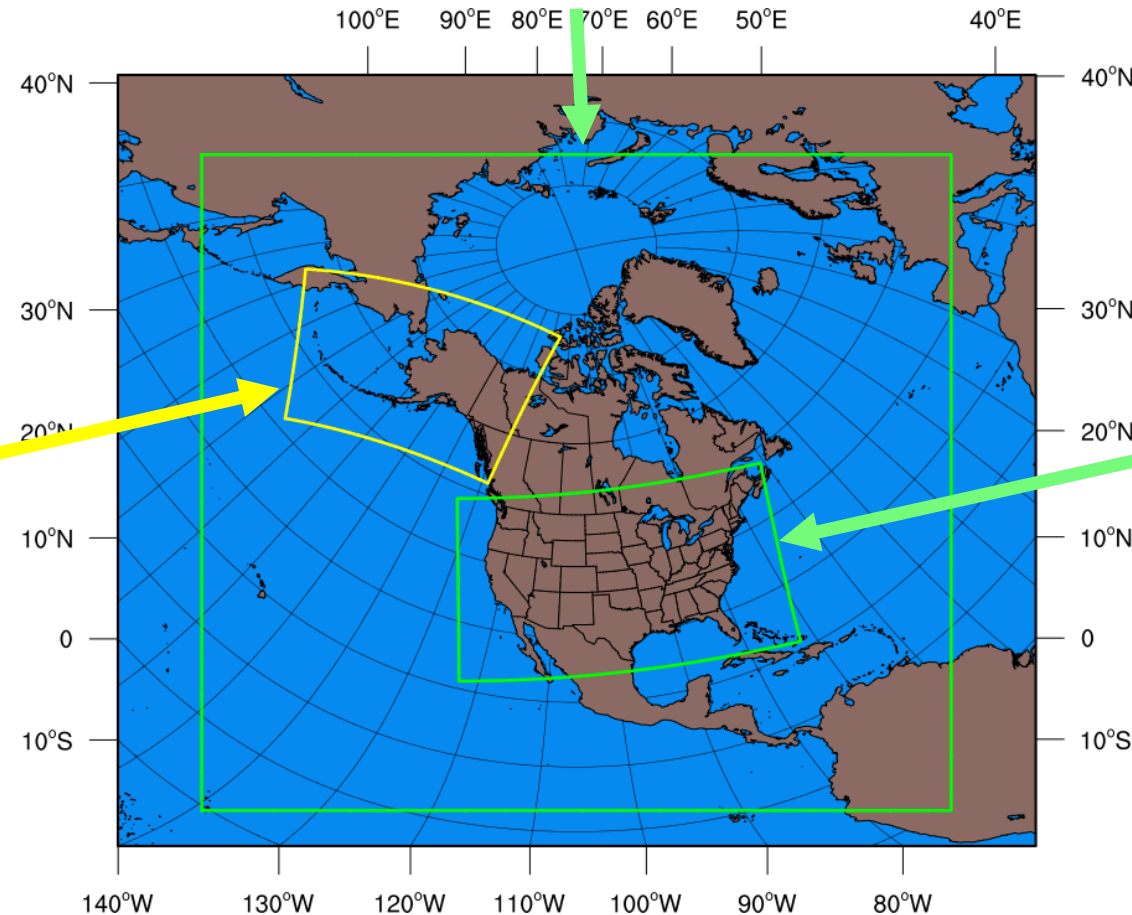
- June 2018 NOAA/NCEP upgrade

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

Initial & Lateral Boundary Conditions

Initial & Lateral Boundary Conditions

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




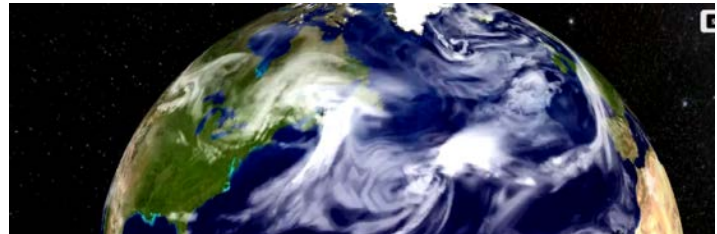
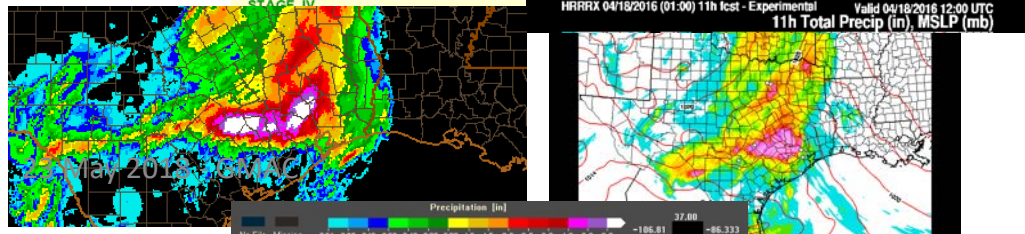
**3-km High-Resolution Rapid Refresh (HRRRv3) – to 36h (Jun 2018)**

- More accurate
- Runs longer (out to 36h)
- Alaska domain added

# Unified model development in NOAA/ESRL

(ESRL divisions: GSD with PSD/GMD/CSD), NCEP, NCAR, etc.)

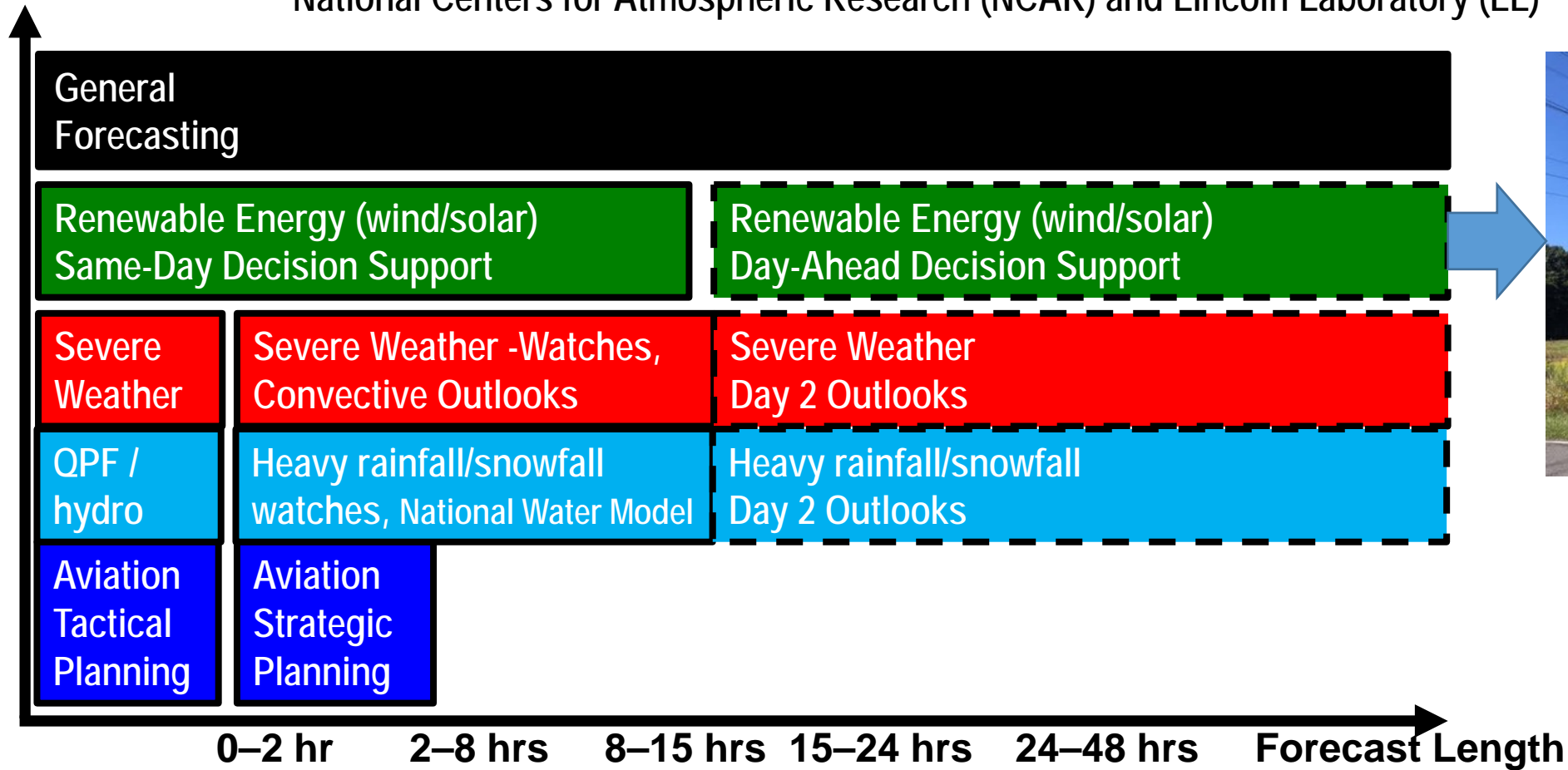
Spatial resolution Forecast range Domain	3km 1-36h Regional		13km 1-39h Regional	10-15km 1-10 day Global	15-30km Week 2 – 9 month Global
<b>Model development area</b>	HRRR (High-Resolution Rapid Refresh model) –		RAP (Rapid Refresh)	NGGPS – FV3 (current physics testing with FIM and FV3)	FIM-HYCOM coupled seasonal (for NOAA SubX experiment, switch to FV3)
<b>Data assimilation</b>	Radar/cloud/surface/land, 3km ensemble DA	↔		4D Ensemble DA (Whitaker-PSD, EMC)	
<b>Dynamic core numerics</b>	Use/refinement of WRF-ARW, hybrid vert coordinate	→		FV3 – cubed sphere, FIM - icosahedral	→
<b>Physical parameterization</b>	PBL/MYNN, cloud microphysics (Thompson), RUC land-surface,	→	Same as HRRR but with Grell-Freitas scale-aware cumulus	GFS physics + Grell-Freitas cu. Testing of HRRR/RAP suite-2017	→
<b>Application of inline chemistry</b>	2-aerosol – NCEP, testing of 18-aerosol		+ gas-phase chemistry	18-aerosol and gas-phase chem	18-aerosol only so far
<b>Systematic error investigations</b>	Clouds, precipitation		Clouds	Clouds, blocking, precipitation	Clouds, blocking, precipitation



