The New Ferrier-Aligo (F-A) Microphysics in the NAM Nest

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Introduction

- **The new F-A scheme will be part of the version 4 upgrade of the North American Modeling (NAM) system.**
- **This presentation will describe the F-A updates and illustrate results from 3-km runs using the Nonhydrostatic Multiscale Model on the B-grid (NMMB).**
- **The modifications to the F-A scheme were based on NMMB runs using the Thompson microphysics.**
- **A brief update on cloud fractions and C&V.**
- **This work fits into the process of working with the community to come up with a unified physics package for the Next Generation Global Prediction System (NGGPS).**
- **Work partially funded by FAA MD&E (Benjamin *et al.*)**

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}.**

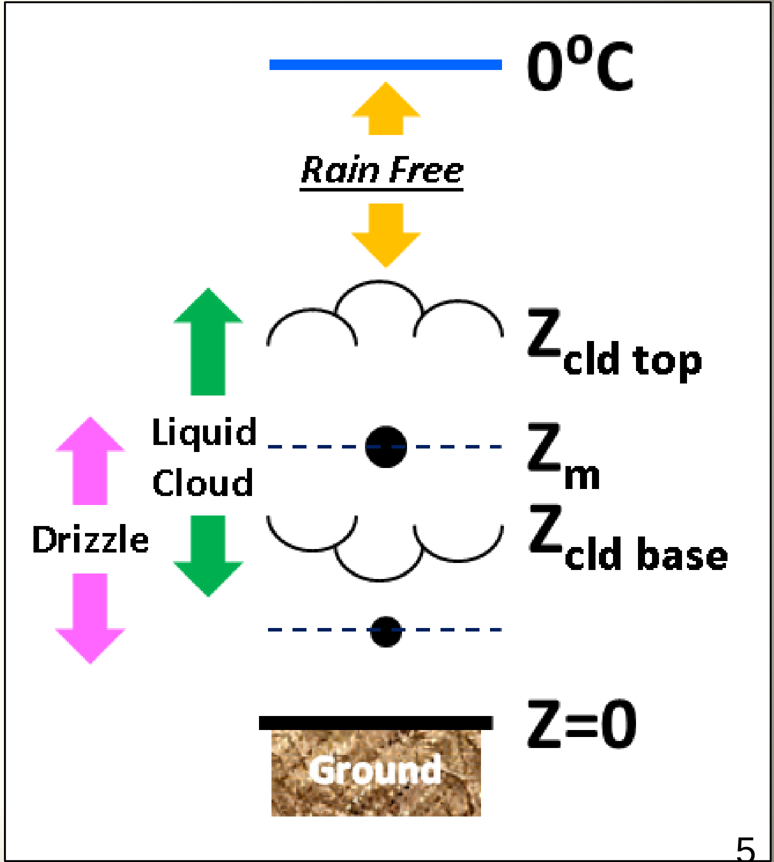
Updates to F-A Microphysics (cont.)

- 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.

Drizzle Parameterization (1 of 3)

Single Cloud Layer

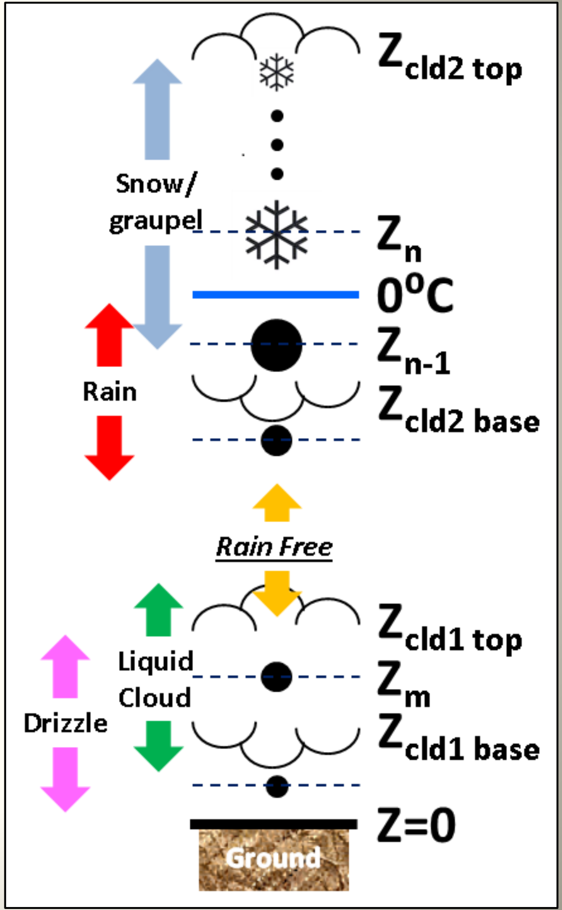
- Drizzle forms from low-level liquid clouds at >0ºC
- Drizzle must be completely disconnected from rain formed from melting ice aloft
- Smaller, more numerous drops are assumed, reduces radar reflectivity from drops that form in PBL-topped clouds



Drizzle Parameterization (2 of 3)

<u>Multiple Cloud Layers</u>

- **Drizzle from low clouds must be completely disconnected from rain formed aloft from melting ice**
- **A *<u>rain-free</u>* layer must separate any stratiform rain layer aloft (cld2) from drizzle forming within low-level liquid clouds (cld1)**

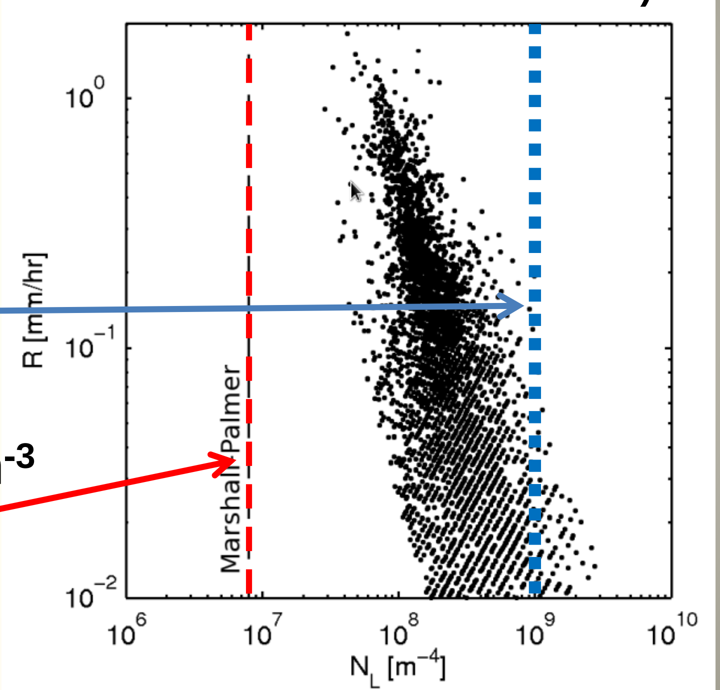


Drizzle Parameterization (3 of 3)

- **Drizzle is limited to rain contents (Q_r) < 0.5 g m^{-3}**
- **N_{0r} increases with decreasing Q_r (=ρ•q_r)**

$$N_{0r} = \begin{cases} 10^9 \text{ m}^{-4}, & Q_r \le 0.02 \text{ g m}^{-3} \\ 8\text{x}10^6 \text{ m}^{-4} * (0.5 \text{ g m}^{-3}/Q_r)^{1.5}, & 0.02 \text{ g m}^{-3} < Q_r < 0.5 \text{ g m}^{-3} \\ 8\text{x}10^6 \text{ m}^{-4}, & Q_r \ge 0.5 \text{ g m}^{-3} \end{cases}$$

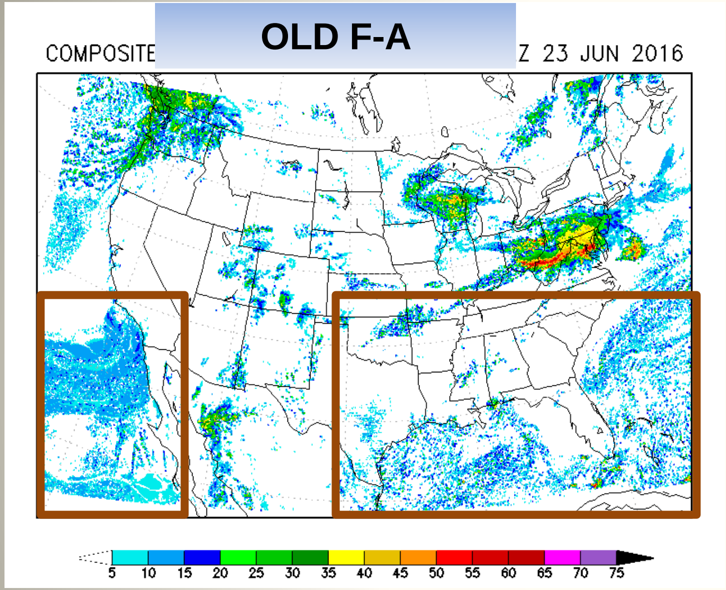
Fig. 12 from Westbrook *et al.* (2010, *Atmos. Meas. Tech.*)

