REQUEST FOR A SPECIAL PROJECT 2019–2021

MEMBER STATE: Italy

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Other researchers:

Project Title: High-impact precipitation events prediction with convection-permitting models nested in the ECMWF ensemble: new tests with the MOLOCH and Meso-NH models

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ITCAPE	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2019	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2019-2021: (To make changes to an existing project please submit an amended version of the original form.)		**2019**	**2020**	**2021**
High Performance Computing Facility	(SBU)	2 900 000	2 900 000	2 900 000
Accumulated data storage (total archive volume)[2]	(GB)	20 000	40 000	60 000

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 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.

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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.

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 and Technical Advisory Committees. 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 will receive a detailed review by members of the Scientific Advisory Committee.

Project description

During the years 2016-2018, the main goal of the SPITCAPE Special Project was to evaluate the accuracy of a cascade of state-of-the-art ensembles, from global-to-local, by re-forecasting three past high-impact precipitation cases occurred in Italy in 2011 and 2014. In particular one of the main question addressed in the scientific plan of the project was "Which is the added value of running a regional convection-permitting and high-resolution ensemble in terms of QPF (Quantitative Precipitation Forecast)?". The project was motivated by the availability in March 2016 of the higher-resolution global ENS ensemble data (at about 18 km of horizontal resolution) which made it possible to test the feasibility of the simple dynamical downscaling technique to initialise limited-area ensemble forecasts at convection-permitting scale. Results demonstrated the added value of convection-permitting simulations for the first two study cases (see interim reports) and current activities regarding the third study case confirm this statement.
The present Special Project is intended to be the continuation of the activities carried out during the SPITCAPE project. The purpose for the years 2019-2021 is to revisit the study cases addressed previously by using two additional models (the MOLOCH and Meso-NH models) for the convection-permitting simulations. The comparison between results obtained with these two models and those obtained previously with the WRF model will contribute to the debate regarding the reliability of these regional models and their strengths and weaknesses with respect to: (I) the accuracy of the results for the three events considered, (II) the integration with ECMWF products, (III) the ease of implementation and (IV) the computational costs in view of a potential use for operational forecasting activities.

Scientific and technical plan

During the SPITCAPE 2016-2018 Special Project, global ensemble forecasts were produced using the ECMWF model cycle 41r2 run at spectral resolution TCo639 for three high-impact weather events occurred in Italy in 2011 and 2014:

- Cinque Terre, 25 October 2011 (study case analysed in Buzzi et al, 2014)
- Genoa, 4 November 2011 (study case analysed in Buzzi et al, 2014)
- Genoa, 9-10 October 2014 (study case analysed in Silvestro et al, 2015)

Data were produced (the last case is currently running) and stored in the MARS archive.
By using the above mentioned data as initial and boundary conditions, we want to perform regional ensemble simulations at convection-permitting scale by using both the MOLOCH model (nested into a BOLAM simulation) and the Meso-NH model. To enable comparisons with previous limited-area simulations, the geographical settings of the domain of integration (number of vertical levels,

extent of the domain, etc...) will be kept as close as possible to the settings used for the WRF model (see Figure 1 below); the target resolution is about 3 km.

