Error Covariance Estimation and Representation for Mesoscale Data Assimilation

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LONG-TERM GOALS

Explore and develop new ideas and methods for error covariance estimation and representation to advance the state of the art in mesoscale data assimilation and numerical weather prediction.

OBJECTIVES

Explore and develop new ways to study and estimate observation and prediction (background) error covariances, especially the non-homogenous, non-isotropic and/or flow-dependent aspects of prediction (background) error covariances. Explore new and efficient representations of the inverse covariances in the variational formulations for mesoscale data assimilation.

APPROACH

The spectral correlation model in the innovation method has been extended into a spline-spectral covariance model in which the horizontal variation of background error variance is modeled by a B-spline expansion with a proper filter. By fitting the spline-spectral covariance function to the innovation covariance data, the horizontal variation (non-homogeneity) of the background error variance can be estimated together with the correlation function. The innovation method can be also reformulated based on the recently derived non-isotropic form of radial-velocity error covariance to estimate error covariances from high-resolution radar velocity innovation (observation minus background) data.

A functional approach can be developed to represent the covariance by an integral operator associated with a Kernel function in the continuous limit, so the inverse covariance can be derived by using the generalized Fourier transformation.

The PI, Dr. Qin Xu, is responsible to derive theoretical formalisms and design computational schemes for the proposed objectives. The related computer algorithm developments, data processing and calculations are performed by project-supported research scientists at CIMMS, the University of Oklahoma. The required innovation data are collected by project collaborators, Drs. Edward Barker, Andrew Van Tuyl and Keith Sashegyi, at NRL Monterey.

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14. ABSTRACT
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15. SUBJECT TERMS

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WORK COMPLETED

The proposed spline-spectral covariance model has been formulated, in which the horizontal variation of the background error standard deviation (square root of the error variance) is expressed by an expansion of B-spline basis functions on finite-element meshes (Xu et al. 2001b) and the correlation function is expressed by a spectral expansion (Xu et al. 2001a; Xu and Wei 2001, 2002). This covariance model was coded into a costfunction to fit innovation covariance data. Since the minimization problem became nonlinear in this case, a new scheme was designed to minimize the costfunction iteratively and alternately in two subspaces of the model parameters: one is composed of the spectral coefficients and the other is composed of the B-spline coefficients. A D-operator filter was designed (using the proposed functional approach) to control the smoothness and improve the convergence of the iteration.

In collaboration with scientists at NRL Monterey, operational NOGAPS-OI innovation data have been continuously collected and archived for the proposed objectives. Innovation data produced by the new Navy's Variational Data Assimilation System (NAVDAS, Daley and Barker 2000) have also been collected since May 2000. The collected data were transferred to a dedicated workstation at CIMMS/OU. The data were processed through quality checks and selected for the proposed studies.

A new method was developed to estimate error covariances from high-resolution radar velocity innovation data. This method is a reformulation of the innovation method of Xu and Wei (2001) based on the non-isotropic form of radial-velocity error covariance (Xu and Gong 2003). The method was coded and applied to quality-controlled radar velocity innovation data. The radar data were collected from the Terminal Doppler Weather Radar (TDWR) at the Oklahoma Airport, while the background vector velocity fields were produced by a real-time radar wind analysis package with the input data from KTLX radar. Since the existing Doppler wind data quality control (QC) techniques were developed mainly for visual and qualitative applications and they do not satisfy the high standard required by radar data assimilation nor by the above innovation method, a part of the effort was devoted to improve radar data QC techniques.

Using the proposed functional approach, advanced mathematical formalisms are being developed to represent the inverse convariances (that is, the weights in the costfunctions of 3dVar and 4dVar) by elliptical differential operators applied to the delta function. With this representation, the background term can be formulated in terms of the Sobolev norm or, equivalently, the L_2 norm of a vector differential operator, called D-operator, applied to the field of analysis increment.

RESULTS

With the spline-spectral covariance model, the extended innovation method was applied to both the OI and NAVDAS innovation data collected from 1 to 31 May 2003 over North America. The results show that the method can estimate the horizontal variation of the background error standard deviation in addition to the background error correlation function. The estimated background (6h prediction) error standard deviation fields are shown by the examples in Fig. 1. As shown, the estimated error for the predictions produced with the new NAVDAS is smaller than that produced with the OI. This quantifies the improvement of the new NAVDAS over the operational OI.

