7. Andre Simon : "Study of the relationship between turbulent fluxes in deeply stable PBL situations and cyclogenetic activity"

New investigations in the study of rapid cyclogenesis in Northern Atlantic

The physics-dynamics interaction in the simulation of the 20 December 1998 storm was explained in [2] using various diagnostic fields and the knowledge about general principles of cyclogenesis (e.g. based on the q.g. equation of vertical motions or surface pressure tendency equation). According to the fact that the turbulent exchange of heat can modify the vertical motions through static stability, we used it as main diagnostic parameter. After increase of the turbulent heat exchange in the PBL, considerable deviations in the field of mean static stability between 700 and 925 hPa were detected in the region eastward from Newfoundland. This area was then supposed to be crucial for the later development of the storm.

This approach had two principle drawbacks:

A) The above mentioned area was probably not the only one important for the deepening of the storm (by other words, the forecast of the cyclone depends not only on the magnitude of the changes done by model physics but on their position as well).

B) The former diagnostic studies didn't explain why we were not able to have realistic simulation of the cyclone without considerable decrease of static stability in the stable stratified PBL. Moreover, this impact helped to forecast the cyclone only in the 84 and 96 hour runs and the resulting changes in static stability were not positive, when compared to the model analysis.

To get a more objective solution in part A it was decided to provide adjoint sensitivity tests with respect to the development of the cyclone between 17.12.1998 12 UTC and 19.12.1998 06 UTC. The idea of these tests was to use forecasts from different runs instead of analysis. Hence we didn't study the sensitivity on initial conditions but the sensitivity created by the impact of different model physics at the beginning of the selected period.

It has to be noted, that at that time the sensitivity on the turbulent exchange of heat was supposed to be only in the first 24 (36) hours of model computation, valid to 17.12.1998 12 UTC (see also [1] and [2]).

On the other hand, it was shown that the rapid development of the storm depends directly on its stage 42 hours later (19.12. at 06 UTC). This knowledge helped us to decrease the computational requirements and to specify the target period of sensitivity tests.

Thus the observed run (used for building the trajectory) was the one with decreased heat exchange, that didn't forecast the storm. For the reference at the beginning of the adjoint run (19.12.1998 at 06 UTC) we used the successful forecast of the storm using the operational values of vertical diffusion.

The tests were done on model ALADIN with 33 km resolution, using the simple physical parameterisation of Buizza and the so-called dry total energy as the cost function. For more details about sensitivity studies using the adjoint of the ALADIN model one can read articles [3] and [4].

At the end of the adjoint model computation period (17.12.1998 12 UTC), the gradients of the 42 hour forecast error should mark the areas, that caused the wrong forecast of the cyclone (Fig.1). The gradient fields differ remarkably from the areas obtained by simple difference of the two forecasts of static stability valid to the same date (compare with the results published in [2], page 85).

This experience confirms our assumptions, explained in the point A. However, the results of the adjoint model could be influenced by the use of simple physical parameterisation over a relatively long period and by the small extent of the target area.

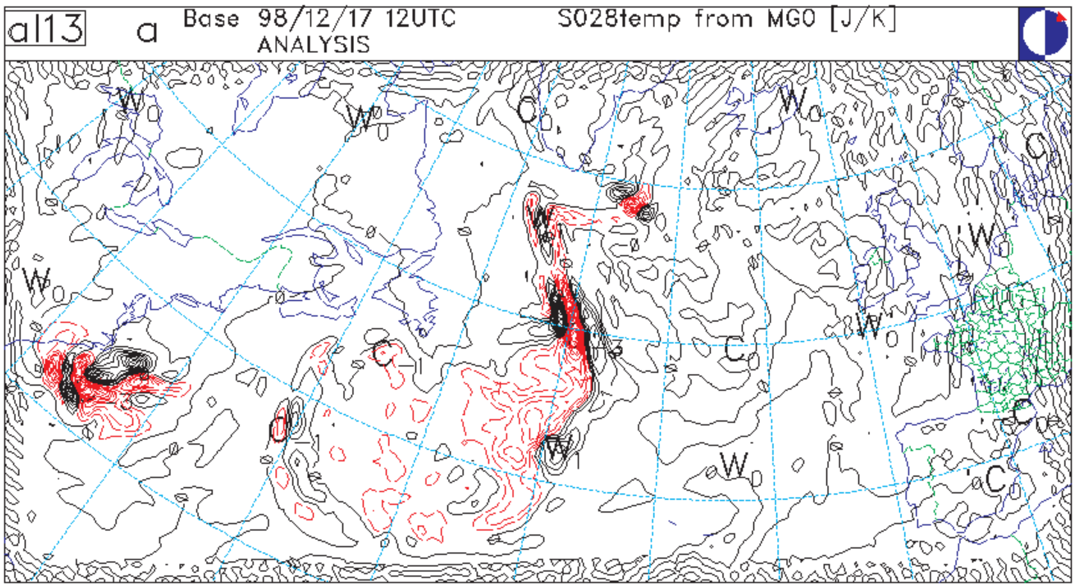

Figure 1 : Gradients of the 42 hour forecast error with respect to the temperature and with the dry total energy as the cost function at model level 28. The results show the sensitivity to errors of forecast with decreased turbulent flux of heat in the PBL valid to 17 December 1998 12 UTC (experiment with USURID=0.14).