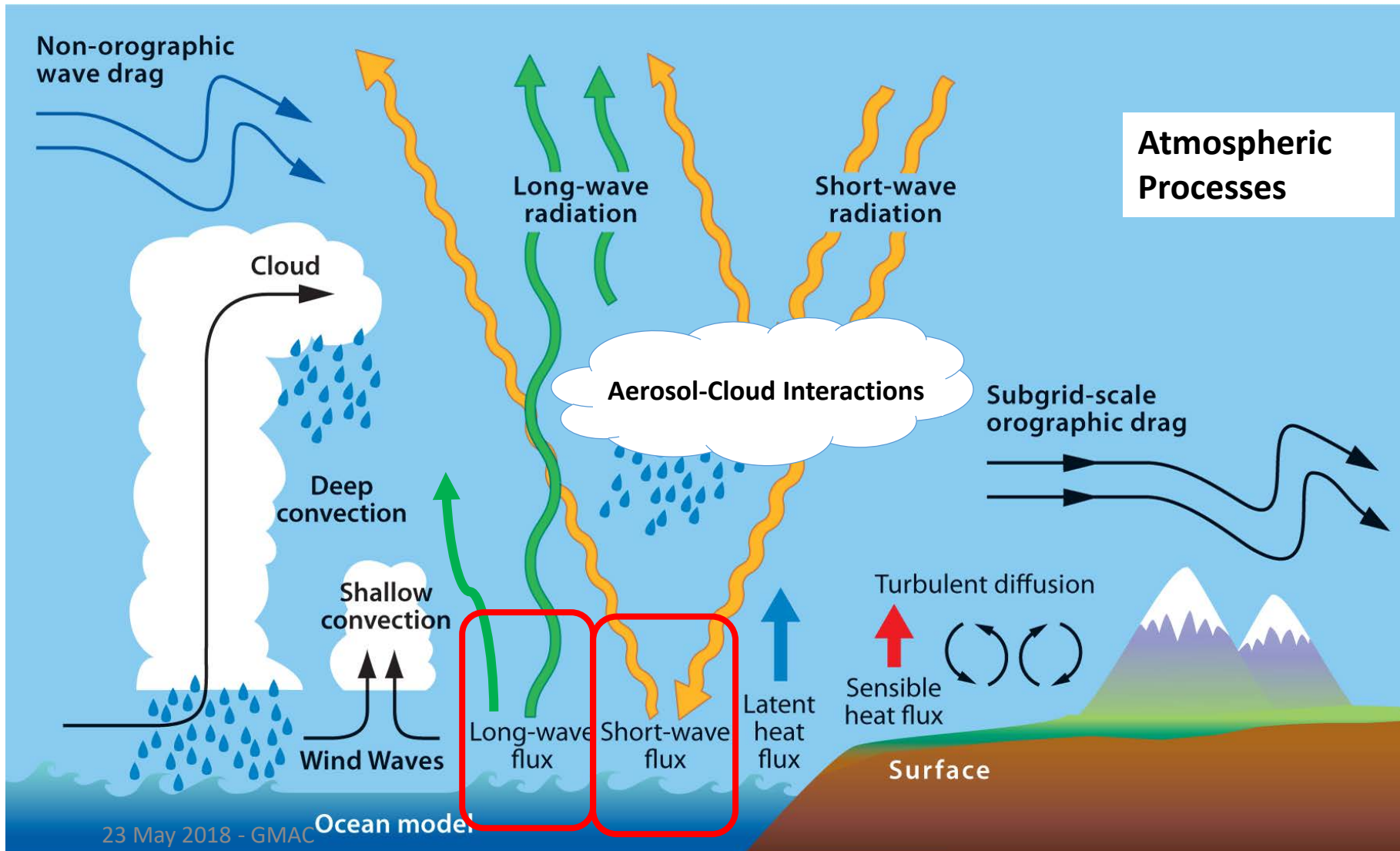


# HRRR Users and Applications

Example: National Weather Service including Storm and Weather Prediction Centers (SPC and WPC)  
 Aviation Weather Center (AWC) and FAA Command Center  
 National Severe Storms Laboratory (NSSL) and Air Resources Laboratory (ARL)  
 National Centers for Atmospheric Research (NCAR) and Lincoln Laboratory (LL)



# Atmospheric process representation necessary for weather prediction (incl. HRRR/RAP)

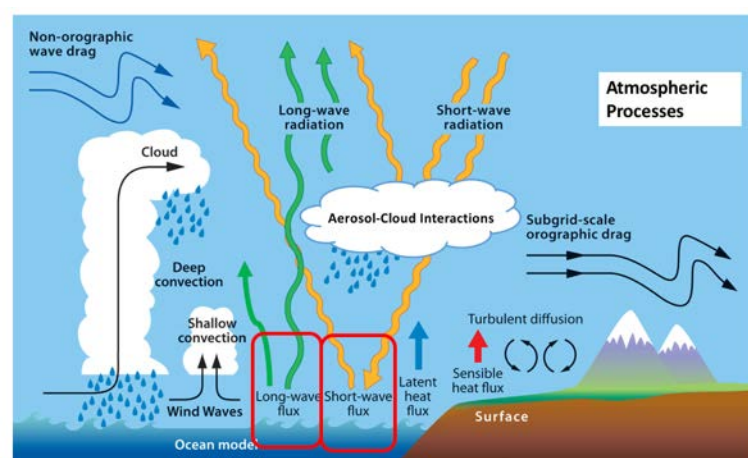


There is an fundamental connection between solar radiation forecasts (both diffuse and direct) and low-level wind forecasts.

Surface Net Radiation

Energy available for SH, LH, and ground heat flux

Drives turbulent mixing, PBL formation, low-level winds, clouds



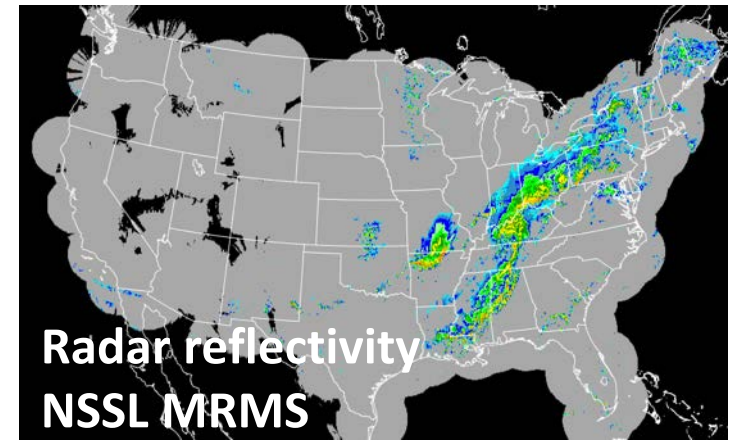
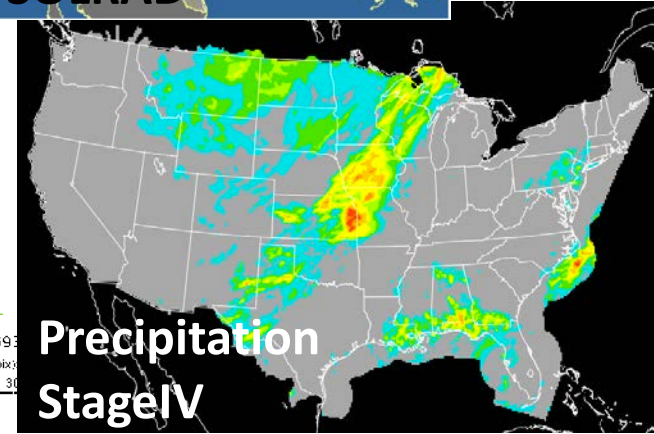
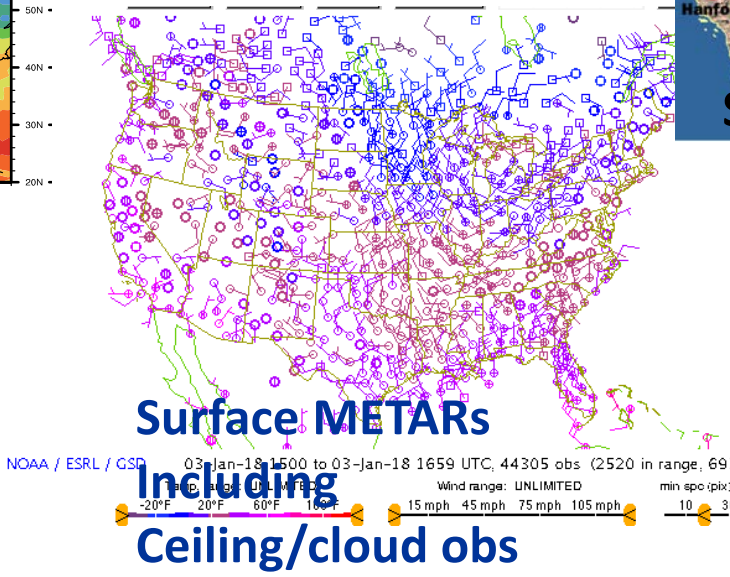
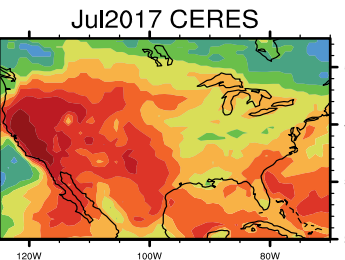
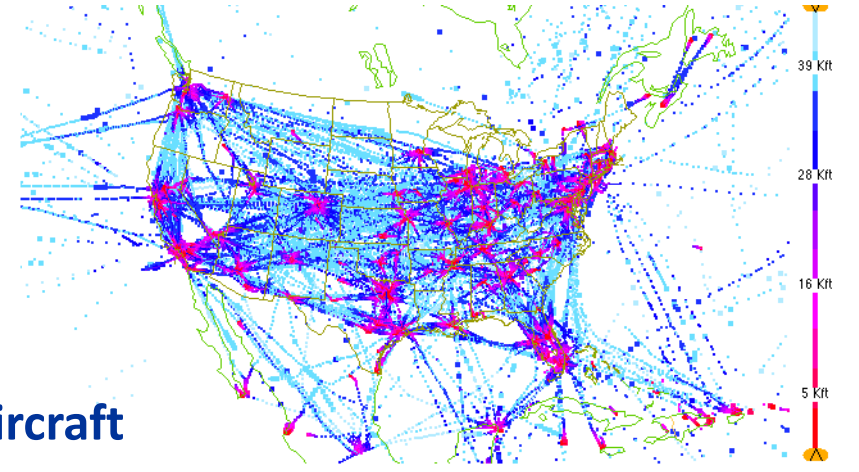
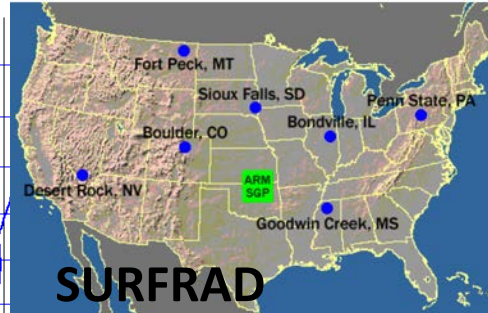
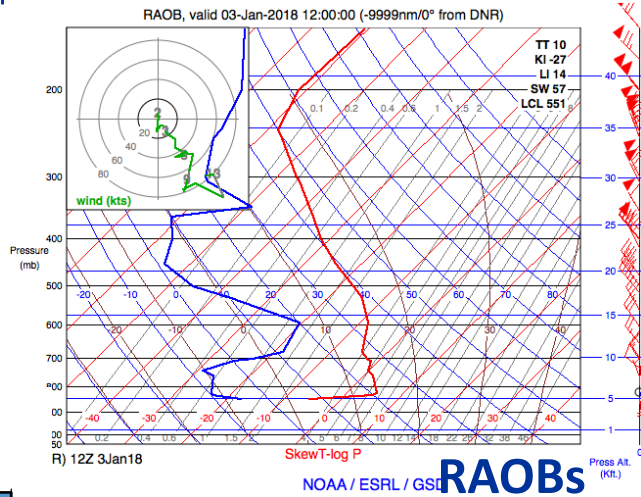
Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	953 x 834	13 km	50	Sigma-Isob Hybrid	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCO	CONUS	1799 x 1059	3 km	50	Sigma-Isob Hybrid	20 mb	RAP	Hourly (pre-forecast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

