REQUEST FOR A SPECIAL PROJECT 2021–2023

MEMBER STATE: Italy

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Project Title: ASIM-CPL - Air-Sea Interactions on the Mediterranean basin, using "atmosphere-ocean-waves" CouPLed numerical models.

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.)	2021	
Would you accept support for 1 year only, if necessary?	YES ☒	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)	10 Mln	10 Mln	10 Mln
Accumulated data storage (total archive volume)[2]	(GB)	10000	20000	25000

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] These figures refer to data archived in ECFS and MARS. 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

Background

The interactions between atmosphere and ocean play a fundamental role in the transfer of energy between the two environments and between different geographical areas (Warner et al 2010), modulating the exchanges of mass, heat, and momentum. The role of these interactions is crucial both on time scales of the order of days, and on longer, seasonal and climatological time scales (Chelton et al 2001, 2005, 2007; O'Neil et al 2003, 2005, 2010). They also act as very small (order of a few kilometers) and larger synoptic (hundreds of kilometers) spatial scales (Meroni et al 2018). These complex feedbacks, which develop at the air-sea interface, are modulated by the Sea Surface Temperature (SST), the sea wave, the surface roughness of the ocean, the air temperature, humidity and wind. Furthermore, a not negligible role is played by marine sprays that detach from the surface of the sea due to the wind and the breaking of the waves, which in addition to carrying mass, provide condensation nuclei and modulate the heat flows between the atmosphere and the ocean (Rizza et al 2018). All these variables interact with each other through the sea interface and can be described by complex equations which require a realistic description of the variables. The sampling of SST, waves, temperature, humidity and wind data in the open sea is a lot and can only be done through point measurements such as buoys, drifters and ships and satellite measurements. While the in-situ measurements are continuous over time, but limited in space, the satellite measurements cover a larger area but (in the case of polar satellites) they are not synchronized at the same synoptic instant and are subject to interference phenomena especially along the coastal areas and in semi-closed basins. This peculiarity is accentuated when studying air-sea interactions in extreme (such as strong cyclogenesis, High precipitation events and heat waves), highly localized phenomena and on very short time scales. The modeling study that aims to simulate marine and atmospheric phenomena is part of this context, starting from initial conditions provided by global numerical models which implement the assimilation of the data described above. The atmospheric, ocean and wave numerical models parameterize the variables that modulate the energy flows at the sea air interface and, in most cases, impose these variables in "static" mode. This means that for example, in the atmospheric model, the SST is provided by satellite data, averaged over 7 days (to limit the "observational holes" and errors previously described) without changing it according to the atmospheric fields and the energy fluxes produced by the atmospheric model. This involves a discrepancy between the condition at the boundary conditions and the evolution of the atmosphere. This phenomenon is amplified when very high numerical grids are used, with a horizontal resolution greater than the satellite SST data. The same problem is valid for the parameterization of the surface roughness of the sea, which is generated by the waves. Surface roughness is fundamental, and therefore the "Drag coefficient" (Cd) is fundamental for the description of heat and momentum fluxes and in the atmospheric model it is parameterized by equations that approximate Cd as a function of wind speed, without taking into account that in reality, the wave is highly variable in space and time and is characterized by different types of waves (young waves, swell waves). In addition, these parameterizations are more reliable only for narrow wind intensity ranges. The same problem also occurs in the oceanic model. The use an atmospheric forcing, produced by atmospheric simulations that have implemented satellite SSTs, inconsistent results will be obtained and not implementing the evolution of the waves you could underestimate both the size of the Mixed Layer, the kinetic energy in the ocean and the distributions and content of heat and salinity (Benetazzo et al 2013). With the increase in computational resources, the increase in observations and for a better description of the sea-air interactions, both the global models and the limited area models (LAM) are evolving to be able to describe the whole environmental system by coupling the different numerical models. In this work we set ourselves the objective of applying the coupled numerical model COAWST (), for the study of a wide variety of atmospheric phenomena with the aim of deepening the physical knowledge of extreme phenomena, the role of sea-air interactions and in order to improve their representations. Furthermore, we will apply, for the first time, the COAWST model in the context of regional scale seasonal climate forecasts. This latter is aimed at investigating the role of SST and waves on the predictability of seasonal anomalies inter-annual variability prediction. The COAWST numerical model is a complex framework that implements the coupling of the atmospheric model WRF (Weather Research and Forecasting System), the oceanic ROMS (Regional Oceanography Model) model and the SWAN wave model (Simulating Wave Nearshore) (or WW3). The study will focus on the Mediterranean basin, both because it is characterized by intense energy exchanges between air and sea (especially during the transition seasons), both for the orographic and topographical complexity, and for the intense (and very localized) atmospheric events and oceanic that develop on it. The atmospheric events chosen for this study are representative of various atmospheric configurations and seasons and we aim to quantify the impact of the role of the sea and to estimate the possible improvements made by the application of numerical models coupled atmosphere-ocean-waves and of the individual components. We will also apply the use of atmosphere-ocean-wave coupling to seasonal forecasts with the aim of understanding the role and impact of SST and OHC (Ocean Heat Content) in particular during the summer season with greater attention to the repercussions on precipitation fields, temperature and humidity on the ground.