These results were used to select a domain for the computation of temperature, water vapour and energy budgets, provided by the DDH tool. The selected domain, called ADJO, covers the areas with estimated highest sensitivity obtained from the adjoint model computations (Fig 2a).

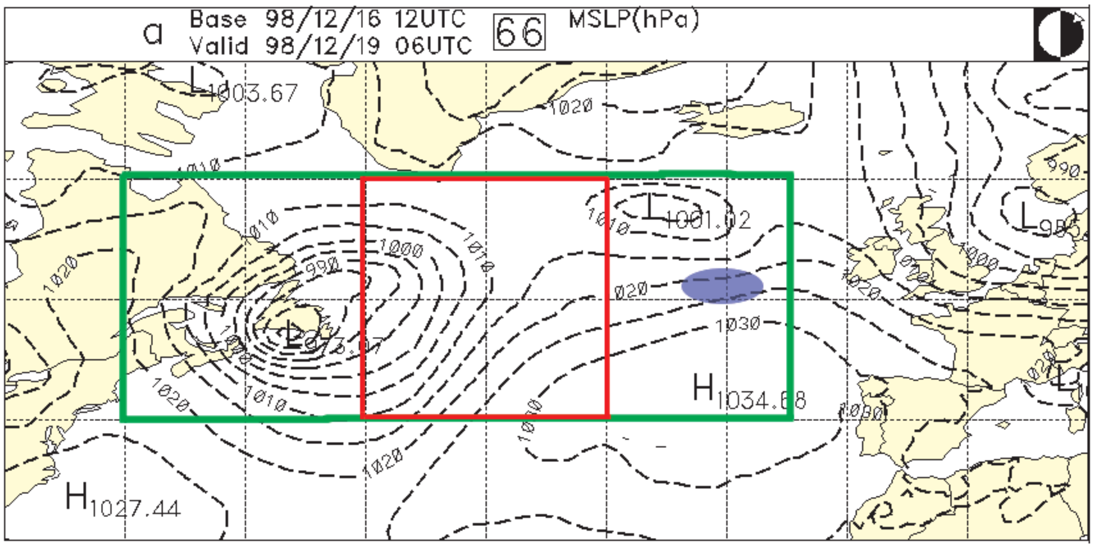

Figure 2a : 66 hour forecast of mean sea level pressure based on 16.12.1998 12 UTC using the modifications of ARPEGE/CLIMAT (experiment *ph1a*).
The area in blue marks the position of the cyclone valid at the same date and it is obtained from the ECMWF analysis and from the operational run (experiment *ric2*). The cyclone forecasted in the experimental run is, compared to the reference analysis and forecasts, shifted towards northwest and it is about 10 hPa deeper. The red rectangle represents the domain ADJO selected for the budget calculations according to the results of the adjoint sensitivity tests. The green rectangle represents the domain LABR used for the budget calculations and tests of the ARPEGE/CLIMAT modifications.

Outputs for the first 24 hours of integration from the 16 December 12 UTC (Fig. 3) show the differences between the reference forecast of the operational model (*ric2*) and the forecast with decreased vertical diffusion of heat (*ric7*), that would not predict the storm.

The horizontal mean of the temperature tendency (grey line) for the domain ADJO shows warming until approximately 850 hPa and cooling above this level, when going to the reference (setting the parameter USURID=0.042 instead USURID=0.14). This means a drop of static stability at the top of the PBL, as it was explained in [2] using simple diagnostic parameters. In addition, we can observe that the warming and cooling of the PBL in the domain is also due to the so-called dynamical terms included in the budget equation of enthalpy (e.g. by divergence of horizontal and vertical fluxes and conversion from potential to internal energy). These terms are related also to the advection of the temperature.

Both the turbulence and the large-scale precipitation terms show oscillations in the lower PBL. The contribution of the turbulence to the overall tendency is dominating around 750 hPa and higher.

