Evaluation of the Performance of the Global Weather Dataset AgERA5 for Sustainable Water Management in Agriculture: A Focus on Reference Evapotranspiration

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Abstract. Assessing water withdrawal for crop irrigation at large scale is a decisive step for arranging a sustainable development in the agriculture sector toward an optimal allocation and management of water resources. Since direct measurements of irrigation volumes are very often not available, indirect estimates are needed. These require the use of consistent time-series of gridded weather data for implementing crop-water balance models. So far, advances in meteorological numerical modelling have been encouraging the use of their outputs, including reanalysis data, as gridded weather data sources for similar purposes. As interest in meteorological weather reanalysis data increases, the need to evaluate their performance and compare the suitability of different databases for various sites becomes central. This study evaluates the performance of the weather dataset AgERA5, which was lately derived from ERA5 reanalysis with a finer resolution, for agricultural water management applications. The AgERA5 is compared with the ERA5-Land dataset, as well as with ground-based weather interpolated observations, which are the primary alternative weather database. The study focuses on the weather variables needed for computing the FAO Penman-Monteith reference evapotranspiration, ET_0, such as wind velocity, surface shortwave radiation, temperature and relative humidity of air: key variables for irrigation volume estimates. The target area for the analyses is the Campania Region, a mediterranean-climate region in the South of Italy. The performances of the databases are evaluated from April to September, when irrigation occurs, respect to the years 2008–2024. Results show that AgERA5 is a reliable dataset for assessing agricultural indicators in regional studies by simply applying a local correction of the bias and it outperforms the weather dataset alternatives for assessing ET_0.

Keywords: Reanalysis data · FAO-56 Penman-Monteith reference evapotranspiration · irrigation season

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1 Introduction

An important goal of the current European policies for climate change adaptation regards the identification of water management strategies and actions able to guarantee water supply for food production, in accordance with the principles of sustainability, under which the environment and ecosystems obtain a central role along with the social and economic development. Then, agricultural water management assumes a significant role toward this goal, since in many European regions, especially in the Mediterranean area, the consumption and quality degradation of water for irrigating crops is the primary stressor on hydrological cycle. In these areas, evaluating water use for irrigation is crucial for designing sustainable policies and making rational and optimal decisions in water resource management [1]. Above all, agricultural water management planning entails the assessment of irrigation water volumes to program suitable actions by identifying priorities and specific needs in single district. Quantifying irrigation and water uses is indeed a condition set by the Water Framework Directive (2000/60/EC), that was later implemented in Italy according to the MiPAAF (i.e., Ministry of Agricultural, Food and Forestry Policies) Ministerial Decree issued on 31 July 2015. The said Decree establishes a set of guidelines to meet the following objectives: (1) build an updated knowledge framework about the irrigation needs of the Italian agricultural context, (2) propose tools and methodologies for quantifying the volumes withdrawn used for irrigation purposes, (3) start setting up a unique and shared platform for collecting and processing the information acquired about irrigation use. Since direct measurements of irrigation volumes are very often not available over a region and for an adequate long span time, indirect estimates are needed. Following the experiences of various irrigation consulting systems, operating across some Italian regions, over Europe and around the globe [2–5], several studies [6–8] proposed to accept the net irrigation requirement for crops under "standard" conditions as defined by the FAO - Food and Agriculture Organization of the United Nations - [9] as operative proxy of the irrigation water volume. In Mediterranean regions, such as Italy and the target area, where precipitations can be assumed negligible in the period April-September, when irrigation is indeed needed, evapotranspiration remains the fundamental variable for assessing crop water requirements [6]. It depends on weather information, such as wind velocity, surface shortwave radiation, temperature and relative humidity of air as well as crop parameters, like LAI (i.e., Leaf Area Index).

