SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2020
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
Computer Project Account:	SPITCAPE
Principal Investigator(s):	Valerio Capecchi (capecchi@lamma.rete.toscana.it)
Affiliation:	LaMMA Consortium - Environmental Modelling and Monitoring Laboratory for Sustainable Development
Name of ECMWF scientist(s) collaborating to the project (if applicable)	
Start date of the project:	2019
Expected end date:	2021

Computer resources allocated/used for the current year and the previous one
(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	2 900 000	2 816 943	2 900 000	2 893 655
Data storage capacity	(Gbytes)	20 000	19 465	40 000	35 553

Summary of project objectives (10 lines max)

The SPITCAPE 2019-2021 Special Project (SP) was conceived to be the continuation of the activities carried out during the SPITCAPE 2016-2018 SP. The goal is to reforecast three heavy precipitation events (Cinque Terre October 2011, Genoa November 2011 and October 2014) by using two mesoscale models (the MOLOCH and Meso-NH models) for the convection-permitting ensemble simulations. The global ensembles produced using the IFS model cycle 41r2 at the spectral resolution TCo639, provide the initial and boundary conditions. The comparison between the results obtained with the WRF model during the first stage of the SPITCAPE SP and those obtained with the two additional models, contribute to the debate regarding the strengths and weaknesses of these three models 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 ensemble forecasting.

Summary of problems encountered (10 lines max)

none

Summary of plans for the continuation of the project (10 lines max)

The ensemble simulations foreseen for the second heavy-precipitation event taken into consideration (the flooding of Genoa occurred on the 4th of November 2011), were performed during the first half of 2020. In the next months, the outputs will be analysed and combined with those of the first event (the Cinque Terre flooding occurred on the 25th of October 2011) to start drawing statistically sounding conclusions.

List of publications/reports from the project with complete references

A contribution containing some preliminary results of the SP has been accepted as oral presentation at the EGU 2020 on-line Conference. The presentation file is available at:
http://doi.org/10.5281/zenodo.3876243
A manuscript is under preparation.

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

Abstract

During the first and the second year of the SPITCAPE 2019-2021 Special Project, we investigated the potential added value of running three limited-area ensemble systems (with the WRF, Meso-NH and MOLOCH models and a grid spacing about 2.5 km) for two cases of heavy precipitation in Italy: the flooding of the Cinque Terre UNESCO site occurred on the 25th of October 2011 (CT case hereinafter) and the flash flood of the city of Genoa occurred on the 4th of November 2011 (GE case hereinafter). The high-resolution ensembles include an explicit treatment of convection processes and dynamically downscale the ECMWF information (the global ENS data with a grid spacing about 18 km). The predictions were verified against rain-gauge data and their accuracy was evaluated over that of the driving coarser-resolution ensemble system. Furthermore, the simulation speed (defined as the ratio between the simulation length and the wall-clock time) of the three limited-area models was compared to estimate the CPU efforts needed for operational convection-permitting ensemble forecasting. It was also studied how the simulation speed scales as the number of computing elements increases (from 36 to 1152 cores). Objective verification methods showed that, in general, convection-permitting forecasts outperform global ones for both cases. As regards the comparison of simulation speeds, the MOLOCH model results the fastest model and the Meso-NH the slowest one. The computational scaling is efficient as regards the WRF model, whereas is limited for the Meso-NH and MOLOCH models beyond 576 cores. However, because of some differences in the implementations of the models further systematic tests are needed to draw more general conclusions.

Data and methods

In the following, we provide a short overview of the models used. We stress again the fact that all are set with explicit treatment of convective processes.

The WRF model is the result of joint efforts by U.S. governmental agencies and the University of Oklahoma. It is a fully compressible, Eulerian, non-hydrostatic mesoscale model, designed to provide accurate numerical weather forecasts both for research activities, with the dynamical core Advanced Research WRF (ARW), and for operations with the dynamical core Nonhydrostatic Mesoscale Model (NMM). In this work, we used the WRF-ARW core updated to version 3.7.1 (August 2015). The micro-physics option adopted is detailed in Thompson et al. (2008); it is a single-momentum parametrization and explicitly predicts the mixing ratios of five liquid and ice species: cloud water, rain, cloud ice, snow, and graupel. The WRF model was compiled on the XC40 Cray supercomputer at ECMWF with the GNU compiler suite version 4.9.3 (released in 2016) using the distributed and shared memory option for building the executables. Optimization level was set to “-O2”. The default Message Passing Interface (MPI) library and settings were kept identical across all the three CP models.

