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

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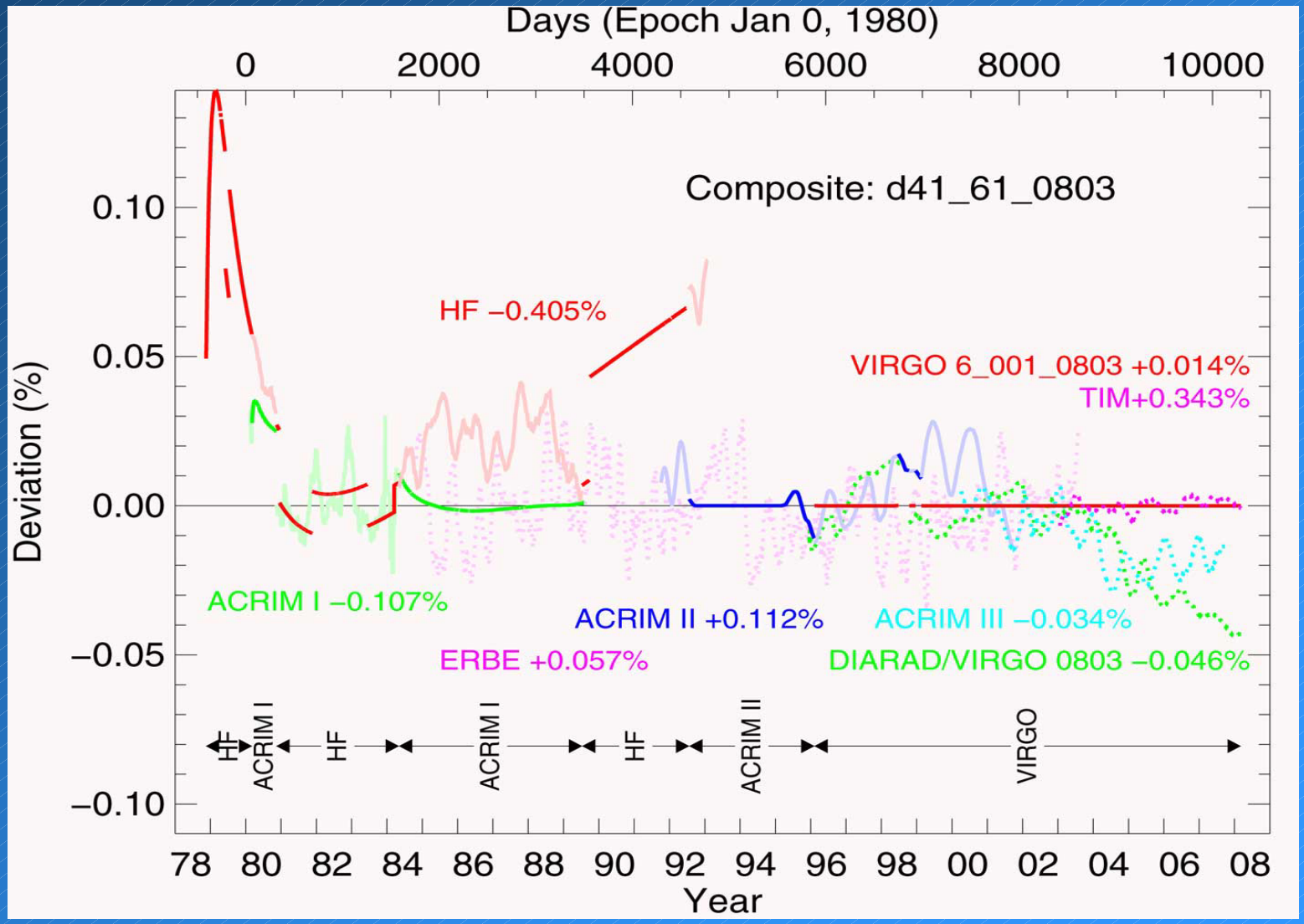
This presentation is based on the most recent data from VIRGO (with help of the VIRGO and SoHO teams) and many discussions mainly with Mike Lockwood, Leif Svalgaard and Jürg Beer.

