<u>LATE</u> REQUEST FOR A SPECIAL PROJECT 2020–2022

MEMBER STATE: Italy

Principal Investigator[1]**:** Vincenzo Mazzarella

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Project Title: Investigating the impact of 3-hourly cycling 3D-VAR with GNSS measurements in Weather Research and Forecasting (WRF) model

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.)	2020	
Would you accept support for 1 year only, if necessary?	YES ☐	NO ☒

Computer resources required for the years: (To make changes to an existing project please submit an amended version of the original form.)		**2020**	**2021**	**2022**
High Performance Computing Facility	(SBU)		950000	950000
Accumulated data storage (total archive volume)[2]	(GB)		1000	1000

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 an annual progress report of the project's activities, etc.

[2] 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.

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Extended abstract

The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

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.

Requests asking for 1,000,000 SBUs or more should be more detailed (3-5 pages).

Following submission by the relevant Member State the Special Project requests the evaluation will be based on the following criteria: Relevance to ECMWF's objectives, scientific and technical quality, disciplinary relevance, and 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.

All accepted project requests will be published on the ECMWF website.

Motivation

The rainfall forecast is still a challenge in region with very complex orography such Italy, characterized by the presence of two mountains chains (Apennines and Alps) with steep and densely urbanized catchments near the sea. In spite of the progress made in Numerical Weather Prediction (NWP) and the development of more accurate parameterization of physical process, predict the exact timing and localization of convective events is still a challenge. About 70% of Italian territory is exposed to landslides and high flood risk and over 90% of Italian municipality are susceptible to floods. The only floods caused 430 deaths and over 19000 million of Euro of damages (Llasat et al., 2010) in the period 1990-2006 alone. In addition, the Mediterranean basin has identified as hotspot for climatic change (Giorgi, 2006). The rise of temperature, expected in the next future, as well as the larger availability of water vapour will lead to an increase in extreme precipitation events in the next years. The precipitation forecast is heavily dependent on the initial conditions because of high spatial and temporal variability and its nonlinearity. Sligh difference in initial conditions can produce significant variations in precipitation forecasts. In this context, the data assimilation techniques, which aim to determine a best possible atmospheric state using observations and short-range forecasts, play a key role. Nowadays, the large availability of in situ and remote sensing measurements with high spatial and temporal resolution, provides a great number of observations that can be assimilated into the numerical models. The 3D-Var (Barker et al., 2004) and 4D-Var (Huang et al.,2009) variational methods, implemented in Weather Research and Forecasting (WRF) model, are now largely used in many forecast centres in USA, China as well as in Europe with positive impact in precipitation forecast (Smith et al, 2008; Wang et al., 2013). The assimilation of radar data, also in combination with conventional observations (SYNOP and TEMP), shows a positive impact in region with complex orography (Maiello et al., 2017; Lagasio et al., 2019; Mazzarella et al., 2020). The radar reflectivity and radial velocity improves the rainfall prediction also in terms of intensity and duration, ensuring a well balancing and physically consistent initial conditions (Choi et al, 2013; Xiao and Sun, 2007). In this context, the capabilities of the new GNSS (Global Navigation Satellite Systems) measurements in combination with the radar reflectivity will be investigated in a 3-hourly assimilation cycling using WRF 3D-Var. To this purpose the impact of GNSS Radio Occultation (RO), GNSS Zenith Total Delay (ZTD) and GNSS Precipitable Water Vapor (PW) will be evaluated for several convective events occurred in Italy. The WRF setup now used at CIMA foundation for operational purpose will be considered. The configuration consists of 3 domains in two-way nesting with a grid spacing of 22.5 km, 7.5 km, and 2.5 km respectively (Fig. 1).

