REQUEST FOR A SPECIAL PROJECT 2025–2027

MEMBER STATE:	Greece
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Project Title:	Mapping the continuum of cyclone dynamics in the phase space of diabatic and baroclinic forcing

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** …………..	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2025	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for project year:		**2025**	**2026**	**2027**
High Performance Computing Facility	[SBU]	8,000,000	12,000,000	
Accumulated data storage (total archive volume)[2]	[GB]	25,000	50,000	

EWC resources required for project year:		**2025**	**2026**	**2027**
Number of vCPUs	[#]	35	35	
Total memory	[GB]	350	350	
Storage	[GB]	25,000	25,000	
Number of vGPUs[3]	[#]			

Continue overleaf.

[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.

Principal Investigator: Emmanouil Flaounas

Project Title: Mapping the yet uncharted continuum of cyclone dynamics in the phase space of diabatic and baroclinic forcing

Extended abstract

All Special Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF and its Scientific Advisory Committee. The requests are evaluated based on their scientific and technical quality, and the justification of the resources requested. Previous Special Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

Requests exceeding 10,000,000 SBU should be more detailed (3-5 pages).

Cyclone systems are long known to produce most of high-impact weather (HIW) in the world (e.g Leckebusch and Ulbrich, 2004; Hawcroft et al., 2018). Despite their catastrophic nature and the ongoing scientific progress (Emanuel 2018; Schultz et al. 2019), the understanding of cyclones' development is still challenged by the involved complex physical processes. As a result, high uncertainty is found when forecasting imminent HIW relevant to cyclones, but also when predicting climate variability and its extremes (Shaw et al., 2016; Catto et al., 2019). In fact, understanding the processes that develop cyclones into catastrophic storms are yet uncharted.

There is a theoretical continuum between tropical cyclones (TC) and Extratropical cyclones (ETC) which connects purely diabatically and purely baroclinically driven systems. Nevertheless, this theoretical continuum has not been demonstrated in detail and it is yet unclear whether baroclinic and diabatic forcings to cyclones development is balanced or biased towards one end of the continuum for specific groups of ETCs. While it is common knowledge that convection and baroclinic forcing are the main processes characterising the two ends of this continuum, the leading processes implicated within the whole range of cyclones is still an open question. Therefore, this project aims to perform a dedicated modelling analysis that replies to this fundamental gap in atmospheric dynamics.

Our analysis will be performed on the basis of potential vorticity (PV) tracers. In the last decades, piecewise PV inversion (PPVI; Davis Emanuel et al. 1991; Davis, 1992) has been recognised as an excellent diagnostic for defining the atmospheric state that is relevant to specific partitions of PV (e.g. McTaggart-Cowan et al. 2001; Ahmadi-Givi et al. 2004; Zhang and Kieu, 2006; Riemer and Jones, 2010). For instance, one may invert only the PV in the upper troposphere to obtain its impact on cyclonic circulation in the lower troposphere (Davis Emanuel et al. 1991). Therefore, one may quantify the contribution of baroclinic processes to cyclones development. Similarly, PPVI of diabatic PV-tracer is an adequate method to obtain insights into the contribution of diabatic processes to cyclones development (Stoelinga,1996; Flaounas et al. 2021a). Using PPVI, we aim to quantify the relative contribution of (1) convection, (2) temperature diffusion and (3) radiation to the development of the cyclones as defined by the relative vorticity at 850 hPa. This provides the means to perform a process-based classification of cyclones and consequently to fill a fundamental research gap in the field of cyclone dynamics: The yet uncharted theoretical continuum between "purely" diabatic (e.g., tropical cyclones) and "purely" baroclinic (e.g., "dry" extratropical cyclones) cyclones.

In Flaounas et al. (2021) they used PV-tracers to analyse the dynamical structure of 100 simulated cyclones with the WRF model. Results were meaningful, compared well with previous studies (e.g., Chagnon et al. 2013) and the residual of the PV-budget (when comparing the sum of all PV-tracers to total atmospheric PV) has been found to be fairly small in all simulations (of the order of 0.2 PVU). In this project we aim to follow a similar methodology. However, to to define cyclones processes continuum through PPVI, we need a large dataset of cyclones. For this reason in this project we will use the Weather Research and Forecasting atmospheric model (WRF; Skamarock et al. 2008). It has been originally developed as a limited-area model and is now used by several weather services for operational NWP (Powers et al. 2017). Taking a high number of cyclone tracks from ERA5 reanalysis (Hersbach et al. 2020), a two-domain simulation will performed for each track of cyclones already tracked in ERA5. A parent domain tightly encompasses the track and a nested square domain of 4,000 km per side always follows the cyclone centre (Gopalakrishnan et al. 2006). The nested domain size is adequate to include the whole cyclone dynamical characteristics such as TC convective eyewalls, fronts and associated airstreams. As an example of scales, Fig. 1 shows a composite of key characteristics of ETCs.

