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Characterizing temporal variability in measurements of surface solar radiation and its dependence on climate

Marc Bengulescu*, Philippe Blanc, Lucien Wald

MINES ParisTech, PSL Research University, Centre for Observation, Impacts, Energy, CS 10207 - 06904 Sophia Antipolis, France

Abstract

The intrinsic temporal scales of the variability of the surface solar radiation are addressed by means of the empirical mode decomposition. High quality measurements of the solar radiation impinging on a horizontal plane at ground level, from different BSRN ground stations, are analysed. By first extracting all the embedded oscillations that share a common local time-scale, followed by Hilbert spectral analysis, the characteristic scales of variability, along with the fluctuations in the intensity of the pyranometric signal, are revealed. It is shown that data from stations with different local climates share some common features, most notably a high-frequency plateau of variability whose amplitude is found to be modulated by the seasonal cycle. The study has possible implications on the modelling and the forecast of the surface solar radiation, at different local time-scales.

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Keywords: solar radiation; temporal variability; climate; empirical mode decomposition; Hilbert spectrum; BSRN

1. Introduction

The surface solar irradiance (SSI) has been identified by the Global Climate Observing System program as one of the Essential Climate Variables that is of utmost importance in characterizing Earth climate, thus better knowledge of the SSI represents a key factor in decision making in both science and policy circles [1]. Furthermore, solar irradiance is the main driver behind the weather and climate systems on the planet, with a dynamic range varying from seconds to millions of years [2]. Despite this wide span of the associated time-scales, most of the studies that have raised the scientific understanding with respect to the SSI have primarily focused on either global averages and long-term trends [3], or have only addressed the short-term, or high-frequency part of its temporal variability [4].

In light of this need to understand the variability of the SSI field at different time horizons, an appropriate data processing technique for extracting the intrinsic modes of variability at vastly different temporal scales is required. Added to this, the nonlinear and nonstationary nature of the measured solar radiation data [5] further restricts the pool

* Corresponding author. Tel.: +33-493-678-947 ; fax: +33-493-678-908.
E-mail address: marc.bengulescu@mines-paristech.fr

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of signal processing candidates to those fit to handle such time-series, without making any beforehand assumptions about the nature of the signal. It has been proposed that the Hibert-Huang Transform (HHT), an adaptive, data-driven analysis method is a suitable technique for analysing such solar radiation datasets [6–8]. Here, this point of view is also adopted, therefore the inner workings and the rationale behind the choice of this particular data processing method will be only briefly reiterated in a dedicated subsection.

The focus of the present work thus lies on extracting and analysing the intrinsic modes of the temporal variability of the SSI, as identified by the HHT. By scrutinizing long-term (i.e. 10+ years) daily measurements of the solar radiation impinging on the ground, at different geographical locations, it is shown that the HHT is able to identify the low frequency variability components, i.e the multi-year trend and seasonal variation, and multiple high-frequency intrinsic variability modes. Although these short-timescale features appear to be distinct from the seasonal cycle, a correlation can nevertheless be found between their amplitude envelopes and the seasonal cycle, indicative of non-linear multiplicative cross-scale coupling [9]. Based on these characteristics, the difference in local climatic conditions of the measuring stations can be inferred. Possible implications of the findings on the modelling and forecast of the SSI are then discussed.

The study is organised as follows. In section 2 the data and the methods used will be described. Sub-section 2.1 discusses the data sources and the preprocessing, while 2.2 will address the analysis method. Section 3 will present the results obtained, with the discussion thereof being deferred to section 4. Lastly, acknowledgements and a bibliographical list conclude the study.

2. Data and methods

2.1. Data sources and pre-processing

The data analysed in this study consist of time-series of high-quality SSI ground measurements at two distinct geographical locations: one located in Carpentras, France (CAR – 44.083° N, 5.059° E), and the other in Payerne, Switzerland (PAY – 46.815° N, 6.944° E). For both stations the data span a ten year period, from January 1st, 2001 to December 31st, 2010 (figure 1). The measuring stations belong to the Baseline Surface Radiation Network (BSRN), a worldwide radiometric network providing accurate readings of the SSI at high temporal resolution [10]. The climate at the CAR station is of a humid subtropical, Mediterranean type (Köppen-Geiger: Csa), while the one at PAY experiences a marine west coast, mild type of climate (Köppen-Geiger: Cfb) [11]. Both stations are set in rural areas, with the surroundings having a cultivated surface type, and local hilly topography [12]. Lastly, since the stations are located in Europe, any reference to seasons and seasonal phenomena shall be understood as occurring in the northern hemisphere.

For the scope of the study, daily means of the global SSI received on a horizontal plane (GHI) were employed. The original time-series of the GHI, having a one-minute integration time, have been quality checked according to [13]. Daily means of GHI were then calculated only if more than 80% of the data during daylight were valid. Isolated missing values in the daily means series were then completed by applying linear interpolation to the daily clearness index.

2.2. Adaptive data analysis

Among the different techniques commonly used in geophysical signal processing, as for exampled those reviewed in [14], a suitable candidate for the study at hand was found to be the Hilbert-Huang Transform (HHT), a completely data-driven and adaptive signal analysis technique [15]. The HHT consists of two steps.

First, by means of the Empirical Mode Decomposition (EMD), oscillations that present a common local time-scale embedded within the signal are extracted. These oscillations, also called Intrinsic Mode Functions (IMFs), can be thought of as being amplitude modulation - frequency modulation (AM-FM) components of the data that have a zero average and a well behaved Hilbert transform. Owing to the adaptive nature of the EMD, the IMFs represent the data-driven, *a posteriori* chosen basis of the decomposition [16]. By contrast, other mathematical transforms employ basis functions that are fixed in advance, such as the trigonometric functions in the case of the Fourier transform or the wavelet functions of the eponymous transform. This adaptive approach of the decomposition not only endows the