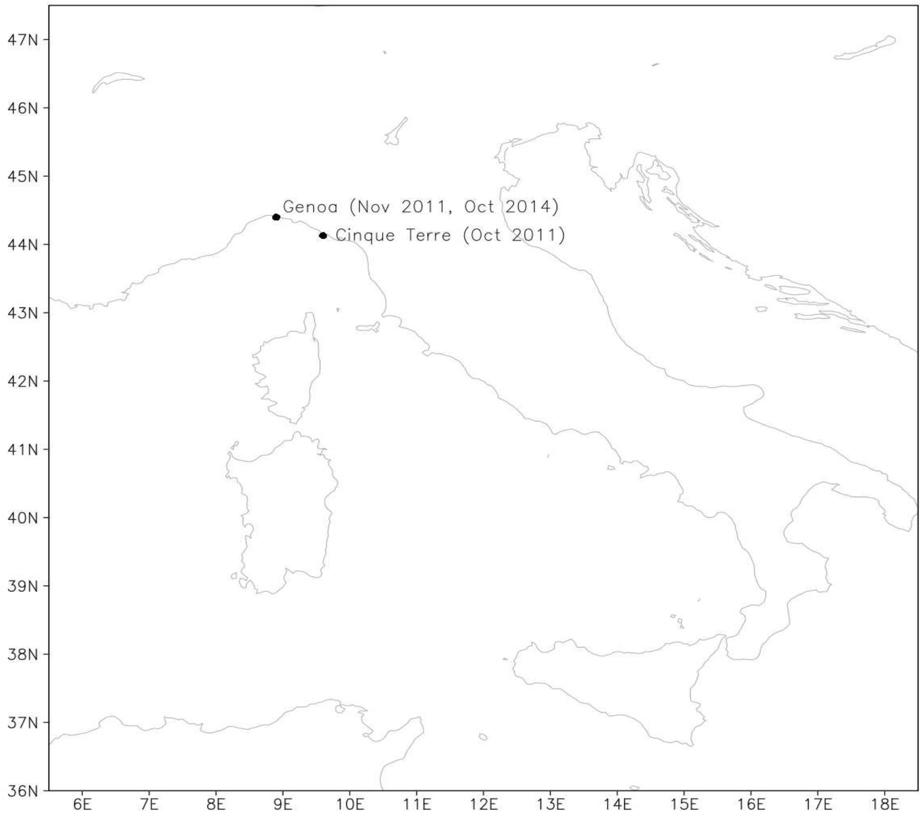

Figure 1: domain of the numerical integrations of the MOLOCH and Meso-NH models

As done during the SPITCAPE 2016-2018 Special Project, the simple dynamical downscaling technique will be adopted to initialise regional models. In fact, in the recent literature (Raynaud et al, 2016 and Tennant, 2015) it has been suggested that the baseline approach of a dynamical downscaling using convection-permitting models nested in global ensemble with a coarser horizontal resolution (eg 33 km) provide valuable information. Besides the fact that this technique simply interpolates, dynamically, the driving ensemble on the high resolution grid, it has been judged to be a valuable method since it captures the large-scale flow which is the dominant driver of variability. Furthermore, it has the advantage of being simple to implement and basically with a very low CPU costs. On the other hand it suffers, if compared to other CPU consuming methods, a spin-up time of about 9-12 h, which makes this method unfit for nowcasting or short range forecast.
The choice of the BOLAM+MOLOCH and Meso-NH models is justified by the fact they are currently used for operational forecasting activities at LaMMA Consortium (see for example http://www.lamma.rete.toscana.it/modelli/atmo/mappe/atmosfera2?model=moloch.0p02.ita.ecm) or for research purposes as part of the collaboration between LaMMA Consortium and the Arcetri Astrophysical Observatory for the prediction of the optical turbulence (see for example http://www.lamma.rete.toscana.it/news/il-meteo-che-aiuta-losservazione-astronomica, page only in Italian).
The BOLAM and MOLOCH models were developed for research purposes at the Institute of Atmospheric Sciences and Climate (ISAC) of the Italian National Research Council (CNR). The numerical chain based on these two models is currently implemented and used for daily forecasting activities at several regional weather agencies in Italy (Toscana and Liguria for example) and in other European countries (Meteocat, Servei Meteorològic de Catalunya).
The BOLAM model is a limited-area hydrostatic model based on primitive equations with a convective parametrisation based on Kain (2004). BOLAM is employed to provide the lateral boundary conditions for MOLOCH at hourly frequency. This current practice has proved to be reliable and economical in bridging the gap between the coarse spatial (about 0.20 for the ENS