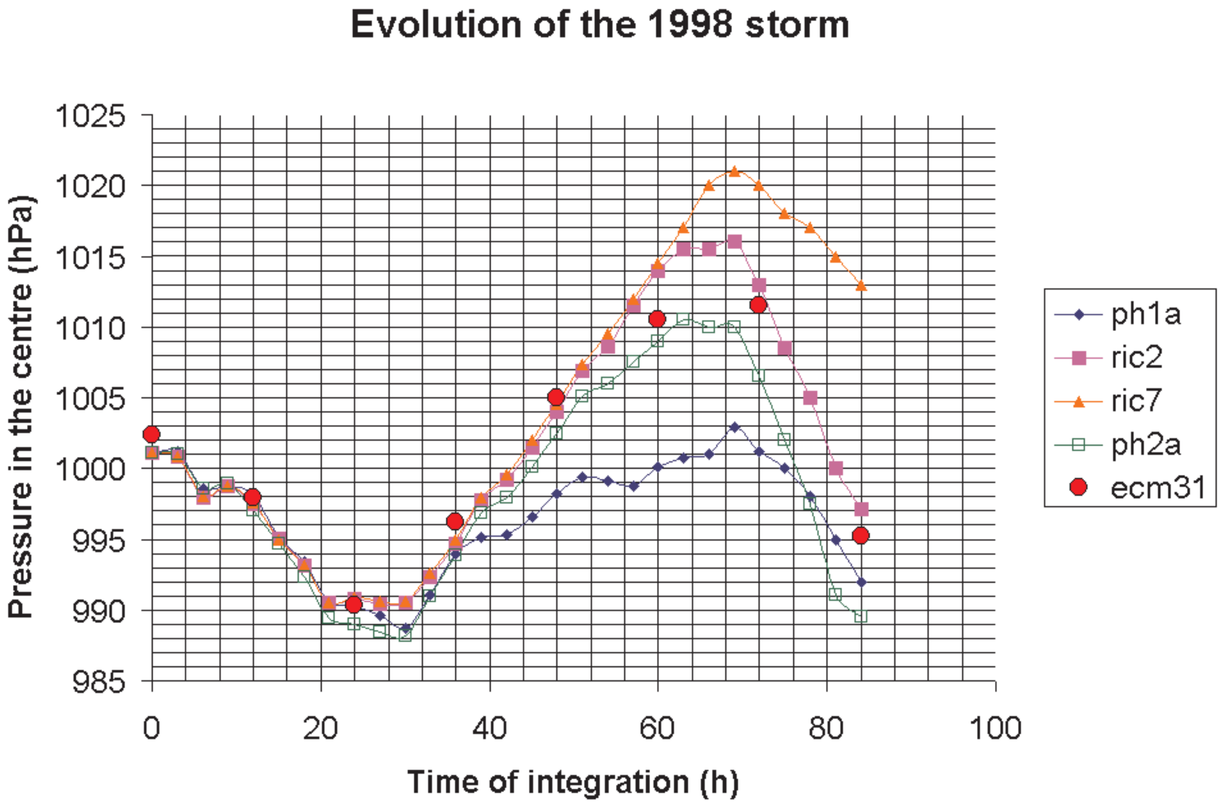

Figure 2b : Time-evolution of mean sea level pressure in the centre of the "20.12.1998 storm". All the 84 hour forecasts of the ARPEGE model were based on 16.12.1998 12 UTC. The meaning of the experiments is as follows :
ric2 - run of operational ARPEGE CY24T1 with USURID=0.042
ric7 - same as *ric2* but with USURID=0.14 (decreased transport of heat in the PBL)
ph1a - run using the modifications of ARPEGE/CLIMAT
ph2a - same as *ph1a* but with the stratiform precipitation scheme of the operational model
ecm31 - objective analysis based on the ECMWF model data

The problem explained in B was reopened after several experiments done in GMAP with the physics of the model ARPEGE/CLIMAT on situations with rapid cyclogenesis (as the winter storms 1998/1999) or false cyclogenesis of mesoscale dimensions (the so-called Arpegeades). This physical parameterisation package includes the Mellor-Yamada second-order closure scheme for turbulent fluxes, different parameterisations of cloudiness and large-scale precipitation fluxes (e.g. taking into account the condensation in the case of non-precipitating clouds and allowing over-saturation). The parameterisation is described in details in the part of ARPEGE/CLIMAT documentation revised by P. Marquet in November 2002 [5].

The application of the above-mentioned modifications in physical parameterisation changed our look at the problem of forecasting the 20 December 1998 storm.

The position and the depth of the cyclone is well forecasted not only in the 84 and 96 hour runs but partially also in the shorter range forecasts valid at 20.12.1998 00 UTC. The main benefit of the modified parameterisation is that it keeps higher static stability in the stable stratified PBL than the operational CY24T1 and CY25T1 versions of ARPEGE (this is going to be improved according to the recent modification of vertical diffusion tested in parallel suite from the middle of December 2002). Moreover, the physics of ARPEGE/CLIMAT solves also some of the problems with "Arpegeades".

Nevertheless, problems occurred while examining the results of the new scheme with respect to more "details". One can see for instance the time-evolution diagram of the forecasted pressure in the centre of the December 1998 storm (Fig. 2b). While using the physics of ARPEGE/CLIMAT, we obtain a very good forecast of the pressure in the centre of the storm at the end of the 84 hour run. But this is compensated by the fact, that during the 36-84 hour period the forecasted storm is unrealistically deep and it's position is artificially shifted towards northwest (see for instance Fig. 2a).

