Evaluating the potential impact of assimilating satellite lightning data utilizing hybrid (variational-ensemble) methods

Karina Apodaca[1], Milija Zupanski[1], Mark DeMaria[2], John A. Knaff[3], Lewis D. Grasso[1], and Man Zhang[1]

[1]Colorado State University-Cooperative Institute for Research in the Atmosphere
[2]NOAA/NESDIS/Regional Mesoscale Meteorology Branch
[3]NOAA/NESDIS/Star
Ft. Collins, Colorado, United States

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1. Introduction and Objectives

- To demonstrate the utility of assimilation of lightning data from the GLM instrument onboard the future GOES-R

- Why lightning data? Benefit of the link between the intensity of deep convection and total lightning flash rates

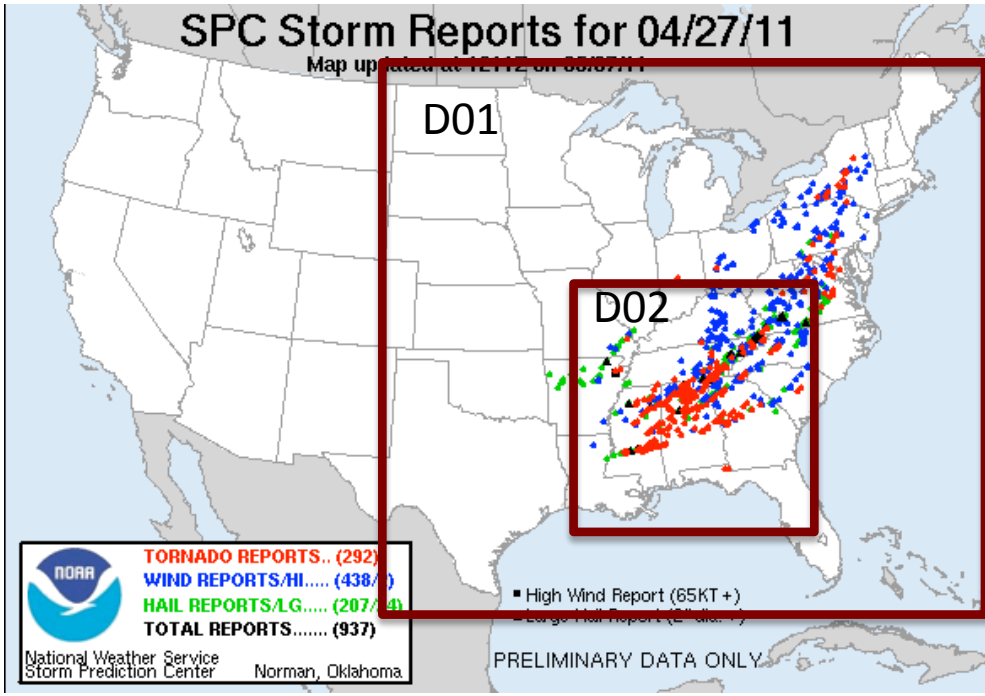
- Past efforts to incorporate lightning data through NUDGING stressed the importance of real-time measurements of lightning data to improve the representation of deep convection in NWP models.

- One of the goals of this study is to correct the location and intensity of severe thunderstorms during the analysis and short rage (6-hr) forecasts steps using a hybrid DA system.

- To asses how the future GOES-R GLM lightning data can assist in correcting the intensity and location of severe weather.

2. Data Assimilation and Model Set-up

- CASE Study: April 27-28, 2011tornado outbreak in the southeastern U. S.
- MLEF is used as a hybrid (variational-ensemble) DA system.
- WWLLN data is used as a proxy for future GOES-R GLM data with 10km location accuracy.
- WRF-NMM --- Two domains at 27km and 9km.
- 32-ensembles at 6-hr assimilation interval.
- Control variables: T, Q, PD (P_{surf} - P_{top}), U, V, CWM.



- Two experiments: with assimilation of lightning data (LIGHT) and without it (NODA).

3. Lightning Observation Operator Development

- Starts with the calculation of maximum vertical velocity from WRF-NMM *(W_{max})*

$$w = \frac{1}{g}\left(\frac{\partial \Phi}{\partial t} + v \cdot \nabla_{\sigma}\Phi + \dot{\sigma}\frac{\partial \Phi}{\partial \sigma}\right)$$

- The algorithm calculates w_{max} at grid points and surrounding points along a vertical column where clouds are present.

- Total cloud condensate (cloud water, rain and snow) above a threshold used to detect clouds.

