REQUEST FOR A SPECIAL PROJECT 2021–2023

MEMBER STATE: ……Italy…………………………..…

Principal Investigator[1]: ……Dr. Stefano Federico…(cm4)…………………….……

Affiliation: ……Institute of Atmospheric Sciences and Climate - Italian National Research Council …(ISAC-CNR)………………

Address: Via Del Fosso del Cavaliere 100, 00133 Rome

…………………………………………………………………….……

Other researchers: ……Claudio Transerici (account cmn); Dr. Rosa Claudia Torcasio (she will apply for an account this year).

…………………………………………………………………….……

Project Title: …Improvement of very-short term forecast using lightning and radar data assimilation…………………….……

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** SPITFEDE_	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2021	
Would you accept support for 1 year only, if necessary?	YES X	NO ☐

Computer resources required for 2021-2023: (To make changes to an existing project please submit an amended version of the original form.)		**2021**	**2022**	**2023**
High Performance Computing Facility	(SBU)	20,000,000	20,000,000	20,000,000
Accumulated data storage (total archive volume)[2]	(GB)	30 TB	35 TB	40 TB

Continue overleaf

1

This form is available at:
http://www.ecmwf.int/en/computing/access-computing-facilities/forms

Principal Investigator: ………Dr. Stefano Federico………………

Project Title: …… Improvement of very-short term forecast using lightning and radar data assimilation ………

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.

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF as well as the Scientific Advisory Committee. The evaluation of the requests is 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.

Requests asking for 1,000,000 SBUs or more should be more detailed (3-5 pages). Large requests asking for 10,000,000 SBUs or more might receive a detailed review by members of the Scientific Advisory Committee.

Abstract

Despite the continuous improvement of weather forecast, the correct prediction of heavy precipitation events is still challenging because of the multitude of scales and physical processes involved in these events (Stensrud et al., 2009). The improvement of numerical weather prediction depends, among others, on the improvement of initial conditions prescribed in numerical models. In the case of localized and heavy rainfall, initial conditions must be improved at the local scale too.

This project evaluates the impact of data assimilation on the short-term forecast (STF, here 3h - 12 h) over Italy at high spatial horizontal resolution (3 km).

Objectives

The general objective of the project is to evaluate the impact of data assimilation on the very-short term forecast over Italy, with emphasis on high precipitation events. This objective is vast and needs to be focused on specific goals that can be tackled in the framework of this special project.

For this project, the data assimilation is focused on lightning and radar reflectivity data, even if some additional data taken from SENTINEL satellites will be explored, while the verification is mainly on precipitation forecast. Some additional parameters, as surface winds, will be considered for verification.

Project description

This project is the continuation of two special projects at the ECMWF:

Years 2013-2014. Special project: "A general-purpose data assimilation and forecasting system"; Years 2017-2020. Special project: "Study of different configurations of the RAMS model for precipitation and lightning forecast over Italy at high horizontal resolution".

In the first special project, a 3D-Var data assimilation system was set-up for the RAMS@ISAC model (Regional Atmospheric Modelling System at the Institute of Atmospheric Sciences and Climate). RAMS@ISAC model is based on the RAMS 6.0 model, in a version with a certain number of modifications and improvements. First, the WSM6 (WRF single moment six species, Hong and Lim, 2006) microphysical scheme is implemented (Federico, 2016), then the model implements a method for predicting lightning (Federico et al., 2014), following Dahl et al. (2011). Furthermore, lightning data assimilation is implemented (Federico et al., 2017a), following the method of Fierro et al. (2012).

In the second special project, the lightning data assimilation method of Fierro et al. (2012) was implemented and evaluated for case studies (Federico et al., 2019) and longer time periods (Federico et al., 2017b).

Also, in the same special project, the method of Caumont et al. (2010) was implemented for radar reflectivity data assimilation.

The data assimilation method for lightning has shown a notable impact on the precipitation forecast. Nevertheless, there are still points that need to be addressed and that will be considered in this project.

a) In the current formulation of lightning data assimilation in the RAMS@ISAC model (a similar approach is used in WRF model that could be also used in the project), flashes are assimilated through pseudo-profiles of saturated mixing ratio between the 0°C and -25 °C isotherms where/when lightning are observed, because this is the layer where cloud electrification occurs. Recent studies (Fierro et al., 2019; Dixon et al. 2016) have suggested that using a lower height, in particular the Lifting Condensation Level (determined from model output) to assimilate pseudo profiles of water vapour where/when flashes are observed can improve the precipitation forecast because: a) the water vapour is adjusted in a deeper layer; b) assimilating for temperature higher than zero adds more water vapour to the analysis because the saturation water vapour increases exponentially with temperature. The impact of using LCL instead of 0°C to assimilate water vapour will be investigated thoroughly in this special project (experiment LCL, see next Section and Table 1 for the complete experiment list).

