frontiers | Frontiers in Astronomy and Space Sciences

TYPE Editorial
PUBLISHED 02 June 2023
DOI 10.3389/fspas.2023.1207120

Editorial: Study of long-term solar datasets: exploring spatio-temporal patterns of solar variability on different time scales and implications in space weather

Subhamoy Chatterjee[1]*, Dipankar Banerjee[2] and Mausumi Dikpati[3]

[1]Southwest Research Institute, Boulder, CO, United States, [2]Aryabhatta Research Institute of Observational Sciences, Nainital, Uttarakhand, India, [3]HAO/NCAR, Boulder, CO, United States

Check for updates

OPEN ACCESS

EDITED BY
Luke Barnard,
University of Reading, United Kingdom

REVIEWED BY
Luca Bertello,
National Solar Observatory, United States

*CORRESPONDENCE
Subhamoy Chatterjee,
subhamoy.chatterjee@swri.org

RECEIVED 17 April 2023
ACCEPTED 23 May 2023
PUBLISHED 02 June 2023

CITATION
Chatterjee S, Banerjee D and Dikpati M (2023), Editorial: Study of long-term solar datasets: exploring spatio-temporal patterns of solar variability on different time scales and implications in space weather.
Front. Astron. Space Sci. 10:1207120.
doi: 10.3389/fspas.2023.1207120

KEYWORDS

solar magnetism, solar cycle, sunspots, chromosphere, solar irradiance, historical datasets, open solar flux, *in situ* heliospheric measurements

Editorial on the Research Topic
Study of long-term solar datasets: exploring spatio-temporal patterns of solar variability on different time scales and implications in space weather

The Sun is an active star revealing spatiotemporal variability in its magnetic activity, which further impacts our terrestrial system. Various MHD models can simulate certain aspects of the evolution of the solar magnetic field on different time scales. Recently data-driven models and coupling data with models by means of data assimilation and information-theoretic approaches are being explored. The use of high-resolution and high-cadence datasets in conjunction with historical solar data, which are being accumulated to date will allow the derivation of a wealth of spatiotemporal patterns in solar activity on various time scales, covering a few days through months to decades, hence providing reliable inputs for model-simulations, and also the magnetic activity features to be predicted by the models.

Regular measurements of the spatially-resolved solar magnetic field started only in 1967. Observations, before that, captured different magnetic features such as sunspots (Mandal et al., 2020), faculae (Muñoz-Jaramillo et al., 2012; Priyal et al., 2014), and filaments/prominences (Chatterjee et al., 2016; Chatterjee et al., 2017a; Chatterjee et al., 2017b; Chatterjee et al., 2020). These features found in modern datasets and historical archives, form at different heights above the solar surface and help immensely in understanding the magnetic field strength and topology. Several studies have found great corroboration between the long-term spatiotemporal evolution of such magnetic proxies and the evolution derived from current magnetic measurements (McIntosh et al. and references therein). Careful treatment of historical datasets may thus provide invaluable information about the evolutionary pattern in solar magnetic fields (Mordinov et al., 2020) in the past and help establish its causal connection with space weather events (Dikpati and McIntosh, 2020).

It must be noted that modern solar image datasets (e.g., SoHO, SDO, STEREO, HINODE) are captured directly through CCDs whereas historical image archives are primarily available as digitized or non-digitized photographic plates and hand-drawn Sun charts or Carrington maps. The most prominent historical archives are namely, Kodaikanal Solar Observatory Multi-wavelength digitized archive (available from the early 1900's, Chatterjee et al., 2016; Chatterjee et al., 2017a; Chatterjee et al. 2017b; Mandal et al., 2017; Chatzistergos et al., 2019c; Jha et al., 2021; Priyadarshi et al., 2023), Mt. Wilson white light directs, Ca II K, H-alpha spectroheliograms and hand-drawn sunspot polarity maps (Lefebvre et al., 2005; Bertello et al., 2010; Pevtsov et al., 2019a; Chatterjee et al., 2019), Meudon hand-drawn Carrington Maps (Malherbe et al., 2023), McIntosh hand-drawn archive (Webb et al., 2018; Mazumder et al., 2021; Harris et al., 2022), Kanzelhöhe prominence archive (Pötzi et al., 2013; Chatterjee et al., 2020), Greenwich sunspot archive (Willis et al., 2013), Coimbra archive (Carrasco and Vaquero, 2022) and Kislovodsk archive (Tlatov et al., 2016). Several studies are focusing on one of these datasets. Several factors such as data gaps, inter-observer variability, data degradation, and calibration problems (Chatzistergos et al., 2018b; Muñoz-Jaramillo and Vaquero, 2019) restrict the unified treatment of such datasets. However, applying indirect and sophisticated approaches (Mordinov et al., 2020) can help to unify these datasets, thereby stretching the study time further in the past.

