Version 4 of the North American Mesoscale Forecast System

EMC CCB Meeting

1 September 2016

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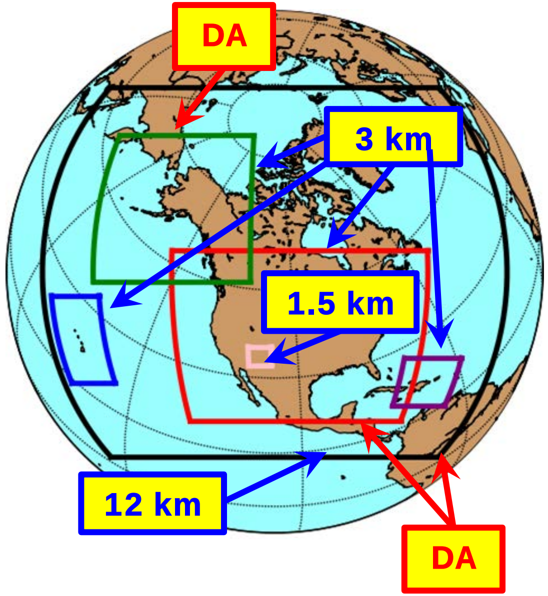
NAM Forecast System - version 4

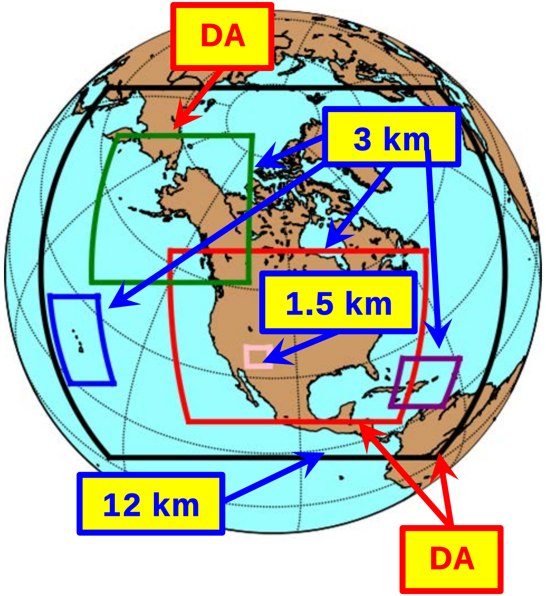
- Resolution Changes
  - CONUS (4 km) and Alaska (6 km) nests → 3km
  - Sync AK and CONUS On-Demand Fire Weather nests → 1.5 km
- Select Model Changes
  - Updated microphysics →Improved stratiform precip., better anvil reflectivity, lower peak dBZs (ops noted to be ‘too hot’), smaller area of light/noisy reflectivity (rain treated as drizzle)
  - More frequent calls to physics → Physics/dynamics more in sync (e.g. improved upper air, potentially improved nest QPF)
  - Improved effect of frozen soil on transpiration and soil evaporation → Improved cold season T/Td biases
  - Convection changes for 12 km NAM parent → Improved QPF
- Data Assimilation:
  - DA cycles for 3 km CONUS and AK nests → Much less ‘spin-up’ time
  - Use of Lightning and Radar Ref.-derived temperature tendencies in initialization
    - Improved short-term forecasts of storms at 3 km
    - Improved 00-12 hr QPF
  - New satellite radiances, satellite winds → Improved IC’s



DA: Data Assimilation Cycle

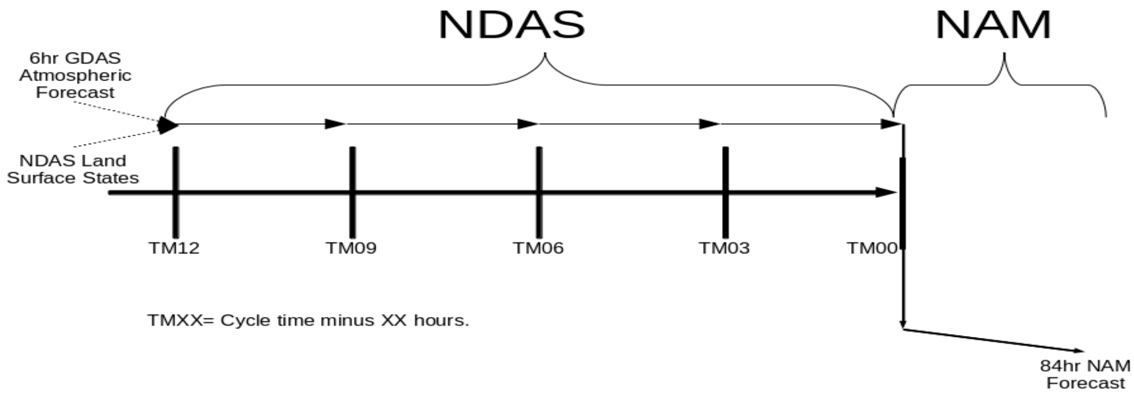
NAM Forecast System - version 4

- **Other Changes**
  - Reinstate use of AFWA snow depth analysis with envelope adjustment
  - FLAKE (Fresh Water Lake) climatology in 3 km CONUS/Alaska nests and 1.5 km Fire Weather nest
  - Reduced terrain smoothing in the 3 km nests
  - Use NESDIS burned area data (30-day and 2-day average) in fire weather nest; greenness fraction and albedo are adjusted based on the 30-day average, top layer soil moisture adjusted based on the 2-day average
  - Tropical cyclone relocation in the 12 km parent domain

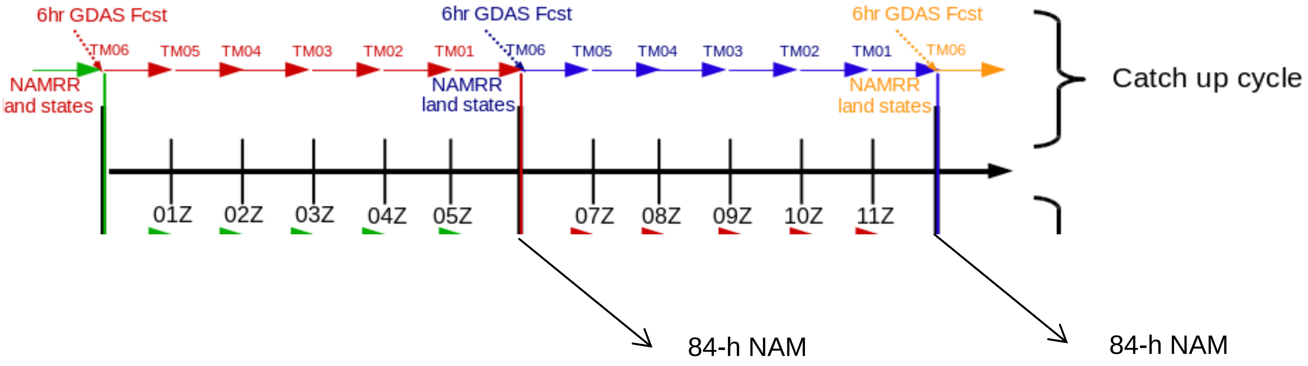


DA: Data Assimilation Cycle

12-h DA vs 6-h DA “Catchup cycle”



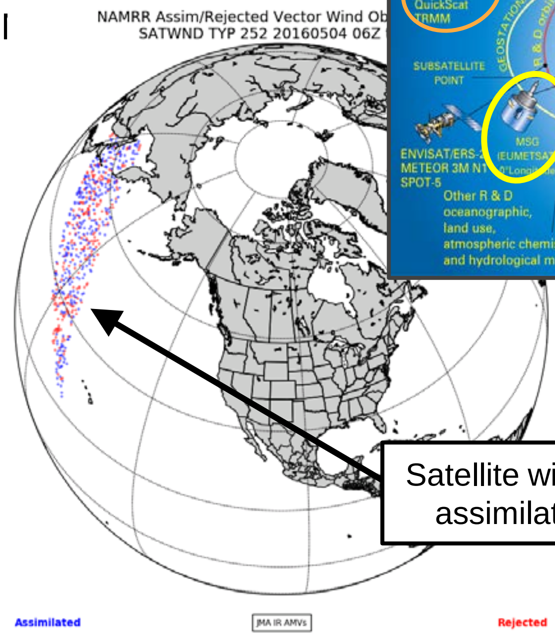
Ops DA = 12-h spin-up of 12 km parent domain, 3-h analysis/forecasts. Nests not cycled; first guess for NAM nests interpolated from NAM 12 km parent



Pll DA : (“Catch-up cycle”) = 6-h spin-up of 12km parent + 3 km CONUS/AK nest, hourly analyses/forecasts. First guess for non-cycled nests interpolated from 12 km parent

New Observations in NAMv4: Aircraft and Satellite

- More aircraft data from Sandy Supplemental & TAMDAR
  - Aeroméxico, ADS-C, Air Wisconsin
- New Radiances:
  - METOP-B: HIRS4 (monitored) AMSUA, I
  - NOAA NPP: ATMS, CRIS
  - METEOSAT-10: SEVIRI
  - DMSP-F17: SSMIS
- New Satellite Winds:
  - Himawari-8
  - METEOSAT-7,-10: Imager WV AMVs
  - NOAA-15, 18, 19: AVHRR IR AMVs
  - METOP-A,-B: AVHRR IR AMVs
- New GPS
  - METOP-B (subtype 3)

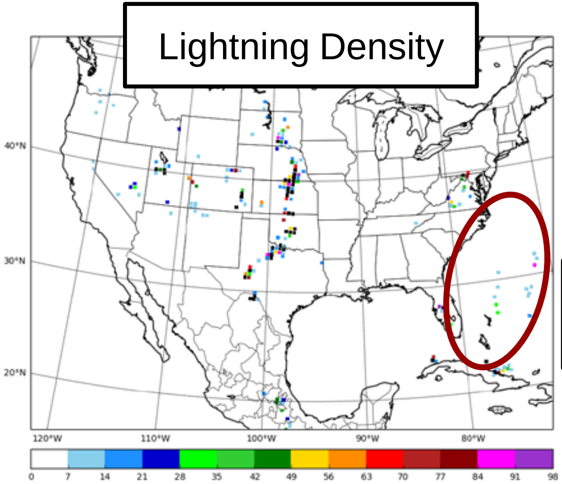


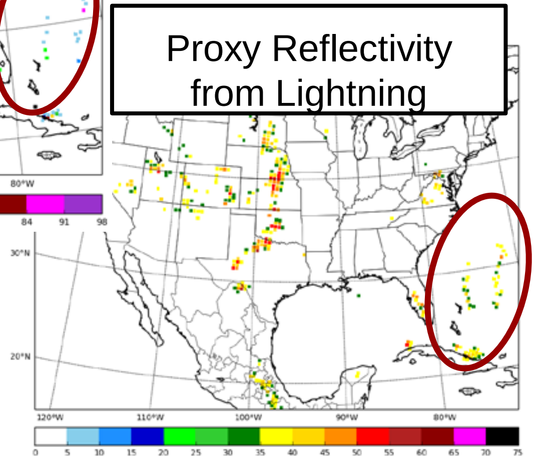
Satellite winds from JMA Himawari-8 (IR) assimilated in developmental NAMv4

New Observations in NAMv4: Lightning Data

Assimilation of Lightning Observations

- Clear indication of convective storm(s)
  - Can provide data where radar coverage is poor or non-existent
  - Current obs from NLDN and ENI networks
- Current approach: Convert lightning observations to reflectivity
  - Use reflectivity in cloud analysis
  - Discussion ongoing with colleagues for other methods
- Future: GOES-R GLM

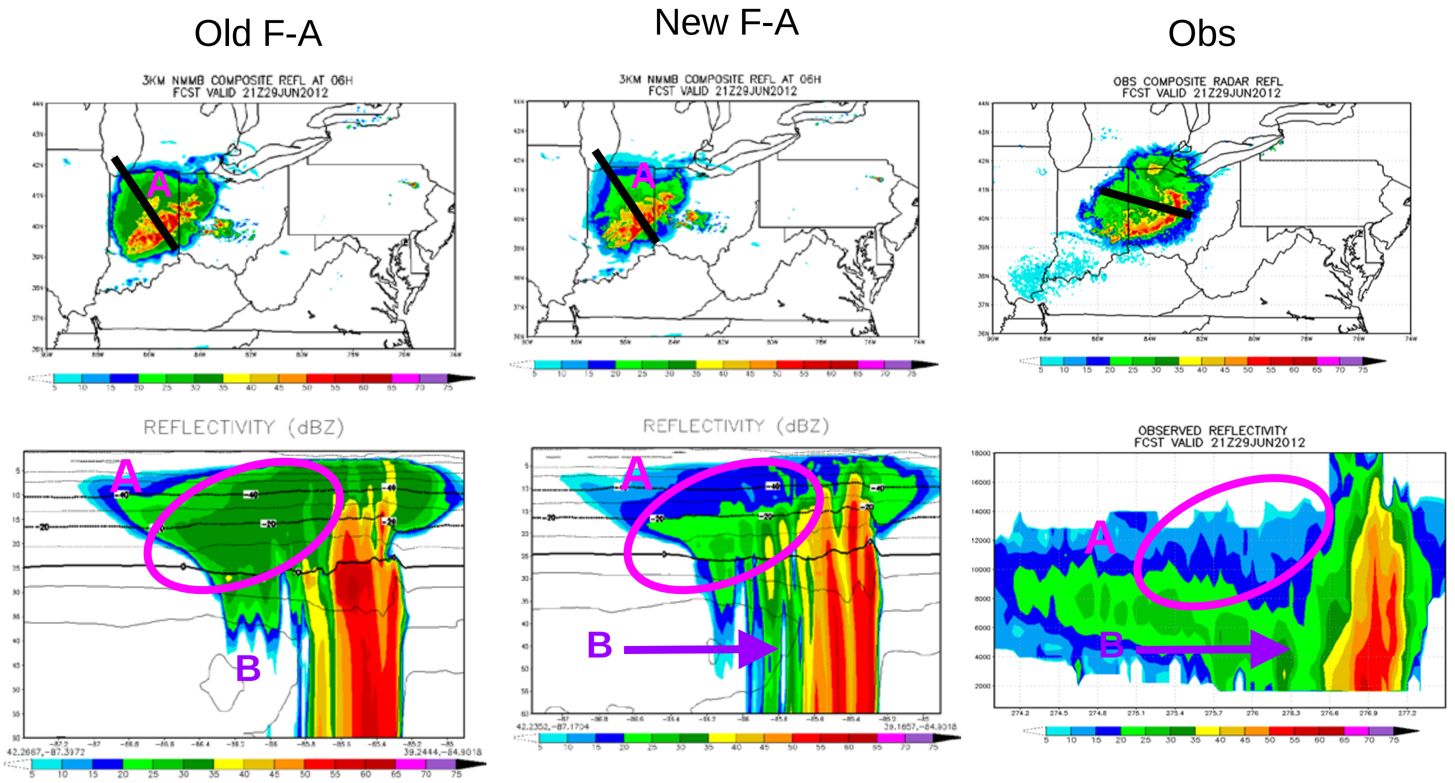




Microphysics Changes (1 of 2)

