GOESR3 Periodic Reporting

Reporting Period: January 2018 – June 2018 (2nd half of FY17 funding cycle)

Team Lead: Milija Zupanski
Team Members: Ting-Chi Wu, Karina Apodaca

Project Title: Data Assimilation of GLM Observations in HWRF/GSI System
Project Number: 410

Executive Summary

In this reporting period we focused on examining and adjusting lightning observation operator. The reporting period addresses the FY17 Milestone #2: Examine and adjust the lightning observation operators for use in HWRF, with tasks: (1) Investigate the applicability of the previously developed lightning observation operators to hurricanes, (2) Adjust lightning observation operators for hurricane applications, and (3) Conduct HWRF experiments with the assimilation of GLM observations. All three tasks are successfully completed.

Since the available lightning observation operators are generally developed and tested for over-land applications, there is a need to investigate and eventually adjust the operators for use in hurricane applications, covered by the first two tasks. The step after that is to use the adjusted operators in preliminary evaluation with HWRF system, covered under the task #3. In overview, the Milestone #2 has been successfully completed as planned.

Progress toward FY17 Milestones

All milestones and tasks covering the reporting period are successfully completed. The reporting period addresses the FY17 Milestone #2: Examine and adjust the lightning observation operators for use in HWRF, with tasks: (1) Investigate the applicability of the previously developed lightning observation operators to hurricanes, (2) Adjust lightning observation operators for hurricane applications, and (3) Conduct HWRF experiments with the assimilation of GLM observations.

1. Investigate the applicability of the previously developed lightning observation operators to hurricanes

The observation operator for lightning is a (nonlinear) regression between lightning flash rate (number of lightning strikes per unit area and unit time) and prediction model variables. The available lightning observation operators have been generally developed and tested over land only, thus requiring additional consideration for hurricane applications. There are two basic types of lightning observation operators that can be adjusted for hurricane applications, relying on: (1) maximum vertical updraft, and (2) vertical updraft and cloud hydrometeor vertical flux (in particular graupel and ice).

The type (1) operator is generally applicable to cloud environment, because the equation for vertical velocity is a function of temperature, wind, humidity and pressure, but not of cloud hydrometeors. One could in principle adjust only vertical velocity in data assimilation, but in that case it would be more difficult for operational data assimilation to make a balanced adjustment to all other variables to maintain dynamical balances. In addition, vertical velocity is currently not a control variable option in

NOAA Gridpoint Statistical Interpolation (GSI) system. Therefore, this operator can only adjust the initial conditions of cloud environment variables. Although this is potentially beneficial for hurricanes, it does not address the adjustments of cloud initial conditions that may be important for a more complete assessment of initial conditions for hurricanes.

$$FR = h_{updraft} = \alpha[w_{\max}]^{\beta} \quad (1.1)$$

$$h_{updraft} = \alpha[w_{\max}(p_s, T, q, u, v)]^{\beta} \quad (1.2)$$

In addition to environment variables (surface pressure, temperature, humidity and winds), it also includes two empirical parameters α and β that can be adjusted.

The type (2) operator is suited for both in-cloud and cloud environment. Its equations include dependence on vertical velocity and cloud variables

$$FR = h_{threat} = r \cdot h_{flux} + (1-r) \cdot h_{integral} \quad (1.3)$$

$$h_{flux} = k_1 \cdot (wq_g)_m \quad (1.4)$$

$$h_{integral} = k_2 \cdot \sum (q_g + q_s + q_i)\rho\Delta z \quad (1.5)$$

In addition to vertical flux of graupel (1.4), the vertical integral of graupel, snow and ice is also included. Given that vertical flux of graupel includes vertical velocity, and therefore variables that define it (e.g. surface pressure, temperature, winds and humidity), this operator includes a dependence on both the cloud environment and the cloud microphysical variables. Therefore, in assimilation of GLM data one can simultaneously adjust all these variables. There are also three empirical parameters, r, k_1, and k_2. Note that one can group the parameters

$$p_1 = r \cdot k_1 \quad (1.6)$$

$$p_2 = (1-r) \cdot k_2 \quad (1.7)$$

effectively reducing the problem to two parameters.

From the above description it appears that the operator of type (2) is better suited for hurricane applications since it includes more variables relevant for hurricanes.

2. Adjust lightning observation operators for hurricane applications

After choosing the operator of type (2) for GLM lightning data assimilation, there is a need for some additional adjustment of the original formulation (e.g., McCaul et al. 2009). This is because this operator was developed and tested for cases over land that include supercells, squall lines, and hailstorm, and calibrated with respect to such synoptic situations. In addition, the WRF model used in tests employed only one microphysics package (WSM-6), that may not be general enough for HWRF applications. It is likely that hurricanes will need an alternative calibration of empirical parameters, and even on-line parameter adjustment. In the original calibration of the lightning operator of type (2) the dominant term was the vertical advection of graupel ($k_1 = 0.95$; $k_2 = 0.05$), although the impact of the vertically integrated hydrometeors significantly varied from case to case. This points to a need for adjusting empirical parameters p_1 and p_2 on-line during data assimilation.

