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Short Communication

Sunshine and synoptic cloud observations at Ebro Observatory, 1910–2006

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ABSTRACT: The aim of this study is to characterize the evolution of the number of bright sunshine hours and cloudiness at Ebro Observatory. Sunshine and synoptic cloud observations, extending over almost a century, are available from the Ebro Observatory in the north–east of Spain. Here, we analyse these time series and find a strong decadal variability in the duration of bright sunshine hours since 1910, but without a statistically significant long-term trend. A comparison with sunshine records from other Spanish Mediterranean observatories was also performed to validate the Ebro time series over the shorter time interval for which comparison stations are available. At the same time, we find a monotonic increase in synoptic cloud amount since the 1920s. Time series of cloudiness at different heights are also available at Ebro in digital form dating from 1954, and their analysis allows us to interpret these results as a change in cloud type frequency, possibly coupled with changes in air transparency. Copyright © 2008 Royal Meteorological Society

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1. Introduction

Clouds are one of the most difficult climate components to parameterize, and a source of large uncertainties in global climate model predictions. Clouds have two simultaneous and opposite effects on the radiative balance of the planet; on the one hand they reflect short-wave solar radiation back into space (a cooling effect), and on the other they prevent long-wave infrared emission from the Earth from escaping into space (a warming effect). On average, the cooling effect of clouds dominates over the warming (Ramanathan *et al.*, 1989), but the net radiative effect strongly depends on the type and altitude of the clouds, with thin high cloud types having an overall warming effect. Especially unknown are the cloud feedback mechanisms, and how do clouds respond to climate changes. For example, the response of clouds to an increase in global mean temperature changes geographically and from model to model (Cess *et al.*, 1996).

In addition to poor understanding of the role of clouds, there is also the lack of accurate long-term data. Cloud observations with global coverage can only be made from satellites, but these measurements are available only for the past two decades and are not exempt from limitations. Inter-calibration and temporal overlapping of the different satellites over a period of decades are not easy to archive. The most complete dataset, in terms of geographical/temporal coverage, is the International Satellite Cloud Climatology Project (ISCCP) series, which extends from 1983 to the present (•Rossow, 1996).

In this sense, synoptic cloud observations and sunshine records (as a proxy for clouds), taken from ground observatories, are our only probes of cloud changes on time scales of centuries. Despite their obvious disadvantage of being a localized measurement, the number of bright sunshine hours has been recorded at various sites worldwide since the widespread installation of Campbell–Stokes sunshine recorders during the second half of the 19th century (Chagnon, 1981; Henderson-Sellers, 1989; Angell, 1990; Jones and Henderson-Sellers, 1992; Stanhill, 1998; Stanhill and Cohen, 2001). Naturally, there is a strong seasonal variation in sunshine hours that is unrelated to clouds, but in principle, averaged over the year, the number of hours of sunshine should give us, on time scales of decades or centuries, indirect information on the cloud cover (Pallé and Butler, 2001). The main limitation of this cloud proxy is that the sunshine records do not give us any information about the cloud type or altitude.

Ground-based observations of cloudiness, sometimes with cloud type distinction, have also been recorded worldwide for several decades (Raju and Kumar, 1982; Angell, 1990; Russak, 1990; Norris, 1999; Sun and Groisman, 2000). These measurements, however, are not

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instrumental, and are more prone to errors and bias introduced by the observers, especially if a single station is used to estimate long-term trends (Pallé and Butler, 2002).

2. Measurements

2.1. Sunshine observations at Ebro Observatory

Sunshine is a basic parameter used to evaluate the amount of sunlight delivered at the top of the atmosphere that is able to reach the ground. According to World Meteorological Organization (WMO, 2003), sunshine duration during a given period is defined as the sum of that sub-period for which the direct solar irradiance exceeds 120 W m^{-2}. Sunshine levels depend mainly on the latitude of the observer and could, in principle, be astronomically calculated (Jansa, 1968). However, sunshine is also conditioned by the existence of physical obstacles in the neighbourhood (mountains or trees), local weather phenomena and the proximity of the sea through cloud and humidity changes.