Paradoxically, we can get the "correction" of the forecast by replacing the stratiform precipitation scheme used by ARPEGE/CLIMAT with the scheme of the operational ARPEGE version, that is generally considered to be less exact (e.g. it doesn't allow over-saturation).

To understand how the parameterisation scheme of ARPEGE/CLIMAT influenced the trajectory and the depth of the forecasted cyclone, budget calculations were done, using the domains already created for the vertical diffusion tests (remember Fig. 2a).

We compared the run with the ARPEGE/CLIMAT physics (experiment *ph1a*) with the run of the operational ARPEGE version of the cycle CY24T1 (experiment *ric2*).

From several experiments came out, that the influence of the ARPEGE/CLIMAT physics is distributed more proportionally during the 84 hour run, but the main changes should be observed during the 24 - 48 hour forecasting period. Figure 4 shows the differences in the mean temperature budget for the domain LABR for the above mentioned period.

The static stability has been increased in the domain for the experiment with the ARPEGE/CLIMAT in the upper part of the PBL. On the other hand, there is a drop of stability in the very low levels, below 900 hPa. The change in the contribution of turbulent fluxes is remarkable, mainly in the levels below 800 hPa. But one should note, that these tendencies are compensated from a big part by the precipitation fluxes. Thus the differences in the temperature tendency are caused by several changes of physical parameterisation and one could not determine the dominating one.

While comparing the energy budget of the two experiments, it is possible to see the increase of kinetic energy in the entire troposphere for the run using ARPEGE/CLIMAT version (Fig. 5). Apart from the fluxes related to the model physics, there are very large contributions of the so-called baroclinic term (containing the conversion of potential and internal energy to kinetic energy) and of the advection term hidden in the residual. The difference in the turbulent transport of momentum has a strong contribution in the PBL and, except in the lowest layers, it acts to increase the overall budget of the kinetic energy, compared to the operational ARPEGE scheme.

Last, but not least, we compared the temperature and energy budgets after change of the precipitation scheme for the operational one, while keeping other modifications of the

ARPEGE/CLIMAT (experiment *ph2a*). On both figures (Fig. 6 and Fig. 7) we can see that the replacement of the scheme pushed the results a bit back towards the operational ARPEGE scheme.

Remarkable is the drop of the temperature in the mid-troposphere and the oscillations of the turbulent and the precipitation fluxes in the PBL. The kinetic energy was decreased almost in the entire profile, with maximal rate of change in the upper troposphere. However, the link between the modification of the precipitation fluxes and the decrease of the kinetic energy of the flow is not obvious from the diagnostics.

We can guess, that bigger release of latent heat coming from the precipitation supports the warm advection (or suppress the cold advection) and this should imply a weaker cyclogenesis and probably also the change of the trajectory of the cyclone in the modified environment.

Because of large contribution of the terms not directly related to local physical fluxes, we can expect significant influence of changes outside of the selected domain. Thus the sensitivity tests, similar to the ones explained above, could help to specify the dimensions and the position of the required domain with more precision.

Conclusion:

The case study of the 20 December 1998 storm confirms, that a big number of tests is needed to understand the impact of physical parameterisations on the simulation of large-scale atmospheric motions. The adjoint of the ARPEGE or ALADIN model and diagnostic methods such as budget calculations seem to be powerful tools, that provide more objective informations about the processes related to the cyclogenesis and its prediction. However, it is still insufficient to recognize the reason of the forecast errors comparing to real atmospheric processes. As it comes from the experiments with the physics of ARPEGE/CLIMAT, there are different ways to obtain a successful forecast of an extreme event. Unfortunately, probably by every experiment mentioned in this article, the success of the storm forecast was balanced by some not realistic features due to physical parameterisations. Thus the introduction of more sophisticated schemes may not improve the forecasts of the polar cyclones in general. The operational implementation of different vertical diffusion or stratiform precipitation schemes will require in the future retuning of several parts of the physical parameterisation setup and additional experiments done on case studies.

