The $F_{10.7cm}$ radio flux revisited

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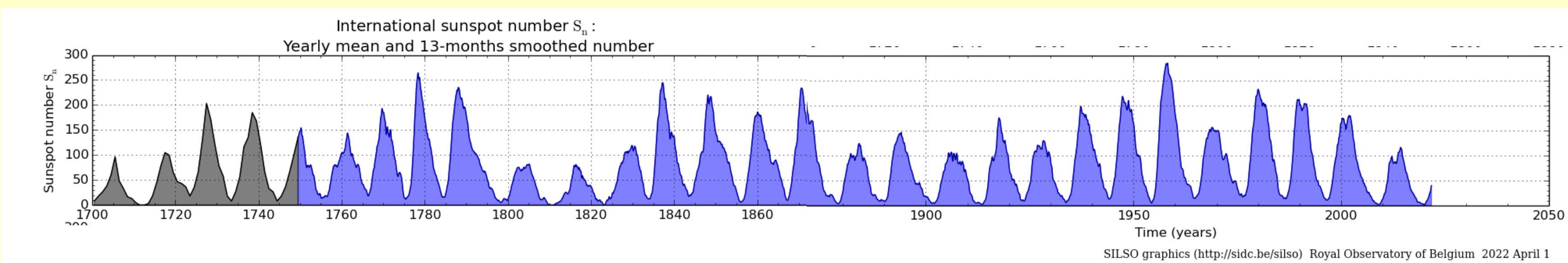
$F_{10.7}$: a reference long-term index

- Background "no-flare" radio flux (λ= 10.7cm)
- Source: mostly thermal radio emission from the lower corona
- **Standard proxy of solar UV irradiance** (back to 1947)

- Tight relation with the sunspot number S_N (since 1700)

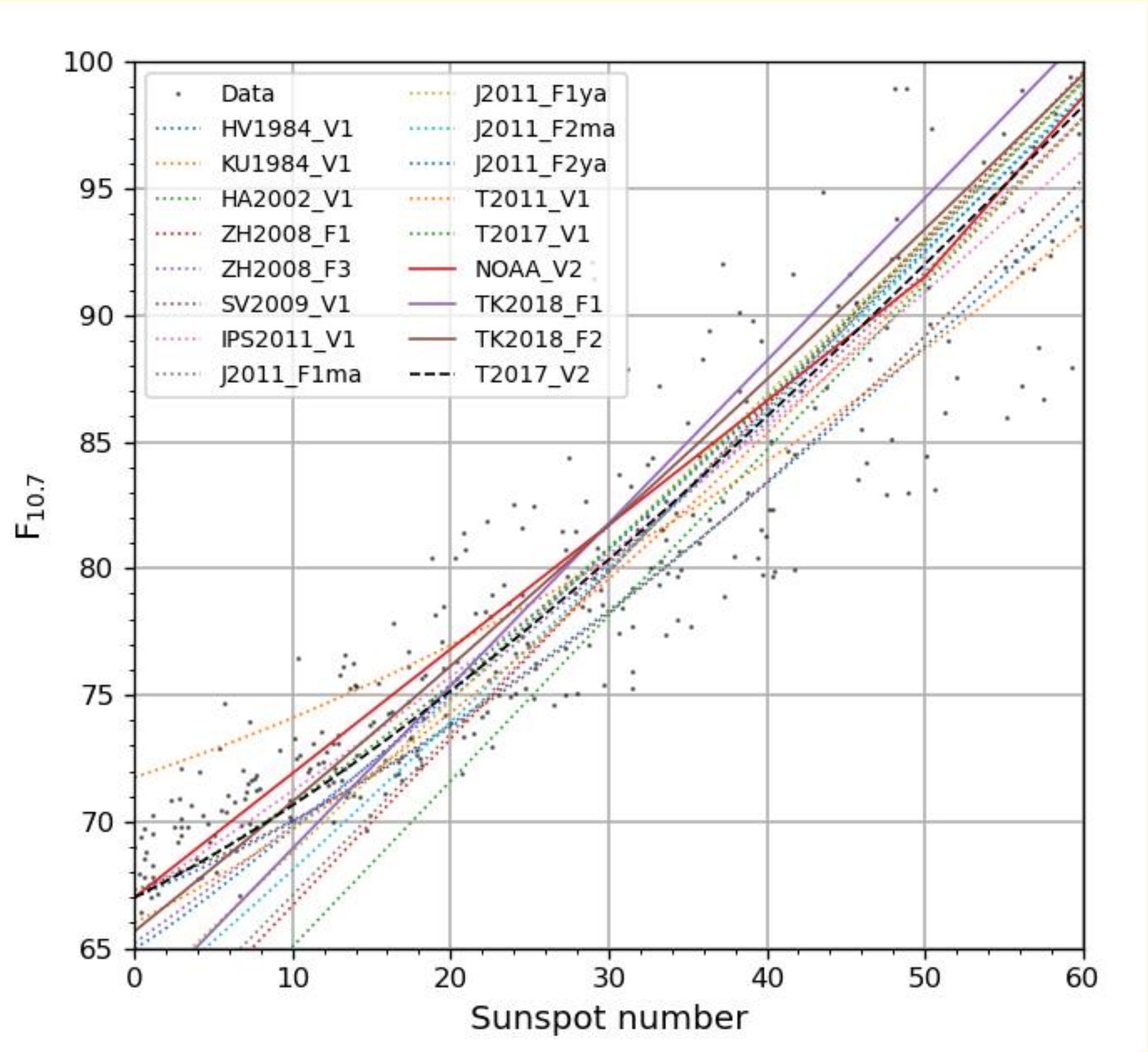


$F_{10.7}/S_N$ proxy relation allows backward reconstructions of UV irradiance over multiple centuries