- An empirical relationship between lightning flash rate and vertical velocity is used (Price and Rind, 1992)

$$f = c\alpha_{opt} w_{\max}^{\beta}$$

$c=5e^{-6}$, α_{opt}=correction parameter, β=4.5

3.1. Lightning Observation Operator Correction

Current version:

- maximum vertical velocity
- works with any microphysics, but less accurate

Next version:

- cloud hydrometeor based (graupel flux, cloud ice – McCaul et al. 2009
- requires more advanced microphysics, but more realistic

Original formulation

$$h = c w_{\max}^{\beta}$$

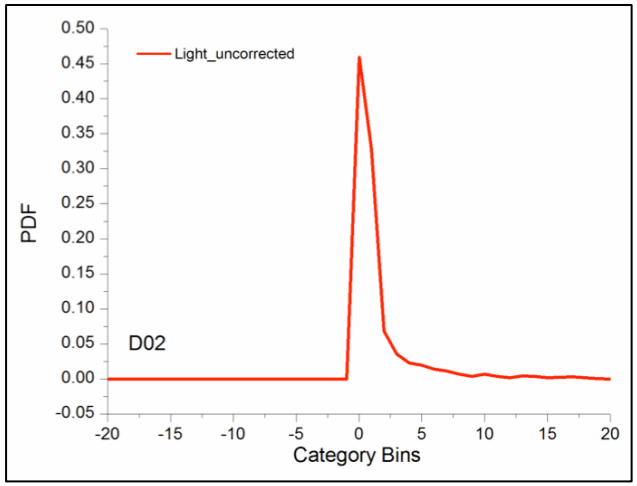
Corrected formulation

$$h = \alpha_{opt} c w_{\max}^{\beta}$$

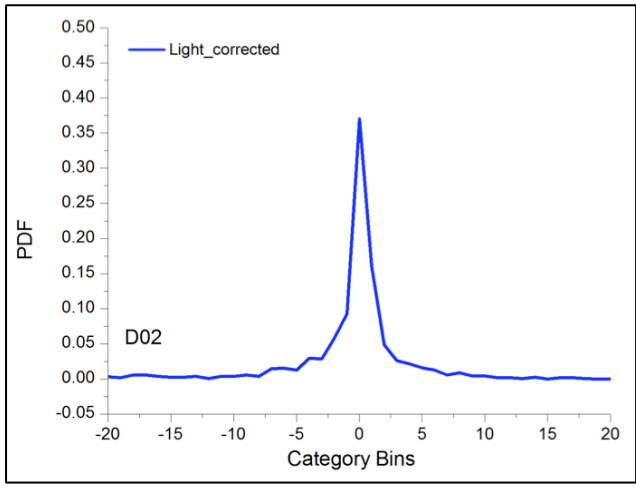
$$\alpha_{opt} = \exp\left[\frac{\frac{1}{N}\sum_{i=1}^{N}\log\left(\frac{y}{h(x)}\right)_i}{1+\frac{r_0}{w_0}}\right]$$