In recent years, satellite-based estimates of crop parameters with very high spatial resolution (e.g., 20 m for Sentinel-2) were used to obtain the actual crop development with satisfying reliability [8, 10, 11]. On the other hand, evapotranspiration estimates require gridded weather data as input source for regional analyses [12–14]. A classical approach to address the need for gridded weather dataset is to use advanced geostatistical interpolation techniques [15] applied to ground-based weather data observed at a restricted number of places along a district. However, although ground-based weather observations may be considered a weather truth at the site of measurement, elsewhere these data are affected by estimation errors that depend on both the geometry and consistency of the observation system and the variability over space of the weather variable itself [6, 12, 14]. Therefore, due to the great development of numerical weather modelling in the last decades, gridded weather data from reanalysis datasets have been becoming

an interesting opportunity for agricultural water management applications and, in particular, for evapotranspiration estimates. In recent years, many studies evaluated reanalysis datasets, such as ERA5 and ERA5-Land, developed by European Centre for Medium-Range Weather Forecasts (ECMWF), for evapotranspiration studies and it was found that these datasets provide a consistent and global source of meteorological data for this purpose [6, 8, 10, 12, 16]. Freely available and easily accessible, reanalysis datasets span extensive time periods and offer high spatial resolution, making them an attractive solution for applications in data-sparse regions [6, 13]. Here, we evaluate the performance of the latest released reanalysis dataset, AgERA5 over a data-sparse region located in Southern Italy. The focus is on the weather variables that have a key role in the assessment of reference evapotranspiration (ET_0) and then, in agricultural water management applications. A recent study was conducted for evaluating ET_0 by employing AgERA5 over the Jucar River system in Spain and Sicily Region in Italy [17]. Interesting discussions are then proposed for comparison among these Mediterranean areas, crucial sites for investments and actions in sustainable water management to prevent water scarcity.

2 Target Region and Weather Datasets

2.1 Target Region

The target region of the study is Campania, depicted in Fig. 1, which is a mediterranean-climate region located in South of Italy. The territory has an extension of 13671 km^2 from the Southern Apennines to the Tyrrhenian Sea. It is mostly characterized by the Mediterranean climate with very warm and semi-arid summers, rainy and cold winters and mild autumns and springs. Although it depends on the specific crops and their cycles, the irrigation season can be set in the span time of the year from April to September [6]. Therefore, in the present study, the analyses are being referred to these months for the years 2008–2024.

2.2 Weather Datasets

In the target area, a monitoring network composed of 18 complete ground-based automatic weather stations (AWSs) is available. The reanalysis data from ERA5-Land and AgERA5 databases cover the area as well. Figure 1 shows the region, with some information about the weather data availability, whose details are described below.

Ground-Based Weather Dataset. The current weather monitoring network has been managing by the Multi-Risk Service of the Regional Civil Protection Department in Campania Region. It is composed of 18 complete ground-based AWSs that sparsely cover the region with an average density of about one station over 750 km^2. The network is very uneven, resulting in some portions of the region that appear not monitored at all, such as the southern coast and the center of the region (Fig. 1). The AWSs have been working continuously since 2008, measuring, with a time resolution of 10 min, the following weather variables: (i) wind velocity at 10 m height, hereinafter denoted as WS, (ii) surface shortwave radiation, hereinafter denoted as RS, (iii) air temperature, hereinafter denoted as T, (iv) air relative humidity, hereinafter denoted as RH, and (v)

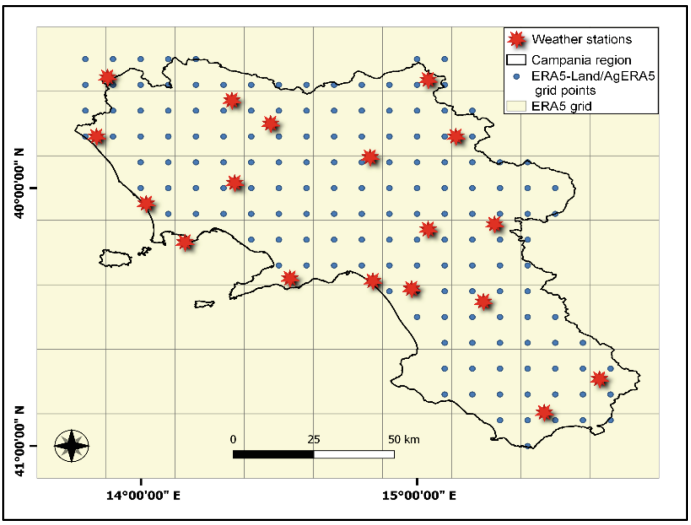

Fig. 1. Target area, ground-based weather stations in red and grid points of ERA5-Land and AgERA5 datasets in blue, in comparison with the mesh of the global ERA5 reanalysis database.