S_N → $F_{10.7}$ → I_{UV}

Published $F_{10.7}$- S_N proxies: a confusing picture

- 12 publications
- 18 formulae:
  - Linear, polynomials, exponentials, ad hoc
  - Fit on monthly, yearly means or smoothed data.



Confusion!

- Empirical models
- Large disagreements
- Systematic underestimate at low values
- **No error determination**

New polynomial regression with errors

- **Data:**
  - New **re-calibrated S_N (version 2)** *(Clette & Lefèvre 2016)*
  - **Daily $F_{10.7}$ series** *(https://www.spaceweather.gc.ca/solarflux/sx-5-en.php)*

- **Polynomial fit:**
  - Unbiased choice of fitted model
  - Orthogonal distance regression (checked against ordinary L-S regr.)
  - Errors on coefficients
  - ⇨ **Limitation to significant terms** (maximum degree)

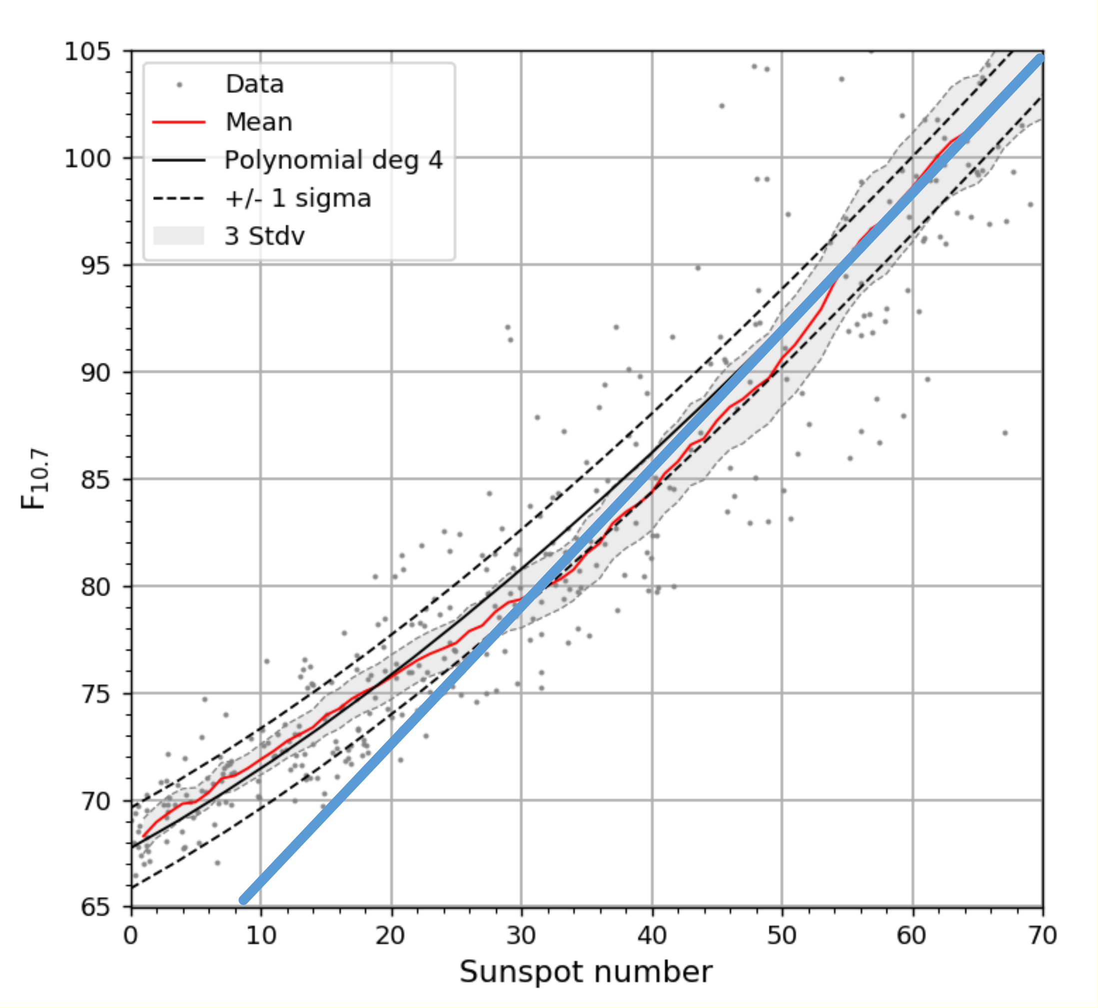
- **Error range around the polynomial proxy:**
  - Errors of different terms are mutually dependent *(no analytical derivation possible)*
  - ⇨ **Conditional error for each degree** from residuals of lower degrees **+ summation** of all degrees

