How Variable is the Solar Constant?

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Introduction

- The solar constant is the total solar irradiance (TSI) at the mean Sun-Earth distance; its value is of the order of 1360 Wm^{-2}
- It is the main energy source for the earth-climate system, which is varying by ±3% due to the orbit of the Earth
- TSI is influenced by the 11-year solar activity with the waxing and waning sunspots and faculae on the solar surface
- To understand the stellar physics of the Sun the luminosity is of importance, but we have no information of e.g. the radiance at the poles – so only rough estimates are possible

Solar Radiometry

- In 1837 Pouillet developed the first solar radiometer, which he called a *pyrheliometer*. The instrument is based on water calorimetry and its simplicity allowed only crude measurements. Hence his solar constant was pretty wrong.
- Based on the same principles Violle, Crova and Michelson developed pyrheliometers. The 2nd Conference of the Directors of the Meteorological Services in Rome, 1879, stated that «research on radiation is not yet sufficiently advanced to propose a method of observation........»

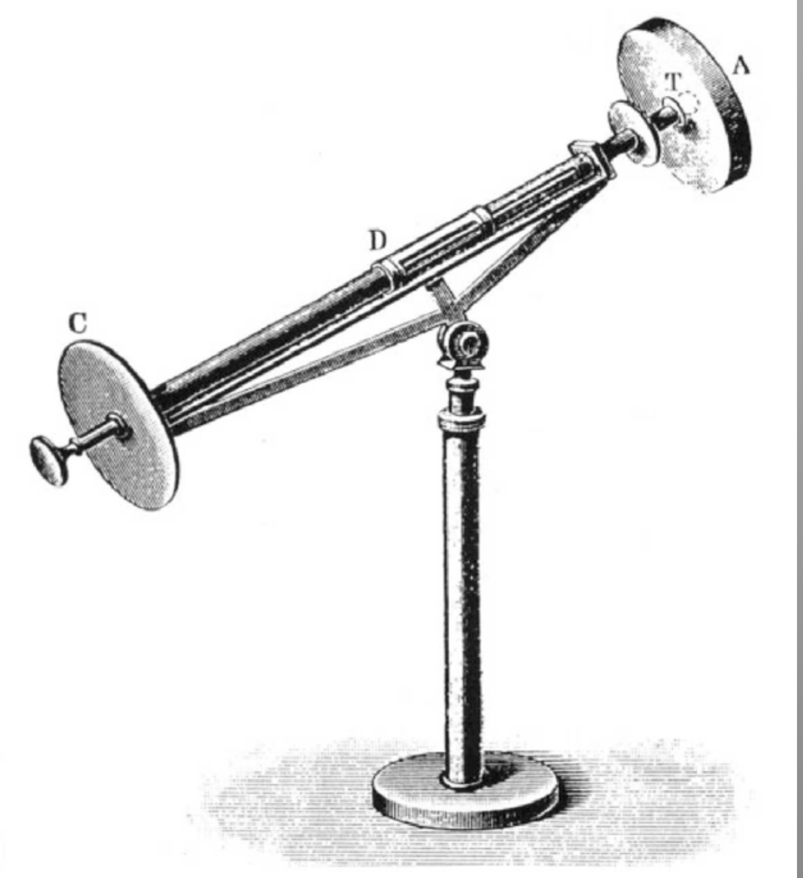
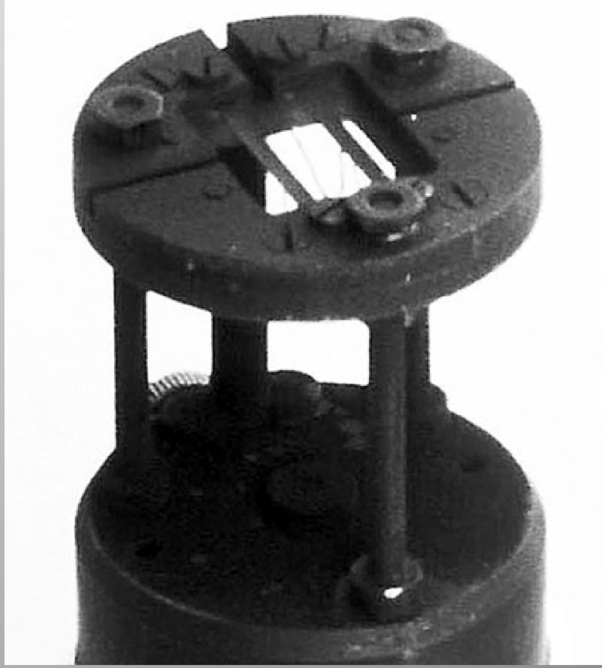


Figure 1. Pouillet's pyrheliometer. A : blackened receiver (metallic container filled with water) ; T : bulb of thermometer ; D, C : alignment check.

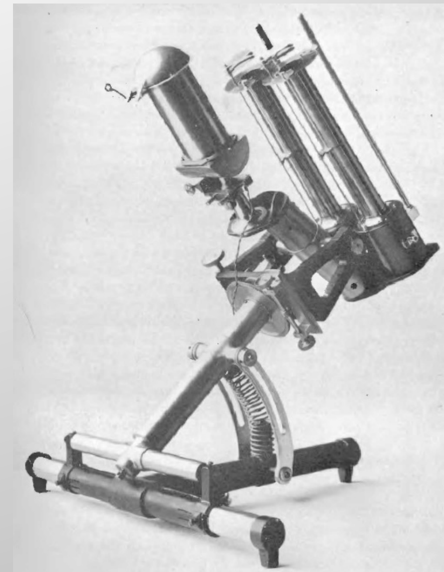
Solar Radiometry

- Knuth Ångström (1857-1910) was the first to use electrical calibration by having two blackened manganin strips which were either illuminated by the sun or heated electrically. The temperature difference is measured by a thermocouple mounted underneath in the middle of each strip and nulled by adjusting the current (Ångström, 1893) and was called the Å- Compensation-pyrheliometer
- At a meeting of the Commission for Solar Radiation (CSR) in 1905 it was recommended for measurements of solar radiation and one of the original Å-pyrheliometer served as reference and it was called the Å-Scale.



Solar Radiometry

- One of the main objectives of the Astrophysical Observatory of the Smithsonian Institution was solar radiation. Samuel P.Langley (1834 –1906) founded the APO and was its director until Charles G.Abbot (1872 –1973) took over. In the 1890ties the silver-disk pyrheliometer was developed and also manufactured for solar radiation measurements.
- This instrument must be calibrated and this was done against a newly developed water-flow radiometer with electrical calibration and a cavity as absorber. This defined the *Smithsonian Scale revised 1913* (SI scale), which was then the basis for all measurements with Silverdiscs.
- At a meeting of the CSR 1912 a difference between the Å and SI scales of 5% was reported, but no action was taken because it was thought to be within the uncertainties.



Solar Radiometry

- There were many comparisons between Å and the SI scales resulting in differences between 3.5 and 5%.
- For the IGY the decison was made the Å reding should be increased by 1.5% and the SI ones reduced by 2% and the resulting scale was called IPS1956.
- This should be implemented during the International Pyheliometer Comparison (IPC) 1959.
- During the IPC1964 it was realized that something was wrong and a detailed analysis of all the results of comparison together with the participation of a modern Electrically-Calibrated Radiometer during IPC1970 was able to resolve the problem.