The Ebro Observatory (Ebro), located at 0°30′E and 40°49′N, at an altitude of 48.5 m above sea level, is a centennial centre devoted to Solar–Terrestrial physics research. Solar observations and atmospheric weather measurements have been regularly carried out since its foundation. As a result, we have long series of meteorological data that allow us to do climate studies of the Ebro and Mediterranean region. The sunshine and cloud series used here have been recorded entirely at Ebro Observatory.

The number of bright sunshine hours is recorded over all daylight hours and read at Ebro once a day in the evening, after sunset. Some of the data from Ebro were completely digitized but other data were in notebooks and bulletins (Rodés, 1934), which the authors have digitized. The Ebro sunshine series starts in 1910 and continues to the present, except for a short period of time (1938–1939) when, because of the Spanish civil war, no data were recorded. The few missing monthly data (October 1930, June–July 1931, October 1933, February 1935 and June–July 1935) have been interpolated based on the corresponding months of the 3 previous and the 3 following years.

Sunshine was recorded at Ebro Observatory using a heliograph with a V cleft (Richard, 1932) from 1910 to 1941, when it was replaced by a Campbell–Stokes heliograph (Observer's Handbook, 1982). Since 1942, when the Campbell–Stokes heliograph was first used, only a change in location in 1993 is recorded in the Observatory's metadata. The heliograph was moved 5 m away from its original position, on the same building roof where it is now located. The site is high enough to ensure that no tree or building could project any shadow over the heliograph.

For a period of 6 months (May–October 1944), sunshine records were obtained simultaneously with both heliographs and have allowed us to perform a time series coherence analysis. First, we checked the sensitivity of the paper and the temporal development of the cylinder of the Richard heliograph by measuring a year of data (1936) and comparing them with data in the bulletins. We performed a similar test with the Campbell heliograph on records corresponding to 1945. We then measured the records of both the Richard and the Campbell heliographs corresponding to the period of simultaneity. We applied two statistical tests of coherence over these two series: a test of the variance ratio and a mean difference test. In both cases, the results show that the two sunshine series are homogeneous, within a 95% confidence level, and that they can be treated as a unique series.

2.2. Synoptic cloud observations at Ebro

Cloudiness at Ebro Observatory is regularly observed at least, three times per day, which we will label as 'morning', 'noon' and 'evening'. In the period 1910–1919 cloudiness was observed at 7 : 00, 14 : 00 and 21 : 00 h. From 1919 to 1938 it was observed at 8 : 00, 14.00 and 21 : 00 h. Finally, since 1939 it has been observed at 7 : 00, 13 : 00 and 18 : 00 h. Thus, the morning time series contains data from 7 : 00, 8 : 00 and 7 : 00 respectively, while 'noon' data contains data from 14 : 00, 14 : 00 and 13 : 00, and 'evening' data from 21 : 00, 21 : 00 and 18 : 00. The Ebro synoptic cloud series has only a small gap between April and December 1938.

Synoptic cloud observations at Ebro Observatory are performed by a team of observers specifically trained for this task. Moreover, the different observers take the measurements at different times of the day and they rotate their observing schedules (to cover weekends for example). Although cloud cover estimates strongly depends on the observer, and can condition the long-term analysis, this observer rotation considerably reduces the bias introduced by a change in single long-time observers. Synoptic cloud observations taken before 1985 were measured in tenths of the sky, which we have converted into modern oktas by multiplying them by 0.8.

To check the homogeneity of the series, we have to analyse the breakpoints in the metadata. For cloud coverage, the site of observation has always been the same and there have been only three changes in the observation hours. To evaluate the influence of the hour of observation in the final result, we checked the homogeneity of the resulting series by performing a contrast test with the partial series (morning, midday and evening) of cloud coverage for a long period (1954–2003) grouped in i, j pairs as $i = 1$ morning, $j = 2$ midday and $i = 2$ midday, $j = 3$ evening. As with the sunshine series, we performed the statistical tests of the variance ratio and the mean difference. We conclude the synoptic cloud coverage series at Ebro are homogeneous to within a 95% confidence level.