- *Comparison with non-parametric means and stdv by bins (S_N= 20)*

Polynomial fit: monthly means

- **4^th^ degree**:
  - Needed for good fit in the low range
- **Linear for S_N > 35**

$$\hat{F}_{10.7}$$
$$= 67.73\ (\pm 1.13)$$
$$+ 0.337(0.056)\ S_N$$
$$+ 3.69\ (\pm 0.77.).10^{-3}\ S_N^2$$
$$- 1.52(\pm 0.38).10^{-5}\ S_N^3$$
$$+ 1.33(\pm 0.62).10^{-8}\ S_N^4$$

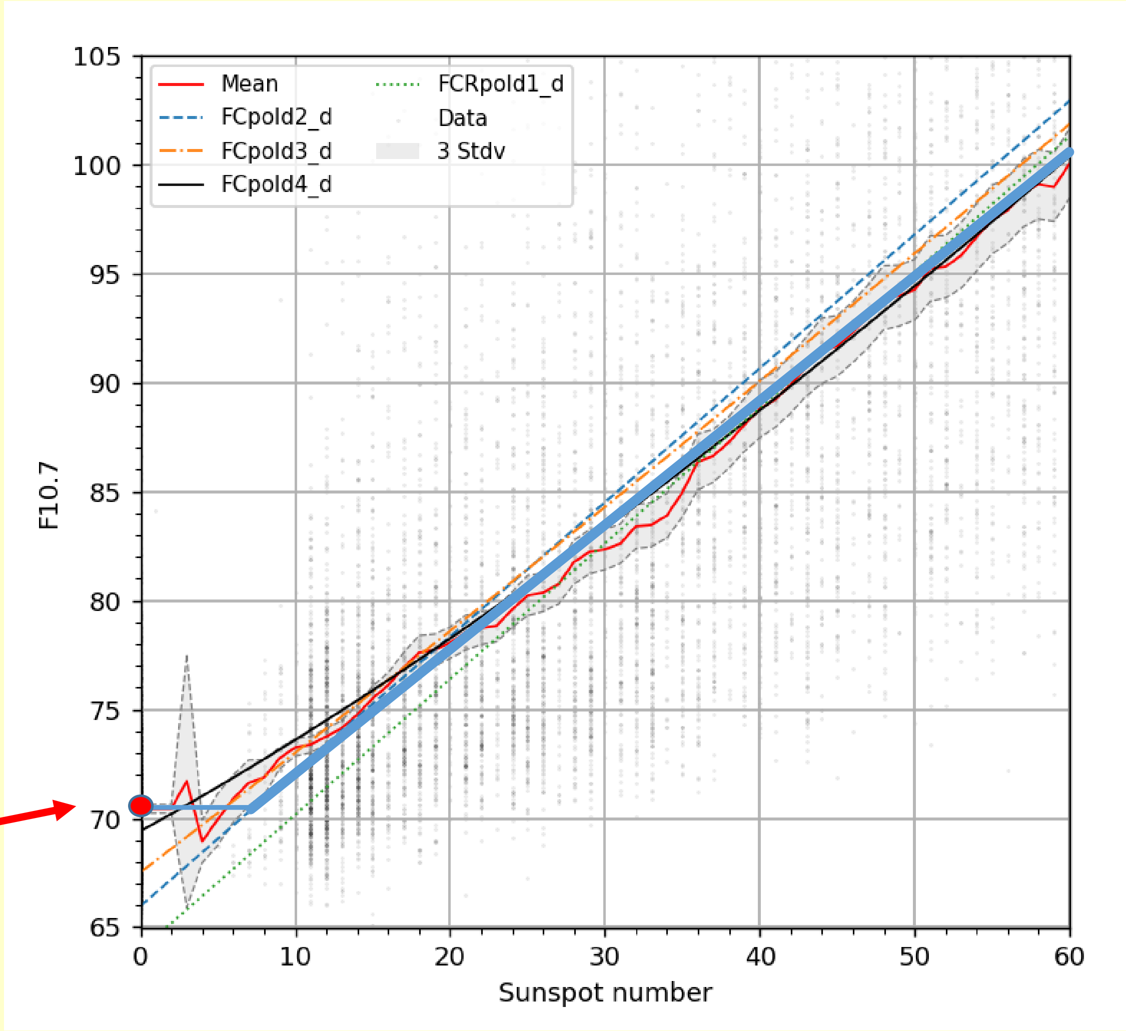


Polynomials vs temporal averaging: raw daily

- High linearity down to lowest values
- Degree 2 down to $S_N = 11$
- Wide jump only for $S_N < 11$