A - Reduced reflectivity in stratiform anvils

B - Increased reflectivity & rainfall below anvils

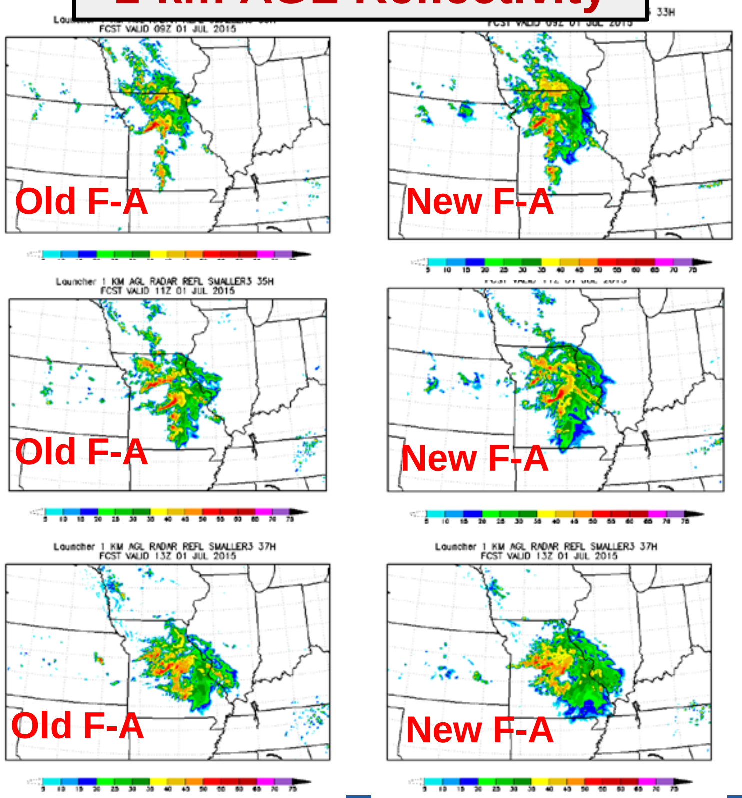


(Note different vertical coordinate)

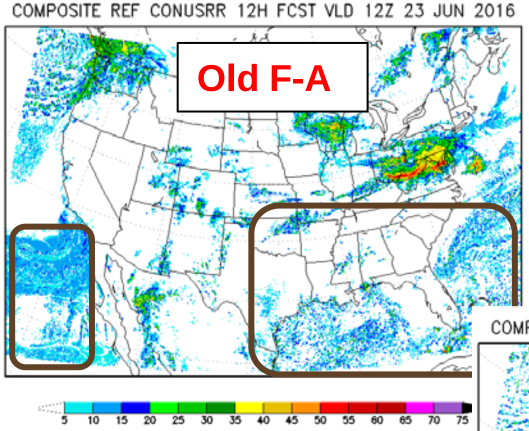
Microphysics Changes (2 of 2)

Increased rainfall below stratiform anvils

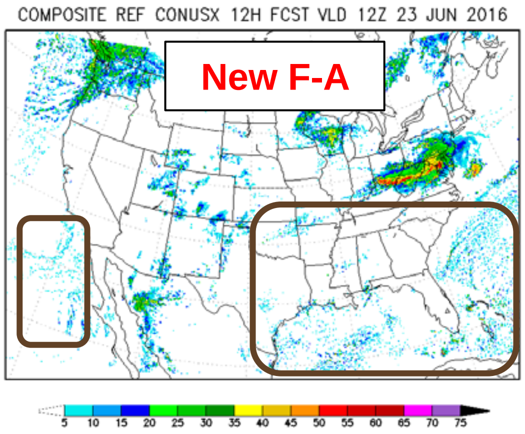
1-km AGL Reflectivity



Composite Reflectivity

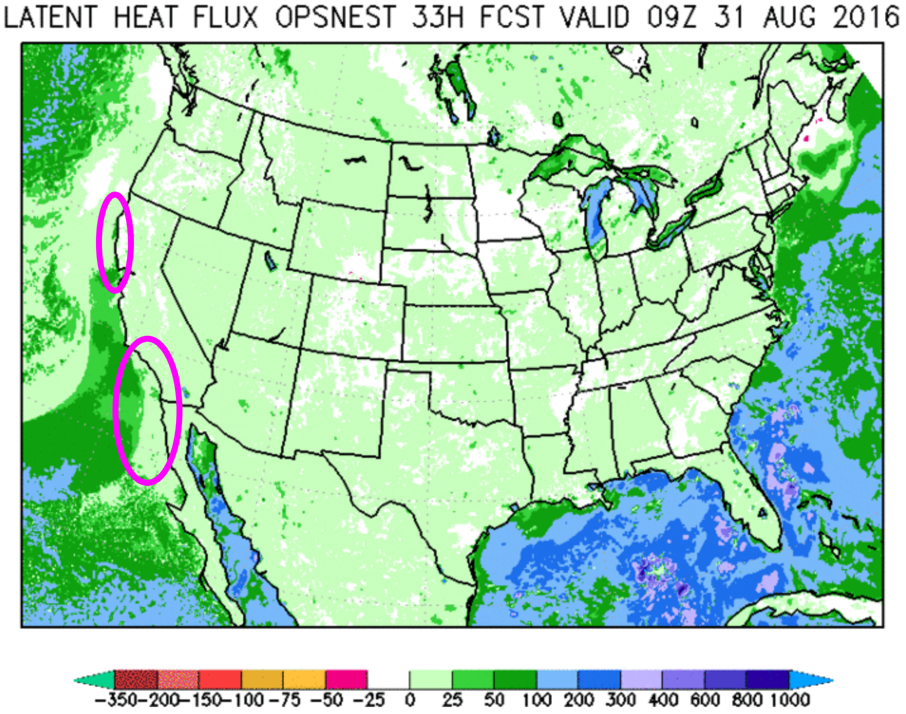


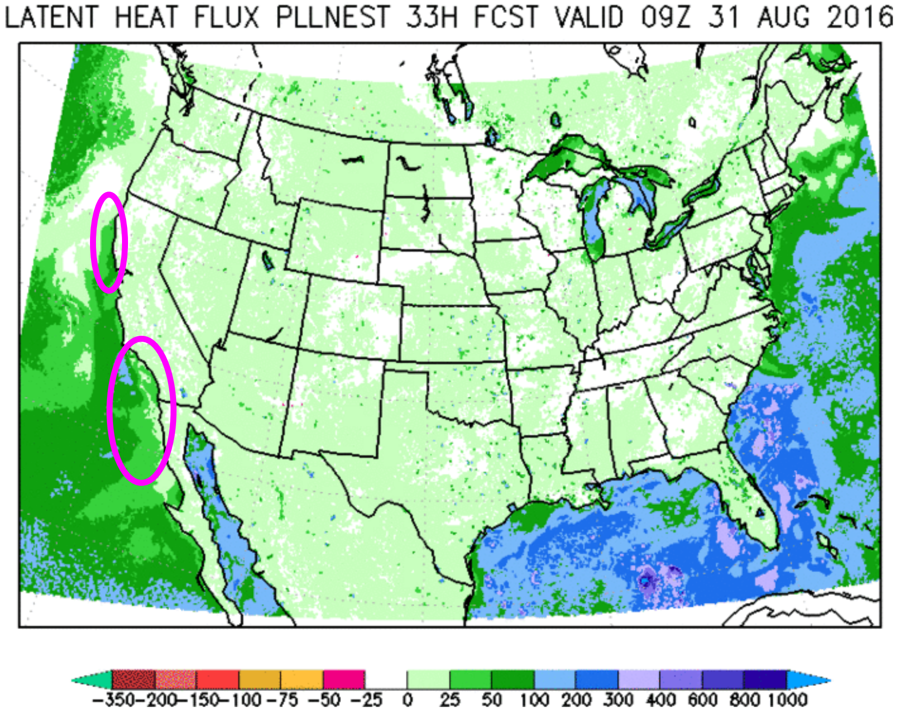
Echoes from small rain drops formed in thin PBL clouds



Reduced dBZ - rain treated as drizzle in thin PBL clouds

Surface Latent Heat (LH) Fluxes changes
(In ops: LH fluxes shut off when RH=95%; removed in pll)

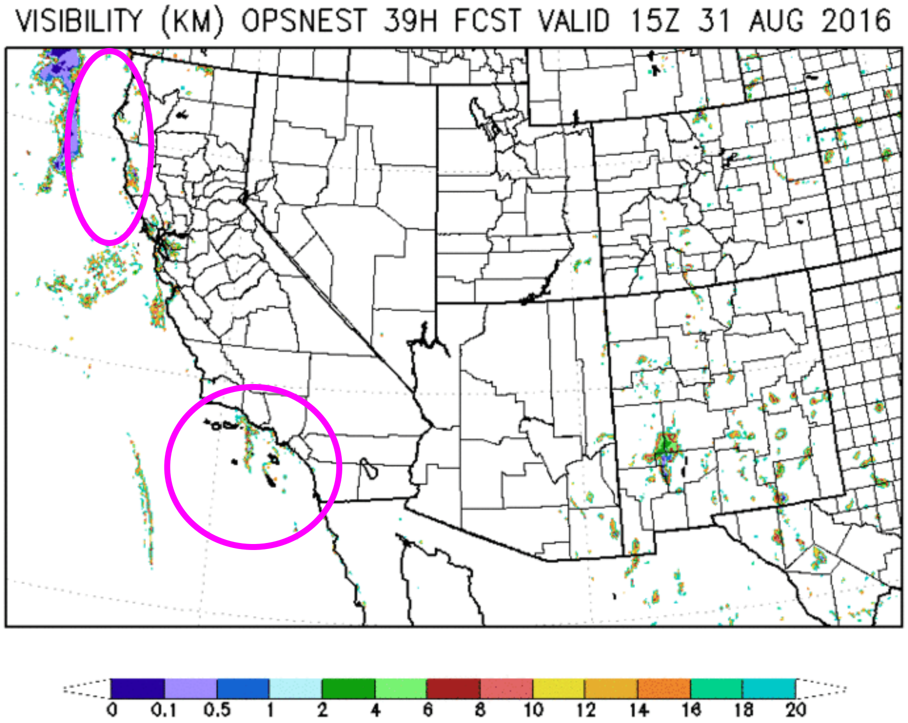


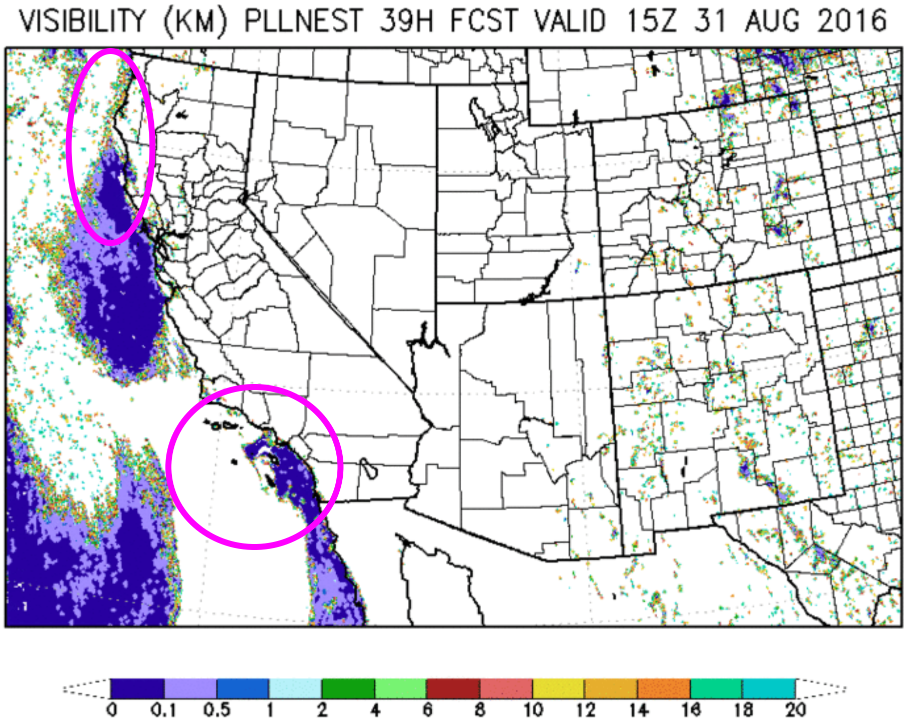


Left (OPS): Latent heat (LH) fluxes when RH>95% at lowest model level

Right (PLL): LH fluxes are not turned off.

