A new reconstruction of the Total Solar Irrandiance during the last Millennium

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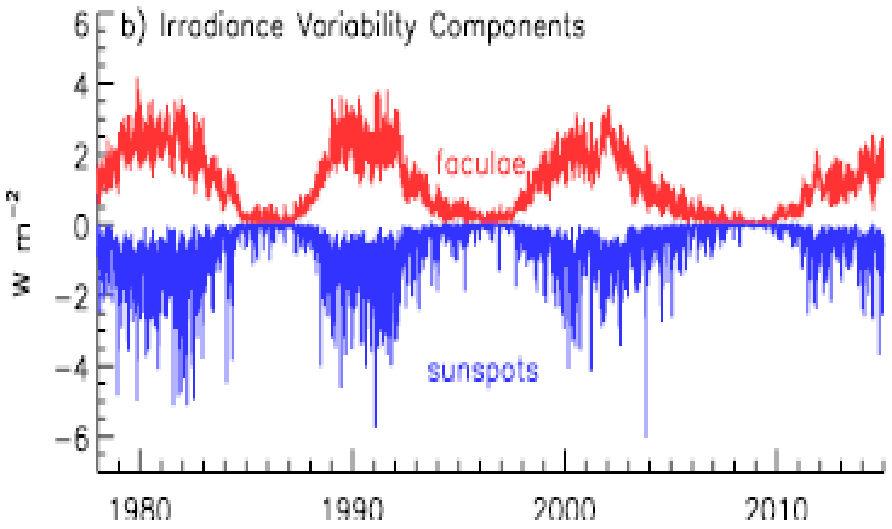
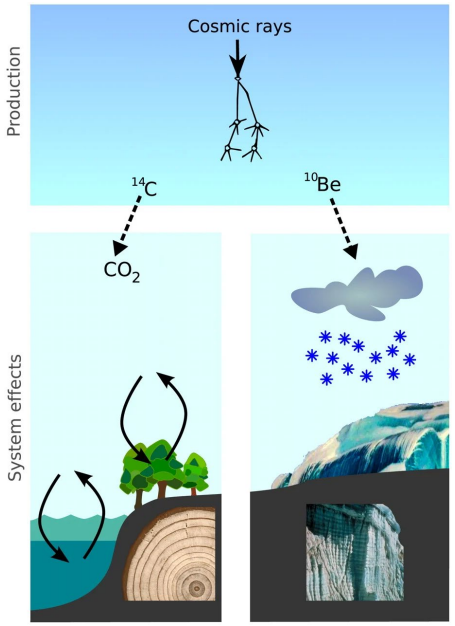
Modeling Solar Irradiance Variability



From Coddington et al. 2016

Bright component -> Plage, Network, started in late 1800
Dark component -> Sunspot, started in 1610

Solar spectrum -> Models/ Radiometric Measurements (started in 1970)



To extend our estimates back in time, we typically use cosmogenic radionuclides ^{14}C and ^{10}Be in the Earth's system

Credits Steinhilber+, 2012

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Total Solar Irradiance during the Last Five Centuries

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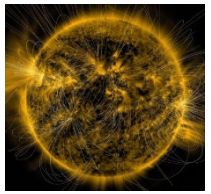
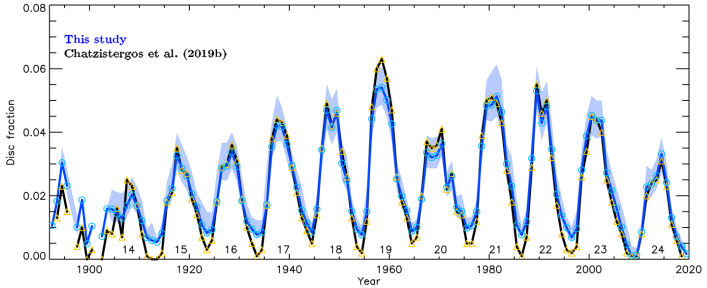
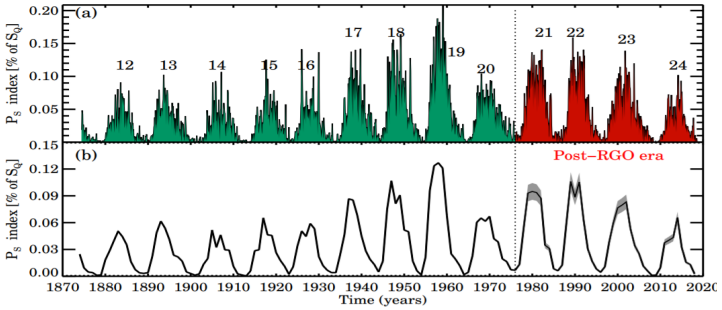


