

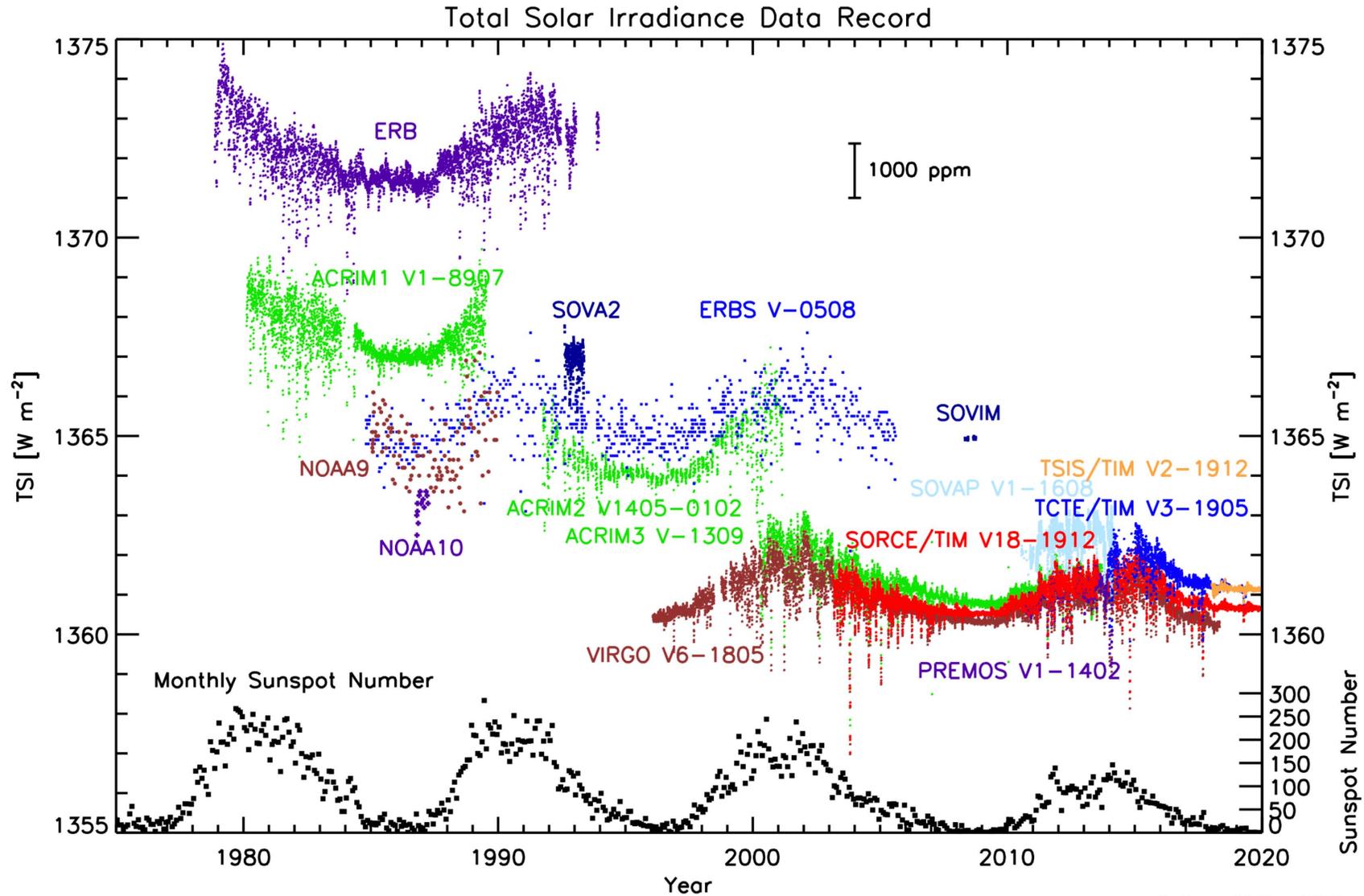
Claus Fröhlich (1936-2019)

What is the value of the solar TSI minima in the space age?

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These are our data sets – so do we know the answer?