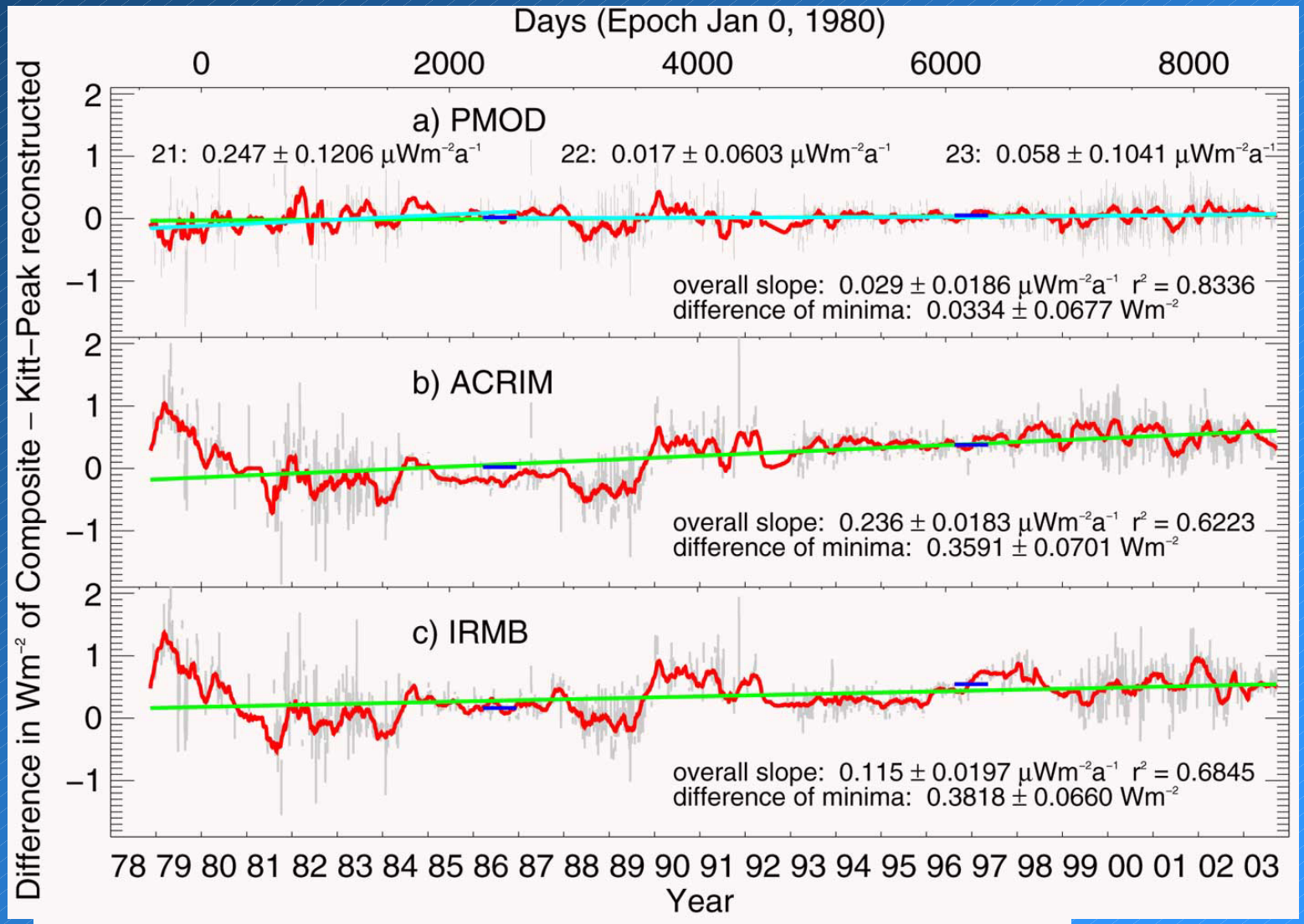
Outline

- 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

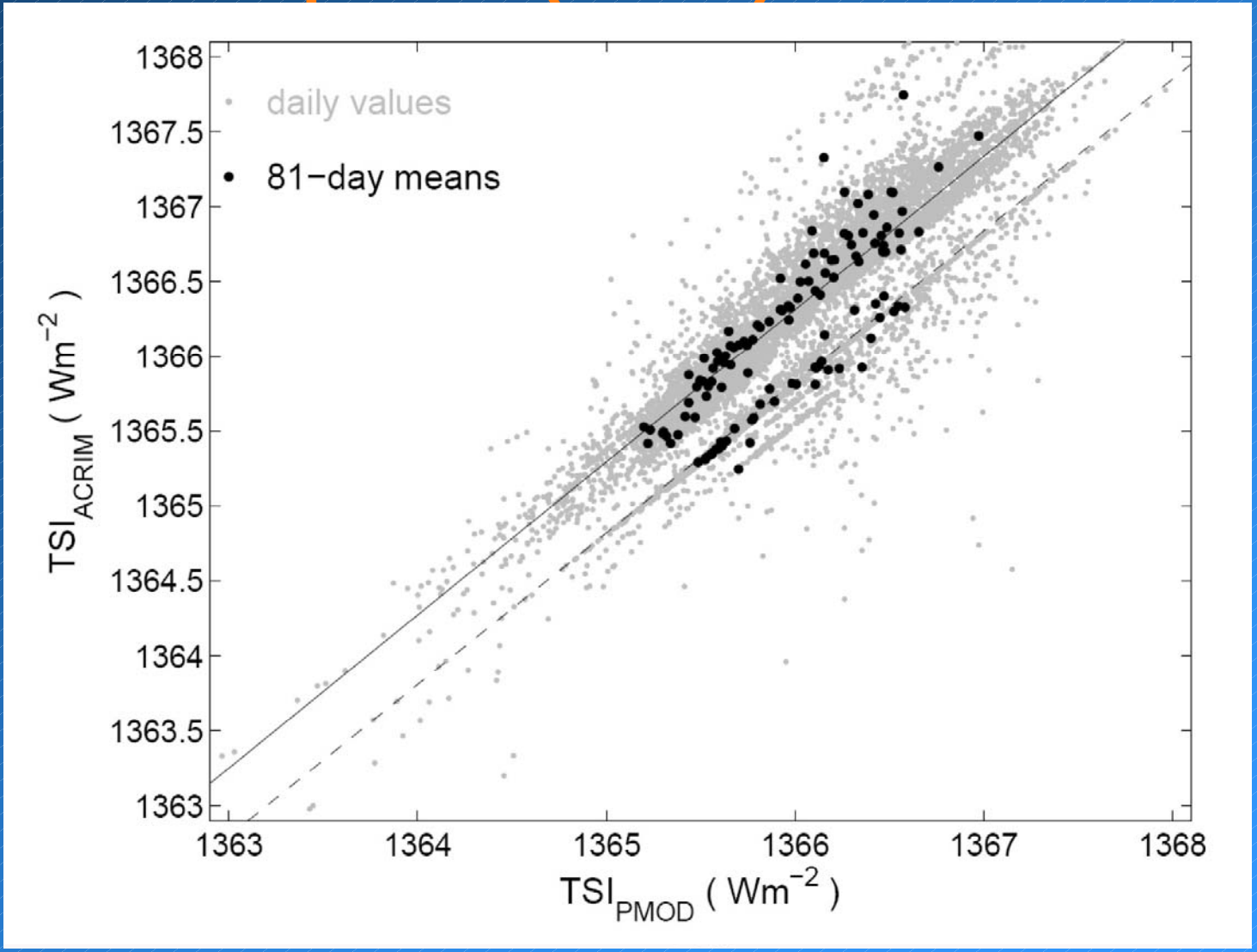
TSI Observations and the construction of a Composite (1 of 4)



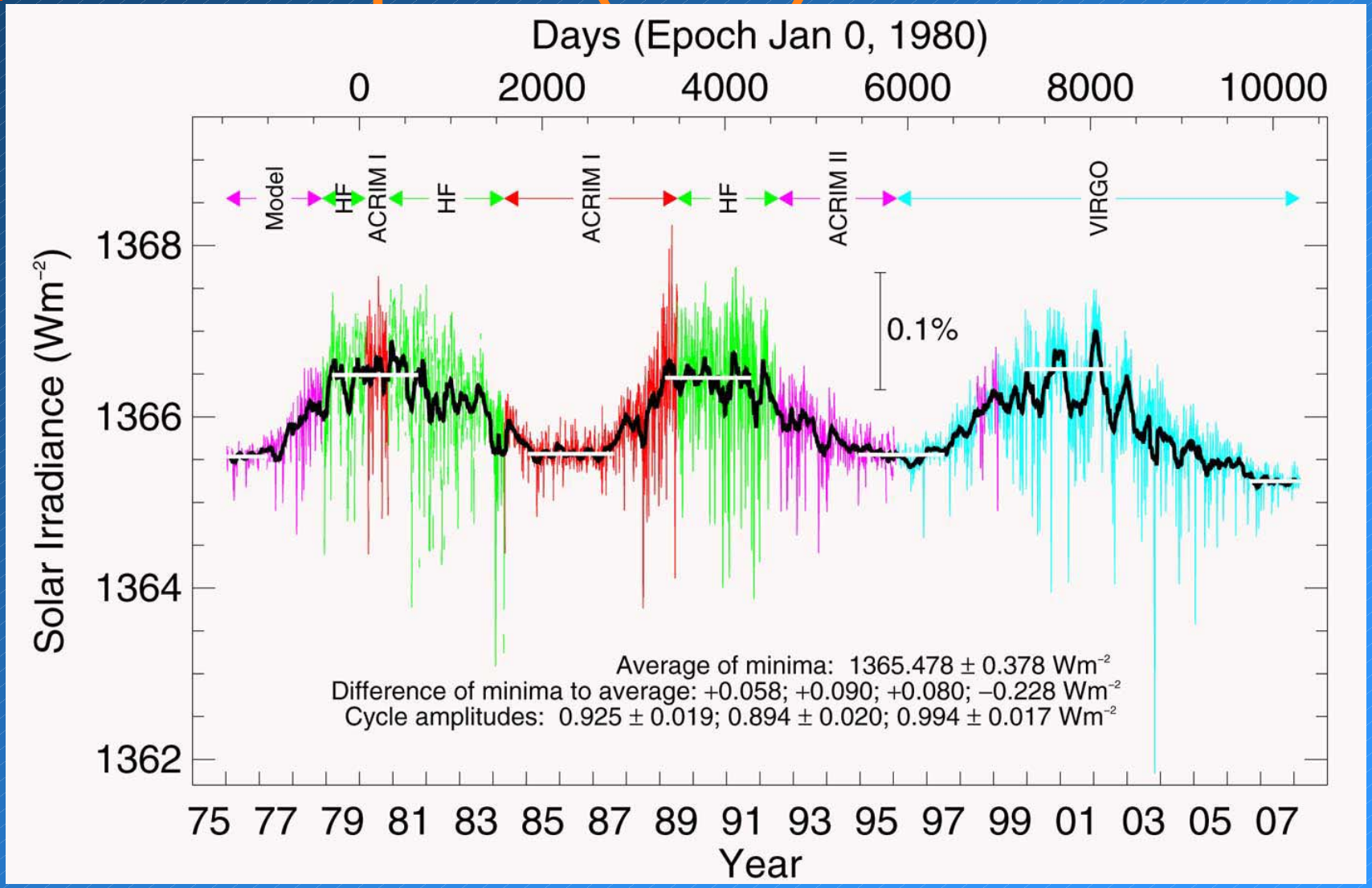
TSI Observations and the construction of a Composite (2 of 4)



TSI Observations and the construction of a Composite (3 of 4)

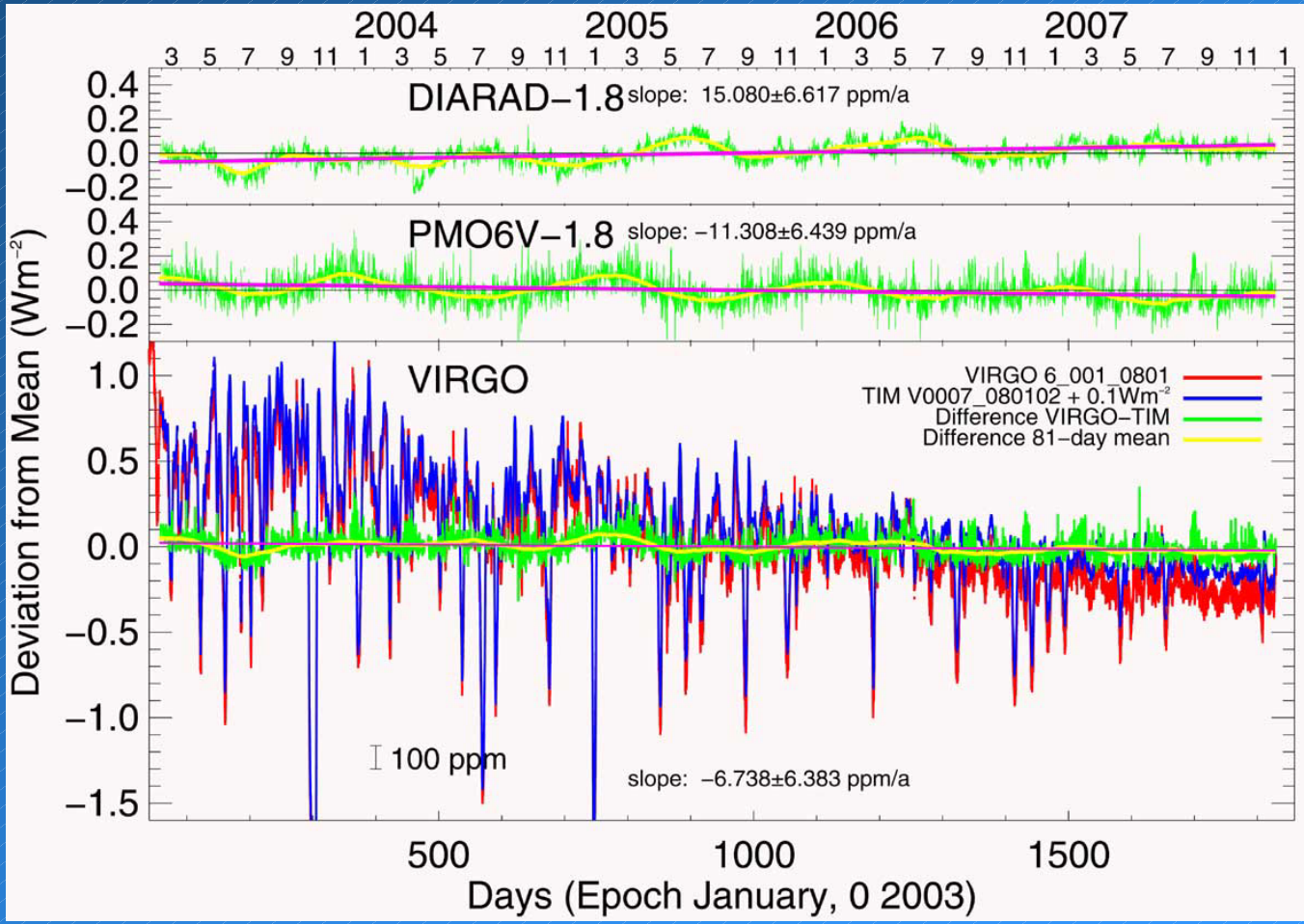


TSI Observations and the construction of a Composite (4 of 4)



