Microwave fluxes in the recent solar minimum

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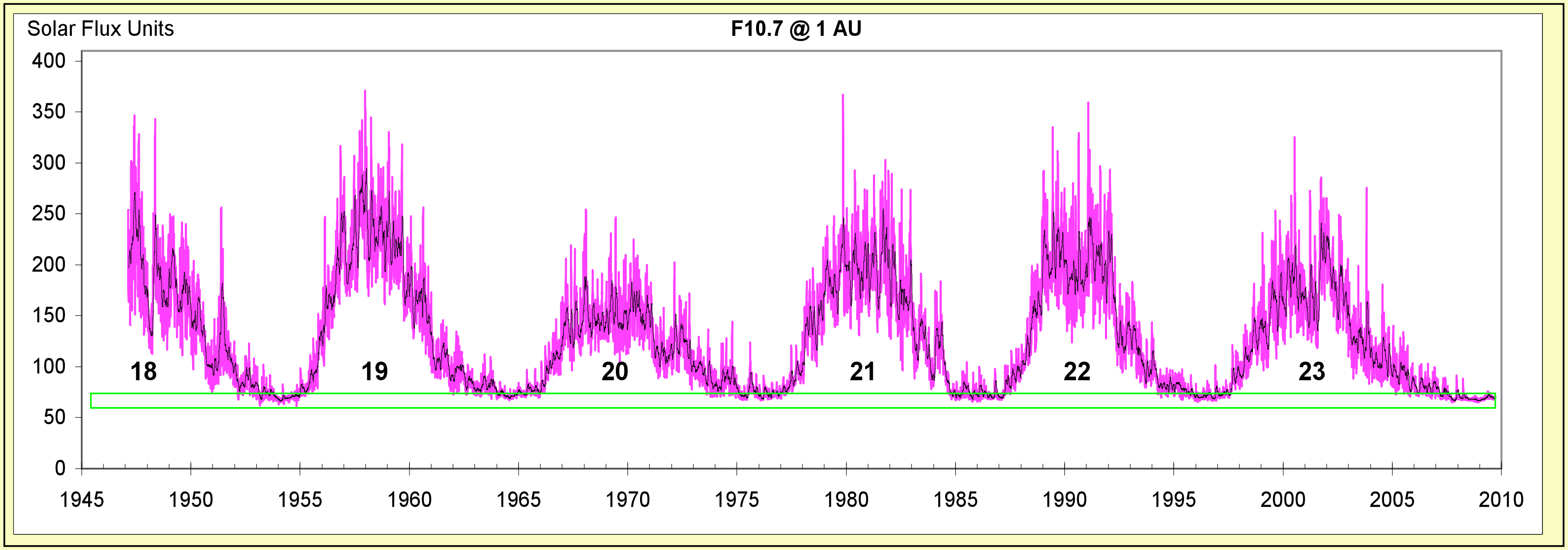
The time series of solar microwave flux traditionally is divided into a flare component, a slowly-varying component, and a base level. Since 1947 there have been routine radiometric measurements, and the non-flare F10.7 index (2.8 GHz) from Penticton has had broad usage. Systematic radiometry at other microwave frequencies (1.0, 2.0, 3.75, 9.4 GHz) have come from Toyokawa and Nobeyama; these and other programs continue to the present time, thus including the five most recent solar maxima. We use the different measurements to show that the preceding maximum epoch (23) differed from the earlier ones. We also study the recent anomalous solar minimum and find that the joint variations of microwave flux, total solar irradiance (TSI), and sunspot number do not follow the patterns expected for TSI variability in maximum periods..

Brief history of solar microwave radiometry

- A.E. Covington's choice of 10.7 cm for the Canadian measurements was due to the available hardware. However, this wavelength proved fortuitously to be close to the peak of gyroresonance emission from kilogauss magnetic fields overlying sunspots.
- H. Tanaka et al. (1973) put the absolute calibration of solar microwave total flux measurements on a firm footing
- Routine Toyokawa observations at 1, 2, 3.75, and 9.4 continue at Nobeyama, with 17 GHz as well, covering a wide range of coronal and chromospheric conditions

The records



• The F10.7 record extends from Cycle 18 maximum to the present

• The minima (green box) have closely the same level, thus confirming the stability of the calibrations