$S_N = 10\,N_G + N_S$

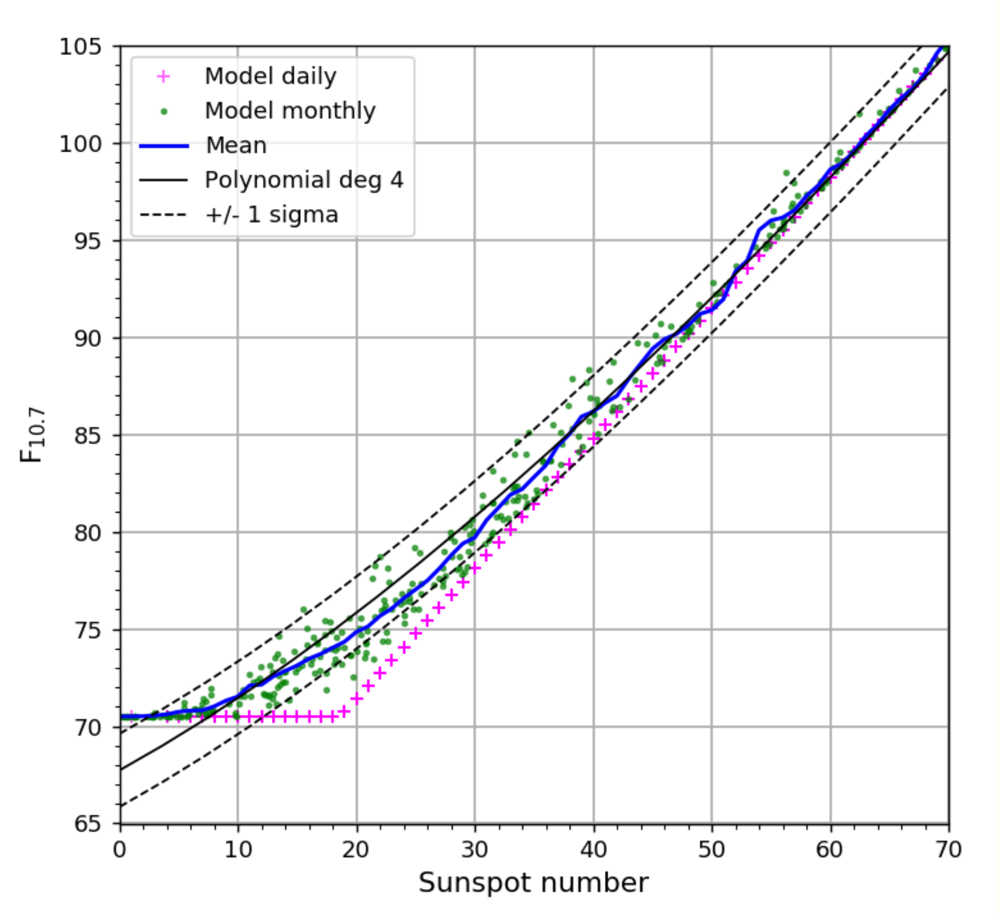
Mean $F_{10.7}(0)$= 70.5 sfu



$F_{10.7}/S_N$ almost exactly linear down to the first spot *+ S_N=0 outlier*

Model: pure temporal averaging effect

- Synthetic $F_{10.7}$ series:
  - **Linear conversion of actual daily S_N series**:
  - SN > 19 (more than 1 group) :
    $F_{10.7}$ // S_N
  - SN <= 19: (constant background)
    $F_{10.7}$ = **70.5 sfu**
- Monthly averaging of synthetic $F_{10.7}$ series



Matches the observed low-range non-linearity (also for yearly means)