The Meso-NH is a French research community model, jointly developed by the Centre National des Recherches Météorologiques (CNRM) and Laboratoire d’Aérologie (LA) at the Université Paul Sabatier (Toulouse). It is designed to simulate the time evolution of several atmospheric variables ranging from the large meso-α scale (~ 2000 km) down to the micro-γ scale (~ 20 m), typical of the Large Eddy Simulation (LES) models. For a general overview of the Meso-NH model and its applications see Lac et al. (2018), while the scientific documentation is available on the model’s website. For this study, we used the version 5.4.1 (released in July 2018). As regards microphysics, we set the one-momentum ICE3 scheme (Caniaux et al. 1994), that takes into account five water species: cloud droplets, raindrops, pristine ice crystals, snow or aggregates, and graupel. The Runge-Kutta centred 4th order scheme was chosen for momentum advection. This scheme is recommended when using, as in the present paper, the CEN4TH (4th order CENtred on space and time) advection scheme. The CEN4TH was chosen because of its numerical stability, although it is more time-consuming than other options (Lunet et al. 2017). For the compilation of the Meso-NH model on the XC40 Cray supercomputer at ECMWF, a specific procedure is made available by the model's developers and relies on both the Intel and Cray compilers. For this study we chose the Intel compiler version 17.0.3, with the optimization level set to "-O2".

The MOLOCH model is a non-hydrostatic, fully compressible model and uses a hybrid terrain-following coordinate, relaxing smoothly to horizontal surfaces. It is developed at the Institute of Atmospheric Sciences and Climate (ISAC) of the Italian National Research Council (CNR).

Details about the models can be found in Malguzzi et al. (2006) and at the model's website www.isac.cnr.it/~dinamica/projects/forecasts/ (link accessed in May 2020). It was initially developed for research purposes, but today it is being used operationally by various Italian agencies and regional meteorological services. For this work we implemented the version released in 2018. The micro-physical scheme is based on the parametrization proposed in Drofa and Malguzzi (2004), which describes the interactions of cloud water, cloud ice, rain, snow and graupel. The ISAC/CNR staff provided full support for the compilation of the Moloch model on the XC40 Cray supercomputer. To the author's knowledge, this was the first time the model was successfully compiled on a Cray supercomputer architecture. The MOLOCH executables were built in less than 10 minutes with the Intel Fortran compiler version 17.0.3. The more aggressive optimization level "-O3" was set.

In Figure 1 we show the geographical domain of integration for the three regional convection-permitting models (plot on the left). Some geometric characteristics of the domains are listed in Table 1.

