The Solar Radio Microwave Flux and the Sunspot Number

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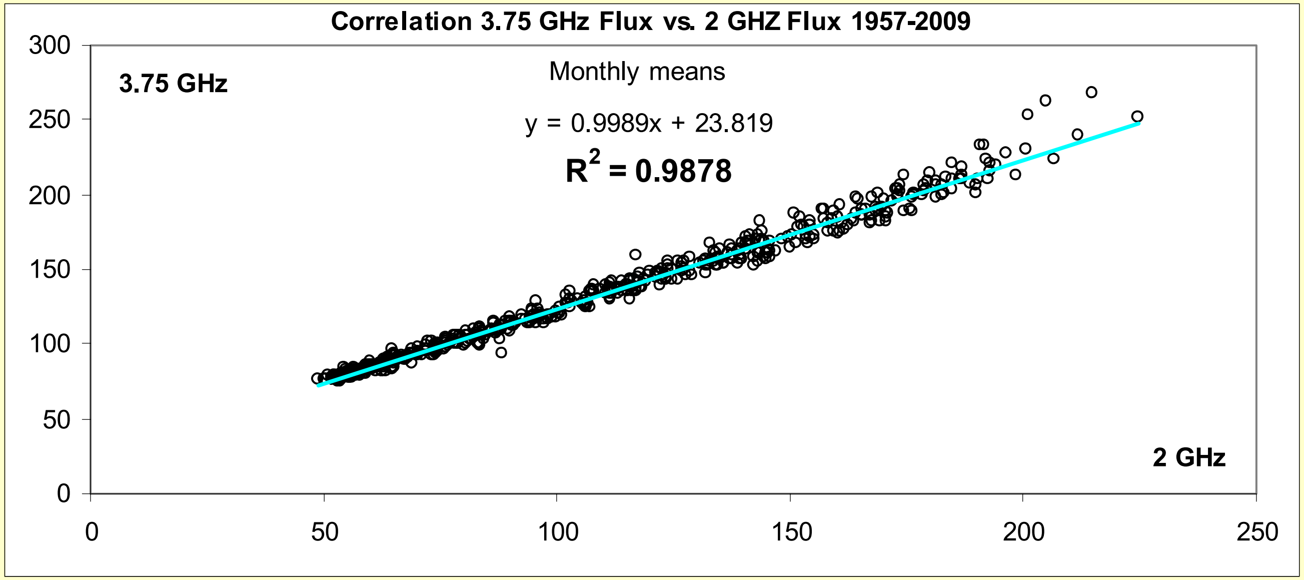
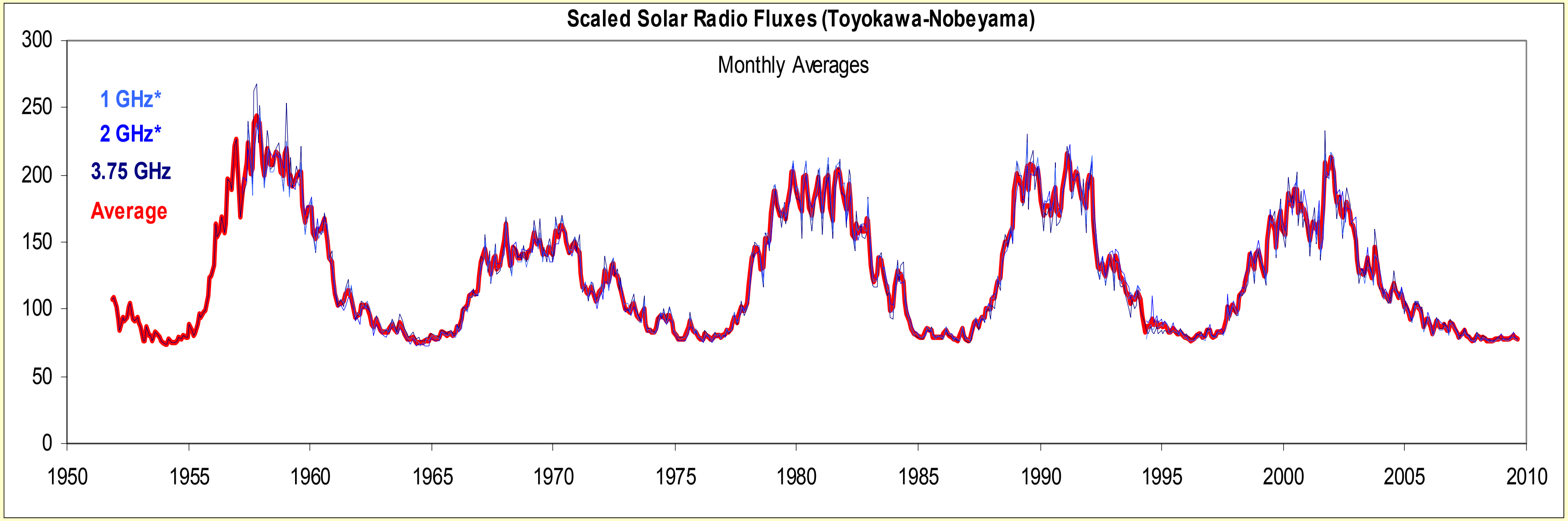
Japanese Observations at Toyokawa (1951-1994) and Nobeyama (1994-now)

The Observations at 1, 2, and 3.75 GHz straddle the 2.8 GHz frequency of the 10.7 cm flux. The 3.75 GHz series begins in 1951 and the other frequencies in 1957. We scale all observations to the longest series (3.75 GHz)

