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Lightning Data Assimilation using an Ensemble Kalman Filter

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1. INTRODUCTION

A lack of observational data over regions such as the eastern North Pacific Ocean can lead to poorly initialized weather forecasts. This can result in forecast failures (McMurdie and Mass 2003; Colle et al. 2001), with obvious implications for public safety and economic activities (Colle and Mass 1998; Lynott and Cramer 1966). With its wide range of coverage, lightning detected by Vaisala's National Lightning Detection Network (NLDN) and Long Range Network (LRN) provides a promising dataset for filling gaps in observational coverage over the eastern Pacific and elsewhere.

Lightning strikes provide information about the dynamical state of the atmosphere at the observation location. Cloud electrification and subsequent lightning strikes can be used to infer the state of atmospheric lapse rates, vertical motions, microphysical conditions and convective rainfall rates, among others (Chang et al. 2001; Pessi et al. 2004; Pessi et al. 2006; Alexander et al. 1999; Petersen and Rutledge 1998). By using the lightning observations from the NLDN/LRN networks we attempt to improve upon weather analyses and forecasts.

This paper describes the assimilation of Vaisala's lightning data as a proxy for convective rainfall into an Ensemble Kalman filter (EnKF) using the Weather Research and Forecasting (WRF) model, with the goal of improving analyses, initializations and forecasts.

2. METHODOLOGY

2.1 WRF-EnKF

Lightning data from Vaisala's NLDN and LRN are assimilated into the University of Washington Department of Atmospheric Sciences WRF-EnKF system (Torn and Hakim 2007; Torn et al. 2006). An EnKF is a data assimilation technique, that combines information from model forecasts with observations, including error statistics, to give the best estimate of the state of the atmosphere (Hakim and Torn 2006; Hamill 2005). The error statistics for the model take the form of a background-error covariance matrix, which provides: the relative weighting to observations and model background forecasts; the effect of an observation at nearby locations and the information needed to spread observational information to other locations and other variables. For example, a pressure observation that increases the pressure in the analysis at a point near the station should be expected to also produce an anticyclonic adjustment to the analysis wind field around the point, if the flow is "balanced".

The EnKF generates flow-dependent model-error statistics by running an ensemble of forecasts and using that sample to estimate the covariance information. One analysis is then produced for each ensemble member. Given the analysis ensemble, new forecasts can be created by running the model again and the cycle is repeated indefinitely.

2.2 WRF-EnKF Setup

A 90 member ensemble is implemented using the non-hydrostatic WRF model for a 100x86 grid with 45-km spacing and 32 vertical levels extending over the western United States and eastern North Pacific Ocean. All model runs employ the Mellor-Yamada-Janjic turbulent kinetic energy scheme (MYJ-TKE), the Kain-Fritsch cumulus parameterization scheme and the WRF single-moment (WSM) three-class (water vapor, liquid water, and "simple" ice) microphysics scheme. The lateral boundary zone is five grid points wide with the outer boundary points specified by interpolated Global Forecasting System (GFS) values and the inner four boundary points by a linear combination of interpolated GFS values and WRF output.

Every WRF-EnKF simulation is performed over a two week period to minimize model spin-up affects. Observations are assimilated every six hours and six hour forecasts are run for all 90 members of the ensemble to the next assimilation time where another 90 analyses are made. Additionally, 24- and 48-hr forecasts are made every 12 hours during the period of available lightning observations for both the control and experimental runs.

The control experiments assimilate thinned and gridded Aircraft Communications Addressing and Reporting System (ACARS), cloud-track winds, Automated Surface Observing System (ASOS) stations, ships, fixed and floating buoys and rawinsondes every six hours (e.g. only every twelve hours for the rawinsondes). The lightning experiments assimilated the above observations along with lightning data.

2.3 Assimilation Techniques

Lightning data was used as a proxy for convective rainfall amounts during the study. We have used two different experimental techniques to assimilate the lightning.

The first technique assimilates all lightning strikes by converting from a lightning flash rate to a convective rainfall rate, following Pessi et al. 2006. The second technique, essentially grids the lightning data before being transformed into convective rainfall amount and assimilated into the WRF-EnKF.

2.4 Experiments

To evaluate the performance of the WRF-EnKF using lightning assimilation techniques three different synoptic regimes were investigated. For each of the three regimes three WRF-EnKF simulations were run: the control, where no lightning is assimilated, and the two experiment techniques described above. Each of the regimes contained either a developing and intensifying extratropical cyclone or a deepening extratropical cylone with associated lightning. The December 2002 event (Case 1) involved record amounts of lightning activity whereas the other two cases (October 2004 and November 2006) had drastically reduced numbers of lightning strikes.