SUN: area of magnetic features

PLAGE area
(Chatzistergos et al.,2020)



SUNSPOT area
(Mandal et al., 2019)

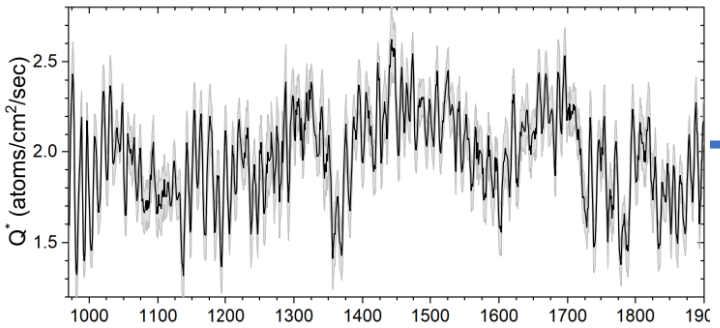


Solar Sunspot Number – SILSO (https://www.sidc.be/SILSO/datafiles)

Total Solar Irradiance - PMOD Composite (Montillet et al. 2022)

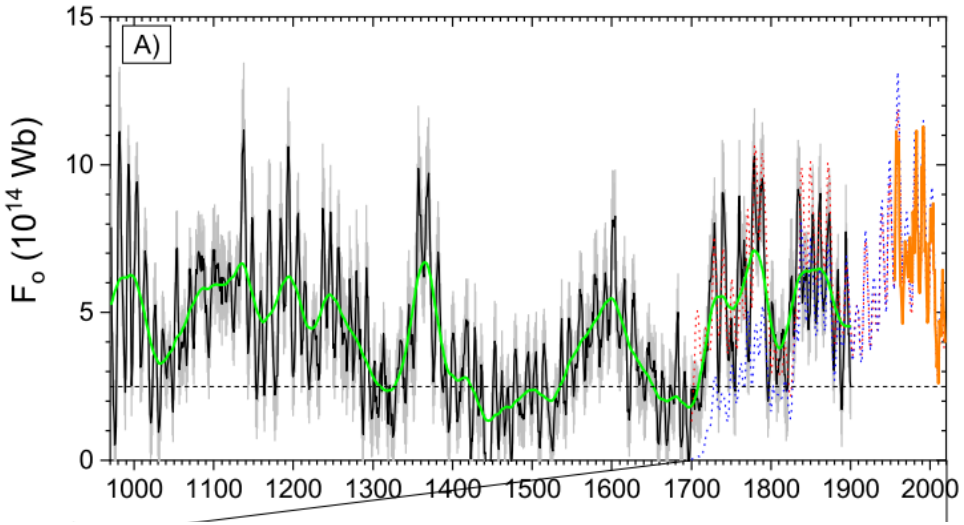
We look for relations between SOLAR and TERRESTRIAL data

