REQUEST FOR A SPECIAL PROJECT 2024–2026

MEMBER STATE: Portugal...

Principal Investigator[1]: Rita Margarida Cardoso...

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Daniela Lima ....

Project Title: Impact of Land-Use Changes on Past and Future Regional Climate over the EURO-CORDEX domain ....

To make changes to an existing project please nalsubmit an amended version of the original form.)

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.)	2024.	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for project year:		**2024**	**2025**	**2026**
High Performance Computing Facility	[SBU]	35.000.000	35.000.000	35.000.000
Accumulated data storage (total archive volume)[2]	[GB]	60.000	120.000	180.000

EWC resources required for project year:		**2024**	**2025**	**2026**
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]			

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.
[3]The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

Principal Investigator: Rita Margarida Cardoso

Project Title: Impact of Land-Use Changes on Past and Future Regional Climate over the EURO-CORDEX domain

Abstract

In the latest Intergovernmental Panel on Climate Change report (IPCC AR5), climate change assessments have an inherent uncertainty which has not significantly decreased over the last three reviews. Additionally, several of the new generation CMIP6 models show stronger warming than their CMIP5 counterparts. This raises the question of their accuracy in the representation of the climate system, relevant for the description of past climate, but more significant to the expected change due to future anthropogenic emissions. Land use and land use changes (LUC) contribute extensively to the overall uncertainty and although their impact can be as large as the greenhouse gas emissions, they are often neglected.

The Earth's surface interacts with the atmosphere through exchanges of heat, momentum, and moisture across the land-atmosphere interface. These exchanges are represented, in climate models, via land surface models being an additional source of uncertainty. The uncertainties stem primarily from missing physics and to the different parametrization schemes used to represent similar processes. Aerosol dynamics and groundwater flow are other processes commonly missing in long-term climate simulations and play a major role in cloud formation, radiative and moisture fluxes. Parameterization schemes for various plant and soil types and their distribution across model grids have a large impact on model performance even in idealised experiments with prescribed vegetation.

The new generation of the WRF model, interactively coupling the atmosphere with further components of the earth system (terrestrial biosphere and hydrosphere), will be used to generate high-quality climate projections for Europe, gaining insight into the systematic errors in the reproduction of the land-atmosphere feedbacks and identify robust biophysical impacts of LUC in regional climate variations. Several climate scenarios will be simulated to provide an uncertainty range of past and future climate change.

The overall objective of this project is to disentangle the impacts of LUC from the effects of greenhouse gases in current and future climate, at regional and local spatial scales. The project seeks to improve the understanding of the influence of surface-atmosphere coupling in the main drivers of atmospheric variability. Since a robust analysis of climate change impacts can only be performed in an ensemble framework, the results from this project will contribute to the ensemble of regional climate simulations of the coordinated Flagship Pilot Study "LUCAS" (Land Use & Climate Across Scales) for Europe. The project seeks to (i) assess the model's ability to reproduce land/atmosphere interactions and extreme events (e.g., droughts, heatwaves, floods) for the current climate, with or without transient land-use; (ii) characterise the impact of land-use changes of future climate and on the climate change signal.

Motivation

Land use/land cover change (LUC) has been recognised as a main driving force of regional and global climate change (Pielke et al 2011, Mahmood et al 2014), modifying local land surface properties (e.g., surface albedo, Bowen ratio, and roughness) that control the land-atmosphere mass, energy, and momentum exchanges. The impact of these changes depends on the scale and nature of land cover changes. However, the influence of this change in climate is still relatively unknown (Davin et al 2010). Increasingly sophisticated Earth System Models (ESM) have been developed in order to explore the biogeophysical impacts of LUC. Ducroudré et al (2012) observed that, for several variables, LUC has an impact of similar magnitude but of the opposite sign, to increased greenhouse gases and warmer oceans. Breil et al. (2020), in an analysis of six RCMs exposed large inconsistencies in the LUC impacts. Despite the use of common land-use maps, the differences in the implementation of LUC, and the representation of vegetation phenology led to contradicting results. Pitman et al. (2009) highlight the need for common LUC across a large ensemble of models to obtain a robust assessment of the biophysical impacts of LUC on climate.

