REQUEST FOR A SPECIAL PROJECT 2015–2017

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.	SPCHBOJO_______________	
Starting year: (Each project will have a well defined duration, up to a maximum of 3 years, agreed at the beginning of the project.)	2015	
Would you accept support for 1 year only, if necessary?	YES	NO

Computer resources required for 2015-2017: (The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2017.)		**2015**	**2016**	**2017**
High Performance Computing Facility	(units)	90'000	70'000	180'000
Data storage capacity (total archive volume)	(gigabytes)	3500	3000	5000

*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):

30 June 2014

Continue overleaf

[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.

Principal Investigator: Maxi Böttcher and Hanna Joos

Project Title: Diabatic effects in mid-latitude weather systems

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

Microphysical processes leading to latent heating or cooling are known to have a strong impact on the evolution and intensification of mid-latitude weather systems like for instance extratropical cyclones (e.g. Davis and Emanuel, 1991; Stoelinga, 1996; Rossa et al., 2000). These temperature tendencies establish a link to the dynamical processes via diabatic modification of potential vorticity (PV). The main effect is a PV production below and a PV destruction above the level of maximum diabatic heating (Wernli and Davies, 1997), and vice versa for diabatic cooling. Thus, diabatic processes can lead to the formation of a low-level positive PV anomaly as well as an upper-level negative anomaly. The diabatically produced low-level PV anomaly is important for the formation and intensification of cyclones and a key ingredient for the maintenance and propagation of a particular category of cyclones, the so-called diabatic Rossby-waves (DRW) (Boettcher and Wernli, 2011). The upper-level negative PV anomaly which forms above the maximum of diabatic heating has the potential to modify the large-scale flow by wave amplification and triggering of downstream development (e.g. Grams et al., 2011). Furthermore, an upper-level negative PV anomaly can lead to quasi-stationary anticyclones, so called blockings (Pelly and Hoskins, 2003; Schwierz et al., 2004). Croci-Maspoli and Davies (2009) stated that diabatic processes could be important for the amplification and/or maintenance of blockings. Among others, these studies show that diabatic processes are important for weather phenomena of different nature like extratropical cyclones, DRWs, and blockings and that a more detailed knowledge of the microphysical processes and their coupling to the dynamics is needed in order to improve the fundamental understanding -and eventually prediction- of the different weather phenomena. The importance of a detailed description of microphysical processes for the accuracy of meso-scale dynamical features has also been shown by previous studies (Parker and Thorpe, 1995; Clough et al., 2000; Forbes and Clark, 2003). Furthermore, Forbes and Hogan (2006) highlighted the usefulness of measurements to constrain microphysical parameterizations and hence to improve NWP by an improved representation of the microphysical details.

In a modelling study with the NWP model COSMO, Joos and Wernli (2012) investigated in detail to what extent the different microphysical processes contribute to the total diabatic heating and the diabatic change of PV. The focus of their study was on a case study of the strongly ascending air masses in an extratropical cyclone's warm conveyor belt (WCB). The results clearly show that the total diabatic PV modification is a complex interaction of various microphysical processes and cannot be explained by condensation only. In recent work within the framework of the special project SPCHBOJO at the ECMWF, the same WCB case study as in Joos and Wernli (2012) has been simulated with the IFS cy40r1 and the results have been compared with the COSMO simulation. In Figure 1, the mean hydrometeor mass, the mean diabatic heating rates (DHR) and the mean diabatic PV rates (DPVR) along the ascending WCB trajectories are shown for IFS (right) and COSMO (left). First of all it can be seen that along the WCB trajectories a liquid, mixed and ice phase cloud evolves (upper row). Associated with the formation of these clouds, various microphysical processes lead to the release of latent heat, mainly due to condensation (purple line) and depositional growth of ice or snow (yellow, red lines) (middle row). These DHRs in turn strongly modify the PV (lower row) and it is shown that the total DPVR (black dashed line) results from a complex interplay of the different microphysical processes.

