IL NUOVO CIMENTO **44 C** (2021) 120
DOI 10.1393/ncc/i2021-21120-8

COMMUNICATIONS: SIF Congress 2020

Correlation of solar activity proxy with solar wind dynamic pressure in the last five solar cycles

R. REDA(1)(2), L. GIOVANNELLI(1), T. ALBERTI(2), F. BERRILLI(1), P. GIOBBI(1) and V. PENZA(1)

(1) *Università degli Studi di Roma "Tor Vergata" - Via della Ricerca Scientifica 1, 00133 Rome, Italy*
(2) *INAF-IAPS - Via del Fosso del Cavaliere 100, 00133 Rome, Italy*

received 15 January 2021

Summary. — Solar variability related to the magnetic activity can be quantified using synthetic indices (*e.g.*, sunspots number) or physical ones (*e.g.*, chromospheric proxies). To connect solar surface variability and its features in the near-Earth, we use Ca II K index and solar wind OMNI data in the time interval between 1965 and 2019, which almost entirely covers the last 5 solar cycles. Using long-term averaged data, anti-correlation between Ca II K index and solar wind dynamic pressure at 1 AU has been found during solar cycles 20 and 21, while this relation seems to change over the last 3 solar cycles.

1. – Introduction

Manifestations of solar magnetic activity include several energetic phenomena which span a wide range of time-scales. The different temporal scales involved lead to a first distinction between events with typical time-scales smaller than the rotational period of the Sun, called transient events (*e.g.*, flares, CMEs, CIRs) and the ones with typical time-scales larger than the Sun's rotational period, named stationary phenomena. An example of stationary phenomena is constituted by solar wind, which is a continuous flow of particles that originates from the outer atmospheric layer of the Sun [1], *i.e.*, corona. Solar wind strongly interacts with the Earth's magnetic field compressing and perturbing it, with the direct result of providing the shape to the Earth's magnetosphere [2]. Moreover, the interaction between the solar wind large-scale structures and the Earth's magnetic field gives rise to the geomagnetic storms. Thus, the relationship between solar activity and solar wind constitutes a topic of fundamental importance.

Space climate analysis focuses on the long-term variations in the solar activity, on scales from years to several millennia. This variability, together with that of the space weather, is of paramount importance to define the habitability in the Solar System as

Creative Commons Attribution 4.0 License (https://creativecommons.org/licenses/by/4.0)

well as in extrasolar systems (see, *e.g.*, [3]). In particular, the solar/stellar wind dynamic pressure plays a major role in defining the extension of a planet's magnetosphere and, accordingly, the atmospheric erosion rate and the possibility to sustain a planetary atmosphere on Gyr time-scales.

Although solar cycle proxies data give information about the Sun's magnetic activity for fairly long time periods, direct measurements of the near-Earth solar wind parameters are available only starting from 1964. A possible relation between solar activity and solar wind variability has been investigated starting from the 1970s. The presence of a possible solar wind cycle was suggested by [4] by using geomagnetic observations as solar wind proxies. He suggested a cycle not in phase with the Schwabe cycle measured by sunspot number, a hypothesis confirmed few years later [5]. Instead, the first direct evidence that long-term changes on the Sun give rise to changes in the solar wind was reported by [6]. Analysis on longer time series has been later performed. Using 20 years (1973–1993) of OMNI measurements, a specific time lag has been shown between sunspot number (SSN) and solar wind speed (ion density) [7], the latter reaching the maximum approximately 750 (350) days before SSN.

In this work we use measures of a physical proxy of the solar activity, the Ca II K index, and of the solar wind dynamic pressure (OMNI dataset), to derive their long-term behaviour and relations by mean of an appropriate filtering.

