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The Trieste Solar Activity Index

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Abstract

Space Weather science and operations need reliable descriptors of Solar Activity, suitable to properly characterise it not only on the long-term but also on the mid- and short-term, which are relevant to the occurrence and evolution of energetic phenomena. In this work, we consider a new Solar Activity index based on the 2800 MHz solar radio flux index and the soft X-ray flare occurrence at the C-, M-, and X-classes. The preliminary analysis indicates that it is capable to match the mentioned requirements, but a definitive interpretation requires its derivation and analysis on a much longer time span.

1 Introduction

A series of indices and proxies have been used to describe the level of Solar Activity and associated phenomena, which are key ones to determine the Space Weather status in planetary environments. The most widely used is the Solar Sunspot Number and the related 2800 MHz Solar Radio Flux. The Sunspot Number is very suitable to define the global Solar Activity level, i.e., its quasi-periodic time evolution, named Solar Cycle. Anyway, a different Solar Activity index is needed to better describe the short- to medium-term evolution of energetic phenomena like, e.g., flares and to favour the estimation of their probability of occurrence. In this summary paper, we present the conceptual framework that led us to conceive a new index and a preliminary analysis of its descriptive capability relevant to Space Weather, which is still subject to analysis.

2 The Solar Activity Cycle

The Sun is a complex physical system made of a set of complex physical subsystems, i.e., plasma layers at different densities and kinetic temperatures, which are nonlinearly coupled and exhibit a chaotic behaviour. The detailed physics of the processes which occur in these layers is not completely understood and this prevents the formulation of a universal model for the phenomena that are triggered and constitute what we call Solar Activity. From ground- and space-based observations we know that these phenomena occur quasi-periodically in time and are of magnetic origin (see, e.g., [1]).

Sunspots are the signature of intense localised magnetic fields as reservoirs of magnetic energy stored in system configurations that are in marginal equilibrium. A small perturbation can trigger the impulsive release of magnetic energy and its conversion into kinetic energy as it occurs in flares and erupting prominences.

The appearance of sunspots from a minimum to a maximum number and back to a minimum is called Sunspot Cycle and is characterised by a periodicity of roughly 11 years. Instead, the sunspot magnetic polarity follows a 22 years cycle. Apart from the relative easiness of observing sunspots, their number was adopted as an index of the Solar Activity level. Sunspot groups are activity centres and therefore this adoption is physically motivated.

Furthermore, magnetised solar plasma in activity centres is emitting radio waves according to thermal and non-thermal mechanisms. The intensity of this broadband radio emission is observed to follow the time evolution of the Sunspot Number, so that the solar radio emission at 2800 MHz (10.7 cm) is considered an effective indicator of the Solar Activity level and has been used as an alternative (proxy) to the Sunspot Number. Obviously, the time series of the Sunspot Number is much more extended in time than that of the S2800 radio index, as solar radio observations started in the second half of the 50's.

Figure 1 depicts the time evolution of the 13-month smoothed monthly total Sunspot Number (SN13) and the monthly averages of solar 2800 MHz (10.7 cm) radio flux (observed flux) (S2800M) in the period Dec. 2019-Dec-2023, i.e., from the start of solar Cycle 25 to date. To better emphasise the good association between the two descriptors, the radio flux S2800 was re-scaled by subtracting the observed value at the minimum activity in Dec. 2019 and renamed as S2800M. The two-periods moving average trend-lines point out the good correlation. In fact, an empirical relationship was derived by the Canadian solar radio astronomy team, which allows to derive the Sunspot Number from S2800: $SSN = (1.14)\ S2800 - 73.21$. The graph in Figure 1 clearly indicates the index increase towards the maximum of the solar cycle.