b) The main drawback of lightning data assimilation is the increase in false alarms, because lightning data assimilation schemes increase the water vapour. This problem has been highlighted for RAMS@ISAC model (Federico et al., 2017b). In this project a method to decrease the water vapour where/when the model simulates lightning that is not observed will be explored (experiment LCL-). This method will be based on the one used for radar reflectivity data assimilation (Caumont et al., 2010; Federico et al., 2019) in which, for each grid point where a lightning is simulated and not observed, the actual vertical water vapour profile is dried. This drying is done by averaging the water vapour profiles of the driest grid points around (<50 km) the actual profile and then substituting the actual profile with this average.

c) In 2021 the lightning imager will be launched on board MTG (Meteosat Third Generation) satellites and will open the possibility to have lightning data at good temporal rate, with spatial resolution compatible with the forecast used in this project. Satellite lightning data do not have problems related to complex orography, as occurs in ground-based lightning networks. Lightning data assimilation of GOES and FY4 observations has shown an important impact on precipitation forecast over US and China (Fierro et al., 2019; Chen et al., 2020). During the development of this project, the data of lightning imager onboard MTG will be available and will be used to assess their impact on the precipitation forecast (experiment LA_MTG).

Radar reflectivity data assimilation in RAMS@ISAC model has also shown a wet bias of the precipitation forecast when radar data are assimilated (Federico et al, 2019). However, this humid bias was determined using a case study approach and a robust quantification of this issue is missing. In this project this point will be explored in detail. In particular, during the first year of the project, the radar reflectivity data assimilation will be applied for a whole month to quantify more robustly the precipitation bias (experiment RAD); during the second year, two numerical experiments will be performed to study the sensitivity of radar data assimilation to two specific aspects:

a) The radar reflectivity data assimilation method implemented in RAMS@ISAC can subtract water vapour whenever reflectivity greater than zero is forecast but not observed. This option, however, needs further studies for an optimal setting. This will be done during the second year of the project in the simulations RAD- considering case studies and a whole month of simulations.
b) The radar reflectivity data assimilation method currently implemented in RAMS@ISAC adjusts the water vapour profile. In this project, the possibility to use radar reflectivity to adjust the hydrometeors will be tested in the second year (RADQ). The impact of this different approach on the rainfall forecast will be tested for a whole month of simulations.

To get information on the impact of lightning and radar reflectivity data assimilation, the above numerical experiments (LCL, LCL-, RAD-, RADQ) will be compared with the following experiments: CTRL, without lightning and radar reflectivity data assimilation, LIGHT, with reference lightning data assimilation, RAD, with reference radar reflectivity data assimilation, RADLI with both reference lighting and radar reflectivity data assimilation.

The lightning "**reference**" data assimilation method is that of Fierro et al. (2012) as implemented in RAMS@ISAC by Federico et al. (2019). The "reference" radar reflectivity data assimilation is that of Caumont et al. (2010) as implemented in RAMS@ISAC by Federico et al. (2019).

During the third year of the project, the possibility to assimilate SENTINEL data into the meteorological model used in this project will be explored. More specifically, two parameters will be considered: the integrated water vapour profile (IWV) and surface winds.

Lightning and radar reflectivity data sources

In this special project, we will use lightning data from LINET network over Italy (Betz et al., 2009) and data from lightning imager onboard the MTG. Radar reflectivity data will be provided by the radar network of the Department of Civil Protection in Italy. These data have been already used in RAMS@ISAC (Federico et al., 2019).

Scientific plan

The project spans three years. During the first year, the study period of one month will be selected and datasets will be transferred on the ECMWF machines (lightning, rainfall data, IC/BC for the month selected, radar reflectivity, etc). Then 4 numerical experiments will be performed: CTRL, without lightning and radar reflectivity data assimilation, LIGHT with the reference method for lightning data assimilation, RAD with the reference method for radar reflectivity data assimilation, RADLI assimilating both lightning and radar reflectivity with the reference method. These experiments determine a reference for comparison of other numerical experiments in the second and third years.

In the second year, the simulations LCL and LCL- will be performed for a whole month. This will clarify the impact of using the lifting condensation level as the starting level to assimilate the water vapour saturated pseudo-profiles and the suppression of spurious convection on the precipitation forecast. These experiments, together with LIGHT, will eventually give an optimal setting of the model assimilating lightning.

