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Climate Initiative for Iberian Mountain Areas (CIMAs)

Improving our understanding of climate variability over mountain areas using high resolution modelling

E. Greciano-Zamorano[1,3], J. F. González-Rouco[1], C. Vegas-Cañas[1], F. García-Pereira[1], J. Navarro-Montesinos[2], E. García-Bustamante[2], E. Rodríguez-Camino[3], E. Rodríguez-Guisado[3]

[1]Dpto. de Física de la Tierra y Astrofísica, Instituto de Geociencias (IGEO, UCM-CSIC), Universidad Complutense de Madrid (UCM).
[2]Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Spain. [3]Agencia Estatal de Meteorología (AEMET), Spain.

emiliogr@ucm.es

Abstract

Mountain areas are particularly sensitive to global warming. The complex orography and distribution of climates, ecosystems and feedbacks tend to amplify the effects of climate change. Additionally, the distributions of precipitation and snow cover in mountainous areas are especially relevant for water resources and stress the need for high altitude observations and high-resolution modelling over complex terrain. However, harsh meteorological conditions and the complex orography associated with this environment that, as part of the Mediterranean domain, has been underscored as a climate change hot-spot, hinder the obtention of a good coverage of high-altitude observations and pose challenges for regional climate models. CIMAs is a joint effort aiming at improving our understanding of climate variability over mountain regions in Iberia. A pilot area has been selected over the Sierra de Guadarrama (Spanish Central range, about 50 km from Madrid) aiming at studying climate variability through very high (1 km) resolution simulations, exploring models' ability to capture relevant processes at that scale. A set of observational sites ranging from high altitudes to low levels at both sides of the range has been used. ERA Interim, ERA5 and different WRF nested simulations, spanning the last three decades and reaching 1 km resolution, have been compared to a dense network of in situ observations. Results show a clear improvement with increasing resolution for temperature, but some altitude-related biases for precipitation. In this sense, some sensitivity tests to changing convection parameterizations and to convection permitting configurations have been performed.

Data

Temperature and precipitation are the main variables studied through observational data and simulations, although subsurface temperature, snow and wind are considered too. Initially, inside the pilot area over Sierra de Guadarrama, observations (Fig. 1) are provided by two sources: the Guadarrama Monitoring Network (GuMNet; [1,2]) and the Spanish Meteorological Agency (AEMET). The GuMNet sites are situated in a mountainous environment, between 902 to 2255 masl. The AEMET sites are at lower altitudes, expanding the altitude range down to 607 masl. Ongoing work will expand this dataset to the whole area of Sistema Central, including sites from other institutions, like the Instituto Português do Mar e da Atmosfera (IPMA) and the Spanish Automatic Hydrological Information Systems (SAIHs). Simulated data correspond to three models: ERA-Interim and ERA5 reanalysis [3]; and a regional simulation with the WRF model [4]. The WRF simulation uses nested domains with different grid spacings, reaching 9, 3 and 1 km resolution (Fig. 1), referred herein as WRF1, WRF2 and WRF3, respectively. The selected physical configuration of the WRF model involves the Thompson et al [5] scheme for the microphysics and a New Tiedtke [6] scheme for the cumulus parametrization.

