REQUEST FOR A SPECIAL PROJECT 2018–2020

MEMBER STATE: Italy
This form needs to be submitted via the relevant National Meteorological Service.

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Project Title: Evaluation of coastal climate trends in the Mediterranean area by means of high-resolution and multi-model downscaling of ERA5 reanalysis

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.)	2018	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2018-2020: (To make changes to an existing project please submit an amended version of the original form.)		**2018**	**2019**	**2020**
High Performance Computing Facility	(SBU)	3 000 000	3 000 000	4 000 000
Accumulated data storage (total archive volume)[2]	(GB)	1000 GB	2000 GB	3000 GB

An electronic copy of this form must be sent via e-mail to: *special_projects@ecmwf.int*

Electronic copy of the form sent on (please specify date):
29/06/2017

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

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 will be 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.

Large requests asking for 10,000,000 SBUs or more will receive a detailed review by members of the Scientific Advisory Committee.

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

Scientific background

In the recent years, the study of the effects on the coasts of shifts in wind/wave regimes due to climate change has received little attention. One of the most studied aspects is undoubtedly the impact of the sea-level rise on the coast, which is highly debated (Rahmstorf, 2010). In the recent literature (see for example Nicholls and Cazenave, 2010) several studies deal with the projections of the future coastline positions. These numerical experiments are mostly intended to establish the intersection of the expected mean sea level with the current shore profile. An explicit way to account the morphodynamic response of the coasts, due to the impact of sea storms (FitzGerald et al. 2008), is an ambitious goal to achieve. Nevertheless it is important to consider that any morphodynamic equilibrium has time scales shorter than those of climate change, and it is important to evaluate this equilibrium for an appropriate management of coastal areas.
On the other hand, the changes observed in a number of worldwide sites have been associated to changes in wind/wave regimes in both hemispheres (Short et al. 2000, Thomas et al. 2010). It was also found that these changes cause important effects such as beach erosion or rotation. These effects are known to take place in a number of sites, even in the Mediterranean Sea, where many coastal sites are seriously affected by the combination of natural and anthropogenic factors. Understanding the beach morphological variability is essential to support coastal risk assessment and to help decision makers. In the Northern Mediterranean Sea, for example, many data and monitoring activities, suggest a relative increase in the frequency of south-easterly winds and seas ('Sirocco') and a relative decrease in north-westerly flow ('Maestrale'), with possible consequences on the morphodynamic equilibrium of several coastal sites.
For all these reasons, it is therefore crucial to understand the effects of meteo-marine variability over the last decades, using the best possible available data. Numerical hindcasts of the wind/wave regimes at the basin scale carried out so far, used a relatively coarse resolution (around 0.1° for the Mediterranean Sea), or have been developed from low resolution reanalysis data (Soares et al. 2002, Music and Nickovic 2008, Contento et al. 2011, Besio et al. 2016). As a consequence some basic elements for the assessment of hydrodynamic/morphodynamic impact along the coasts appear to be inaccurate. The wave energy flux investing the coast has a strictly local character and its proper evaluation requires high-resolution reliable numerical models, whereas extreme wave conditions appears under-estimated in many hindcasts realized so far over the Mediterranean area.

Motivation of the Special Project

The aim of this project is to build a new climatic database of wind/wave regimes over the last 30-35 years (ie a hindcast), at high resolution along the coasts of the Mediterranean Sea. This will be achieved by using a cascade of state-of-the-art atmospheric and wave numerical models, forced by the best (in terms of model cycle, output temporal frequency and horizontal resolution) reanalysis data currently available (ERA5; Hersbach and Dee, 2016). This new climatic database can provide many important inputs for the Integrated Coastal Zone Management (ICZM), with a particular focus on the North-Western Mediterranean. This work will be partially connected with other ongoing initiatives, such as the MAREGOT (www.lamma.rete.toscana.it/en/maregot), project funded by the EU in the framework of the Italian-France Cross-border program, to which the LaMMA Consortium is involved as a partner. This latter project is aimed at identifying the best strategic actions for mitigating the impact of climate change along the coasts.
From a scientific point of view, the novelties of the adopted approach are related to:

- assessment of the new reanalysis metocean dataset with coastal validity (resolution up to 500 m along the coast), with no need for further downscaling;
- identification, by cluster analysis of coastal wind/wave and spectra trends over the last 30-35 years;
- archiving the full spectrum data (see Figure 2), useful for a complete spectral information; these are believed to be much more sensitive for the identification of sea climate trends;
- building a database to enable the implementation of new morphodynamic services, to help the design of scenarios linked to the impact of climate change along the coast, in order to widen the knowledge on the impacts assessed so far (such as the impact of the sea-level rise).
- evaluation of uncertainty associated with the metocean hindcast, through the full use of all ERA5 members.

