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	2024
Project Title:	**S**ensitivity of regional **M**odels to **I**mproved **L**and-air interactions and **E**xternal forcings setup: **A**pproaching a "*seamless*" s**T**rategy to reduce s**Y**stematic biases in very high-res**O**lution climate sim**U**lations (***SmileAtYou***)
Computer Project Account:	spesgonz
Principal Investigator(s):	J. Fidel González Rouco
Affiliation:	IGEO- CSIC (previously UCM-IGEO)
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Félix García-Pereira (IGEO), Cristina Vegas-Cañas (IGEO), Jorge Navarro Montesinos (CIEMAT), Elena García Bustamante (CIEMAT), Nagore Meabe (IGEO)
Start date of the project:	01/01/2024
Expected end date:	31/12/2026

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)	-	-	15.500.000	3.746.665
Data storage capacity	(Gbytes)	-	-	350.000	12.000

Summary of project objectives (10 lines max)

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 (spesgarc) from CIEMAT. Together with them, the objective is to achieve a refined version of the regional simulations over the EURO CORDEX by incorporating the external climatic forcings to the regional model and by increasing the realism of the soil component. The latter implies augmented consistency of the RCM simulations with respect to the driving ESM model (Max-Planck). 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. 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. Finally, we will provide multi-decadal historical and scenario CP-RCM simulations over the EURO-CORDEX domain based on the optimal recalibrated WRF configuration.

Summary of problems encountered (10 lines max)

The difficulties associated with the very high spatial resolution CP-RCM simulations are mainly devoted to the selection of a configuration (domain, parametrizations and model physics) that suitably represents convective phenomena at the spatial scales under 4 km and imply an added value with respect to simulations with coarser resolution. We have performed multiple pre-experiments in order to be able to adequately represent the realism of the climatic variability over a region over very complex terrain in convection permitting simulations. This implied a considerable effort in testing multiple simulation set ups.

Summary of plans for the continuation of the project (10 lines max)

Our following steps can be summarized as follows: first we will continue with our assessment of the added value of the pool of sensitivity CP-RCM experiments, especially what regards precipitation (rain and snow), by comparing them to observed values over the Central System of the Iberian Peninsula.

Subsequently, after the sensitivity study of different model physics we will select an ‘optimal’ configuration and we will generate long m*ulti-decadal historical and scenario CP-RCM simulations over the Iberian Peninsula domain and EURO-CORDEX domains*. Historical and future projection analysis of trends and extreme variability based on CMIP6 downscaling experiments using our final *SmileAtYou* revised CP WRF model version is the final target of this project.

List of publications/reports from the project with complete references

- "Evaluación de la variabilidad de la precipitación en la Sierra de Guadarrama - Evaluation of the precipitation variability over the Sierra de Guadarrama". Master thesis of Emilio Greciano Zamorano, Universidad Complutense de Madrid, dirigido por J. Fidel González Rouco, Elena García Bustamante y Jorge Navarro Montesinos. Febrero 2023.
- "Análisis del viento superficial en Europa: variabilidad y tendencias - Analysis of surface wind in Europe: variability and trends". Master thesis of Celia Pérez Souto, Universidad Complutense de Madrid, dirigido por J. Fidel González Rouco, Elena García Bustamante y Jorge Navarro Montesinos. Septiembre 2023.
- "Simulación numérica de alta resolución en la Península Ibérica con el modelo acoplado WRF-SFIRE de atmósfera e incendios forestales". Master thesis of Leidy Laura Salazar Domínguez. Universidad Complutense de Madrid, dirigido por Robert Monjo i Agut J. Fidel González Rouco. Junio 2024.
- 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. (in press).
- Roldán-Gómez P., J. F. González-Rouco, J. Smerdon, F. García-Pereira Model and proxy evidence for coordinated changes in the hydroclimate of distant regions over the Last Millennium". Climate of the Past, **19 (11)**, 2361-2387, DOI: 10.5194/cp-19-2361-2023.
- de Vrese P., G. Georgievski, J. F. Gonzalez Rouco, D. Notz, T. Stacke, N. J. Steinert, S. Wilkenskjeld, and V. Brovkin: "Representation of soil hydrology in permafrost regions may explain large part of inter-model spread in simulated Arctic and subarctic climate". The Criosphere, **17 (5)**, 2095-2118, DOI: 10.5194/tc-17-2095-2023.

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

This project can be considered a coordinated effort with the project "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" (project account spesgarc, PI: Elena García Bustamante from CIEMAT). We have developed a refined version of the WRF model within the experiments and simulations designed for that specific project targets. Full forced regional simulations can be used within our experiments herein as a result of the coordination with the experimental set up of the mentioned project.

