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UNCERTAINTIES IN PHOTOVOLTAIC ELECTRICITY YIELD PREDICTION FROM FLUCTUATION OF SOLAR RADIATION

Marcel Šúri[1], Thomas Huld[1], Ewan D. Dunlop[1], Michel Albuisson[2], Mireille Lefèvre[2], Lucien Wald[2]
[1] European Commission, Joint Research Centre, Institute for Environment and Sustainability,
Renewable Energies Unit, TP 450, via E. Fermi 1, Ispra, (VA) 21020 Italy,
[2] Ecole des Mines de Paris, Centre Energétique et Procédés, BP 207, 06904 Sophia Antipolis cedex, France,
email: marcel.suri@jrc.it, thomas.huld@jrc.it, ewan.dunlop@ec.europa.eu
michel.albuisson@ensmp.fr, mireille.lefevre@ensmp.fr, lucien.wald@ensmp.fr

ABSTRACT: We have analyzed the variability of solar radiation in the Mediterranean and Black Sea regions by comparing yearly and monthly averages to long-term average values calculated from the HelioClim-1 database. Daily sums of global horizontal irradiation are considered for 18 years in the period 1985-2004. Standard deviation of yearly sums of global horizontal irradiation shows low interannual variability, being mostly in the range of 4% to 6%. While in arid climate of Northern Africa, Middle East, and Southern Europe standard deviation goes below 4%, values up to 10% are identified along coasts and in mountains. In the least sunny year out of 18, the solar resource was generally never more than 9% below the long-term average, and only in a few regions the radiation deficit reached 15%. The most stable weather is found in summer with standard deviation in June below 12%. The least stable season is winter, with variability higher then 20% in December, and regionally going above 35%. The solar resource has distinctive time and geographical patterns that might affect financing of large photovoltaic systems, as well as management of the distributed electricity generation.

Keywords: HelioClim, PVGIS, solar radiation, interannual variability, PV yield prediction

1 INTRODUCTION

Photovoltaic (PV) electricity yield prediction is often based on estimates of long-term averages of solar radiation. However, uncertainty due to year-on-year variability of solar resource should also be considered, especially for financing large PV projects and for management of electricity grids in regions with high concentration of PV. The required information includes the quantification of how much the yearly and/or seasonal values of solar radiation may vary from the long term averages.

In this paper we analyse the variability of global horizontal irradiation by comparing yearly and monthly averages to long-term average values calculated from the HelioClim-1. Geographically this study covers the regions around Mediterranean and Black Seas.

2 DATA AND METODS

2.1 Solar radiation database HelioClim-1

HelioClim-1 was developed from Meteosat satellite images by the application of the Heliosat-2 method [1, 2]. The primary data include daily means of global horizontal irradiation, calculated over the period 1985-2005. The reduced ISCCP-B2 satellite images have been used in calculation and therefore the HelioClim-1 database is composed of pixels of approx. 5 km in size, whose centers are spaced by approx. 30 km in each direction [2]. The extent of the database corresponds to the field of view of the Meteosat Prime disc (the satellite being centered at latitude 0° and longitude 0°), however in this study we focused only on regions around the Mediterranean Sea and the Black Sea.

The accuracy of the HelioClim-1 data was assessed by comparisons with measurements of the WMO radiometric network in Europe (55 sites) and Africa (35 sites) for the period 1994-1997 [2]. The RMS error is 35 W/m^2 (17%) for daily mean irradiance, and 25 W/m^2 (12%) for monthly mean irradiance. Bias is less than 1 W/m^2 for the whole data set, but at individual sites it may range from -15 to +32 W/m^2.

2.2 Data processing in PVGIS

The HelioClim-1 database (daily values, and averages) can be accessed through the SoDa web system [3]. However, raw data can be used only by a limited number of specialists. Therefore the daily values were integrated into the Photovoltaic Geographical Information System (PVGIS) in order to calculate long-term averages, estimate irradiation on inclined planes, and for the map analysis [4]. Complementary to SoDa, the PVGIS web interface provides a number of derived parameters from the HelioClim-1 database for any chosen location [5].