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Cloud Microphysics	Cumulus Param	Turb /PBL	Land-sfc scheme
RAP	WRF-ARW v3.8.1+	GSI Hybrid Ensemble to 0.85	13-km DFI, 20-min LH	RRTMG/RRTMG	Thompson Aerosol v3.8.1	GF + Shallow	MYNN v3.8.1, EDMF/cl	RUC v3.8.1, 2mT/snow, mosaic
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, EDMF/cl	RUC v3.8.1, 2mT/snow, mosaic

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	Diffusion Option	6 <sup>th</sup> Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5 <sup>th</sup> /5 <sup>th</sup>	Positive-Definite	w-Rayleigh 0.2	Full (2)	Yes 0.12	20 min	MODIS Seasonal, VIIRS GVF	0.01 K/s	60 s
HRRR	5 <sup>th</sup> /5 <sup>th</sup>	Positive-Definite	w-Rayleigh 0.2	Full (2)	Yes, 0.25 no slope	15 min with SW-dt	MODIS Seasonal, VIIRS GVF	0.07 K/s	20 s

# RAPv4/ HRRRv3 Summary of Changes

# GSD model verification vs. observations

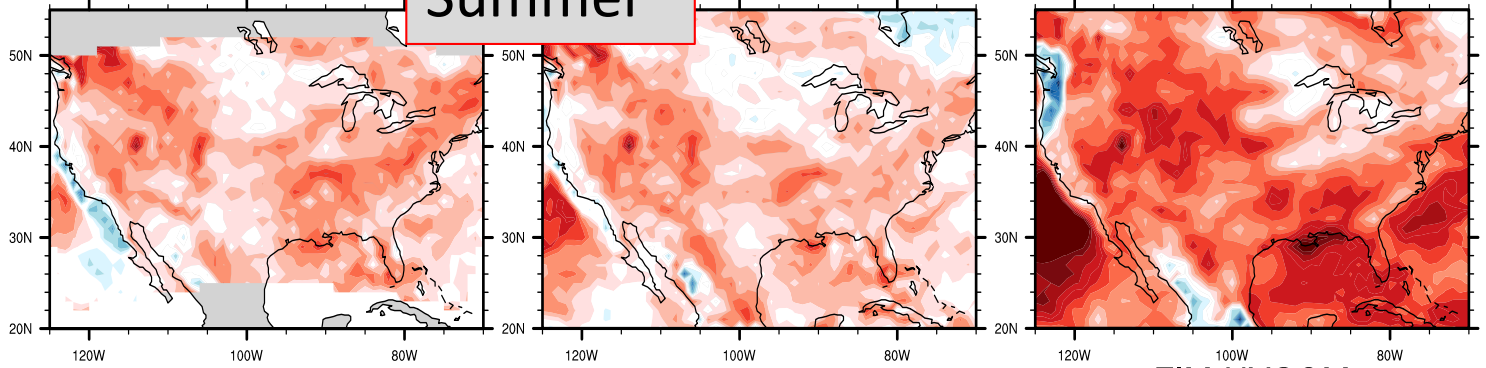


Summer

HRRR

RAP

FIM-HYCOM

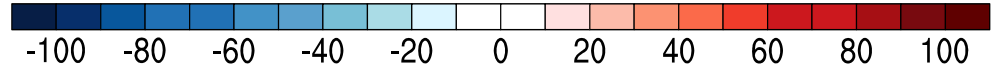
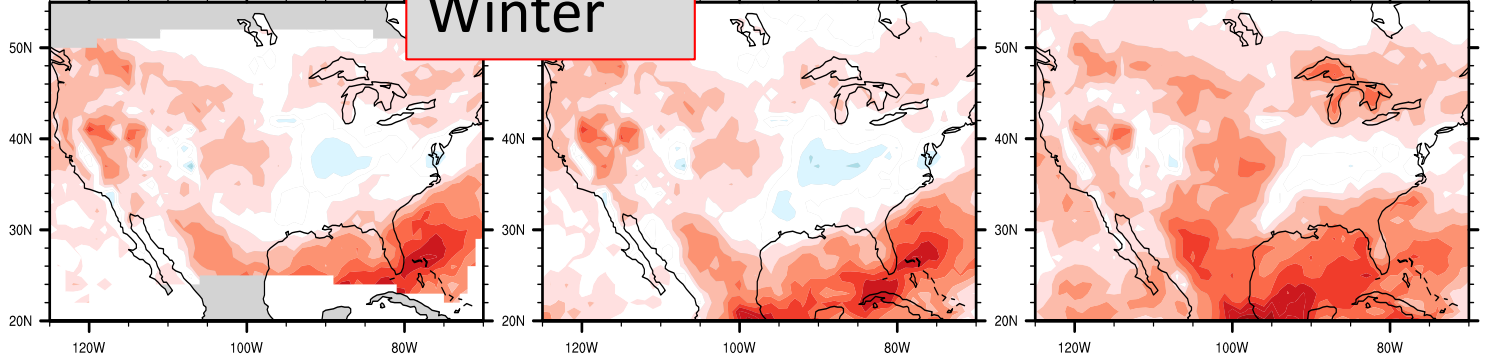


Winter

HRRR

RAP

FIM-HYCOM



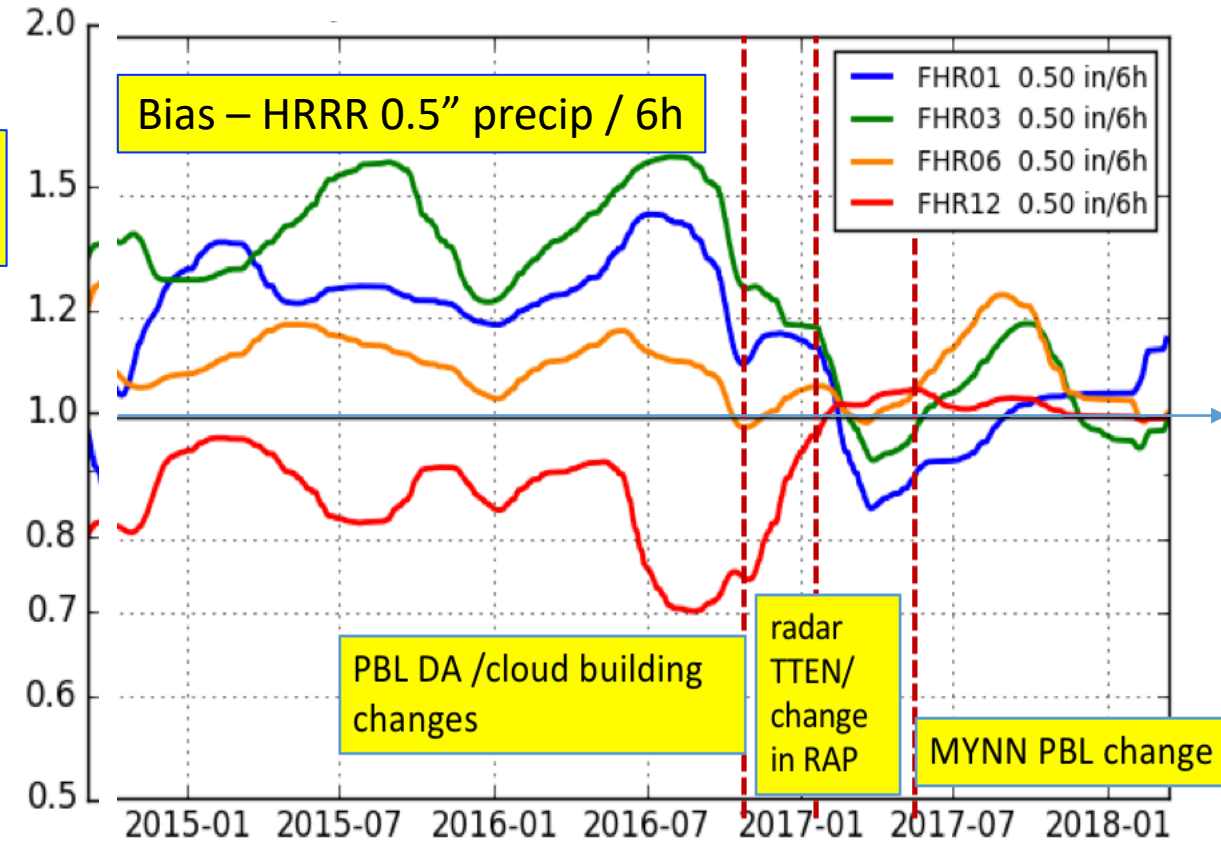
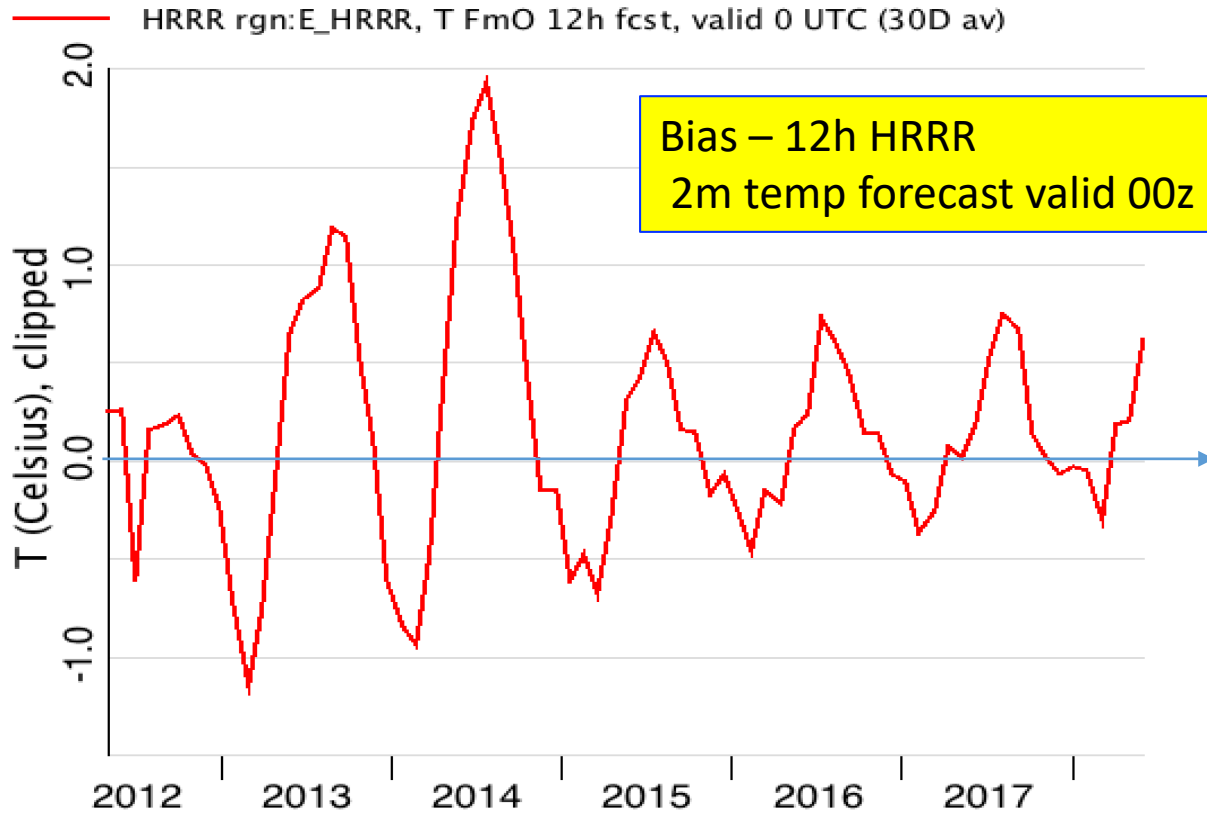
July 2016 / Jan 2017 –  
**Downward SW error –**  
models minus from CERES  
(W/m<sup>2</sup>, day 1)