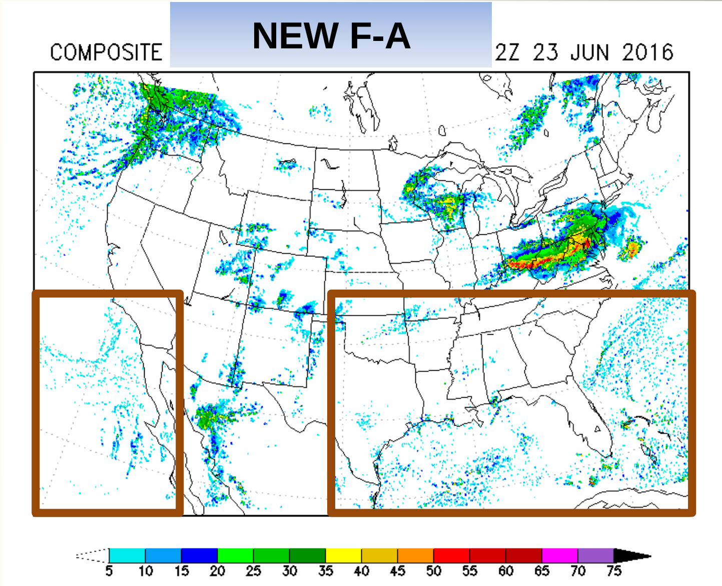


(N_L = N_0 for exponential distributions)

Composite Reflectivity

12-h (12Z/23 June 2016)





Echoes from small raindrops formed in thin PBL clouds.

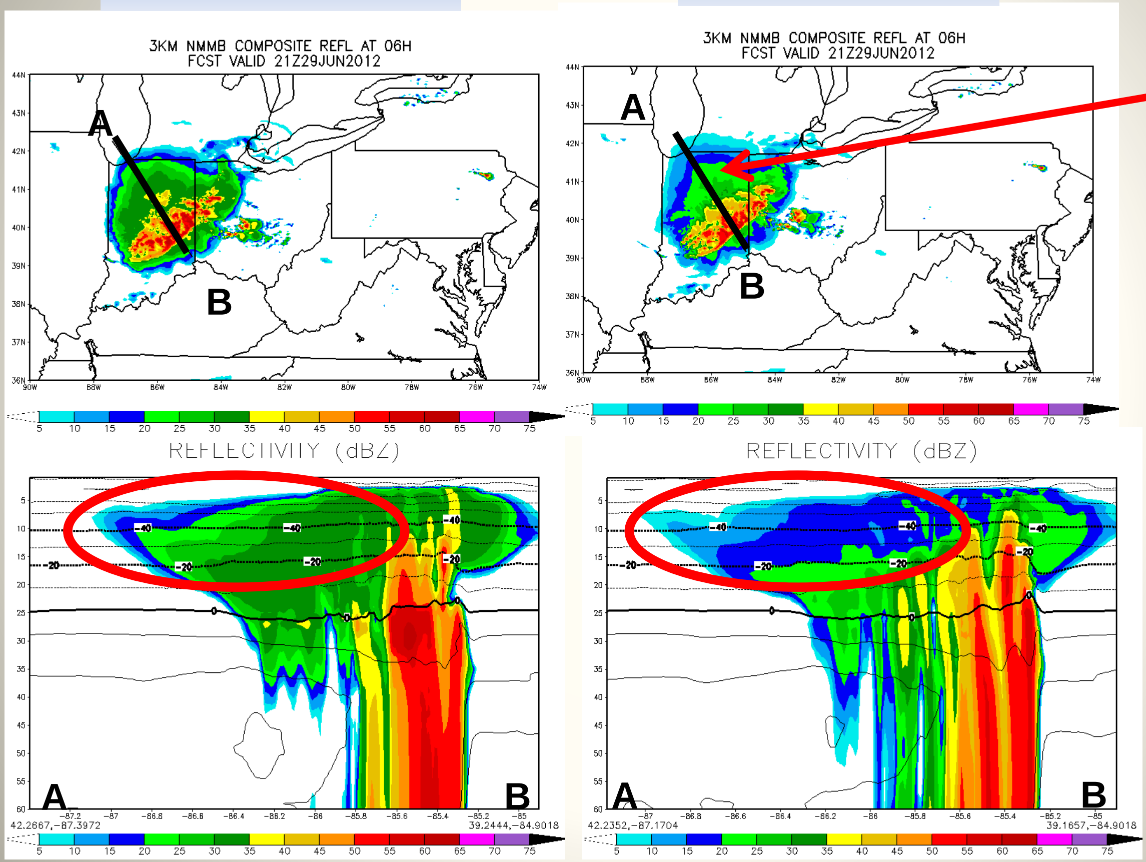
Reduced areas of < 20 dBZ echoes with new **drizzle parameterization** + increased cloud droplet # conc.

June 29 2012 Derecho

OLD FA | **NEW FA**

06-h (21Z/29)

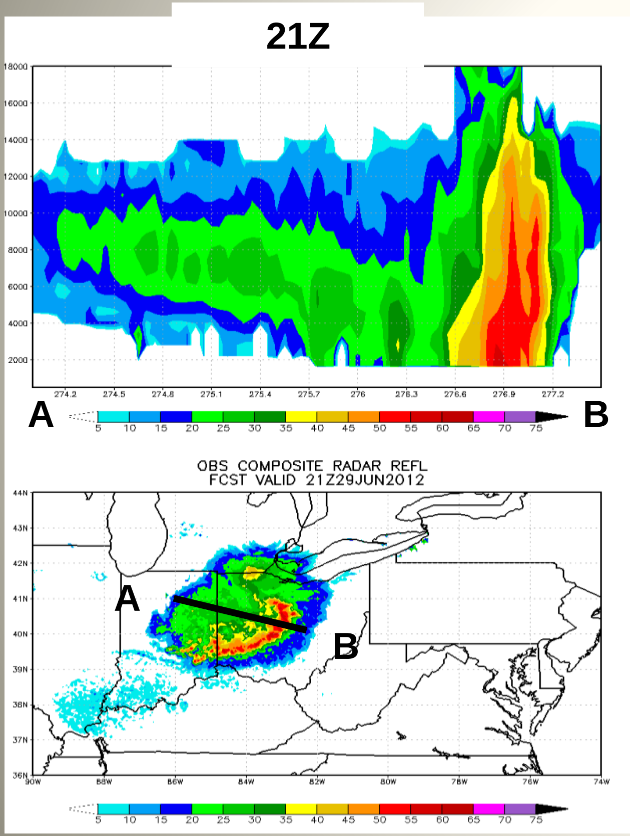
Composite Reflectivity

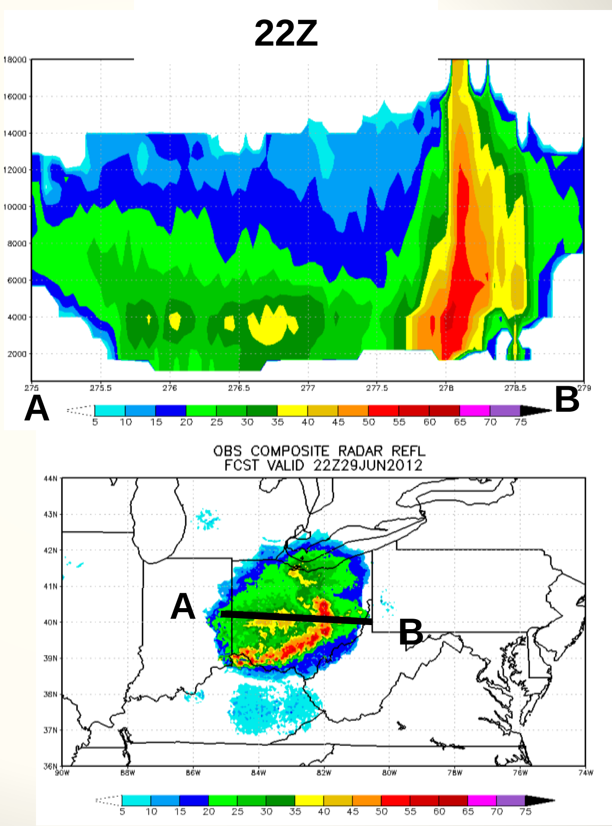


- **Lower reflectivity in anvil due to changes shown on slide 3, which allow much higher # conc of snow aloft (<-10C).**

Native model levels used for vertical axis.

