SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2025
Project Title:	Sensitivity of regional climate models to improved soil thermo-hydrodynamics and land-air interactions: impacts on future climate and renewable energy resources over the EURO CORDEX domain
Computer Project Account:	spesgarc
Principal Investigator(s):	Elena García Bustamante
Affiliation:	CIEMAT
Name of ECMWF scientist(s) collaborating to the project (if applicable)	J. Fidel González Rouco, Jorge Navarro Montesinos (CIEMAT), Elena García Bustamante (CIEMAT), Félix García-Pereira (IGEO), Cristina Vegas-Cañas (IGEO), Nagore Meabe (IGEO), Sara Madera Sánchez (CIEMAT), Luana Cardoso (University of Lisbon)
Start date of the project:	01/01/2023
Expected end date:	31/12/2025

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	9.500.000	15.521.684	9.500.000	17.717.842
Data storage capacity	(Gbytes)	350.000	150.200	350.000	166.047

Summary of project objectives

The project main objective is to perform regional simulations at very high spatial resolution with a regional climate model (RCM, WRF) and it is a combined effort together with another special project (*spesgonz*) from CIEMAT. Together with them, the objective is to achieve a refined version of the regional simulations over the EURO CORDEX domain by incorporating the external climatic forcings to the regional model and by increasing the realism of the soil component in high resolution simulations. The latter implies, among other expected benefits, augmented consistency of the RCM simulations with respect to the driving ESM model (Max-Planck). We will provide multi-decadal historical and scenario CP-RCM simulations over the EURO-CORDEX domain based on the optimal recalibrated WRF configuration. A smaller region of complex terrain (Central System) within the Iberian Peninsula is selected due to its availability of observational data, to generate convection permitting RCM (CP-RCM) simulations with the aim of testing the ability of the model to resolve the atmospheric physics at convective scales making use of convection permitting schemes. Therefore, the main objectives within the present project imply a pool of sensitivity experiments of those parametrizations that remain active when the cumulus scheme is muted (convection permitting scheme) in shorter and smaller domain within the Iberian Peninsula.

Summary of problems encountered

We have performed multiple modifications of the raw code of the WRF model version we are using, such us the inclusion of 4D files for the aerosol depth to include the stratospheric and tropospheric aerosol forcings in our simulations. Our group is the first within the community introducing such changes and we have faced different difficulties at this regard.

Additionally, we have found inconsistencies between our lake mask and the land-sea lake mask that is being used by some members of the LUCAS CORDEX community so we have detected anomalous temperature surface temperature signals that forced the community teams to rerun some of our model simulations. Differences can be found in Figure 1 of this report.

During this year we have faced several difficulties mostly related to 1) the amount of storage needed for the heavy outputs from the RCM simulations considering their length the very high spatial resolution and the resulting amount of fields and variables simulated, which ultimately points to a need of longer/larger storing capacity for the outputs of our simulations, 2) the subsequent download of the simulated fields to our institutional servers and 3) difficulties related to the technical part that seeks improving the RCM code standards to allow for an innovative approach, mainly connected to the management of databases that feed our running system. Nonetheless, it is worth mentioning that our simulations have been running mainly on a twin account connected with this project, due to a mislabelling in our scripts. However, by the end of the year, the full amount of allocated space for this project is planned to be used with the progress of the simulations planned.

Summary of plans for the continuation of the project

Until the end of the year, we plan to launch ALL-Forcing reanalysis and CMIP6 driven experiments. Fully forced WRF simulations (GHGs, AER+VOL, LULCC, SOL) during the historical period (1990-2020) will be carried out using first in ERA5 reanalysis and finally with *MPI*-ESM_{deep} driving fields, our own refine version of the parent Earth System Model providing initial and boundary conditions to the RCM simulations. This implies a data flush to our collaborators from the *spesgonz* project at the CIEMAT. The first of the two runs will be the reference fully forced simulation driven by closer-to-reality fields (reanalysis) and the second constitutes the first CMIP6 downscaling experiment with a deeper soil module and will be the basis for the future scenario projections and for the following analysis about the soil physics options. The viability of running *MPI-ESM$_{deep}$* outputs downscaled with WRF has already been ensured during previous experiments and projects.