*General problem – excessive  
downward short-wave  
radiation, too little resolved  
and subgrid clouds*

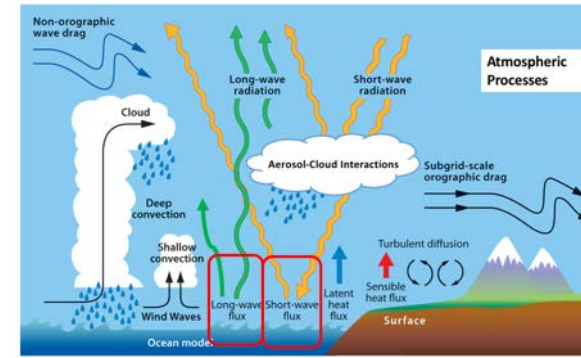
- RAP – 13km
- HRRR – 3km
- Global FIM/HYCOM – borrows from cumulus physics for RAP (Grell-Freitas conv)
  - Part of NOAA SubX subseasonal experiment



# Goal: More accurate weather guidance (via improved process understanding, modeling, assimilation)



*Progress toward lower biases*



# Candidates for warm bias / too-little cloud

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)

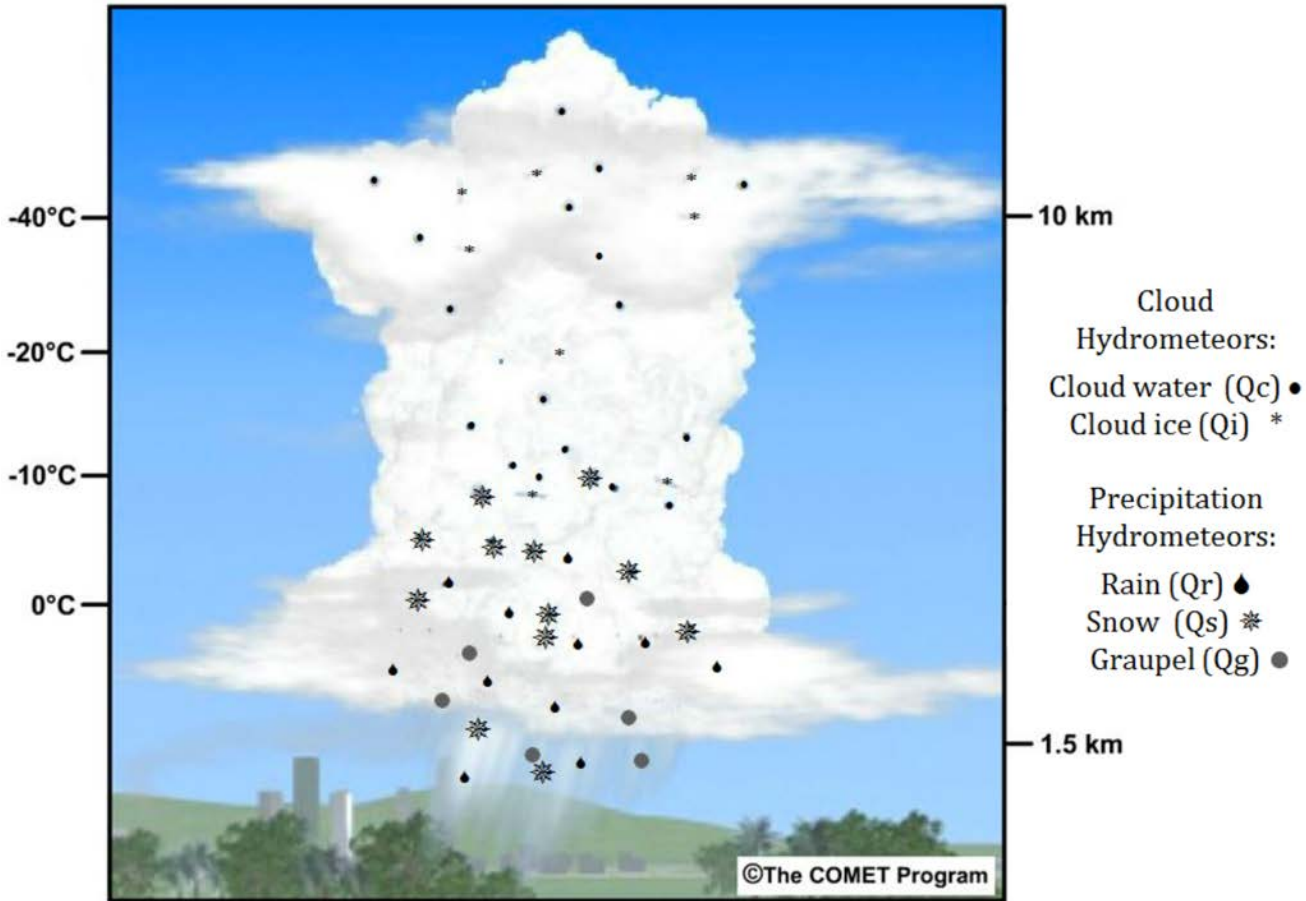
Model	Version	Assimilation	Radar DA	Radiation LW/SW	Cloud Microphysics	Cumulus Param	Turbulence PBL	Land-sfc scheme
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HRRR	5 <sup>th</sup> /5 <sup>th</sup>	Positive-Definite	w-Rayleigh 0.2	Full (2)	Yes, 0.25 no slope	15 min with SW-dt	MODIS Seasonal, VIIRS GVF	0.07 K/s	20 s

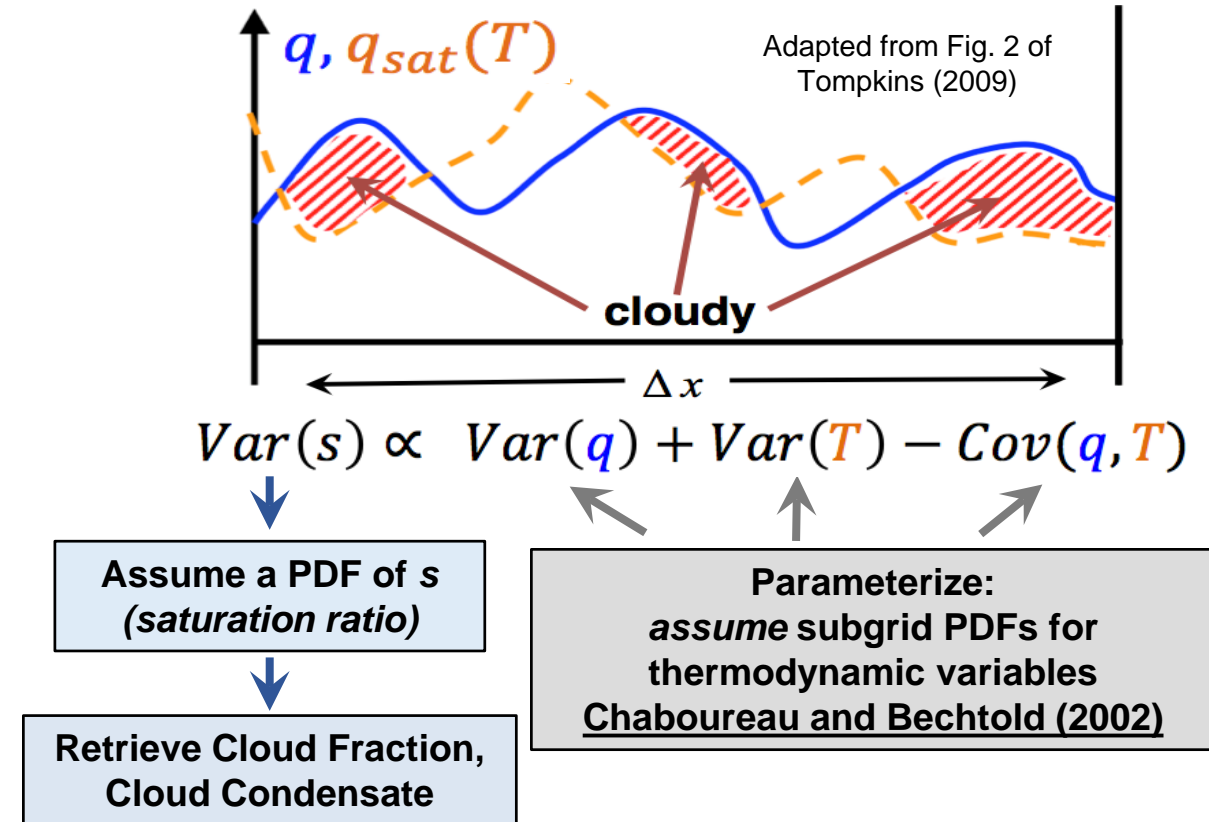
# Physics Development Emphasis: Sub-Grid Clouds