3. RESULTS

One way to visualize the impact of assimilating lightning data into the WRF-EnKF is by examining the analysis field. Figure 1 contours the sea-level pressure (SLP) fields of lightning assimilation technique 1 and the control run, which withholds lightning observations, for the December 2002 case. The color shaded regions represent the difference between the SLP fields for the lightning assimilation experiment and the control. Lightning strikes are plotted as dots. Information from the lightning assimilation lowers the surface pressure fields throughout the extent of the extratropical cyclone relative to control. Figure 2 shows the impact of the analysis on SLP for lightning assimilation technique 2. In technique 2 the lightning observations also deepen the low pressure center and move the storm center to the southeast toward the frontal and post-frontal cold-pool lightning. The other two test cases show impacts of the lightning when storms have less strike amounts than the displayed December case, suggesting that even a small number of lightning flashes can have a significant affect on the analyses. The lightning strikes along the frontal band and cold-pool regions also have an impact upstream into the western and northern sides of the storm, illustrating the power of the WRF-EnKF system to spread observational information to other locations and variables.

The lower central pressures resulting from lightning assimilation are in agreement with GFS and NCEP analysis during maximum storm intensity shown in Figure 3. The figure displays the minimum sea-level pressure associated with the December 2002 extratropical cyclone.

Figures 4 and 5 display the 12-hour forecast errors for the control and lighting assimilation technique 1, respectively, with relation to the GFS analysis. SLP contours are plotted for the GFS analysis with the control and experimental run forecasts. Shaded regions are the difference between the control (Figure 4) and the lightning assimilation experiment (Figure 5) with the GFS analysis. Large forecast improvements can be seen in the 12-hour forecast of the SLP fields in the region of the extratropical cyclone when lightning is assimilated compared to the control. There is some degradation to the SLP fields over the western United States which is being investigated.

4. CONCLUSIONS

In this study we have tested the assimilation of lightning into the University of Washington Department of Atmospheric Sciences WRF-EnKF system in three separate synoptic regimes. Results show that the assimilation of lightning has a large impact on the analyses. SLP and H500 fields (not shown) are impacted, among others, and there is improvement to the predicted intensity and location of the extratropical cyclone during its lifetime. 12-hr forecasts with lightning assimilation show promising improvements over the control around the storm.

5. REFERENCES

Alexander, D. G., J. A. Weinman, V. M. Karyampudi, W. S. Olson, A. C. L. Lee, 1999: The effect of assimilating rain rates derived from satellites and lightning on forecasts of the 1993 superstorm. *Mon. Wea. Rev.*, **127,** 1433-1457.

Chang D.-E., J. A. Weinman, C. A. Morales, and W. S. Olson, 2001: The effect of spaceborne Microwave and ground-based continuous lightning measurements on forecasts of the 1998 Groundhog day storm. *Mon. Wea. Rev.*, **129,** 1809-1833.

Colle, B. A. and C. F. Mass, 1998: Windstorms along the western side of the Washington Cascade mountains. Part I: A high-resolution observational and modeling study of the 12 February 1995 event. *Mon. Wea. Rev.*, **126,** 28-52.

Colle, B. A., C. F. Mass, and D. Ovens, 2001: Evaluation of the timing and strength of MM5 and Eta surface trough passages over the eastern Pacific. *Wea. Forecasting,* **16,** 553-572.

Hakim, G. J., and R. D. Torn, 2006: Ensemble synoptic analysis. *Fred Sanders Monograph.* American Meteorological Society.

Hamill, T. M., 2005: Ensemble-based atmospheric data assimilation: A tutorial. *Predictability of Weather and Climate,* Palmer, T. and R. Hagedorn, Eds., Cambridge Press, 124-156.

Lynott, R. E., and O. P. Cramer, 1966: Detailed analysis of the 1962 Columbus Day windstorm in Oregon and Washington. *Mon. Wea. Rev.*, **94,** 105-117.

McMurdie L., and C. F. Mass, 2003: Major numerical forecast failures over the northeast Pacific. *Wea. Forecasting,* **19,** 338-356

Pessi, A., S. Businger, and T. Cherubini, 2006: Comparison of two methods for assimilation of lightning data into NWP models. *Preprints, 1st International Lightning Meteorology Conference,* 26-27 April 2006, Tucson, Arizona.

Pessi, A., S. Businger, K. L. Cummins, and T. Turner, 2004: On the relationship between lightning and convective rainfall over the central Pacific ocean. *Preprints, 18th International Lightning Detection Conference,* 7-9 June 2004. Helsinki, Finland.

Petersen, W. A., and S. A. Rutledge, 1998: On the relationship between cloud-to-ground lightning and convective rainfall. *J. Geophys. Res.*, **103,** 14025-14040.

Torn, R. D., and G. J. Hakim, 2007: Performance characteristics of a pseudo-operational ensemble Kalman filter. *Mon. Wea. Rev.*, **135,** submitted.

