Diagnostic Tools for the Navy Global and On-scene Three Dimensional Variational Data Assimilation System

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1. Introduction

The US Navy requires meteorological, oceanographic and other environmental data to improve threat detection, ship routing, electromagnetic parameter estimation, mission decision-making, target acquisition etc. For the atmosphere this information is provided by a global forecast/analysis system (NOGAPS) run at a central site (FNMOC). FNMOC also runs centrally 3-5 windows using a mesoscale analysis/forecast system at much higher resolution (30 km). Windows can also be specified to run at even higher resolution, depending upon the geopolitical situation. It is envisaged that COAMPS will also be run regionally at forecast centers such as San Diego or Rota and on selected ships of the various fleets (the on-scene problem). At present the analysis function of both NOGAPS and COAMPS is performed using a multivariate (volume form) optimal interpolation algorithm, which went operational in the mid-1980's.

Beginning in 1996, a completely new data assimilation system has been built, based on the three dimensional variational methodology. It is hoped to replace the OI suite for both the on-scene and regional applications (run on workstations) and the global application (run on a supercomputer?) with a single 3DVAR code over the next couple of years. This paper briefly describes the mathematical formulation, background error statistics, instruments etc. and then goes on to describe some of the diagnostics used with this system.

2. Formulation and properties

The cost function and method of minimization

The NRL 3DVAR algorithm minimizes the cost function,

$$\mathbf{J} = [\mathbf{H}(\mathbf{x}_a) - \mathbf{y}]^T \mathbf{R}^{-1}[\mathbf{H}(\mathbf{x}_a) - \mathbf{y}] + [\mathbf{x}_a - \mathbf{x}_b]^T \mathbf{P}_b^{-1}[\mathbf{x}_a - \mathbf{x}_b] , \qquad (1)$$

where $\mathbf{x}_a, \mathbf{x}_b$ are the grid analysis and background, $\mathbf{R}, \mathbf{P}_b$ are the observation and background error covariances, $\mathbf{H}$ is the forward (instrument) operator and $\mathbf{y}$ is the observation vector. Minimization of (1) with respect to $\mathbf{x}_a$ and application of the Sherman-Morrison-Woodbury formula leads to the observation space algorithm,

$$\mathbf{z} = [\mathbf{H}\mathbf{P}_b\mathbf{H}^T + \mathbf{R}]^{-1}[\mathbf{y} - \mathbf{H}\mathbf{x}_b], \qquad \text{solver} \qquad (2)$$

and $\mathbf{x}_a - \mathbf{x}_b = \mathbf{P}_b\mathbf{H}^T\mathbf{z}$, post-multiplier. (3)

A pre-conditioned conjugate gradient descent algorithm is used for the solver. The pre-conditioner directly solves a reduced problem which is obtained by dividing the domain into observation prisms, whose size depends on the local observation density. Normally there would be 200-800 observations in a prism.

Background error statistics

The background error covariance is formulated in physical space in the horizontal and modal space in the vertical. The vertical modal space is obtained by eigenvector decomposition of the background error vertical correlation matrices. Background error correlations may be non-separable, permitting vertical and horizontal variation of both horizontal and vertical correlation lengths and coupling parameters. In addition, a transformation of the vertical independent variable from pressure to potential temperature permits a considerable amount of flow dependence in the error covariances.

The vertical eigenvector decomposition has important computational advantages for profile instruments (such as radiosondes) and sounders (such as TOVS). In particular, sounders which normally have coarse vertical resolution, essentially affect only a few of the gravest vertical eigenmodes.

Instruments

At this time the algorithm assimilates radiosonde temperatures, wind and moisture on all significant and mandatory levels. It assimilates surface data, ACARS winds and temperature, pilot reports etc. It directly assimilates TOVS radiances, SSM/I windspeeds and SSM/I total precipitable water.

Present configuration

The system has been completely re-written from data ingest to model interface. It has 39 vertical pressure levels to 1 mb. All horizontal positions are defined in terms of latitude and longitude, so it is completely independent of model grid. Thus, it is designed to interface to our T159 global model or COAMPS with three nests down to 9 km. It is coded in FORTRAN 77/90 and MPI, and has been run globally on a 32 processor CRAY T3E and regionally on various workstations. It is presently undergoing cycling tests with COAMPS running over the eastern Pacific using CALJET data.

3. Diagnostic tools

A number of new diagnostic tools will be provided for the new system.

(1) Complete observation tracability

(2) Web-based observation (and innovation) monitoring

(3) The synthetic residual vector

(4) χ^2 testing of the scalar $\gamma = [\mathbf{y} - \mathbf{Hx}_b]^T [\mathbf{HP}_b\mathbf{H}^T + \mathbf{R}]^{-1} [\mathbf{y} - \mathbf{Hx}_b]$

(5) Innovation and buddy checks based on γ.

(6) The adjoint of the 3dvar code for observation targeting and sensitivity testing.

References

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