ESTIMATION OF OBSERVATION VALUE USING THE NAVDAS ADJOINT SYSTEM

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A new adjoint-based "observation impact" procedure has been developed for assessing the value (in terms of forecast impact) of any or all observations used in a data assimilation / forecast system. The procedure can be applied as a diagnostic tool to monitor the assimilation and quality control of any observation type, and can also be used in the design of improved observing networks. It can be applied to any forecast and data assimilation system for which adjoints exists. Here we describe implementation using the Navy Operational Global Atmospheric Prediction System (NOGAPS) and the NRL Atmospheric Variational Data Assimilation Procedure (NAVDAS).

The calculation of observation impact uses the adjoints of both NOGAPS and NAVDAS. We seek the gradient ($\partial J/\partial \mathbf{y}$) of a forecast error costfunction (J) with respect to the vector of observations ($\mathbf{y}$).

We first define a forecast error norm:

$$\mathbf{e}_{\mathrm{f}} = \left\langle (\mathbf{x}_{\mathrm{f}} - \mathbf{x}_{\mathrm{a}}), \mathbf{C}(\mathbf{x}_{\mathrm{f}} - \mathbf{x}_{\mathrm{a}}) \right\rangle \quad , \quad (1)$$

where $\mathbf{x}$ is the vector of model predictive variables, vorticity, divergence, potential temperature, and surface pressure (humidity is predicted by the model but not used in the error norm calculation). The subscripts, f and a, refer to "forecast" and verifying "analysis", respectively, of the NOGAPS forecast and assimilation. In (1) $\mathbf{C}$ is a matrix of energy weighting coefficients that represents dry total energy. An energy metric is used because it is an appropriate choice for applications to predictability in the absence of an acceptable estimate of the actual analysis error covariance metric. The brackets $\langle \ , \ \rangle$ represent a Euclidean inner product $\langle \mathbf{x}, \mathbf{y} \rangle = \Sigma\, \mathbf{x}_i \mathbf{y}_i$. The error norm in (1) has units of J kg^{-1}, and is summed between the lowest near-surface model level and a level near 150 hPa. The forecast verification area (FVA) in which the error is calculated can be any region, including the complete global domain. The costfunction for the adjoint gradient calculations is defined as $J_f = \frac{1}{2}\mathbf{e}_{\mathrm{f}}$ and the starting condition for the adjoint integration, at forecast verification time is:

$$\partial J_{\mathrm{f}} / \partial \mathbf{x}_{\mathrm{f}} = \mathbf{C}(\mathbf{x}_{\mathrm{f}} - \mathbf{x}_{\mathrm{a}}) \quad . \quad (2)$$

One integration of the forecast model (NOGAPS) adjoint provides a three-dimensional sensitivity vector for the initial conditions (t=0):

$$\partial J_{\mathrm{f}} / \partial \mathbf{x}_0 = \mathbf{L}^{\mathrm{T}}\, \partial J_{\mathrm{f}} / \partial \mathbf{x}_{\mathrm{f}} \quad , \qquad (3)$$

where $\mathbf{L}^{\mathrm{T}}$ is the operator representing the adjoint of the discretized NOGAPS model. This adjoint sensitivity is obtained in a tangent linear and perfect model framework, and is linearized with respect to a trajectory provided by the nonlinear global forecast model (including moist physics), that is updated every second time step ($2\Delta t = 1800$ s). The second step in the sensitivity calculations is to extend the initial condition sensitivity gradient into observation space using the adjoint of NAVDAS:

$$\partial J_f \big/ \partial \mathbf{y} = \mathbf{K}^{T} \, \partial J_f \big/ \partial \mathbf{x}_0 \quad , \qquad (4)$$

where $\mathbf{K}^{T}$ is the operator representing the adjoint of the Kalman gain matrix in the data assimilation procedure. The quantity $\partial J_f / \partial \mathbf{y}$ is the sensitivity of the forecast error costfunction with respect to the complete set of observations, **y**, in observation space. If we consider that the background ($\mathbf{x}_b$) is fixed, then $\partial J_f / \partial \mathbf{y}$ is also the sensitivity to the innovations (observation – background). It should be noted that it is necessary to interpolate the sensitivity gradient $\partial J_f / \partial \mathbf{x}_0$, which is obtained on the forecast model grid in (3), onto the analysis grid before it can be used in (4), and care must be taken in this step to consider special properties of the sensitivity gradient.

We can use observation sensitivity gradients provided by (4) to estimate the impact of observations on various measure of short-range forecast error. Once calculated, the observation impact can then be correlated with other quantities such as background or observation error to identify potential problems in quality control or statistics used in the assimilation, or to investigate other research issues. For example, Fig. 1 depicts the correlation of observation impact with cloud cover, demonstrating that observations in cloudy regions have more impact on 72hr global forecast error. Fig. 2 depicts the sensitivity of 72hr global forecast error to ATOVS observation at one assimilation time. Accuracy of the observation sensitivity calculations is relatively good, even when applied to forecasts as long as 72h. Additional details about results and procedures used in observation impact calculations can be obtained from the author.

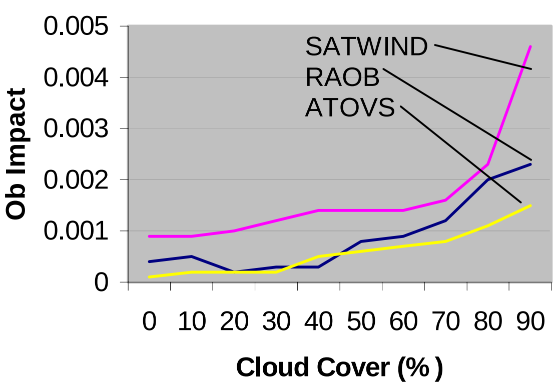

Fig. 1: Observation impact (average magnitude per observation type) on 72hr global forecast error (J kg^{-1}) as a function of model-diagnosed cloud-cover. Based on results from 29 June – 28 July 2002.

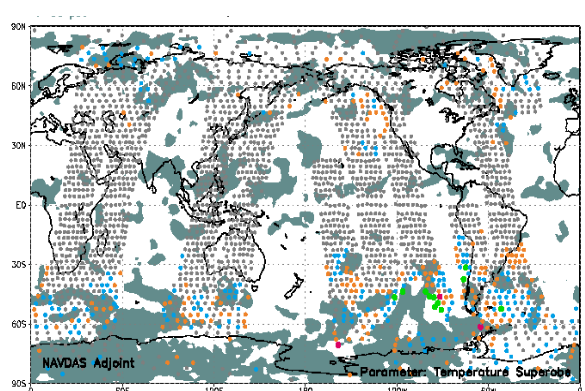

Fig. 2: Impact of ATOVS temperature profiles on 72 hr global forecast error for the assimilation at 00UTC 6 Sep 2002, with forecast verification at 00UTC 9 Sep 2002. Color dots indicate higher impact. Shading indicates diagnosed cloud cover > 60 percent. Each dot represents the combined impact of ~30 temperature observations in a profile through the entire depth of the troposphere.