atmospheric pressure. Table 1 reports some regional statistics about observations in the analyzed period that spans from April to September of 2008–2024. Since in the following analyses the interest is in the daily minimum and maximum temperatures (T_{min} and T_{max}, respectively), their statistics are also reported as follows.

Table 1. Means and coefficients of variation referred to the daily weather observations within the period April-September of 2008–2024 for the target area, i.e., Campania Region.

Weather Variable	Mean	Coefficient of variation
T	20.5 °C	0.0041
T_{max}	27.0 °C	0.24
T_{min}	14.7 °C	0.21
RS	244.9 W m^{-2}	0.31
RH	69.3%	0.18
WS	2.4 m s^{-1}	0.38

Interpolated Ground-BASED Data (IGD). Ground-based weather observations are generally available in discrete points over a region. Spatial interpolation permits us to assess the values of the observation elsewhere in unmonitored sites and, eventually, on a regular grid for obtaining a gridded weather dataset. Among the spatial interpolation methods, geostatistical interpolation by kriging is one of the most used and advanced techniques [15]. Here, ordinary kriging is employed for interpolating the daily observations of wind velocity, surface shortwave radiation, air relative humidity and atmospheric

pressure. Daily minimum and maximum air temperature are interpolated with regression kriging, using elevation as predictor for improving the estimates [6, 12, 14]. The interpolated ground-based data, after in the text referred to as IGD, are computed at each AWS site by means of the leave-one-out crossvalidation method, which allows to assess the interpolated value in a point where the measure is available by applying the interpolation technique on the remaining set of observations obtained by excluding the measure at the point of interest.

Reanalysis Data. The reanalysis databases considered in this study are ERA5-Land and AgERA5, developed by ECMWF and available for free downloading on the web application Copernicus Climate Data Store. Both of them cover a period from 1979 to the near present (few days back) and both are derived product from ERA5 data for land and agricultural applications, respectively. However, while the resolution in space of ERA5 is 0.25 × 0.25°, the horizontal resolution for ERA5-Land and AgERA5 is 0.10 × 0.10°. The temporal resolution of data is always one hour. Figure 1 shows the grid points of these datasets, compared with the native grid of ERA5. The weather outputs of the datasets are WS at 10 m height, RS, then T, atmospheric pressure, dew point temperature (T_{dew}), all available at a height of 2 m above ground. To have consistent datasets with ground-based observations, the dew point temperature is converted to relative humidity by applying the following formula [9]:

$$RH = 100\frac{e_a}{e_s} \tag{1}$$

where e_s is the mean saturation vapor pressure [9], while e_a is the actual vapor pressure computed by Eq. (2) as function of T_{dew}:

$$e_a(T_{dew}) = 0.6108exp\left[\frac{17.27T_{dew}}{T_{dew} + 273.3}\right] \tag{2}$$

Both ERA5-Land and AgERA5 data are corrected with a simple and efficient bias correction technique [12, 18], which consists of subtracting the monthly regional mean bias for each variable of interest. For the objectives of the current analysis, the correction bias is computed over the same span time of the analyses, by assuming that the ground-based observations are available and for testing the case that, despite this availability, the gridded reanalysis data represent a good alternative data source for weather observations in regional studies.

