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	2023………………………………………………….……
Project Title:	Diabatic heating rates and moist tendencies along airstreams associated with different weather systems
Computer Project Account:	SPCHBOJO……………………………………..……
Principal Investigator(s):	Hanin Binder, Hanna Joos ………………………….……
Affiliation:	ETH Zürich, Institute for Atmospheric and Climate Science, Zurich, Switzerland
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Dr. Richard Forbes………………….…… ………………………………………………………….……
Start date of the project:	1. January 2021……………………………..……
Expected end date:	31. December 2023……………………

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)	800 000	14 218	800 000	54 436
Data storage capacity	(Gbytes)	43 000		48 000	

Summary of project objectives (10 lines max)

In this project we make use of our special IFS version that allows to output hourly all moisture, temperature and momentum tendencies from the parameterized physics. We are using moisture tendencies in order to increase our knowledge about the hydrological cycle in different regions of the world, like the trade-wind regions and the extratropical stormtracks, as well as to improve our understanding of the interaction of the temperature tendencies with the atmospheric circulation by modifying the potential vorticity in the tropopause region, in warm conveyor belts and in Mediterranean cyclones. Furthermore, the importance of radiative tendencies for extratropical dynamics is investigated.

Summary of problems encountered (10 lines max)

In the last calendar year, we worked with Dr. Richard Forbes to implement the functionality of allowing additional output of momentum, temperature and moisture tendencies to the IFS CY47R3b version. Some compilation errors were encountered and significant residuals in the budget equations were present initially. Thanks to the great support by Dr. Richard Forbes, several trial forecast experiments have been performed, all compilation errors are solved and the budget equations are closed. This special branch will be used for simulations in the second half of 2023.

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

With the special branch based on IFS CY47R3b ready to be used, forecast experiments are planned to study the evolution of the tropopause region during selected periods when clear air turbulence (CAT) is detected by commercial aircraft. Currently 5 short forecast experiments (forecast length of maximum 72 hours) at TCo1279 resolution are planned in autumn 2023 to study 5 selected cases respectively. The additional output of momentum and temperature tendencies allows investigation of the cause of the CAT events and their impact to the tropopause region through derived potential vorticity tendencies and offline Lagrangian trajectory analysis. The CAT diagnostic developed by ECMWF will also be assessed for these case studies. Re-run with even higher resolution may be considered depending on the results obtained and available computational resources.

List of publications/reports from the project with complete references

Scherrmann, A., Wernli, H., and Flaounas, E.: Origin of low-tropospheric potential vorticity in Mediterranean cyclones, Weather Clim. Dynam., 4, 157–173, https://doi.org/10.5194/wcd-4-157-2023, 2023

Summary of results

1) Diabatic processes in Mediterranean cyclones (A. Scherrmann, Dr. E. Flaounas)

In the PhD project of A. Scherrmann, we are investigating and quantifying the PV modification by different diabatic processes in Mediterranean cyclones which are identified in the one year simulation with the special IFS version. This simulation has been performed in the framework of the previous special project "Diabatic effects in mid-latitude weather systems". We combine the available PV tendencies with 48 hours backward trajectories (calculated using LAGRANTO) to (i) determine the most dominant diabatic processes in the Mediterranean basin that shape the lower-tropospheric PV anomaly found in Mediterranean cyclones, and (ii) determine where with respect to the cyclone centre the PV modification occurs, to define so called "cyclonic" and "environmental" PV with which we distinguish self- and remotely-driven cyclones and the dominant process inside and outside the cyclones. Figure 1 shows results obtained in step (i), where the PV modification accumulated along trajectories is shown as distribution for all cyclones. Overall we find the main source of PV production to be dominated by convection, turbulence and microphysics (panel a CONVT, TURBM, MP), where as turbulence and radiation are the main source of PV destruction (TURBT, RAD). Similar results were shown by Attinger et al 2022 in North Atlantic extratropical cyclones. Splitting the contribution into its cyclonic and remote parts (b,c) shows that convection and microphysics are the main sources of PV production associated with the cyclone (b) and turbulence for the remote processes (c).

