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:	**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
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), Sara Madera Sánchez (CIEMAT), Luana Cardoso (University of Lisbon)
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	20.312.275	15.500.000	1.025.630
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 (*spesgarc*) 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

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 (*spesgarc*), due to a mislabelling in our scripts. Our aim was to equally make use of both accounts at a similar rate. 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 from our collaborators from the *spesgarc* 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 *spesgarc*. 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.

Finally, we plan to perform a series of regional simulations testing structural improvements to the land surface scheme that might lead to a more realistic sub-surface physics and the corresponding land-air interactions in WRF simulations with full forcing over the historical period.

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 *spesgarc* that finalizes this 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. Figures 1 and 2 in this document illustrate the part of the analysis that focuses on the volcanic aerosol regional 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.

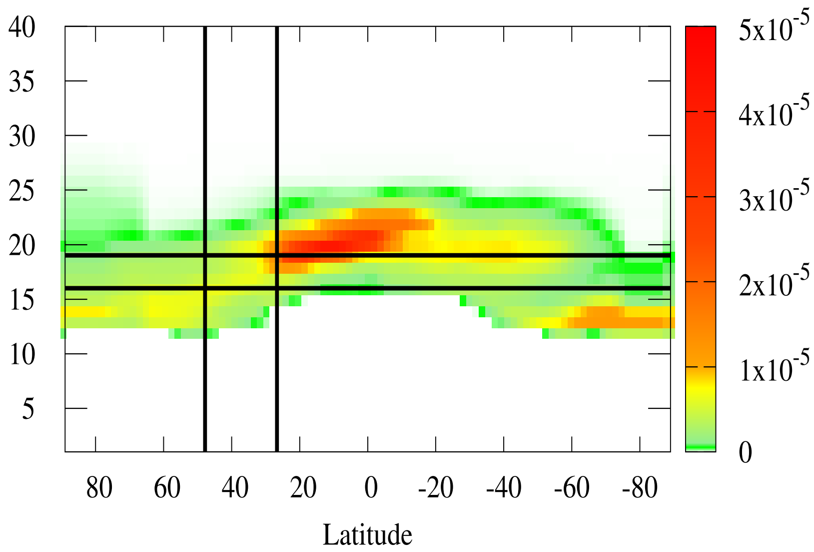

Fig. 1. Shortwave extinction coefficient as a function of latitude and altitude for October 1991 in the simulation including stratospheric aerosols within the visible spectral band.

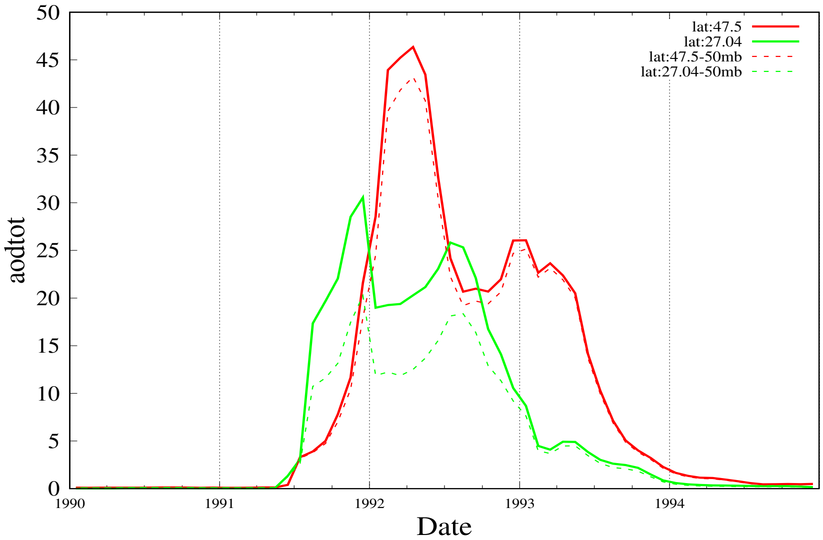

Fig. 2. Temporal evolution of Aerosol Optical Depth (AOD) integrated over all altitudes and spectral bands of the model. Values are shown in red for latitude 47.5ºN (upper boundary of the WRF simulation domain) and in green for latitude 27.0º

