Assimilation of radar and lightning data in NAM system at NCEP

Shun Liu, Jing He, David Parrish, Wan-Shu Wu

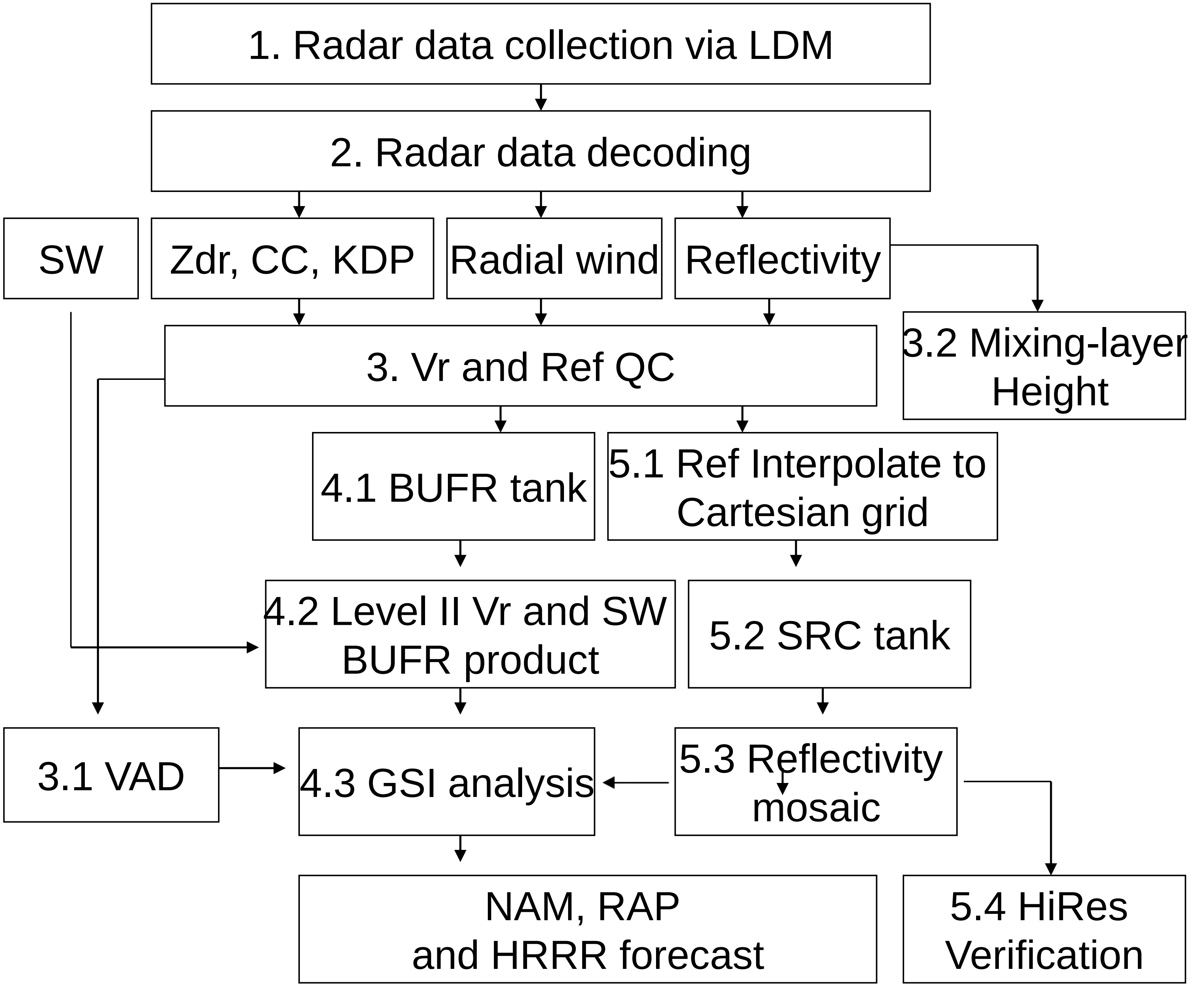
OUTLINE

- Radar data processing at NCEP
- Lightning data at NCEP
- Radar and lightning data assimilation
- Impact of DA on analysis and forecast

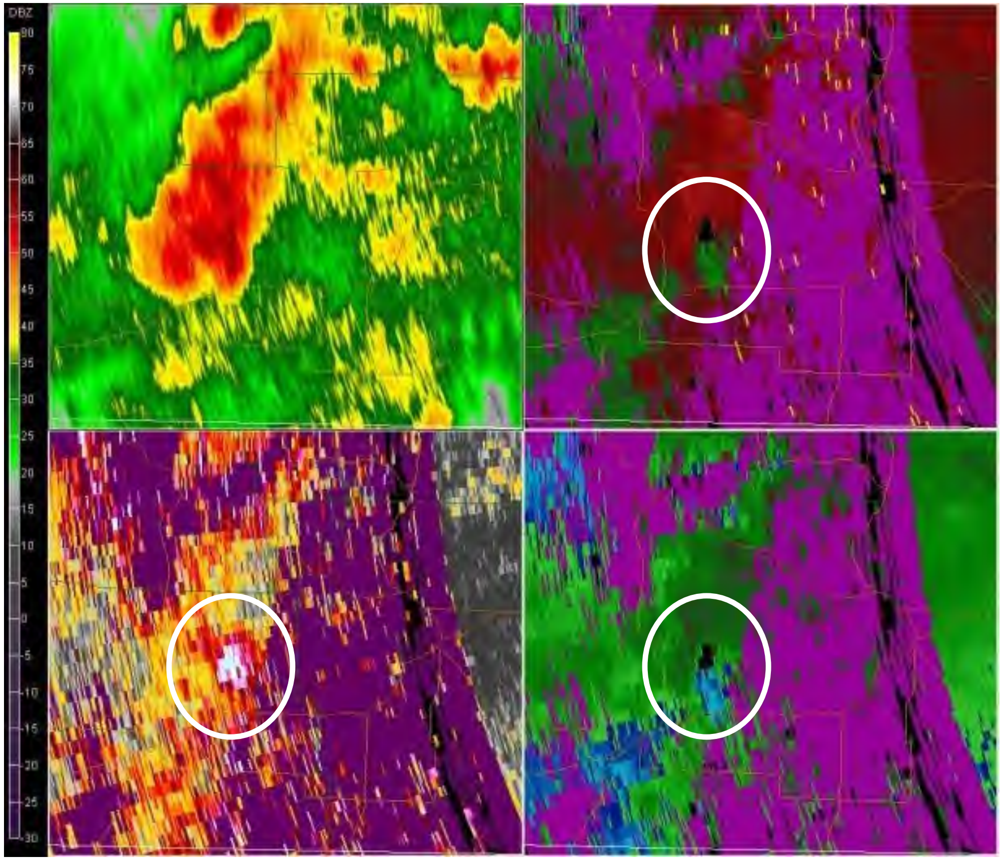
MOTIVATION

- WSR88D radar data and Lightning data available at NCEP
- Clear indication of convective storm
- Potential to improve storm scale NWP forecast
- Algorithm for operational use

Radar data processing at NCEP

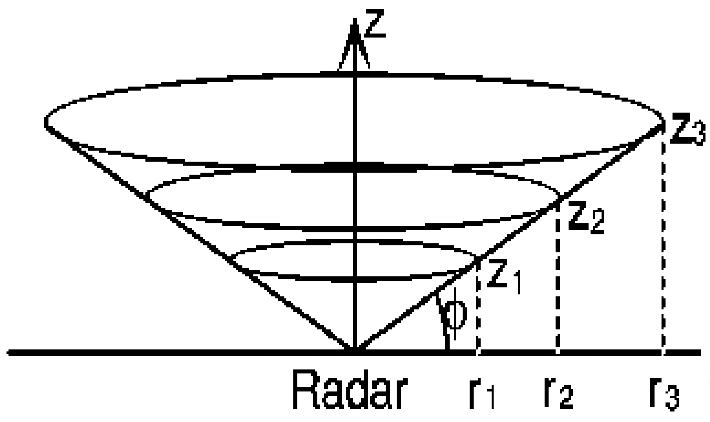


Spectrum Width

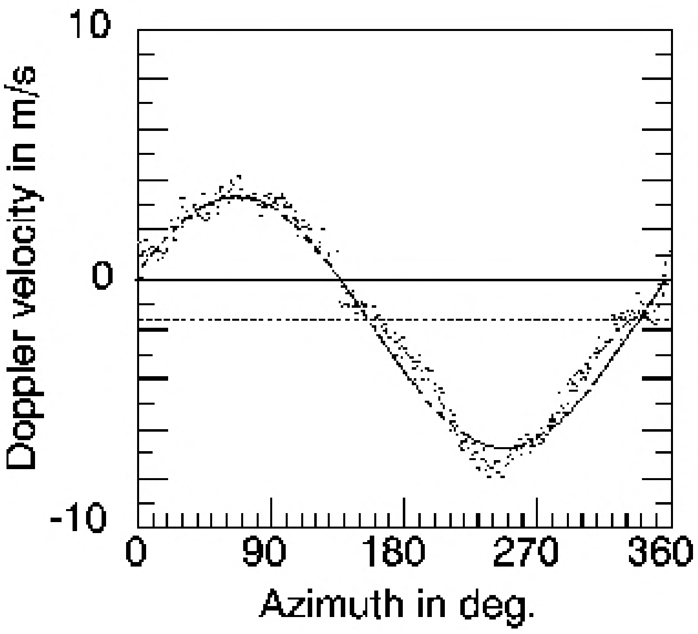


Velocity data (upper right) showed a weak circulation, but spectrum width (lower left) clearly showed high values due to turbulent flow associated with the circulation. **Tornado** associated with circulation in white circle (image is 10-15 minutes prior to touchdown).

Velocity Azimuth Display



Estimation of the wind profile with a PPI at elevation phi. r1 to r3 are different ranges from the radar.



Velocity Azimuth Display (VAD) of the Doppler velocity along a circle. Shown are data points and fitted sine curve. Note a negative offset from the falling velocity of the scattering particles.

ZDR

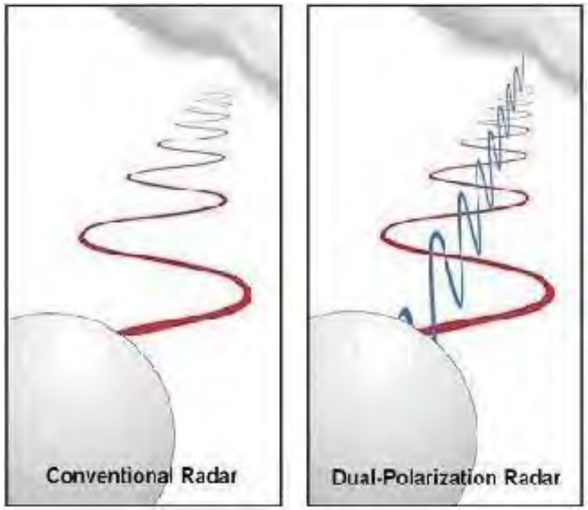
Definition: ratio of the reflected horizontal and vertical power returns.

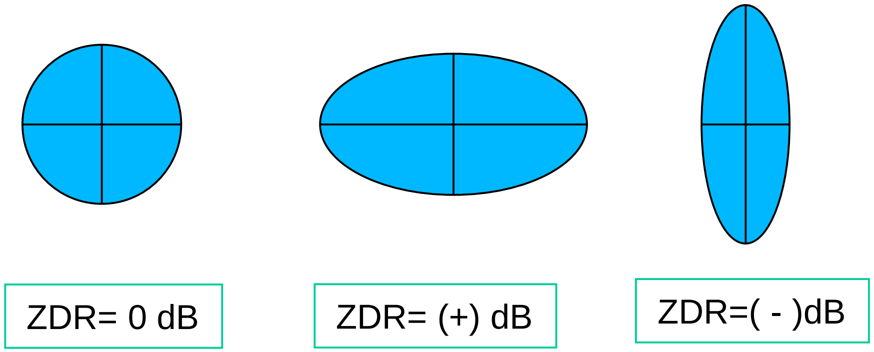
Value depends on the median shape and size of hydrometeors:

Hail often takes on a more spherical shape, and ZDR values closer to zero would likely indicate the presence of hail

Insects are less reflective than precipitation targets and usually have more horizontal extent than vertical when flying through the air

ZDR is also very useful for winter applications, The change in ZDR associated with **winter precip** event indicating transition from liquid to snow.





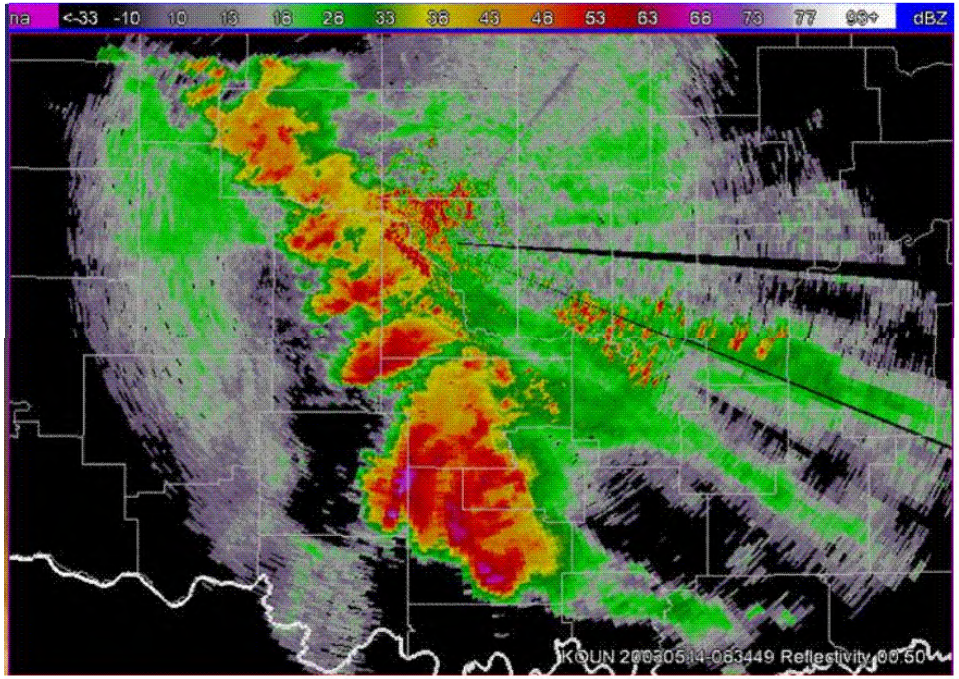
CC

A measure of the correlation of the horizontal and vertical back scattered power within a radar sample volume.

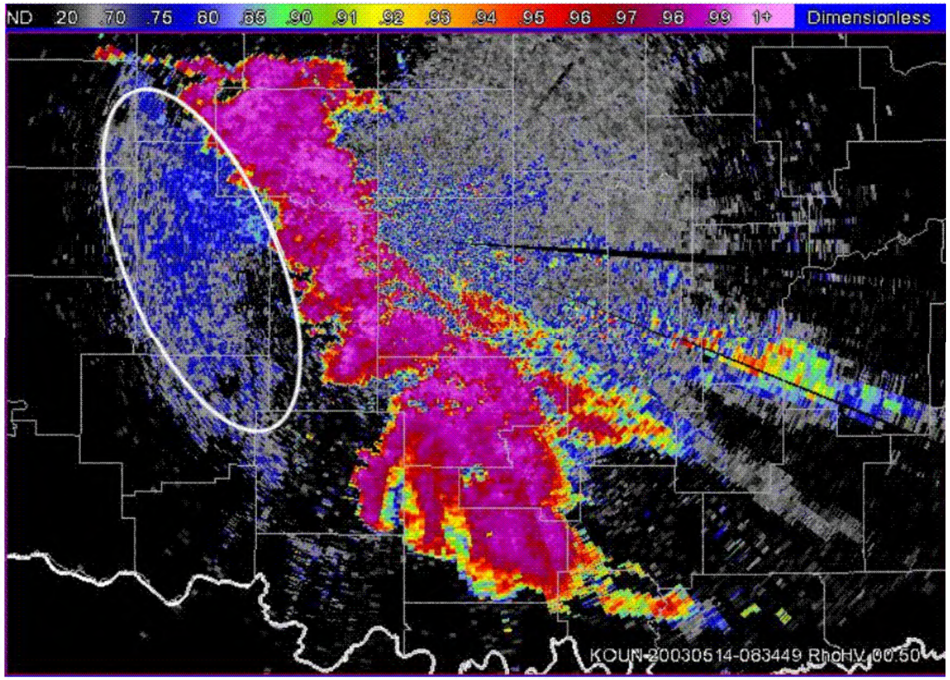
VALUE

0.96 to 1	Small diversity in hydrometeors within the sample
0.85 to 0.95	Large diversity in hydrometeors
< 0.85	Non-hydrometeorological targets

Correlation Coefficient (cc)



Reflectivity (Z)

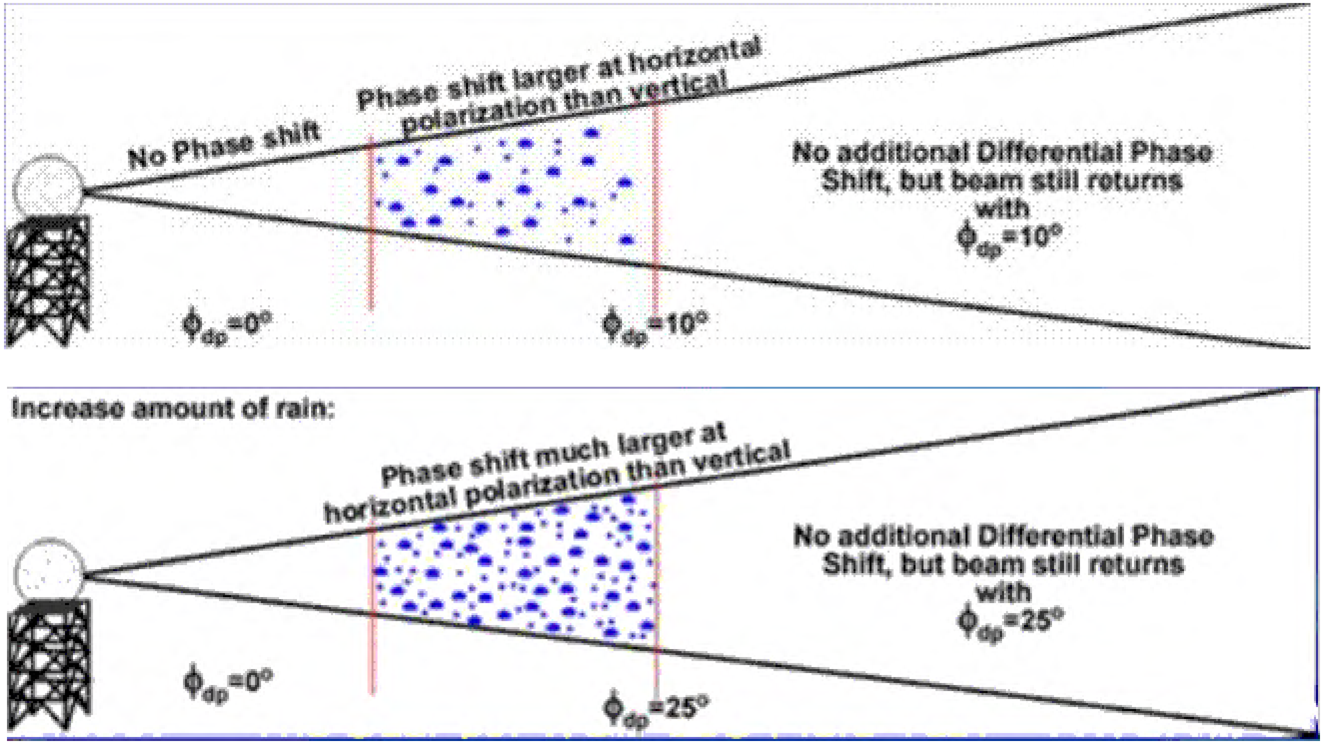


Correlation Coefficient(cc)

Area of weaker returns west of higher reflectivity, characterized by lower values of CC, indicating non-meteorological targets (insects in this case)

KDP

Represents the difference in phase shift between horizontal and vertical polarized returned energy due to forward propagation.
Excellent product to capture higher rainfall rates with certain storms.



