Total Solar Irradiance Variations: What can we learn from the last three Cycles?

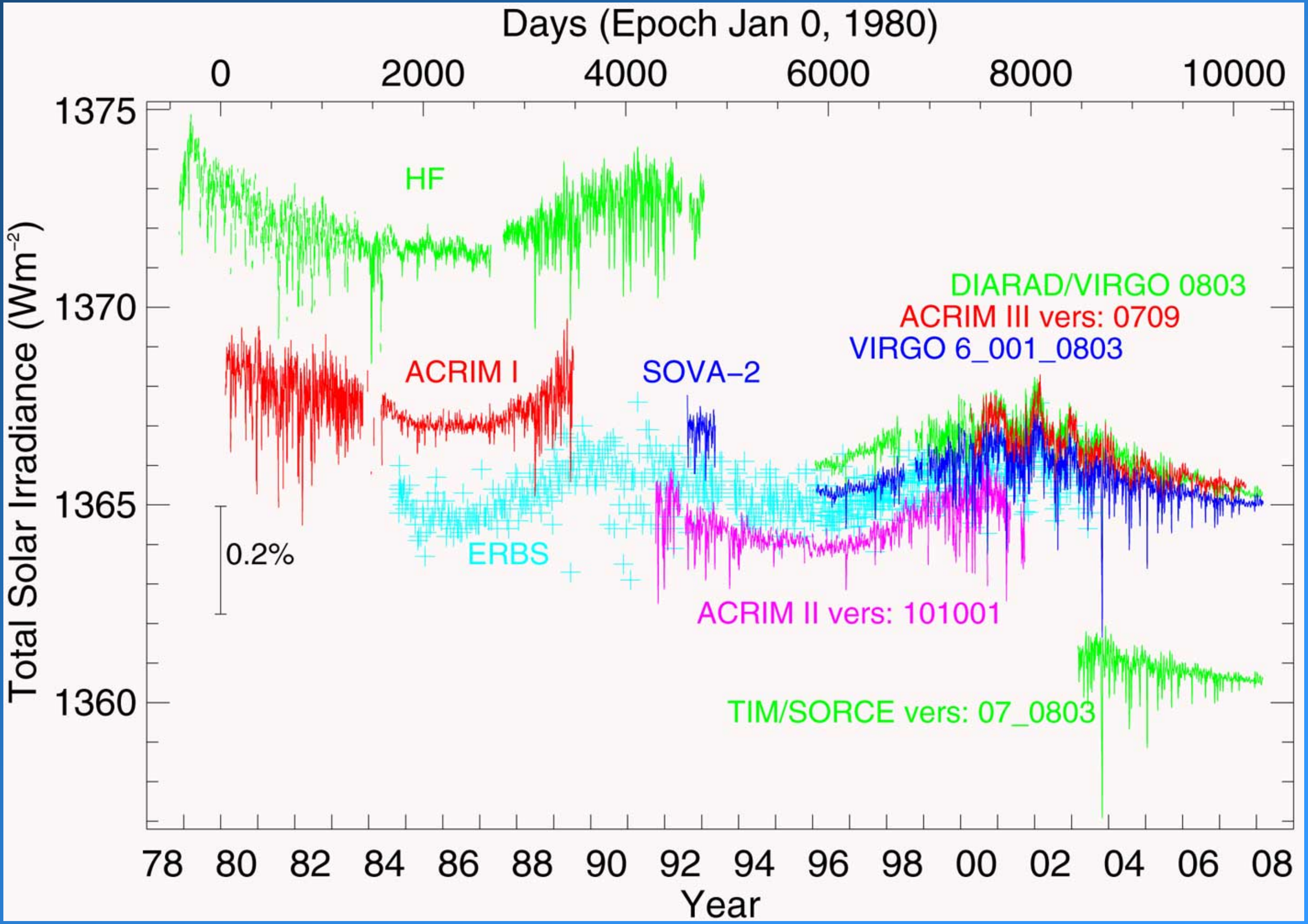
Claus Fröhlich
Physikalisch-Meteorologisches Observatorium Davos
World Radiation Center
CH 7260 Davos Dorf

This presentation is based on the most recent data from VIRGO (with help of the VIRGO and SoHO teams) and many discussions mainly with Mike Lockwood, Leif Svalgaard and Jürg Beer.

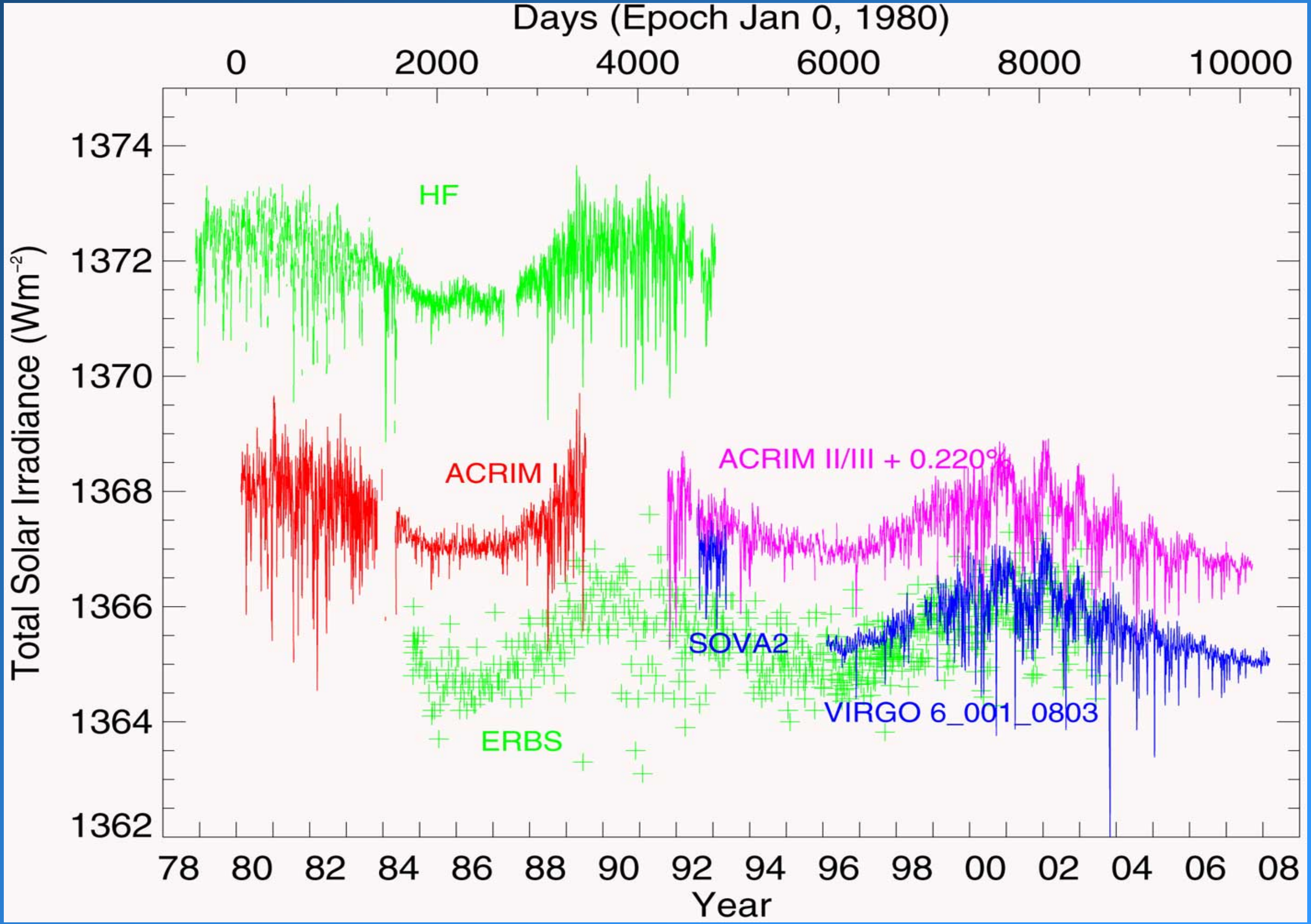
Outline

- Total solar irradiance data: Observations
- Proxy models from activity indices: development and results from 3-component model
- How is TSI connected to the open magnetic field of the Sun which in turn modulates the cosmic rays
- Conclusions

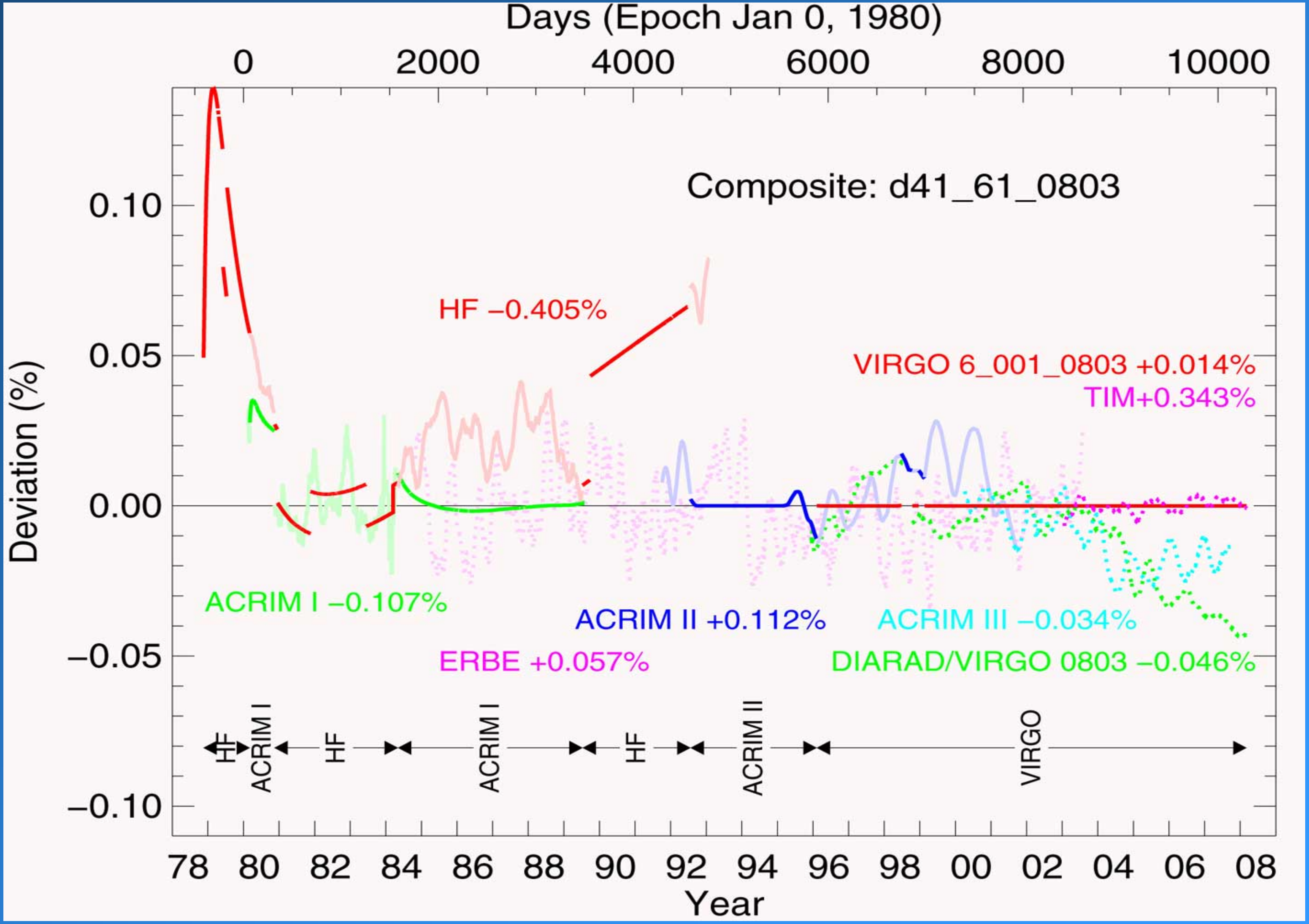
TSI Observations and the construction of a Composite