The availability of a new reanalysis dataset (ERA5) at a higher resolution with respect to past datasets, is believed to give much greater reliability to specific products for coastal areas. These final downscaled products can provide both a much more accurate assessment of the wave climate along the Mediterranean coastlines, characterized by a marked variability, and possibly validate climate projection models (Hemer et al. 2013) to be able to draw more robust statistically sound conclusions.

Technical plan

From a technical point of view, the wind/wave hindcast centered over the North-Western Mediterranean Sea will be performed downscaling the reanalysis ERA5 dataset and by using a cascade of state-of-the-art numerical models based through the implementation of:

- a hydrostatic atmospheric numerical model (BOLAM model), run at synoptic scale
- a non-hydrostatic atmospheric numerical model (Moloch model), run at meso-alpha scale
- a finite element wave model (WW3 model) able to compute high-resolution waves along the coast at a resolution up to 500 meters, run at meso-beta scale

The first step will be performed with the BOLAM hydrostatic model running over the whole Mediterrenean basin at an horizontal resolution of 0.075 deg (around 8.3 km) on a rotated lat-lon grid with 60 vertical levels and a time-step of 60 s. ERA5 reanalysis will provide initial and boundary conditions and will be updated every 3 hours. The BOLAM model will be run in long-term mode with periodic central nudging to the ERA5 data and periodic model restarts (e.g. 1 week). The use of the BOLAM model is necessary to bridge the gap between the coarse resolution of the ERA5 data (around 30 km) to the higher resolution of the non-hydrostatic model Moloch model (around 2.7 km) where the convection is fully resolved.
The second step will be performed with the non-hydrostatic Moloch, nested into the BOLAM 1-hour outputs, over the central portion of the Mediterranean basin (see Figure 1 for the domains of integration) with a regular lat-lon grid of 0.0346 x 0.0247 degree of horizontal resolution (around 2.7 km) with 25 s of time-step and 50 vertical levels. The MOLOCH model will be run in quasi-operational mode with hot restarts (surface fields) every 24-36 hours.