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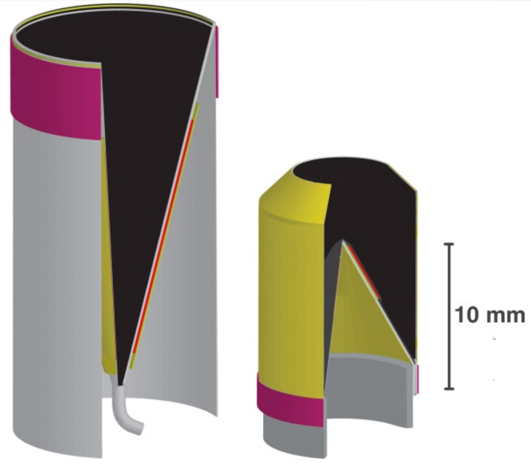
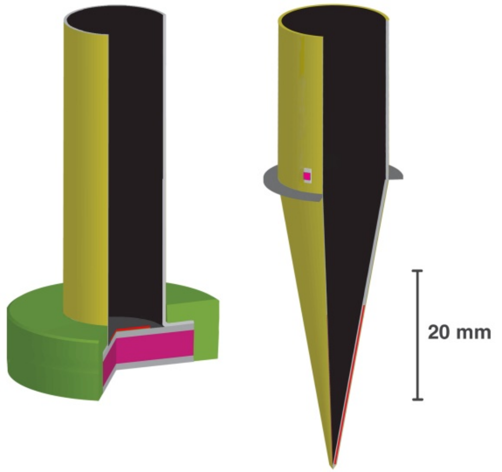
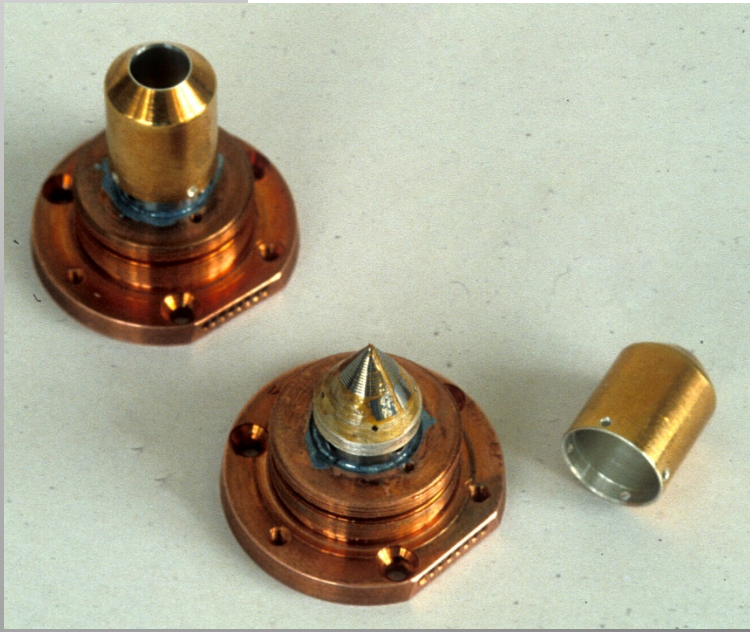




- Modern radiometers are ECR with a cavity as receiver. The cavity is connected wih a thermal resistor to a heatsink and with thermometers at both ends it forms the heatflow meter.
- These radiometers can be used in an active or passive mode. In the normally used active mode a shutter is open/closed periodically and a controller maintains the heatflow constant by regulating the electrical power. The solar irradiance is $C(P_{closed}-P_{open})/A$ with *A*, the area of the precision aperture and *C* a correction factor determined experimentally.
- The uncertainty of *A, C* and *P* determines the uncertainty of the radiometer. And most importantly if you forget one correction term, there is no correction and no uncertainty of this missing effect.



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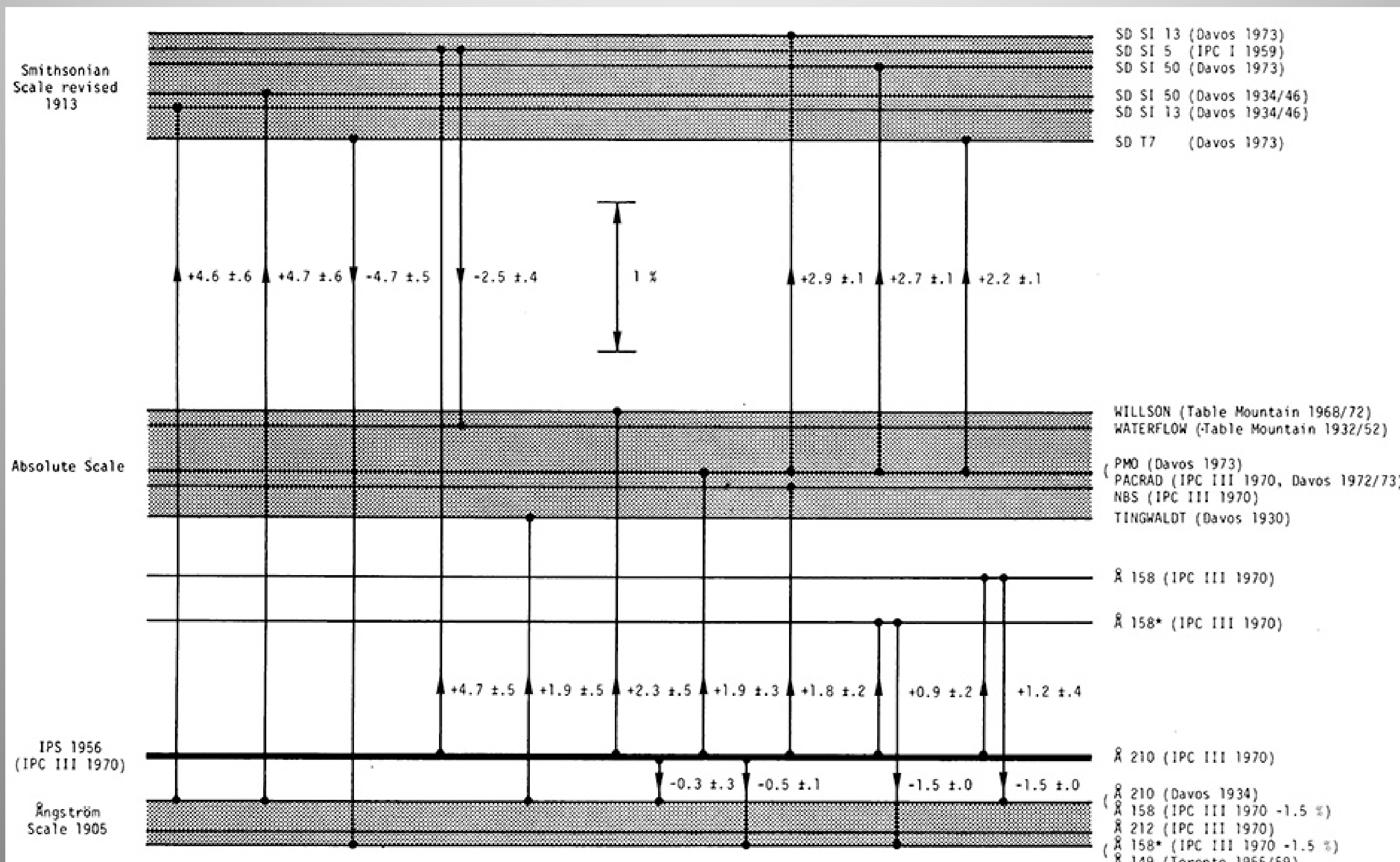
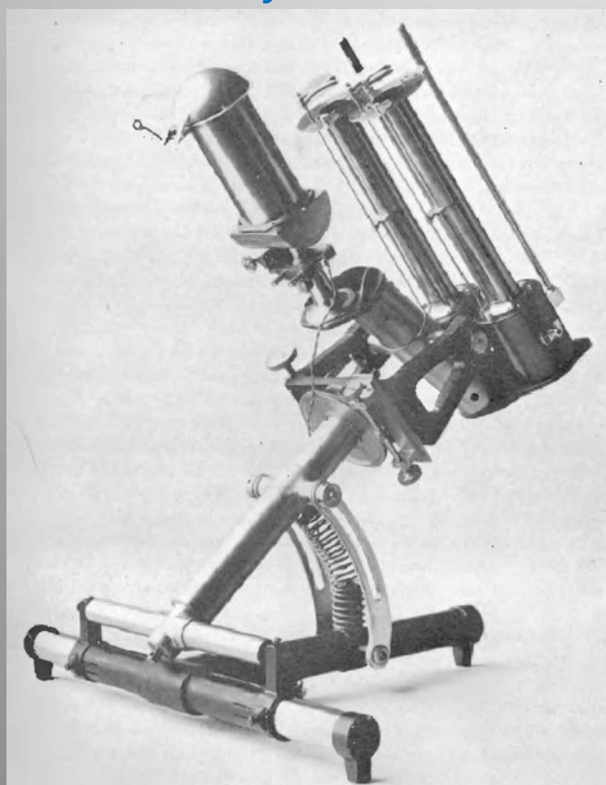
Further comparison of more ECR and many discussions of the correction needed in 1974 and the IPC1975 provided the information to define the World Radiometric Reference (WRR) which was then adopted by WMO as the reference for solar radiometry



