REQUEST FOR A SPECIAL PROJECT 2024–2026

MEMBER STATE:	Switzerland………………………………………………………………
Principal Investigator[1]:	Dr. Hanna Joos, Dr. Michael Sprenger…………………………………
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Other researchers:	Franco Lee, Dr. Jacopo Riboldi, Franziska Schnyder
Project Title:	Diabatic processes and their impact on extratropical dynamics and the hydrological cycle

To make changes to an existing project please submit an amended version of the original form.)

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.)	2024	
Would you accept support for 1 year only, if necessary?	YES X☐	NO ☐

Computer resources required for project year:		**2024**	**2025**	**2026**
High Performance Computing Facility	[SBU]	500 000	1 010 000	510 000
Accumulated data storage (total archive volume)[2]	[GB]	9 Tb	30 Tb	40 Tb

EWC resources required for project year:		**2024**	**2025**	**2026**
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]			

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.
[2] These figures refer to data archived in ECFS and MARS. 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 etc.
[3]The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

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Extended abstract

Latent heat release and consumption associated with the manifold microphysical processes occurring during cloud and precipitation formation as well as radiative temperature tendencies modify the atmospheric circulation. This impact can be described by the concept of potential vorticity (PV) modification by diabatic processes (Hoskins et al., 1985). Furthermore, the formation and dissipation of clouds and precipitation exhibit sources and sinks for atmospheric water vapour and is therefore strongly linked to the hydrological cycle.

In this special project we would like to make use of a special IFS version which allows for hourly output of temperature and momentum tendencies from the parameterized physics, like cloud microphysics, radiation, convection and turbulence. Furthermore, moisture tendencies which are associated with phase changes during cloud formation (e.g. sublimation of snow, condensation of water vapour, depositional growth of snow) are also output hourly. This special IFS version has been developed in the framework of our previous special projects in close collaboration with Dr. Richard Forbes.

The output of all the temperature and moisture tendencies provides a unique possibility to investigate the impact of diabatic processes on the circulation and the hydrological cycle in different synoptic situations. More precisely, we plan to investigate (i) the importance of diabatic processes for the formation of clear air turbulence near the tropopause region (WP1), (ii) the impact of surface radiative cooling on the storm track regions (WP2), and (iii) the moisture sources for precipitation that is formed in warm conveyor belts (WP3).

In the following, the work packages are described in more detail, including an estimation of the required computer resources.

Work packages

WP1: Potential Vorticity Modification and Clear Air Turbulence in the Tropopause Region (Franco Lee, Dr. Michael Sprenger)

From previous studies (Spreitzer et al., 2019) on potential vorticity (PV) modification and stratosphere-troposphere exchange (STE) (e.g. Shapiro, 1980), clear air turbulence (CAT) is suggested to be of first-order importance in PV modification, especially near tropopause fold and/or upper-level frontal regions. However, while the recent study (Spreitzer et al., 2019) aimed at studying different diabatic PV modification processes in one case, we would like to focus on turbulent PV modification on several observed CAT cases (as obtained from commercial aircraft and saved in IATA's turbulence aware database). The selected CAT events occurred in various synoptic weather situations, e.g., during Rossby wave breaking and/or warm conveyor belt outflows. In particular, whether the PV modification by turbulent processes has an impact on the large-scale flow or the triggering of STE will be assessed through the employment of offline trajectories, following the Lagrangian methodology introduced by Spreitzer et al. (2019). In this project, we would like to make use of the special IFS version with additional output of all temperature and momentum tendencies to answer the following questions:

1) Is there a signal of PV modification by turbulent processes in model simulations at the time and location of the observed CAT event?

2) How important are turbulent processes in PV modification compared to other diabatic processes? To which degree does the turbulence-induced PV modification modulate the evolution of the tropopause?

3) Is there STE occurring in the vicinity of the CAT events? Is it related to the PV modification by turbulent processes?

