FACTORS GOVERNING SUNSHINE IN SAN FERNANDO (CÁDIZ): A CLIMATOLOGICAL REVIEW OF WESTERN EUROPE'S SUNNIEST REGION

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RESUMEN
La región de Cádiz es una de las más soleadas del oeste de Europa. Este trabajo presenta los resultados de un estudio de la serie de observaciones de las horas de sol del observatorio de San Fernando, analiza la importancia de los sistemas de presión en la insolación recibida sobre la península Ibérica y propone conclusiones respecto a los cambios en las horas de sol durante el siglo veinte.

Palabras clave: Insolación, cambio del clima, presión atmosférica, climas urbanos

SUMMARY
The Cádiz region is the sunniest in western Europe. This paper presents the results of a study of the observations of daily sunshine totals prepared at the famous observatory at San Fernando. The importance of Iberian-based pressure systems in controlling surface insolation is examined and the paper offers conclusions on the factors that have determined sunshine changes during the twentieth century.

Key words: Sunshine, climate change, air pressure, urban climates

1. INTRODUCTION

The San Fernando Observatory situated close to Cádiz in south-west Spain possesses one of the longest and most detailed climatological records in Europe (WHEELER 1992a, 1992b, 1993 and 1995). Whilst climatologists tend to focus their attention on temperature and rainfall records, sunshine is often overlooked as a climatological element. But it is sunshine that most often plays upon our senses and provides the impression of 'good' weather. Few visitors to southern Spain would dispute this view in a region where the long hours with cloudless skies form the basis of the country's biggest industry - tourism. Indeed, the available statistics indicate that the coastal regions of the province of Cádiz can lay justifiable claim to being the sunniest region of western Europe and the average annual sunshine totals at San Fernando are just over 3000 hours (Table I). Such frequently cloud-free conditions explain why Cádiz was chosen in the eighteenth century as the site of Spain's principal astronomical observatory, and it was from those activities that the meteorological studies began around 1800 (WHEELER, 1992a)

2. SUNSHINE IN THE CÁDIZ AREA

Table 1 summarises the sunshine statistics for San Fernando for the period 1933 to 1995. The record begins in 1881 when a Campbell-Stokes sunshine recorder was purchased - possibly the first to be used regularly in Spain. Unfortunately a close examination of the daily and monthly records for the site indicates that the series is unreliable for much of the period before 1933. The problem lies in the gradual decrease of hours recorded over the period from 1900 to 1932 when the average annual totals fell by nearly one half from 2800 to 1500 hours. Observer error is an unlikely cause and a more plausible explanation is some progressive obstruction of the site, perhaps by the growth of nearby trees and vegetation. The recorded sunshine figures recover to their 1880 levels quite suddenly in 1933 when it is possible that the obstructions were removed or the recorder relocated. Unfortunately the Observatory accounts provide no clue to help identify the cause of these statistical peculiarities.

	J	F	M	A	M	J	J	A	S	O	N	D	year
mean	178.7	177.5	219.7	255.5	305.2	327.0	360.4	340.8	267.3	226.5	181.4	170.8	3011.7
standard deviation	37.1	36.8	36.8	46.7	44.6	35.4	31.7	38.8	28.7	37.8	31.2	38.6	274.6
maximum	245.8	247.9	308.4	338.3	375.7	376.6	407.4	390.6	327.6	293.6	247.9	236.6	3474.8
minimum	75.8	104.4	149.9	137.6	212.5	236.9	276.4	232.6	209.0	149.0	112.5	77.1	2423.2
hours/day	5.8	6.3	7.1	8.5	9.8	10.9	11.6	11.0	8.9	7.3	6.0	5.5	8.2
mean as % of possible	57.6	57.8	59.1	64.8	69.7	74.5	80.8	81.2	71.7	64.8	58.9	56.7	67.6

Table I. Summary of monthly and annual sunshine data (in hours) for the San Fernando Observatory (Cádiz) based on 1933 to 1995 data.

For north Europeans more familiar with the cloudy skies of the mid-latitudes, the data in Table I make for pleasant reading recalling perhaps memories of summer holidays. Even in mid-winter an average of over five hours sunshine per day can be anticipated, whilst the summer months average over ten. Yet such sunshine figures are high even by Iberian standards. The traditionally popular tourist areas of Mediterranean Spain to the east of Gibraltar rarely average more than 3000 hours and are often closer to 2800 hours. Average annual totals decline yet further towards the north through Andalusia and Central Spain and more rapidly as the Cantabrian Mountains are crossed and the influence of Atlantic frontal depressions becomes more marked and frequent.