For the specific purposes of the present project and during the first year of computational availability, we have designed the domain where the convection permitting simulations with the WRF model will be focused, covering the whole Central System of the Iberian Peninsula (Figure 1a). A pool of initial experiments has been carried out that will help outline the configuration of the final simulations of the agreement. The experimental design is represented in Table 1, where the number

EXPERIMENTO 1		
Nº procesadores	**Tiempo real**	**Tiempo simulado**
440	1 hora 2.5 meses	5 horas 1 año
EXPERIMENTO 2		
Nº procesadores	**Tiempo real**	**Tiempo simulado**
256	1 hora 15 días	24 horas 1 año
EXPERIMENTO 3		
Dominio 1 (5 km)		
Nº procesadores	**Tiempo real**	**Tiempo simulado**
440	1 hora 2.5 días	6 días + 12 horas 1 año
Dominio 2 (1 km)		
Nº procesadores	**Tiempo real**	**Tiempo simulado**
512	1 hora 2.5 días	6 días + 9 horas 1 año
EXPERIMENTO 4		
Dominio 1 (5 km)		
Nº procesadores	**Tiempo real**	**Tiempo simulado**
640	1 hora 1.5 días	~ 10 días 1 año
Dominio 2 (1 km)		
Nº procesadores	**Tiempo real**	**Tiempo simulado**
640	1 hora 1.5 días	~ 10 días 1 año

Table 1. Computation times for the different sensitivity experiments (see text). The real time necessary to develop experiments of a temporal length indicated in the last column (simulated time) is indicated.

of processors and simulation time is denoted.

One of the tested configurations considers two levels of nesting where the horizontal resolution increases from 4 km in the first domain to 1 km in the domain of interest. The smallest domain (D2 in Figure 1a) and therefore the highest resolution, covers the entire target area. This two-level nesting configuration is based on a modification of the approach used in previous simulations (see Greciano-Zamorano, 2023 master thesis) with the intention of improving the realism of high-resolution simulations. The simulation periods will cover from 2009 to 2014 and from 2014 to 2022. The initial year of each simulation is reserved as a spin up for adapt slow variation processes, especially related to the soil, to the boundary conditions and decrease the influence of reset. The 2m temperature, total precipitation and wind speed averages for the parent D1 domain are represented in the Figures 1b, 1c and 1d, respectively.

The use of the *ndown* approach allowed the computing time to be reduced from 1 year of simulation to 2.5 days, which increases the feasibility of performing multi-decade simulations by simulating approximately 1 decade each month. Optimization techniques of computing time by scaling the number of processors, reducing the cost of 1 year of simulation to 1.5 days and the possibility of doing several decades in one month. Therefore, it is confirmed that this approach allows developing climate simulations of very high resolution and multidecadal extension.