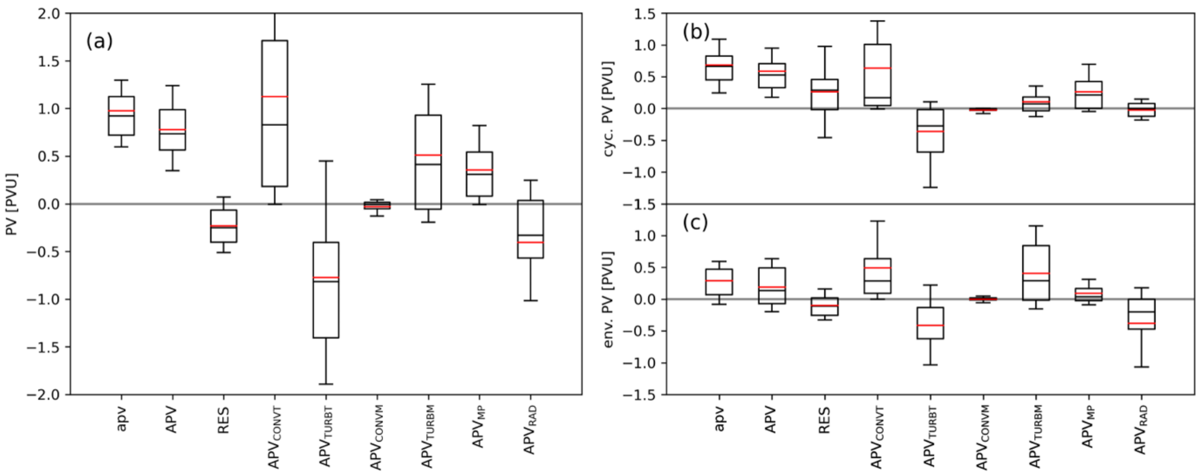

Figure 1: Distribution of the average PV modification cyclones experience due to diabatic processes along 48h backward trajectories initialized from the lower-troposphere in the cyclone center. (a): overall modifications; (b): modifications that are associacated with processes occuring inside the cyclone; (c): modifications associated with remote processes outside the cyclone.

This work has been published in Weather and Climate Dynamics:

Scherrmann, A., Wernli, H., and Flaounas, E.: Origin of low-tropospheric potential vorticity in Mediterranean cyclones, Weather Clim. Dynam., 4, 157–173, https://doi.org/10.5194/wcd-4-157-2023, 2023

2) Clear air turbulence (Franco Lee, Dr. Michael Sprenger)

A trial forecast experiment at TCo639 resolution was performed for a CAT case observed near Japan on 25 Dec 2019. A quick comparison with ERA5 reanalysis shows good agreement and we will perform more higher resolution forecast experiments in autumn 2023 for observed CAT events to investigate the evolution near the tropopause region before and after the occurrence of CAT.

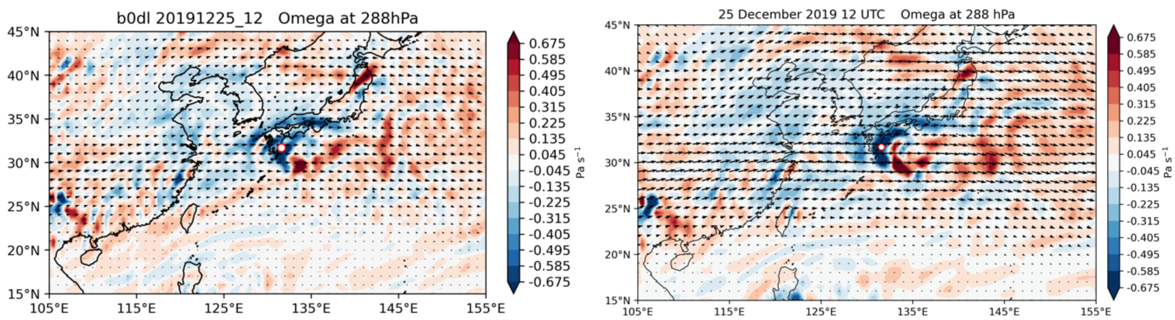

Figure 2: Vertical velocity (Pa s^{-1}) at observed CAT event pressure level (288hPa) for (left) the trial forecast experiment and (right) ERA5 reanalysis.