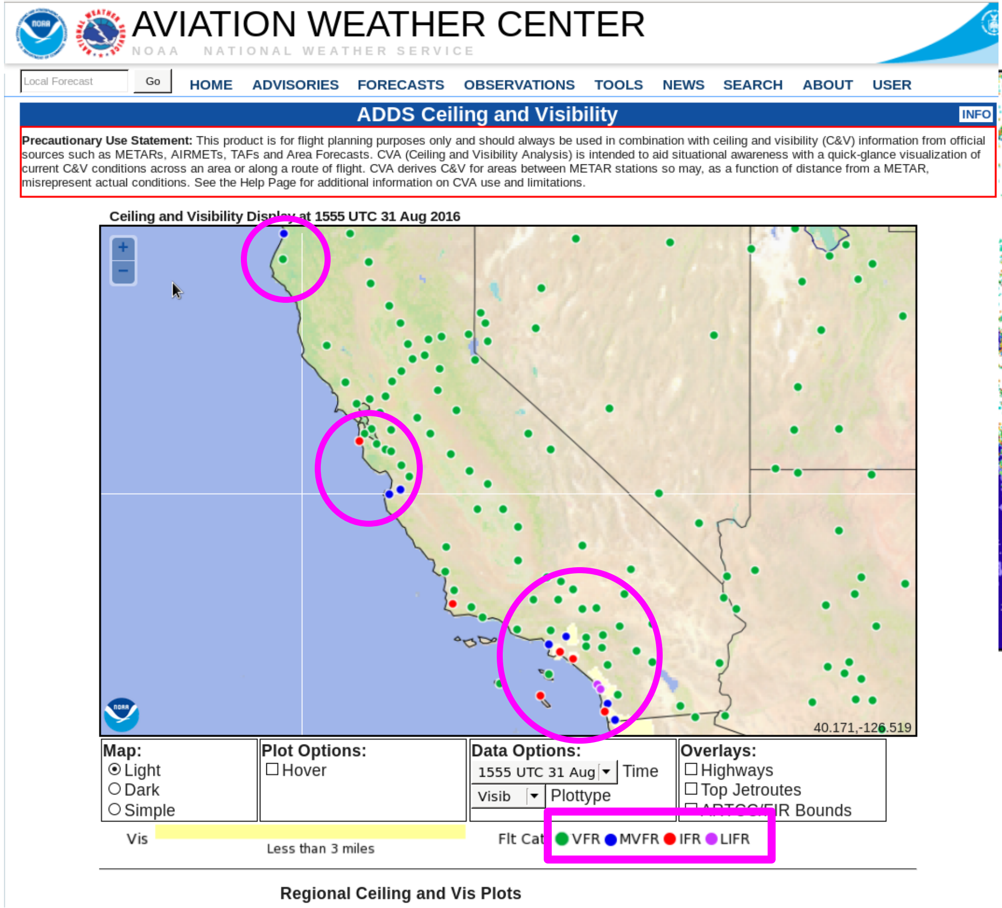
LH Fluxes Impact on Visibility (2 of 3)

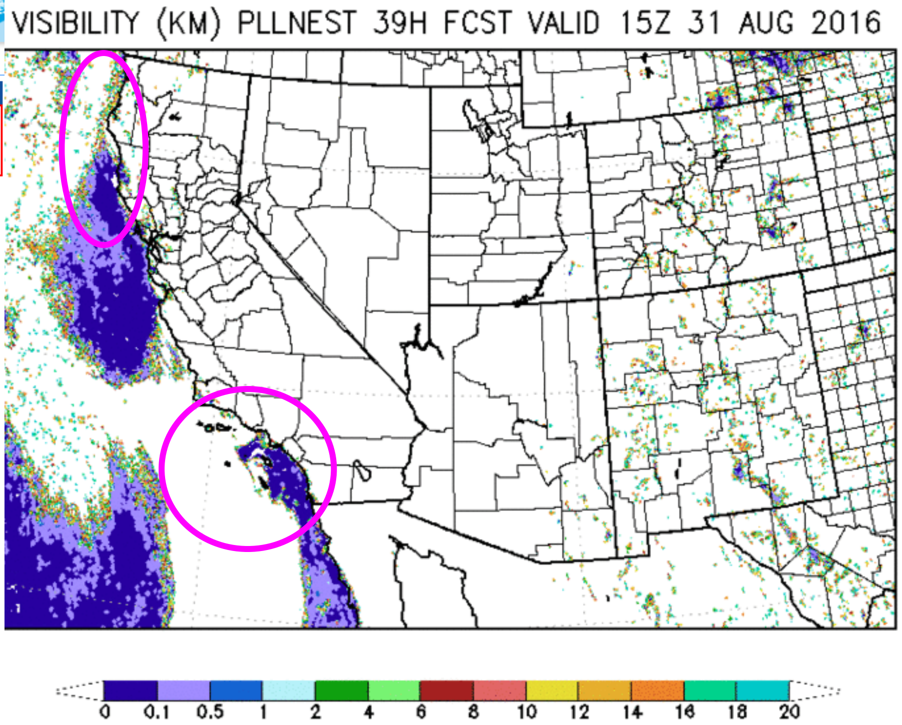




Left (OPS): Very little visibility reduction
Right (PLL): Visibilities are significantly reduced

LH Fluxes Impact on Visibility (3 of 3)





Visibility obs (55 min later) from AWC showed areas of reduced visibilities

Additional Model Changes

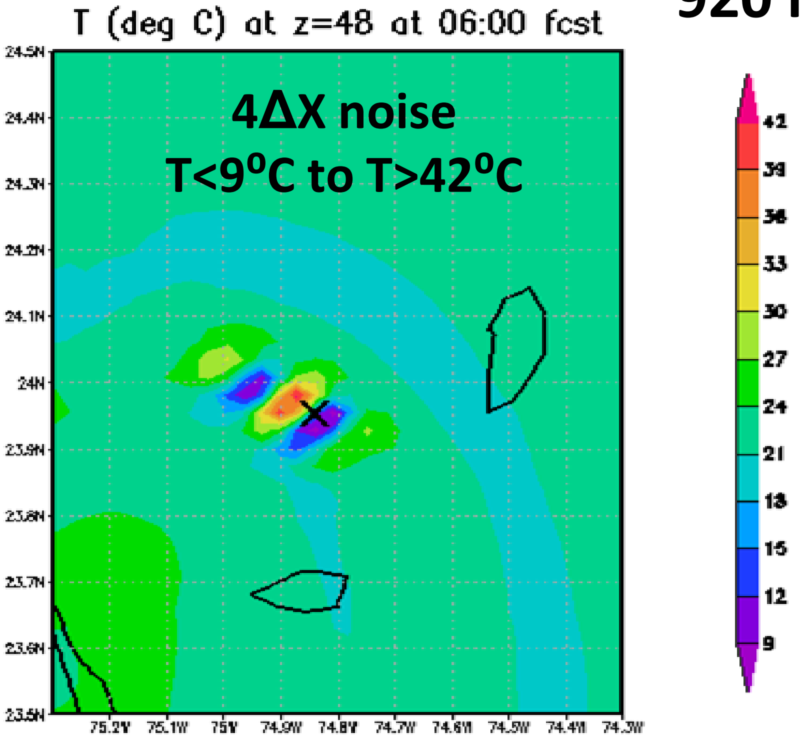
1. Update moist processes every other time step (sfc layer, land sfc, PBL, & microphysics for all domains; GWD & convection in parent only)
2. Advect specific humidity every time step (rather than every other time step)
3. Calculate cloud condensation every time step to remove supersaturations
4. Mix out superadiabatic layers that form in strong updrafts
5. These were part of the “Joaquin” changes

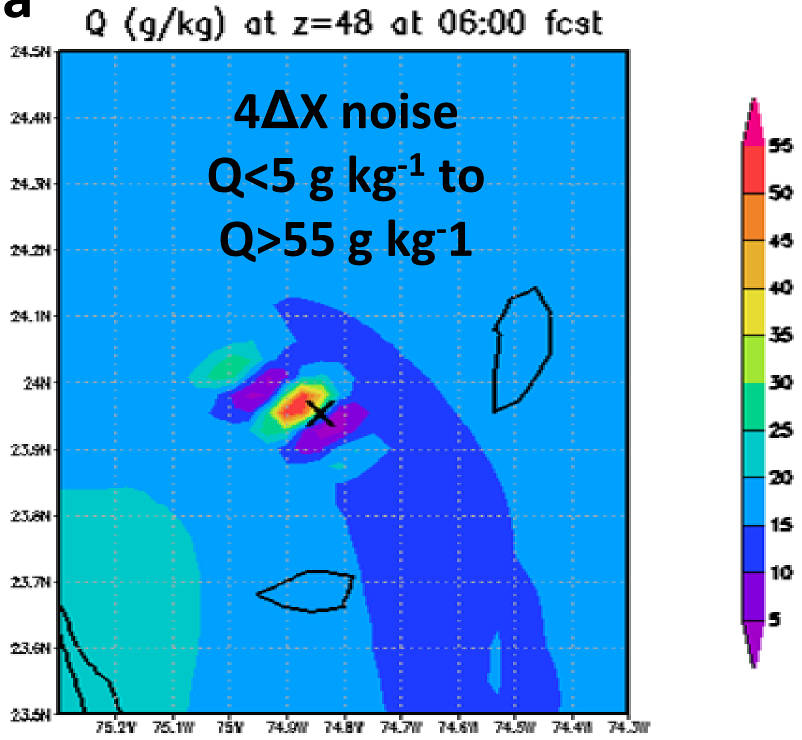
Changes to address CONUS nest failures with Joaquin

- **Production 4-km NAM CONUS nest had 3 failures associated with Hurricane Joaquin (20150929 – 20151002)**
  - **Temporary fix was to run pre-2014 nest configuration with "BMJ lite" for stability**
    (small amount
    of deep convection)
- **There was also a failure in the 3-km real-time parallel NAM nest**

Numerical Instability

~920 hPa





Large instabilities at 880 – 950 hPa

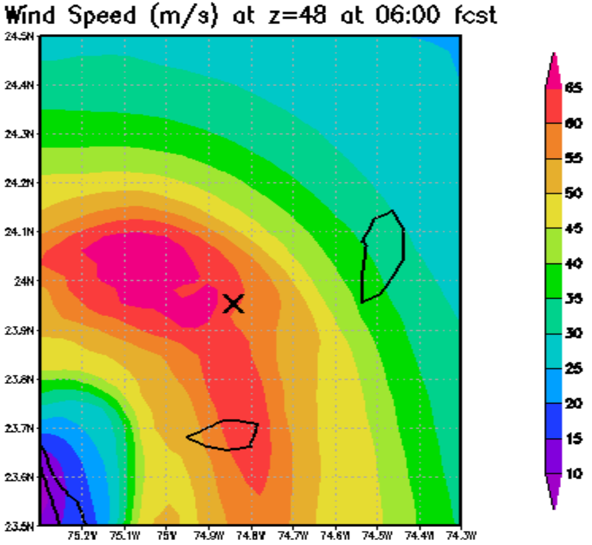
Numerical Instability

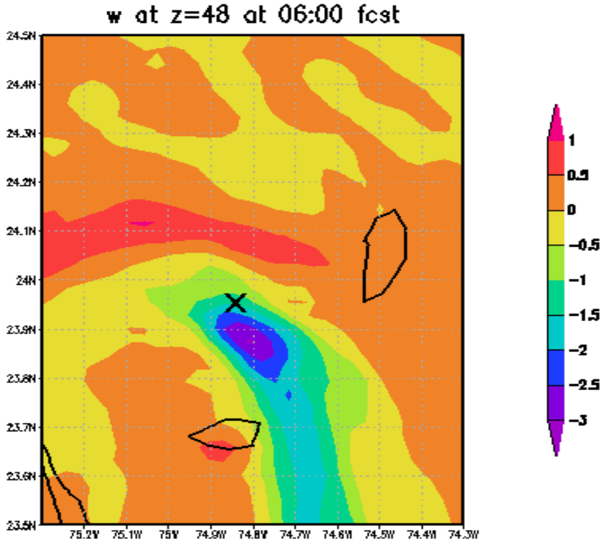
- Numerical instability was eliminated when
  - Advecting moisture fields every time step
  - Did not require updating moist physics every time step

Left: Instability appeared along the outer edge of a local wind maximum.

Right: It developed at the leading edge of modest ***descent***. Vertical motions were generally weak and well behaved.

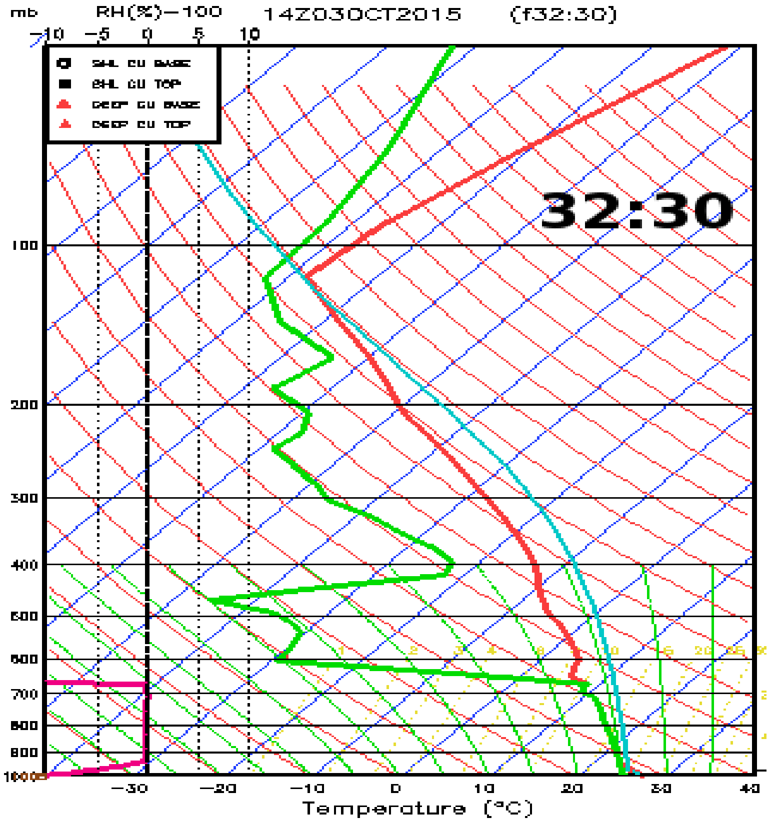
The instability led to the model failures.





Noisy Temperature Profiles

- But high-frequency oscillations (noise?) remained even in runs where all fields were advected and moist processes were updated every time step (right; 5-min skew-Ts from 32 h 30 min to 33 h 30 min).
- Also seen in other runs for different cycles with different physics options.
- Oscillations are transient.
- Many more runs were made with 5-min output to study cause(s).

