REQUEST FOR A SPECIAL PROJECT 2019–2021

MEMBER STATE: …………………Italy……………………………...…

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Project Title:

Towards seamless development of land processes for Earth System prediction and projection ……………………………….……

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.)	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)	5.5 milllion	5.5 million	5.5 million
Accumulated data storage (total archive volume)[2]	(GB)	15500	31250	47000

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.

Principal Investigator: ....

Project Title: ....

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.

The Italian National agency for new technologies, Energy and sustainable economic development (ENEA) is member of EC-Earth (Consortium of research institutes from 10 European countries to collaborate on the development of an Earth System Model), partner in several international efforts including European Union H2020 projects and in WCRP activities in the context of the Coupled Model Intercomparison Project (CMIP6) as well as new WCRP initiatives aimed at evaluating the impact of including Earth System processes over land (from the latest Earth System Model developments in the frame of CMIP6) on the skill of short-term climate forecasts by state-of-the-art dynamical prediction systems (e.g GLACE-ESM, https://tinyurl.com/GLACE-ESM, and LFMIP-Pobs, https://wiki.c2sm.ethz.ch/LS3MIP).
ENEA is partner in the European Union H2020 project CRESCENDO (Research in Earth Systems and Climate: Experiments, kNowledge, Dissemination and Outreach). The aim of CRESCENDO is the improvement of the process representation and simulation quality of European Earth System Models (ESMs) and ENEA contribution is particularly aimed at improving the representation of land surface processes in the EC-Earth ESM.
ENEA is also partner in the Circulation and Climate Change (C3) consortium for the H2020 project proposal that addresses LC-CLA-08-2018a call (in stage 2 of evaluation) to Improve the understanding of key climate processes for reducing uncertainty in climate projections and predictions.

The climate prediction group of the Barcelona Supercomputing Center Earth Sciences department (ES-BSC) undertakes advanced research to forecast climate variations from one month to several years into the future (also known as seasonal-to-decadal predictions) and from regional to global scales. The climate prediction group coordinates the work of the Climate Prediction Working Group of the EC-Earth consortium and is responsible for generating and disseminating Initial Conditions (ICs) used to initialize climate prediction experiments using the EC-Earth model.

The Royal Netherlands Meteorological Institute (KNMI) is coordinating a new H2020-MSCA project, PROCess-based sEamless development of useful Earth system predictions over lanD (PROCEED), which aims to achieve improved Earth system predictions on multiple time scales by filling the gap between the models used for short-term prediction (verification-based) and the latest developments in the Earth System Models (process-based).

The objectives of this special project are (i) to include the representation of the Earth System processes and feedbacks over land (from the latest Earth System Model developments in the frame of CMIP6 and beyond) that can suitably contribute to the the short-term climate predictions performed using EC-Earth (Hazeleger et al., 2012), (ii) to evaluate the impact of including Earth System processes over land on the skill of the retrospective seasonal forecasts, (iii) to contribute towards new frontiers in the seamless development of Earth system predictions/projections across multiple time-scales.

