Parameterization of turbulent fluxes with respect to cyclogenesis

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Introduction

The study presented in this paper is a part of the ALAdin Training NETwork program (ALATNET) and the main work has been done at one of the ALATNET centres, at CNRM/GMAP department of Mètèo France [7].

The topic of the research is connected to experiences with forecasts of rapidly developing cyclones in ARPEGE/ALADIN models, above all with the case study of the 20 December 1998 cyclone and the devastating "Christimas storms" of 1999. Both cases showed a strong dependency on parameterization of turbulent fluxes, especially on turbulent fluxes of heat in very stable stratifications in the Planetary Boundary Layer (PBL). The first aim of the study was to describe the mechanism of cyclogenesis resulting from enhanced turbulent transport of heat in areas with very stable PBL. The second goal was to modify the operational model parameterization with respect to prediction of severe cyclonic events, while keeping good performances in forecasting very stable states of atmosphere as by temperature inversion.

Theoretical considerations

The current operational scheme of ARPEGE/ALADIN model parameterization of turbulent fluxes is based on computation of the exchange (K-) coefficients for momentum and heat. The dependency on the stability of the stratification is introduced via function of Richardson number [4]. However, a limitation is applied through the so called critical Richardson number Ri_{cr}, thus, keeping a necessary (but small) turbulent diffusion in very stable PBL layers:

$$Ri' = \frac{Ri}{(1 + \alpha Ri/Ri_{cr})^{\frac{1}{\alpha}}}, \tag{1}$$

where the parameter α separates the scheme for momentum and heat and Ri' is finally used to compute the exchange coefficients [3]. Decrease of Ri' (through Ri_{cr} or α) leads generally to warming below the mean height of the PBL top and to cooling of the upper levels. Hence, static stability has to decrease around the top of the PBL.

The relationships to dynamics of the cyclone were explained using the quasigeostrophic equations of vertical motion and height tendencies. Decrease of static stability can play an important role in the support of vertical motions, thus, accelerating the development of the cyclone.

Diagnostic methods

To prove the above mentioned relations, several experiments were done, mostly on the case study of the 20 December 1998 storm. It was shown, that the parameterization setup for the heat diffusion has impact on the development of the cyclone only during the first 24 hours of the model integration. This knowledge was used at first by comparing runs with different tuning via simple parameter representing the static stability [5] and later by examining the areas of main sensitivity with the help of the adjoint of the ALADIN model [6].

It was confirmed, that areas crucial for the storm development can be found in the track of the cyclone during the period, that preceds its reinforcement and rapid deepening. Calculations of temperature budgets showed a remarkable drop of static stability in the PBL around areas with maxima of sensitivity gradients with respect to forecast error. Finally, vertical cross sections report about enhanced vertical motions in the environment of the cyclone after enhancing the turbulent flux of heat in examined areas with stable stratification.

Parameterization of turbulent fluxes with respect to dry and conditional symmetric instability

Unfortunately, the discovery of the above mentioned relationships between the parameterization of turbulent fluxes and rapid cyclogenesis does not help to develop further the current scheme used for computation of the exchange coefficients. Support of cyclogenesis via enhanced turbulent transport does not fit with the corresponding model analysis of static stability distribution in the most sensitive areas. Moreover, experiments with different kinds of physical parameterizations [6] showed, that impact of cloudiness and stratiform precipitation scheme might be also very important to the evolution of the storm. Hence a new approach was tried to make the parameterization of turbulent fluxes more flow dependent and possibly find a good compromise with forecasts of situations with temperature inversions.

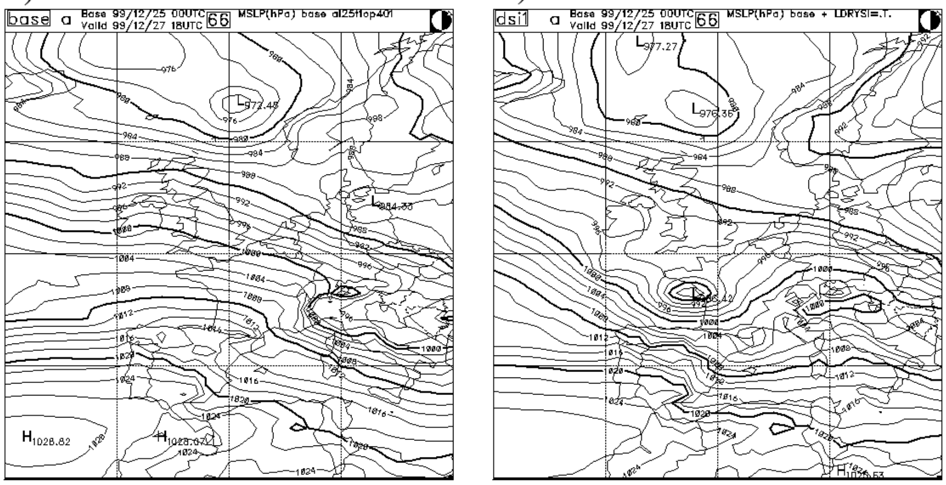
The idea was to find an analogue to application of symmetric instability relationships in parameterization of convection [2]. According to the definition of dry and conditional symmetric instability as described in [1], it was decided to further modify the Richardson number used in equation (1). In cases of negative values of the modified Richardson number Ri_p the exchange coefficients are computed as by neutral conditions, supposing well mixed PBL if dry or conditional symmetric instability appears. Hence we apply:

$$Ri_p = \frac{N_w^2}{N^2}\frac{\zeta}{f}Ri - 1, \tag{2}$$

where ζ is the absolute vorticity, f the Coriolis parameter, N^2 and N_w^2 are the squares of the Brunt-Väisälä frequency and its moist version, respectively.

The application of the equation (2), while considering only dry symmetric instability (without computations of the Brunt-Väisälä frequencies), showed a considerable impact in the case of the second "Christimas storm" of 27 December 1999 (see the Figure below).

a) b)



a) 66 hour forecast of mean sea level pressure in the reference ARPEGE run with the operational package of physical parameterization based on 25.12.1999 00 UTC (cycle 25 t1 op4). Note the pattern of shallow trough towards west from coast of France.

The figure in b) shows the result of activation of the parameterization of dry symmetric instability inside the scheme of vertical diffusion.

The full parameterization of conditional symmetric instability gave promising results in the case of the 20 December 1998 cyclogenesis, further, it solved some problems with false mesoscale cyclogenesis. However, calculations of temperature budgets showed, that the scheme is largely decreasing the static stability in the PBL - so it can hardly be used in forecasting of atmospheric conditions with very stable stratification.

Conclusion and plans for future

Although the proposed parameterization of turbulent fluxes has some positive impacts on forecasting cyclogeneses, it seems, that the diagnostics through the modified Richardson number overestimates conditions for symmetric instability. Hence the research will try in the future to improve this diagnostics and to specify the turbulent fluxes in environment with dry and conditional symmetric instability with more precision.

A parameterization dependent on the type of the flow can be a solution for problems with forecasting cyclogenesis and situations with very stable stratification in the PBL. Except of the modification of the Richardson number, another approaches will be tested in the future, e.g. a flow dependent representation of mixing length.

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