SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2020……………..……
Project Title:	Diabatic effects in mid-latitude weather systems
Computer Project Account:	SPCHBOJO
Principal Investigator(s):	Maxi Böttcher and Hanna Joos
Affiliation:	Institute for Atmospheric and Climate Science, ETH Zürich
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Dr. Richard Forbes
Start date of the project:	1 January 2018……
Expected end date:	31 December 2020……………………….……

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	1500000	1221770.32	500000	10997.09
Data storage capacity	(Gbytes)	118 000			

Summary of project objectives (10 lines max)

In this project we investigate the impact of diabatic processes on the dynamics of weather systems such as extratropical cyclones, atmospheric blocks and the extratropical tropopause. By modifying the potential vorticity, diabatic processes have the potential to influence the atmospheric circulation and thus the wind field. The main goals of this project are to i) quantify the contribution of diabatic processes to the PV modification in extratropical cyclones. This quantification is done for a detailed case study of an extratropical cyclone as well as a climatological analysis of all cyclones occurring in a one year simulation, ii) to improve the understanding of the influence of diabatic processes on the characteristics of the extratropical tropopause and iii) to investigate the influence of latent heat release on the formation and maintenance of atmospheric blocking.

Summary of problems encountered (10 lines max)

No major problems were encountered and the technical support is highly appreciated and very helpful.

Summary of plans for the continuation of the project (10 lines max)

The data set consisting of 12 monthly IFS simulations archiving hourly instantaneous momentum and temperature tendencies from every physical process are and will be used in several projects. The climatological analysis of PV-modifying processes in extratropical cyclones will be finished. Additionally, this dataset will be used in order to investigate how diabatic processes modify air parcel trajectories undergoing stratosphere-troposphere exchange and we will investigate which diabatic processes lead to a moistening or drying of air parcels and might thus be important for the hydrological cycle. As this project will be finished at the end of 2020, a more detailed description of the continuing projects can be found in the new request report.

List of publications/reports from the project with complete references

1) Attinger. R., Spreitzer, E., Boettcher, M., Forbes R., Wernli, H. and Joos, H.: Quantifying the role of individual diabatic processes for the formation of PV anomalies in a North Pacific cyclone, Q. J. R. Meteorol Soc., 145, 2454-2476, doi.org./10.1002/qj.3573, 2019

2) Spreitzer, E., Attinger, R., Boettcher, M., Forbes, R., Wernli, H. and Joos, H.: Modification of potential vorticity near the tropopause by non-conservative processes in the ECMWF model. J. Atmos. Sci., 76, 1709-1726, doi.org/10.1175/JAS-D-18-0295.1, 2019

3) Steinfeld, D., Boettcher, M., Forbes, R. and Pfahl, S.: The sensitivity of atmospheric blocking to upstream latent heating-numerical experiments, Weather and Climate Dynamics, doi.org/10.5194/wcd-2020-5

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

In order to investigate the impact of diabatic processes on the modification of potential vorticity (PV) and thus the atmospheric circulation, a special IFS version allowing for archiving hourly output of all diabatic heating rates as well as temperature and momentum tendencies from the turbulence and convective schemes, is used. The model is run for selected case studies as well as 12 monthly simulations covering a one year period, allowing for a more systematic analysis of diabatic processes. Furthermore, another IFS version has been used where temperature tendencies due to clouds and convection can be altered artificially in a predefined limited area in order to investigate the impact of latent heating on atmospheric blocking. In the following, the results of each project are described in more detail.

1) Systematic assessment of the diabatic processes that modify potential vorticity in extratropical cyclones (Dr. Roman Attinger)

So far, our knowledge of the modification of PV in extratropical cyclones by diabatic processes is primarily based on various case studies. In order to generalize this knowledge, we performed twelve 35-day simulations using the special IFS version which allows for hourly archiving all temperature and momentum tendencies. Based on this output, the corresponding change in PV is calculated for every process separately. In order to investigate the potential of each process in modifying PV, 15h backward trajectories are started from low to mid-level positive and negative PV anomalies in extratropical cyclones and all PV-modifying tendencies are accumulated along these trajectories separately. This procedure is applied to all PV anomalies which are associated to all cyclones (144 cyclones in total) during the extended winter season from October to March of the simulated year. The results show that at the cold front, condensation, convection and long-wave radiative cooling primarily increase PV, leading to a positive PV anomaly, while the turbulent exchange of momentum and long-wave radiative heating produce a negative PV anomaly at the cold front. At the warm front and in the cyclone centre, PV anomalies are predominantly generated by condensation, turbulent exchange of momentum and convection. For the formation of a negative PV anomaly along the warm front, long-wave radiative heating, sublimation of snow and turbulent exchange of temperature are most relevant. In Fig. 1, the percentage of cyclones with the indicated most and second most important process in modifying PV is shown exemplarily for the positive PV anomalies at all sampled cold fronts.