3 Methods

FAO-56 ET_0. The reference evapotranspiration, ET_0 was here calculated by employing the Penman–Monteith formula proposed by the paper FAO-56 [9], as stated in the next equation:

$$ET_0 = \frac{1}{0.408}\frac{\Delta(R_n - G) + \gamma\frac{900}{T+273}WS(e_s - e_a)}{\Delta + \gamma(1 + 0.34\,WS)} \tag{3}$$

where γ is the psychometric constant; Δ is the slope of the vapor pressure law; T is the daily mean air temperature at 2 m height that has to be determined by averaging T_{min} and T_{max}; WS is the wind velocity related to an height of 2 m above the ground; e_s (kPa) and e_a (kPa) are, respectively, the daily saturation vapor pressure and daily actual vapor pressure; R_n is the net solar radiation at the crop surface and G is the soil heat flux density. The net solar radiation (R_n) is the difference between the incoming net shortwave radiation and the outgoing net longwave radiation. The incoming net shortwave radiation is a fraction of the incoming shortwave solar radiation, called RS, by means of the albedo (i.e., equal to 0.23 for the hypothetical grass crop for the computation of ET_0). The wind velocity at 2 m, WS (m s^{-1}), is given by the wind velocity at 10 m that is the available information, by using a very common logarithmic wind velocity profile as also proposed by the paper FAO-56 [9]. Detailed information on input data can be found in [9].

In the following, Table 2 reports some regional statistics about daily ET_0 computed by using observations in the analyzed period (April-September of 2008–2024).

Evaluation of the Performance. Let V_j be the observed daily value of each variable of interest for the analyses at the ground-based network and F_j the corresponding daily value as predicted by the different databases, i.e., AgERA5, ERA5-Land and IGD data, the two statistical indicators here applied to assess the performance of AgERA5, compared with the one of the remaining datasets of interest are:

$$PBIAS(\%) = \frac{1}{\overline{V}} \frac{\sum_{j=1}^{m} (F_j - V_j)}{m} 100 \tag{4}$$

$$PRMSE(\%) = \frac{1}{\overline{V}} \sqrt{\frac{\sum_{j=1}^{m} (F_j - V_j)^2}{m}} 100 \tag{5}$$

where $\overline{V}$ is the average value of ground-based observations in the period of interest made of m days.

Table 2. Means and coefficients of variation of the ET_0 calculated by using ground-based observations as input data, within the period April-September of 2008–2024 for Campania.

Daily ET_0	Mean (mm day^{-1})	Coefficient of variation
April	2.7	0.20
May	3.5	0.18
June	4.5	0.15
July	5.0	0.15
August	4.5	0.17
September	3.0	0.24

4 Main Outcomes and Discussion

In the current section, the major outcomes of the analyses are given. Primarily, in Figs. 2, 3, 4, 5, 6 and 7 are proposed the performance of all the weather variables proposed for the ET_0 assessment. In particular, the results refer to bias corrected reanalysis data. Wind speed is the most biased variable, which is also affected by the highest values of PRMSE, followed by solar radiation and then, air relative humidity.

Air temperature is the best predicted variable, however the T_{max} estimates outperform the T_{min} estimates that show an average regional PRMSE equal to about 16%–17% for the IGD, ERA5-Land and AgERA5 data, compared with the 6%–7% related to T_{max}.