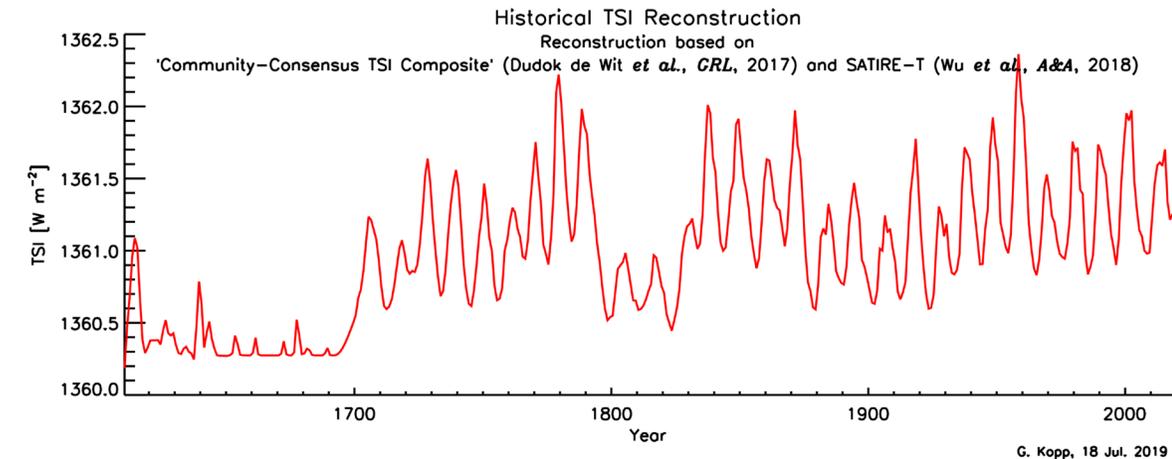
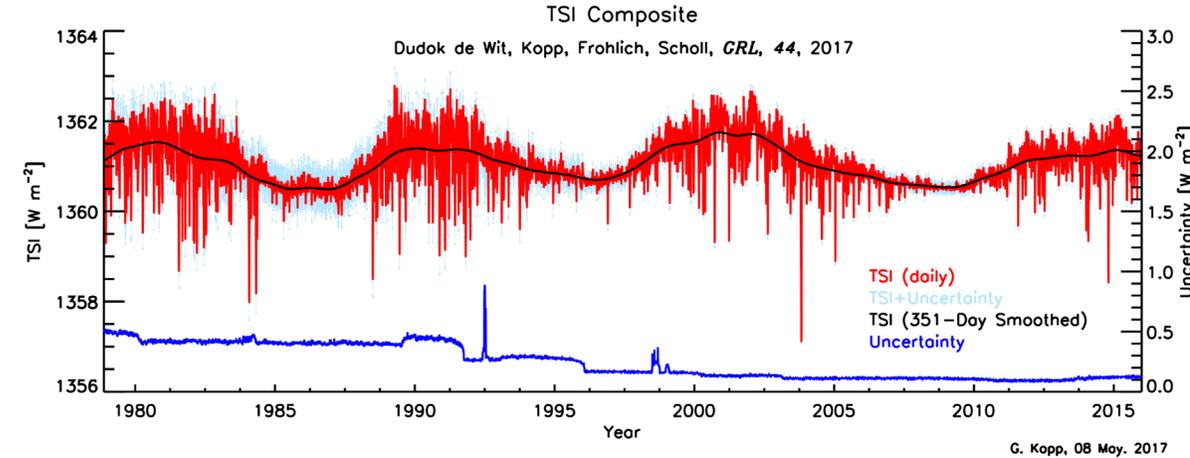


- Precision $\approx 0.01 \text{ W}$
- Accuracy $\approx 0.4 \text{ W}$
- Stability $< 0.15 \text{ W/decade}$

G. Kopp, 09 Dec. 2019

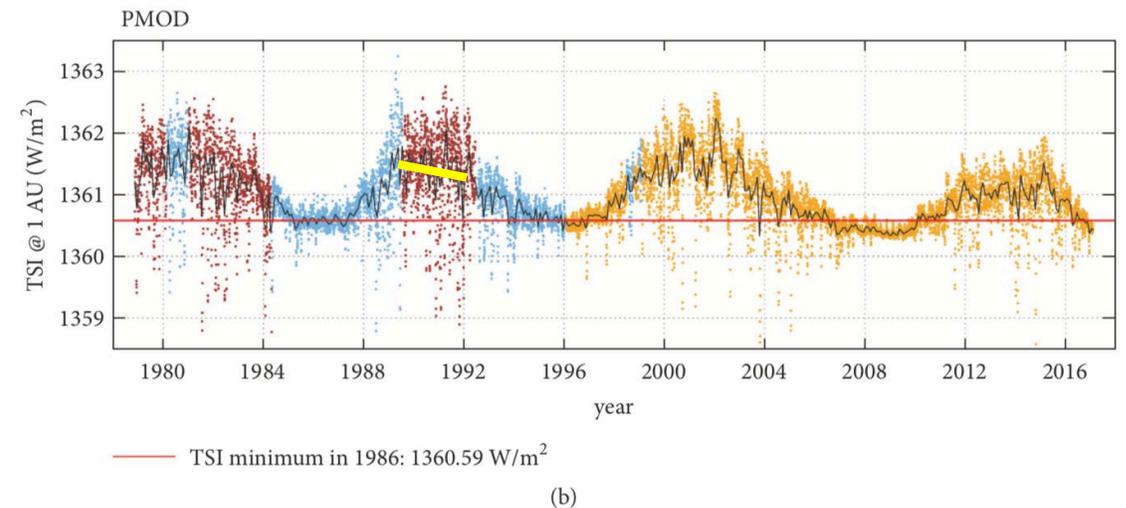
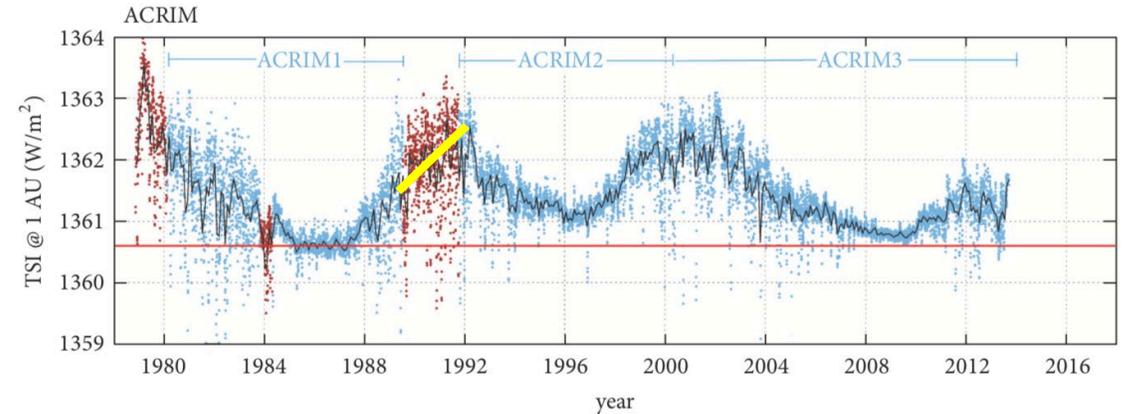
Two major questions and several consequences

- What is the absolute value of TSI in W/m^2 ?
 - Impact on solar modelling
 - Impact on global climate models on Earth and potential influence on global climate change
- What is the TSI variability over the last 40 years?
 - Reference point of proxy modelling of historical TSI variation
 - Impact on potential influence on historical climate change
- The historical reconstructions of TSI by proxies have been done by several groups (SATIRE, NRLSSI2, Lean & Fröhlich ++) are completely dependent on the scaling of the TSI composite the last 40 years.