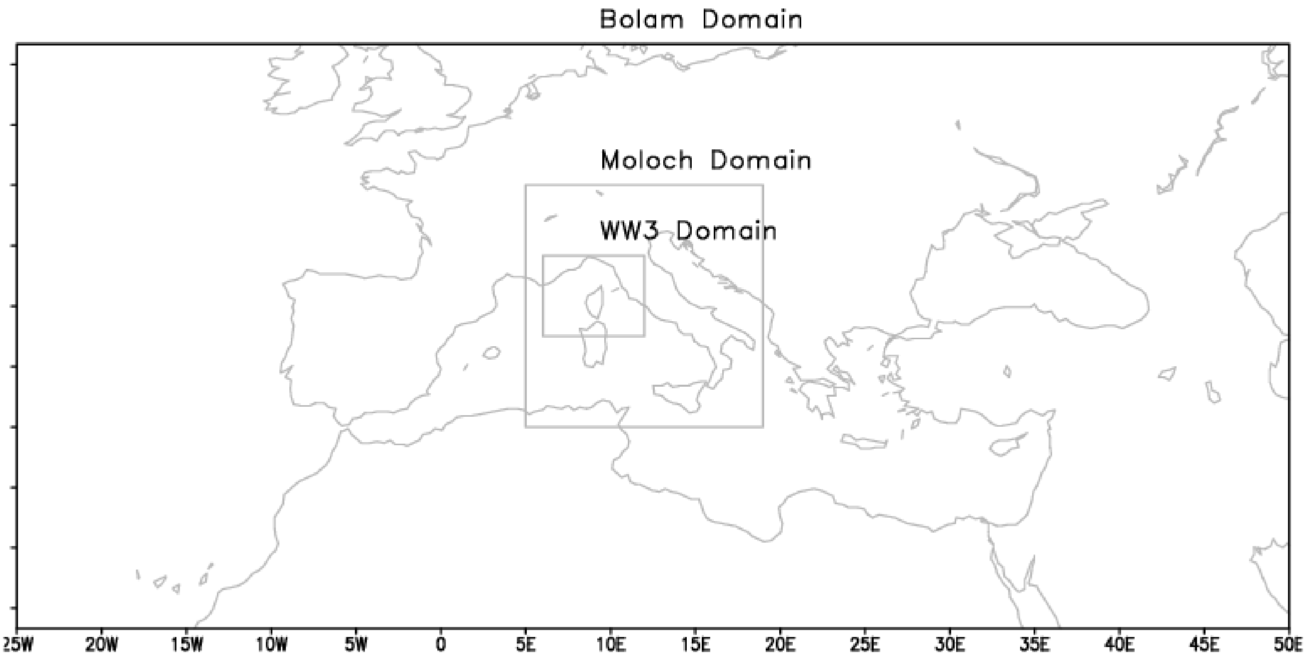

Figure 1: Domains of integration for the BOLAM, Moloch and WW3 models

The BOLAM and Moloch numerical models are running daily at Consorzio LaMMA and are used for the operational weather service. These numerical models (see Buzzi et al, 1994 and Drofa and Malguzzi, 2004) are written in Fortran 90. They are fully parallelized, applying the domain splitting technique, and are compatible with MPICH2 and OpenMP parallel computing environments.
The BOLAM and Moloch models are very efficient in terms of CPU costs, resulting at least 3 times faster than an equivalent WRF-ARW model configuration used for example in the SPITCAPE Special Project (test based on 3 nodes - 144 cores - Intel(R) Xeon(R) CPU E5-2699 v3 @ 2.30GHz).

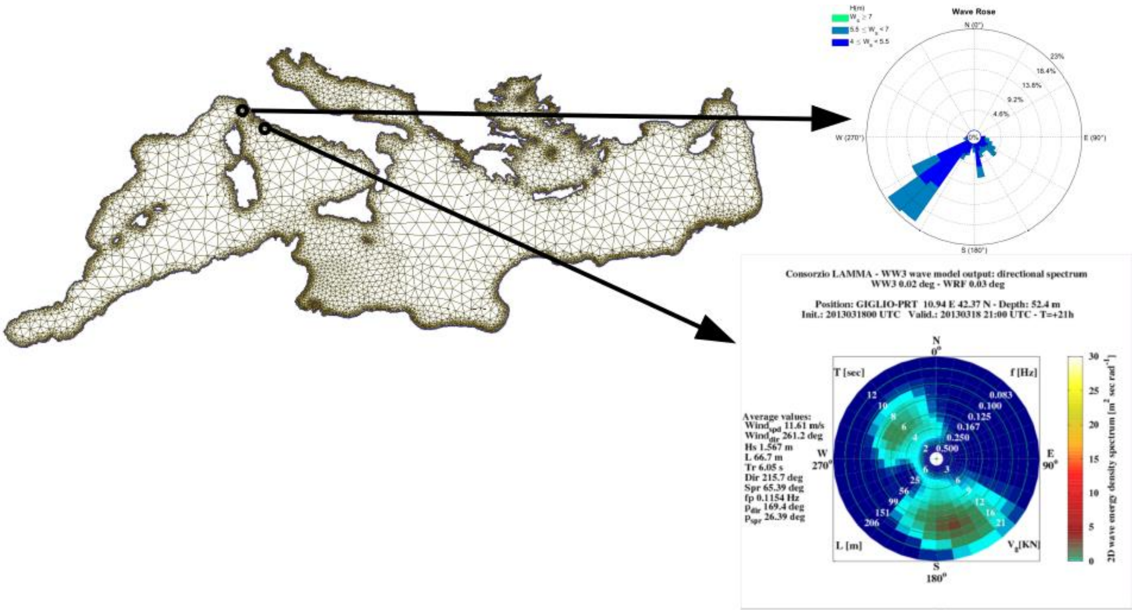

Figure 2: Example of a triangular unstructured mesh for the Mediterranean Sea, wave rose (top) and wave spectrum (bottom)

Atmospheric outputs will be with 1-hour frequency at full resolution and will be stored in raw format (ascii files on the native grid) and post-processed over a regular lat-lon grid in GriB2 format.
Relevant atmospheric fields for input to wave models are: 10 m wind speeds, temperature and atmospheric stability, but all the model outputs will be stored for possible future analysis and use.
Output data from the Moloch model will provide input data for the WW3 model (Tolman 2009). The WW3 model will be implemented using triangular unstructured grid, having different sizes that depend on their position with respect to the coast. Only coastal cells will reach 500 m resolution.