2. – Dataset

To quantify the solar magnetic activity we use the Ca II K index time series from National Solar Observatory [8], for which monthly means are available for the time interval between February 1907 and October 2017. Unlike SSN, a solar activity proxy which is biased in favour of highly concentrated magnetic structures, Ca II K index is a physical measure of the mean properties of the solar chromospheric emission along all phases of the solar cycle. Together with Hα and white light emission, these are the only proxies related to solar cycle activity that are available on time scales of 100 years and useful for long-term space climate analysis. Furthermore, Ca II K emission can be used as a proxy for the line-of-sight unsigned magnetic flux density (see [8] and references therein), which in turn can be related to solar wind strength (see, *e.g.*, [9]). Accordingly it is reasonable to expect that an analysis of the solar wind properties in the long term can benefit from a comparison with the Ca II K index. Although measurements of the Ca II K index are not publicly available later than October 2017, it is possible to overcome this lack of data using the Mg II composite from the University of Bremen, whose measurements are available to date. Due to the fact that, in the time interval from November 1978 to October 2017, the Ca II K index strongly correlates with Mg II index ($R = 0.95$), we use the latter to extend the Ca II K index until December 2019. The linear relation between them is Ca II K index $= 0.5619$ Mg II $- 0.0014$. As has been show in refs. [10, 11] the Ca II K index can be further extended in the past. If a clear relation between this index and the solar wind properties were found, this could open to a long-term reconstruction of the solar wind time series.

Solar wind parameters can be obtained by means of the OMNI database, freely available at `https://cdaweb.gsfc.nasa.gov/index.html/`. It contains magnetic field and plasma measurements at different resolutions (from 1 minute to 1 hour) collected by a spacecraft located near the L1 Lagrangian point at 1 AU then shifted to the Earth's bow shock nose. In this paper we considered plasma measurements of density n and speed v at hourly resolution to compute the solar wind dynamic pressure.

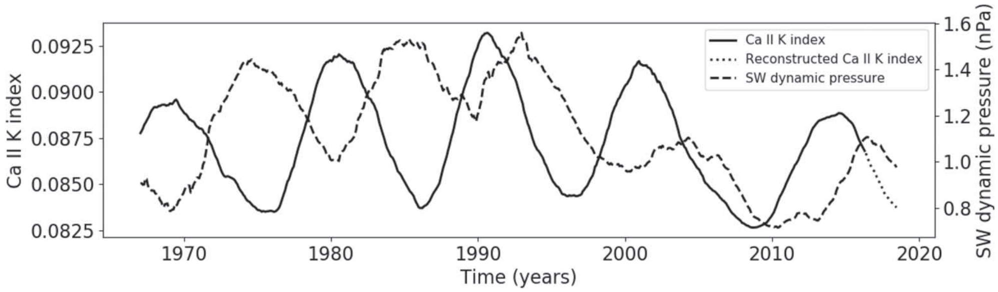

Fig. 1. – 37 month moving averages of the Ca II K index (continuous line) and solar wind dynamic pressure (dashed line). The dotted line shows the reconstructed Ca II K index obtained using the linear relation with the Mg II index.

Therefore, the overlap time interval of the Ca II K index and solar wind dynamic pressure time series goes from July 1965 up to December 2019, which almost entirely covers the last 5 solar cycles (20–24).

3. – Data analysis

Starting from the hourly averages, we first compute the monthly values of solar wind ion density (n) and speed (v). Then, we calculate the solar wind dynamic pressure for each month as $P = 1/2\, m_p n v^2$, where m_p is the proton mass. In order to study the long-term relation between the Ca II K index and solar wind pressure, we use long-term averaged data to remove the variability due to transients (CMEs, CIRs) related to the solar rotation time-scale and other sources of variability at yearly time-scale. We apply 37 month moving averages on the two monthly time series, following the approach of [7]. The filtered time series are shown in fig. 1. In this case the solar wind dynamic pressure does show a cycle with a period similar to the 11 year solar cycle, clearly visible in Ca II K index filtered data, as in fig. 1. Nevertheless, no clear relation between solar

