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	2025…………………………………………….……
Project Title:	Diabatic processes and their impact on extratropical dynamics and the hydrological cycle
Computer Project Account:	SPCHBOJO……………………………………….……
Principal Investigator(s):	Dr. Hanna Joos, Dr. Michael Sprenger
Affiliation:	Institute for Atmospheric and Climate Science, ETH Zürich, Switzerland
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Dr. Richard Forbes
Start date of the project:	1. January 2024……………….……
Expected end date:	31. December 2026……………………

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)	500 000	71740	1 010 000	41507
Data storage capacity	(Gbytes)	9 Tb		30 Tb	

Summary of project objectives (10 lines max)

In this project we make use of our special version of the IFS that allows for output of all moisture, momentum, and temperature tendencies due to parameterized physics. We use these tendencies to investigate the importance of diabatic processes for the connection of clear air turbulence to the dynamics at tropopause levels (WP1), for the formation of a sting jet in an extratropical cyclone (WP2) as well as the impact of surface radiative cooling on the storm track regions (WP3). Furthermore, we quantify the different moisture sources contributing to the inflow of a warm conveyor belt (WP4).

Summary of problems encountered (10 lines max)

We did not encounter any problems

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

We plan to perform further simulations with our special IFS version to work on the following projects: (WP3) case studies of cold air outbreaks (CAOs) along the Kuroshio and Gulf Stream regions with reduced diabatic heating over the upstream continents. Our current work suggests that strongest CAOs are a result of air experiencing prolonged diabatic cooling (mainly radiative cooling form the land surface) over the upstream continent. In the planned simulations the diabatic heating over the continent will be reduced for several days leading up to the CAO events to test this hypothesis. (WP4) simulation of several case studies of warm conveyor belts in different regions of the world to quantify their moisture sources. For this, the output of hourly moisture tendencies due to parameterised physics will be essential.

List of publications/reports from the project with complete references

So far there are no accepted publications because the work is still ongoing, however the results of WP2 will be submitted for publication this year.

Summary of results

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

In this work package, we used the IFS forecast experiments to understand how turbulence in the tropopause region affects the dynamics through its modification of potential vorticity (PV). Two experiments were run with IFS model CY47R3 at TCo1279 resolution and the extra output of temperature and momentum tendencies allowed us to derive the PV tendencies for each parametrisation scheme. We further used backward trajectories to trace the evolution of PV of air parcels and partitioned the change in PV into individual sub-grid scale processes.

Our analysis shows that turbulence is the dominant process contributing to the change in PV in the tropopause region, for example, in the upper-level jet-front system (Fig. 1a). The accumulated PV of the air parcels is organised into elongated bands with alternating positive and negative values (Fig. 1b). The pattern is found to stem from the instantaneous tripolar PV tendency due to turbulence near the tropopause. Figure 2 displays a vertical cross section across the upper-level jet, which clearly shows the tripolar patterns above and below the jet core. We can understand this pattern through theoretical derivation and it is shown that turbulence generally results in such tripolar PV tendency centring at the shear zone. This is verified in another forecast experiment where the same tripolar pattern is recognised above the tropopause in a ridge fed by warm conveyor belt outflow. The experiments hence allowed us to discover and confirm the systematic behaviour of PV modification by turbulence in the tropopause region and we will continue to explore the impact of the modified PV field on the dynamics.