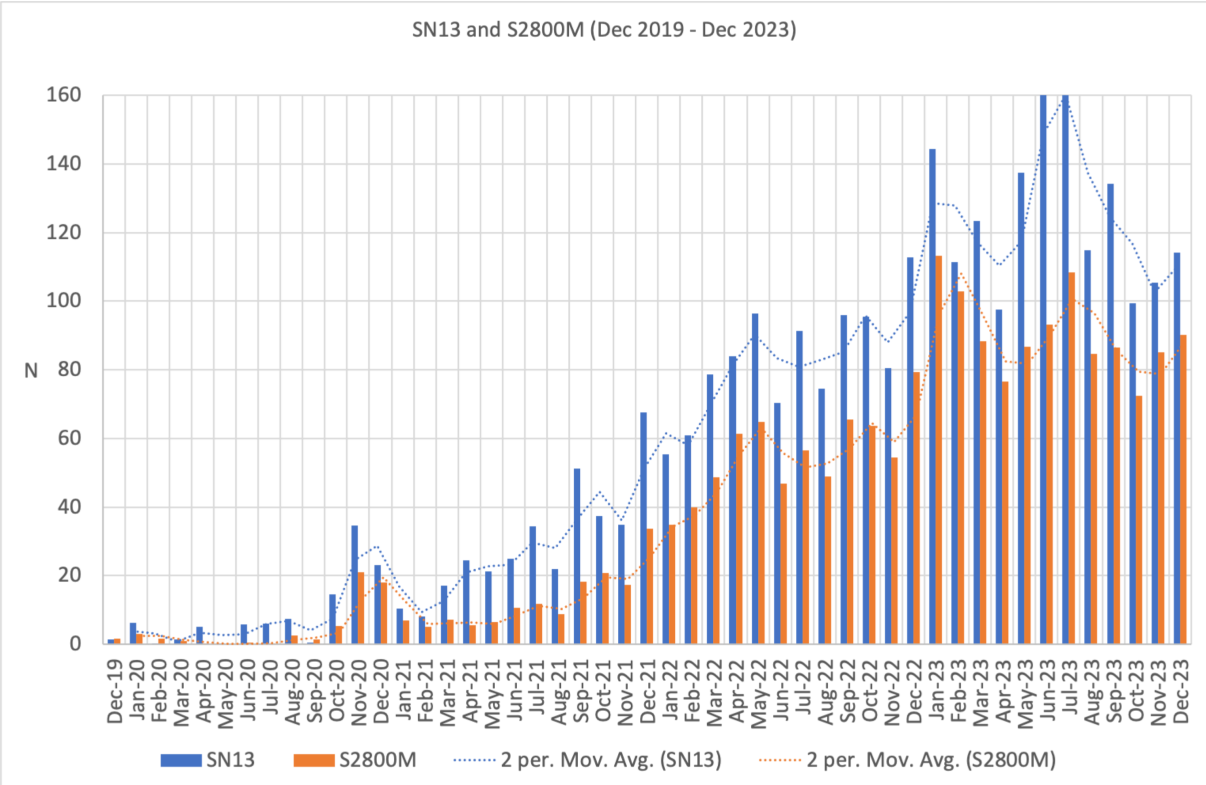

Figure 1. Time evolution (Dec. 2019-Dec. 2023) of the 13-month smoothed monthly total Sunspot Number (SN13) and the monthly averages of solar 10.7 cm radio flux (S2800M, observed flux minus its value at solar minimum). The 2-periods moving average trend-lines are superimposed.

