WRF-Var - A Unified Variational Data Assimilation System for WRF

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1. Introduction

The WRF-Var system is a community variational data assimilation system developed and supported by MMM Division of NCAR, in collaboration with a number of US and international agencies[4]. Although primarily designed for use with WRF, WRF-Var is also being used in operational applications with other forecast models including MM5 (India), a global spectral model (Korea), and the Nonhydrostatic Forecast System (NFS - Taiwan).

WRF-Var is built within the WRF Advanced Software Framework (ASF - Michalakes *et al.* 2004) in order to make use of the ASF's I/O API and distributed memory parallelism software. Close coordination with the ASF is also necessary for an efficient four-dimensional variational (4D-Var) capability, in which the forecast component of WRF becomes a sub-model of the data assimilation system. A progress report on the development of 4D-Var within WRF-Var is given in Huang *et al.* (this volume). The development of linear and adjoint models for the Advanced Research WRF (ARW) core, required for 4D-Var, is described in Xiao et al. (this volume).

In the past year, the WRF-Var system (based on the WRF 3D-Var system described in Barker *et al.* 2004) has seen a number of upgrades culminating in the release of WRF-Var Version 2.1 in June 2005. Key components of the new release include

- A unified WRF/WRF-Var framework (V2.1).
- Additional observation types: Radar reflectivity, local GPS refractivity, AIRS/MODIS retrievals, MODIS atmospheric motion vectors (see Fig. 1).
- An extended range of background error covariance models.
- A global 3D-Var option.
- A new utility *gen_be* used to provide background error covariances for WRF-Var.

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In the remainder of this abstract, WRF-Var's new global 3D-Var option is briefly described, followed by a summary of the main feature of the *gen_be* error covariance calculation utility.

2. A Global 3D-Var Capability for WRF-Var

The majority of the 3D-Var algorithm used in WRF-Var is common to both regional and global applications (observation operators, minimization, background error preconditioning, interpolation, etc). Technically, the main changes required to extend the regional application to global are related to the presence of a) The polar singularity, and b) Periodic East-West boundary conditions. Of course, there are also scientific questions concerning the optimal mix of observations required for global/regional models, and the choice of control variables and balance constraints. The major difference between regional and global options in WRF-Var is in the definition of horizontal background error covariances. In regional mode, recursive filters (Purser et al 2003) are used whereas in global mode, a spectral decomposition is applied. Work is underway to represent flow-dependent error covariances in the global application via additional control variables.

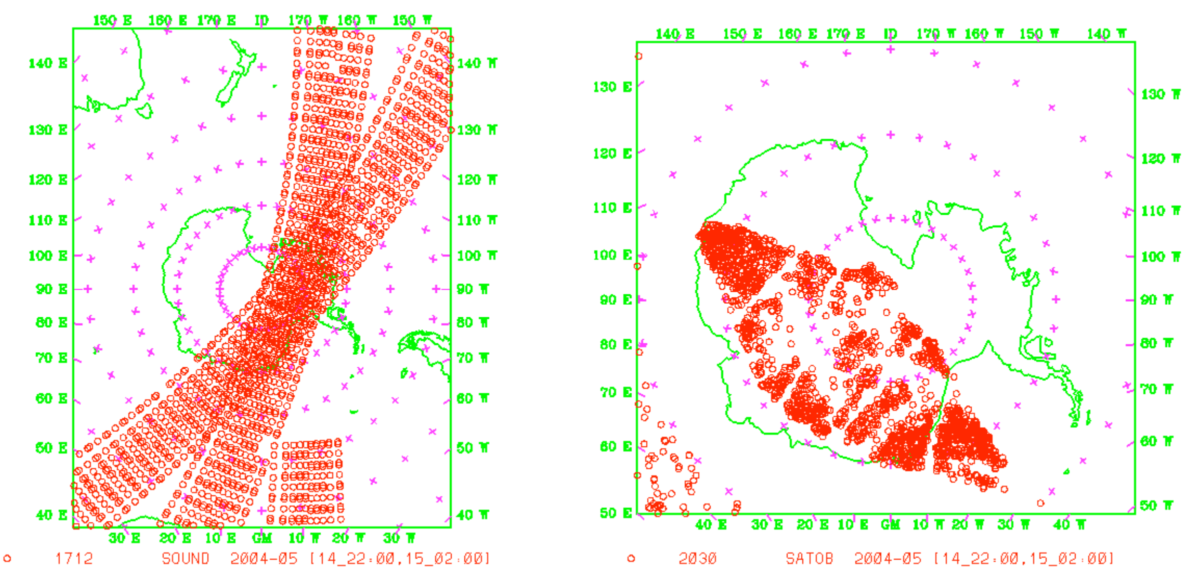

Fig. 1: a) 60km and b) 20km resolution test WRF domains of the Antarctic Mesoscale Prediction System (Powers *et al.* 2003). Example observation distributions are valid within the 4-hour time window centered on 00 UTC May 15th 2004. In a) AIRS/AMSU thinned swath data (before Quality Assurance checks) is shown, whereas in b) the position of (unthinned) MODIS atmospheric motion vectors is indicated.

The WRF-Var global 3D-Var option has been tested in case studies using a first-guess forecast from the KMA global spectral model and conventional observations. Adjoint tests and minimization results are satisfactory.