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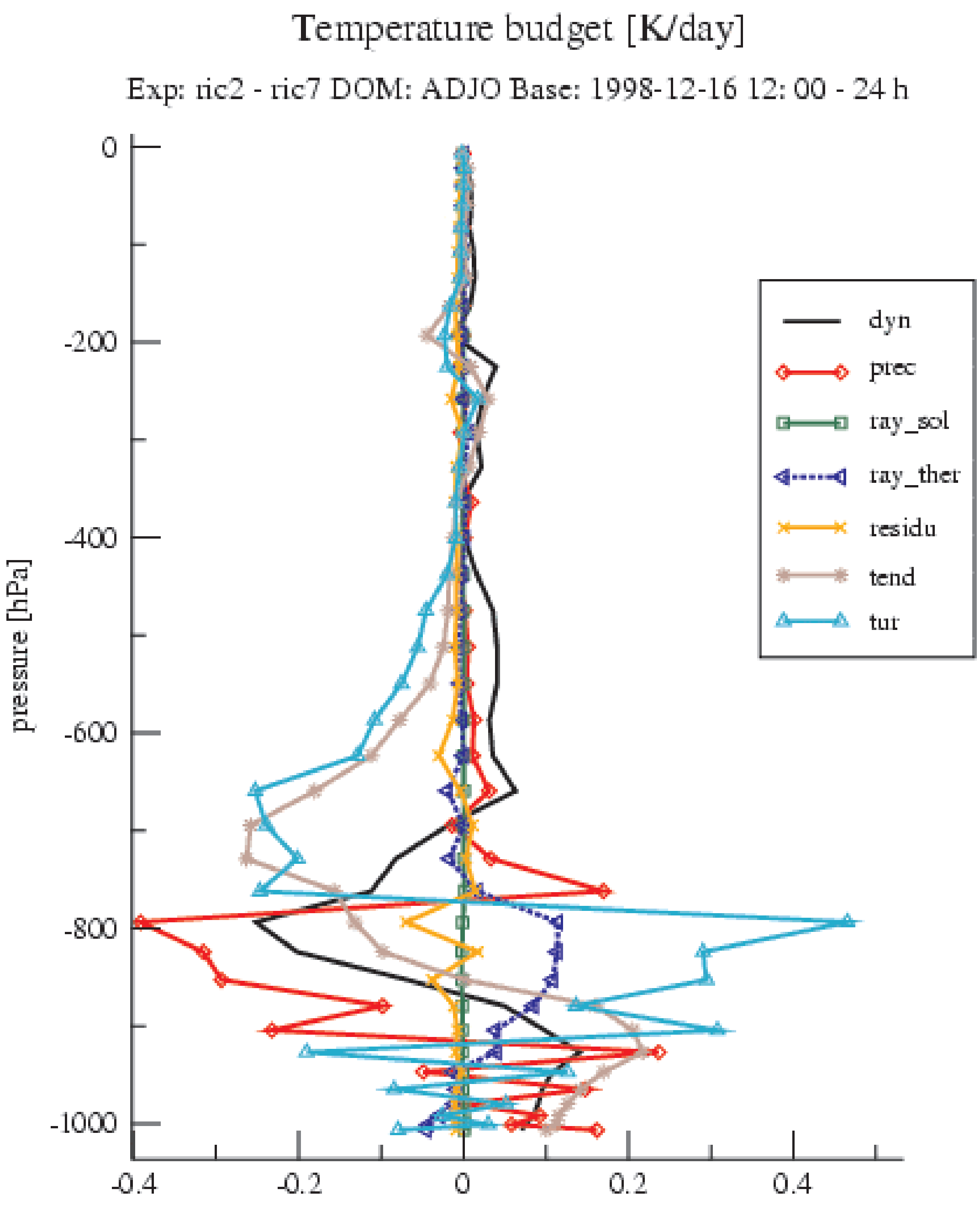

Figure 3 : Comparison of the temperature budgets between the operational CY24T1 run (USURID=0.042) and the run with decreased transport of heat in the PBL (USURID=0.14). Note the contribution of the terms not including physical fluxes (black line), the contribution of the turbulent fluxes (light blue line) and the overall tendency (tend).