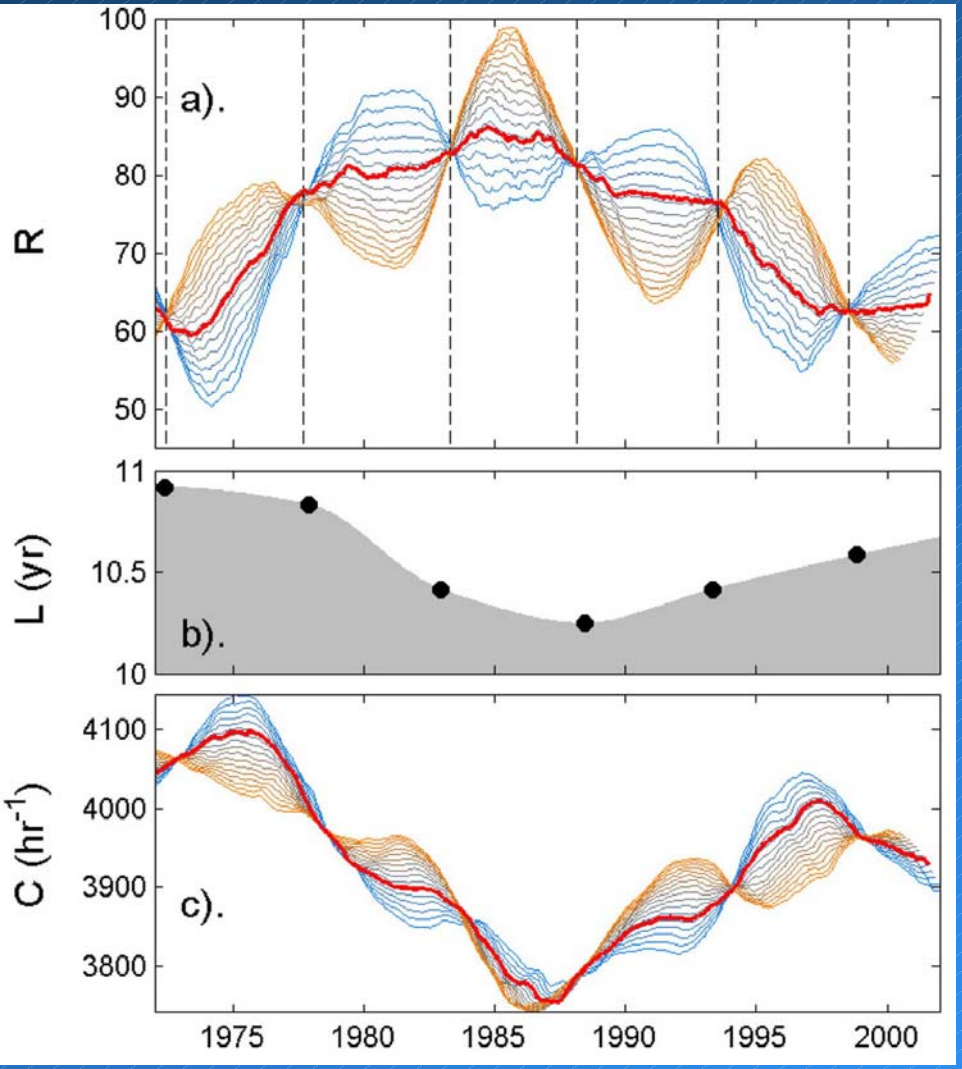
Comparison with other TSI

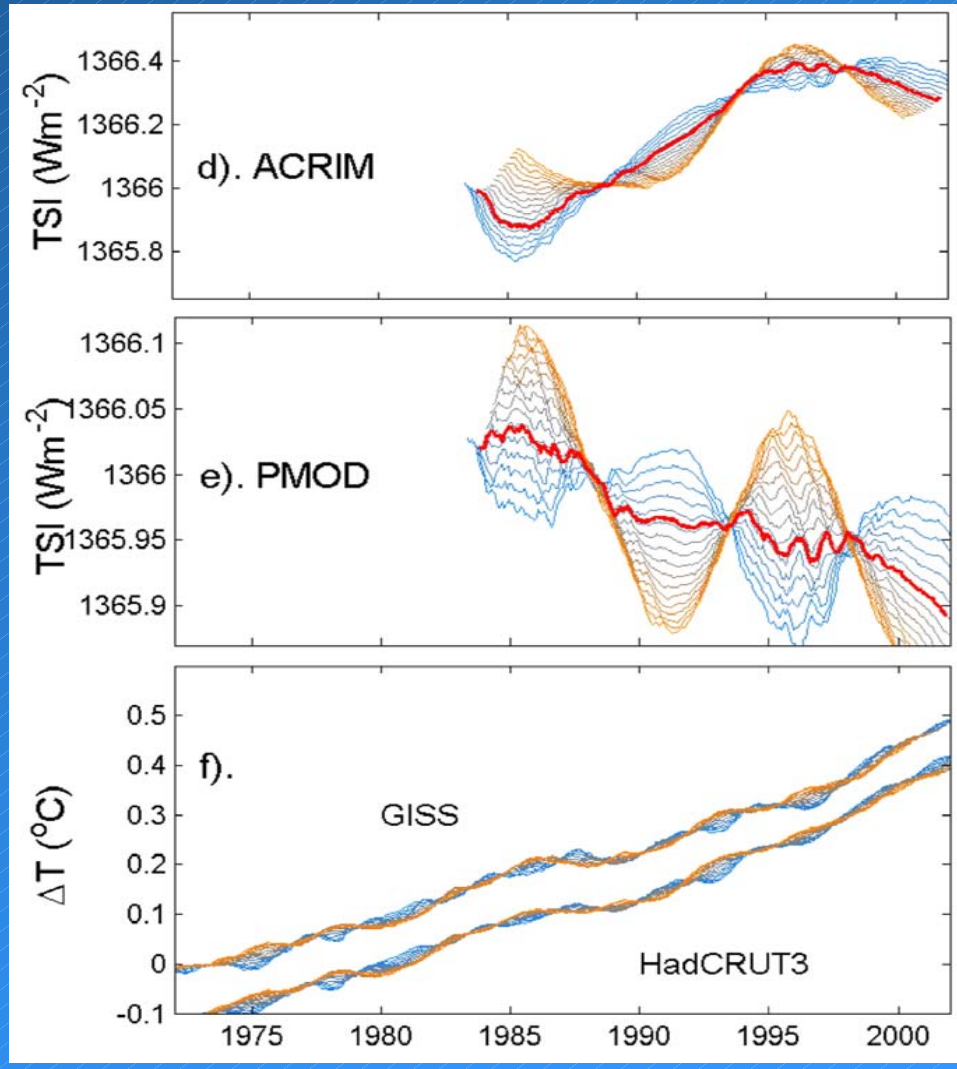
- Before we go on we need to be sure that we have data representing the true solar variability
- So we need to demonstrate that the trend of TSI as observed during cycle 23 is real.
- We do this by comparison of VIRGO which covers most of cycle 23 with ACRIM II on UARS, continued by ACRIM-III and with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

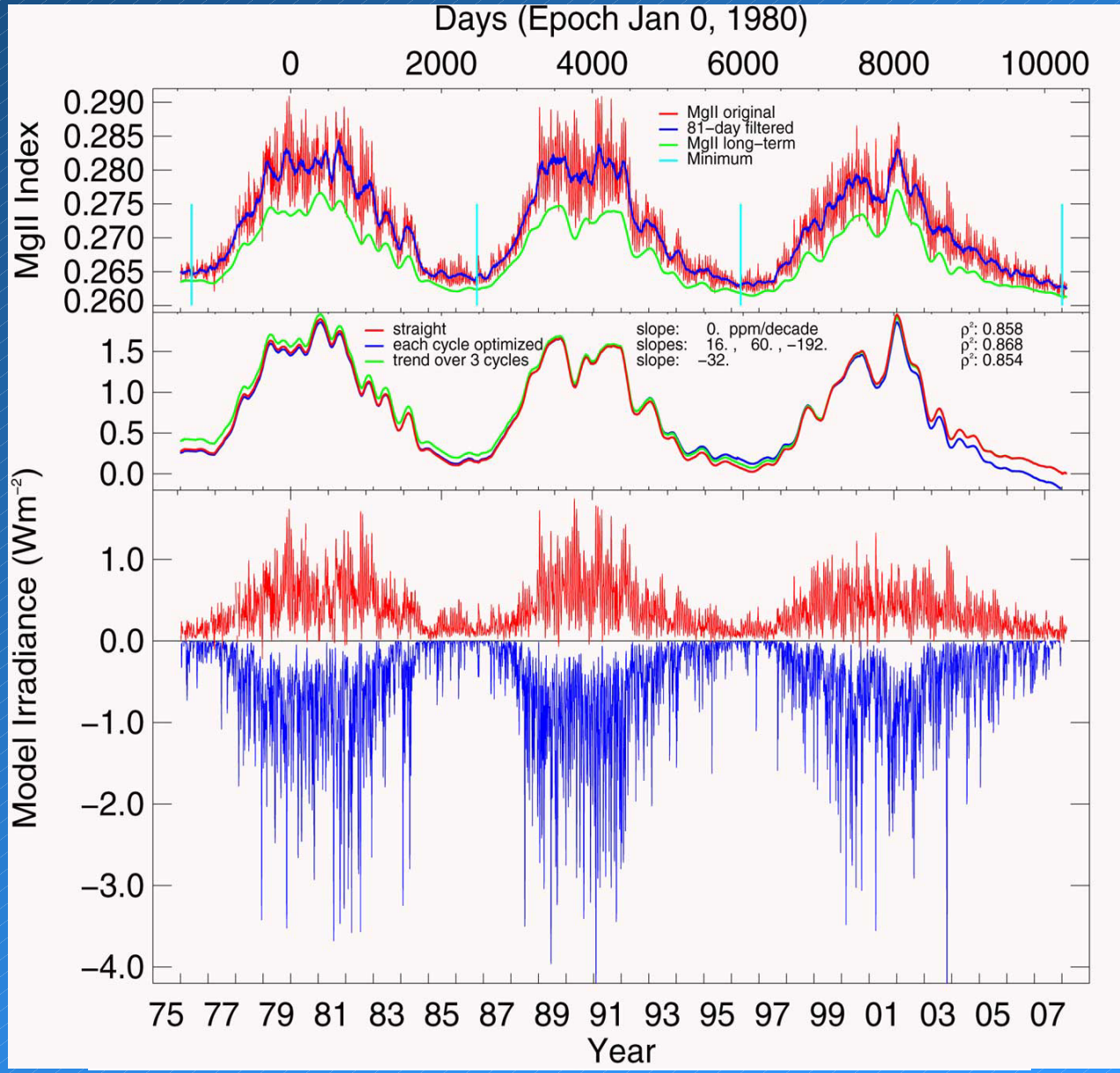
What about a long-term trend?