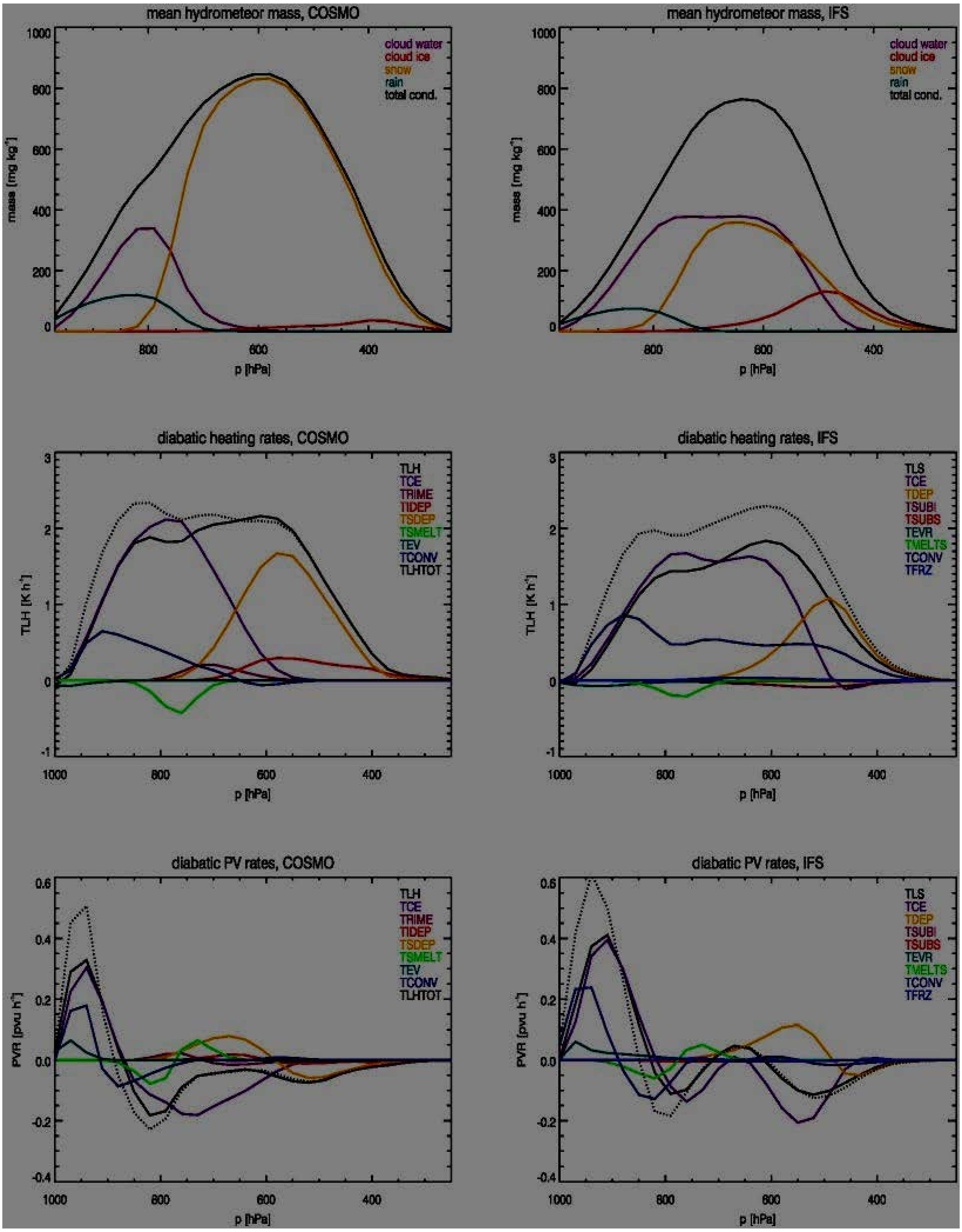

Figure 1: Evolution of the mean over all WCB trajectories of hydrometeor mass (upper row), diabatic heating rates (middle row) and associated diabatic PV rates (lower row) for simulations with COSMO (left column) and IFS (right column). Different colours in the middle and lower rows show the contributions from the different microphysical processes: for COSMO: TLH-total large-scale heating; TCE-condensation/evaporation; TRIME-riming;TIDEP-depositional growth of ice; TSDEP-depositional growth of snow; TSMELT-melting of snow; TEV-evporation of rain; TCONV-convection; TLHTOT (dashed line) TLH+TCONV; for IFS: TLS-total large-scale heating; TCE-condensation/evaporation; TDEP-depositional growth of ice; TSUBI-sublimation of ice; TSUBS-sublimation of snow; TEVR-evaporation of rain; TMELTS- melting of snow; TCONV-convection; TLHTOT (dashed line) TLH+TCONV