3. Background Error Covariance Generation: the *gen_be* Utility

The "NMC-method" code developed for MM5 3D-Var (Barker et al 2003) is nearing the end of its useful life. The development of a unified global/regional WRF-Var system, and its application to a variety of models has required a new, efficient, portable forecast (background) error covariance calculation code to be written. There is also a demand for such a capability to be available and supported for the wider 3/4D-Var research community for application to their own model and geographic areas of interest (the default statistics supplied with the WRF-Var release are designed only as a starting point). The process of background error covariance generation in *gen_be* may be broken down into four stages:

a. Conversion of model-specific forecast perturbations to standard perturbation fields.
b. Multivariate covariances: Perform regression against streamfunction (Wu *et al.* 2002).
c. Vertical Covariances: Represented via decomposition into eigenvectors/eigenvalues.
d. Horizontal correlations: Calculate recursive filter lengthscales (regional domain), or power spectra (global domain).

To illustrate the use of *gen_be*, forecast error covariances have been computed from KMA T213 global model 48 minus 24 hour forecast difference data for January 2004. The calculation of regression coefficients can be verified by comparing the actual forecast difference values of particular fields, with the "balanced" component of the field estimated via the regression on streamfunction. Fig. 2 shows this correlation for velocity potential and temperature fields. Fig. 2 indicates that up to 60% of the velocity potential forecast error can be estimated from streamfunction error in the mid-latitude boundary layer. Similarly, up to 90% of the temperature foreast error can be predicted (in a climatological sense) knowing the streamfunction error. These significant correlations show the importance of using the unbalanced (rather than full) components of velocity potential and temperature as control variables within 3D-Var. Neglect of these multivariate correlations would result in a significantly poorer analysis.

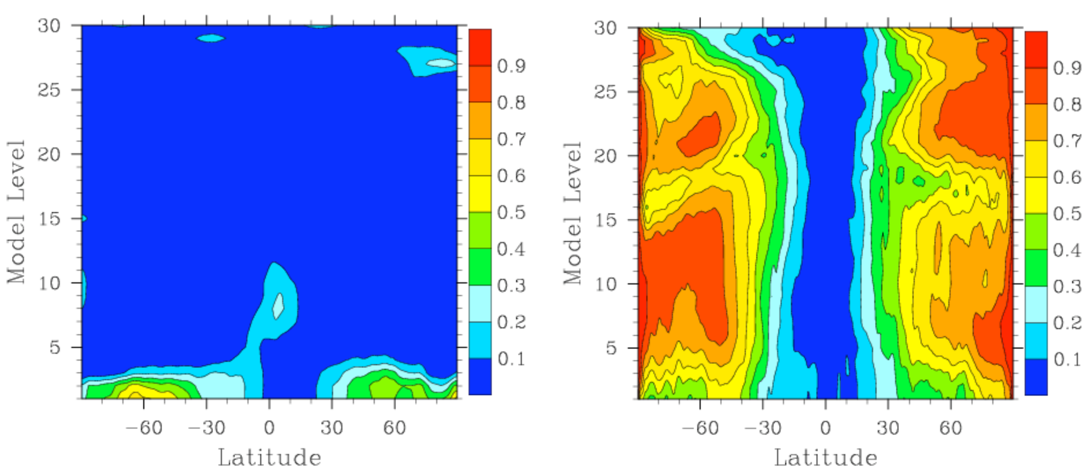

Fig. 2: Correlations between balanced and full components of velocity potential (left) and temperature (right) error fields as estimated from January 2004 KMA T213 48 minus 24 hour forecast difference files.

4. Summary

Current efforts are geared towards the tuning of seasonal forecast error statistics for particular applications, studies of the impact of satellite data at high latitudes, further computational efficiency improvements, and the direct assimilation of radiances. Extended testing of the global 3D-Var in the KMA operational system will be performed in 2006.

References

Barker, D. M., W. Huang, Y.-R. Guo, and A. Bourgeois, 2003: A Three-Dimensional Variational (3DVAR) Data Assimilation System For Use With MM5. *NCAR Tech Note*, NCAR/TN-453+STR, 68 pp. [Available from UCAR Communications, P.O. Box 3000, Boulder, CO, 80307.]

Barker, D. M., W. Huang, Y.-R. Guo, and Q. N. Xiao, 2004: A Three-Dimensional (3DVAR) Data Assimilation System For Use With MM5: Implementation and Initial Results. *Mon. Wea. Rev.*, **132**, 897-914.

Ingleby, N. B., 2001: The statistical structure of forecast errors and its representation in the Met. Office global 3-D variational data assimilation scheme. *Quart. J. Roy. Meteor. Soc.*, **127**, 209-232.

Powers, J. G., A. J. Monaghan, A. M. Cayette, D. H. Bromwich, Y. -H. Kuo, and K. W. Manning, 2003: Real-time mesoscale modeling over Antarctica: The Antarctic Mesoscale Prediction System. *Bull. Amer. Metor. Soc.,* **84**, 1533-1545

Purser, R. J., W. -S. Wu, D. F. Parrish, and N. M. Roberts, 2003: Numerical aspects of the application of recursive filters to variational statistical analysis. Part I: Spatially homogeneous and isotropic Gaussian covariances. *Mon. Wea. Rev.*, **131**, 1524-1535.

Wu, W. -S., R. J. Purser, and D. F. Parrish, 2002: Three-Dimensional Variational Analysis with Spatially Inhomogeneous Covariances. *Mon. Wea. Rev.*, **130**, 2905-2916.