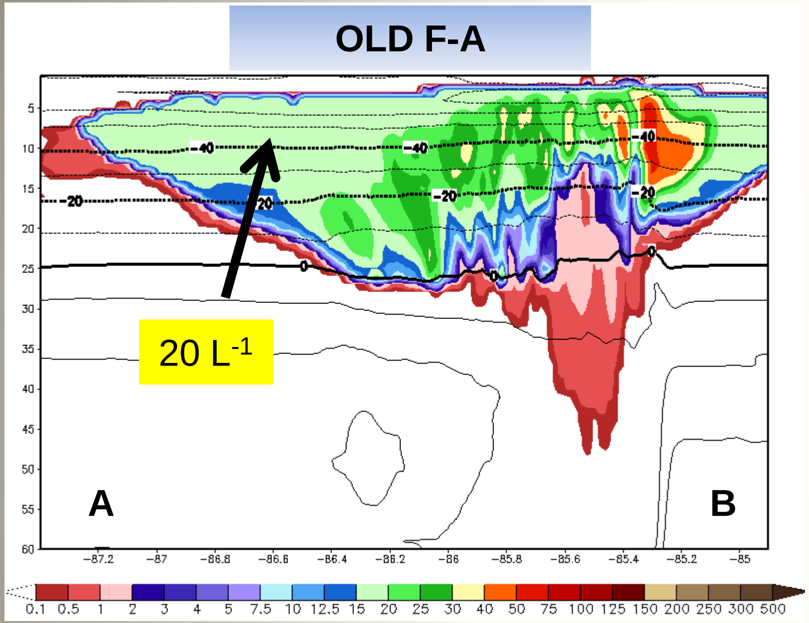
Observed Reflectivity: 29-30 June 2012 Derecho

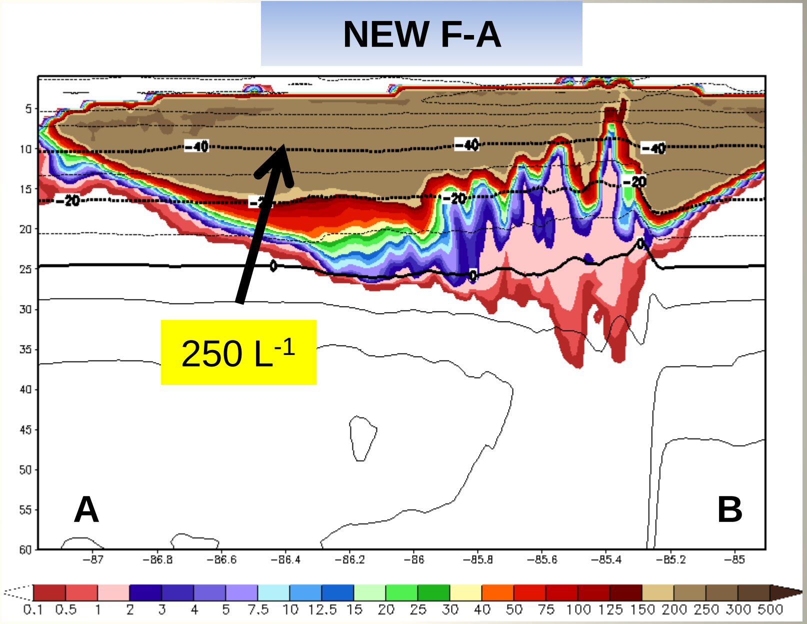




- **Lower reflectivity in anvil at <0C better simulated in the new F-A scheme due to the increase in # conc. of snow noted on slide 3.**

Large Ice # Concentration





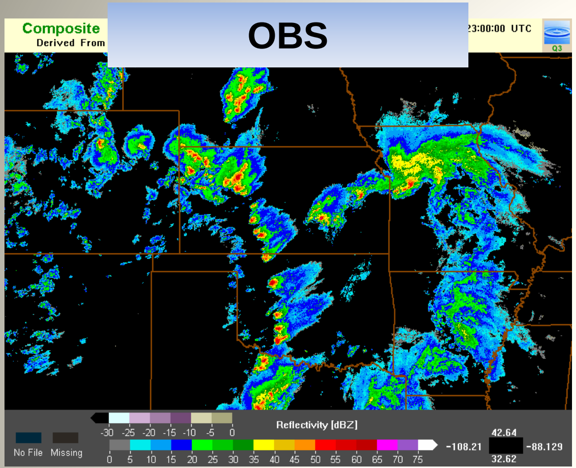
Native model levels used for vertical axis.

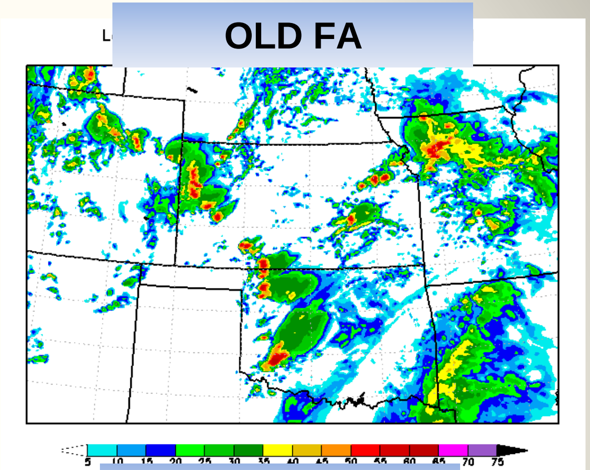
Features of New F-A:

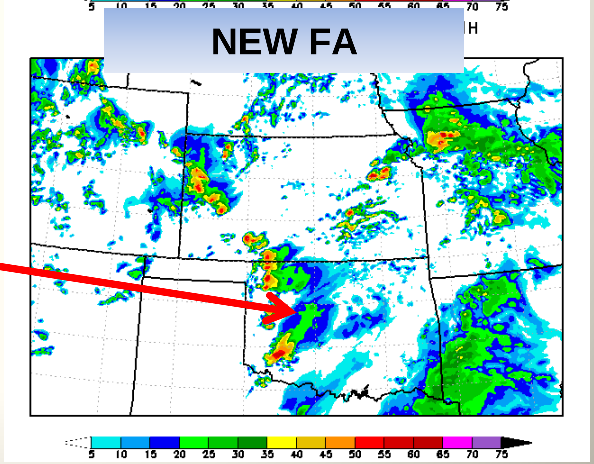
- **Larger # conc. of snow at cold temps in stratiform region of new F-A run (following results from Thompson scheme).**

6-h forecast valid at 21Z/29

Composite Reflectivity: 23Z on 08 May 2016



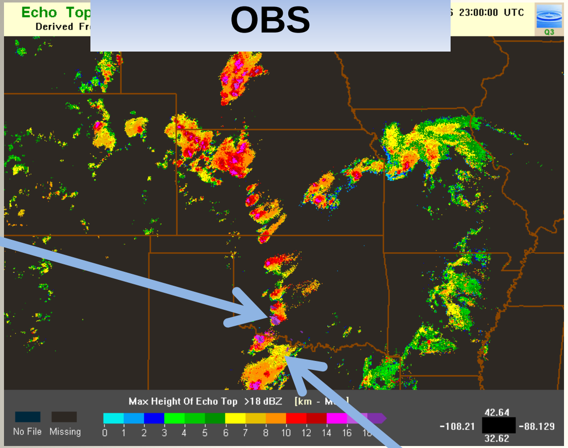




<u>Reduced</u> reflectivity in the anvil region

Echo Tops: 23Z on 08 May 2016

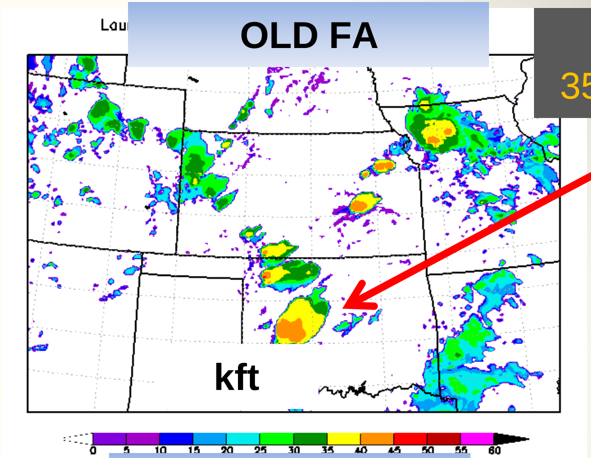
OBS



55-60 kft

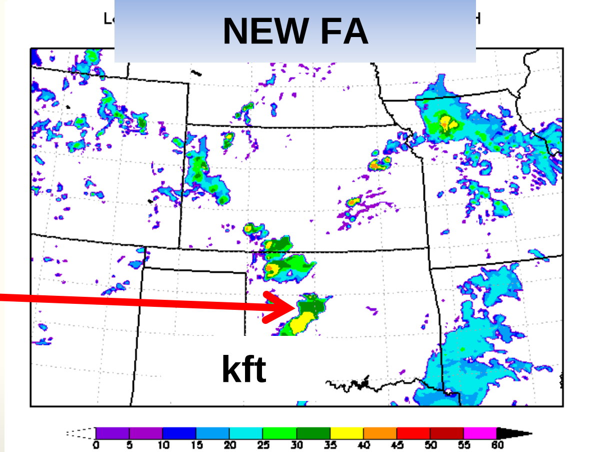
25-35 kft

OLD FA



45-50 kft in conv. region,
35-40 kft in anvil/strat region.

