5REQUEST FOR A SPECIAL PROJECT 2018–2020

MEMBER STATE: Switzerland

This form needs to be submitted via the relevant National Meteorological Service.

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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** CHBOJO_____________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2018	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2018-2020: (To make changes to an existing project please submit an amended version of the original form.)		**2018**	**2019**	**2020**
High Performance Computing Facility	(SBU)	4’250’000	1’500’000	500’000
Accumulated data storage (total archive volume)[2]	(GB)	71’000	118’000	122’000

***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): 30.06.2017

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.

2 If e.g. you archive x GB in year one and y GB in year two and don’t delete anything you need to request x + y GB for the second project year.

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Extended abstract

Motivation and research questions

The formation of clouds and the associated release of latent heat have a strong impact on the dynamics of extra-tropical cyclones (e.g. Davis and Emanuel, 1991; Stoelinga, 1996; Rossa et al., 2000). During cloud formation, manifold microphysical processes like condensation, depositional growth of ice particles, evaporation of rain and melting or sublimation of snow lead to latent heating or cooling. The link between the different heating/cooling rates and atmospheric dynamics can be described by the concept of diabatic modification of potential vorticity (PV) (Hoskins et al., 1985), whereas the dominant process is a production of PV below and a destruction of PV above the maximum of the diabatic heating (Wernli and Davies, 1997) and vice versa for cooling processes. Thus, the formation of clouds can produce a positive PV anomaly in the lower troposphere and a negative anomaly in the mid/upper troposphere. These positive (negative) PV anomalies generate a cyclonic (anticyclonic) wind field which then exhibits the strong link of microphysical processes and atmospheric dynamics. The positive low level PV anomaly can be important for the intensification and propagation of cyclones (Davis et al., 1993; Rossa et al., 2000, Stoelinga 1996, Campa and Wernli, 2012, Binder et al., 2016) whereas the upper level negative anomaly can modify the upper level PV pattern and therefore the downstream flow evolution (Pomroy and Thorpe, 2000; Massacand et al., 2001, Grams et al., 2011). Furthermore, a negative upper level PV anomaly can lead to quasi-stationary anticyclones, so called blockings (Pelly and Hoskins, 2003; Schwierz et al., 2004). Pfahl et al., (2016) state that a substantial part of the blocks is influenced by air parcels that have been modified by heating processes generated by clouds in ascending air streams.

The sensitivity of the formation of the upper level negative PV anomaly depending on the microphysical setup in the IFS and its impact on the downstream flow evolution has been analysed in Joos and Forbes, (2016). They investigated in detail how differences in the representation of microphysics can impact the upper level flow. Therefore, two IFS simulations with different microphysics have been performed. In the control simulation (CTRL), the microphysical parametrizations implemented in cycle 40r1 and in the experiment (EXP), the microphysical parametrizations implemented in cycle 41r1 are used. In Fig. 1, left, the position of the tropopause in the CTRL and EXP run 30 h after the start of the simulation are shown as well as the position of the warm conveyor belt (WCB) outflow (see pink and green line). It can be clearly seen, that a small area with distinct differences in the tropopause and WCB outflow positions develop around 68 and 72°N and 5 and 8°W (see Fig. 1, left). In order to link the difference in the WCB outflow position to microphysical processes, the diabatic heating rates (DHRs) along trajectories ending in this area are investigated in detail in CTRL and EXP. In Fig.1, right, the time evolution of the DHR is shown for both simulations. Clear differences in the total DHR (see black solid and dashed lines) appear from t=10-14h and t=20-24h. The different DHR translate into different upward motions for both trajectory bundles. They therefore reach regions with different horizontal wind speeds, especially as the ascent occurs in a strongly baroclinic environment, and start to diverge at mid and upper levels. The differences in the position of the two trajectory bundles in the upper troposphere is connected to the difference in the tropopause position and hence also to differences in the downstream flow evolution. These results therefore nicely highlight the importance of a correct representation of microphysics for the downstream flow evolution.