In this study, the daily means of global horizontal irradiation were analysed. Due to gaps in data, we have chosen a time series covering 18 complete years: 1985, 1987, and 1989-2004. For each year, we have calculated monthly and yearly averages. To quantify weather variability, we calculated standard deviation of monthly and yearly values from the long-term averages. For each pixel in the region, we have also found the extreme minimum and maximum values of monthly and yearly averages.

3 RESULTS

3.1 Yearly global irradiation on horizontal plane

Figure 1 shows the geographical distribution of long-term average of global horizontal irradiation representing years 1985, 1987, and 1989-2004. The highest potential for solar electricity generation is in Northern Africa, Middle East, Mediterranean islands and Southern regions of Portugal, Spain, Italy, Greece, and Turkey, with annual global irradiation higher than 1600 kWh/m^2.

Except in the mountains, and in the North, the radiation potential is still high in the rest of the region of our interest (higher than 1200 kWh/m^2). In countries, such as Spain, Italy, Turkey, and even much smaller Croatia, clear North-South gradient in global irradiation can be seen.

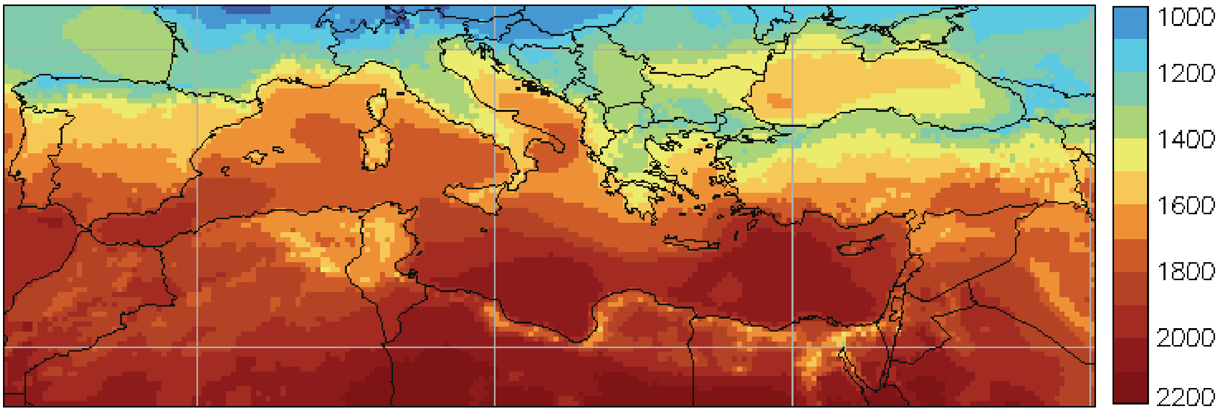

Figure 1: Long-term average of yearly sums of global horizontal irradiation (kWh/m^2, time series representing years 1985, 1987, and 1989-2004)

3.2 Variability of yearly global horizontal irradiation

Standard deviation of yearly averages gives an indication of the overall variability of the solar resource in the region (Figure 2). It is not surprising that in the arid climate of Northern Africa and Middle East, the year-on-year variability is very low, with a standard deviation not exceeding 4%. Similar weather stability can be observed in Mediterranean islands, and inland of the Iberian Peninsula, and Turkey. Large parts of Europe and Turkey show standard deviation between 4% and 6%, while higher degree of variability (up to 10%) has been identified along coasts, and in mountains (where it is even more pronounced by terrain with stronger altitude gradients). However the latitudinal pattern is not as clear as in the map of long-term irradiation averages (Figure 1) as the weather variability is more determined by regional impacts of sea, land masses, and mountains.

The distribution of yearly averages is shown in Figure 3 for 11 locations in the region. The results show that the standard deviation does not always give the right impression of the possible weather extremes within the studied 18 years period. The dispersion of yearly values over time is not always distributed symmetrically along the long-term average.

Figure 4 indicates that occurrence of years with lowest or highest radiation may bias the information given by the standard deviation. For example, the sunniest year in Marrakech (Morocco; standard deviation 2.7%) was 2% above the long-term average, while in the 'worst' year the annual solar resource was 5% below. Although the amount of sunshine in Udine (Italy; standard deviation 9.6%) in the best year exceeded the deviation in the worst year by more than 4%, it has happened more often that yearly sum was below the long-term average (10 out of 18 times).

