Hybrid variational-ensemble assimilation of lightning observations in a regional model

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Introduction

- Development of a technique to incorporate GOES-R Geostationary Lightning Mapper (GLM) observations using a hybrid variational-ensemble data assimilation system
- Evaluate the impact of lightning observations in regional data assimilation (DA) applications

Completed Milestones

- Benchmark system

WRF-NMM at 27, 9km, and 6-hr DA frequency (SEMI-OPERATIONAL)
Ferrier microphysics
Vertical updrafts and total condensate lightning observation operator
WWLLN data as a proxy for GLM

Ongoing Project

-Enhanced system

WRF-ARW at 9, 3, 1 km resolution, 6, 3, 1-hr assimilation frequency
WSM6 Microphysics
Lightning observation operator based on hydrometeor-flash rate link (McCaul et al. 2009
WWLLN and/or Earth Networks Total Lightning Network (IC+CG)

Lightning Observation Operator

- Lightning flash rate from McCaul et al. (2009) lightning threat forecast algorithm currently used operationally in NOAA High Resolution Rapid Refresh (A version of WRF-ARW)

- Combination of upward flux of graupel in mixed phase region (-15 C)

$$F_1 = k_1 \left(w q_g \right)_m$$

- with gridded-vertically integrated ice-phase hydrometeors (graupel, ice, and snow)

$$F_2 = k_2 \int \rho \left(q_g + q_s + q_i \right) dz$$

- F_3 is a blended threat thus improving temporal and areal coverage of lightning activity

$$F_3 = r_1 F_1 + (1 - r_1) F_2$$

Parameter	Description
w	Vertical velocity
r	Local air density
q_g, q_s, q_i	Graupel, snow and ice mixing ratios
k_1, k_2	0.042, 0.20 – Calibration coefficients of peak flash density
r_1	0.95 – From sensitivity of various weights

Lightning Observation Operator

- The goal is to minimize the following cost function:

$$J(x) = \frac{1}{2}\left[x - x^f\right]^T P_f^{-1}\left[x - x^f\right] + \left[y - h(x)\right]^T R^{-1}\left[y - h(x)\right]$$

- Control variables: T, U, V, P cloud mixing ratios (water, rain, snow, vapor, ice, graupel)

- F_3 is the observation operator (h)

Parameter	Description
r_1	0.95 – From sensitivity of various weights
x	Control Variables (CV)
P_f	Error covariance of CV
f	Denotes forecast guess
y	Lightning flash rate observations
R	Error covariance of observations

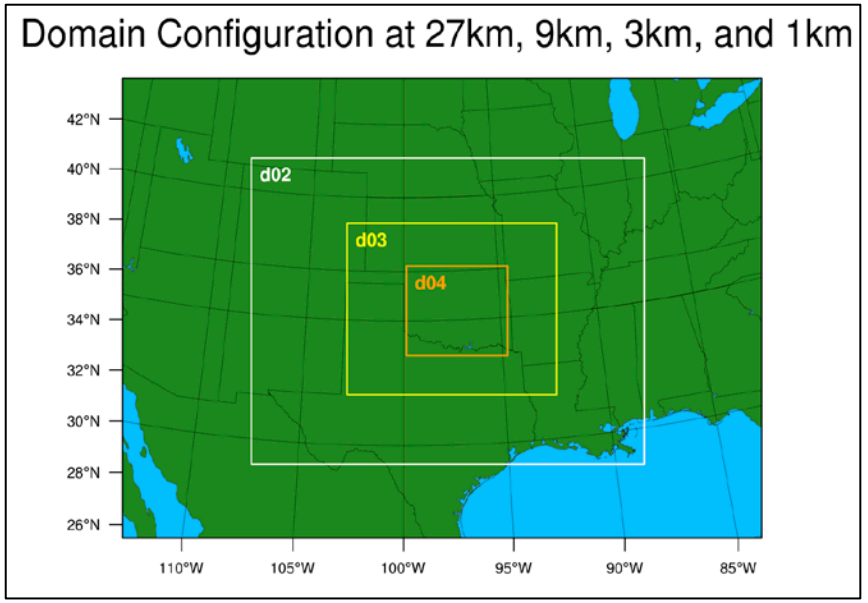
Data Assimilation System

- 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.
- 32-ensembles
- 6-hr assimilation frequency (currently testing 3-hr and 1-hr)
- Control variables: T, P, U, V, W, Cloud hydrometeors (cloud, vapor, rain, graupel, snow, and ice).