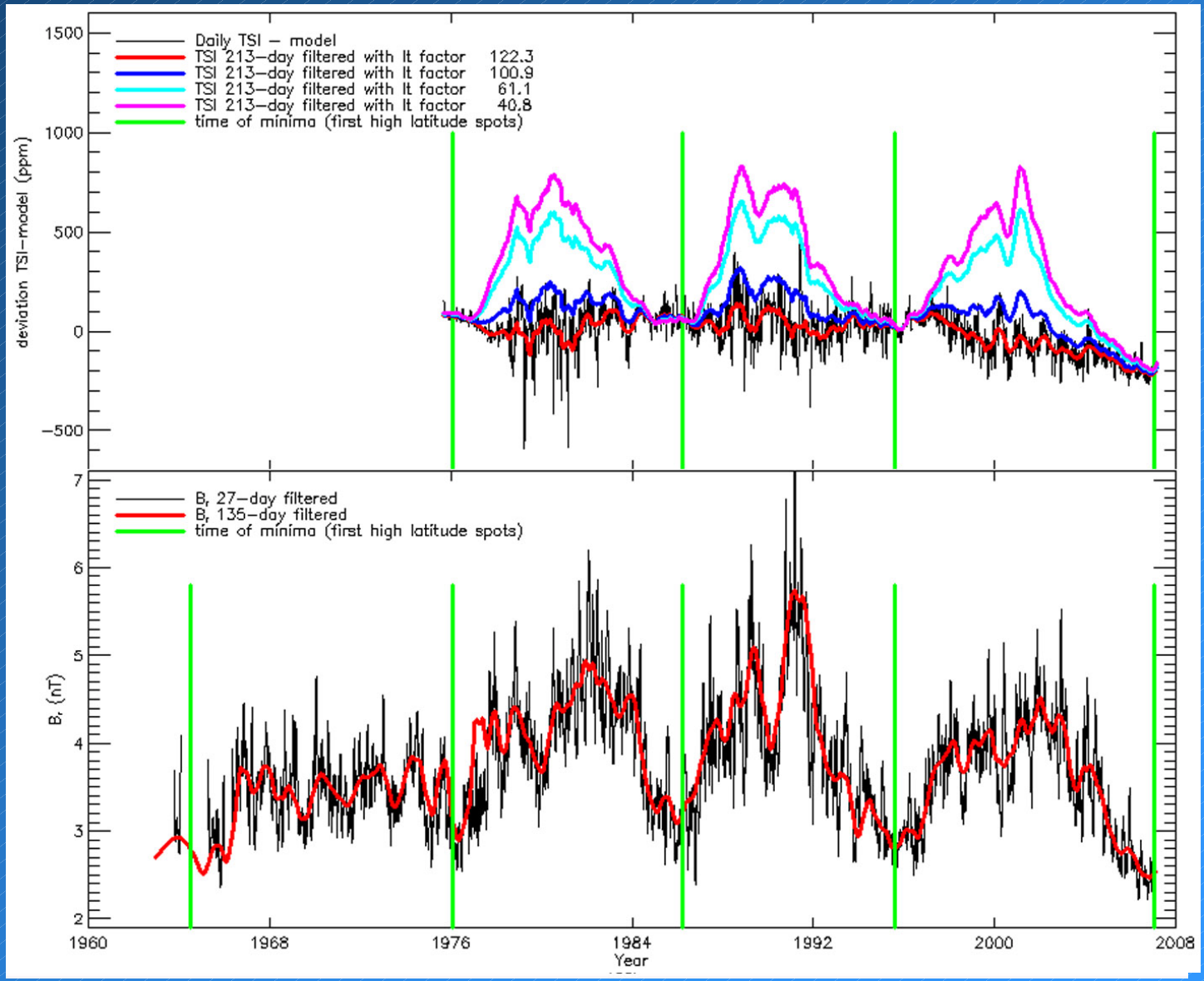


Proxy Model of Irradiance Variations

- 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
- The Mg index can be devided into short and long-term parts representing the active region faculae and the network within and outside active regions respectively.



How to explain the recent decrease



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

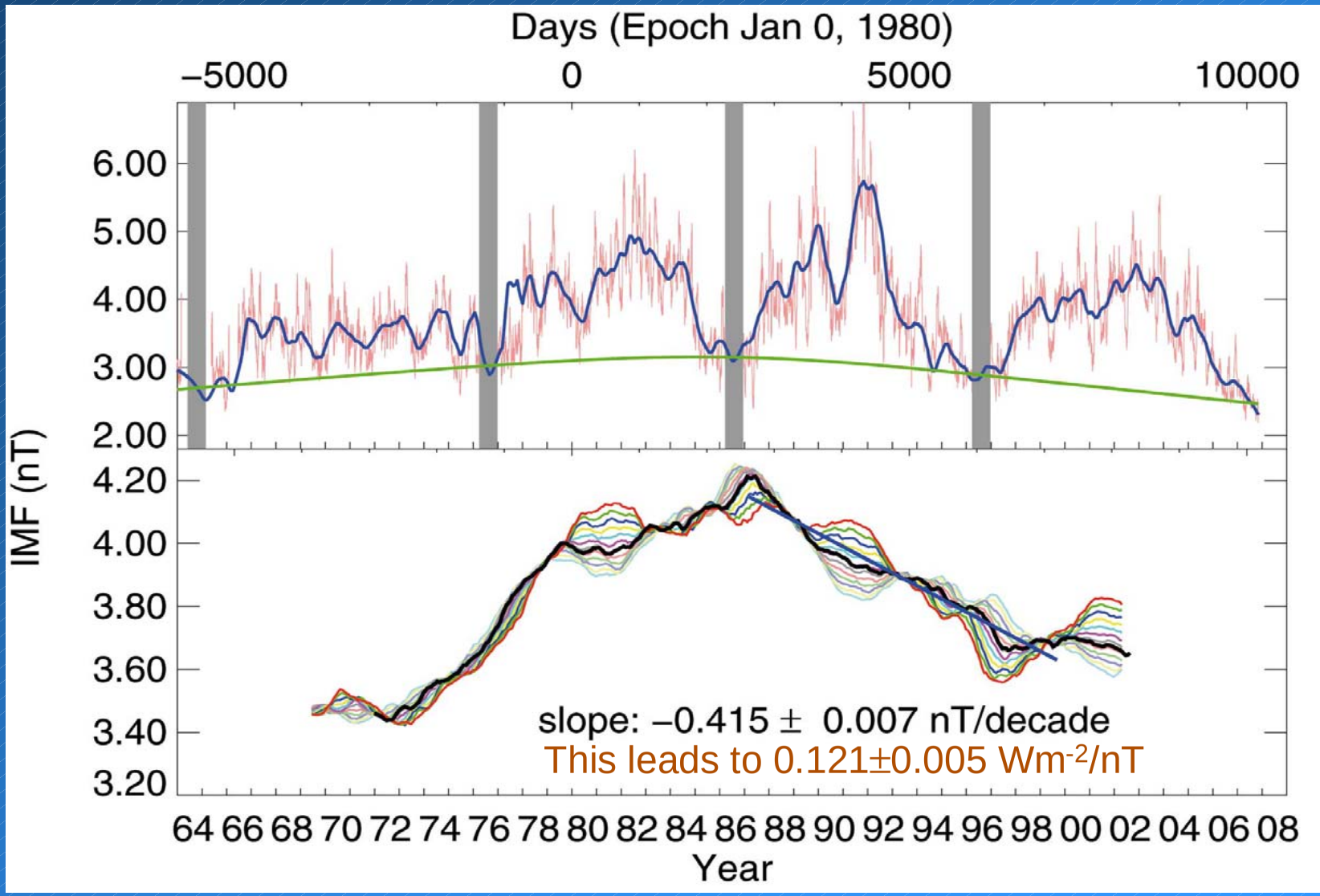
Now we can compare the trends between minima: the results are shown for the different cycles in the following table.

The straight mean yields for the TSI sensitivity 0.61 ± 0.39 Wm^{-2}/nT and iff we allow for the full uncertainty range for 22 (larger) and 23 (smaller) we get 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 the open field and thus seen by the cosmogenic isotopes.

