REQUEST FOR A SPECIAL PROJECT 2024–2026

MEMBER STATE: ITALY……………………………………..….

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Other researchers: ……Claudio Transerici (cmn)…………………………….…

… Rosa Claudia Torcasio (it85)…

Project Title: …Improvement on NWP prediction at the short-range for high impact meteorological events…………………………………….

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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.	**SPITFEDE**	
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]	20000000	20000000	20000000
Accumulated data storage (total archive volume)[2]	[GB]	100000	100000	100000

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

Project Title: ……………………………………………………………………

Extended abstract

1. Introduction

This project is a continuation of the special project SPITFEDE that we did at the ECMWF in the years 2021-2023, with the addition of new observations and methods. Indeed, the special project of 2021-2023 was focused on the lightning and radar reflectivity data assimilation and on its impact on the precipitation forecast at the short-term (up to 3h after the last assimilation) and we started to investigate the problem of the impact of lightning data assimilation on the lightning forecast as well as the assimilation of GNSS-ZTD data on the precipitation forecast. In the latter case the focus was up to the sixth forecast hour, while most of the studies were focused on the 0-3h forecast range.

This project is in continuation with the old project because it considers very similar physical problems and continues to investigate the impact of radar reflectivity, lightning and GNSS-ZTD on the precipitation and, more in general, on the meteorological forecast, nevertheless a new and large data assimilation experiment, using pseudo observations of the WInd VElocity Radar Nephoscope (Wivern) project, will be performed.

In this project we will use the WRF model (version 4.1 or higher) and the WRFDA package to assimilate observations into the WRF model. By far the 3D-Var approach will be used. A second data assimilation package (Federico, 2013), recently adapted to the WRF model, will be used during the project. This is a home made 3D-Var data assimilation software that was firstly developed in the framework of ECMWF special projects and then was adapted to the WRF model. This package can ingest different data types including winds, lightning, GNSS-ZTD and radar reflectivity.

In previous projects at the ECMWF we focused on the 0-3h forecast range after the last analysis time. In this project we will also focus on the 3-6h forecast range starting to explore the added value of data assimilation at the local scale for longer forecast ranges compared to previous projects.

Finally, the estimation of the SBU for simulations discussed below are obtained on the ATOS supercomputer using 256 or 512 computing cores. Hereafter, we give details about the activities and numerical experiments to be performed in this project. It is important to note that the estimation of the computational resources is made considering the whole project duration (3 years). If the support is given for less than this period, the experiments will be reduced accordingly.

2. Continuation with the previous project

The Mediterranean basin is one of the world's most exposed regions to hydro-meteorological hazards (Llasat et al., 2013). The very complex terrain of the territory, characterized by high mountains close to the coastlines, can enhance or trigger deep atmospheric convective phenomena that often originate over the sea (Ducroq et al., 2014). Despite the relatively good prediction of the large-scale conditions favouring convective event development, heavy convective rain events are usually associated with low forecast probabilities in numerical weather prediction (NWP) models due to the high spatial-temporal variability of precipitation and uncertainties in convective initiation. The study of forecast of severe weather events and deep convective events will be pursued in this project.

Several works made by the authors of this project (see the reports of the SPITFEDE project 2021-2023) showed that lightning and radar reflectivity data assimilation is a very useful tool to improve the precipitation forecast of deep convective events at the short-range (0-3h). In addition, an operational setting of the WRF model at 3km horizontal resolution over Italy, assimilating both lightning and radar reflectivity of the Italian radar network composite was implemented in the last year. The exercise of this operational forecast confirmed that data assimilation has a positive and notable impact on the precipitation forecast at the short-range over Italy (0-3h). This forecast can be useful in case of adverse weather conditions, related to fast developing and deep convection, to take immediate actions.