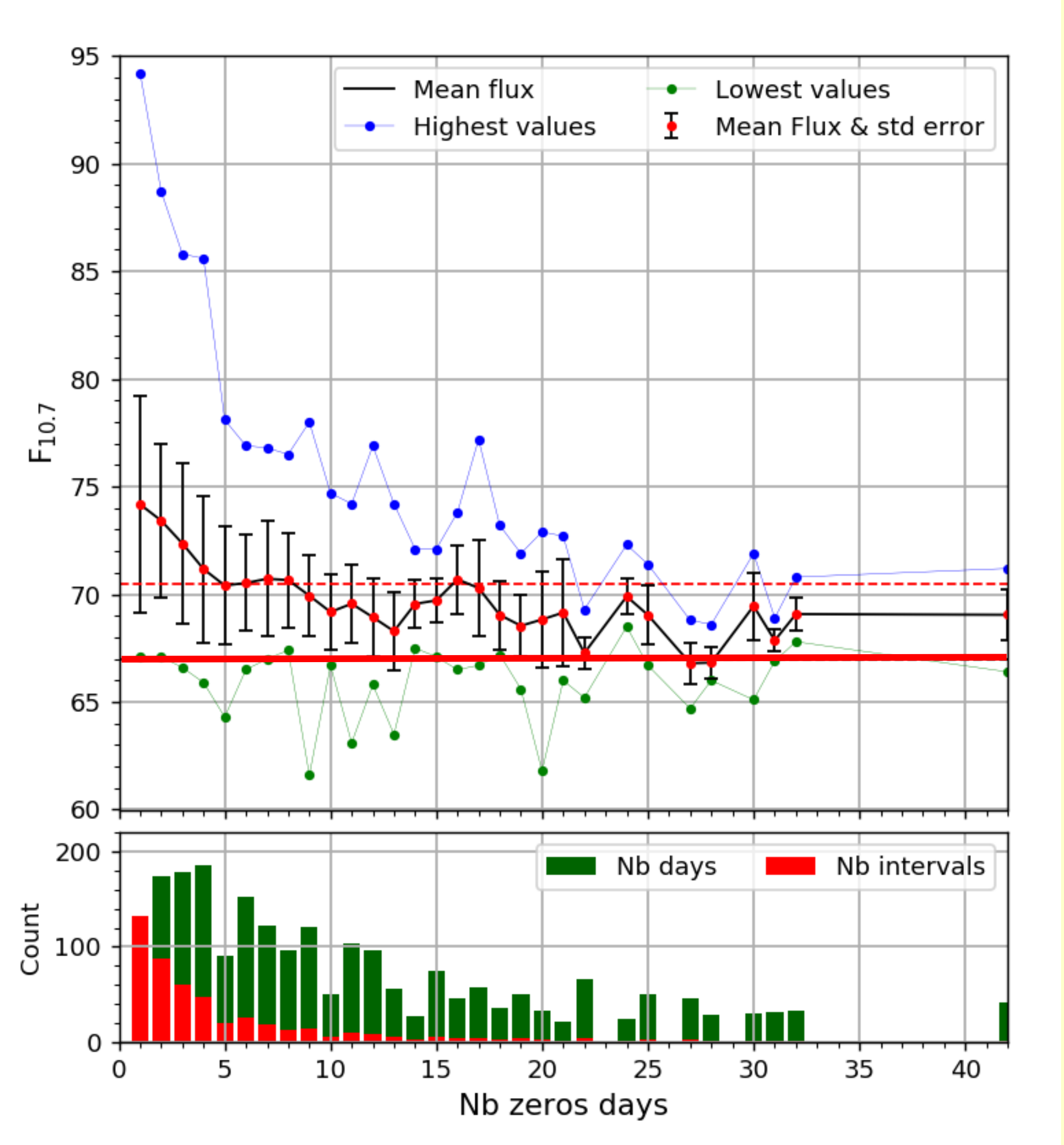
Non-linearity due to the S_N=0 offset point temporally convolved with the frequency of spotless days.

Background "all-quiet" flux: effect of chronology

- *Many disagreeing determinations of the minimum "all-quiet" $F_{10.7}$ flux (spotless Sun):*
  64 to 74 sfu
- **Sorting spotless intervals as a function of their duration**
  - Distribution for each duration (mean, stdv, highest/lowest value)

Rise of average background for short intervals
68 (@30d) to 74 sfu (@ 1d)

Constant lower limit: **67sfu ("true" minimum for $F_{10.7}$)**



Background flux: implications for averaging

- **Short intervals dominate**

➡ Background for daily values is high (~70.5 sfu)

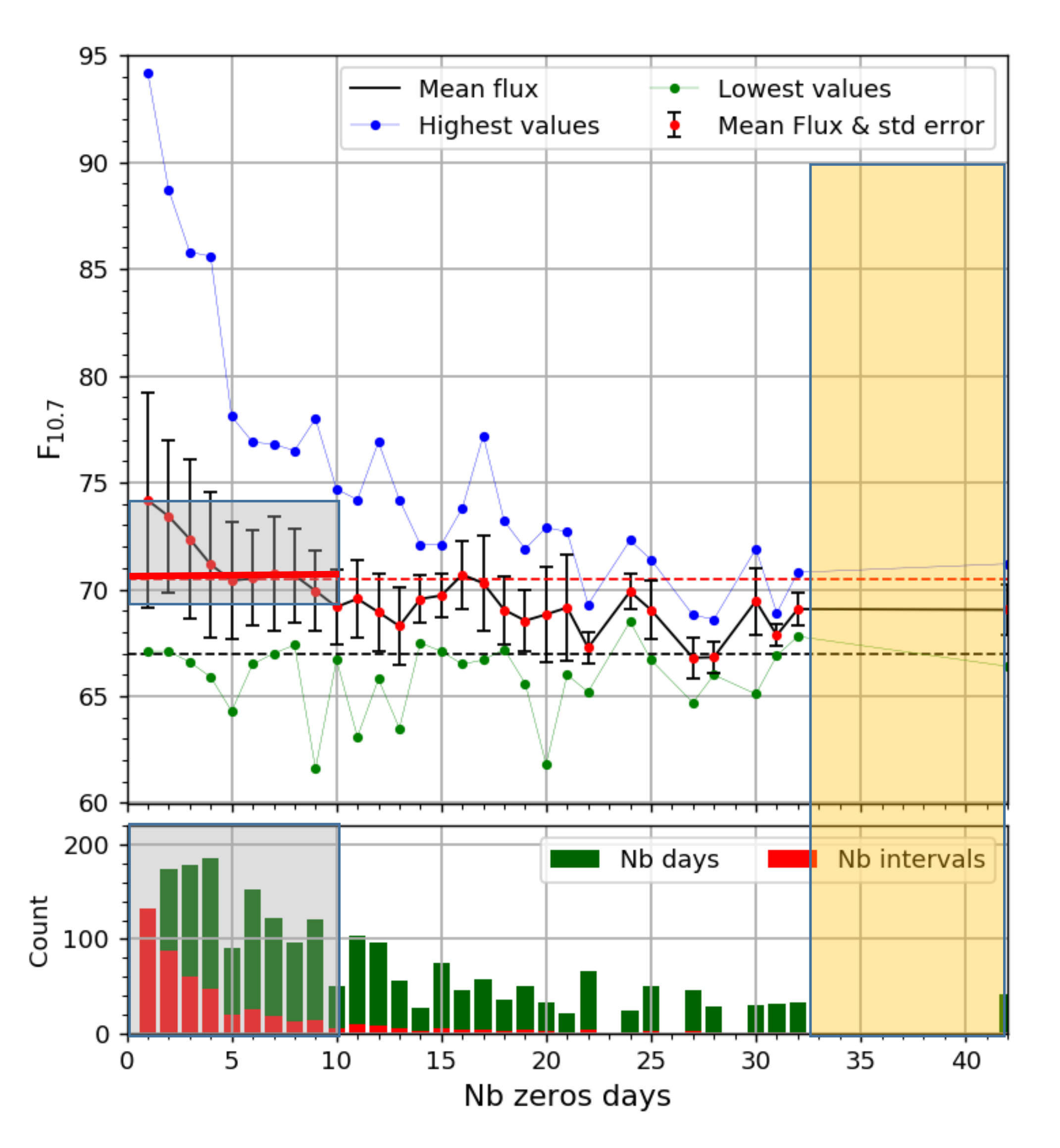
- **No spotless interval longer than 32 days**