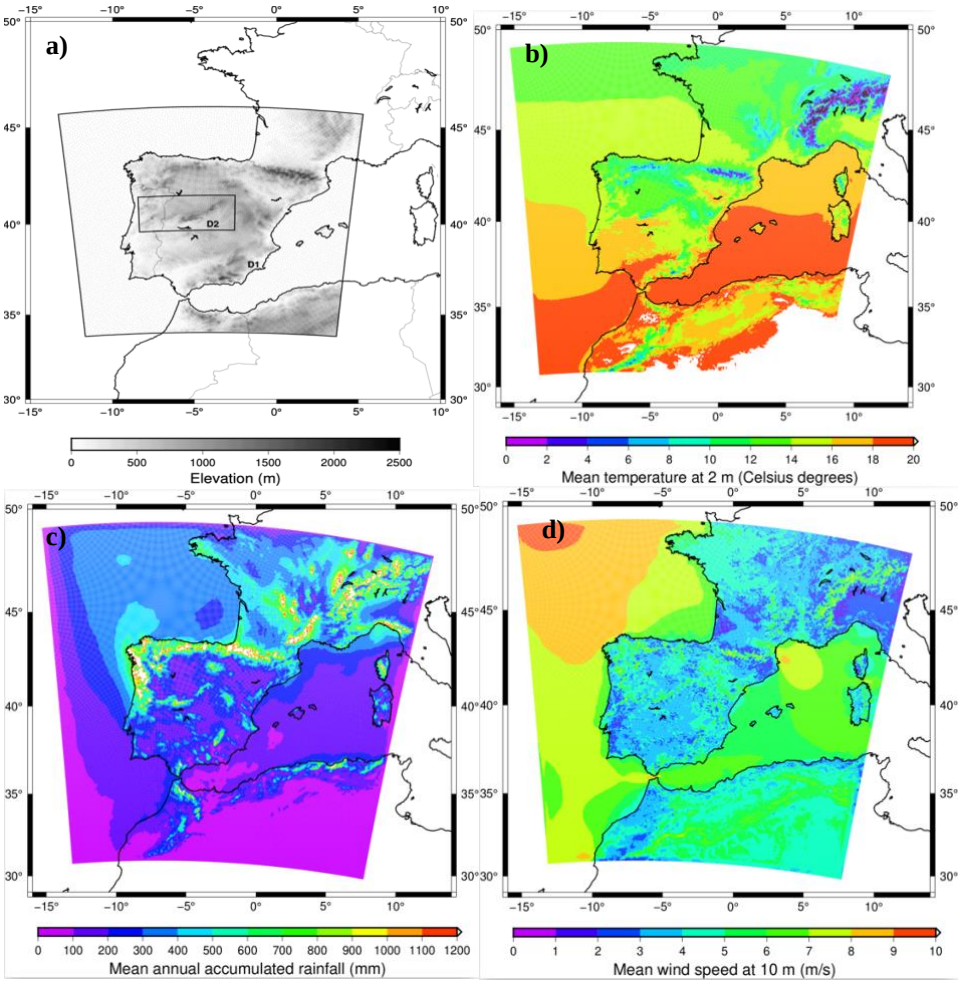

Figure 1. a) WRF domains over the Iberian Peninsula, b, c and d: averages of temperature at 2m, annual accumulated precipitation and wind speed for the period 2015-2019 in the D1 domain, with 4 km horizontal resolution.

Results from previous work indicate a notable improvement in the simulation of temperature in complex terrain when increasing the resolution. However, the response of precipitation to an increase of resolution and the possibility of considering specific parameterizations or schemes that allow direct simulation of convection by the model are not clear as previously shown by different authors within the community.

In general, all simulations overestimate the probability of precipitation occurrence. The simulations are comparable to observations when considering only days of observed appreciable precipitation, but they generate many days with appreciable precipitation when they are recorded as dry in observations. The number of simulated wet days generally increases with resolution. On the other hand, WRF tends to overestimate total precipitation with increasing resolution.

The model evaluation work has also focused on analyzing the model's capacity to adequately simulate the snow depth in the Sierra de Guadarrama region. The model adequately simulates snowfall at the observed in several specific sites where there are instrumental measurements of snow depth. In Figure 2, the orographic influence on the distribution of snow and the increase in thickness with increasing resolution can be observed, also consistent with the behavior observed in precipitation. The experiments carried up to obtain an understanding of the realism of the model when reproducing the snow depth in the Sierra de Guadarrama provide useful information to make adjustments and improvements in the future configuration of the model.

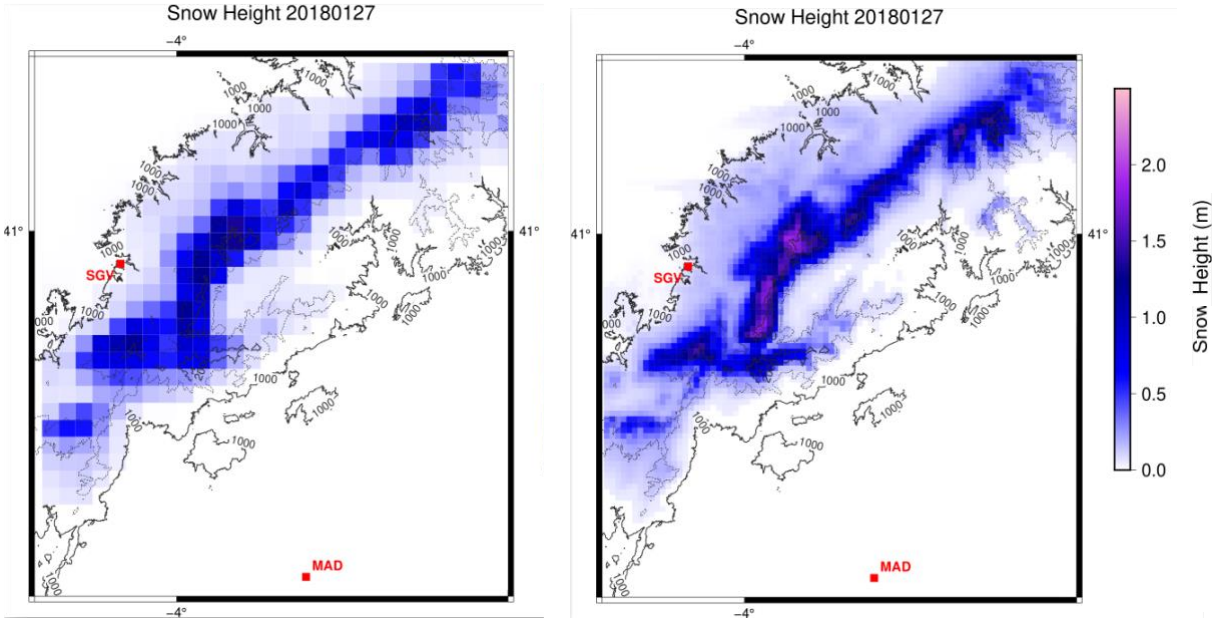

Figure 2. Snow depth daily average simulated in a dynamic downscaling experiment with the WRF model using simulated snow depth from domains 1 (left) and 2 (right), of 4 and 1 km respectively, for 01/27/2018.

During the next year we expect a considerable increase in the amount of computation required to carry out the sensitivity to physics within our experimental set up as well as the production runs of convection permitting simulations over the Central system and the whole Iberian Peninsula.