Of all the various climatic parameters, monthly sunshine totals must be viewed with greatest caution. Firstly, months vary in their length between 28 and 31 days. A second factor is the possible hours of daylight which, even at this latitude (36^{o}N), varies between just over 300 hours in December to nearly 450 in June. For these reasons Table I expresses sunshine in a number of different forms including mean hours per day for each month as well as the monthly averages expressed as a percentage of all daylight hours. Such re-expressions of the data notwithstanding, the annual sunshine regime is clear from its mid-winter minimum to summer maximum. It might be thought that the proximity of the Azores anticyclone governs and explains this important aspect of the Iberian climate. Nowhere in mainland Spain is closer to this important centre of activity than the Cádiz region and its well-known annual expansion in summer and contraction in winter is seemingly evident in these data.

Such a proposition would be regarded as plausible and accepted by most climatologists. It is therefore all the more remarkable to observe (Fig. 1) that average air pressure over the same 63-year period in San Fernando has been higher in winter than in summer. Figure 1 emphasises this point further by showing how the maximum winter air pressures far exceed anything experienced in summer when the range between the extremes is much reduced. The explanation for this apparent contradiction lies in the quasi-continental behaviour of the Iberian massif which is large enough, being close to 500,000km^2 in extent and much of it above 500m ASL, to exercise a profound influence on its climate. In particular the continental extremes of temperature over the Meseta, which vary between mid-summer maxima in excess of 35^{o}C and mid-winter minima falling as low as -10^{o}C, encourages corresponding changes in air pressure similar to those observed over the Eurasian land mass. Thus in winter, cold, shallow anticyclones form over the Meseta and the low-lying expanses of the Guadalquivir depression. CAPEL MOLINA (1981) has argued that the development of the winter anticyclones may also be linked to extensions of similar systems over mainland Europe, especially Russia. In summer, on the other hand, high surface temperatures encourage the formation of the thermal 'lows'. These systems dominate the lower troposphere during the Iberian summer but are themselves overlain by the Azores anticyclone's summer extension. This vertical structuring, with upper level stability, limits deep convection over Iberia and hampers cloud formation. The high air temperatures also lower the relative humidity. Thus despite the relatively low atmospheric pressure the potential for long hours of sunshine, minimum cloud and low rainfall is fully realised and in the height of summer (Table I) the average percentage of possible sunshine is over 80. In winter the monthly hours of sunshine fall but Table I shows that there is also an important reduction of sunshine when measured as a percentage of the maximum possible total, which falls to less than 60 per cent - yet this is the season of highest, if most variable air pressure (Fig.1).

These regular seasonal, temperature-driven, surface pressure changes over Iberia provide an indelible imprint on the monthly regime that modifies and obscures the hold of the Azores anticyclonic system. It is not, of course, easy to distinguish the relative importance of these contrasting seasonal climatic elements and to quantify the contributions that each of them make to sunshine in the Cádiz region. It is nonetheless arguable that the 'continental' character of the Iberian climate increases the sunshine totals above those directly resulting from the proximity of the Azores anticyclone. As noted above, the summer thermal 'low' contributes to the high sunshine totals. It is also possible that the winter 'cold' anticyclones are more important in this respect and have a strong positive influence on sunshine. Winter is the season when the Azores anticyclone is at its weakest and the cold thermal 'highs' probably act as a means of sustaining clear skies, stable weather and 'blocking' the Atlantic cyclonic systems which might otherwise bring more frequent cloudy conditions to the region. This advantage appears to be only slightly offset by the inversion fogs that are common at this season and are a particular problem in the Guadalquivir valley.

month	maximum (hours)	% of possible	year	minimum (hours)	% of possible	year
January	245.8	79.2	1944	75.8	24.4	1970
February	247.9	81.4	1945	104.4	34.0	1969
March	308.4	83.0	1938	149.9	40.3	1991
April	338.4	85.8	1940	137.6	34.9	1981
May	375.7	85.8	1953	212.5	48.5	1993
June	376.6	85.8	1950	236.9	54.0	1992
July	390.6	87.6	1946	276.2	61.9	1979
August	407.4	97.0	1956	232.6	52.2	1982
September	327.6	87.9	1954	209.0	56.0	1972
October	293.6	84.0	1949	149.0	42.6	1993
November	247.1	80.3	1944	112.5	36.5	1993
December	236.6	78.4	1988	77.1	25.5	1988
annual	3273.6	73.4	1953	2423.2	54.4	1995

Table II. Extreme monthly sunshine data from the San Fernando record (1933-1995).