## Explicit (Resolved) Clouds/Precipitation

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

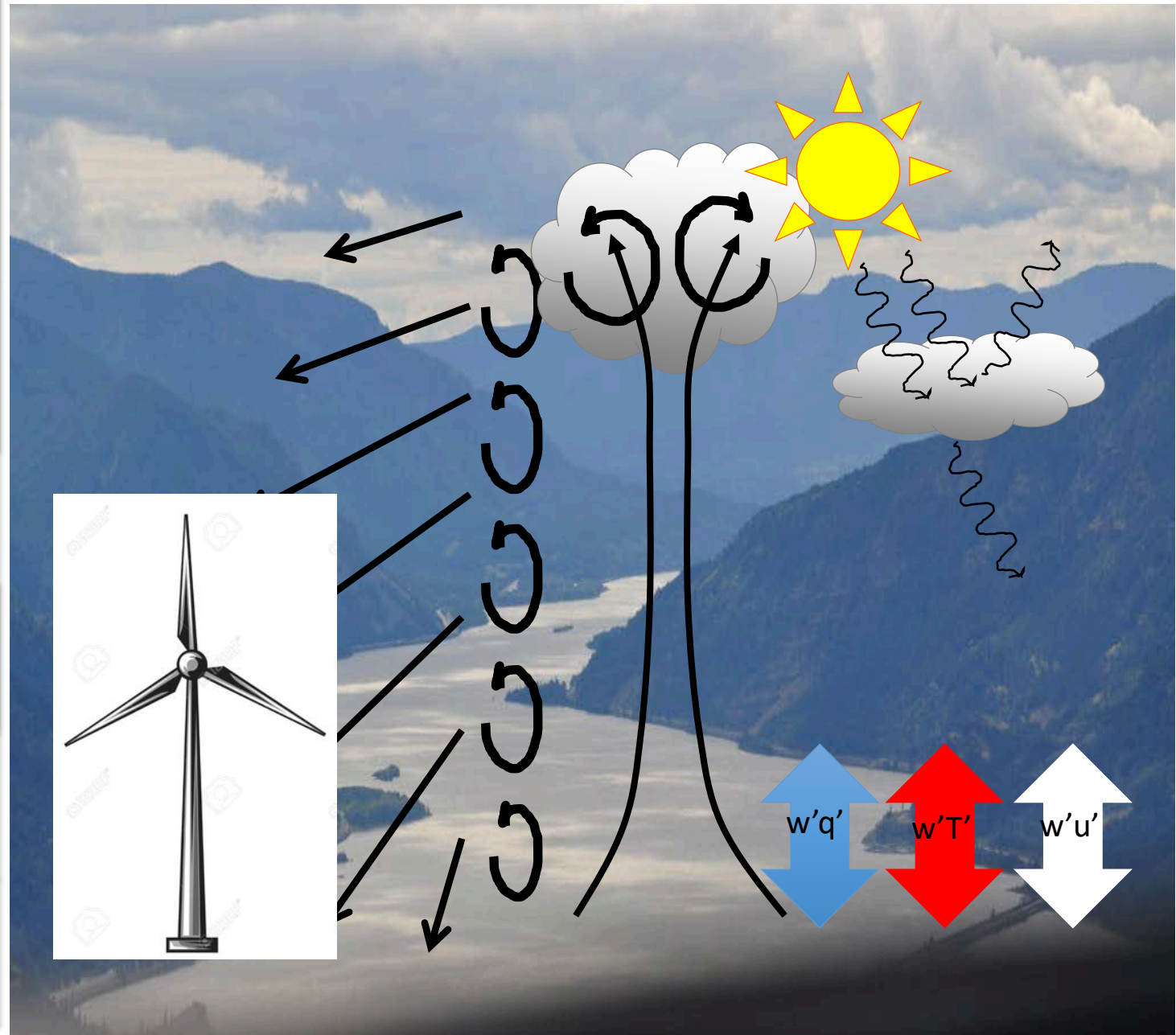


## Sub-Grid (Unresolved) Clouds



# HRRR/RAP: Physical Processes and Representations

Process	Model Component	Change/Addition
Turbulent Diffusion	MYNN PBL/ 3d-Blended TKE	<ul style="list-style-type: none"> <li>• Mixing length                             <ul style="list-style-type: none"> <li>○ Scale-aware</li> <li>○ Z-less</li> </ul> </li> <li>• 1D <math>\rightarrow</math> 3D as <math>f(\Delta x) \rightarrow 0</math></li> </ul>
Non-local Turbulent Transport	MYNN Mass-flux	<ul style="list-style-type: none"> <li>• Multi-plume</li> <li>• TKE transport</li> <li>• Momentum transport</li> <li>• Scale-aware</li> </ul>
Surface Fluxes	RUC LSM/ MYNN Sfc Layer	<ul style="list-style-type: none"> <li>• Scalar roughness</li> <li>• M-O alternatives</li> <li>• 3D surface stress</li> </ul>
<b>Clouds</b>	Thompson Aerosol / Chaboureau-Bechtold	<ul style="list-style-type: none"> <li>• Subgrid scale clouds</li> <li>• Coupled to radiation</li> <li>• prognostic</li> </ul>
Numerics/ Dynamics	Vertical Coordinate, Advection	<ul style="list-style-type: none"> <li>• Hybrid WRF-ARW Vertical Coordinate</li> </ul>
Turbine Drag	Wind Farm Parameterization	<ul style="list-style-type: none"> <li>• Wind direction effects</li> <li>• Power calculation.</li> </ul>



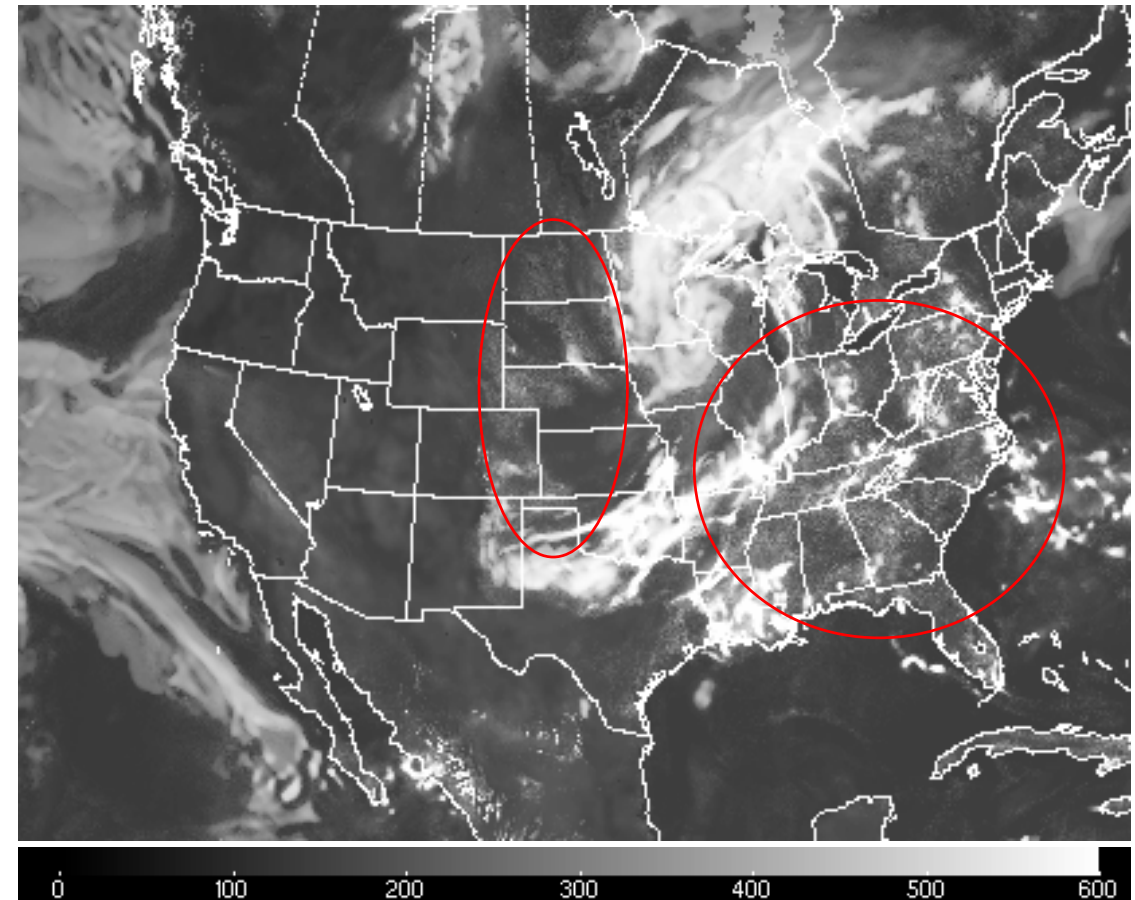
# Improvements to mass-flux scheme: not enough coverage

5-h GHI forecasts  
valid 1800 UTC 19  
August 2015

Visible Imagery



Previous version (v3.9)



$W m^{-2}$

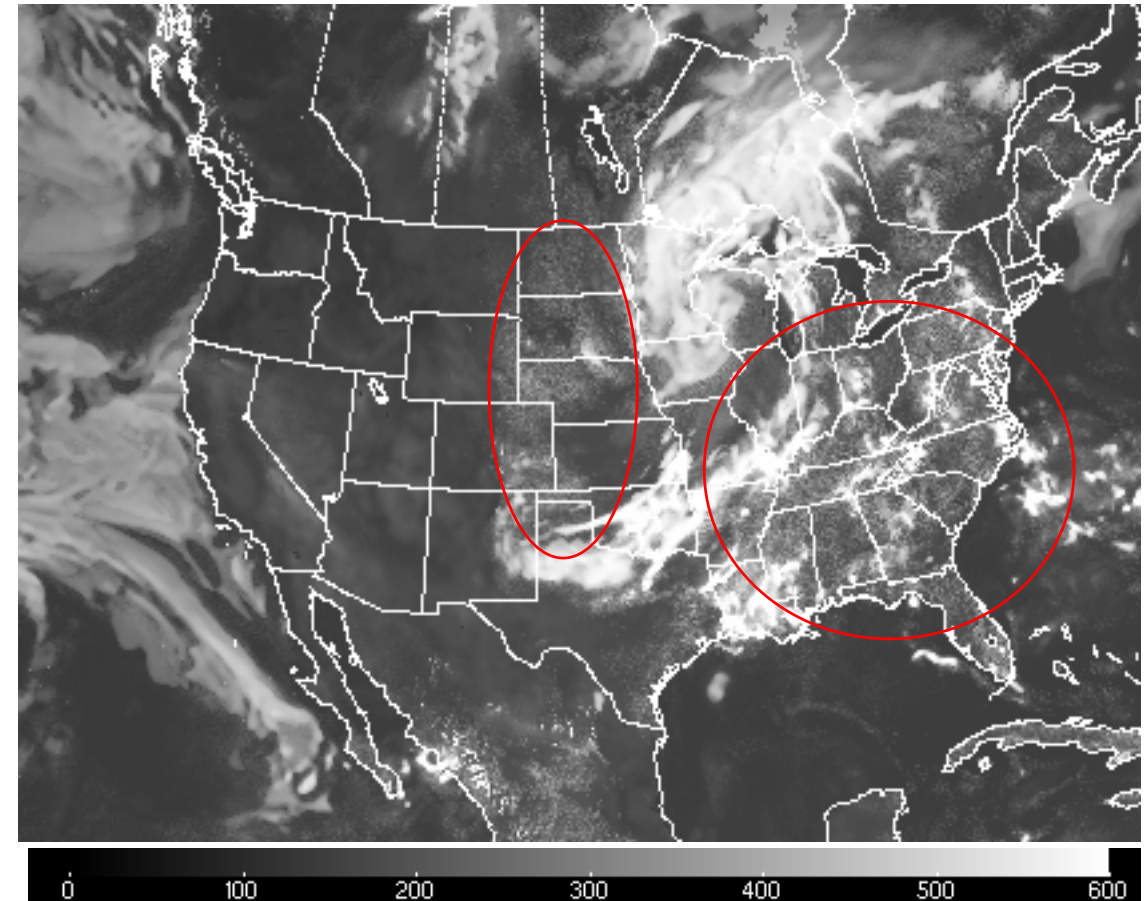
# Improvements to mass-flux scheme: better