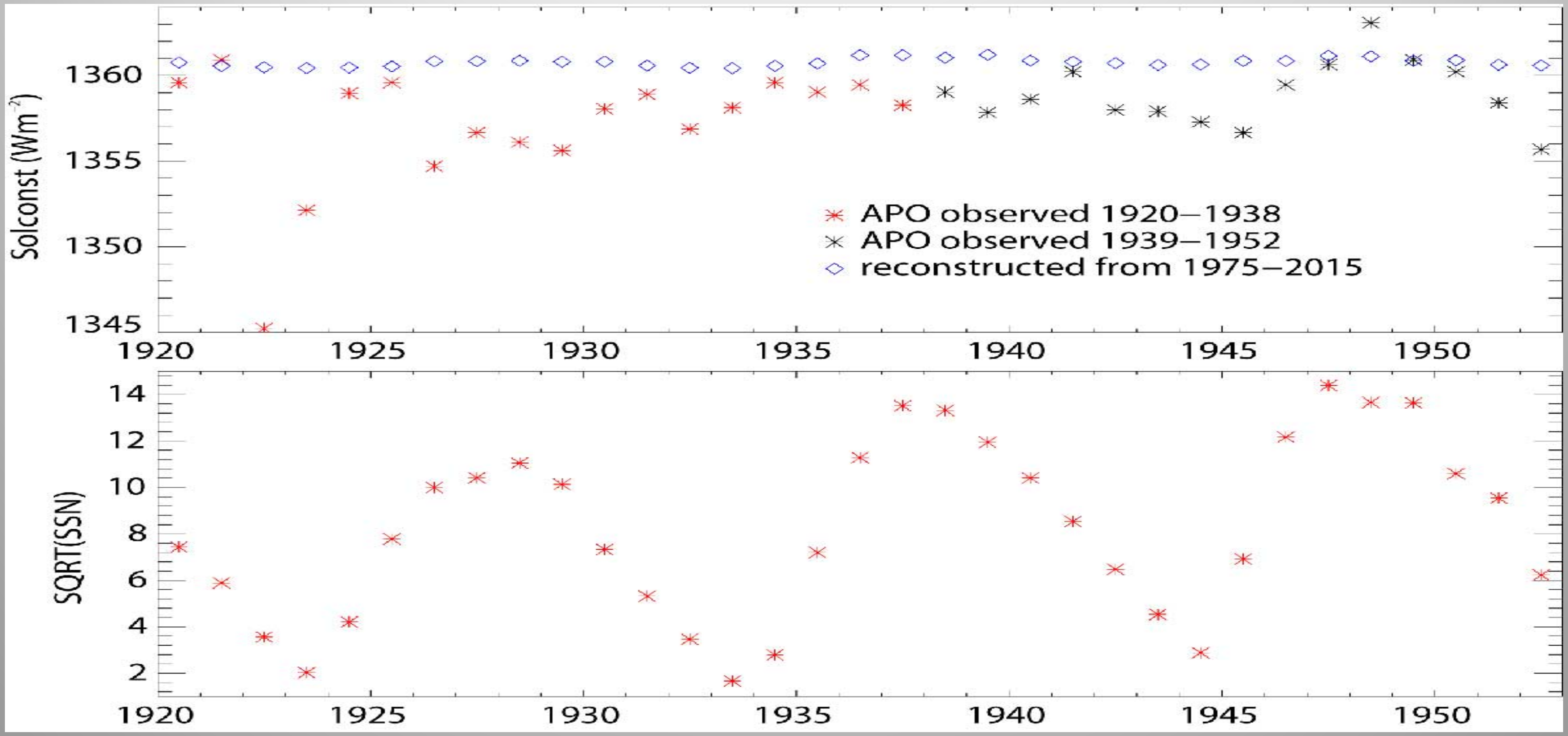
Solar Constant of APO 1920-1952

We start with the determinations by APO from 1920-1952. The 2 main stations were located at Table Mountain in California and Montezume in Chile. The observations consist of: (i) total intensity (by pyrheliometer), (ii) distribution of intensities in the solar spectrobolometer, (iii) altitude of the sun by theodolite. With these data the solar constant amounts to:



$$(\rho)^2 \times \text{Pyrh.} \times \frac{\Sigma e_0 + \text{extra-atmospheric (UV and IR) bands}}{\Sigma e + \text{infra-atmospheric (UV and IR) bands}}$$