PDF Innovation – Histograms

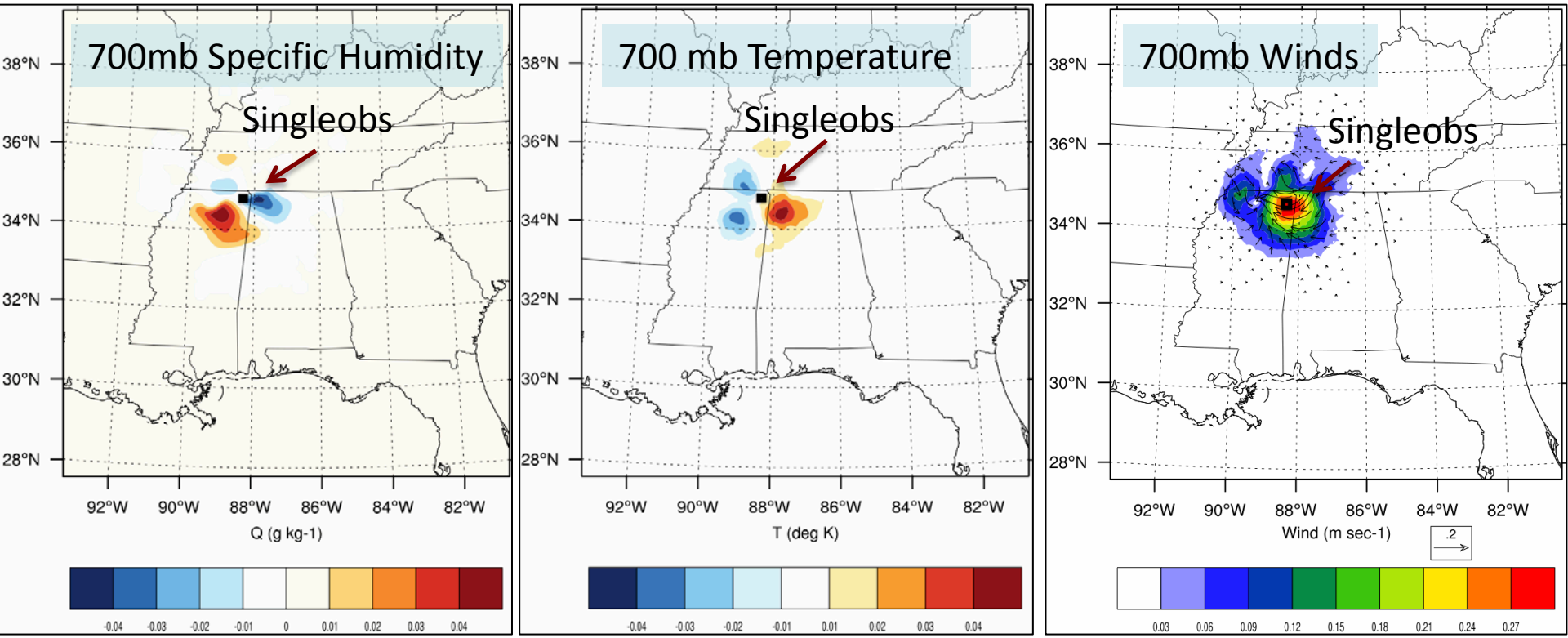
Original



Corrected



4. Results --- Singleobs test, Impact on the Analysis

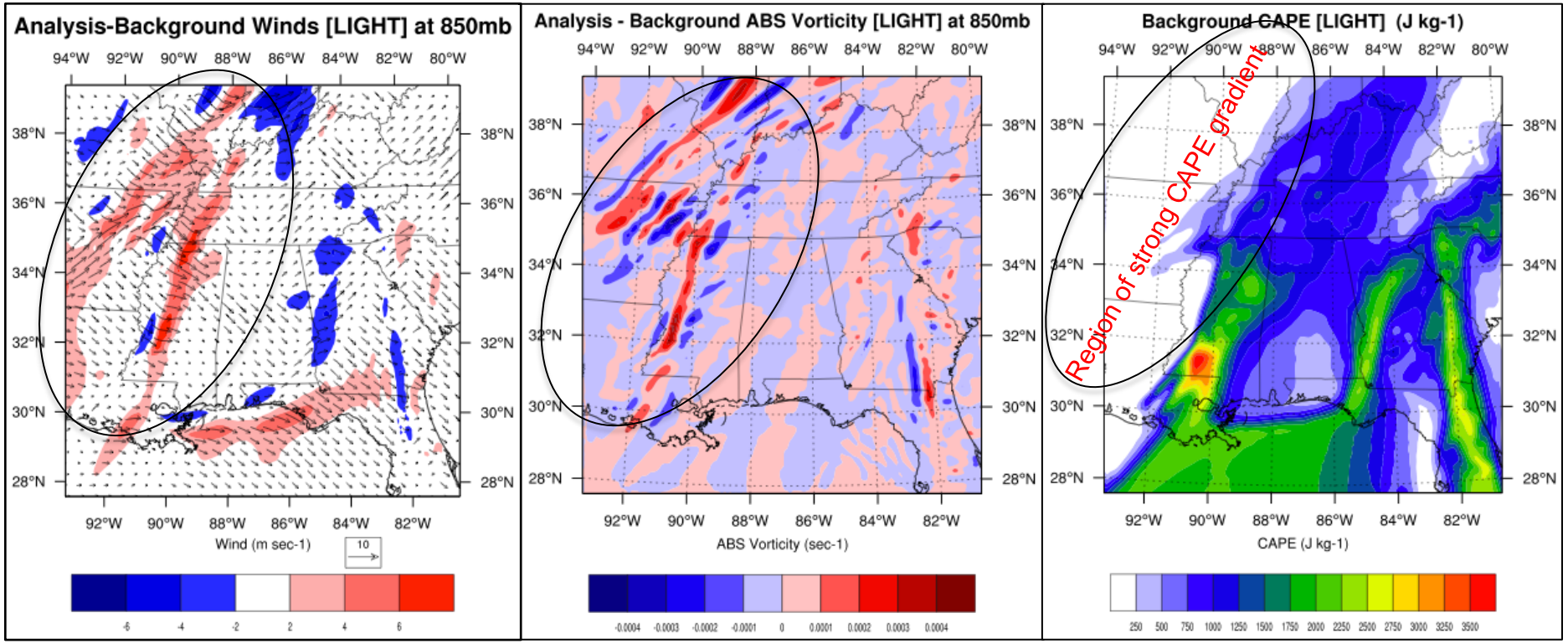


- $x^a - x^f$ – SPECIFIC HUMIDITY, TEMPERATURE, WIND at 700mb.
- $w_{\max} = w_{\max}(x) \qquad x = (T, pd, q, u, v, cwm)^T$
- Lightning DA impacts the initial conditions of dynamical variables from the model

Impacts on Storm Environment

- Analysis increments ($x^a - x^f$) at 0000UTC, April 28, 2011