Of additional interest are the individual months of extremely high or low sunshine totals. Table II lists the maximum and minimum values for each month. The data reveal some remarkable statistics. January and February are alone in not having at least one month when over 80 per cent of the possible sunshine total has been recorded. The 407.4 hours recorded in August of 1956 represents a notable 97 per cent of the possible total, i.e. bright sunshine failed to be recorded for only 13 daylight hours in the month. A study of the daily data shows that no day recorded less than 11 hours of sunshine. At the other extreme, January 1970 produced only 24.4 per cent of the possible - the lowest in the reliable record. Only in the winter months do the percentages of possible sunshine fall below 30. Yet even the worst of the summer months, August 1982 could produce over 52 per cent of the possible total. These seasonal contrasts result from the more frequent activity of Atlantic weather systems which move into the Gulf of Cádiz in winter as the Azores anticyclone recedes to its winter position.

3. LONG TERM AND SEASONAL TRENDS IN SUNSHINE

3.1 Local controls on sunshine trends

The most notable feature of the annual figures is the decline in recorded sunshine over the past three decades (Fig.2). This decline was particularly marked around 1970 but appears to have stabilised more recently. It will also be noted from Table II that the sunniest months in the record tend to fall in the first half of the series but the dullest months are in the second half. Given the current exposure of the sunshine recorder this decline cannot be explained by changing shelter or observational error. It may however be a consequence of the increased turbidity of the atmosphere in the immediate vicinity of the Observatory. Both Cádiz (some 7 km to the north-west) and San Fernando have grown rapidly in population since the 1960's in common with so many cities in a country which has only recently experienced the rural-urban demographic transition: it was only in 1944 that the size of Spain's urban population became greater than the rural. In addition Cádiz is one of Spain's busiest ports and the accompanying industrial expansion and intensification of road traffic has probably added significant quantities of particulate material and photo-sensitive chemicals to the atmosphere. Dispersal of such material will be limited by the frequently anticyclonic and settled nature of the local climate. The consequent accumulation of particulate matter will reduce the effectiveness of the sun, particularly towards dusk and immediately after sunrise when its rays must pass through the greatest depth of atmosphere. LANDSBERG (1981) has suggested that city climates show a 5 to 15 per cent reduction in hours of sunshine compared with nearby rural areas. This range is in agreement with the 10 per cent reduction seen in Cádiz between the 1940's and 1990's. The general problems of urban climate modification through aerosols and photochemical reactions are too well-known for reiteration here and are reviewed in BARRY and CHORLEY (1998).

This picture of diminishing recorded sunshine differs only marginally between the seasons (Fig. 3); a slight decrease is detectable in spring, autumn and winter as early as the 1950s, at about the time that rapid urban growth began. The summer decline is more abrupt but is detectable only from early 1960s. In more recent times the picture is less certain. Winter, summer and spring sunshine hourages have shown a tendency towards recovery in more recent years, but autumn's decline, the least marked of the four seasons, has continued. This general stabilisation may be the consequence of more rigorous air pollution controls.

3.2 Dynamical controls on seasonal sunshine

It is interesting to note the degree to which air pressure governs the duration of sunshine and how the character of that control differs between the seasons. Over the four seasons only the correlation between winter air pressure and sunshine hours is significant at the 0.01 level with $r = +0.445$. In all other seasons the correlation is weaker; in spring it is only +0.100, in summer -0.281 and in autumn +0.136. The negative correlation between summer air pressure and sunshine, although statistically significant at only the 0.05 level, supports the hypothesis suggested earlier that the effect of the Azores anticyclone is subordinate to that of the thermal 'low' and indicates that longer hours of sunshine are associated with lower, and not with higher, air pressure. On the other hand, higher winter air pressure is associated with longer hours of sunshine through its positive correlation. But in winter high pressure is more commonly a result of the Iberian thermal 'high' and not with the Azores 'dynamic' anticyclone which is then at its weakest.

The association between winter sunshine and air pressure is clearly seen in figure 4. The close correlation in the earlier years is strikingly evident. However, and in a picture not unfamiliar to those who examine the behaviour of long climatic series, this relationship appears not to be wholly stable and there is evidence that it has weakened over the 1990's. The correlation over the whole series 1933-1995 is $r = +0.445$ but is higher at $r = +0.616$ if the series is limited to the period 1933 to 1989. This most recent period is however one in which the North Atlantic Oscillation has demonstrated the most marked positive phase of its known record (WMO, 1995). The unusual development of the Azores anticyclone at this time may have modified the relationship between sunshine hours and the behaviour of the Iberian systems.