Radar data QC at NCEP

1. Input Vr, Ref, Zdr, CC, KDP, SW
2. Non-meteorological echo removal
3. Radial velocity dealiasing
4. Sunbeam removal
5. Calculate QC parameters
6. Migrating bird detection
7. Statistics-based QC

QC Parameters

Mean reflectivity (MRF)

$$MRF = \sum ref(n) / N_{ref}$$

Velocity data coverage (VDC)

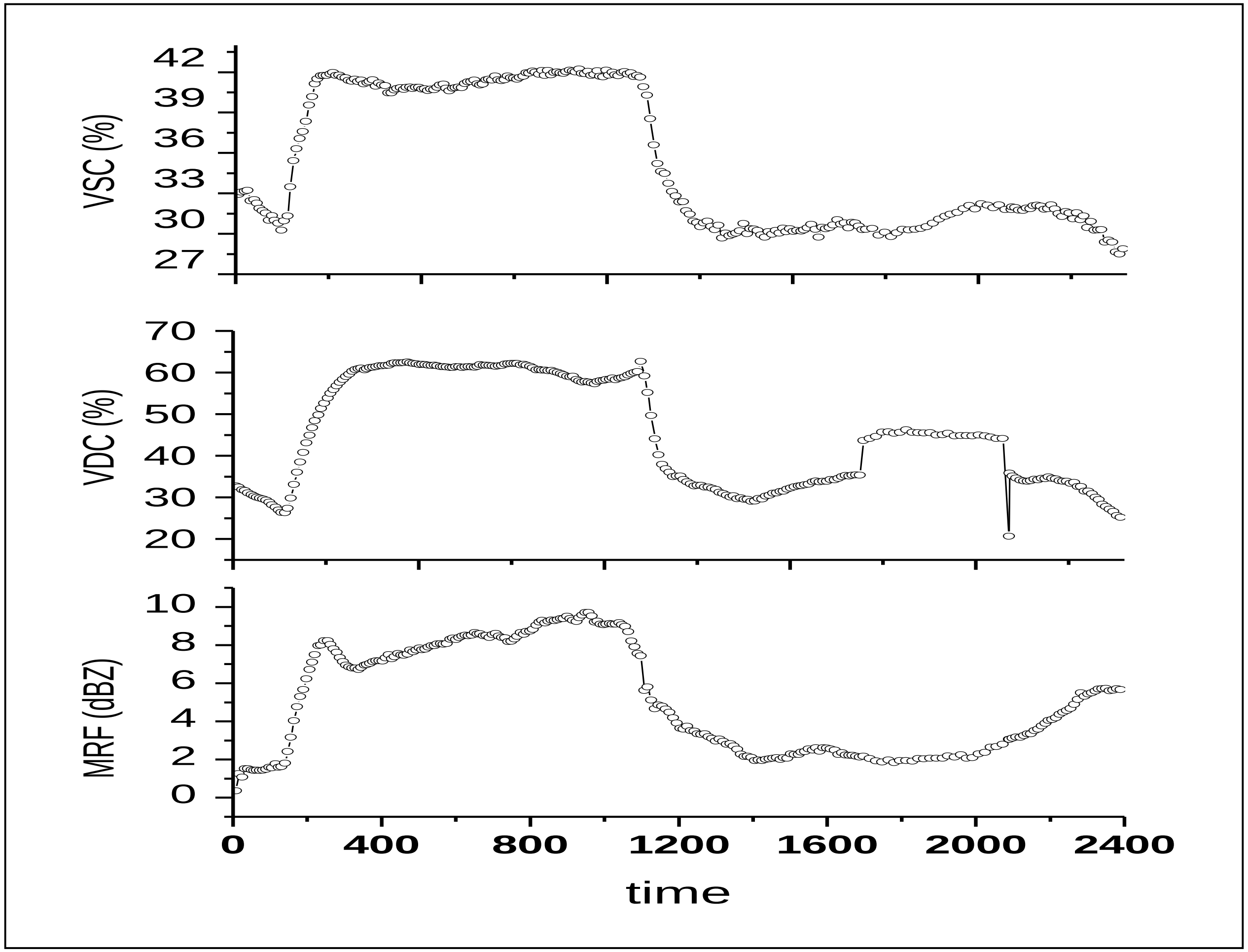
$$VDC = N_{vr} / N_{\max}$$

Along-beam perturbation velocity sign changes (VSC)

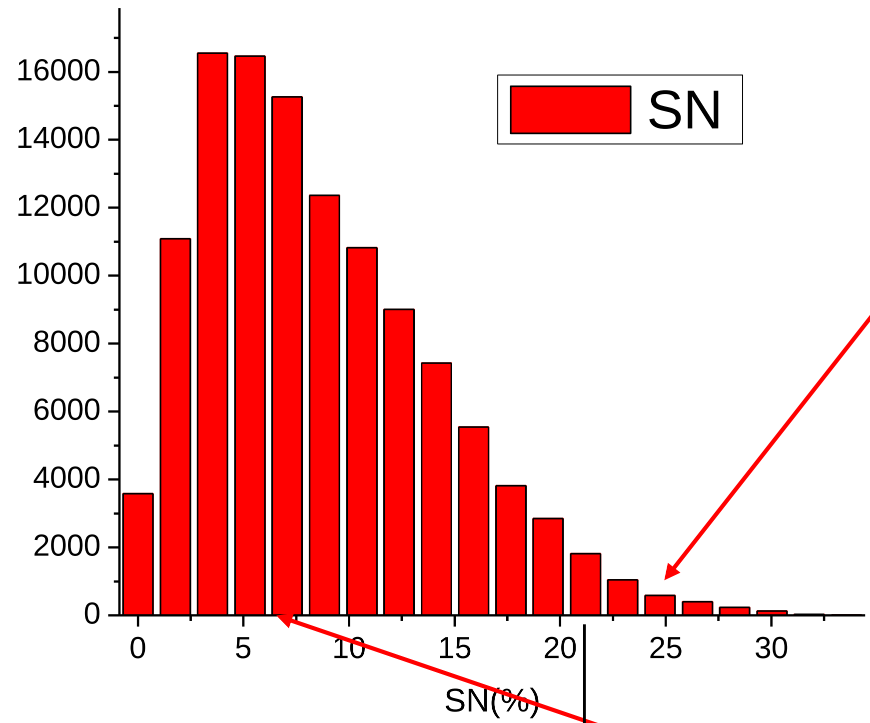
$$VSC = [\sum I_{psc}(j) / I_{vr}(j)] / J_{bm}$$

Along-beam velocity sign changes(SN)
Standard deviation of radial wind (STD)

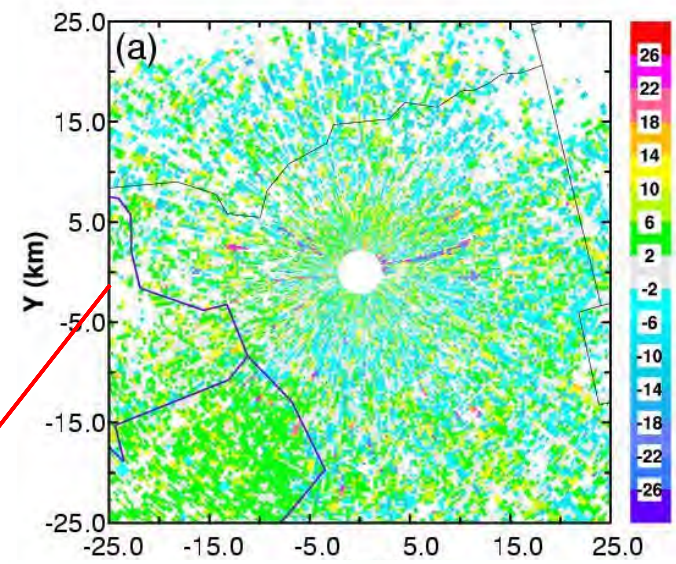
Recorded QC parameters



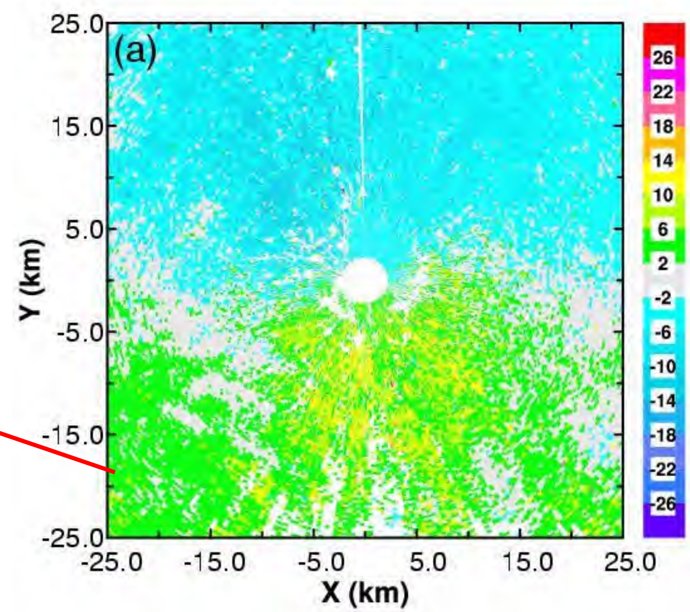
Along beam velocity sign change (SN)