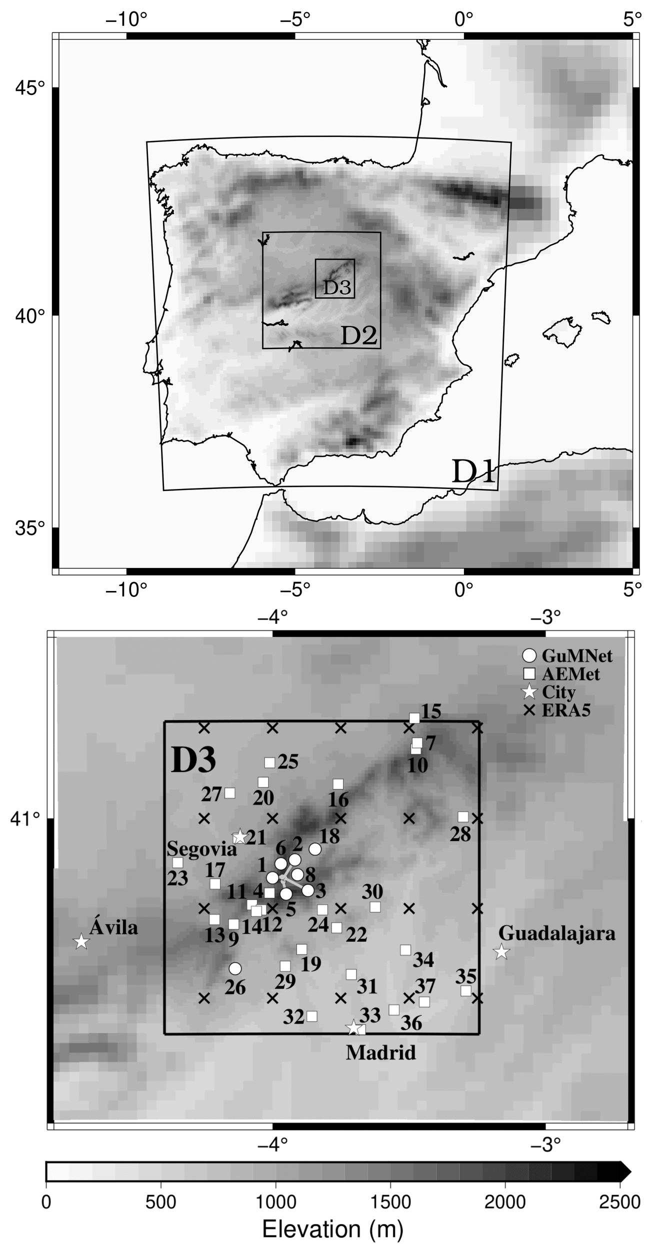

Fig. 1. Top: domains D1 through D3 of the WRF simulation. The orography is shown with elevation in grey shading. Bottom: zoom of D3 with the GuMNet (circles) and AEMet (squares) sites used to evaluate precipitation and ERA5 points inside D3 (crosses). Sites are ordered by altitude.

