Parameter Estimation for Gravity Wave Schemes using a Genetic Algorithm

M. Pulido[1,2], S. Polavarapu[3], T. G. Shepherd[1], J. Thuburn [4]

(1) University of Toronto, Canada
(2 UNNE-CONICET, Argentina
(3)) Environment Canada,
(4) University of Exetter, UK

Parameters of a gravity wave scheme are estimated objetively using data assimilation principles. A variational data assimilation technique does not converge because the cost function presents multiple minima and ill-conditioning. To overcome these dificulties we propose a genetic algorithm that determines the global minimum of the cost function. We performed a series of twin experiments, concluding that the parameter estimation using a genetic algorithm is robust over a broad range of prescribed 'true' parameters. Realistic estimations of the parameters using Met Office analysis as observations are also presented.

1. Motivation

The drag (GWD) imposed by small-scale gravity waves to the general circulation is represented by means of schemes in GCMs. These schemes need to specify the launch momentum flux which at the moment is poorly constrained from GW observations. We develop an inverse technique that is able to estimate the optimal parameters that fit a known GWD profile.

Because most gravity wave drag schemes assume instantaneous vertical propagation of GWs in a column, GWD observations in a single column can be used to obtain information about the parameters.

The GW scheme is the hydrostatic one from McLandress and Scinocca's (2005). This simplified scheme was prefered because it has a minimum number of switches and free parameters.

The 'observed' GWD is determined seperately by a variational data assimilation technique that uses a global model and analysis to estimate the missing force (Pulido and Thuburn 2008).

2. Technique details

The experiments use monthly averaged zonal mean *u* and *T* (from which *N* and ρ are derived) from Met Office analysis for July 2002 .

The cost function is defined as:

$$J(E_*,\lambda_*,S_*) = (\mathbf{x}-\mathbf{y})^T \mathbf{R}^{-1}(\mathbf{x}-\mathbf{y})$$

where ***y*** is the observed GWD profile and $x=X(E_*,\lambda_*,S_*)$ is the forcing resulting from the GW scheme.

The variational assimilation technique is based on the conjugate gradient-secant method, the gradient of the cost function is calculated with the adjoint model of the GWD scheme.

Since the variational method fails an alternative method is proposed, which is based on the genetic algorithm developed in NCAR by Charbonneau et al. (1998). The minimisation is performed in a constrained domain. In particular the parameters are assumed to be nonnegative. We set the number of individuals in a population to 100 . and the number of generations to 200.

3. Results: Twin experiments

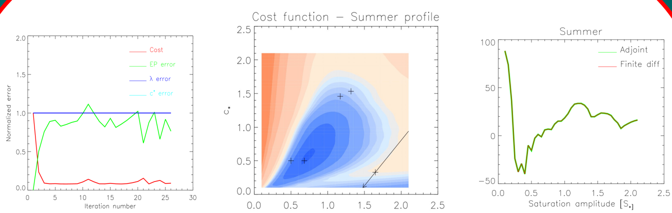

Fig. 1. Normalised error in the estimation as a function of the minimisation iteration (left panel). A cross-section of the cost function (middle panel). Derivative of the cost function with the adjoint method and with finite difference in a search direction (right panel).

For some initial guess parameters there is no convergence towards the true parameters with the variational technique (Fig. 1) because the conjugate gradient algorithm finds multiple critical points. The adjoint model gives the same result as a finite difference calculation of the derivative, even in the direction with a complex cost function geometry.
The genetic algorithm converges toward the true parameters for any set of true parameters (Fig 2). An initial guess does not need to be provided, so that the estimation for these twin experiments is robust.

Fig. 2. Estimation of the three unknown parameters using the genetic algorithm. The estimated parameters are normalised with the true parameter for each case. The number of generations is 100 (red curves) and 500 (green curves).

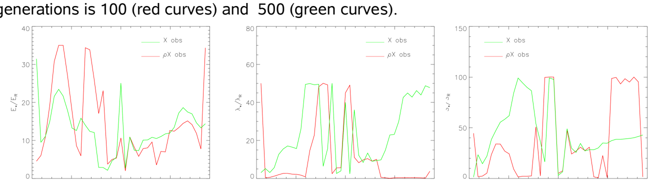

Fig 3. Parameters E_* (left) λ_* (middle) and S_* (right) estimated for Met Office analysis in July 2002 and observed GWD .

4. Results: Realistic estimations

The GWD field estimated with the ASDE-4DVar technique (Pulido and Thuburn, 2008) for July 2002 is used as observational forcing profile, this GWD field is the 'optimum missing force' between a middle atmosphere model and Met Office analysis. The estimated parameters with the genetic algorithm are shown in Fig. 3, the cost function is only formed by one column (zonal means) so that the parameters are for this experiment completely uncorrelated between different latitudes (columns).
In realistic GWD profiles, case y=X fits better the higher altitudes, upper stratosphere and lower mesosphere (Fig 4) while y=ρ X fits better the lower stratosphere, of the observed drag profile (Fig 5); except at the tropics.

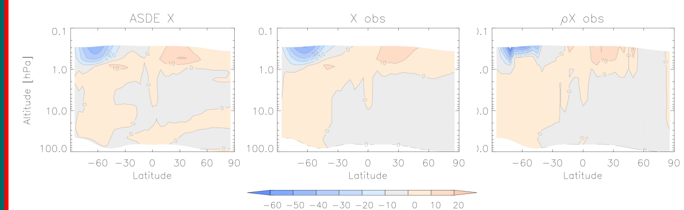

Fig 4. Observed GWD (ASDE, left panel) estimated GWD case *y=X* (middle panel) and case *y=ρ X* (right panel).

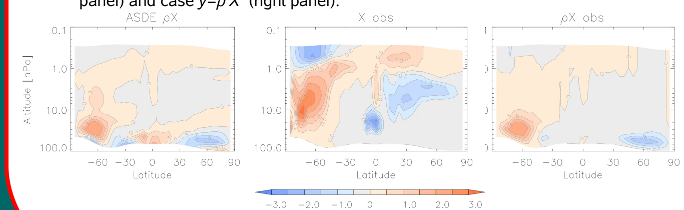

Fig 5. Observed EP flux divergence (ASDE, left panel) estimated EP flux divergence case *y=X* (middle panel) and case *y=ρ X* (right panel).

5. Conclusions

- **The structure of the cost function contains multiple unphysical minima and maxima. A genetic algorithm is proposed to overcome these problems. It determines the global minimum in a constrained domain if a physically reasonable parameter range is provided. The algorithm is computationally efficient for this low dimension estimation (the GWD scheme has only three tuneable parameters).**
- **Scinocca's GW scheme with the optimum parameters appears to reproduce rather well the observed GWD at high latitudes in the winter and summer hemispheres. On the other hand it is not able to reproduce the observed GWD at the Equator (Fig 4 and 5).**

References

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