

Reconstructing solar irradiance from Ca II K observations

T. Chatzistergos, N. A. Krivova, I. Ermolli, K. L. Yeo, S. K. Solanki,
C. C. Puiu, F. Giorgi, S. Mandal

To understand the influence of the Sun on Earth's system, long and accurate measurements of solar irradiance are a prerequisite (Haigh 2007; Gray et al. 2010; Solanki et al. 2013; Ermolli et al. 2013; Intergovernmental Panel on Climate Change AR5 WG1 2013). The available direct measurements of solar irradiance since 1978 (e.g. Fröhlich 2013; Kopp 2014, 2016) are clearly not sufficient for this purpose. This stimulated development of models used to reconstruct solar irradiance variations from alternative observations (e.g. Foukal & Lean 1986; Chapman et al. 1996, 2013; Solanki & Fligge 1999; Ermolli et al. 2003; Krivova et al. 2003; Ambelu et al. 2011; Yeo et al. 2014, 2017a; Tebatal et al. 2015; Coddington et al. 2019; Choudhary et al. 2020). The main driver of the irradiance variations on time scales longer than about a day is the evolution of the solar surface magnetic field in form of dark sunspots and bright faculae and network (Shapiro et al. 2017; Yeo et al. 2017b). Therefore models require input data describing the contributions of these various magnetic regions on the Sun at earlier times. Unfortunately, records that can be used to describe the facular and network contributions are barely longer than the direct irradiance measurements. Thus, irradiance reconstructions to earlier periods have to rely on sunspot data alone (Solanki & Fligge 1998; Krivova et al. 2007, 2010; Dasi-Espuig et al. 2014, 2016; Wu et al. 2018; Lean 2018). Data that have hardly been used for past solar irradiance reconstructions until now are full-disc solar observations in the Ca II K line. Such data from various observatories exist since 1892 (Chatzistergos 2017; Chatzistergos et al. 2020c) and include all the needed information describing faculae and the network. However, they are plagued by a bunch of various problems and artefacts, and recovering the non-linear response of the photographic material to the radiation is non-trivial since the required information is usually missing, too. We have developed a method to process Ca II K observations from various sources and demonstrated the higher accuracy achieved by our method compared to other techniques presented in the literature (Chatzistergos et al. 2016, 2018c,a,b, 2019b,c,a, 2020c,b). Here we use the carefully reduced Ca II K observations from multiple archives to reconstruct solar irradiance variations. We reconstructed the total solar irradiance (TSI) with two models, an empirical regression model based on the photometric sum approach (Chatzistergos et al. 2020a) proposed by Chapman et al. (1996) and the semi-empirical Spectral And Total Irradiance REconstruction (SATIRE; e.g. Krivova et al. 2003, 2010; Yeo et al. 2014; Tagirov et al. 2019) model (Fig. 1) adapted to work with Ca II K observations. Both reconstructions show a good agreement with the PMOD (named after Physikalisches-Meteorologisches Observatorium Davos; Fröhlich 2006). The Ca II K observations used were taken with the Precision Solar Photometric Telescope (Ermolli et al. 1998, 2007) at the Rome observatory between 1996 and 2020. Both our reconstructions show a declining trend between the minima 1996–2008 and no trend between 2008–2019 (Fig. 1).