- Lightning DA increases the advection of low-level vorticity into the region of strong CAPE gradient
- Not at a tornado resolving scale, yet, but impact is noticeable

Wind increment at 850 hPa Vort. increment at 850 hPa Background CAPE

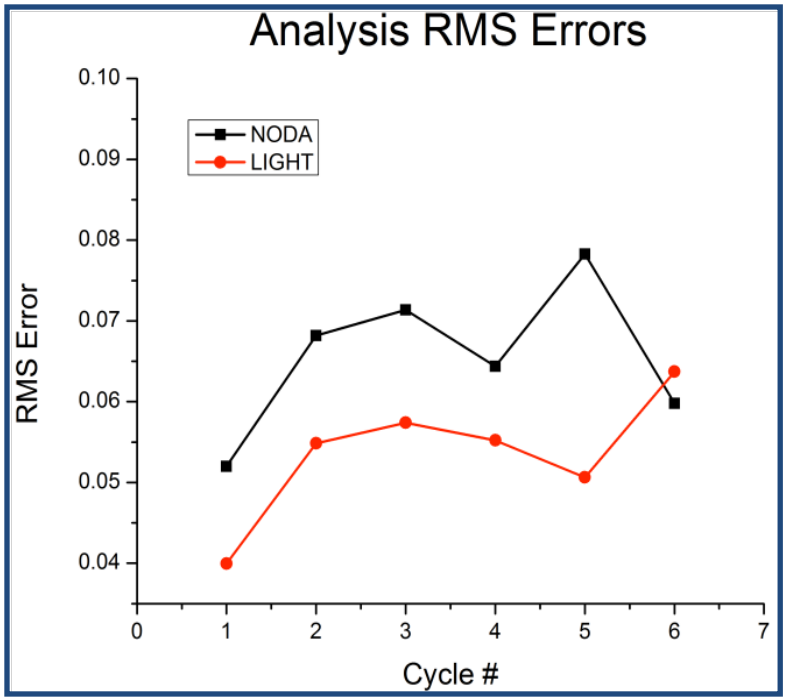


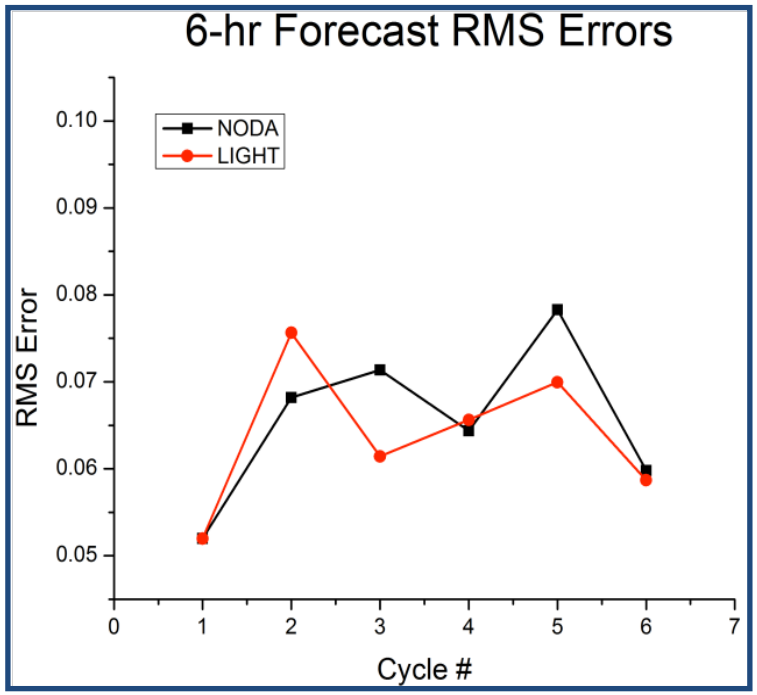
Statistics --- RMS Errors

- RMS errors are calculated from a subset domain containing all the lightning observations at 10km resolution to match WRF 9km resolution.