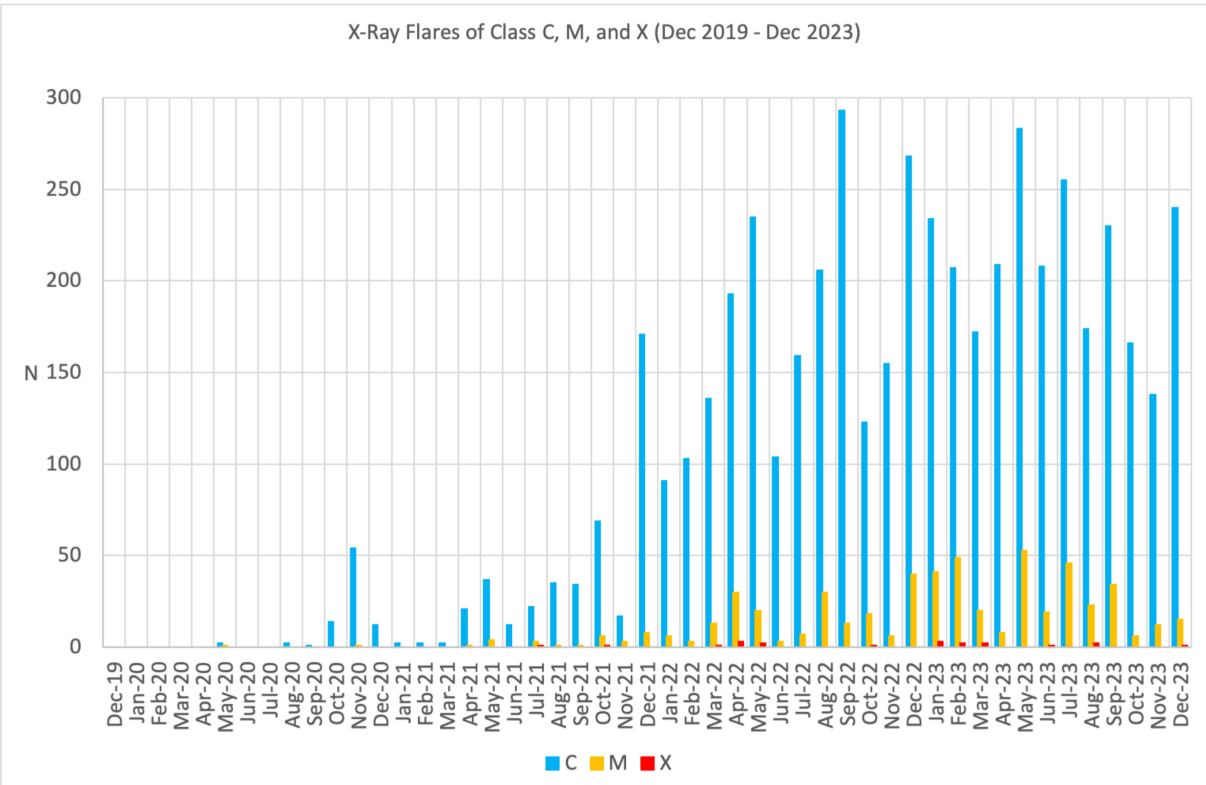

Figure 2. Occurrence of soft X-ray solar flares observed by GOES in the period Dec. 2019-Dec. 2023. (Cyan - C-class flares; Orange - M-class flares; Red - X-class flares).

3 Intrinsic Limitations of Activity Indices

The Solar Sunspot Number is a global descriptor of Solar Activity, because it expresses the potentiality of occurrence of energetic phenomena, but it does not provide any information of which ones have to be expected. Hence, the SSN cannot provide any indication about the kind of energetic phenomena which will be associated with the Sunspot Groups, but one can only guess that an increase in the number of Sunspot Groups will result in an increase of energetic phenomena like, e.g., flares and their by-products (photon outbursts, particle acceleration, and, eventually, the release of Coronal Mass Ejections, CME).

On the other hand, the occurrence of solar flares and their characterisation for Space Weather forecasting has been still under investigation (see, e.g., [2, 3, 4]). In fact, due to the variety of the experimental scenarios, the most promising approaches also for activity indices prediction are based on Deep Learning techniques (see, e.g., [5, 6]).
Figure 2 depicts the occurrence of soft X-ray flares of class C, M, and X, where the less energetic C ones indicate a trend of increase with Solar Activity as the more energetic M ones, but, as observed in past cycles, the most energetic X ones can occur at any phase of the cycle.

These detailed variations cannot be reproduced by a global index based on a unique observable like the SSN.

4 The Trieste Solar Activity Index

In the attempt to overcome the intrinsic limitations of global activity indices, we have considered a new index (TSAI, Trieste Solar Activity Index), which is based on the modified index of the solar radio flux at 2800 MHz augmented by a linear combination of the occurrence of soft X-ray flares of class C, M, and X, weighted by coefficients that take into account their occurrence probability.