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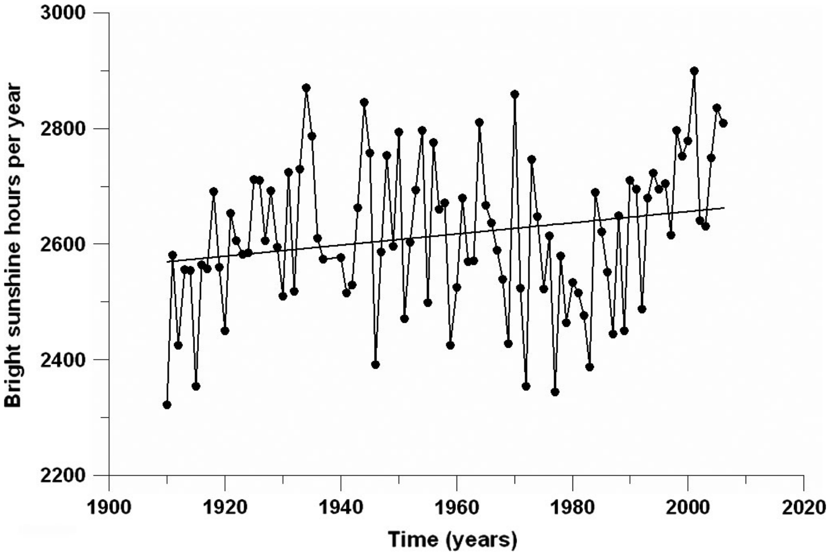

Figure 1. Total number of sunshine hours recorded at Ebro Observatory over the period 1910–2006. The solid line is the best linear fit to the data. There is an apparent overall increasing trend since the beginning of the times series, although period of decreasing sunshine hours are also observed.

3. Long-term trends

3.1. Inter-annual variability in bright sunshine hours at Ebro

In Figure 1, the annual sunshine hours recorded at Ebro Observatory 1910–2006 are plotted as a time series. There is an overall increasing trend in the number of bright sunshine hours, amounting to about 100 h in the last 100 years (0.96 h/year), which represents an increase in bright sunshine hours of about 4% in a century. However, due to the great variance and decadal oscillations of this series, this trend is not statistically significant (Table I). It is noticeable, however, that over the 1960–1984 period there is a general decrease in bright sunshine hours (a surface dimming), followed by a recovery from the mid-1980s till the present. These changes are consistent with the so-called 'global dimming' phenomena observed at other ground-based observatories worldwide from the 1960s to the mid-1980s (Stanhill and Cohen, 2001; Liepert, 2002) and the 'global brightening' that followed, starting in the mid-1980s (Pallé *et al*., 2004; Wild *et al*., 2005). Seasonal trends in sunshine hours are detailed in Table I.

3.2. Inter-annual variability in cloudiness at Ebro

Annual means of cloudiness at Ebro over the period 1910–2006 are displayed in Figure 2. Over the past 100 years, total cloudiness at Ebro increased from 3 to 4 oktas, an increase of around 12%. The trend, however, is not continuous in time: from 1910 to 1925 there is a small decrease in cloud amount, while from approximately 1925 to present a monotonic increasing trend of about 0.025 okta/year is observed. Seasonal trends of cloudiness are shown in Table I, and indicate that the trends are larger during autumn and winter.

The consistency of the cloud observations is further strengthened when the Ebro cloud observations are subdivided into three time series according to observing time (morning, noon and evening). In Figure 3 we show the number of days with clear sky (Figure 3(a)) and the number of days with overcast sky (Figure 3(b)). The general behaviour is a decrease in clear and an increase in overcast days. This is simultaneously visible in the morning, noon and evening time series. However, while the decrease in clear sky is more evident in the early 1980s, the increase in the overcast sky begins in the late 1950s.

Although the hour of observation (another factor which could condition the homogeneity of the series) has changed twice at Ebro since 1910, there is strong coherence among these three series, which strongly suggest that the observed changes are real (changes in

Table I. Annual and seasonal trends in sunshine hours (hours/year) and cloudiness (oktas/year) at Ebro Observatory over the period 1910–2006. The error in the trend estimate corresponds to 1 sigma. From the table it is easy to determine that the trends in cloud cover are highly significant (the error is an order of magnitude smaller), while the trends in sunshine hours are not significant.