The comparison between the IFS and COSMO model nicely shows the differences in the representation of the microphysical processes. The total condensate is approximately the same for both models. However, the partitioning between the different hydrometeor species differs strongly. While in the IFS there is still liquid water up to ~400hPa, the cloud is completely frozen above ~600 hPa in COSMO. This also leads to a very different structure in the associated DHR and DPVR. For example, the total DPVR in IFS gets positive at a height of ~650 hPa whereas it stays negative in COSMO (see black dashed lines). Thus, the PV is modified in a different way along these WCB trajectories, which has implications for the meso- and large-scale dynamics. These results therefore highlight the importance of validating and improving the representation of microphysical processes for NWP in general, for the dynamics of weather systems in particular. An emerging necessity is to compare the parameterized processes to measurements. Another project in our research group focuses on the impact of moist-diabatic processes on WCBs with idealized COSMO model simulations which could nicely contribute to our studies with the IFS.

Based on the existing literature and our recent work we would like to expand our analysis of the influence of microphysical processes on the dynamics of extratropical weather systems and the evaluation of the representation of microphysics with aircraft measurements to answer the following two main research questions:

(1) What is the importance of microphysical processes for the formation or amplification of different weather phenomena like explosive cyclogenesis, diabatic Rossby-waves and blockings?

(2) How well are ice phase clouds represented in the IFS in different synoptic situations?

In order to address research question (2), the measurements from the ML-Cirrus aircraft campaign, which took place in March 2014 will be used. Our group participated in the campaign by providing support for the flight planning. The campaign focussed on the formation and life cycle of mid-latitude ice-phase clouds in different weather situations (http://www.pa.op.dlr.de/ML-CIRRUS/). With a number of successful research flights an outstanding data set resulted from a large set of in-situ and remote sensing instruments. The study of the representation of mid-latitude cirrus nicely complements with the recent activities about measurements in the different phases of the WCBs, which were taken during the T-NAWDEX-Falcon aircraft campaign (Schäfler et al., 2014).

Work packages

Two work packages are planned to address the above mentioned research questions.

WP1: Importance of diabatic heating rates for different weather phenomena in the extra-tropics (lead: Dr. Hanna Joos)

The IFS will be used in order to investigate the influence of diabatic heating and cooling on different weather phenomena. The diabatic heating rates (DHR) occurring due to the different microphysical processes like condensation, evaporation, depositional growth, freezing, melting, sublimation as well as the radiative heating rates can be calculated within the IFS model. Therefore we have the possibility to investigate in detail the contribution from each microphysical process to the total diabatic heating. Based on these DHRs it is then possible to determine the diabatic modification of potential vorticity (PV) separately for every microphysical process. Additionally, the DHR and the diabatic PV rate (DPVR) can be traced along selected trajectories representing the desired weather phenomena. Until now this technique has been used for a detailed study of the DHR and DPVR in a warm conveyor belt (Joos and Wernli,2012). Here we want to expand this method in order to investigate the effect of DHRs and the associated DPVRs on phenomena like cold fronts, explosive cyclogenesis, DRWs and blockings. In these phenomena, diabatic processes are either essential for the formation and growth (DRW) or have the potential to strongly amplify (blocking, explosive cyclogenesis) or influence the mesoscale structure of rain bands or the wind fields (cold fronts). It is therefore crucial to gain more insight into the interaction of the microphysical processes with the large and mesoscale flow. In experiments, specific diabatic processes will be turned off in predefined regions similar to the humidity experiments in the first phase of the special project. With the aid of these experiments the impact of various microphysical processes and the subsequent downstream flow evolution can be quantified. The combination of the DHR diagnosed directly in the IFS together with the Lagrangian approach of

tracking the DHR and DPVR along relevant trajectories allows to improve our understanding of the underlying fundamental physical processes leading to the formation or modification of the mentioned phenomena.