Significance of Measurement

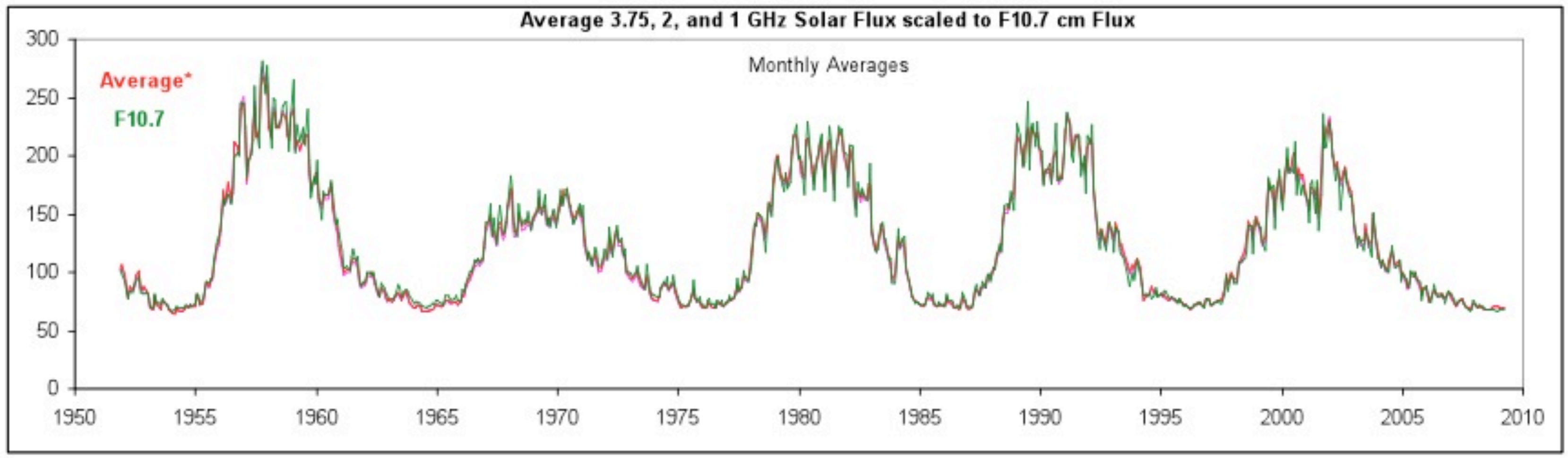
- The microwave continuum reflects the mean structure of the atmosphere, with frequency mapping to height
- As shown by Tanaka et al. (1973), these data (fixed frequencies, integrated Sun) can be calibrated precisely
- The microwave flux is more objective than the sunspot number
- The main high-quality data sources (Canada for F10.7, Japan for five frequencies at present), have been maintained very well