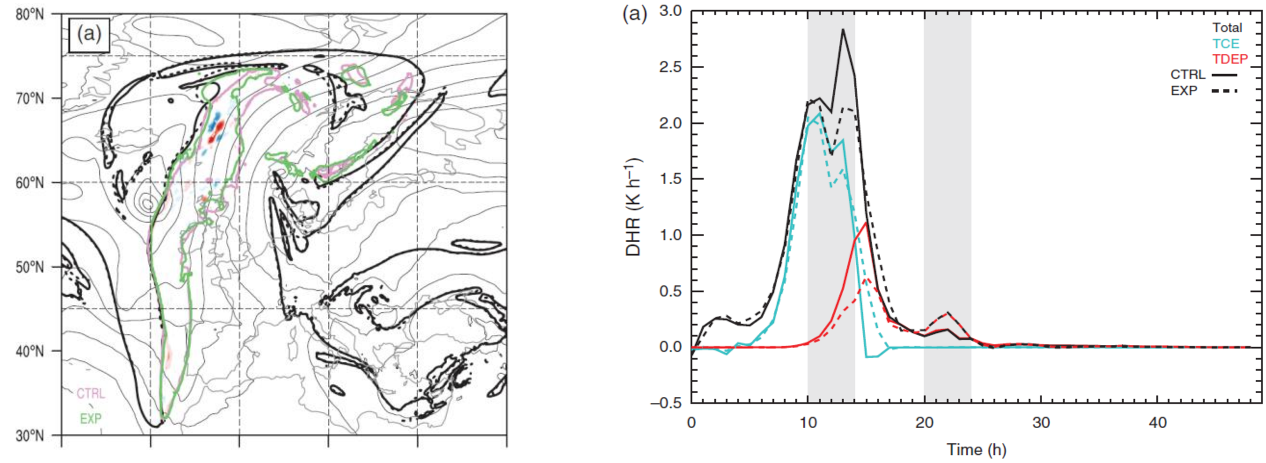

Fig.1:
Left: Position of the tropopause (2 pvu iso-line on 310 K) at 12 UTC 30 January 2009 for CTRL (black solid line) and EXP (black dashed line) and the position of the WCB outflow on 310 K with at least five trajectories inside for CTRL (purple) and EXP (green). Right: Time evolution of trajectories ending in the tropopause bulge (region between 68 and 72°N and 5 and 8°W) in EXP (dashed) and trajectories with the same starting positions calculated in CTRL (solid) for DHR with total DHR (black) and the most important contributions from condensation (TCE, cyan) and depositional growth (TDEP, red). From Joos and Forbes (2016).

On the other hand, the strong impact of microphysical (cooling) processes on meso-scale features as e.g. fronts, have also been investigated in many studies (e.g. Szeto and Stewart, 1997; Huang and Emanuel, 1991; Parker and Thorpe, 1995; Forbes and Clark, 2003; Forbes and Hogan, 2006). In a recent paper, Crezee et al., (2017) also highlighted the complex interplay of manifold microphysical processes in building meso-scale positive and negative PV anomalies at the warm front of an idealized extratropical cyclone. In Fig. 2, a cross section through a warm front is shown. Colour shading denotes the positive (negative) PV anomalies in red (blue) and the coloured lines show the 24h time integrated change in PV (CDPV) due to the different microphysical processes.

