Project Progress Report

Award Number:	NNX13AG96G
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Project Title:	Ensemble-based assimilation and downscaling of the GPM satellite precipitation information: further development and improvements of WRF-EDAS
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Report

The focus of this project is to continue methodology improvements of the WRF-EDAS system and produce an operation-ready assimilation/downscaling system for assimilation of GPM data. This will be achieved by:
(1) Developing hybrid variational-ensemble capability, and
(2) Developing bias correction scheme for precipitation-affected microwave radiances.

Main efforts during the first year have been focusing on the preparatory development of the basic system and making the system component updates.

1. Preliminary development of the benchmark system

The benchmark assimilation/downscaling system used in this project is an ensemble-based data assimilation system at cloud-resolving scales that has been developed jointly by NASA/GSFC and Colorado State University (CSU). The system consists of the following components: (i) Weather Research and Forecasting (WRF) model with multiple nesting capability and NASA cloud-microphysics (ii) NASA Satellite Data Simulation Unit (SDSU), (iii) NOAA/NCEP Gridpoint Statistical Interpolation (GSI) forward observation operators and (iv) the CSU Maximum Likelihood Ensemble Filter (MLEF) data assimilation algorithm. WRF-EDAS has capabilities of assimilating precipitation-sensitive microwave radiances at pixel scale and estimating flow-dependent and terrain-dependent forecast error covariance. Its current resolution is 9 km /3 km in horizontal with 31 vertical layers, with planned refinement to 1 km horizontal grid.

Main accomplishments of the Year-1 research include the upgrade of the system components for improved performance in operational-like computing environment. We also made the WRF-EDAS system applicable to related NASA efforts in coupled land-atmosphere data assimilation (NASA project NNX13AO10G, PI: Christa Peters-Lidard), by choosing the case studies of mutual interest. The link with the NASA coupled assimilation project will also serve as an additional verification venue of the WRF-EDAS system developed for GPM. In particular we updated our previous system to include more recent versions of the Weather Research and Forecasting (WRF) model and the NOAA/NCEP Gridpoint Statistical Interpolation (GSI) system used as a forward observation operator to access conventional and cloud-cleared satellite radiance observations. We also made some upgrades to the NASA Satellite Data Simulation Unit (SDSU) that is used to access rain-affected satellite radiances.

A recent version of the WRF-EDAS system was described in Zhang et al. (2013a), in applications to tropical storm Erin (2007) and a southeastern U.S. heavy rain event in 2009. The system includes an extended capability of accessing trough G-SDSU operator the following observations: AMSR-E, AMSU-B, Dual-frequency Precipitation Radar (DPR), GPM Microwave Imager (GMI), MHS, TRMM Precipitation Radar (PR), TRMM Microwave Imager (TMI), Special Sensor Microwave Imager (SSM/I), and Special Sensor Microwave Imager Sounder (SSMIS). In addition to the above observations, the system also assimilates NOAA operational observations (conventional and clear-sky satellite radiances) through the GSI module.

The system has been also successfully evaluated in a severe weather situation over France in 2010. Sensitivities to observation error specifications, background error covariance estimated from ensemble forecasts with different ensemble sizes, and MW channel selections are examined through single-observation assimilation experiments. This system also includes an empirical bias correction for precipitation-affected MW radiances based on the statistics of radiance innovations in rainy areas. Results show that the assimilation of MW precipitation observations from a satellite constellation mimicking GPM has a positive impact on the accumulated rain forecasts verified with surface radar rain estimates. This study also revealed that the accuracy of ensemble-based background error covariance can be limited by sampling errors and model errors such as precipitation displacement and unresolved convective scale instability.

In order to address the sampling errors and partially model errors of an ensemble system, a hybrid ensemble-variational improvement of the MLEF system was introduced (Zupanski, 2013). A unique feature of this improvement is that it maintains an optimal Hessian preconditioning, otherwise not possible with straightforward hybrid methods. The results suggest that the new methodology is mature and can be included as an upgrade to the WRF-EDAS, planned for the Year 2 of this project. The process of building a reduced-rank static error covariance is illustrated in Fig.1.