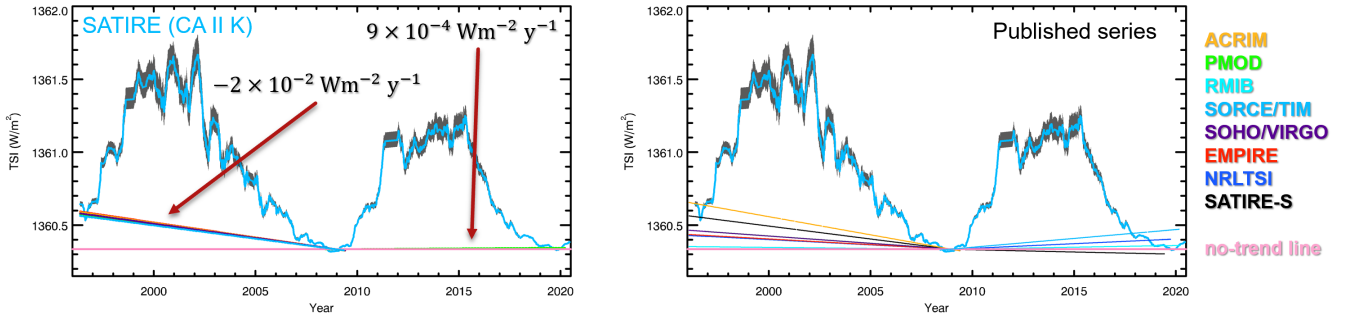


Figure 1: *Left*: TSI reconstructed with various reference series using the Rome/PSPT Ca II K observations with the SATIRE model. The solid ciel line is 81-day running mean values for the series with PMOD as the reference, while the grey shaded surface shows the range covered by the reconstructions with all other TSI reference series. *Right*: TSI values from the various published series. The lines are linear fits to the TSI values during subsequent activity minima. All series were offset to match their mean value within a 12-month interval centred at the minimum of 2008 to that of the PMOD TSI composite. The value of the PMOD TSI composite over this period is marked with the horizontal dash-dotted pink line.

References

- Ambelu, T., Falayi, E. O., Elemo, E. O., & Oladosu, O. 2011, *Latin-American Journal of Physics Education*, 5, number: 4
- Chapman, G. A., Cookson, A. M., & Dobias, J. J. 1996, *Journal of Geophysical Research*, 101, 13541
- Chapman, G. A., Cookson, A. M., & Preminger, D. G. 2013, *Solar Physics*, 283, 295
- Chatzistergos, T. 2017, *Analysis of historical solar observations and long-term changes in solar irradiance*, PhD thesis (University of Cambridge)
- Chatzistergos, T., Ermolli, I., Falco, M., et al. 2019a, in *Il Nuovo Cimento*, Vol. 42C, 5
- Chatzistergos, T., Ermolli, I., Giorgi, F., Krivova, N. A., & Pui, C. C. 2020a, *Journal of Space Weather and Space Climate*, 10, 45, publisher: EDP Sciences
- Chatzistergos, T., Ermolli, I., Krivova, N., & Solanki, S. K. 2018a, in *AGU Fall Meeting Abstracts*, Vol. 2018, SH41C–3662
- Chatzistergos, T., Ermolli, I., Krivova, N. A., & Solanki, S. K. 2018b, in *IAU Symposium*, Vol. 340, *Long-term Datasets for the Understanding of Solar and Stellar Magnetic Cycles*, ed. D. Banerjee, J. Jiang, K. Kusano, & S. Solanki (Cambridge, UK: Cambridge University Press), 125–128
- Chatzistergos, T., Ermolli, I., Krivova, N. A., & Solanki, S. K. 2019b, *Astronomy & Astrophysics*, 625, A69
- Chatzistergos, T., Ermolli, I., Krivova, N. A., & Solanki, S. K. 2020b, *Journal of Physics: Conference Series*, 1548, 012007, publisher: IOP Publishing
- Chatzistergos, T., Ermolli, I., Krivova, N. A., et al. 2020c, *Astronomy & Astrophysics*, 639, A88, publisher: EDP Sciences
- Chatzistergos, T., Ermolli, I., Solanki, S. K., & Krivova, N. A. 2016, in *Astronomical Society of the Pacific Conference Series*, Vol. 504, *Coimbra Solar Physics Meeting: Ground-based Solar Observations in the Space Instrumentation Era*, ed. I. Dorotovic, C. E. Fischer, & M. Temmer, San Francisco, 227–231
- Chatzistergos, T., Ermolli, I., Solanki, S. K., & Krivova, N. A. 2018c, *Astronomy & Astrophysics*, 609, A92
- Chatzistergos, T., Ermolli, I., Solanki, S. K., et al. 2019c, *Solar Physics*, 294, 145, number: 10
- Choudhary, D. P., Cadavid, A. C., Cookson, A., & Chapman, G. A. 2020, *Solar Physics*, 295, 15, number: 2
- Coddington, O., Lean, J., Pilewskie, P., et al. 2019, *Earth and Space Science*, 6, 2525
- Dasi-Espuig, M., Jiang, J., Krivova, N. A., & Solanki, S. K. 2014, *Astronomy and Astrophysics*, 570, A23
- Dasi-Espuig, M., Jiang, J., Krivova, N. A., et al. 2016, *Astronomy and Astrophysics*, 590, A63
- Ermolli, I., Caccin, B., Centrone, M., & Penza, V. 2003, *Memorie della Societa Astronomica Italiana*, 74, 603
- Ermolli, I., Criscuoli, S., Centrone, M., Giorgi, F., & Penza, V. 2007, *Astronomy and Astrophysics*, 465, 305
- Ermolli, I., Fofi, M., Bernacchia, C., et al. 1998, *Solar Physics*, 177, 1
- Ermolli, I., Matthes, K., Dudok de Wit, T., et al. 2013, *Atmospheric Chemistry & Physics*, 13, 3945
- Foukal, P. & Lean, J. 1986, *The Astrophysical Journal*, 302, 826
- Fröhlich, C. 2006, *Space Science Reviews*, 125, 53
- Fröhlich, C. 2013, *Space Science Reviews*, 176, 237
- Gray, L. J., Beer, J., Geller, M., et al. 2010, *Reviews of Geophysics*, 48, 4001
- Haigh, J. D. 2007, *Living Reviews in Solar Physics*, 4, 2
- Intergovernmental Panel on Climate Change AR5 WG1, ed. 2013, *Climate change: the physical science basis: Working Group I contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (New York, NY: Cambridge University Press)
- Kopp, G. 2014, *Journal of Space Weather and Space Climate*, 4, A14