The articles published on this Research Topic focus on a range of problems such as multi-wavelength long-term data generation and calibration, detection of magnetic proxies, data-driven simulation to generate spatiotemporal patterns of magnetic evolution, prediction of the solar cycle amplitude and drawing correlations between solar open flux estimated from solar images and heliospheric *in-situ* measurements. They employ a diverse set of methodologies encompassing—1) edge detection and Hough transform techniques to detect solar discs for data calibration, 2) iterative polynomial fits to extract limb-darkening profiles for photometric calibration, 3) morphological operators to detect sunspots and OTSU thresholding to detect sunspot umbra, 4) Hilbert transform to predict the solar cycle, 5) flux transport simulations to record spatiotemporal patterns of solar magnetic fields using sunspot polarity and plage data, 6) PFSS extrapolation to estimate open solar flux using magnetograms as input, 7) Monte-Carlo method for ensemble reconstruction.

We hope that the articles on this Research Topic will expose the readers to a subset of the wealth of long-term multi-wavelength solar data that are vital in constraining the existing models to extrapolate the magnetic behavior of the sun as well as understand new physics that was previously unknown. We expect that this Research Topic will inspire applications of state-of-the-art data processing (including Machine Learning) approaches to generate high-quality homogeneous data series combining multiple surveys and enable the scientific community to establish causal connections between phenomena happening at different time scales from the solar surface to the heliosphere.

We list below the detailed description of each article published on this Research Topic.

Lockwood et al. Paper-I presents updated mean reconstructions of the interplanetary magnetic field, solar wind speed, and open solar flux (OSF) for the past 186 years using geomagnetic indices and modern *in-situ* measurements. They use the Monte Carlo technique that generates an ensemble of 1 million members for each pairing of indices and enables the reconstruction of the mentioned parameters with uncertainty estimates. The study reports an increase in the solar cycle average of open solar flux from 2.46 × 10 14 Wb in 1906 to 4.10 × 10 14 Wb in 1949.

Lockwood et al. Paper-II shows how the geomagnetic observations presented in paper-I can be combined with long data series of solar observations to gain a deeper understanding of the long-term change in the solar corona and heliosphere during the rise and fall of the Modern Grand Solar Maximum. The study finds close agreement between the polar coronal hole fluxes and the values derived from open flux continuity modeling based on sunspot numbers. It also suggests that one possible solution to the "open flux problem" (i.e., mismatch of OSF derived from PFSS reconstruction from solar magnetograms and *in-situ* observations) is open flux within the streamer belt that potential-based modeling of coronal fields from photospheric fields is not capturing.

Jha et al. extend the sunspot area series from Kodaikanal Solar Observatory to 1904–2017 by adding data for the period 1904–1911 and 2011–2017. The article discusses important aspects such as calibration of the newly added digitized images, semi-automated detection of sunspots, automated detection of sunspot umbra, and validation of extracted features with currently available composite series.

Chatzistergos et al. provide a comprehensive overview of the currently known full-disk Ca II K data archives The article discusses sources of the inhomogeneities in the data, existing processing techniques, and the important results derived with such data so far.

Ermolli et al. provide a detailed overview of The Rome Precision Solar Photometric Telescope (Rome/PSPT) which started solar observation in 1996 and is still continuing to record multi-wavelength solar data. The article encompasses aspects like data acquisition, photometric calibration, image characterization, and different scientific studies that have been enabled by PSPT.

McIntosh et al. use Hale cycle termination points as anchors and forecast amplitude for SC25 to be 184 ± 63 at 2σ (13-month smoothed sunspot number). Using the superposed epoch analysis they also estimate the maximum timing to be between the last quarter of 2023 and the last quarter of 2024. The paper highlights the importance of studying solar longitudinal evolution and the need for a multi-point observing capability to achieve the same.