Temperature

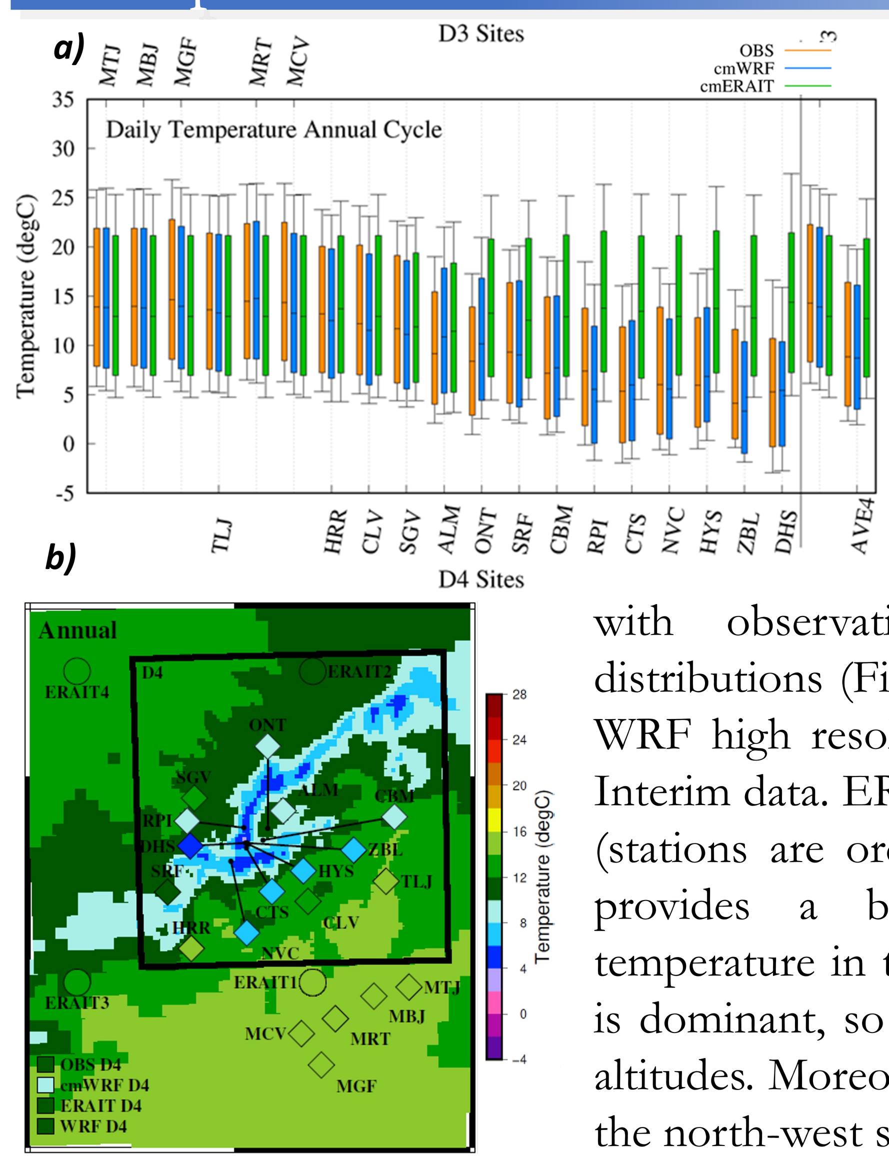

Fig. 2. a) Distribution of daily temperature annual cycles from obs. (orange) and co-located model data (cmWRF, blue; cmERAIT, green). Regional averages are separated by a vertical line on the right. B) Mean temperature for the simulated and observed data: the shading represents WFR; the diamonds, observations; and the circles, ERAIT. The squares at the bottom left, the regional averages. Both from Vegas et al, 2020 [1].

Fig. 2 compares a simulation with WRF (driven by ERA Interim) and ERA Interim with observations. Daily temperature annual cycle distributions (Fig. 2, left) show a clear improvement for the WRF high resolution simulation in comparison with ERA Interim data. ERA Interim shows increasing bias with height (stations are ordered by altitude). The map (Fig. 2, right) provides a basic climatological description of the temperature in the Sierra de Guadarrama, where orography is dominant, so the coldest temperatures are at the highest altitudes. Moreover, temperatures in the northern plateau, in the north-west side of the mountain range, seem to be milder than in the southern plateau. ERA Interim shows an increasing bias with height, while WRF-1 km resolution capture well the observed values.

Precipitation

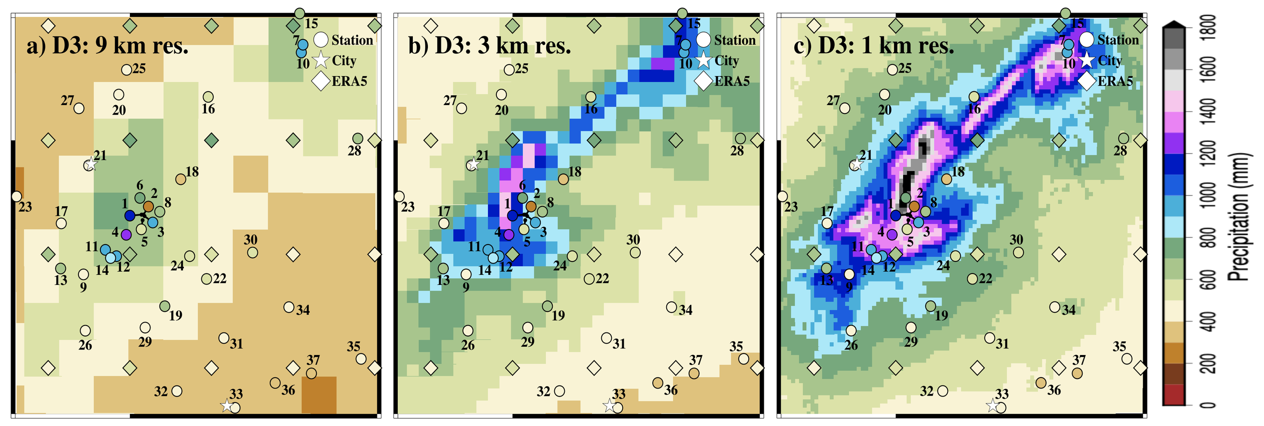

Fig. 3. Accumulated annual precipitation means for ERA5 (diamonds), observations (circles) and the 3 resolutions of WRF (9 km, WRF1; 3 km, WRF2; and 1km, WRF3) over the D3 domain (Fig. 1).