In Figure 3 we show the three nested model domains of the WRF model with horizontal resolutions of 9 km, 3 km, and 1 km used in a 30-year experiment focusing on the eastern sector of the target region over the Iberian Peninsula Central System. In this area, an initial compilation of precipitation data was carried out for both mountainous locations and, for comparison, lowland sites (symbols shown in Figure 9). The model configuration followed the reference setup described in Table B1. The analysis compared the occurrence and magnitude of simulated precipitation—both annually and seasonally—with observations, selecting the grid point closest to each observational station (Greciano-Zamorano, 2023).

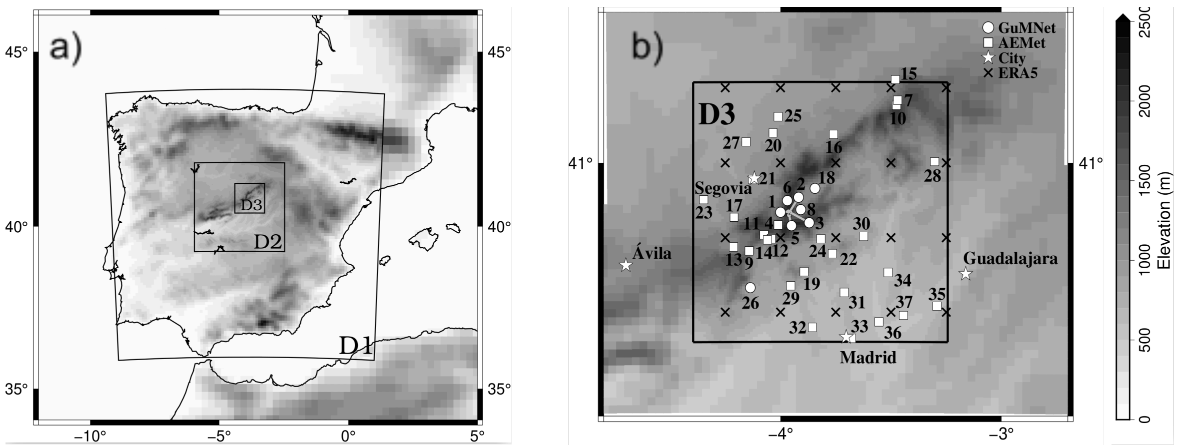

Figure 3. Configuration of the three WRF domains and distribution of the available observational stations used in the study by Greciano-Zamorano (2023a,b). a) WRF simulation domains D1 to D3. **b)** Zoom into domain D3, showing the locations of GuMNet stations (circles) and AEMET stations (squares), ERA5 grid points within domain D3 (crosses), and reference cities (stars). Grey shading represents terrain orography at ERA5 resolution outside the WRF domains, which increases in detail across the nested domains as they focus on the Sierra de Guadarrama region.

The analyses in this part indicated that, in general, all simulations overestimate the probability of precipitation occurrence. The latter can be appreciated in Figure 4. We have observed that model outputs were comparable to observations when only days with appreciable observed precipitation were considered; however, the model frequently produced wet days that were recorded as dry in the observational data. The number of simulated wet days tended to increase with horizontal resolution. In addition, WRF simulations exhibited a positive bias in total precipitation that also increased with resolution. In this configuration, convection was not explicitly resolved but was instead parameterized.

