REQUEST FOR A SPECIAL PROJECT 2012–2014

MEMBER STATE: Switzerland

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Project Title: Diabatic effects in mid-latitude weather systems

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ________________	
Starting year: (Each project will have a well defined duration, up to a maximum of 3 years, agreed at the beginning of the project.)	2012	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2012-2014: (The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2014.)	**2012**	**2013**	**2014**
High Performance Computing Facility (units)	90'000	70'000	
Data storage capacity (total archive volume) (gigabytes)	3500	3000	

*An electronic copy of this form **must be sent** via e-mail to:* *special_projects@ecmwf.int*

Electronic copy of the form sent on (please specify date): 27 April 2011

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[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide an annual progress report of the project's activities, etc.

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Extended abstract

It is expected that Special Projects requesting large amounts of computing resources (500,000 SBU or more) should provide a more detailed abstract/project description (3-5 pages) including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The Scientific Advisory Committee and the Technical Advisory Committee review the scientific and technical aspects of each Special Project application. The review process takes into account the resources available, the quality of the scientific and technical proposals, the use of ECMWF software and data infrastructure, and their relevance to ECMWF's objectives. - Descriptions of all accepted projects will be published on the ECMWF website.

Motivation and research questions

Diabatic processes, in particular the release of latent heat due to cloud condensation, have been found to be crucially important for the evolution of mid-latitude weather systems, in particular extratropical cyclones (e.g., Davis and Emanuel 1991). Warm conveyor belts (WCBs) are cross-isentropically ascending, coherent airstreams in developing extratropical cyclones associated with elongated cold frontal cloud bands and intense precipitation (Browning 1990). In terms of potential vorticity (PV), the latent heating that occurs in WCBs goes along with a diabatic production of PV in the lower troposphere and a diabatic destruction of PV in the upper troposphere (Wernli and Davies 1997). In this way, diabatic processes within WCBs potentially both influence the evolution of the low-tropospheric cyclonic vortices and modify the PV structure near the jetstream level (Grams et al. 2011). The WCB outflow typically enhances the size and amplitude of the upper-level ridges and in this way impacts upon the downstream flow evolution. In a few cases, it has been reported that the modification of the upper-level flow by WCBs can be essential for the downstream occurrence of Rossby wave breaking (e.g., Massacand et al. 2001). Our recent work has indicated that inaccuracies in the representation of WCBs in medium-range forecasts can lead to significant errors in the downstream flow evolution. In terms of PV, the interpretation is that for instance a too weak WCB leads to an underestimation of the amplitude of the upper-level ridge (i.e., of the negative PV anomaly), which in turn produces a too weak amplification of the downstream Rossby wave evolution (preliminary results of this work have been presented by H. Wernli at the ECMWF seminar in 2010). This linkage between medium-range forecast errors and upstream diabatic processes is consistent with the PV error statistics by Dirren et al. (2003), who found significant forecast errors in the region of pronounced upper-level ridges. These (and other) studies reveal the importance of diabatic processes for the dynamics and forecasting of mid-latitude waveguide disturbances and (intense) weather systems. However, important aspects of this linkage between diabatic processes and the large-scale flow evolution in mid-latitudes are not yet fully understood and require further research efforts. This project aims at addressing the two following open questions with the aid of numerical experiments with the IFS:

(1) What is the importance of different microphysical processes occurring in WCBs for the resulting net latent heating and PV modification?

(2) What is the relative importance of the various diabatic processes within WCBs for the medium-range downstream evolution of Rossby waves and surface weather systems?

Research on these questions with the IFS will complement our current activities to quantify the role of diabatic/microphysical processes on extratropical weather systems with the limited-area model COSMO (e.g., Boettcher 2010; Joos and Wernli 2011). Whereas experiments with the non-hydrostatic, high-resolution model COSMO allow detailed analyses of the impact of WCBs and the associated microphysics on the synoptic-scale flow evolution, the work with the global IFS model will enable studying the effects of WCBs on the mid-latitude flow on larger spatial and temporal scales. Also, the planned research with the IFS would very nicely contribute to the WCB activities in our research group funded by the Swiss National Foundation.

Work packages

Two work packages are planned to address the above overarching research questions:

WP1: Diagnostic study of microphysical processes in extratropical cyclones (lead: Dr. Hanna Joos)

The IFS can be used to investigate the role of diabatic processes for different weather phenomena like the intensification of extratropical cyclones or the modification of the upper level PV pattern and the downstream flow by WCBs. Therefore, the diabatic heating rates (DHR) arising due to different microphysical and other diabatic processes in the model will be quantified in order to obtain a detailed knowledge of the contribution of each single process to the total diabatic heating rate. Processes that will be considered include condensation and evaporation of cloud water, formation and sublimation of cloud ice, both in convective and stratiform clouds, the evaporation or melting of snow and rain as well as the thermal and solar radiative heating rates. Based on these heating rates, the associated diabatic PV rates (DPVR) can be calculated for each microphysical process. With such an approach the potential of each of the diabatic processes in modifying the PV field can be investigated in detail. So far, this approach has been applied to simulations with the regional model COSMO (Joos and Wernli 2011). Here, the method will be applied to forecasts of different extratropical weather phenomena. The influence of microphysics on the dynamics can then be analyzed also in the Lagrangian framework by tracking the DHR and DPVR along selected trajectories representing the considered phenomena. Knowledge of the specific microphysical contributions together with a high output frequency of the model (typically 1 hour) will allow examining the influence of various diabatic processes on the dynamics in detail. By varying the resolution of the simulations, additional information can be gained about the sensitivity of the results on the model configuration.