5-h GHI forecasts  
valid 1800 UTC 19  
August 2015

Visible Imagery



Updated Version

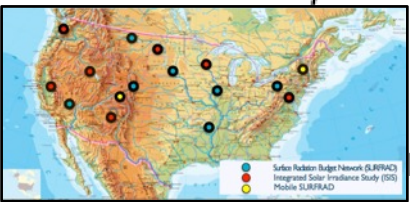
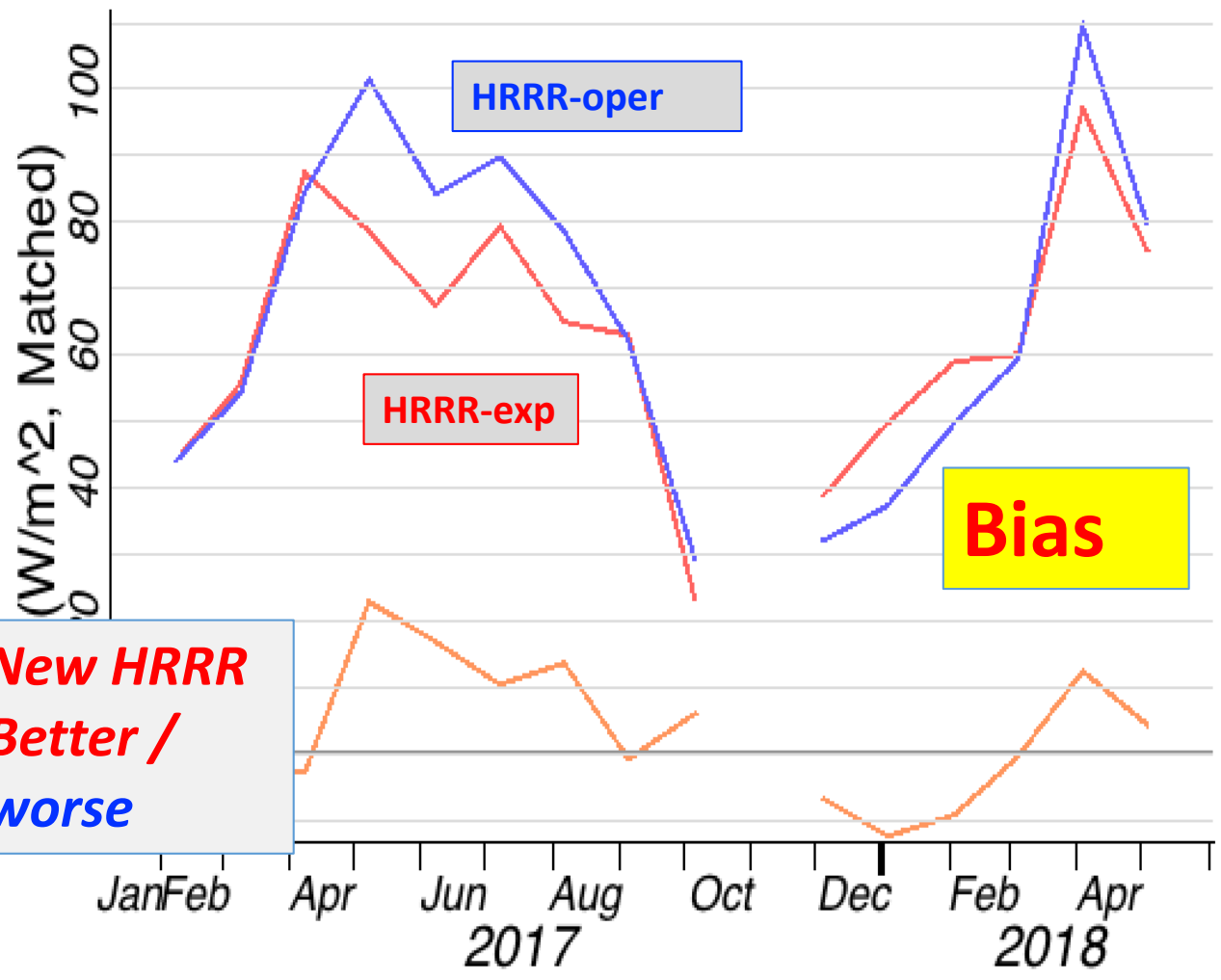
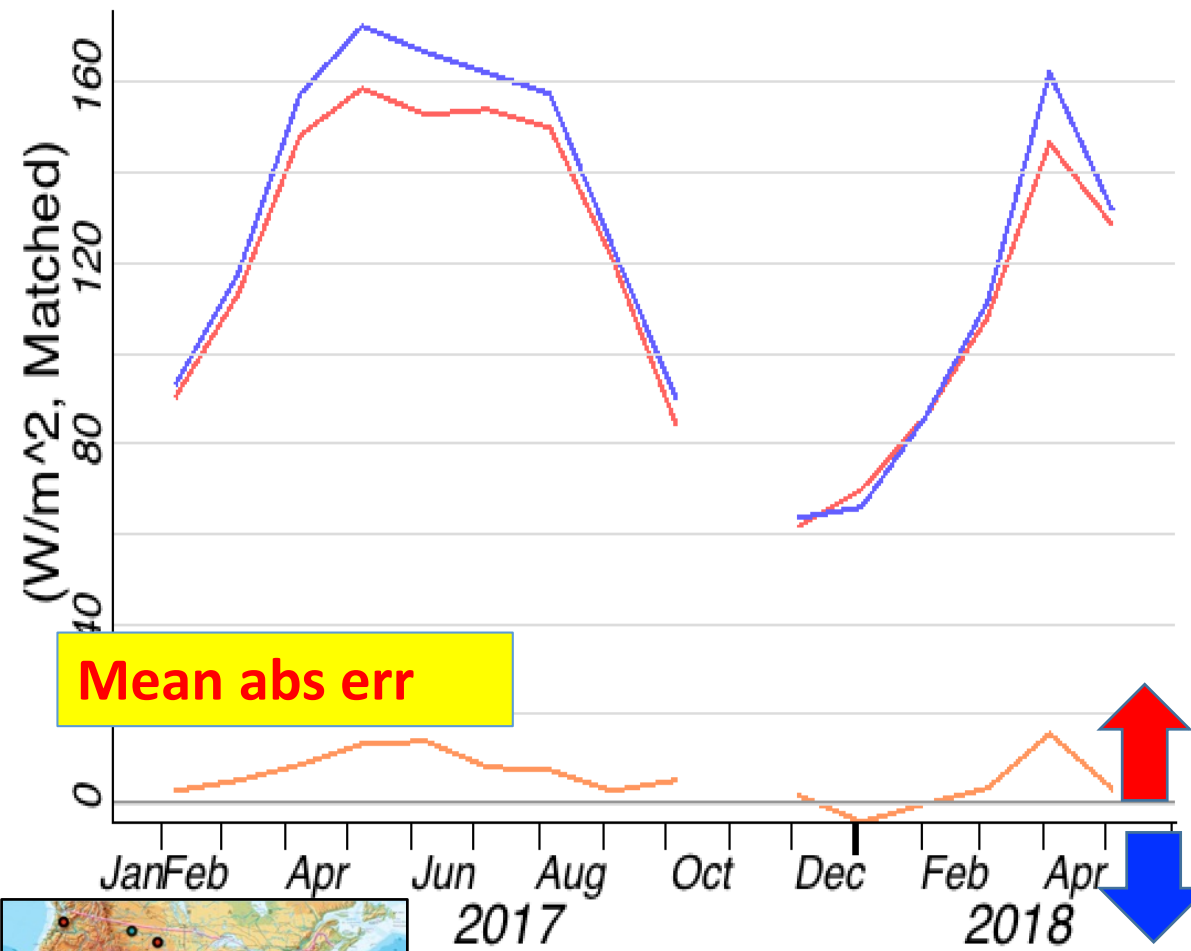


$W m^{-2}$

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

- HRRR\_OPS-HRRR dswrf MAE 13km scale 12h fcst , valid 15-21 Z (30D avg)
- HRRR\_OPS dswrf MAE 13km scale 12h fcst , valid 15-21 Z (30D avg)
- HRRR dswrf MAE 13km scale 12h fcst , valid 15-21 Z (30D avg)

- HRRR\_OPS-HRRR dswrf bias 13km scale 12h fcst , valid 15-21 Z (30D avg)
- HRRR\_OPS dswrf bias 13km scale 12h fcst , valid 15-21 Z (30D avg)
- HRRR dswrf bias 13km scale 12h fcst , valid 15-21 Z (30D avg)

