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	2021……………………………………………
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)	-	-	1 000 000	0
Data storage capacity	(Gbytes)	-	-	20 000	0

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 will use these tendencies in order to increase our knowledge about the hydrological cycle in different regions of the world as well as to improve our understanding of their interaction with the atmospheric circulation by modifying the potential vorticity in the tropopause region, in warm conveyor belts and in Mediterranean cyclones.

Summary of problems encountered (10 lines max)

No problems encountered.

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

In September 2021 we will start with the investigation of the hydrological cycle in an extratropical cyclone in the framework of a MSc project. The comparison of diabatic heating and potential vorticity rates in the IFS and ICON model will be continued based on a case study of a warm conveyor belt. For this WP technical preparatory work has almost been completed which will enable this model inter-comparison (see first results below).
A detailed case study on an event of clear air turbulence (CAT) over Iran and near tropopause altitude will be done in the second half of 2021. Aircraft recordings (eddy-dissipation rate, EDR) in a commercial SWISS plane indicate that the severe CAT event is associated with negative potential vorticity (PV), whose origin will be studied with the dedicated IFS simulations. Further simulations, with focus on CAT and implications for stratosphere-troposphere exchange, are planned for 2022.

List of publications/reports from the project with complete references

Sara Mueller: Diabatic processes associated with an extratropical dry intrusion reaching into the western North Atlantic trade-wind region, MSc thesis ETH Zurich, 2021

Summary of results

1) Extratropical dry intrusions into the North Atlantic trades (Dr. Franziska Aemisegger, Leonie Villiger, Dr. Maxi Boettcher)

An IFS simulation with heating rate output has been performed for an extratropical dry intrusion (EDI) reaching the Caribbean at the end of January 2018 (Fig. 1a). The case has been studied extensively in a Master Thesis (Mueller, 2021). The three aims of this research are to (1) analyse the heat budget along a North Atlantic EDI during its descent, (2) quantify the impact of boundary layer clouds on the EDI's heat budget and outflow, and (3) study the interaction of the EDI with the cold front and its impact on the cold front's southward propagation.

Intrusions of dry upper-level extratropical air into the tropics play an important role in shaping the synoptic time-scale variability of the low-level cloud cover over the subtropical and tropical oceans. In this WP, we have performed a detailed Lagrangian analysis of an EDI in the western North Atlantic, which occurred in January-February 2018. During this period, the easterly trade winds were interrupted for several days by coherent packages of rapidly descending air parcels reaching from the mid-latitude jet stream region into the sub-cloud layer in the trades (Fig 1a). As those air parcels are anomalously dry and cold, they have a notable impact on diabatic processes in the vicinity of the trade-wind cloud tops such as longwave cooling and cloud evaporation and sublimation (Fig 1b-d). To quantify the Lagrangian heat budget along the EDI, we performed a simulation with the Integrated Forecasting System (IFS, 0.4° horizontal resolution, 137 vertical levels) with diabatic heating rate (DHR) output. We calculated back-trajectories based on hourly three-dimensional wind fields and analysed the DHR along the EDI air parcels.

In the first part of their descent from the mid-tropospheric jet stream region, the EDI air parcels' heat budget is dominated by adiabatic warming of about 1 K h^{-1}. In the second part of their descent, they experience strong diabatic cooling at cloud tops (net cooling of about -0.8 K h^{-1}), due to radiative (-0.5 K h^{-1}) and microphysical processes (-0.3 K h^{-1}) and to a lesser extend due to turbulent cooling (-0.05 K h^{-1}). This leads to cross-isentropic flow, which allows these air parcels to pass through the inversion and to penetrate into the boundary layer. Thereafter, the EDI air parcels experience strong diabatic warming by turbulent fluxes and shallow convection (by +0.2 to +0.5 Kh^{-1}) in the lower part of the boundary layer. A net heating rate dipole is therefore experienced by EDI trajectories upon penetration into the boundary layer, with much larger prior cooling in regions with large cloud fractions (-0.7 K h^{-1}, Fig. 1b,c) than in regions with more scattered boundary layer clouds (-0.1 K h^{-1}, Fig. 1d). The rapid diabatic warming in the boundary layer leads to a strong modification of the vertical structure of the cold front and to an erosion of the cold and dry anomaly in the lower free troposphere behind the southward propagating cold front.

