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TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

NSO

HISTORICAL TSI RECONSTRUCTION: A NEW APPROACH

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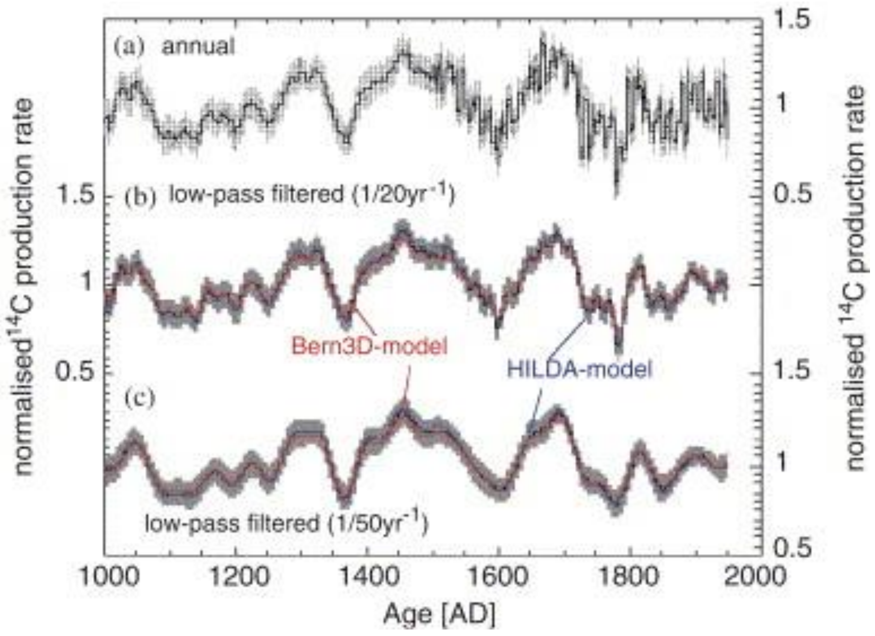
Model Formulation

- The contribution of sunspot, faculae and quiet sun to irradiance variability is estimated from different components of the solar modulation potential ϕ (*Muscheler et al., 2007*).

- To estimate the long-term modulation in the TSI, and separate the possible contributions to the TSI of the different solar magnetic structures, we compute the temporal modes present in the solar potential ϕ to determine the principal components and to carry out appropriate reconstructions that dismiss common components.

- To separate the components of different time scales and therefore extract the trend in the variability of the solar potential ϕ we use the empirical mode decomposition (EMD) algorithm (*Huang et al., 1998*).

- To estimate the time dependence of the bright (plage/network) and dark (sunspot) area coverages we describe each cycle through a monoparametric functional form (*Volobuev, 2009*).



The Shape of The Sunspot Cycle: A One-Parameter Fit 329

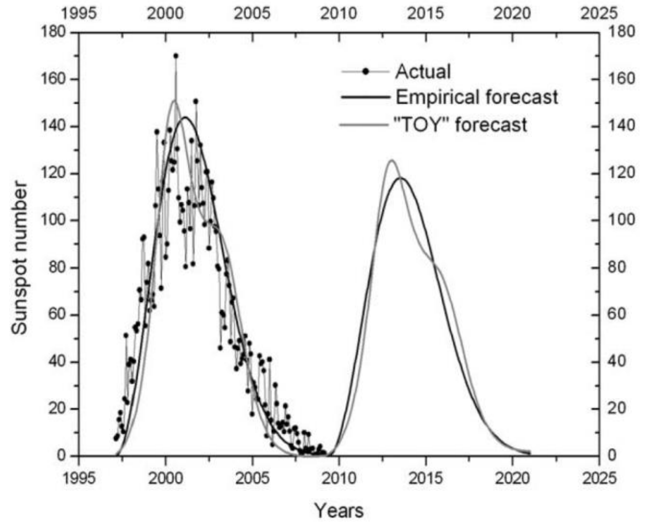


Figure 7 Predicted shape of the cycles #23 and 24. "Actual" is for the Monthly International Sunspot Number. "Empirical forecast" uses the empirical one-parameter fit, Equations (5), (9). "TOY" forecast uses the one-parameter fit with the functional derived from the "TOY" dynamo Equation (11).