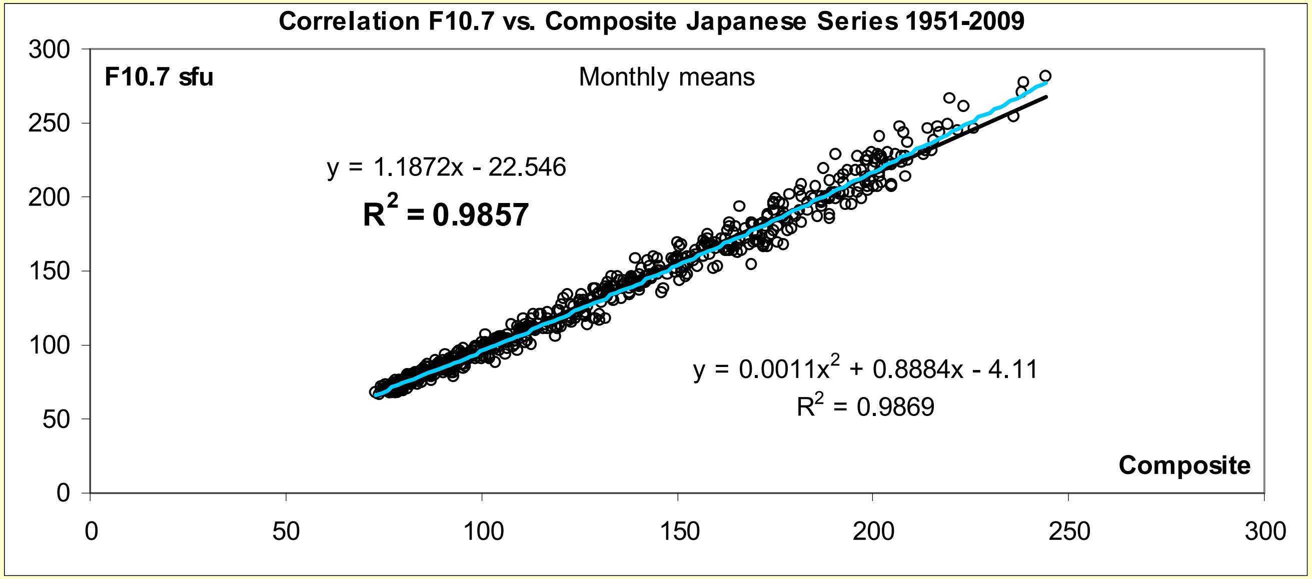


Composite Japanese Microwave Flux

The three (two of them scaled) series agree very well and it makes sense to construct a composite series as the simple average

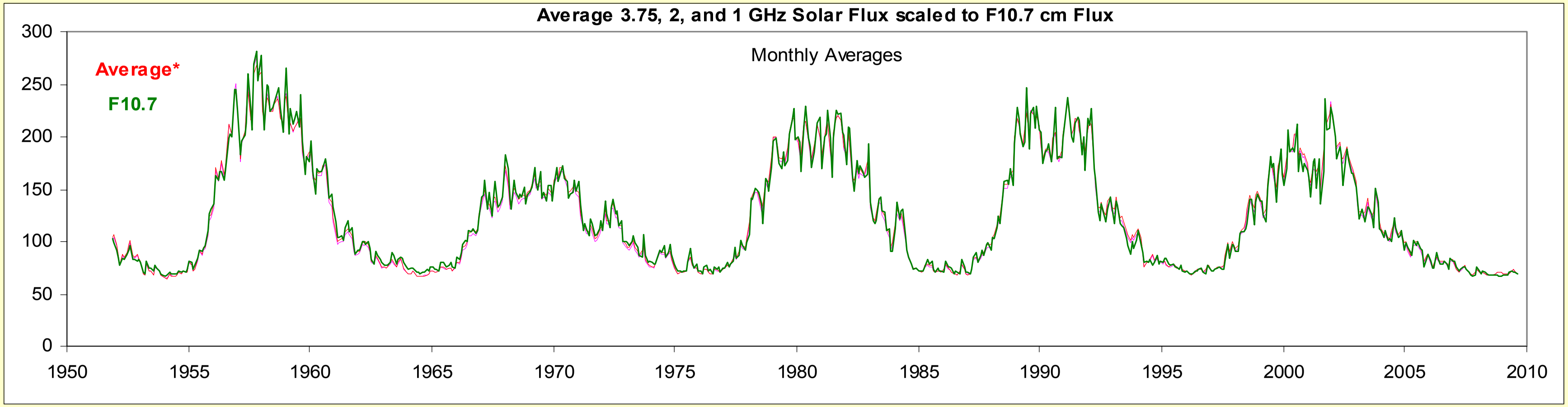


Scaling to the Canadian F10.7 Flux



Correlation F10.7 vs. Composite Japanese Series 1951-2009

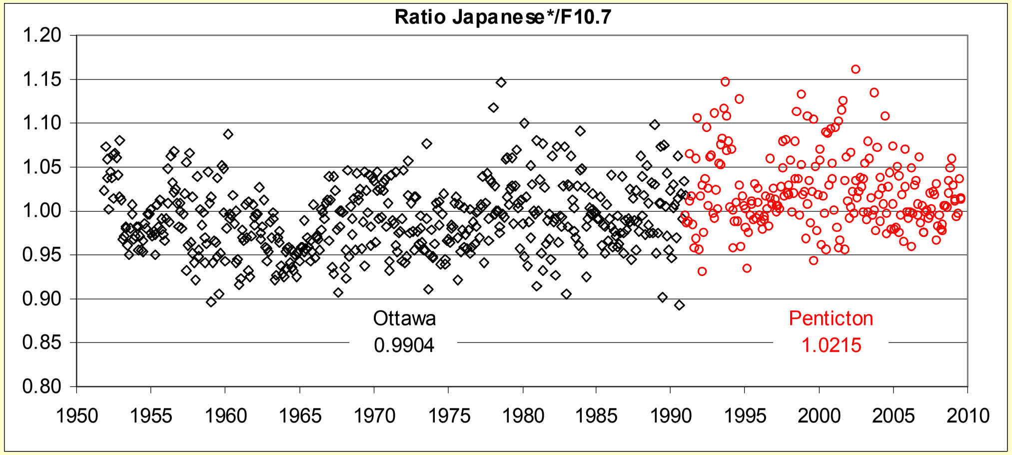
The next step is to scale to the 10.7 cm flux

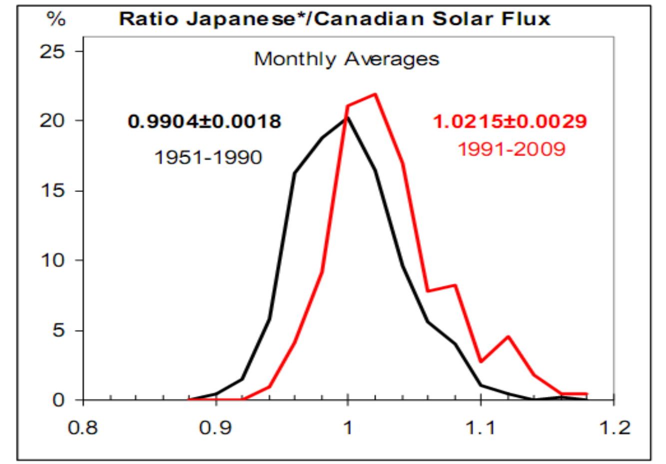


Average 3.75, 2, and 1 GHz Solar Flux scaled to F10.7 cm Flux

Stability of the Series?