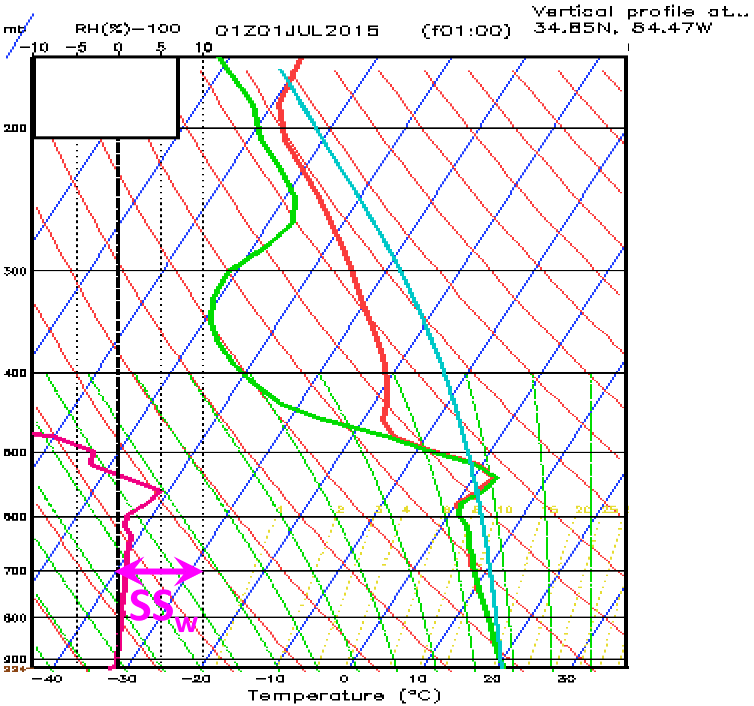


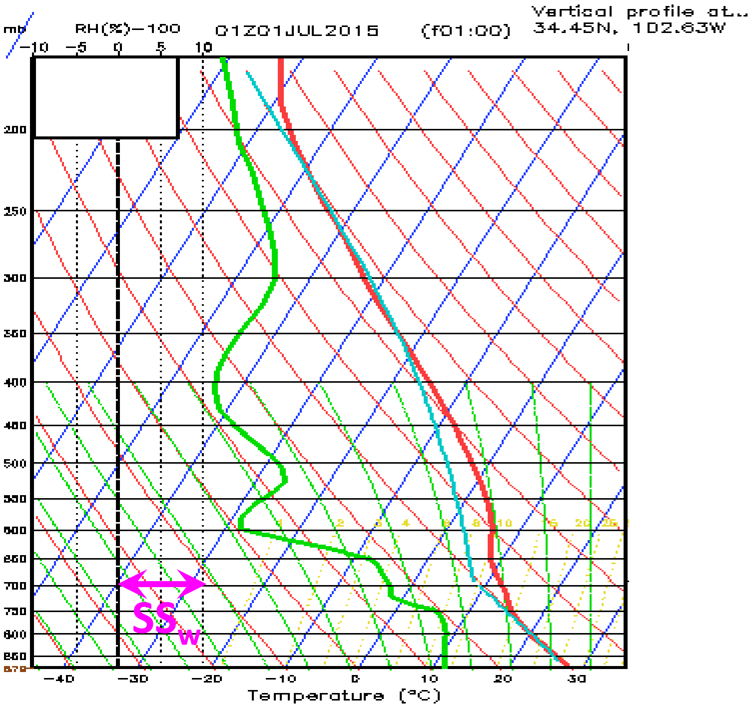
Noisy Temperature Profiles

- The following changes were tested
  - Adjustments to Crank-Nicholson vertical advection off-centering
  - Minimum TKE (function of height) increased by 10x from surface to model top
  - Run with different versions of shallow convection
  - Horizontal averaging (filtering) of vertical velocity
  - T, Q adjustments(only this was successful)
    - T adjust: mix out all superadiabatic layers ($\Gamma > \Gamma_d$)
    - Q adjust: remove supersaturations w/r/t water by cloud condensation every other time step when moist physics are not called
- Tens of thousands of profiles were analyzed from 5-min forecast output at locations where domain-maximum values occurred in updraft velocities, surface rainfall rates, lapse rates, and supersaturations

Most Extreme Examples (2016070100 – WPC Case)

Without (left) and with (right) Joaquin changes





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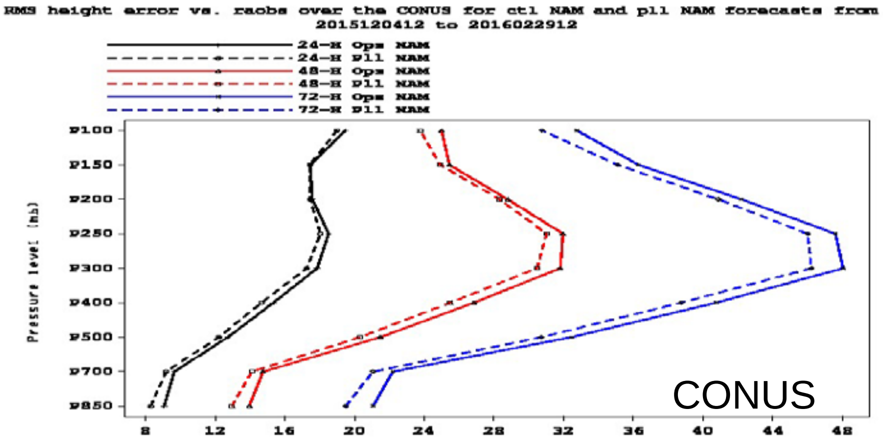
Case Studies and Verification

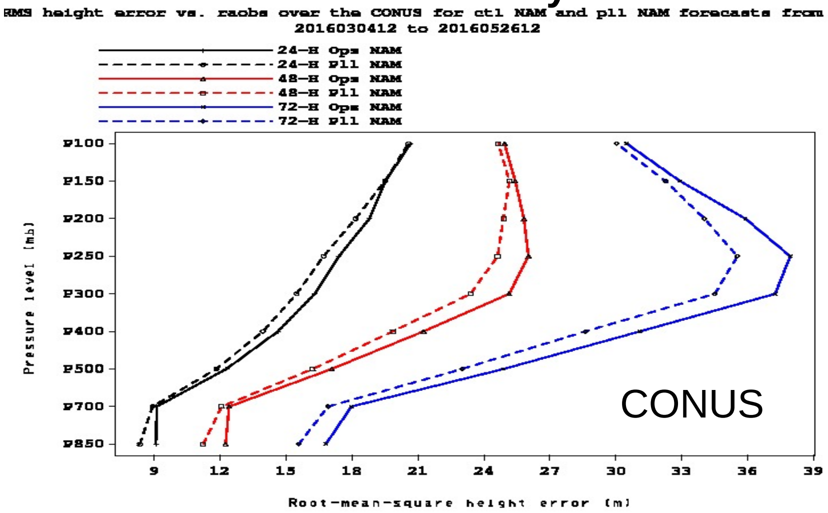
Note : Until 5/26, “NAMX” was test of all model/anl changes except for hourly data assimilation; “NAMRR’ was NAMX + hourly assimilation

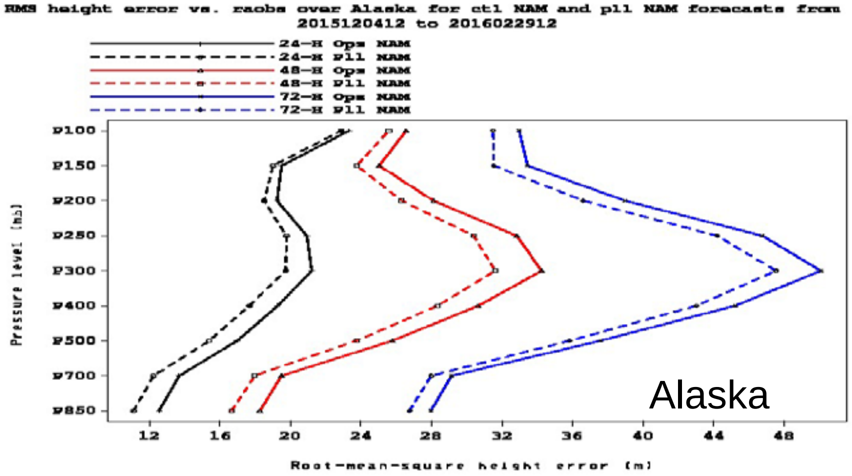
12 km parent Day 1,2,3 Height RMS errors : NAM=solid, NAMX=dashed

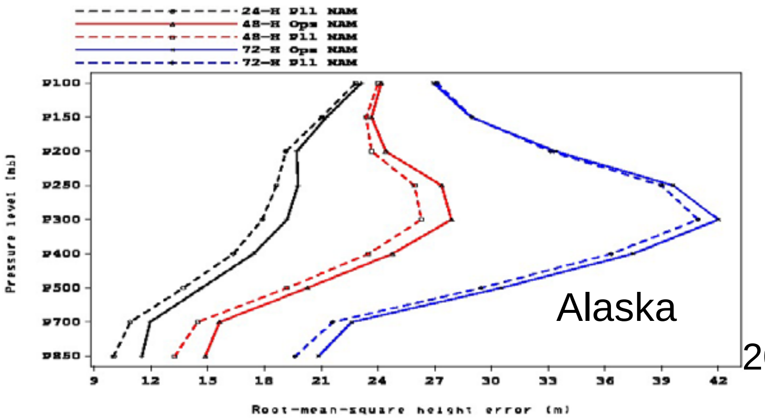
Dec 2015 – Feb 2016

1 March – 26 May 2016



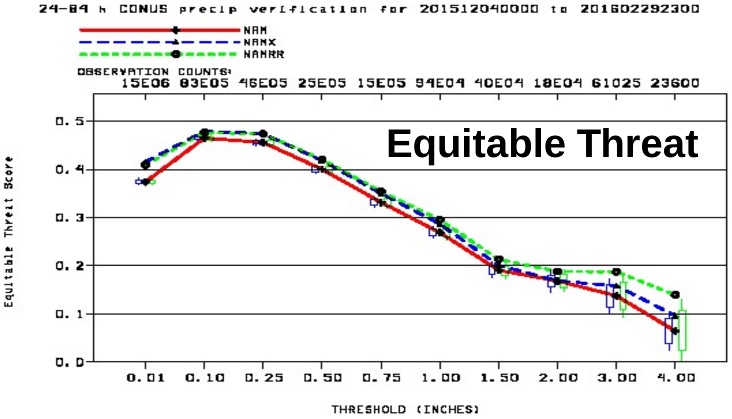


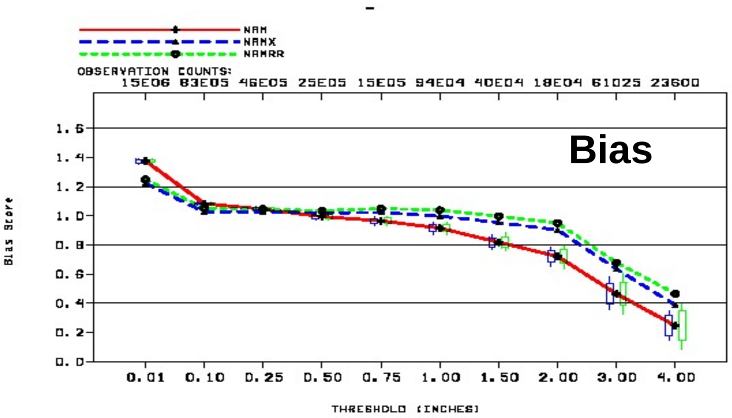




12 km parent 24-h QPF scores for all fcsts : NAM=Red; NAMX (model+anl changes) =Blue, NAMRR (NAMX+DA changes)

December 2015 - February 2016

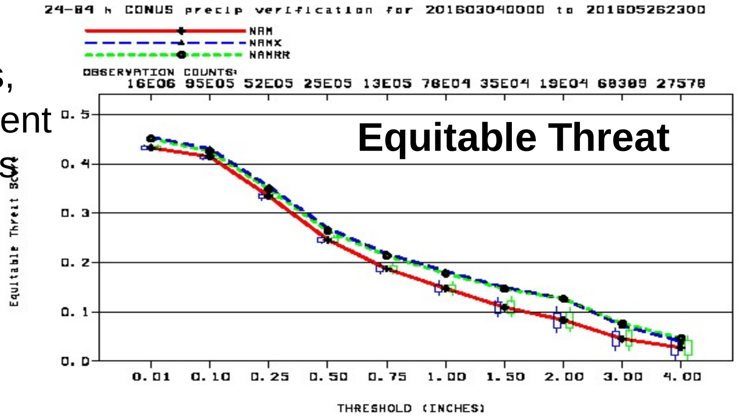


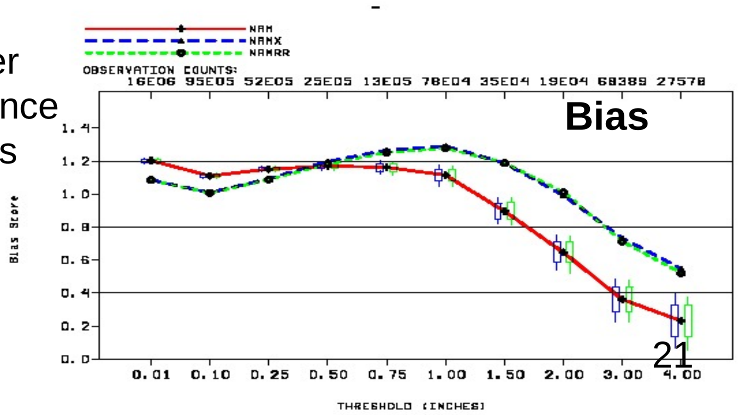


Winter : higher ETS; higher bias, Some improvement from DA changes

Spring : higher ETS; much better bias, little difference With DA changes

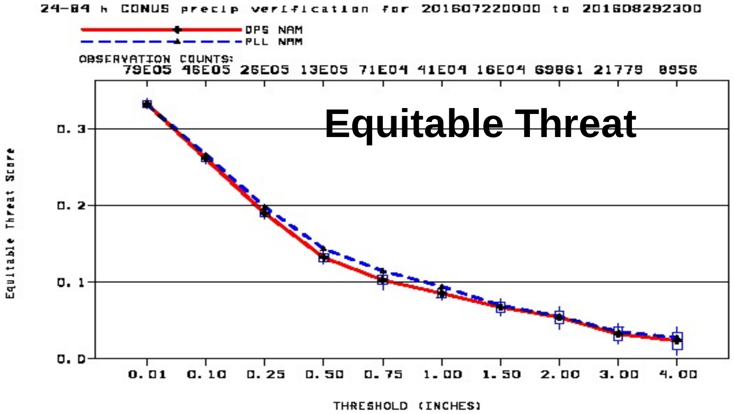
March – May 2016

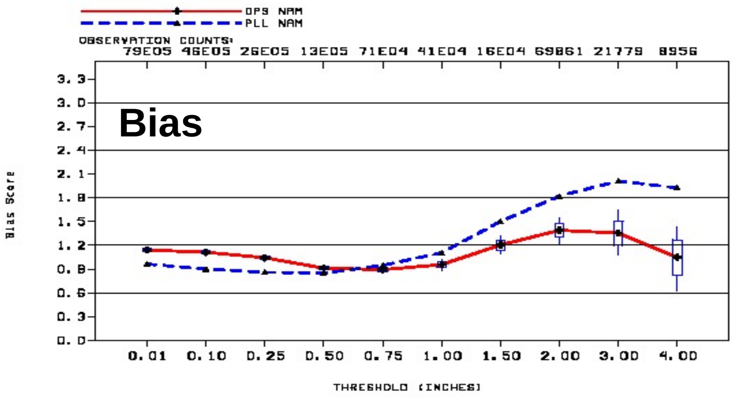




12 km parent 24-h QPF scores for all fcsts : NAM=Red; NAMX (final version with all changes) = Blue