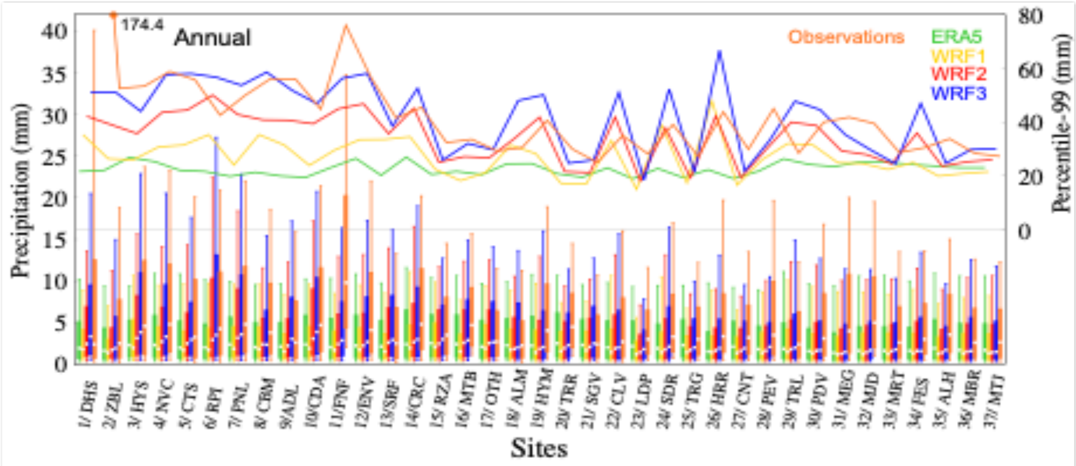

Figure 4. Top: box plots of the daily appreciable (> 0.2 mm) precipitation of the three resolutions of WRF, ERA5 and the observations at each station. WRF and ERA5 data has been co-located for each observational site, as well as temporally masked to data existence. On each box plot: the bottom whisker represents the percentile-10; the lowest part of the box shows the first quartile; the highest part of the box shows the third quartile; the top whisker shows 90-percentile and the lines above show the 99-percentile (note the different axis). Median is represented with a white dot inside the box. Bottom: analogous representation for the seasonal assessment, focusing on WRF2, WRF3 and observations.

During this second project year, sensitivity experiments were conducted by modifying the reference configuration to explicitly resolve convection using a convection-permitting scheme (CPS), along with changes in the model's microphysics and cumulus parameterizations. The aim was to assess whether employing a CPS configuration at 1 km resolution (Figure 3; WRF3) could yield a more realistic simulation of precipitation. A comparative analysis was carried out between a reference simulation using the standard configuration previously adopted in earlier project and six additional simulations that implemented different combinations of cumulus and microphysics parameterizations (Table 1).

	PARAMETERIZATION					
	WRF1		**WRF2**		**WRF3**	
	Microphysics	Cumulus	Microphysics	Cumulus	Microphysics	Cumulus
Reference (Ref)	Thompson (Thompson et al., 2008)	New Tiedke (Zhang et al., 2017)	Thompson (Thompson et al., 2008)	New Tiedke (Zhang et al., 2017)	Thompson (Thompson et al., 2008)	New Tiedke (Zhang et al., 2017)
Simulation 1 (S1)	NSSL2 (Mansell et al., 2010)	New Tiedke (Zhang et al., 2017)	NSSL2 (Mansell et al., 2010)	New Tiedke (Zhang et al., 2017)	NSSL2 (Mansell et al., 2010)	New Tiedke (Zhang et al., 2017)
Simulation 2 (S2)	Thompson (Thompson et al., 2008)	Kain-Fritsch (Kain, 2004)	Thompson (Thompson et al., 2008)	Kain-Fritsch (Kain, 2004)	Thompson (Thompson et al., 2008)	Kain-Fritsch (Kain, 2004)
Simulation 3 (S3)	Thompson (Thompson et al., 2008)	Grell-Freitas (Grell et al., 2014)	Thompson (Thompson et al., 2008)	Grell-Freitas (Grell et al., 2014)	Thompson (Thompson et al., 2008)	Grell-Freitas (Grell et al., 2014)
Simulation 4 (S4)	Thompson (Thompson et al., 2008)	New Tiedke (Zhang et al., 2017)	Thompson (Thompson et al., 2008)	New Tiedke (Zhang et al., 2017)	Thompson (Thompson et al., 2008)	-
Simulation 5 (S5)	Thompson (Thompson et al., 2008)	Kain-Fritsch (Kain, 2004)	Thompson (Thompson et al., 2008)	Kain-Fritsch (Kain, 2004)	Thompson (Thompson et al., 2008)	-
Simulation 6 (S6)	Thompson (Thompson et al., 2008)	Grell-Freitas (Grell et al., 2014)	Thompson (Thompson et al., 2008)	Grell-Freitas (Grell et al., 2014)	Thompson (Thompson et al., 2008)	-