The “ACRIM gap” is the main problem during the last 40 years!

- All the ACRIM instruments, VIRGO, SORCE and later instruments has reference cavities to evaluate degradation in space.
- The gap between ACRIM1 and ACRIM2 is only covered with instruments of lower absolute quality.
- The discrepancy between the the different composites is mainly based on how different groups treat the ERB and ERBS corrections in the ACRIM gap.
- The two extremes in the treating of the gap are shown. For the gap and pre-gap the PMOD version is used in the composite of Dudok de Wit et al.



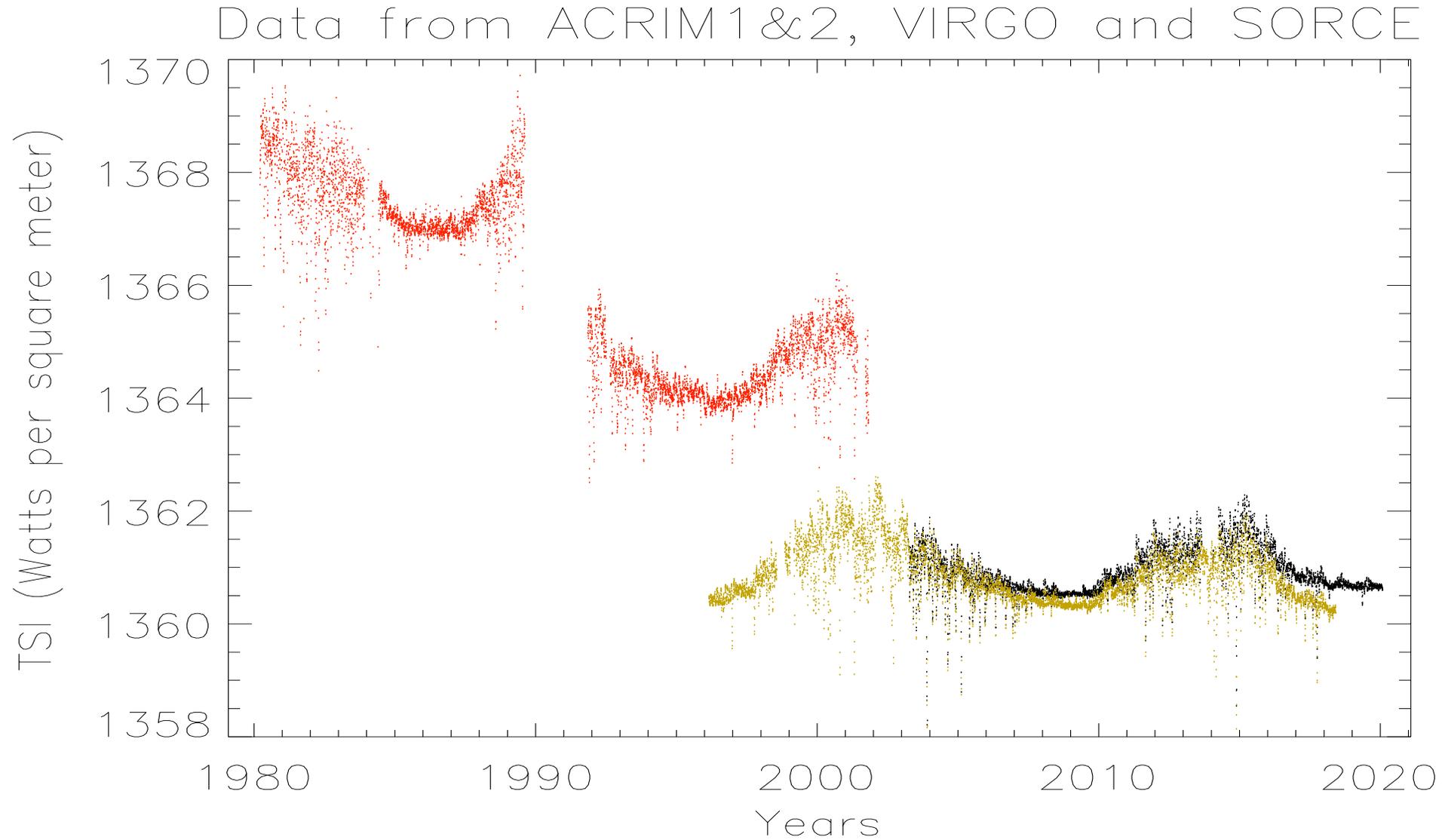
From Scafetta & Wilson 2019, Advances in Astronomy ID 1214896

What can we do to correct across the gap determine the 1986 minimum value ?



- I do not use the the ERB and ERBS data across the gap, thus not going into this correction discussion.
- Assume that the the ACRIM, VIRGO, SORCE PIs have control of their instruments degradation.
- Only look at the solar minima, so sunspots and associated faculae have little influence on the TSI value and the noise levels of the measurements are the smallest. Hopefully the signal will then be dominated by the so called ephemeral magnetic regions. We do not know if a proxy connection with TSI is the same for high and low solar activity. This is different than what Fröhlich (2016)¹ did with using the square root of SSN as the proxy.
- Attempt to select proxies that have some variation in phase with the TSI around the solar minima.