The simulations' initial conditions are starting 3 hours prior to the time of the first track point and finish at the time of the last track point. The ERA5 cyclone tracks are already available using an updated cyclone tracking method by Flaounas et al. (2014). This method has been assessed in several studies of the IMILAST cyclone-tracks intercomparison project (e.g., Pinto et al. 2016) and has been extensively used in the context of Mediterranean and other ETCs (e.g., Flaounas et al. 2014, 2015, 2018b; Galanaki et al. 2016; Lin et al. 2019; Malakar et al. 2020). The parent and nested domains use horizontal resolutions of 30 and 10 km, respectively. The latter is consistent with near future capabilities of EPSs, forming a nested domain of about 400x400 grid points and about 71 vertical levels. The wind field in the parent domain is strongly nudged by ERA5 to assure that the cyclone has consistent track and life stages with ERA5. However, the fairly tight nested domain for meso-scale systems is not nudged and thus allows the model to freely resolve important fine scale processes. WRF is thus forced to reproduce similar cyclones to ERA5 (in terms of tracks and life-stages) and is considered to resolve cyclone dynamics with "optimal skill" and "zero model errors" in the large-scale flow.

Our purpose is to perform ~500 simulations for the Euro Atlantic domain. This will provide a meaningful continuum of cyclones, where we aim to identify cyclones of different categories as the ones emerging from purely diabatic or mixed/pure baroclinic processes. Classification of cyclones will focus on different stages of cyclones development to reply to questions about the change of dominant processes while the systems intensify or when they transition e.g. while a cyclone undergoes tropical or extratropical transitions. This will provide an important contribution to vividly debated issues in the field of cyclone dynamics. For instance, what is the palette of driving processes for the development of ETCs? How common is tropical transition in the mid-latitudes? In another example, it was recently shown that frictional forces occasionally have a counter-intuitive, positive and dominant role in cyclones development (Flaounas et al., 2021b). An ECMWF special project is an adequate framework to generate the datasets that allow us to look into these questions.

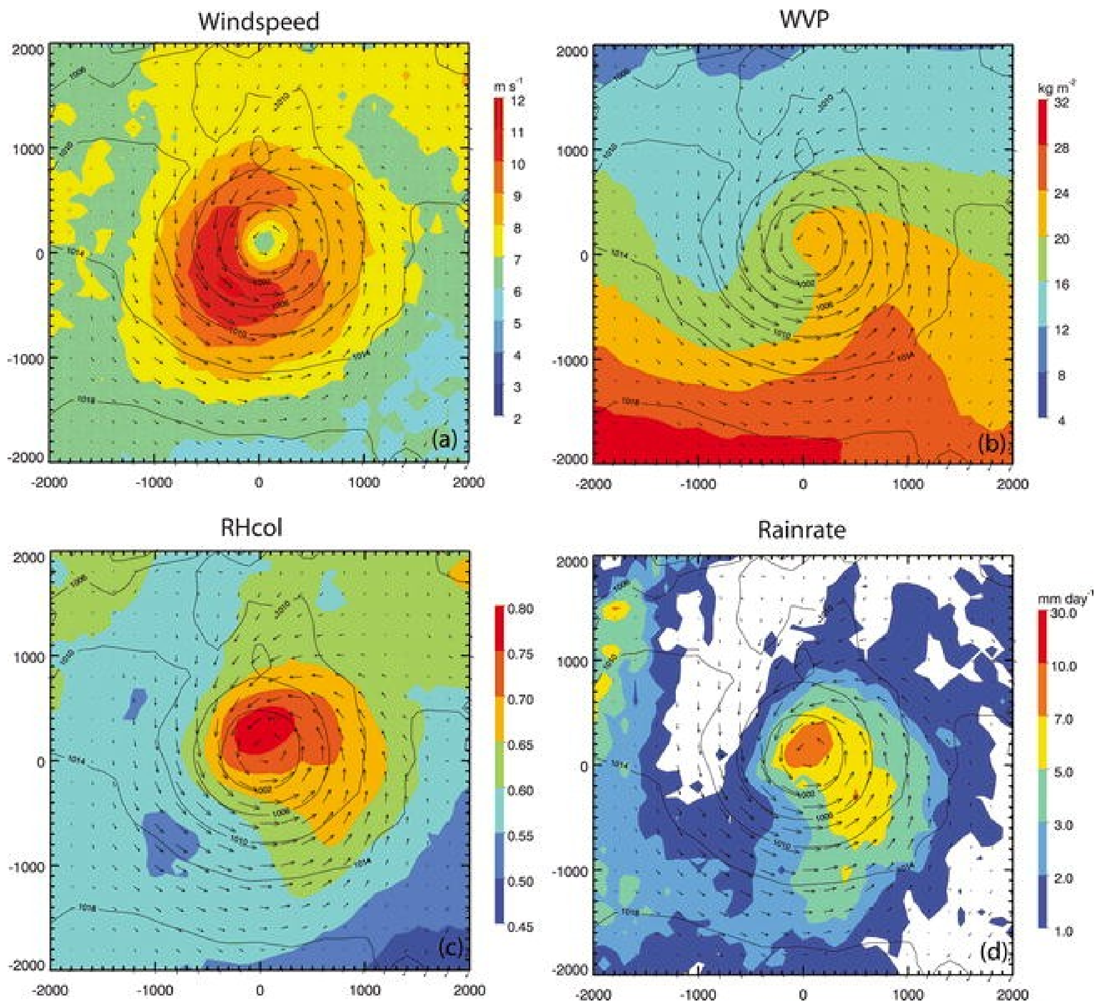

Fig. 1 North Atlantic composite mean fields from ~400 individual cyclones. The mean field mean sea level pressure and surface wind vectors are overplotted in each diagram. The filled contours represent (a) surface wind speed, (b) water vapor path, (c) column relative humidity and (d) rain rate (from Field and Wood, 2007).

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