An Adjoint Technique to Analyse Vortex-Vortex Interactions in the Stratosphere

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1. Motivation and Aim

On September 24th 2002, the Southern Hemisphere underwent its first ever major stratospheric warming event, splitting the cold stratospheric polar vortex into two parts (Baldwin et al, 2002).

This research project investigates the cause of the split from the perspective of non-linear vortex dynamics and aims to test the hypothesis that:

'The vortex is potentially unstable when highly elongated'

Observational analysis has revealed the development of a negative, (cyclonic) PV anomaly directly under the highly elongated tip of the vortex around the same time as the vortex split.

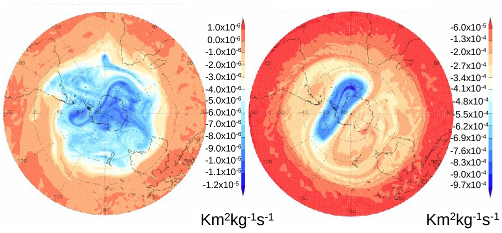


Figure 1. Fields of Ertel's PV on 22nd September 2002 on the (a) 350K and (b) 850K isentropic surfaces of the Southern Hemisphere.

2. Methods

The Adjoint Technique

The concept of the adjoint model is used here to estimate the sensitivity of the polar vortex evolution during September 2002 with respect to previous conditions in the troposphere. This work builds on the previous work of Jung and Barkmeijer (2004) who used this technique to study the sensitivity of the tropospheric circulation to changes in the strength of the polar vortex.

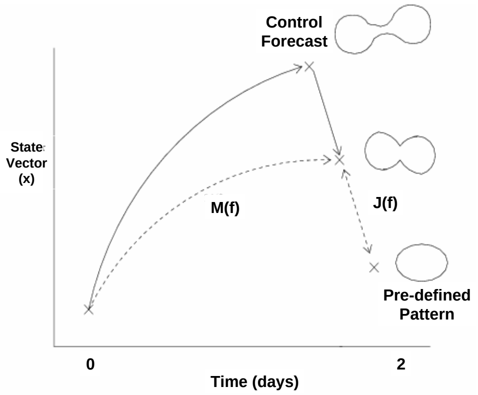


Figure 2. Concept of the Adjoint Technique. A control forecast using the tangent linear model produces a split vortex. By integrating backwards in time using the adjoint model a set of forcing perturbations are obtained which are applied to the initial model state over a 48hr optimisation period and produce a new state. The aim is obtain a set of forcing perturbations which push the vortex to a pre-defined pattern taken to be the non-split state.

3. Results

a) The Sensitivity Gradient

The Sensitivity gradient identifies regions of the atmosphere where adding a forcing perturbation will have the greatest impact on reducing the magnitude of the cost function.

By confining the forcing perturbations just to the troposphere (i.e. below 200hPa) the sensitivity gradient reveals a region of high sensitivity in the same location and of the same spatial scale as the negative PV anomaly directly underneath the elongated tip of the vortex.

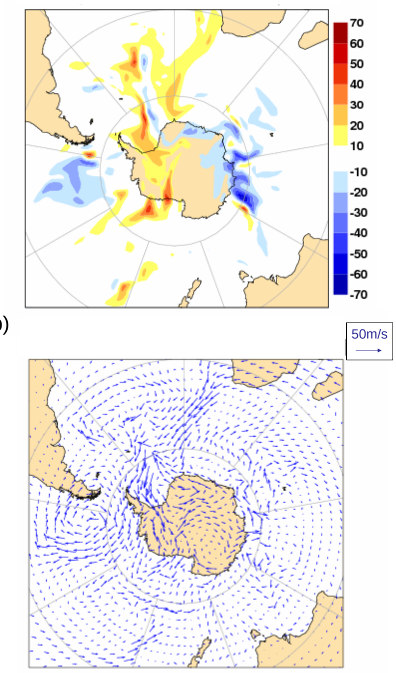
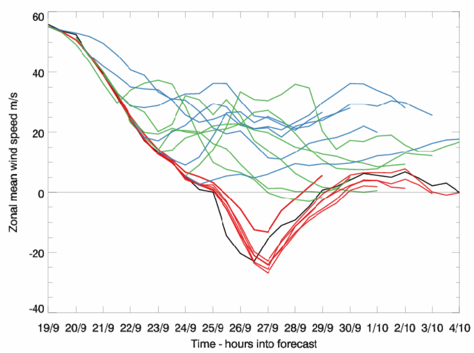


Figure 3. Sensitivity gradient in terms of (a) temperature and (b) wind, both at 500hPa (Units are JKs^{-1} and Jms^{-1} s^{-1}).

d) Non-Linear Forecasts

The optimal forcing perturbations are applied to the initial model state and a fully non-linear forecast is produced to see whether the vortex split can be inhibited.



= Observed conditions
= Control forecast
= Perturbed (Troposphere only)
= Perturbed (Troposphere & stratosphere)

Figure 7. Zonal mean wind at 10hPa, 60°S for the fully non-linear forecasts starting on 6 different start dates between the 19th-24th September, each a day apart.

b) Optimal Forcing Perturbations

Minimisation of the cost function yields a set of optimal forcing perturbations which when applied to the model state over the linear regime will push the split vortex towards the pre-defined pattern.

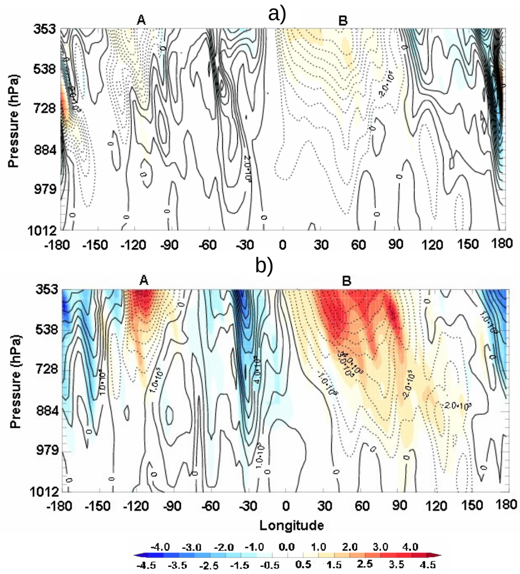


Figure 5. Vertical gradient of sensitivity gradient (contours) (units are JK^{-1}s^{-1}) and optimal perturbations (shaded) (K^{-1}s^{-1}) on (a) 19th September and (b) 22nd September

c) Interpretation of the Sensitivity Gradient and Optimal Perturbations

- Region of high negative sensitivity in the same location and of the same spatial scale as the negative PV anomaly.
- Distinct vertical gradient indicates that perturbations in the upper troposphere will have a greater impact on minimising the cost function than perturbations lower in the troposphere.
- The optimal perturbations act to dampen the structures.

3. Conclusions

- The adjoint technique reveals a region of high sensitivity located directly underneath the elongated lobe of the vortex,
- The sensitivity gradient and optimal perturbations display a distinct vertical gradient.
- By forcing the initial model state for 48hrs with optimal forcing perturbations confined only to the troposphere, the major sudden stratospheric warming has been inhibited.

4. Future Work

a) PV Inversion

This area of work aims to quantify the flow induced across the edge of the vortex by the negative PV anomaly. The PV Inversion tool will be used firstly to compare the magnitude of the balanced winds With and without the PV anomaly and secondly to advect the modified PV fields over a 2 day period to examine how the stratosphere evolves.

b) Idealised Vortex Dynamics

Further work involves simulating the non-linear interactions of vortex pairs under varying conditions.