- From Figures below for each 6-hr assimilation window, LIGHT achieves a better fit in the assimilation, only partially kept in the forecast.

- Improving dynamical balances in the model could positively impact forecast RMS errors.

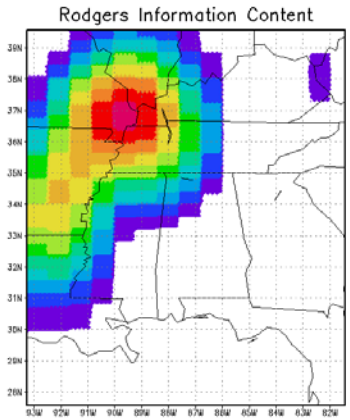




Shannon Information Content, degrees of freedom for signal

- Lightning DA is quantified through information theory (ENTROPY)
- Shows the actual use of observations in each DA cycle

2011_04_27-00:00:00
Cycle 1



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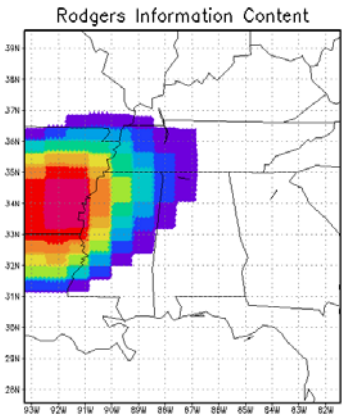
Cycle 3



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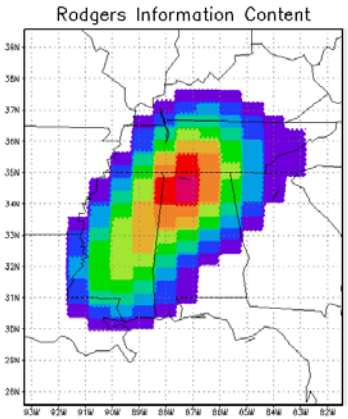
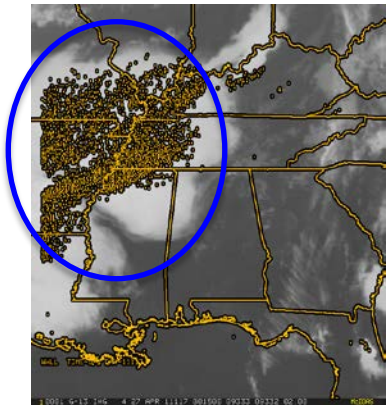
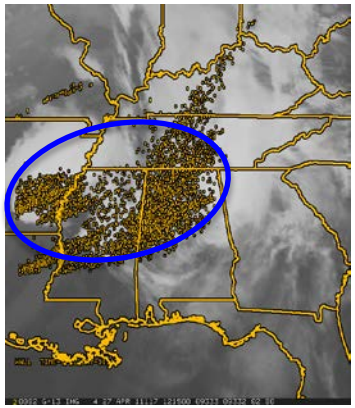
Cycle 5



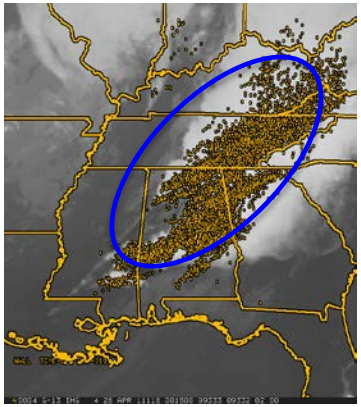
WWLLN Observations



WWLLN Observations



WWLLN Observations



- Each pixel ➔ Error covariance localization used in each DA cycle
- Time-flow dependent forecast error covariance is directly related to the observations

Bottom plots credit: Mark DeMaria, Gregory DeMaria and Jack Dostalek

Summary

- Lightning DA can spread new information into a NWP model
- Lightning leads to strengthening of deep convection, in this case
- Even though we are not using a tornado resolving scale, results are promising
- This methodology can be applied to other lightning measurements, NWP models and case studies

Future Work

- Use a more advanced lightning obs. operator (McCoul et al. 2009)
- Test the combined assimilation of lightning and NCEP observations (e.g., GSI+CRTM)
- Test the combined assimilation of GLM and ABI observations

Acknowledgements and References

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