In this project we will continue the study of the impact of lightning and radar reflectivity data assimilation on the short-term rainfall forecast focusing on specific case studies as well as on the exercise of the operational

forecast. While the operation forecast is conducted in the computational framework of the CNR-ISAC in Rome, ten case studies will be considered in this project to have a good dataset to assess the following points: a) the impact of each data source on the precipitation forecast; b) the potential of suppressing spurious convection through lightning data assimilation; c) the impact of lightning and radar reflectivity data assimilation for longer time ranges (3-6h). The horizontal resolution of these simulation is 2-3km, depending on the case, while initial and boundary conditions will be provided by the ECMWF-IFS forecasting system. The approach is the VSF (Very Short Term forecast) at 6h in which a 6h data assimilation phase is followed by a 6h forecast. With this approach, to perform the forecast for a whole day four simulations are needed.
Past experience with the ECMWF computing environment shows that the forecast of one day requires about 100.000 SBU at 2 km horizontal resolution. Considering 10 cases and the fact that each case study must be simulated with at the least 5 different configurations (radar reflectivity data assimilation only, lightning data assimilation only, assimilation of both data sources, suppression of spurious convection through lightning data assimilation, control forecast) about 5-7 million SBU are required for this activity during the three years. It is finally noted that, during this project, the Meteosat Third Generation (MTG) data will be available, and in particular the dataset of the lightning imager (LI). Because of the long experience of the participants to this project on lightning data assimilation, experiments with the assimilation of the MTG-LI data will be performed for some cases.
It should be mentioned that we are currently running a numerical experiment whose aim is to quantify the impact of lightning data assimilation on lightning forecast over Italy. This experiment is rather ambitions because it runs the WRF model at 3km horizontal resolution for a period of 6 month in two different configurations, i.e. with or without lightning data assimilation. The approach is the very short-term forecast at 6h and the model output is saved every 3h to assess the impact of LDA on lightning forecast for the periods 0-3h and 3-6h after the assimilation phase of 6h. With this approach four 12h simulations are needed to run a whole day and, because a period of 6 months is required for each configuration, two years of simulations are required. We asked for additional SBU during the project SPITFEDE this year, to finish the experiment. If these SBU will not be available this year, part of this experiment will be done in the framework of this project.

3. *Assimilation of winds*

In this project, we will consider the assimilation of winds in the framework of the Wivern project (Illingworth, 2018). Wivern will use a Polarimetric Doppler radar at 94 GHz with a conic scan, the first of this type (see Fig. 1) for the observation of the winds inside the clouds following a cycloid pattern. For the first time we will assimilate the pseudo observations of Wivern in an ensemble context, to better quantify the impact of winds data assimilation for a case study. The case study is the Medicane Ianos, occurred between 16 and 19 September 2020 over the Southern Mediterranean Sea. The basic idea for testing the impact of Wivern winds data assimilation is the following: we run an ensemble of 51 members at 2km horizontal resolution for the event. From these run we select a member that has the best agreement with the ECMWF analysis (we will use the ERA5 dataset to define the best track of the Medicane Ianos). Then we do a high horizontal simulation (500 m) of the Medicane Ianos for this best member and, through a Wivern simulator, we generate pseudo-observations of Wivern. These pseudo-observations will be assimilated in all the 50 remaining member of the ensemble at 2km horizontal resolution and finally the impact of the Wivern pseudo observations data assimilation will be quantified. Few sensitivity tests will be considered for the following problems: sensitivity to the background error matrix, and quantification of the impact of winds data assimilation for different temporal ranges. The 3D-Var of Federico (2013) will be used in this experiment. All these simulations, however, will be done in an ensemble framework, requiring large computational resources.