Methodology

COAWST (Couple Ocean Atmosphere Wave System) (Warner et al 2010) numerical model is a complex framework coupling, through MCT libraries (Jacob et al 2005), the atmospheric model WRF (Skamarock et al 2008), the oceanic model ROMS (Shkepteckin et al 2005)) and the wave model SWAN (Booij et al 1999) (or WW3 in the latest versions). The purpose of numerical models coupling is to reproduce complex feedbacks characterizing air-sea interaction. The WRF model is an atmospheric state-of-art, finite-difference, three-dimensional, multi-scale and hybrid-vertical coordinate numerical model developed by NCAR (). The ROMS oceanic numerical model is also a three-dimensional finite difference model with sigma terrain-following coordinates, developed by Rutgest university, while the SWAN numerical model is a spectral model that simulate the generation and propagation of sea wave. WRF in the "standalone" version uses the Sea Surface Temperature (SST) fields as a static boundary condition (or updated every 6 hours using satellite data) and Charnock scheme for estimating sea surface roughness (Charnock et al 1955). This widely used approach presents some limitations. As far as SST is concerned, imposing a “static” field which does not change according to the energy fluxes produced by the atmospheric model is not representative of what really occurs. It also results into an inconsistent system in terms of energy budget and ocean heat content (OHC). For what concerns the estimatation of surface roughness, parameterizations included in the above mentioned scheme, represent the state of surface roughness only within a certain range of wind intensity and do not take into account the variability and types of sea waves (gravity waves, swell waves etc). COAWST allows to use these models both in "standalone" mode and with various degrees of coupling (Figure 3).
In the case of use AO approach (atmosphere-ocean coupling), atmosphere and ocean exchange SST, heat fluxes and momentum. In the case of application the AOW (atmosphere-ocean-waves coupling) approach, the wave model communicates the “geometry” of waves to the atmospheric model and to the oceanic model which, in turn, formulates the distribution of surface roughness through three different approaches: Taylor-Yelland (Taylor et al 2001), Oost (Oost et al 2002), Drennan (Drennan et al 2003).
Project’s purpose is performing a two-fold investigation of the impacts of atmosphere-ocean-wave coupling and the air-sea interactions. Firstly, on short-term extreme events forecasting. Secondly, the effect of AOW coupling on longer time scale seasonal climate forecast. The Mediterranean basin represents the study area for both the above mentioned modeling experiments. The reason behind choosing short- and mid-term applications, consists on the possibility of evaluating coupling effect on