Sunshine hours	Trend (hours/year)
Annual mean	0.959 ± 0.463
Spring	0.126 ± 0.085
Summer	0.056 ± 0.073
Autumn	0.003 ± 0.061
Winter	0.057 ± 0.087
Cloud cover	**Trend (oktas/year)**
Annual mean	0.018 ± 0.001
Spring	0.018 ± 0.002
Summer	0.017 ± 0.002
Autumn	0.020 ± 0.002
Winter	0.020 ± 0.002

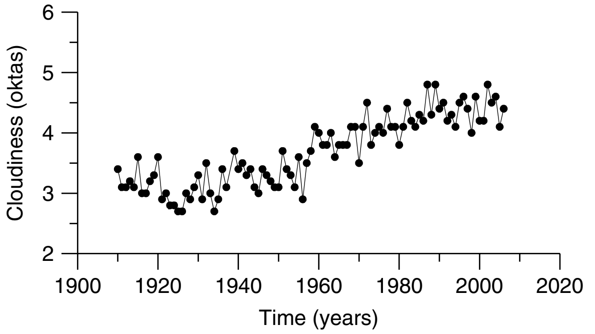

Figure 2. Annual mean cloudiness levels (measured in oktas) at Ebro Observatory over the period 1910–2006.

observing time are independent for each series). Clear sky days are more sensitive to the changes in observing time (1919 and 1938) than overcast days, which generally represent an overcast synoptic situation.

3.2.1. Cloud type evolution at Ebro

Digitized cloud type observations are available at Ebro Observatory dating from 1954 and offer some insight into the cloud evolution over the past five decades. At Ebro, separate sky coverage, is measured for low, mid and high clouds. Because the observer from the ground can only see the high clouds if they are not blocked by low clouds, there is a possibility of artificial trends in the mid and high cloud amount, due to real changes in low clouds. This is the inverse problem of satellite observations, where low clouds cannot be detected if high clouds are present, introducing a bias in the cloud trends (Pallé, 2005). Thus, for ground-based observatories, the low cloud amount is considered the most reliable record.

In Figure 4 are plotted the Ebro Observatory time series of cloudiness at three heights. For simplicity, mid and high cloud amount are plotted together. An increase in total cloudiness is clearly visible for morning, noon and evening observations. This increasing trend is common to all cloud types, although mid and high level clouds increased faster than low clouds, especially in the evening. The fact that the trends for the different cloud types go in the same direction (increase) diminishes the possibility of an artificially induced trend in the high clouds. In case of bias, the observations may be underestimating the mid and high cloud increase in 1954–2006. It is also noticeable that the cloud trend is larger later in the day.

Thus the increase in cloudiness seen at Ebro during the last half of the 20th century is mostly due to the increase of mid and high level clouds, which are generally optically thin and have a smaller impact on the sunshine records. This high level cloud increase could be an effect of increasing high-altitude jet air traffic, which has the potential for altering the properties and extent of cirrus clouds (Carleton and Lamb, 1986; Sassen, 1997), with aircraft condensation trails (contrails) persisting to create new, or supplement existing, cirrus clouds.

4. Comparison of the Ebro sunshine series with other observatories

One of the factors affecting sunshine data is the geographical location of the observatory. To evaluate to what degree Ebro data are affected by local conditions or representative of a larger region, we compare the Ebro sunshine records with those from other Spanish observatories in the Mediterranean region. The geographic coordinates of these observatories are given in Table II. Data from Hospitalet de l'Infant were obtained from •González (1998) while for the other stations we use data provided by •INM (VVAA, 1996). The advantage of the Ebro data resides in their long-time coverage, and

