ESTIMATING DAILY SUNSHINE DURATION OVER THE UK FROM SEVIRI

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Abstract

In situ observations of daily sunshine duration over the UK are sparse and require extensive interpolation to produce spatially complete fields. Spinning Enhanced Visible and Infra Red Imager (SEVIRI) observations are used here to estimate daily sunshine duration over the UK in 2007 and 2008 at the pixel level, with a view to using them to improve and evaluate interpolation between station locations. The analysis uses the operational SEVIRI cloud mask produced by the Satellite Application Facility for supporting NoWCasting and very short range forecasting (SAFNWC). Evaluation of the SEVIRI-based sunshine duration with collocated in situ data indicates good agreement in winter. In summer, the satellite estimates tend to be lower than the corresponding station values, with more variance in the differences than in winter.

INTRODUCTION

The Met Office National Climate Information Centre (NCIC) routinely produce climate data sets for the United Kingdom (UK; www.metoffice.gov.uk/climate/uk/), including maps of monthly sunshine totals. These are derived from a network of stations that record daily sunshine duration. The network consists of two types of instrument: (1) Campbell-Stokes recorder, which is a glass ball that burns a trace on a piece of card, and (2) the more modern Kipp & Zonen sunshine duration sensor, which uses photo-diodes to determine when insolation exceeds 120 W/m^2. The latter is generally regarded as more reliable. Currently, there are approximately 90 Campbell-Stokes, and 35 Kipp & Zonen instruments deployed across the UK.

As the station network is sparse, the in situ sunshine data undergo extensive interpolation to produce a spatially-complete data field. As a result, the maps have quite low confidence. The aim of this study is to establish the potential for using satellite estimates of sunshine duration to aid interpolation and/or to evaluate the maps in areas where there are no in situ observations. The satellite sunshine duration data are derived from a time series of cloud observations from geostationary satellite data: where cloud occurs, no sunshine is assumed, and where no cloud is observed, full sunshine is assumed. The remotely sensed data used in this study are completely independent of the in situ observations.

METHOD: SATELLITE SUNSHINE ESTIMATE

Geostationary satellite observations provide frequent observations of top of atmosphere (TOA) radiances throughout the day; modern sensors are capable of providing full-disc observations every 15-30 minutes. A number of techniques exist for the detection of cloud in the radiance data, the most common of which involves the use of multi-channel threshold-based tests (e.g. Ackerman et al, 2002; Saunders, 1986; Saunders & Kriebel, 1988). This method compares satellite radiances from one or more channels, often expressed as a ratio or difference, with a pre-determined threshold. If the radiance exceeds the threshold (or falls short, depending on the specific test), the pixel is flagged cloudy. Typically, a number of tests are employed on a pixel-by-pixel basis; if any of the tests indicate the presence of cloud, the pixel is flagged as cloud-contaminated. The result is a binary pixel cloud mask, comprising of zeros (cloud-free) and ones (cloud contaminated), that corresponds exactly to the satellite radiance data set. Common applications for cloud mask data include the removal of cloudy radiance observations where the objective is to study surface properties, such as land surface temperature (LST) and vegetation indices. In this study, we present an alternative application for cloud mask data, whereby sunshine duration over the UK is estimated from a time series of geostationary data.

As the operational geostationary satellite at 0° longitude, 0° latitude, the Meteosat Second Generation (MSG) platform provides regular observations over the UK. The Spinning Enhanced Visible and Infrared Imager (SEVIRI), onboard MSG, supports a number of visible and infrared channels that are suitable for cloud detection, including channels at 0.6, 3.9, 8.7, 10.8 and 12 μm. Full-disc observations are acquired every 15 minutes throughout the diurnal cycle at a resolution of approximately 3 km at the sub-satellite point. An operational cloud mask is produced routinely by the Satellite Application Facility for supporting NoWCasting and very short range forecasting (SAFNWC; see SAFNWC (2009) for further information on the cloud mask product). This cloud mask product forms the basis of the satellite sunshine duration estimates presented in this study. Figure 1 shows an example of the SAFNWC cloud mask over Europe (land only; note, the SAFNWC cloud mask includes both land and ocean).