- Kopp, G. 2016, *Journal of Space Weather and Space Climate*, 6, A30
- Krivova, N. A., Balmaceda, L., & Solanki, S. K. 2007, *Astronomy and Astrophysics*, 467, 335
- Krivova, N. A., Solanki, S. K., Fligge, M., & Unruh, Y. C. 2003, *Astronomy and Astrophysics*, 399, L1
- Krivova, N. A., Vieira, L. E. A., & Solanki, S. K. 2010, *Journal of Geophysical Research (Space Physics)*, 115, 12112
- Lean, J. L. 2018, *Earth and Space Science*, 5, 133, number: 4
- Shapiro, A. I., Solanki, S. K., Krivova, N. A., et al. 2017, *Nature Astronomy*, 1, 612
- Solanki, S. K. & Fligge, M. 1998, *Geophysical Research Letters*, 25
- Solanki, S. K. & Fligge, M. 1999, *Geophysical Research Letters*, 26
- Solanki, S. K., Krivova, N. A., & Haigh, J. D. 2013, *Annual Review of Astronomy and Astrophysics*, 51, 311, number: 1
- Tagirov, R. V., Shapiro, A. I., Krivova, N. A., et al. 2019, *Astronomy and Astrophysics*, 631, A178
- Tebabal, A., Damtie, B., Nigussie, M., Bires, A., & Yizengaw, E. 2015, *Journal of Atmospheric and Solar-Terrestrial Physics*, 135, 64
- Wu, C.-J., Krivova, N. A., Solanki, S. K., & Usoskin, I. G. 2018, *Astronomy & Astrophysics*, 620, A120
- Yeo, K. L., Krivova, N. A., & Solanki, S. K. 2017a, *Journal of Geophysical Research: Space Physics*, 122, 3888
- Yeo, K. L., Krivova, N. A., Solanki, S. K., & Glassmeier, K. H. 2014, *Astronomy and Astrophysics*, 570, A85
- Yeo, K. L., Solanki, S. K., Norris, C. M., et al. 2017b, *Physical Review Letters*, 119