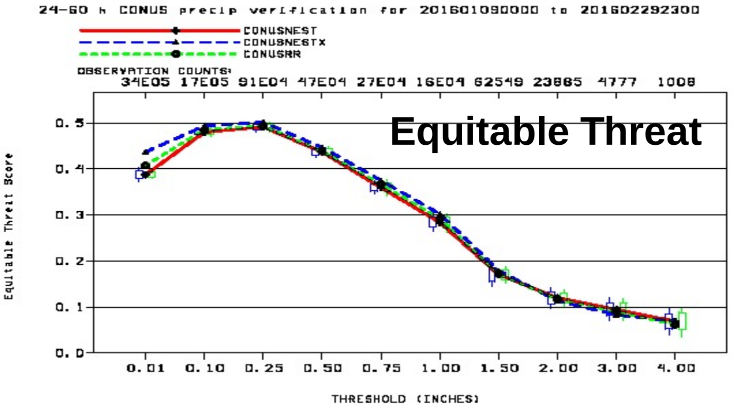
19 July – 29 August 2016

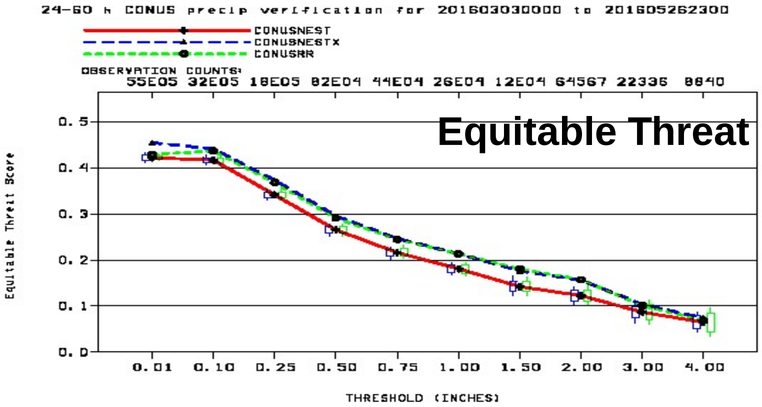


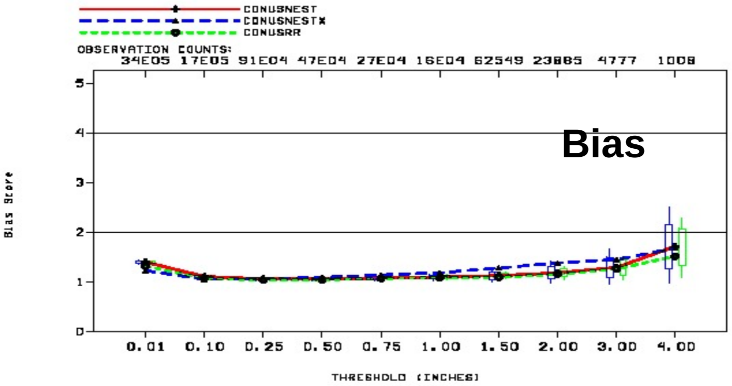


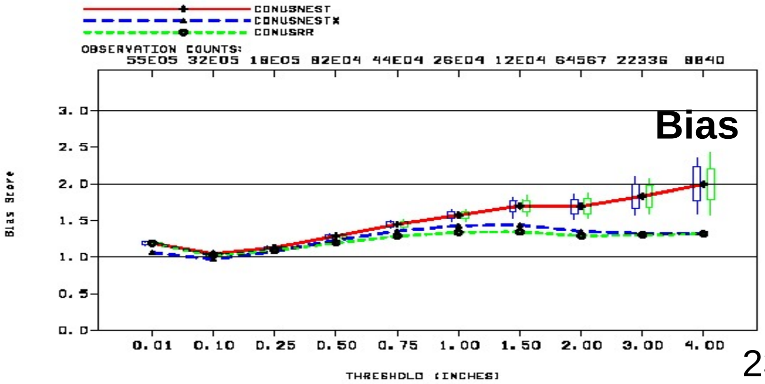
CONUS nest 24-h QPF scores for all fcsts : Red = Ops ; Blue = NESTX ; Green = NESTRR

Jan –Feb 2016 | **1 March – 26 May 2016**



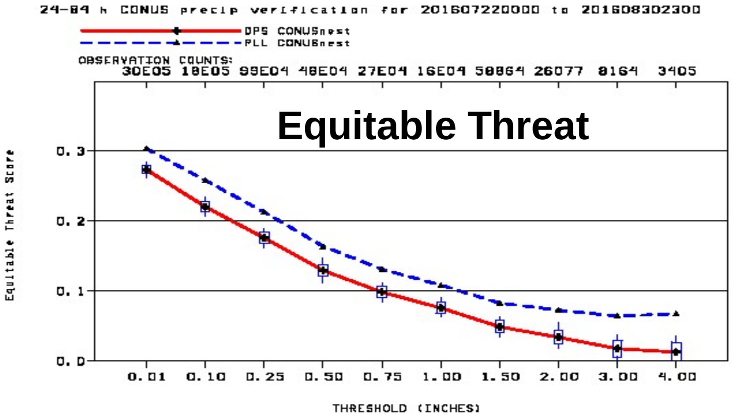


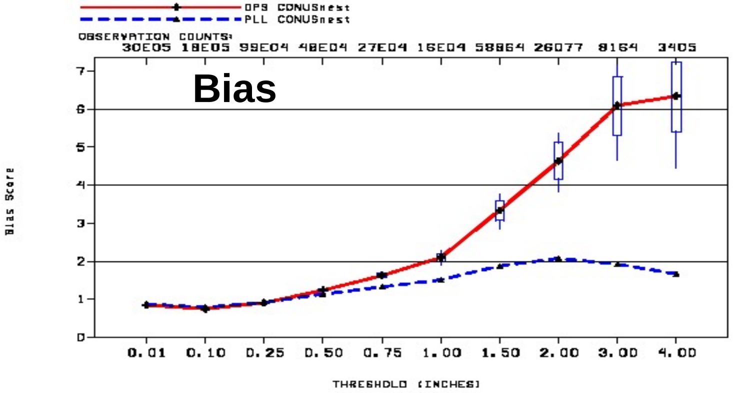




CONUS nest 24-h QPF scores for all fcsts : Ops 4 km=Red; Parallel 3 km (final version with all changes) = Blue

19 July – 29 August 2016



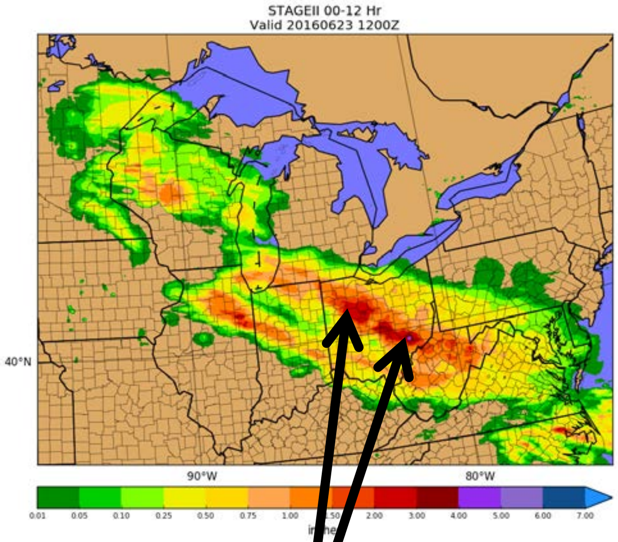


Warm Season High Bias in Heavy Rainfall in CONUS Nest

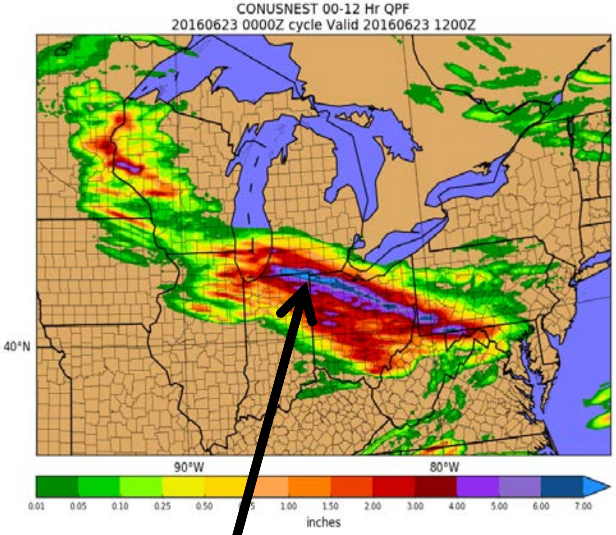
- Pointed out by WPC and those in the field.
- Seasonal, with largest biases in the summer.
- Much improved heavy rain bias in the 3-km parallel NAM nest over the 4-km operational nest:
  - Improved data assimilation.
  - Calling physics more frequently.
  - Advecting specific humidity every dynamics time step.
  - Removal of supersaturated and superadiabatic layers.
  - Removed vertical advection filter.
  - Microphysics modifications

June 23 2016 OH Heavy Rain Event:
0-12h Accumulation

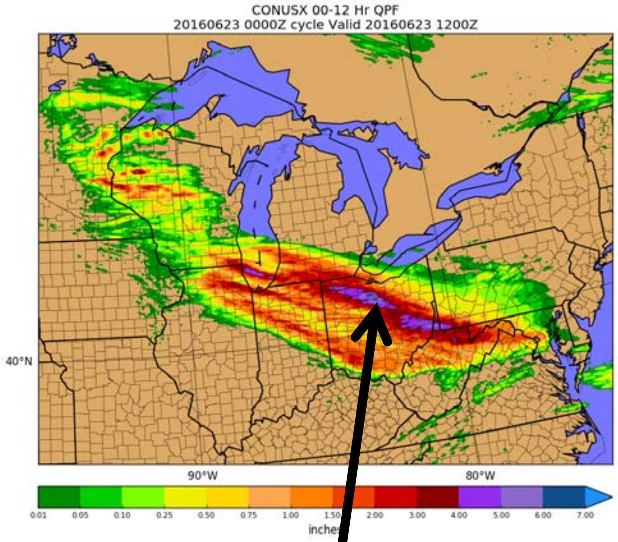
Observations



4-km Ops Nest



3-km Parallel Nest



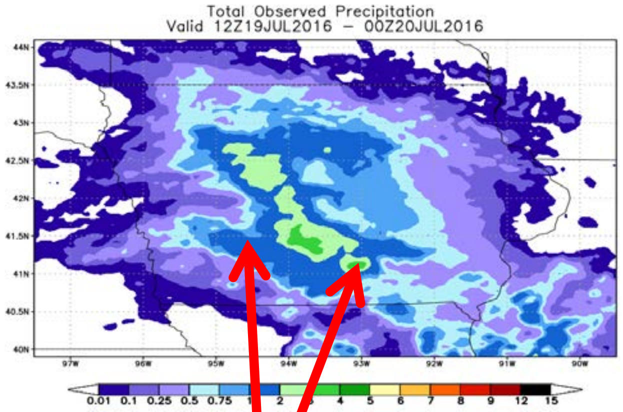
Up to 4 inches

≥7 inches

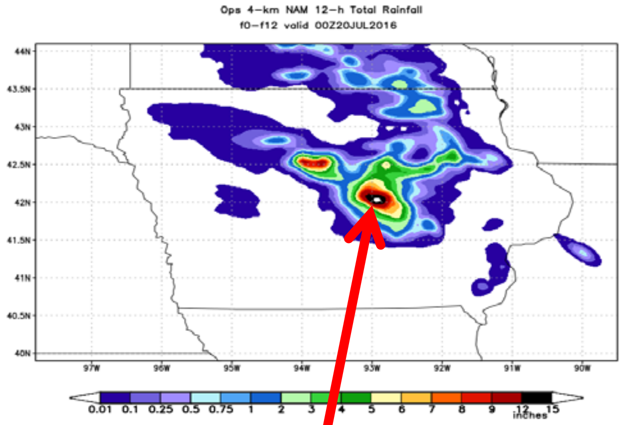
4 - 6 inches

July 19 2016 IA Rain Event: 0-12h Rain Accumulation

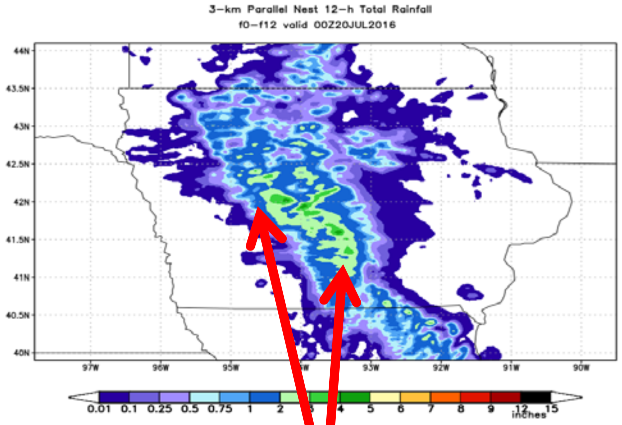
Observations



4-km Ops Nest



3-km Parallel Nest



1 - 3 inches

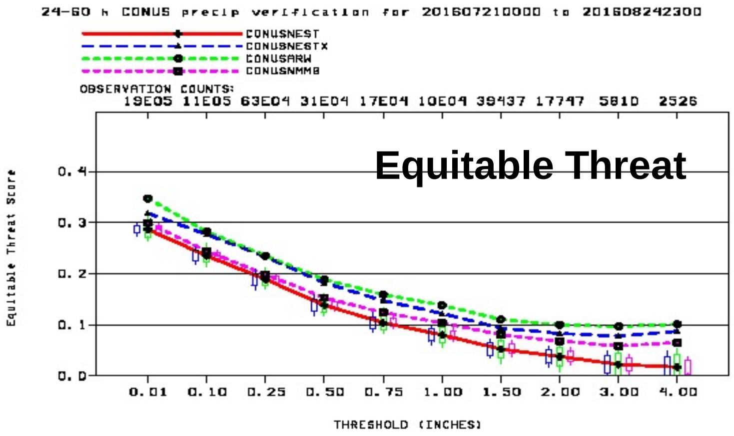
15 inches

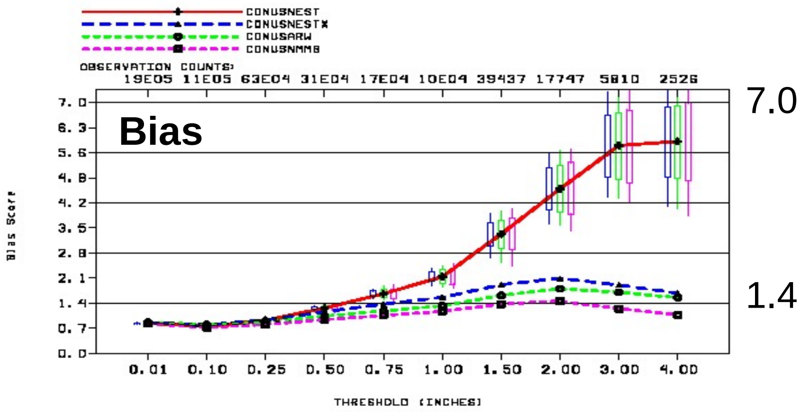
1 – 4 inches

Nest QPF scores for July-August 2016 vs HiresW ARW/NMMB

Ops 4 km Nest = Red
Pll 3 km Nest = Blue
Ops 3 km Hiresw ARW = Green
Ops 3 km Hiresw NMMB = Magenta