Table 1. Microphysics and cumulus parameterization configurations for domains D1 (WRF1), D2 (WRF2), and D3 (WRF3) (see Figure 9) in the reference simulation and the six sensitivity experiment simulations for the year 2009**.** Experiment S1 modifies the microphysics parameterization across all domains. Experiments S2 and S3 introduce changes in the cumulus parameterizations. Experiments S4 to S6 disable cumulus parameterization in the innermost domain (D3), allowing convection to develop explicitly.

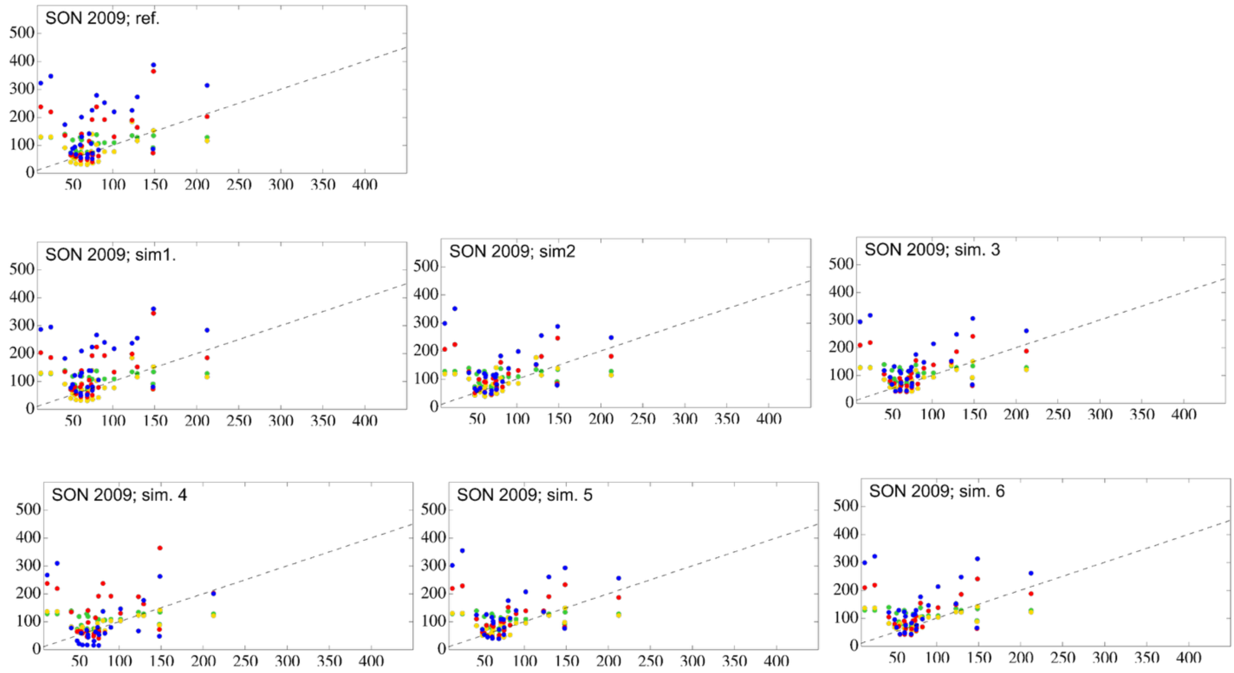

Figure 5. Comparison between observed and simulated mean of seasonal accumulated precipitations by WRF and ERA5 within the D3 domain. Big coloured circles represent appreciable precipitation during the time of data availability for each site (unmasked data). The numbers labeled in the top panel correspond to stations in Table 1.