Regional Climate Models (RCMs) have been used to downscale ESMs and realistically represent regional to local scale processes (Rummukainen 2010). The challenges for RCMs include the creation of Regional Earth System Models by incorporating coupled ocean models, water-table, dynamic vegetation, and variable aerosols, as well as other components. An additional challenge is the use of high resolution (<12 km), but such finer resolution requires careful attention both to numerical aspects and to physical parameterizations suitability (Arritt and Rummukainen 2011). The WRF model is increasingly used as an RCM for continental to local scale climate simulations, correctly describing climate statistics in different regions (Soares et al 2012a, Cardoso et al 2013, Katragkou et al 2015). Leung et al (2006) recommended the advance of WRF towards a Regional Earth System Model to address a wide range of science questions specific to regional-scale processes. Examples include the interactive coupling of the RCM with an ocean model to represent air-sea interactions and the comprehensive treatment of land surface and hydrological processes to enable a better description of land-atmosphere feedbacks.

The spatial fragmentation of land use dynamics in Europe requires fine-scale modelling techniques, and their biophysical impacts on climate are often dominant on local to regional scales. Subgrid-scale heterogeneity, however, is rarely incorporated explicitly in climate models (Pielke and Niyogi 2010). Such models often assume homogenous subgrid landscapes and fail to characterize key land surface forcing variables on local and regional scales (Avissar and Pielke

1989). Spatiotemporal patterns of landscapes should be taken into account in order to accurately assess the climatic effects of LUCC and develop adaptation and mitigation strategies (Georgescu et al 2014). The representation of subgrid-scale land surface heterogeneity can be mitigated through very high-resolution and often LSMs are used offline in order to solve the subgrid scales. However, the discrepancies observed by Ducroudré et al (2012) suggest that offline evaluation though necessary should be complemented by the evaluation of the same model coupled to the atmosphere.

Through soil moisture and vegetation changes, the land-atmosphere coupling contributes significantly to the evolution of extreme events (Seneviratne et al 2006, Fisher et al 2007, Ward et al 2011). and can lead to the development of mesoscale circulations that may intensify/suppress convection and feedback to large-scale circulations. Yet the heterogeneity of land use representation in current land surface schemes (LSM) leads to contradicting results even under idealised experiments (Davin et al. 2020, Breil et al. 2020). Additionally, most of the current LSMs lack any representation of regional groundwater which is relevant to soil drainage and moisture, and vegetation changes (Fan et al 2013). Aerosols have strong effects on regional climate variability on several time scales (from daily to decadal) owing to their effects on radiation, cloud cover and atmospheric circulation. Due to their relatively short lifetime, aerosols are one of the main sources of uncertainty in past and future climates (Nabat et al. 2015).

More realistic simulations of land use/land cover changes (LUC) may be important towards reducing the uncertainty and inconsistencies in climate scenarios (Wang et al. 2016, Davin and de Noblet-Ducroudré 2010). Yet, significant methodological inconsistencies remain in the analysis of surface-atmosphere coupling (Careto et al. 2018, Sippel et al. 2017). In recent years Europe has been struck by record-breaking extreme events with unprecedented socio-economic impacts, including the mega-heatwaves of 2003 in Europe (Trigo et al., 2005), the large droughts in southern Europe in 2005 (Garcia-Herrera et al 2007) and 2013 (Trigo et al 2013) and by major flood events in central Europe in 2013. Extreme events are expected to increase in frequency, intensity, spatial extent, and duration under climate change. It is thus, imperative to further investigate land use atmospheric feedbacks, especially within the framework of risk assessment (IPCC 2013) and future warming scenarios (Schubert et al 2014).

Present Proposal

The overall objective is to identify robust biophysical impacts of land use changes (LUC) on climate across regional to local spatial scales and at various time scales from extreme events to multiple decades. The project seeks to improve the understanding of the influence of LUC in the main physical mechanisms and systems governing European climate and is integrated in EURO-CORDEX Flagship Pilot Study "LUCAS – Land Use and Climate Across Scales" an initiative of the World Climate Research Programme. The new generation of RCMs which couple the regional atmosphere interactively with further components of the regional earth system, e.g., terrestrial biosphere and hydrosphere will be used to build regional climate projections to generate high-quality climate projections and contribute to identify robust biophysical impacts of LUC. The project will seek to ascertain how LUC impacted past climate trends and how it can be used to mitigate future climate change. Special emphasis will be given to the development and mitigation of extreme events such as heatwaves, droughts, and extreme precipitation. The research strategy is based on the one hand, on the deep knowledge of the physical mechanisms and of the model parameterization schemes, and on the other hand, on the quantification methodologies and state-of-the-art modelling, both global and regional, for climate change assessment.

