Sun in the Antipodes: Temporal Behavior and Trends of Sunshine Duration in the Iberian Peninsula

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Abstract: A number of series of sunshine duration for the period 1951-2004, corresponding to main weather stations in the Iberian Peninsula, are analyzed in this study. First, the series were checked for their homogeneity, and some of them were withdrawn from the further analyses. With the remaining data, at monthly, seasonal, and annual resolution, a mean series representing the whole peninsula was computed in order to perform temporal analyses. The series of annual sunshine duration shows a negative, but not significant, trend. However, the trend is not monotonic during the analyzed period: it is negative during the first part of the period (what could be the signal of the phenomenon known as global dimming), and then, clearly positive in the most recent years. This behavior is also found for most of the monthly and seasonal series, in particular in spring and summer. Significant trends are found for some monthly series, and also for some monthly series of the Mediterranean climate regions (found after applying a Principal Component Analysis). Spectral analysis techniques (FFT, MESA) were also applied to sunshine duration data, and two significant peaks, of about 2.5 and 5 years, were found. In addition, the influence of the North Atlantic Oscillation (NAO) on sunshine duration was explored. Results of this latter analysis show that there is a high positive correlation between NAO index and sunshine duration in winter months, for all stations of the Iberian Peninsula except for some in the Northern areas.

1. Introduction

The analysis of solar radiation that reaches the earth's surface is very important in the context of recent climate change, since its variation might show some indications of anthropogenic disturbances (Ramanathan *et al.*, 2001). It is well known and documented a reduction of solar radiation between the 1950s and 1980s, commonly named 'global dimming', that in global average corresponds to reductions of -0.51±0.05 Wm^{-2} per year, equivalent to a decrease of 2.7% per decade (Stanhill and Cohen, 2001), although it shows important spatial variations (Gilgen *et al.*, 1998; Liepert, 2002). A reversal in the negative trend is detected in the late 1980s, and since these years a progressive brightening appears in the measurements of solar radiation (Wild *et al.*, 2005; Pinker *et al.*, 2005).

Both the global dimming and the recent brightening trends have important uncertainties; in particular, some authors have suggested significant influences of human activities at local level, so the temporal variability of solar radiation should be considered as a local or regional dimming, but not as a global phenomenon (Alpert *et al.*, 2005).

Thus, to better describe and know this phenomenon, it is necessary to use more accurate measurements (with better spatial resolution and not recorded exclusively in large urban areas), and to extend the analysis using longer series of records (with better temporal resolution if possible), since the global dimming evidence is so far based on few measurements of solar radiation (Stanhill, 2005). For this purpose, it is useful to support and extend the analysis using other climatic variables (proxy measures) as evaporation, visibility, cloudiness, or sunshine duration. The advantages of sunshine duration series, respect to other variables, are that they started more than one hundred years ago and have less subjectivity than visibility or cloudiness observations.

2. Data

The sunshine duration data used in this study were obtained from the Spanish and Portuguese institutes of meteorology (Instituto Nacional de Meteorología and Instituto de Meteorologia, respectively). We also obtained the Gibraltar sunshine duration record from Wheeler (2001) and updated it to present time from the UK MetOffice; the series of Perpignan, in Southeast France, was taken from the European Climate Assessment & Dataset (ECA&D) (Klein Tank *et al.*, 2002). Although it is difficult to know with absolute certainty (because of the few metadata available), the Campbell-Stokes recorder is possibly the only type of instrument used during this period at all stations. The present study is limited to the period 1951-2004, because few of the 115 initials series have digitized records for earlier years.

We applied different quality control checks on daily resolution data to improve the database of sunshine duration, and following the recommendations of Aguilar *et al.* (2003). Specifically, we tried to: (1) detect, correct and/or remove gross errors, as aberrant (more hours registered than the maximum possible) or negative values; (2) confirm the consistency of calendar dates (days per year or month); and (3) remove false zeros, which is a common problem in meteorological series that could have important consequences in the total sunshine duration at monthly, seasonal, or annual resolution. After these checks, we discarded series with more than 10% of missing data.

In locations with more than one station covering different periods, without any overlaps and in general being documented as relocations of the official meteorological stations on different sites, we generated a composite series. The t-Student and F-Snedecor tests were applied to verify the similitude of the mean and variance of the series that were joined for creating a composite series.