We characterize the cycles through the monoparametric functional form *(Volobuev, 2009, Solar Physics, 258, 319)*:

$$x_k(t) = \left(\frac{t - T0_k}{Ts_k}\right)^2 e^{-\left(\frac{t-T0_k}{Td_k}\right)^2} \quad \text{for} \quad T0_k < t < T0_k + \tau_k$$

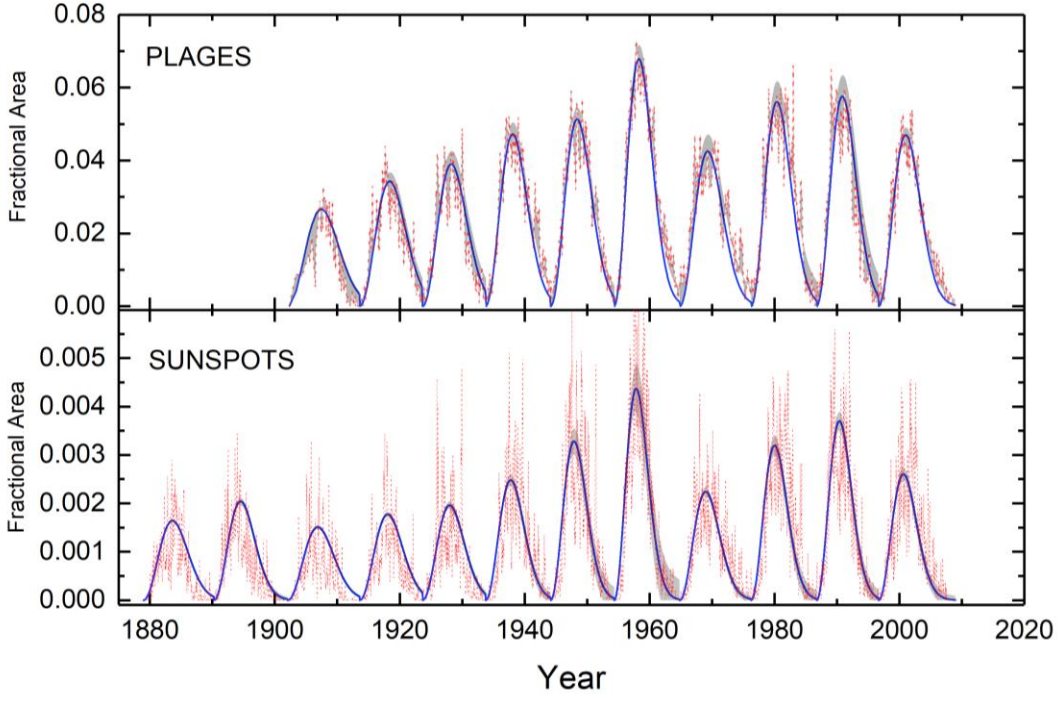
$T0_k$ = initial time of k-cycle

τ_k = duration of k-cycle

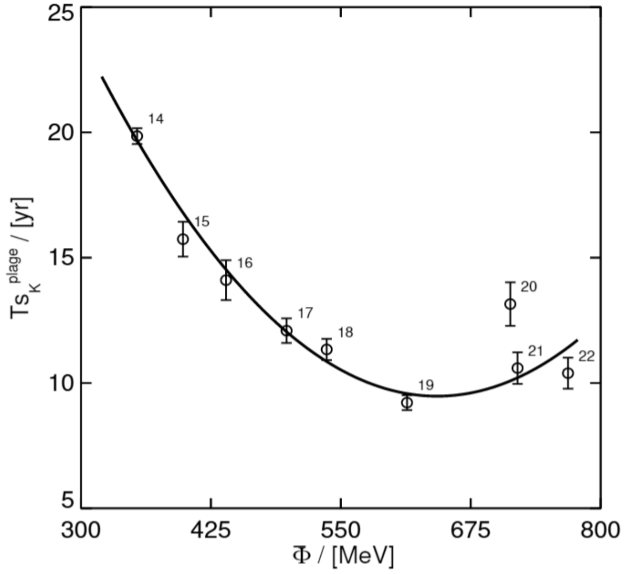
Each cycle proxy A(t) can be reconstructed once the Ts_k parameters are known, because Td_k and Ts_k are related to each other. We obtain Ts_k values from a parametric fit of **plage and sunspot composites** *(Chatzistergos et al., 2019, A&A, 625, 22; Mandal et al., 2020, A&A, 640, A78)*