One main objective next year is to launch the refined 1km CP-RCM simulation, probably reaching the 200 m spatial resolution region for some specific regions within the smaller domain over the Iberian Peninsula located over the Central System (see results below) to explore the added value of the convection permitting schemes over the mountainous area mentioned. A parent 4km has already been performed in collaboration with the special project *spesgonz*. Previously, the group has applied effort in experimenting with increasing resolution and sensitivity to specific boundary layer physics and microphysics parametrizations over a smaller subdomain over the eastern bound of the Central System in Iberia (Sierra de Guadarrama) is to allow for an insight in the potential of the model to capture the mean and climate and variability at different timescales. Some results are shown below

List of publications/reports from the project with complete references

PUBLISHED

- Steinert N., F. J. Cuesta-Valero, F. García-Pereira, P. de Vrese, C. Melo Aguilar, E. García-Bustamante, J. Jungclaus and J. F. González-Rouco: " Underestimated land heat uptake alters the global energy distribution in CMIP6 climate models". *Geophys. Res. Lett.*, **51**, e2023GL107613. DOI: 10.1029/2023GL107613, 2024.
- García-Pereira F., J. F. González-Rouco, C. Melo-Aguilar, N. J. Steinert, E. García-Bustamante, P. de Vrese, J. Jungclaus, S. Lorenz, S. Hagemann, F. J. Cuesta-Valero, A. García-García and H. Beltrami: "First comprehensive assessment of industrial era land heat uptake from multiple sources". *Earth System Dyn.*, **15**, 547-564, DOI: 10.5194/esd-15-547-2024.
- Arribas, L., Domínguez, J., Borsato, M., Martín, Ana M., Navarro, J., García-Bustamante, E., Zarzalejo, L.F., Cruz, I.: "The potential of utility-scale Hybrid Wind - Solar PV power Plants deployment: from data to results. A simplified application for the Spanish potential." *Wind.* In press.

IN PREPARATION

- García-Bustamante, E., González-Rouco, Navarro, J., Rojas-Labanda, C., García-Pereira, F., Palomares-Losada, Ana M., Greciazo, E.: "Evaluation of the NEWA wind atlas". *Int. J. Climatol*. In prep.
- Cardoso, R. M., Santos, L.C., García-Bustamante, E., Lima, D.C.A., Soares, P.M.M., da Camara, C., Rechid, D. Russo, A:, the LUCAS CORDEX Team: "What is the compound effect of re/af-forestation and extreme heat on summer land-atmosphere coupling across Europe?". In prep.
- García-Bustamante, E., González-Rouco, Navarro, J., Madera-Sánchez, S., Santos, L. C., García-Pereira, F., Muñoz-Roldán, A., Greciazo, E.: "Increasing the realism of the forcing conditions in regional climate simulations: a case-study in the Euro-Mediterranean CORDEX domain". In prep.

CONFERENCES AND WORKSHOPS

- García-Pereira, F., González-Rouco, J. F., Melo-Aguilar, C., Steinert, N. J., de Vrese, P., Jungclaus, J., Lorenz, S., Hagemann, S., García-Bustamante, E., and Roldán-Gómez, P. J.: Land heat uptake: from Last Millenium proxy and model simulations to observational and CMIP6 products, EMS Annual Meeting 2023, Bratislava, Slovakia, 4–8 Sep 2023, EMS2023-584, https://doi.org/10.5194/ems2023-584, 2023.
- García-Pereira, F., González-Rouco, J. F., Meabe-Yanguas, N., Steinert, N. J., Jungclaus, J., de Vrese, P., and Lorenz, S.: Permafrost thermal response to improved soil hydro-thermodynamics in historical and scenario simulations with a modified version of the MPI-

ESM , EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-4769, https://doi.org/10.5194/egusphere-egu24-4769, 2024.