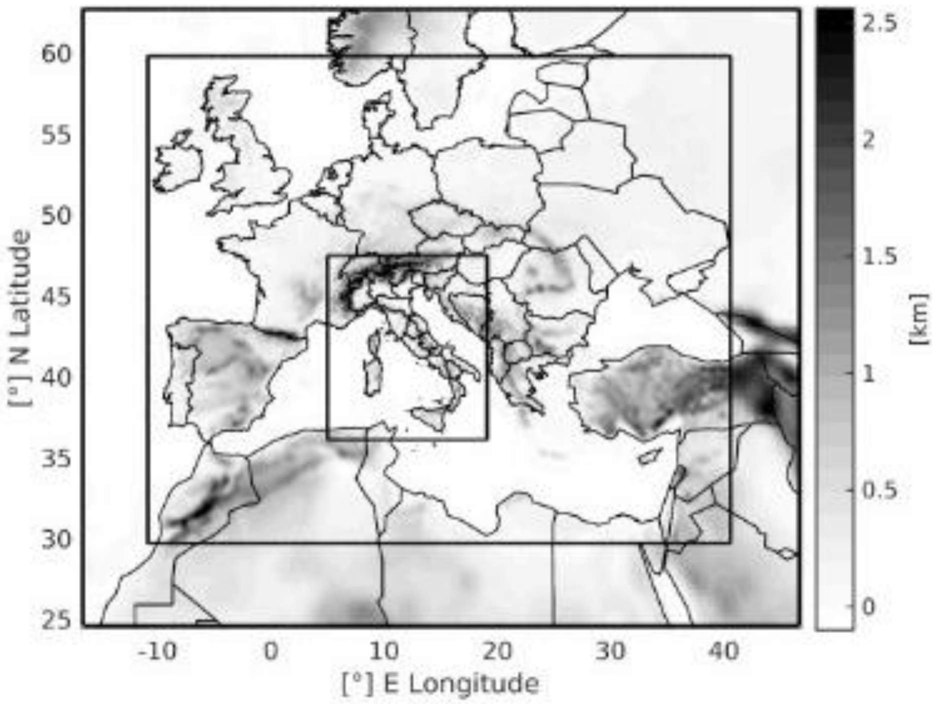

Figure 1: The three domains configuration for WRF simulations.

The performance of the different experiments will be evaluated in terms of Quantitative Precipitation Forecasts (QPF) adopting a spatial verification technique. This method identifies the spatial patterns (or objects) in observed/predicted precipitation fields and compare them through a few attributes, e.g., distance between centroid, area of intersection, orientation, that are calculated based on fuzzy logic. The statistical analyses will be performed with the Model Evaluation Tools (MET) verification package, developed by the National Center for Atmospheric Research (NCAR) Developmental Testbed Center (DTC). This special project aims to clarify the impact of the different type of GNSS measurements and to which extent this ingestion produces benefits in terms of the uncertainty in severe weather forecast.

Scientific plan

The scientific plan is organized as follows:

- Identify a number of severe convective events occurred in Italy
- Quality check to the radar reflectivity and GNSS data before to ingest them in WRFDA
- Perform a control simulation without data assimilation
- Perform 3 experiments with GNSS-RO, GNSS-PW and GNSS-ZTD in combination with radar data and a single experiment with radar data only.
- Evaluating the simulations in terms of QPF using MODE tool

Technical characteristics of the numerical codes

In the framework of this special project, we will use the following codes:

WRF model

The Advanced Research Weather Research and Forecasting (ARW-WRF) model in its version 4.0 will be used for this Special Project (Skamarock et al., 2019). WRF is a fully compressible non-hydrostatic mesoscale model, supported by National Center for Atmospheric Research (NCAR) and largely used by the atmospheric modelling community. The model uses terrain-following, hydrostatic-pressure vertical coordinate with the top of the model being a constant pressure surface, a staggered Arakawa-C grid, and a third order Runge-Kutta scheme as time integration scheme. The advantages of WRF are the possibility to run on single-processor, shared- and distributed-memory computers and the use of a highly portable and flexible code that optimizes the use of computational resources.

WRFDA

Weather Research and Forecasting (WRF) model data assimilation system (WRFDA; Barker et al., 2012) will be adopted for the 3D-Var cycling assimilation. The system is freely available for the scientific community and include the source codes for the two most common variational techniques, 3D-Var and 4D-Var respectively. WRFDA is portable and efficiently compiled on parallel computing platforms as well as it is suitable for a wide range of applications from global to mesoscale or regional scale. In addition, WRFDA supports the assimilation of different types of observations, from the conventional measures such as SYNOP, TEMP observations to the weather radar and satellite data.

MET-MODE

Model Evaluation Tools (MET, Brown et al., 2009) verification package will be used for the statistical analysis. The package is developed by the Developmental Testbed Center (DTC) through the generous support of the 557th Weather Wing of the United States Air Force, the National Oceanic and Atmospheric Administration (NOAA), and the National Center for Atmospheric Research (NCAR). MET provides a wide range of verification methods: conventional comparing point by point or gridded data, spatial object based and ensemble probabilistic methods. For this special project we adopt a spatial approach using the Method for Object-Based Diagnostic Evaluation (MODE) tool. The tool identifies a series of objects from the observed and predicted precipitation fields and compare them through several attributes (centroid distance, curvature, area etc.) based on a fuzzy logic.

Computational resources

With the aim to evaluate the impact of the assimilation of GNSS data we plan to perform at least 5 simulation, assimilating, GNSS-RO, GNSS-PW and GNSS-ZTD in combination with radar reflectivity and a control experiment without data assimilation. The cycling 3D-VAR will be applied on the three domains that consists of 216X191, 523x448 and 430x469 grid points respectively, and 50 vertical levels from the ground up to 50 hPa. The computation cost of each experiment is estimated to be 85,000 SBU. In order to achieve the proposed goals and considering at least two case study, we estimate a computational cost of about 1 MSBU for each year, considering a simulation period of 72h and the high spatial resolution of the inner domain (2.5 km). In addition, we estimate about 100,000 SBU for debugging purposes.

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