Assessing the impact of lightning observations in a hybrid data assimilation system

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Background

◆ We previously tested a lightning data assimilation (DA) technique in a semi-operational environment (WRF-NMM+MLEF) at coarse resolution (9km) and 6-hour assimilation frequency

◆ The lightning observation operator used was based on and empirical relationship between lightning flash rate and vertical velocity (Price and Rind, 1992)

◆ Even if assimilation frequency was low and the model resolution was coarse lightning data was capable of spreading information content into WRF-NMM+MLEF

◆ A single observation test reveled that lightning observations have an impact in all analysis variables (e.g. T, P, U, V, Q), which is important to achieve dynamical balance. This is indicates that lightning flash rate can have a potential for improving the forecast (Fig. 1)

◆ Analysis RMS with respect to the lightning observations are reduced over 2 days of assimilation. As the storms move outside of the domain the impact on the analysis is smaller (Fig. 2)

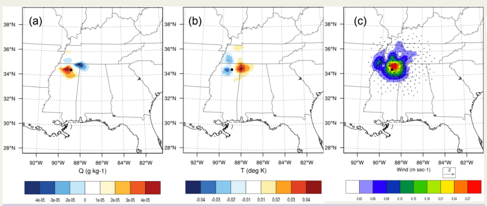

Figure 1. Single observation of lightning flash rate. Analysis increment (x^a-x^b) at 700 hPa, valid 1200 UTC 27 April 2011: (a) specific humidity (g/kg), (b) temperature (K), and (c) wind (m/s).

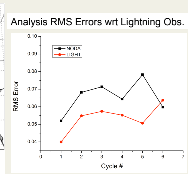

Figure 2. Analysis RMS Errors

Introduction and Goal

◆ We are currently testing a similar technique, but in WRF-ARW at higher resolution and assimilation frequency, with more complex microphysics

◆ Implementing a lightning observation operator with a strong link between upward ice fluxes and lightning flash rate

◆ The eventual goal is to develop a comprehensive multivariate, multi-scale, multi-sensor operational data assimilation system with the capability to assimilate lightning along with conventional observations

Lightning Observation Operator

◆ Lightning flash rate based on McCaul et al (2009) lightning threat forecast algorithm for WRF-ARW

◆ This formula combines the upward flux of graupel (F1) with gridded-vertically integrated ice-phase hydrometeors (graupel, ice, and snow) (F2). F3 is a blended threat, thus improving temporal and areal coverage of lightning activity

$F_1 = k_1(wq_g)_m$ $\quad F_2 = k_2 \int \rho(q_g + q_s + q_i)dz$ $\quad F_3 = r_1 F_1 + (1 - r_1)F_2$

◆ The goal is to minimize the following cost function:

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

◆ F_3 is the observation operator *(h)* in (1)

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

Parameter	Meaning
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 coeficient of peak flash density
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 Sets and Case Study

Data Sets

◆ Initial experiments with World Wide Lightning Location Network (WWLLN) data – 10km location accuracy

◆ Next set of experiments with Earth Networks Total Lightning Network (ENTLN)

◆ GFS data for initial and boundary conditions

◆ NOAA operational observations using GSI and CRTM as forward observation operators

Case Study

◆ The 05/20/13 severe weather outbreak with special emphasis on the Moore, Oklahoma tornado

◆ 25 reported fatalities, 337 injured and about $2 billion in damages

◆ Fig. 3a shows the Storm Prediction Center Storm Reports for 05/20/13 with 356 total storms, the WWLLN lighting observations (Fig. 3b), and a MODIS image of the severe weather event (Fig. 3c)

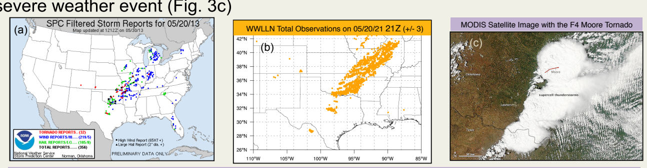

Fig. 3. (a) Storm Prediction Center Storm Reports for May 20, 2013, (b) WWLLN observations, and (c) A NASA's MODIS image of the event.

DA and Modeling System Set-up

Data Assimilation System and Experiments

◆ The Maximum Likelihood Ensemble Filter (MLEF) developed at Colorado State University is used as a hybrid variational-ensemble DA system

◆ 32-ensembles at 6 to 3-hr assimilation intervals starting on May 19, 2013 at 00Z and covering the landing time of the Moore, Oklahoma tornado

◆ 3 experiments with lightning data assimilation and conventional observations (GSI+LIGHT), conventional observations only (GSI) and an single observation experiment (1-OBS)

WRF-ARW Configuration

PARAMETER	CHOICE
Horizontal resolution	27km, 9km, 3km, 1km (Fig. 4)
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)

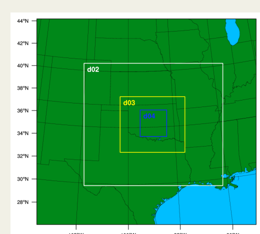

Fig. 4. WRF-ARW domain configuration

Future Work

❖ Perform the GSI, GSI+LIGHT, and 1-OBS experiments with Earth Networks total lightning data

❖ Evaluate the impacts of combined lightning and all-sky satellite radiances on severe weather at cloud-resolving scales

❖ Apply the hybrid GSI+MLEF in regional data assimilation experiments

❖ Assess the utility of lightning DA for NO_x production in WRF-Chem

Acknowledgements and References

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