Development of Operational Weather Research and Forecasting Model Ensemble Sensitivity/Data Assimilation Tools

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Visitor's Program Project Report
WRF Developmental Testbed Center (DTC)

I. Introduction

The primary goal of this project was to develop and test a set of forecast sensitivity and data assimilation tools based on a WRF-model ensemble Kalman filter (EnKF). Ensemble-based forecast sensitivity allows the examination of how a chosen forecast aspect at some forecast time, such as cyclone central pressure or precipitation amount, is related to weather features present in the analysis or early forecast hours. Investigating these sensitivities can lead not only to a better understanding of important precursors to high-impact events in general, but may also play a role operationally by raising forecaster awareness of important features related to severe weather. The manipulation of ensemble-based sensitivity within an EnKF further allows the calculation of 1) observation impact, which reveals the relative value of each assimilated observation, and 2) observation targets, which show preferred locations where additional observations would be most beneficial.

A primary focus of this work was to develop the sensitivity/assimilation tools described here in a user-friendly, namelist-driven framework to be accessible to a variety of users. The first phase of this work involving the development of an ensemble-based sensitivity module has been completed. Further collaboration with the WRF DTC is planned to complete the second phase of this work to create observation impact and targeting tools within an EnKF. A detailed description of the work completed is found below.

II. Methodology and Work Performed

The process of calculating forecast sensitivity begins with the generation of an ensemble of forecasts. There are several ways in which this can be accomplished, and for this project, the Data Assimilation Research Testbed (DART) EnKF system was utilized. Initially, a WRF analysis was perturbed with 3DVAR statistics obtained through the WRFVAR system to initialize the ensemble. The EnKF was then cycled every 6 hours over a 3-day period to achieve flow dependence within the ensemble covariance relationships. Surface, aircraft, satellite-derived wind, and radiosonde data were assimilated throughout the cycling period. On the completion of this cycling, an extended 36-hour forecast run of the ensemble was intended in order to provide the framework to develop the desired ensemble forecast sensitivity and data assimilation tools.

Forecast sensitivity requires the choice of a forecast aspect, often referred to as a response function. An example of such a forecast aspect is the 24-hour forecast 2-meter temperature over Boulder, CO. The sensitivity of this aspect can be produced with respect to any model field valid at any forecast time or at the initial time (e.g. sensitivity to initial-time sea level pressure). The sensitivity field in this case is calculated by a simple linear regression of the 24-hour forecast 2-meter temperatures at Boulder onto the initial-time sea level pressure field within the ensemble (Ancell and Hakim 2007). The intention of this work is to allow the calculation of sensitivities for a variety of applications, which could include a number of state variables or derived parameters. A primary goal was to create a namelist interface which allows for flexibility and ease in the generation of sensitivity fields.

In accordance with these project goals, Fortran code was developed to calculate ensemble forecast sensitivity. This code uses a namelist (Figure 1) that allows users to identify various parameters specific to their own applications. It can be seen that the user has options including the name, time, and location of the response function, as well as the variables with respect to which the sensitivity is calculated. It is clear that there are many additional derived variables that could describe any given case, so it is necessary to allow new parameters to be added to this methodology relatively easily. Currently, basic model variables and a few derived parameters are included as options in the code, and users will be encouraged to add further options that they feel apply specifically to their cases.

Due to inability to get the DART system running error-free during this project, an ensemble forecast from a different EnKF system (the University of Washington EnKF, Torn and Hakim 2008) was used to test the sensitivity code. This case involves an 80-member ensemble forecast of a November 2009 Pacific Ocean cyclone. Figure 2 shows the sensitivity of the 24-hour accumulated rainfall averaged over the black box near the British Columbia coastline with respect to the initial-time 2-meter temperature field. Also plotted are the ensemble mean initial-time 2-meter isotherms. It can be seen that the area of greatest sensitivity is collocated with a thermal ridge, which suggests that the position or strength of this feature is related to the precipitation 24-hour forecast in the box. The bright red color corresponds to a sensitivity of 0.9 mm/°C, which indicates that a 1°C increase in temperature at that point is related to a 0.9 mm increase in the average rainfall within the black box.

The sensitivity code exists in the directory */lfs0/projects/dtc/bednarcz/sensitivity* as the file *ens_sensitivity.f*, and there are five additional modules required: *module_netcdf.f*, *module_wrf_tools.f*, *module_map_utils.f*, *conversions_mod.f*, and *wrfdimsvars_mod.f*. More detailed documentation can be found in the file *sensitivity_doc.txt*.

III. Future Work

There are improvements that can be made to the current version of the program, which would allow for additional flexibility in the choices of sensitivity. Making these improvements will be an ongoing process through further collaboration with the WRF DTC. Furthermore, plans will be made in concert with WRF DTC personnel to disseminate the sensitivity code created during this project to interested users. The creation of similar Fortran code that manipulates ensemble sensitivity and allows observation impact and targeting calculations within a WRF EnKF is a planned extension of this work in the near future.

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References

Ancell, B.C. and G.J. Hakim, 2007: Comparing ensemble and adjoint sensitivity analysis with applications to observation targeting. *Monthly Weather Review*, Vol. 135, 4117 - 4134.