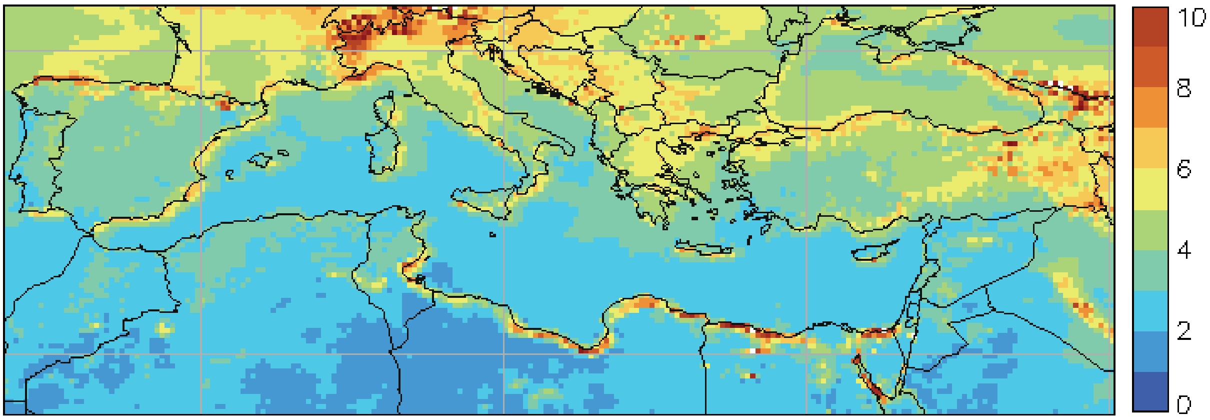

Figure 2: Standard deviation (in %) of yearly sums of global horizontal irradiation (years 1985, 1987, and 1989-2004)

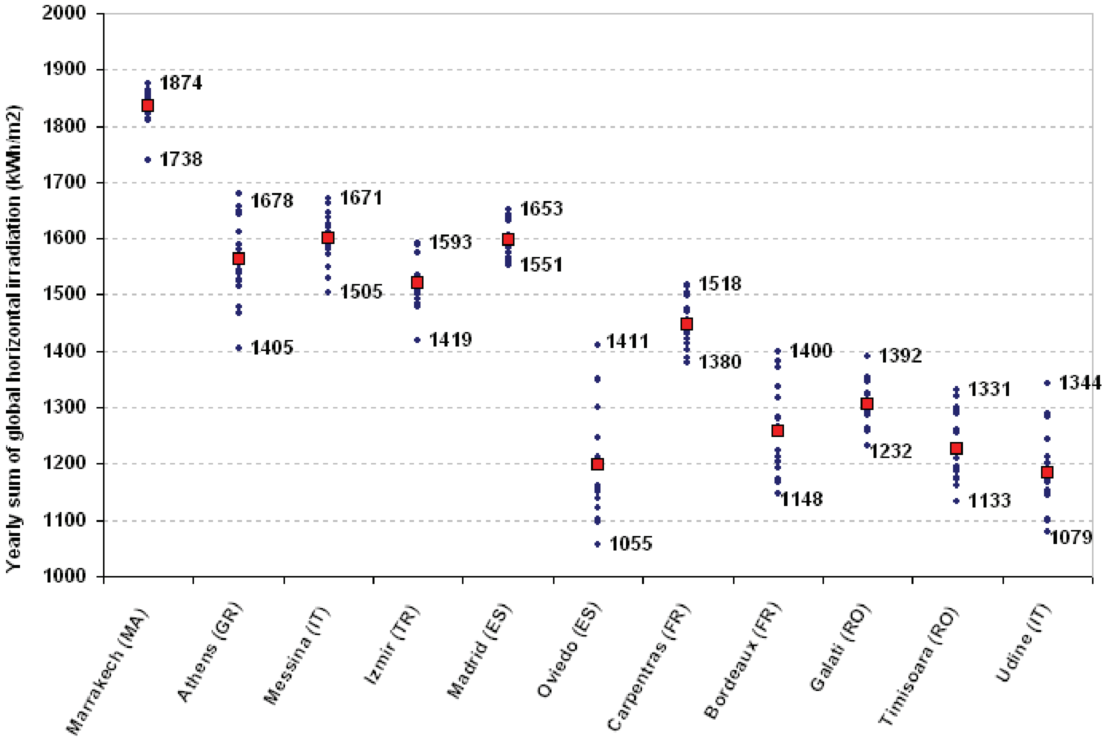

Figure 3: Distribution of yearly sums of global horizontal irradiation (kWh/m^2) around the long-term average in 11 locations (years 1985, 1987, and 1989-2004).