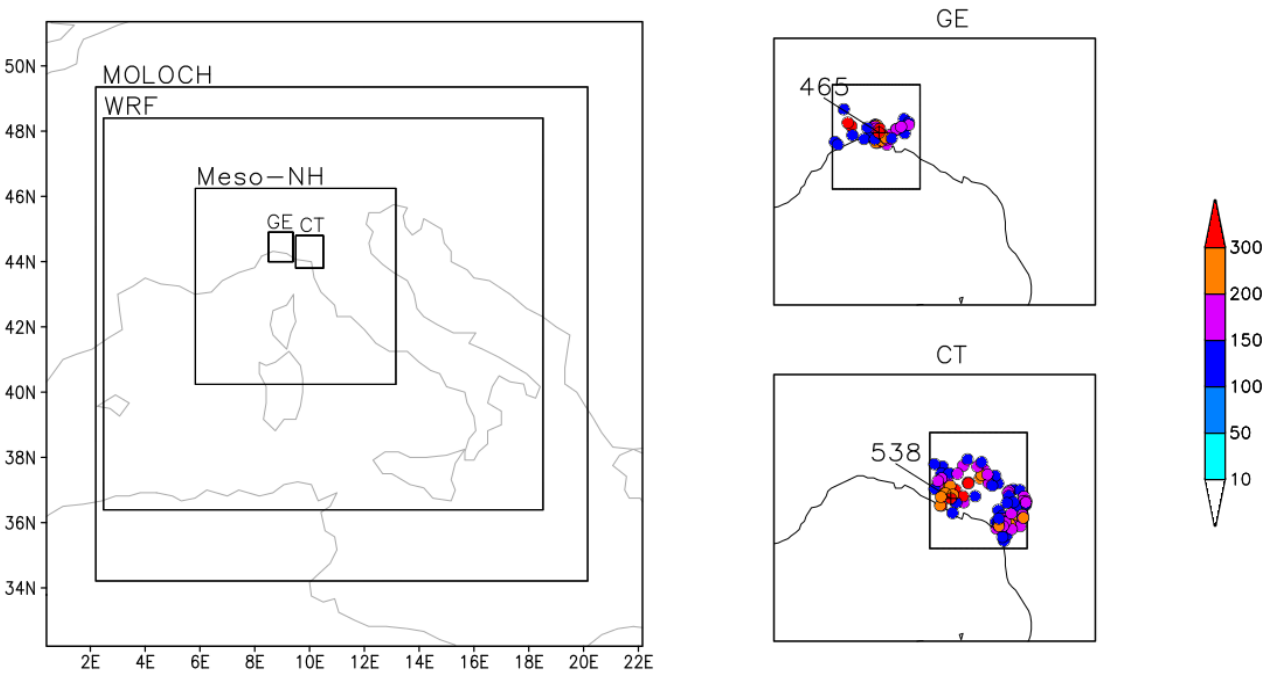

Figure 1: Domain of integration for the three convection-permitting models (map on the left) and daily rainfall data registered by rain-gauges (plots on the right) for the two cases under examination: Genoa 4th of November 2011 (top) and Cinque Terre 25th of October 2011 (bottom)

Model	***RowsXColumns***	***Vertical Levels***	***# of grid points***	***Time step (sec)***
WRF	400X440	55	~9.7 million	18
Meso-NH	225X270	52	~3.1 million	6
MOLOCH	514X614	50	~15.4 million	30

Table 1

Starting dates that have been considered for the CT (GE) case are from 00 UTC 23 October (2 November) 2011 to 12 UTC 24 October (3 November) 2011 every 12 hours. Ending dates are 00 UTC 26 October 2011 for CT and 00 UTC 5 November 2011 for GE, so that forecast length ranges from 72 hours to 36 hours for both cases; forecast lengths shorter than 36 hours were not considered.
In the Table below, we summarise the codes adopted to name the forecast runs.

CT case	***Starting date of the simulations***	***Forecast length to 00 UTC 26 October 2011***	***Forecast code***
	00 UTC 23/October/2011	72 hours	CT+72h
	12 UTC 23/October/2011	60 hours	CT+60h
	00 UTC 24/October/2011	48 hours	CT+48h
	12 UTC 24/October/2011	36 hours	CT+36h
GE case	***Starting date of the simulations***	***Forecast length to 00 UTC 5 November 2011***	***Forecast code***
	00 UTC 2/November/2011	72 hours	GE+72h
	12 UTC 2/November/2011	60 hours	GE+60h
	00 UTC 3/November/2011	48 hours	GE+48h
	12 UTC 3/November/2011	36 hours	GE+36h

Table 1 : Starting dates and forecast lengths of the simulations for the CT and GE cases. The forecast codes are shown on the forth column

Ensembles QPF data are compared with observed precipitation amounts collected at the rain-gauges belonging to the inset boxes shown in Figure 1 (panels on the right). Such boxes are chosen subjectively, by drawing a 1 degree×1 degree rectangle around the area whose rain-gauges registered the highest precipitation amounts. To reduce the effects of the double-penalty error, when extracting the QPF values for each rain-gauge location, we picked the four nearest-neighbor grid values and average them to provide the forecast value at that location.
The performance of the ensemble mean, chosen as the representative member of each ensemble system, is assessed by looking at the performance diagrams (Roebber 2009). Such diagrams plot four measures of dichotomous forecast: probability of detection (POD), success ratio (SR), frequency bias and critical success index (CSI). The probabilistic skills of the CP ensembles are compared to those of ENS by constructing the ROC (relative operating characteristic) curve and calculating the area under it. The ROC curve contrasts the hit rate (POD) versus false alarm rate (POFD), using a set of increasing probability thresholds to make the yes/no decision. The area under the ROC curve is frequently used as an index of the accuracy of an ensemble system to be able to discriminate between the occurrence and non-occurrence of weather events (Mason 1982); the higher the better, 1 is the upper limit and values below 0.5 indicate no skill compared to random forecast. In the following text, we use the acronyms WRF-ENS, MNH-ENS and MOL-ENS to refer to the CP ensembles data produced using the WRF, Meso-NH and MOLOCH model respectively and the ENS data as initial and boundary conditions.