Observed precipitation increases with altitude as well as WRF simulated precipitation with a more realistic representation of orography (Fig. 3). However, with 1 km res. overestimation seems to occur. Instead, ERA5 tends to underestimate except for the lower values.

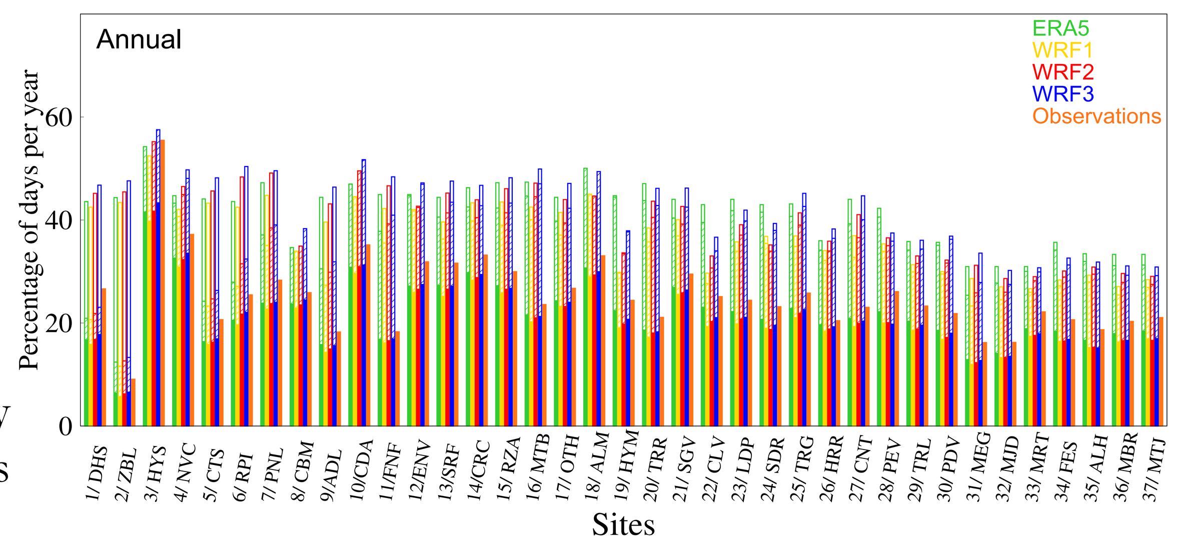

Fig. 4. Percentage of days per year with detectable precipitation both for observations and simulations for unmasked data (hollow), masked to obs. data availability (hatched) and masked to obs. wet days (filled solid).

The percentages of wet day per year (Fig. 4) shows model-data agreement if we consider only observational wet days (Fig. 4; filled solid). However, both ERA5 and all WRF1, WRF2, and WRF3 overstate the occurrence of precipitation during dry days in observations (Fig. 4; hatched boxes). Additionally, the dispersion diagram for simulated and observed accumulations (Fig. 5) shows that ERA5 underestimates precipitation above 700 mm, while WRF3 overestimates in comparison to WRF2 at almost all sites, except for sites with highest values. At the highest altitudes, WRF3 and WRF2 improve ERA5 and WRF1.

