The GMAO 4DVAR and its Adjoint Tools

Abstract

The GMAO 4DVAR extends the Assimilation System for GMAO (ASSO) to a 4-dimensional variational data assimilation system. The new system was developed in collaboration with NCEP and a general circulation model derived from an existing assimilation package. The 4DVAR system is designed to be compatible with the original 3DVAR package and to provide a reliable hydrological correction. It is based on the assimilation package used for the NCEP Global Data Assimilation System (GDAS) and has been extensively tested and used for operational purposes. The system provides a framework for assimilating various types of data, including surface observations, satellite data, and model output. The system is flexible and can be adapted to different applications.

Four-dimensional Variational Approach

The general cost function of the variational formulation

\[ J(u) = \frac{1}{2} (u - f)^	op W (u - f) + \frac{1}{2} (v - h)^	op R (v - h) \]

where

- \( u \) is the 4D state vector;
- \( u_0 \) and \( u_1 \) are the background and dynamical model predictions, respectively;
- \( v \) and \( h \) are the background and model, and observation error concentrations, respectively;
- \( W \) and \( R \) are the background and model, and observation error concentrations, respectively;
- \( J \) represents a balance constraint.

Incremental Variational Formulation

The formulation of the 4DVAR generally followed the GMAO 4DVAR, where the forward propagation is due to the finite propagation from the initial time to the present time as the problem is to a quadratic minimization problem for the increments:

\[ J_i = \frac{1}{2} (v - h)^	op R (v - h) \]

where

- \( v \) and \( h \) are the background and model, and observation error concentrations, respectively;
- \( J_i \) is the cost function increment.

The observation vector \( v \) can be solved by:
- Conjugate gradient
- Quasi-Newton (such as BFGS)
- Levenberg

Convergence of the \( J_i \) minimization is determined by the Hessian matrix, which is the finite difference in such a way that good preconditioning is essential, particularly in the gradient

Summary and Conclusions

- NASA GES DIS has extended the 4DVAR method for GMAO.
- Numerical aspects of the new 4DVAR system are available in public domain.
- The 4DVAR system is capable of performing studies for several applications, such as climate prediction, model validation, and monitoring.
- The system provides a framework for assimilating various types of data, including surface observations, satellite data, and model output.
- The system is flexible and can be adapted to different applications.