Technically, we would like to perform two 5-day forecasts with a resolution of TCo639 and two 2-day forecasts with a resolution of TCo1279 with hourly output. The simulations are planned to start from 2024.

WP2: Diabatic processes at the entrance of the storm tracks and their role for extratropical cyclone dynamics (Dr. Jacopo Riboldi, Franziska Schnyder)

This part of the project is dedicated to study the physical mechanisms behind the impact of surface radiative cooling onto the storm track regions. Land/sea temperature contrast is regarded as an important driver of storm track activity, in particular over the Northern Hemisphere (Brayshaw et al., 2009). Such a temperature difference becomes particularly large during winter: this is due to energy loss from radiative cooling during the long winter night and to the smaller heat capacity of the soil with respect to water. As cloud cover, turbulent mixing, and the presence of snow can modulate energy loss via infrared radiation, the strength of radiative cooling is not necessarily constant across the cold season and, therefore, the generation of cold air might be at times enhanced or hindered. This modulation can then reverberate itself onto the eddy activity at the entrance of the North Pacific and Atlantic storm tracks, which are located directly downstream of Siberia and of Canada – the two "cold poles" of the Northern Hemisphere (Portal et al., 2022). As cold, dry air is drawn over the warm ocean, strong sensible and latent heat fluxes warm and moisten the cold sector of deepening extratropical cyclones located just offshore (Papritz and Spengler, 2017; Tilinina et al., 2018). While it is known that latent heat release in clouds can strengthen cyclonic circulations (e.g., Binder et al., 2016; Büeler et al., 2017), less is known about the impacts of diabatic heating from heat fluxes in the cold sector onto cyclone structure and intensity. The magnitude of such fluxes is proportional to the temperature difference between the sea surface and the air mass, suggesting a linkage to the amount of radiative cooling that occurred during previous days over land.

After selecting few representative cases of extratropical cyclones occurring in periods of particularly strong land/sea contrast, we plan to perform and contrast two types of simulations: 1) a full-physics run, serving as control; and 2) a sensitivity run where temperature tendencies associated with longwave radiation over land are damped and/or relaxed to climatology. The modification of the radiative temperature tendencies would correspond to a temporary optical thickening (simulating the presence of clouds) over the source region of the cold air that will be ingested into the extratropical cyclone. The exact timing and the region of cooling will be determined from the analysis of backward trajectories from the cyclone's cold sector in the control run, in order to make the modification as targeted as possible. The approach is similar to the one employed by Steinfeld et al. (2020) to investigate the sensitivity of atmospheric blocking to upstream diabatic processes, which was also conducted using dedicated IFS simulations.

The questions that will be addressed in this work package are:

1) Is the amount of radiative cooling over land, in the days preceding cyclogenesis, affecting extratropical cyclone structure in terms of, e.g., precipitation distribution and intensity?

2) Does upstream cold air also influence the background flow in which the cyclone is embedded, e.g., in terms of jet stream speed and position?

We would like to perform three simulations for two case studies, one over the North Atlantic and one over the North Pacific, for a total of six simulations. These will be 7-day long forecasts at Tco639 resolution using the special IFS version that features 3D temperature and momentum tendencies, with hourly output.

WP3: Moisture sources of warm conveyor belt precipitation (Dr. Hanna Joos, Dr. Michael Sprenger)

Warm conveyor belts (WCBs) are the main cloud and precipitation forming airstreams in extratropical cyclones (Browning, 1986; Wernli, 1997). Pfahl et al. (2014) showed that in the extratropical storm tracks up to 60% of the precipitation and up to 80% of extreme precipitation can be linked to WCBs. In this work package we, therefore, would like to investigate the moisture sources for precipitation that is formed in the ascending airstream of WCBs. More precisely, we will analyse the moisture cycle in WCB inflows, with a particular focus on the moisture supply from below-cloud processes like the evaporation of rain and sublimation of snow that is falling out of the WCB as well as on the contribution from surface evaporation. Additionally, we will evaluate how the importance of the different moisture sources is influenced by the existence of atmospheric rivers (AR) and dry intrusions (DI), i.e., both weather features that can be co-located with WCB inflow regions.