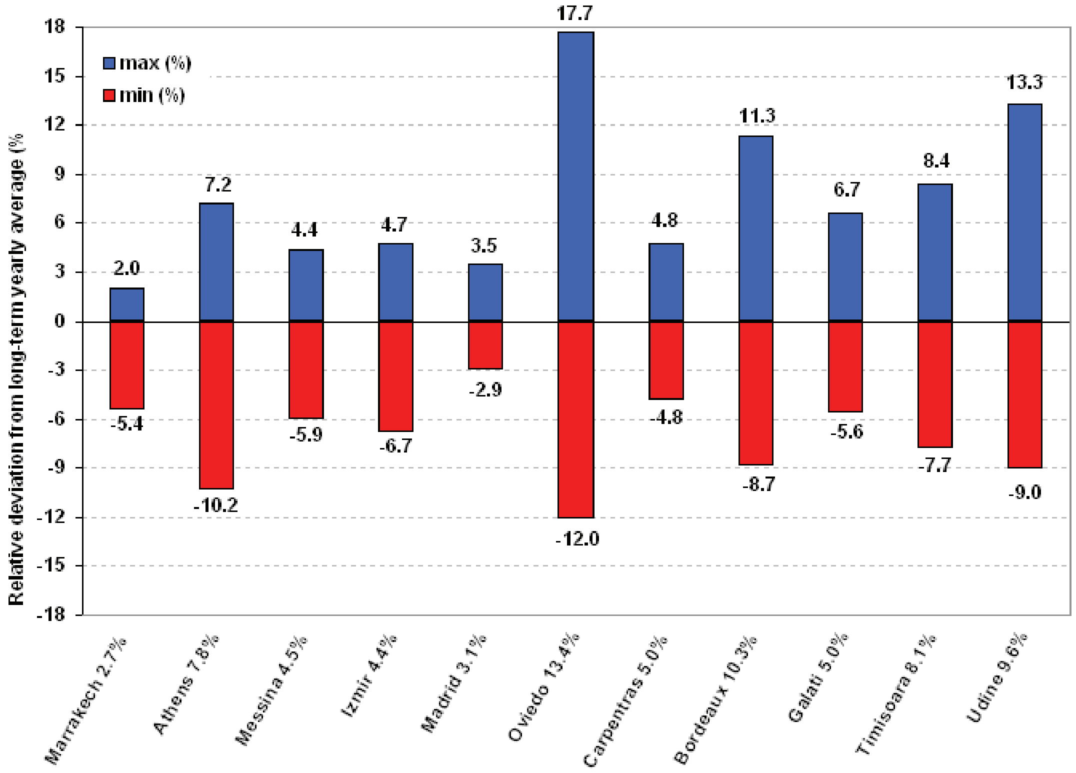

Figure 4: Relative difference of years with lowest and highest sum of global horizontal irradiation in relation to the long-term average. For comparison, the relative standard deviation is shown after the name of each city.

Figures 5 and 6 show the geographical distribution of the relative differences of lowest and highest yearly sum of global horizontal irradiation compared to the long-term average, thus identifying the deviation of the most and least sunny years from the long-term average. Within the 18 years' period, the absolute minimum yearly value rarely went below 15% from the long-term average. Low negative excursions (less than 6% down) are found in arid regions but are observed also in Europe (parts of Spain, Portugal, Italy, Romania). The deficit of the least sunny year exceeded -9% of the long-term average in few regions, including some coastal zones, the Marmara Sea, the Alps, and the Balkan mountains. The map of the deviation of the sunniest yearly values from the long-term average shows a similar pattern, although in several regions the variance from the long-term average is bigger.