- González-Rouco, F., García-Pereira, F., Melo-Aguilar, C., Steinert, N. J., García- Bustamante, E., de Vrese, P., Jungclaus, J., Lorenz, S., Hagemann, S., Cuesta-Valero, F. J., García-García, A., and Beltrami, H.: Using a last 2k baseline to derive a first comprehensive assessment of industrial era land heat uptake, EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-8123, https://doi.org/10.5194/egusphere-egu24-8123, 2024.
- Greciano-Zamorano, E., González-Rouco, J. F., Vegas-Cañas, C., García-Pereira, F., Navarro-Montesinos, J., García-Bustamante, E., Rodríguez-Guisado, E., and Rodríguez-Camino, E.: Climate Initiative for Iberian Mountain Areas (CIMAs): improving our understanding of climate variability over mountain areas using high resolution modelling., EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-19237, https://doi.org/10.5194/egusphere-egu24-19237, 2024.
- Emilio Greciano-Zamorano, Jesús Fidel González Rouco, Cristina Vegas Cañas, Félix García Pereira, Jorge Navarro Montesinos, Elena García Bustamante, Ernesto Rodríguez Camino, and Esteban Rodríguez Guisado: Climate Initiative for Iberian Mountain Areas (CIMAs): improving our understanding of climate variability over mountain areas using high resolution modelling. EMS Annual Meeting 2024, Barcelona 2-6 Septiembre. https://meetingorganizer.copernicus.org/EMS2024/session/50848.
- Nuria P. Plaza, Marcos Martinez-Roig, Cesar Azorin-Molina, Miguel Andres-Martin, Jorge Navarro, Jesus Fidel Gonzalez-Rouco, Elena Garcia-Bustamante, Jose A. Guijarro, Amir A. S. Piroz, Deliang Chen, Tim R. McVicar, Zengzhong Zeng, and Sergio M. Vicente-Serrano: Applying citizen weather data and AI for developing a high-resolution wind speed monitor in the Valencia region (Spain). EMS Annual Meeting 2024, Barcelona 2-6 Septiembre. 2023. https://meetingorganizer.copernicus.org/EMS2024/session/50857
- E. García-Bustamante, J. F. González-Rouco, J. Navarro, C. Rojas-Labanda, F. García-Pereira, A. Palomares-Losada, E. Greciano-Zamorano, C. Vegas-Cañas, S. Madera: Evaluación del atlas eólico europeo NEWA. XIII Congreso de la Asociación española de Climatología, San Lorenzo de El Escorial, 22-24 Jan 2025.
- E. Greciano Zamorano, J.F. González Rouco, C. Vegas Cañas, F. García Pereira, J. Navarro Montesinos, E. García Bustamante, E. Rodríguez Camino, E. Rodríguez Guisado: Climate Initiative for Iberian Mountain Areas (CIMAs): variabilidad y cambio climático en zonas de montaña con modelización regional de alta resolución espacial. XIII Congreso de la Asociación española de Climatología, San Lorenzo de El Escorial, 22-24 Jan 2025.
- Rita M. Cardoso, Luana C. Santos, Elena García Bustamante, Daniela C.A. Lima Lima, Pedro MM Soares, Carlos da Camara Camara, Diana Rechid, and Ana Russo and the Lucas Team: What is the compound effect of re/af-forestation and extreme heat on summer land-atmosphere coupling across Europe? EGU General Assembly 2025, 27 zbril-2 mayo 2025, Viena, Austria. https://meetingorganizer

Summary of results

This special project is part of a common effort among several institutions sharing research targets in regional simulations. Therefore, the use of the accounts is designed through the year jointly and the usage of the special project accounts in shared. Here we reflect the progress of the project assigned to this account, which is common to the special project *spesgonz* running its second year. Our plan is to continue with the present project for which we will need the maximum allowed capacity to perform the simulations scheduled. The report is essentially common to the two special project accounts (*spesgonz* and *spesgarc*).

We have launched experiments related to a sensitivity analysis to the inclusion of individual forcings in regional simulations for the historical period. The experiments with individual forcings driven by reanalysis data. They incorporate annual variations of Greenhouse Gases (GHGs), Land Use and Land Cover changes (LULC), tropospheric aerosols, natural stratospheric aerosols (AER + VOL), and Total Solar Irradiance (SOL). These simulations have been completed and are currently under analysis.

The objective is to identify the role of regionally forced variations. Part of the analysis this have been focused on the volcanic aerosol regional impacts on the simulations, evidencing a moderate impact of the most significant historical volcanic eruptions (e.g., Pinatubo, 1991)..These individual forcing simulations show an amplified response in specific periods and subdomains, we are conducting an insightful analysis of their local and regional-scale impacts. Further time is required to comprehensively estimate the individual and combined influence of these forcings. Nevertheless, preliminary results already suggest distinct global *vs*. regional features of these impacts over the study domain.

A WRF simulation based in three nested model domains with horizontal resolutions of 9 km, 3 km, and 1 km have been performed for a 30-year experiment focusing on the eastern sector of the target region over the Iberian Peninsula Central System. The analyses in this part indicated that, in general, all simulations overestimate the probability of precipitation occurrence.

We have as well performed a 4 km simulation that will serve as the forthcoming 1 km simulation over the Central System in the Iberian Peninsula with an optimized configuration after the experiments we have commented about above. It can be said that the simulated temperature evidences a climatological pattern spatial and altitude dependent. More detailed analysis can be found in the final project report.