➡ Background for yearly means is high *(always include active days!)*

- Lowest background values, near 67 sfu, near 30-day averaging

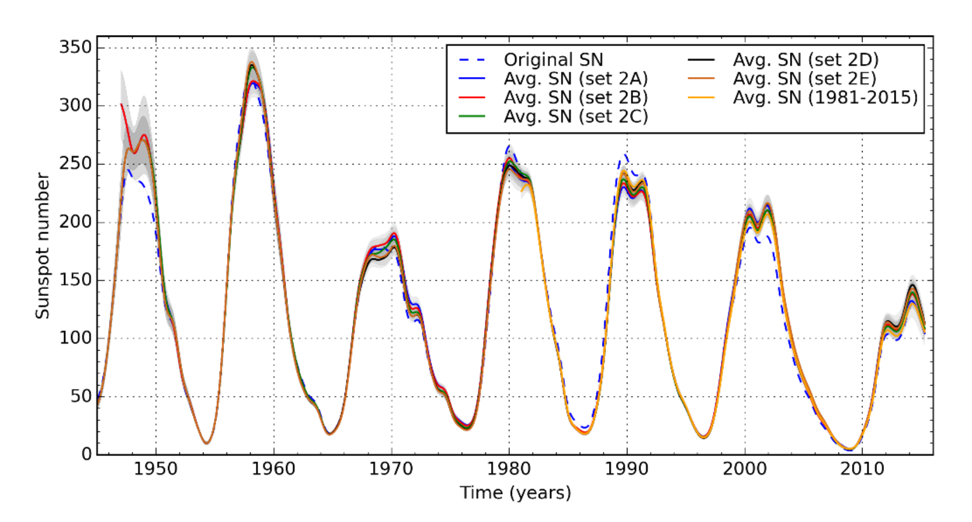
➡ **Monthly is optimal!**

- Probable mechanism: **Extended & delayed contribution of plages**

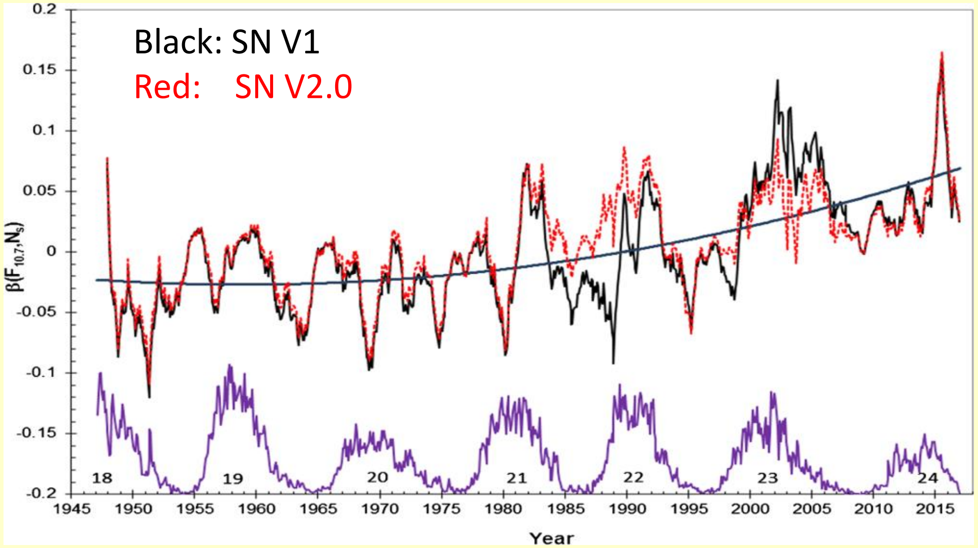


Is the $F_{10.7cm}$ series homogeneous?