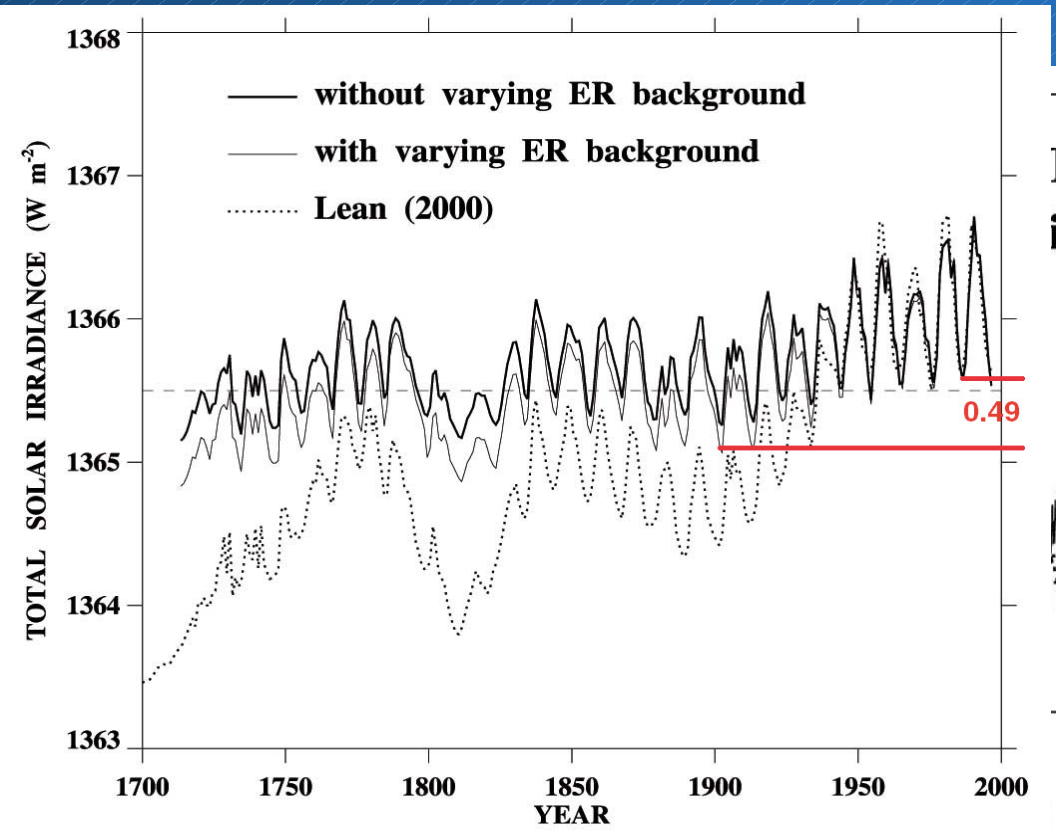
Parameter:	SSN	f10.7	IMF	TSI	Sens	PSI	MgII
Units:	-	-	nT	mWm^{-2}	Wm^{-2}/nT	ppm	mWm^{-2}
diff over 20:	5.5	1.5	0.26				
diff over 21:	1.0	-0.9	0.06	40.4	0.628	-62.68	-73.2
diff over 22:	-7.0	-0.9	-0.38	-89.5	0.204	-3.86	-103.5
diff over 23:	-4.8	-2.4	-0.22	-221.7	0.847	-30.03	175.1

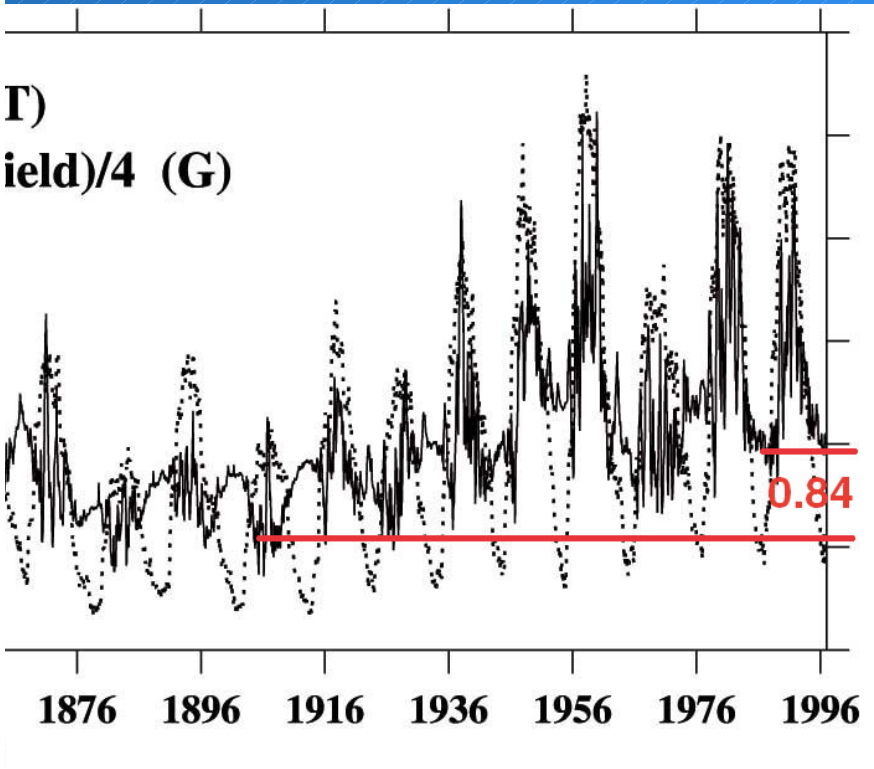
How is the sensitivity for long-term changes as averaged over the solar cycle?



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.





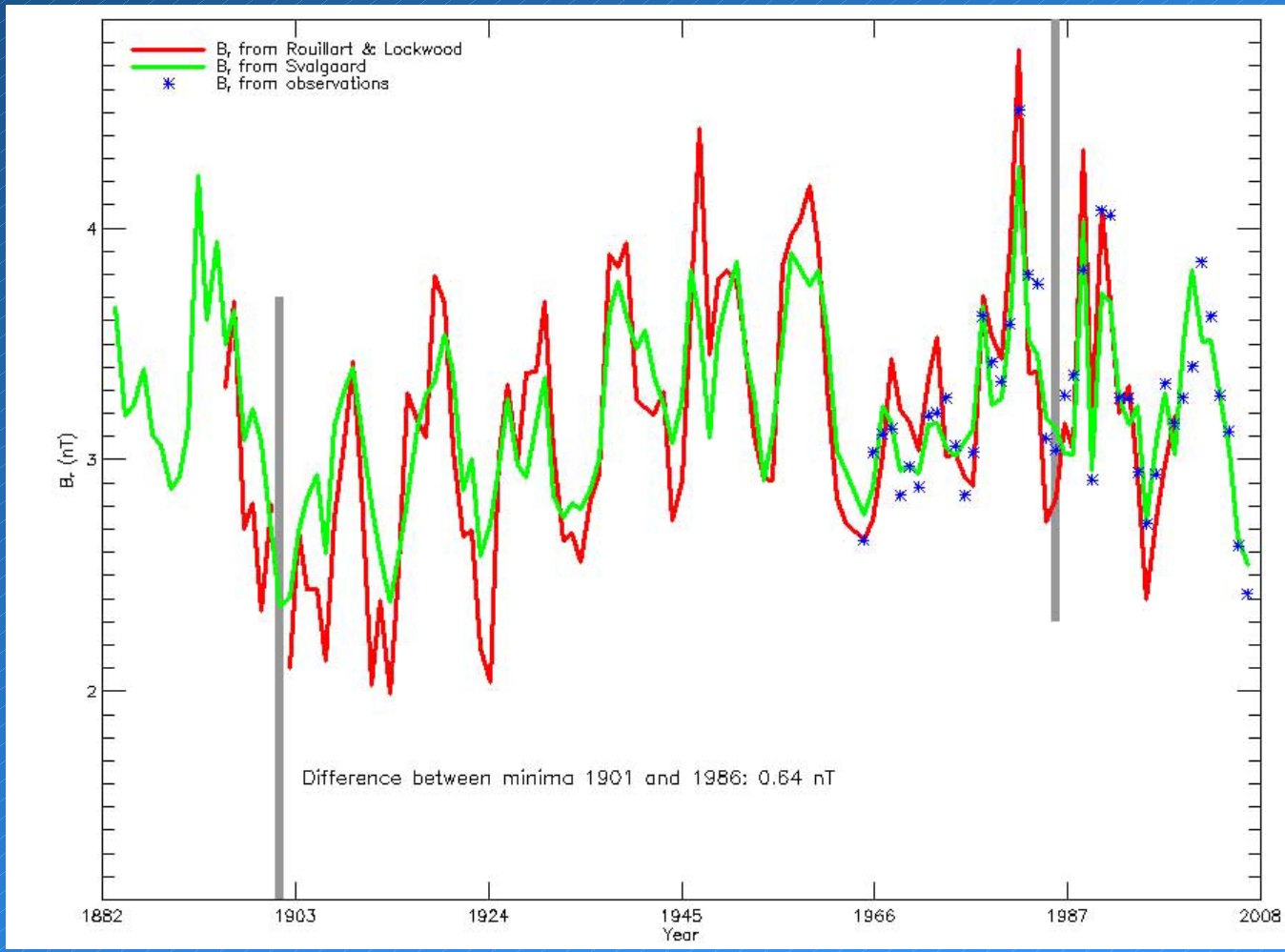
How does the open magnetic field of the Sun behaved during the last century?

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?