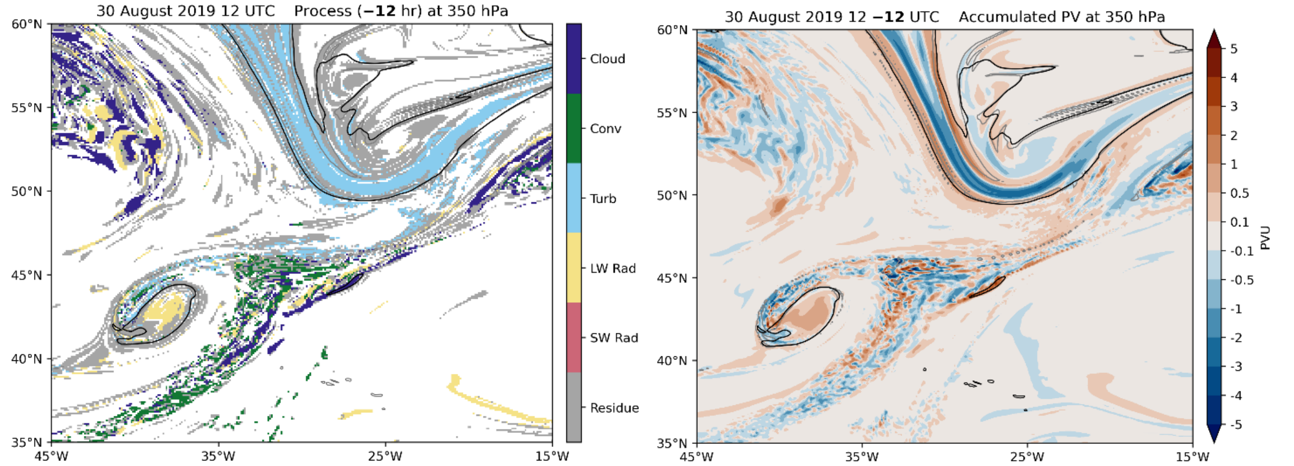

Fig. 1: (a) The dominant sub-grid scale process that contributed to the change in PV and (b) the accumulated PV from all sub-grid scale processes over the last 12 hours at 350 hPa, on 30 August 2019, 12 UTC. The black line indicates the 2-PVU isoline (treated as the tropopause) of the current PV field. The acronym "Turb" stands for turbulence.

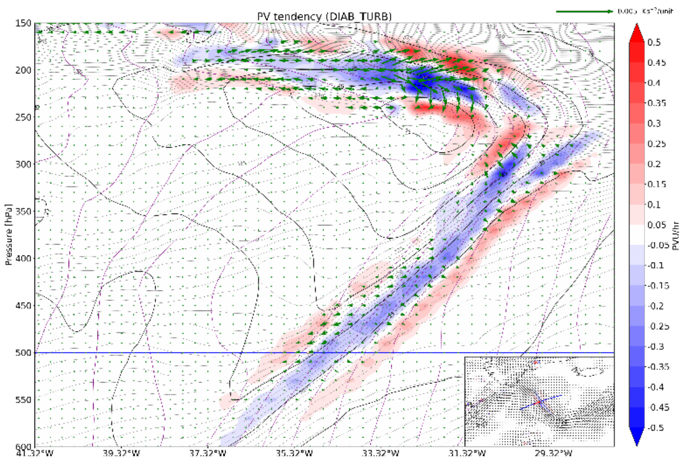

Fig. 2: Vertical cross section of the instantaneous PV tendency due to turbulence on 30 August 2019, 12 UTC. The isotaches (black contours), isentropes (grey contours), and isopleths of absolute momentum (purple contours) are overlaid. The blue line corresponds to that in the map on the lower-right. The green arrows indicate PV-substance fluxes, the convergence (divergence) of which implies positive (negative) PV tendency.

WP2: Sting jet in storm Ciarán (Dr. Ambrogio Volonté (University of Reading), Dr. Hanna Joos, Franco Lee)

We used the IFS model CY47R3 with a resolution of TCo1279 (~9km) and hourly output of all temperature tendencies to perform a case study simulation of storm Ciarán which occurred in November 2023 in the eastern North Atlantic. The storm featured a small-scale region of extremely strong low-level winds (> 50 m/s at 850 hPa) belonging to the airstream called "sting jet". Sting jets develop along local in-cloud regions of moist and, in most intense cases, dry symmetric instability on the cold side of the bent-back front. This instability is then released as the sting jet descends out of the cloud-head tip. Dry symmetric instability is indicated by negative potential vorticity (PV) and the IFS simulation does indeed display a region of negative PV and can therefore be used in order to investigate its formation (Fig. 3).