Solar Constant of APO 1920-1952



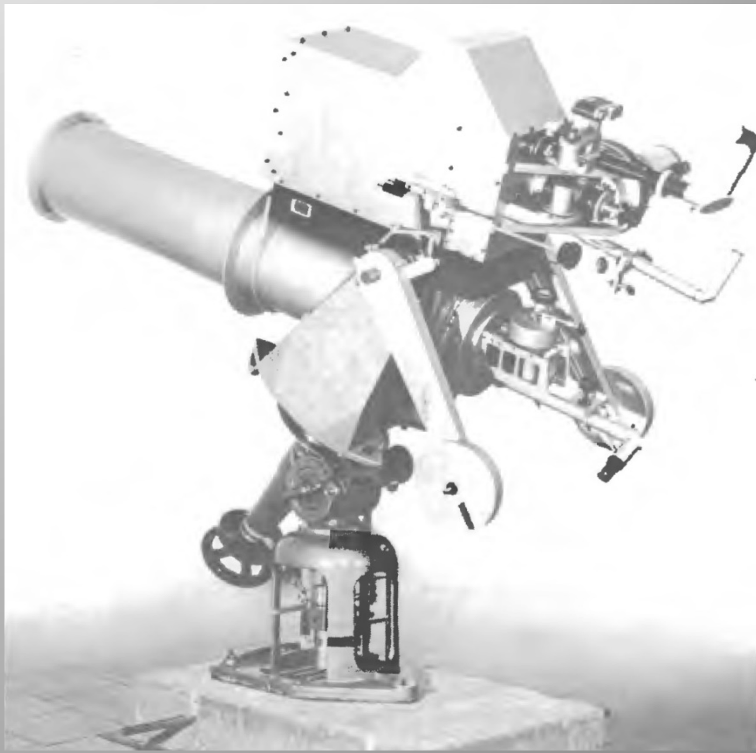
Tsi correlates with the sqaqre root of the sunspotnumber. The slope for the the Smithsonian data is with 0.25 Wm^{-2}/sqrt(SSN) about 3 times larger than for the modern data, which is also obvious from the difference between the two datasets in the above Figure.

Solar Constant determinations in the 60ties and 70ties

In 1973 the Smithonian Institution organized a meeting at the Biology Lab in Rockville Maryland, November 13-15, 1973

Solar Constant determinations in the 60ties and 70ties

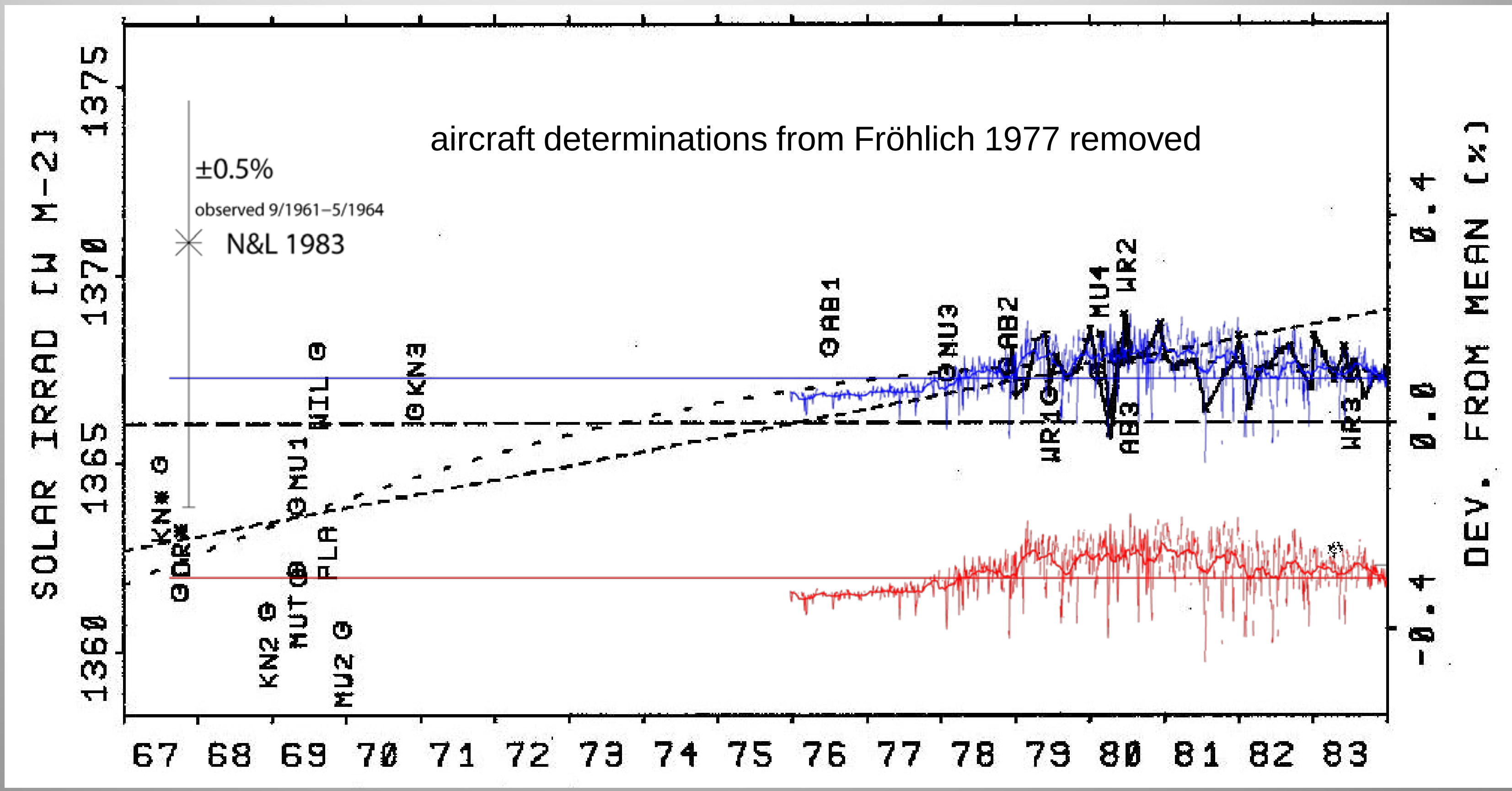
- During 9/1961-10/1961, 9/1962-10/1962 and 4/1964-%/1964 D. Labs and H. Neckel observed the Sun with a dedicated Spectrometer.
- The calibration laboratory in Heidelberg - setup by Labs – was the ‘world-best’ calibration lab for spectral irradiance. The main reference was a blackbody with the temperature of melting gold. Which was used to calibrate Tungsten band lamps, which then can be used as transfer standards.
- Neckel on the other hand was a solar physicist and contributed to the project his understanding of the solar surface radiation.
- This combination of an excellent experimentalist with a theoretician who was interested in measurements and methods was ideal and guaranteed success.
- For the observations only days with the best conditions were used, another important ingredient for excellent data.
- Another important point is that the setup had an almost rectangular bandpass of 2nm.