Torn, R.D. and G.J. Hakim, 2008: Performance characteristics of a pseudo-operational ensemble Kalman filter. *Monthly Weather Review*, Vol. 136, 3947 - 3963.

```
&sensitivity_nml

  ensnum          =     80,
  outfilename     =     'wrfplot_esens'
  initialvar      =     'SLP',
  timeinitial     =     1,
  initiallevel1   =     850.0,
  initiallevel2   =     500.0,
  vertunit        =     'P',
  responsevar     =     'SLP',
  timeresponse    =     5,
  responselevel1  =     850.0,
  responselevel2  =     700.0
  respx           =     90,
  respy           =     80,
  dx              =     2,
  dy              =     2,
  avgminmax       =     'avg',
  debug           =     .false.,
 /
```

Figure 1 - Namelist created for the Fortran ensemble sensitivity program.

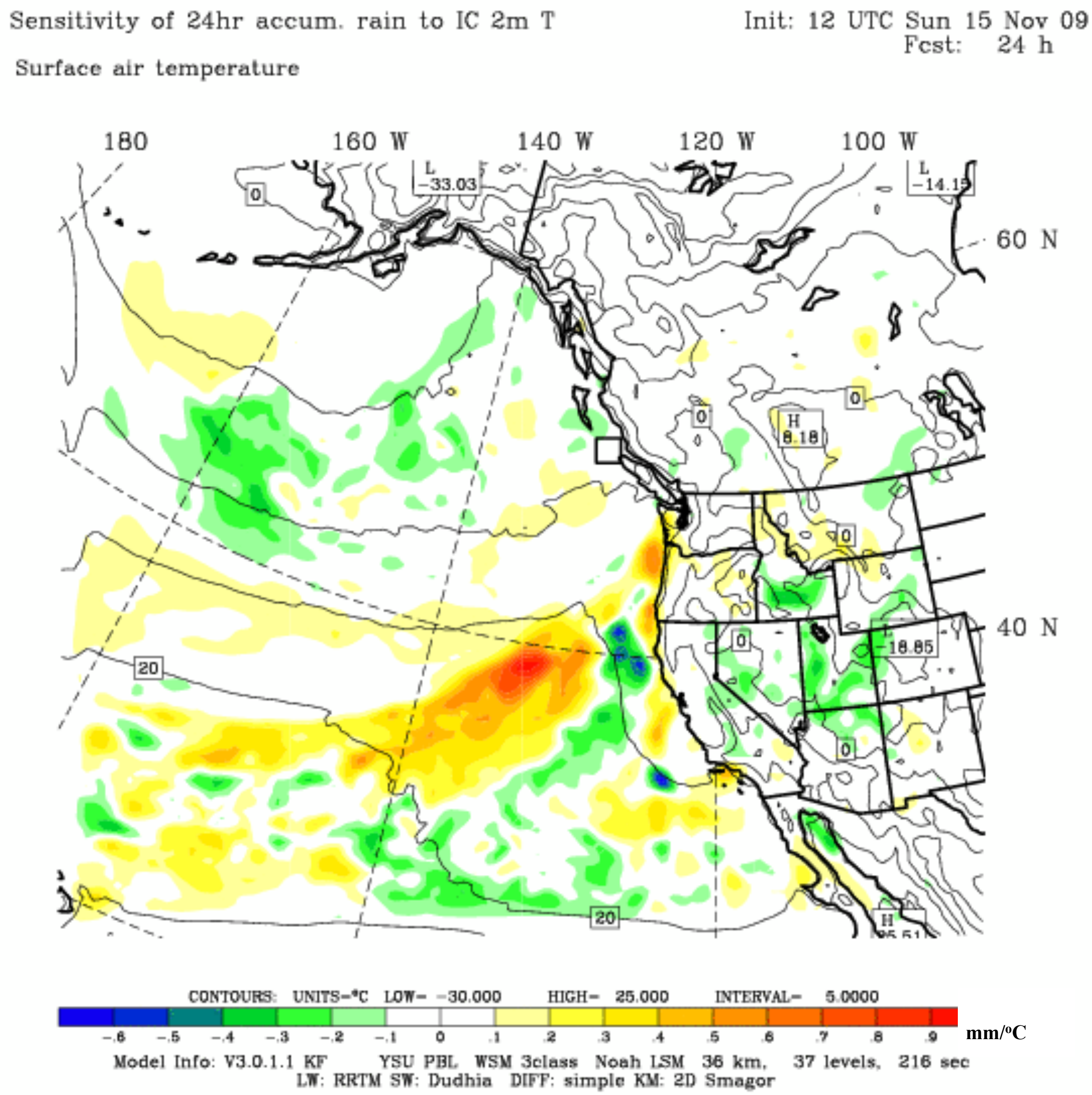

Figure 2 - Sensitivity of 24-hour forecast rainfall in the black box near the British Columbia coastline to initial-time 2-meter temperature (shaded, units are mm/°C), and initial-time ensemble mean 2-meter temperature (black contours, contour interval is 5°C).