These simulations focused on repeatedly modelling the year 2009 in order to isolate the sensitivity of precipitation output to the selected parameterizations. The modifications described in Table 1 were applied across the three spatial resolutions (9 km, 3 km, and 1 km) and domains previously used in related studies (Greciano-Zamorano, 2023). For this analysis, only the area enclosed by domain D3 in Figure 3 (Sierra de Guadarrama) was considered, along with the observational stations available within this subregion (Figure 3b).

This study analyses precipitation data from 37 meteorological stations located in the Sierra de Guadarrama and the adjacent lowlands in central Spain, encompassing an altitudinal range from approximately 600 to 2200 meters above sea level (masl). These observational datasets are compared with the ERA5 reanalysis and with outputs from the Weather Research and Forecasting (WRF) regional climate model at three horizontal resolutions—9 km, 3 km, and 1 km—for the period 1990–2019. The comparison aims to characterize the spatial distribution of precipitation in the region, evaluate the performance of ERA5, and assess the added value associated with increasing the horizontal resolution of WRF simulations in capturing observed precipitation patterns.

The sensitivity analysis results indicate that increasing WRF resolution from 9 km to 3 km improves the model's ability to reproduce observed precipitation. The 1 km resolution further enhances the spatial representation of precipitation distribution, particularly in complex terrain, although it tends to overestimate total precipitation amounts. An altitudinal gradient in precipitation is clearly detected, and it is most accurately simulated by the highest-resolution WRF configurations.

As before, precipitation occurrence exhibits the highest model–observation agreement when the analysis is restricted to observed wet days, indicating that the model successfully reproduces the days on which precipitation occurs in reality. Conversely, all model configurations tend to overestimate the number of wet days, independent of horizontal resolution and parametrization. These additional wet days are typically associated with low-intensity rainfall, yet they contribute to an overall overestimation of total precipitation, both on annual and seasonal timescales.

Among the tested configurations, WRF3 (1 km resolution) shows the largest positive bias in precipitation amounts at most sites. Nevertheless, both WRF3 and WRF2 (3 km resolution) demonstrate added value compared to lower-resolution configurations, particularly at high-altitude locations, where ERA5 and WRF1 (9 km resolution) tend to underestimate precipitation. This improvement is attributed to the enhanced representation of topography in higher-resolution simulations, which allows a better characterization of the orographic influence on precipitation. Consequently, WRF3 yields the most accurate spatial distribution of precipitation at high elevations, although it slightly overstates precipitation totals in these regions. This overestimation is likely related to the representation of convection within the WRF model, which is consistent across the three configurations used in this study. A more detailed investigation into the sensitivity of simulated precipitation to variations in cumulus parameterization schemes (e.g., Zhang and Wang, 2017) and convection-permitting configurations (e.g., Belušić et al., 2020) could provide further insight into the causes of this positive bias, particularly in high-altitude areas.

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. In this region an extended data base shown in Figure 6 together with the WRF domain is shown.