data) and temporal (6 hours for the study cases considered) resolutions of global model fields and the high-resolution forecasts. For a description of the model see Buzzi et al. (2003) and Davolio and Buzzi (2004).
The MOLOCH model is a non-hydrostatic, fully compressible, convection-permitting model without parametrisation of convection. It was initially developed as a scientific tool in dynamic meteorology for high resolution atmospheric simulations and mesoscale weather forecasting, allowing the explicit treatment of atmospheric convection. Further details can be found in Malguzzi et al. 2006 and Davolio et al. 2009.
The Meso-NH model is a non-hydrostatic mesoscale atmospheric model, jointly developed by LA (Laboratoire d'Aérologie) and CNRM-GAME (a CNRS/Météo-France joint research unit). It uses a non-hydrostatic system of equations to handle the whole range of scales, from synoptic to large eddy. It is the research version of the operative French model AROME and it is used for a wide range of applications such as chemistry and aerosols, electricity and lightning, hydrology, wild-land fires, volcanic eruptions and cyclones with ocean coupling. More details can be found in Lafore et al (1998) and Lac et al (2018). Since version 5.1, Meso-NH is freely available under CeCILL-C license agreement.
The evaluation of the reliability of the two models for the study cases considered and the comparison between results obtained with the MOLOCH and Meso-NH models and those obtained with the WRF model will be focused on Quantitative Precipitation Forecast (QPF). Predictions will be evaluated on the basis of objective metrics (eg. the continuous ranked probability score, the relative operating characteristic, the Brier score) and on a visual comparison between the patterns of the observed precipitations (obtained by rain-gauges) and the forecast patterns. Maps of Probability of Precipitation (PoP) will be produced to evaluate the probability that a high impact precipitation event may occur with three to one days in advance. See Figure 2 for an example obtained using WRF data for the Genoa 4 November 2011 case.
The number of SBUs needed by the two models to run a full ensemble forecast (50 members + control run) will be compared with the WRF's one. The SBUs requested represent a measure of the computational cost of the three models and serve as a benchmark when evaluating the potential implementation of a limited-area ensemble system in operational forecasting activities.

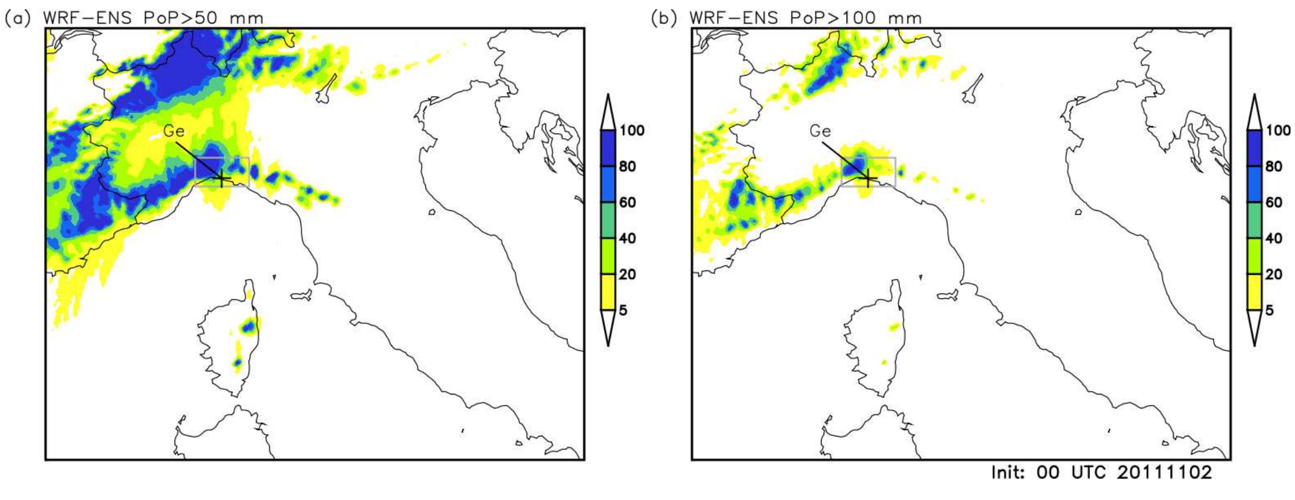

Figure 2: Example of Probability of Precipitation maps for the Genoa 4 November 2011 study case for rainfall exceeding the thresholds 50 mm (left) and 100 mm(right) in 24 hours (data from SPITCAPE 2016-2018 Special Project)

Justification of the computer resources requested

The SBU needed to run the numerical experiments described above are estimated on the following considerations and on the basis of the previous experience with the WRF model within the framework of the SPITCAPE 2016-2018 Special projects.