Author contributions

SC wrote the first draft. DB and MD edited the manuscript causing further improvements. All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Funding

MD acknowledges support by NASA-LWS grant 80NSSC20K0355 and NASA-HSR grant 80NSSC21K1676 to NCAR, and two sub-awards respectively from NASA Cooperative Agreement 80NSSC22M0162 to Stanford University for the COFFIES Drive Science Center and NASA-HSR grant 80NSSC21K1678 to JHU/APL. This editorial work is supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under cooperative agreement 1852977. SC acknowledges the funding support by NASA HGIO grant 80NSSC23K0416.

Acknowledgments

We thank all the reviewers for their insightful comments. We gratefully acknowledge the assistance of the staff in the Editorial Office of Frontiers.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Bertello, L., Ulrich, R. K., and Boyden, J. E. (2010). The Mount wilson Ca II K plage index time series. *SoPh* 264, 31. doi:10.1007/s11207-010-9570-z

Carrasco, V. M. S., and Vaquero, J. M. (2022). A catalog of faculae, prominences, and filaments for the period 1929–1944 from the astronomical observatory of the university of Coimbra. *ApJS* 262, 44. doi:10.3847/1538-4365/ac85dd

Chatterjee, S., Banerjee, D., McIntosh, S. W., Leamon, R. J., Dikpati, M., Srivastava, A. K., et al. (2019). Signature of extended solar cycles as detected from Ca ii K synoptic maps of kodaikanal and mount wilson observatory. *ApJL* 874. doi:10.3847/2041-8213/ab0e0e

Chatterjee, S., Banerjee, D., and Ravindra, B. (2016). A butterfly diagram and Carrington maps for century-long Ca II K spectroheliograms from the Kodaikanal observatory. *Astrophys. J.* 827, 87. doi:10.3847/0004-637X/827/1/87

Chatterjee, S., Hegde, M., Banerjee, D., and Ravindra, B. (2017a). Long-term study of the solar filaments from the synoptic maps as derived from H α spectroheliograms of the kodaikanal observatory. *Astrophys. J.* 849, 44. doi:10.3847/1538-4357/aa8ad9

Chatterjee, S., Hegde, M., Banerjee, D., Ravindra, B., and McIntosh, S. W. (2020). Time-latitude distribution of prominences for 10 solar cycles: A study using kodaikanal, Meudon, and kanzelhohe data. *Earth Space Sci.* 7, 000666. doi:10.1029/2019EA000666

Chatterjee, S., Mandal, S., and Banerjee, D. (2017b). Variation of supergranule parameters with solar cycles: Results from century-long kodaikanal digitized Ca II K data. *Astrophys. J.* 841, 70. doi:10.3847/1538-4357/aa709d

Chatzistergos, T., Ermolli, I., Solanki, S. K., and Krivova, N. A. (2018b). Analysis of full disc Ca II K spectroheliograms - I. Photometric calibration and centre-to-limb variation compensation. *Astron. Astrophys.* 609, A92. doi:10.1051/0004-6361/201731511

Chatzistergos, T., Ermolli, I., Solanki, S. K., Krivova, N. A., Banerjee, D., Jha, B. K., et al. (2019c). Delving into the historical Ca ii K archive from the kodaikanal observatory: The potential of the most recent digitized series. *Sol. Phys.* 294, 145. doi:10.1007/s11207-019-1532-5

Dikpati, M., and McIntosh, S. W. (2020). Space weather challenge and forecasting implications of Rossby waves. *Space weather.* 18, 002109. doi:10.1029/2018SW002109

Harris, J., Dikpati, M., Hewins, I. M., Gibson, S. E., McIntosh, S. W., Chatterjee, S., et al. (2022). Tracking movement of long-lived equatorial coronal holes from analysis of long-term McIntosh archive data. *ApJ* 931, 54. doi:10.3847/1538-4357/ac67f2

Jha, B. K., Priyadarshi, A., Mandal, S., Chatterjee, S., and Banerjee, D. (2021). Measurements of solar differential rotation using the century long kodaikanal sunspot data. *Sol. Phys.* 296, 25. doi:10.1007/s11207-021-01767-8

Lefebvre, S., Ulrich, R. K., Webster, L. S., Varadi, F., Javaraiah, J., Bertello, L., et al. (2005). The solar photograph archive of the Mount Wilson Observatory. A resource for a century of digital data. *Mem. S.A.It.* 76, 862.