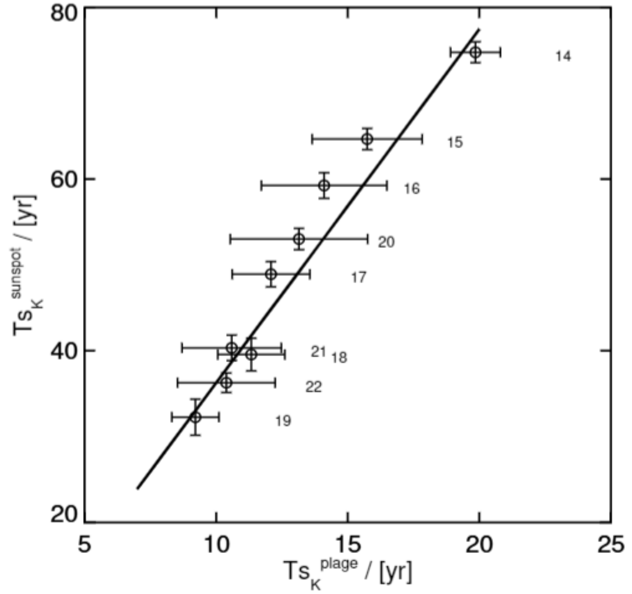
COMPARISON BETWEEN DATA AND PARAMETRIC RECONSTRUCTION

$$A(t) = \sum_k x_k(t)$$



The correlation between the parameters Ts_k (plage and sunspots) and the correlation with the Solar Modulation Potential ϕ (integrated over the k-cycle) are used for the plage and sunspot area coverage reconstructions.
We use the annual estimates of the Solar Modulation Potential derived from the analysis of the ^{14}C (*Muscheler et al. 2007*).