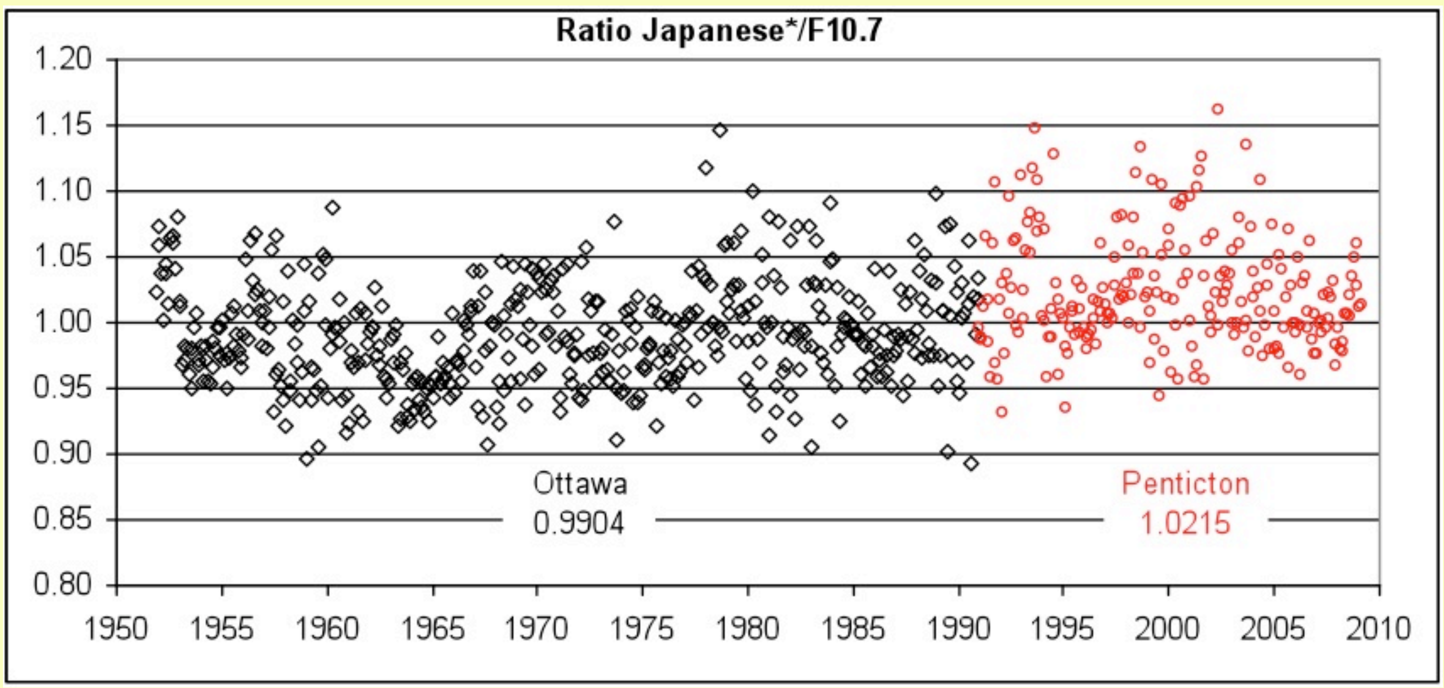
Sources of F10.7

- The features that contribute include
  - Active regions (spots and plage)
  - The quiet solar atmosphere
  - Enhanced network
  - Polar faculae
  - Prominences