dynamics occurring and characterizing different temporal horizons involving both the atmosphere and the ocean. A further planned step will be to take advantage of project results to carry out climatological temporal scale simulations and Pseudo Global simulations Warming Approach with high resolution coupled models (convection permitting). Methodologically, the work will be carried out using three different approaches based on Ricchi et al 2016: uncoupled (UNC), atmosphere-ocean coupled (AO), atmosphere-ocean-wave coupled (AOW), in order to isolate the effect of the different levels of coupling and the role of various environmental components. The simulations will be carried out on two different types of numerical grids for the "short-term" or "mid-term" simulations. In the first case (Figure 1) the numerical grids will be nested at a horizontal resolution of 3 km-1 km, 55 vertical levels with the first level 15 meters above the ground. The first grid (3km) covers the central portion of the Mediterranean basin, whereas the second grid, at 1 km resolution, will be located around the phenomenon studied maintaining a ratio of dimensions such as to have the same computational weight between the different cases (same number of horizontal grid points). The initialization of the atmospheric model will be based on ECMWF data at 9 km resolution and for marine and wave models, a 1-month spin-up (on external machines and based on CMEMS-Copernicus datasets) will be carried out, forced with the AOW approach. For the seasonal simulations (mid-term) the calculation grid will consist of a first 12 km horizontal resolution grid, centered over Italy and extending over the whole Central Europe and the Mediterranean basin (Figure 2) with a nesting at 4 km resolution covering the Italian peninsula with 45 vertical levels. Initial and boundary conditions will be provided by ensemble-based global-scale forecasting systems (e.g, ECMWF, NCEP). The computational resources required are estimated based on runs performed in previous projects. The amount of 10 Mln of SBU required for each year is the estimated average value. The request takes into account any slower calculation times according to the physics used for each phenomenon.