NEW FA



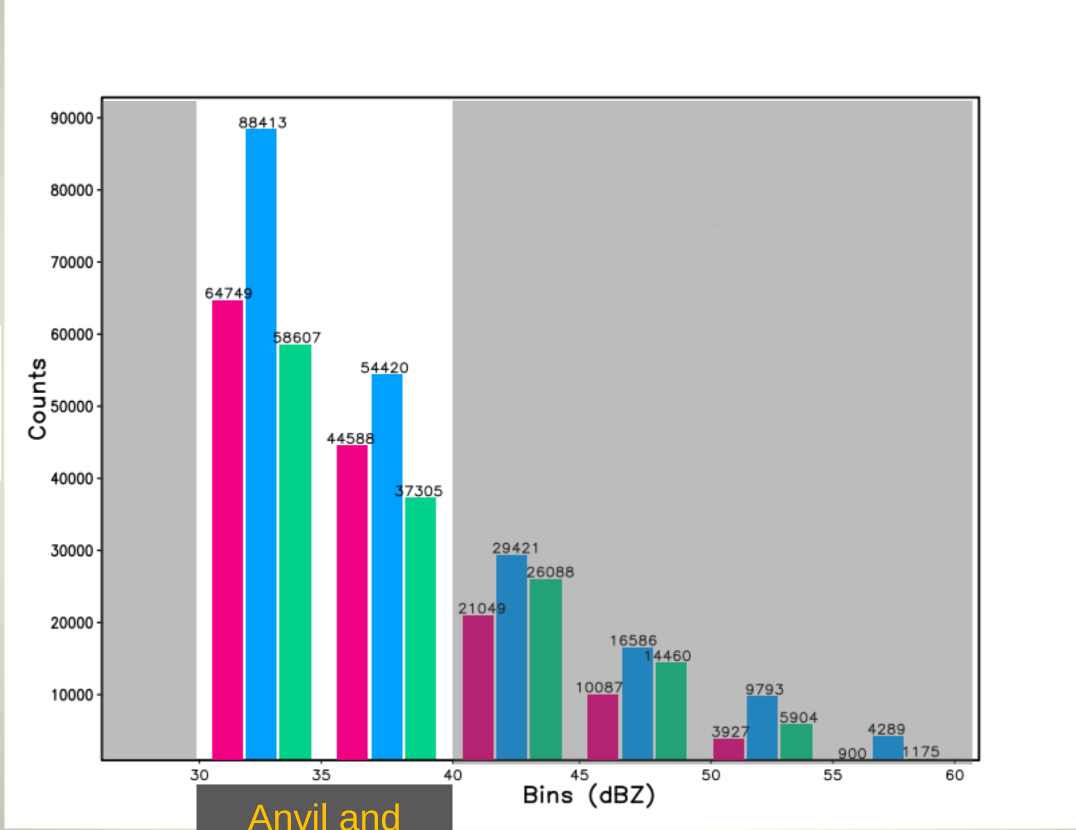
Reduced echo tops:

35-45 kft in conv. region
25-35 kft in anvil/strat. region

Aggregated Composite Reflectivity Histograms

Hourly Reflectivity from 7 Warm Season Cases

Obs
Old FA
New FA

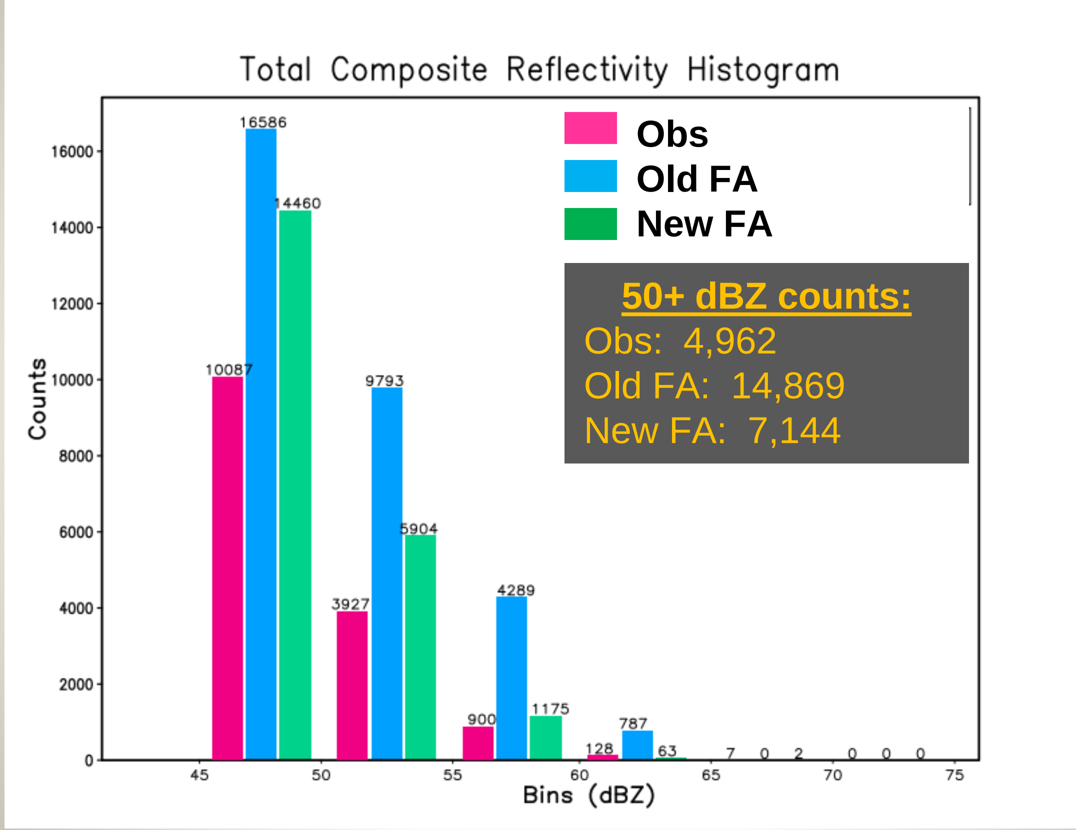


Anvil and Stratiform Region

- **Improved bias for all bins ≥ 30 dBZ.**
- **Largest improvement in 30-40 dBZ reflectivity associated with anvil and stratiform regions.**

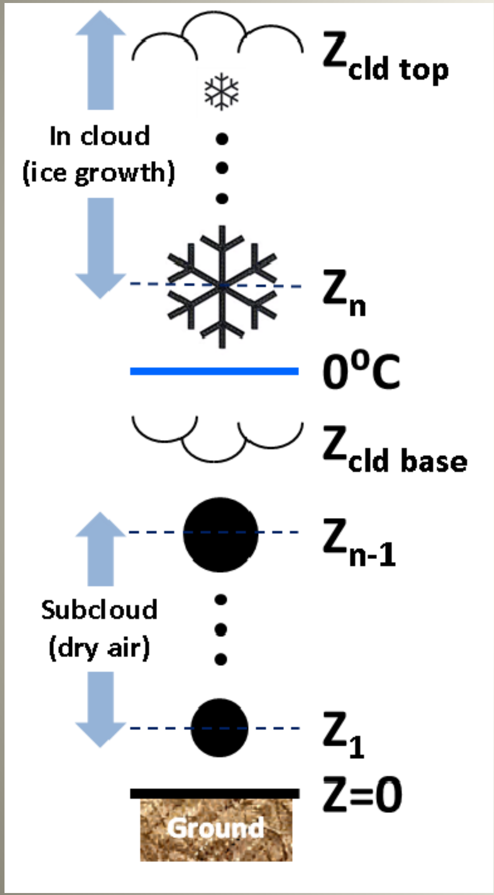
Aggregated Composite Reflectivity Histograms

Hourly reflectivity from 7 warm season cases



- **Improved high bias in new F-A for ≥ 50 dBZ reflectivity, ~ 50% reduction in reflectivity counts.**