TSI Observations and the construction of a Composite

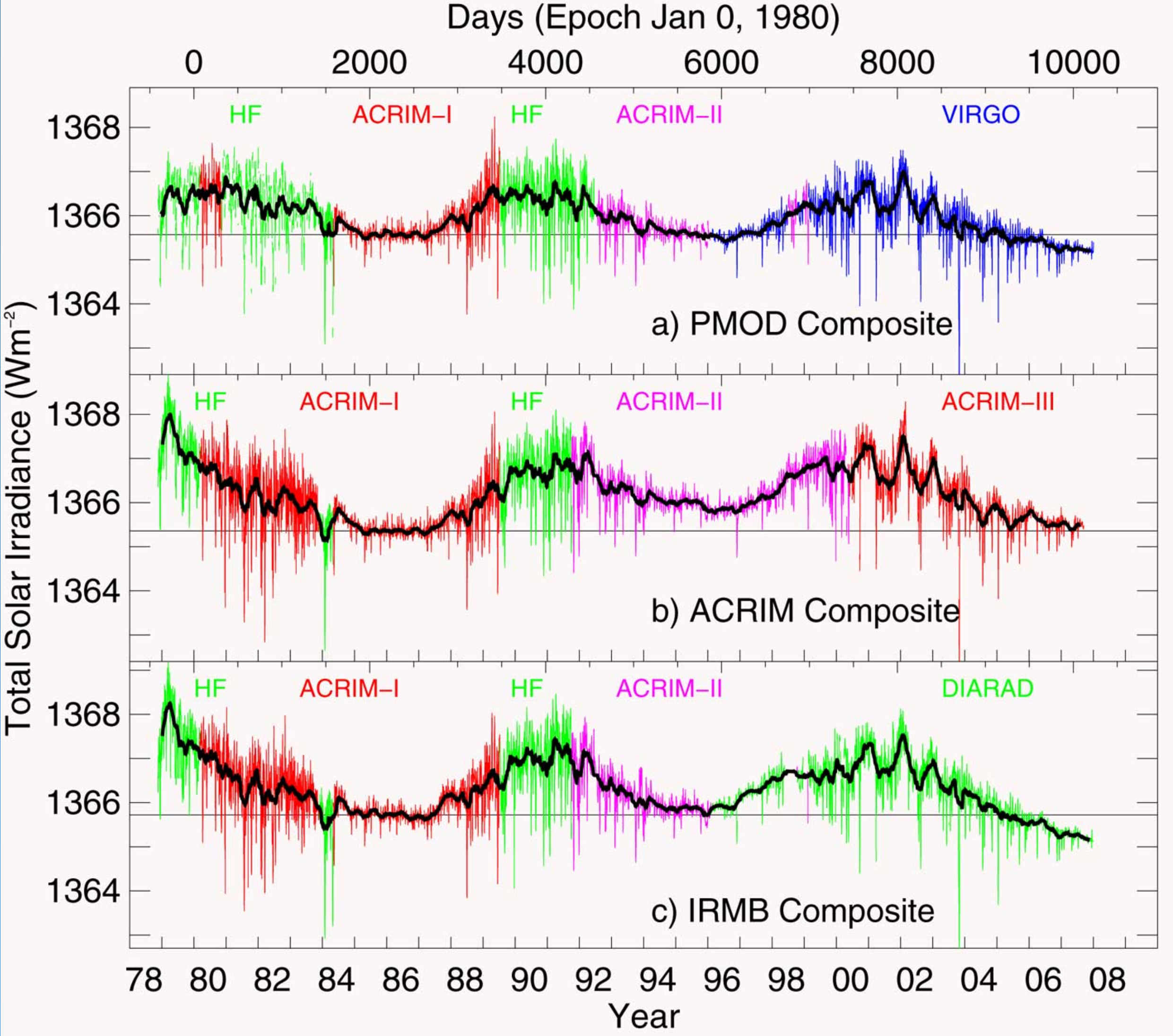


TSI Observations and the construction of a Composite



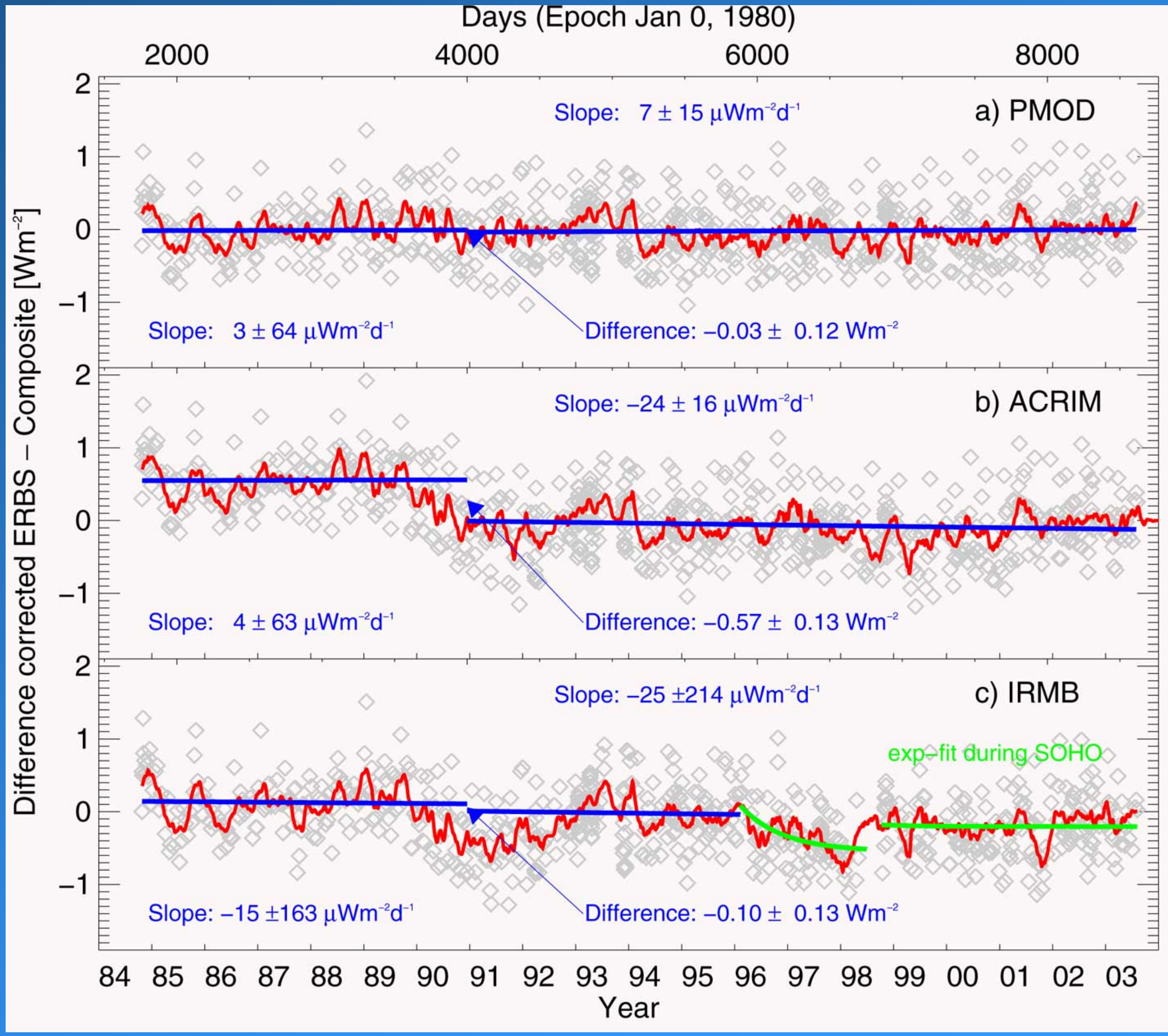
TSI Observations and the construction of a Composite

- Two differences between the three composite are quite obvious
  - for the maximum of cycle 21 which is clearly due to the neglect of a correction for degradation and other long-term changes of HF.
  - The other is due to the uncorrected increase of HF during the ACRIM gap.
- Others are less obvious, but become clear from a comparison with ERBE



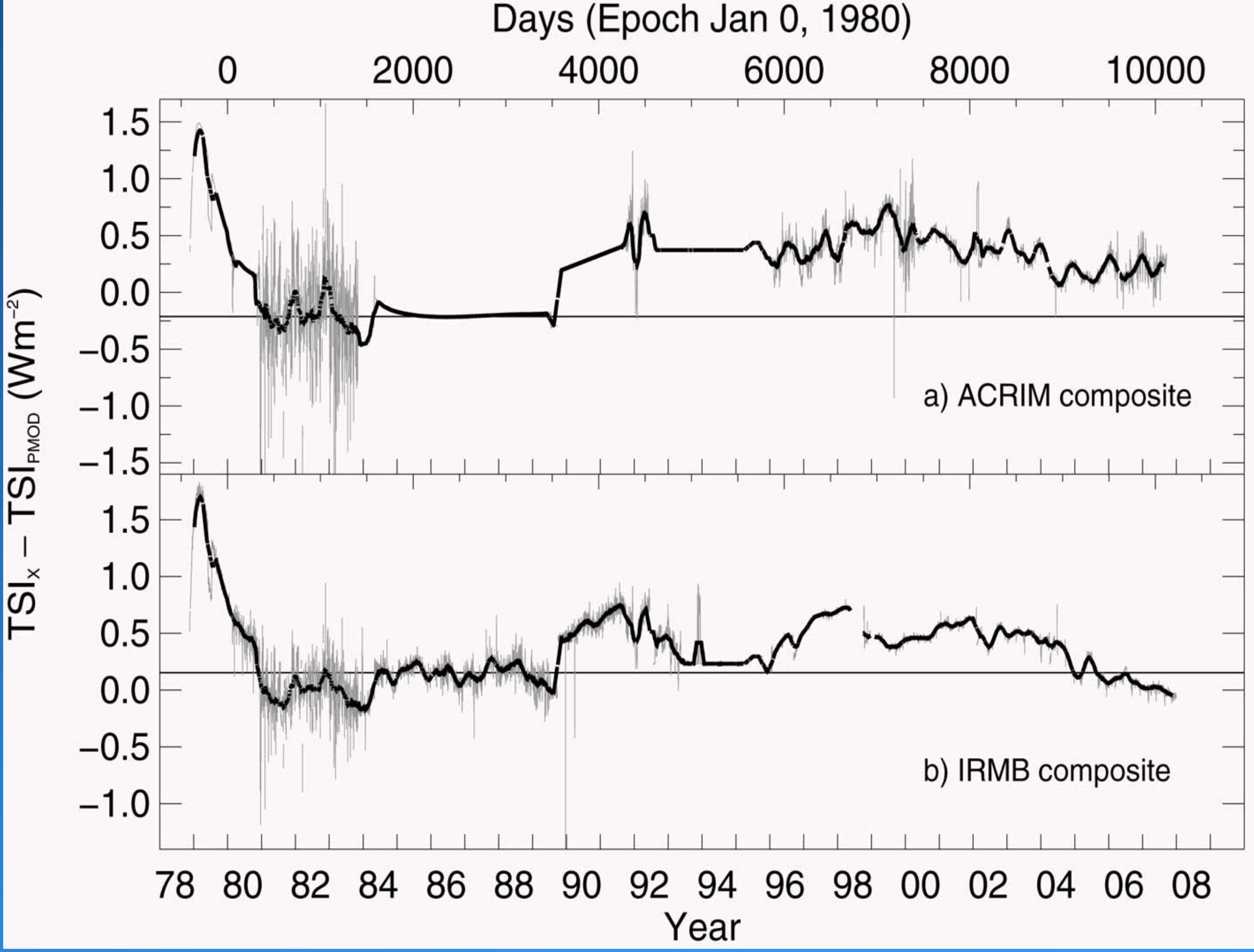
TSI Observations and the construction of a Composite

- This comparison is shows that the PMOD composite has the highest correlation with ERBE. But, there are also other differ-ences partly due to the change over the ACRIM gap and partly due the way the IRMB composite is con-structed.