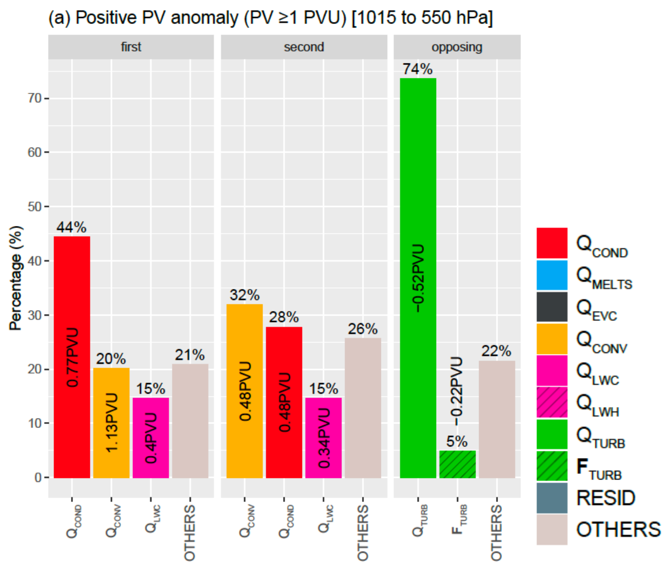

Fig.1: Percentage of cyclones with the indicated process as the most important, second most important and strongest opposing along the cold front for the positive PV anomaly (PV>1pvu) between the surface and 550 hPa. The averaged PV modification by each process is indicated.

It can be seen that in 44% of all cyclones, condensation is the most important PV producing process with an average PV production of 0.77 pvu. In 20% of the cyclones, convection is more relevant than condensation with an on average higher production of PV of 1.13 pvu. In 15% of the cases, long-wave radiative cooling is the most important process contributing with on average 0.4 pvu.

It is remarkable that in about one third of all cyclones, other processes than condensation and convection are more relevant for the generation of PV along the cold front. Turbulent temperature tendencies are the most dominant opposing process in 74 % of the cases.
This analysis has been performed for all positive and negative PV anomalies in all cyclones in the dataset. In general it can be seen that although condensation is often the dominant process in producing the positive PV anomalies, there is also a substantial fraction of cyclones where other processes like radiative heating/cooling rates or melting of snow becomes the dominant process.

This work is part of the Doctoral Thesis of Dr. Roman Attinger:

Attinger, R., Quantifying the diabatic modification of potential vorticity in extratropical cyclones, Doctoral Thesis, Zurich, ETH Zurich, 2020

This work is in preparation for publication as:

Attinger, R., Spreitzer,E., Boettcher,M., Wernli,H. and Joos,H.: Systematic assessment of the diabatic processes that modify potential vorticity in extratropical cyclones, in preparation

2) Climatological analysis of diabatic processes in the North Atlantic tropopause region (Dr. Elisa Spreitzer)

The case study presented in Spreitzer et al. (2019) showed that diabatic PV modification in the vicinity of the tropopause can be substantial. In order to generalize these findings, IFS simulations of one winter season with temperature and momentum tendencies from the physical parameterizations are used (see also dataset used for Project 1). It is investigated in detail how diabatic PV changes modify the vertical structure of the tropopause region, how they act on isentropic PV structures near the waveguide and how the vicinity of a large number of jet streaks is modified by diabatic processes.
As an example, Fig. 2 shows an overview of the instantaneous PV tendencies across the tropopause in troughs and ridges separately.