Subsequently, daily sunshine duration for each station was summed over each month, season, and year. Then, we applied the absolute homogeneity tests of Thom (Thom, 1966) and Von Neumann (Buishand, 1982) on the monthly resolution series, and discarded all series with clear inhomogeneities. Finally, 37 locations across the Iberian Peninsula (Fig. 1), covering the period 1951–2004, were used in our further analyses.

The monthly, seasonal, and annual sunshine duration were normalized, i.e. converted to percentage of possible sunshine (hereafter called relative sunshine), by calculating the maximum possible sunshine duration during the period. This calculation was made by astronomical formulae, and considering that the sun can shine strong enough to burn the cardboard of the heliograph when it lays more than 3º above the horizon (Pallé and Butler, 2001).

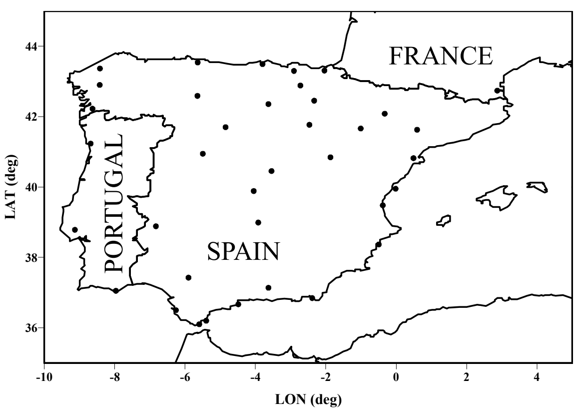

Fig. 1 Location of the 37 stations finally considered in our analyses.

3. Annual sunshine duration climatology

Mean annual absolute sunshine duration in the Iberian Peninsula (IP) (Fig. 2.a) shows large spatial variability. Note that in the North, annual sunshine duration is slightly greater than 1500 hours (relative sunshine, 35%), while in the Southwest may be greater than 3000 hours (relative sunshine, 70%).

Regarding the inter-annual variability, we have used the coefficient of variation (CV), which removes the dimensionality from the magnitudes and considers the proportionality between mean and standard deviation. At annual resolution (Fig. 2.b), CV takes low values, and its spatial behavior is opposite from other variables such as precipitation (Rodriguez-Puebla *et al.*, 1998). Minimum values are close to 4% in the South and East of the Iberian Peninsula, while maximum values (14%) are found in the North and Northwest.

Finally, we have computed asymmetry and kurtosis coefficients, and also applied the Kolmogorov-Smirnov test. All results obtained from these tests and coefficients confirm the normality of most of the series at monthly, seasonal, and annual resolution.

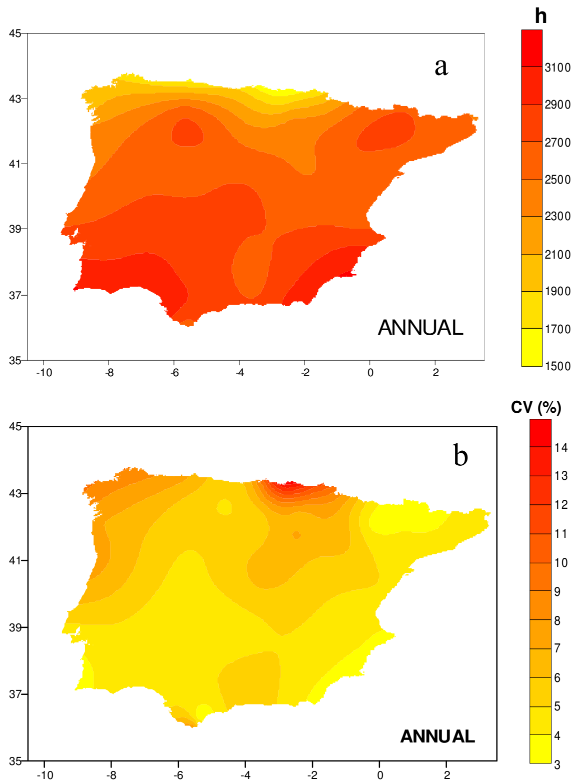

Fig. 2 Annual (a) absolute sunshine duration and (b) coefficient of variation (CV) over the Iberian Peninsula.