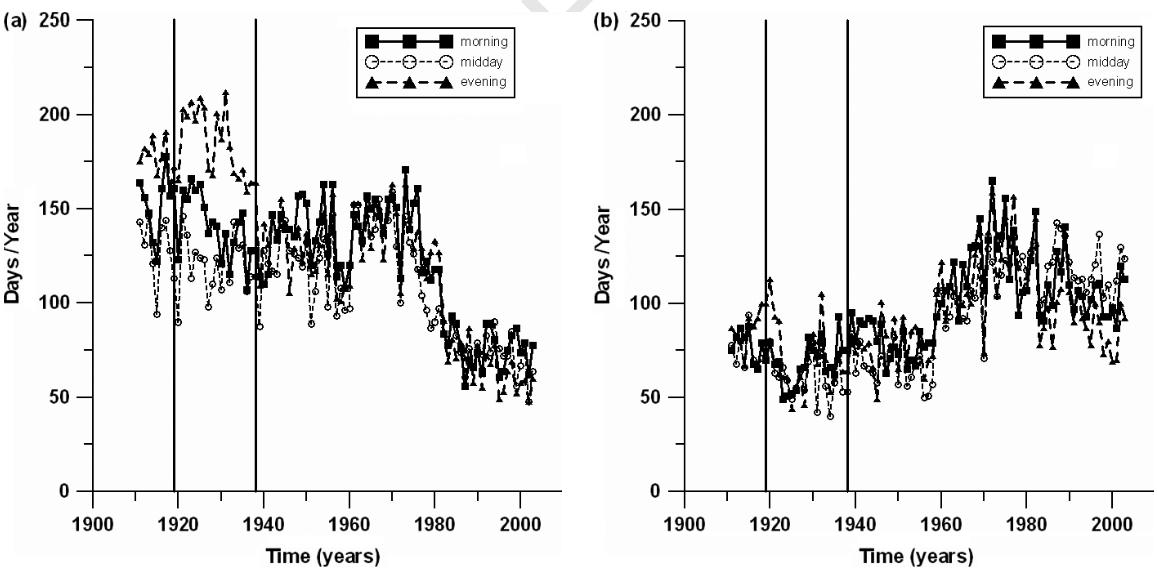

Figure 3. (a) Number of days per year with sky free of clouds (0 or 1 oktas) observed at morning, noon and evening at Ebro Observatory since 1910. (b) Number of days per year with sky completely overcast (7 or 8 oktas) observed at Ebro Observatory since 1910. Vertical lines represent the dates when the observing times changes for some of the series.

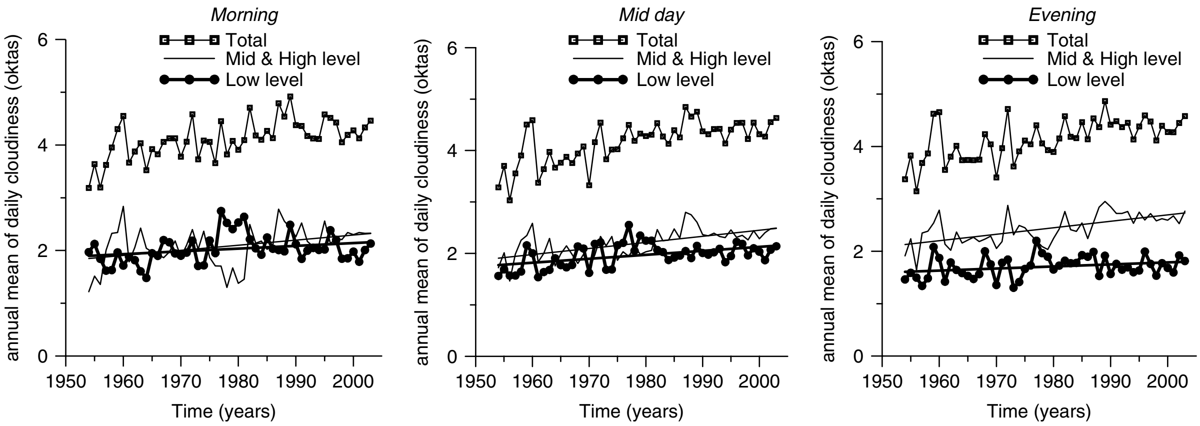

Figure 4. Evolution of the low, mid, high level and total cloudiness for the last 50 years over the Ebro Observatory.