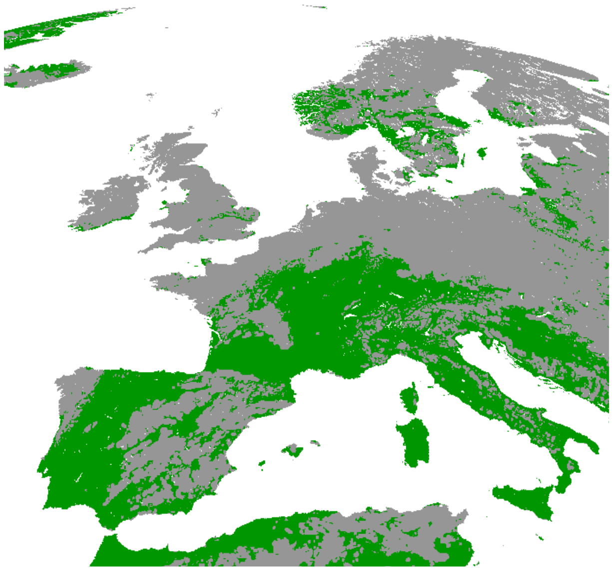

Figure 1: **Example of NWCSAF SEVIRI cloud mask over Europe on 10 July 2008 (slot time = 12:00 GMT). Grey = cloud, green = cloud-free, white = ocean or missing data.**

To estimate daily sunshine duration, the NWCSAF cloud mask product is analysed for each SEVIRI pixel as follows:

1. Valid cloud mask observations between sunrise and sunset are collected and counted.
2. The proportion of cloud-free observations, P, is established from the cloud-mask data.
3. The number of hours daylight, H, is calculated.
4. The sunshine duration, D, is estimated as:

$$D = P.H \qquad (1)$$

In practise, daylight is defined to be where the solar elevation angle (SEA) is greater than 2.5 degrees. This limit is imposed to ensure consistency between the resulting satellite and in situ data sets, as the latter are unlikely to record any sunshine for smaller SEAs (P. Fisher, Met Office, Personal Communication). Occasionally, as is common with any satellite data set, the SEVIRI observational record is incomplete, where individual pixels are missing or interpretable, or data for an entire time slot are absent. To ensure the SEVIRI observations provide representative coverage during the day, D is only calculated for pixels where a minimum of 90% of all available 15-minute observation slots are valid and available. This process usually provides close to 100% spatial coverage for each day (Figure 2).

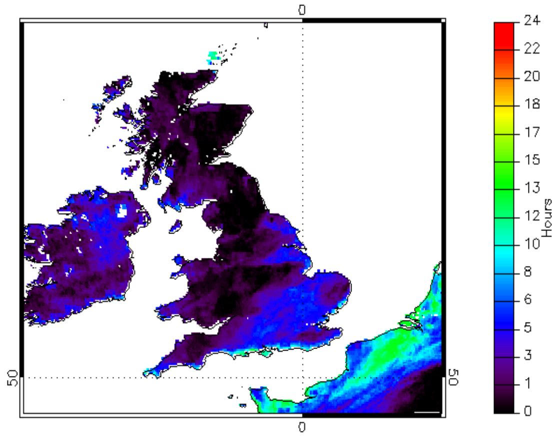

Figure 2: **Example of sunshine duration estimated from SEVIRI for 10 July 2008. White areas correspond to missing data, or pixels over ocean or inland water bodies.**

Monthly totals, comparable to those produced by NCIC, are produced by summing the daily values (Figure 3). Owing to occasional missing days of SEVIRI data, a tolerance of up to two missing daily totals for each month is adopted. The monthly total is adjusted to account for any missing days by using the average sunshine duration for all other days in the month. Figure 4 shows an example of a monthly sunshine duration estimated from SEVIRI data. Visual comparison with the equivalent NCIC map demonstrates strong similarities in the spatial patterns.