Technically, about six 7 to 10 day forecasts with a resolution of T799 from the last years will be performed. For these forecast all diabatic heating rates have to be saved with a high temporal frequency of 1h.

WP 2: Comparison of IFS ice-phase clouds with aircraft measurements (lead: Dr. Maxi Böttcher)

During the ML-Cirrus aircraft campaign cirrus clouds that formed in different synoptic situations have been measured. This includes cirrus in high-pressure areas, in deeply ascending air masses in extratropical cyclones where cirrus is produced via the mixed-phase, and orographic cirrus generation by strong vertical motion in the lee of mountains (http://www.pa.op.dlr.de/ML-CIRRUS/science-overview.html). Measurements have been performed in fairly clear air and in polluted or Saharan dust-containing conditions. As our group was involved in the campaign by planning the research flights, data access is warranted and scientific contributions and collaborations are heavily desired. With the special model version described in WP 1, which allows for additional output of the heating rates due to microphysical processes, aircraft probed weather situations will be reforecast with the IFS. Cloud-active regions will be identified and compared with available in-situ and remote sensing measurements of, e.g. specific humidity, ice water content, size and number of cloud particles as well as temperature and specific humidity profiles. With the aid of this measurements the location and microphysical properties of the clouds in IFS can be assessed. In situations where cirrus was well predicted the cloud species and their concentration will be compared. Regions where strong deviations between the modelled and measured data are found can be further investigated. Erroneous heating rates emerging from these deviations could affect the temperature and humidity distribution and hence the dynamics of weather systems and the development of the forecast. Weather systems were such error-prone processes are found could also be interesting cases for the investigations planned in WP 1 where the spread of the errors and their impact on the dynamics could be studied.

Technically, for this work package about six cirrus situations will be selected and reforecast with the IFS T1279 model resolution and saved with a high output frequency.

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

References

Boettcher, M. and H. Wernli, 2011: Life cycle study of a diabatic Rossby wave as a precursor to rapid cyclogenesis in the North Atlantic – dynamics and forecast performance. Mon. Wea. Rev., 139, 1861–1878.

Clough, S. A. , Lean, H.W., Roberts, N. M.; Forbes, R. M. 2000: Dynamical effects of ice sublimation in a frontal wave. Quart. J. Roy. Meteorol. Soc. 126, 2405-2434.

Croci -Maspoli, M. and Davies, H. C. , 2009: Key Dynamical Features of the 2005/06 European Winter. Mon. Wea. Rev., 137, 664-678.

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

Forbes, R. M. and Clark, P. A. 2003: Sensitivity of extratropical cyclone mesoscale structure to the parametrization of ice microphysical processes. Quart. J. Roy. Meteorol. Soc., 129, 1123–1148.

Forbes, R. M., Hogan, R. J.,2006: Observations of the depth of ice particle evaporation beneath frontal cloud to improve NWP modelling. Quart. J. Roy. Meteorol. Soc., 132, 865–883.

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., 137, 2174–2193.

Joos, H and Wernli, H. 2012: Influence of microphysical processes on the potential vorticity development in a warm conveyor belt: a case-study with the limited-area model COSMO. Quart. J. Roy. Meteor. Soc., 138, 407–418.

Parker, D. J. and A. J. Thorpe, 1995: Conditional convective heating in a baroclinic atmosphere: A model of convective frontogenesis. J. Atmos. Sci., 52, 1699–1711.

Pelly, J. L., and B. J. Hoskins, 2003: A new perspective on blocking. J. Atmos. Sci., 60, 743–755.

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.

Schäfler, A., Boettcher, M., Grams, C. M., Rautenhaus, M., Sodemann, H. and Wernli, H. 2014: Planning aircraft measurements within a warm conveyor belt. Weather,69, 161-166.

Stoelinga, M., 1996: A potential vorticity-basecd study of the role of diabatic heating and friction in a numerically simulated baroclinic cyclone. Mon. Wea. Rev., 124, 849-874.

Schwierz, C, Croci-Maspoli, M, Davies, HC, 2004. Perspicacious indicators of atmospheric blocking. Geophys. Res. Lett., 31, L06125. DOI: 10.1029/2003GL01934.

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.