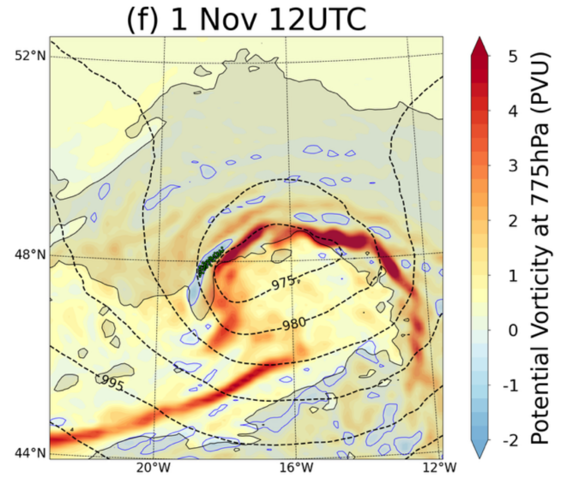

Fig. 3: Potential vorticity (colours), relative humidity (grey shading > 80%) at 775hPa and mean sea level pressure (dashed balck contours) on 1 November 2023, 12 UTC. Black circles indicate the starting positions of the sting-jet trajectories that are located in an area of negative PV.

Backward trajectories started from the regions of highest wind speeds show the importance of microphysical processes like evaporation of clouds, sublimation of snow and melting of snow in reducing potential vorticity and building up the negative PV. The accumulated PV tendencies from these processes along the sting jet trajectories can be seen in Fig. 4.

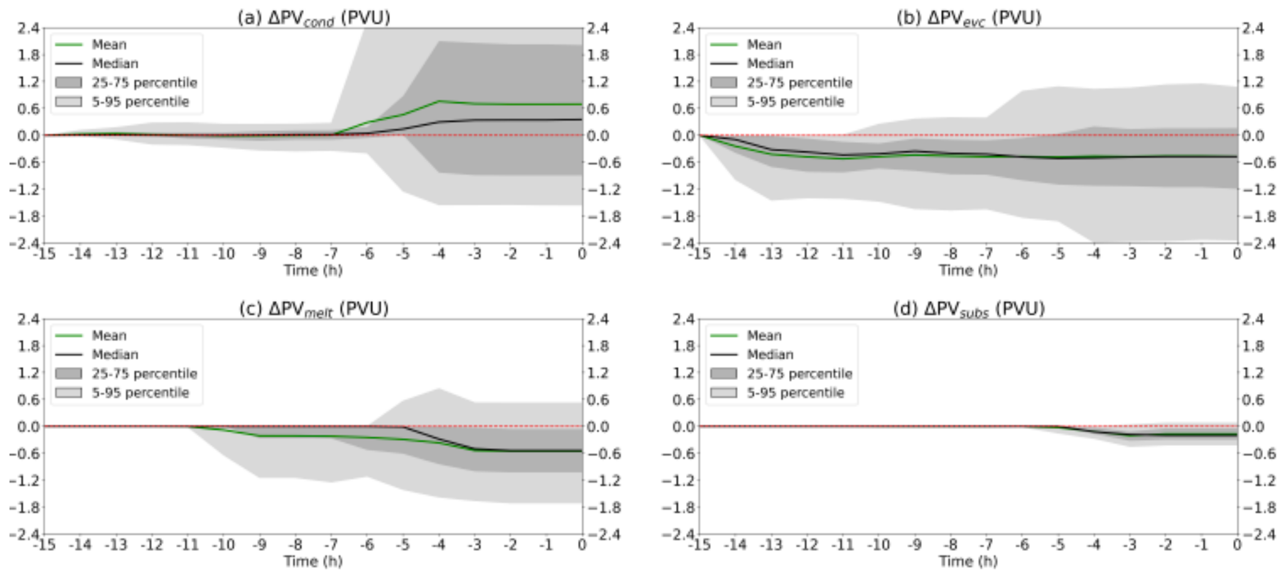

Fig. 4: Accumulated PV tendencies (pvu) due to condensation (a), evaporation of clouds (b), melting of snow (c) and sublimation of snow (d) along sting jet trajectories.