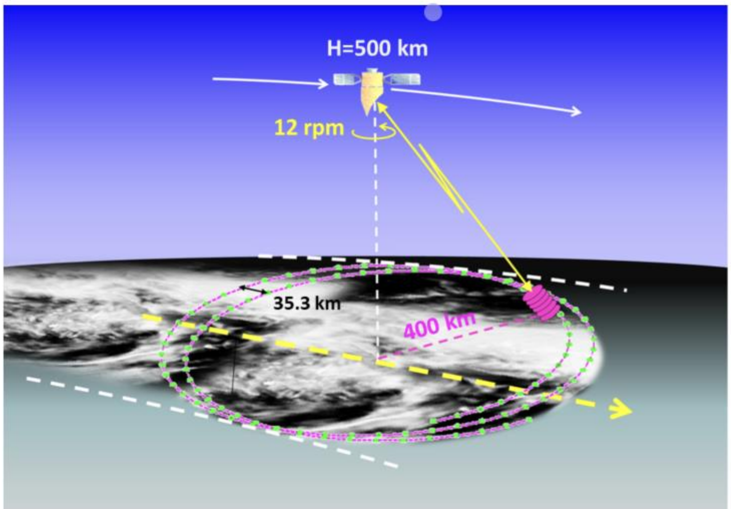

Figure 1: Artistic impression of Wivern. The doppler radar at 94GHz uses a conic scan at 42° with 12 cycles per minute, leaving a cycloid at the surface. From Battaglia et al., 2022.

Most of the simulations will have a 2km horizontal resolution, with some specific simulation at 500 m. The simulation with 2 km horizontal resolution will cover the central Mediterranean Sea. The domain size is about 1600 km and 800*800 grid points are required to cover the domain; in addition, to cover the whole period of the Medicane Ianos, each simulation will last 60 hours. Each simulations uses about 150.000 SBU and because we must run an entire ensemble of 51 members about 7.5 million of SBU are required to run the whole ensemble. Now, at least 2 runs of the whole ensemble must be done, one with winds data assimilation and the other for the control run, without data assimilation and the request is about 15 million of SBU at least. In addition, sensitivity tests will be considered to study the dependence of the results on the background error matrix, requiring additional two run of the ensemble. In this way the requests goes to more than 30 million SBU for this experiment. Another point considered in this project is to quantify the impact of wind data assimilation on the Medicane Ianos simulation for different temporal ranges.

4. *Assimilation of GNSS-ZTD*

There is evidence that at midlatitudes the spatial distribution of the water vapor field can be correlated to the development of convective rainfall (Shoji, 2013). Experimental GNSS (Global Navigation Satellite Systems) networks designed for meteorological applications have been deployed to study the local variability of water vapor distribution in the atmosphere (Sato et al., 2013).
We started to investigate this problem in a recent work (Torcasio et al., 2023). In this work we compared two sets of simulations, one without GNSS-ZTD data assimilation and the other without GNSS-ZTD data assimilation for the month of October 2019, characterized by several heavy rainfall events in the northwest of Italy.
Results are promising because they show that both the integrated water vapour and the precipitation forecasts are improved by GNSS-ZTD data assimilation. Specifically, while the impact of GNSS-ZTD decreases with forecasting time, the precipitation forecast is improved at least up to 6h from the last data assimilation time. In addition, results show that the improvement of the precipitation forecast is statistically robust up to the 30mm/3h threshold, which is rather intense.
In this project we will continue the study of GNSS-ZTD data assimilation to explore better its impact on the precipitation forecast of moderate to intense convective events at the local scale. Indeed, despite the large use of GNSS-ZTD data assimilation around the world, their usage is still limited over Italy and additional works assimilating GNSS-ZTD are necessary to better understand and quantify the impact of GNSS-ZTD on the precipitation and, more in general, on the weather forecast. In this project the research goes in different directions: a) assessing more in detail the impact of GNSS-ZTD for intense convective events and comparison with other data assimilation experiments (for example the comparison with data assimilation experiments with different datasets as those discussed in Section 2); b) the impact of data thinning; c) the impact of the

bias removal on the model performance in an operational environment.
About ten millions of SBU will be dedicated to this activity. Likely, not all the experiments outlined above will be considered in this project, nevertheless we hope to reach a good maturity level for GNSS-ZTD data assimilation.

Computing resources requested

The computational resources requested for this project (60.000.000 over the three years) are based on past research done in the SPITFEDE project on the Atos computing facility. Not all the computations described above can be afforded in this special project and some of the experiments will be performed in our computational facility in Rome. For example, the operational weather forecast using both lightning and radar reflectivity data assimilation will be continued in our computational facility and will be supported by this special projects for some case studies.

References

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