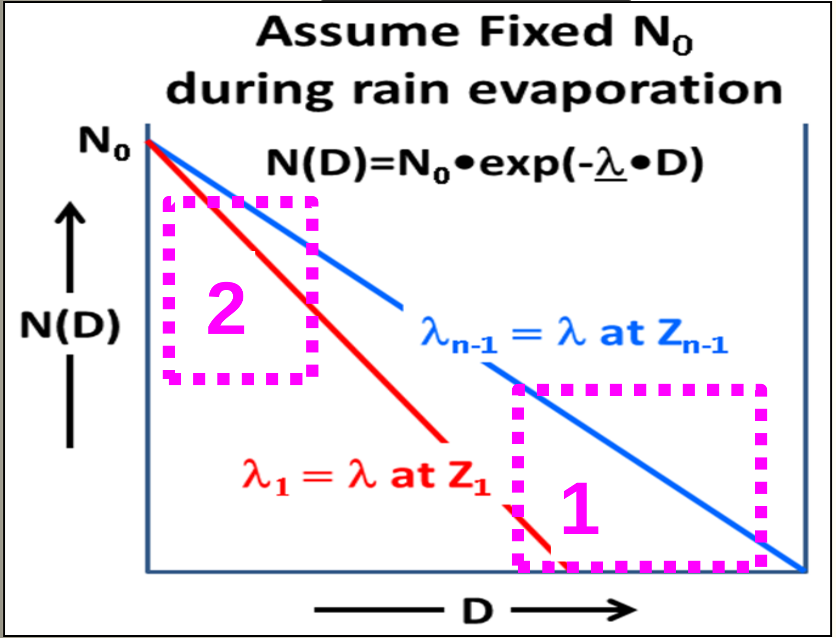
Stratiform Rain Parameterization (1 of 3)



- Z_n is the first model level above (colder than) the 0^oC level
- Ice melts to form rain at $\geq 0^oC$ at $z \leq Z_{n-1}$
- Rain drops evaporate as they fall into dry air below cloud base
- Two different assumptions for drop size distributions (DSDs):
  1. Fixed intercept (N0) … vs …
  2. Fixed mean diameter ($Đ=\lambda^{-1}$)
- Large impact on rain evaporation down to surface

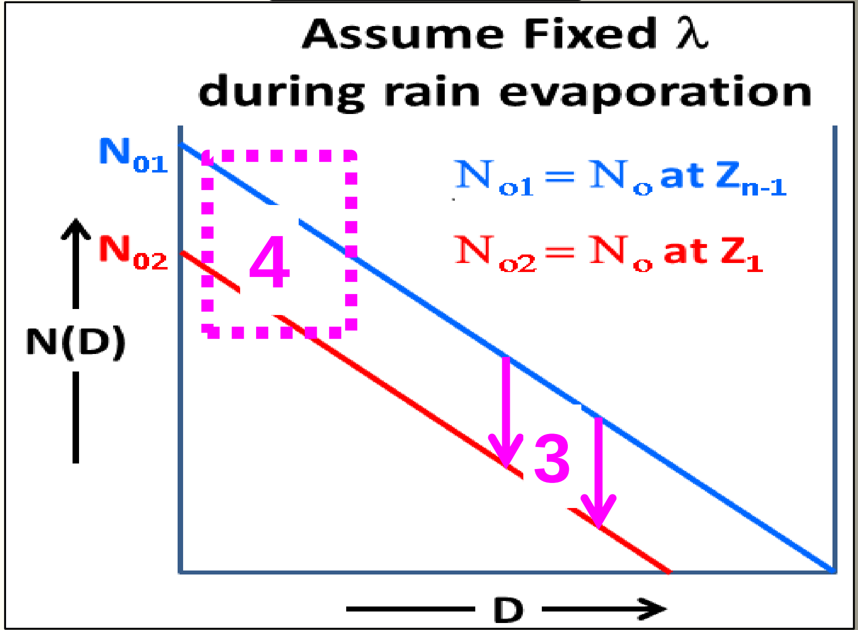
Stratiform Rain Parameterization (2 of 3)

Old F-A



1. Largest change in large drops.
2. Number of small drops remain roughly constant.

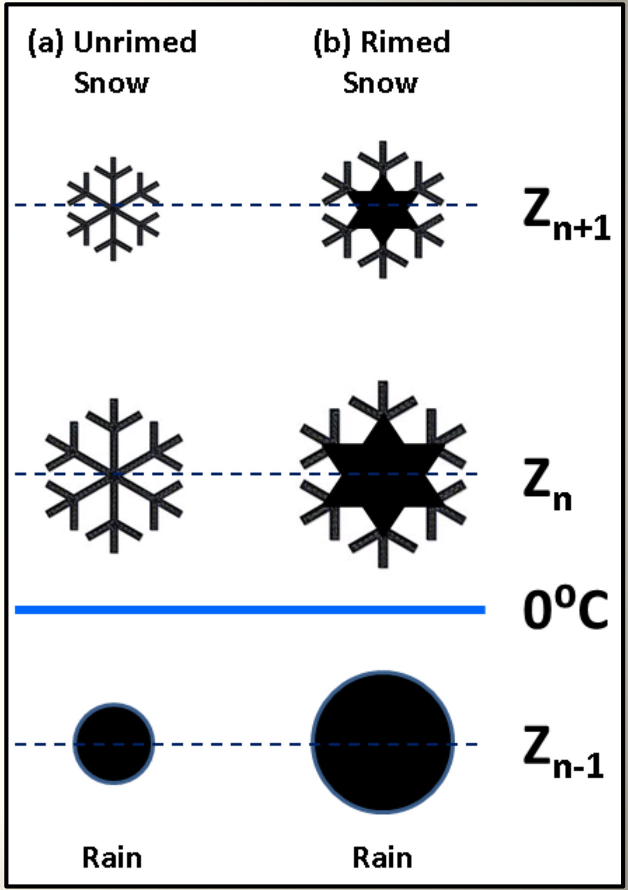
New F-A



3. Proportional change in number of drops at different levels.
4. Fewer small drops leads to reduced rain evaporation.

Stratiform Rain Parameterization (3 of 3)

- ***Assume*** **mean mass of snow/graupel at Z_n = mean drop mass at Z_{n-1}**
- **Mean drop diameter $(Đ_r)_{n-1}$ at Z_{n-1} calculated from mean snow/graupel mass at Z_n**
- **$(Đ_r)_{n-1}$ acts as a *lower limit* for mean drop sizes ($Đ_r$) at lower levels ($z<Z_{n-1}$) *within the rain shaft***
- **This mode is valid only when**
  1. **Snow/graupel density at Z_n is <225 kg m^{-3}**
  2. **Rain content ≤ 1 g m^{-3} at all levels**
  3. **There is vertical continuity with rain formed from melting ice at Z_{n-1}**

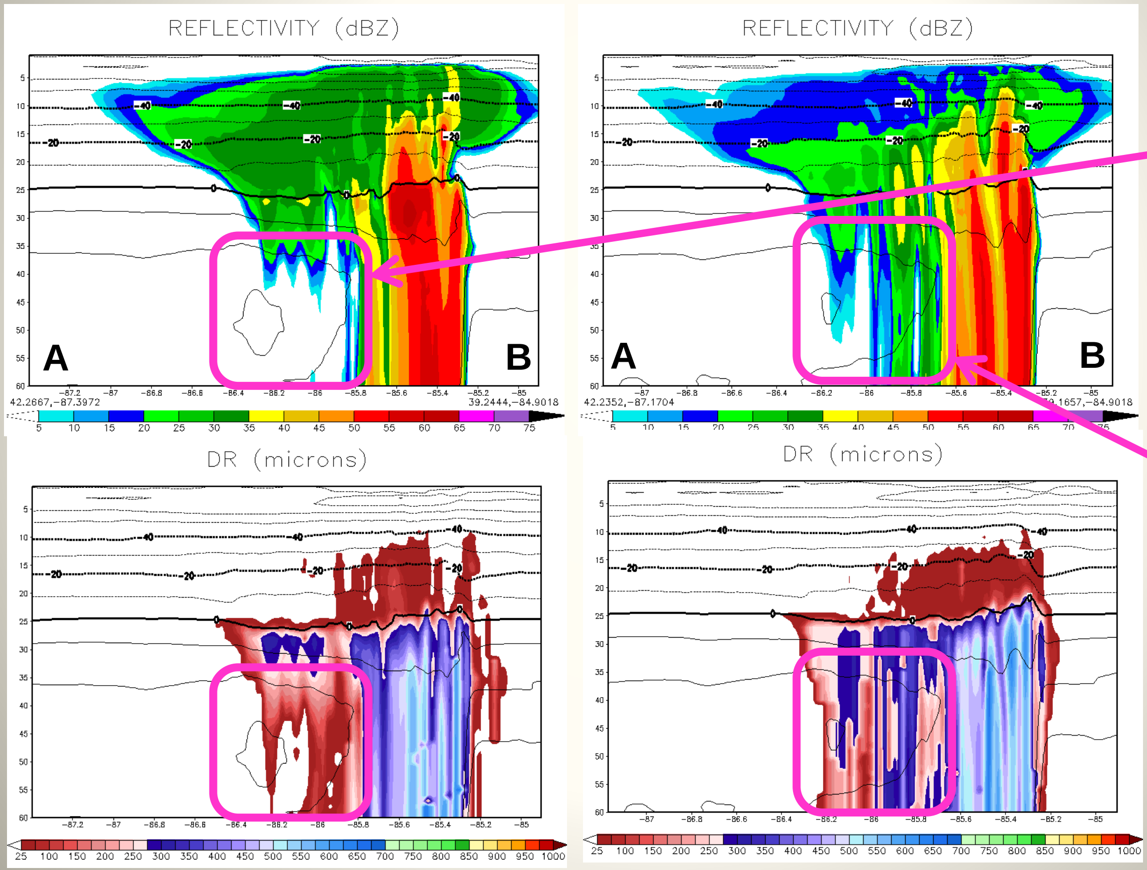


June 29 2012 Derecho

OLD FA | **NEW FA**

06-h forecast valid @ 21Z/29

Native model levels used for vertical axis.