WP3: Diabatic processes at the entrance of the storm tracks and their role for extratropical cyclone dynamics (Dr. Jacopo Riboldi, Franziska Schnyder)

In this work package we plan to perform simulations of case studies of cold air outbreaks (CAOs) along the Kuroshio and Gulf Stream regions. Our current work suggests that strongest CAOs are a result of air experiencing prolonged diabatic cooling (mainly radiative cooling form the land surface) over the upstream continent. To test this hypothesis, we plan to perform simulations where the intensity of diabatic heating over the continent will be reduced during the days leading up to the CAO event.

Preparation work to appropriately design and perform the sensitivity studies is under way. In an ongoing MSc project, backward trajectories originating from the CAO region were analyzed to determine, at each time step and location, the dominant physical process responsible for the occurrence of cooling. This is done using an offline version of the ecRad radiation parameterization, applied following each air parcel along their motion. In the example below (Fig. 5), relative to a CAO that occurred in January 2023, the locations where each trajectory experienced clear-sky cooling are marked in green, while cooling related to ice clouds (i.e., freezing fog) are marked in blue.

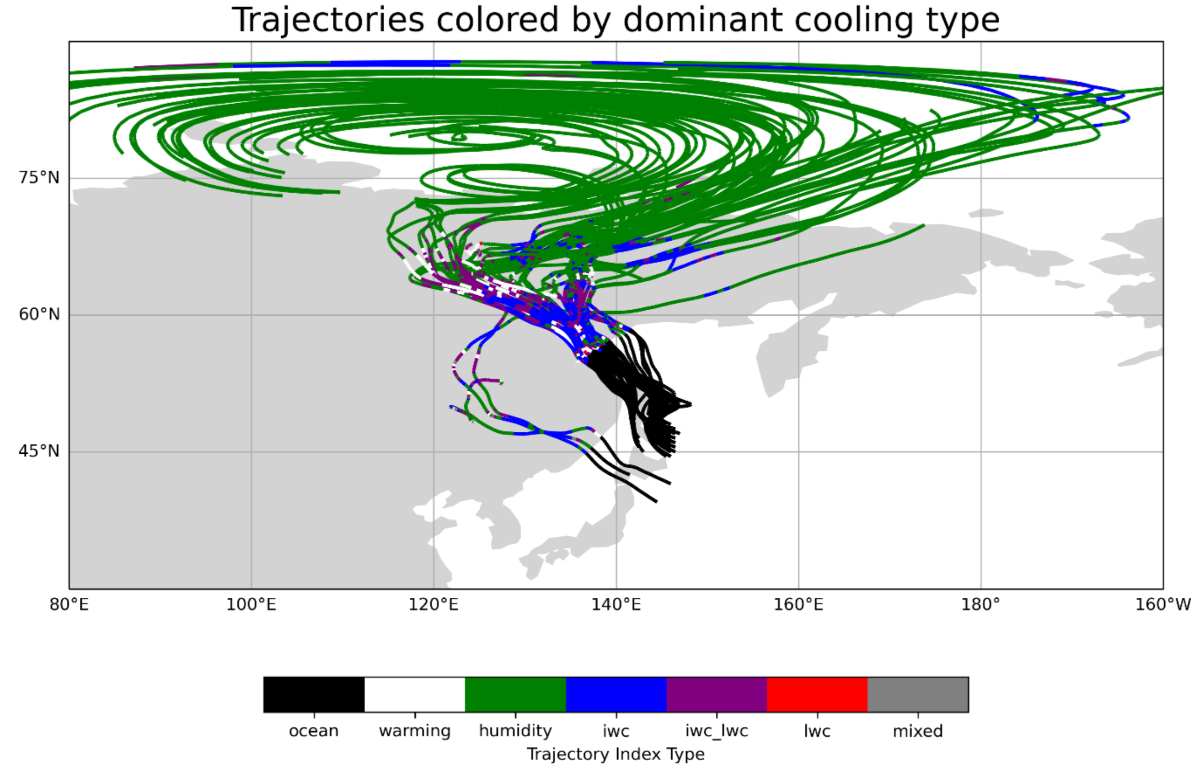

Fig. 5: A selection of 66 backward trajectories originating from the cold air outbreak of the 24th of January 2023 over the northern Japan sea, colored according to the variable that was responsible for the largest portion of diabatic cooling at each location. Figure by Jesse Connelly.