4. CONCLUSIONS

Several points can be made in conclusion:

4.1. Winter sunshine in the far south-west of Spain depends greatly on the development of thermal anticyclones over Iberia; when they are at their most well-developed sunshine hours are at their longest. When the Iberian systems are weaker there is a more powerful Atlantic influence over south-west Spain with cloudier, less settled conditions resulting in lower sunshine totals.

4.2. Summer sunshine shows a significant but negative correlation with the season's air pressure. This finding also shows the importance of Iberian pressure systems which now operate in a different direction and when the summer thermal 'low' is well-developed (and surface pressure is lower) sunshine hours are increased beyond the high totals already ensured by the summer extension of the Azores anticyclone.

4.3. Autumn and spring, when neither of the major Iberian systems are effective and the climate is generally more variable, show no relationship between sunshine and air pressure.

4.4. The role of the Azores anticyclone in controlling sunshine in the Cádiz region appears, thus, to be modified significantly by the pressure systems generated by the quasi-continental land surface of Iberia.

4.5 Anthropogenic controls on the urban climate are also important and have caused a 10 per cent decline in recorded hours of sunshine since the 1960's. This figure agrees closely with those for other World cities.

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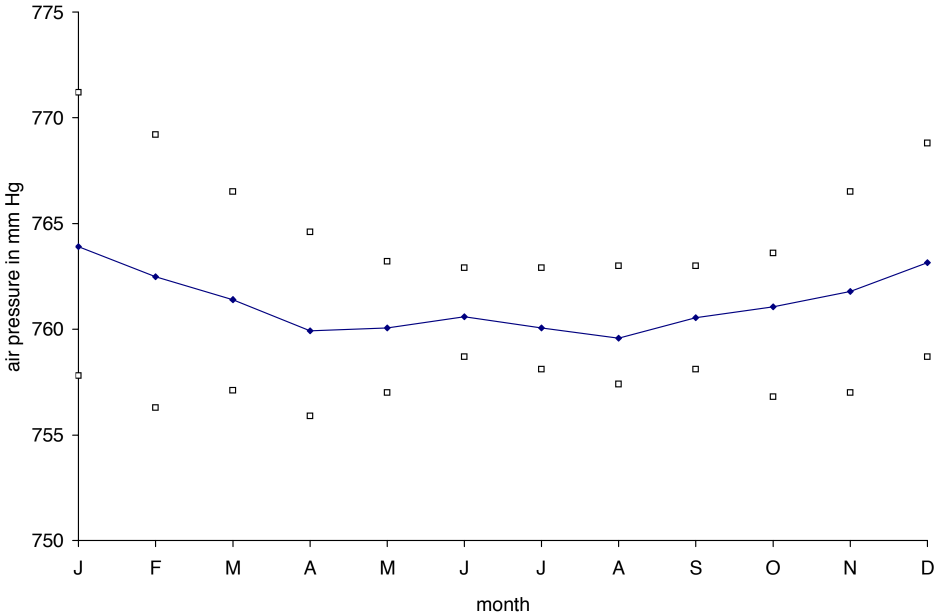

Figure 1. Mean monthly and absolute maximum and minimum monthly air pressure (corrected to sea level and zero degrees Celsius) at San Fernando (Cádiz) for the period 1933 to 1995.