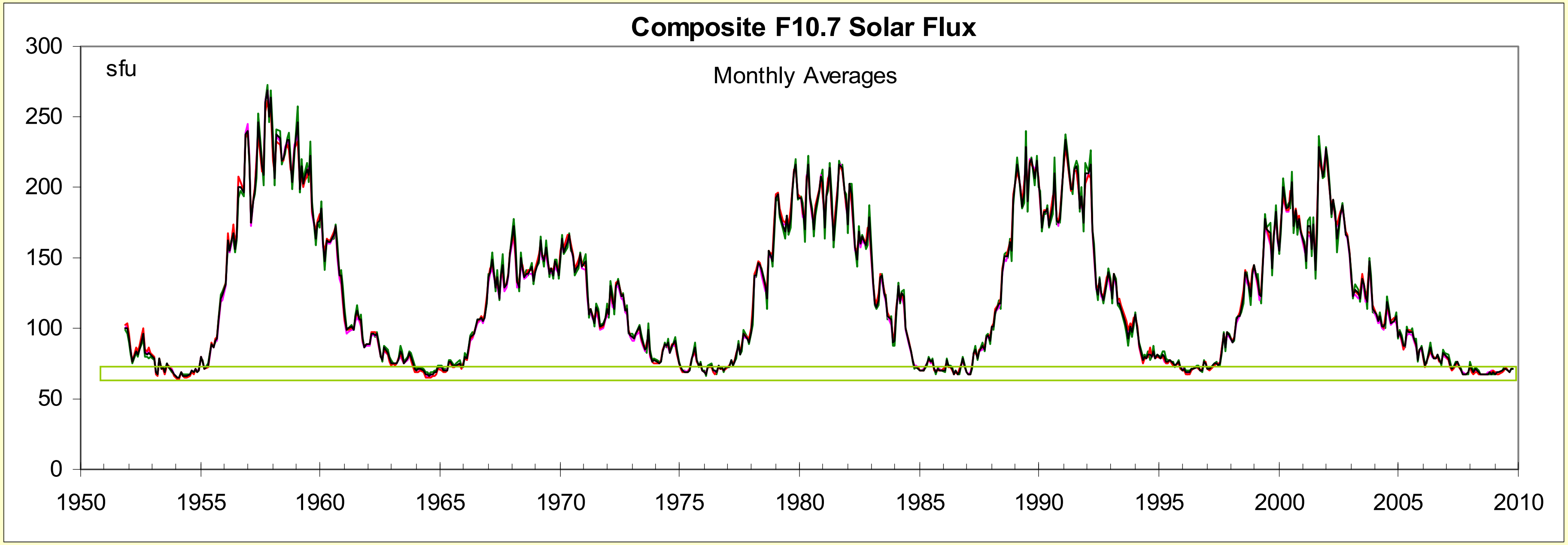
If both series have a stable calibration, their ratio should be constant in time. There is an indication that the move from Ottawa to Penticton introduced a small difference in level. We compensate for this by dividing the Ottawa values by 1.0314 (and then rescale)



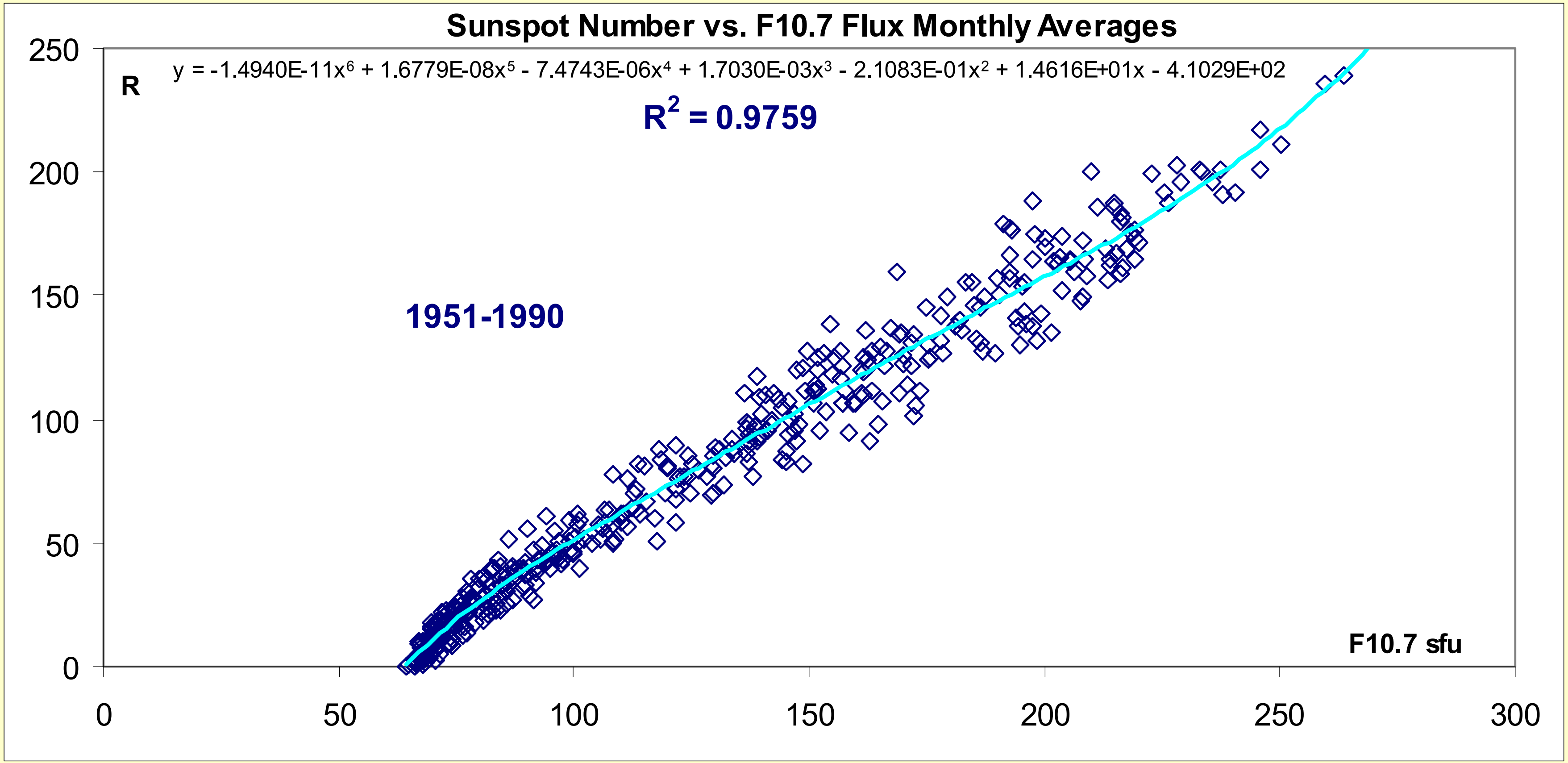


The Final Composite ‘F10.7’ Flux

The average of the Japanese and the Canadian series is our final composite, which we shall use in the following. We have considerable confidence in the stability and calibration of this series. The constant level at each minimum is notable (green box) and argues against secular changes

