On the use of physical parametrizations in linearized NWP models

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Linearized versions of Numerical Weather Prediction (NWP) models are used in three main areas:

- *Variational data assimilation* where the adjoint of a NWP model (transpose of the tangent-linear model) provides, in an efficient way, the gradient of a cost-function with respect to the model initial state, to be used in a minimisation algorithm (Talagrand and Courtier, 1987 ; Rabier et al. 1997).
- *Singular vectors*, corresponding to the most rapidly growing initial perturbations in the linear regime, which are used to define the initial states of the Ensemble Prediction System (Buizza, 1994 ; Molteni et al., 1996).
- *Sensitivity studies*, where the knowledge of short-range forecast errors is used to trace back errors in the initial conditions (analysis errors) (Rabier et al., 1996)

So far, only adiabatic versions of the ECMWF forecast model have been developed and few studies have been undertaken to include physical parametrizations in tangent-linear and adjoint models (Zou et al., 1993; Zupanski and Mesinger, 1995 ; Tsuyuki, 1996b). Buizza (1994) has shown that the inclusion of vertical diffusion in necessary to avoid the estimation of non-meteorological singular vectors close from the surface.

Moist convection represents the dominant physical process in the tropical belt and is an essential component to get a correct analysis of the divergence field in these regions. The spin-up problem (imbalance of the hydrological state in the early stages of the forecast) experienced in most operational models clearly shows that tropical analysis needs to be improved. In the 4D-Var assimilation, the use of the adjoint of convection will provide a model initial state where the dynamics is consistent with the moisture field. Moreover, it will be possible to assimilate new

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types of satellite observations related to the hydrological cycle (like precipitation rates as in the future Tropical Rainfall Measuring Mission ; see Simpson et al. (1996)) which could improve the quality of operational analyses, as already shown by empirical physical initialization techniques (for example, Kasahara et al., 1996). Moist convection is certainly one of the most non-linear parametrizations making the validity of the tangent-linear approximation questionable. Various authors have shown that the regularization of thresholds in convection schemes improves the convergence of minimization algorithms (Zupanski, 1993 ; Tsuyski, 1996a).

At ECMWF, a set of physical parametrizations has been linearized for the following processes: vertical diffusion, sub-grid scale orographic effects, large scale condensation, radiation and moist convection. Simplifications and regularizations have been necessary with respect to the operational physics (Mahfouf et al., 1997). The chosen approach for moist convection is based on an explicit computation of the Jacobian matrices in finite differences. This method may not be suitable for operational purposes being computationally expensive, but has the advantage to avoid an explicit adjoint coding. The Jacobians are also an interesting diagnostic tool to understand the sensitivities of convection schemes (Errico, 1997).

Computation of singular vectors in the extra-tropics when the large scale condensation scheme is included shows that the amplitude of unstable modes is larger than with a dry model. The maximum of the energy spectrum is shifted towards larger wave numbers in agreement with various studies on the influence of latent heat release on the development of baroclinic waves (Thorpe and Emanuel, 1985).

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