The results of a recent MSc thesis (Perger, 2023) already showed that air parcels ascending in a WCB exhibit a complex history of moisture loss and uptake in the five days prior to the ascent, which can be seen in Figure 1.

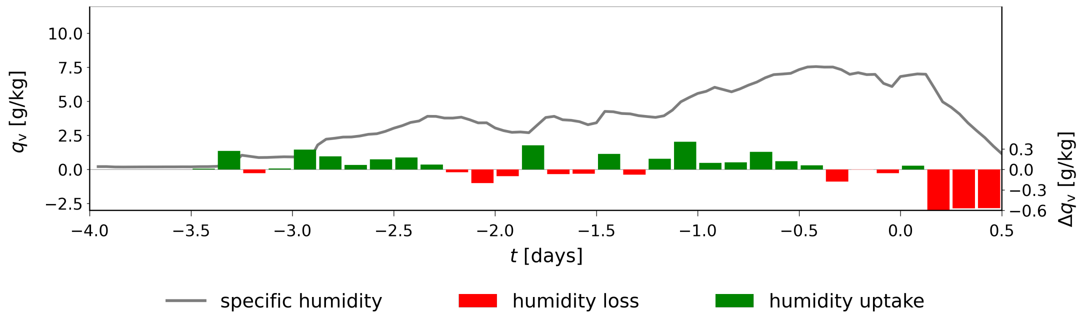

Fig.1: Temporal evolution of specific humidity (g/kg, left axis) and specific humidity change (g/kg, right axis) along five-day backward trajectories started from a WCB ascent region (Figure taken from Perger, 2023).

In the study by Perger (2023), however, the moisture uptake and loss could not be linked to cloud-microphysical processes. We will therefore extend this analysis in two important aspects: (i) by including information about moisture supply by below-cloud processes; and (ii) by simulation WCB cases that are strongly influenced by ARs or DIs. To do so, we will apply a Lagrangian approach and track the moisture changes along backward trajectories originating from WCB inflow regions. Thereby the questions that we will address are the following:

1) Which processes contribute to the moistening of air masses that form precipitation in WCBs?

2) What is the relative contribution from below-cloud processes like sublimation of snow and evaporation of rain?

3) Does the relative importance of different processes change when a WCB is associated with an AR or a DI?

In order to investigate these questions we would like to perform three 7-10-day forecasts with a resolution of TCo639 and three 7-10-day forecasts with TCo1279, both with hourly temporal resolution and output of all moisture tendencies.

Estimation of Computer resources

Year	Description of the forecasts	Estimation of billing units and data storage
2024	*WP1:* i) 2 case studies, TCo639, 5-day lead time, 1-hourly output of all heating/ momentum tendencies ii) 2 case studies, TCo1279, 2-day lead time, 1-hourly output of all heating/ momentum tendencies *WP3:* i) 1 case study, TCo639, 10-day lead time, 1-hourly output of all heating/momentum and moisture tendencies	100 000 SBU 3 Tb 300 000 SBU 3 Tb 100 000 SBU 3 Tb
2025	*WP2:* i) 3 case studies, TCo639, 7-day lead time, 1-hourly output of all heating and momentum tendencies *WP3:*	210 000 SBU 5 TB 200 000 SBU

	i) 2 case studies, TCo639, 10-day lead time, 1-hourly output of all heating/momentum and moisture tendencies ii) 2 case studies, TCo1279, 10-day lead time, 1-hourly output of all heating/momentum and moisture tendencies	6 Tb 600 000 SBU 10 TB
2026	*WP2:* i) 3 case studies, TCo639, 7-day lead time, 1-hourly output of all heating and momentum tendencies *WP3:* i) 1 case study, TCo1279, 10-day lead time, 1-hourly output of all heating/momentum and moisture tendencies	210 000 SBU 5 TB 300 000 SBU 5 Tb

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