3) Modification of potential vorticity by radiation in the extra-tropics (Noè Zardi, Dr. Roman Attinger, Dr. Sophia Schäfer (German Weather Service), Dr. Hanna Joos)

We made use of the one year IFS simulation, which has been performed in the framework of the previous special project "Diabatic effects in mid-latitude weather systems", providing all physical tendencies with an hourly time resolution in order to investigate in which synoptic situtions radiative temperature tendencies have the potential to modify potential vorticity (PV) substantially. We therefore selected two case studies where radiation contributed to the formation of (i) a positive PV anomaly in the lower troposphere which developed into an extratropical cyclone and (ii) an area with absolute negative PV close to the dynamical tropopause in an upper-level ridge. For both cases we could show that the shortwave and longwave heating as well as the longwave cooling leads to PV modification in a complex way. If these heating/cooling tendencies and the corresponding PV tendencies are accumulated along backward trajectories that originate from the considered PVanomalies, it can be seen that radiation can substantially modify PV as the air parcels experience these modification over several hours.
Figure 3 shows vertical time-height sections of the longwave heating/cooling rates (left) and the corresponding PV rate due to longwave heating (right) along trajectories ending in the upper-level negative PV region.

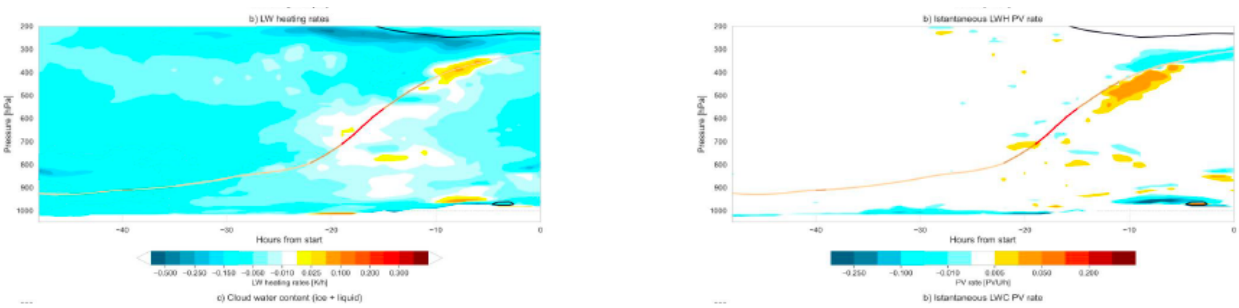

Figure 3: Vertical time-height section along trajectories originating from an upper-level negative PV region. Colours denote the longwave heating/cooling rates (K h^{-1}) (left) and PV rates due to longwave heating (pvu h^{-1}) (right). The coloured line denotes the mean height of the considered trajectories coloured with their mean PV value (colourbar not shown). The black line denotes the 2 pvu-isoline.

It can be seen that trajectories ascend from the lower to the upper troposphere,whereas they do not experience PV modification due to radiation between -48h and ~-10h before they arrive in the upper troposphere. In the last ten hours before arrival PV is reduced, caused by the combination of longwave heating and cooling. PV is reduced above the heating maximum as well as below the cooling maximum. The trajectories therefore loose PV as they are traveling through this region and thus contribute to the formation of the absolute negative PV region. The accumulation of negative PV rates due to all radiative heating rates can also be seen in Figure 4. It shows that the PV values of the air parcels decrease between -0.5 and -1.5 pvu in 48h due to radiation.

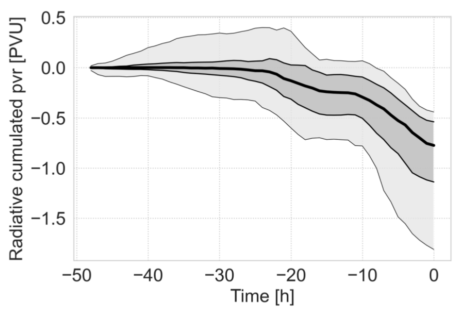

Figure 4: Accumulated PV rates due to radiation (shortwave and longwave heating and longwave cooling) along 48h backward trajectories started from a region with absolute negative PV values in the upper troposphere.