4. Variability and trends of sunshine duration series

4.1 Time evolution and trends of the mean series over IP

For each station, we calculated the monthly, seasonal and annual anomalies (values minus the average for the 1961-1990 period). Then, the mean series of the Iberian Peninsula was obtained simply by calculating the arithmetic mean over all the 37 anomaly series. The mean series gives a more synthetic description of the climatic signal than single station series and allows for a higher signal-to-noise ratio and a better identification of long-term trends. Finally, slopes of trends were calculated for the mean series by least-square linear fitting, and in order to detect significant trends (at a confidence level higher than 95%) the method used was the Mann-Kendall non-parametric test (Sneyers, 1999).

The temporal evolution of the Iberian Peninsula sunshine duration mean anomaly series (Fig. 3.a) shows an impressive concave aspect. Specifically, from the 1950s until the beginning of the 1980s there is a clear decreasing of sunshine duration (i.e., negative trend); this trend is reversed later, showing a clear sunshine duration increase until the beginning of the 21st century. For the whole period, the trend is slightly negative (sunshine duration has decreased in -0.49%) but this trend is not significant.

Important differences appear among the temporal evolution of seasonal series. In winter (Fig. 3.b), sunshine duration is quite stable during the whole period, although it shows relevant minima between 1977 and 1979. The overall trend is +0.80% (not significant). Both spring and summer series show an aspect similar to the annual series, i.e. with a marked concave shape (Fig. 3.c-d). In spring, there is a clear negative trend from the 1960s to middle of the 1980s, and an absolute minimum in 1971. Later, a sharp increase (during 10 years) in sunshine duration compensates the earlier decrease. Apparently, sunshine duration in spring has stabilized in recent years. In the total spring series, the trend is +1.13% (not significant). The behavior in summer is similar, but the minimum in 1982 and 1983 is more marked. On the other hand, the recent increase has not already reached stabilization. The total trend in summer is a reduction of -2.54% (not significant), which results from the important sunshine duration decrease in the beginning of the analyzed period (1960-1983 approximately). Finally, the autumn series, like in winter, shows more stability of sunshine duration (Fig. 3.e), despite of large variability during the first 20-25 years and a clear minimum in 1959-1961. The total trend for the autumn series is -1.23% (not significant).

We have also studied the monthly series. This analysis has shown important differences relative to the seasonal and annual series. From January to April, and in June and September, trends are positive. For the other months, trends are negative. However, there are only four months with significant trends (Table 1). The most interesting is March, with an important (and significant) positive trend that corresponds to a relative increase in sunshine duration in as much as +9.02%. Contrarily, the other three significant trends are negative: -5.78%, -4.32% and -5.35%, corresponding to May, July and August respectively.

4.2 Regional series construction and trends.

In order to further investigate our results regarding sunshine duration trends in the Iberian Peninsula, we applied Principal Component Analysis (PCA), with the