Solar Constant determinations in the 60ties and 70ties

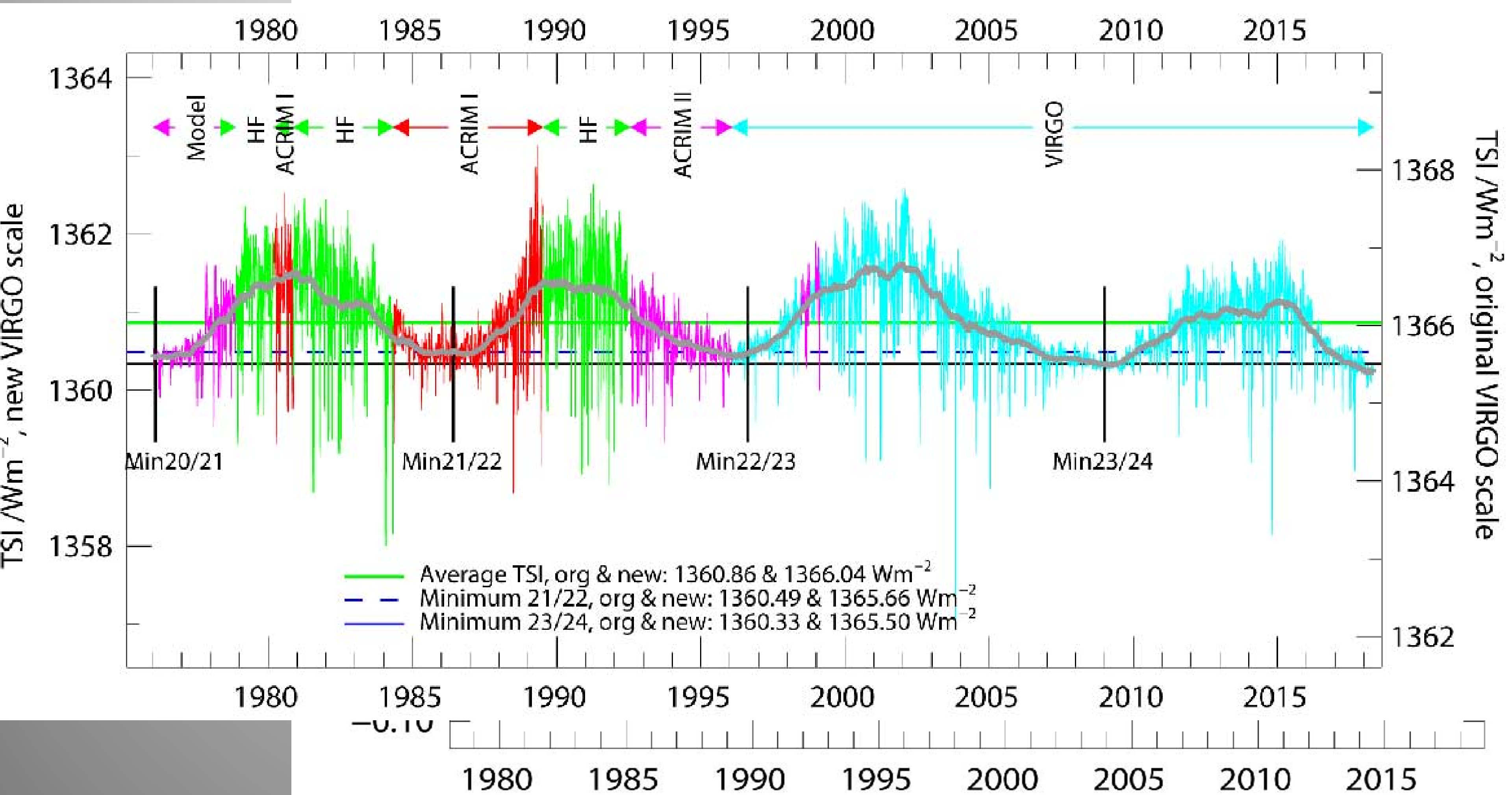
- The results of these measurements were the best available at the time and the spectrum was widely used as refencence.
- L&N (1971) presented a comparison of 13 different solar constant determinations (L&N,1968: 1358 Wm^{-2}) and concluded that the most probable value was 1360±4 Wm^{-2}
- Using a similar set of solar constant determinations I got 1363.3 Wm^{-2} (without the airplane measurments).
- These results are consistent, but a new evaluation of N&L 1984 yielded 1370.7 Wm^{-2}, which is rather high.
- The conclusion is, that these measurements are not accurate enough the say something about TSI variability.

Solar Constant determinations in the 60ties and 70ties



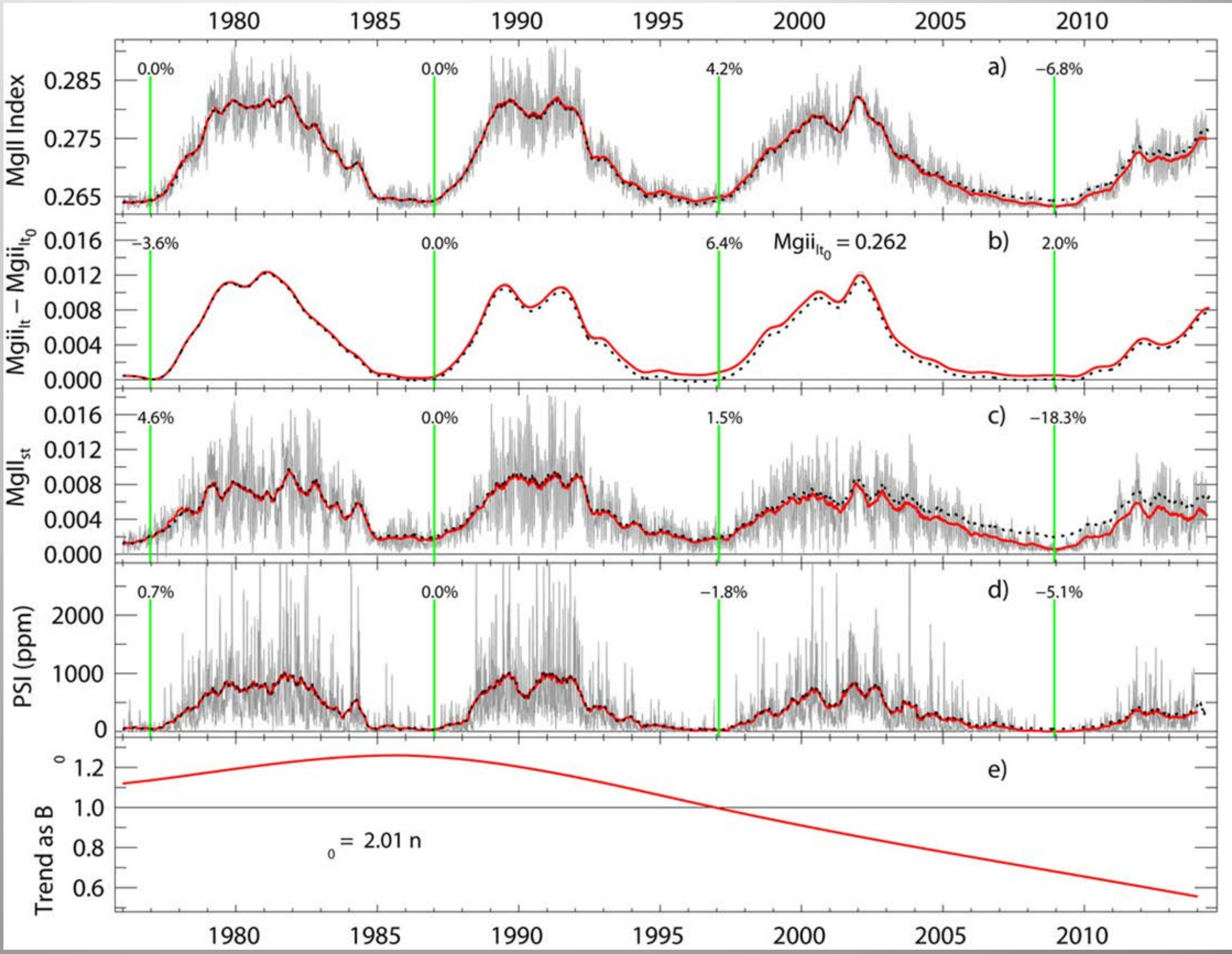
PMOD composite TSI

The modern TSI data from satellite since November 1978 provide the basis for a composite and the one called *PMOD composite* will be presented



