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	2019………………………………………………………..……
Project Title:	Diabatic effects in mid-latitude weather systems
Computer Project Account:	SPCHBOJO………………………………….……
Principal Investigator(s):	Maxi Boettcher and Hanna Joos
Affiliation:	ETH Zuerich…………………………….……
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)	4250000	952215.57	1 500 000	28268
Data storage capacity	(Gbytes)	71000		118 000	

Summary of project objectives (10 lines max)

This project aims to investigate the impact of diabatic processes on the dynamics of weather systems such as extratropical cyclones, atmospheric blocks and the extratropical tropopause. Diabatic processes have the potential to modify the potential vorticity (PV) and can thus affect the atmospheric circulation and wind field. The main goals of this projects are to i) quantify the contribution of microphysical processes, turbulence and radiation to the formation of PV anomalies in extratropical cyclones and atmospheric blockings, ii) to improve the understanding of processes that have an impact on the position and shape of the extratropical tropopause and iii) to compare detailed IFS simulations to measurements taken during the NAWDEX campaign.

Summary of problems encountered (10 lines max)

1. A new interpolation routine for spectral fields for download from the mars archive has been implemented in January 2019. The routine produces much smoother fields and the data which has been downloaded before the change is not compatible with the new data. Especially for the extensive data set for work package (WP) 1, a massive re-download and postprocessing becomes necessary.
2. Diabatic processes often occur on timescales shorter than 1 hour. A higher temporal output frequency would be highly beneficial for our project (~ 15 min).

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

According to WP1 of the request for the special project, the systematic assessment of the diabatic processes modifying PV in extratropical cyclones is planned. To this end, we performed 12 monthly IFS simulations archiving hourly instantaneous momentum and temperature tendencies from every physical process. Using the method outlined in part 1 of the results section, we will investigate the influence of individual diabatic processes on the generation of low-level PV anomalies for each storm contained in the dataset. Thereby, we seek to identify common patterns or differences across different seasons and regions.
Additionally, cut-off cyclone «Sanchez», a case from the NAWDEX field campaign, has been simulated with the special version of the IFS. The ongoing study investigates the diabatic processes at the breakup zone of the PV streamer. In a next step, clouds and moisture in the IFS simulation will be compared with NAWDEX measurements.

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, Quart. J. Roy. Meteorol. Soc., doi.org./10.1002/qj.3573, 2019, accepted

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

Summary of results

A special IFS version that provides hourly output of all diabatic heating rates as well as temperature and momentum tendencies from the turbulence scheme has been used in order to investigate the impact of these processes on different atmospheric phenomena. In the following, each project (called work package, WP in the request form) is described in more detail. The results of project 1 and 2 have also been published (see above).

1a) Quantifying the role of individual diabatic processes for the formation of PV anomalies (PhD project Roman Attinger)

Subgrid-scale physical processes have a considerable influence on the dynamics of extratropical cyclones. Previous research highlights their relevance for the intensity, evolution and meso-scale details of selected weather systems. Moreover, certain atmospheric flow settings have been found to be highly sensitive to diabatic processes and are associated with low predictability. Finally, the representation of these processes in numerical weather prediction models is associated with large uncertainties.

Since potential vorticity (PV) is not conserved when diabatic processes occur, the PV framework is ideally suited to quantify the impact of specific physical processes on the dynamics of individual storms. This project aims at quantifying and improving the understanding of how and when physical processes modify PV in extratropical cyclones. To this end, the IFS model version 43R1 was modified to archive hourly instantaneous temperature tendencies from each microphysical process as well as from the convection, turbulence, and radiation scheme. Additionally, hourly instantaneous momentum tendencies from the convection and turbulence scheme are archived. Using these diabatic temperature and momentum tendencies, instantaneous PV rates associated with every parametrized process can be computed. By integrating these diabatic PV rates along backward trajectories, the relative contribution of individual processes for the PV budget can be assessed at every grid-point.

Using this approach, we investigated how individual diabatic processes modify PV in a marine North Pacific cyclone that occurred in April 2017. This storm was selected based on its complete evolution over the ocean, clearly defined frontal features and recent occurrence. The cyclone was simulated using a 6-day forecast and comparisons with ECMWF analyses revealed good agreement with the model. A novel approach was developed to identify the cyclone and its associated fronts. By tracking individual PV rates along backward trajectories started from the frontal regions, the primary processes responsible for the generation of positive and negative PV anomalies along the cold, warm and bent-back fronts as well as in the cyclone center have been identified.

Our Lagrangian diagnostic revealed that the processes responsible for the modification of PV remained fairly consistent during the cyclone's life cycle. Figure 1 provides a schematic overview of the main results summarized in the following.

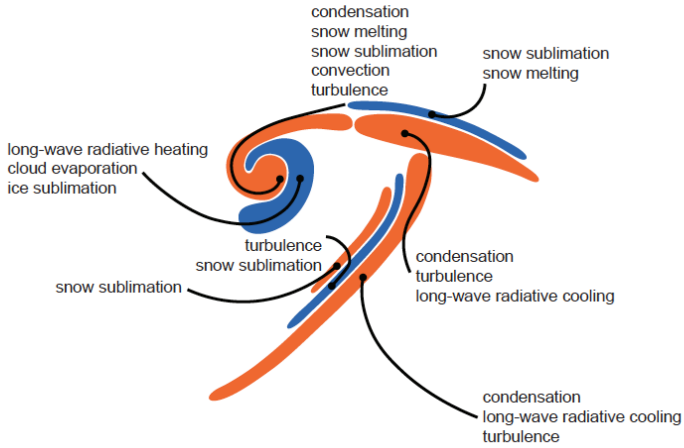

Fig. 1: Synthesized depiction of the low-level PV field at the time of maximum intensity of the North Pacific cyclone. Areas of anomalously negative and positive PV are displayed in orange and blue, respectively. The origin of air masses is shown by the lines and the most important processes are indicated for each feature.