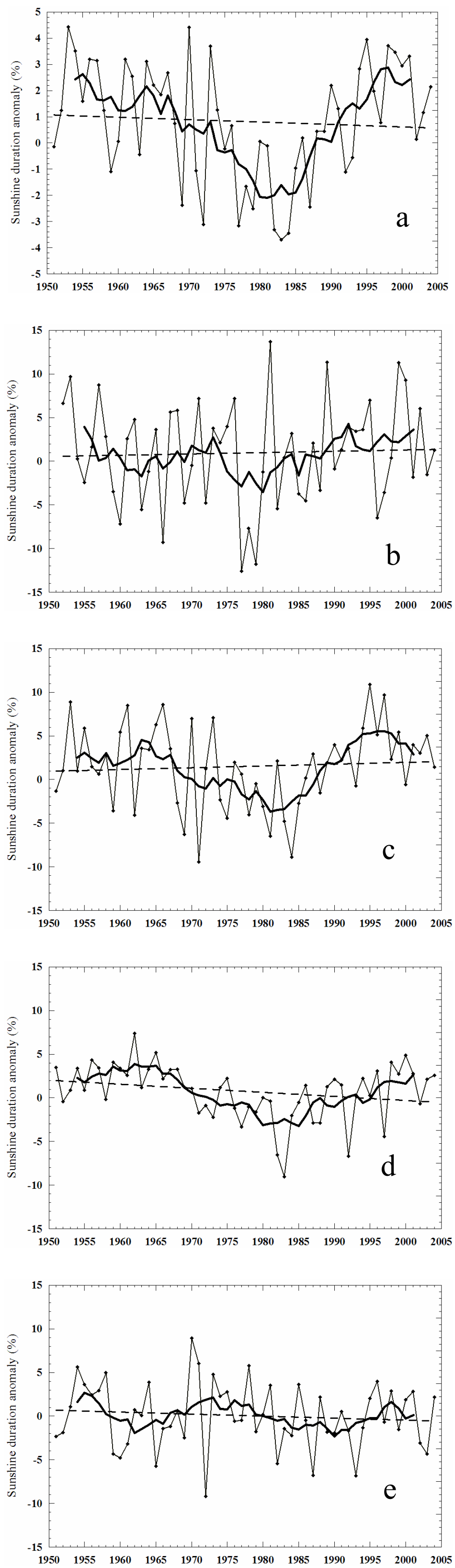

Fig. 3 Temporal evolution of sunshine duration in the IP: a) annual, b) winter, c) spring, d) summer, e) autumn. Series are anomalies of relative sunshine duration from the 1961-1990 mean. Bold line is the 7-yr running mean. Dashed line is the fitted linear regression.

objective of clustering the 37 series into sub-regions with similar sunshine duration variability. Specifically, the regionalization approach was based in the PCA from the correlation matrix (R) considering all 12 months of the year, and using the monthly anomalies in *S* Mode (Preisendorfer 1988). We used all months of the year in order to obtain only one regionalization, and to avoid different sub-regions for different temporal resolutions (Brunetti *et al.*, 2006). This analysis was applied to the period 1961-2004.

Results of the PCA show that 4 Empirical Orthogonal Functions (EOF) account for more variance than the original variables (that is, their corresponding eigenvalues are greater than 1) and that they explain around 80% of the total variance of the data set. We only considered the first 3 EOF, which have eigenvalues greater than 2 and, together, explain more than 75% of the variance. These selected EOF were rotated by means of a Varimax rotation that redistributes the variance into the components and gives stable and physically meaningful patterns (Von Storch, 1995). Finally, for each region we selected the stations that have their maximum loading in the corresponding EOF.

With this methodology, 3 regions were identified (Fig. 4): East and South (ESI), that corresponds with the area with Mediterranean climate modified by the nearest Mediterranean Sea; the Western part of the IP (WI); and the North (NI), a part of the Iberian Peninsula with oceanic climate. Then, regional series were obtained by simply calculating the arithmetic mean over all the stations available in the corresponding regions.

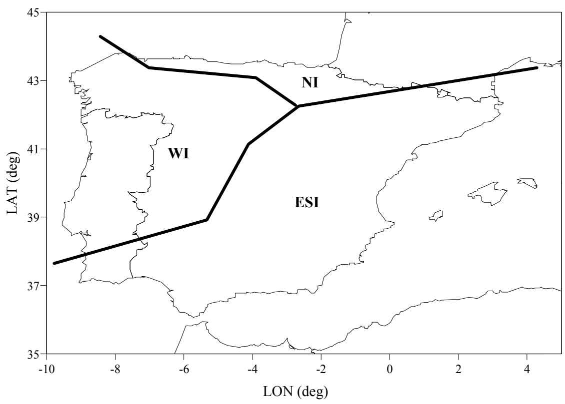

Fig. 4 Map of the regions (approximate) based on a PCA applied on the monthly sunshine duration series of the IP.

Like in the whole Iberian Peninsula, neither the annual nor any seasonal series for any region show a significant trend. Contrarily, at monthly resolution there are significant trends for March (positive) and May, July, and August (negative) but only for the Mediterranean climate regions (ESI and WI) (Table 1). The only region with no significant trends is NI, which is the region that represents the areas in the Iberian Peninsula with oceanic climate.

Month	**IP**	**ESI**	**WI**	**NI**
March	9.02*	10.10*	10.21*	4.16
May	-5.78*	-6.32*	-7.51*	-1.78
July	-4.32*	-4.05*	-7.02*	-1.40
August	-5.35*	-6.10*	-5.29*	-1.40

Table 1. Trends (%) of sunshine duration over all period in the IP (second column) and the three regions (3-5 columns). * Significant trend (level of significance, 0.05).