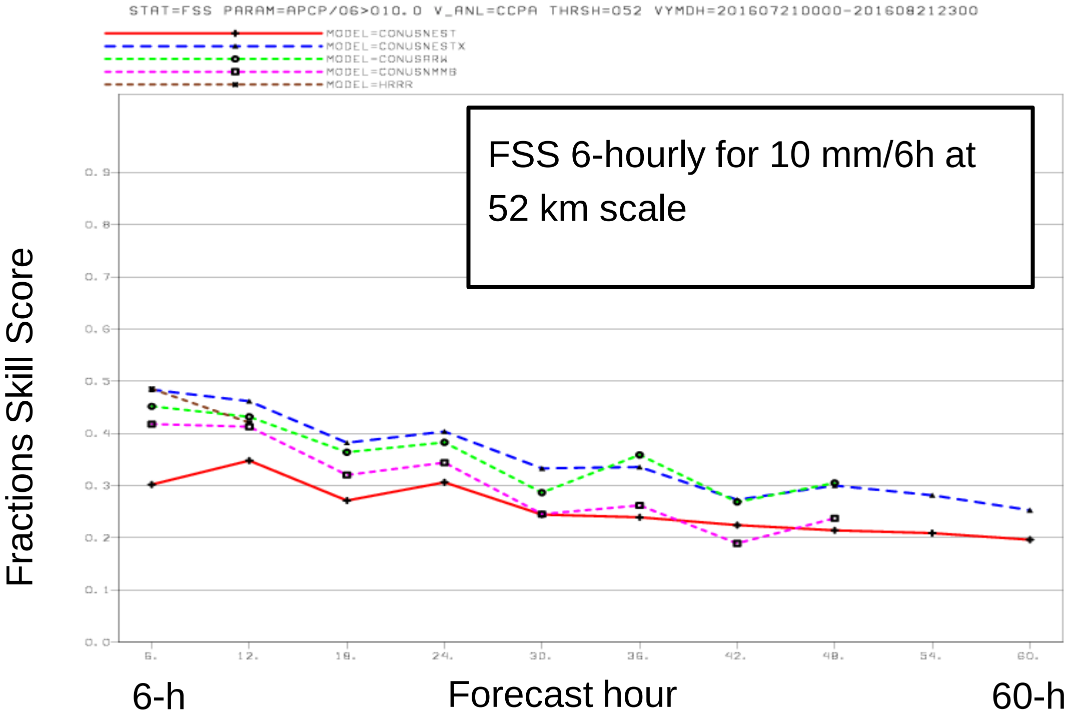
Note significant improvement
In NAM Nest QPF Bias

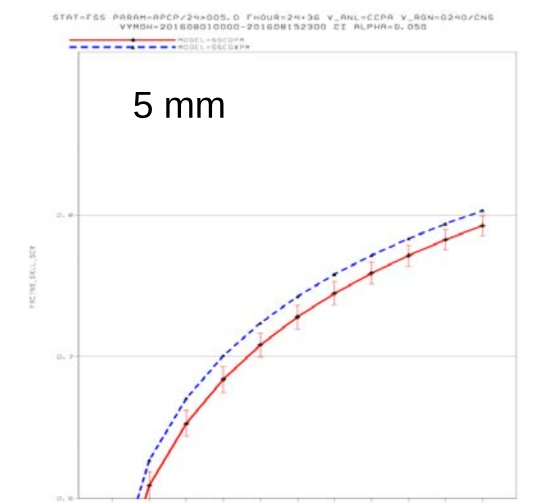


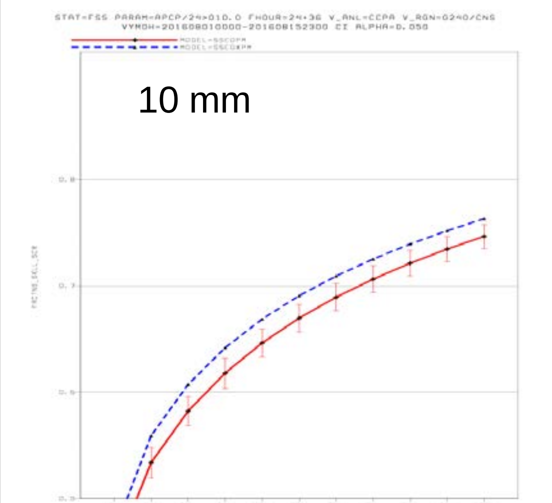


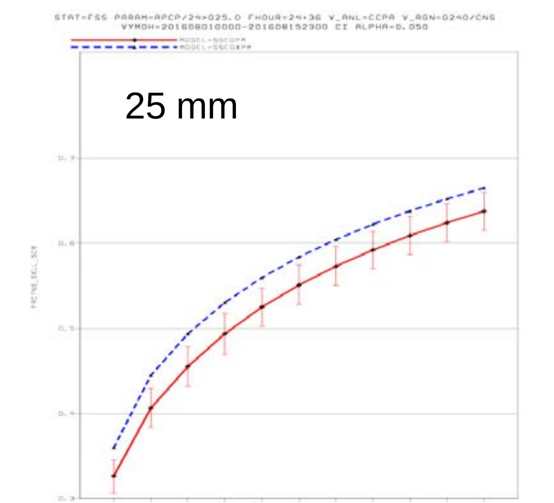
Precip Verif : July 21 – August 21 2016

4 km Ops NAM Parent
3 km Ops CONUS ARW HiResw
3 km Parallel NAM CONUS nest
3 km Ops CONUS NMMB Hiresw
3 km Ops HRRR



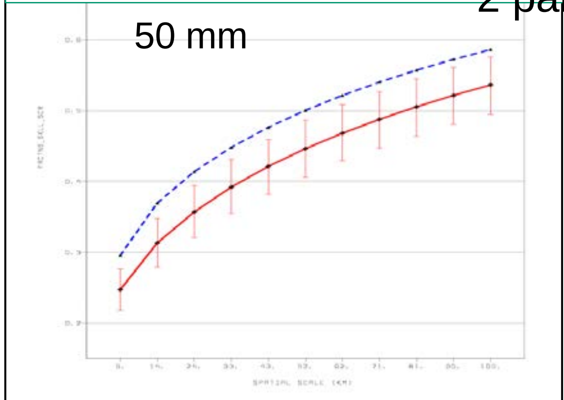


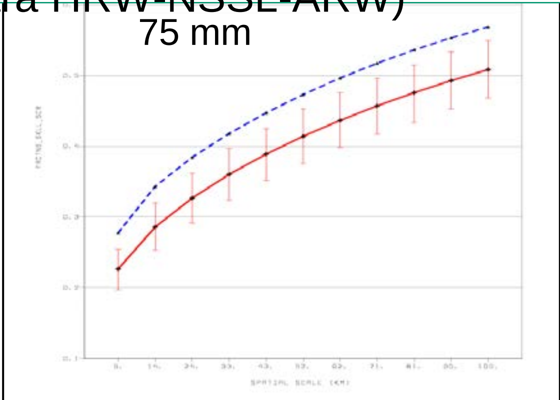


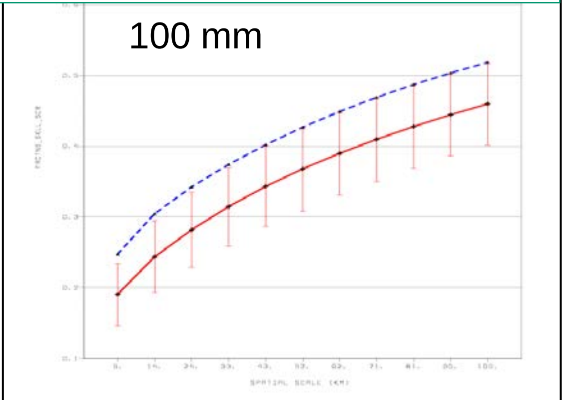


HREF SSEO (1 *ops* NAM nest, 2 HRW-ARW, 2 HRW-NMMB, 2 para HRW-NSSL-ARW)

HREF SSEOX (1 *para* NAM nest, 2 HRW-ARW, 2 HRW-NMMB, 2 para HRW-NSSL-ARW)







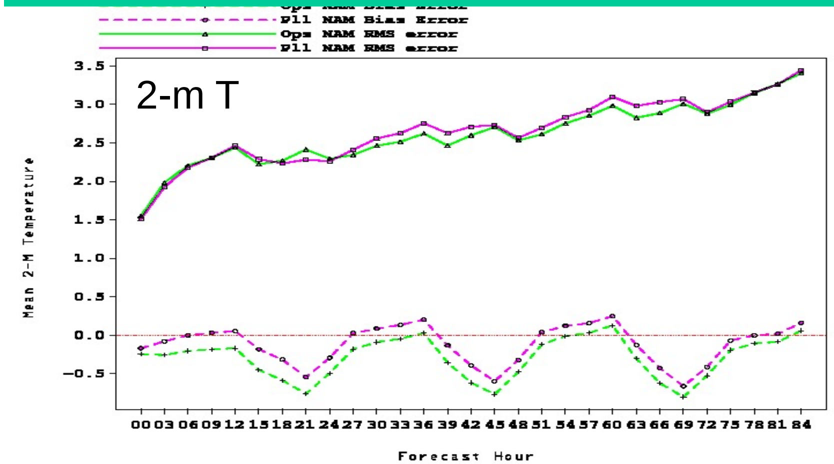
Changes affecting near-sfc fields

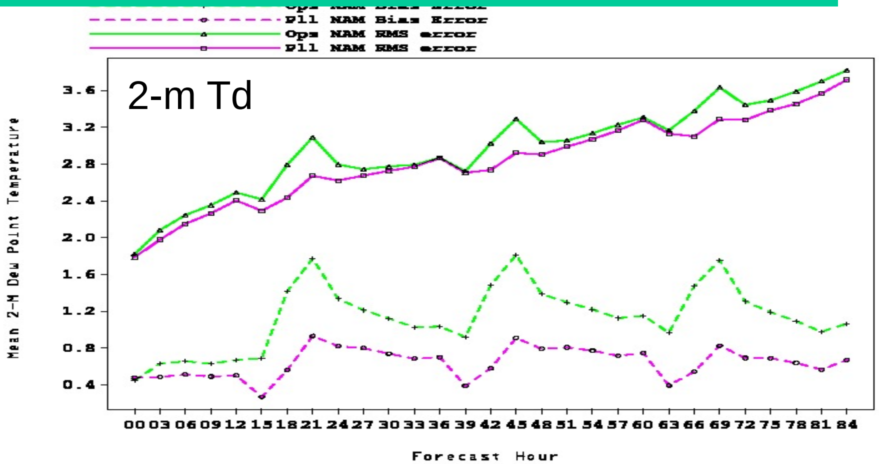
- **Threshold snow depth (water equivalent in meters) that implies 100% snow coverage is increased by 4x**

- **Consider effects of frozen soil on plant transpiration and canopy conductance (reduce direct evaporation from the soil → ice not available to plants for evaporation). Leads to improved latent heat calculation from frozen soil.**

- **Targeted to reduce cool/moist bias during cool season**

Dec 2015- Feb 2016 2-m T/Td Diurnal RMS (solid)/Bias (dashed); NAM=green, NAMX=magenta

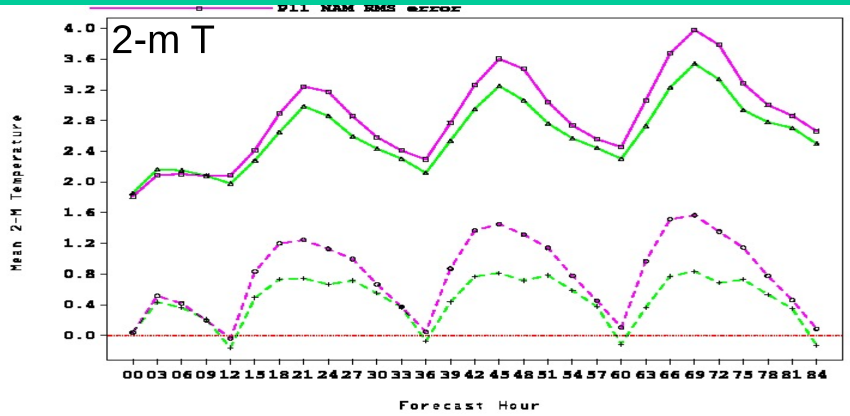




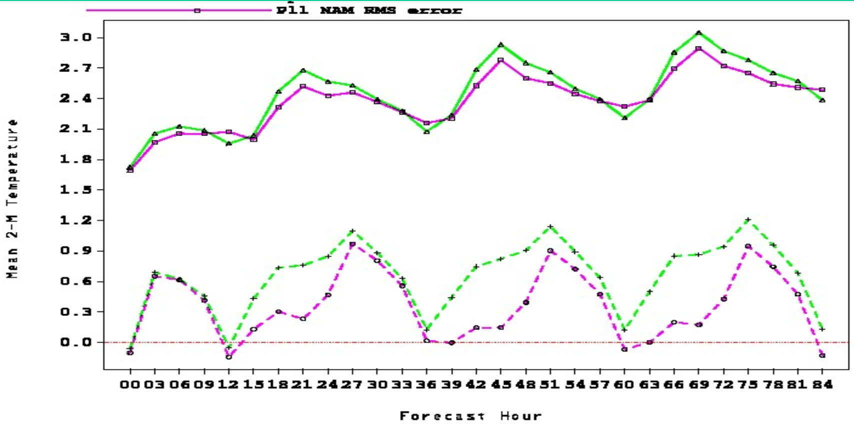
Changes affecting near-sfc fields

- **Radiation / microphysics change :**
  - **Cloud droplet effective radius no longer forced to be between 10-15 microns, can be as low as 5 microns**
  - **Set cloud droplet number concentration in radiation to be the same as the F-A microphysics (200 cm^{-3})**
  - **Will reduce incoming sfc shortwave flux → reduce warm season 2-m T warm bias**

Before change : June 2015 2-m T Diurnal RMS (solid) / Bias (dashed); NAM=green, NAMX=magenta