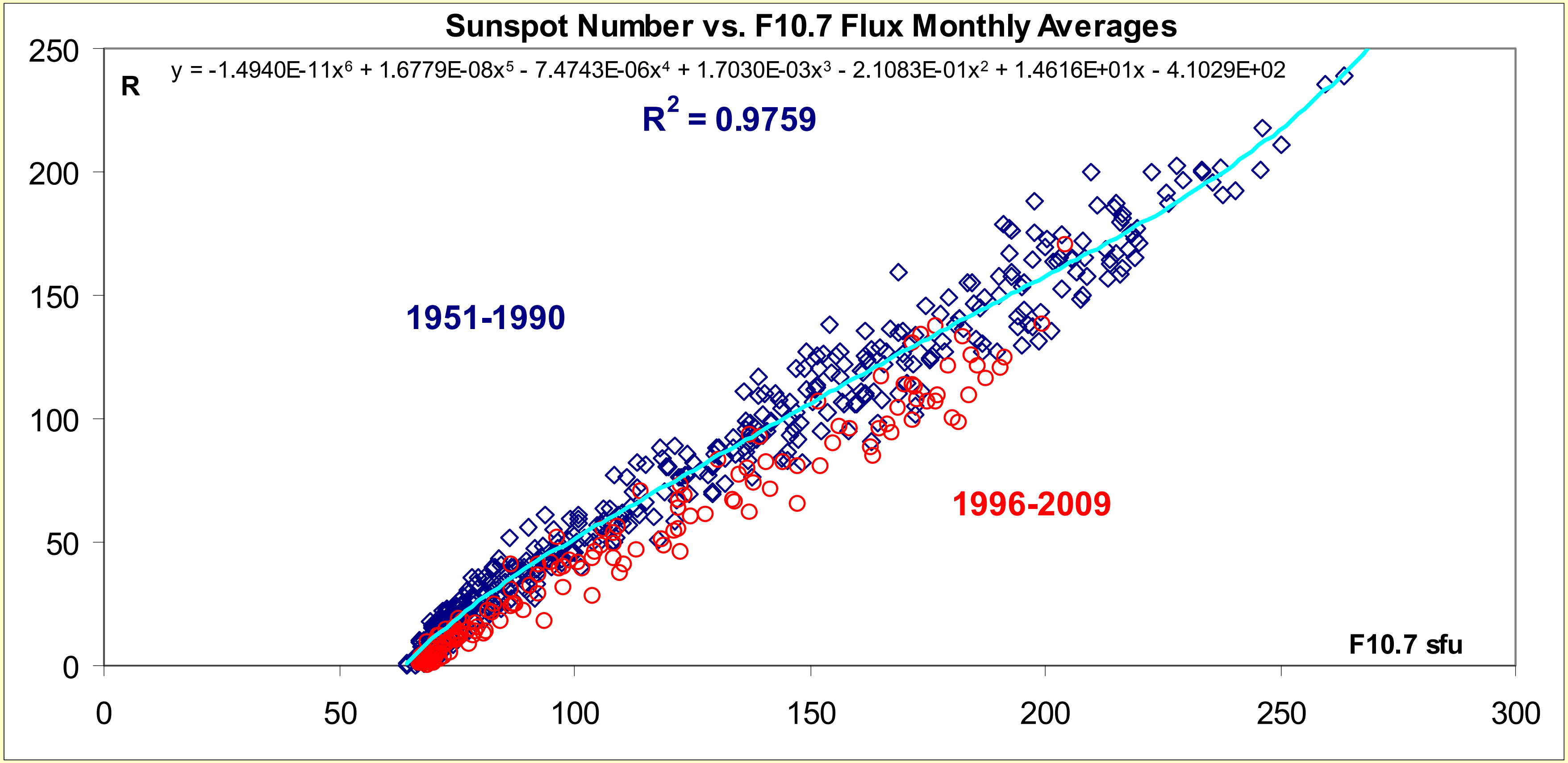


The well-known Relationship between the Sunspot Number and F10.7



The polynomial formula has no particular physical significance

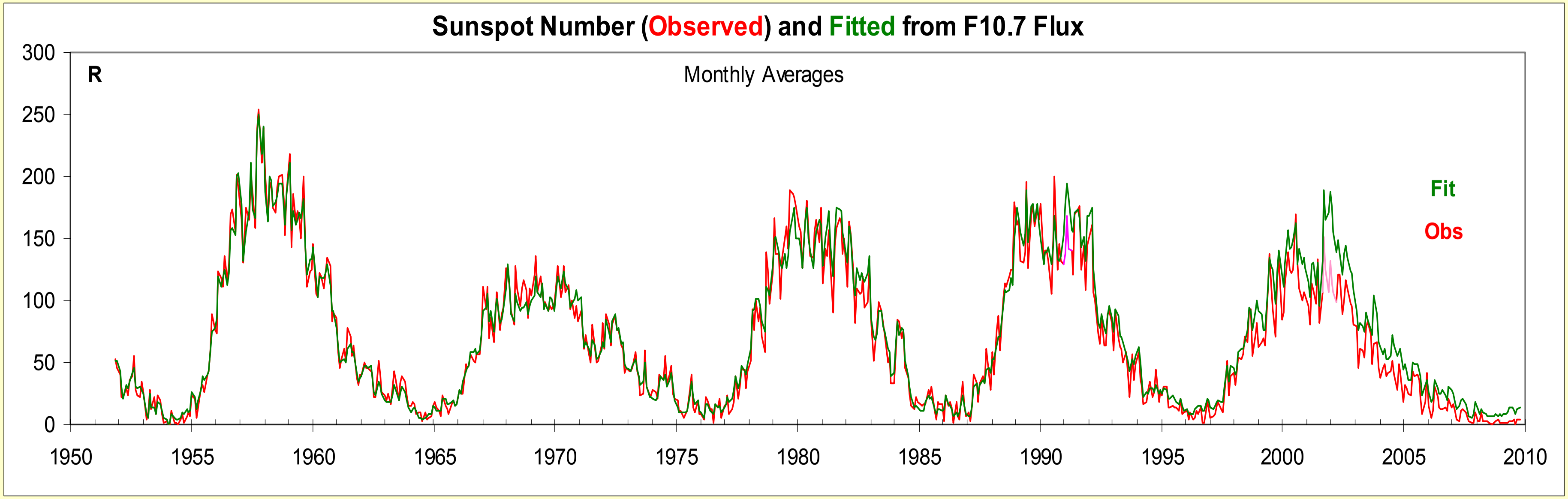
The well-known Relationship between the Sunspot Number and F10.7



Changes significantly in solar cycle 23 (Tapping 2009)