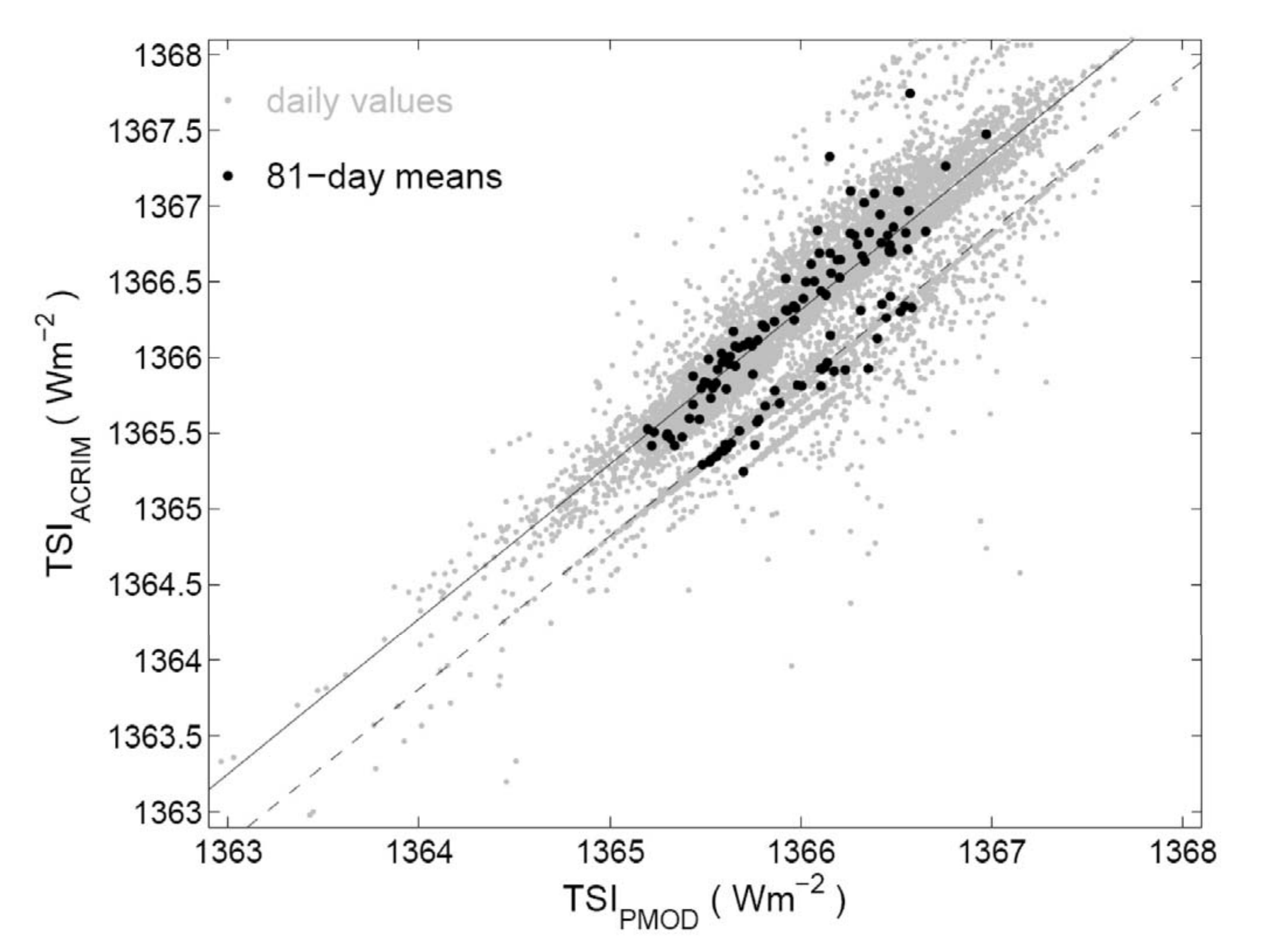
TSI Observations and the construction of a Composite

The direct comparison of ACRIM and IRMB composite with the PMOD one summarizes the differences.



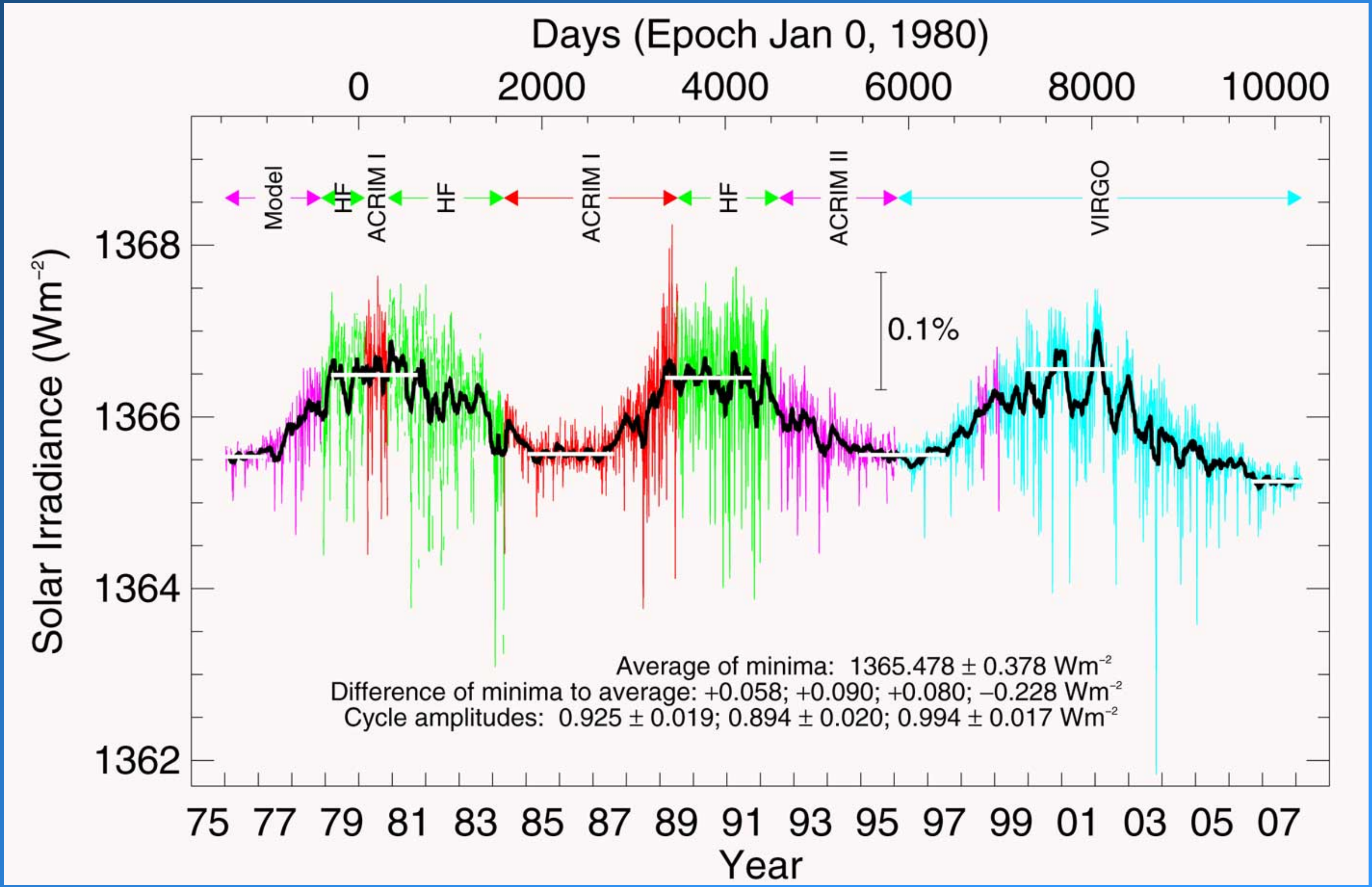
TSI Observations and the construction of a Composite

The direct correlation between the ACRIM and PMOD composite illustrates the step over the ACRIM gap.