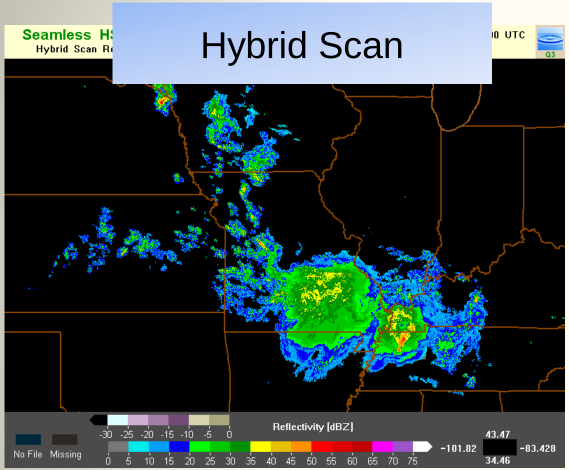


Forecast Feedback

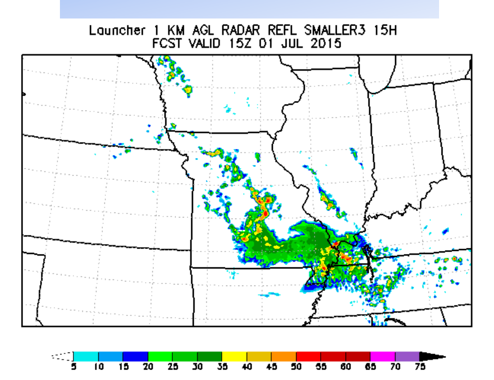
- **Sharp horizontal gradients in reflectivity, lack of light stratiform reflectivity & rainfall in old F-A.**
- **Better-defined stratiform region with ~ constant mean drop sizes with height below stratiform melting layers in new F-A**

01 July 2015: 1-km AGL Reflectivity

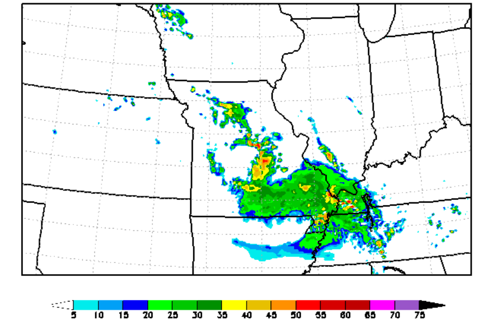
15Z 1 July 2015



Old FA



New FA



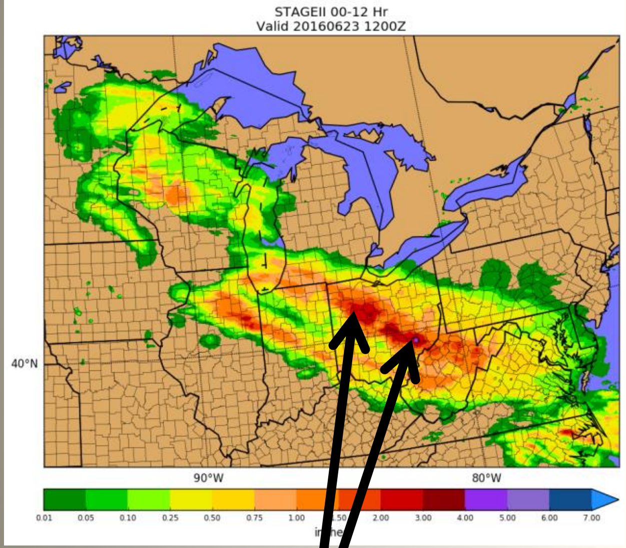
- **Spatial extent of rain was improved in the new F-A run but still underdone**

High Bias in Heavy Rainfall

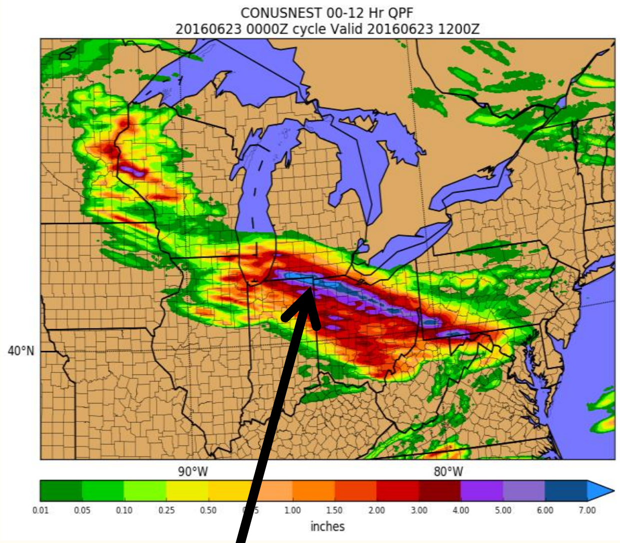
- Pointed out by WPC and those in the field.
- Seasonal, with largest biases in the summer.
- Much improved heavy rain bias in the 3-km parallel NAM nest over the 4-km operational nest:
  - Improved data assimilation.
  - Calling physics more frequently.
  - Advecting specific humidity every dynamics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