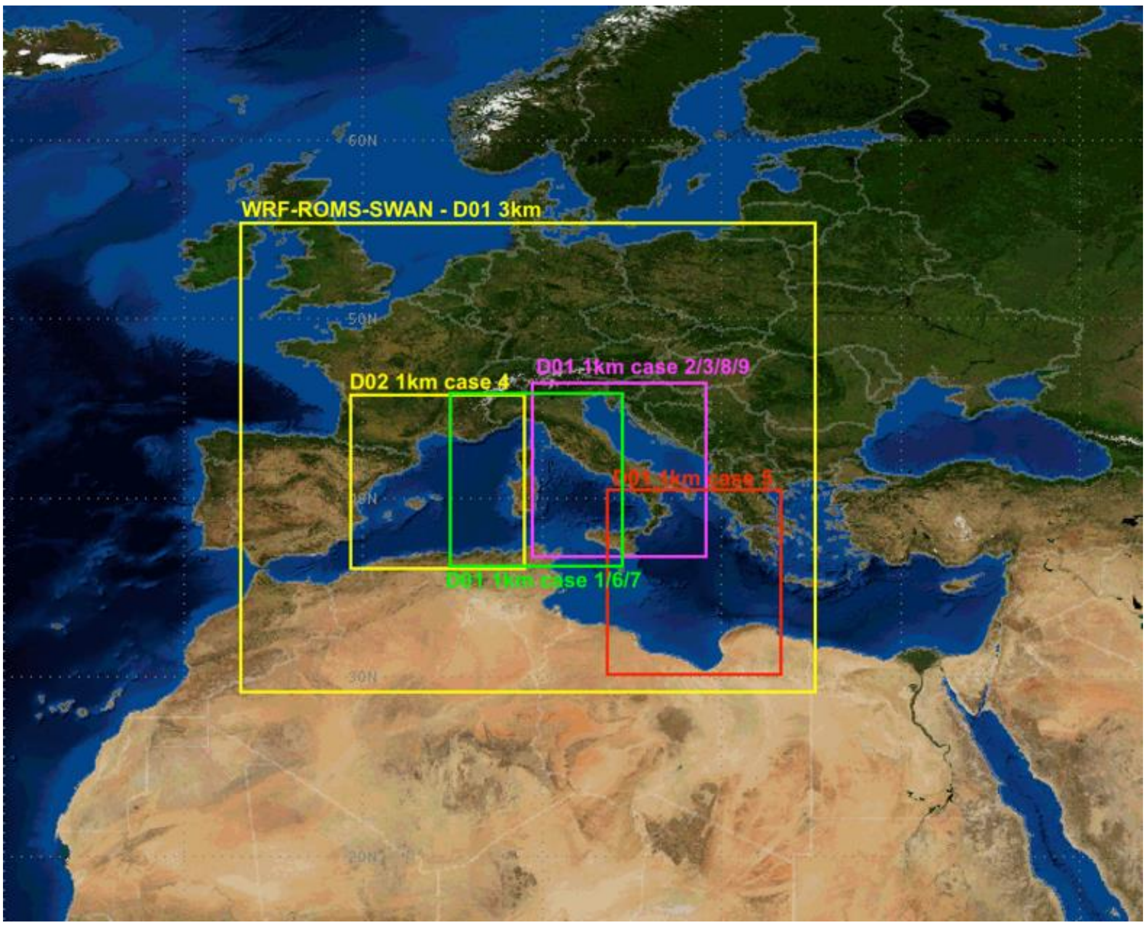

Figure 1. Numerical domain configuration for “short term” case study

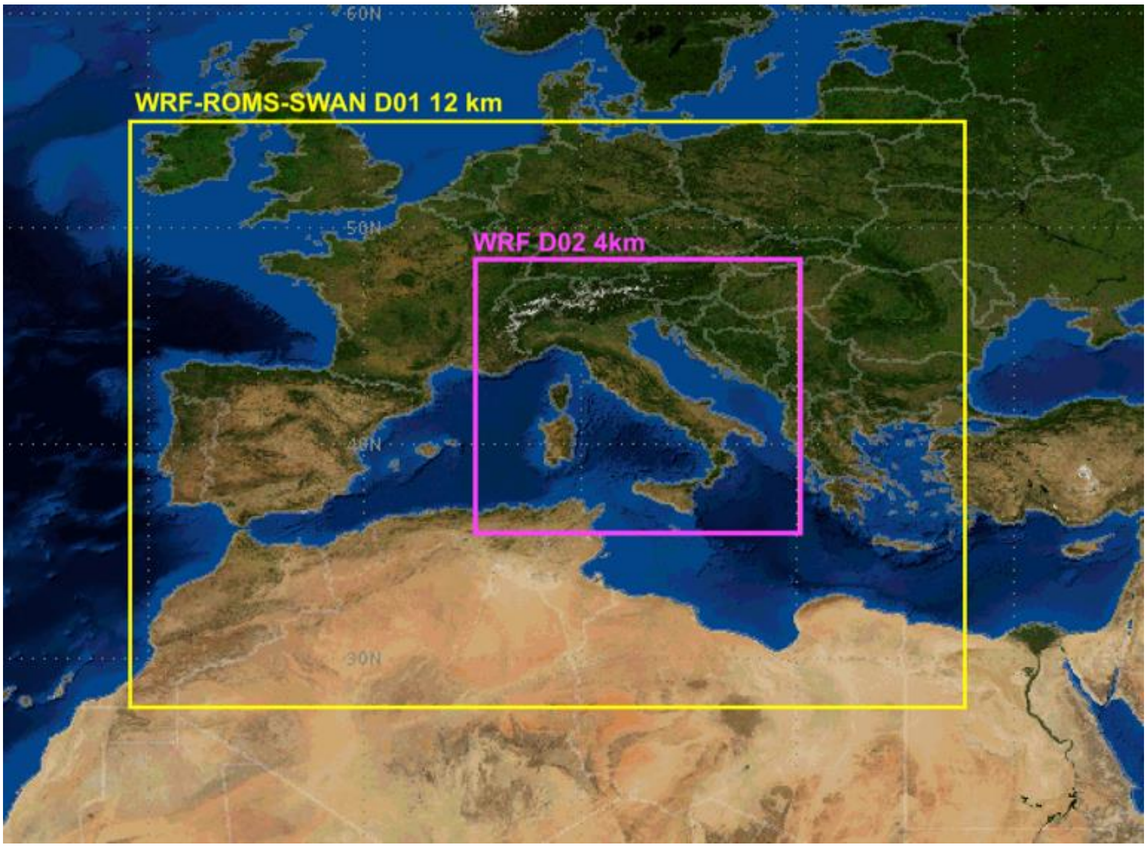

Figure 2. Numerical domain configuration for the “mid term” case study

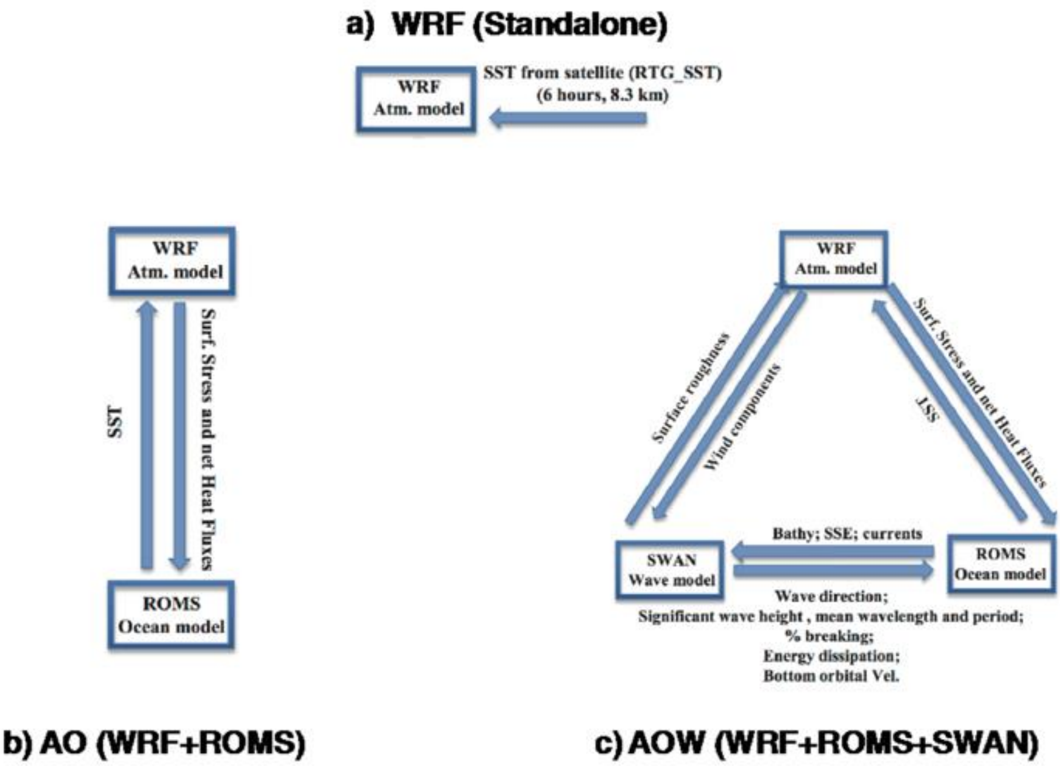

Figure 3. Taken from Ricchi et al 2017 shows the different COAWST approaches.

Proposed work and case study

The purpose of this project is to investigate the effect of atmosphere-wave-sea interactions on the Mediterranean basin, with the aid of coupled numerical models at different time scales. The study will focus on short- and mid-term temporal scale events at high spatial resolutions (Figure 1). The selected atmospheric events are representative of different levels of intensity and spatial extent. In detail, thanks to this project, we will study the role of air-sea interactions in the formation and intensification of Mediterranean cyclogenesis (extra-tropical and tropical-like) such as the Tropical-Like Cyclones Rolf and Zorbas and the "rapid-cyclogenesis" of October 2019 (VAIA storm) and December 1998. We will also focus on particularly intense and durable heat waves such as those that occurred on the central Mediterranean in August 2012 and 2013 and in July 2007 and on the role of the oceans in the formation of HPE (High Precipitation Events) such as the Flash Flood of the 10 October 2014 on the Ligurian Sea, and the hail storms of Pescara (10 July 2019) and Naples (15 September 2015). In a second phase of the work, the coupled model will be applied to seasonal simulations (Figure 2) which will be performed with a "convection permitting" approach on the Italian territory. Finally, the impact of using a coupled model will be evaluated in terms of Quantitative Precipitation Forecasts (QPF) and temperature forecasts. In this respect, two different methods will be considered: spatial- and object-oriented. The first method, that compares the observed and forecast fields, is useful to determine the scales at which forecasts become skillful. The second approach identifies the spatial patterns (objects) in the predicted/observed fields and compares them through several attributes (distance between centroid, area of intersection, orientation) that are calculated based on fuzzy logic. The object-based approach detects specific features with the aim of evaluating the ability of the model to represent them. The statistical analyses will be performed with the Model Evaluation Tools (MET) verification package (Brown et al. 2009), developed by NCAR Developmental Testbed Center (DTC).