3.3 Variability of global irradiation in seasons

To see climate variability in seasons, we compared monthly averages of 18 years to the long-term averages of each month in the year. The four maps below (Figures 7 to 10) show that the most stable weather is in summer with standard deviation in July rarely exceeding 12%. The least stable season is winter, with rather high variability (more than 20%, and regionally up to 36%), mainly in Eastern Turkey, Greece, Balkan countries and in high mountains. Spring and autumn show intermediate stability, again with more pronounced dynamics in the mountains and in some regions.

It should be noted that even the most stable months show much higher deviations than the entire year since the statistical base of the average is much smaller for individual months than for the whole year (about 560 days in July vs. approximately 6650 in the entire period)..

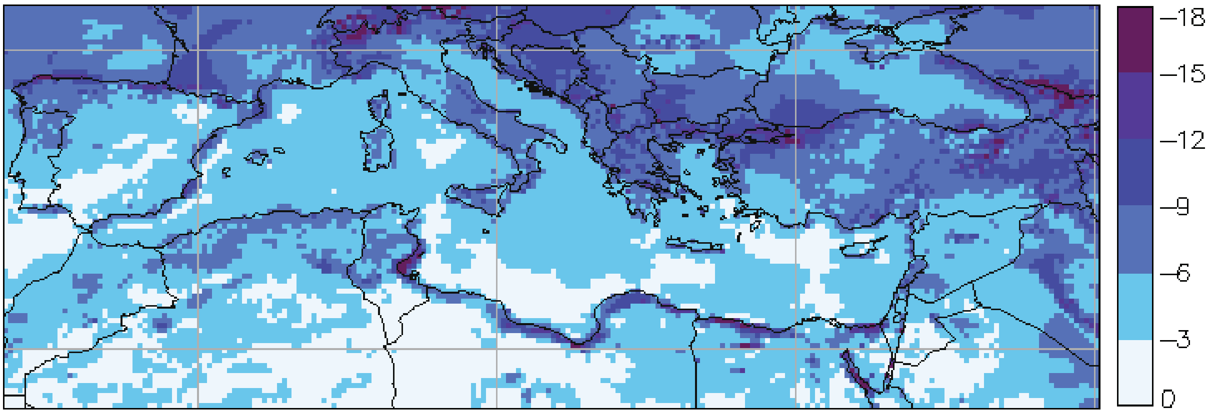

Figure 5: Relative difference of the lowest yearly sum of global horizontal irradiation in relation to the long-term average (in %).

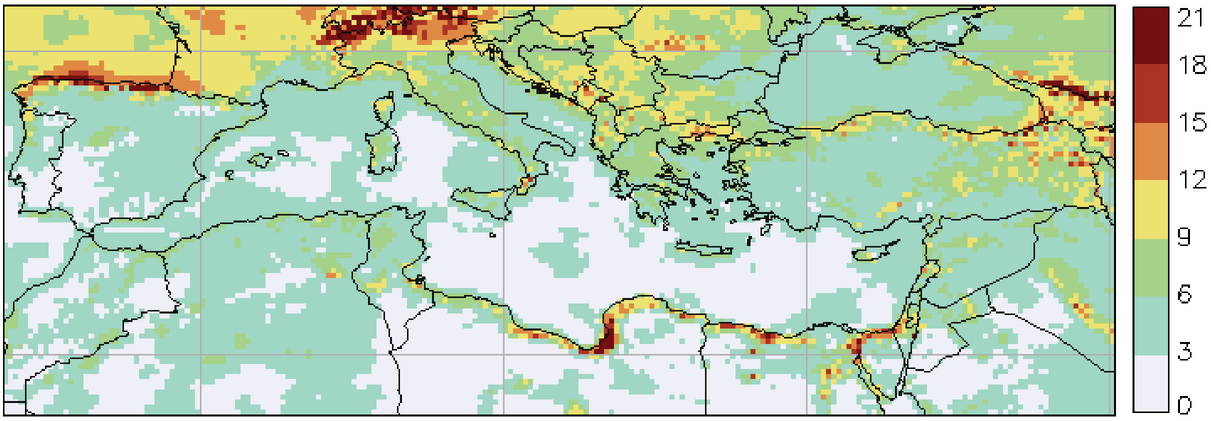

Figure 6: Relative difference of the highest yearly sum of global horizontal irradiation in relation to the long-term average (in %).