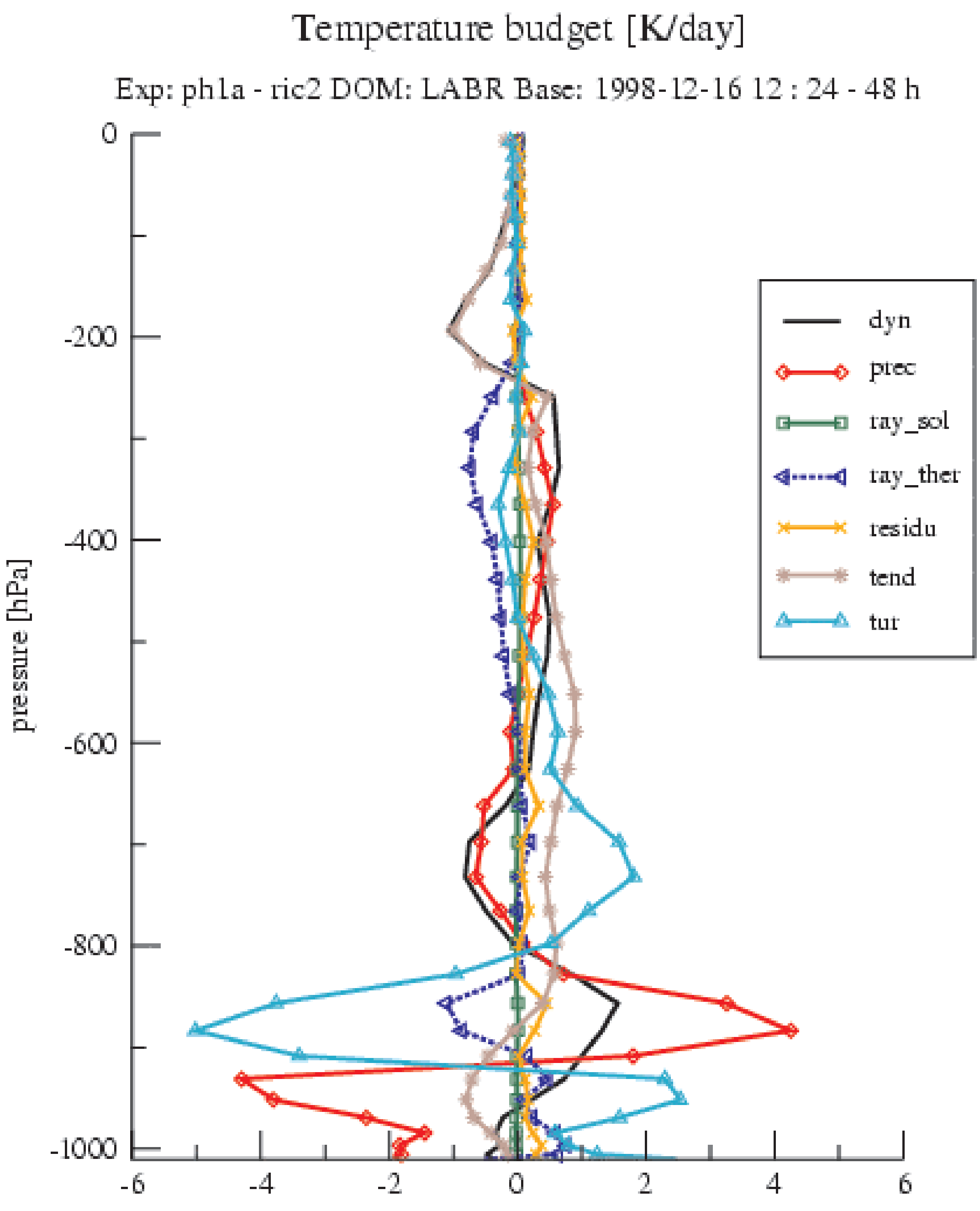

Figure 4 : Difference of the temperature budgets between the experimental run with physical parameterisation of ARPEGE/CLIMAT and the operational CY24T1 run.