EARTH: Radiocarbon (^{14}C) production rate, that depends on the solar activity

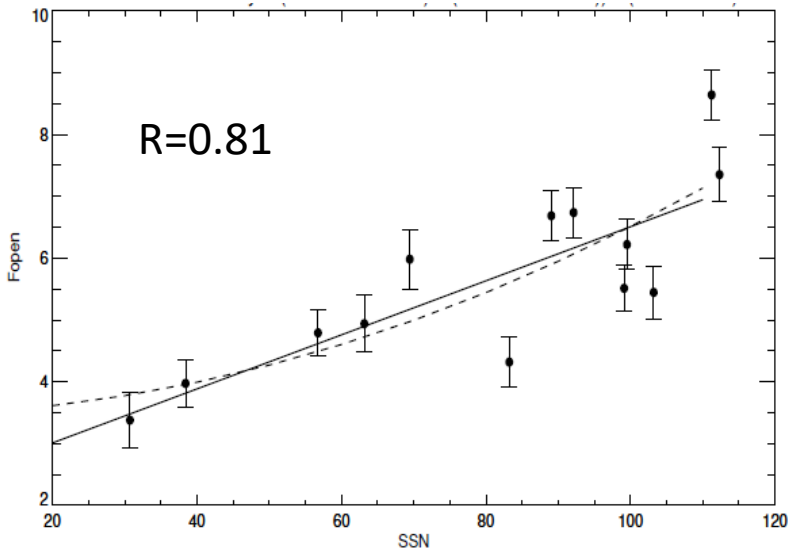


Solar Open Field

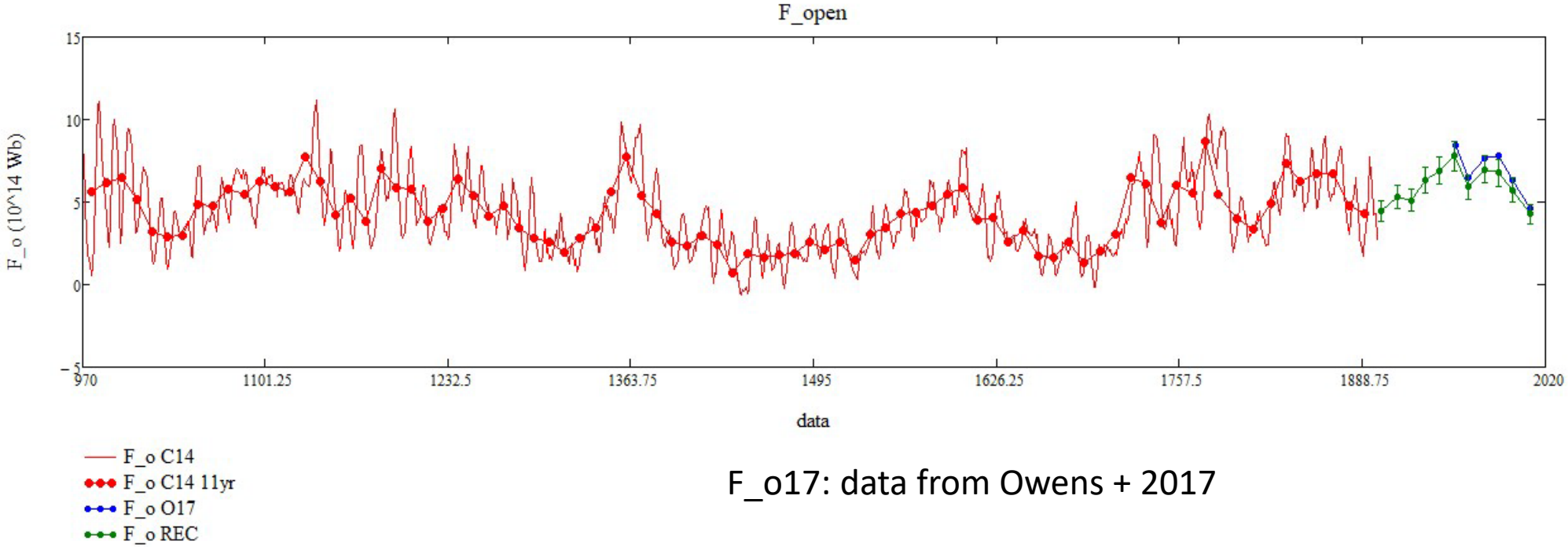
(Usoskin et al., 2021)



Step 1: Reconstruction (1900 on ward) of F_open by relation F_open vs SSN



$$Fo = (0.044 \pm 0.004)\ SSN + (2.137 \pm 0.381)\ 10^{14} W\ b$$



F_o17: data from Owens + 2017

Step 2: Reconstruction of AR coverage by relation area parameter vs F_open

Functional form *(Volobuev, 2009)*:

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

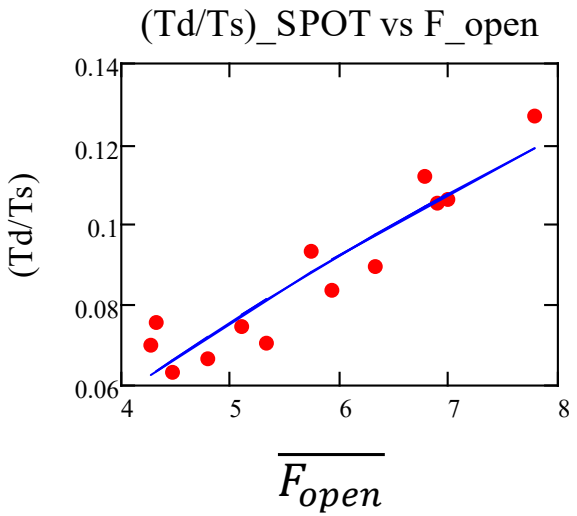
$$Td_k^{spot} = s1 Ts_k^{spot} + s2 \quad yr.$$

