REQUEST FOR A SPECIAL PROJECT 2022–2024

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

Principal Investigator[1]: ……Andrea Alessandri …………………………………….……

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Project Title: Exploit observations to constrain land cover, vegetation and hydrology processes for improved near-term climate predictions over land

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.)	2022	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2022-2024: (To make changes to an existing project please submit an amended version of the original form.)		**2022**	**2023**	**2024**
High Performance Computing Facility	(SBU)	8000000	11000000	-
Accumulated data storage (total archive volume)[2]	(GB)	40000	70000	-

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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Project Title: …Exploit observations to constrain land cover and hydrology processes for improved near-term predictions over land …………

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 Advisory Committee. The evaluation of the requests is based on the following criteria: Relevance to ECMWF's objectives, scientific and technical quality, 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 3,000,000 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.

The Institute of Atmospheric Sciences and Climate at the National Research Council of Italy (ISAC-CNR) is member of EC-Earth (Consortium of research institutes from 10 European countries to collaborate on the development of an Earth System Model), where it coordinates the Land and Vegetation working group and the CMIP and Tuning working group. ISAC-CNR is partner in several international efforts including European Union H2020 projects, WCRP activities in the context of the Coupled Model Intercomparison Project (CMIP6) as well as new emerging initiatives such as a proposal for a GEO Community Activity aimed at exploiting latest land observations to improve and better constrain Earth system predictions. ISAC-CNR is partner in the European Union H2020 project CONFESS ("**Con**sistent representation of temporal variations of boundary **f**orcings in reanalys**es** and **s**easonal forecasts"). The aim of CONFESS is the improvement of the near-term climate prediction by enhancing the representation of Earth system processes and ISAC-CNR contribution is particularly aimed at seamlessly improving the representation of land cover, vegetation and hydrology components in the land model used in the EC-Earth ESM and the ECMWF IFS.

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 Italian National agency for new technologies, Energy and sustainable economic development (ENEA) is member of the EC-Earth consortium, contributing in particular to the activities of Land & Vegetation and Climate Prediction working groups. ENEA is taking part in the activities of CMIP6 and is partner in EU H2020 projects and several other international efforts.

In a set of prediction experiments performed in a previous special project (SPNLALES), it was shown that improved representation of vegetation variability can enhance the skill of decadal climate predictions in EC-Earth (Hazeleger et al., 2012; Doscher et al., 2021). This motivates further experimentation to include better representation of land cover, vegetation dynamics and hydrology to further enhance decadal climate predictions. To this aim, the objective of this special project is to exploit the latest available observational data over land to improve the representation of processes related to land cover, vegetation and hydrology that can positively contribute to skillful near-term climate predictions. Parameter-fitting and/or inverse modelling techniques will be employed to better constrain the land surface parameterizations to the available observations followed by careful verification that will be first conducted off-line through ERA-5 forced land-only simulations. Finally, a set of decadal predictions with enhanced representation of land cover, vegetation and hydrology processes will be performed to assess the improvement of the predictions.

Enhance representation of land cover and vegetation/hydrology processes for improved near-term predictions

Given the unprecedented land surface global-scale information that are being issued by the latest satellite campaigns [GCOS-WMO, 2016], the Earth prediction community have no excuses for not planning a substantial development/revision of our land surface models by properly constraining land surface parameters and develop more reliable processes representation based on observations. To this aim, the latest land surface observational data from the Copernicus programme and other international sources will be exploited to obtain better-constrained representation of land cover, vegetation and hydrology processes in the land surface model included in EC-Earth (HTESSEL-LPJGuess; Alessandri et al., 2017, 2021; Miller et al., 2021).
The satellite observations from the Copernicus Land Monitoring Service (CLMS; https://land.copernicus.eu/) of land-cover (based on ESA-CCI; ESA, 2017) and of the vegetation state expressed by the Leaf Area Index (LAI; Verger et al., 2014) along with the green Vegetation Fractional Cover (FCOVER; Baret et al., 2013) will support the improved representation of the processes related with land cover and vegetation dynamics in climate models. The unprecedented availability of consistent datasets for the period 1993-onwards will permit to close gaps between short-term prediction and latest developments in land modelling for long-term climate simulation/projection. An improved parametrization will be developed to model the vegetation effective cover variability as a function of vegetation state (e.g. Lambert_Beer Law based on LAI and vegetation clumping index; Chen et al., 2005) for each of the vegetation types described by the land cover classification. Consistent with the land cover/vegetation developments, the hydrological processes will be constrained using river discharge observations (Global Runoff Data Centre; https://www.bafg.de/GRDC/EN/02_srvcs/21_tmsrs/riverdischarge_node.html) and surface fluxes from stations (Fluxnet towers; Pastorello et al., 2020) and global gridded datasets (FLUXCOM; Jung et al., 2019). A climate-controlled root zone parameterization will be designed to shape the soil water storage capacity according with the Memory Method (van Oorschot et al., 2021). If possible, the irrigation over crop areas (as identified by ESA-CCI LC) will be as well accounted for in HTESSEL.