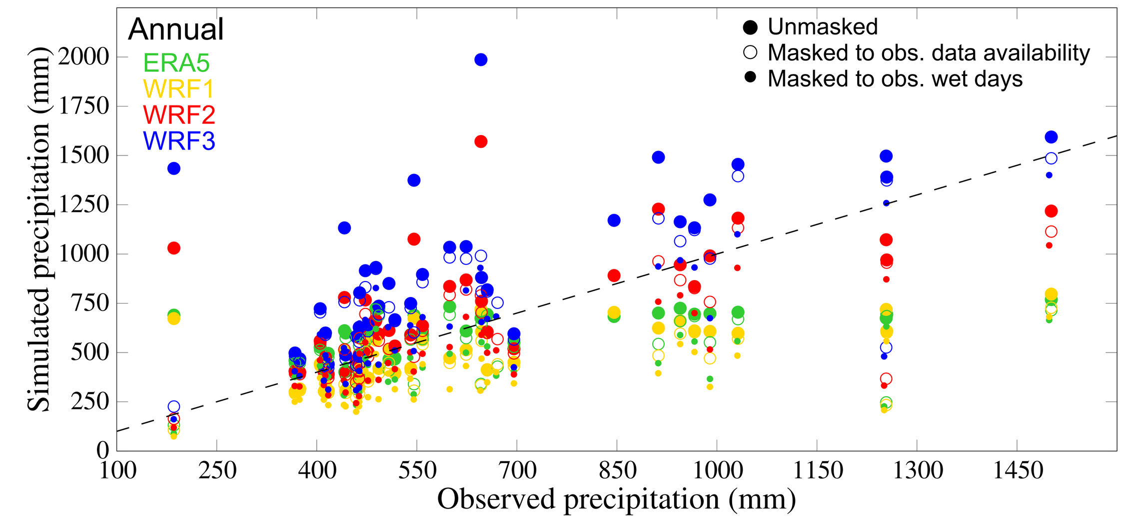

Fig. 5. Dispersion plot of detectable observed and simulated mean of total accumulated precipitation within the D3 domain. Masking is defined as in Fig. 4. The dashed line indicates equal values.

Overestimation is due to an excess in the number of simulated rainy days. Fig. 6. shows that for NVC these extra days correspond to days with little rainfall. 75% of wet days distribute with amounts below 10 mm and 25% of wet days with amounts below 1 mm. The distribution of observations tends to be better represented by WRF3. The most extreme values at high elevations are best represented by WRF2 and WRF3.