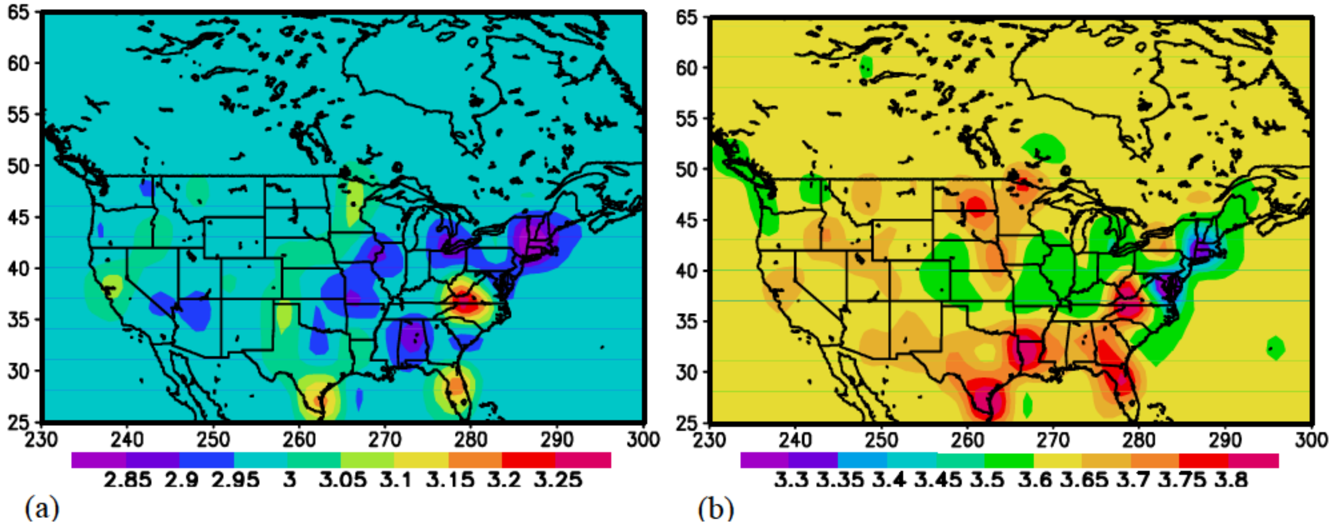

Fig. 1. Estimated error standard deviations (ms^{-1}) for 500 mb background (6h prediction) winds produced by NOGAPS with the operational OI (a) and with the new NAVDAS (b) for May 2003.

Four major types of data quality problems were detected from WSR-88D level-II velocities by using the real-time wind analysis package (http://gaussian.gcn.ou.edu:8080/rtime.shtm). By extracting the main features and key signatures exhibited in each type of problems, a prototype QC package was developed and tested (Liu et al. 2003; Zhang et al. 2003). In addition, a three-step method was developed for Doppler radar velocity dealiasing. The method was succcessfully tested with Doppler radar data for several difficult cases (see Fig. 2 and Gong et al. 2003)