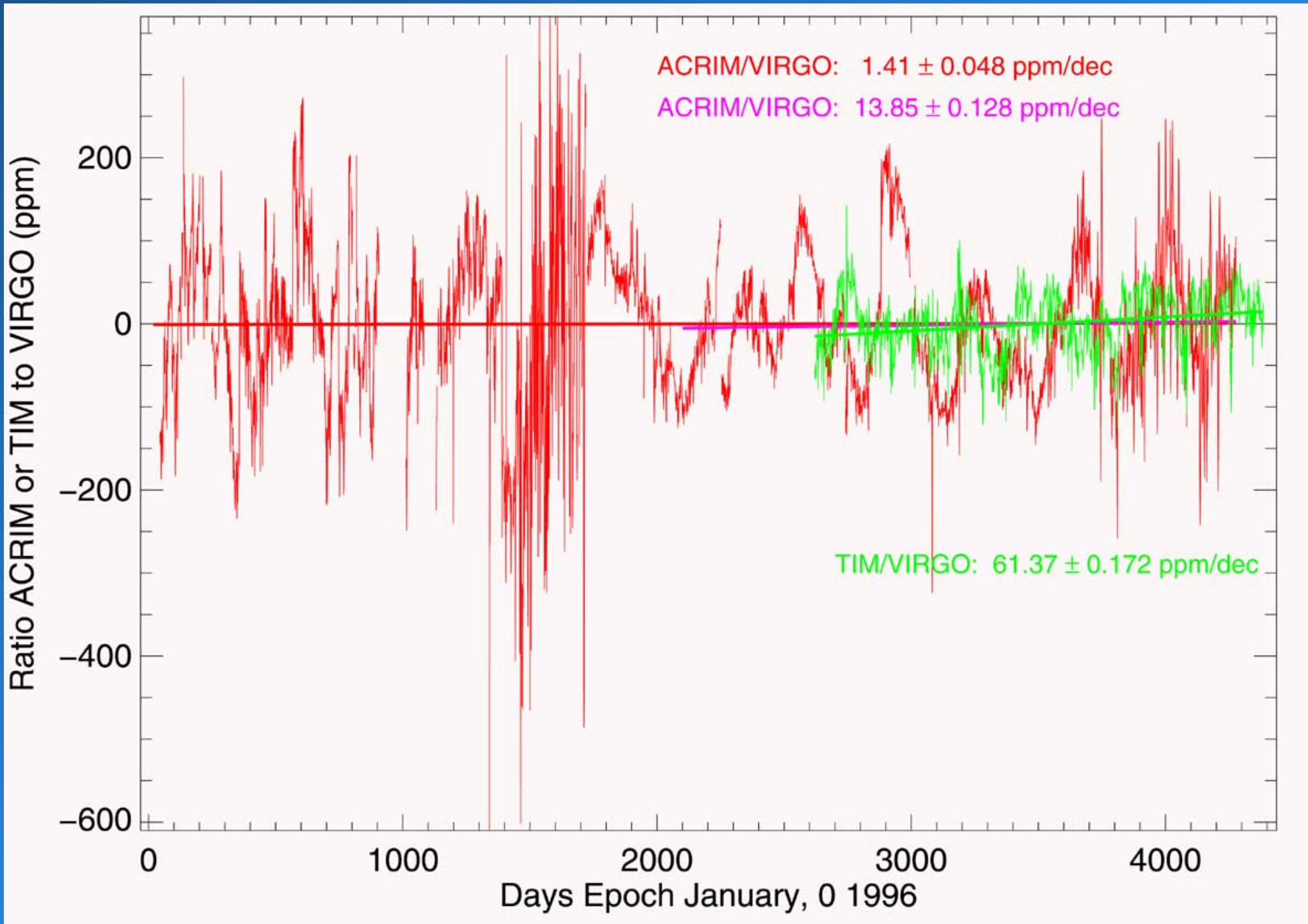
The PMOD Composite

The PMOD composite has been extended back to the minimum in 1975 with a proxy model. It can be downloaded from http://www.pmodwrc.ch/pmod.php?topic=tsi/composite/SolarConstant



Comparison with other TSI

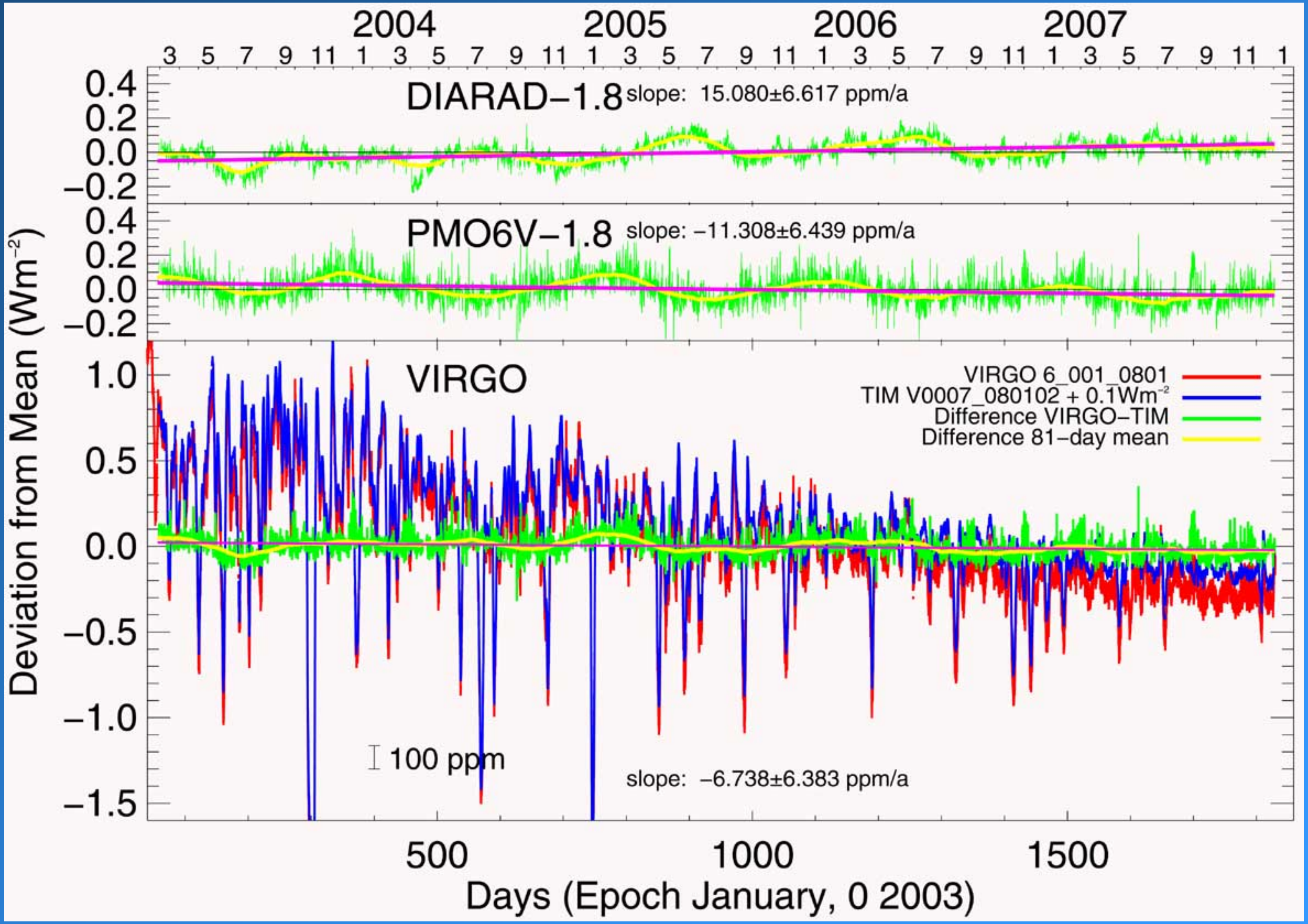
- Before we can go on we need to be sure that we have data representing the true solar variability
- So we need to demonstrate that the trend of TSI as observed during cycle 23 is real.
- We do this by comparison of VIRGO which covers most of cycle 23 with ACRIM II on UARS, continued by ACRIM-III and with TIM on SORCE.



From this slope we may estimate the uncertainty as ± 35 ppm/decade, which corresponds almost exactly to an earlier estimate based on a detailed analysis of the different corrections used for the construction of the composite.

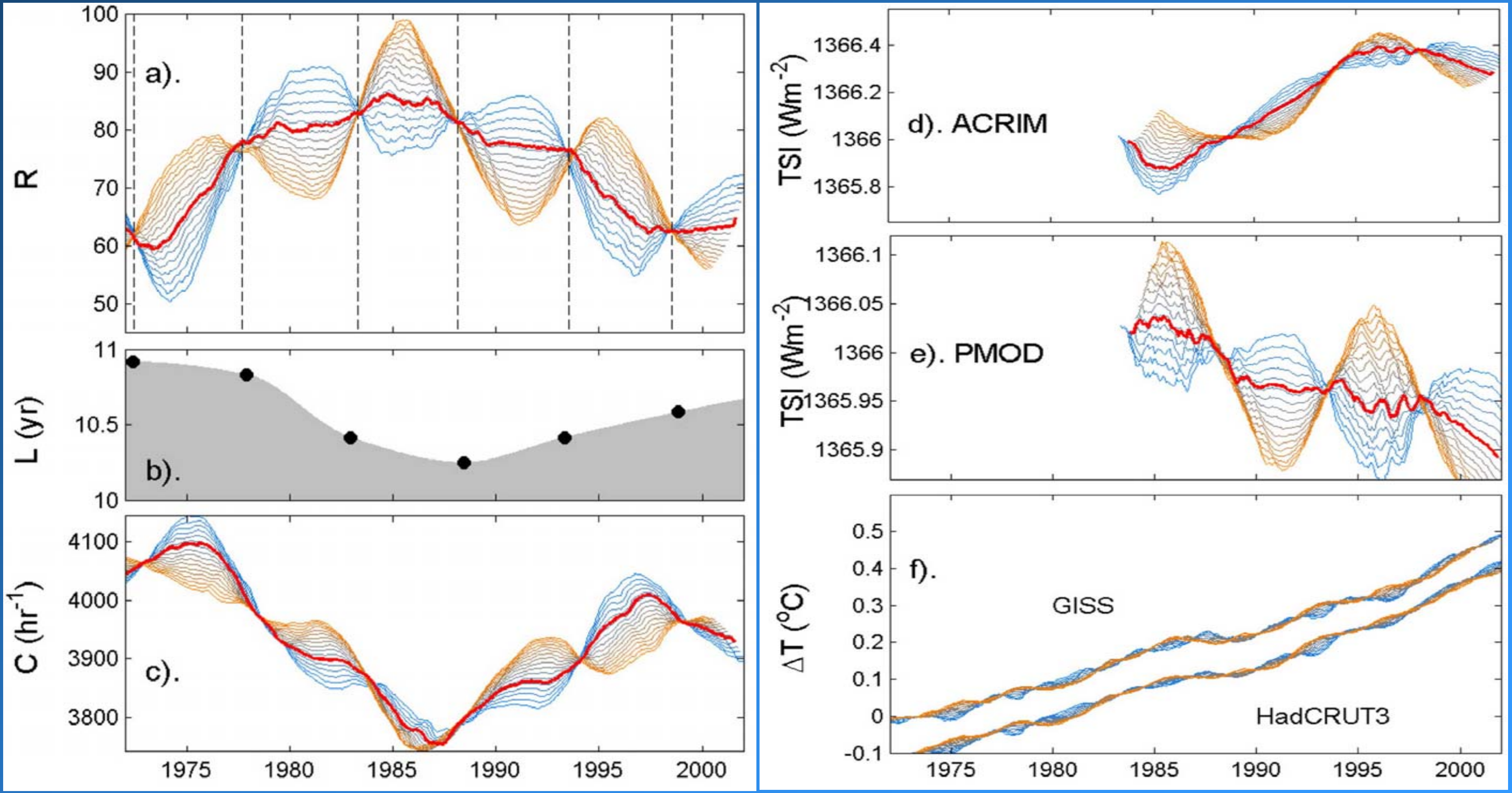
Comparison with other TSI

Some details about the comparison of VIRGO with TIM/SORCE. Note the regular annual cycle of the PMO6V radiometer which is probably due to the ± 3% irradiance variation and a non-linearity of the sensitivity



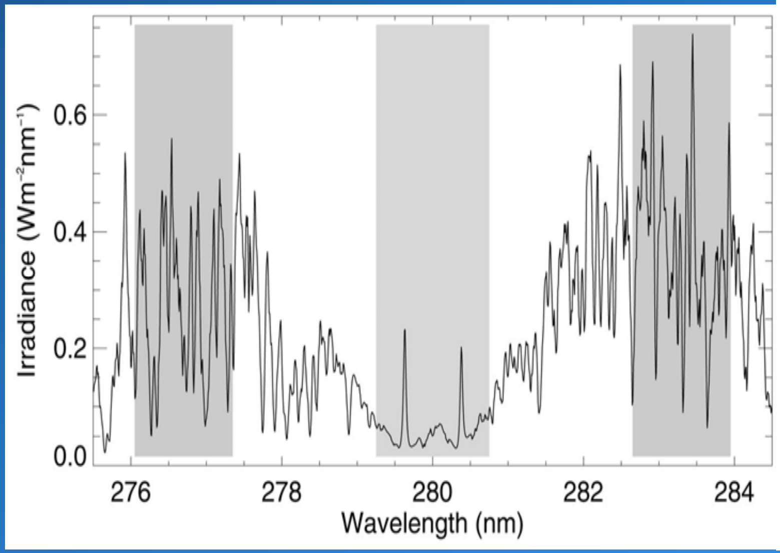
What about a long-term trend?

