Utility of GOES-R Geostationary Lightning Mapper (GLM) Using Hybrid Variational-Ensemble Data Assimilation in Regional Applications

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Project goals

(1) **Demonstrate the utility of GOES-R GLM in severe weather data assimilation application**.

(2) **Use NOAA operational codes and scripts:**
- WRF-NMM
- NCEP operational observations (forward GSI, CRTM)
- additional assimilation of all-sky MW satellite radiances and lightning flash rates

(3) **Use CIRA MLEF as a prototype hybrid variational-ensemble DA system**

Milestones:
- Interface the MLEF-NMM system with NOAA operational observations and MW cloudy radiances
- Make initial evaluation of the system in application to severe weather and make benchmark experiments (without lightning data)
- Develop forward observation operator for lightning data and make initial evaluations
- Compare the complete system (including lightning observations) with the benchmark system
- Evaluate the impact of GOES-R GLM observations in severe weather
- Assist NOAA/NCEP/EMC and JCSDA in transferring the developed DA capability to operations, and provide support as required

Achieved accomplishments

Benchmark system setup

Data Assimilation and modeling system:
- WRF-NMM model at 27km / 9km resolution
- Use MLEF as a prototype HVEDAS
- 32 ensembles
- 6-hour assimilation interval
- Control variables: PD, PINT, T, Q, U, V, CWM

Observations:
- NOAA operational observations using GSI and CRTM forward operators
- All-sky AMSU-A radiances: Use the approach originally developed by M.-J. Kim for global DA system, adapted by M. Zhang for use in regional DA system and for hurricanes

Experiments:

1) Benchmark experiment (without lightning observations): assimilation of NCEP operational observations and all-sky AMSU-A MW radiances

2) Control experiment: no data assimilation

Benchmark system evaluation

Severe weather outbreak over the Southeastern U.S. on April 25-28, 2012

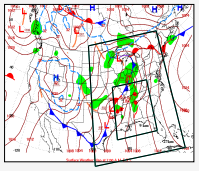

Fig. 1. Surface weather map valid 1200 UTC on April 27, 2012. The frames represent the WRF-NMM model integration domains.

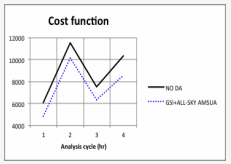

Fig. 2. Cost function for the 9 km nest from the control (solid line) and the benchmark (dotted line) experiments, valid from 0600 UTC on April 27, 2012 to 0000 UTC on April 28, 2012.

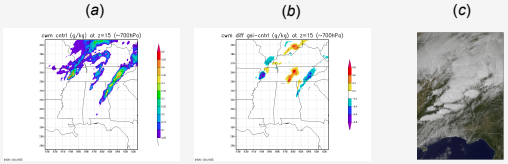

Fig. 3. Total cloud condensate (g/kg) valid 0000 UTC 28 April, 2012: (a) control forecast ,and (b) 6-hour forecast difference between benchmark and control. The GOES-13 visible image is used for verification (panel c).

Lightning flash rate observation operator development

Strategy: Use relationship that has a potential for operational applications
- less complex microphysics,
- link to basic DA control variables,
- balanced impact on mass and wind adjustments, thus impact the forecast

Observation operator:

(1) Use empirical relationship between lightning flash rate and maximum vertical velocity

$$f = \alpha \times w_{\max}^{\beta} \qquad \alpha = 3\times10^{-4}\left[\frac{hour}{km^2}\right]^{3.5} \qquad \beta = 4.5$$

(2) Calculate w_{max} from calculated vertical velocity

$$w = \frac{1}{g}\left(\frac{\partial\Phi}{\partial t} + v\cdot\nabla_{\sigma}\Phi + \sigma\frac{\partial\Phi}{\partial\sigma}\right) = f(pd,T,q,u,v)$$

Calculated using reduced WRF-NMM codes

Time derivatives are not calculated, they are extracted from the model output file

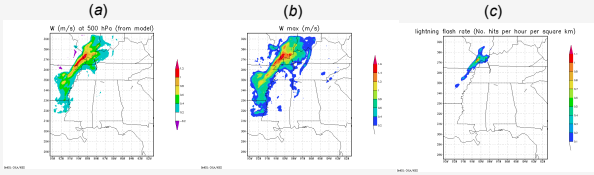

Fig. 4. Lightning flash rate observation operator development: (a) vertical velocity from the model output (m/s), (b) calculated w_{max} (m/s), and (c) lightning flash rate (No. hits/km²/hr). All fields are valid 0600UTC on April 27, 2011.

Accomplishments anticipated at end of Year 2

(1) Combine all components into a complete HVEDAS, including lightning observations, and compare the complete system with the benchmark system.

(2) Evaluate the impact of GOES-R GLM observations in severe weather.

(3) Produce lightning forecast using WRF-NMM.

Preliminary results: Assimilation of WWLLN lightning observations using WRF-NMM

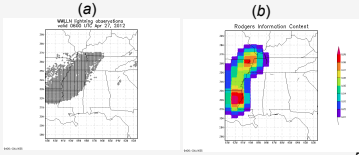

Fig. 5. Lightning observations: (a) location, and (b) information content, valid 0600 UTC on April 27, 2011. The assimilation system is clearly capable of extracting information from WWLLN lightning observations.

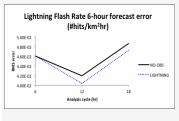

Fig. 6. Lightning flash rate 6-hour forecast RMS error w.r.t. lightning observations during first three DA cycles.

Initial feedback from potential users

We plan to create a mechanism to collect feedback by making our lightning DA product available to forecasters via the proving ground.

What can be accomplished with a 3rd year of funding?

Develop the operational data assimilation capability to assimilate GLM lightning observations:

- Operational use of lightning observations is straightforward, it does not require complex new development (in GSI it would require only a simple adjoint F^T of f(PD,T,Q,U,V)).
- Lightning observations have positive impact at 9 km model resolution, thus they could benefit the current operational system.
- Assist NOAA in preparing for use of lightning observations in operational DA.

Manuscripts:

Apodaca, K., M. Zupanski, M. Zhang, M. DeMaria, L. D. Grasso, J. A. Knaff, and G. DeMaria: Evaluating the potential impact of assimilating GOES-R GLM satellite lightning observations. In preparation, to be submitted to *Mon. Wea. Rev.*

Zhang, M., M. Zupanski, M.-J. Kim, and J. Knaff, 2012: Direct Assimilation of all-sky AMSU-A Radiances in TC inner core: Hurricane Danielle (2010). To be submitted to *Mon. Wea. Rev.*