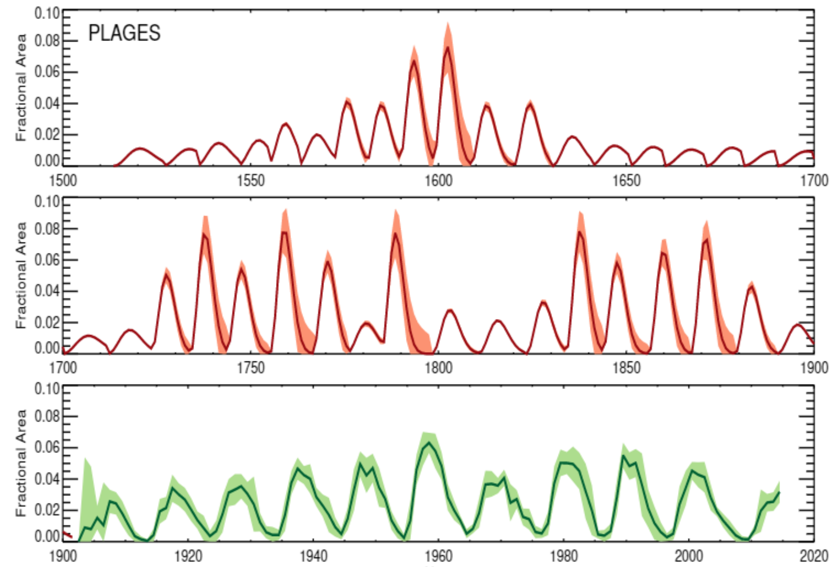
ϕ_k → $Ts_k^{(plage)}$

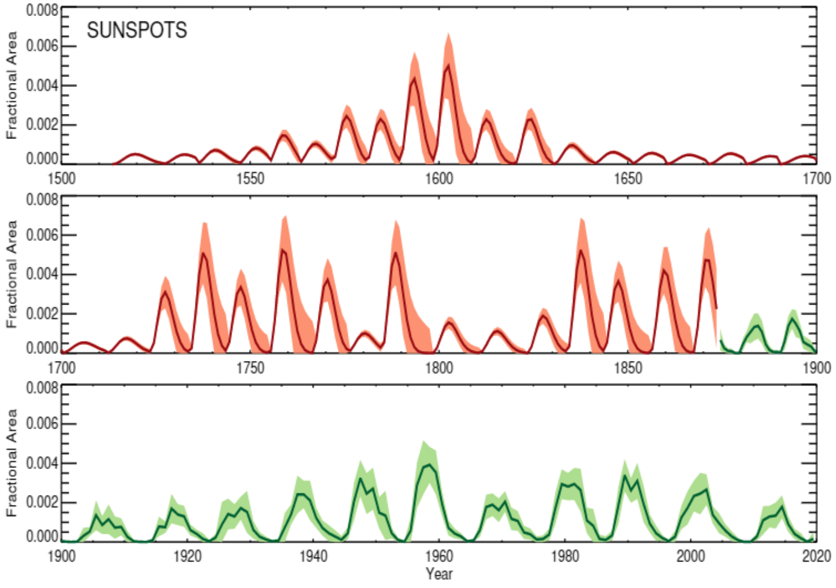
↓

$Ts_k^{(sunspot)}$

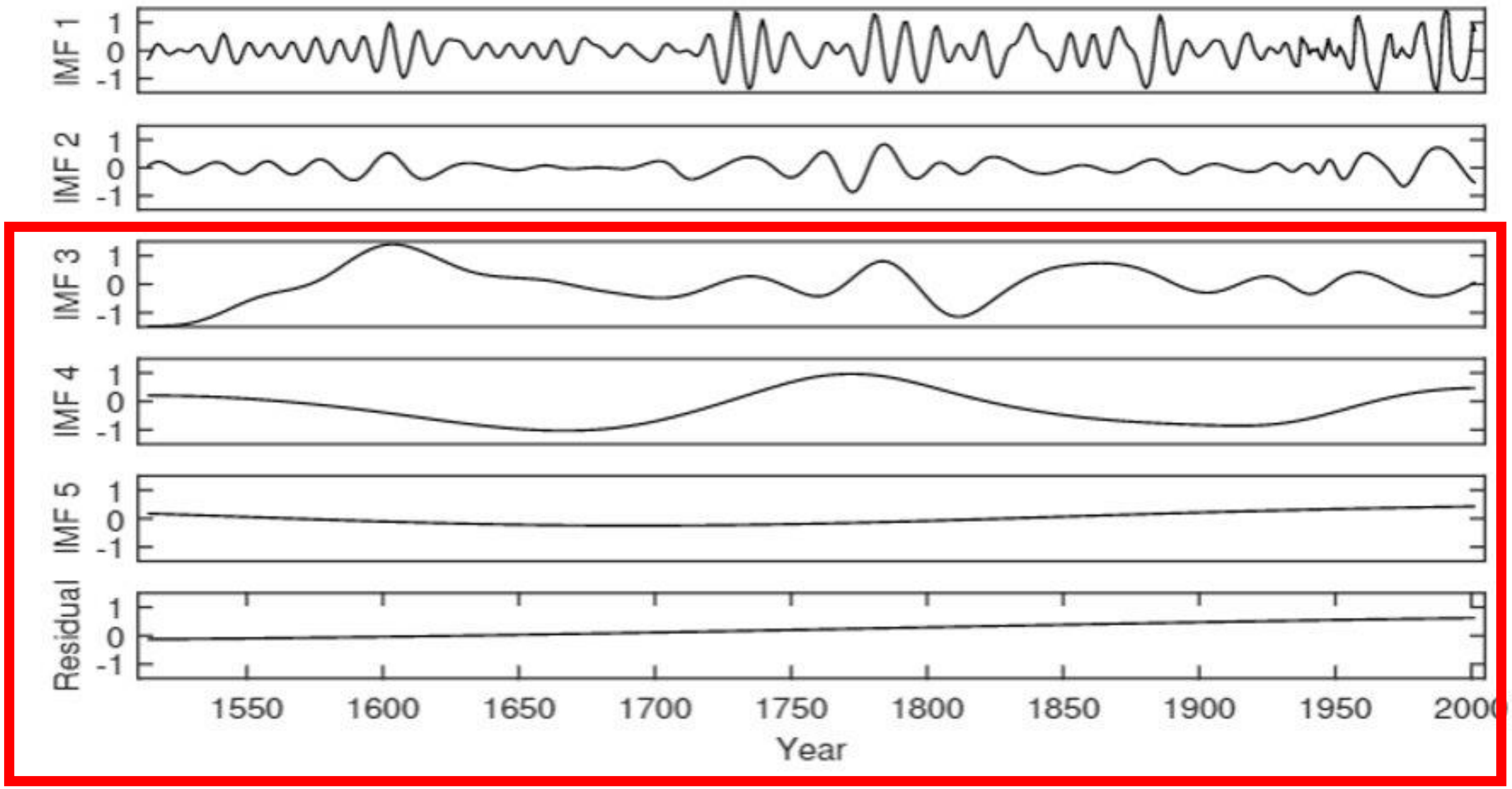
↓

$\alpha_p(t)$ and $\alpha_s(t)$



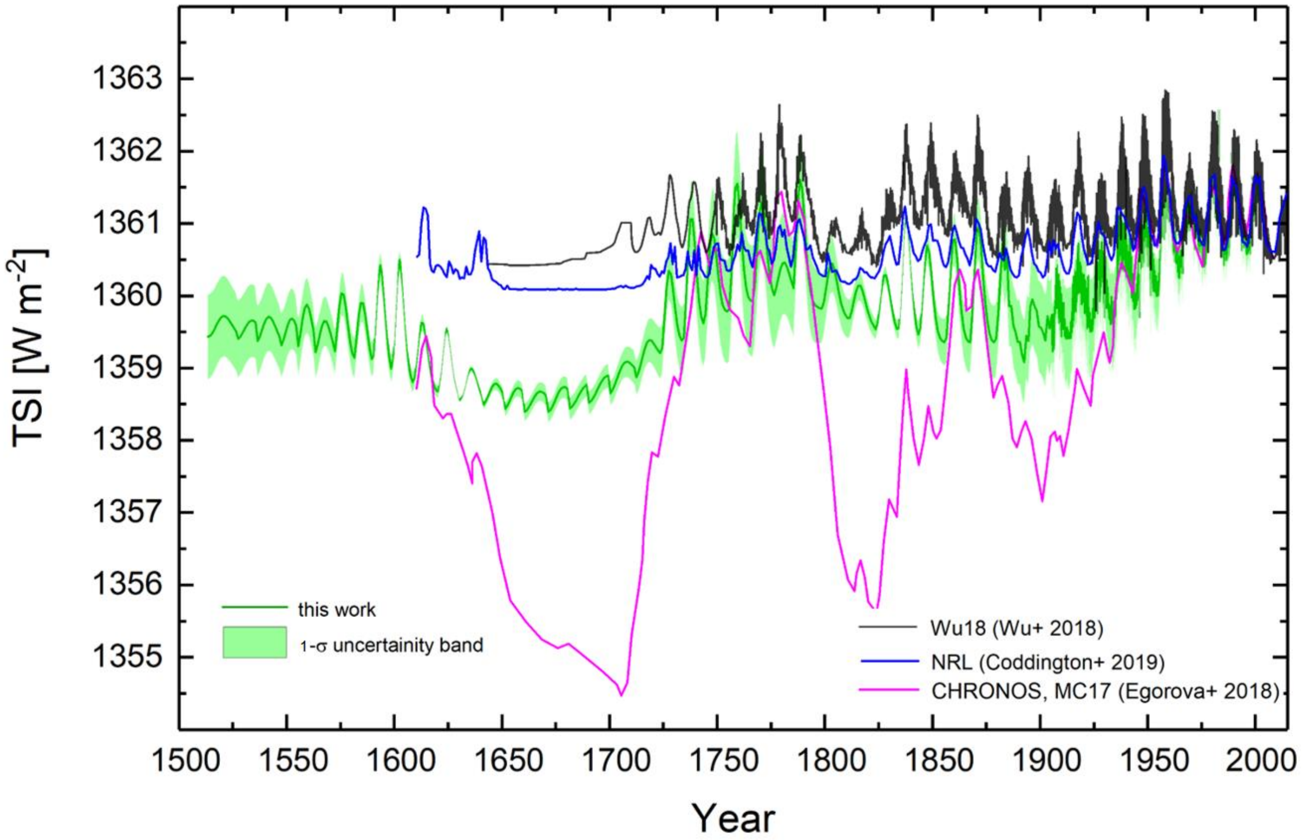


Empirical Mode Decomposition of Solar Modulation Potential



To capture the low-frequency modulation from the solar function ϕ : $\sum_{i=3}^{5} C_i \cdot IMF_i(t) + C_R \cdot R(t)$
the signal ϕ is primarily decomposed as superposition of simpler quasi-periodic components called Intrinsic Mode Functions (IMFs). C_i are the weights associated with the different IMFs derived from the EMD procedure.

TSI RECONSTRUCTION



$$\delta F(t) = \underbrace{C_n \,\mathrm{mod}(\phi)} + \underbrace{\alpha_f \delta_{fn}} + \underbrace{\alpha_s \delta_s}$$

Long - term component | Bright component | Dark component

The contrasts (δ) and C_n are derived by fitting the TSI PMOD composite (1985-2010)

Conclusions

- We reconstruct, cycle for cycle, the plage and sunspot coverage from 1513 to 2000, by using correlation between the cycle parameter and Solar Modulation Potential ϕ

- We derive a low-frequency modulation through the Empirical Mode Decomposition of the Solar Modulation Potential ϕ

- We reconstruct the Total Solar Irradiance from 1513 to 2000. The obtained TSI shows an intermediate behavior if compared to the many reconstructions proposed in the literature.

- In particular we find a modulation of the facula and spots coverage in the Maunder minimum. This minimum has an average difference of approximately 2.5 W m^{-2} with respect to the current TSI value.

- In the first half of the last century (1900-1950) we observe a growth of the TSI of about 1.5 W m^{-2}.