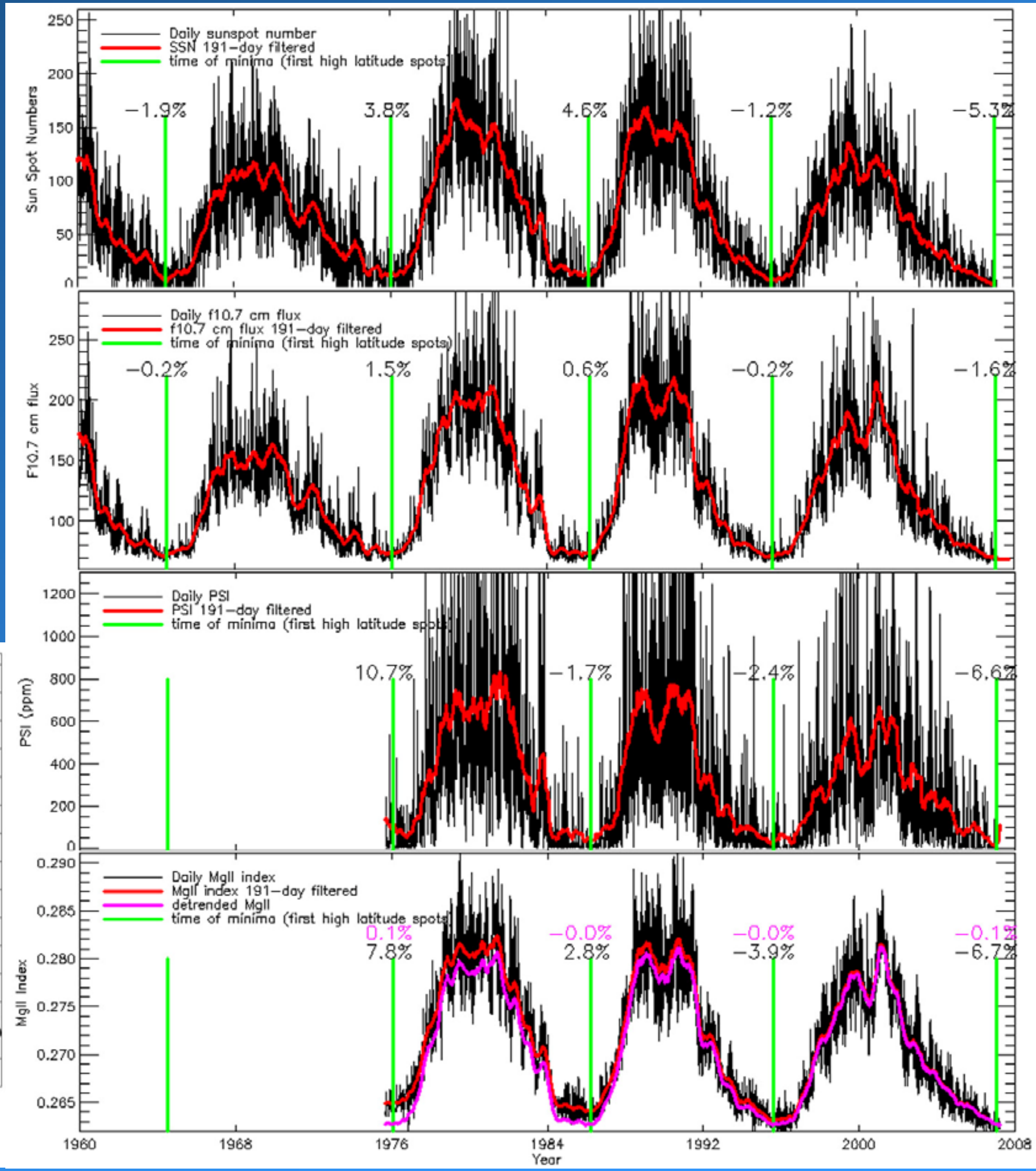
Lockwood and Fröhlich (2007) have shown that all the indices show a downward trend if we look at solar cycle averages. a) shows the sunspot number, b) the length of the cycles, c) the cosmic ray count which is inversely proportional to TSI. d) and e) show the ACRIM and PMOD composite and f) is the Earth temperature anomaly.



Proxy Model of Irradiance Variations

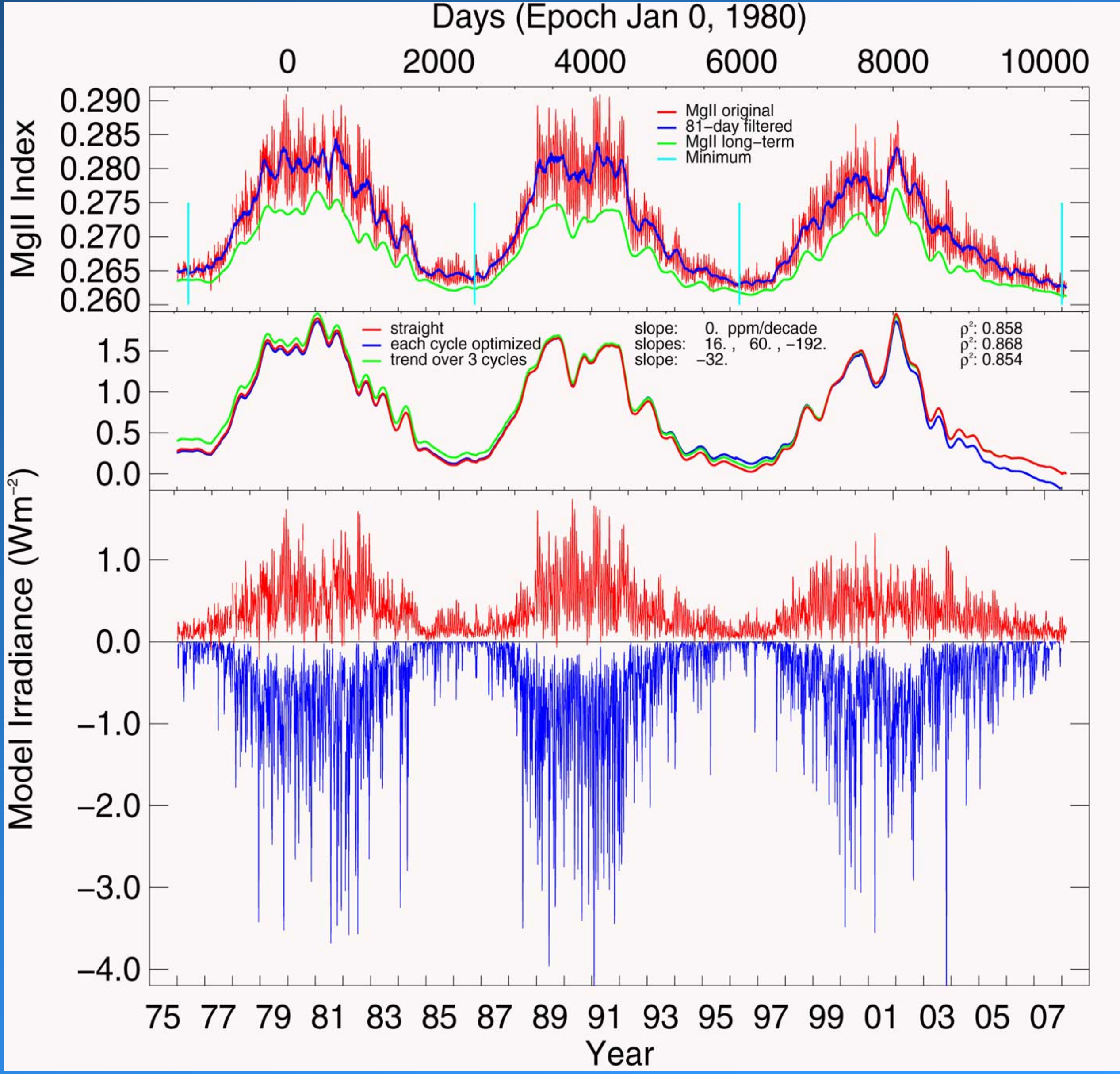
- Sunspots can be modeled from their area and position on the disk by using an appropriate contrast. The result is the photometric sunspot index (PSI)
- For faculae a similar approach as for PSI could be applied. However, the areas are difficult to observe directly. So they have to be derived from plages, magnetograms or spot areas. Here, we use the MgII Index as a surrogate for faculae and net-work. This index is a core-to-wing ratio as indicated below.





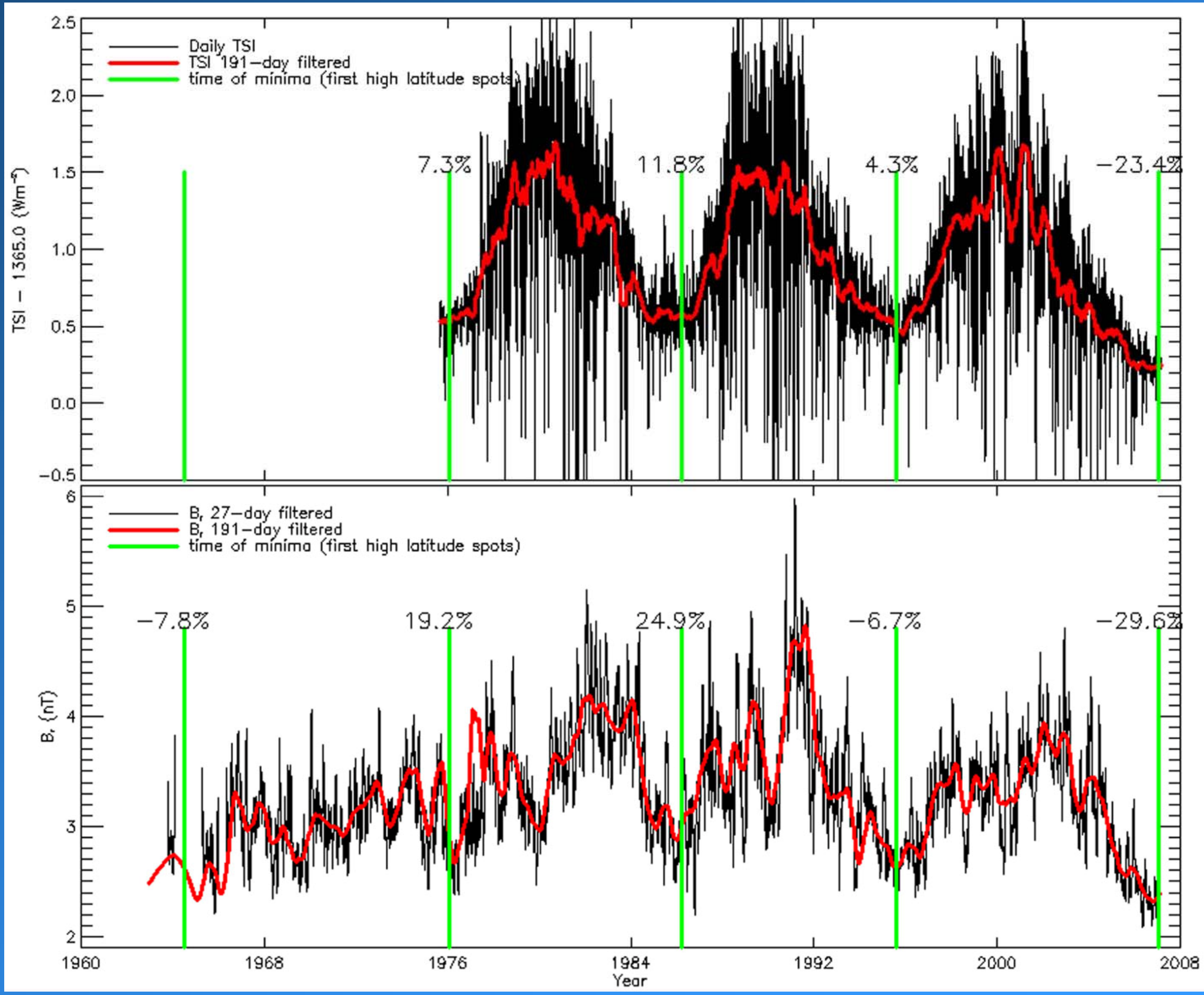
Proxy Model of Irradiance Variations

The Mg index can be divided into short and long-term parts representing the active region faculae and the network within and outside active regions respectively. To explain the recent decrease of TSI we need to include a trend which is due to another physical mechanism. We do the same for each cycle separately and the result is shown in the row 'each cycle optimized'