Towards improved Earth System Predictions over land

Several works have been showing the importance of the land biosphere (i.e. vegetation/land cover including anthropogenic effects and land-use changes) in forcing interannual climate anomalies (Alessandri and Navarra 2008) and in modulating the forcing from soil moisture (Catalano et al., 2016) or snow (Loranty et al., 2014). In particular, a recent paper by Alessandri et al. (2017) showed significant effects of the representation of realistic vegetation-cover anomalies in the prediction of temperature and precipitation at multiple time-scales. Large effects have been shown at multiple time-scales [seasonal hindcasts, decadal (5-years) potential predictions and in a 4-day NWP case-study for spring 2015] over boreal winter middle-to-high latitudes due to the implemented time-varying shadowing effect by tree-vegetation on snow surfaces. Significant multi-scale improvements of the prediction of 2m temperature and rainfall have been also shown over transitional land surface hot spots (Alessandri et al., 2017).
Earth System Models (ESMs) development has seen in the last decade an accelerated effort for the land biosphere and the atmosphere chemistry components [e.g. Myhre et al., 2013; Eyring, et al., 2016.]. Up to date land surface models prepared for the forthcoming CMIP6 exercises are therefore implementing detailed description of (i) interactive or prescribed dynamics of natural vegetation, (ii) changes of anthropic land cover and land use changes from historical reconstructions, and (iii) including anthropogenic forcing such as representation of CO2 fertilization, of water flux from irrigation over croplands, of anthropogenic crop fertilizers and of the effects from atmospheric nitrogen deposition. However, there is still a gap between the models used for short-term prediction and the latest developments in modeling the land surface that is believed to considerably limit the current level of performance and usefulness of predictions. In fact, the models that are developed for short time-scales (Weather and seasonal) include only that part of the surface and near-surface variability for which observations have been routinely available during the last decades and that can be suitably modeled/initialized in order to positively contribute to the forecasts (verification-based approach). Therefore, to limit prediction errors, short time-scale models did not include so far those processes related to biosphere and their seasonal, interannual and sub-grid variability. Even the ECMWF seasonal prediction system (from which EC-Earth is based) appears ill-equipped for this task. In fact, the land surface model developed at ECMWF (HTESSEL; van den Hurk et al., 2003; Balsamo et al. 2009), and included in the ECMWF Integrated Forecasting System (IFS; Molteni et al., 2011), assumes land cover, vegetation characteristics, and modeled snow-free albedo to be constant in time, therefore evidencing considerable biases and weak prediction signal over the interested land areas (Weiss et al., 2012).
There is no scientific basis to draw artificial boundaries between synoptic-scale numerical Weather forecast, seasonal prediction, ENSO prediction, decadal prediction and climate change (Shukla 2009; Brunet et al., 2010). In fact, as highlighted in the WCRP Strategy for 2005-15 (WCRP 2005), WCRP Strategy and Priorities: Next Decade (Asrar et al., 2013) and WMO Book on Seamless prediction (WMO 2015), the Earth System exhibits a wide range of dynamical, physical, biological, and chemical interactions involving spatial and temporal variability continuously spanning all weather/climate scales. Therefore, the gaps

between the models used for short-term prediction and the latest developments in modelling the land Earth system processes are believed to considerably limit the current level of performance and usefulness of predictions.

Planned experiments and analyses

An improved representation of the Earth System processes and feedbacks over land (from the latest Earth System Model developments in the frame of CMIP6 and beyond, i.e. also including the developments in the framework of ongoing H2020 projects) will be incorporated in the seasonal hindcasts performed using EC-Earth. Thereafter, by employing the two-way strategy that is being developed in the frame of the H2020 PROCEED project (http://projects.knmi.nl/proceed/), the verification at the seasonal time scales will provide knowledge back to better constrain the land processes also for the longer projection time-scale.
The Autosubmit software (Manubens-Gil et al., 2016) will be used to manage the workflow and ensure a uniform and optimal use of the resources.

Seasonal climate hindcasts:
Building from already established efforts (e.g. SNOWGLACE, LFMIP-Pobs), a set of soil-moisture and snow initialized hindcasts (covering some portion of the satellite-era) will be taken as the reference to further quantify the impact of land Earth System processes on seasonal forecasts. Long memory biophysical states will be either persisted (from available satellite observations prior of the onset of the hindcast) or (optionally) initialized and dynamically simulated by the land models. These states or processes will possibly include:
-Natural Vegetation density (Leaf Area Index) and effective vegetation fractional covers
-Interannual Land cover/Land use changes from historical reconstructions
-Water flux from irrigation over crop areas
-Anthropogenic CO2 fertilization and use of crop fertilizers (implicit in the LAI and land cover or [optional] explicit)
-Nitrogen deposition
-Fire occurrences

The new set of retrospective forecasts will be compared with control seasonal hindcasts that are already planned at BSC (in the framework of APPLICATE and other projects) and expected to be completed by mid 2019.

Climate projection:
The two-way strategy that is being developed/tested in the frame of the H2020 PROCEED project (http://projects.knmi.nl/proceed/) will be employed in order to provide knowledge back to the longer time-scales. To this aim, the verification at the seasonal time scales will be used to better constrain the land processes for the climate-projection simulations. To this aim, we'll also exploit the latest generation land-biosphere data [Essential Climate Variables (ECVs) over land to be provided as part of the implementation of the Global Climate Observing System (GCOS); GCOS-WMO, 2016] from satellite campaigns in order to identify the observational emerging constraints to the land biophysical feedbacks on climate change and variability/predictability. This will provide fundamental information to address the major gaps in understanding and modelling the Earth System processes that are expected to have considerable effects in shaping the atmosphere-land feedbacks on climate change and variability/predictability.
For the climate projection time-scale, following the LS3MIP protocol (Hurk et al., 2017) aimed at disentangling the contributions of land surface coupling to atmospheric variability, we'll perform sensitivity experiments, using EC-Earth, with and without the inclusion of the

interactive land Earth System processes. Following Seneviratne et al. (2013), a set of climate projections will be carried out, where land Earth system states are prescribed from a climatology derived from “present climate conditions” (1980-2014), aiming at diagnosing the role of land-atmosphere feedback at the climate time scales. At least the sensitivity to prescribed climatology of vegetation/land cover and land-use (including irrigation and CO2/NO2 fertilization) from present-climate conditions (1980-2014) will be performed, and will be compared with a standard set of climate projections that interactively simulate the Earth system changes following the scenario pathway.