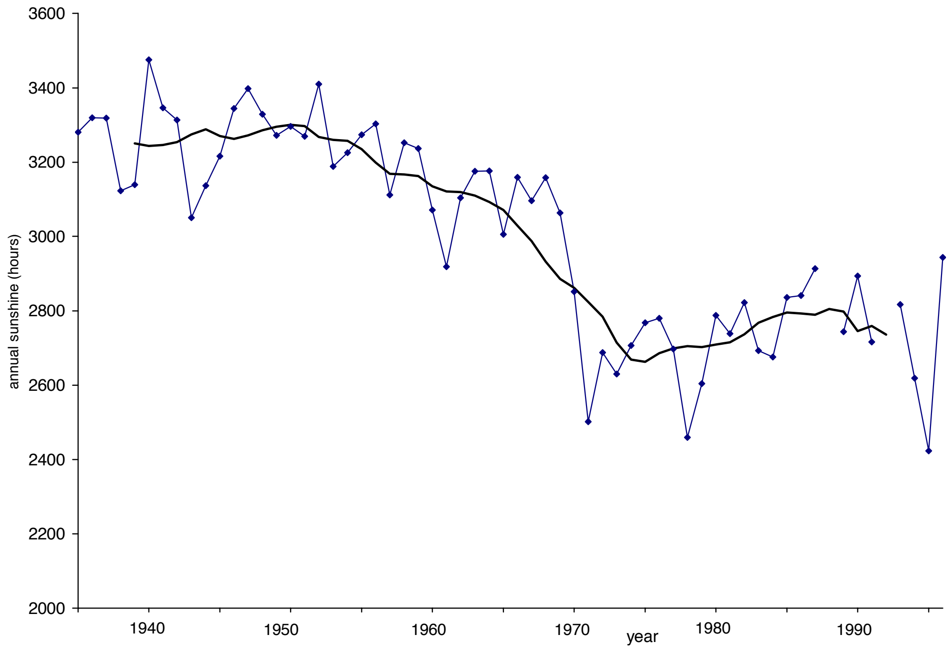

Figure 2. Annual sunshine hours in San Fernando (Cádiz) for the period 1933 to 1995. The ten-year running mean is also shown. Note: some data are missing from the final years of the series

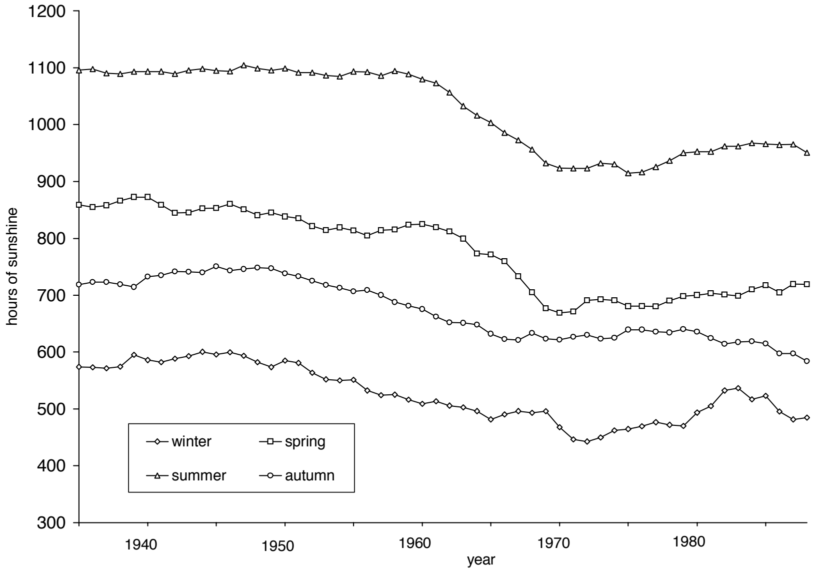

Figure 3. Seasonal sunshine totals at San Fernando (Cádiz) for the period 1933 to 1995. Winter = December, January, February; spring = March, April and May: summer = June, July and August; autumn = September, October and November.

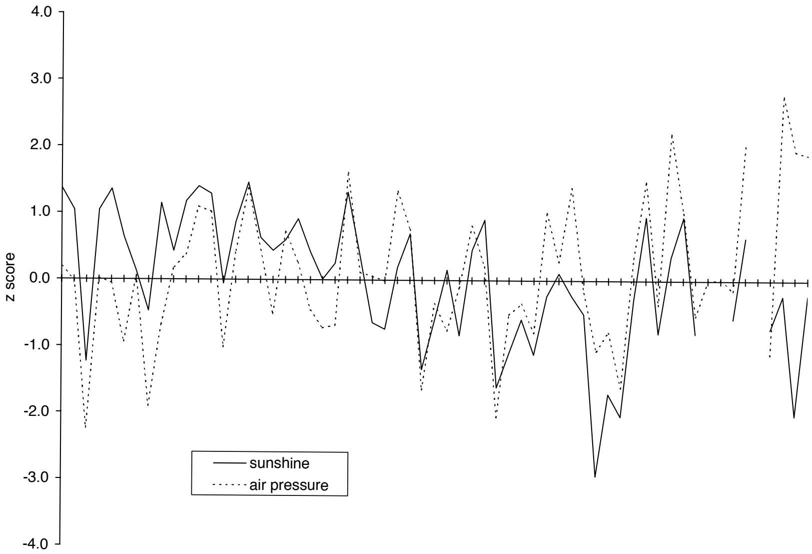

Figure 4. Standardised scores (expressed in standard deviations about the respective long-term means) of winter air pressure and hours of sunshine at San Fernando (Cádiz). Note: some data are missing from the final years of the two series.