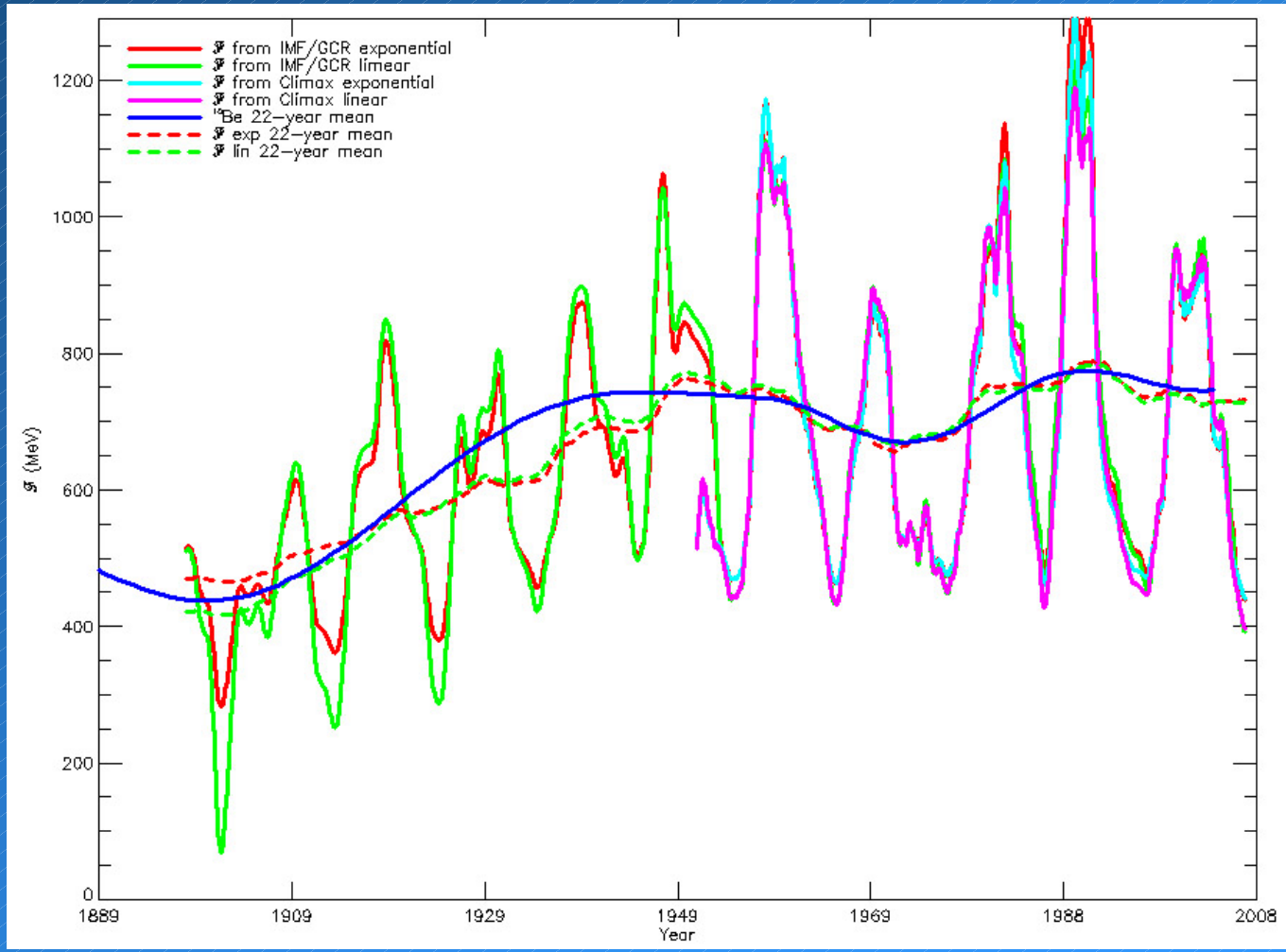
The difference is now only 0.64 nT, compared to 1.6 nT in the Nature paper.

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.

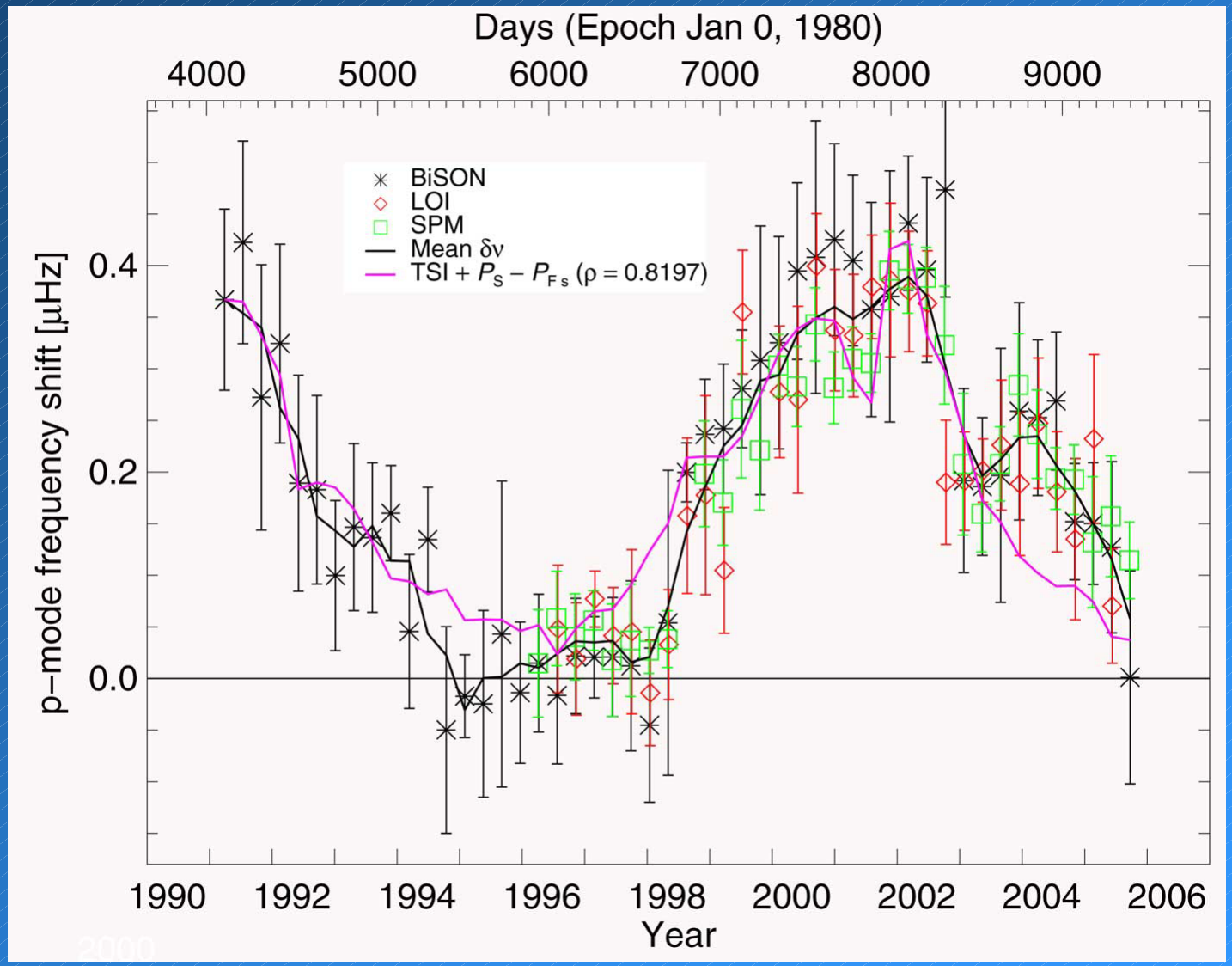


How can cosmogenic isotopes help?

- Rouillard et al have extrapolated the Climax data back to 1880 from their reconstructed IMF.
- From this the function Φ 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 year averaged, but higher time resolution data should be possible. We need both the amplitude and the minima!