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

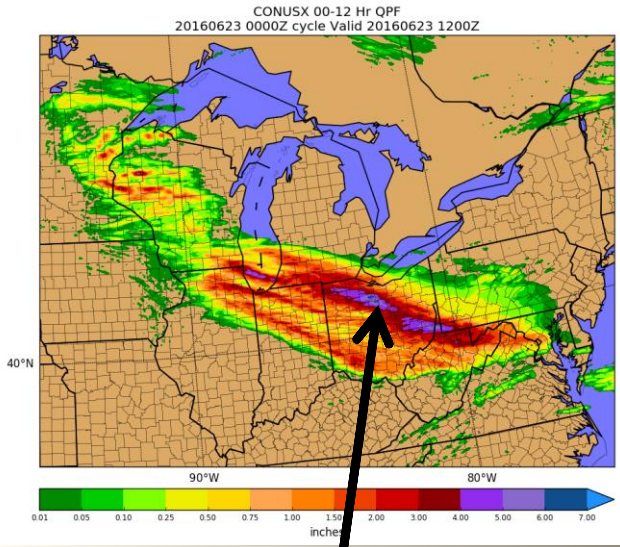
Observations



4-km Ops Nest



3-km Parallel Nest



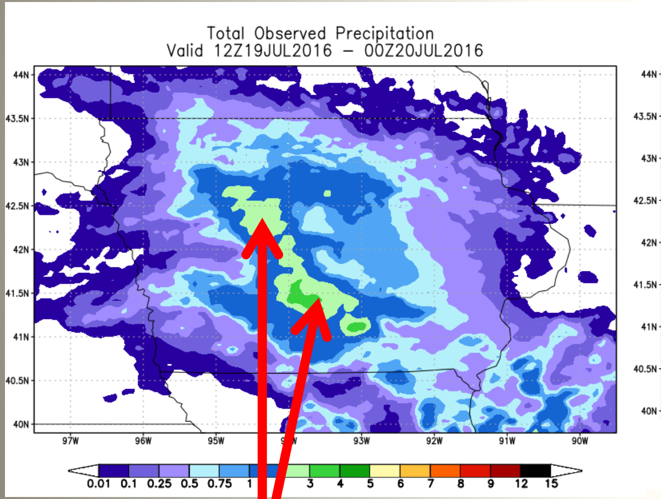
Up to 4 inches

≥7 inches

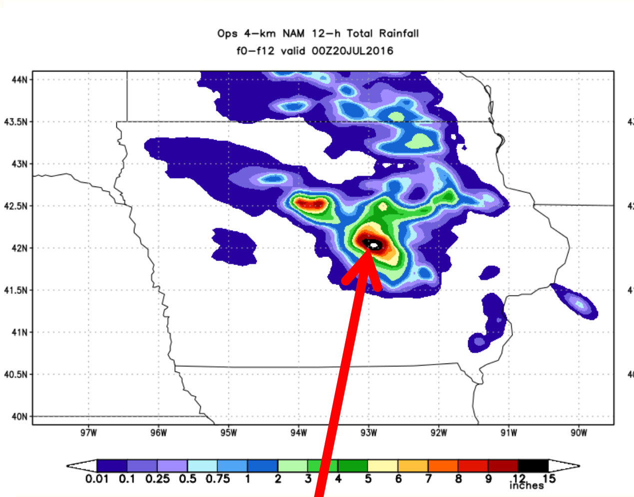
4 - 6 inches

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

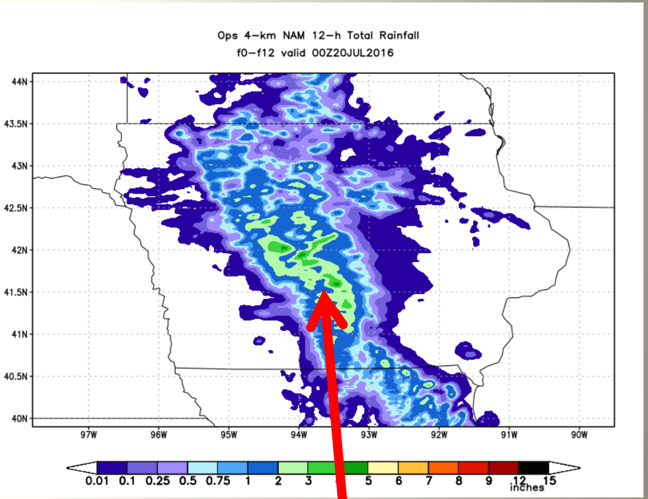
Observations



4-km Ops Nest



3-km Parallel Nest

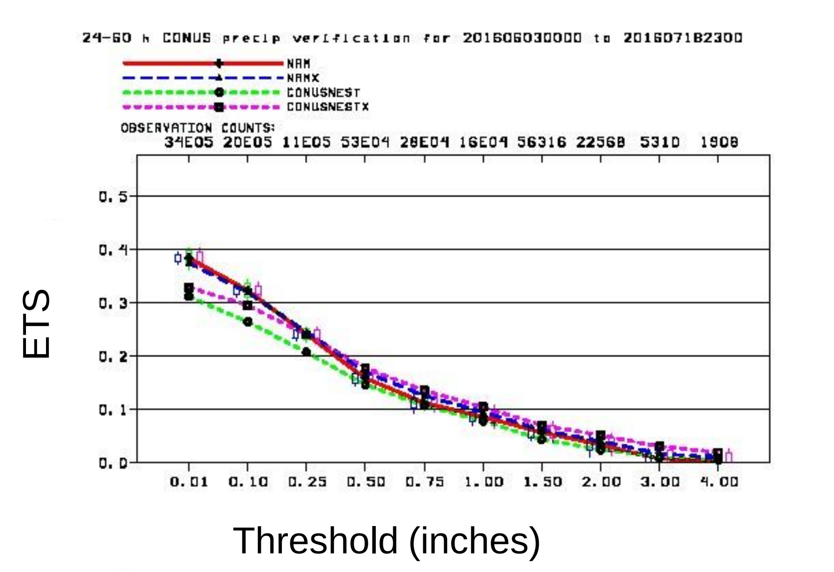


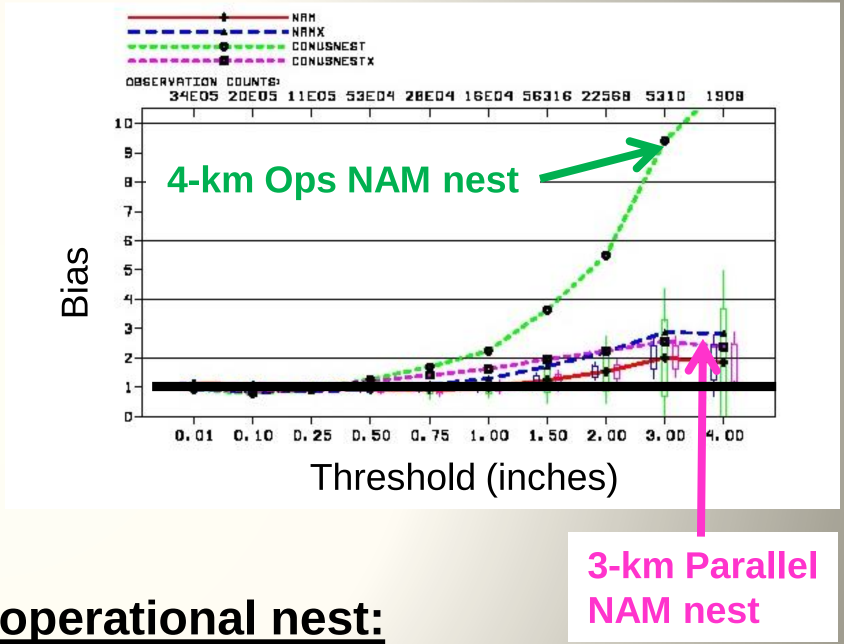
1 - 3 inches

15 inches

1 – 4 inches

24-60 h CONUS Precip Verification: June 03 2016 – July 18 2016





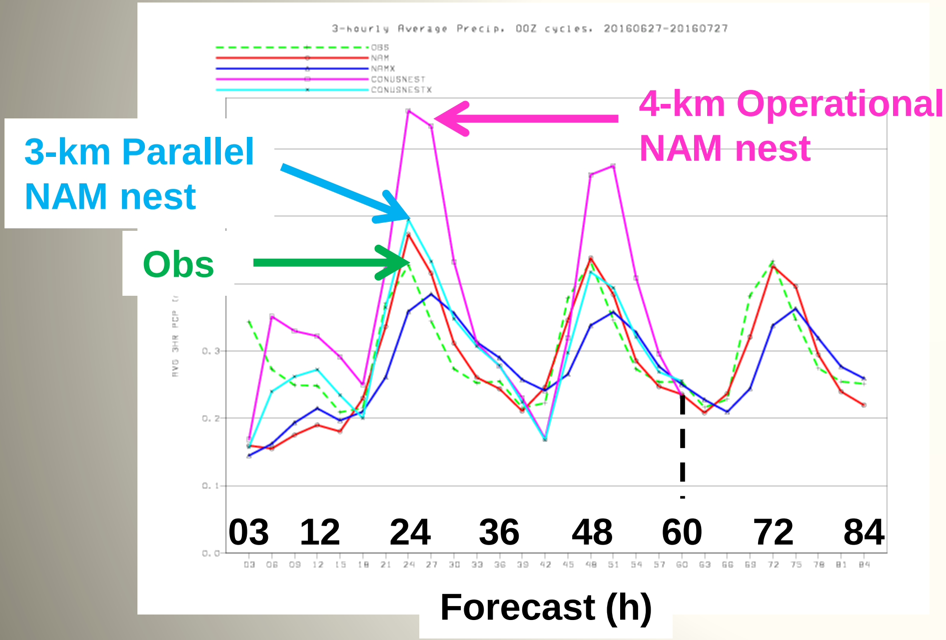
Improvements in parallel vs operational nest:

- **Slightly higher skill for the heavier rainfall thresholds.**
- **A 5X reduction in high bias for heavy rainfall.**