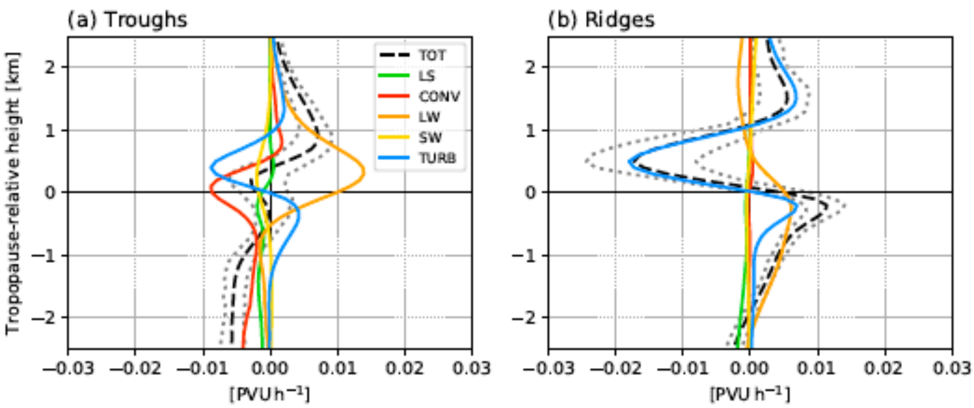

Fig. 2: Average tropopause-relative vertical profiles of instantaneous PV tendencies across the tropopause for the winter season DJF. Vertical coordinates are relative to the 2 pvu surface for each parameterized process in a) troughs and b) ridges, where TOT denotes the total PV modification, LS the modification from the large-scale cloud scheme, CONV from the convective scheme, LW (SW) denote longwave(shortwave) radiative heating and TURB the modification due to the turbulence scheme. The greys dashed lines indicate the interquartile range of the total diabaitc PV rate of profiles at individual time steps.

It can be seen that in troughs, all parameterized processes are active. The convective tendency (CONV) shows a pronounced negative peak directly at the tropopause, which is probably due to mixing in overshooting convection. The strongest instantaneous PV tendencies originate from long-wave radiation. They are positive below the tropopause and throughout the stratosphere with a maximum just above the tropopause, in agreement with strong moisture gradients and cloud top

cooling. In contrast, in ridges, turbulent mixing is the dominant process, leading to PV destruction at the stratospheric side of the tropopause. The long-wave cooling tendencies in ridges are much weaker that in troughs and have a maximum below the tropopause, probably due to a lower moisture content in the upper troposphere, thinner clouds and a higher variability of cloud top heights in ridges compared to troughs.
A more detailed analysis as well as the results for the isentropic analysis and the composites of jet streaks is published in the Doctoral Thesis of Dr. Elisa Spreitzer.

Spreitzer, E., Diabatic processes in mid-latitude weather systems – a study with the ECMWF model, Doctoral Thesis No. 26649, Zurich, ETH Zurich, 2020

3) The sensitivity of atmospheric blocking to changes in upstream latent heating – numerical experiments (Dr. Daniel Steinfeld)

The impact of latent heat release during cloud formation on anticyclonic circulation anomalies such as atmospheric blocking has been investigated in this project. Therefore, simulations with the IFS of five selected blocking events have been performed where the latent heat release during cloud formation upstream of the blocking area has been eliminated artificially. This elimination has substantial effects on the upper tropospheric circulation with a large case to case variability whereas in some cases, the blocking system does not form and in others only the amplitude is reduced.
In Fig.2, the effect of latent heat release on the formation of block Thor, occurring in October 2016, is shown as an example.