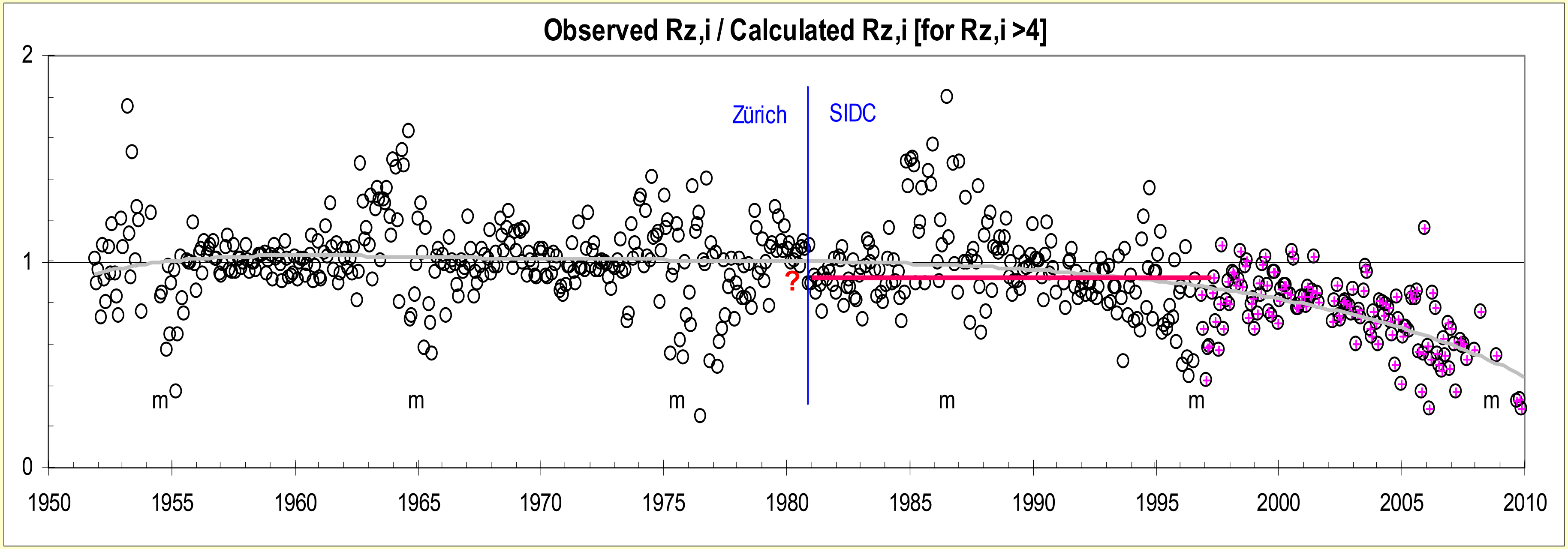
Comparing the Synthetic Sunspot Number with Observations

The observed International Sunspot Number, R_i, is systematically and *progressively* ‘too low’ compared to what we would expect from F10.7 starting in ~1991 [the reason the interval 1951-1990 was used]

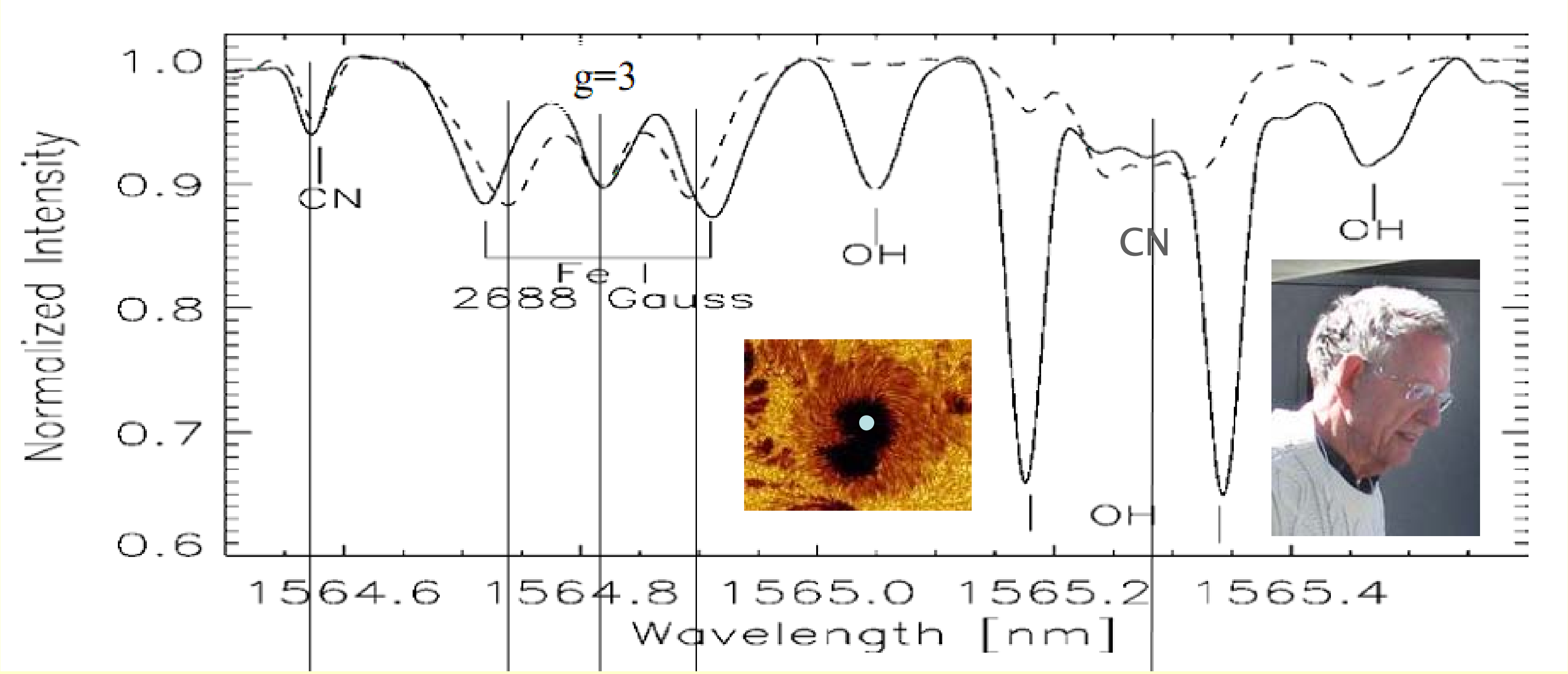


Comparing Ratios

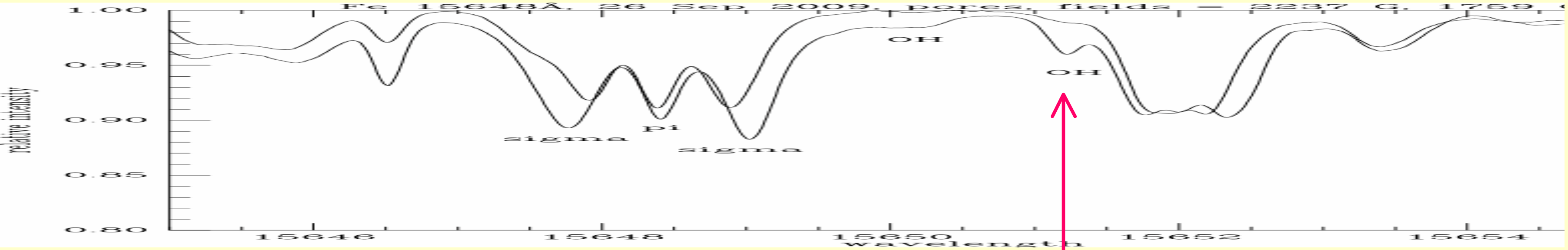
The ratio between observed and fitted Sunspot Numbers should be one [avoiding cases where R is too small – and still we have large noise near solar minima – marked by small *m*’s on the graph]. The change in SSN observers from Zurich to Brussels might introduce a small offset (less than 5%), but cannot account for the decrease during solar cycle 23



The Fe I line at 1564.8 nm has a very large and easily measured Zeeman splitting. The Hydroxyl radical OH is very temperature sensitive and the lines weaken severely at higher temperatures.