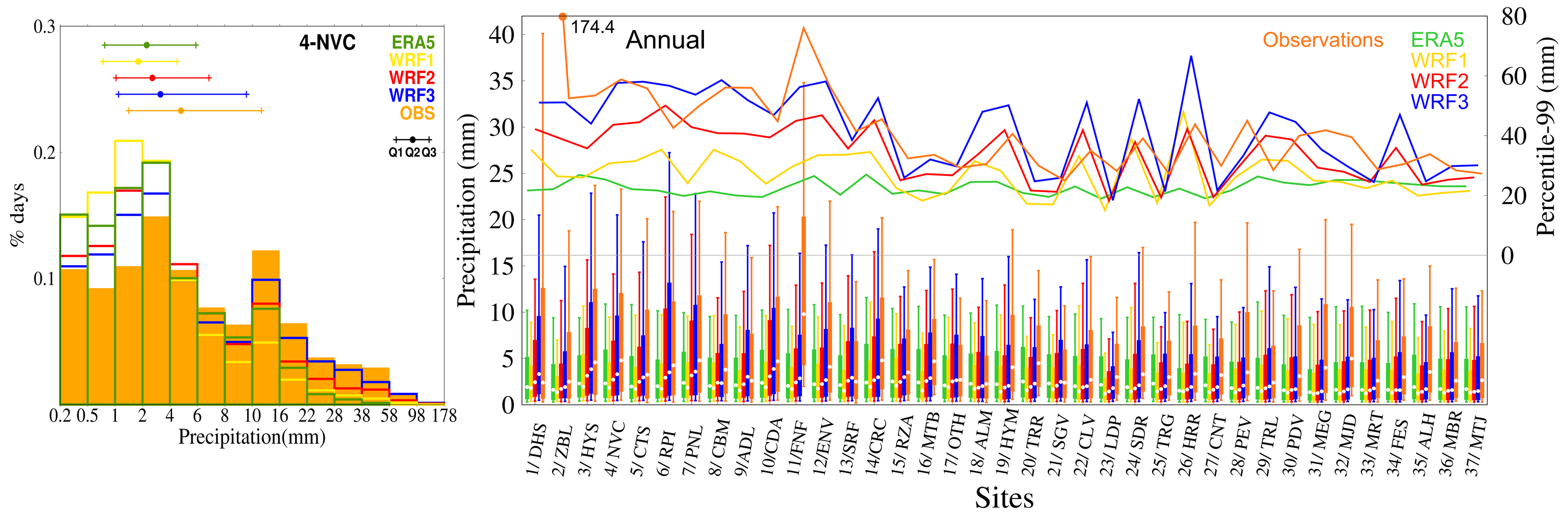

Fig. 6. Left: Histograms of daily precipitation relative frequencies for observations and simulations at Navacerrada (4-NVC). Segments depict quartiles: Q1, Q2 (median) and Q3. Right: Boxplots of observed and simulated precipitation. The whiskers refer to percentiles 10 and 90; the limits of the box refer to Q1 and Q3; and the white point to Q2. Lines represent the 99th percentile.

Kain-Fritsch cumulus parameterization [7] reduces overestimation compared to New Tiedtke. Convection Permitting Schemes (CPS) reduce overestimation for WRF3 with New Tiedtke configuration but show similar results with Kain-Fritsch (Fig. 7).

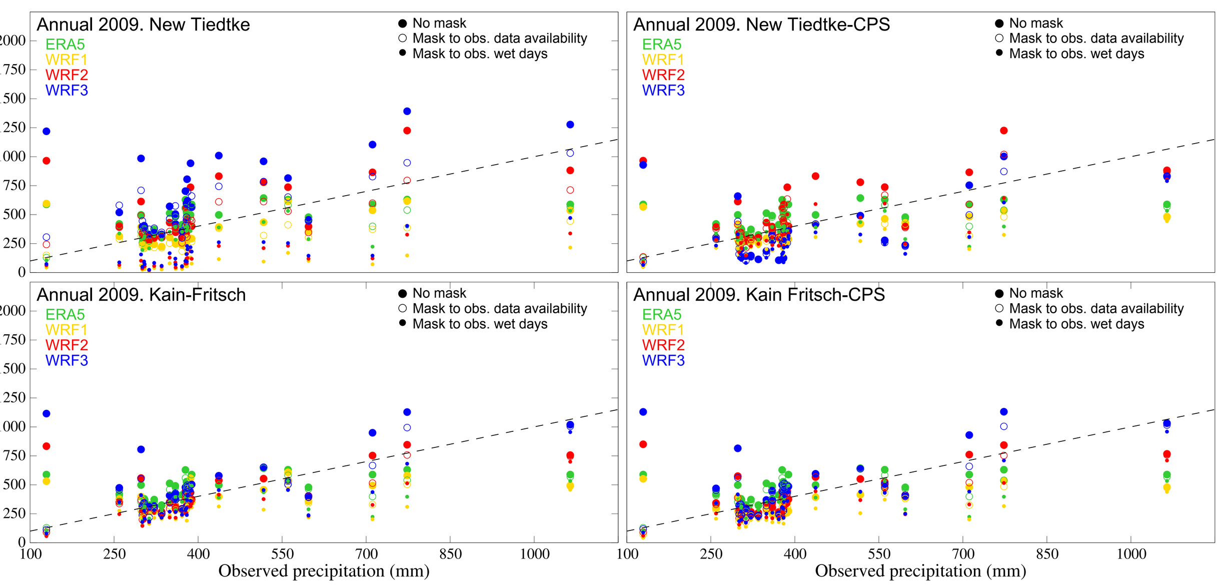

Fig. 7. Sensitivity tests for 2009. Simulated and observed accumulations are compared for different cumulus parameterizations: New Tiedtke (reference) and Kain-Fritsch with and without cumulus parameterization for WRF3.

Conclusions

Increasing the spatial resolution of the models improves the representation of the temperature field. In terms of precipitation, some altitude-related bias appears. Its improvement will depend on future work related to different cumulus parameterizations and convection permitting schemes.

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