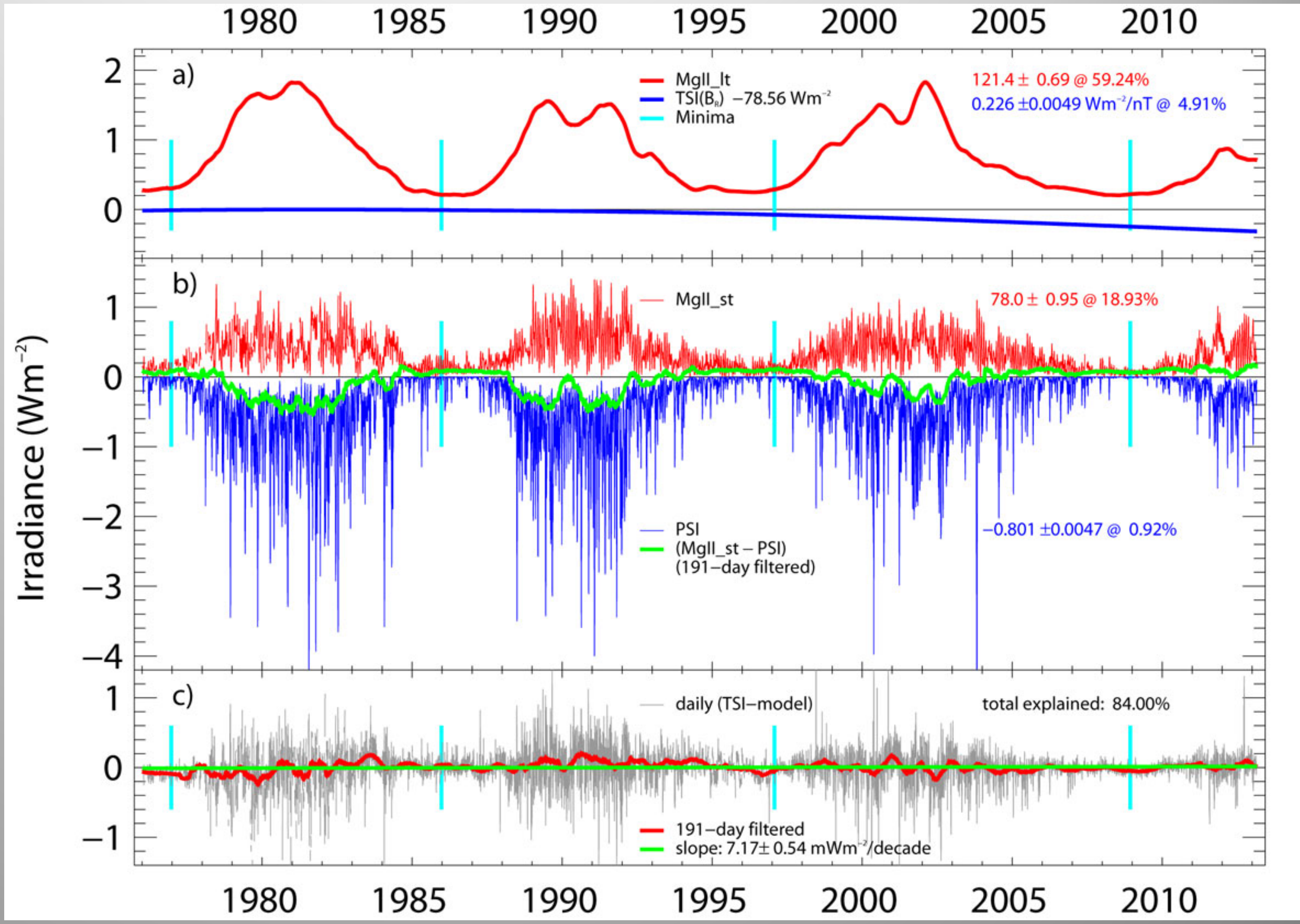
Proxy model for TSI

- We use the MgII index (top panel)m and separate it into a long- (2nd panel) and short-term (3rd panel) component to reflect the solar cycle modulation due to network and the active region influence due to faculae.
- The 4th panel shows PSI calculated from the SOON data (area and position) .
- The bottom panel shows the smoothed variation of B_R at minima.