Modeling System Setup

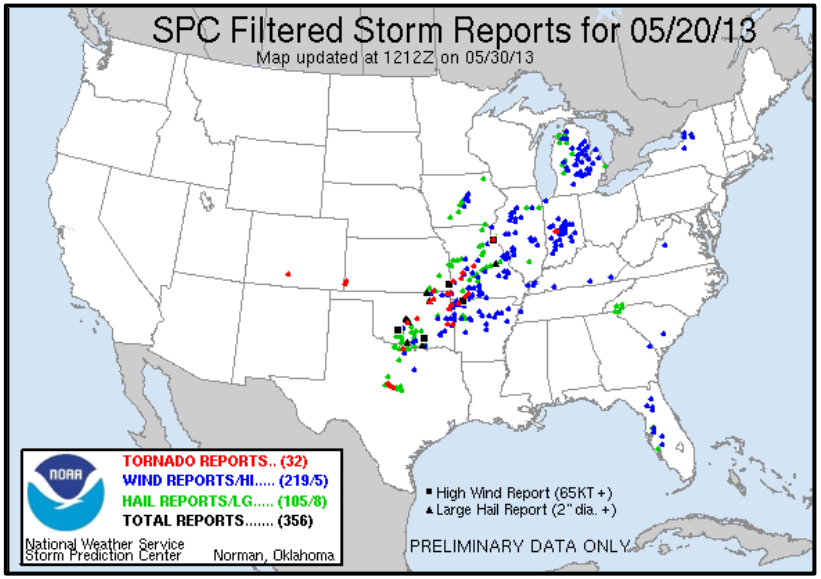
WRF-ARW

PARAMETER	CHOICE
Horizontal resolution	27km, 9km, 3km, 1km
Sigma Levels	27
PBL scheme	YSU
Short & long wave radiation	Dudhia and RRTM
Land Surface	Noah
Microphysics	WRF 1-Moment 6-class
Initial & lateral BC	Global Forecast System (GFS)

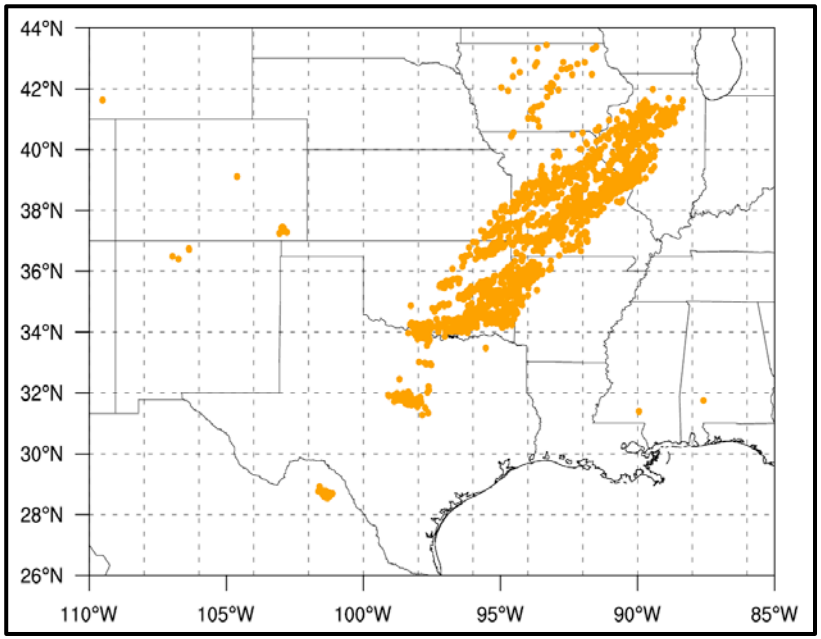


Case Study: The May 20, 2013 Severe weather outbreak

Storm Prediction Center Storm Reports



WWLLN lighting observations 05/20/13 (6Z to 12Z)