- Base elements:
  - A new homogeneous reference: S_N version 2.0 *(Clette et al. 2016)*

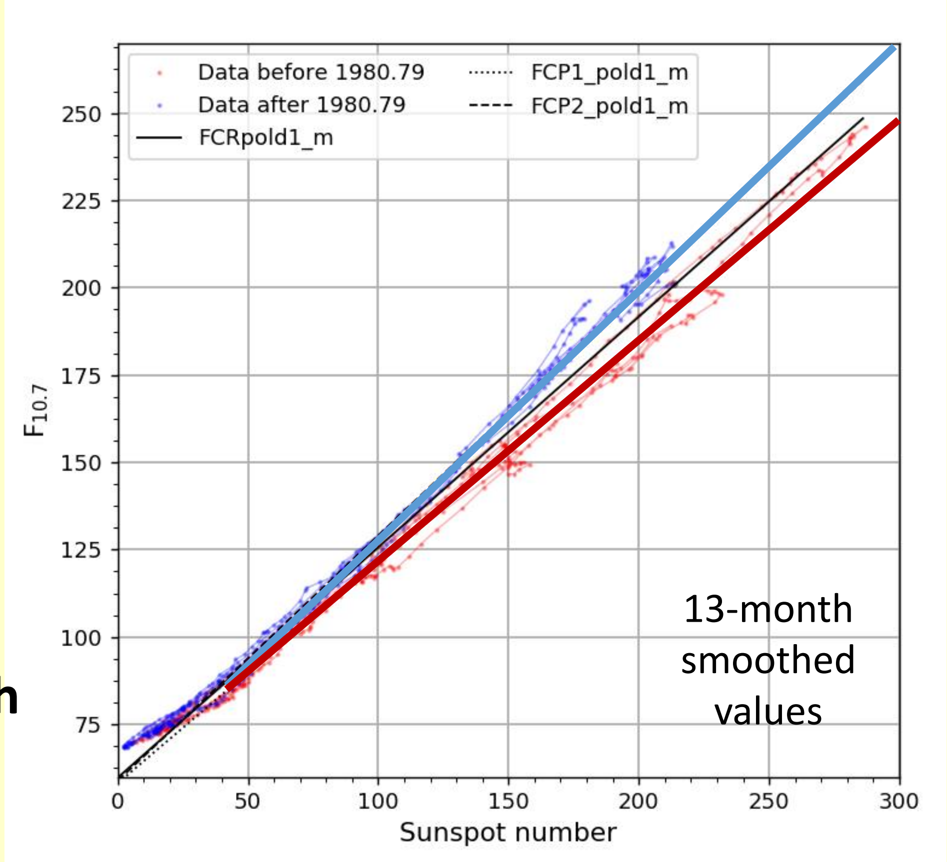


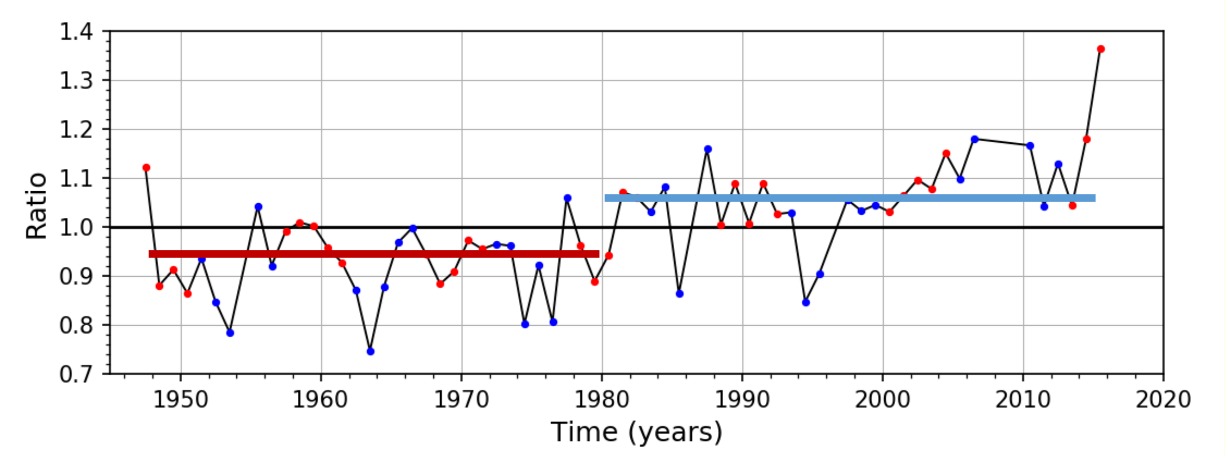
  - Global upward trend? (*Tapping & Morgan 2017)*:
    - Simple quadratic fit $F_{10.7}$ / time
    - *Attributed to a putative change in the Sun*