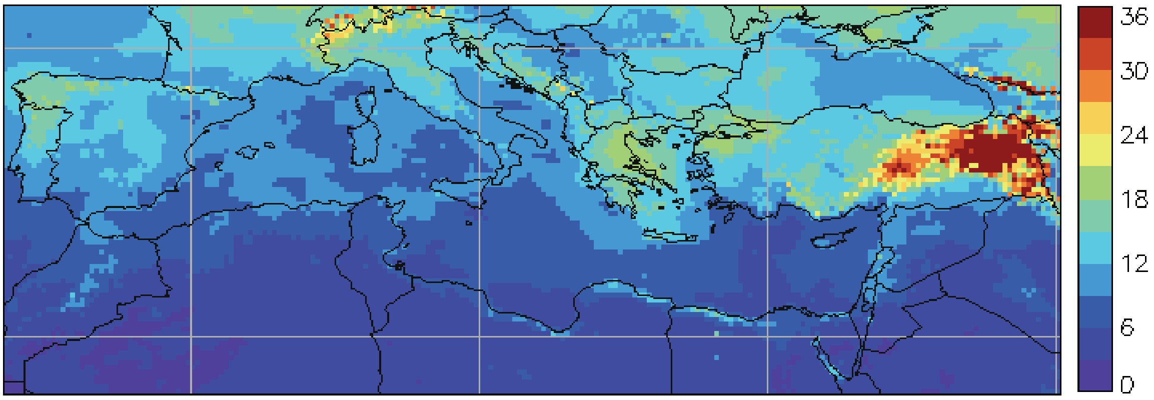

Figure 7: Standard deviation (in %) of monthly averages of global horizontal irradiation – March (years 1985, 1987, and 1989-2004)

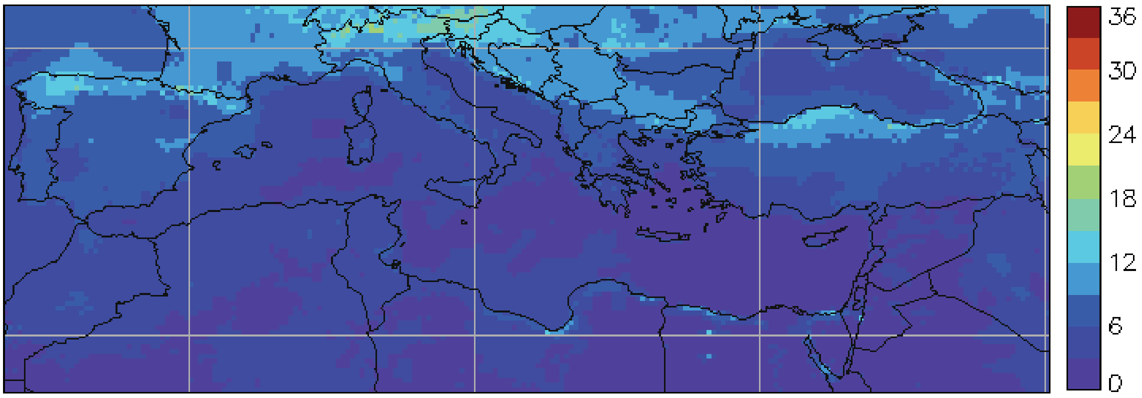

Figure 8: Standard deviation (in %) of monthly averages of global horizontal irradiation – June