In summary, this detailed EDI case study illustrates how the rapidly subsiding EDI air interacts with the parametrised subgrid-scale processes at cloud top in the model, thereby affecting the thermodynamic conditions in the boundary layer and impacting the southward propagation of the cold front.

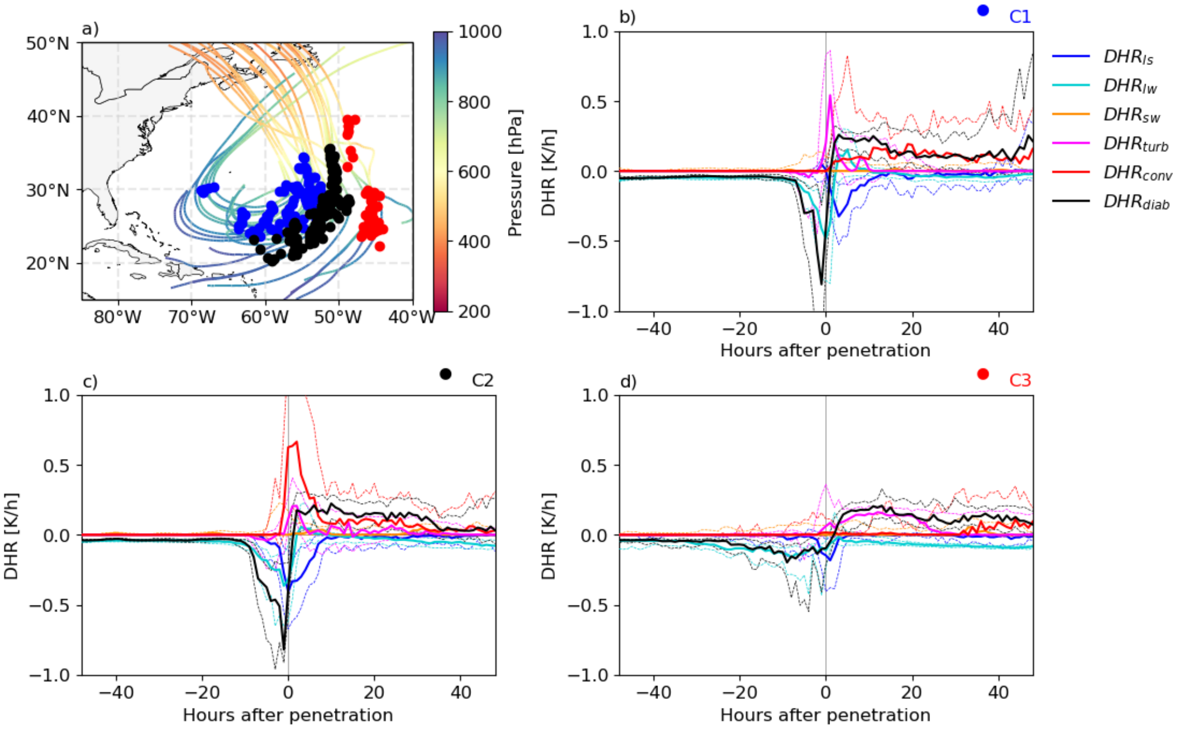

Fig. 1: Diabatic heating rates along three sub-airstreams belonging to a North Atlantic EDI intruding into the trades (28 January-31 January 2018). (a) Overview of EDI trajectories belonging to the three selected sub-airstreams C1 (blue), C2 (black), and C3 (red). The dots indicate the time at which the EDI trajectories penetrate into the boundary layer. (b-c) Time evolution of diabatic heating rates from different physical processes in the model centered at the time of penetration into the boundary layer where DHR denotes the diabatic heating rates due to the large-scale cloud scheme (ls), longwave radiation (lw), shortwave radiation (sw), turbulence (turb), convection (conv) and the total DHR (diab).

2) Diabatic heating and PV rates in a warm conveyor belt in the ICON and IFS model (Dr. Annika Oertel)

For the inter-model comparison (IFS vs. ICON) of heating and PV rates from individual microphysical processes in WCBs, we first set up global ICON simulations with a horizontal resolution of R3B07 (approx. 13 km) for the selected WCB case study in October 2016. Further, 3D microphysical heating and PV rates were implemented in the ICON code, similarly to heating and PV rates in our special IFS version.