Therefore, we pose the data assimilation problem in two-steps: (1) Estimate optimal empirical parameters p_1 and p_2, and (2) assimilate GLM lightning observations using optimized parameters. In principle this procedure can be iteratively improved, but we begin by applying it only once. After optimizing the parameters, the lightning flash rate observation operator used in data assimilation is

$$FR = p_1^{opt}\left(wq_g\right)_m + p_2^{opt}\sum\left(q_g + q_s + q_i\right)\rho\Delta z \qquad (2.1)$$

The adjustment of the lightning flash rate observation operator will have impact not only in assimilation but also in the ensuing forecast of GLM lightning flash rate after data assimilation.

3. Conduct HWRF experiments with the assimilation of GLM observations

We conducted preliminary experiments with lightning data assimilation to test how code is working. At this point the computer we use is UCAR Cheyenne, since we are still waiting for security clearance to use NOAA Theia computer. After obtaining Theia accounts we will transfer the codes from Cheyenne.

The experiments are aimed as an evaluation of the GSI data assimilation with lightning. The experimental details are described in Apodaca and Zupanski (2018). Here we note that in this experiment we evaluate the impact of lightning observations on the 3-hour forecast after data assimilation. Therefore, we conduct two experiments: (i) the assimilation of conventional observations, and (ii) the assimilation of combined lightning and conventional observations. The results, shown in Fig.1, indicate positive impact of lightning assimilation and a close fit of the 3-hour flash rate forecast to lightning observations. This is an important result since in year-3 of this project we plan to evaluate in detail the GLM lightning flash rate forecast product in collaboration with NHC.

We also prepare for assimilation of GLM lightning observations for hurricane Maria (2017). We considered several options for choosing the GLM data set for assimilation that include *group*, *event*, and *flash*. We opted for the *group* GLM data (Fig.2). In Fig.2 we show the GLM lightning observations each hour over the 6-hour period centred on 17 SEP 2017 at 1800 UTC. The hourly lightning values are shown in different colors, indicating the movement of the hurricane. One can also notice the implied structure of the hurricane Maria from lightning observations over the 6-hour data assimilation interval.

Plans for Next Reporting Period

In the next reporting period we plan to continue adjusting the lightning observation operator with GLM lightning observations and hurricane WRF (HWRF) model and evaluate the GLM lightning data assimilation performance in more depth.

Additional Information

1. Interaction with operational partners –

A meeting with Stephanie Stevenson, GOES Tropical Applications Developer at National Hurricane Center (NHC), was held in Fort Collins. We discussed the optimal use of GLM lightning observations and the collaboration with NHC on the GLM lightning flash rate forecast product planned in this project.

2. <u>Conference/workshop participation</u> –

3. <u>Outside project publicity</u> –

4. <u>Journal articles</u> –

Apodaca, K., and M. Zupanski, 2018: Variational and Hybrid (EnVar) Methodologies to Add the Capability to Assimilate GOES-16/GLM Observations into GDAS. *JCSDA Quarterly*, No. 58, Winter 2018.