(a) (b) (c)

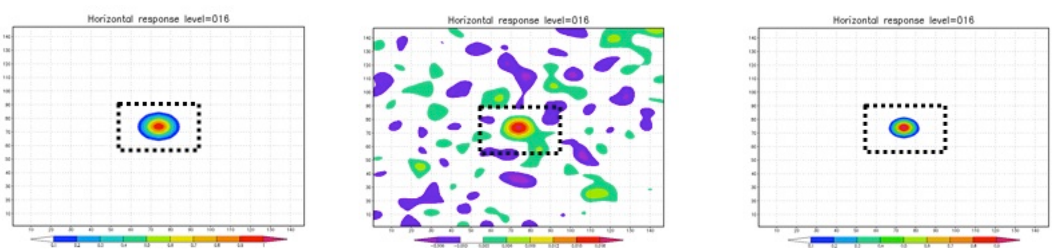

Figure 1. Phases in developing the static error covariance for hybrid WRF-EDAS: (a) the verifying column of true static error covariance, (b) an intermediate step after straightforward application of localized singular-value truncation approach, and (c) the resulting column of reduced-rank static error covariance after re-scaling. The doted domain represents local domain used for singular value decomposition.

One can notice a noisy error covariance column after a direct application of singular value decomposition and truncation (Fig.1b). However, after applying a covariance localization procedure and re-scaling, the reduced-rank approximation becomes acceptable (Fig.1c).

The static and ensemble (square-root) error covariances are initially combined as a simple liner combination

$$P_f^{1/2} = \alpha P_{ENS}^{1/2} + (1-\alpha) P_{STAT}^{1/2}$$

where α is a prescribed scalar. Several data assimilation experiments have been performed with the WRF model at 27 km resolution and assimilation of GSI real observations: ensemble only, static only, and hybrid data assimilation with $\alpha = 0.7$. This choice of the parameter gives more weight to the ensemble component. The results of data assimilation are illustrated in Fig.2, by showing the analysis increments of temperature at 700 hPa. Although the linear combination is defined to strengthen the impact of ensemble component, as seen from the areas circled in black, there are areas (circled in red) that indicate a dominant role of static error covariance. Measured by the cost function decrease, the hybrid system performed better than either of the component systems.

(a) (b) (c)

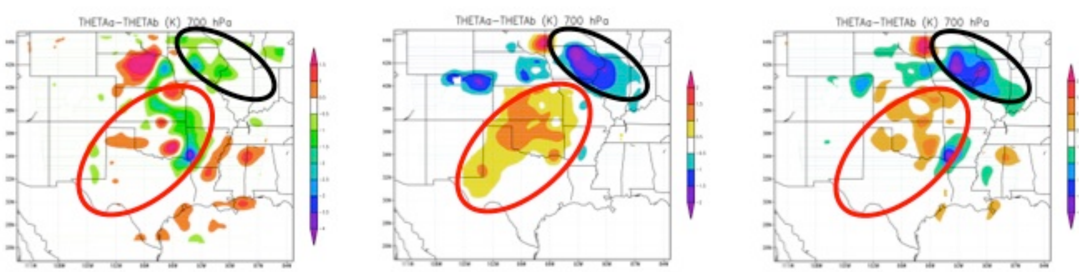

Figure 2. Analysis-minus-background temperature increments (K) at 700 hPa, valid 0000 UTC 20 May 2013, in: (a) static, (b) ensemble, and (c) hybrid system. The are circled in red indicates a dominant impact of the static error covariance, while the area circled in black suggest a dominant role of the ensemble error covariance.

We also developed an improvement of the satellite radiance bias correction (Zhang et al. 2013b) that is needed for cloudy radiance assimilation, and will be further refined in the updated WRF-EDAS system. The originally developed bias correction algorithm employs a scattering index overland (SIL) of radiances as a predictor (Zhang et al. 2013a). The upgraded algorithm is physically based and uses radar dual frequency ratio (DFR) and hydrometeor physical properties (PSD) to produce a radar data adjusted parameters.