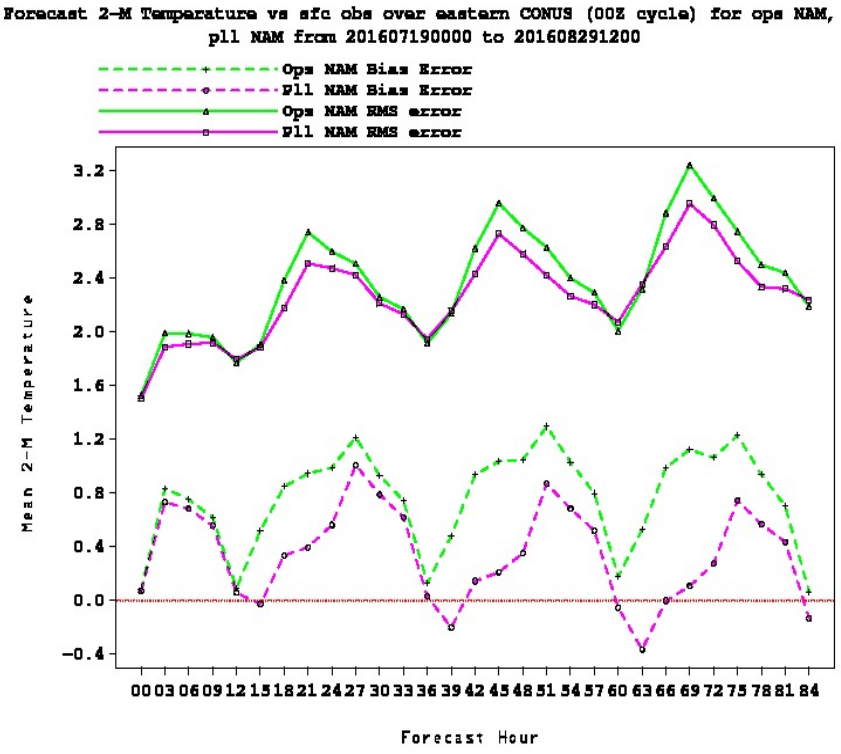


After change: July 2015 2-m T Diurnal RMS (solid) / Bias (dashed); NAM=green, NAMX=magenta



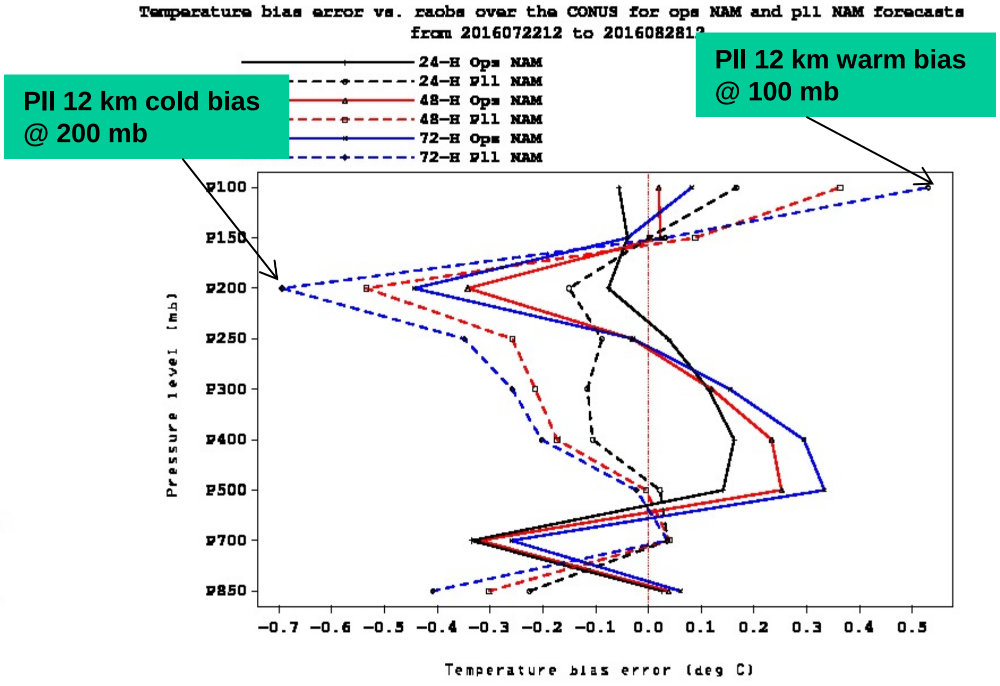
Changes affecting near-sfc fields

- Improvement in 2-m T still seen this summer..



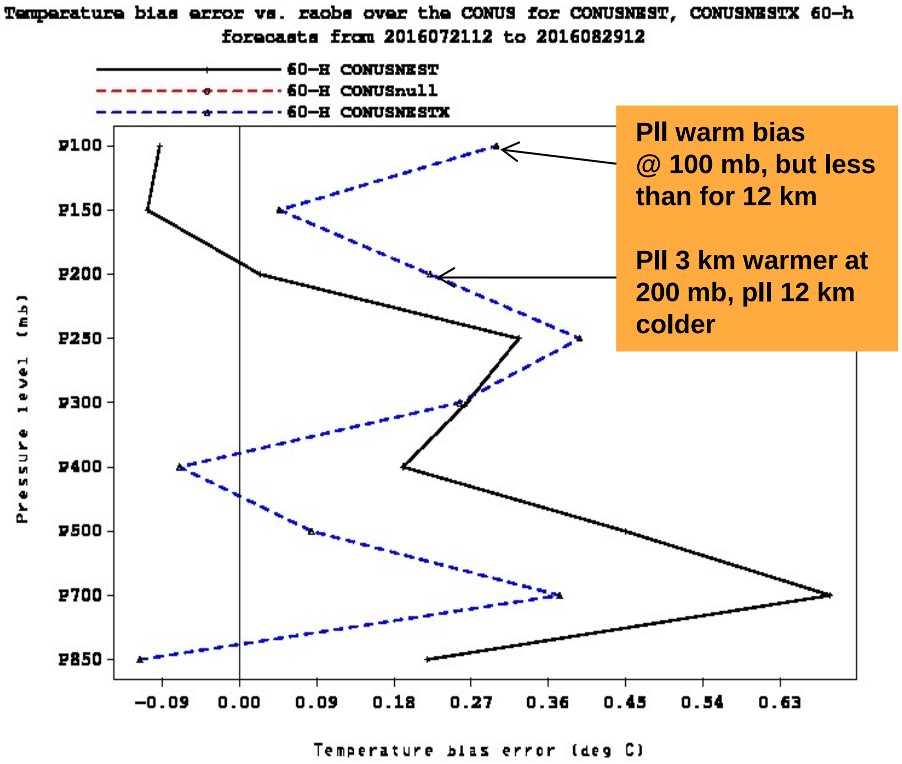
19 July – 29 August 2016 2-m T Diurnal RMS (solid) / Bias (dashed); NAM=green, NAMX=magenta

- But this plus convection changes to improve QPF → upper tropospheric T-biases in parallel (was also present last summer)



Day 1 (black),2 (red), 3 (blue) CONUS T bias; NAM=solid, NAMX=dashed

3 km NAMv4 CONUS nest: Temp bias



Shown : 60-h tropospheric T bias from 19 July – 15 August 2016

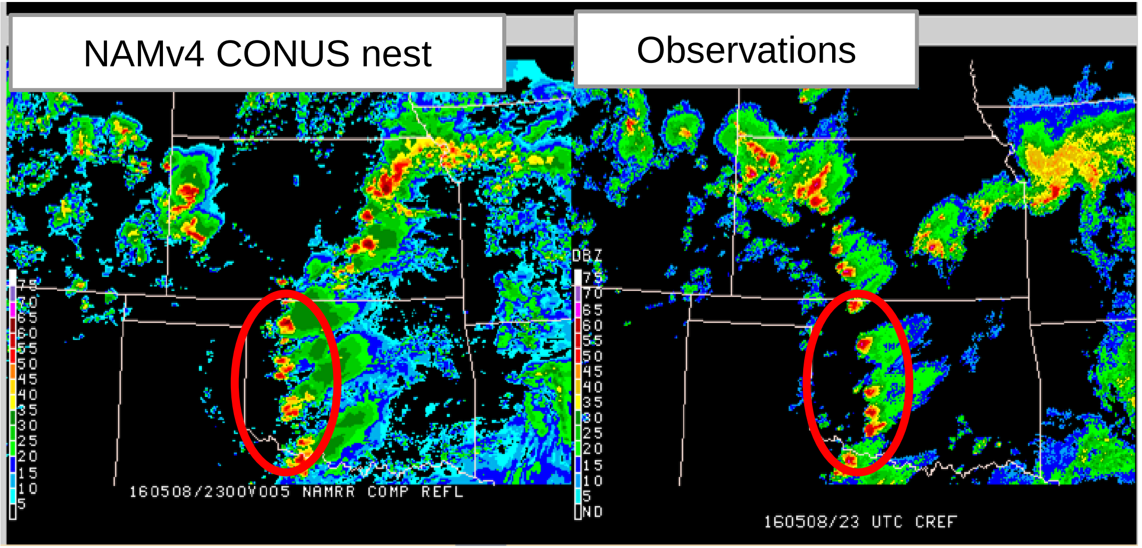
Black = Ops 4 km CONUS nest
Blue = Pll 3 km CONUS nest

Lesser warm bias @ 100 mb in pll nest
Slight warm bias @ 200 mb in pll nest

Conclusion : convection changes driving most of the 100 mb/200 mb temperature biases in 12 km parent (“robbing Peter to play Paul”)

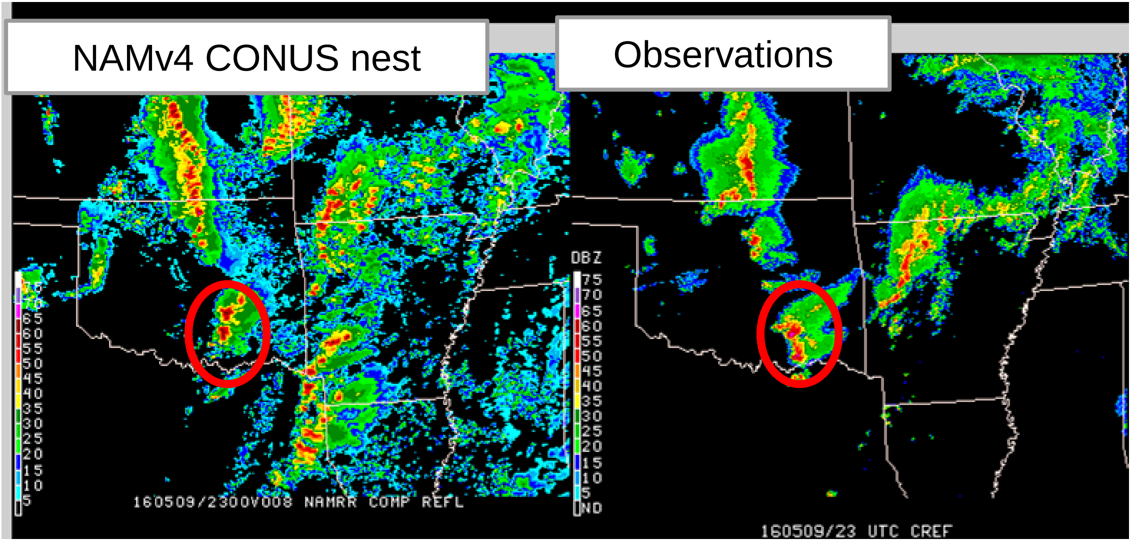
HWT Case Study 1: May 8th, 2016

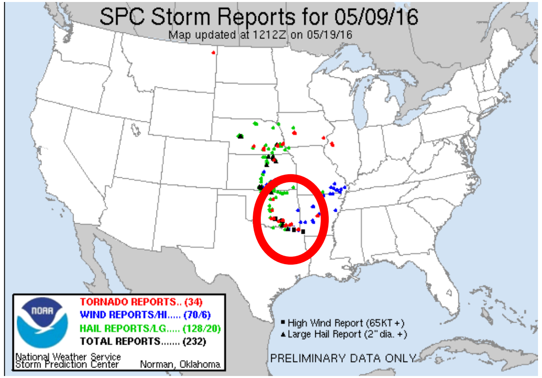
- 18Z Cycle
- 5 hour forecast
- NAMv4 3 km CONUS nest



HWT Case Study 2: May 9th, 2016

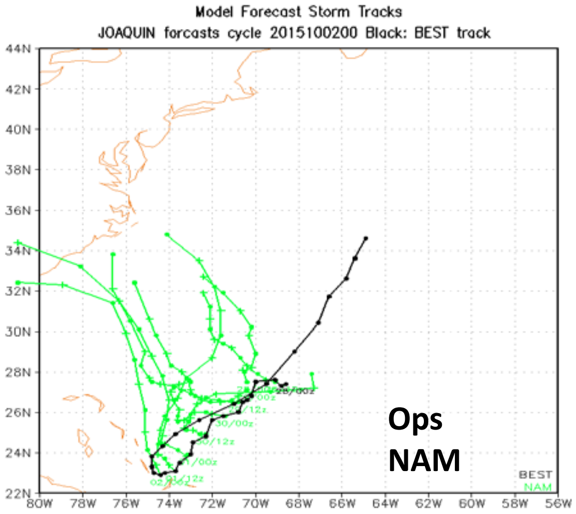
- 15Z Cycle
- 8 hour forecast
- NAMv4 3 km CONUS nest
- Strongly tornadic supercell well forecast by 3 km NAMv4 CONUS nest