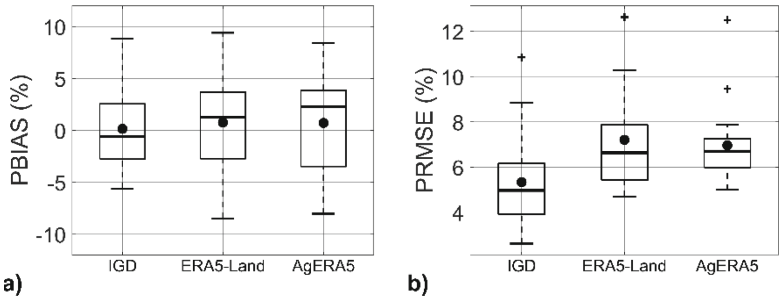

Fig. 2. Boxplot of the regional a) PBIAS and b) PRMSE for T

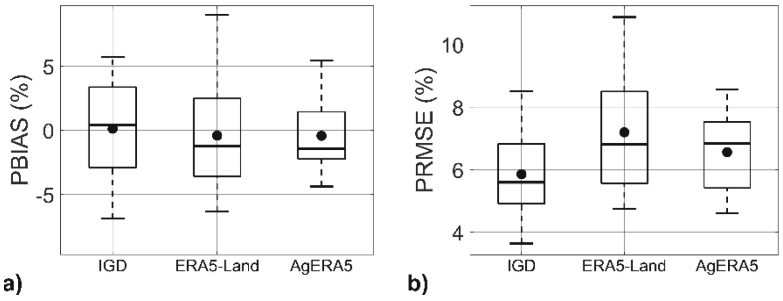

Fig. 3. Boxplot of the regional a) PBIAS and b) PRMSE for T_{max}

Solar radiation estimates show average regional PRMSE equal to 18.6%, 22.4% and 18% respectively for the IGD, ERA5-Land and AgERA5 databases while the same statistics equal values of 10%, 12.5% and 14% for the IGD, ERA5-Land and AgERA5 relative humidity estimates.

Wind speed estimates show average regional PRMSE equal to 60.5%, 49.1% and 48.2% respectively for the IGD, ERA5-Land and AgERA5 databases.

For all the variables, the three databases, i.e., IGD, ERA5-Land and AgERA5, slightly differ each other by supporting the hypothesis that gridded reanalysis is a good proxy for weather observations if a bias correction technique is applied. However, it is noted that AgERA5 outputs slightly outperform ERA5-Land data for air temperature

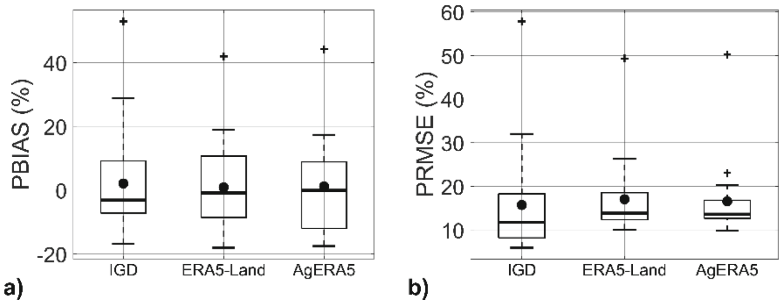

Fig. 4. Boxplot of the regional a) PBIAS and b) PRMSE for T_{min}

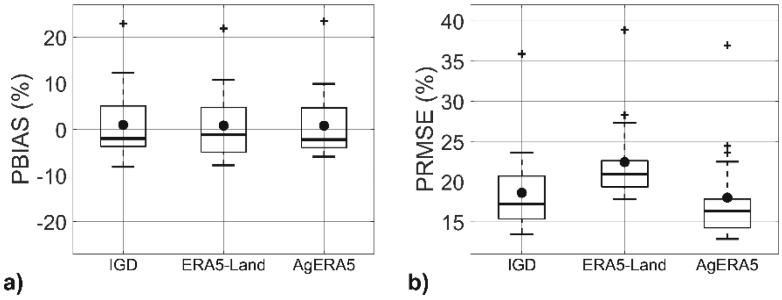

Fig. 5. Boxplot of the regional a) PBIAS and b) PRMSE for RS

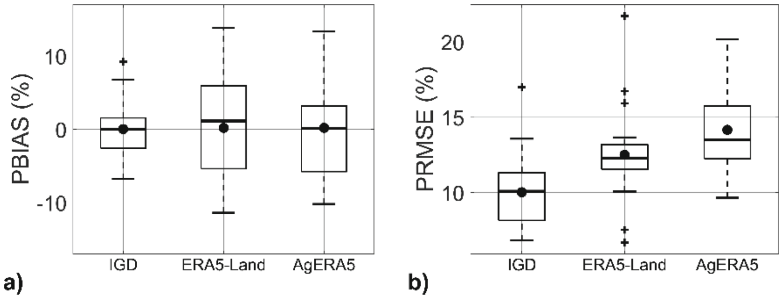

Fig. 6. Boxplot of the regional a) PBIAS and b) PRMSE for RH

and solar radiation. Similar results were also found by [17] in two area located in Spain and Italy as well: in that study wind speed also remained the most biased meteorological variable.