Summary of experiments and resources

The summary of experiments planned in this project is reported in Table 1.

Experiment name	Description	Start	End	Start dates (years)	Ens	Frcst length	Total years	Schedule
Preliminary testing	Testing land parameterization, forcing and initialization/spin-up	-	-	-	-	-	50	2019
Seas-EXP	seasonal hindcasts with additional Earth System processes	1982	2015	1st May and 1st Nov (33x2)	10	6 months	260	2019
							70	2020
PROJ-EXP	(i) Historical and (ii) scenario run with improved Earth System representation	1900	2100	-	(i) 1 (ii) 2	-	160	2020
							160	2021
PROJ-CTL	scenario run with prescribed 1980-2014 climatological Earth System states	1980	2100	-	2	-	85	2020
							155	2021

Table 1: Summary of the Experiments planned in this project, total years of simulation and indicative schedule.

Overall, we plan to perform a total of 940 years of simulations at T255 horizontal resolution (corresponding to approximately 80 km lat x lon) and 91 vertical levels in the atmosphere, and ORCA1 grid in the ocean (irregular grid corresponding to nominally an average of 1 deg lat x lon) with 75 vertical levels.

The scheduling of the simulations is as follows:
-2019:, [Preliminary testing] (50 years) of the configuration of the land model/forcings and of the autosubmit software for the management of the workflow. Partial execution of a first set of seasonal hindcasts [Seas-EXP] (260 years); TOT 2019 = 310 years

-2020: Completion of seasonal hindcasts [Seas-ESP] (70 years), Partial execution of historical-projection simulations [PROJ-EXP] (160 years) and of of [PROJ-CTL] (85 years); TOT 2020 = 315 years

-2021: Completion of scenario runs Proj-ESP (160 years) and Proj-CTL (155 years); TOT 2021 = 315 years

Configuration and justification of resources

We will use EC-Earth3.2 in the standard configuration: IFS cycle 36r4, NEMO 3.6, LIM 3, LPJG v4, OASIS3-MCT and XIOS 2 (input/output server). The default resolution is T255 with 91 vertical levels in the atmosphere, and ORCA1 with 75 vertical levels in the ocean. Based on the extensive evaluation performed in the framework of the EC-Earth consortium using EC-Earth 3.2beta (Boussetta et al., 2016), the optimal configuration on cca is obtained by using 11 nodes, i.e. 396 total cores. The processors are allocated such that 216 are for IFS, 108 for NEMO, 1 for XIOS and 1 for the runoff mapper. With this optimal configuration, we estimate that the model requires about 16600 SBUs per year. Overall, the total resources estimated for the project is rounded to 16500000 SBUs, which includes a small buffer of 5% to account for failing jobs that will need to be repeated (See simulation summary reported in Table 2).

Experiment name	Years of simulation
Preliminary testing	50
SEAS-EXP	330
PROJ-EXP	320
PROJ-CTL	240
5% buffer	47
Total Years of simulation	987

Table 2: Summary of experiments planned in this project and corresponding counts of years of simulation

For comparison, the computing resources allocated (2nd column) and used (percent with respect to allocated; 3rd column) for the previous special project (SPITALES; https://www.ecmwf.int/sites/default/files/special_projects/2016/spitales-2016-request.pdf) in 2016 and 2017 are reported in Table 2.

Table 2. Use of SPITALES resources during the previous years of the project.

Year	Allocated budget	Percent used (with respect to request)
2016	4 Million	101%
2017	5 Million	90%

The storage (atmosphere+ocean) required is about 50 GB per year of simulation assuming 6-hourly output storage for the atmosphere and monthly means for the ocean. Therefore, the total storage required for the project is 47000 GB

In case additional resources will become available through applications to PRACE and analogous programmes, further simulations will be performed to possibly enlarge the sampling for the experiments described in Table 1, i.e. increase the number of ensemble members, increased hindcast length, and/or increased number of start dates.

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