4) Impact of below-cloud processes on PV in North Atlantic extratropical cyclones (Max Frei, Alexander Scherrmann, Dr. Hanna Joos)

In a Master thesis, we are investigating where and how often below-cloud processes as sublimation or melting of snow, or evaporation of rain can lead to substantial cooling and consequently to PV modification in extra-tropical cyclones. We make use of the one-year IFS simulation providing hourly output of all physical tendencies in order to find the regions in cyclones where cooling occurs. To do so, we use a random forest which is trained on the 1-year IFS simulation and which predicts the time and locations where below-cloud cooling occurs based on relative humidity, the existence of snow and/or rain water, temperature, cloud cover and vertical velocity. The predictions are validated based on the 1-year IFS dataset which includes all cooling rates from the model output. First results from the random forest are shown in Figure 5.

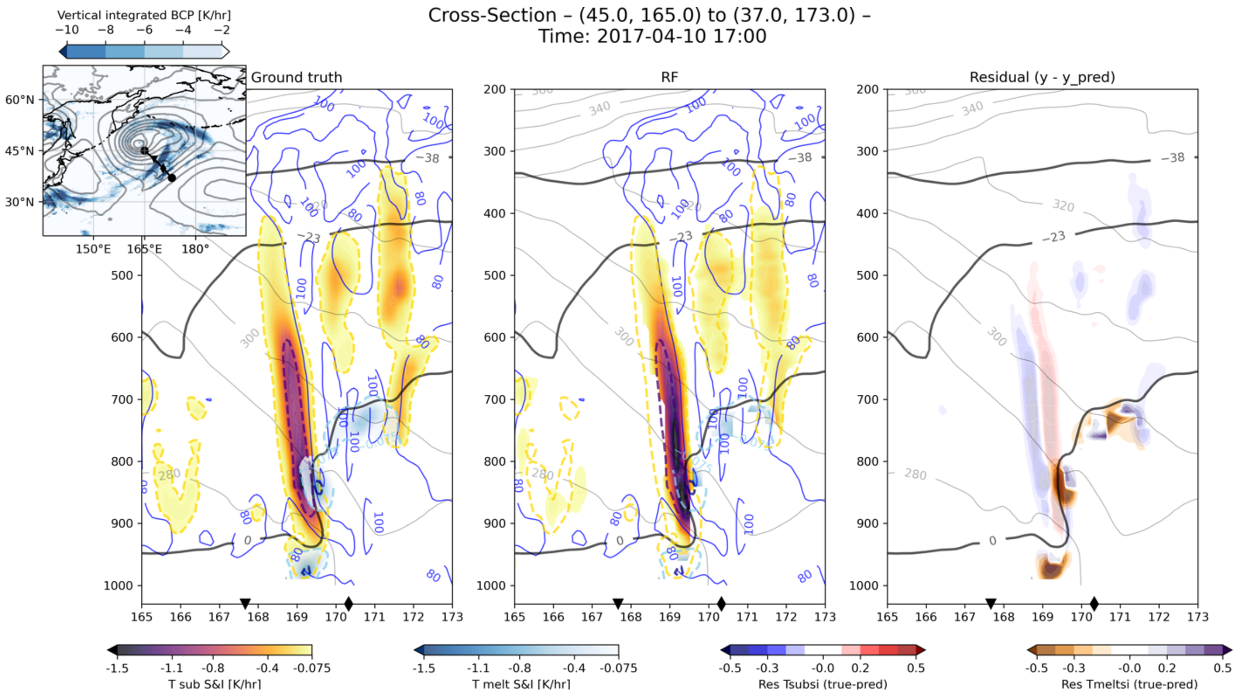

Figure 5: Vertical cross section through a cold front. Cooling due to sublimation of snow and ice (yellow-purple colours, K h^{-1}), due to melting of snow and ice (bluish colours, K h^{-1}) from the IFS output (left panel) and the prediction from the random forest (middle panel). The right panel shows the difference in cooling rates between the IFS and random forest for cooling due to sublimation (red-blue colours, K h^{-1}) and due to melting (brown-blue colours, K h^{-1}).

In a next step we will trace the predicted cooling rates along selected air parcel trajectories in the vicinity of extra-tropical cyclones in order to determine how much different regions around the cyclones have been cooled by which process. After testing the diagnostic based on the 1-year IFS simulation, we will apply it to the whole ERA5 dataset. This will enable us to determine how many cyclones are affected by below-cloud processes and to what extent, where in the cyclone the strongly cooled airparcels arrive and where they are geographically located.