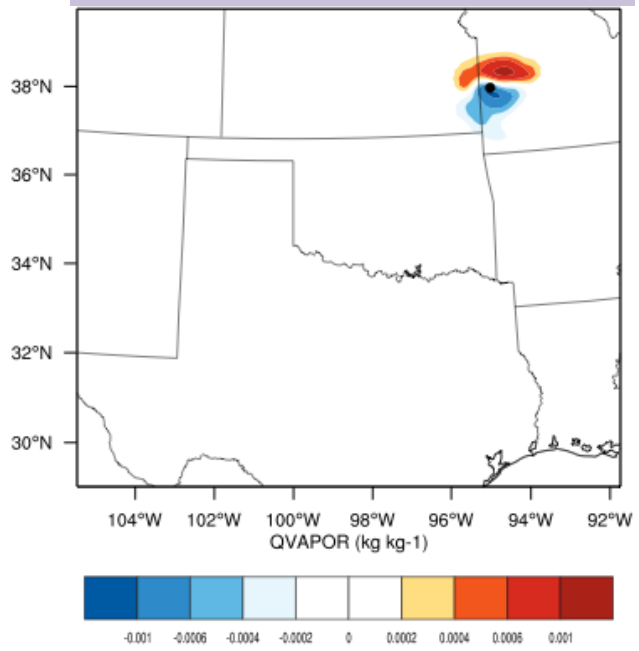


Preliminary Results: Single Observation Test

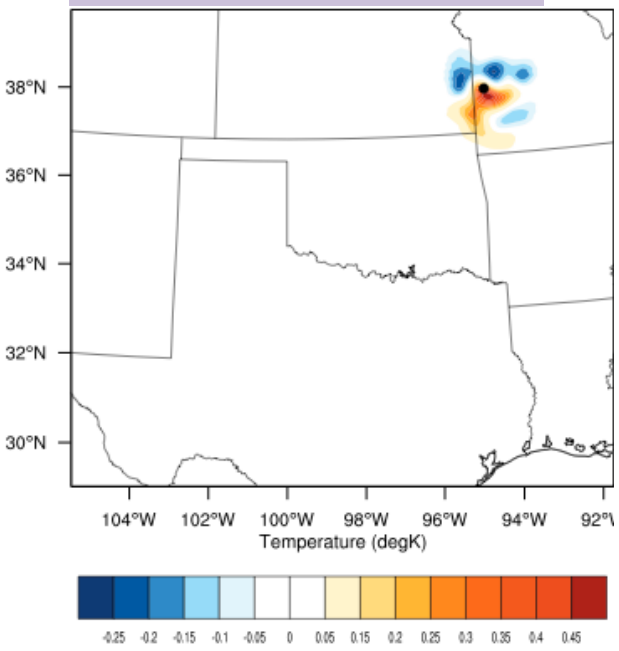
Impact of a single lightning observation on the analysis: $(x^a - x^b)$