Torn, R. D., G. J. Hakim, and C. Snyder, 2006: Boundary conditions for a limited-area ensemble Kalman filter. *Mon. Wea. Rev.*, **134,** 2490-2502.

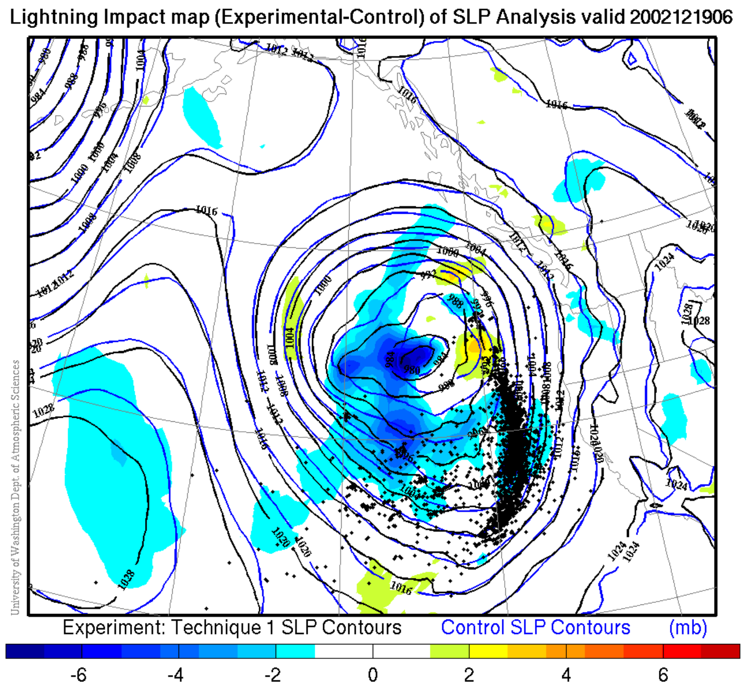

Figure 1. Contoured SLP analysis of lightning assimilation experiment technique 1 (black) and control (blue). Color fill represents SLP field of (experiment – control). Lightning strikes plotted as black circles.

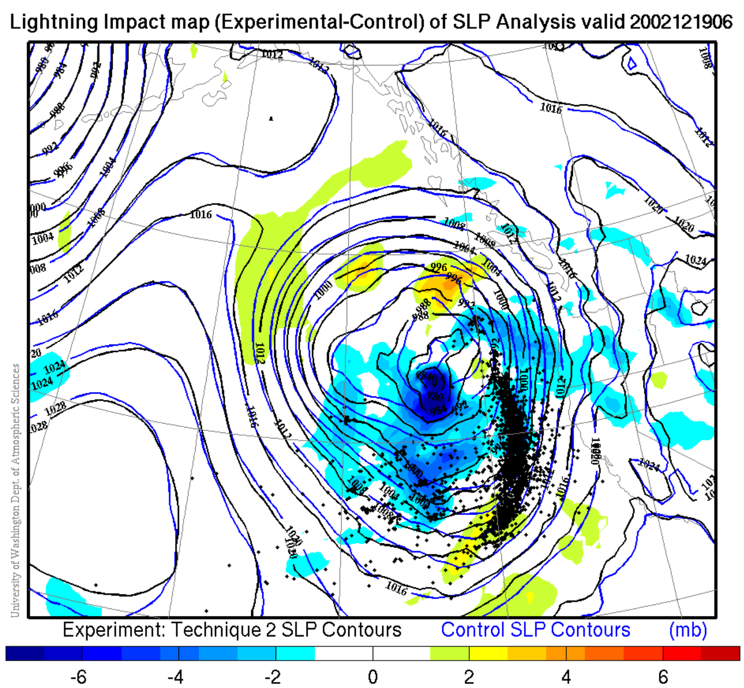

Figure 2. Contoured SLP analysis of lightning assimilation experiment technique 2 (black) and control (blue). Color fill represents SLP field of (experiment – control). Lightning strikes plotted as black circles.