One day (a 24-hour period) of simulation with the WRF model at 3 km of horizontal resolution (400X440, rows X columns) with 60 vertical levels and 15 seconds as time step costs about 2540 SBU (SPITCAPE 2016-2018 Special Project) with the following PBS directives for the parallel job:

- EC_total_tasks=240
- EC_threads_per_task=1
- EC_hyperthreads=1

Thus running a full regional ensemble simulation (50 members+1 control simulation) with forecast lengths from 72 hours to 24 hours, with starting dates every 12 hours would cost about 1 300 000. For details, see the table below tailored for the Cinque Terre study case occurred on 25 October 2011.

inidate	inihour	enddate	endhour	fcst_lenght (hours)	fcst_lenght (days)	SBU_cost (single run)	ENS_SBU_cost (51 members)
2011/10/23	00:00	2011/10/26	00:00	72	3	7620	388620
2011/10/23	12:00	2011/10/26	00:00	60	2.5	6350	323850
2011/10/24	00:00	2011/10/26	00:00	48	2	5080	259080
2011/10/24	12:00	2011/10/26	00:00	36	1.5	3810	194310
2011/10/25	00:00	2011/10/26	00:00	24	1	2540	129540
						TOTAL 3 DAYS	1295400

We assume that the computational costs of the MOLOCH and Meso-NH models are similar to the cost of the WRF model, so the total number of SBU needed to run the two models is 2 600 000 for a single study case. Nevertheless it has to be noted that it is known (daily operative experience at LaMMA) the MOLOCH model is cheaper than the WRF model and the Meso-Nh model is more expensive than the WRF model. We finally calculated an overhead of about 10% of the total of 2 600 000 SBU obtaining a final request of 2 900 000 SBU for each year.

As regards the data storage, on the basis of the experience with the WRF model with the SPITCAPE Special Project, about 10 TB are required to archive the forecasts for a single study case. Thus the total data storage needed for each year is 20 TB.

Technical characteristics of the code to be used

The BOLAM model is based on a single Fortran 90 code. It is fully parallelized, applying the domain splitting technique, and is compatible with MPICH2 and OpenMP parallel computing environments. A single BOLAM simulation consists in (I) the prebolam procedure, (II) the model and (III) the postbolam procedure. The prebolam prepares the geographic static data and interpolates the global initial and boundary conditions on the user defined model grid. The BOLAM model is the temporal integration and the postbolam procedure computes additional diagnostic fields.

The MOLOCH model is based on a single Fortran 90 code. It is fully parallelized, applying the domain splitting technique, and is compatible with MPICH2 and OpenMP parallel computing environments. The MOLOCH model is normally nested into the BOLAM simulations performed at coarser resolution.

Both the BOLAM and MOLOCH models have been successfully compiled on cca during the SPITBRAN 2018-2020 Special Project. They rely on the ecCodes tools (version 2.7 tested) and on the ECMWF radiation scheme.

The source code of the Meso-NH model is written in standard Fortran 90. The required libraries to run Meso-NH are NetCDF because the output files are in nc4 format, MPI and grib_API/ecCodes tool. To perform a full Meso-NH numerical experiment the steps are:

1. PREP_PGD: this program computes the physiographic data file such as the projection, horizontal resolution and domain. The PGD file contains all the physiographic data necessary to run the Meso-NH model with interactive surface schemes for vegetation and town
2. PREP_NEST_PGD: this program checks all the PGD files to impose conformity of orography between them. This program is only used with grid-nesting simulations

3. extractecmwf: it extracts the surface and altitude fields for a specific date from the MARS archive. Files are written in a GRIB format file, on the Gaussian grid
4. PREP_REAL_CASE: this program performs the change of orography and vertical grid by interpolating horizontally and vertically for a GRIB file or only vertically for a Meso-NH file
5. SPAWNING: this program performs the horizontal interpolations from a Meso-NH file into another Meso-NH file, with a finer resolution and smaller domain
6. MESONH: it is the temporal integration of the model
7. DIAG: this program performs diagnostic computations after the simulation

All the information required to perform a given step are provided by namelist files.

The Meso-NH model has been successfully compiled and used on cca in the framework of the SPITFOT 2014-2016 Special Project. For the compilation of the model a specific procedure is available on cca: qsub job_make_mesonh_CRAY_cca

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