Threshold to reject data

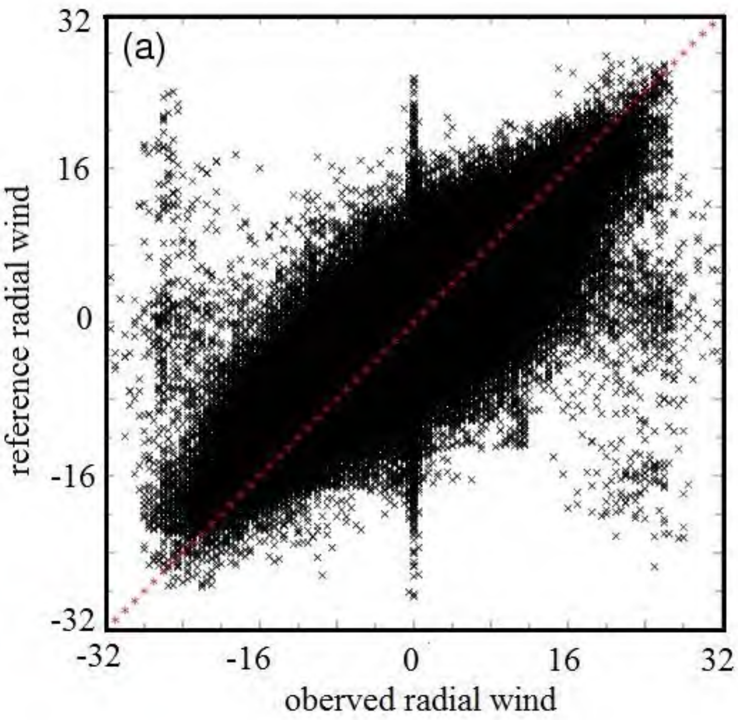


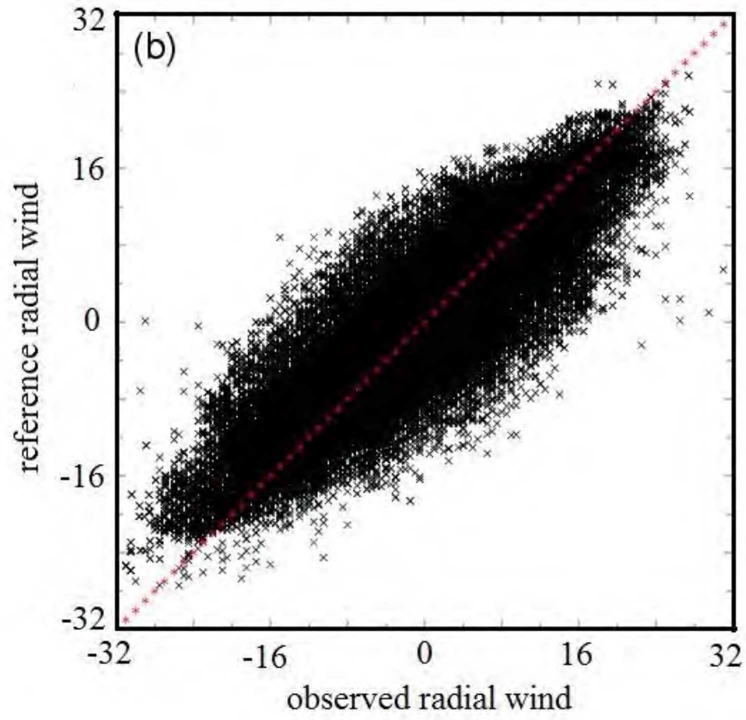
23%



6%

Performance of Radial Wind QC

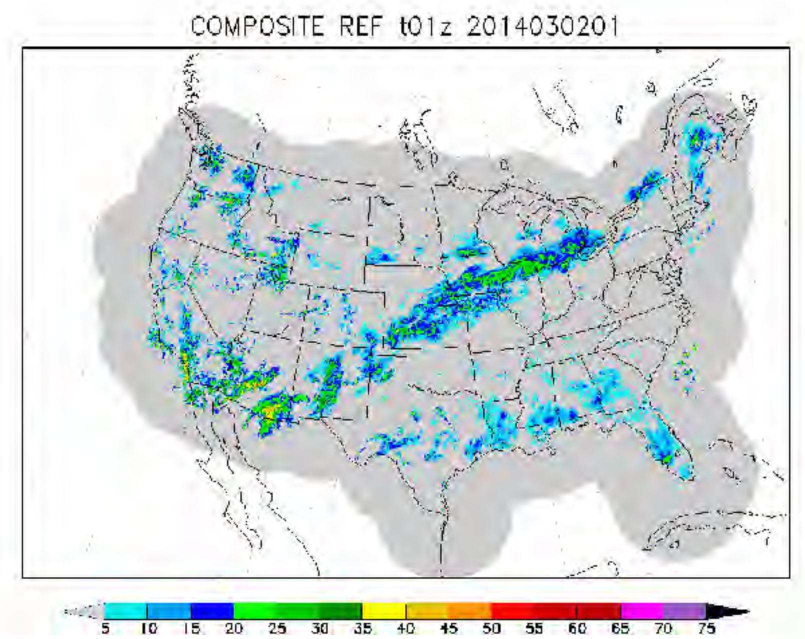


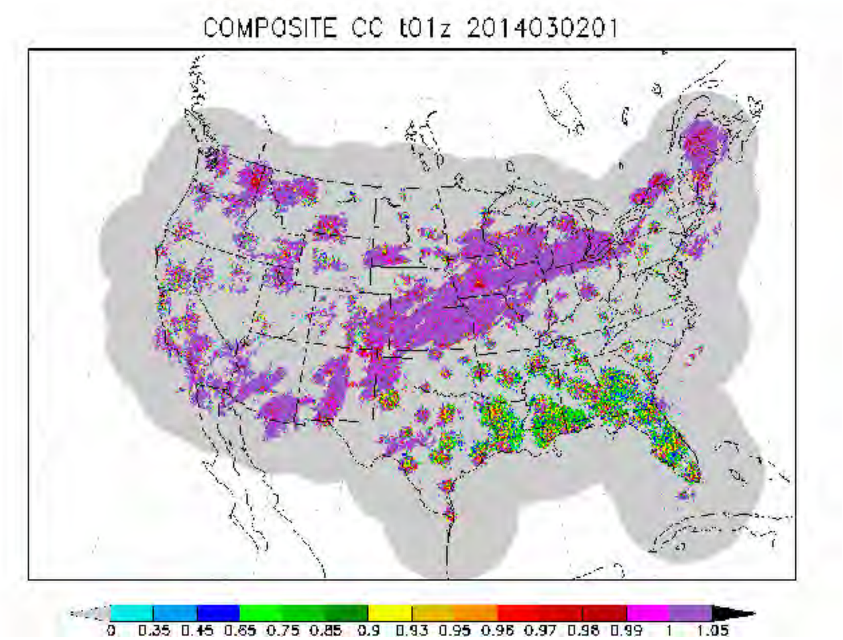


before QC **after QC**

Radar Mosaic vs Satellite Product

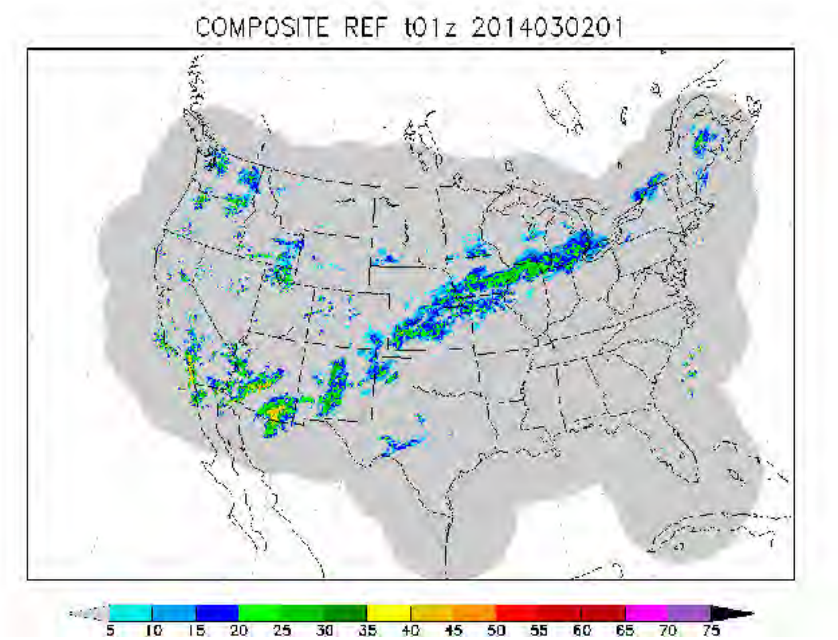
before QC

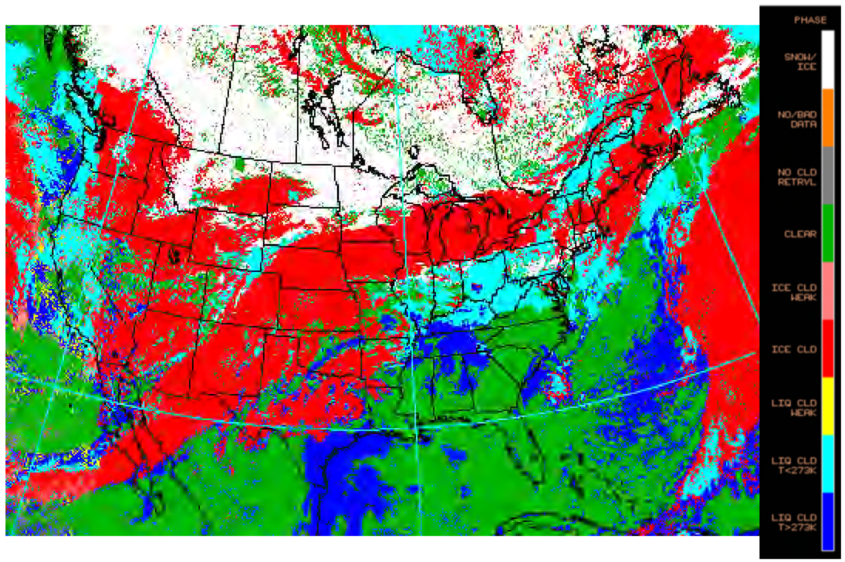




CC

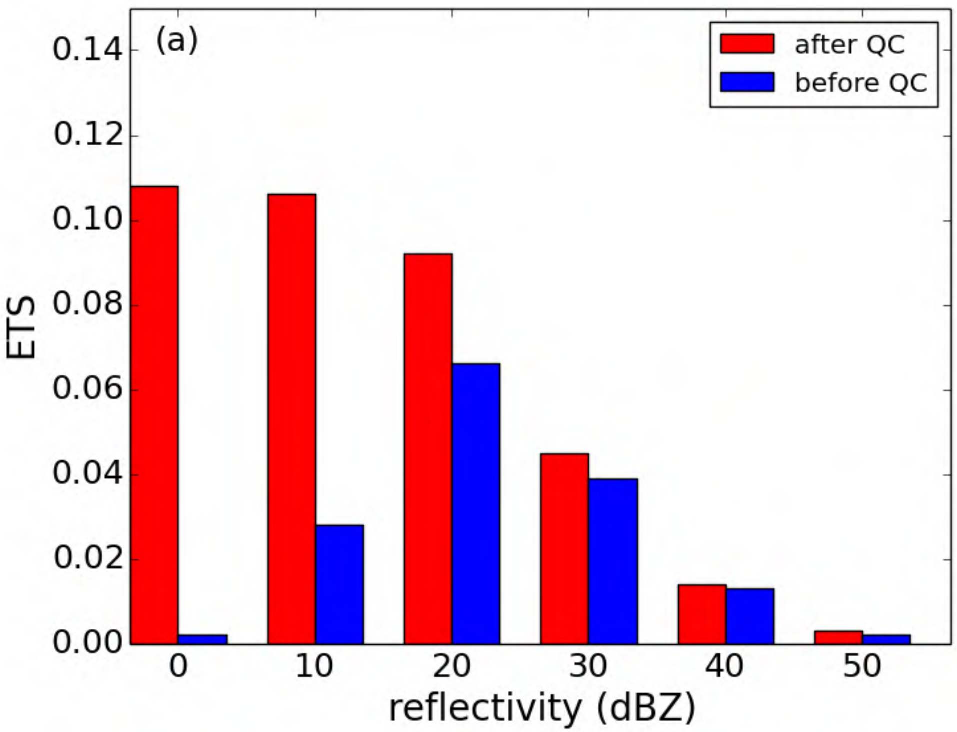
after QC

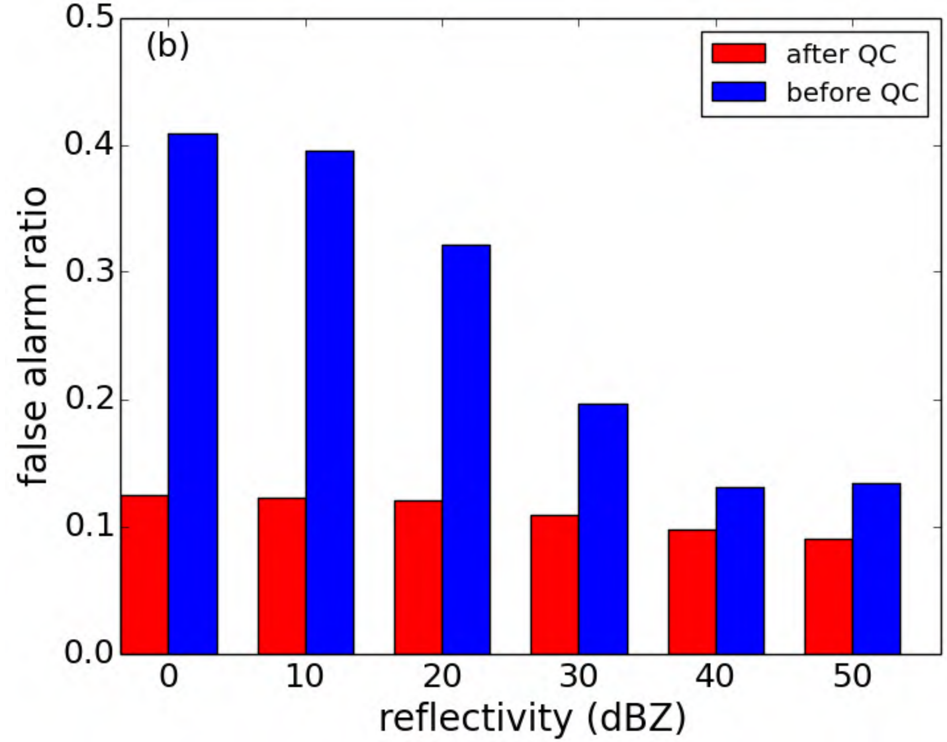




Sat

Performance of Reflectivity QC





Equitable Threat Score and False Alarm Ratio of composite reflectivity coverage against cloud coverage
(Averaged over 2 weeks)

Lightning data at NCEP

NLDN Lightning Variables and Description

004001	YEAR	2015.0	YEAR	YEAR
004002	MNTH	6.0	MONTH	MONTH
004003	DAYS	16.0	DAY	DAY
004004	HOUR	22.0	HOUR	HOUR
004005	MINU	30.0	MINUTES	MINUTES
004006	SECO	5.411	SECONDS	SECONDS
005001	CLATH	37.02378	DEGREES	LATITUDE (HIGH ACCURACY)
006001	CLONH	-89.16837	DEGREES	LONGITUDE (HIGH ACCURACY)
020117	AMPLS	6000.0	AMPS	AMPLITUDE OF LIGHTNING STRIKE
020119	PLRTS	2.0	CODE TABLE	POLARITY OF STROKE
020023	OWEP	8192.0	FLAG TABLE(5)	OTHER WEATHER PHENOMENA
013059	NOFL	1.0	NUMERIC	NUMBER OF FLASHES (THUNDERSTORM)
035200	RSRD	16.0	FLAG TABLE(5)	RESTRICTIONS ON REDISTRIBUTION
035201	EXPRSRD	MISSING	HOURS	EXPIRATION OF RESTRICTIONS ON REDISTRIBUTION

The time of the lightning strike

The location of the lightning flash

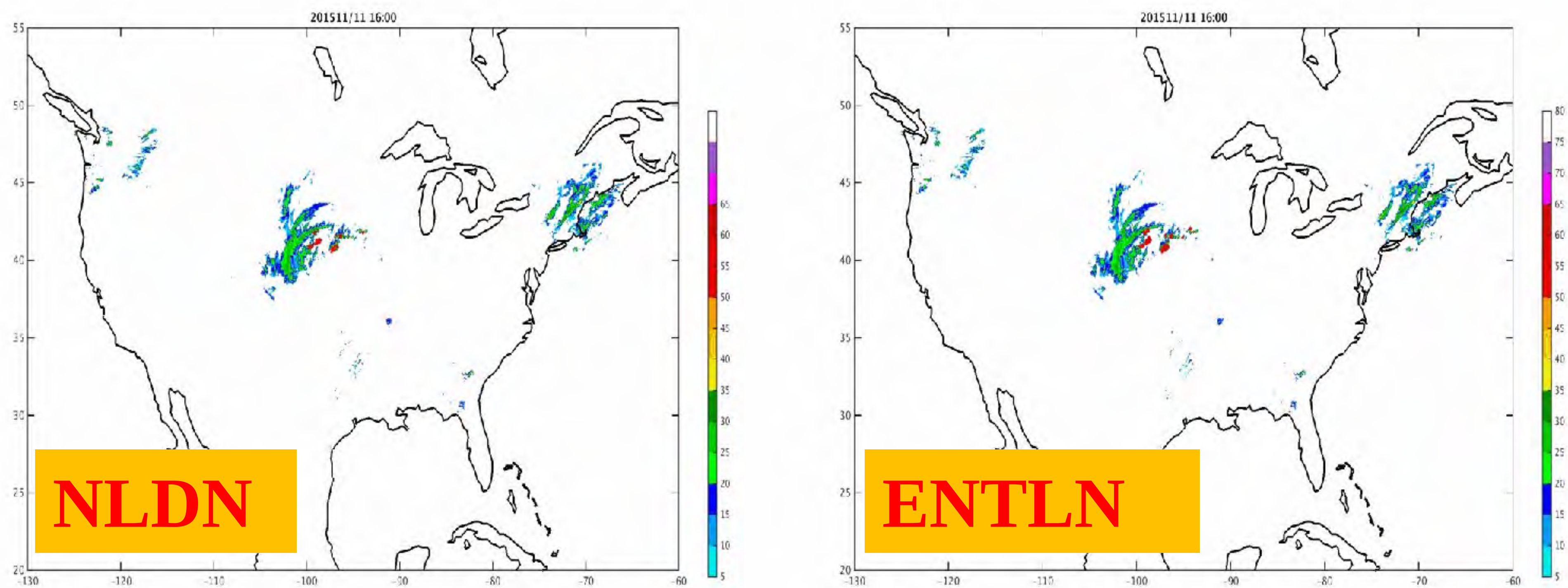
1.0 :positive lightning
2.0 :negative lightning

The strength of the Lightning

4086:Cloud-Cloud Lightning
8192:Cloud-Ground Lightning

The number of the Lightning flash strike of each flash

Lightning data at NCEP



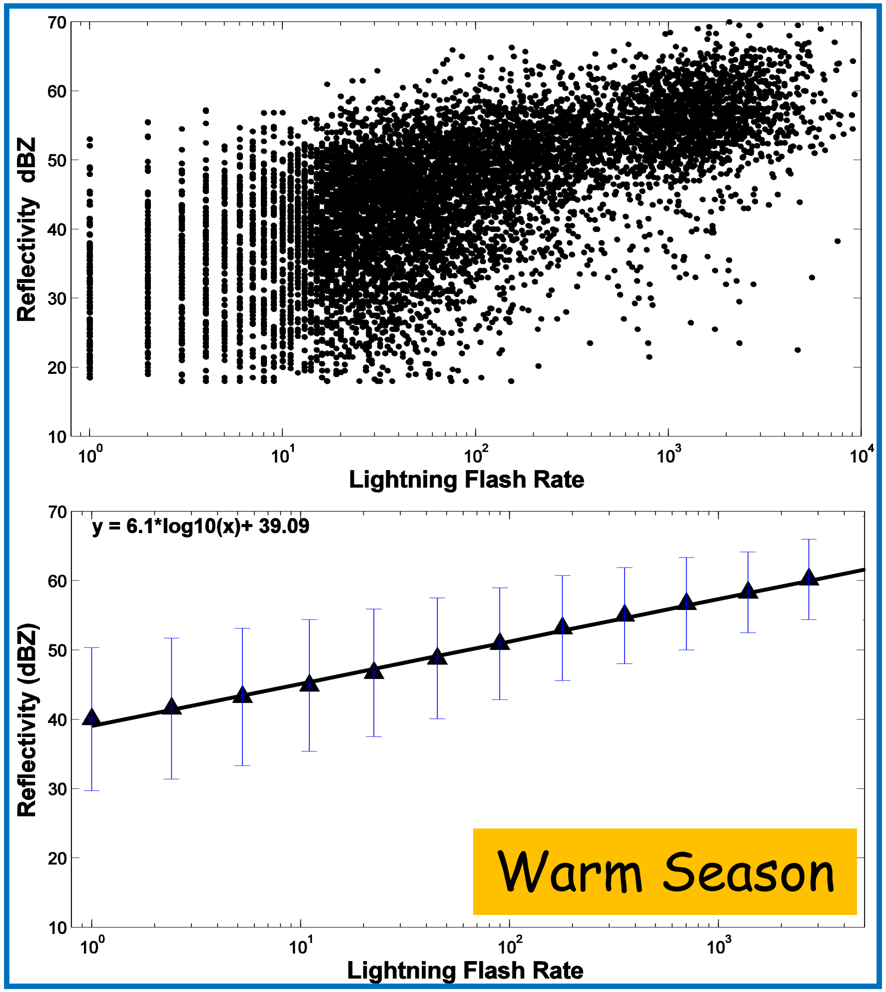
- **NLDN**: **National Lightning Detection Network**
- **ENTLN**: **Earth Networks Total Lightning Network**

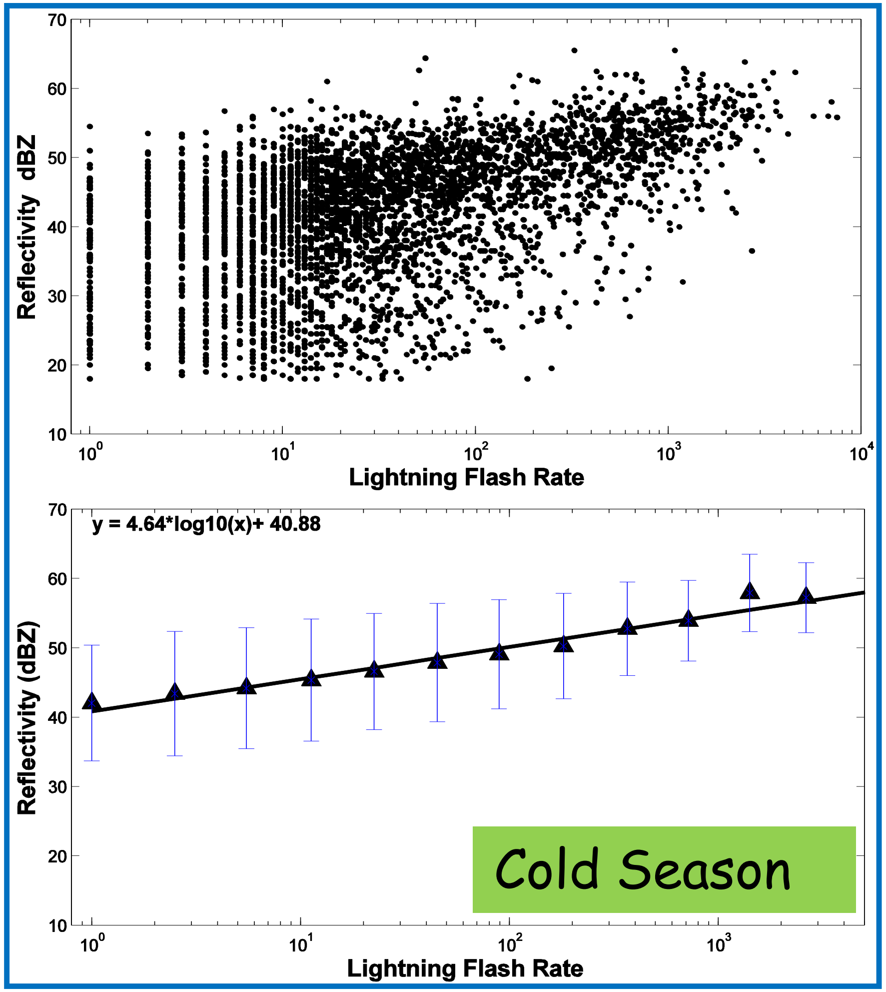
(Unit: flash / 20km**2 /15 min)