The cold front is characterized by an elongated filament of increased PV, generated by latent heating due to condensation at the front as well as long-wave radiative cooling at the surface. Turbulent mixing at the interface of the boundary layer and the free troposphere decreases PV behind the cold front in the early stage of the cyclone, while sublimation of snow produces negative PV behind the cold front during the mature phase. A broad region of enhanced PV is found along the warm front, generated by condensation and turbulence at the front as well as long-wave radiative cooling at the surface. The region of decreased PV north of the warm front is mainly modified by snow melting and sublimation. High values of PV along the bent-back front are produced by condensation, snow melting and sublimation. Finally, the cyclone center is characterised by a PV tower generated by condensation, convection, snow melting and sublimation. In general, turbulent mixing offsets intense PV modification induced by the other processes.

This investigation highlighted the relevance of condensation, melting and sublimation of snow, long-wave radiative cooling, turbulence, and convection for the production of low-level PV anomalies and underlined the importance of correctly representing these processes in weather prediction models. The results have been published in Attinger et al. 2019.

1b) The origin and lifecycle of diabatically modified PV anomalies in atmospheric blocks: a case study (MSc thesis Katharina Heitmann)

In this project, which has been realized in the framework of a Master thesis by Katharina Heitmann, we quantified the importance of microphysical and radiative heating (or cooling) rates as well as turbulence for the formation and maintenance of an atmospheric block and the associated negative PV anomaly in the upper troposphere. Therefore, a simulation with the special IFS version has been performed which provides hourly output of all diabatic heating rates (DHR). Based on the DHR the associated change in PV has been calculated for each process separately and traced and integrated along trajectories that end inside the block in the upper troposphere. The results nicely show that i) strongly rising airparcels that experience pronounced diabatic heating due to cloud formation undergo a net PV destruction and contribute to the intensification of the upper tropospheric negative PV anomaly, and thus, as more strongly ascending trajectories reach the block, the block intensifies, ii) trajectories that originate at high altitudes experience PV production by turbulence and longwave radiation and therefore lead to a destruction of the negative PV anomaly and iii) the PV modification of each trajectory bundle characterised by a certain ascent remains almost constant during the evaluated 4-day blocking period.

2) Diabatic processes near the extratropical tropopause (PhD project Elisa Spreitzer)

This project is also based on the IFS simulations with temperature and momentum tendency output. The trajectory-based reverse domain filling approach is applied to the upper troposphere and lower stratosphere to quantify the impact of individual physics parametrizations (large-scale cloud, convection, radiation, vertical diffusion and gravity wave drag) to the near-tropopause flow associated with an extratropical cyclone in a case study. PV anomalies of diabatic origin are attributed to specific model parametrizations and their evolution is studied in detail.
In particular turbulence in the vicinity of the jet stream is a relevant process for the mesoscale PV structure near the tropopause (i) in an upper-level front-jet system, where previous observation-based findings of positive PV anomalies (Shapiro, 1976) are corroborated, (ii) causing the decay of a tropopause fold and strong stratosphere-troposphere exchange, and (iii) in a ridge, where the vertical diffusion scheme creates a PV feature that is potentially relevant for the tropopause inversion layer. Cloud processes (both from the large-scale cloud and the moist convection parametrization) affect the upper-level PV pattern above warm conveyor belt-outflow in a ridge and in the upper troposphere below troughs. Long-wave radiation dominates in regions of anomalously low tropopause, where it tends to sharpen the vertical PV gradient across the tropopause jointly with cloud processes, which is in agreement with previous studies (e.g. Chagnon and Gray, 2015).
This study was published as Spreitzer et al. (2019).

3) The sensitivity of atmospheric blocking to changes in upstream latent heating (PhD project Daniel Steinfeld, manuscript in preparation)

Moist processes, and in particular the release of latent heat in ascending airstreams, can modify the mid-latitude flow and contribute to the formation of prolonged circulation anomalies such as atmospheric blocking.
In order to investigate the effect of latent heating on blocking, numerical sensitivity experiments for a subset of 5 blocking events are performed with a special IFS version in which temperature tendencies due to clouds and convection are artificially altered in a predefined limited area upstream of the block. This allows for a systematic investigation on how sensitive the upper-level wave dynamics to the details of cloud microphysics and convection are.

A key finding of the numerical sensitivity experiments is that the intensity, spatial extent and lifetime of all simulated blocking events strongly benefits from latent heating, and in some cases even determines weather or not blocking occurs at all. The primary effects of latent heating on the tropopause arise from a direct injection of low PV within cross-isentropic ascending "warm conveyor belt" airstreams and an indirect enhancement of the divergent outflow.

These sensitivity experiments demonstrate that moist processes, that have not been taken into account in current blocking theories, can provide the required flow amplification in addition to dry-dynamical forcing.