Courtesy Bill Livingston



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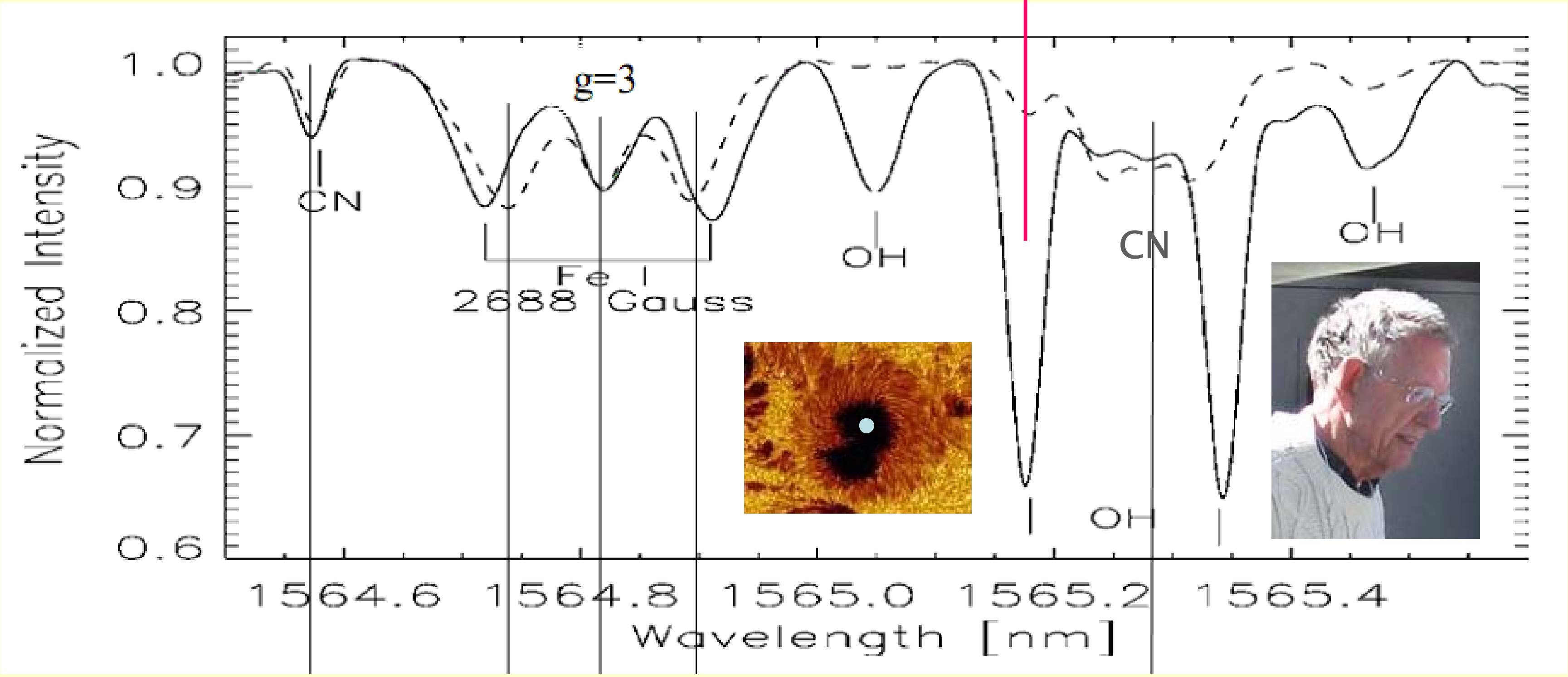
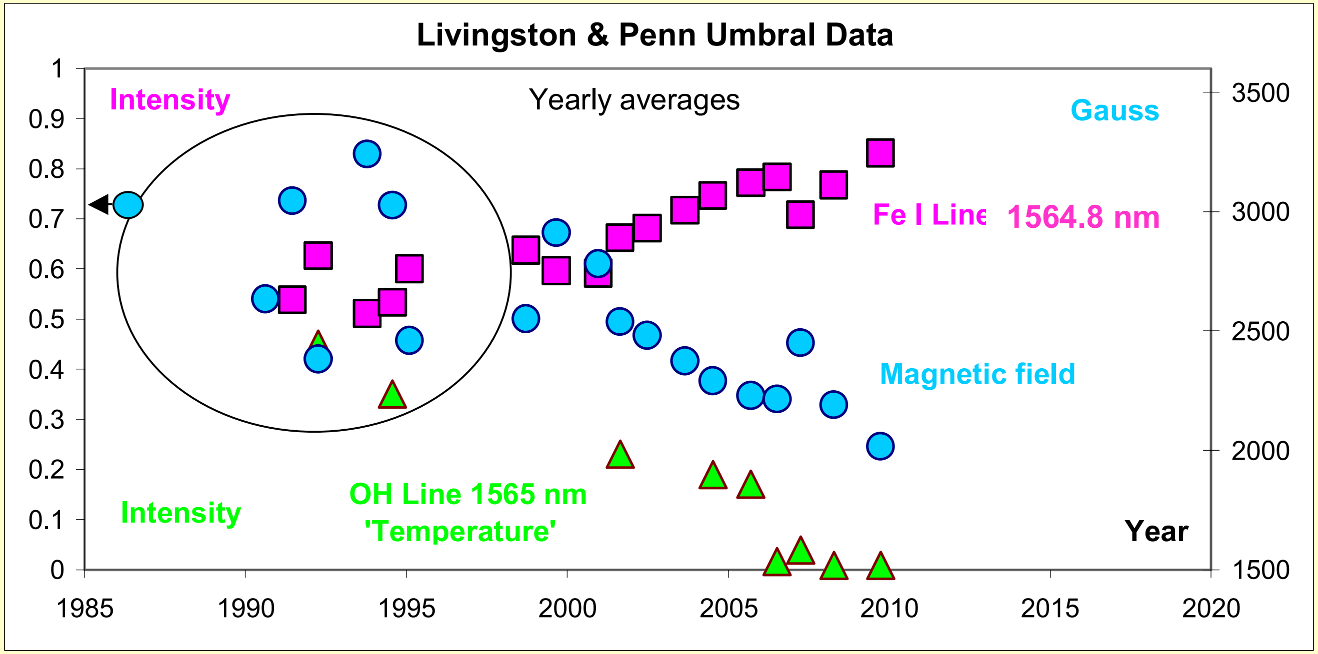


Courtesy Bill Livingston

The Magnetic Field has Steadily Decreased During SC23. The Temperature has Steadily Increased. At B = 1500 G, the Spot is Effectively Invisible.