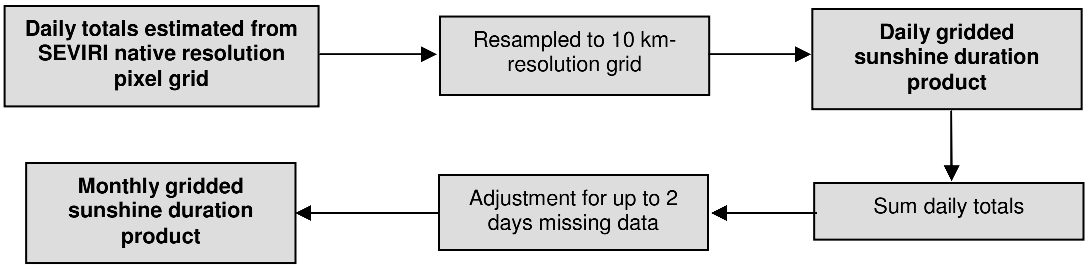

Figure 3: **Processing steps for deriving monthly totals from daily data.**

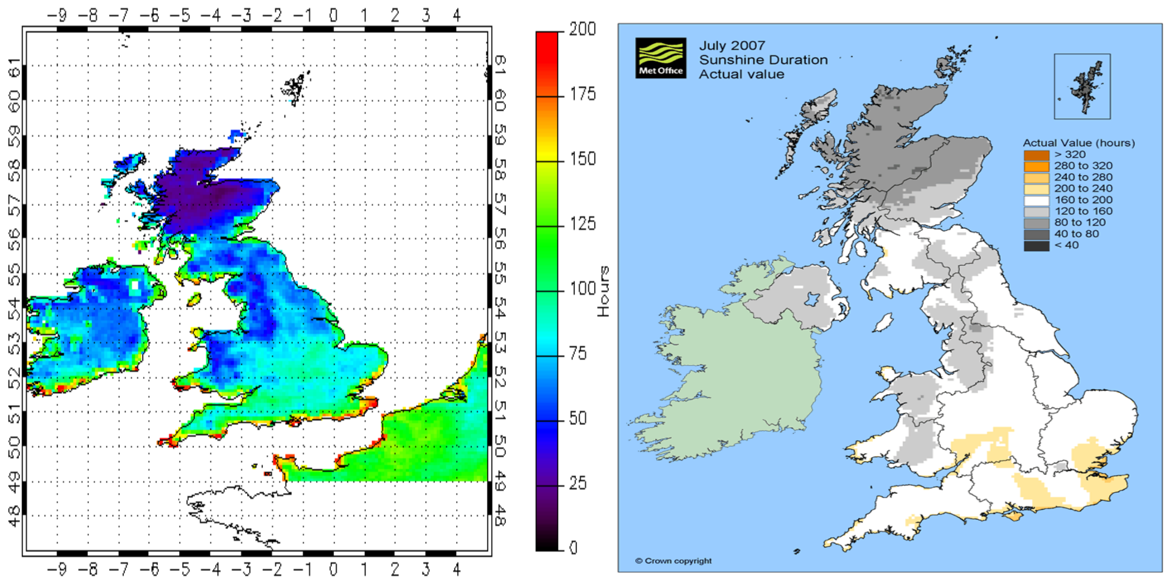

Figure 4: **Sunshine duration estimated from SEVIRI (left), and the NCIC standard product (right) for July 2008.**

EVALUATION WITH IN SITU DATA

The accuracy and precision of the SEVIRI-derived sunshine duration estimates has been assessed by comparing the daily pixel-based estimates with collocated daily station totals obtained in 2007 and 2008. Owing to the differing performance of the Campbell-Stokes and Kipp & Zonen sensors, the evaluation has been performed separately for each type of ground-based instrument.

Figure 4 shows a scatter plot of the SEVIRI estimates vs the corresponding Campbell-Stokes in situ observations for 1 January 2007. Excellent agreement is obtained for the 84 matched data points: the Pearson correlation coefficient, *r*, is 0.91, with the differences exhibiting only a small bias and standard deviation (-0.01 hours and 0.81 hours, respectively). However, there are a few notable outliers where the SEVIRI estimates differ from the Campbell-Stokes data by as much as one to two hours.

Figures 5 and 6 show the daily time series of differences for the Kipp & Zonen, and Campbell-Stokes evaluations, respectively. Agreement is notably better between the SEVIRI and Kipp & Zonen data compared with the results for the Campbell-Stokes comparisons. In particular, the inter-quartile ranges are much smaller with fewer outliers in the data and the correlations are higher. Although the in situ data have undergone quality-control, this suggests that at least some of the disagreement between the SEVIRI and in situ data may originate from errors in the latter. Both analyses indicate the SEVIRI-in situ agreement is worse in the summer than in the winter. While the overall bias is close to zero in the winter, the SEVIRI estimates are lower than the in situ during the summer, with increased variance compared with winter. The problem appears to be more acute for the Campbell-Stokes analysis. Intermediate results are obtained for spring and autumn.

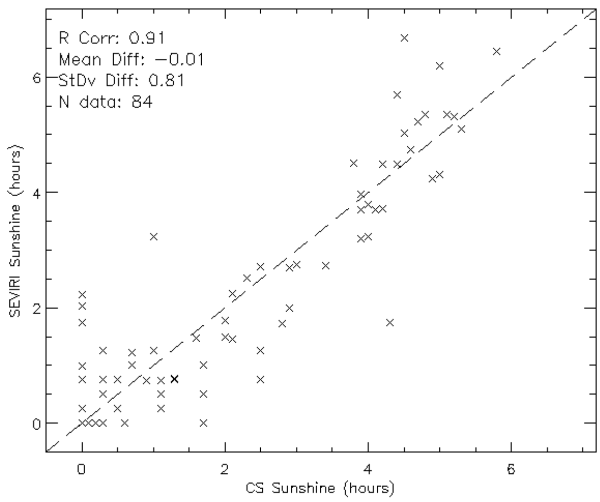

Figure 4: **Comparison between SEVIRI and collocated station-derived sunshine duration for Campbell-Stokes instruments on 1 January 2007.**