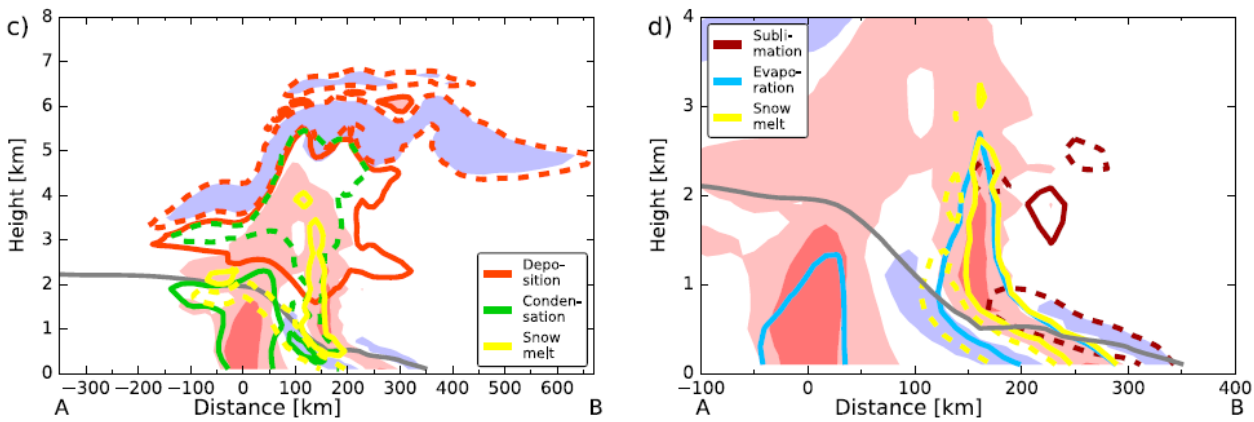

Fig.2: Vertical section across the warm front. The 0°C isotherm is shown as a gray line and regions where CDPV exceeds a certain threshold are shaded. Regions with CDPV< - 0.2 PVU are light blue, regions with 0.2<CDPV<0.75 PVU are light red, and regions with CDPV>0.75 PVU are red. Different (left) in-cloud and (right) below cloud diabatic PV contributions (solid and dashed contours denote values of +0.2 and -0.2 PVU, respectively). Note that the left panel is a zoom into the warm front. From Crezee et al. (2017).

It can be nicely seen that the complex PV structure at the front can be explained when considering the contributions to PV modification for each process separately. A PV production due to condensation of water vapour, due to snow melting and due to depositional growth is mainly responsible for the formation of the positive low and mid-level PV anomalies at the front. The upper level negative anomaly is also produced by depositional growth (see Fig.2, left). In the right panel, the contributions from below cloud processes can be seen. Here, the evaporation of rain is the main contributor to a strong low level PV anomaly. However, it can be also seen that airparcels that are at a height of approx. 3 km at the point in time shown here also gained PV due to the

evaporation of rain. They experienced that production of PV when they were still close to the surface, some hours before reaching the location of this cross section. The produced PV is then transported into the mid troposphere.
The results of this study highlight the diversity of processes that are responsible for the formation of PV anomalies at fronts and they highlight the need for a Lagrangian method in order to understand the observed PV pattern.

All these studies demonstrate the complex way in which atmospheric dynamics can be influenced by various microphysical processes and on different scales. However, as these processes are not yet resolved by the model grid, they have to be parametrized which introduces a source for uncertainties in atmospheric models and also in weather prediction. A better understanding and a validation of the representation of microphysics in NWP models with the aid of measurements and the link to the dynamics is therefore crucial for an improved understanding of the mid-latitude weather.

Our recent work and knowledge about the link of microphysics and dynamics is mainly based on single case studies of extra-tropical cyclones. We therefore would like to expand our work to

i) an improved understanding of the role of latent heating for the amplification/maintenance of atmospheric blocking

ii) a climatological analysis of the importance of microphysics for the formation of positive and negative low and upper level PV anomalies in extra-tropical cyclones and atmospheric blocks

iii) a systematic investigation of the impact of different microphysical parametrizations on the upper-level and downstream flow evolution as well as on meso-scale PV patterns at fronts. Furthermore, a comparison of the model output to measurements taken during the NAWDEX campaign will be done in order to better constrain microphysical parametrizations.

A special IFS version (provided by Dr. Richard Forbes) which allows to output all the different microphysical and radiative heating rates at a high time resolution is a perfect tool in order to work on the research questions mentioned above.

Work packages

Four work packages are planned to address these research questions.