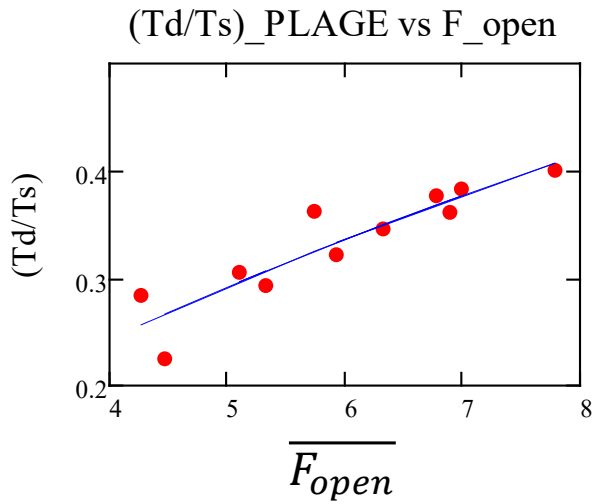
$$Td_k^{plage} = p1_k Ts_k^{plage} + p2_k \quad yr.$$

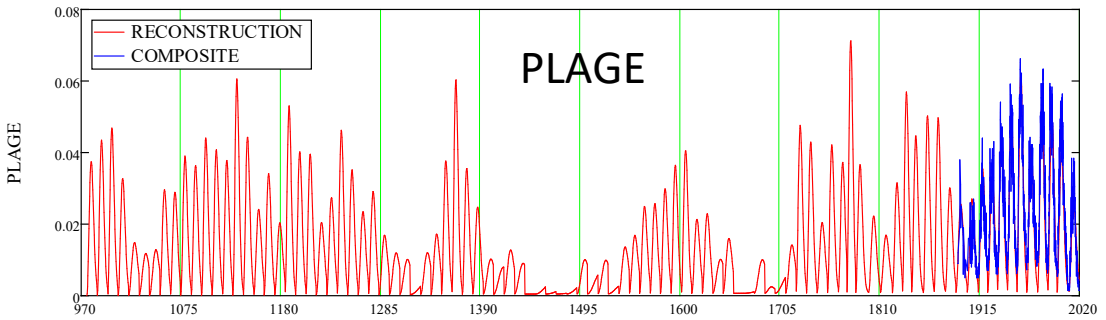
Td_k and Ts_k are not independent

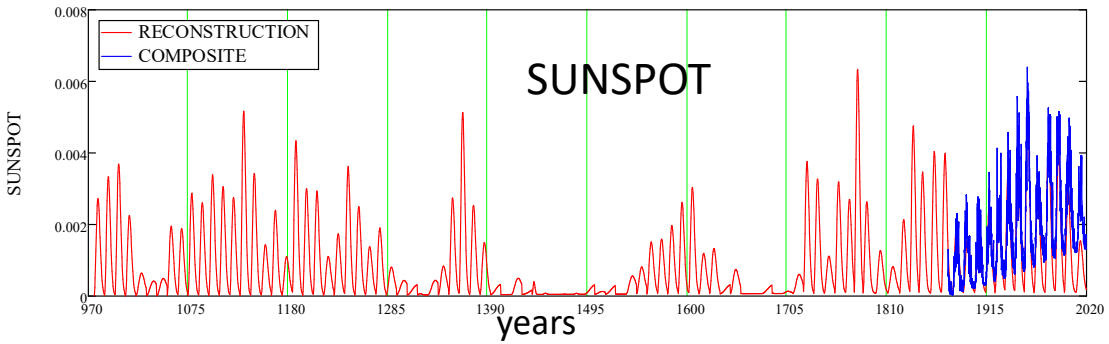
$$P_k \equiv \frac{Td_k}{Ts_k} = a\ \overline{F_{ok}} + b$$