TSI raw data used



What should be the reference TSI value after ACRIM gap?

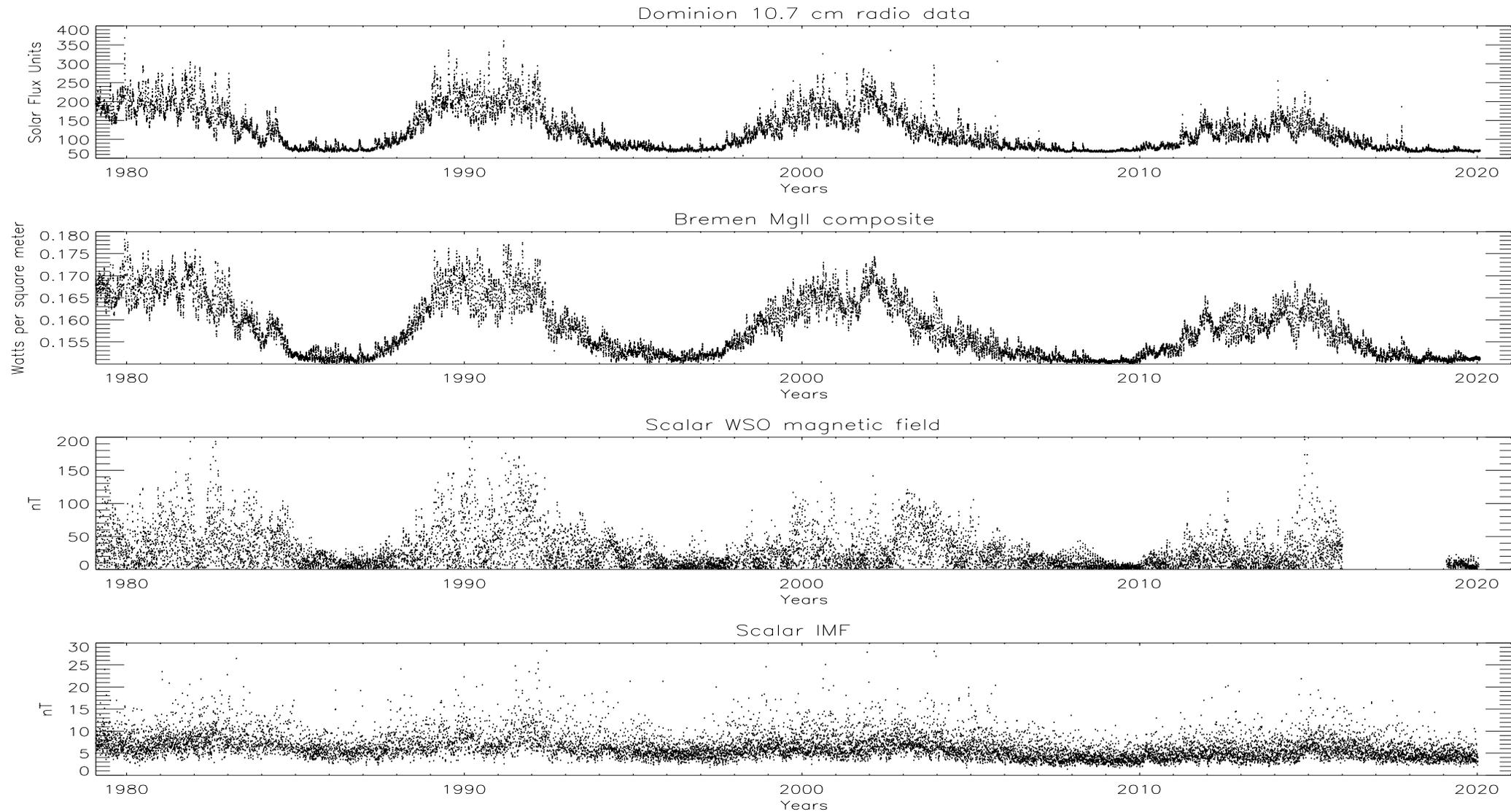


- SORCE, PREMOS, TSIS, TCTE and CLARA have been calibrated with the same instrument before launch. But of these, only SORCE/TIM have long term measurements.
- SORCE and VIRGO TSI measurements are very similar on the short term noise level and show very little long term discrepancy initially, but increasing with time. After 2006 VIRGO clearly falls below SORCE, while SORCE, TSIS and TCTE follow each other closely.
- ACRIM3 has nearly twice as much short term noise as compared to VIRGO and SORCE individually around the 2008 minimum, so it is not used in this study.
- No averaging of the data, just daisy chaining around the minima.
- The fitting of the composite starting with the ACRIM gap is using data from:
 - SORCE as reference from 2007 to now
 - VIRGO from minimum 1996 towards minimum 2008
 - ACRIM2 data from gap to the 1996 minimum