Key Graphics

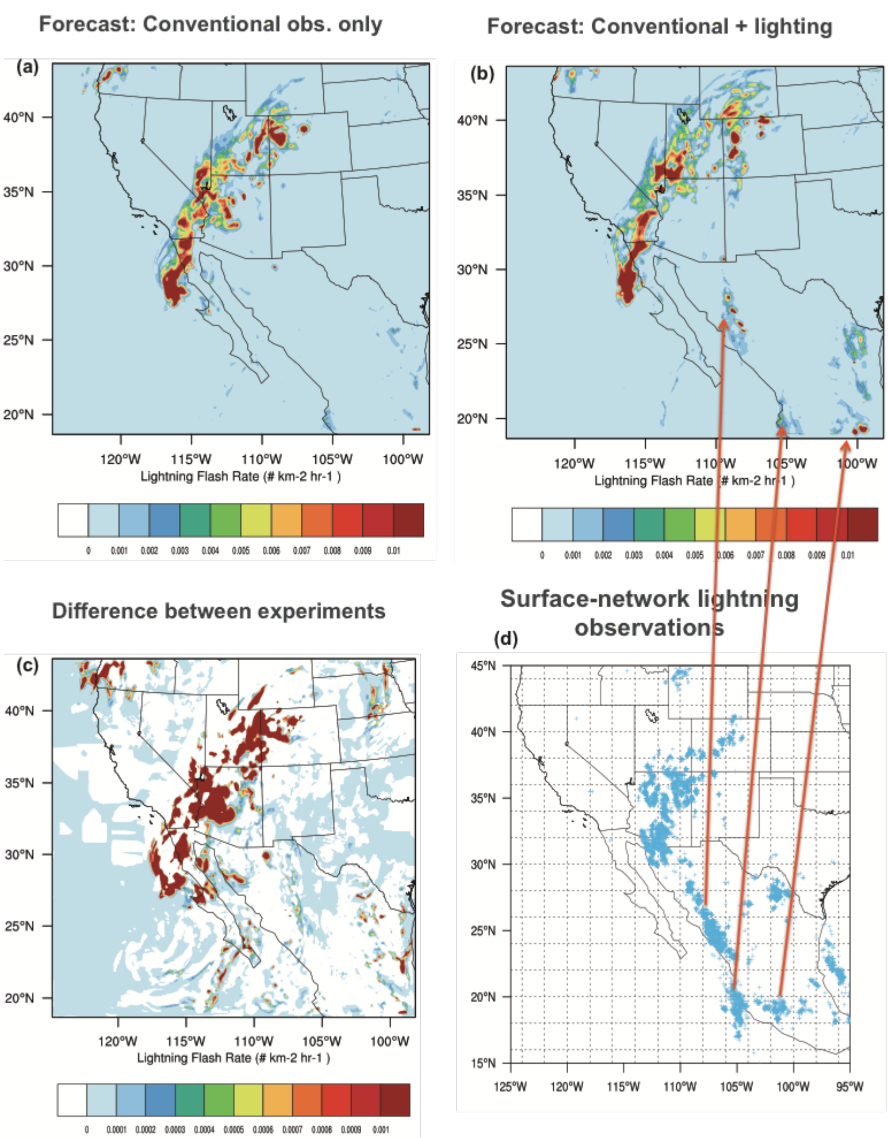

***Figure* 1.** 3-hour forecast of lightning flash rate valid 25 AUG 2013 at 1200 UTC: (a) after assimilating conventional observations only, (b) after assimilating conventional AND lightning observations, (c) the difference between experiments (a) and (b), and (d) verifying lightning observations. The results show a good match between 3-hour forecast of lightning flash rate and lightning observations.

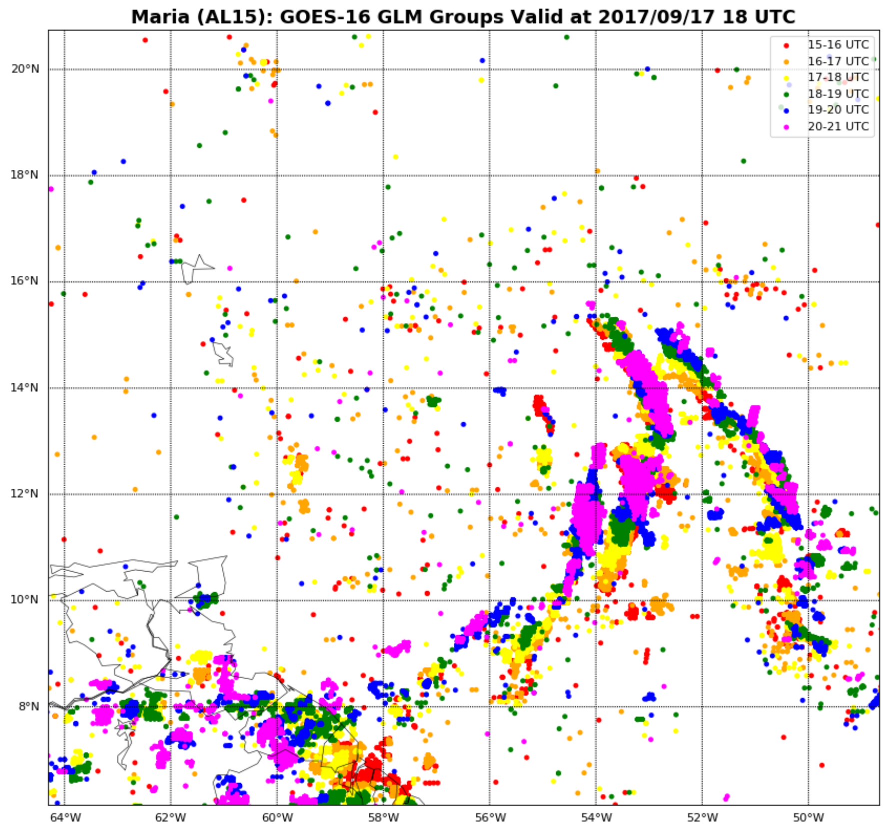

Figure 2. GOES-16 GLM lightning groups observations valid 17 AUG 2017 at 1800 UTC. Different colors denote hourly groups and indirectly the movement of the hurricane Maria over the 6-hour period. Important to note is that GLM lightning observations capture the position and to some extent structure of the hurricane in great detail.