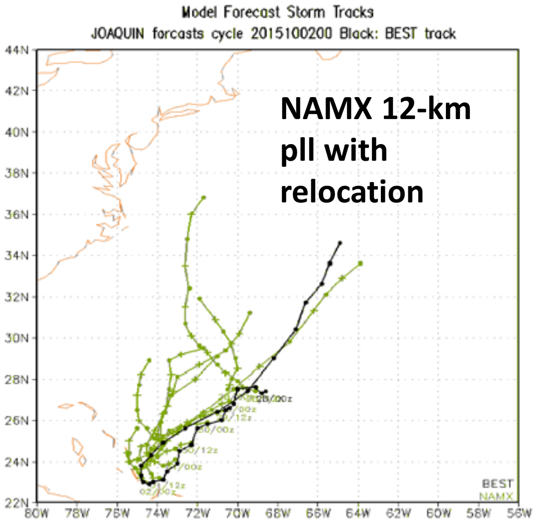


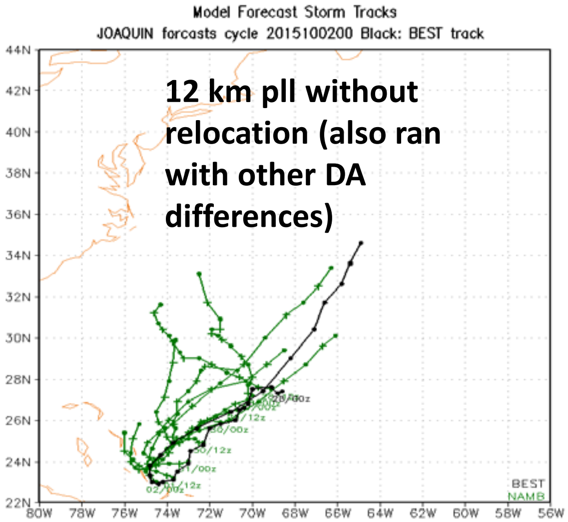


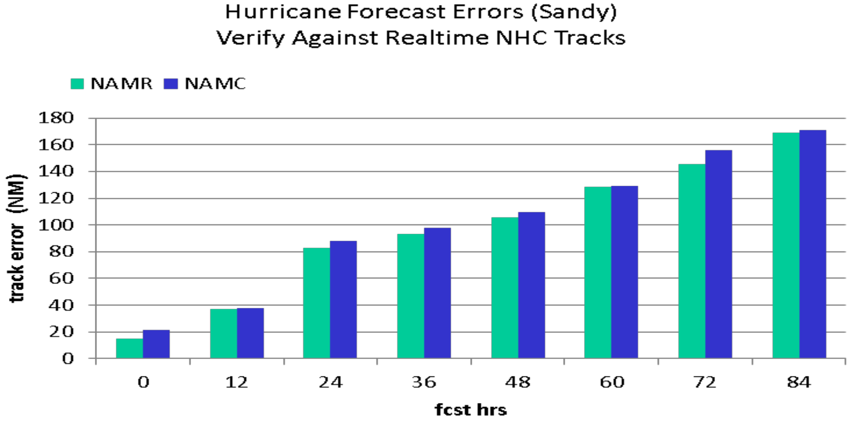
Tropical cyclone relocation/performance in NAM V4

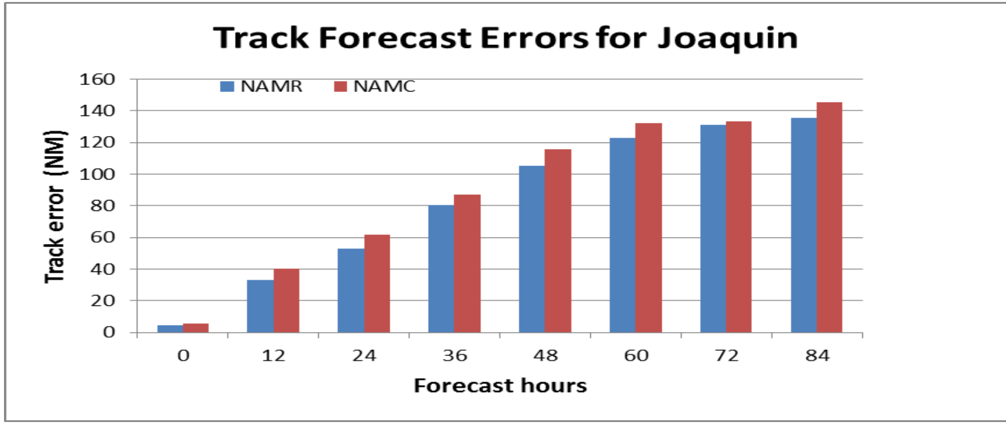
- TC relocation in NAM is Sandy Supplemental funded effort
- Done at start of 6-h assimilation cycle (tm06) and for the on-time NAM (tm00) analysis
- NOTE : NAMv4 physics changes (convection) lead to better TC tracks in NAM 12 km parent for Joaquin, probably bigger impact from this than TC relocation









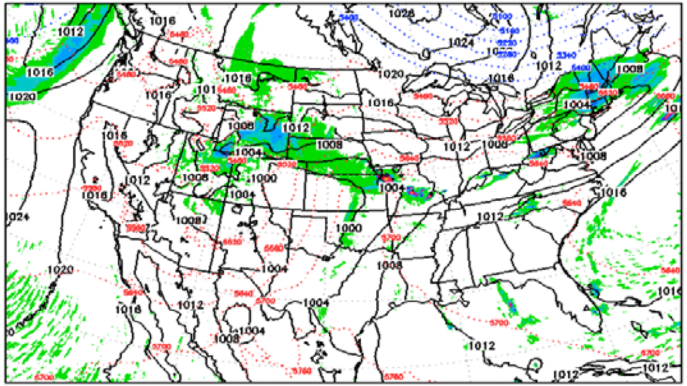


NAMR = NAM run with TC relocation, NAMC = control run without TC relocation

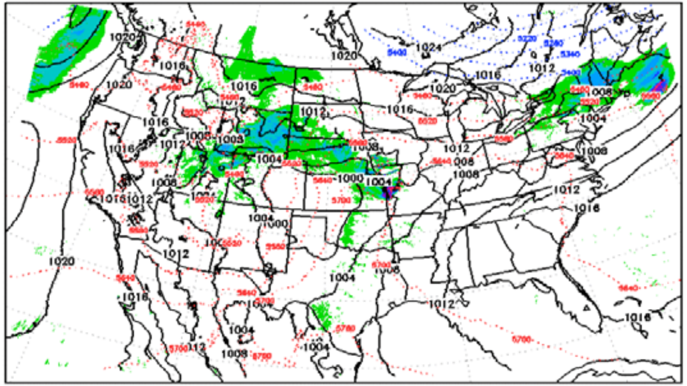
Post-processing changes

- All NAM output will be GRIB2 direct from the post-processing (current ops makes GRIB1 which is converted to GRIB2 for distribution)
- Add output GSD version of visibility calculation (labeled w/vertical level = cloud base, not surface, so that only AWC will use it)
- CONUS nest output grid will change to the same grid as that from the HRRR ; 3 km Alaska nest will be output on the 3 km Alaska DNG grid
- Threshold precip rate for categorical precip-type calculation set to 0.01 mm/h for all NAM domains instead of varying by resolution; the latter led to spotty p-type depiction in ops NAM nests (especially in the fire weather nest as noticed by Steve Z. at LWX)

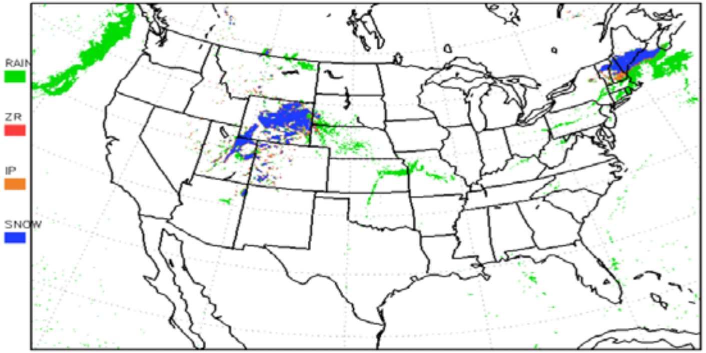
SLP,3-H APCP OPSNEST 18H FCST VALID 18Z 26 APR 2016



SLP,3-H APCP PLLNEST 18H FCST VALID 18Z 26 APR 2016

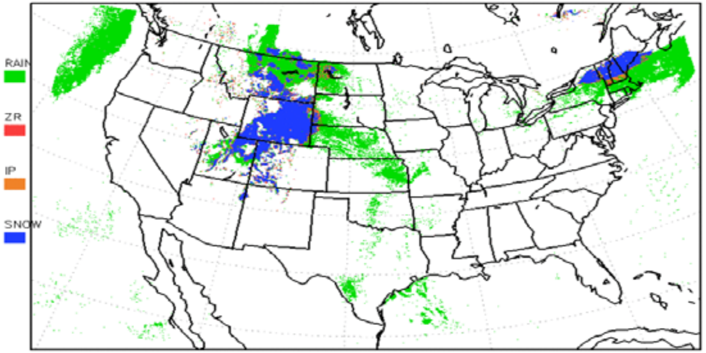


PRECIP TYPE OPSNEST 18H FCST VALID 18Z 26 APR 2016



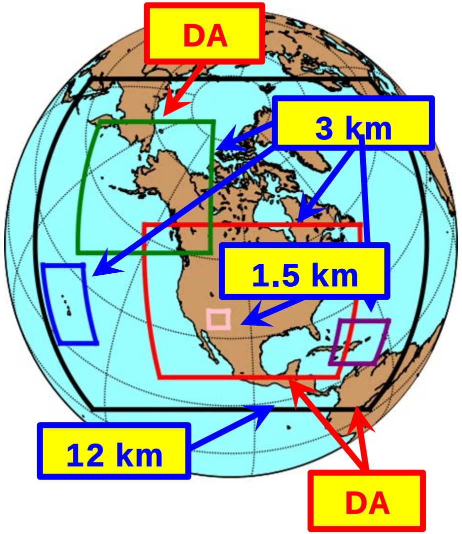
Based on Prate=0.325 mm/h

PRECIP TYPE PLLNEST 18H FCST VALID 18Z 26 APR 2016



Based on Prate=0.01 mm/h

Summary of Forecast Impacts



Improvements

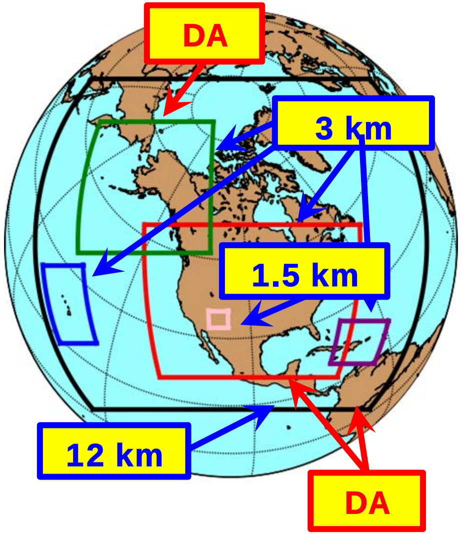
Improved QPF, storm structure ; generally improved upper level and surface stats; better spin-up for the AK (not shown) and CONUS nests

Timeline

Deliver code to NCO by end of next week

Begin 30-day test in mid-late October 2016

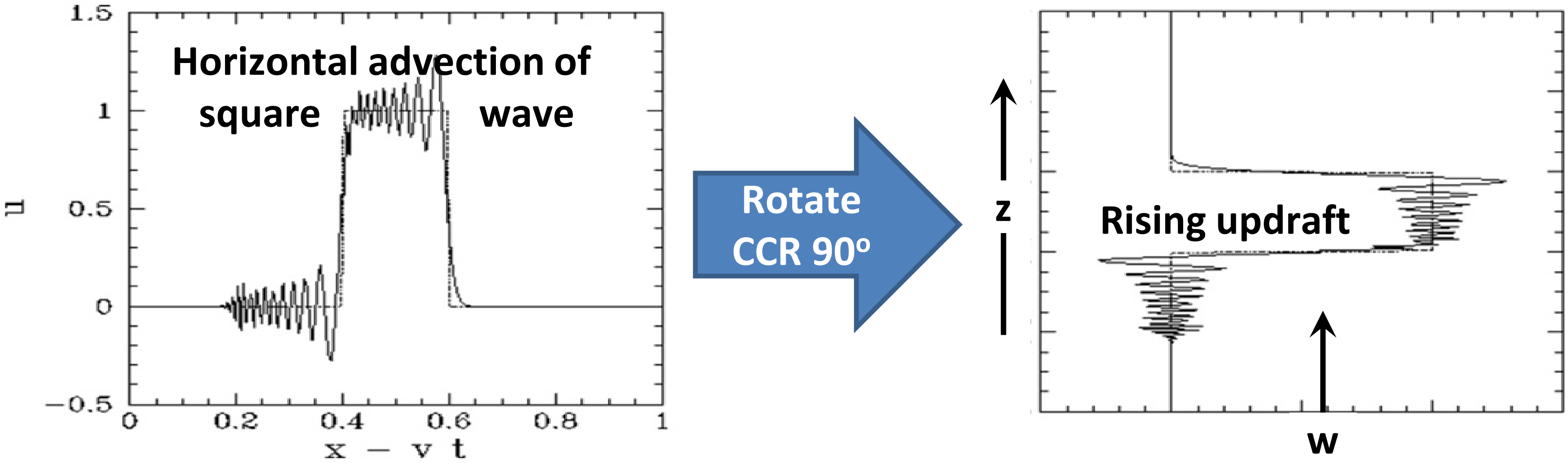
Implement in early December 2016



BACKUP SLIDES

Noisy Temperature Profiles : Why?

- **Oscillations primarily due to Crank-Nicolson (CN) vertical advection (Vadv)**



"Unfortunately, the Crank-Nicholson scheme does a very poor job at advecting wave-forms with *sharp leading or trailing edges*…. It turns out that all *central difference* schemes for solving the advection equation suffer from a similar problem." (Left figure & notes from Prof. Richard Fitzpatrick, Univ. Texas)

Updates to F-A Microphysics

- **Increased relative humidity threshold for the onset of condensation from 98% to 100% in the 3-km NAM nest.**
- **Nucleation of small ice crystals uses Fletcher for T ≥ -21°C and Cooper for colder temperatures; their number concentrations (# conc.) are ≤ 250 L^{-1} as in Thompson scheme.**
- **Allow much larger # conc. of snow at cold temperatures (also limited to ≤ 250 L^{-1} as in Thompson scheme), which increased size of anvils and reduced high reflectivity bias.**
- **Reduced widespread light reflectivity from shallow PBL clouds:**
  - **Added a new drizzle parameterization that reduced drop sizes & increased their # conc based on Westbrook *et al* (2010, *Atmos Meas. Tech.*).**
  - **Delayed onset of drizzle/rain by (1) increasing assumed cloud droplet # conc. from 200 to 300 cm^{-3}, and (2) allowing cloud water autoconversion (self collection) to rain to occur only for cloud water content >1.25 g m^{-3}.**

Updates to F-A Microphysics (cont.)

- Use Thompson graupel fall speeds for large graupel/hail (D_{mean}=1 mm) to reduce area of broad convective regions seen in operational NAM nest.
- Assume mean drop sizes fixed in stratiform rain with height below stratiform melting layers (following Thompson scheme)
  - Reduced rain evaporation in drier subcloud air.
  - Improved vertical structure of radar reflectivity.
- Reduced high bias in heavy rainfall:
  - Added a transition to allow for more gradual changes in graupel density and # conc. between convective and stratiform regions.
  - Reduced light-moderately rimed ice fall speeds.
  - Fixed a bug pointed out by ESRL-PSD, in which the change reduced the size of the snow/graupel particles and reduced their fall velocities.