Tellus **000**, 000–000 (0000) Printed 16 January 2008 (Tellus LaTeX style file v2.2)

Impact of evolved HSV and TESV for adaptive observations targeting in a 4-D Var framework with a finite volume S-W model

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16 January 2008

ABSTRACT

In the present paper we present a comparison of total energy singular vectors (TESVs) and Hessian singular vectors (HSVs) for adaptive observations targeting using a global finite volume shallow-water equations (SWE) model, along with its first and second order adjoint model.

A methodology of interactive adaptive observations distributed in both time and space as introduced by Daescu and Navon is employed.

To obtain the HSVs a generalized eigenvalue problem was solved using the generalized Jacobi-Davidson algorithm the framework of the JDQZ package developed by Sleijpen et al. A full 4-D Var procedure without incremental approximation was used leading to an accurate second order adjoint and derivation of a consistent Hessian matrix. To assess the potential benefits of targeting methods using second order adjoint information a number of numerical experiments involving TESV and HSV as alternative adaptive strategies were carried out.

The results obtained point to an advantage of using HSV as a tool for adaptive targeting where interaction between targeted observations taken at distinct instants in time has a significant impact on efficiency of both adaptive strategies. Additional metrics such as similarity indices between HSV and TESV also point to the same conclusion.

1 Introduction

Singular vectors identify directions in phase space which provide the maximum growth over a finite period in time with respect to specified norms.

Several techniques have been put forward to identify optimal sites for additional observations. Adjoint based techniques such as sensitivity to initial conditions and singular vectors (have been proposed) have been tested for such tasks by many groups of researchers.

As summarized by Langland (2006) targeted observing is a process in which supplementary atmospheric observations are assimilated to improve analyses in selected regions of the atmosphere, and reduce the uncertainty in forecasts of weather events that have large societal or economic impact.

Initial efforts were carried out by Lorenz and Emanuel (1998), Berliner et al. (1999), Barkmeijer et al. (1998), Leutbecher (2003), Langland et al. (1999), Pu and Kalnay (1999) , Morss et al. (2001), Baker and Daley (2000). It has become evident through the work of Barkmeijer et al. (1998, 1999) that use of Hessian singular vectors (HSVs) where the Hessian of the cost function (if the background error and observation errors are uncorrelated) is equal to the inverse of the analysis error covariance matrix (Rabier and Courtier 1992, Fisher and Courtier 1995) holds promise for improving adaptive targeting observations. A methodology of interactive adaptive observations distributed in both time and space was introduced by Daescu and Carmichael (2003) and Daescu and Navon (2004) while the impact of data interaction on targeted observations with a 4-D Var data assimilation and forecast system was presented by Daescu et al. (2006). See also the relevant work of Bergot and Doerenbecher (2002), Bergot (2001), Buizza and Montani (1999), Palmer et al. (1998), Langland and Baker (2004) and Langland (2005).

The advantage of using HSVs (apart from the overhead to have to solve a generalized eigenvalue problem) is that initial time HSVs evolve into leading vectors of the propagated analysis error covariance at verification time.

Barkmeijer et al. (1998, 1999) have shown that the Hessian of the cost function in a variational data assimilation scheme can be used to compute SVs that incorporate an estimate of the full analysis error covariance at initial time. The resulting SVs, referred to as Hessian SVs or (HSVs), are consistent with the data assimilation scheme used to

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