5. Spectral analysis

Another analysis that we carried out was a search for cycles or periodicities in our sunshine duration data. We applied both a classical Fourier analysis and the Maximum Entropy Spectral Analysis (MESA). MESA is based on the spectrum of a random series with an autocorrelation function that fits the initial values. Before applying the Fourier analysis, the linear trend of the series was removed in order to avoid high spectral power at low frequencies. Then, we applied a zero padding to get a series with a number of records that is power of 2, and applied a fast Fourier transform (FFT). The module of the transform coefficients, divided by the series length is the spectral power, which was smoothed by a three-point filter to partially reduce the effect of the non-infinite series length. It is well known that the spectral power allows identifying the main periodicities in the original series.

Both techniques resulted in detected periodicities of 2.5 and 5 years, which were close to the threshold of the level of significance of 0.05. This fact, and given also the limited length of the series, suggests that further research is to be made in the future in order to confirm the periodicities and to find physical explanations for them.

6. Winter sunshine duration and NAO

The North Atlantic Oscillation (NAO) is a low frequency variability pattern that greatly affects climatic variability in the North Atlantic. The NAO was first identified at the beginning of the 20th century (Walker, 1924). More recently, the NAO has been studied and defined with better precision; currently it is accepted that the NAO is one of the more influent tele-connection patterns on the Northern Hemisphere climate (Hurrell, 1995), particularly in wintertime. In the Iberian Peninsula, most important effects of NAO are found in the coldest semester, while in summer its signal is almost inappreciable.

In the present work we have tried the correlation, by means of the Pearson's *r*, between series of relative sunshine and of NAO index (NAOi), only for the winter season. The NAOi was defined as the difference between the standardized sea level pressure at Ponta Delgada, Azores, and at Reykjavik, Iceland.

Figure 5 shows a spatial representation of the results of this analysis. These confirm some previous results derived from shorter series and lower temporal resolution

(Pozo-Vázquez *et al.*, 2004). Specifically, positive and significant (at the 95% confidence level) correlations are obtained for most of the Iberian Peninsula. Actually, only in some small areas in the North correlations are below the significance level. The higher correlations correspond to the center and South of the peninsula.

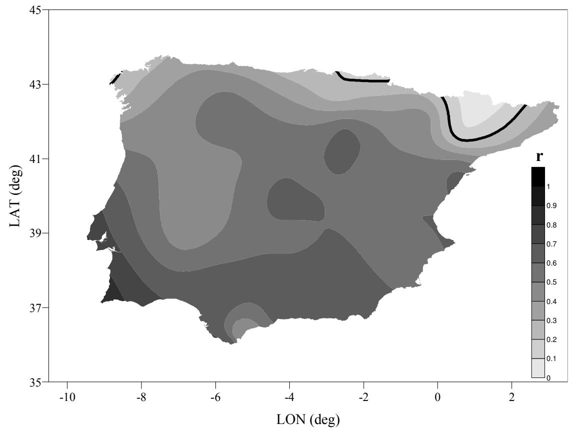

Fig. 5. Isopleths of Pearson's *r* between relative sunshine and NAOi during winter. The thick black line indicates the threshold of the 95% confidence level.

7. Conclusion

In this paper, we have analyzed sunshine duration series in the Iberian Peninsula. The temporal evolution of the mean (for the whole peninsula) annual series shows a decrease in sunshine duration from the 1950s until the early 1980s, followed by a constant increase until the end of the 20th century. This evolution is quite similar to what has been described in other parts of the World: the "global dimming" and the subsequent and recent "brightening". The mean series for spring and summer show a similar behavior with the concave shape, while in autumn and winter sunshine duration has been quite constant during the analyzed period.

As far as overall trends for the whole series are concerned, the only trends that are statistically significant correspond to the monthly series of March (positive trend) and May, July, and August (negative trends). These trends are also found in the two regions (objectively obtained by means of a Principal Component Analysis) that correspond to a Mediterranean climate.

The search for periodicities in the sunshine duration data has resulted in the finding of two relevant frequencies, corresponding to 2.5 and 5 year approximately. On the other hand, we have confirmed the effect of the North Atlantic Oscillation on the climate of the Iberian Peninsula: in winter, sunshine duration is highly and positively correlated with the NAO index for almost the whole peninsula.

Future work will be devoted to extend the temporal length of the series, further improve their homogenization and quality control checks, and obtain more robust results regarding trends, periodicities, and regionalization of the results.

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