Decreasing Visibility due to this Effect may lead to an Undercount of Sunspots and partly Explain the Changed Relationship with the Microwave Flux

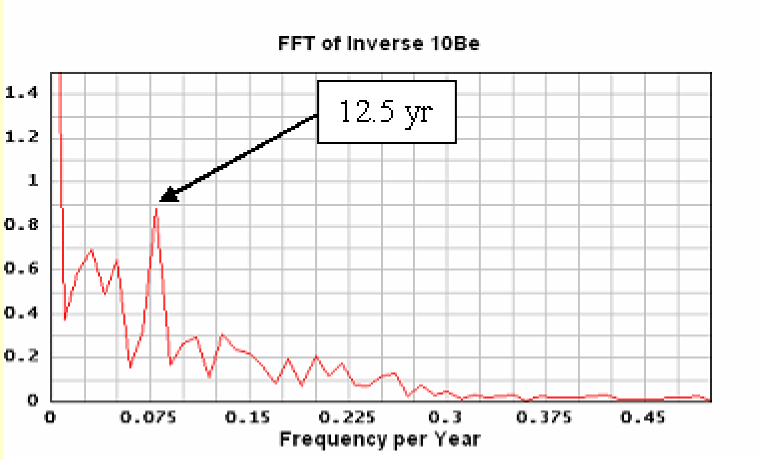


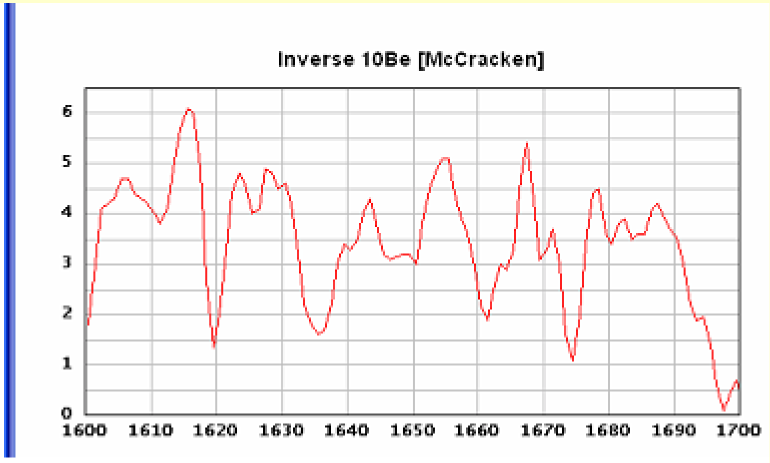
1403 measurements since 1998

Wild Speculation

Was the Maunder Minimum Just an Example of a Strong L&P Effect?

Cosmic Ray proxies show that during both the Maunder Minimum and the Spörer Minimum, the modulation of cosmic rays proceeded almost as ‘usual’. So the Heliosphere was not too different then from now, and perhaps the spots were there but just much harder to see because of low contrast because of B ≈ 1500 G.

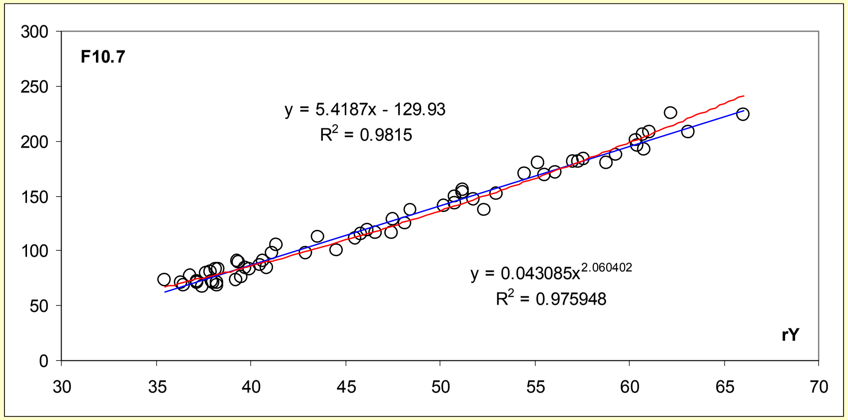


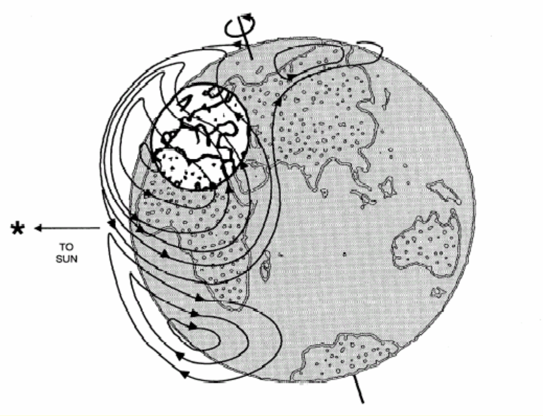


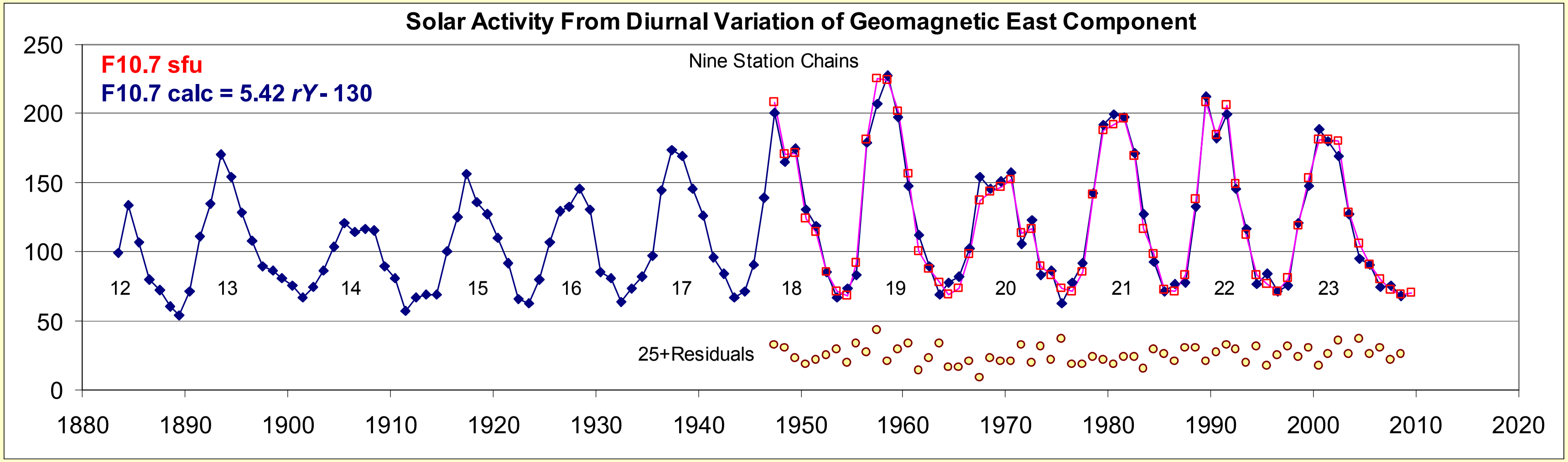
Conclusions

- The Canadian and Japanese microwave radiometry is stable, robust, and of high quality
- The SSN began departing from its usual correlation in Cycle 23
- The Livingston-Penn sunspot measurements are consistent with the SSN change
- The nature of solar activity appears to be changing as we watch