The relevant formula reads

$$TSAI = S2800M + 0.5 \cdot C + M + 10 \cdot X. \qquad (1)$$

Figure 3 depicts the time evolution of the smoothed Sunspot Number (SN13) and the TSAI with the respective 2-periods moving average trend-lines superimposed. Whereas SN13 describes well the global evolution of Solar Activity, TSAI is emphasising the periods when activity was higher in terms of impulsive energy release via flares.

As expected, this behaviour is similarly evident in Figure 4, which depicts the time evolution of the TSAI and the modified S2800 index, as this latter is embedded into TSAI.

5 Conclusions

We have considered the capability of standard Solar Activity indices, like the Sunspot Number and the Solar radio flux at 2800 MHz, to describe its phenomenological aspects relevant to Space Weather. It became evident that, due to the way they are derived, these indices are suitable to describe Solar Activity on a global time scale, because they express the potentiality of occurrence of energetic phenomena like flares, but are not adequate to represent the time evolution of their occurrence. Hence, we have considered a new hybrid index (TSAI, Trieste Solar Activity Index), which is based on a weighted combination of S2800 and the occurrence of C-, M-, and X-class soft X-ray flares. The preliminary analyses indicate that TSAI can match the Space Weather requirements and fill the gap in adequately describing Solar Activity. The analyses are in progress.

6 Acknowledgements

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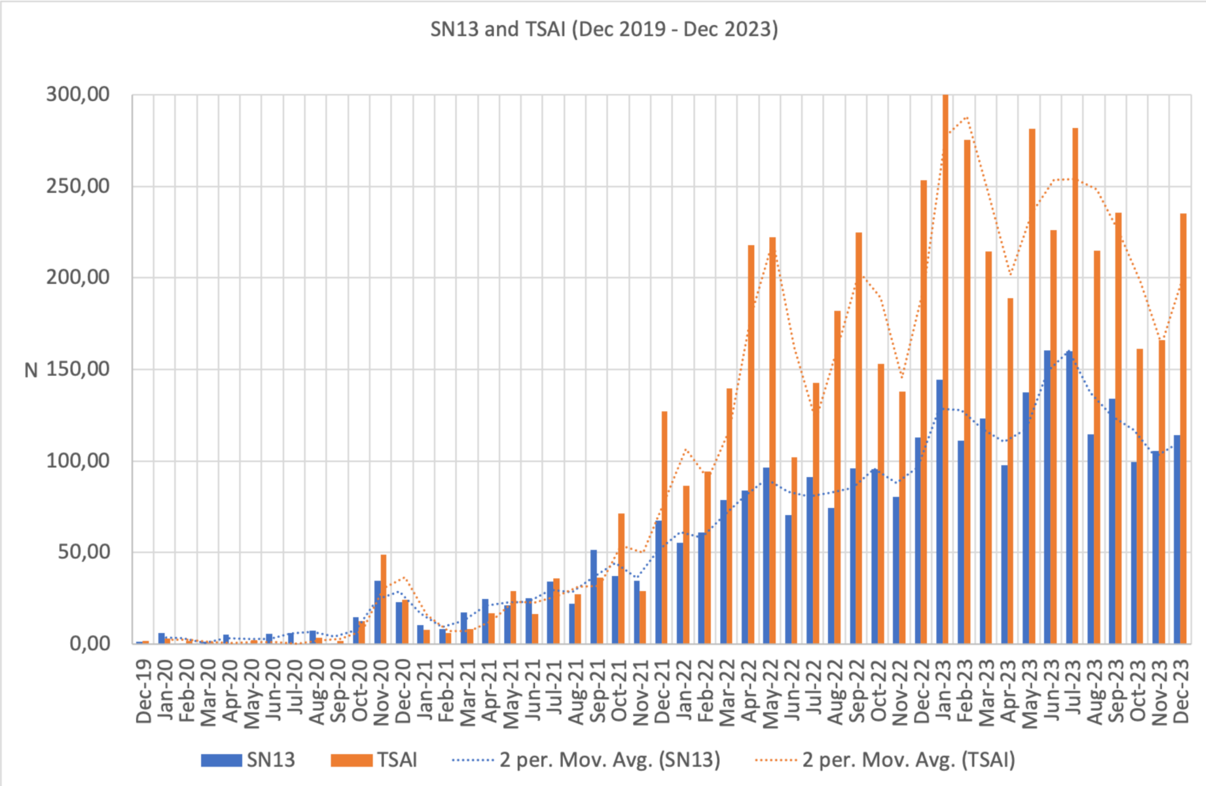