- The base level, 66-70 SFU (= 10^{-22} W m^{-2} Hz^{-1}) has an unknown mixture of residual network and quiet atmosphere components

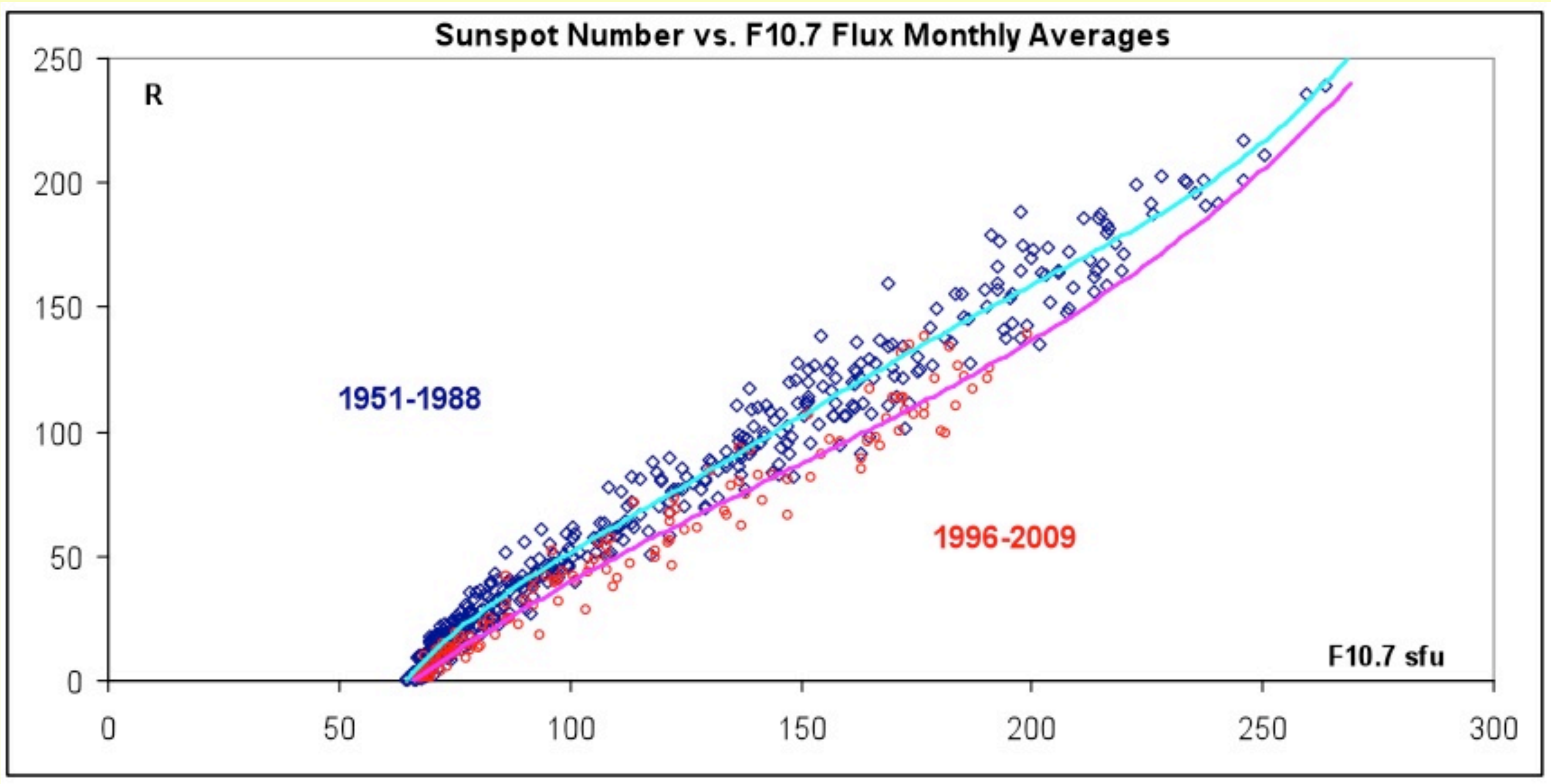
See Tapping (JGR 92, 829, 1987)