$$P_k = a\sqrt{\bar{F}_{Ok}} + b$$







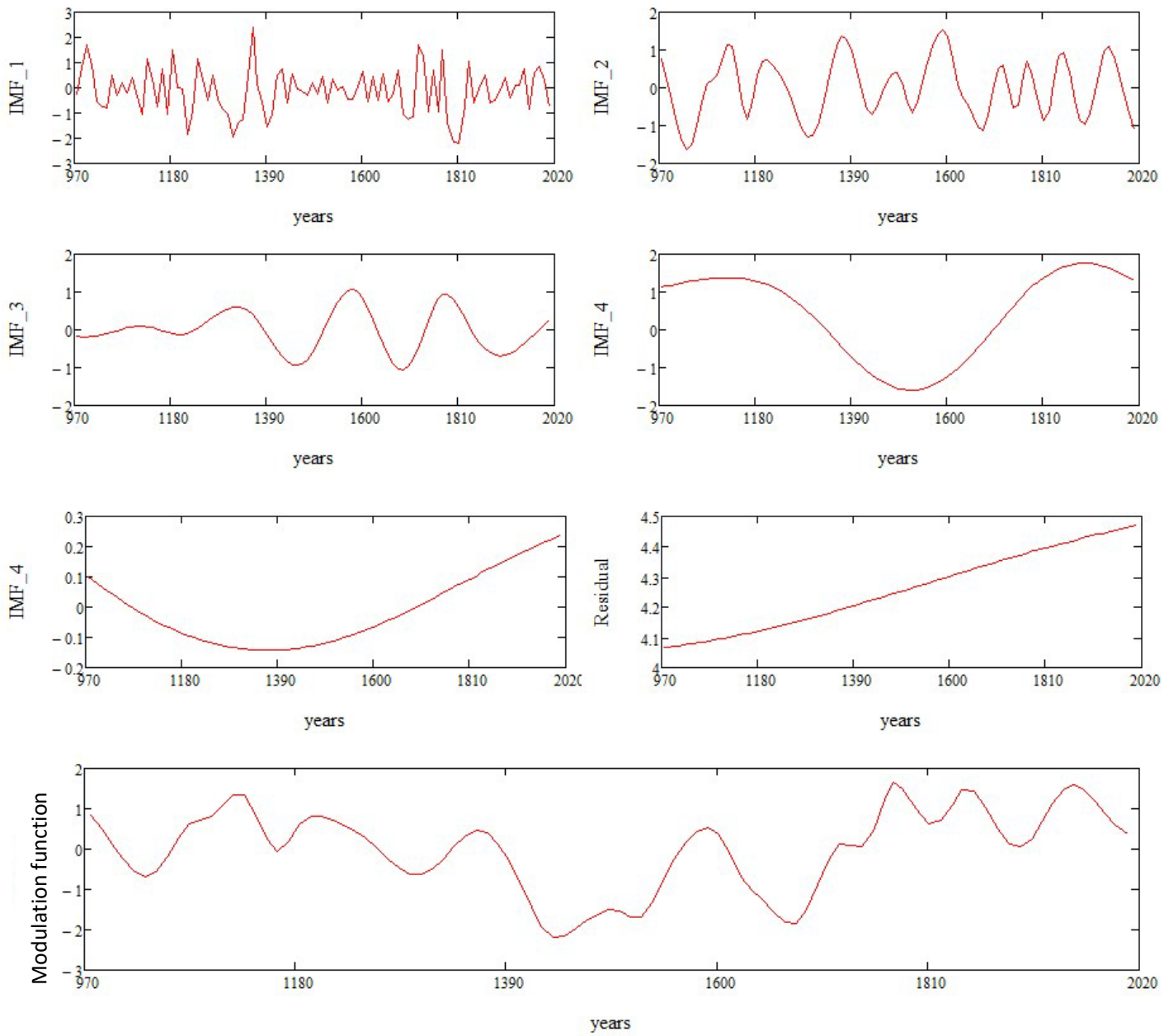


The parameter P_k shows **linear** dependence on F_o for Sunspots area and **quadratic** dependence on Plage area.

