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# Preface: Forecast and projection in climate scenario of Mediterranean intense events: uncertainties and propagation on environment (the MEDUP project)

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## 1 Introduction

The Mediterranean basin is a particularly vulnerable region to climate change, partly due to its quite unique character that results both from physiographic conditions and societal development. The region features indeed a near-closed sea surrounded by very urbanised littorals and mountains from which numerous rivers originate. This results in a lot of interactions and feedbacks between oceanic–atmospheric–hydrological processes that play a predominant role on climate and extreme events that frequently cause heavy damages and human losses in the Mediterranean. These high-impact weather events are heavy precipitation and flash flooding during the fall season, severe cyclogenesis associated with strong winds and large swell or heat waves and droughts accompanied by forest fires during summer. If during the last decade, numerical weather prediction (NWP) have made considerable progress in terms of realistic modelling of intense events, especially with the implementation by national weather services of convection-permitting models, they still have difficulties to predict the precipitation location and amount with the precision required to drive hydrological models, and more generally, to meet societal demands in the field of early warning and risk prevention. One of the current challenges is to quantify the uncertainties associated with these atmospheric model forecasts and to study their spread throughout the forecasting and warning chains. Also, the Mediterranean region is qualified as a "hot spot" for climate change. However, the evolution of intense events in the Mediterranean with climate change is still an open question. Studies on the evolution of extremes with climate change rely on a cascade of models and methods; all sources of uncertainty that need to be better quantified to assess the likelihood of climate projections and of their impacts. The MEDUP project (2008–2011), sponsored by the French National Research Agency (ANR) *Vulnérabilité Milieux et Climat* program, focused on these issues. Its objectives were to quantify and reduce the uncertainties associated with NWP and regional climate models and to study how they propagate on the environment and may combine with the intrinsic uncertainties of the vulnerability and risk analysis methods. An original feature of MEDUP was to address these questions at one and the same time for weather forecasting (1–4 day range), seasonal forecasting (1–3 month range) and climate scenario simulations (50–100 yr range). MEDUP was also innovative in considering the whole uncertainty chain, from the atmospheric modelling of high-impact weather events to their consequences on the environment. The region of interest was the northwestern Mediterranean in southern France, a region with complex coast shapes and mountains. High-impact weather events considered in MEDUP are heavy precipitation, severe winds and long dry weather periods (favouring droughts). This special issue of *Natural Hazards and Earth System Sciences* contains 14 articles presenting most of the studies carried out within the MEDUP project. In the following, we summarize, for each of the prediction ranges, the content and main results of the papers published in this special issue together with references to some other studies performed within MEDUP.

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## 2 Short-range forecast

Ensemble modelling is the recognised methodology to assess uncertainties associated with atmospheric or hydrological prediction. MEDUP has developed and evaluated new perturbation ensemble methods to best sample the different uncertainty sources at various spatial and temporal scales (initial and boundary conditions, process modelling). Vié et al. (2011) assessed the impact of uncertainty on convective-scale initial conditions and the uncertainty on lateral boundary conditions on convection-permitting model forecasts. An ensemble data assimilation technique has been used for assimilation of perturbed observations to generate different convective-scale initial conditions whereas different lateral boundary conditions are provided by the members of a larger scale ensemble prediction system (EPS). The uncertainty on convective-scale initial condition was shown to have an impact at short range (under 12 h), whereas the uncertainty on lateral boundary conditions showed an impact at longer range. In this special issue, Nuissier et al. (2012) further examined the impact of lateral boundary conditions, and more specifically how to select a subset of members from the larger scale EPS as generally their size is larger than the convection-permitting ensemble one. The selection based on a cluster analysis was found generally performing better against a random selection. Fresnay et al. (2012) had addressed the issue of process modelling errors. They investigated the sensitivity of a convection-permitting model to cloud physics parameterization uncertainties for two cases with contrasting level of predictability. Three types of perturbations were implemented in the warm microphysical scheme. The sensitivity to the microphysical perturbation method was found dependent on the case studied and on the horizontal resolution. The method that introduced random perturbations on the time tendencies of each microphysical processes obtained the largest spread for most forecasted fields. Vincendon et al. (2011) designed a different approach to sample uncertainties of convection-permitting NWP rainfall forecasts prior to using them to drive an hydrological model. Perturbations were designed according to the convection-permitting NWP-model error statistics. The resulting rainfall ensemble forecasts were then used to drive an hydrological model dedicated to flash-flood forecasting to produce ensemble streamflows. Results for two flash-flood events showed that the perturbation method performed better than the determinist NWP rainfall forecast.