Stability of microwave data





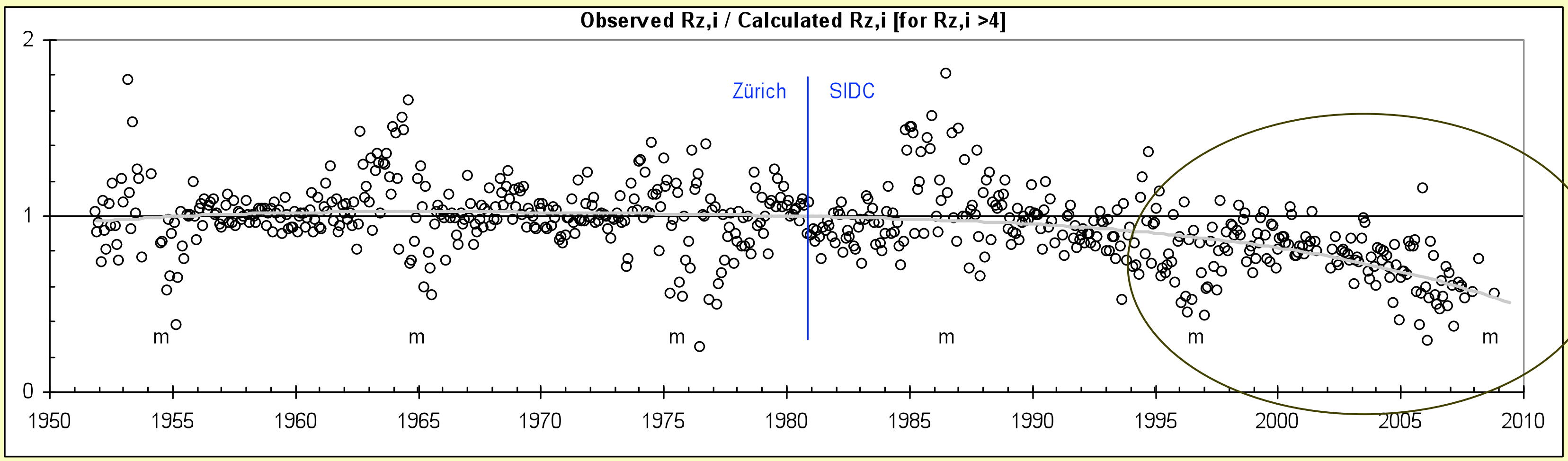
Comparison of F10.7 with SSN



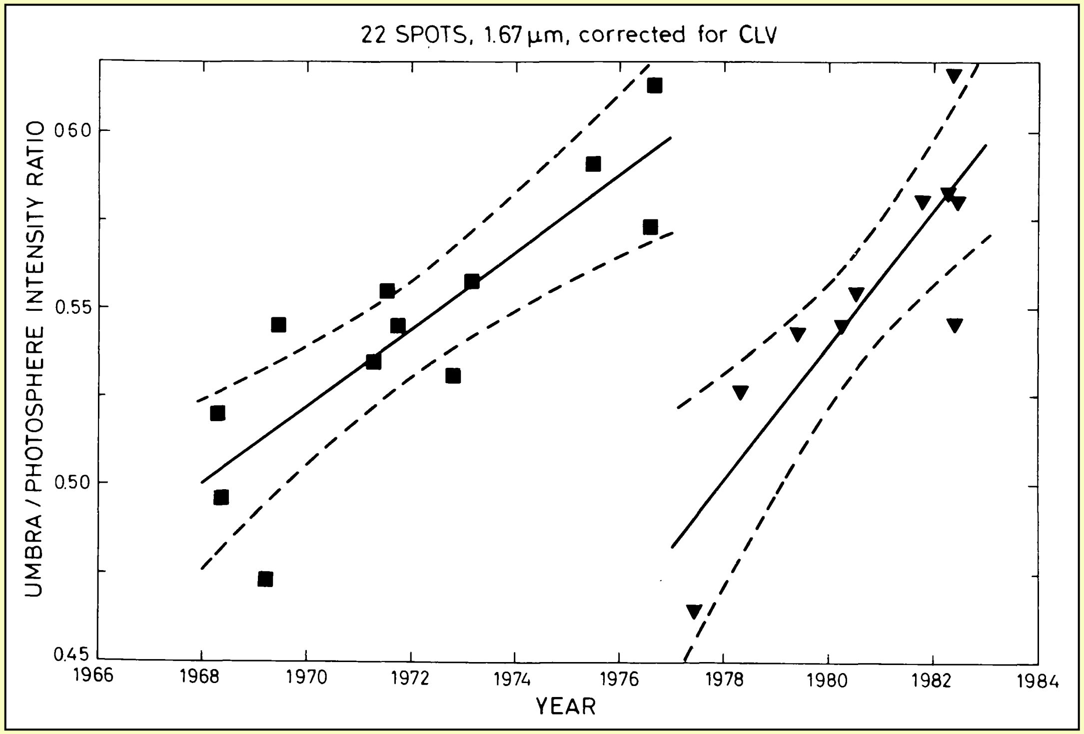
The correlation *changes significantly* during the current cycle (Tapping, 2009)

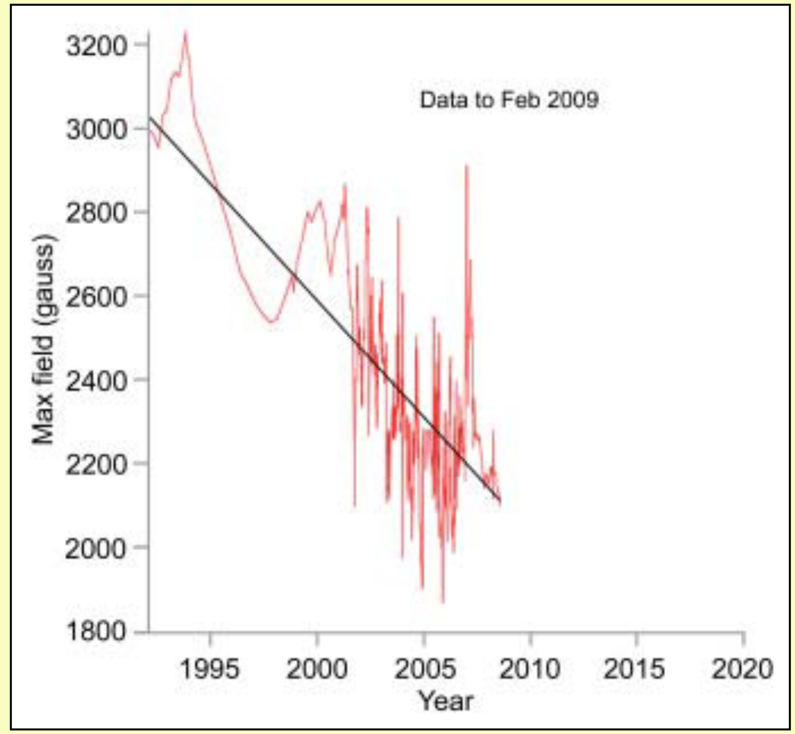
Comparison of F10.7 with SSN

- Ratio of observed SSN and SSN calculated from the good correlation 1947-1988, for months where SSN is greater than 4
- There is a serious deficit during Cycle 23