Malherbe, J-M., Bualé, I., Crussaire, D., Cornu, F., and Corbard, T. (2023). The potential of Meudon spectroheliograph for investigating long term solar activity and variability. *Adv. Space Res.* 71 (4), 1922–1938. ISSN 0273-1177. doi:10.1016/j.asr.2022.07.058

Mandal, S., Hegde, M., Samanta, T., Hazra, G., Banerjee, D., and Ravindra, B. (2017). Kodaikanal digitized white-light data archive (1921-2011): Analysis of various solar cycle features. *Astron. Astrophys.* 601, A106. doi:10.1051/0004-6361/201628651

Mandal, S., Krivova, N. A., Solanki, S. K., Sinha, N., and Banerjee, D. (2020). Sunspot area catalog revisited: Daily cross-calibrated areas since 1874. *Astron. Astrophys.* 640, A78. doi:10.1051/0004-6361/202037547

Mazumder, R., Chatterjee, S., Nandy, D., and Banerjee, D. (2021). Solar cycle evolution of filaments over a century: Investigations with the Meudon and McIntosh hand-drawn archives. *ApJ* 125. doi:10.3847/1538-4357/ac09f6

McIntosh, S. W., Leamon, R. J., Egeland, R., Dikpati, M., Altrock, R. C., Banerjee, D., et al. (2021). Deciphering solar magnetic activity: 140 Years of the 'extended solar cycle' – mapping the Hale cycle. *Sol. Phys.* 296, 189. doi:10.1007/s11207-021-01938-7

Mordvinov, A., Karak, B., Banerjee, D., Chatterjee, S., Golubeva, E., and Khlystova, A. (2020). Long-term evolution of the Sun's magnetic field during cycles 15–19 based on their proxies from kodaikanal solar observatory. *Astrophys. J.* 902, L15. doi:10.3847/2041-8213/abba80

Muñoz-Jaramillo, A., Sheeley, N., Zhang, J., and DeLuca, E. (2012). Calibrating 100 years of polar faculae measurements: Implications for the evolution of the heliospheric magnetic field. *Astrophys. J.* 753, 146. doi:10.1088/0004-637X/753/2/146

Muñoz-Jaramillo, A., and Vaquero, J. M. (2019). Visualization of the challenges and limitations of the long-term sunspot number record. *Nat. Astron* 3, 205–211. doi:10.1038/s41550-018-0638-2

Pevtsov, A. A., Tlatova, K. A., Pevtsov, A. A., Heikkinen, E., Virtanen, I., Karachik, N. V., et al. (2019a). Reconstructing solar magnetic fields from historical observations: V. Sunspot magnetic field measurements at mount Wilson observatory. *Astron. Astrophys.* 628, A103. doi:10.1051/0004-6361/201834985

Pötzi, W., Temmer, M., Veronig, A., Hirtenfellner-Polanec, W., and Baumgartner, D. (2013). The Kanzelhöhe observatory. *EGU Gen. Conf. Abstr.* 15, EGU2013–1459.

Priyadarshi, A., Hegde, M., Jha, B. K., Chatterjee, S., Mandal, S., Chowdhury, M., et al. (2023). Detection of solar filaments using suncharts from kodaikanal solar observatory archive employing a clustering approach. *ApJ* 943, 140. doi:10.3847/1538-4357/acaefb

Priyal, M., Banerjee, D., Karak, B., Muñoz-Jaramillo, A., Ravindra, B., Choudhuri, A. R., et al. (2014). Polar network index as a magnetic proxy for the solar cycle studies. *Astrophys. J.* 793, L4. doi:10.1088/2041-8205/793/1/L4

Tlatov, A. G., Kuzanyan, K. M., and Vasil'yeva, V. V. (2016). Tilt angles of solar filaments over the period of 1919 – 2014. *Sol. Phys.* 291, 1115–1127. doi:10.1007/s11207-016-0880-7

Webb, D. F., Gibson, S. E., Hewins, I. M., McFadden, R. H., Emery, B. A., Malanushenko, A., et al. (2018). Global solar magnetic field evolution over 4 solar cycles: Use of the McIntosh archive. *Front. Astronomy Space Sci*.

Willis, D. M., Coffey, H. E., Henwood, R., Erwin, E. H., Hoyt, D. V., Wild, M. N., et al. (2013). The Greenwich photo-heliographic results (1874–1976): Summary of the observations, applications, datasets, definitions and errors. *Sol. Phys.* 288, 117. doi:10.1007/s11207-013-0311-y