Results

Figures 2 and 3 show the performance diagrams of the ensemble mean for the CT and GE case respectively for a set of increasing precipitation thresholds (25-mm, 50-mm, 75-mm and 100-mm) to make the yes/no decision; results are averaged among the all forecast ranges listed in Table 2. As regards the precipitation threshold equal to 25-mm (panels (a) in the Figures 2 and 3), results lie close to the upper right corner for both cases (i.e. close to the perfect score) and for all the ensemble systems. As we consider higher thresholds, MNH-ENS provides more skilful predictions as regards CT, whereas for the GE case both ENS and MOL-ENS outperform the other systems. We underline the fact tha ENS data are comparable with those of the CP ensembles up to 75-mm, although they overestimate rainfall for GE for 25-mm and 50-mm thresholds. As we consider precipitation amounts exceeding 100 mm/day (panels (d) in the Figures), all the forecasts provide poor results.

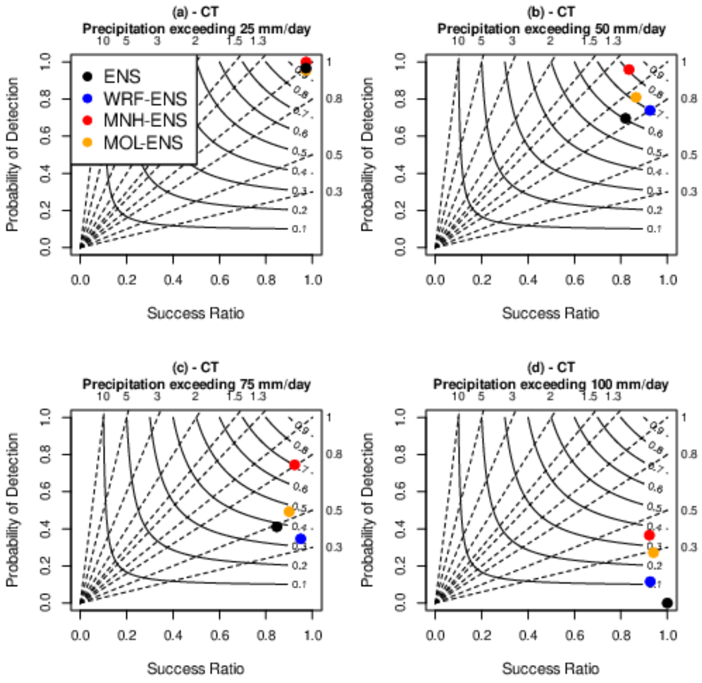

Figure 2

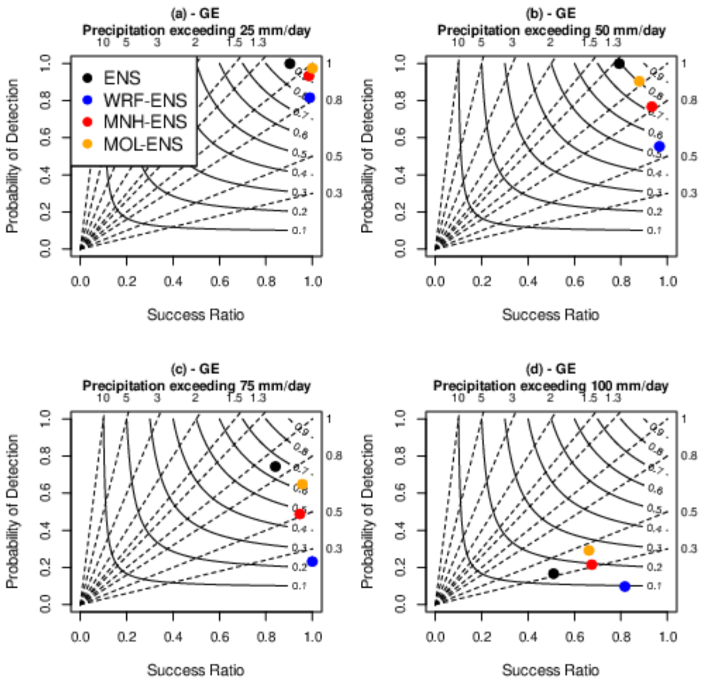

Figure 3

To evaluate quantitatively the probabilistic skills of the ensembles, we show in Figures 4 and 5 the area underneath the ROC curve for the CT and GE case respectively by varying the precipitation thresholds on the X-axis and considering different forecast ranges.