For what concerns the seasonal forecasting, it will be assessed the capability of the downscaled simulations to improve the forecast produced by the driving global-scale system. This will be done both in terms of:

- Improving the representation of climate variable physical values considering both mean and extreme percentile values.
- Improving the predictability of anomalies inter-annual variability respect to the driving global-scale system.
- Sensitivity of the two systems to the large scale forcing provided by the global-scale system. That is, how much of the interannual variability of the downscaled simulations is triggered and driven by the global-scale forcing.

These three work phases will be performed according to the above mentioned coupling approaches (UNC-AO-AOW). Analyses will consider deterministic metrics i.e., considering ensemble mean skills (e.g., Anomaly Correlation Coefficient (ACC)) and probabilistic metrics which consider distributional properties of the ensemble members (e.g., Continuous Ranked Probability Score (CRPS) and related “reliability” and “potential” components).

- **Short term case study**:

1. Genova Flash Flood 10 Ottobre 2014
2. Pescara Hail Storm 10 Luglio 2019
3. Napoli Hail storm 15 Settembre 2015
4. Tropical-Like Cyclones “ROLF” 09 Novembre 2011
5. Tropical-Like Cyclones “Zobas” 2 Ottobre 2018
6. Rapid Cyclogenesis VAIA 29 Ottobre 2018
7. Rapid Cyclogenesis 28 December 1998
8. Heat Wave 2-9 Agosto 2013
9. Heat Wave 18-25 Agosto 2012
10. Heat Waves 17-24 Luglio 2007

- **mid-term case study** consist on simulating a climatological period of at least 20 years. On a first step only winter season will be considered.

Resources

The computational resources required will be used to perform the simulations with the numerical model COAWST in the Uncoupled (UNC) and coupled (AO-AO) approach. The use of the coupled model requires greater computational resources than the use of the uncoupled model. This is because, in addition to the simultaneous execution of multiple numerical models, the data exchange times between models are added. The increase in machine time in the AO approach is approximately double compared to the UNC case, and in the AOW application the calculation times are approximately tripled. In order to achieve the proposed goals, we estimate a computational cost of about 10 MSBU per year. The short-term simulations proposed will be between 2 and 5 days long and the computational weight is estimated taking into account the physical settings used for each case. The "mid-term" simulations have a lower horizontal resolution but will be longer, and use the "perfect-restart" technique.

Cases	**Uncoupled**	**Atm-Ocean**	**Atm-Ocean-Waves**
Case 1-9	2 mln SBU	4 mln SBU	6 mln SBU
Case 10	3 mln SBU	6 mln SBU	9 mln SBU

Table 1. The table shows the estimates of the calculation resources necessary for each simulation, taking into account a margin of machine-time necessary for the optimal configuration of the runs.

Workplan

i) Configuration of the COAWST model
ii) Creation of numerical grids and initial/boundary conditions for each event and for each model
iii) Spinup of the oceanic and wave model, for each coupled approach
iv) **"Short Term"** - execution of "UNC" runs
v) Validation and analysis of the results and of the physical approach used
vi) Run of the AO-AOW simulations
vii) **"mid-term"** - configuration of the calculation grids
viii) Creation of initial conditions
ix) Runs seasonal UNC simulation
x) Debug and validation of UNC simulation
xi) Run of AO-AOW seasonal simulation

Involved Software

- WRF-ROMS-SWAN/WW3
- COAWST model
- Model Evaluation Tools (MET)
- Required module : Intel compiler, netcdf4, jasper, zlib, szip, mpich
- Compilation of the COAWST package does not require any additional support compared to the compilation of the WRF model. The requests are the same as the other models.

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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.