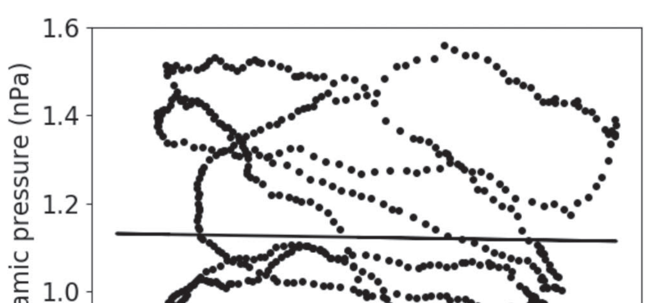

Fig. 2. – Relationship between 37 month moving averaged solar wind dynamic pressure and Ca II K index. The solid line shows the linear fit. The correlation coefficient is $R = -0.0195$.

chromospheric activity and solar wind dynamic pressure seems to hold across the entire period of the last five solar cycles. Both data appear to be in anti-phase during the solar cycles 20 and 21, while this trend is not visible in the last 3 cycles. Looking to the entire time interval there is no significant correlation between Ca II K index and solar wind dynamic pressure. This is well visible in fig. 2, where the points of the two time series are plotted one against the other, and is confirmed by the fact that the Pearson correlation coefficient between them is around zero ($R = -0.02$).

4. – Conclusions

We analyzed the long-term behaviour of a solar activity proxy, *i.e.*, the Ca II K index, and the solar wind dynamic pressure. In order to study the relation between them, we used 37 month averaged data in the time interval between 1965 and 2019, which almost entirely covers five solar cycles. We did not find a clear correlation between the Ca II K index and solar wind dynamic pressure over the entire time interval ($R = -0.02$). Despite this, as is clearly visible in fig. 1, the two time series are anti-correlated during the solar cycles 20 and 21, while their relative lag seems to change in subsequent solar cycles 22, 23, and 24, moving towards correlation behaviour. This confirms the result recently reported by [12] on SSN and solar wind dynamic pressure. A more detailed analysis of the two time series is foreseen in an upcoming article, to fully exploit the long-term relation between solar variability and solar wind properties.

* * *

The Time series of the Ca II K index uses SOLIS data obtained by the NSO Integrated Synoptic Program (NISP), downloaded from the SOLIS website (`https://solis.nso.edu/0/iss/`). NISP is managed by the National Solar Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA), Inc. under a cooperative agreement with the National Science Foundation. The OMNI data are available from Coordinated Data AnalysisWeb (CDAWeb; `http://cdaweb.gsfc.nasa.gov`). The Mg II composite is available from the University of Bremen (`http://www.iup.uni-bremen.de/UVSAT/datasets/mgii`). RR and PG are PhD students of the PhD course in Astronomy, Astrophysics and Space Science, a joint research program between the University of Rome "Tor Vergata", the Sapienza University of Rome and the National Institute of Astrophysics (INAF).

REFERENCES

[1] Parker E. N., *Astrophys. J.*, **128** (1958) 664.
[2] Russell C. T., *J. Geophys. Res.*, **98** (1993) 18681.
[3] Dong C. *et al.*, *Astrophys. J. Lett.*, **837** (2017) L26.
[4] Hirshberg J., *Astrophys. Space Sci.*, **20** (1973) 473.
[5] Feynman J., *J. Geophys. Res.*, **87** (1982) 6153.
[6] Intriligator D. S., *Astrophys. J.*, **188** (1974) L23.
[7] Kohnlein W., *Astrophys. Space Sci.*, **245** (1996) 81.
[8] Bertello L. *et al.*, *Solar Phys.*, **291** (2016) 2967.
[9] Schwadron N. A. and McComas D. J., *Astrophys. J.*, **686** (2008) L33.
[10] Berrilli F. *et al.*, *Solar Phys.*, **295** (2020) 38.
[11] Lovric M. *et al.*, *J. Space Weather Space Clim.*, **7** (2017) A6.
[12] Samsonov A. *et al.*, *J. Geophys. Res.*, **124** (2019) 4049.