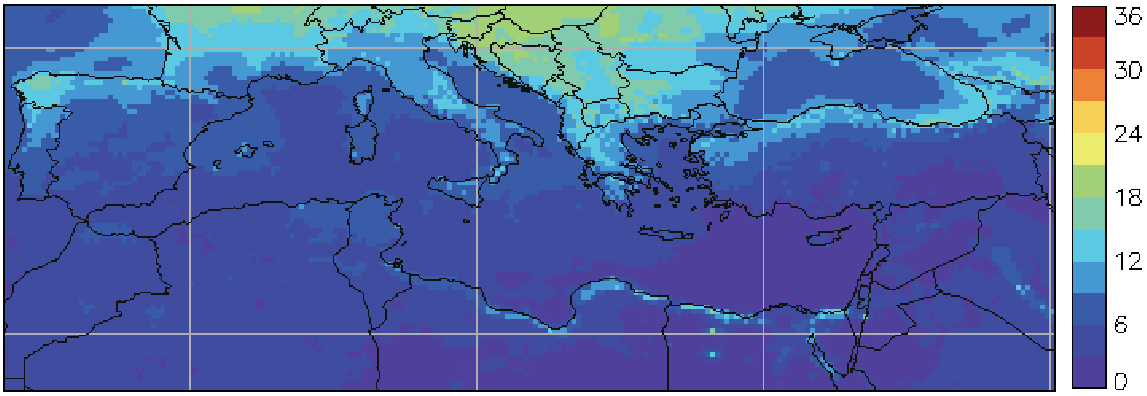

Figure 9: Standard deviation (in %) of monthly averages of global horizontal irradiation – September

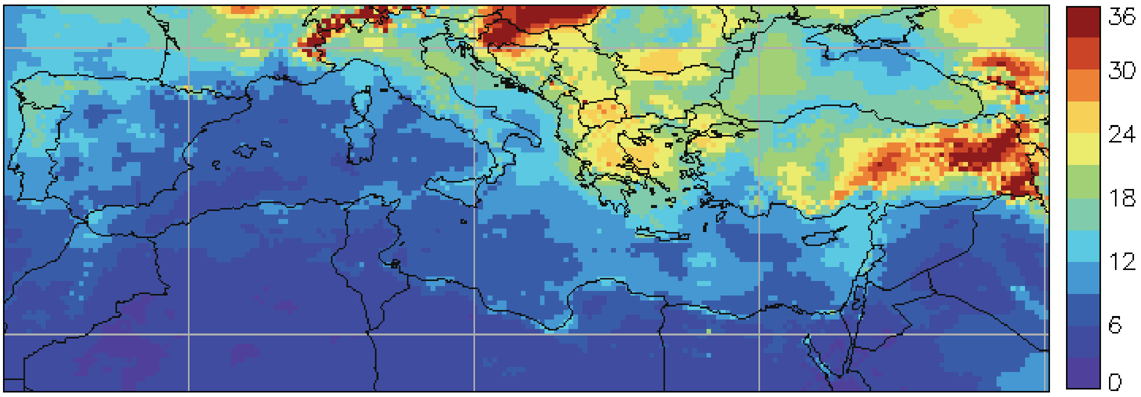

Figure 10: Standard deviation (in %) of monthly averages of global horizontal irradiation – December

4 DISCUSSION AND CONCLUSIONS

Although the amount of global irradiation impinging on a horizontal plane decreases with increasing latitude, the year-to-year variability of weather does not follow this pattern. Standard deviation of yearly values typically stays below 6% in most regions around the Mediterranean and Black Seas, while in some coastal zones and in high mountains the interannual variability is higher. During the analysed 18 years the amount of solar resource in least sunny year deviated from the long-term average by more than -9% only in some coastal regions and higher mountains.

Ideally, the results should be cross-compared with ground-based measurements, but long-term, high-quality measurements were not at our disposal. It is known that satellite-derived irradiances in the mountainous regions have a tendency of underestimation due to problems of terrain dynamics and cloud/snow detection. Therefore results over mountains need more rigorous validation.

The standard deviation of yearly values indicates the possible uncertainty of estimated long-term averages of global horizontal irradiation a user can experience when consulting various solar radiation databases, see e.g. [6]. This analysis shows that one of the reasons is that the various databases are developed from different data sources covering different time periods. Large excursions in even a single year can give a significant contribution to differences in long-term averages, depending on whether that year is included in the average or not.

The weather is more stable in summer with 3-6 times more solar resource available compared to winter. This gives good prospects for reliable prediction and management of distributed electricity generation in the studied region. However, once penetration of solar photovoltaics is higher, fluctuations of weather in some regions will call for deeper analysis, based on the use of hourly radiation data.

The year-on-year variability of global horizontal irradiation indicates the uncertainty of cash flow for investors financing larger PV projects. It should be noted that year-to-year variability of yields from PV systems with fixed-inclined or tracking modules might be slightly higher as these configurations favour direct component of global radiation over diffuse. The other sources of higher uncertainty are mathematical models that estimate direct and diffuse radiation for inclined surfaces. These topics have to be analysed further.

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