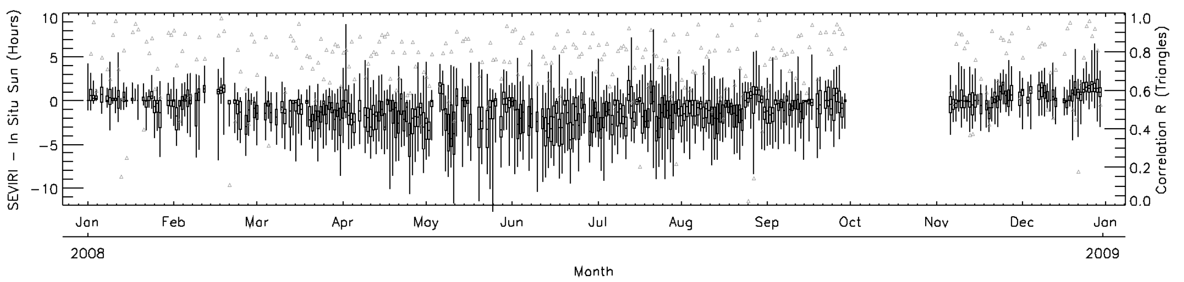

Figure 5: **SEVIRI minus Kipp & Zonen in situ sunshine duration for each day in 2008. The boxes indicate the inter-quartile range for data from all available stations over the UK, the central lines indicate the 50th percentile, and the whiskers show the max and min values. The triangles show the correlation between the satellite and in situ data (right-hand axis).**

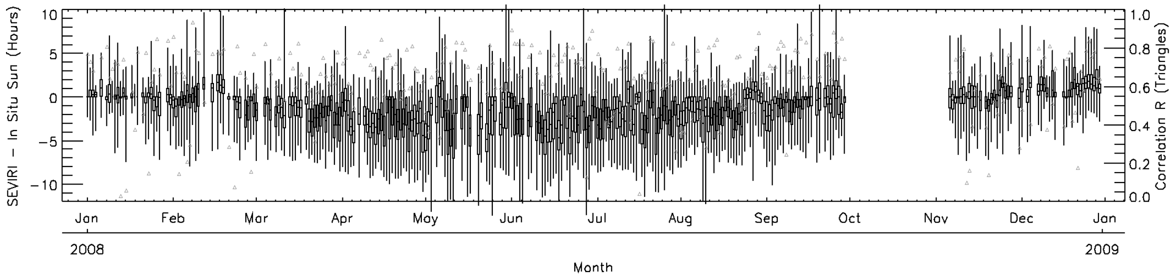

Figure 6: **As for Figure 5 but showing the results for the Campbell-Stokes analysis.**

The low bias during summer months may be due to increased occurrence of broken cloud in summer, causing individual pixels to be flagged as cloudy while the in situ data may record some sunshine. The Campbell-Stokes instruments also tend to overestimate sunshine duration during periods of broken cloud due to over-burning, particularly when the sun is high. Kerr and Tabony (2004) discuss the difference between Campbell-Stokes and Kipp & Zonen estimates of sunshine duration. Biases in the satellite data may also occur when there is only cirrus cloud present: currently, the satellite method assumes that the presence of any cloud corresponds to no sunshine. However, cirrus may still transmit enough sunlight for the ground-based sensors to record bright sunshine. This problem would be less acute during the winter months where the SEA is lower and the optical path through cirrus longer, increasing the effective optical thickness of the cloud and therefore lessening the chance of bright sunshine being recorded on the ground through this type of cloud. Future work will focus on trying to resolve these discrepancies between the satellite and in situ data and achieving an improved product, particularly for the summer months.

CONCLUSIONS AND FURTHER WORK

A simple method for estimating sunshine duration over the UK from time series of cloud mask data from SEVIRI has been presented. The method provides a gridded daily data set with near-complete spatial coverage that could be used as an independent data source to improve or validate UK maps of sunshine duration produced by the Met Office. Currently, these maps have low confidence owing to the scarcity of in situ data, and reliance on interpolation methods.

The daily satellite sunshine duration estimates have been compared with independent, spatially and temporally collocated in situ data during 2007 and 2008 for more than 100 stations. Evaluation has been carried out separately for the two types of in situ sensors used in the UK. Results are notably better for the Kipp & Zonen compared with the more traditional Campbell-Stokes instruments. For both analyses, very good agreement is obtained during winter months, but the satellite data tend to underestimate the daily sunshine totals in summer. Increased variance in the satellite-station agreement is also observed during summer compared with winter. This is attributed to the effects of cirrus and/or broken cloud: currently the satellite method assumes no sunshine for either of these cloud types, whereas the ground stations may record some bright sunshine, particularly in the summer. Future work will focus on improving the sunshine estimates for these cloud types, for example, by incorporating the NWCSAF cloud type product into the analysis and making appropriate adjustments. Work is also underway to assess whether the satellite sunshine duration estimates significantly improve the sunshine duration maps currently produced by the Met Office.

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