Lightning data assimilation

- Lightning data control Kain-Frisch **convection parameterization** scheme and add **water vapor** (Mansell et al. 2007)
- Assimilate retrieved **water vapor** from lightning data using 3DVAR method (Fierro et al. 2013)
- Assimilate lightning data by building forward model between lightning and **CAPE** using 1D+4DVAR method (Stefanescu et al. 2013)
- Assimilate lighting data using ensemble Kalman filter by converting lighting to **rain rate** (Hakim et al. 2008) or graupel volume (Mansell et al. 2014)
- Assimilate lightning data by converting lighting data to **radar reflectivity** using rapid update cycle (Weygandt et al. 2008)

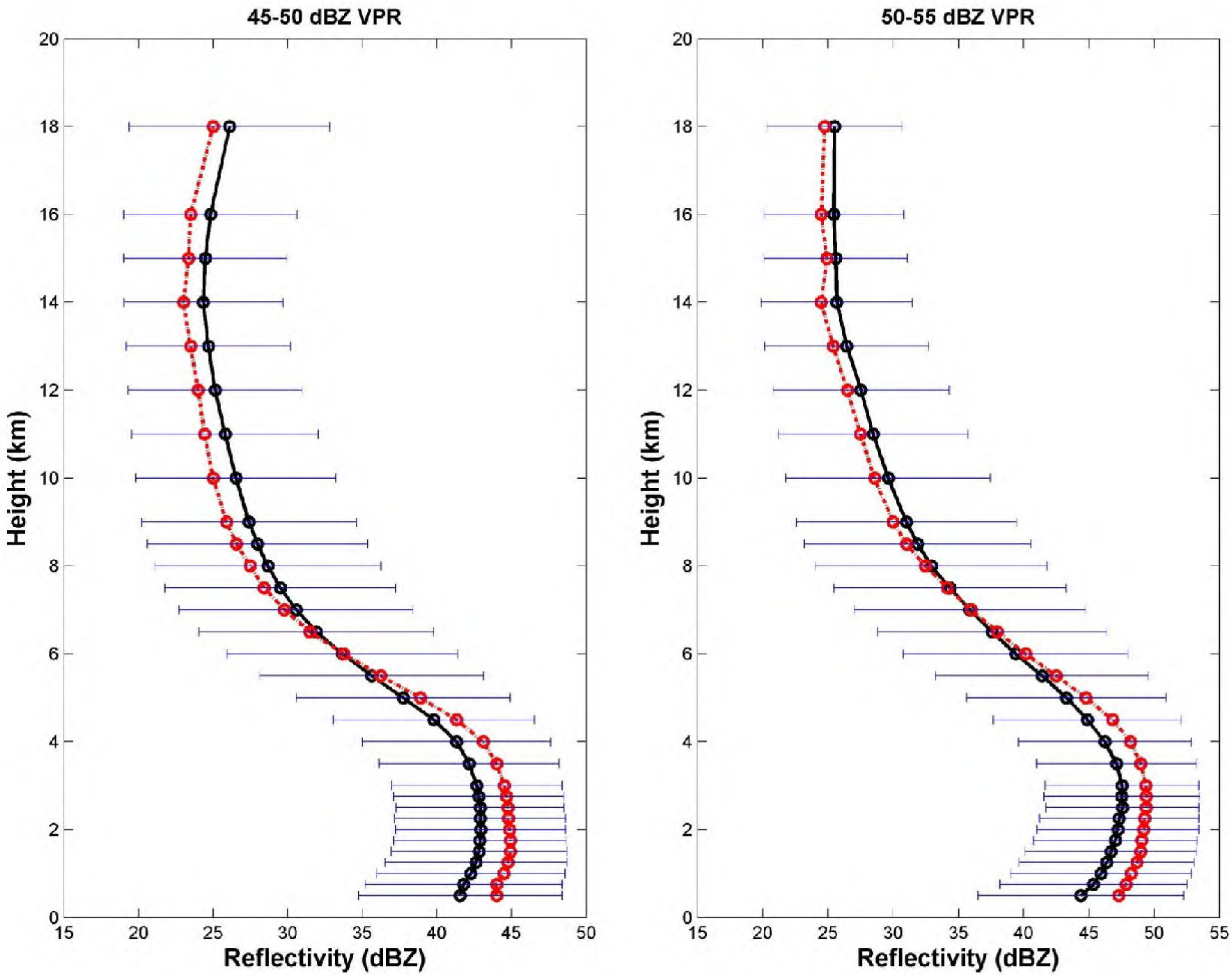
Comparison and Relationship



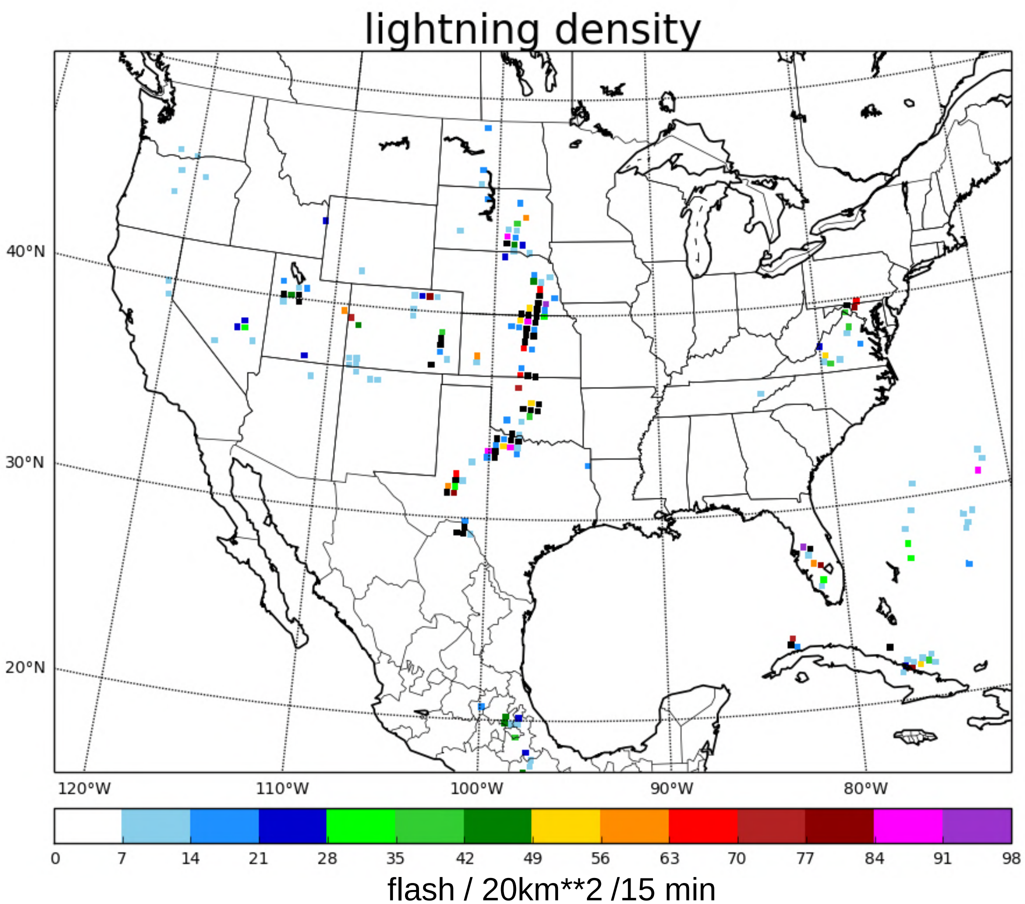


The scatter plots (top) shows the radar reflectivity increases with the increasing of lightning flash rate in both warm and cold season

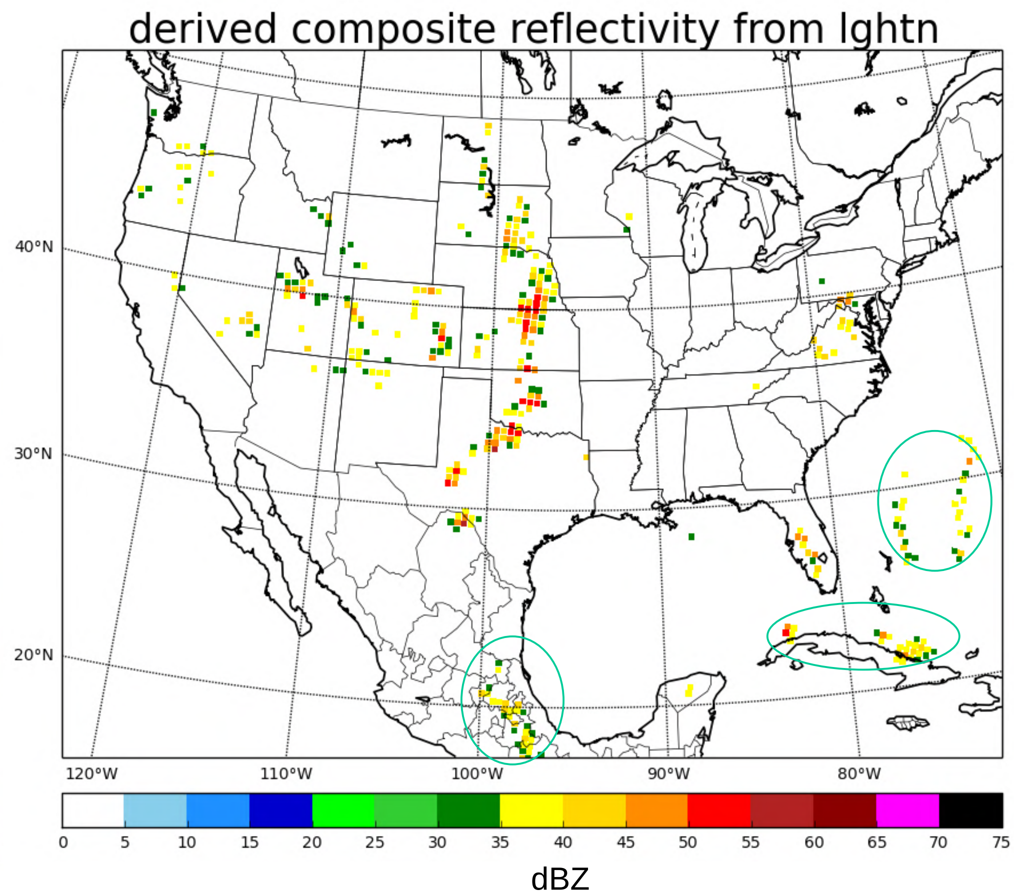
The radar reflectivity is in logarithmic relationship with lightning flash rate (bottom)


45-50 dBZ VPR
Height (km)
Reflectivity (dBZ)
50-55 dBZ VPR
Height (km)
Reflectivity (dBZ)

Proxy Composite reflectivity from Lighting observations



Lightning density



Proxy composite reflectivity

Assimilation of radar radial wind and VAD wind with GSI

- The radial wind and VAD wind are directly analyzed by GSI.
- Hybrid vairational-Ensemble GSI are used

$$J\left(x_{\mathrm{f}}', \boldsymbol{\alpha}\right) = \beta_{\mathrm{f}} \frac{1}{2}\left(x_{\mathrm{f}}'\right)^{\mathrm{T}} B_{\mathrm{f}}^{-1}\left(x_{\mathrm{f}}'\right) + \beta_{\mathrm{e}} \frac{1}{2} \sum_{\mathrm{n}=1}^{\mathrm{N}} \left(\boldsymbol{\alpha}^{\mathrm{n}}\right)^{\mathrm{T}} L^{-1}\left(\boldsymbol{\alpha}^{\mathrm{n}}\right) + \frac{1}{2}\left(Hx_{\mathrm{t}}' - y'\right)^{\mathrm{T}} R^{-1}\left(Hx_{\mathrm{t}}' - y'\right)$$

$$x_{\mathrm{t}}' = x_{\mathrm{f}}' + \sum_{\mathrm{n}=1}^{\mathrm{N}} \left(\boldsymbol{\alpha}^{\mathrm{n}} \circ x_{\mathrm{e}}^{\mathrm{n}}\right)$$

β_{f} & β_{e}: weighting coefficients for fixed and ensemble covariance respectively

$\mathbf{x}_{\mathrm{t}}$': (total increment) sum of increment from fixed/static **B** ($\mathbf{x}_{\mathrm{f}}$') and ensemble **B**

α: extended control variable; x_e:ensemble perturbations

L: correlation matrix [effectively the localization of ensemble perturbations]

Assimilation of radar radial wind and VAD wind with GSI

$$\mathrm{V}_r(\theta,\alpha)=\mathrm{u}\cos\alpha\cos\theta+\mathrm{v}\cos\alpha\sin\theta+\left[\mathrm{w}\sin\alpha\right]$$

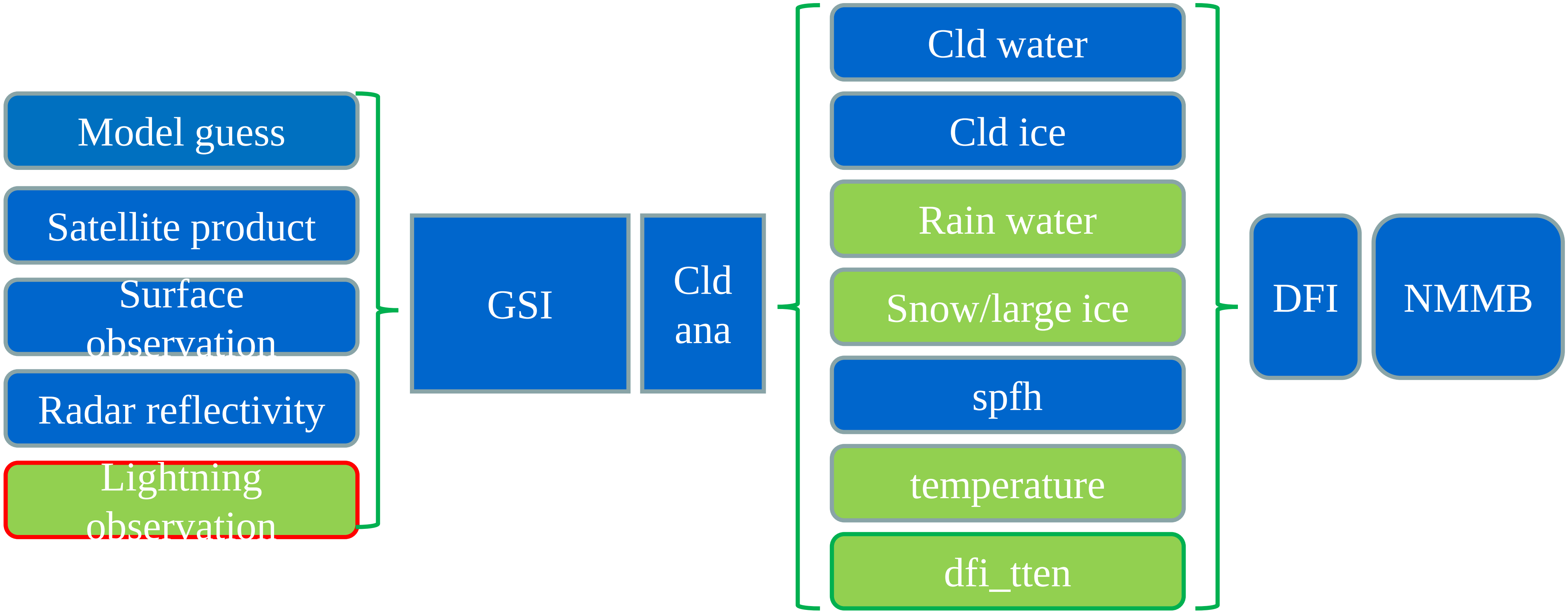
$$W = W_{balance} + W_{unbalance}$$

$$W_{balance} = \frac{\partial h}{\partial t} + u\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y} + \dot{\varsigma}\frac{\partial h}{\partial \varsigma}$$