Planned experiments and analyses

Each development in the HTESSEL-LPJGuess land surface model will be first evaluated offline and carefully benchmarked by performing land-only simulations forced by ERA5 meteorology and fluxes. The assessment of the impact of each improvement in the parameterizations of HTESSEL-LPJGuess will be done by comparing offline model outputs with observational data, such as river discharge observations from the Global Runoff Data Centre, satellite soil moisture from ESA-CCI, observationally derived evapotranspiration and sensible heat flux from FLUXCOM and C3S satellite surface albedo.
The EC-Earth ESM with the improved land surface representation will be used to perform a sensitivity experiment (hereinafter DCPP-sens) covering a subset of the tier-1 (Component A1) decadal hindcasts already performed in the framework of DCPP. The additional DCPP-sens set of decadal hindcasts will allow to assess the effect of the improved representation

of land surface by comparison with the control DCPP hindcasts (DCPP-ctrl) already performed as part of BSC's contribution to DCPP (DCPP - Component A1).
The usefulness of the improved decadal hindcasts (DCPP-sens) will be evaluated with respect to the prediction of the basin-scale surface-climate and hydrological variables as compared with the available observations. As shown by Chikamoto et al. (2015; 2020), soils act as an integrator and natural low-pass filter of white noise precipitation variability, leading to long-term predictability (several years) of basin-scale soil water and associated hydrological quantities such as river runoff and basin-scale evapotranspiration.

Summary of experiments and resources

Offline land-only simulations:
Each development in the HTESSEL-LPJGuess land surface model will be evaluated in offline simulations at the same horizontal resolution of the coupled simulations (T255) but forced by ERA5 meteorology and fluxes for the period 1979-onward. It is envisaged that 40 sensitivity simulations of 50-years (including adequate spinup) will cover the benchmarking of all the HTESSEL-LPJGuess developments being tested, including the updated land-cover, vegetation and hydrology parameterizations. The off-line simulations are planned to be accomplished during 2022.

Coupled decadal hindcasts:
Overall, the improved set of decadal (5-years) hindcasts (DCPP-sens) will cover at least 20 start dates in the recent 1993-2015 period, i.e. when reliable satellite-derived vegetation observations are available. Selection of the start dates will also follow from an in-depth evaluation of the available satellite-derived vegetation observations, so that the years when vegetation is expected to have the strongest impact will be identified. For each start date, we will perform ensembles of 10-member hindcasts, of 5-year forecast-length each, for a total of 1000 years of simulation The simulations will be performed using EC-Earth at T255 horizontal resolution (corresponding to approximately 80 km in latitude and longitude) 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 simulations are planned for the second half of 2022 and first half of 2023; no additional HPC resources have been requested for year 2024.

Configuration and justification of resources.

Offline land-only simulations:
We will use the offline version of HTESSEL-LPJGuess with an interface to prescribe meteorological fields from observations/reanalysis obtained from the latest OpenIFS release (https://www.ecmwf.int/en/research/projects/openifs). The same reference cycle of HTESSEL is used as for the coupled decadal hindcasts (IFS cycle 36r4). No parallelization of the code has been included so far in offline mode, therefore requiring on cca 200SBU per year of simulation.

Coupled decadal hindcasts:
We will use EC-Earth3.3 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, 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 16900 SBUs per year. Overall, the total resources estimated for the project is rounded to 18560 SBUs per year, which includes a small buffer of 10% to account for the migration to

the new Atos machine in Bologna in early 2022 and for failing jobs that will need to be repeated (See simulation and resource cost summary reported in Table 1).

Experiment name	Description	Start dates	Ensemble members	Resource per year (kSBU/yr)	Total years	Total resource (kSBU)	Schedule
Offline land-only	Offline HTESSEL land surface model simulations for benchmarking.	-	-	0,20	2000	400	2022
DCPP-sens	Decadal prediction experiment with improved vegetation sensitivity	20	10	16,9	400	6800	2022
					600	10100	2023
10% buffer						1700	
Total						**19000**	

Table 1: Experiments planned in this project, resource costs (kSBU) and scheduled year of simulation. See text for details.

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/2019/spitales-2019-request.pdf) in 2019 and 2020 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)
2019	6.5 Million	106%
2020	5.5 Million	91%

The storage requested by the land-only simulations is 10 GB per year of simulation assuming 3-hourly output storage, leading to a total storage estimate for the offline simulations of 20000 GB.

The storage for the coupled decadal hindcasts (atmosphere+ocean) reaches 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 hindcasts is rounded to: 50000 GB.

In case additional resources will become available through applications to PRACE and analogous programmes, further simulations will be performed with enlarged sampling (i.e. increase the number of ensemble members from 10 to 20), increased hindcast length (10 years instead of 5 years), and/or increased number of start dates.

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