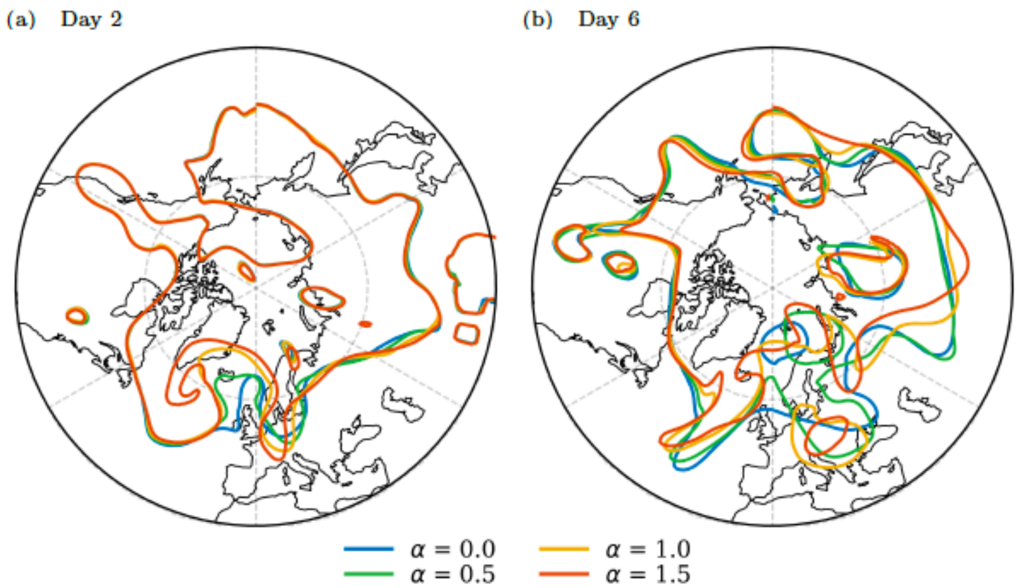

Fig.3: Dynamical tropopause (upper-level 2 pvu contour) for Thor onset during a) 2 October 2016 (day 2) and b) 6 October 2016 (day 6) for different α values (blue for α=0, green for α=0.5, yellow for α=1 and red for α=1.5).

The amount of latent heating has been modified in a predefined area over the North Atlantic (not shown here) by multiplying the instantaneous temperature tendencies due to parameterized cloud and convection processes with a factor α=0,0.5,1 and 1.5. It can be seen that the reduction of the latent heat release (blue and green lines) leads to a strong reduction in the amplitude of block Thor and that also the further maintenance and evolution of the upper-level flow is strongly affected.

This work has been published as:

Steinfeld, D., Boettcher, M., Forbes, R. and Pfahl, S.: The sensitivity of atmospheric blocking to upstream latent heating-numerical experiments, Weather and Climate Dynamics, doi.org/10.5194/wcd-2020-5

4) The role of diabatic processes for the cutting-off process of NAWDEX-cyclone 'Sanchez' (Dr. Maxi Böttcher)

In this study it is investigated which processes lead to the break-up of the PV streamer associated with the NAWDEX-cyclone Sanchez. Therefore a case study has been simulated with the special IFS version, which outputs heating and momentum tendencies for each parameterized process.
It could be shown that overall, dry dynamical processes dominate the break-up of the PV streamer. However, the WCB affects the position of the tropopause by negative PV advection due its divergent outflow and negative PV production at the tropopause caused by turbulence and convection contributes to the break-up of the PV streamer. NAWDEX radar and lidar measurements also confirm the presence of strong diabatic processes in the break-up zone of 'Sanchez'.

This work has been present at the 19th Cyclone Workshop:

Boettcher, M., Attinger, R., Joos, H., Papritz, L., Spreitzer,E., Sprenger, M. and Wernli,H.: The role of diabaitc processes for the cutting-off process of NAWDEX-cyclone 'Sanchez', Posterpresentation at the 19th Cyclone workshop, October 2019, Seeon, Bavaria, Germany, 2019

5) A closer look at Lagrangian PV changes (BSc-Arbeit Gabriel Vollenweider, ETH Zürich)
In a case study, the material evolution of PV along air parcel trajectories is studied in the two dimensional phase space of stability and vorticity. In this phase space, it is investigated how the contribution of the two terms to PV evolves under diabatic heating/turbulent mixing using the physical IFS tendencies. Several regions are studied, including a tropopause fold and surface fronts.

6) Contributions to the Virtual Workshop: Warm conveyor belts – a challenge to forecasting, ECMWF, Reading, March 2020

Research that is based on the special IFS version described in this report lead to 3 contributions at the Virtual Workshop: Warm conveyor belts – a challenge to forecasting.

- Spreitzer, E., Attinger, R., Boettcher, M., Forbes, R., Wernli, H. and Joos,H.: The effect of clouds, radiation and turbulence on upper-level PV, oral presentation
- Heitmann, K., Attinger, R., Wernli, H. and Joos, H.,: The origin and life cycle of diabatically modified PV anomalies in atmospheric blocks: a case study, poster presentation
- Steinfeld, D., Boettcher, M., Forbes, R. and Pfahl, S.: The sensitivity of atmospheric blocking to changes in upstream latent heating, poster presentation