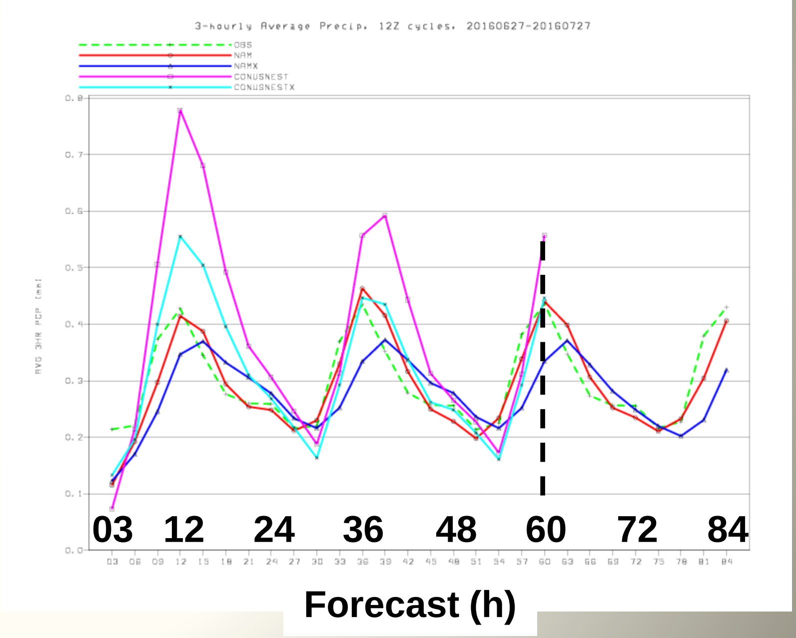
Average Precipitation

3-hourly CONUS

00Z cycles



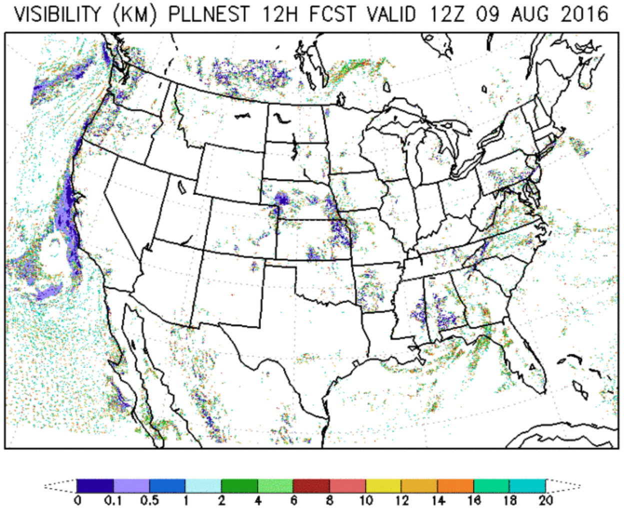
12Z cycles

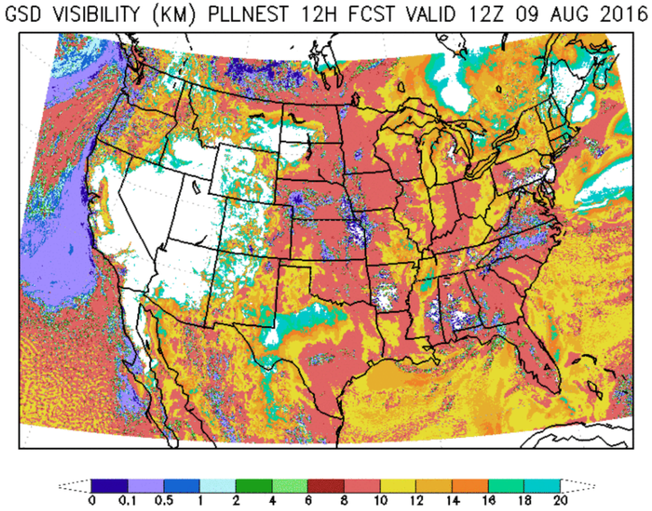


June 27 2016 – July 27 2016

Visibility: 12Z 09 August 2016

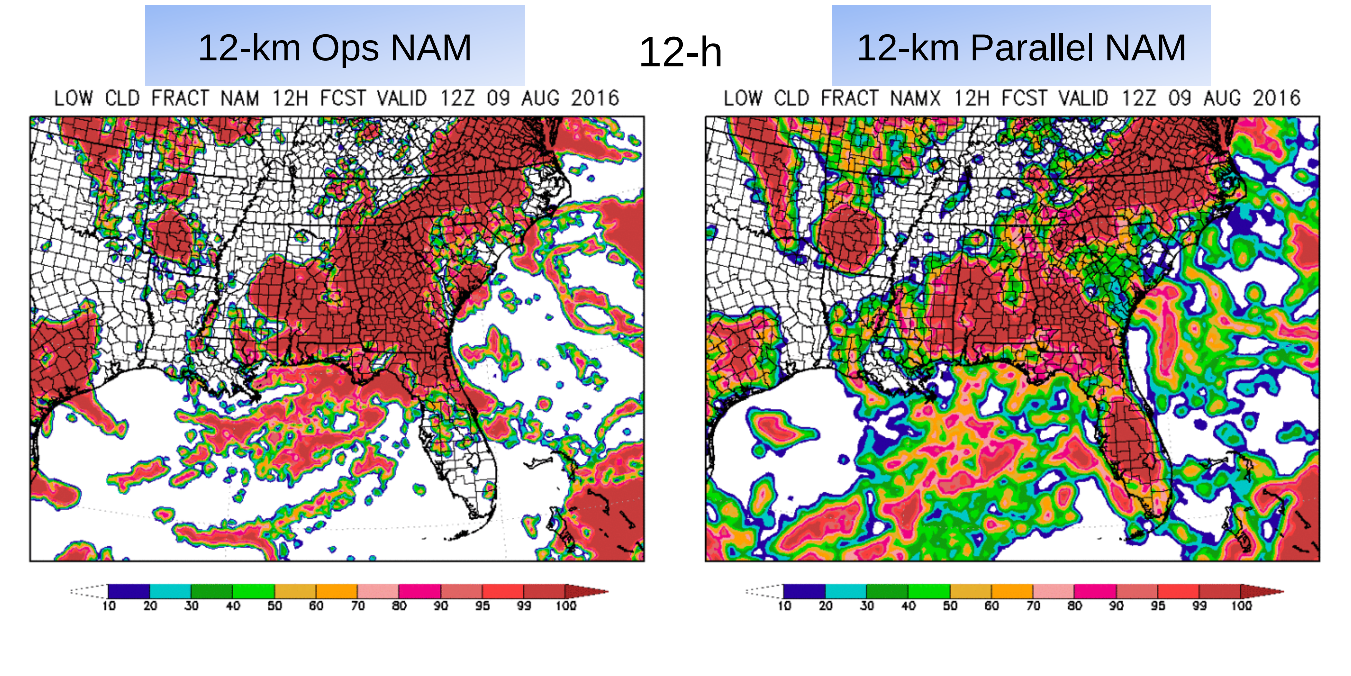
EMC Method | 12-h | GSD Method





- **EMC method is based on hydrometeor information from the lowest model level (hybrid level 1).**
- **GSD method is more complex, uses multiple fields over various levels. *This will have a GRIB2 level as being at cloud top.***

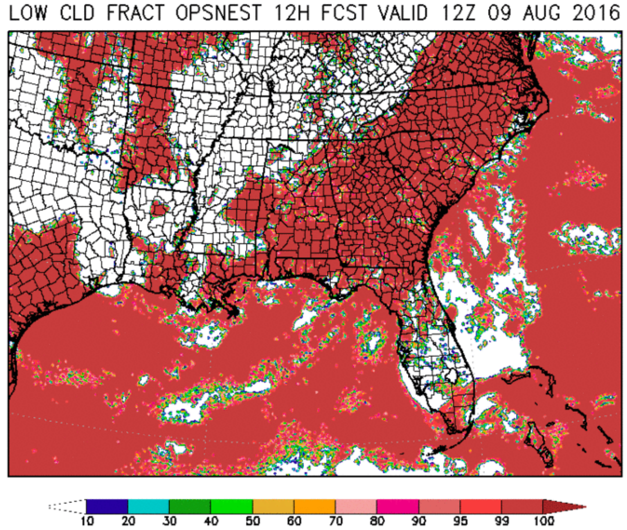
Low Cloud Fraction:



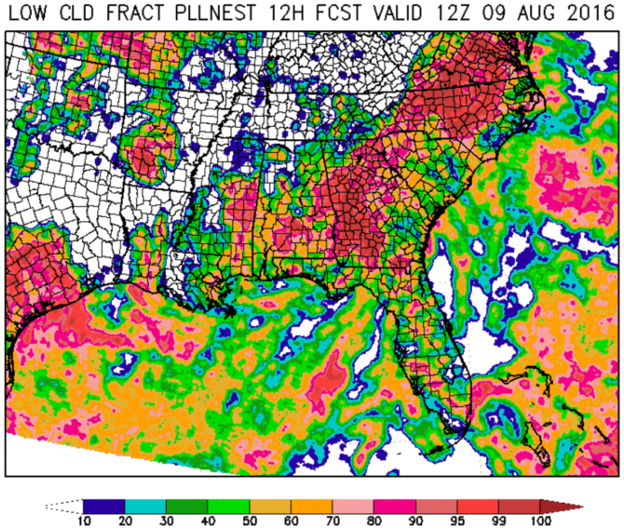
- **New cloud fractions in parallel NAM are averaged over a 10-mile radius area, leading to larger areas of partial cloudiness.**

Low Cloud Fractions from CONUS Nest: 12Z 09 August 2016

4-km **Ops** NAM Nest



3-km **Parallel** NAM Nest



- **Cloud fractions are almost "binary" (clear or overcast) in ops nest.**
- **More partial cloudiness in parallel nest (more grid points are averaged)**

C&V Summary

- Two sets of visibilities will be provided to AWC: one from the EMC algorithm and the other from the GSD algorithm.
  - The product using the GSD algorithm will be identified as being at cloud top in GRIB2.
- No changes will be made to the cloud ceiling height.

  (Will vertical visibility algorithm be evaluated in the future?)
- Instantaneous low/middle/high/total cloud fractions will be spatially averaged over a 10-mile radius (adapted from some GSD algorithms in the UPP).

Overall Summary

- The new F-A scheme will be part of the version 4 upgrade of the North American Modeling (NAM) system.
- Model and microphysics upgrades addressed concerns from various centers and those from the field by reducing a very high QPF bias, and improving upon the vertical structure of warm season MCSs.
- Many of the microphysics changes were based on results from 3-km NMMB runs using the Thompson scheme and include the following:
  - Adding a drizzle parameterization to reduce widespread light reflectivity.
  - Increasing the number concentrations of snow in the anvil/stratiform region to increase anvil size and reduce a high bias in anvil reflectivity,.
  - Keeping drop sizes constant below melting layers to reduce rain evaporation and increase stratiform rainfall.
  - Using Thompson fall speeds for large graupel/hail to simulate more narrow convective regions.