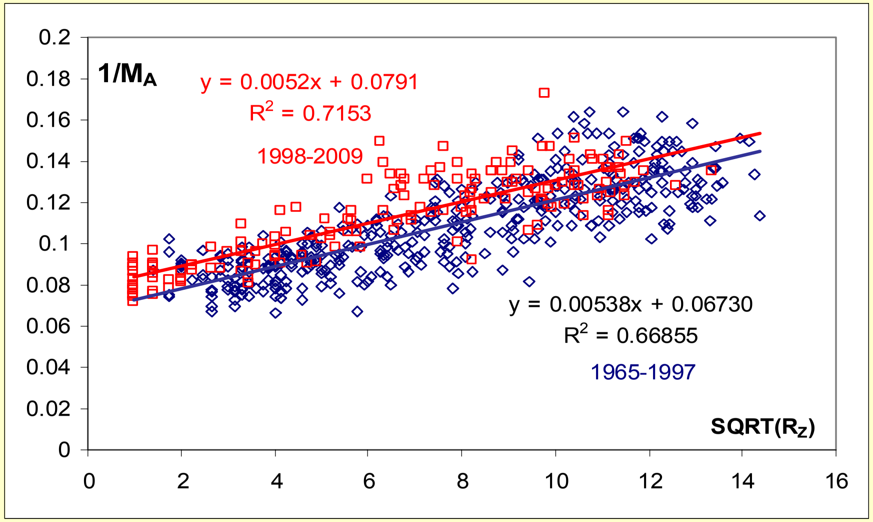
F10.7 and Geomagnetic Diurnal Variation Agree in Detail

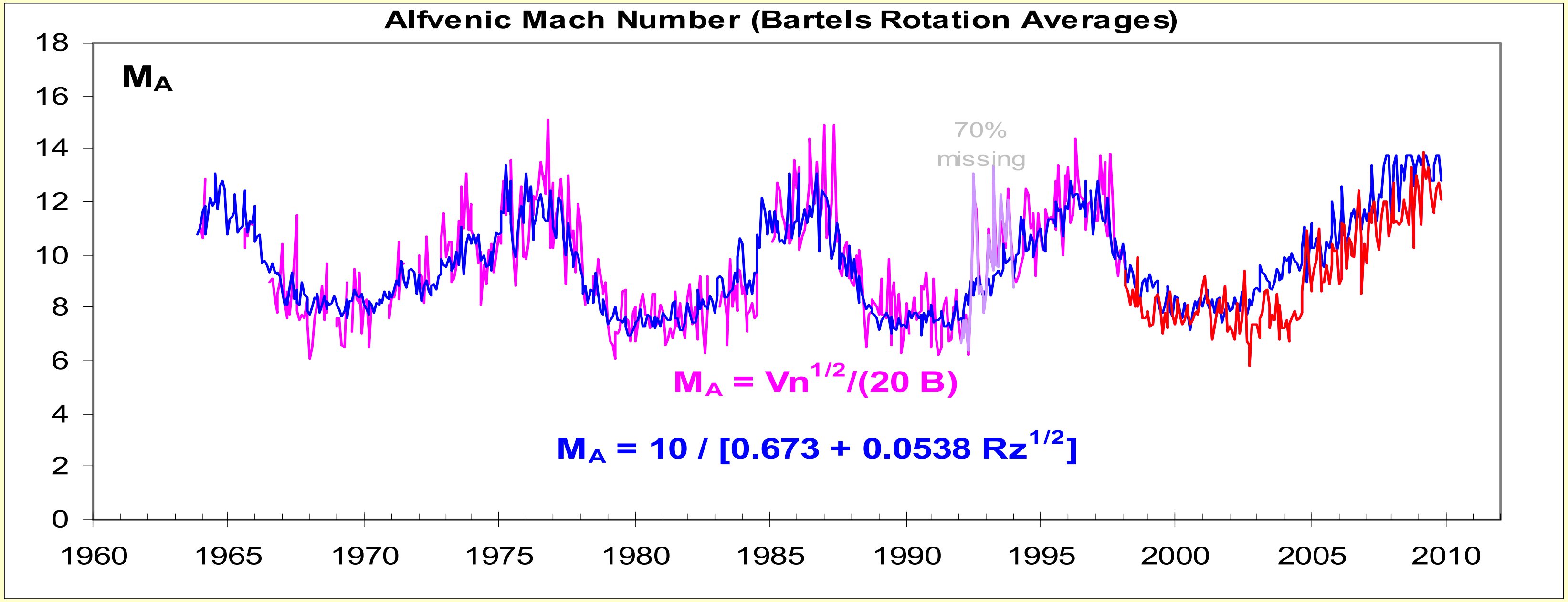






The Relationship between the Alfvenic Mach number in the solar wind (at 1AU) and the sunspot number has also changed in SC23





Abstract

Since 1947 the flux of microwaves from the Sun at wavelengths between 3 and 30 cm [frequencies between 10 and 1 GHz] has been routinely measured. This emission comes from both chromosphere and the corona and has two main sources: thermal bremsstrahlung (free-free emission) and thermal gyroradiation. These mechanisms give rise to enhanced radiation when the density and magnetic field increase, so the microwave radiation is a good measure of general solar activity. Strong magnetic fields occur in the network and can persist for weeks or longer; hence there is a strong rotational signal in the emission superposed on a solar cycle variation of the background coronal signal. The radio flux measurements can be calibrated absolutely and are not very sensitive to observing conditions, and in principle have no personal equation. They may thus be the most objective measure of solar activity, and our many decades-long flux record could throw light on the important issue of the long-term variation of solar activity. The longest series of observations F10.7, begun by Covington in Ottawa, Canada in April 1947 and is maintained to this day. Other observatories also have long and continuing series of measurements of the microwave flux. One can now ask how this measure of solar activity compares to other measures, in particular the sunspot number. We correlate the sunspot number against the F10.7 flux for the interval 1951-1990, and obtain a good polynomial fit (R^2 = 0.976) up until ~1991.0 after which time the observed sunspot number falls progressively below the fitted number. Three obvious hypotheses present themselves:

1) The sunspot counting procedure or observers have changed, with resulting artificial changes of the sunspot number as they have in the past.

2) Physical changes in the corona or chromosphere have occurred.

3) Livingston & Penn's observations that the sunspots are getting warmer during the last decade, leading to a decreased contrast with the surrounding photosphere and hence lessened visibility, possibly resulting in an undercount of sunspots

The near constancy of the flux at minima since 1954 argues against a change of the physical conditions at the source locations, leaving the exciting possibility that Livingston & Penn may be correct.