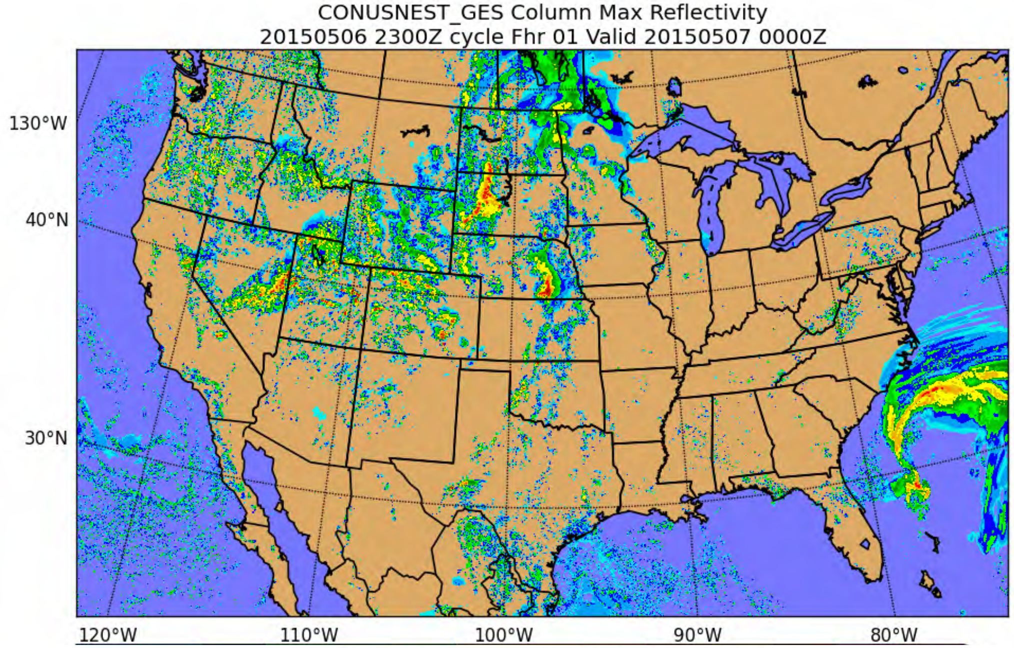
Assimilation of radar reflectivity and lightning data with cloud analysis

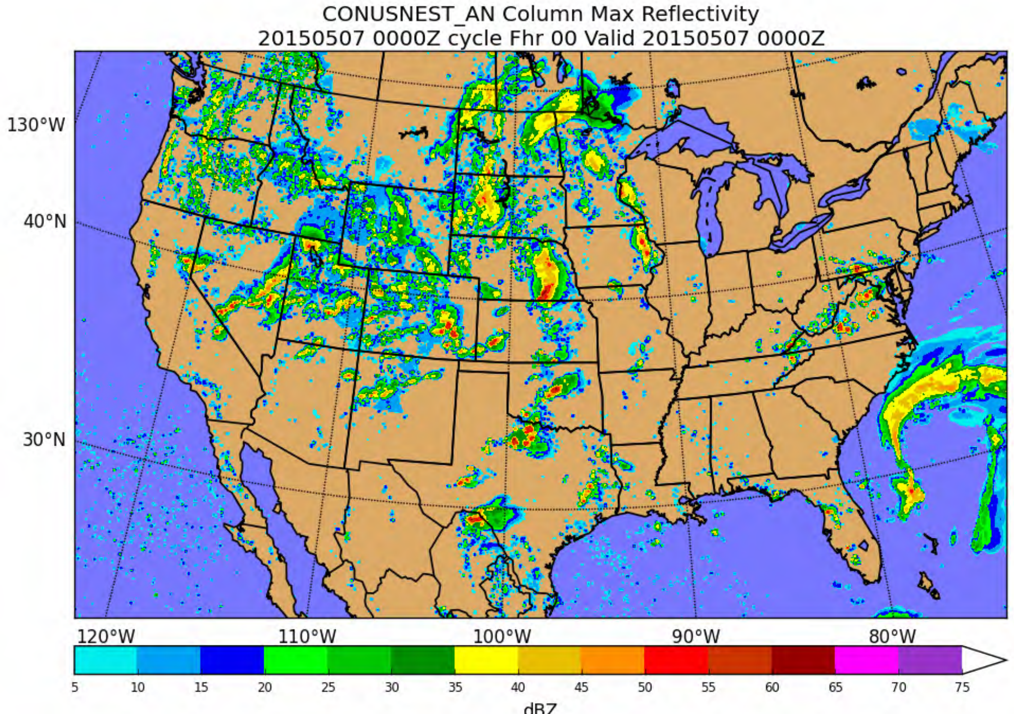
- Cloud analysis originally developed by GSD
- Cloud analysis is used in RAP, HRRR, NDAS and NAM
- Cloud analysis update hydrometeors and temperature
- Satellite product, METAR data and radar reflectivity and lighting are used in cloud analysis

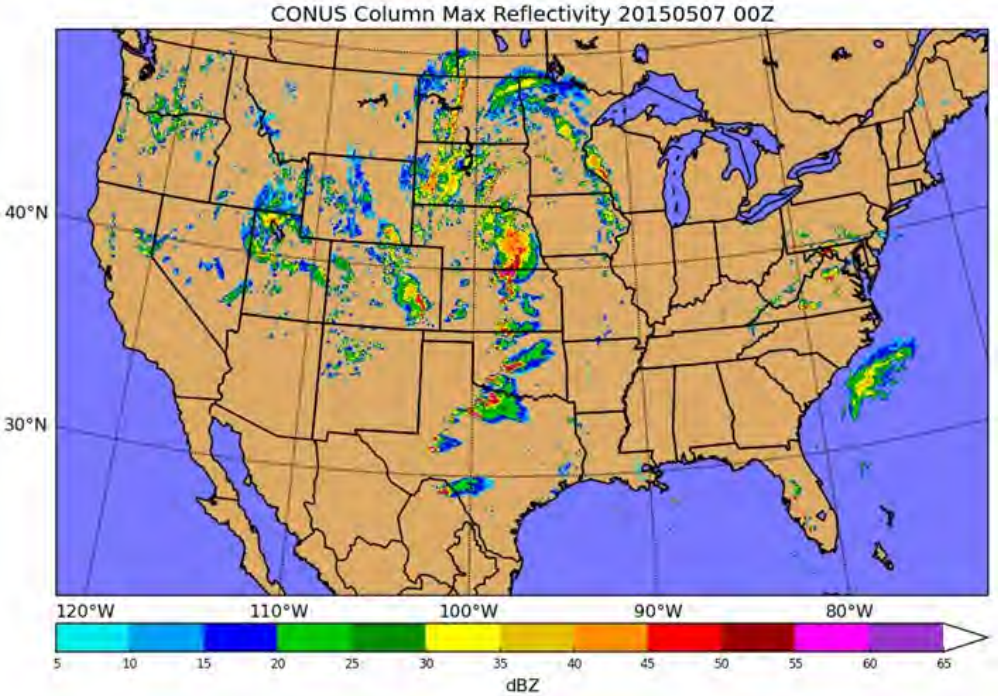
Cloud analysis for NDAS/NAMRR



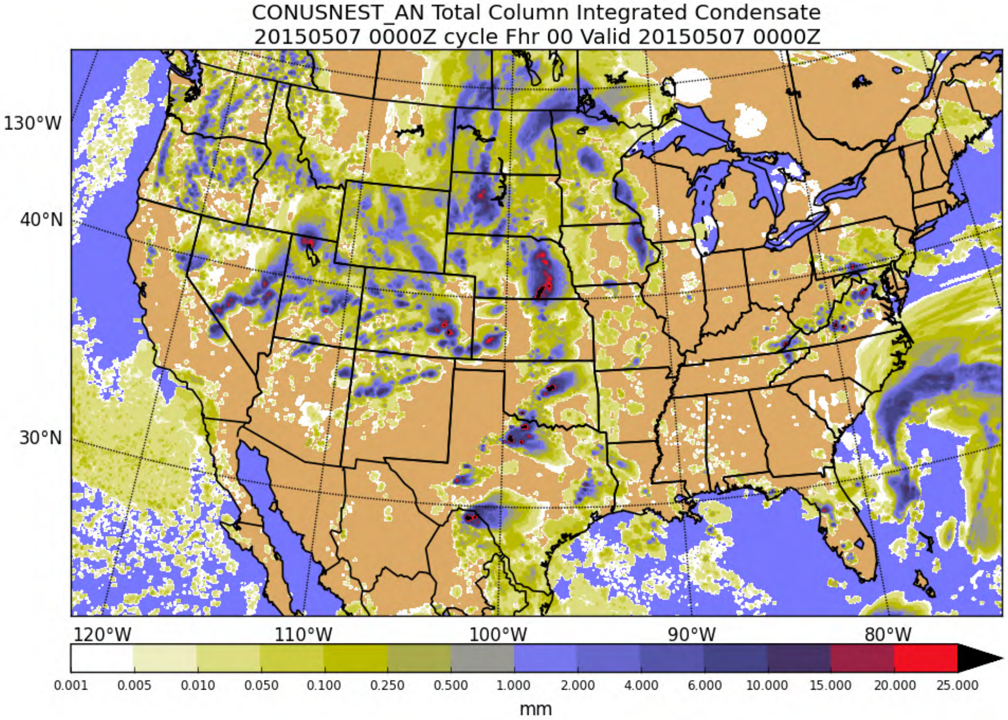
Model guess, analysis and reflectivity observation