Technically, for this work package, a selection of about ten 7-day reforecasts will be performed with the IFS with T511 resolution of episodes during the last years with particularly interesting weather phenomena related to WCBs in the North Atlantic / European region (e.g., rapid cyclogenesis; heavy precipitation; diabatic intensification of blocking). For these forecasts, all individual diabatic heating terms will be stored with high temporal frequency (every hour). The relative importance of the various processes will then be investigated diagnostically. For a selection of three events, the same experiments will be performed with T1279 resolution to assess the effect of model resolution.

WP2: Sensitivity experiments on the role of diabatic processes on the downstream flow evolution (lead: Dr. Maxi Böttcher)

Sensitivity studies will be performed to investigate the downstream impact of the diabatic processes associated with WCBs. The focus will be on the property of WCBs to modify the upper-level PV and downstream flow evolution by moist diabatic processes. For selected case studies that feature strong WCBs in extratropical cyclones sensitivity simulations will be conducted with a modified environment of the WCB and/or with artifically modified physical processes. In experiments of the first category moisture will be specifically reduced and/or enhanced in the WCB starting region at the initial time. In experiments of the second category, specific diabatic processes will be turned off in predefined regions (e.g., in regions where a WCB develops). The selection of these processes will be influenced by the results from WP1. This technique of modifying physical processes only in predefined regions (e.g., Rossa et al. 2000; Boettcher 2010) is subtler than the classical approach of performing global "dry experiments" and allows for a more specific interpretation of the results. With the aid of these sensitivity experiments the impact of various microphysical processes on the strength of the WCB, the associated negative PV anomaly in the WCB outflow, and the subsequent downstream flow evolution will be quantified. This experimental setup allows to investigate the response of the large-scale flow to the details of the cloud formation process and to assess the importance of each single process (e.g., neglecting the latent heat release due to the formation of ice in a WCB). This will be an important step towards investigating the relationship between the accuracy of the representation of microphysical processes in the model and forecast errors of (intense) extratropical weather systems.

Technically, for this work package about five WCB case studies will be selected and a set of sensitivity experiments with modified initial conditions or physical processes will be performed for each case with the T511 model version.

The project will involve close collaboration with Dr. Richard Forbes at ECMWF.

References

Boettcher, M., 2010. Dynamik diabatischer Rossby-Wellen. PhD thesis, University of Mainz.

Browning, K. A., 1990. Organization of clouds and precipitation in extratropical cyclones. Pp. 129-154 in: *Extratropical cyclones. The Erik Palmen Memorial Volume.* C. Newton and E. O. Holopainen (Eds). American Meteorological Society, Boston.

Davis, C. A. and K. A. Emanuel, 1991. Potential vorticity diagnostics of cyclogenesis. *Mon. Wea. Rev.,* **119,** 1929-1953.

Dirren, S., M. Didone and H. C. Davies, 2003. Diagnosis of forecast-analysis differences of a weather prediction system. *Geophys. Res. Lett.*, **30,** 2016, doi:10.1029/2003GL017986.

Grams, C. M., H. Wernli, S. C. Jones, M. Boettcher, J. Campa, U. Corsmeier, J. H. Keller, C.-J. Lenz, and L. Wiegand, 2011. From the extratropical transition of *Hanna* (2008) to a Mediterranean cyclone: the key role of diabatic processes. *Quart. J. Roy. Meteorol. Soc.,* submitted.

Joos, H., and H. Wernli, 2011. Influence of microphysical processes on the potential vorticity evolution in a warm conveyor belt. *Quart. J. Roy. Meteorol. Soc.,* in preparation.

Massacand, A. C., H. Wernli and H. C. Davies, 2001. Influence of upstream diabatic heating upon an Alpine event of heavy precipitation. *Mon. Wea. Rev.,* **129,** 2822-2828.

Rossa, A. M., H. Wernli, and H. C. Davies, 2000. Growth and decay of an extratropical cyclone's PV-tower. *Meteorol. Atmos. Phys.,* **73,** 139-156.

Wernli, H. and H. C. Davies, 1997. A Lagrangian-based analysis of extratropical cyclones. I: The method and some applications. *Quart. J. Roy. Meteor. Soc.,* **123,** 467-489.