A preliminary analysis of the ICON simulation shows a large number of WCB trajectories ascending from the lower into the upper troposphere for the selected case study, thereby forming the characteristic extended cloud band in the extratropical cyclone’s warm sector (Fig. 2). During the slantwise WCB ascent, phase changes associated with the formation of liquid, mixed-phase and ice clouds (Fig. 3a) substantially heat the airstream allowing for a cross-isentropic ascent of more than 25 K (Fig. 3b, black line). A discrimination between fast and slow WCB ascent shows larger maximum hydrometeor contents for fast ascent originating in particular from increased and more sudden condensation and vapour deposition (Fig. 3b), suggesting that diabatic heating from microphysical processes plays an important role for the detailed WCB ascent behaviour. Despite the large total net heating of 25 K, the WCB trajectories also experience cooling, primarily from rain evaporation and melting of falling hydrometeors in the beginning of the ascent in the lower troposphere (Fig. 3b). These preliminary results from the ICON model confirm the important role of individual microphysical processes for determining the isentropic outflow level of the WCB.

To compare the impact of different representations of microphysical processes in ICON and the IFS on the WCB ascent behavior and the upper-level PV structure, the same case study will be simulated with the IFS with a comparable setup using a resolution of TCo1279 with the special version that allows the additional output of all 3D temperature tendencies. The simulation of the presented case study is planned for July/August 2021. Further simulations of additional case studies will follow later.

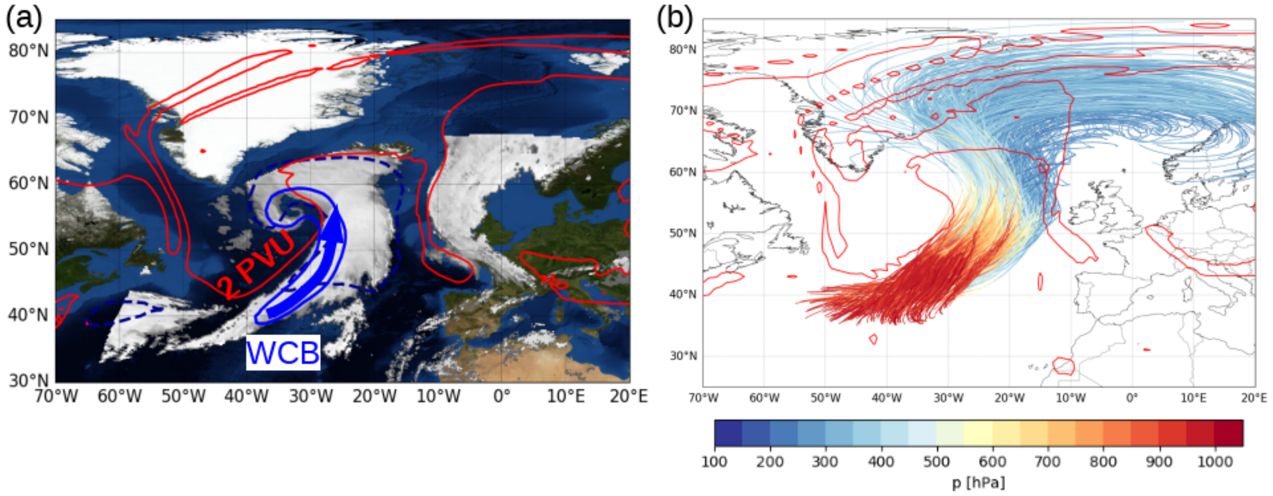

Fig. 2: (a) Satellite cloud top pressure (MSG-3 SEVIRI) of the WCB cloud band in October 2016 and (b) WCB trajectories calculated from 3D ICON output coloured according to pressure. The red line shows 2 PVU at 320 K from (a) ERA-5 reanalysis and (b) the ICON simulation.