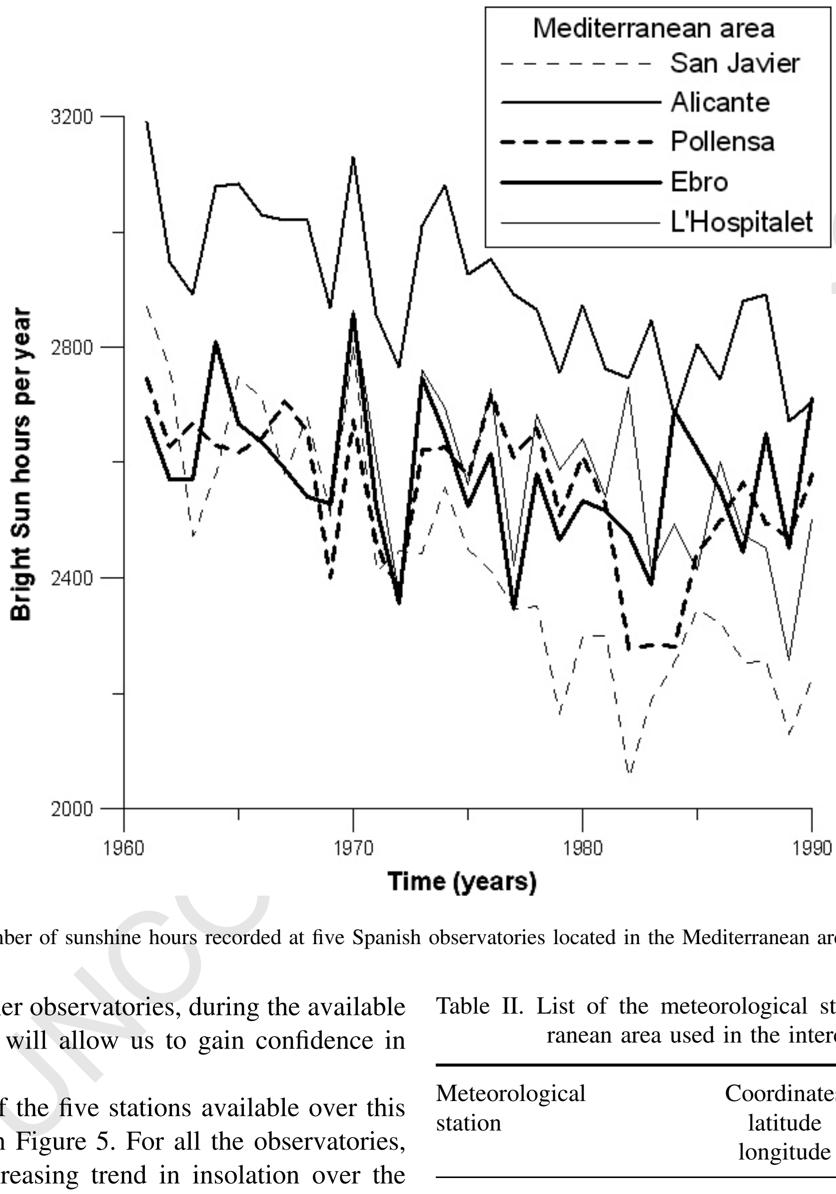

Figure 5. Total number of sunshine hours recorded at five Spanish observatories located in the Mediterranean area given in Table II.

comparison with other observatories, during the available overlapping period, will allow us to gain confidence in the Ebro data.

The time series of the five stations available over this region are plotted in Figure 5. For all the observatories, there is a clear decreasing trend in insolation over the period 1960–1990, and the variability in the time series is similar. The correlation coefficients between Ebro and the rest of the observatories range between 0.42 and 0.59 (Table II) with a high degree of significance. The biggest correlation is obtained for Hospitalet de

Table II. List of the meteorological stations in the Mediterranean area used in the intercomparison.

Meteorological station	Coordinates latitude longitude	Correlation coefficient (and significance)
San Javier	37°47′N 0°48′W	0.48 (0.5)
Alicante	37°22′N 0°30′W	0.52 (0.5)
Pollensa	39°55′N 3°06′W	0.42 (2.9)
Ebro	40°49′N 0°30′E	–
L' Hospitalet de l'Infant	40°57′N 0°52′E	0.59 (0.2)

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l'Infant, which is the closest meteorological station to Ebro. L'Hospitalet de l'Infant on the coast, 70 km away from Ebro Observatory to the north–east.

In conclusion, as expected due to their geographical proximity, we find the Ebro sunshine time series to be coherent with the rest of the series in the same climatic region. The seasonal variability of sunshine at Ebro is also consistent with that computed by Font (1984) for the Spanish map of radiation, where Ebro had typical Mediterranean values.