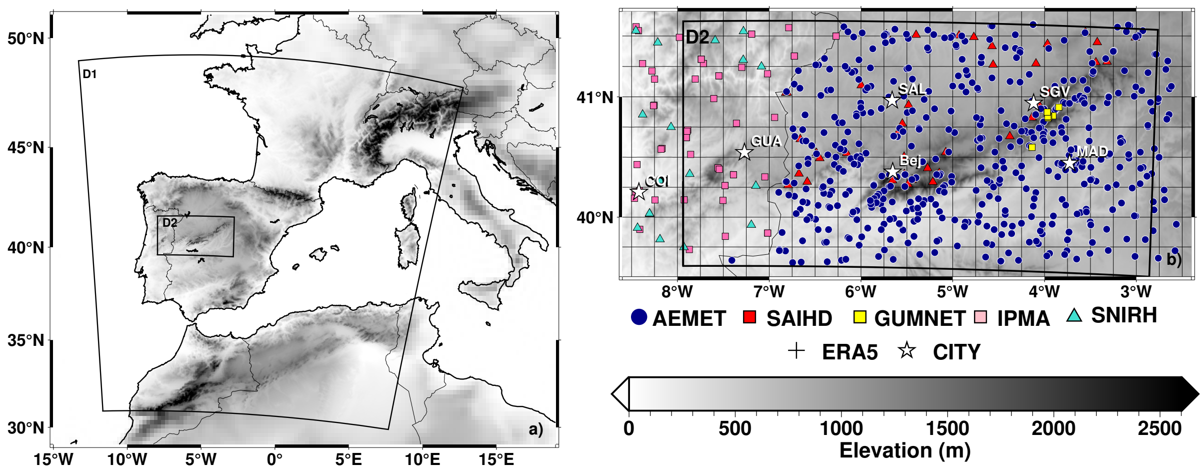

Figure 6. Configuration of the two Weather Research and Forecasting (WRF) domains of WRF´s simulation. Spatial distribution of observational sites within the smallest ND1 WRF domain including AEMET (red points), DUERO (blue triangles), GumNet (green squares), IPMA (black crosses) and ULisboa (yellow diamonds) observational sites. The white stars represent the nearest relevant cities which are Segovia (SGV), Madrid (MAD) and Salamanca (SAL) in Spain and Guarda (GUA) and Coimbra (COI) in Portugal. Grey shading depicts the orographic altitude.

Collaborations with other research groups directly linked to the project

The *SmileAtYou* project maintains regular collaboration with the IGEO-CSIC group led by J.F. González Rouco, with whom coordinated regional modelling efforts have been conducted historically. Stable collaborations are ongoing with the University of Lisbon (Instituto Dom Luiz, Rita Cardoso and Luana Santos Cardoso), the regional WRF modelling department at NCAR (USA, J. Dudhia), and the CORDEX community, particularly within the Flagship Pilot Study LUCAS (Dr. Rechid et al.).

These collaborations are instrumental in the technical implementation of code modifications to WRF, as many of the changes applied in our simulations are novel to the scientific community. The joint analysis of the impacts, enriched by the collective expertise of these institutions—many of whose members are part of this project—takes place in nearly weekly discussions.

Collaborations with companies or socio-economic sectors directly linked to the project

AEMET (Climate Evaluation and Modelling Area) collaborates within the CIMAs project (Climate Research Initiative for Iberian Mountain Areas), focusing on high-resolution climate simulations in complex orographic regions. This collaboration enables in-depth analysis of land surface components and addresses challenges in high-resolution convection-permitting simulations.

In parallel, collaboration with CSIC's PTI Clima in a Climate Services initiative alongside AEMET fosters idea exchange in a regional high-resolution context. These interactions are particularly valuable, given that future developments under *SmileAtYou* could feasibly support the provision of climate services for the Iberian Peninsula based on the very high-resolution simulations produced, which would be a highly desirable objective for the project's continuation.

BIBLIOGRAPHY

Belušić, D., de Vries, H., Dobler, A., Landgren, O., Lind, P., Lindstedt, D., Pedersen, R.A., Sánchez-Perrino, J.C., Toivonen, E., van Ulft, B. and Wang, F., 2020. HCLIM38: a flexible regional climate model applicable for different climate zones from coarse to convection-permitting scales. *Geoscientific Model Development*, *13*(3), pp.1311-1333.

Greciano-Zamorano, E.; González-Rouco, J.F.; García-Pereira, F.; Vegas-Cañas, C.; Navarro-Montesinos, J.; García-Bustamante, E.; Rodríguez-Camino, E.; Rodríguez-Guisado, E. Evaluation of Precipitation Variability over the Sierra de Guadarrama. EGU General Assembly 2023, 24-28 Abril, Viena (Austria). 2023

Zhang, C.; Wang, Y. *Projected Future Changes of Tropical Cyclone Activity over the Western North and South Pacific in a 20-km-Mesh Regional Climate Model*. J. Climate, 30, 5923–5941, DOI: 10.1175/JCLI-D-16-0597.1. 2017.

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 September. 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 September. 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.copernicus.org/EGU25/session/51896