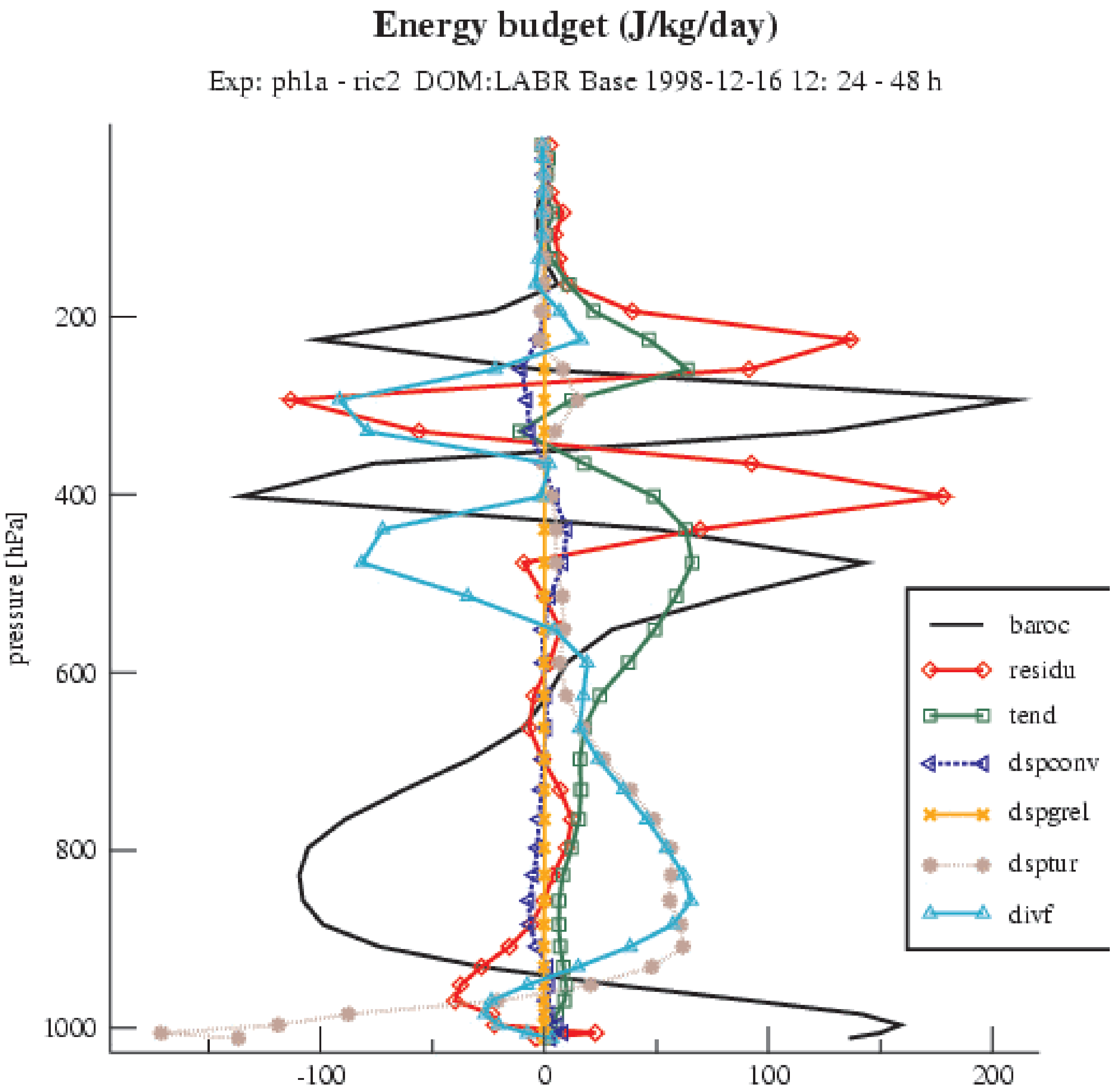

Fig. 5 : Difference of the kinetic energy budgets between the experimental run with physical parameterisation of ARPEGE/CLIMAT and the operational CY24T1 run. Note the contribution of the so-called baroclinic term (black line), the turbulent dissipation term (dsptur) and the overall tendency (green line). The residual term (red line) can contain, beside others, the contribution of the horizontal diffusion or the advection of the kinetic energy.