Figure 8 exhibits the performance of the three different analyzed input weather databases for the assessment of the FAO ET_0 by means of Eq. (3). It is clear that both of the reanalysis datasets are excellent proxy of weather observations for this purpose, showing a regional average mean PBIAS equal to 0.8% and 1.6% for ERA5-Land and AgERA5 estimates, respectively, compared with the 1.5% showed by the IGD estimates. The maximum absolute PBIAS values for the IGD, ERA5-Land and AgERA5 ET_0 estimates

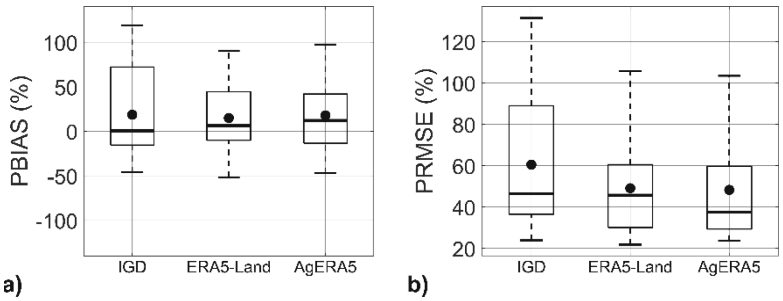

Fig. 7. Boxplot of the regional a) PBIAS and b) PRMSE for WS

are 17.7%, 13.6% and 15.9% respectively. The average values of the PRMSE are 18.2%, 19.4% and 18.3% respectively for the IGD, ERA5-Land and AgERA5 ET_0 estimates while the maximum values of the PRMSE are 29.7%, 31.4% and 28.9% respectively.

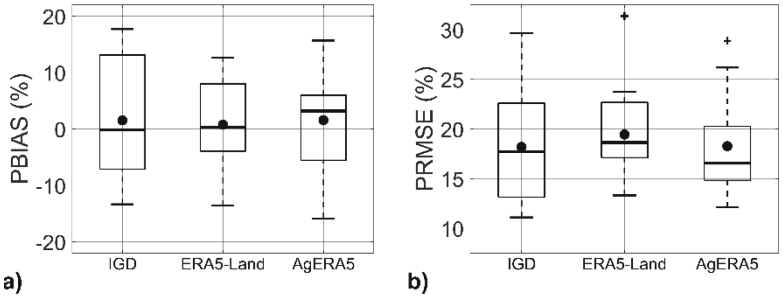

Fig. 8. Boxplot of the regional a) PBIAS and b) PRMSE for ET_0

As also pointed out by [17], AgERA5 showed superior performance than ERA5-Land.

5 Conclusions

Sustainable agricultural water management requires knowledge of irrigation water volumes for planning investment and actions as well as for identifying critical areas and preventing water scarcity. Since direct measurements of water volumes for irrigation purposes are unavailable at the level of analysis, alternative methods that use gridded weather data to implement crop-water balance models are necessary.

To obtain gridded data at a regional scale, sparse ground-based weather observations must be spatially interpolated, which introduces interpolation errors that depend on the variable of interest and the density of the monitoring network. On the other hand, in recent years the development of numerical weather modeling provides the opportunity to use weather reanalysis data as gridded data in regional applications.

The proposed analyses demonstrate that gridded reanalysis datasets, such as ERA5-Land and the latest AgERA5, are accurate and reliable alternative of weather observations

when a bias correction technique is applied. In particular, their use for assessing reference evapotranspiration—a key variable for estimating irrigation water volumes—appears to be a promising possibility. Indeed, both ERA5-Land data and AgERA5 data, derived from ERA5 with a finer spatial resolution for specific land and agricultural applications, are acceptable substitutes of weather data observed at the ground-based monitoring network as data input for the assessment of ET_0 at the district scale.

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Disclosure of Interests. The authors state that they do not have any competing interests, which can be significant to the matter of the present paper.

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