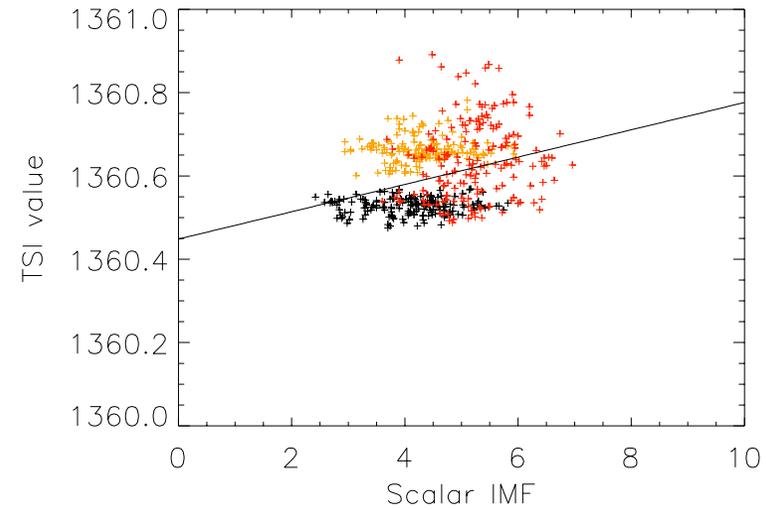
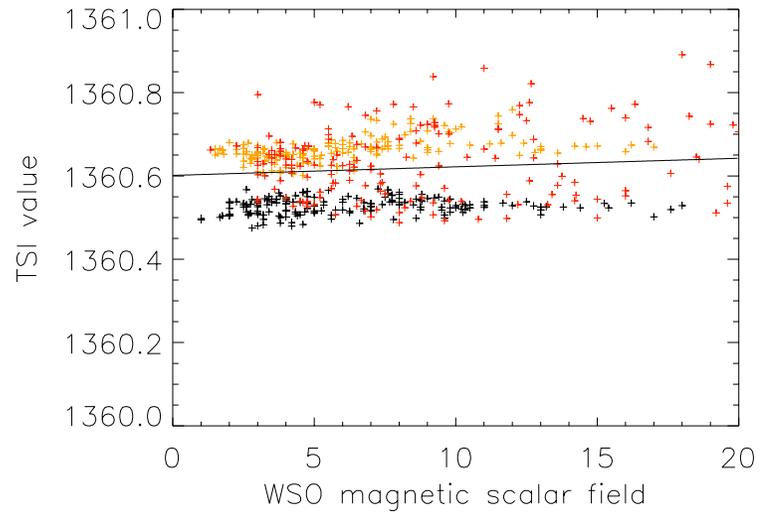
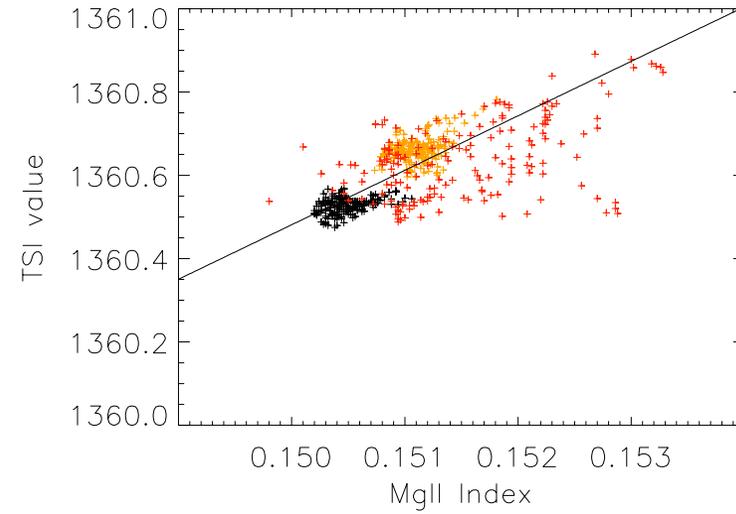
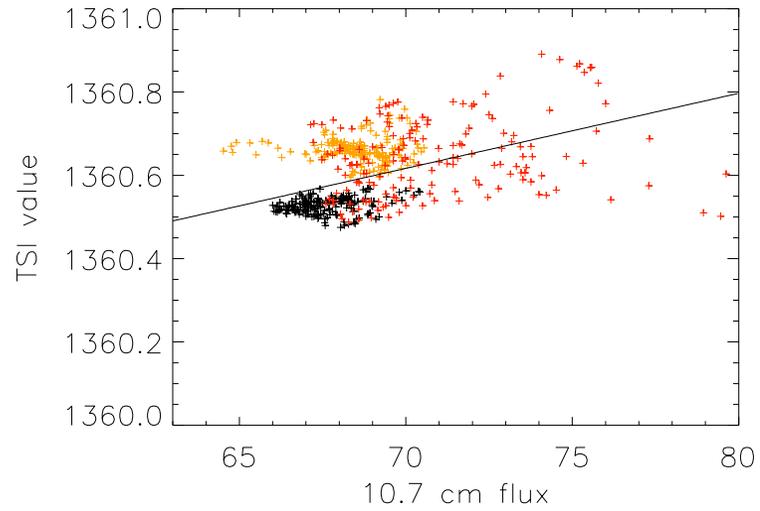
What proxies should be used?

- For long historical reconstructions like SATIRE and NRLSSI2, sunspot numbers have to be used. However for my work with the last four minima, the near zero SSN at the minima makes this type of reconstruction difficult for the minima times.
- In addition the proxies should be least coupled with the active regions and only proxy connections at the solar minima are used. This implies fewer data points, thus higher noise, but less influence from deeper seated activity.
- Both Fröhlich (2009¹, 2011²) and Broomhall (2017³) have looked at number of potential proxies with some success. Broomhall finds that the effects on the solar oscillation frequencies comes from very shallow magnetic structures (ephemeral regions) that dominate at solar minima, so proxies should be related to these magnetic structures.
- On this basis I use the following proxies that all have reasonably good time coverage:
 - Dominion 10.7 cm radio flux
 - Bremen MgII composite
 - WSO solar magnetic fields
 - Scalar IMF field