WP1: Influence of diabatic processes on the dynamics of extratropical cyclones and blocks: a climatological analysis (PhD Roman Attinger)

The work carried out in this PhD project continues the investigation of the importance of diabatic processes for the dynamics of extratropical weather systems. Following the approach chosen by Joos and Wernli (2012), the modification of PV is evaluated using heating rates associated with different diabatic processes. While preceding studies investigating the diabatic modification of PV usually only focused on single events, a systematic investigation of a simulation over several months using the IFS is considered in the current project.
To setup the methods, a 5-day case-study simulation of an Atlantic cyclone is performed using our modified version of the IFS. 3-dimensional hourly outputs of the microphysical and radiative heating rates are used to derive the respective diabatic PV rates. The dominant processes modifying PV in key regions, associated with either cyclone centre, warm front or cold front, are computed along backward trajectories. Since PV as a result of cloud microphysical processes can occur in various scales, the simulations need to be run with the full set of model levels and a high horizontal resolution.

First results indicate that radiative and microphysical processes are responsible for up to 60% of the modification of PV in this cyclone. We found that various processes such as convection, long wave radiation, condensation and evaporation of clouds, sublimation and melting of snow as well as deposition of snow are all relevant for the exact PV distribution. However, as an equally large portion of PV is modified by diabatic processes other than microphysics and radiation, we will additionally investigate the effect of heating due to mixing in future simulations. Thereby, we hope to achieve an improved closure of the diabatic PV budget. In a next step, a much longer simulation period of 2-4 seasons (that is 3 months in a row each) is planned to analyse a larger number of weather systems systematically.

Again, hourly outputs of the complete set of temperature tendencies is used to systematically investigate the diabatic modification of both extratropical cyclones as well as atmospheric blocking events. Thereby, this study aims at advancing the understanding of when and where diabatic processes occur and how they potentially affect the dynamics of extratropical weather systems.

First results of this project have been presented at the bilateral WCB-meeting at ECMWF in May 2017.

WP2: Sensitivity of tropopause level PV anomalies and the downstream flow evolution to the representation of microphysics (PhD Elisa Spreitzer)

In this project, the effect of diabatic processes on the dynamics of extratropical cyclones is investigated on a case study basis. As shown by Joos and Forbes (2016) in a case study of a warm conveyor belt related to an extratropical cyclone, IFS simulations with different versions of microphysical parametrizations yield small-scale differences in the upper-level PV structure associated with the warm conveyor belt outflow. This study will be continued and extended here. Sensitivity experiments with altered IFS microphysics will be performed for a series of case studies of extratropical cyclones in various synoptic settings. The aim is to quantify dynamical impacts of changes in details of the microphysical parametrizations and to explain them physically. This involves identifying the diabatic processes that are dynamically most relevant, in which region of the cyclone they occur and how they determine the structure of fronts and associated warm conveyor belts. The detailed understanding of these processes requires an in-depth look into the smaller-scale structures of the weather systems and therefore a very high model resolution.
The focus will be on changes in upper-level PV anomalies due to altered microphysics and their interaction with the jet and downstream development as well as on low-level PV anomalies and circulation along the surface fronts. Moreover, ensemble simulations with altered parametrizations will be performed for some cases, in order to evaluate the robustness of the dynamical response to modified microphysics and to assess how the magnitude of these effects compare to the ensemble spread. A first event studied in this project occurred during the NAWDEX field campaign in 2016. For this case, observational data will be compared to re-forecasts and ensemble runs in addition to the model sensitivity experiments.
Technically, 3-4 case studies of extra-tropical cyclones will be simulated, and 5-7 additional simulations with altered microphysical heating rates for each case. For 2 of the case studies, ensemble runs with a reduced number of members are aimed. For all simulations, the 3-dimensional temperature tendencies will be outputted. As for WP2, this project requires a high horizontal and vertical resolution to capture the different scales of the PV structures, so we plan to run the simulations in TCo1279 or TCo639 for the high-resolution runs, depending on prior tests, and the ensemble simulations in TCo639.

First results of this project have been presented at the bilateral WCB-meeting at ECMWF in May 2017.