Target questions (TQ):

The main target questions this proposal aims to contribute are:
TQ1: What is the relative contribution of selected LUC to regional climate changes in Europe in past climate trends?
TQ2: How strongly can local LUC attenuate negative impacts of climate change, e.g., extreme events in Europe?
TQ3: How does spatial resolution affect the magnitude and robustness of LUC-induced climate changes?
TQ4: How large is the contribution of LUC to detected potential future climate trends in Europe?
TQ5: How does the models' response to the LUC signal compare to the response to other changes?
TQ6: How does LUC modify the partitioning of available energy in latent and sensible heat fluxes?

Methods

A new set of continental-scale RCM simulations will be carried out with the WRF model for the EURO-CORDEX domain. These simulations will downscale global reanalyses and two global climate scenarios using harmonised reconstructed land use dynamics and thus allow the quantification of the relative contribution of LUC to the climate evolution in Europe. These will constitute ensemble members of the coordinated Flagship Pilot Study "LUCAS" (Land Use & Climate Across Scales) for Europe, as a EURO-CORDEX & LUCID initiative supported by WCRP CORDEX international program. The periods covered by the simulations are 1979-2020 forced by ERA5, 1960-2014 for the historical run, and 2015-2100 for future climate, forced by MPI-ESM1-2-HR, in agreement with the new scenarios – SSP2-4.5 and SSP3-7.0. These simulations will be performed with 0.11° resolution.

Workplan

The work will be organized into 3 tasks. The purpose of the tasks is to perform the simulations with transient and static land cover, to evaluate the model performance in current climate and to assess the evolution of climate extremes in future climates, for the European domain.

Task 1. The contribution of vegetation to current climate. A new set of continental scale simulations, with and without land-use change, will be performed for the EURO-CORDEX domain with the regional climate model WRF. These simulations will downscale global reanalyses data using harmonised reconstructed land use dynamics and thus allow the quantification of the relative contribution of LUC to the past climate evolution in Europe. Model setup and efficiency testing will be performed before the start of the 42-year runs. Relevant variables will be extracted from the raw output as the model results become available. These will be analysed and stored, and the extra output will be discarded. The analysis will be focused on land-atmosphere interactions, development, and characteristics of extreme events.
Task 2. The contribution of vegetation to historical climate. For this task, the setup from the previous task is considered, however, the WRF model is forced by the MPI-ESM1-2-HR GCM for a CMIP6 historical period (1960-2014). As in task 1, relevant variables will be extracted from the raw output. A similar analysis to task one will be performed along with an assessment of the differences between the results from the two tasks in order to ascertain the differences between both climates (a historical driven by a GCM and a reanalysis driven past climate)
Task 3. The contribution of vegetation to future climate. In this third task, the same domain will be pursued but for a future period and therefore the WRF model will be forced by the MPI-ESM1-2-HR GCM results for the 21st century, between 2015 and 2100 in agreement with the new scenarios SSP2-4.5 and SSP3-7.0. The impact of vegetation on the climate change signal will be the primary outcome of this task. The analysis of the changes in land-atmosphere interactions and in the intensity and frequency of extreme events will be pursued.

Resources
The resources for the first and second tasks is similar:

- A total of 42 for the first task and 55 years for the second.
- Approximately 26.250.000 SBU per task
- Approximately 2.8 TB of data will be generated for each year of each task.

The two tasks will be performed in one and a half years. A total of 35.000.000 SBUs in the first year and 17.500.000 SBUs in the second year.
The resources needed for the third task will be:

- A total of 85 years per simulation.
- Approximately 52.500.000 SBU
- Approximately 2.8 TB of data will be generated for each year of each simulation.

The task will be performed in one and a half years. A total of 17.500.000 SBUs in the first year and 35.000.000 SBUs in the second year.
The storage will be managed to keep the relevant output of these simulations while temporary testing and extra output will be removed after the analysis.

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