WP4: Moisture sources of warm conveyor belts (Rémi Bouffet-Klein, Franco Lee, Dr. Hanna Joos, Dr. Michael Sprenger)

We used our special version of the IFS model (Cy47R3) to perform a simulation of a warm conveyor belt (WCB) that occurred in February 2022 in the North Atlantic. All moisture tendencies from the parameterized physics, including moisture tendencies from turbulence, convection and the large-scale cloud scheme are output hourly and traced along trajectories that feed into the WCB. The WCB is represented by trajectories that ascend at least 600 hPa in 48 hours. From the WCB inflow, the WCB trajectories are extended five days backward in time in order to investigate which processes contribute to the moistening of the WCB inflow (Fig. 6, left). The trajectories, coloured by specific humidity (q) originate from a large area over the North America continent, exhibiting different values of q. In Fig. 6, right, the accumulated moisture tendencies along all backward trajectories are shown as a mean over all trajectories, separately for each process. Turbulent (red line) and convective moisture tendencies (blue line) show the largest values whereas they are strongly cancelling each other. Furthermore, evaporation of clouds (cyan line) substantially contributes to the moistening of the WCB inflow whereas evaporation of rain (grey line) and sublimation of snow (pink line) has on average, only small contributions. In the coming months we will first analyse the moisture sources of the presented case study in more detail and extend the project by simulating additional case studies of WCBs that ascend in different regions of the world and in different seasons.

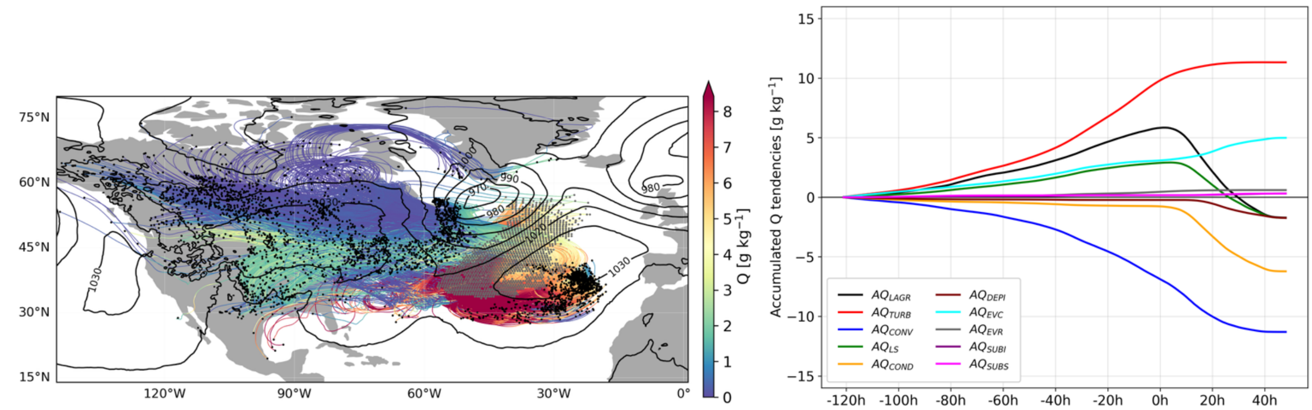

Fig. 5: (left) Specific humidity q along the 5-day backward trajectories for a WCB starting at 18 UTC on 24 February 2022. The black dots are the positions of the air parcels at -5 days, the grey dots are the positions of the air parcels at the start of the WCB ascent. The SLP corresponds to the start of the ascent. (right) Time-evolution of the accumulated moisture tendencies as a mean over all trajectories. The coloured lines denote the tendencies from all processes (black), turbulence (red), convection (blue), the large-scale cloud scheme (green), condensation (yellow), depositional growth of ice (brown), evaporation of clouds (cyan), evaporation of rain (grey), sublimation of ice (purple) and sublimation of snow (pink).