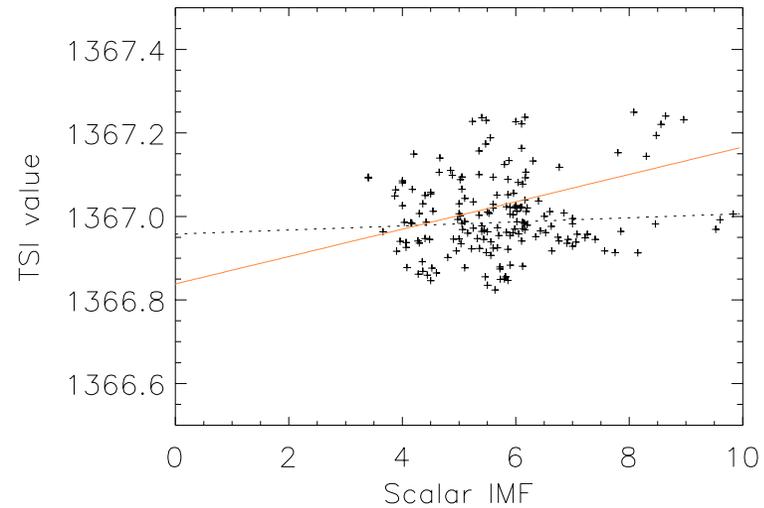
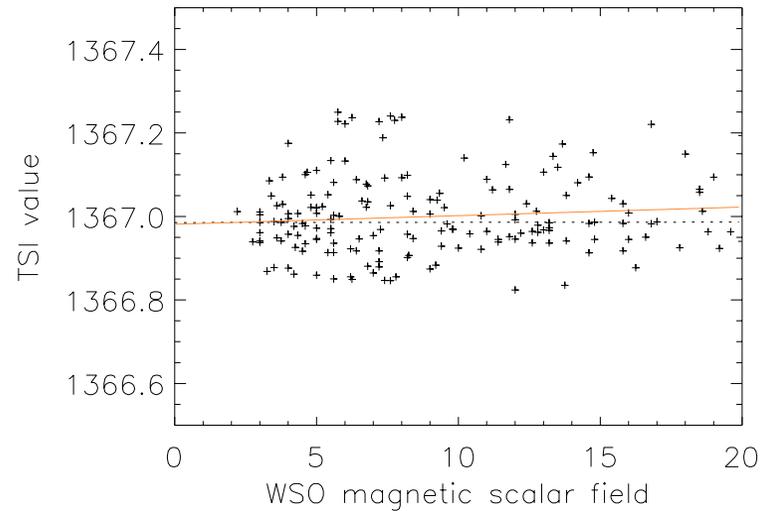
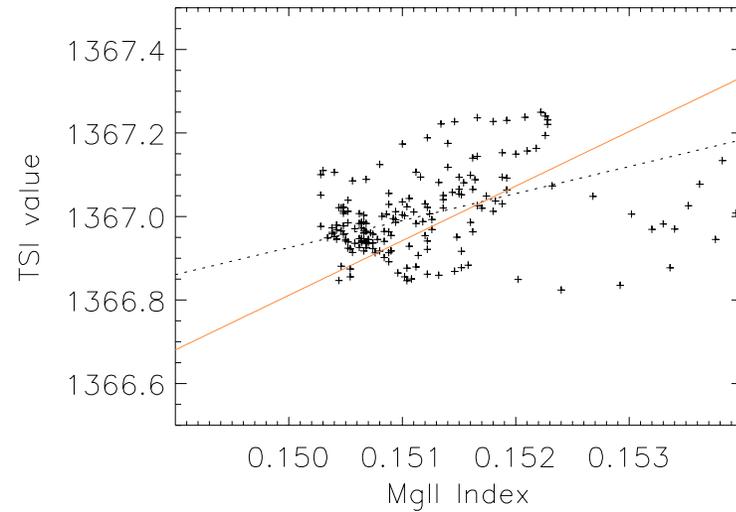
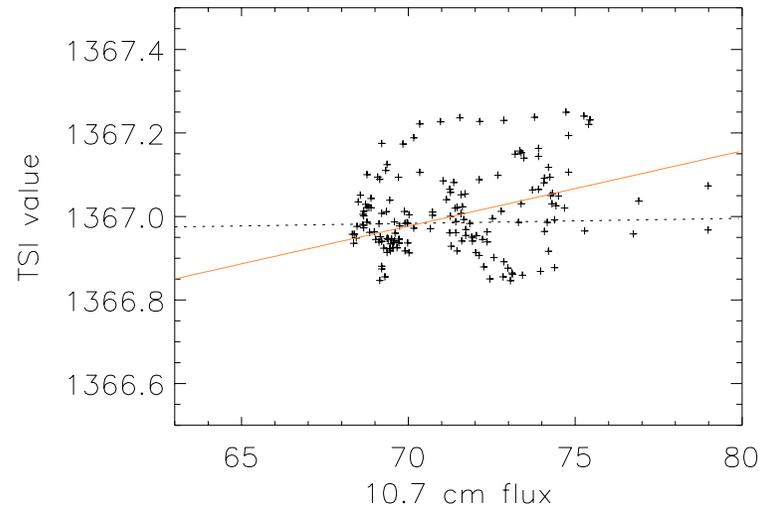
Time series of proxies