$a^{plage} = 0.208$ (W $b^{-0.5}$)
$b^{plage} = -0.173$

$a^{spot} = 0.078$ (W $b^{-0.5}$)
$b^{spot} = -0.098$

Step 3: Empirical Mode Decomposition of F_open



$$X(t) = \sum_{i}^{n-1} \mathrm{IMF}_i(t) + R_n(t)$$

Oscillatory components

Residual monotonic signal

$$\sum_{i=2}^{5} IMF_i(t) + R(t)$$

Step 4.1 Reconstruction of the Total Solar Irradiance: comparison with the measurements.

$$\alpha_n(t) = A_n + B_n \alpha_f(t)$$

$$\Delta F(t) = A_n \delta_n + \alpha_f(t)(B_n \delta_n + \delta_f) + \alpha_s(t)\delta_s$$

$$= C_n + \alpha_f(t)\delta_{fn} + \alpha_s(t)\delta_s$$

Network Facula Sunspot

The (δ) and C_n parameters are derived by fitting the PMOD composite, separately each cycle:

$C_n = 1.233 \cdot 10^{-3}$ Product of network area and contrast

$\delta_{fn} = 0.032$ Linear combination of network and facular contrast

$\delta_s = -0.13$ Sunspot contrast

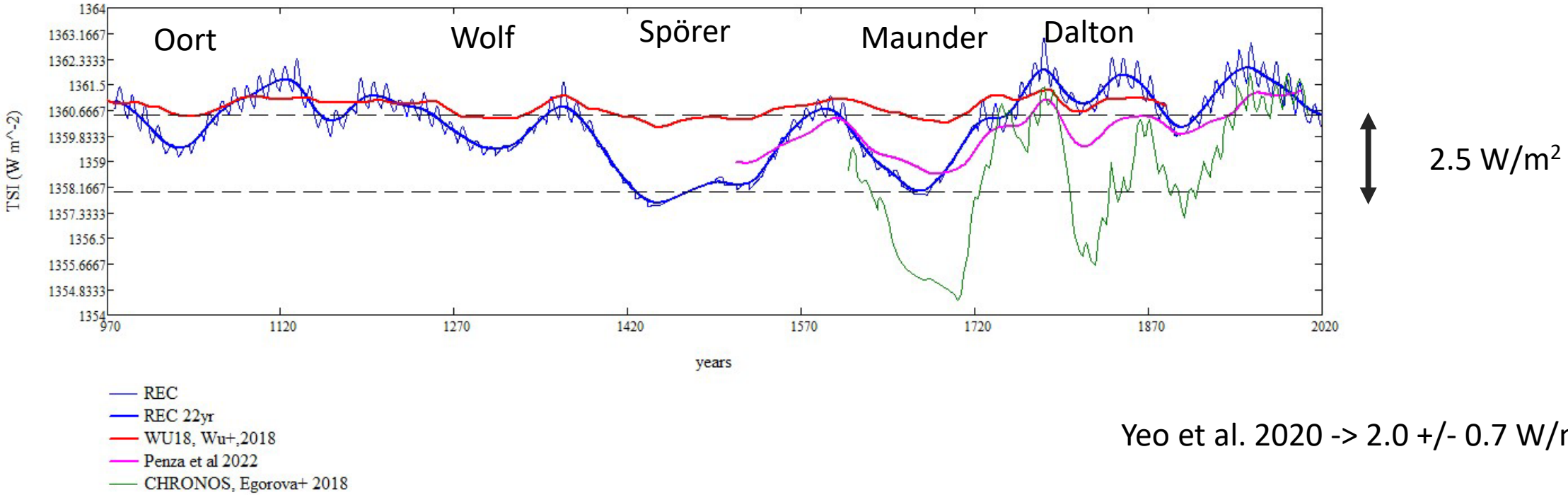
Step 4.2 Reconstruction of the Total Solar Irradiance over long temporal scales

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

Long - term component | Bright component | Dark component

$$\mathrm{mod}_\Phi(t) = (\Phi_{LT}(t) + 1) N_{ref}$$

Again via fit
N_{ref} = 0.56



2.5 W/m^2

Yeo et al. 2020 -> 2.0 +/- 0.7 W/m^2

Conclusions

- Reconstruction, cycle by cycle, of the plage and sunspot coverages from 970 - 2020 A.C., by exploiting the correlation between cycle parameters and the solar open magnetic field.

- "Extraction" of the long-term modulation from F_{open} via empirical mode decomposition

- Reconstruction of TSI for period 970 - 2020 A.C.

  - difference from Maunder Minimum irradiance level to today about 2.5 W/m^2.
  - difference from Spörer Minimum irradiance level to today about 2.7 W/m^2.

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