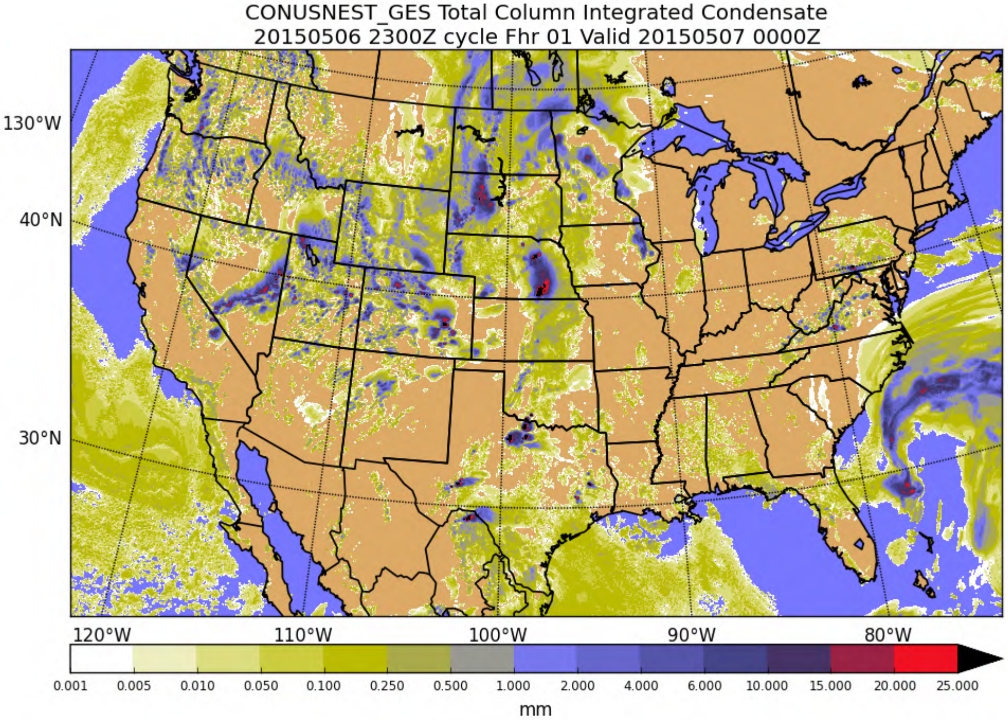




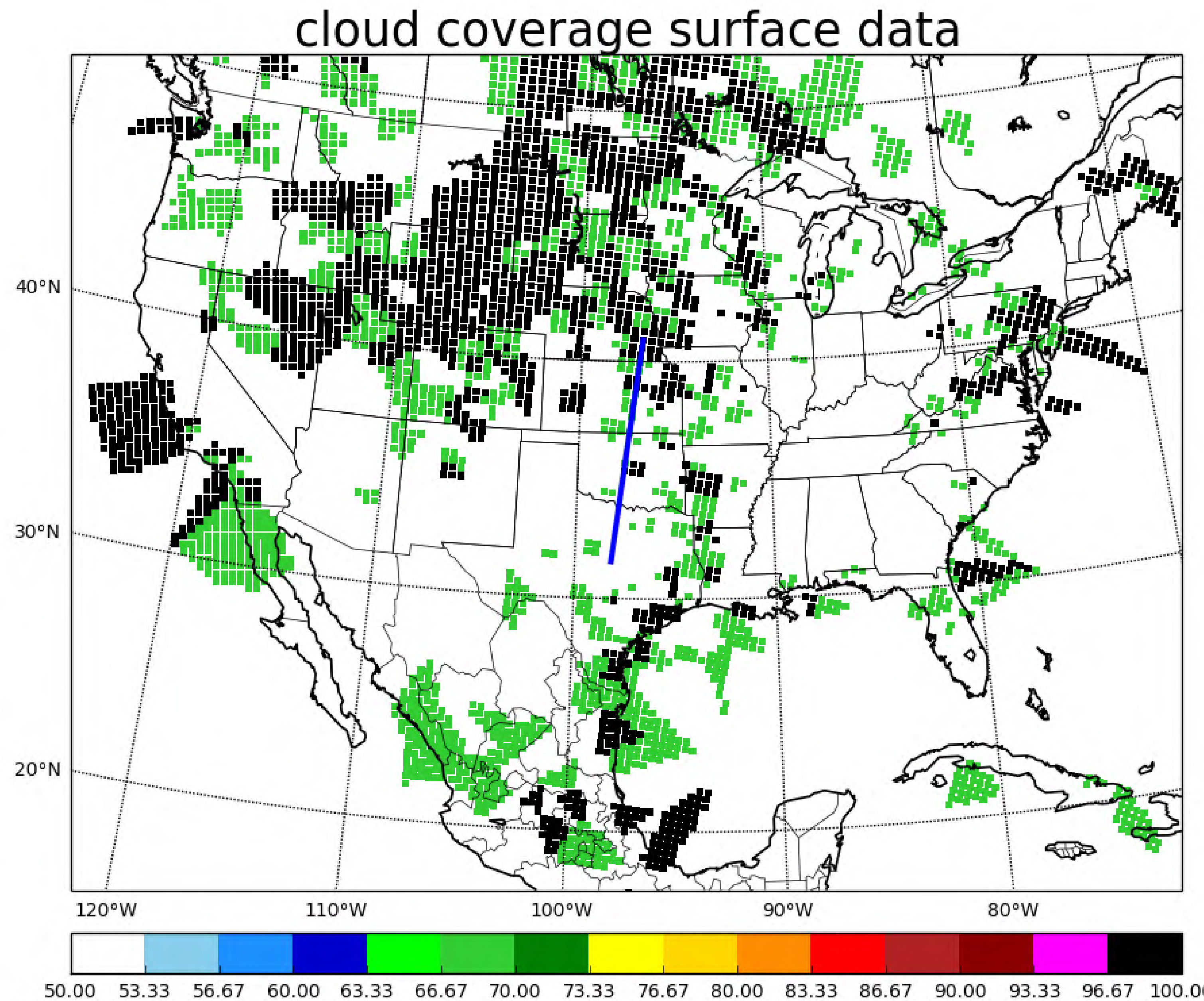


Total condensate: guess and analysis

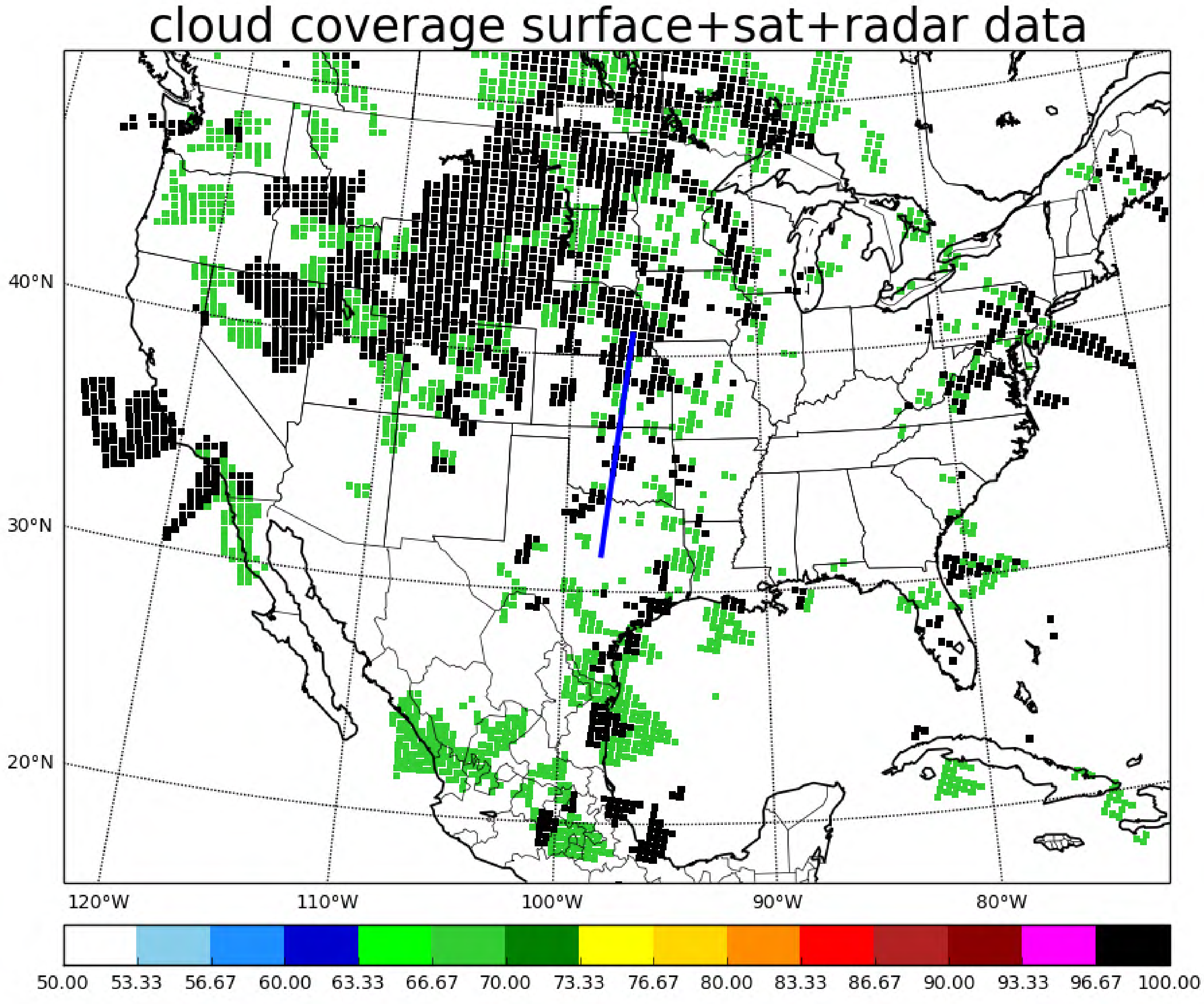




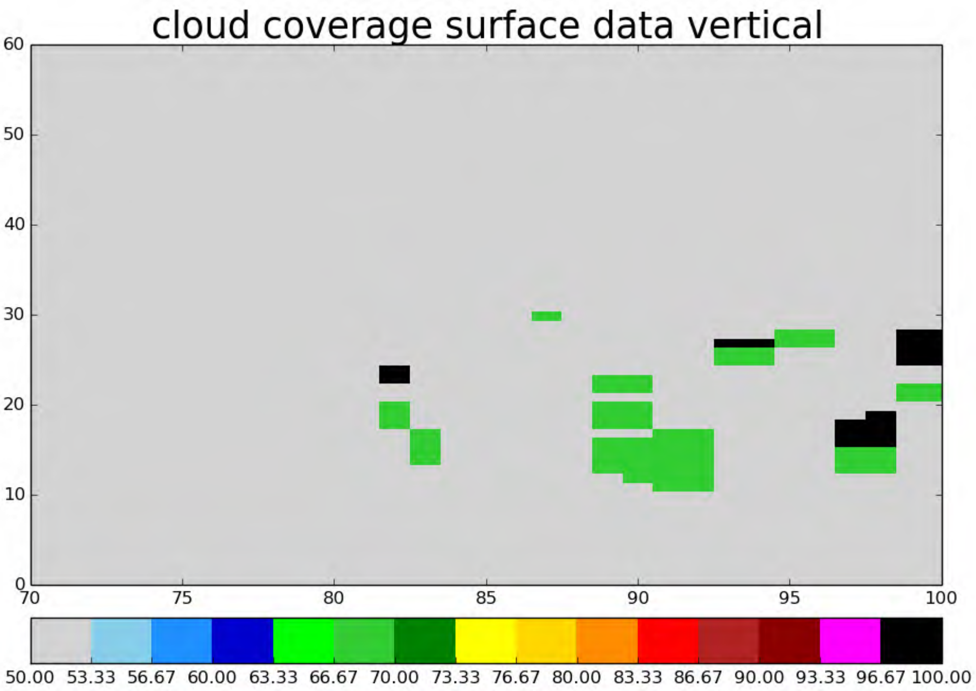
Cloud detection with obs

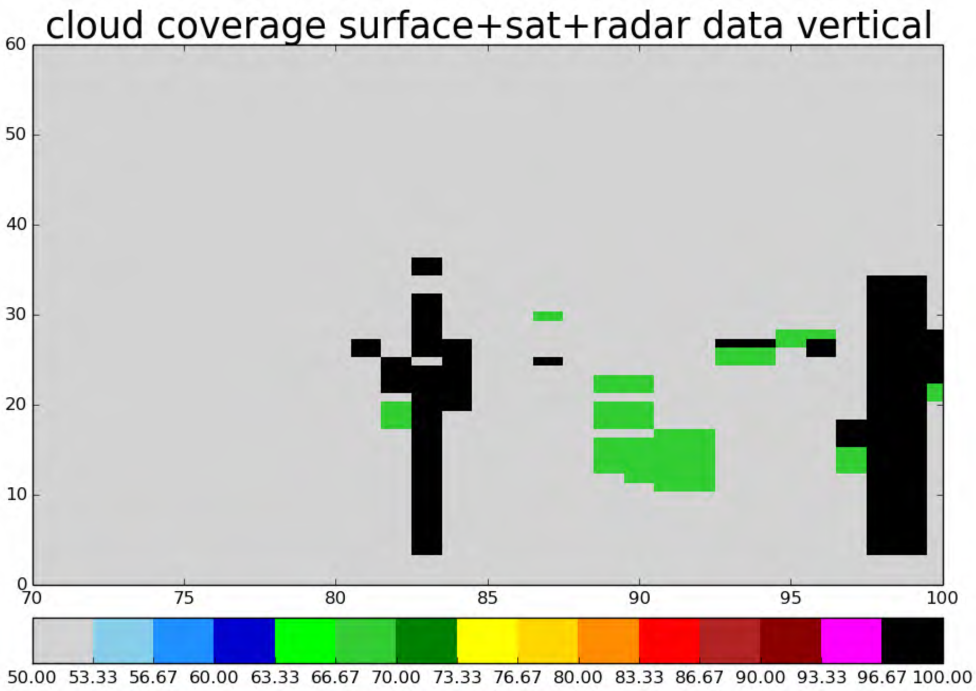


cloud detection with obs



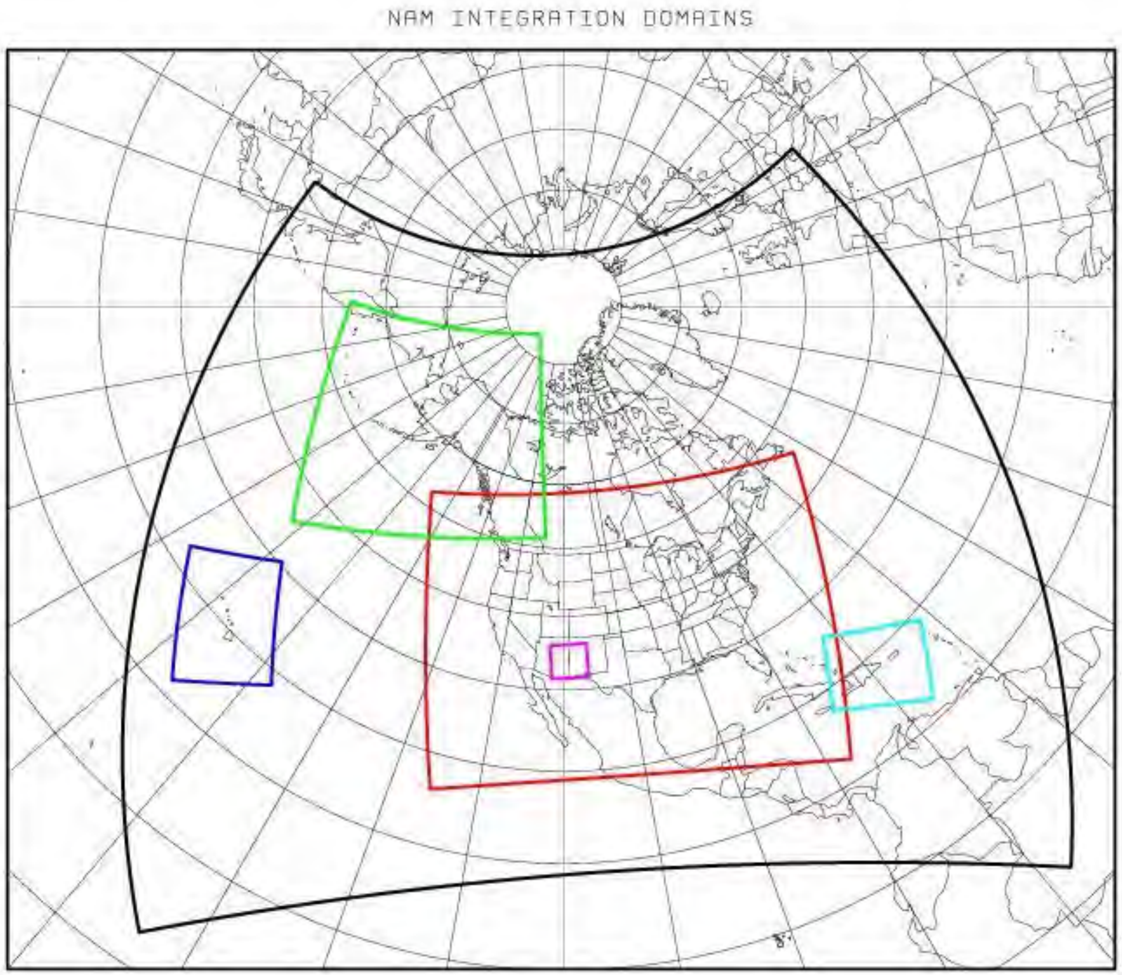
Build cld coverage with obs





Forecast Initialization

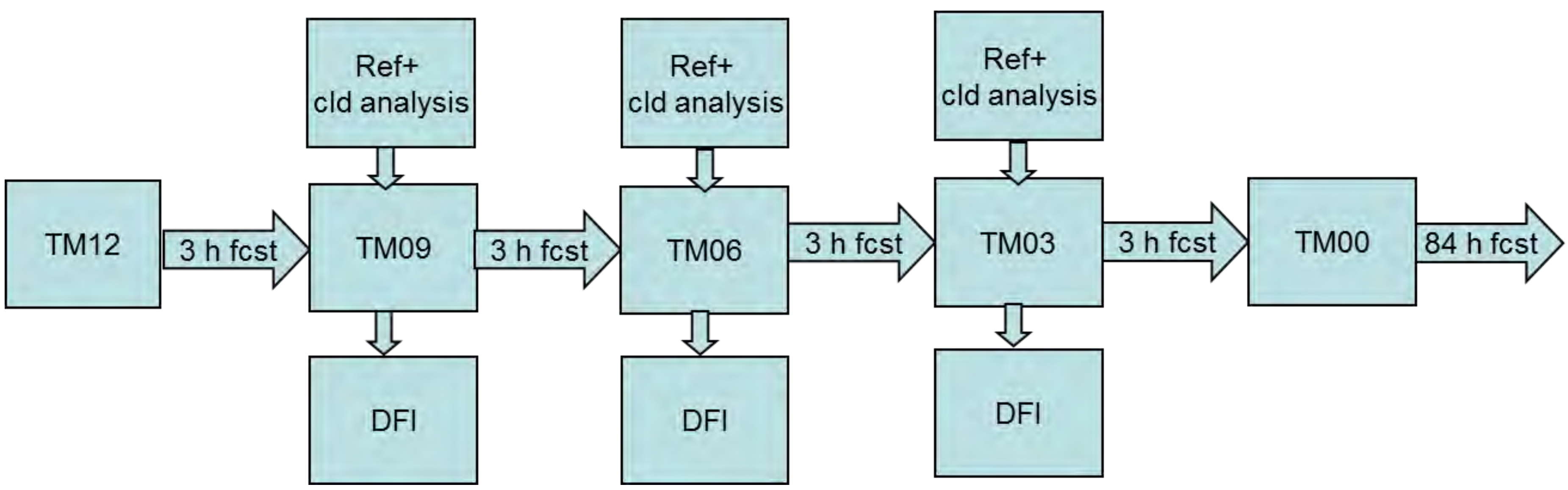
NAM: North American Model
NDAS: NAM Data Assimilation



- 12 km resolution for parent domain
- 3 km resolution for CONUS nest

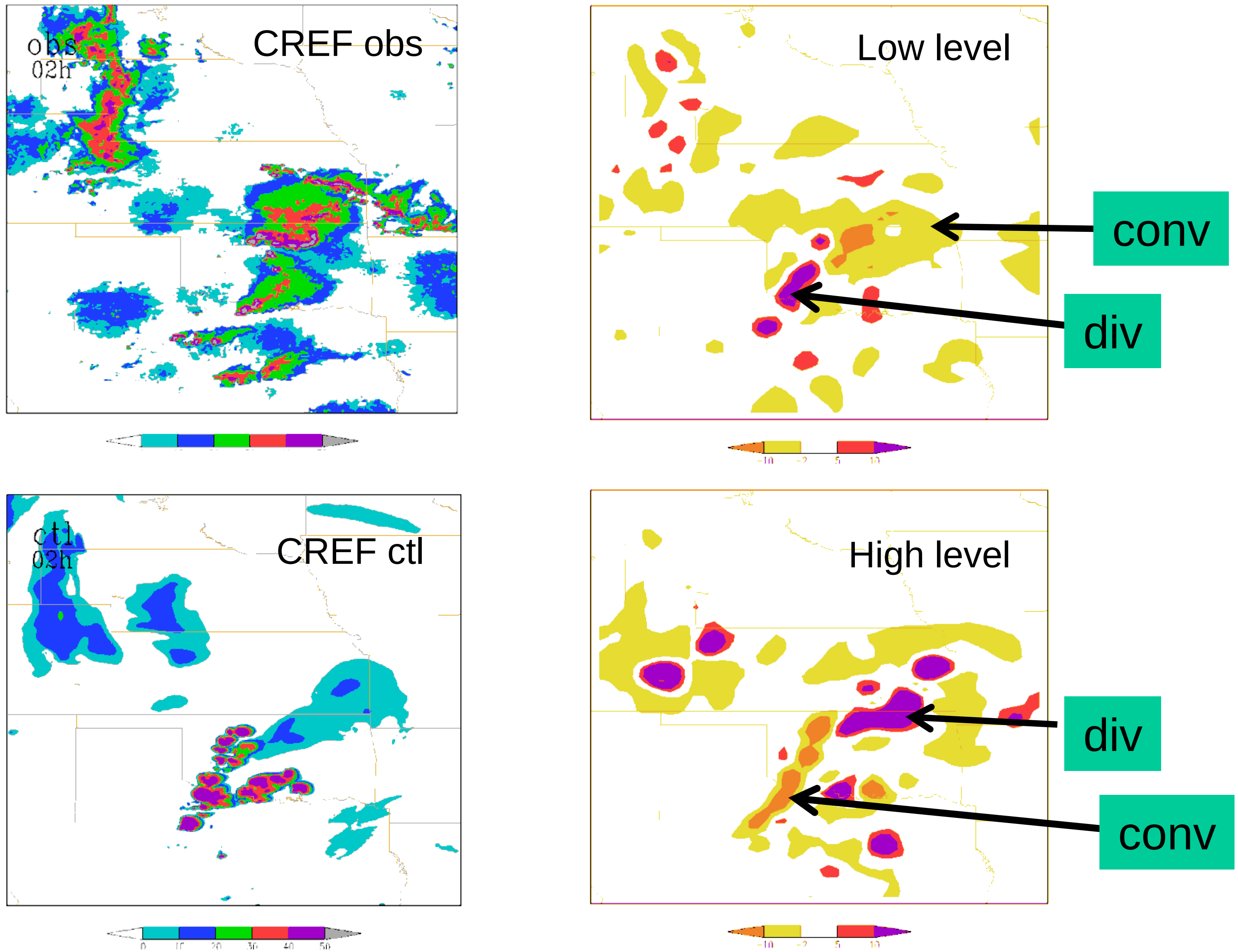
Use cloud analysis in NAMv3 Data Assimilation System (NDAS)

- Hybrid varational-Ensemble GSI is employed.
- VAD & radial wind are directly analyzed by GSI.
- GSD cloud analysis + DFI are used to assimilate radar reflectivity
- Metar and Satellite observations are used in cloud analysis to detect cloud.
- Latent heat rate estimated from reflectivity.
- Wind, cloud water and cloud ice mixing ratio and specific humidity are updated.