WP3: Case studies of diabatic effects on blocking events (PhD Daniel Steinfeld)

Trajectory-based climatological research has shown that latent heating in strongly ascending airstreams can contribute in a substantial way to the formation and maintenance of blocking anticyclones at upper levels. Here the cause and effect relationship between latent heat release and blocking as well as the representation of this interaction in a weather prediction model will be investigated in detail for a subset of 3-4 selected blocking events and 2-3 lead times per event. In the first part, re-forecast simulations with different lead times will be performed for each event, and the forecast performance will be quantified with the help of anomaly correlation coefficients of PV and geopotential height and a feature-based verification measure. Forward and backward trajectories associated with the blocking regions will be calculated, and the contributions of diabatic trajectories will be compared to the results from ERA-Interim data. The potential linkages between errors in the representation of such diabatic contributions and forecast errors of blocking onset, maintenance and decay will be evaluated. In the second part, IFS sensitivity experiments will be performed with altered latent heat release during cloud formation. The altered latent heating will be confined to specific time periods in order to separately evaluate its effect on blocking onset, maintenance and decay.

All simulations for this project will be run in the coarser horizontal resolution TCo319 and with 91 vertical levels. The lead time will vary between 6 and 10 days. The output of the temperature tendencies is not necessary in WP3.

Expected outcome:
The results of this study corroborate the crucial role of diabatic processes, which are not yet taken into account in current blocking theories.

First results of this project have been presented at the bilateral WCB-meeting at ECMWF in May 2017.

WP4: Investigation of diabatic processes in NAWDEX cyclones (Dr. Maxi Böttcher)

During the international measurement campaign NAWDEX in autumn 2016, various research flights through different parts of extratropical cyclones could be realized. A main focus was on regions where moist diabatic processes, and in particular WCBs, potentially influence the cyclone and where these diabatically modified air masses impinge upon the waveguide. In this project, the IFS will be used in combination with the unique measurement data set we obtained during NAWDEX.

The topics we want to address are: (1) how are the cloud structures represented in measurements compared to the model in the region of the WCB, especially were embedded convection is indicated, and (2) how does heating due to cloud-related processes and the dry dynamics interact in the development of selected cyclones. For these investigations, 5-7 cases studies will be simulated using the special IFS version with complete temperature tendencies. For the model validation with measurements, the operational high resolution will be used.

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

Table 1: Listing of the concrete simulations planned per work package and year. The billing units are calculated generously to account for computing time for testing.

Year	Description of the forecasts	Estimation of billing units and data storage[1]
2018	*WP1:* systematic investigation of 2 seasons (6 months): TCo639, T137, 1-hourly output, all heating rates (16 additional 3-d output fields)	500'000SBU 15 Tb
	WP2: 10 sensitivity simulations of case studies with different microphysical setups: 7 days lead time, TCo1279, L137, 1-hourly output, all heating rates	2'500'000 SBU 23 Tb
	2 ensemble simulations with 10 members: 7 days lead time, TCo639, L137, 1-hourly output, all heating rates	500'000SBU 30 Tb
	WP3: 3 case studies a 6 simulations: 10 days lead time, TCo319, L91, 6-hourly output	200'000SBU 1 Tb
	WP4: 2 case studies, 7 days lead time, TCo1279, L137, hourly output, all heating rates	250'000SBU 2 Tb
2019	*WP1:* systematic investigation of 1 season (3 months): TCo639, T137, 1-hourly output, all heating rates	250'000SBU 15 Tb
	WP2: 10 sensitivity runs for case studies with different microphysical setups: 7 days lead time, TCo1279, L137, 1-hourly output, all heating rates	2'500'000SBU 15 Tb
	2 ensemble simulations with 10 members: 7 days lead time, TCo639, L137, 1-hourly output, all heating rates	500'000SBU 15 Tb
	WP4: 2 case studies, 7 days lead time, TCo1279,L137, hourly output, all heating rates	250'000 SBU 2 Tb
2020	*WP4:* 4 case studies, 7 days lead time, TCo1279,L137, hourly output, all heating rates	500'000SBU 4 Tb

[1] Note that previous simulations will be overwritten in order to save data storage for some simulations.

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