$$x = (T, P, U, V, W, QVAPOR, QSNOW, QICE, QGRAUP, QRAIN, QCLOUD)^T$$

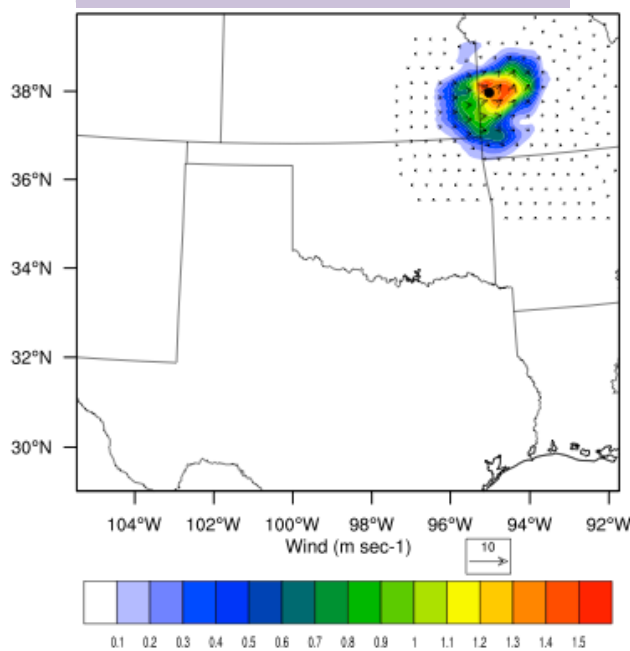
QVAPOR Increment at 850hPa



T Increment at 850hPa



Wind Increment at 850hPa

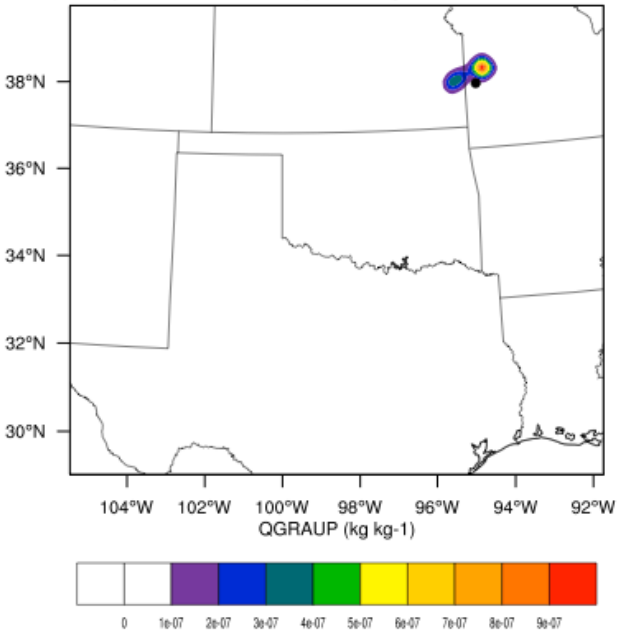


- Lightning can potentially impact the initial conditions of dynamical variables in the model

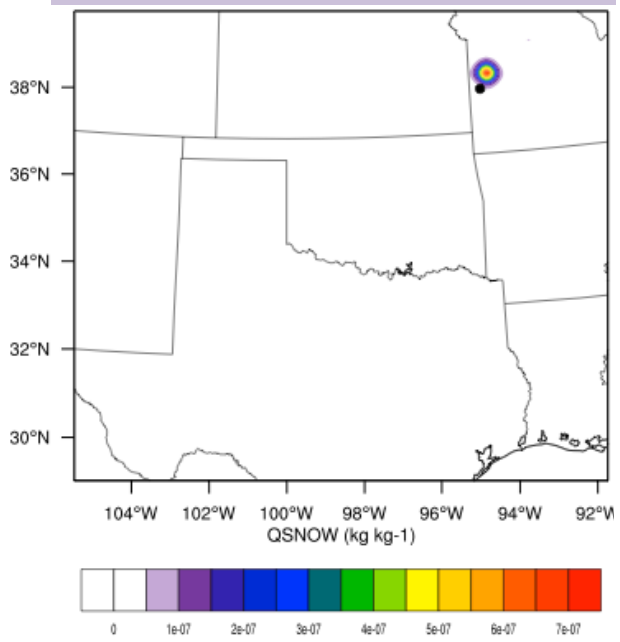
Preliminary Results: Single Observation Test

Impacts on Cloud Hydrometeors (Graupel, Snow, and Ice) at 500hPa:

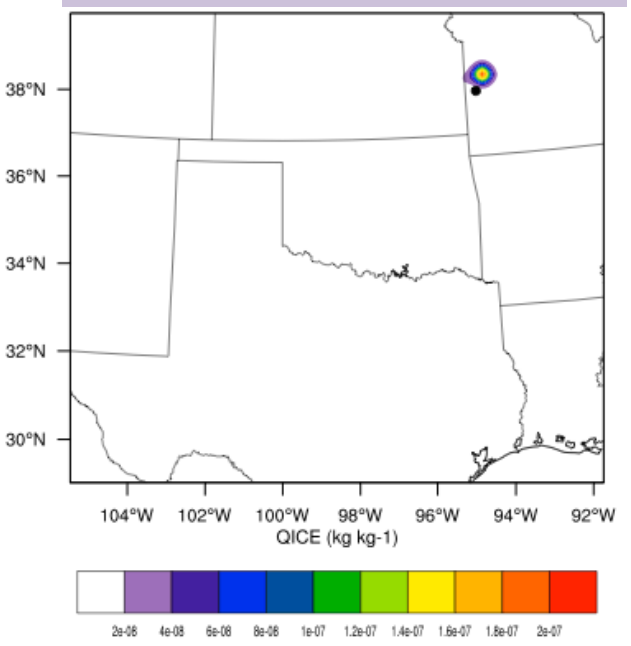
QGRAUP Increment at 500hPa



QSNOW Increment at 500hPa



QICE Increment at 500hPa



- Lightning can impact the initial conditions of cloud microphysical variables in the model
- Cloud variables have a positive response to a single lightning observation
- Indicative of an adequate forecast error covariance structure

Future Work

- Test the effect of combined GOES-R ABI and GLM observations
- DA experiments with combined lightning, conventional observations and All-Sky satellite radiances using NOAA codes (GSI and CRTM)
- Test the lightning DA methodology developed for WRF-NMM for hurricane inner-core with HWRF
- Test the lightning DA methodology developed for WRF-ARW for lightning NO_x production with WRF-Chem

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