Effect of temperature tendency update

EXP-CTL divergence
at end of assimilation cycle

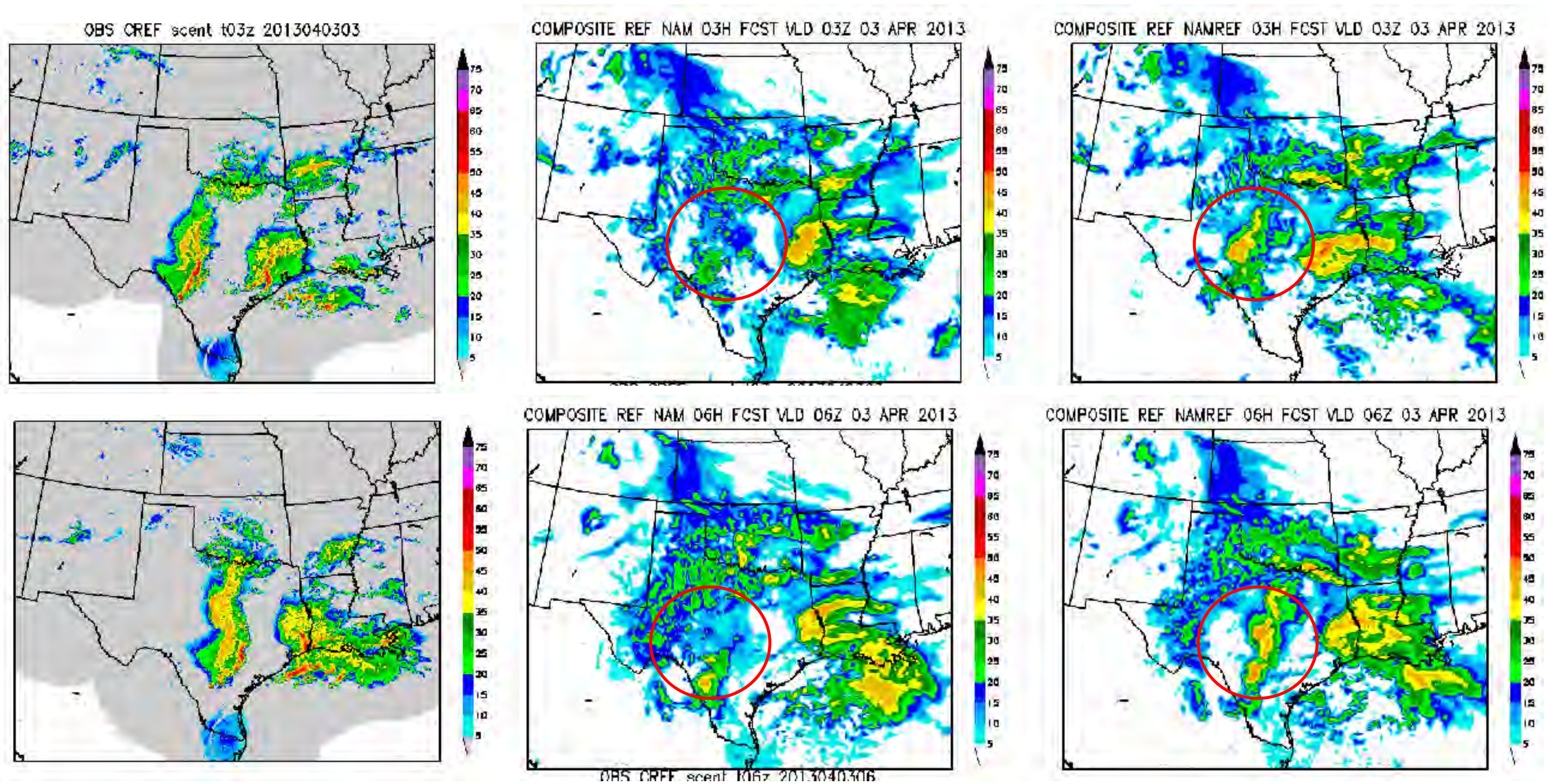


Performance of Reflectivity Assimilation with Cloud Analysis

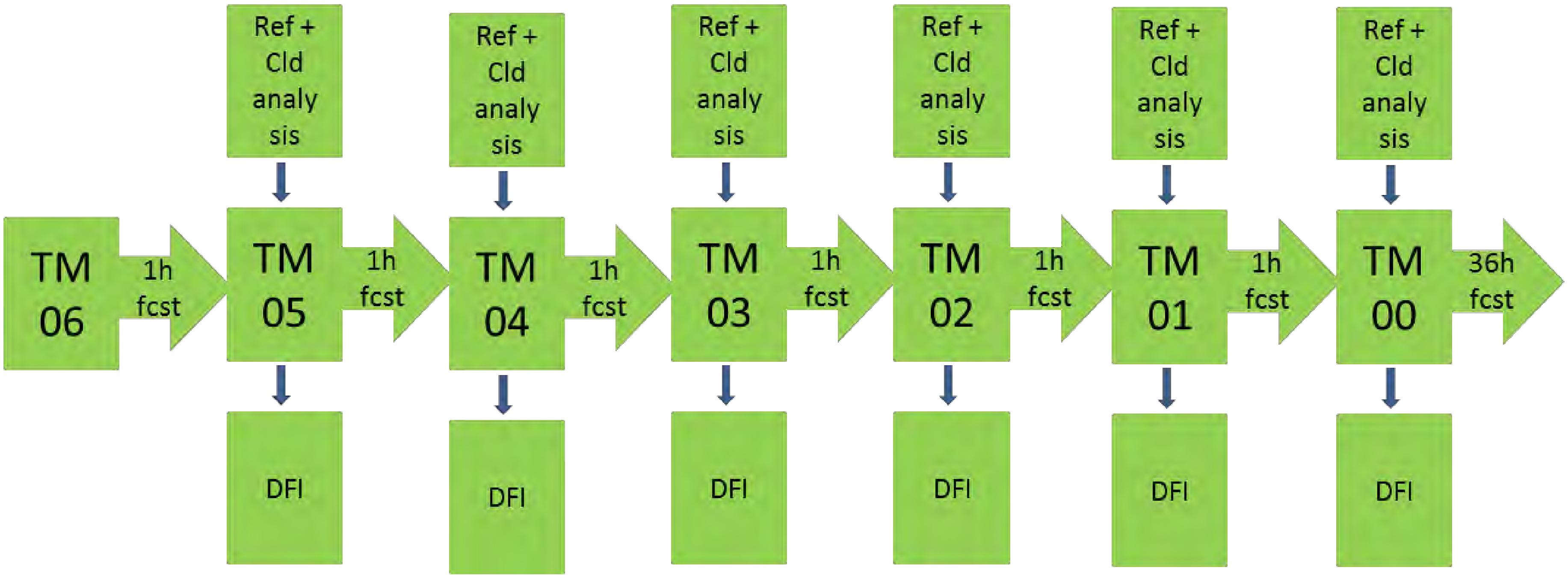
OBS NOREF REF

F03

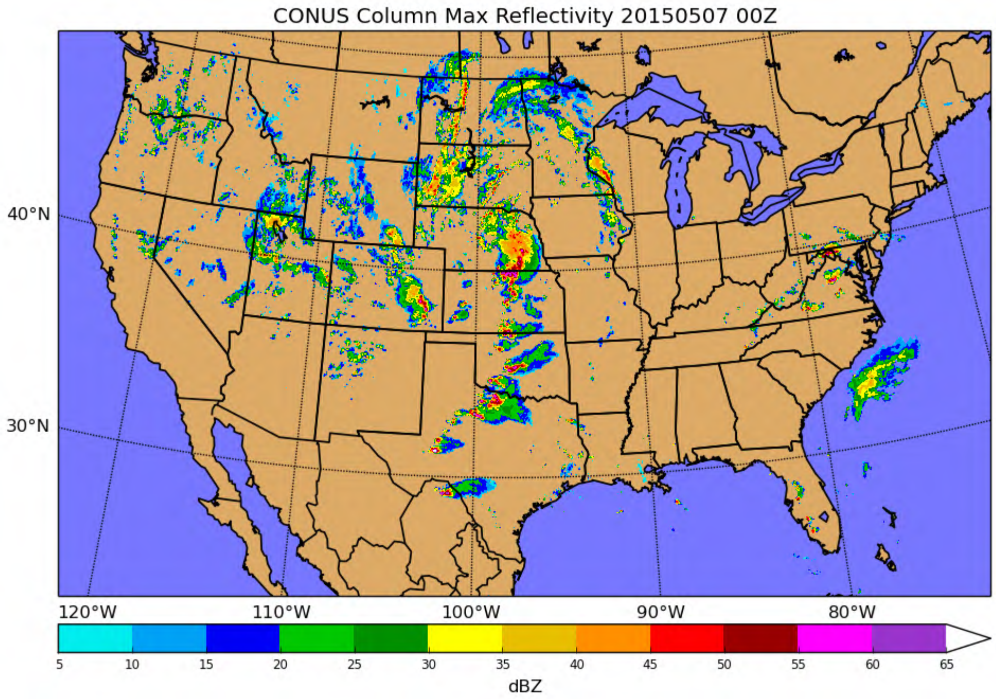
F06

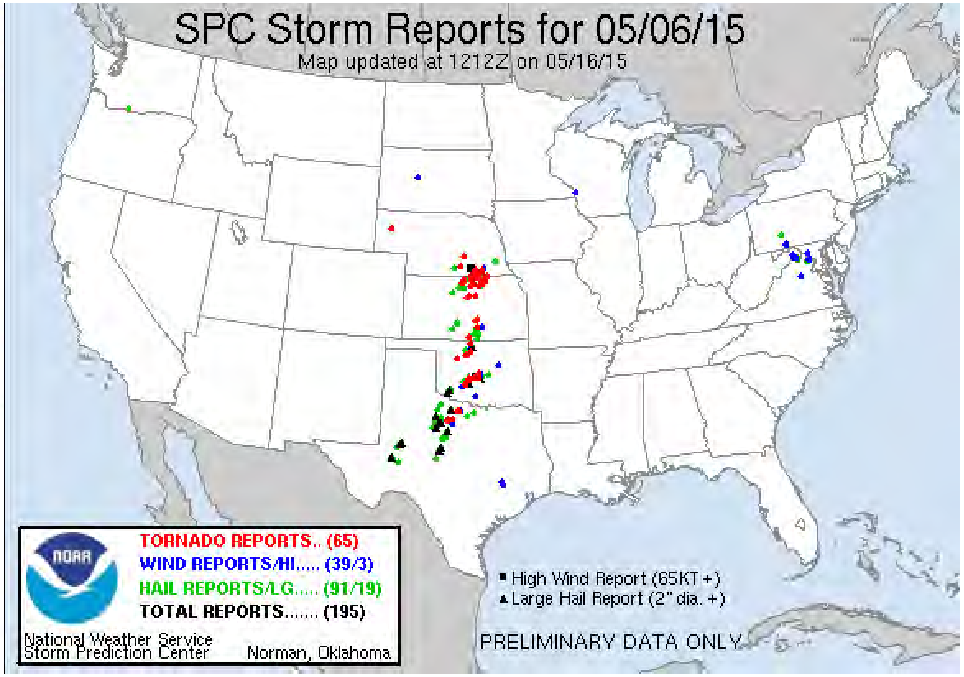


Use radar and lighting data in NAMv4

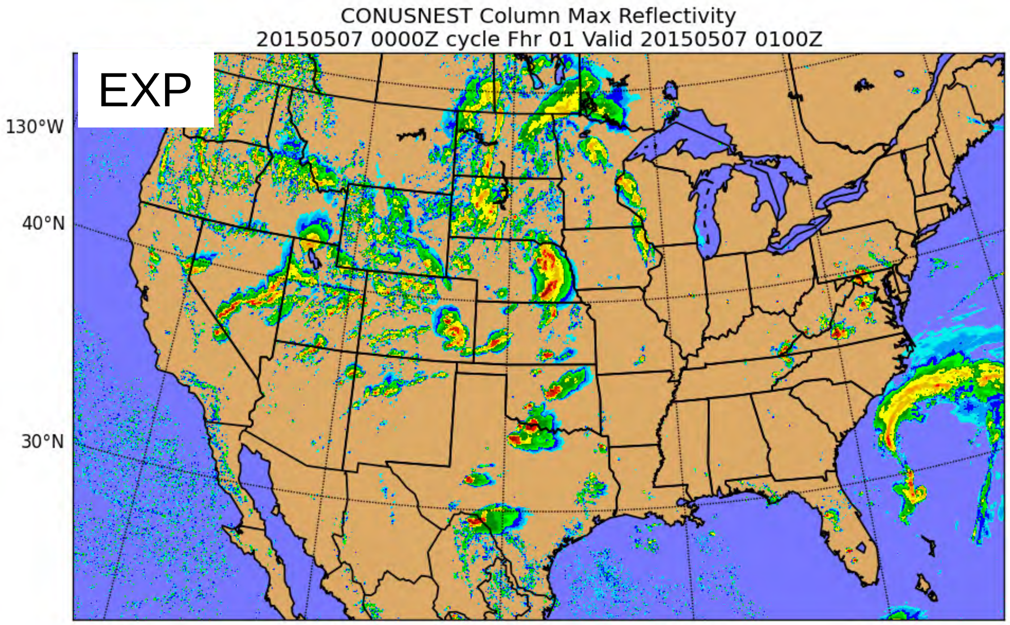


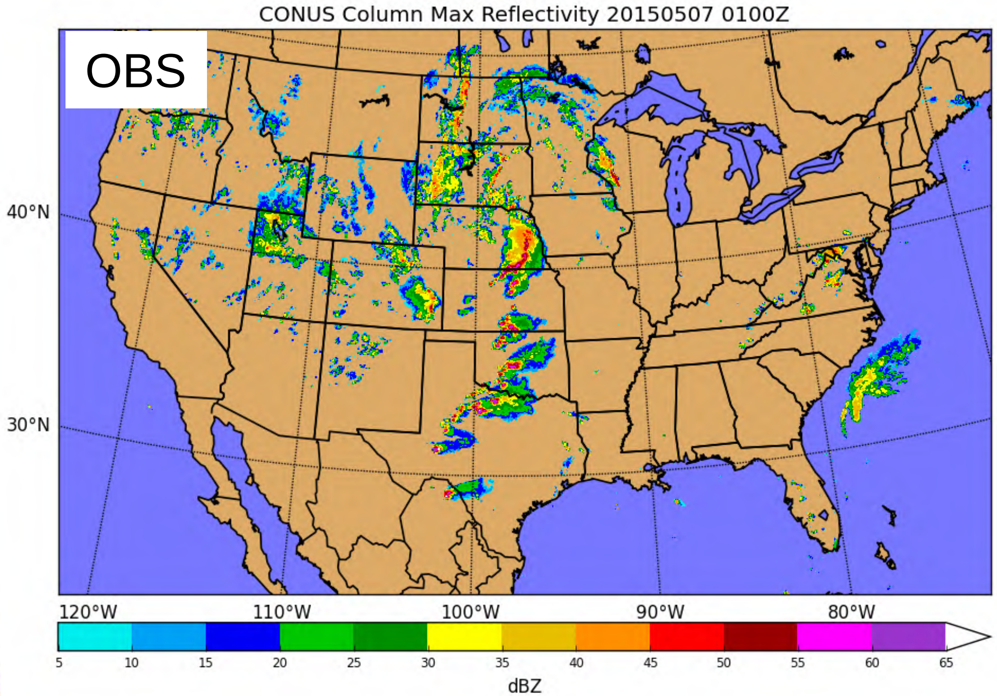
Case study

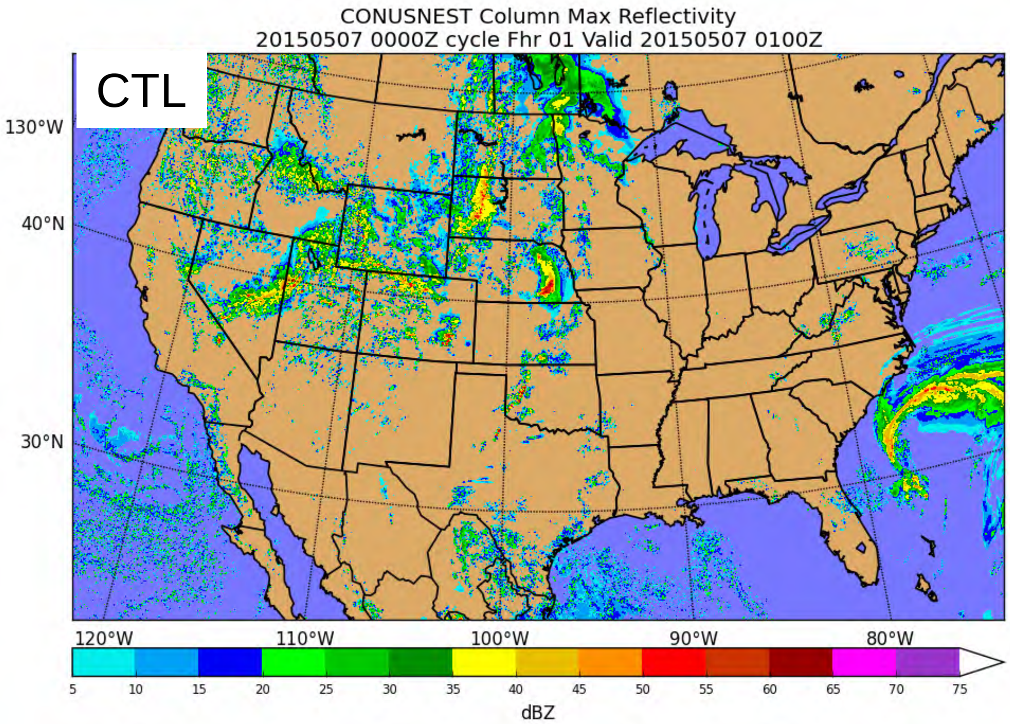




Tornado, high wind, hail reported

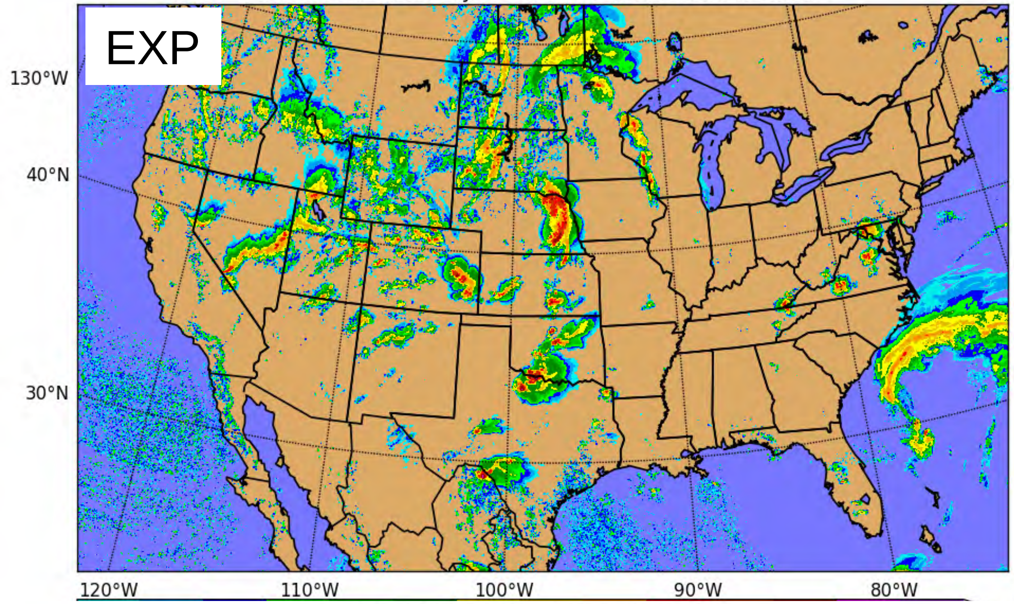




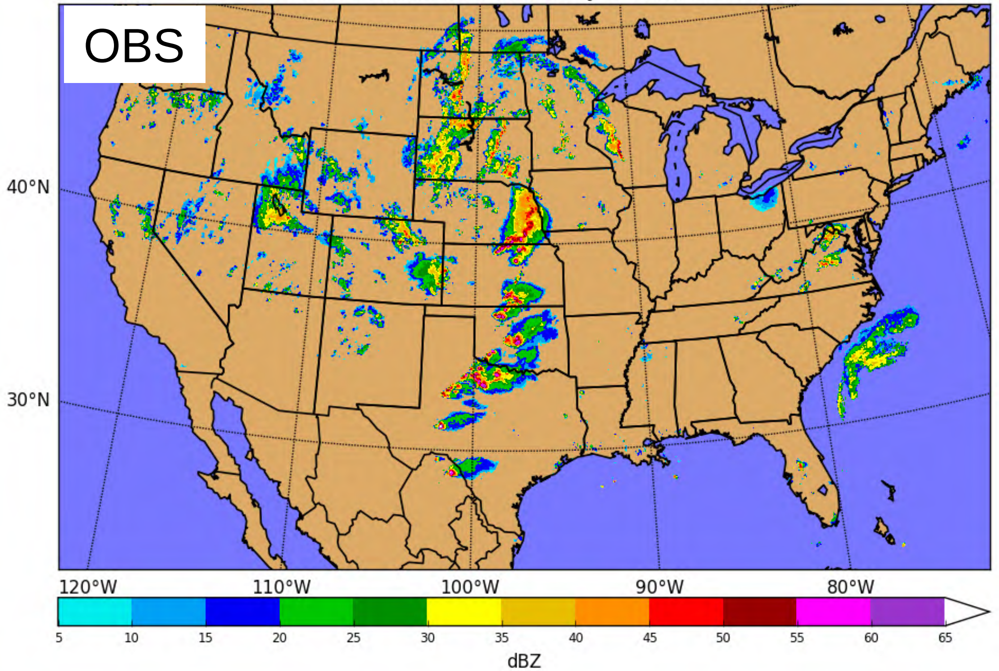


1 hour forecast

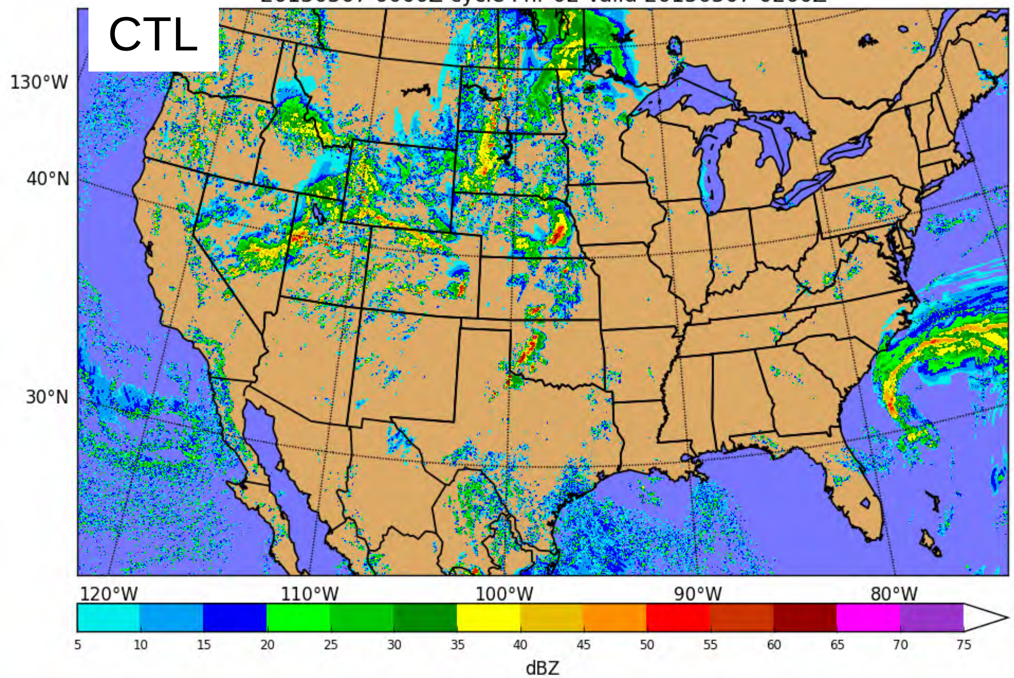
CONUSNEST Column Max Reflectivity
20150507 0000Z cycle Fhr 02 Valid 20150507 0200Z



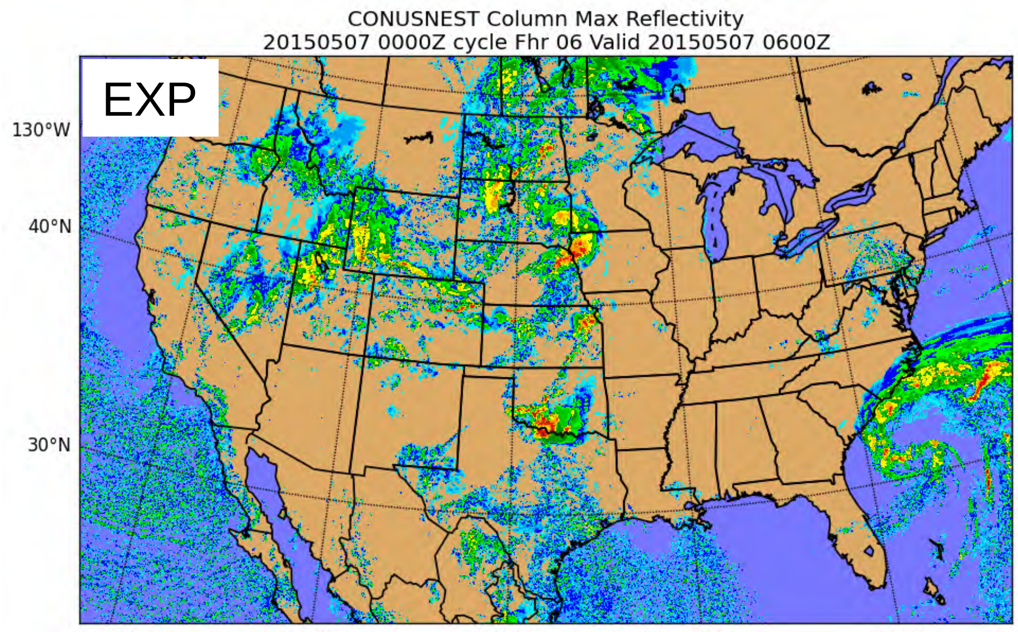
CONUS Column Max Reflectivity 20150507 0200Z