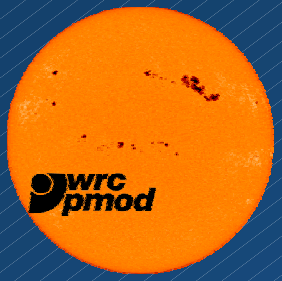


How are p-mode frequency changes related to TSI variability



Conclusions

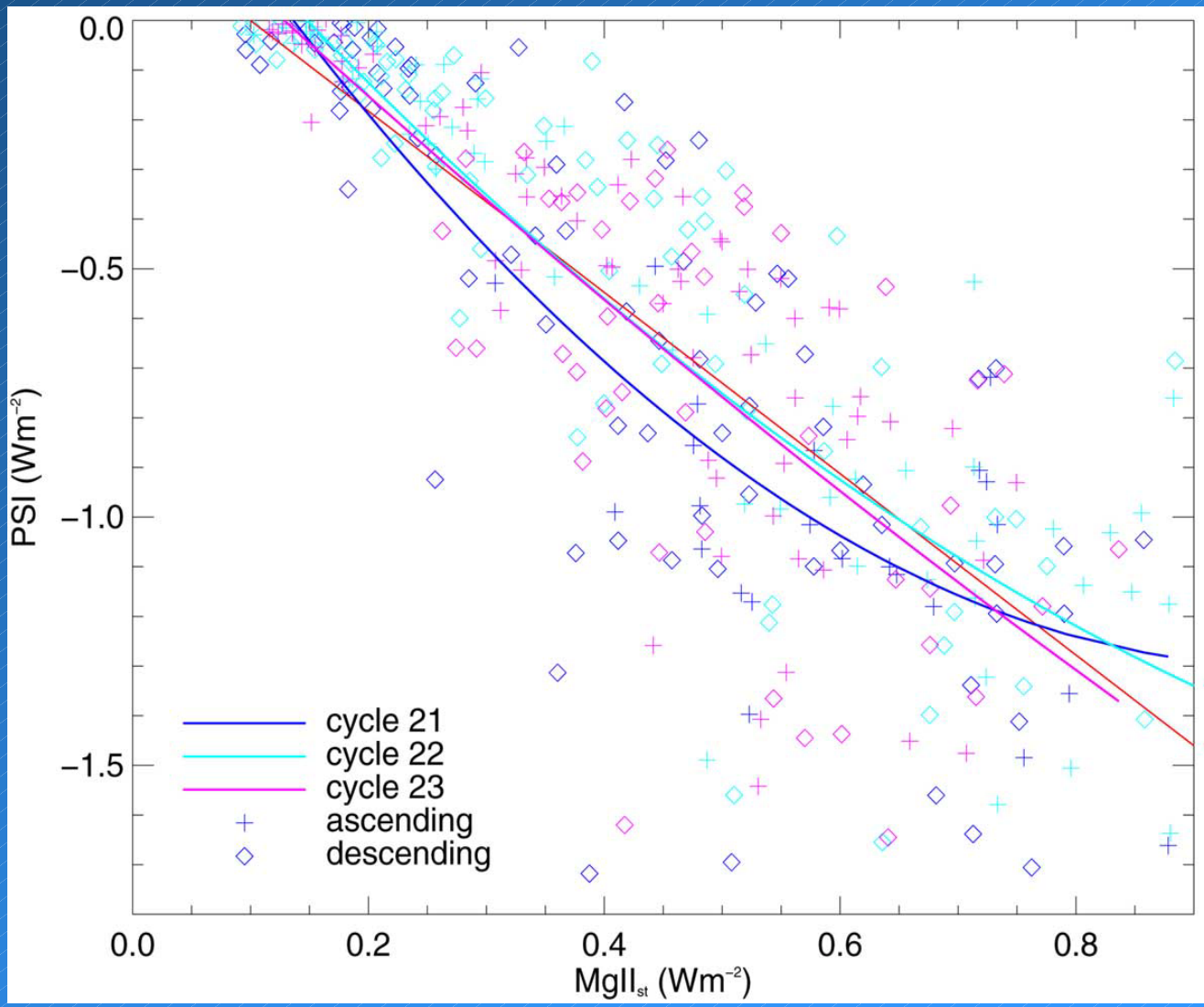
- Solar irradiance varies with the 11-year solar cycle, being higher during solar maximum (about 0.1% for TSI)
- During the last 30 years of space measurements, TSI shows a decline after 1980 of about 50 mWm^{-2} /decade. Comparing the minima values this is most pronounced in cycle 23. This recent decrease cannot be explained by the changes deduced from MgII index or F10.7. The only solar parameter showing such a decrease is the open magnetic field of the Sun.
- Comparison with the observed radial IMF and 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 seems to be about 1.5 to 2 times the one observed in B_r.
- We must distinguish between the influence of the active regions and the underlying cycle variation and sunspot numbers alone cannot do it!
- There is still a lot of work to be done……



This the end……Thanks

Reconstruction of Irradiance Variations in the Past

- The problem with sunspot numbers as proxies surfaced with the quite different solar cycle 23 which shows no longer a very good correlation between sunspot numbers and irradiance.
- The short-term correlation works for the influence of sunspots, and during these strong cycles there is also a correlation between sunspots and faculae. But the variations are no longer correlated to the degree observed for cycles 21 and 22 due to the 'Maunder Minimum' maximum in TSI.
- One should certainly look for an other proxy, maybe the production function Φ for ^{10}Be is better suited.

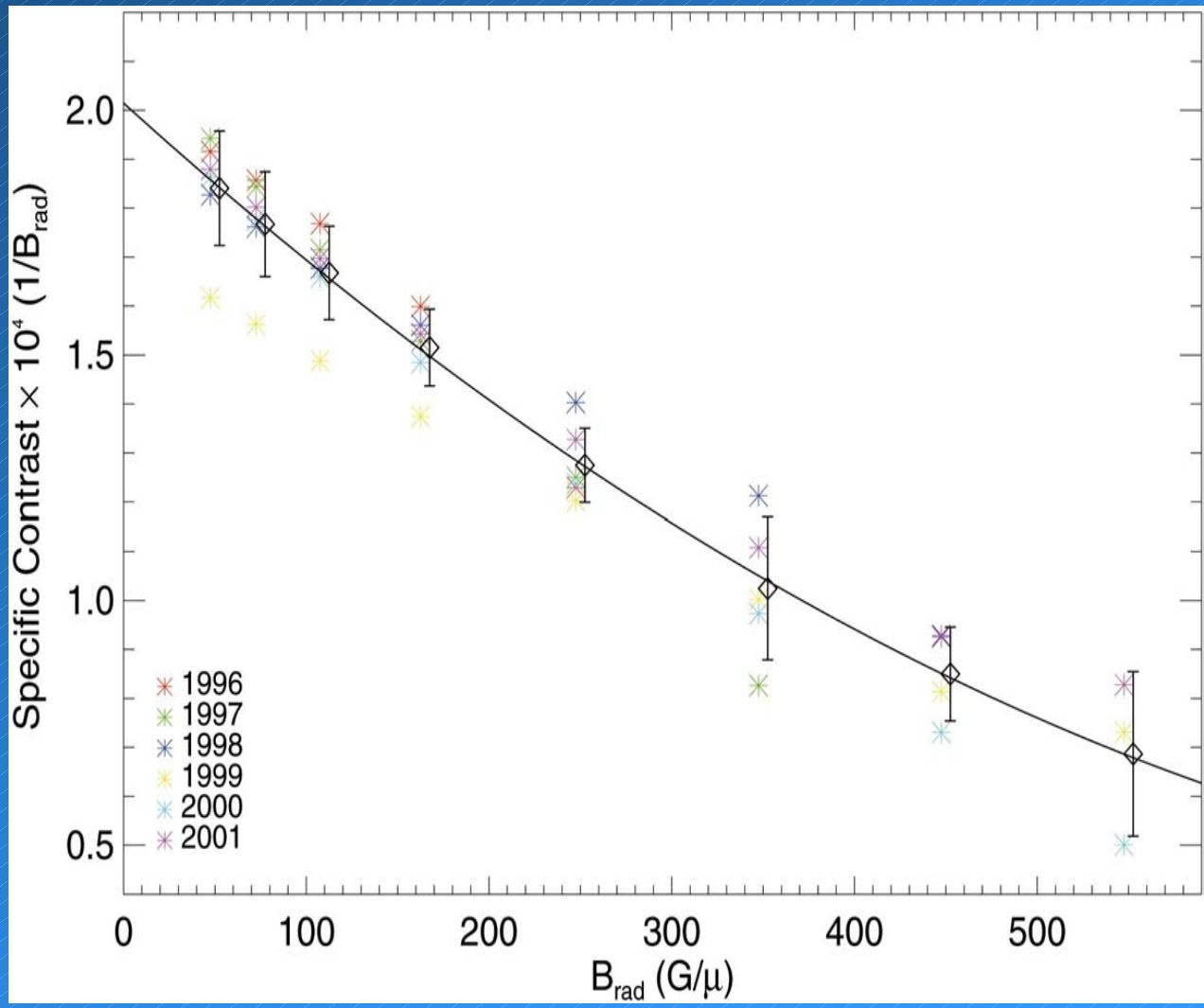


Proxy Model of Irradiance Variations

The coefficients of the multiple regression are different for the long and short term MgII: MgII short-term is 93 and for the long-term 120, the difference may be explained by the difference in specific contrast of the network and faculae as shown by Ortiz (2005) from MDI data.

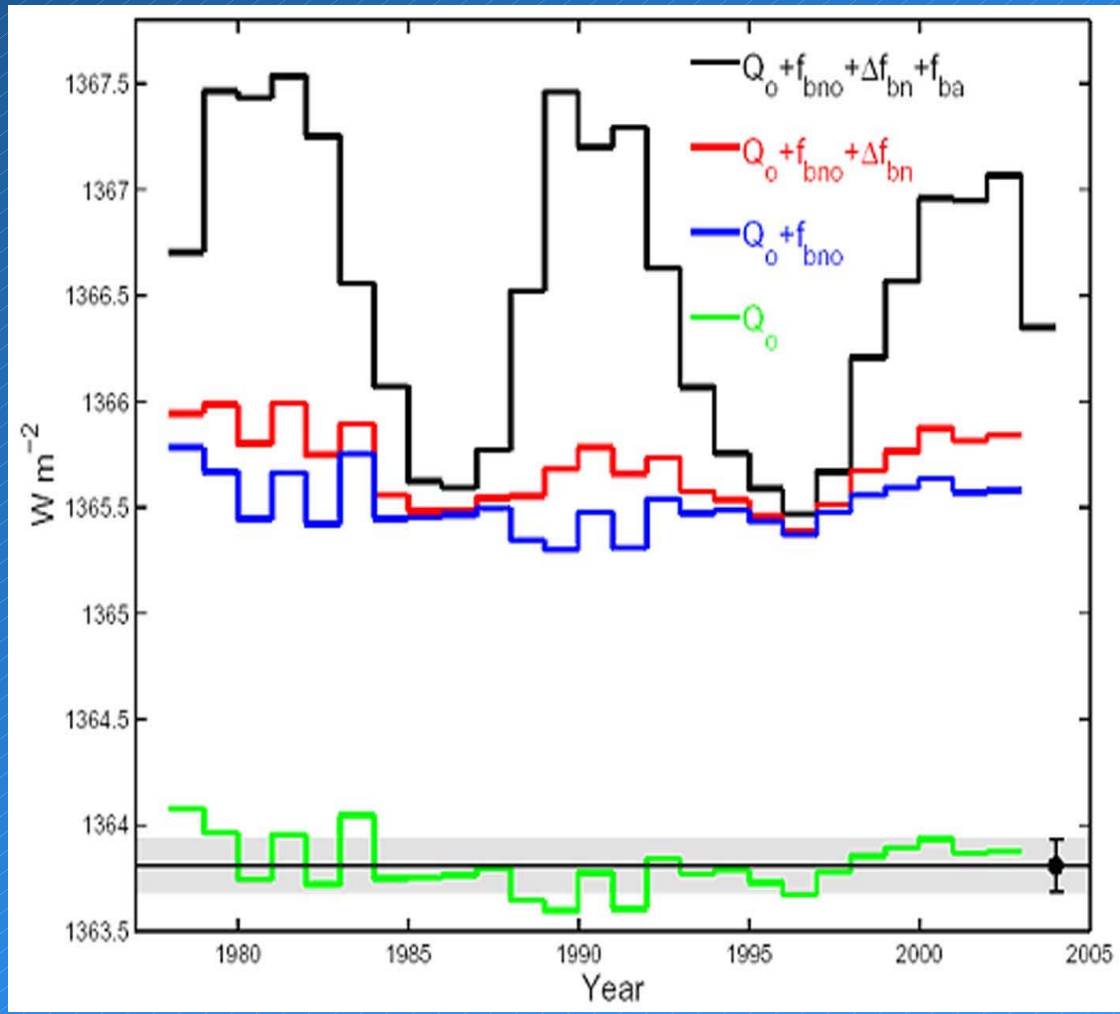
From this it becomes evident, that the solar cycle variation is mostly determined by the network, whereas faculae only contribute to the active region variability.