Figure 3. Time evolution of the Sunspot Number (SN13) index and the proposed Trieste Solar Activity Index (TSAI) with the respective 2-periods moving average trend-line superimposed.

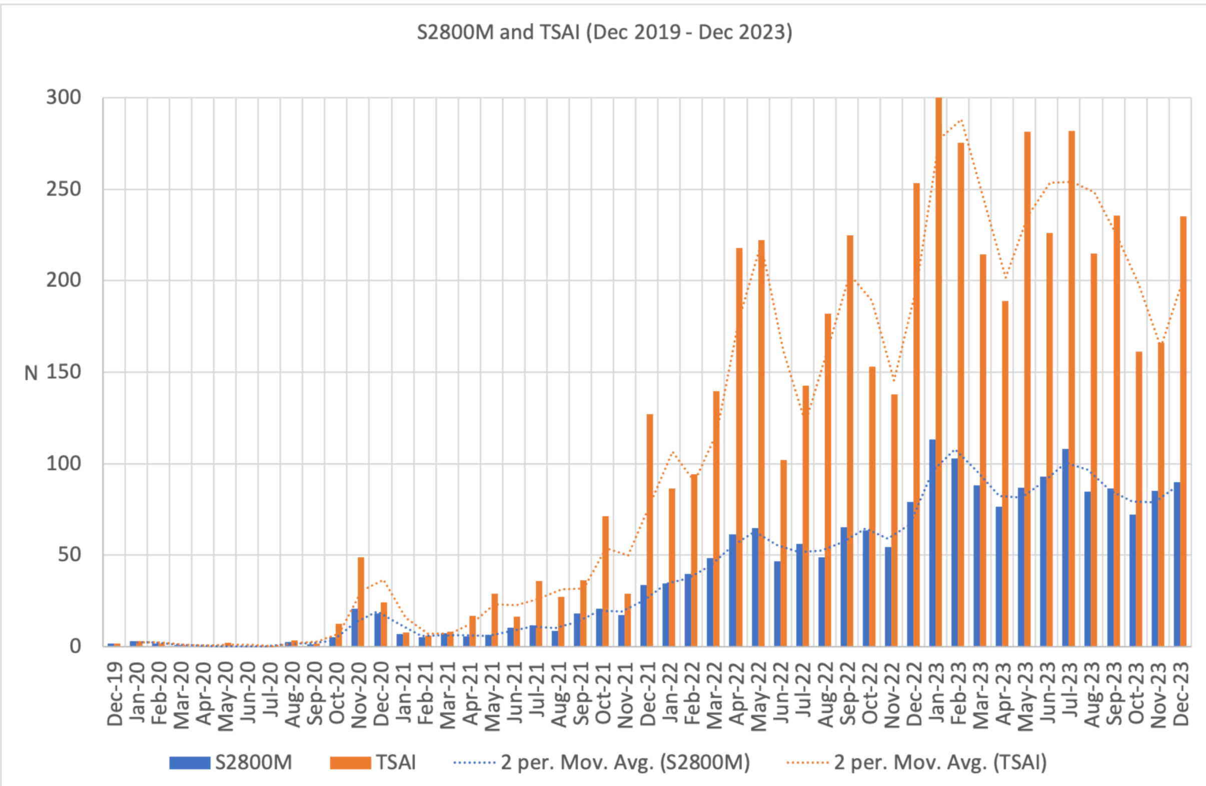

Figure 4. Time evolution of the modified solar radio flux at 2800 MHz (S2800M) and the proposed Trieste Solar Activity Index (TSAI) with the respective 2-periods moving average trend-line superimposed.