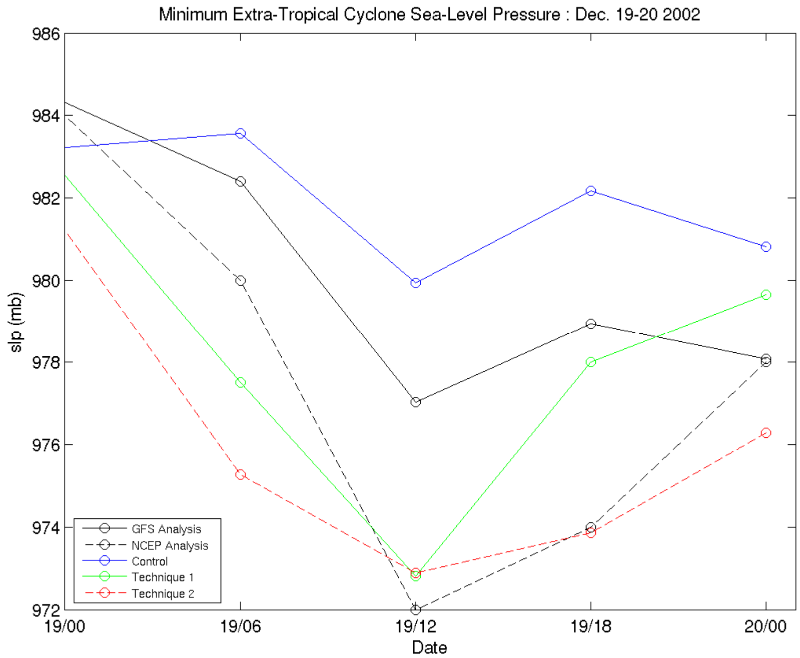

Figure 3. Minimum SLP values of GFS Analysis, NCEP Analysis with analysis values from control, and lightning assimilation experiments

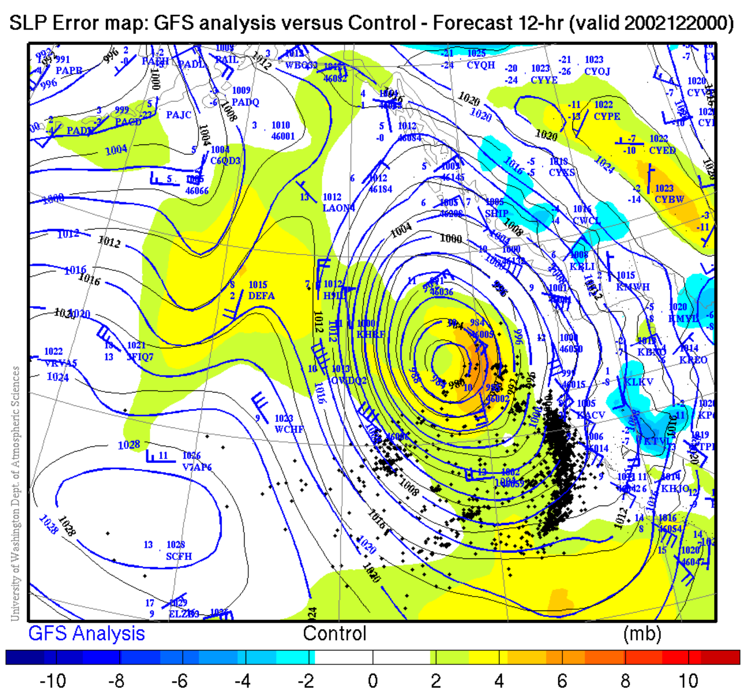

Figure 4. Contoured SLP GFS analysis (blue) with 12-hr forecast of control. Color fill represents difference in (control – GFS analysis).

SLP Error map: GFS analysis versus Experiment Technique 1 - Forecast 12-hr (valid 2002122000)

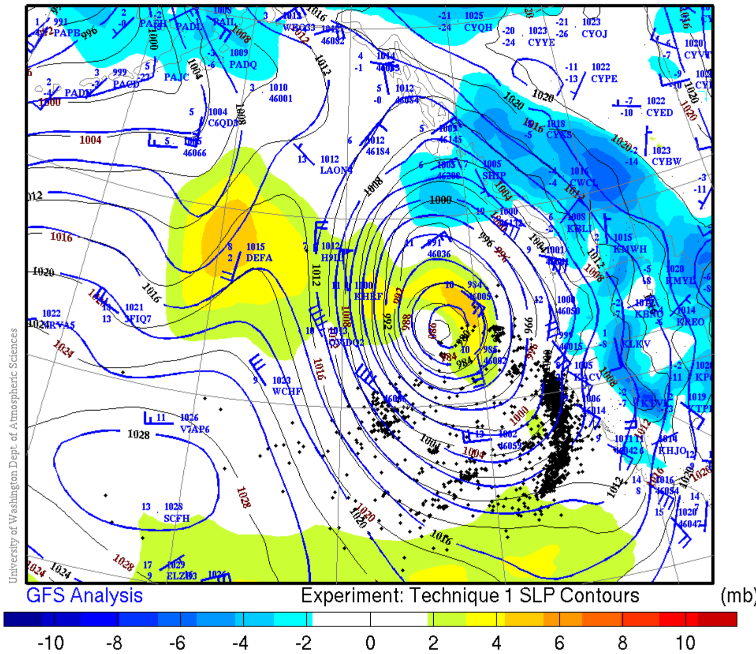

Figure 5.Contoured SLP GFS Analysis (blue) with 12-hr forecast of lightning assimilation experiment technique 1. Color fill represents difference in (experiment – GFS analysis).