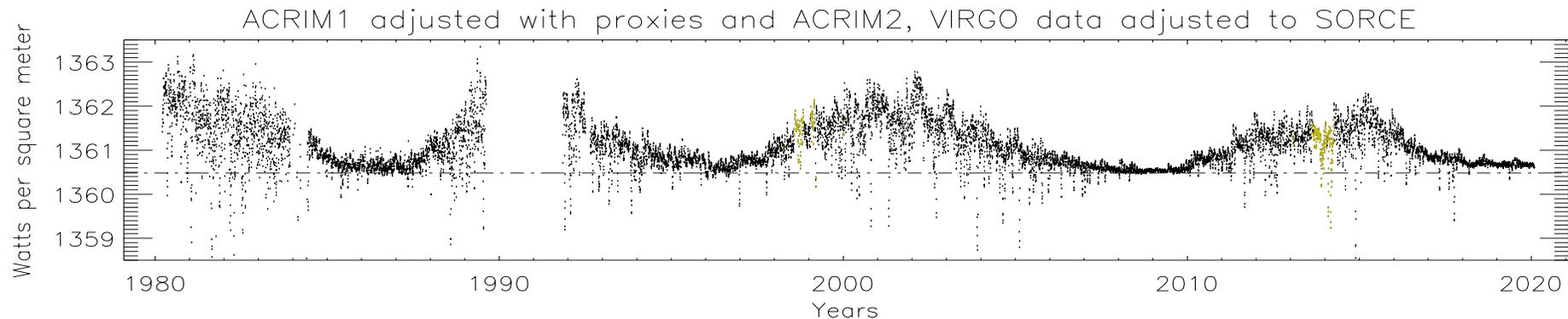
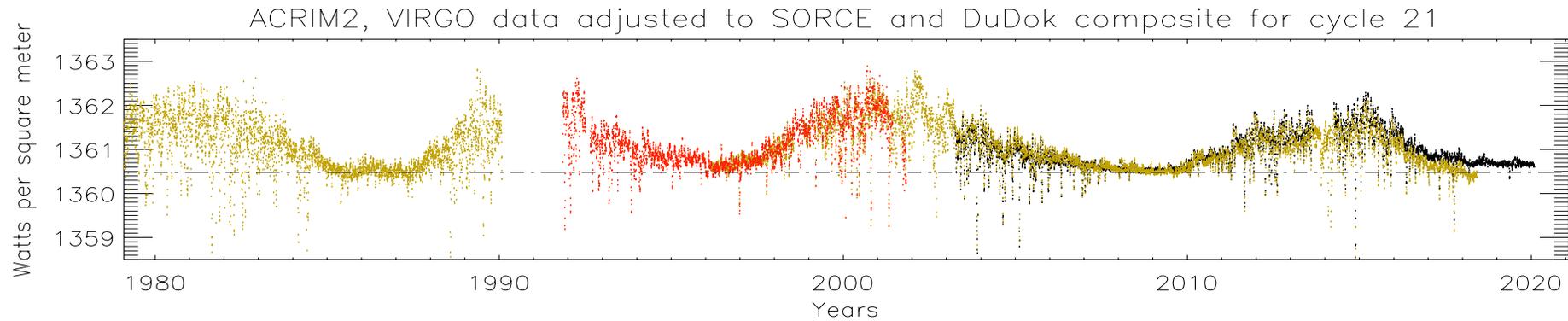
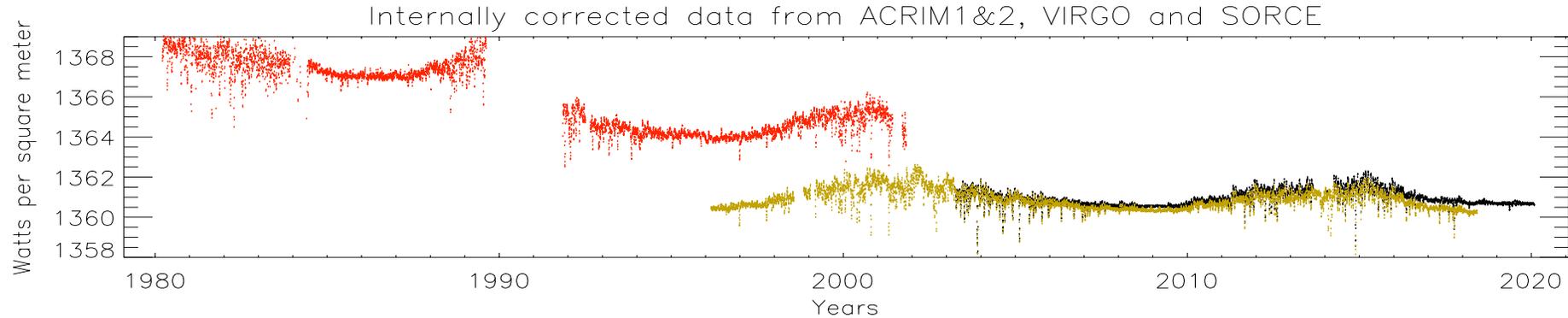
Proxies and solar minima TSI values (96,08,19)