(Fig. 2). This method will avoid the need to implement wave models with multiple nesting techniques. For what concerns wave models, an important phase in the implementation of the procedure will be a proper model calibration of the chosen configuration (ERA5->BOLAM->Moloch->WW3). This will be achieved by a choice of the most suitable wave sources parameterization for a selected test period (at least 1 year). Tunable parameters can be identified inside the model options in particular for the input and dissipation source terms (such as in WAM-cycle 4). Standard model configuration (DIA, Discrete Interaction Approximation) will be used for the simulation of the nonlinear wave-wave interaction terms.
As a reference metrics to evaluate model parameters, standard statistical skills will be computed (correlation, standard deviation and RMSE) through the use of Taylor diagrams.

The computer-resource requirements have been estimated on the previous experience with the Special Project SPITCAPE and considering that the BOLAM+Moloch configuration is three times cheaper (in terms of CPU time) than the WRF-ARW configuration:

- the SBU needed to perform 1 year of wind/wave hindcast is estimated in about 300 000 SBUs, thus the whole 35-year period hindcast (1982-2016) is estimated in about 10 000 000 SBUs. The decade 2016-2007 will be performed during the first year of the Special Project (2018), the decade 2006-1997 during the second year (2019), the 15-year period 1995-1982 during the third year (2020).
- The total data storage required to store the whole 35-year period hindcast (1982-2016) is estimated in 3 TB.

References

Besio, G., Mentaschi, L., & Mazzino, A. (2016). Wave energy resource assessment in the Mediterranean Sea on the basis of a 35-year hindcast. Energy, 94, 50-63.
Buzzi, A., Fantini, M., Malguzzi, P., and Nerozzi, F.: Validation of a limited area model in cases of Mediterranean cyclogenesis: surface fields and precipitation scores, Meteorol. Atmos. Phys., 53, 137–153, 1994.
Contento, G., Lupieri, G., Venturi, M., & Ciuffardi, T. (2011). A medium-resolution wave hindcast study over the Central and Western Mediterranean Sea. Journal of marine science and technology, 16(2), 181-201.
Drofa, O. and Malguzzi, P.: Parameterization of microphysical processes in a non hydrostatic prediction model, Proc. 14th Intern. Conf. on Clouds and Precipitation (ICCP), Bologna, IT, 2004
FitzGerald, D. M., Fenster, M. S., Argow, B. A., & Buynevich, I. V. (2008). Coastal impacts due to sea-level rise. Annu. Rev. Earth Planet. Sci., 36, 601-647.
Hemer, M. A., Fan, Y., Mori, N., Semedo, A., & Wang, X. L. (2013). Projected changes in wave climate from a multi-model ensemble. Nature climate change, 3(5), 471-476.
Hersbach, H. and Dee, D. “ERA5 reanalysis is in production”, ECMWF Newsletter, Number 147 – Spring 2016
Music, S., & Nicković, S. (2008). 44-year wave hindcast for the Eastern Mediterranean. Coastal Engineering, 55(11), 872-880.
Nicholls, Robert J., and Anny Cazenave. "Sea-level rise and its impact on coastal zones." Science 328.5985 (2010): 1517-1520.
Rahmstorf, Stefan. "A new view on sea level rise." Nature reports climate change (2010): 44-45.
Short, A. D., & Trembanis, A. C. (2004). Decadal scale patterns in beach oscillation and rotation Narrabeen Beach, Australia-time series, PCA and wavelet analysis. J. of Coastal Research, 523-532.
Soares, C. G., Weisse, R., Carretero, J. C., & Alvarez, E. (2002, June). A 40 years hindcast of wind, sea level and waves in European waters. In Proceedings of 21st International Conference on Offshore Mechanics and Arctic Engineering.
Thomas, T., Phillips, M. R., & Williams, A. T. (2010). Mesoscale evolution of a headland bay: Beach rotation processes. Geomorphology, 123(1), 129-141.
Tolman, H. L. "User manual and system documentation of WAVEWATCH III TM version 3.14." *Technical note, MMAB Contribution* 276 (2009): 220.