5. Sunshine – Cloudiness comparison at Ebro

It is surprising that a statistically significant increase in cloudiness is not accompanied by a simultaneous decrease in sunshine at Ebro Observatory over the past century. The explanation may lie in a change in the proportions of the cloud types. We have shown how high clouds, less dense and optically more transparent than low clouds, have increased during the last part of the century, with perhaps little effect on the sunshine records. This hypothesis has been formulated in other works. For instance, the cloudiness and sunshine duration over the United States of America (Angell, 1990), show a different increasing/decreasing trend, with a greater increase in cloudiness than decrease in sunshine. Evidence for an increase in cirrus cloudiness has been reported by various authors (Himebrook and Griffiths, 1976; Karl *et al.*, 1986). Still, even though the increasing cloudiness does not necessarily imply a decrease in sunshine, it is difficult to explain the overall increase in sunshine hours based on cloudiness changes.

In Figure 6 the total annual sunshine hours over the past 50 years are shown. Over-plotted, are the low cloud amount observations, which are digitized from 1954. The good correspondence between the two series over the 1954 to mid-1980s period is noticeable when the increase in low cloud types is reflected in a decrease in sunshine hours (note that the cloud scale is inverted).

From the mid-1980s to present, however, the low cloud amount did not change much, while the number of sunshine hours increased. Over that period of time, high clouds increased seemingly without any strong effect on the sunshine records. Approximately around the mid-1980s, a global change in tendency to the previous 'global dimming' has been attributed by some authors to a reduction in overall pollution in the atmosphere (Wild *et al.*, 2005). For Ebro, this hypothesis could explain the increase in sunshine records (increasing sky transparency) without significant changes in cloud amount. We also note that the time of the day in which the cloud increase occurred may play a role in affecting the sunshine. The largest increase in high clouds is detected in the evening, when the Campbell heliograph is no longer recording bright sunshine.

Finally, although there is no direct correspondence between the long-term trend of previous sunshine and cloudiness series, one can check for correspondence for shorter time scales. As discussed earlier, cloud types can change, sometimes affecting the sunshine records and sometimes not. However, the short-term seasonal and inter-annual variability is more prone to be well matched among the two series. Seasonal variation of normalized sunshine hours and the inverse of cloudiness observed at Ebro over the 1910–2006 period is shown in Figure 7. They are highly correlated ($r = -0.89$, $P \gg 99\%$). From January to October, both series have the same overall behaviour while November and December show different tendencies.

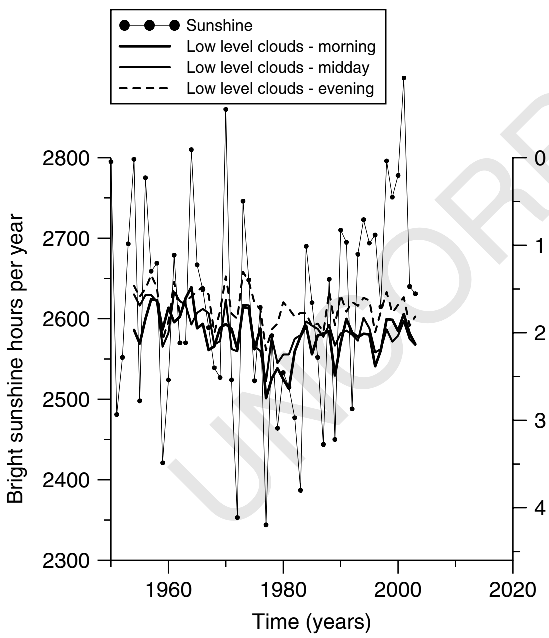

Figure 6. Total annual sunshine hours over the 1954–2004 period and low cloud amount observations during the same period. Cloudiness series are inverted to show coincidences of the peaks.