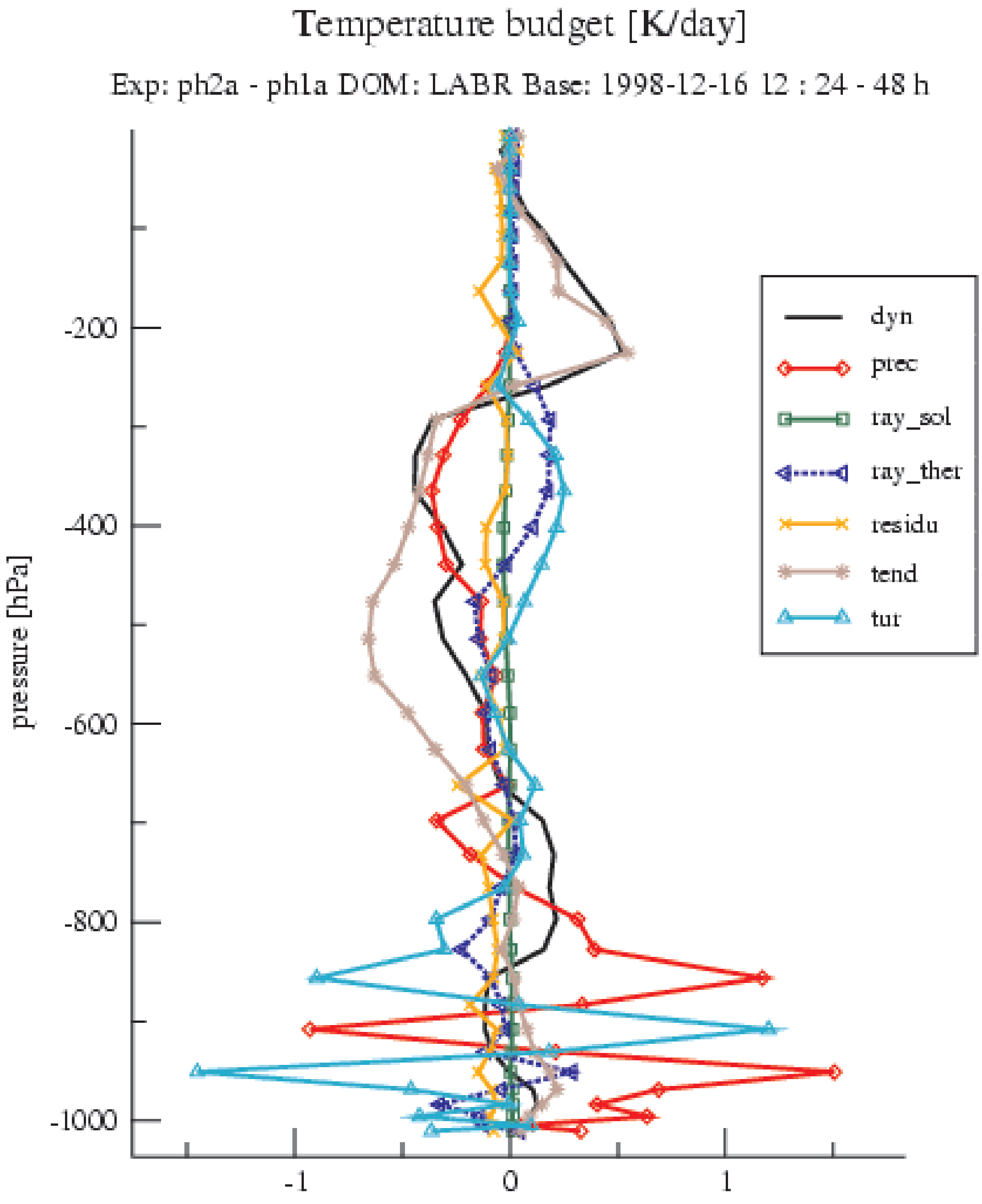

Figure 6 : Difference of the temperature budgets between the experimental runs using physical parameterisation of ARPEGE/CLIMAT but different large scale precipitation schemes.
Experiment *ph2a* - operational Kessler's type of precipitation scheme
Experiment *ph1a* - Smith's type of scheme for precipitation fluxes (ARPEGE/CLIMAT)

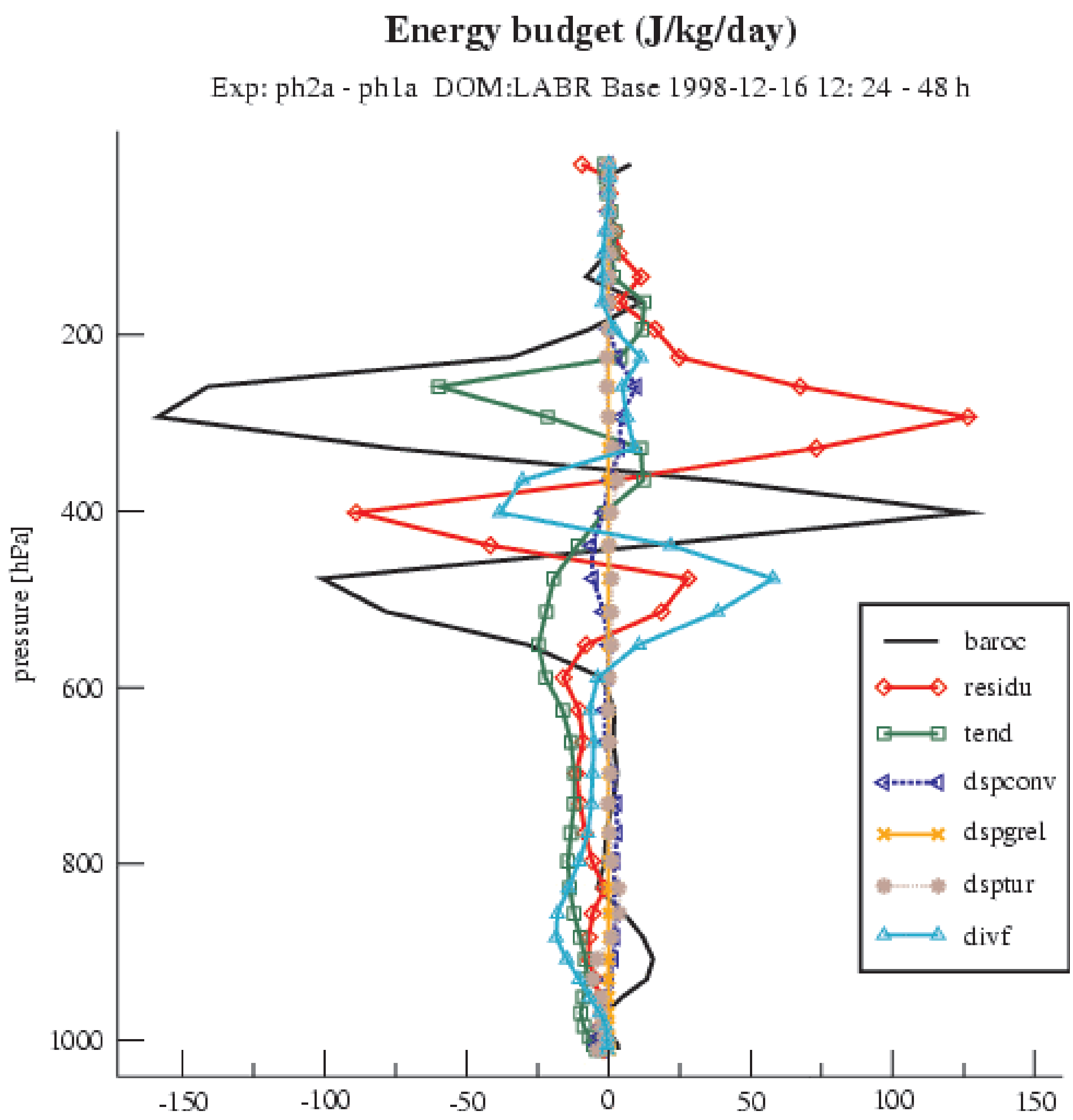

Figure 7 : The same as in Fig. 6 but for the differences of the budgets of the kinetic energy