In the second year, the simulations RAD- and RADQ will be performed. These simulations will span a whole month and will be used to find the best configuration to assimilate radar reflectivity.

During the third year, the simulations using the lightning imager data will be performed. These experiments will be focused on specific cases. For these cases, the comparison of assimilating lightning data from the LINET network and lightning data from lightning imager will be considered (experiment LA_MTG).

During the third year, the possibility to use the SENTINEL data to assimilate surface winds and the integrated water content (IWC) will be explored. These experiments will extend the analysis to other meteorological parameters than precipitation.

Year 1	Year 2	Year 3
CTRL	LCL	LA_MTG
LIGHT	LCL-	SENTINEL
RAD	RAD-	/
RADLI	RADQ	/

Table 1: Table of experiments considered in this special project for all three years. Each experiment will span a whole month. Case studies can be added to the numerical experiments above.

Computer resources

In this project 20 million SBU are required for each year. The request comes for the experience with RAMS@ISAC model on ECMWF CCA supercomputer and it is tailored using this machine as reference. Recently, the WRF (Weather Research and Forecast Model) was also installed on CCA. The resources requested by WRF and RAMS@ISAC are similar, so the considerations in the following apply for both models.

A basic simulation consists of running a 6h data assimilation period followed by a 12 h forecast. One-hourly output will be saved. With these simulations, the impact of lightning and radar reflectivity data assimilation at different forecast ranges (1h, 3h, 6h, 12h) can be evaluated.

During the assimilation stage, 3D-Var analyses are performed every 1h (radar reflectivity data assimilation). So, seven analyses are considered using 3D-Var, including the initial time, when the model starts completely dry. In the case of nudging, the assimilation is performed continuously for the 6h assimilation period, starting from a cold start.

A basic simulation (6h data assimilation + 12 h forecast) takes about 17000 SBU (this number slightly varies with the geometry of the batch; in previous Special Projects we used between 108 and 180 cores, depending on the simulation). Our primary focus is the 3h short term forecast (STF) and 8 simulations, each lasting 18h, are needed to cover a day with this configuration. So, to forecast a whole day we need

136.000 SBU. Considering some errors in the simulations performed, we assume that the simulation of a whole day requires 150.000 SBU.

To have a robust statistical evaluation of the scientific problems investigated in the project, we consider a period of 1 month (to be decided, probably October 2018 or November 2019, because these months were characterised by severe precipitation events over Italy). To simulate a whole month for each model configuration we need: 30*150.000=4.500.000 SBU.

For the first and second years, four configurations will be evaluated each year, while for the third year 2 different configurations have been already indicated. The resources required for the first and second years are 4*4.500.000 SBU each year, i.e. 18.000.000 SBU each year. This leaves some CPU available to run/improve the post-processing of the model and to do sensitivity tests for specific case studies.

For the third year, the performance of two additional configurations are considered, using 9.000 .000 SBU. This leaves space to further explore other aspects of the data assimilation and its impact on the weather forecast. In particular, the attention will be focused on the assimilation of tropospheric integrated water content, surface winds and, eventually, soil humidity, whose observations are available from the SENTINEL satellites of the Copernicus mission. The examination of these additional data and their impact on model forecast cover the remaining 11.000.000 SBU of the third year and will not limit the project to the evaluation of precipitation forecast. The precise quantification of the SBU necessary for these experiments is not possible at the moment of writing. Also, the impact of MTG-LI data assimilation will probably require more than one month of simulations because of the importance of the subject.

Technical characteristics of the code

During this project WRF and RAMS@ISAC models will be used. Both models use MPI (Message Passing Interface) and Open-MP. WRF needs NETCDF libraries, while RAMS@ISAC needs HDF5 libraries. Both models were successfully compiled on CCA and are currently used in the third year of the special project 2017-2020, which is assigned to two of the investigators of this proposal.

The post processing is performed by homemade fortran software using NCAR-Graphics or NCL for graphical output. The wgrib, wgrib2 utilities are used to initialise the RAMS@ISAC model, while IDL (Interactive Data Language) is used for some post-elaboration. IDL is not available on ECMWF machines and GDL doesn't implement all the functionalities needed. When IDL is needed, the simulations will be transferred to machines at ISAC-CNR and then elaborated. All the software components, excluding IDL, are already available and used on CCA.

Considering the disk request (ecfs), 30 TB are enough to store most (likely all) simulations made during this project. Having all simulations in one place will help the post-processing of the model. At the moment of writing, the user cm4 already occupies 9 TB of disk space. Part of this space will be recovered by deleting some simulations, nevertheless the software and ancillary data (about 5 TB) can't be removed.