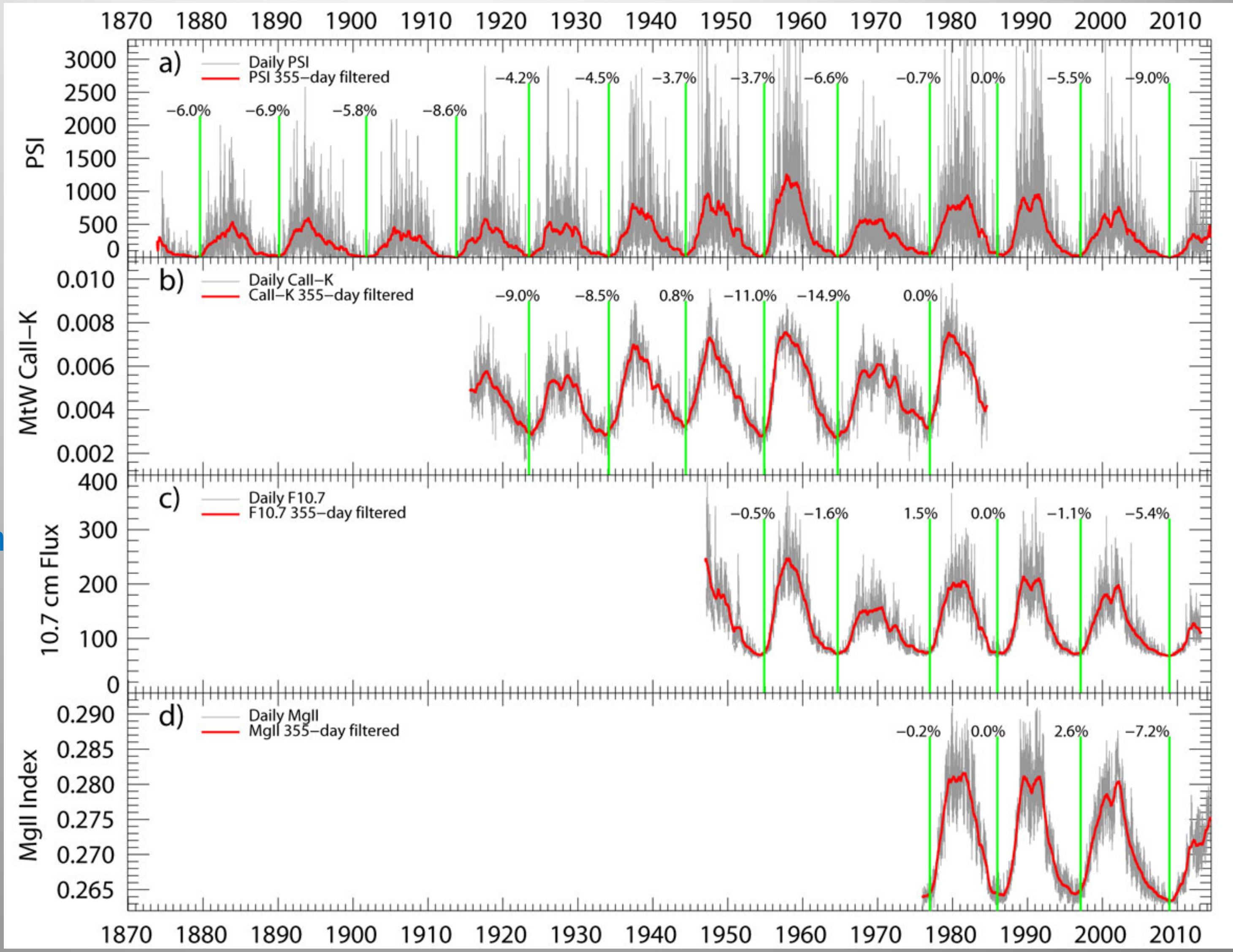
Calibrate the model against TSI

- Now we calibrate the model with a multi-linear regression against TSI over the full period of the composite.
- The overall explanation of the variance is 84% with partition of 59% by the long-term, 19% by the short-term 1% by PSI and 5% by the trend related to B_R.
- For the B_R. Correlation we get a larger factor of 0.23 Wm-2/nT than we found be linear regression.



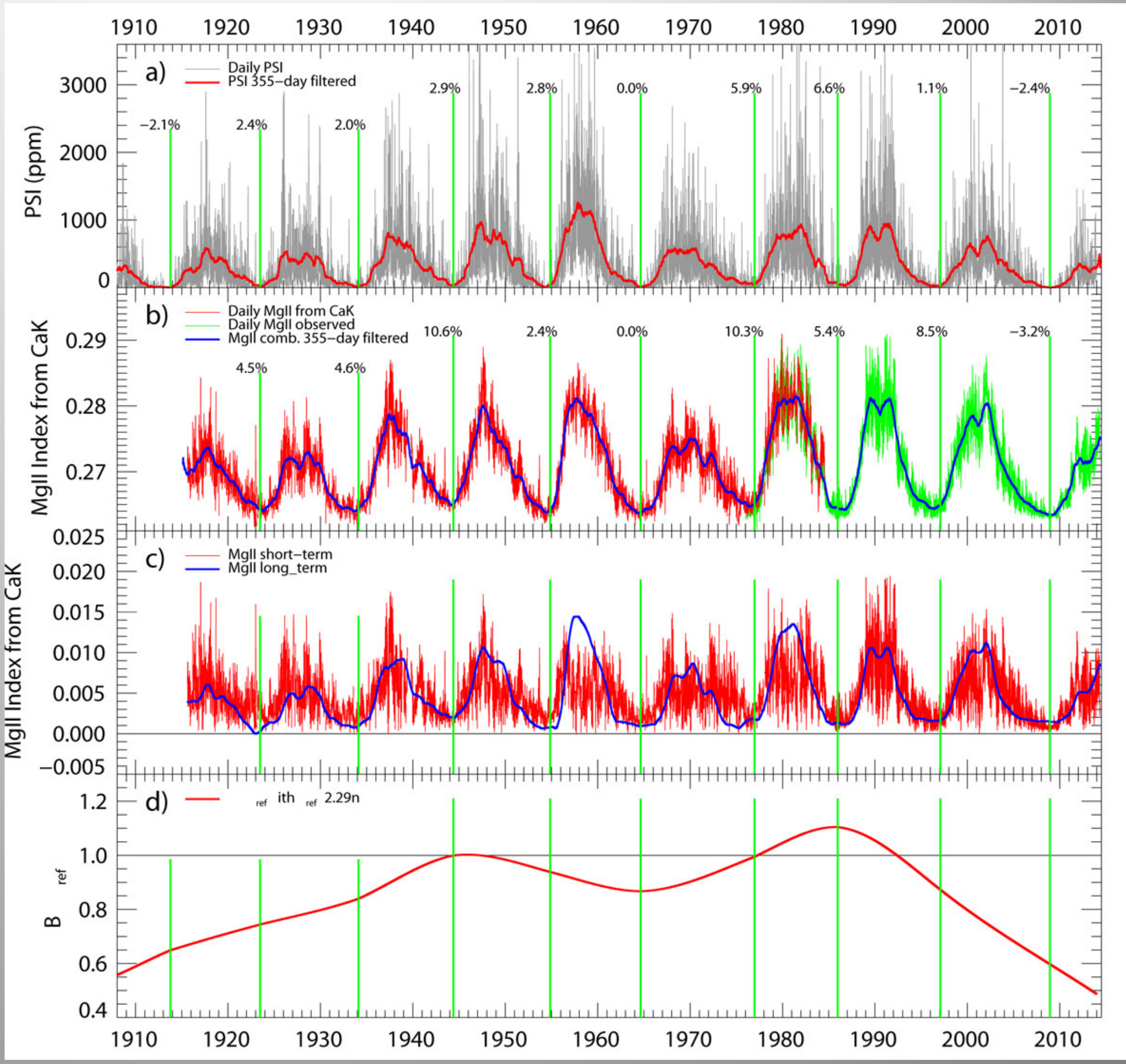
How can we extend the model back to 1900 ?

- We have PSI from the RGO and SOON data.
- We have a CaK index determined from Mount WIlson plates.
- We have F10.7 which overlaps the CaK and the modern MgII index period. And can thus be used to transform CaK to MgII index.