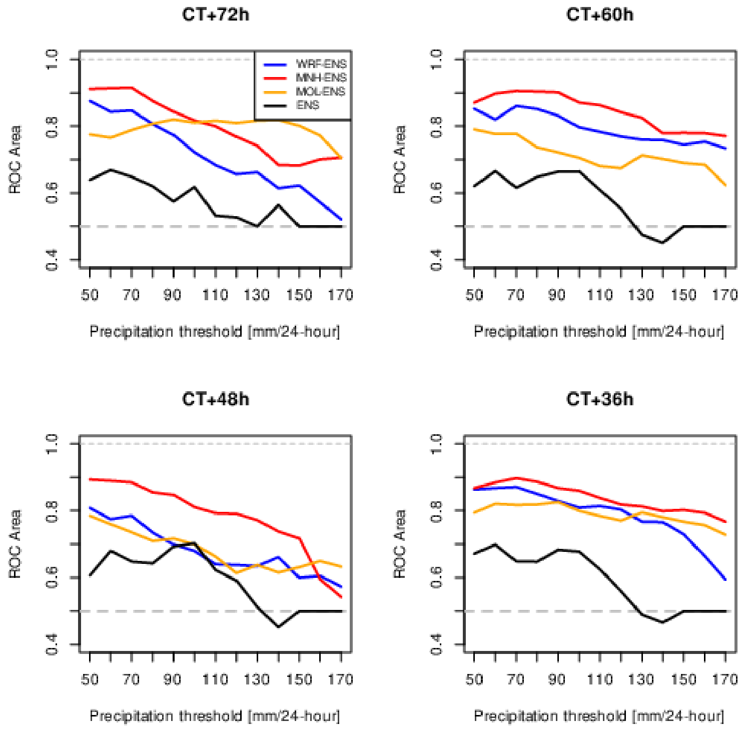

Figure 4

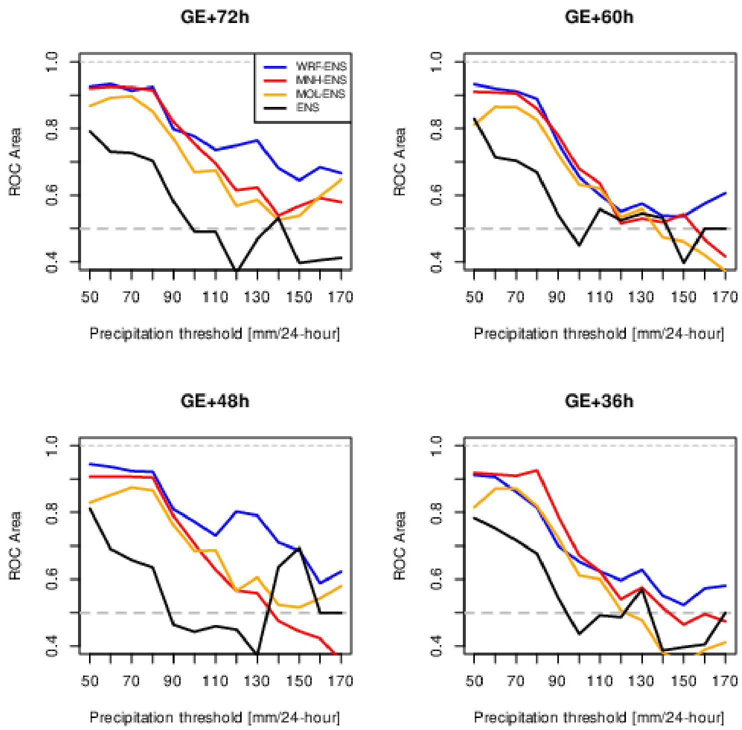

Figure 5

For both cases, CP ensembles outperform ENS data for all the thresholds and for all the lead times (with few exceptions, namely CT+48h). As regards the CT case (Figure 4), the skill of ENS drops below the critical value of 0.5 at about 130-mm precipitation threshold, whereas CP ensembles provide valuable information up to 170-mm and beyond (plots not shown). The MNH-ENS outperform in general the other two CP ensembles. Predictions are slightly more skilful as the

forecast range decreases, although the improvement is not dramatic. As regards the GE case (Figure 5), the profiles of CP ensemble systems are very similar one to each other with WRF-ENS providing better results for GE+72h and GE+48h. CP ensembles (ENS) profiles approach the 0.5 horizontal line when evaluating precipitation thresholds in the interval 120-140 mm (90-100 mm). Surprisingly, the longer forecast range (GE+72h) is as skilful as shorter forecasts.
In light of the potential use for operational forecasting, in Figure 6 we show the scaling of the simulation speed, defined as the ratio between simulated time and the elapsed wall-clock time, for the three CP models by varying (namely by doubling at each step) on the X-axis the number of cores used to realize a 36-hour long simulation (the CT+36h forecast). The value shown on the Y-axis are obtained by averaging the simulation speeds of selected members of the CT+36h forecast. The wall-clock time taken into account considers only the time spent to compute the evolution of the state variables and to write output files and not that one spent for reading the initial conditions and post-processing the model outputs.