It could, however, also mean that we have still another component and now comes the new stuff!



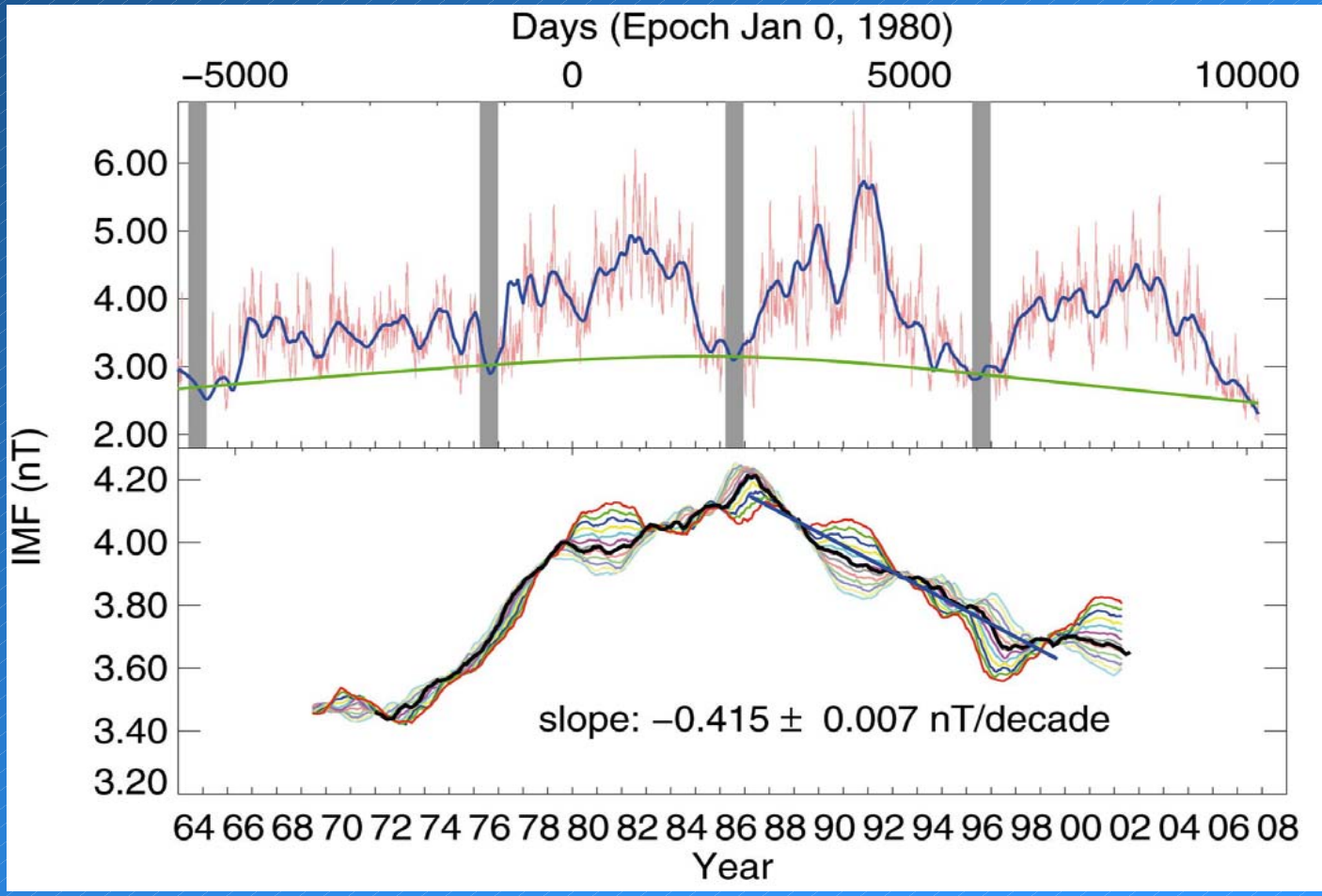
Where is Zero Magnetic Field in TSI?

- Before we go on let us have a look at Fosters PhD Thesis
- From MDI magnetograms one can determine the distribution of the radial magnetic field within an active region. From such distributions one can distinguish between faculae and network. So the facular and network contributions within an active region can be estimated separately.
- The remaining magnetism at solar minimum value can also be determined and extrapolated to zero magnetic field.
- This is the basic idea for possible long-term changes of TSI on top of the solar cycle variation



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

One way is to compare the long-term trends: the result is 0.121 ± 0.005 Wm^{-2}/nT

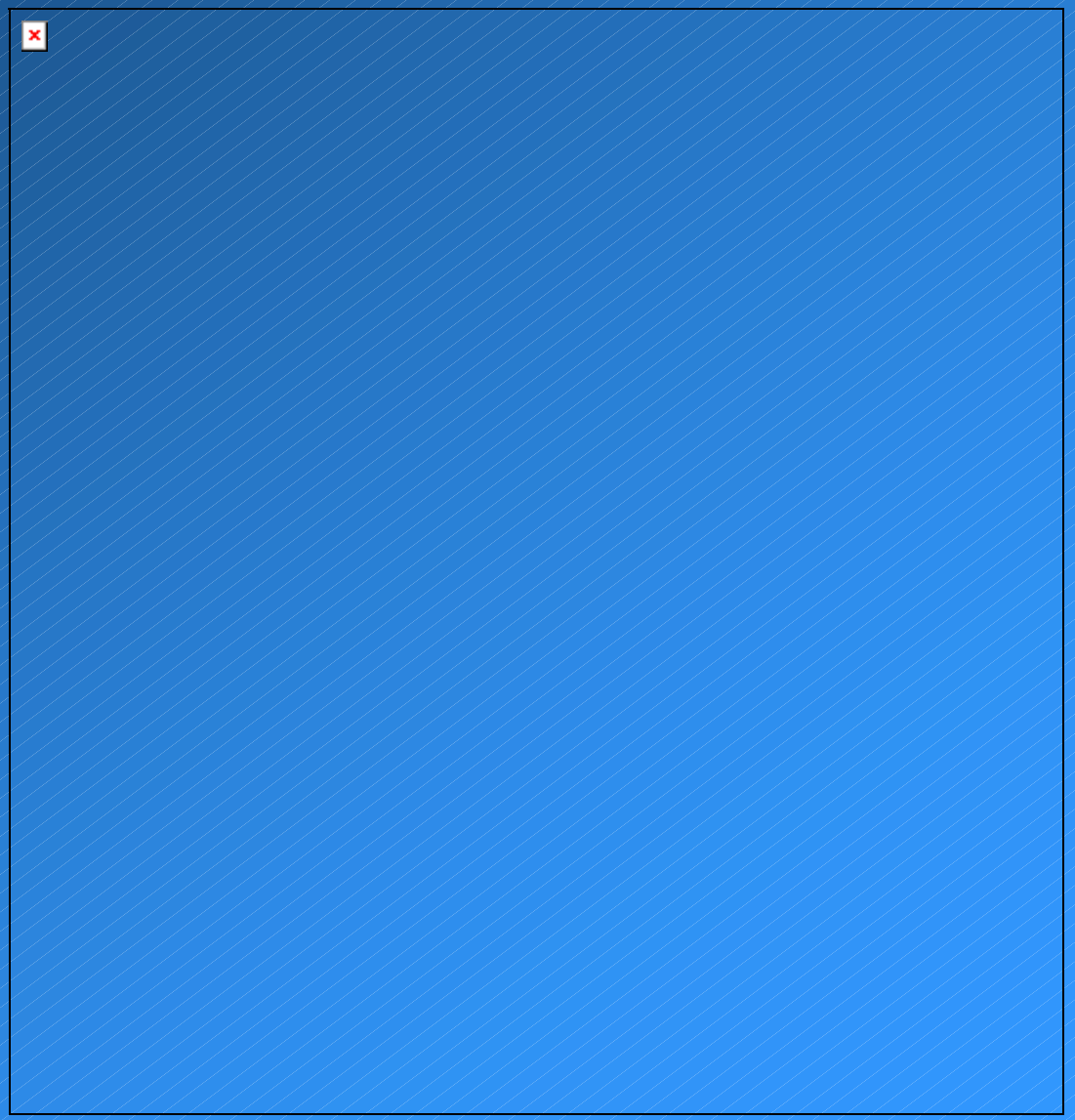


Long-term Changes of TSI

By the way, this longterm trend is from the paper with Mike in June this year, which gave quite a bit of revolution for greenhouse sceptics – so we have a follow-up……

The point is: the temperature of the Earth increased since the seventies and the Sun does not follow this trend and thus does not seem to be responsible for this increase.

This does not mean that the Sun has no influence on climate!



There is another problem of modulating TSI with magnetic fields

Low-order p modes are influenced by all magnetic fields, threading the solar surface, whereas TSI sees only part of it due to the Spruit effect.