A sharp jump in 1980

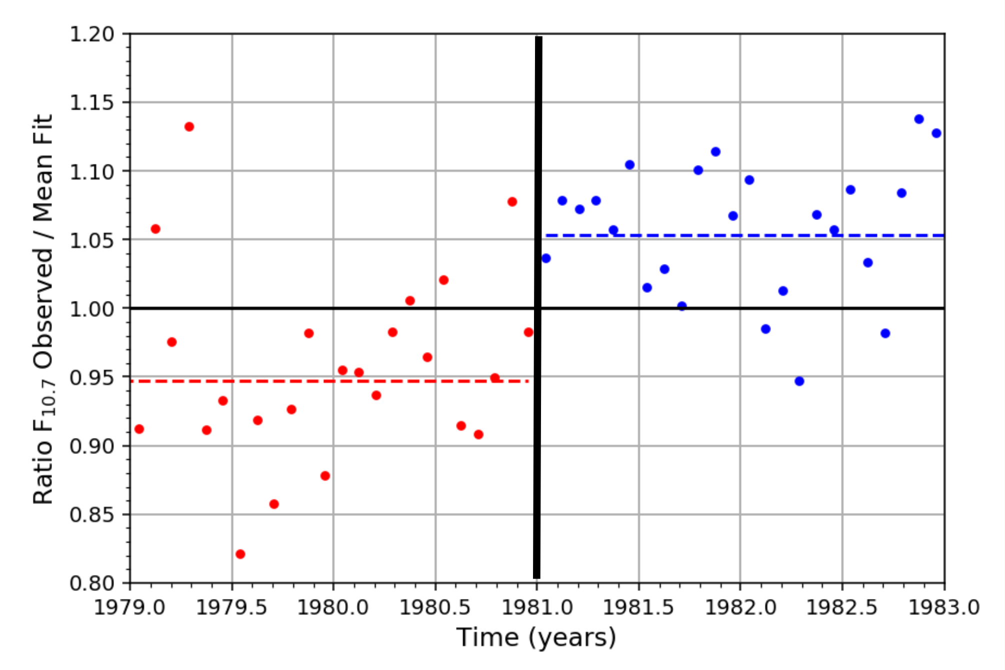
- **Abrupt upward jump in 1980**:
  - Before 1980: S= 0.6345 (±0.0066)
  - After 1980: S= 0.7020 (±0.0089)
  - Ratio: **1.106 ± 0.017 (10.6 %)**
- No significant trend over 1947-1979 and 1980-present
- **Good global homogeneity of both series before and after the jump** (benchmark)





Pinpointing the date

- Monthly mean ratio:
  - 80% below 1 before **Nov. 1980**
  - 85% above 1 from **Jan. 1981**



➡ **A solar explanation is excluded**

- Sanity check:
  - ***S_N : Zurich-Locarno transition in January 1981***
- Comparison with raw S_N from 28 individual stations
  - **Jump present in 24/28 cases**

➡ **Inhomogenity belongs to $F_{10.7}$**

1980 jump: retracing the historical cause

- Two main $F_{10.7}$ construction eras *(non-overlapping)*:

Covington (1947-1979)
- Manual measuring from paper recorder rolls

Tapping (1982-now)
- Computer processing of digital measurements

Transition team (1979-1981)
- Development of an automated computerized processing
  - No satisfying results > abandoned
- No clear stable method

- **Double disruption**:
  - Change of team (no Covington-Tapping overlap)
  - Change of processing method
- **Not an instrument calibration issue** !
  - Careful and constant procedure throughout
  - Two instrument re-locations (1962, 1990): not detectable in the data

Separate proxies needed for each half-series !

1947-1980

$$\hat{F}_{10.7} = 66.64\ (\pm 1.48) + 0.366(0.067)\ S_N + 2.59\ (\pm 0.86).10^{-3}\ S_N^2 - 0.99(\pm 0.40).10^{-5}\ S_N^3 + 1.33(\pm 0.62).10^{-8}\ S_N^4$$

1981-present

$$\hat{F}_{10.7} = 67.84\ (\pm 1.06) + 0.386(0.044)\ S_N + 2.86\ (\pm 0.45).10^{-3}\ S_N^2 - 0.73(\pm 0.13).10^{-5}\ S_N^3$$

Whole series

$$\hat{F}_{10.7} = 67.73\ (\pm 1.13) + 0.337(0.056)\ S_N + 3.69\ (\pm 0.77.).10^{-3}\ S_N^2 - 1.52(\pm 0.38).10^{-5}\ S_N^3 + 1.97(\pm 0.60).10^{-8}\ S_N^4$$

Conclusions

www.sidc.be/silso

- **Base $F_{10.7}/S_N$ relation fully linear except for 0 point**
  - Non-linearity entirely due to temporal smoothing
- **Mean quiet-Sun $F_{10.7}$ flux varies with spotless duration**
  - Invariable base flux = 67 sfu
- **Optimal proxy: 4th order polynomial on monthly means**
- **10.5% upward jump occurring in 1980-1981**
  - Two proxies currently needed

Clette, F. (2021), J. Space Weather and Space Climate, Vol. 11, id.2, 25 pp. DOI: 10.1051/swsc/2020071

Questions ?