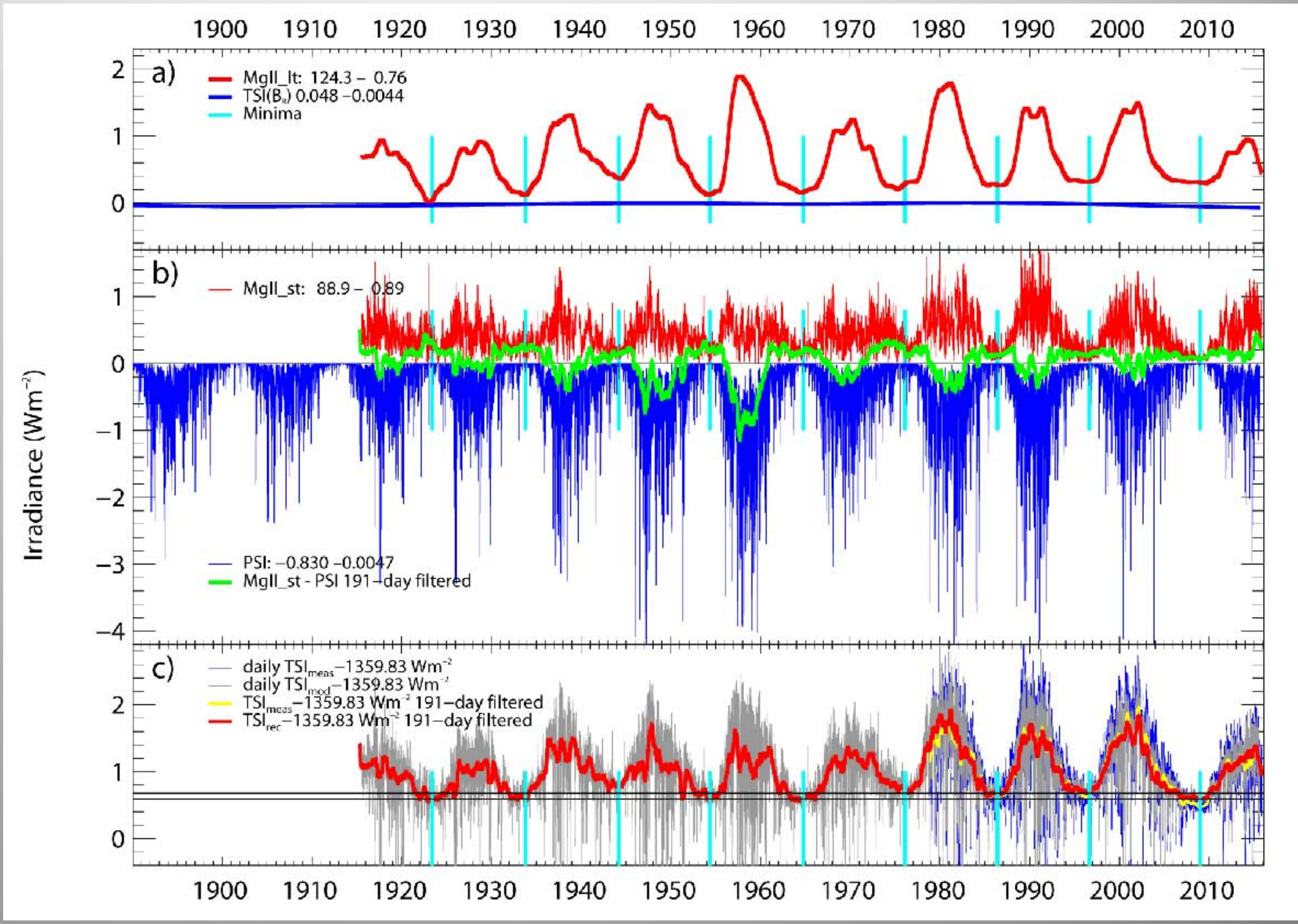
How can we extend the model back to 1900 ? 4 of 4

- Now we have all parameters needed for the proxy model and we can with the same method also determine the separation of the MgII index.
- It seems that we may have a problem as we get an amplitude of the long-term component for cycle 21 which is higher than the original one. We get also an extra low minimum in 1924. Both may be a problem due to the analysis and need some more investigation.



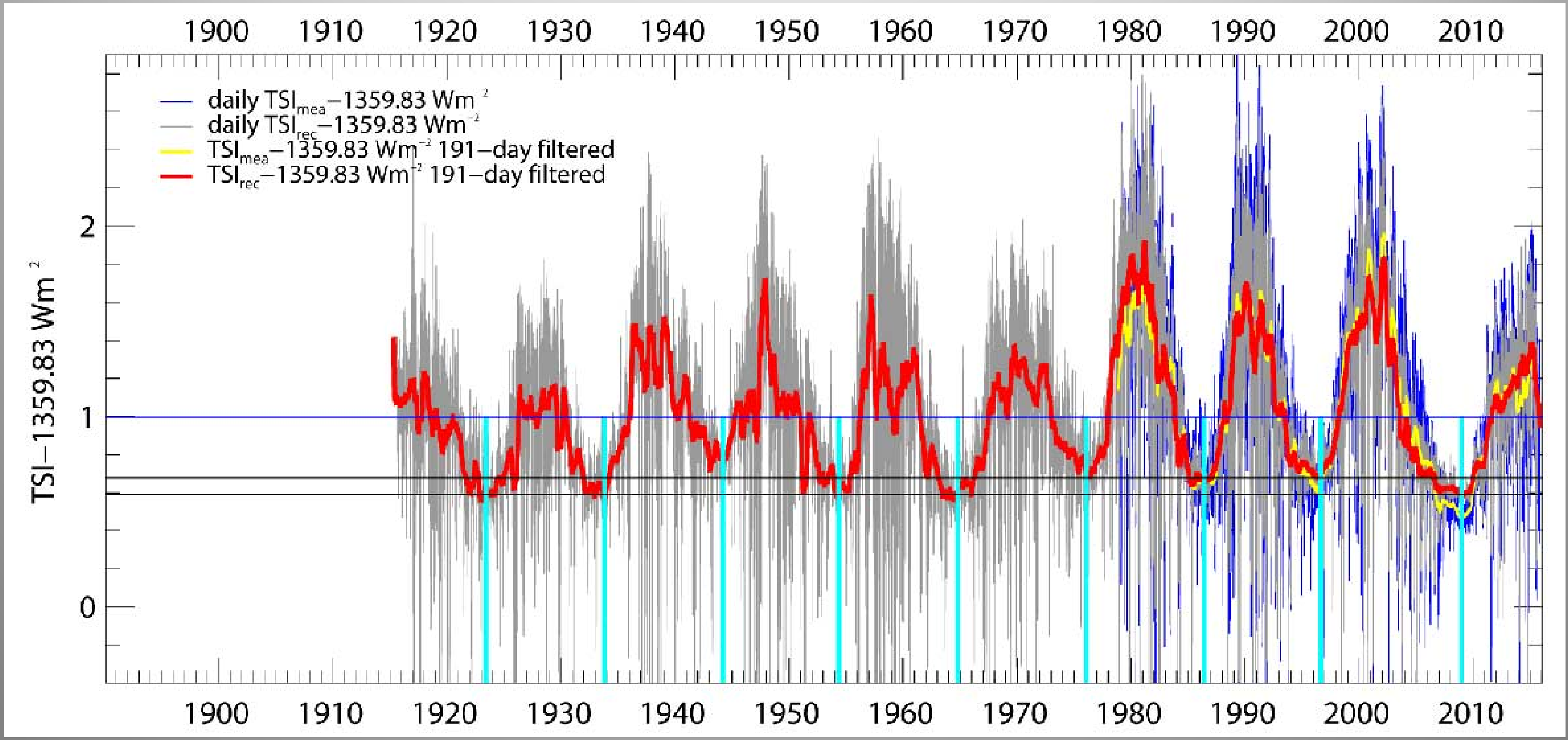
Using the calibration during the last three cycles.... 1 of 2

- With the calibration during the last 3 cycles we can now determine the 4 components of the proxy model back to 1915.
- As mentioned before the amplitude of cycle 21 may be too high.
- There are substantial differences between the different cycles in the share of sunspot darkening and facular brightening, in particular for cycle 19.



Using the calibration during the last three cycles.... 2 of 2

The result of the model compared to TSI during the last 3 cycles shows again the possible amplitude problem with cycle 21. We probably need to review the overlap of the reconstructed and measured MgII index.



Conclusions

- Single measurements in time are difficult to judge if coexistant measurements from space are not available.
- Only since reliable measurements from space (which however may need some corrections) we learn more about TSI variability.
- The analysis of TSI variability is now a diagnostic tool for solar variability in general. The main point is that TSI variability is the result of changing magnetic fields which however influence TSI in a number of different ways............
- The low value of the minimum in 2008 shows in the reconstruction without the most recent data that in 1924 the value of the minimum was similar. This may also mean that the normally accepted minimum during the Maunder Minimum may be too low.