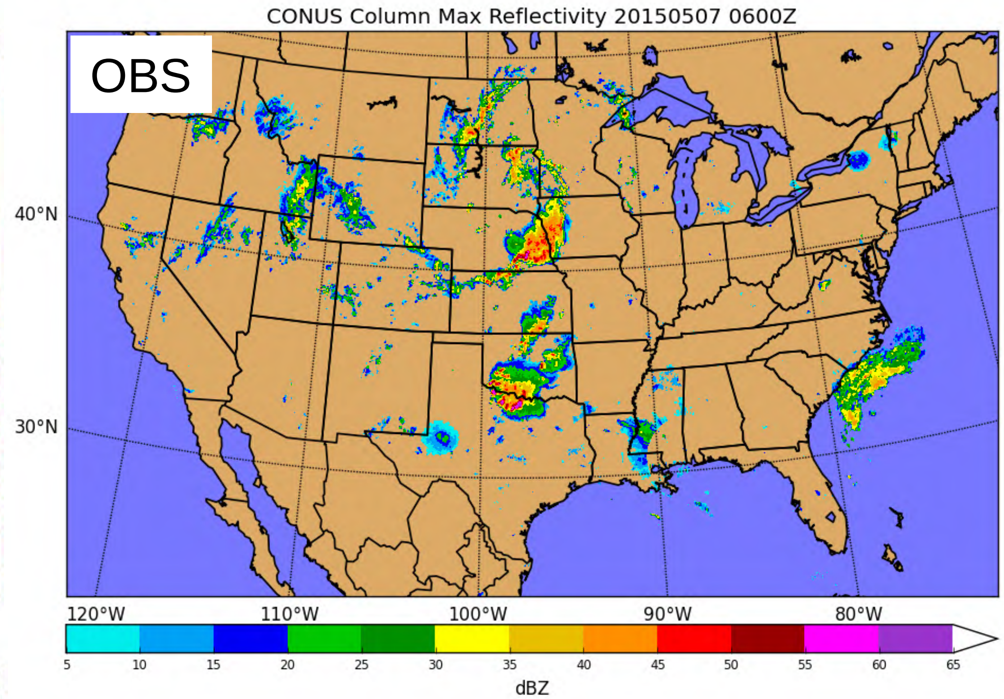


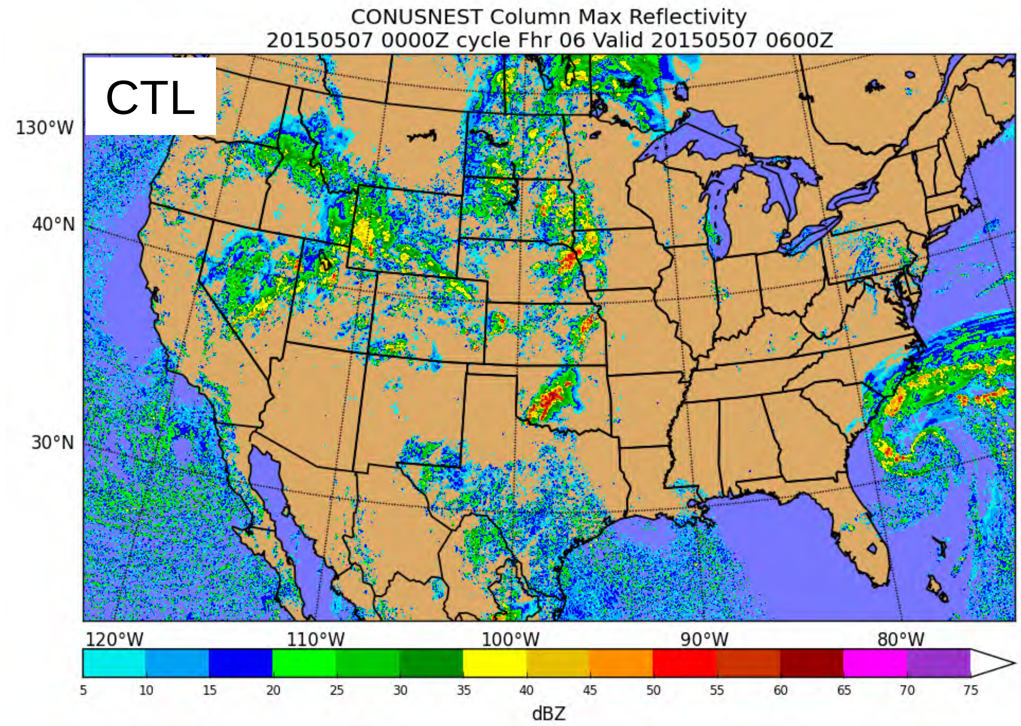
CONUSNEST Column Max Reflectivity
20150507 0000Z cycle Fhr 02 Valid 20150507 0200Z



2 hour forecast





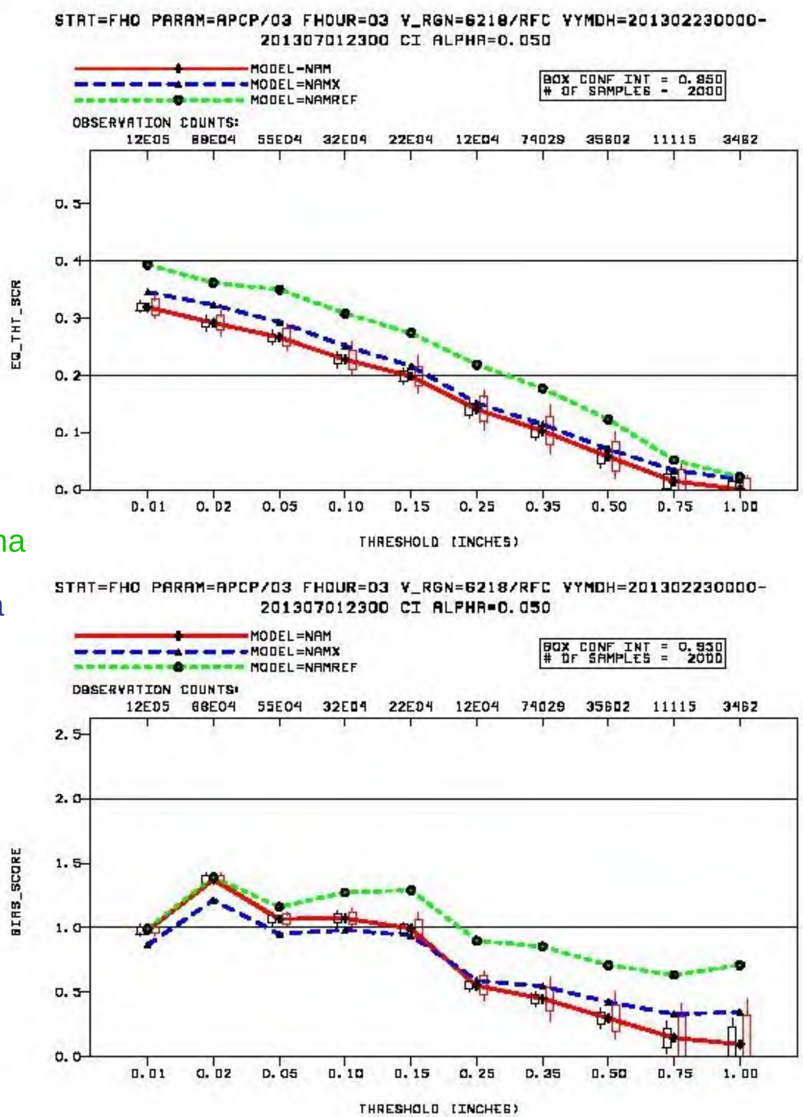


6 hour forecast

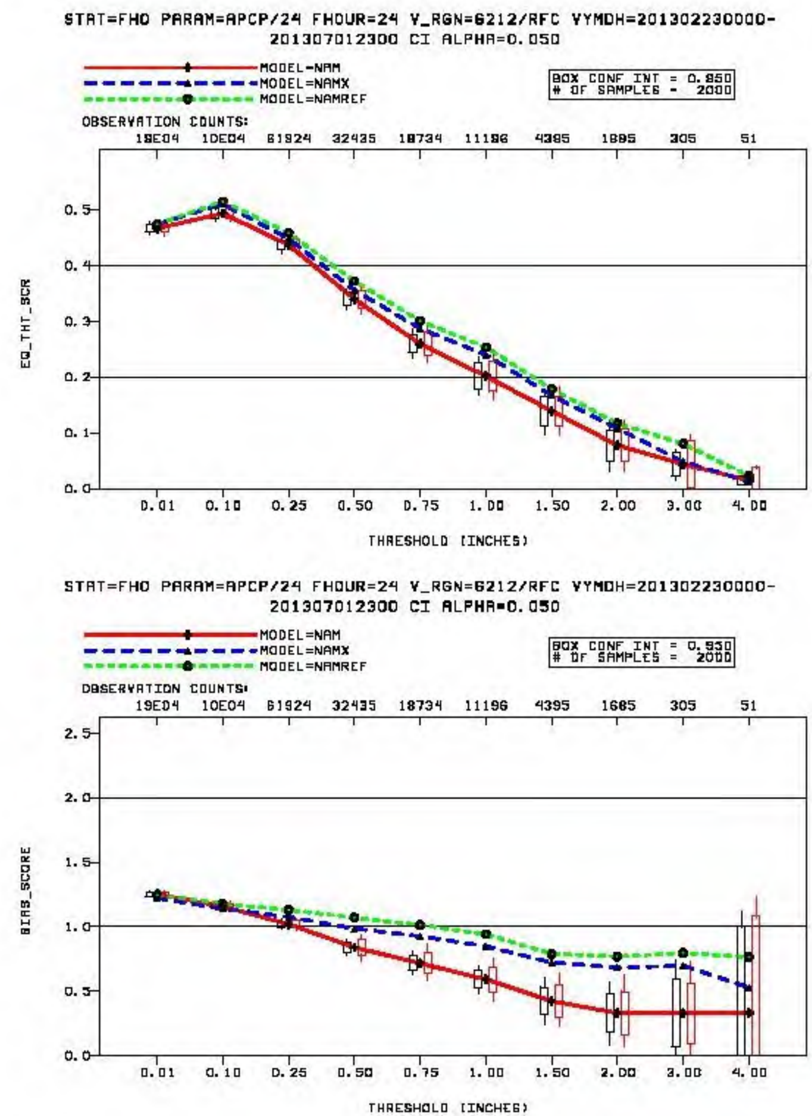
Precipitation (PCP) Verification:
cloud analysis DA vs No cloud analysis DA

---with cld ana

---no cld ana



3 h PCP verification



24 h PCP verification

Summary and Future Plan

- ❖ lightning DA algorithm is developed and tested to be use operationally at NCEP.

- ❖ Radar data (radial wind and reflectivity) are used operationally at NCEP.

- ❖ Use global lightning data in NAM domain.

- ❖ Test radar and lightning data assimilation with hybrid ENKF system.

- ❖ Analyze hydrometeors derived from cloud analysis in hybrid ensemble data assimilation system with regional ensemble.