On the lower boundary condition of tangent-linear models

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1 Introduction

A number of studies (Buizza, 1994; Janisková et al., 1999; Mahfouf, 1999) have shown that adiabatic tangent-linear (TL) versions of numerical weather prediction models produce too large evolved perturbations close to the surface when compared to pairs of non-linear (NL) model integrations (ranging between 6 and 48 hours). As a result, non-physical modes are generated in the computation of singular vectors and the convergence of 4D-Var can be affected when assimilating near-surface observations. This problem has been solved by including linearized vertical diffusion schemes in order to describe dissipative processes generated by turbulence near the Earth's surface. Simple schemes based on an analytical (and linear) formulation of the eddy exchange coefficients as the one proposed by Buizza (1994) are sufficient to make the TL model much more realistic in the boundary layer. More sophisticated schemes have been also been considered (Mahfouf, 1999; Laroche et al., 2002) but the strong non-linear dependence of the exchange coefficients with the basic flow can produce too large perturbations in the TL model that need to be filtered.

2 The lower boundary condition

One aspect that has not been examined in details up to now is the specification of the lower boundary condition. The turbulent flux F_ψ of a given prognostic variable ψ (wind, potential temperature, specific humidity) in the surface layer is expressed by the classical bulk formula:

$$F_\psi = K(\psi_L - \psi_s)$$

with $K = \rho C_D |U_L|$ where C_D is a drag coefficient depending upon static stability and surface roughness, U_L the wind speed at the lowest model level, ρ the air density. This flux is proportional to the gradient of ψ between the lowest model level Z_L and the surface Z_s.

For the momentum flux, the lower boundary in a TL model is obvious since the wind vanishes at the surface (i.e. $\psi_s = 0$), then for the wind perturbation: $\psi'_s = 0$. However, for potential temperature and specific humidity, the specification of model variables at the surface is more complicated.

The perturbed flux can reasonably be approximated by:

$$F'_\psi = K(\psi'_L - \psi'_s)$$

Moreover, when $K' \neq 0$ noise can appear in the TL model.

Over oceans, the surface boundary condition θ_s is specified from a sea surface temperature analysis and kept constant during the integration of the forecast model. Specific humidity, being equal to the saturation value, is also constant with time. This behavior of the NL model (i.e. $\psi_s = cst$) implies a similar boundary condition as for momentum in the TL model : $\psi'_s = 0$.

Over continents, θ_s evolves during the forecast according to the surface energy balance where the radiative forcing induces a strong diurnal cycle. Similarly, $q_s = \alpha q_{sat}(\theta_s)$, where α depends upon soil characteristics (soil moisture principally), has also strong diurnal variations. For these two quantities, imposing $\psi'_s = 0$ is not a reasonable assumption but it was nevertheless implemented at ECMWF and Météo-France for convenience. The consequence is a damping of the temporal evolution of near surface perturbations as shown recently by Trémolet (2003) and previously noticed by M. Janisková (personnal communication). To take into account the evolution of q'_s and θ'_s in a proper way one would need a linearized version of a land surface scheme and of a radiation scheme (including clouds). We propose here a simple solution that produces more realistic perturbations near the surface than when $\psi'_s = 0$ is imposed without having to consider additional linearized versions of physical processes.

In our proposal, we impose $\psi'_s = \psi'_L$ which corresponds to a zero perturbed flux (when $K' = 0$). It can also be interpreted as keeping the vertical gradient from the trajectory between the surface and the lowest model level.

3 Summary

In this short paper we are suggesting the following boundary conditions for application in TL numerical weather prediction models :

- $U'_s = 0$
- $\theta'_s = LSM \times \theta'_L$
- $q'_s = LSM \times q'_L$

where $LSM = 0$ over oceans and 1 over continents. This proposal has been tested in the TL version of the GEM model with a beneficial impact on the evolution of analysis increments for temperature and specific humidity in the planetary boundary layer.

4 References

Buizza, R., 1994: Sensitivity of optimal unstable structures. *Quart. J. Roy. Meteor. Soc.*, **120**, 429-451

Janisková, M., J.-N. Thépaut, and J.-F. Geleyn, 1999: Simplified and regular parameterizations for incremental four-dimensional variational assimilation. *Mon. Wea. Rev.*, **127**, 26-45

Laroche, S., M. Tanguay, and Y. Delage, 2002: Linearization of a simplified planetary boundary layer parameterization. *Mon. Wea. Rev.*, **130**, 2074-2087

Mahfouf, J.-F., 1999: Influence of physical processes on the tangent-linear approximation. *Tellus*, **51A**, 147-166

Trémolet, Y. 2003: Diagnostics of linear and incremental approximations in 4D-Var. ECMWF Technical Memorandum No 399, 16pp.