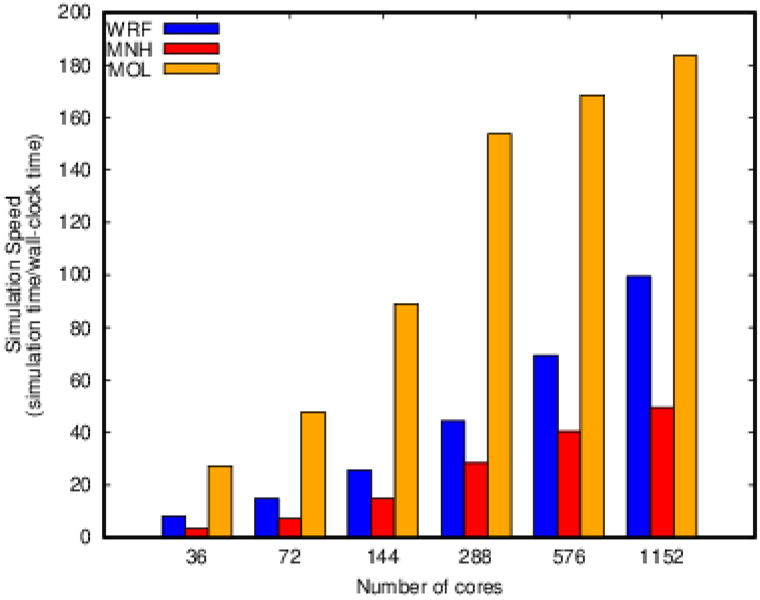

Figure 6

The MOLOCH model is the fastest one, being on average about 2.5 times faster than the WRF model and about 4.5 times faster than the Meso-MH model.
As regards the preliminary results shown in Figure 6, we intended to provide some guidance to the user interested in having a comprehensive idea about the CPU efforts requested to accomplish a CP ensemble simulations and caution should be taken when commenting such results. In fact, different Fortran compilers were used to build the executables (Intel Fortran compiler for the Meso-NH and MOLOCH models and GNU compiler for the WRF model) and different optimization levels were set (“-O2” for the WRF and Meso-Nh models and “-O3” for the MOLOCH model).
Recently, newer versions of the WRF executables are available on the ECMWF supercomputer. These versions were built with the Intel Fortran compiler, which has the reputation to create faster executables than those produced with the GNU one. However, the default compilation Intel Fortran flags of the WRF model are nudged towards accuracy at the expense of performance, with a potential reduction in elapsed wall-clock time up to 5% when using more aggressive optimization on floating-point data. Currently, we’re performing some tests aimed at evaluating the improvement of the simulation speed due to the use of WRF executables built with the Intel Fortran compiler.
In our experiments, the Meso-NH model resulted the slowest model among the ones considered. However, we have to stress the fact that the adoption of the fourth-order centred advection scheme, strongly limits the possible values of the time step to satisfy the CFL stability criterion (Lunet et al. 2017). Some sensitivity tests performed during the SPITCAPE projects, demonstrated (results not shown) that the time step should not be higher than 6/8 seconds to avoid numerical overflow/underflow. To overcome such constraint, a preliminary test was performed using the cheaper WENO5 scheme, which allows the use of an inflated time-step (up to 40-60 seconds when

using a grid spacing of 2.5 km). Results demonstrated a potential gain in simulation speed about 10%. However a systematic verification has to be carried out to assess any potential loss in forecast accuracy due to the use of the WENO5 scheme with respect to the CEN4TH one.
As regards the simulations performed with the MOLOCH model, we have to underline that, because of some constraints in the decomposition of the horizontal domain (Cioni 2014), the number of grids points is not constant as the number of cores varies. The bigger domain (514 × 650 grid points) is achieved when using 1152 cores, the smaller one (506 × 602 grid points) when using 144 cores. Taking into account such differences, the variations in the computational speed of the model are estimated in less than 9% of the wall-clock time.

Final remarks

We have to stress the fact that all the data/plots shown in the Figures above are the results of preliminary analyses. Further investigations during the second half of 2020, will eventually confirm the comments and conclusions drawn so far.

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