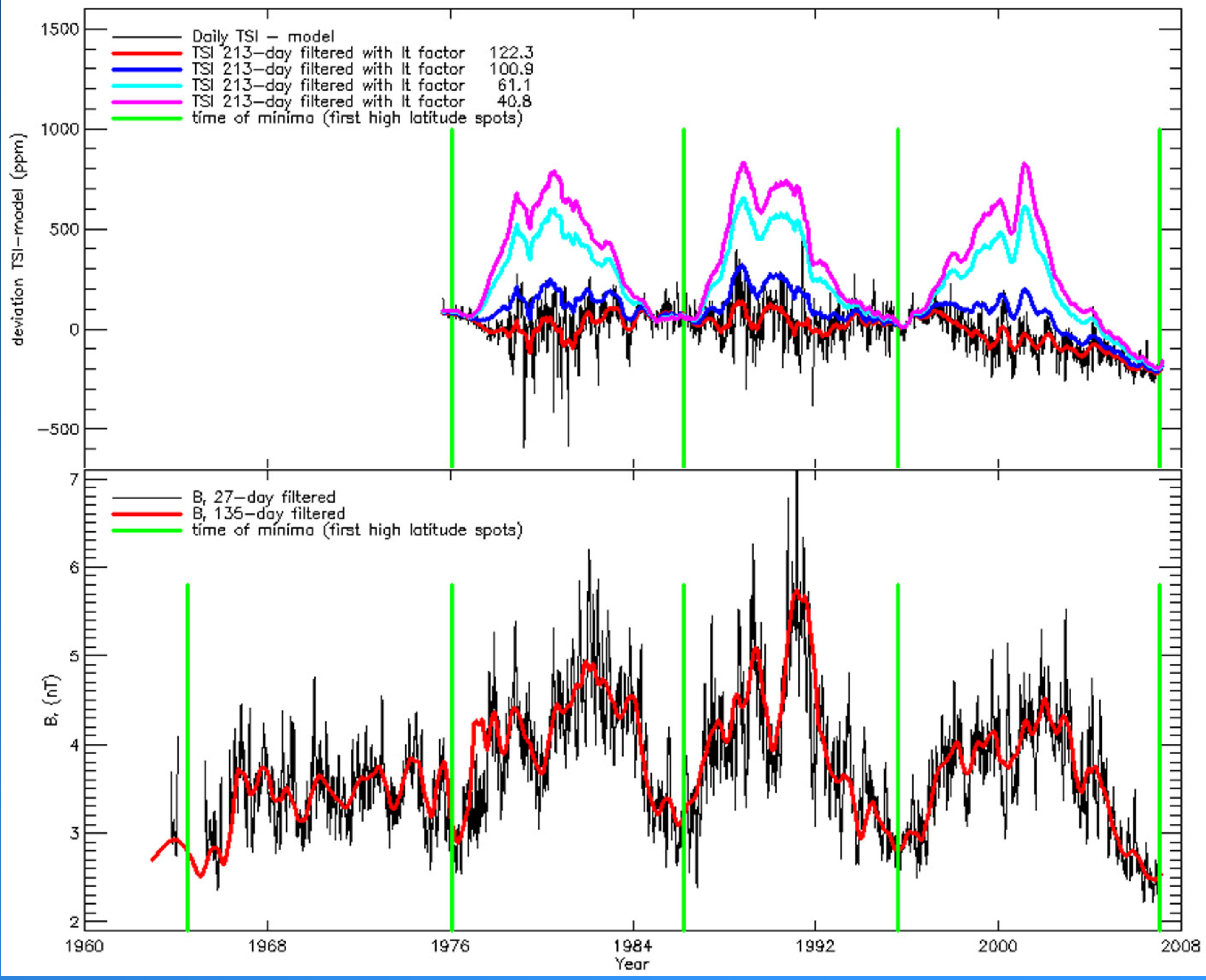
How to explain the recent decrease

The only activity related parameter which shows a similar decrease of the minima is the open field B_r of the sun.



How to explain the recent decrease

It is clear that the correlation of the minima is very good. The question is whether the cycle variation of B_r may also influence TSI. From the upper panel it is seems unlikely. One reason is that the cycle variation is basically different as B_r e.g. at the maximum of the cycle is depressed because the polar field changes the polarity.



Can we determine the sensitivity of TSI relative to changes in open field

Now we can compare the trends between minima: the results are shown for the different cycles in the following table.

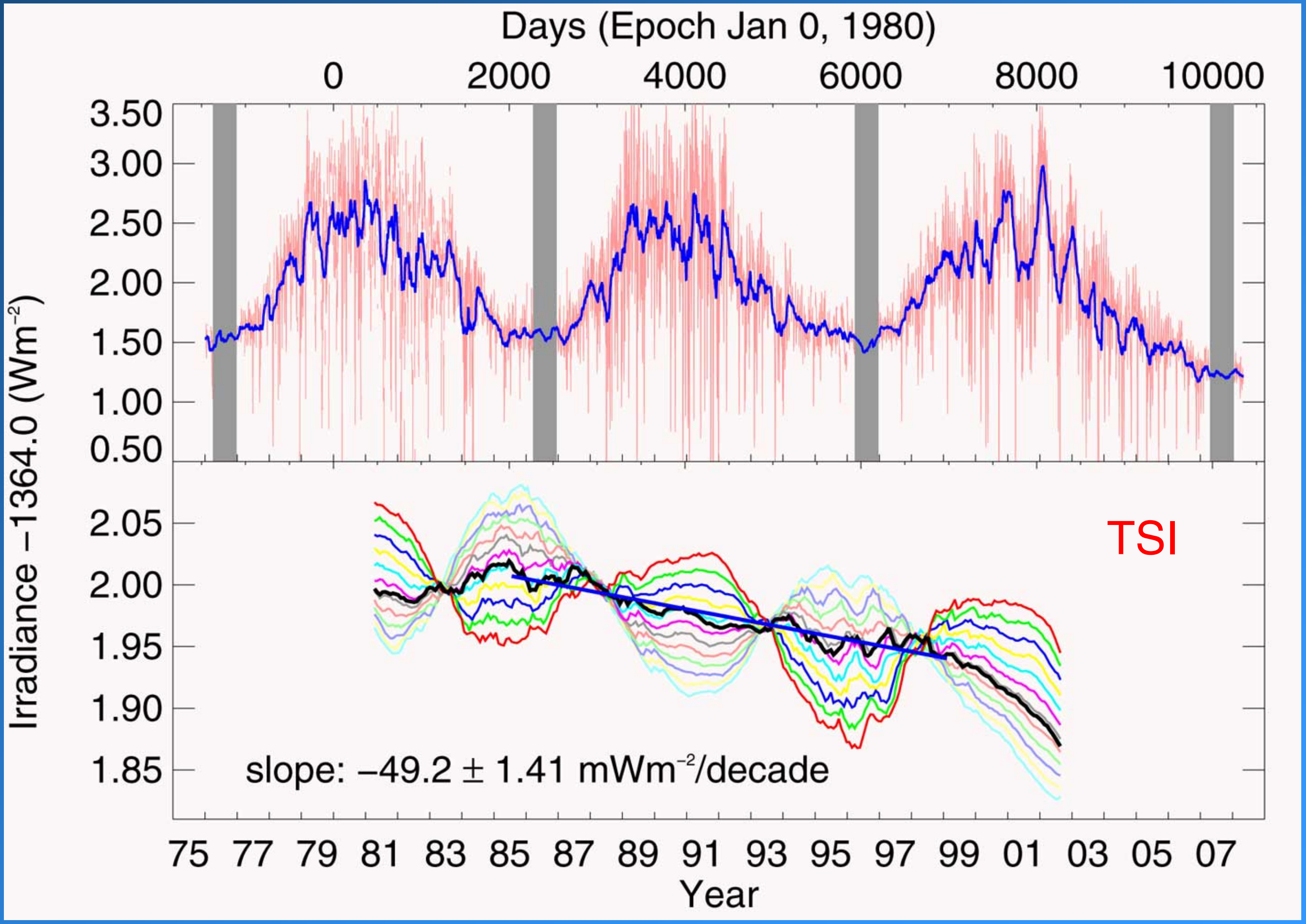
The straight mean yields for the TSI sensitivity 0.61 0.39 Wm^{-2}/nT and if we allow for the full uncertainty range for the minima of cycle 22 (larger) and 23 (smaller) we find 0.59 0.17 Wm^{-2}/nT.

By changing the long-term part of the model we can estimate how much of the TSI variation is contained in B_r. As this is modulates the galactic cosmic rays we may finally reconstruct TSI back in time from the production rate for cosmogenic isotopes.