Two innovative approaches for verification of the high-resolution forecasts have been proposed within the MEDUP framework. Chaboureau et al. (2012) illustrated the advantage of using satellite observations and the model-to-satellite approach to verify convection-permitting ensemble forecasts. Brightness temperature images for the infrared and microwave channels were computed from forecast fields, allowing a model verification over data-sparse areas such as the Mediterranean Sea. This model-to-satellite approach confirmed the under-dispersion of the ensemble forecasts evidenced by the evaluation against raingauge observations over land surfaces. A different approach is proposed by Ceresetti et al. (2012a) to compare the convection-permitting rainfall forecasts with the ground rainfall observations through the maximum intensity diagrams and severity diagrams. These diagrams need estimates of return levels of extreme rainfall at ungauged sites. Ceresetti et al. (2012b) evaluated different methods to estimate these return levels, and in particular the uncertainty due to the extreme-value density function and the interpolation scheme used in these methods. The methods that minimised uncertainties were found to be the peaks-over-threshold method with kriging.

Finally, Vié et al. (2012) proposed a common evaluation of the convection-permitting methods developed by Vié et al. (2011) and Fresnay et al. (2012) using classical probabilistic scores and the scale-dependent analysis of Ceresetti et al. (2012a) for heavy precipitation. An evaluation of the ensembles performance for flash-flood forecasting was performed through the computation of hydrological ensemble discharge forecasts using the same hydrological model than in Vincendon et al. (2011). A clear improvement was found when uncertainties on initial conditions and on lateral boundary conditions were considered together, whereas the impact of microphysical perturbations have no significant impact on the probabilistic scores over the 18 day period although they may affect ensemble forecast of some heavy precipitation events.

Créton-Cazanave and Lutoff (2013) presented the socio-geographical approach developed during MEDUP about how the French “actors” manage forecast uncertainties during flash-flood warning process. Five actors profiles were identified based on their descriptions of the problems they faced during the flash-flood warning. The practice-based approach allowed to highlight what is at stake in the hours that precede an extreme event for the actors and how each deals with discrepancies between the forecasts and the reality at local scale.

## 3 Seasonal forecast

The seasonal predictability of precipitation at mid-latitudes is low, including for Mediterranean heavy precipitation extreme. In order to take advantage of the better predictability of the large-scale conditions encountered during heavy precipitation events (Nuissier et al., 2011), Guérémy et al. (2012) designed a methodology based on weather regimes that were statistically correlated with heavy precipitation occurrence over the northwestern Mediterranean. The economical value of the seasonal forecast was doubled when this method was used instead of the raw simulated precipitation. The uncertainties associated with the methods such as the parameters used as predictors and of the statistical models were also assessed.

## 4 Regional climate prediction

General circulation models (GCMs) used generally for climate scenarios have been recognised to be able to represent reasonably well the main features of the global distribution of basic climate parameters, but these models so far could not reproduce well the details of regional climate conditions at temporal and spatial scales of relevance to extreme weather impact studies. Indeed, surface winds and precipitation exhibit variability at much smaller spatial scales than that resolved by GCM, whose horizontal resolution is typically 200 km. Hence, tools for downscaling GCM predictions of climate change to regional and local scales are required. The MEDUP project aimed to evaluate their associated uncertainties. Two broad categories of downscaling procedures currently exist: (i) dynamical downscaling (DD) techniques, involving the extraction of regional scale information from large-scale GCM data based on the modelling of regional/local dynamical processes; and (ii) statistical downscaling (SD) procedures that rely on the empirical relationships between observed (or analysed) large-scale atmospheric variables and observed (or analysed) surface environment parameters. SD methodologies include weather typing approaches, regression methods, and stochastic weather generators. DD methodologies involve regional climate models.