During the first year we have two peer-reviewed publication (Zhang et al. 2013a; Chambon et al. 2013). We also participated at the 6th World Meteorological Organization Data Assimilation Symposium in College Park, MD, 7-11 October 2013, where we had one poster (Zupanski et al. 2013) and two oral presentations (Zhang et al. 2013b; Zupanski 2013).

The web page dedicated to this project has been developed (http://www.cira.colostate.edu/projects/ensemble/applications_with_complex_models.php).

2. Year 1 goals and accomplishments (overview)

The goals and accomplishments for Year 1 are:

1) Assess applicability of currently available hybrid variational-ensemble methods for use in WRF-EDAS and develop/adapt new methodology.

***Status**: Completed. We developed a new hybrid data assimilation methodology that has a unique addition that makes possible optimal Hessian preconditioning. The results indicate that the upgrade is ready for use within WRF-EDAS (Zupanski 2013).*

2) Assess applicability of currently available radiance bias correction methods for use in WRF-EDAS and develop/adapt new methodology.

***Status**: Completed. The empirical bias correction algorithm developed by Zhang et al. (2013a) has been improved by adding radar dual frequency ratio (DFR) and hydrometeor physical properties (PSD) (Zhang et al. 2013b).*

3) Chose case study and prepare data required for WRF-EDAS (e.g., model initial and boundary conditions, observations).

***Status**: Completed. We have chosen a set of cases over the southeastern US hydrometeorological testbed that coincides with test cases used with coupled land-atmosphere data assimilation (related NASA project). In particular, our first case study is for a storm event on 25-31 August 2008.*

4) Prepare a web-page documenting the work progress and research results.

***Status**: Completed. This report and other results are presented at https://www.cira.colostate.edu/projects/ensemble/show_page.php?page=nasa_gpm_2013*

5) Present results at science team meetings, scientific conferences.

***Status**: Completed. During this year we completed publishing two peer-reviewed manuscripts (Zhang et al. 2013a; Chambon et al. 2013). We have also one poster (Zupanski et al. 2013) and two oral presentations (Zhang et al. 2013b; Zupanski 2013) presented at workshops/conferences.*

All goals have been accomplished on schedule.

References:

Peer-reviewed publications:

Chambon, P., S. Q. Zhang, A. Y. Hou, M. Zupanski, and S. Cheung, 2013: Assessing the impact of pre-GPM constellation microwave precipitation radiance data in the Goddard WRF ensemble data assimilation system. *Quart. J. Roy. Meteorol. Soc*., DOI:10.1002/qj.2215.

Zhang, S. Q., M. Zupanski, A. Y. Hou, X. Lin, and S. H. Cheung, 2013a: Assimilation of precipitation-affected radiances in a cloud-resolving WRF ensemble data assimilation system. *Mon. Wea. Rev*., **141**, 754-772.

Workshops/Conferences:

Zhang, S. Q., P. Chambon, W. S. Olson, M. Zupanski, and A. Y. Hou, 2013b: Precipitation-related radiance bias correction and how GPM can help. *Sixth Symposium on Data Assimilation, World Meteorological Organization, October 7-11, 2013, College Park, Maryland*.

Zupanski, M., S. Q. Zhang, A. Y. Hou, and C. Peters-Lidard, 2013: Forecast error covariance in a coupled land-atmosphere data assimilation with NASA-Unified WRF model. *Sixth Symposium on Data Assimilation, World Meteorological Organization, October 7-11, 2013, College Park, Maryland*.

Zupanski, M., 2013: A Hybrid Variational-Ensemble Data Assimilation Method with an Implicit Optimal Hessian Preconditioning. *Sixth Symposium on Data Assimilation, World Meteorological Organization, October 7-11, 2013, College Park, Maryland*.