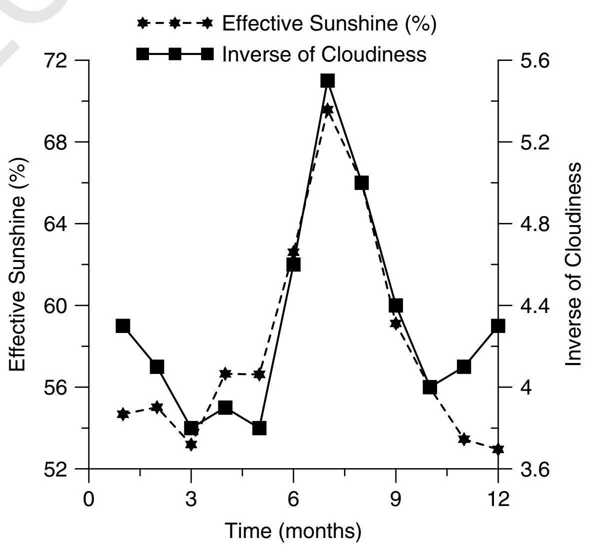

Figure 7. Seasonal variation of normalized sunshine hours and cloudiness observations over the 1910–2006 period. Cloudiness series are drawn in inverse sense [8 – cloudiness (oktas)] to show coincidence of the peak. Note that the seasonal variability in both time series is highly correlated ($r = 0.89$, $P \gg 99\%$).

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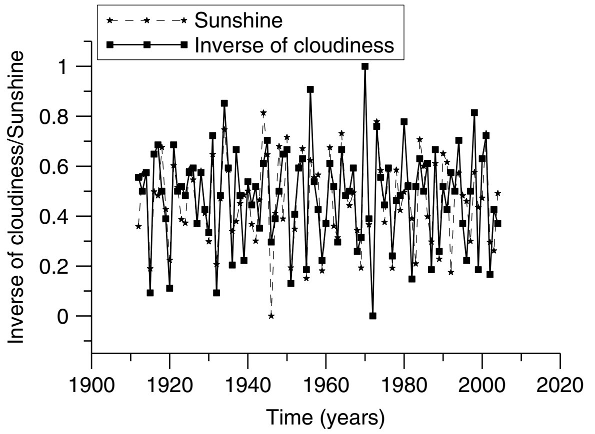

Figure 8. Time series of the detrended and normalized total sunshine hours and the inverse of cloud amount at Ebro Observatory 1910–2006. Note that the year-to-year variability in both time series is highly correlated ($r = 0.83$, $P \gg 99\%$), as expected *a priori*, indicating that the removed trends might be artificial in one of the two series or due to a different physical mechanism.

If there are spurious trends in the cloud records due to changes in the subjective observer's criteria, removing long-term trends in the series should increase the correlation with sunshine observations (Pallé and Butler, 2002). To remove the long-term frequency changes in the Ebro sunshine and cloud series, we have calculated the 5-year running mean of each series and we have subtracted this running mean from the original data. This eliminates any variability with frequencies longer than 5 years. The resulting detrended series are plotted in Figure 8, where both have been normalized and cloud data has been inverted for comparison purposes. The correlation coefficient between these two time series ($r = -0.83$) is highly statistically significant, indicating a closely matched inter-annual variability.

This increase in the correlation between the two time series when detrended, indicates that their difference lies mostly in the long-term decadal variability. This is a sign that either there is a calibration error in one of the two time series, or that the underlying physical mechanism(s) responsible for the changes in each series is (are) different, at least over some intervals of time. Given the consistency of the sunshine records as compared to other observatories and the internal consistency of the cloud observations at different observing times, the authors believe that the second option is the correct one.

6. Conclusions

In this work, we have analysed the time series of sunshine and cloudiness at Ebro Observatory. The sunshine series has been compared with several available observatories in the Spanish Mediterranean area since the 1960s. It is found that the Ebro observations are coherent with those of the Mediterranean region. The advantage of the Ebro series, however, is the larger temporal coverage of the observations. Since 1910, we find that there has been an overall increase in the number of sunshine hours, but with large oscillations that make this increase statistically insignificant, while over the same time period cloudiness has increased by a larger amount (about 12%) with high statistical significance.

We associate the increase in both sunshine hours and cloud amount with a shift in cloud types during the 100-year period covered by the observations. Digitized cloud height observations at Ebro Observatory date from 1954. We have used these data to study the evolution of the clouds at different levels over the past five decades. We find that there is an increase in all cloud types, but that it is most pronounced for the high cloud types. We also find a negatively significant correlation between low cloud amount and sunshine observations over limited time periods. Our analysis indicates that the seasonal and inter-annual variability are well matched between the sunshine and synoptic cloud observations, but their long-term (decadal) variability is probably affected by other factors, possibly atmospheric transparency, although data in this respect are not locally available at Ebro.

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