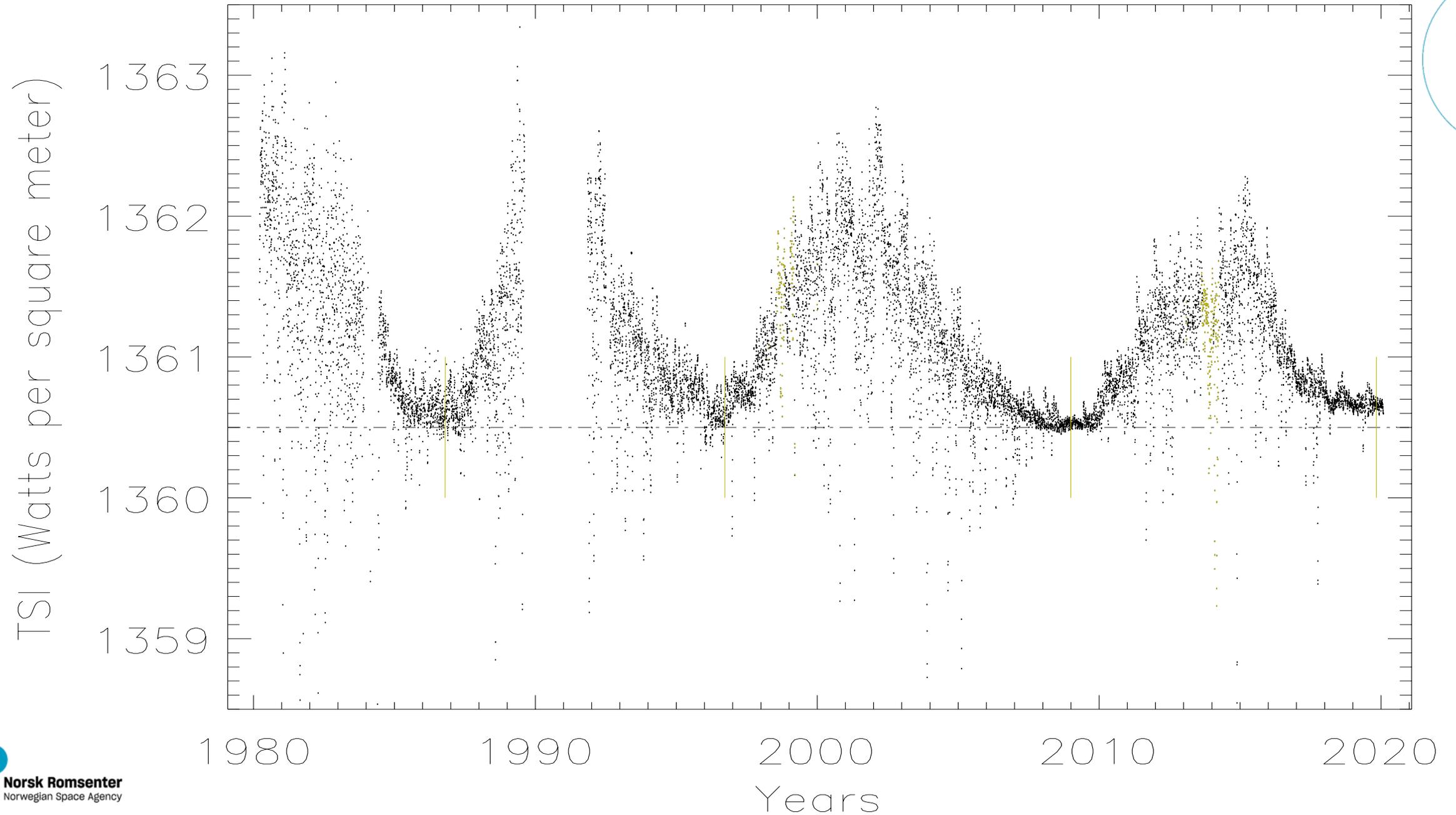
Proxy dependencies applied to 1986 minimum



Sequence of creating composite



Final composite



Results



- The resulting TSI values referring to the SORCE calibration are:
 - 1986 1360.60 W/m²
 - 1996 1360.61
 - 2008 1360.52
 - 2019 1360.65
- This implies that within 1- σ there is no variation of the TSI value for the last four minima, but still the 2008 minimum is measured as the lowest and with the least noise.
- There is a significant variation of the total noise level at the minima:
 - 1986 0.1 W/m²
 - 1996 0.12
 - 2008 0.02
 - 2019 0.03
- This implies that the noise levels of the solar magnetic activity or TSI for the last two minima were lower than for the 1996 and 1986 minima.

Discussion (1)

- All the proxies by themselves give very similar results, a maximum variation of ACRIM data in 86 minimum around the given value of 0.04 W/m^2 .
- The chosen region for calculating the proxy-TSI dependence around the four minima is 6 months, varying this from 4 to 8 months shifts the 86 values within 0.03 W/m^2 .
- The unknown time of the 2019/2020 minimum has even less impact.
- Reasonable shifting the minima times for the 2008 minimum has no impact, while a similar shifting of the minima times of 1986/1996 minima can influence the results up to 0.1 W/m^2 .
- All of these potential errors are well within the accuracy and possibly the stability of the different TSI instruments.
- The dominant source of the noise level variation at the minima is clearly solar, as the VIRGO observes this directly for the 1996 and 2008 minima.

Discussion (2)

- How reliable are the stability SORCE data after about 2007 when there is a clear and different trend from VIRGO. A closer analysis of this should be done by comparison of SORCE, TSIS until the end of SORCE (this may come in Stéphane Bélonds talk later today). Typically the standard deviation between SORCE and TSIS is about 30 ppm ($0.04\text{W}/\text{m}^2$) and no change in the mean difference of about 351 ppm over 2018/2019.
- There are issues with the current SORCE data value being higher than the 2008 minimum while the 10.7 cm proxy are lower than the 2008 values. This is interesting with reference to Schrijver et al (2011)¹ who indicate that the TSI in 2008 may be very close to the Maunder minimum value. However, the MgII data used here, as well as the Oulu neutron measurements indicate that the 2019 TSI should be higher than 2008.
- VIRGO data are not currently updated after May 2018 because of Claus death. The VIRGO data are a combination of the PMOD-6 and DIARAD data and currently the VIRGO team cannot extend Claus work for the newest data. We are looking into new methods to do this consistently.

Conclusion

- This study shows that the TSI for the last four minima do not have variation outside the observational uncertainty.
- The 2008 minimum has the lowest measured value, as several studies have previously described.
- The increasing discrepancy between the VIRGO and SORCE instruments is not yet resolved.
- There are no indications that the variation of the solar minimum TSI value has had significant influence on the global warming since 1979. However the stable values obtained have implications on the total solar forcing for the period.

New TSI (ACRIM gap filled with Dudok de Witte et al (2017))