Three regional climate models were evaluated as dynamical downscaling methods for precipitation (Colin et al., 2010; Flaounas et al., 2013a) and winds (Herrmann et al., 2011; Flaounas et al., 2013b) within the MEDUP project. Some studies were also devoted to the influence of the model set-up (Colin et al., 2010; Herrmann et al., 2011; Omrani et al., 2012a, b). For instance, Herrmann et al. (2011) assessed the influence of the configuration of a regional climate model on the representation of wind speed variability and intense wind events at daily scale. They showed that the DD method reduced the underestimation of the wind speed over the Mediterranean Sea with respect to the large-scale analysis. The increase of horizontal resolution, which enables to represent more realistically the complex orography of the Mediterranean region, explained most of this improvement. Differences associated with the configuration of the regional climate were globally one order of magnitude smaller.

For their part, Lavaysse et al. (2012) analysed the uncertainties associated with a specific SD method, which is the "Cumulative Distribution Function Transform", by comparing this method with observations of height weather stations in Southern France for wind, temperature and rainfall distributions. The method was applied to three GCM projections. Results showed that the uncertainties associated with rainfall and wind speed are still too important to derive a robust trend in the projections. Vrac et al. (2012) evaluated both dynamical and statistical downscaling methods and their combination. Simulations from three regional climate models and the SD method above-mentioned were used to evaluate the uncertainties in downscaling wind, temperature and rainfall distributions at the same weather stations as those used by Lavaysse et al. (2012). Despite their differences, the three regional climate models displayed very similar performance, lower than the SD method. This SD method applied to the RCM outputs did not however produce better results than the RCMs alone.

Efforts were also focused during the MEDUP project on establishment of observed reference data sets and on qualifying their uncertainties for validation of regional climate models (Aznar et al., 2010; Claud et al., 2012; Flaounas et al., 2012). Claud et al. (2012) described a new precipitation and convection occurrence data set from 1999 to 2010, based on microwave satellite sensors. The potential of this data set for evaluating model uncertainties were illustrated on two cases, one of them being a multi-year simulation from a regional climate model.

The influence of SD methods in simulating the impact of climate change on the hydrology of the Mediterranean basin was examined by Quintana-Seguí et al. (2010) and more specifically for the high and low extremes of river flow by Quintana-Seguí et al. (2011). These studies showed very different flow projections depending on the downscaling methods used. Queguiner et al. (2011) evaluated the uncertainty associated with the impact model itself (land surface scheme). For that, a $CO_2$ responsive version of a land surface model was compared with its standard version with respect to the impact on the hydrological cycle. This study illustrated the importance of the role of the vegetation in the response at the seasonal scale. However, the use of a $CO_2$ responsive land surface scheme did not lead to significantly different results in term of total run-off impact despite different evaporation, water stress and vegetation variations formulations.

Finally, Dumas et al. (2013, this issue) proposed a method to project the possible evolution of river flood damages due to climate change. Their results showed that future flood losses may change in a very significant manner over France. They found however that a very large uncertainty arose from the climate downscaling methods, as two methods with same skills at producing reference river discharges provide very different estimates of future flows and thus of future local losses. They concluded that estimating future flood losses is still out of reach, even though at the national level future losses are expected to significantly change.

## 5 Final remarks

The MEDUP project has evaluated downscaling methods for extreme weather events and showed that uncertainties associated with all the steps of the chain from the global climate models and gas emission scenarios to the impact evaluation (downscaling methods and impact models) should be considered when evaluating the climate change and their impacts.

Regarding high-impact weather event forecasting, a full hydro-meteorological ensemble forecasting suite has been developed for evaluating uncertainties associated with flash-flood forecasting. To actually use this information during the decision-making process, the communication of the uncertainties during the flash-flood warning process should include a translation in information that could be understood by the different parties.

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