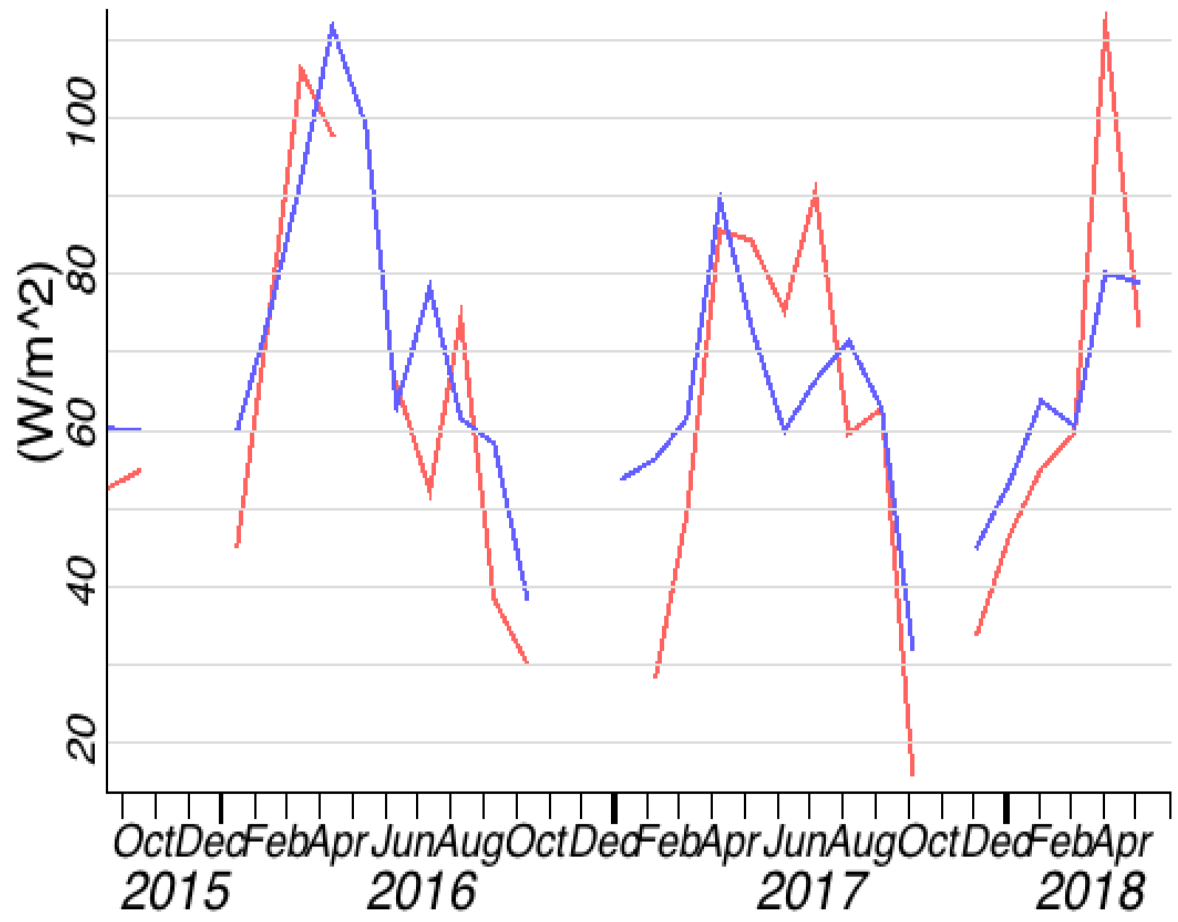


SURFRAD geographical diversity critical for model evaluation

New HRRR Better / worse

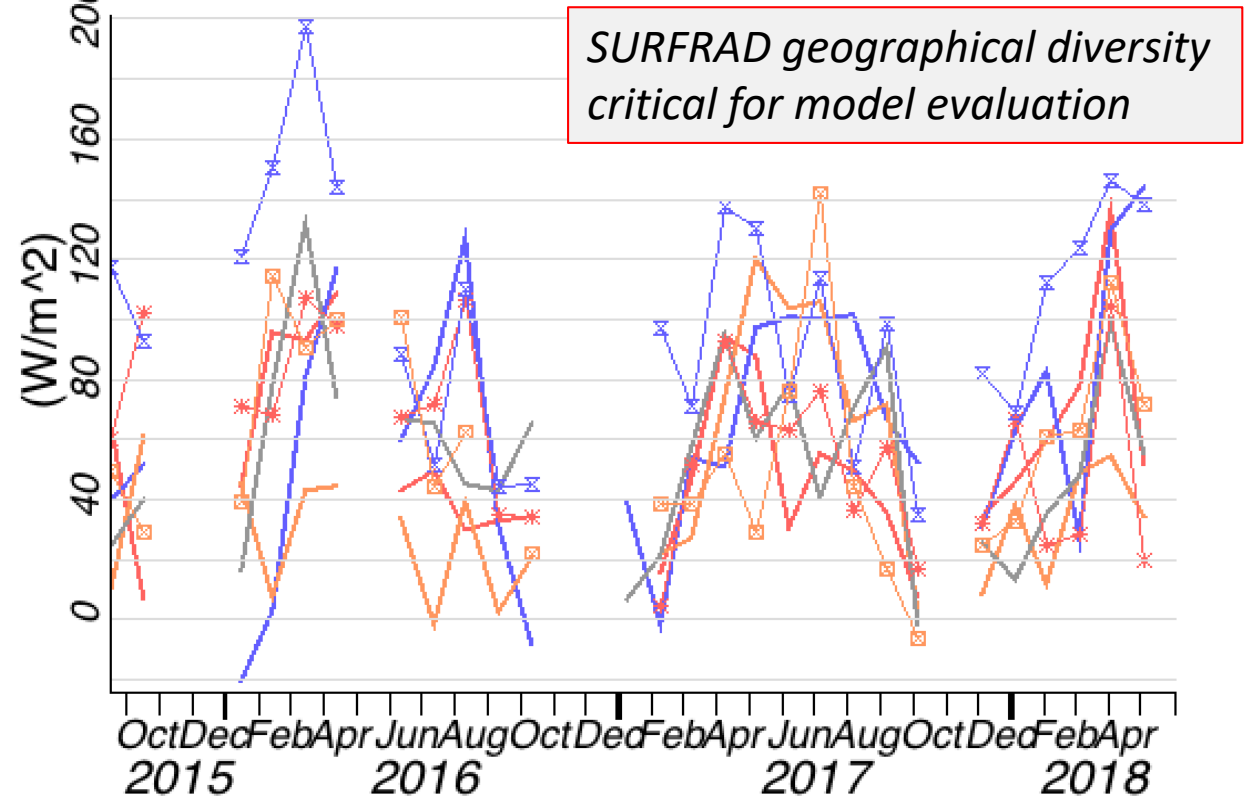
# 12h HRRR Downward SW bias vs. SURF/SolRAD – Mean 15-21z

— HRRR dswrf bias 13km scale 12h fcst All-Solrad, valid 15-21 Z (30D avg)  
— HRRR dswrf bias 13km scale 12h fcst All-Surfrad, valid 15-21 Z (30D avg)



*Similar excessive downward SW (HRRR) for SURFRAD vs. SOLRAD obs.*

— □ HRRR dswrf bias 13km scale 12h fcst Sioux Falls, SD, valid 15-21 Z (30D avg)  
— △ HRRR dswrf bias 13km scale 12h fcst Penn State, PA, valid 15-21 Z (30D avg)  
— \* HRRR dswrf bias 13km scale 12h fcst Goodwin Creek, MS, valid 15-21 Z (30D avg)  
— — HRRR dswrf bias 13km scale 12h fcst Fort Peck, MT, valid 15-21 Z (30D avg)  
— — HRRR dswrf bias 13km scale 12h fcst Desert Rock, NV, valid 15-21 Z (30D avg)  
— — HRRR dswrf bias 13km scale 12h fcst Table Mountain, CO, valid 15-21 Z (30D avg)  
— — HRRR dswrf bias 13km scale 12h fcst Bondville, IL, valid 15-21 Z (30D avg)