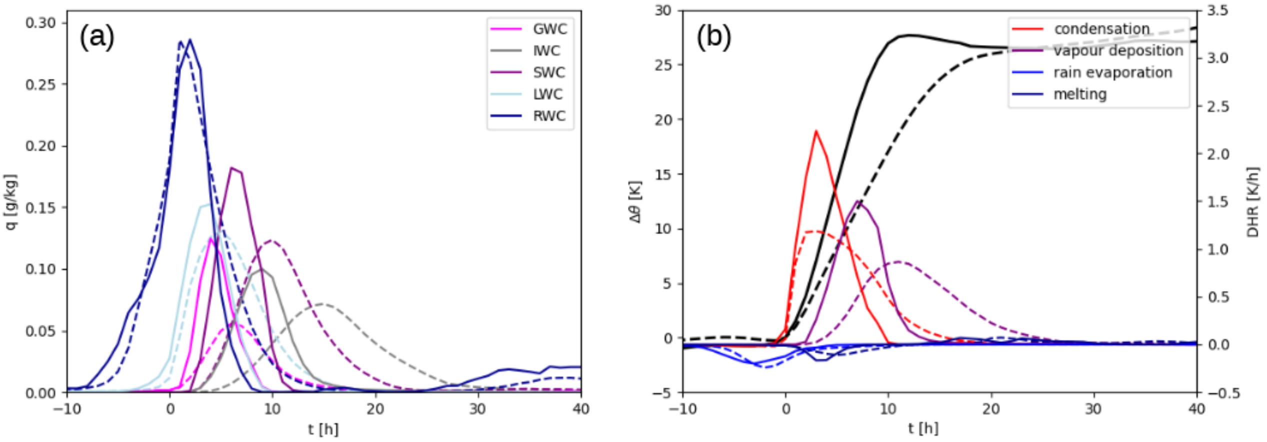

Fig. 3: (a) Rain (RWC), cloud liquid (LWC), ice (IWC), graupel (GWC), and snow (SWC) water content along selected fast (solid) and slowly (dashed) ascending WCB trajectories (in g/kg). (b) Total diabatic heating ($\Delta\theta$, in K, black lines) and diabatic heating rates (DHR, in K/h) for selected microphysical processes for fast (solid) and slowly (dashed) ascending WCB trajectories.

3) 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 trajectories (calculated using LAGRANTO) to (i) determine the most dominant diabatic process in the Mediterranean shaping 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 3 shows results obtained in step (ii), where the PV modification accumulated along trajectories is shown for one particular cyclone. We find the dominant process inside the cyclone to be the temperature tendencies by convection (orange). This particular cyclone is a self-driven one, as most of the PV modification occurs within the cyclone (solid lines).

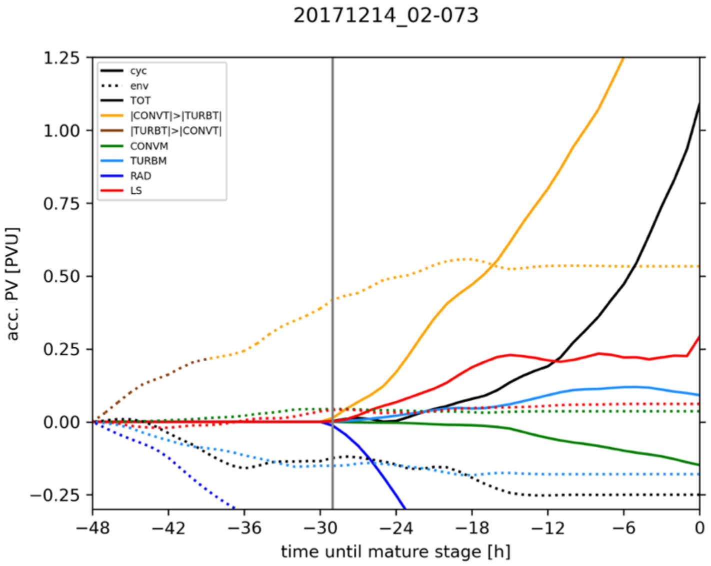

Fig. 4: Time evolution of total (black) accumulated PV and accumulated PV modified by individual diabatic processes (see legend) for one particular cyclone. Solid lines indicate PV modifications within and the dotted outside the cyclone. The grey line marks the first track point of the cyclone.