The increase of additional 5 TB for each year accounts for new simulations, software development and saving of new post-processing statistics; however having most of the disk available at the start of the project will help to manage the project. If necessary, part of the simulations will be transferred to machines at ISAC-CNR.

References

Betz, H. D., Schmidt, K., Laroche, P., Blanchet, P., Oettinger, P., Defer, E., Dziewit, Z., and Konarski, J.: LINET-an international lightning detection network in Europe, Atmos. Res., 2009, 91, 564–573.

Caumont, O., Ducrocq, V., Wattrelot, E., Jaubert, G., and Pradier-Vabre, S.: 1D+3DVar assimilation of radar reflectivity data: a proof of concept, Tellus A: Dynamic Meteorology and Oceanography, 62:2, 173-187, https://www.tandfonline.com/doi/abs/10.1111/j.1600-0870.2009.00430.x, 2010.

Chen, Y.; Yu, Z.; Han, W.; He, J.; Chen, M. Case Study of a Retrieval Method of 3D Proxy Reflectivity from FY-4A Lightning Data and Its Impact on the Assimilation and Forecasting for Severe Rainfall Storms. Remote Sens. 2020, 12, 1165.

Dahl, J. M. L., Höller, H., and Schumann, U.: Modeling the Flash Rate of Thunderstorms. Part II: Implementation. Monthly Weather Review, 139, 3112-3124, 2011.

Dixon, K., Mass, C.F., Hakim, G.J., Holzworth, R.H.,The Impact of Lightning Data Assimilation on Deterministic and Ensemble Forecasts of Convective Events, J. Atmos. Oceanic Tech., 2016, 33(9), https://doi.org/10.1175/JTECH-D-15-0188.

Federico, S., Avolio, E., Petracca, M., Panegrossi, G., Sanò, P., Casella, D., and Dietrich, S.: Simulating lightning into the RAMS model: implementation and preliminary results, Nat. Hazards Earth Syst. Sci., 14, 2933-2950, https://doi.org/10.5194/nhess-14-2933-2014, 2014.

Federico, S., Implementation of the WSM5 and WSM6 Single Moment Microphysics Scheme into the RAMS Model: Verification for the HyMex-SOP1, Adv. Meteorol., 17 pp., https://doi.org/10.1155/2016/5094126, 2016.

Federico, S., Petracca, M., Panegrossi, G., and Dietrich, S.: Improvement of RAMS precipitation forecast at the short-range through lightning data assimilation, Nat. Hazards Earth Syst. Sci., 17, 61–76, https://doi.org/10.5194/nhess-17-61-2017, 2017a.

Federico, S., Petracca, M., Panegrossi, G., Transerici, C., and Dietrich, S.: Impact of the assimilation of lightning data on the precipitation forecast at different forecast ranges. Adv. Sci. Res., 14, 187–194, 2017b.

Federico, S., Torcasio, R. C., Avolio, E., Caumont, O., Montopoli, M., Baldini, L., Vulpiani, G., and Dietrich, S.: The impact of lightning and radar reflectivity factor data assimilation on the very short-term rainfall forecasts of RAMS@ISAC: application to two case studies in Italy, Nat. Hazards Earth Syst. Sci., 2019, 19, 1839–1864, https://doi.org/10.5194/nhess-19-1839-2019.

Fierro, A. O., Mansell, E., Ziegler, C., and MacGorman, D.: Application of a lightning data assimilation technique in the WRF-ARW model at cloud-resolving scales for the tornado outbreak of 24 May 2011, Mon. Weather Rev., 2012, 140, 2609–2627.

Fierro, A.O., Y. Wang, J. Gao, and E.R. Mansell: Variational Assimilation of Radar Data and GLM Lightning-Derived Water Vapor for the Short-Term Forecasts of High-Impact Convective Events. Mon. Wea. Rev., 2019, 147, 4045–4069, https://doi.org/10.1175/MWR-D-18-0421.1

Hong, S.Y., Lim, J.J.O.: The WRF single-moment 6-class microphysics scheme (WSM6). J. Korean Meteorol. Soc. 42, 129–151, 2006.

Stensrud, D.J., M. Xue, L.J. Wicker, K.E. Kelleher, M.P. Foster, J.T. Schaefer, R.S. Schneider, S.G. Benjamin, S.S. Weygandt, J.T. Ferree, and J.P. Tuell: Convective-Scale Warn-on-Forecast System. Bull. Amer. Meteor. Soc., 2009, 90, 1487–1500, https://doi.org/10.1175/2009BAMS2795.1.