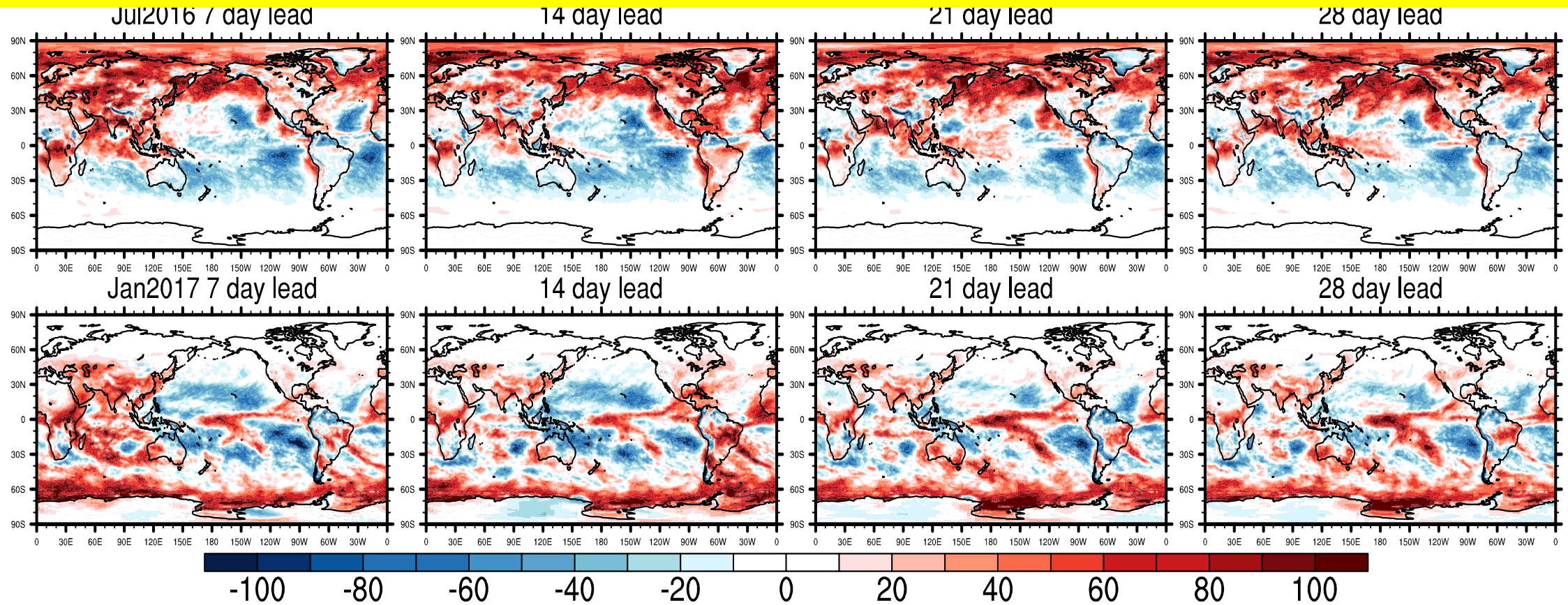


*SURFRAD geographical diversity critical for model evaluation*

*Similar excessive downward SW (HRRR) for different SURFRAD stations*



# Downward SW radiation - FIM-HYCOM vs. CERES

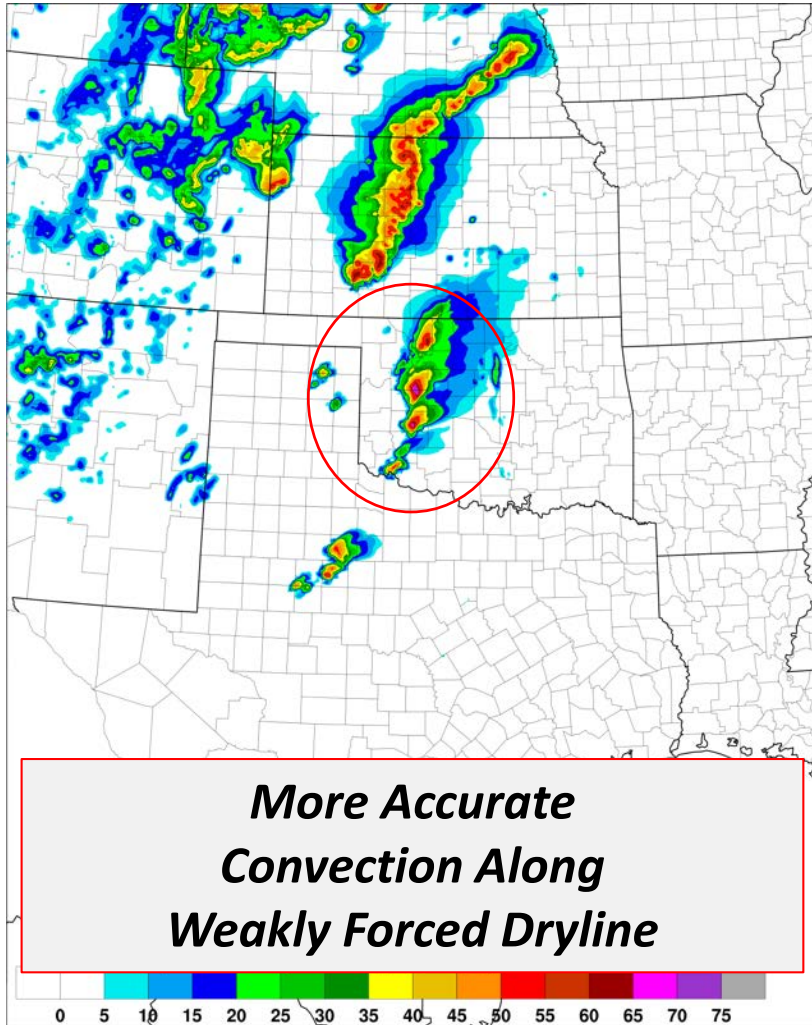


*FIM-HYCOM uses Grell-Freitas deep/shallow convection (same as RAP).*

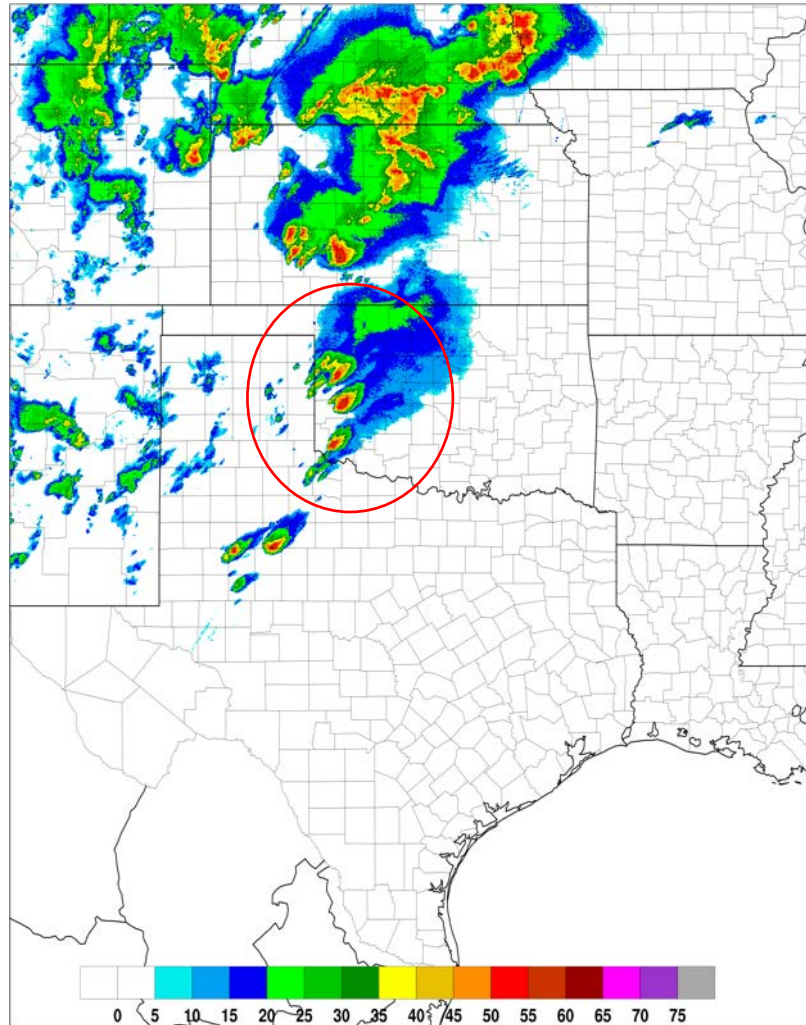
- *Similar downward SW bias for all 4 weeks.*
- *Warm season: **model too high SW over land, cold ocean stratocum zones, high-latitude ocean.***

# HRRR Improved Convective Forecasts

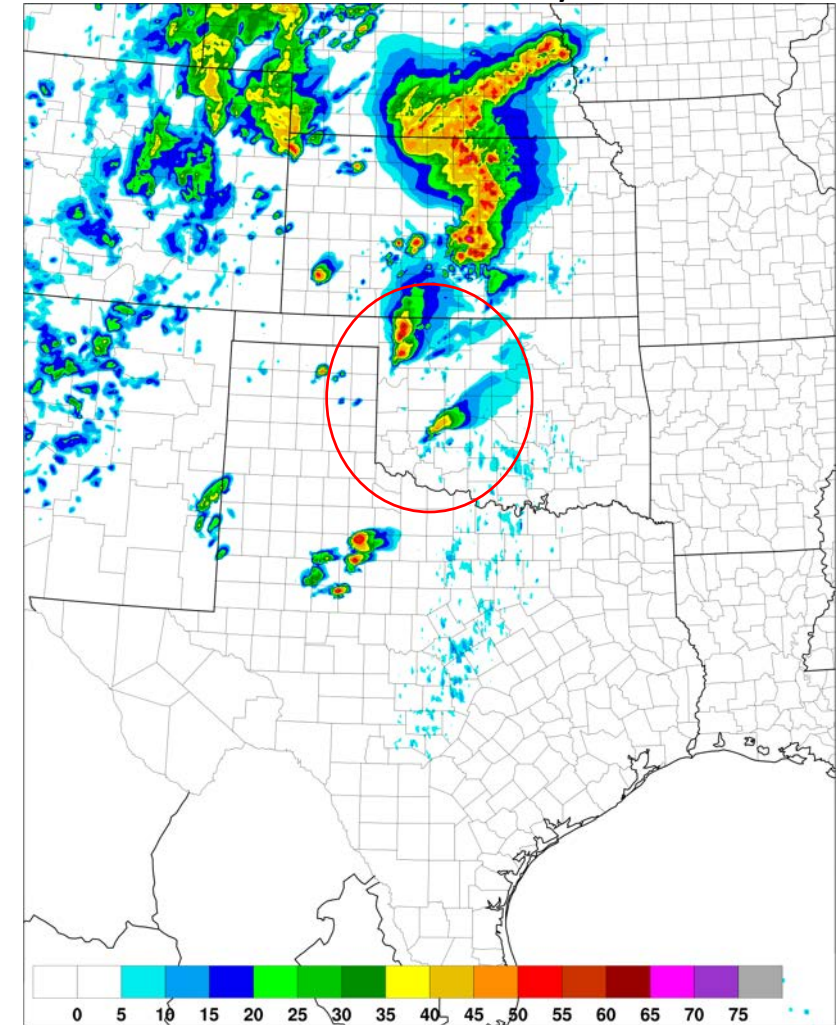
Experimental **HRRRv3** 13 hr fcst  
Valid 00 UTC 17 May 2017



Composite Reflectivity **Observations**  
00 UTC 17 May 2017



Operational **HRRRv2** 13 hr fcst  
Valid 00 UTC 17 May 2017



# RAPv5/HRRRv4 upcoming changes - 2020

Larger impact for wind/ solar forecast accuracy

Model	Data Assimilation	Land-surface / post
<p>WRF-ARW v3.9+ incl. phys changes</p> <p><i>Physics changes:</i></p> <p><b>MYNN PBL update – yet better sub-grid clouds, improved EDMF mixing length, goal: retaining stable layers</b></p> <p><b>Aerosols sources/sinks – fire/smoke, dust - Add smoke with VIIRS fire radiative power</b></p>	<p>Merge with GSI trunk – 2018</p> <p><i>New Observations for assimilation:</i></p> <p>GOES-16 radiances, GLM lightning            MRMS dual-polarization radar mosaics  <b>Extra mesonet data incl. anemometer hgt            TC vitals for trop cyclone location/ strength            Satellite-based AOD (aerosol optical depth)            Aircraft/raob moisture obs for p&lt;300 hPa</b></p> <p><i>Assimilation Methods:</i></p>	<p><b>Switch to MODIS albedo (higher), replace 1-deg albedo.            Add zenith-ang albedo adj</b></p> <p>Fractional sea/lake ice concentration            ? – FVCOM SST/ice</p> <p>VIIRS/MODIS/GOES fire radiative power  <b>HRRRE prob products            Full cycle RAP land-sfc</b></p>
<p>Improved land-surface/snow model including better 2m T/Td diagnostics            - no snow mosaic for T&lt;271K</p> <p>Latest Grell-Freitas conv (RAP only)</p>	<p><b>HRRR - 3km ensemble DA (40 members out to 1h) – effective in 2017/18 tests.            Reduced LH for radar assim in HRRR</b></p>	<p><b>Enabled by GMD radiation obs</b></p>
<p>Lake model for small lakes</p> <p><b>Enhanced gravity-wave drag</b></p>	<p><b>Cloud/hydrometeor assim within ens DA            DA for subgrid cloud fraction/cloud water w/ METAR, satellite cloud fraction</b></p> <p>Revised hydrometeor assim (project to resolvable scale) to improve 1h precip</p>	

# RAPv4/HRRRv3 – May 2018-NCEP

Larger impact for wind/ solar forecast accuracy

Data Assimilation	Model	Land-surface/post
<p><b><u>New Observations for assimilation:</u></b> Add satellite cloud-drift winds over land Add TAMDAR aircraft observations Add new polar-orbiter satellite data IASI, CrIS, SEVIRI radiances</p> <p><b><u>Assimilation Methods:</u></b> Revised PBL pseudo-observations from sfc –better winds/RH Cloud building (satellite, surface) - more cloud droplets now specified</p> <p><b>Radar reflectivity assimilation</b> - Latent heating reduced by 50% - RAP only - In HRRR – reduces too much convection</p>	<p>WRF-ARW v3.8.1+ incl. physics changes</p> <p><b><u>Physics changes:</u></b> Thompson cloud microphysics – improved ice clouds (not excessive)</p> <p>MYNN PBL update – better sub-grid clouds, EDMF (local/deep) mixing</p> <p>Land-sfc model update – mosaic snow, 2m temp diagnostic</p> <p>Revised Grell-Freitas cumulus (RAP)</p> <div style="border: 1px solid red; padding: 5px;"><ul style="list-style-type: none"><li>• <i>HRRR/RAP implementations at NCEP – scheduled Jun 2018. Following in 2020.</i></li><li>• <i>GMD network radiation obs critical for model improvement for NOAA RAP/HRRR/global models.</i></li></ul></div>	<p>MODIS higher-res 15” land-use data</p> <p>VIIRS real-time greenness veg fraction</p> <p>Revised roughness length</p> <p>10m wind (not ~8m)</p> <p>Wind gust diag fix (stronger at night)</p>