Parameter:	SSN	f10.7	IMF	TSI	Sens	PSI	MgII
Units:	-	-	nT	mWm^{-2}	Wm^{-2}/nT	ppm	mWm^{-2}
diff over 20:	5.5	1.5	0.26				
diff over 21:	1.0	-0.9	0.06	40.4	0.628	-62.68	-73.2
diff over 22:	-7.0	-0.9	-0.38	-89.5	0.204	-3.86	-103.5
diff over 23:	-4.8	-2.4	-0.22	-221.7	0.847	-30.03	175.1

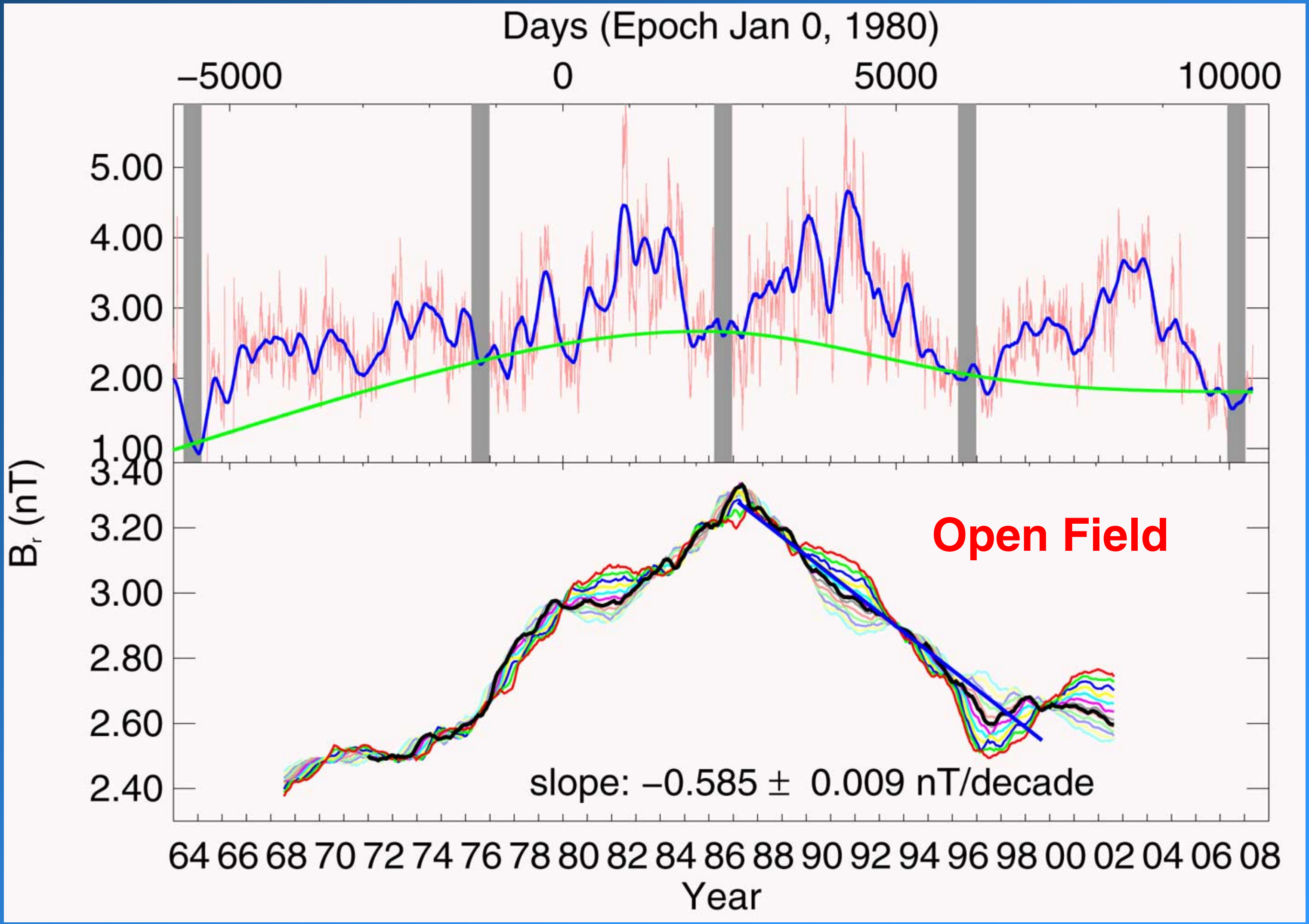
Sensitivity from cycle-averaged trend

From the cycle-averaged trends of TSI and B_r one can also determine a sensitivity. This sensitivity is, however, more determined by the amplitude of the cycle



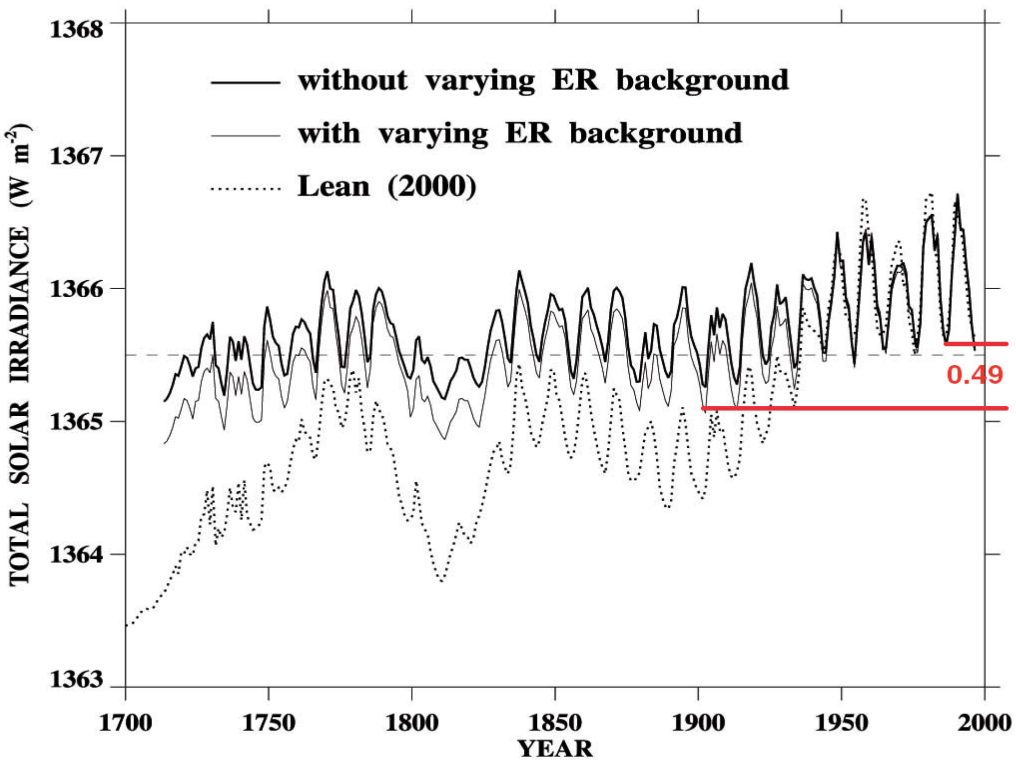
Sensitivity from cycle-averaged trend

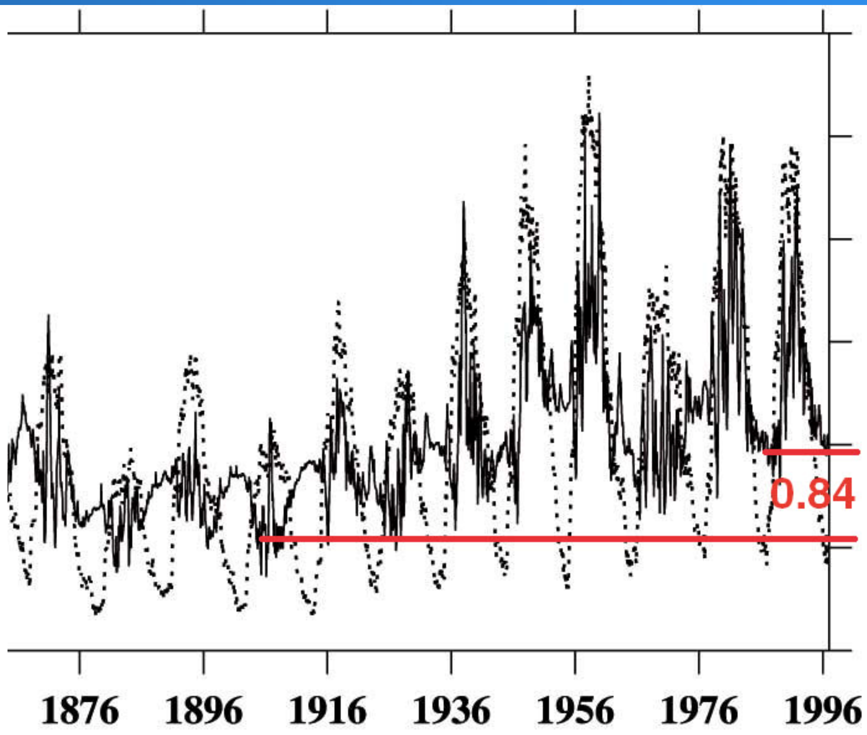
This leads to 0.084 0.005 Wm^{-2}/nT, which is about seven times smaller than the value determined from the minima. From this we conclusde that the amplitude of B_r is probably not relevant for TSI changes – anyway it is highly varying, mainly due to changes in the polar field.



How do the values of Wang et al. compare to the sensitivity we derive from the measurements during last three cycles?

- The difference between 1901 and 1986 is 0.84 nT (just read from Fig 7c).
- The difference in TSI is 0.49 Wm^{-2} including the ephemeral fields (read from Fig.15). The fields from the ephemeral regions, however, are most likely included in the open field. But Judith has to take them extra as her normal reconstruction of the solar cycle is mostly due to active regions.
- So the value of the sensitivity is 0.58 Wm^{-2}/nT.





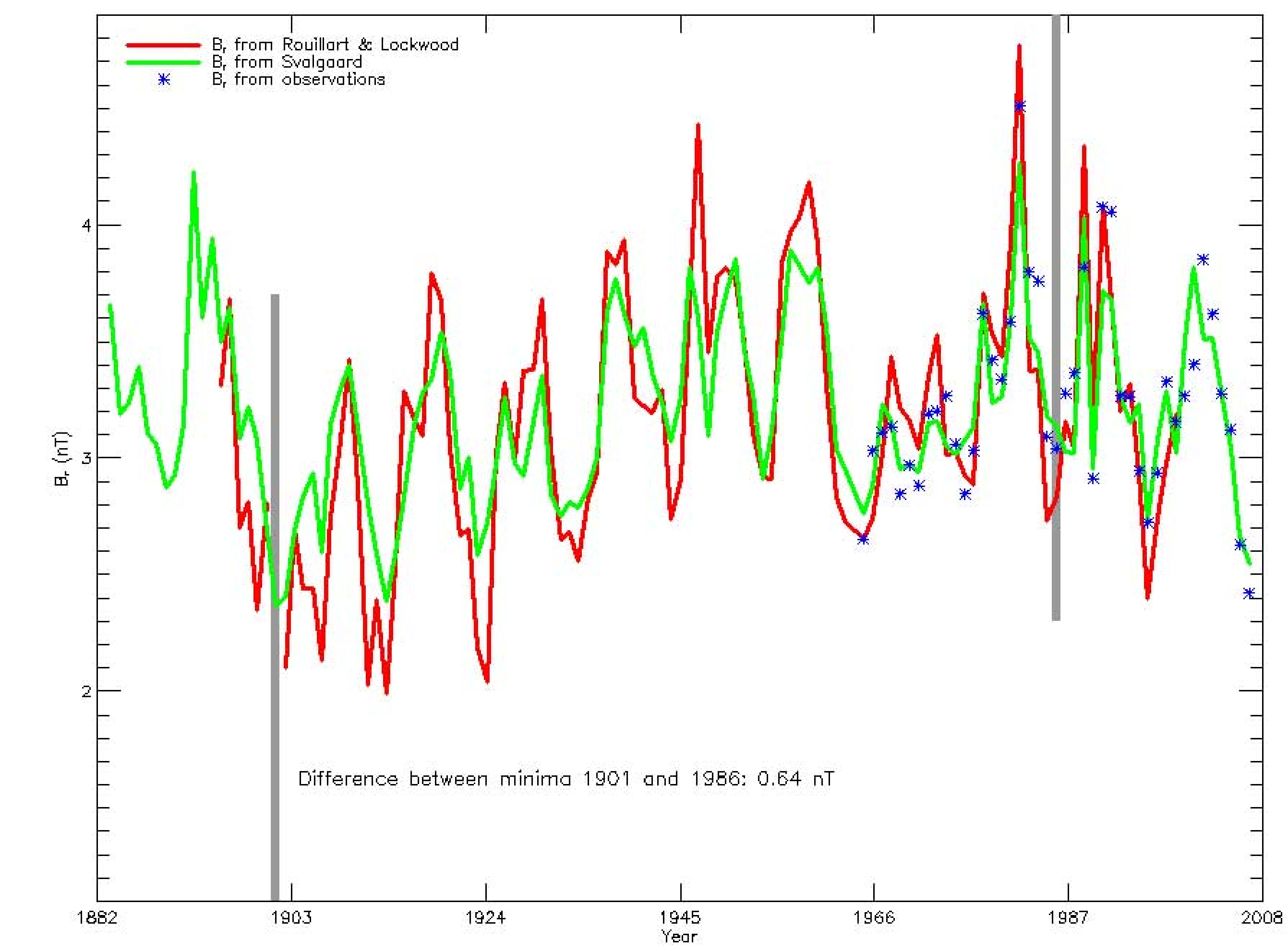
How does the open magnetic field of the Sun behaved during the last century?