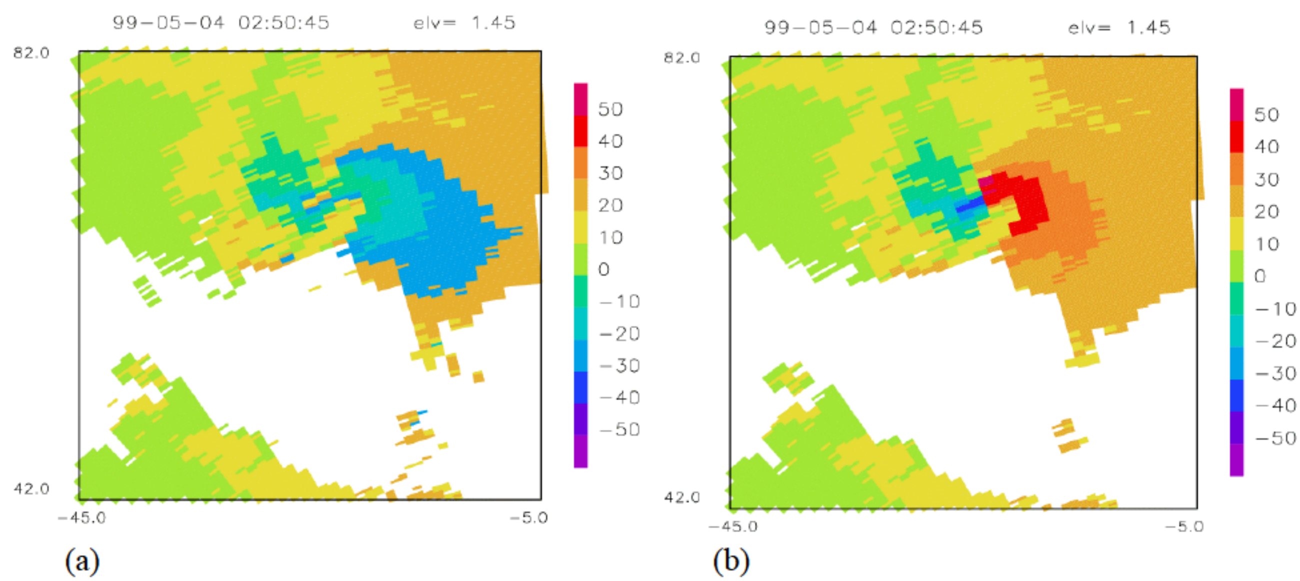

Fig. 2. Raw data field (a) and dealiased data field (b) of radial velocity (ms^{-1}) on 1.5º tilt at 02:51 May 4, 1999, displayed over the vicinity area of the mesocyclone. The KTLX radar is at the origin of the coordinates to the southeast outside the map.

As the new innovation method was applied to the aforementioned radar innovation data, the divergent part of the background velocity error covariance was found to be larger than the rotational part. As a mesoscale feature, the enhanced divergent part was dynamically consistent with the reduced scale (from synoptic to mesoscale). The new method has also relaxed the conventionally assumed non-correlation in the horizontal between observation (measurement plus sampling) errors. This has enabled the new method to detect the true observation error correlation between neighborhood gates of radar scans. When the method was applied to high-resolution radar velocity data, a sharp observation error correlation was detected between neighborhood gates (Xu et al. 2003).

IMPACT/APPLICATIONS

With the spline-spectral covariance model, the extended innovation method provides the very-needed capability to estimate the horizontal variation of background error variance. The observation error variance can be then estimated station-by-station by subtracting the estimated background error variance from the innovarion variance. These estimations provide important and necessary information for future improvements of NAVDAS data assimilation.

To optimally assimilate Doppler radar velocity data into a numerical model, it is necessary to estimate their (measurement plus sampling) error statistics. No statistical method existed for this purpose until the innovation method was newly reformulated. The new method provids, for the first time, an objective and statistical way to estimate radar velocity observation error statistics as well as mesoscale background error covariances by using high-resolution radar velocity innovation data.

TRANSITIONS

The algorithm package of the existing innovation method was delivered to Dr. Edward Barker at NRL Monterey for NAVDAS applications. The new 3.5dVar radar data assimilation package upgraded with multivariate background error covariances was delivered to Dr. Alan Zhao at NRL Monterey for nowcast applications and COAMPS radar data assimilation (Zhao et al. 2003).

The executable code of the three-step radar velocity dealiasing algorithm was requested by and given to Dr. Peter May for research applications (as a part of our research exchange) at Bureau of Meteorology Research Centre, Melbourne, Australia. The code will be also made available to NCEP and NRL Monterey for operational tests and applications.

RELATED PROJECTS

Radar Velocity Data Quality Controls (funded by NOAA/USWRP to NSSL and OU).
6.2 Shipboard Data Assimilation System/Doppler Radar (funded by ONR to NRL Monterey).
6.2 Data Assimilation for Mesoscake Prediction (base funding BE-435-009 to NRL Monterey).

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