In the famous paper of Lockwood et al. in Nature 1999 they were claiming that the Sun's magnetic field doubled during the 20th century.

How does it looks like today?

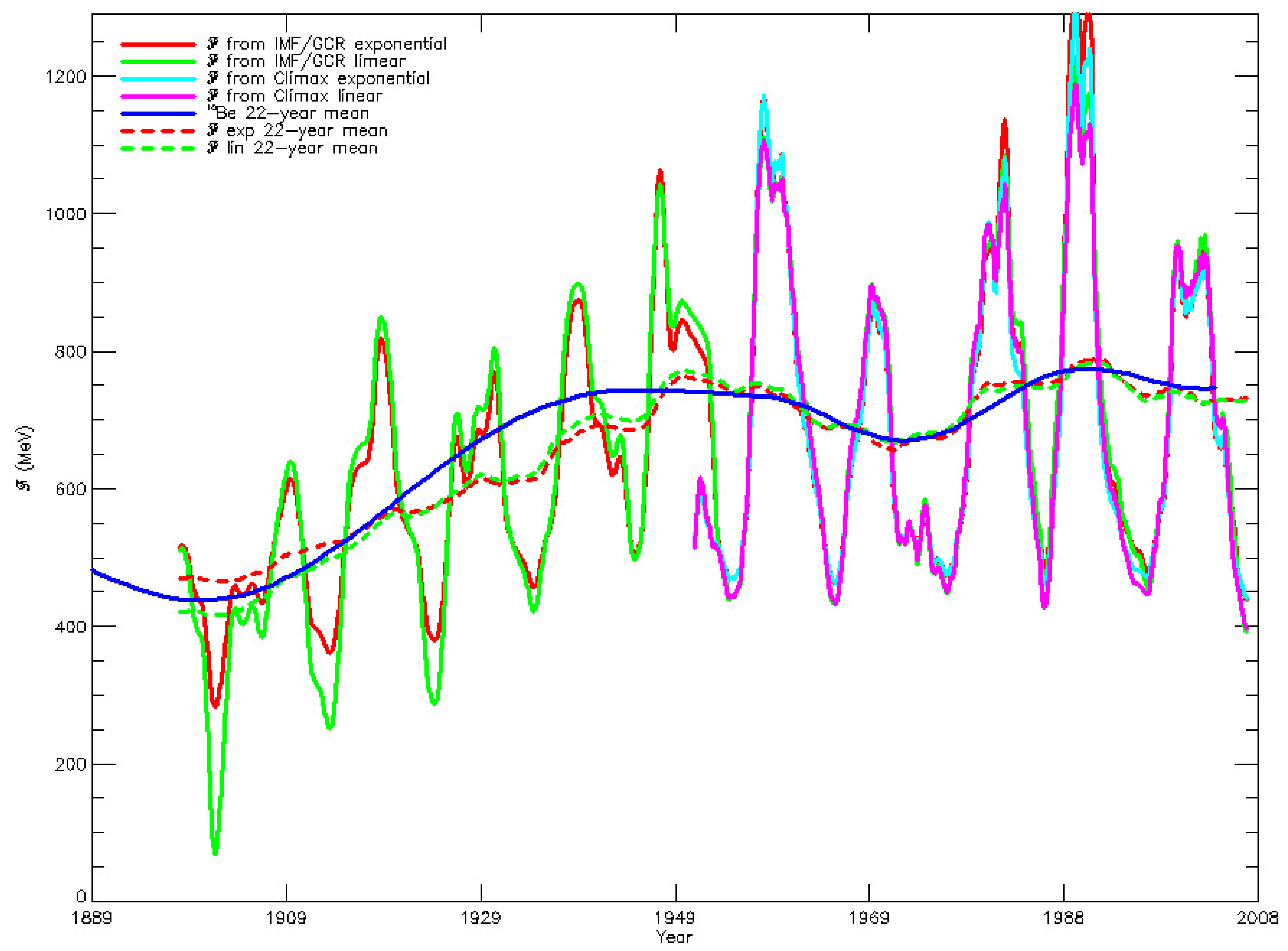
The difference is now only 0.64 nT, compared to 1.6 nT in the Nature paper.

With the sensitivity we determined earlier this corresponds to a TSI value being lower from the minimum of 1986 by 0.37 Wm^{-2} during the minimum of 1901.



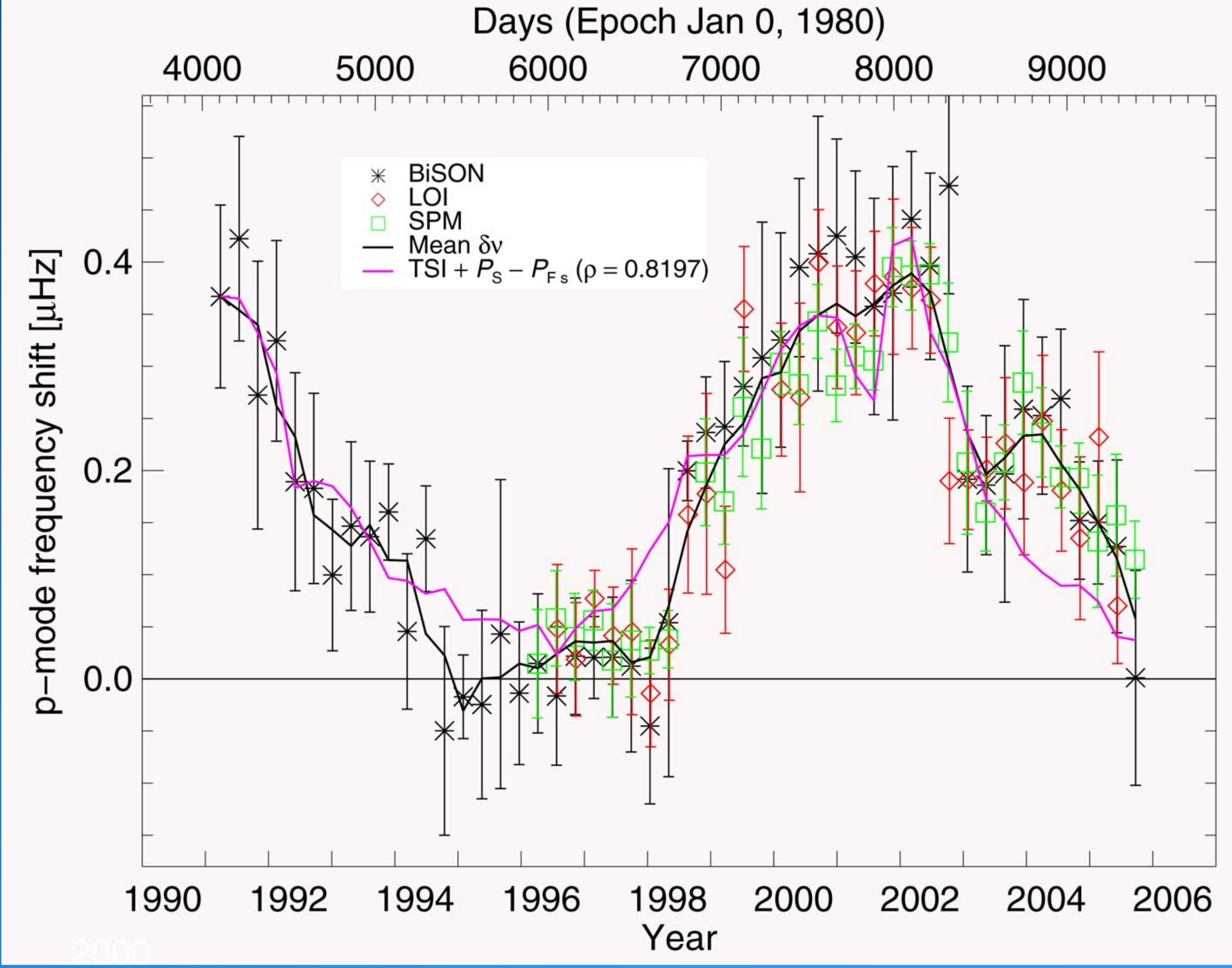
How can cosmogenic isotopes help?

- Rouillard et al (2007) have extrapolated the Climax data back to 1880 from their reconstructed IMF.
- From this the function can be calculated which determines the production of ^{10}Be. Compared to the observed one, which I got from Jürg Beer, the agreement is impressive.
- This is several years averaged, but higher time resolution data are or will be available soon. We need both the amplitude and the minima!



How are p-mode frequency changes related to TSI variability

The p-mode frequency changes were highly correlated with TSI, corrected for the short-term variations (TSI + P_s - $P_{F,}$) up to the maximum of cycle 23, but during the descending phase we observe an increase which is not in TSI. The data around 1993 may indicate a similar feature – so it may be related to the magnetism at high latitudes during the descending phase of a cycle which is not seen in TSI. Further investigations are definitively needed.



Conclusions

- Solar irradiance varies with the 11-year solar cycle, being higher during solar maximum (about 0.1% for TSI)
- During the last 30 years of space measurements, TSI shows a decline after 1980 of about 50 mWm^{-2} /decade. Comparing the minima values this is most pronounced in cycle 23. This recent decrease cannot be explained by the changes deduced from the MgII index or F10.7. The only solar parameter showing such a decrease is the open magnetic field B_r of the Sun.
- Comparison with the observed radial field B_r, allows to determine a sensitivity of TSI of about 0.58 Wm^{-2}/nT. B_r can be reconstructed back to about 1880 and so can the minima of TSI. This covers the long-term changes of the minima and comparison with ^{10}Be production rate may then be used to go further back in time. The solar cycle amplitude of TSI depends mainly on the surface feature of the magnetic cycle but the long-term changes of TSI may be related to e.g. a temperature change which is more related to the overall level of activity as reflected by the open field at minima.
- We must distinguish between the influence of the active regions and the underlying cycle variation; so, sunspot numbers alone cannot do it. They may still give a good estimate of the overall magnetic field involved in a given cycle, as e.g. by the number of bipolar magnetic regions involved.
- There is still a lot of work to be done………….