Sunspot variations - 1

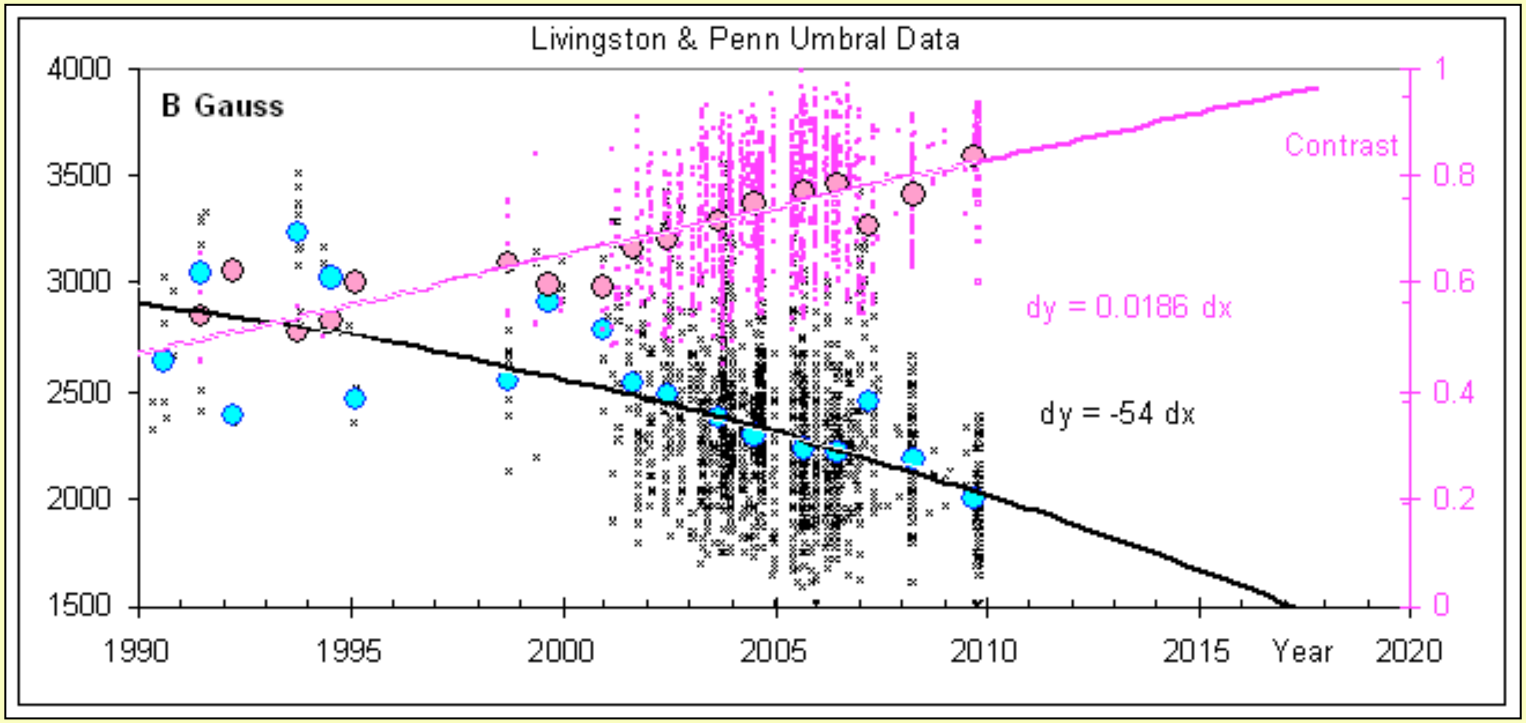




Albregtsen & Maltby, 1984:
Intensity variations

Livingston & Penn 2009:
Magnetic variations

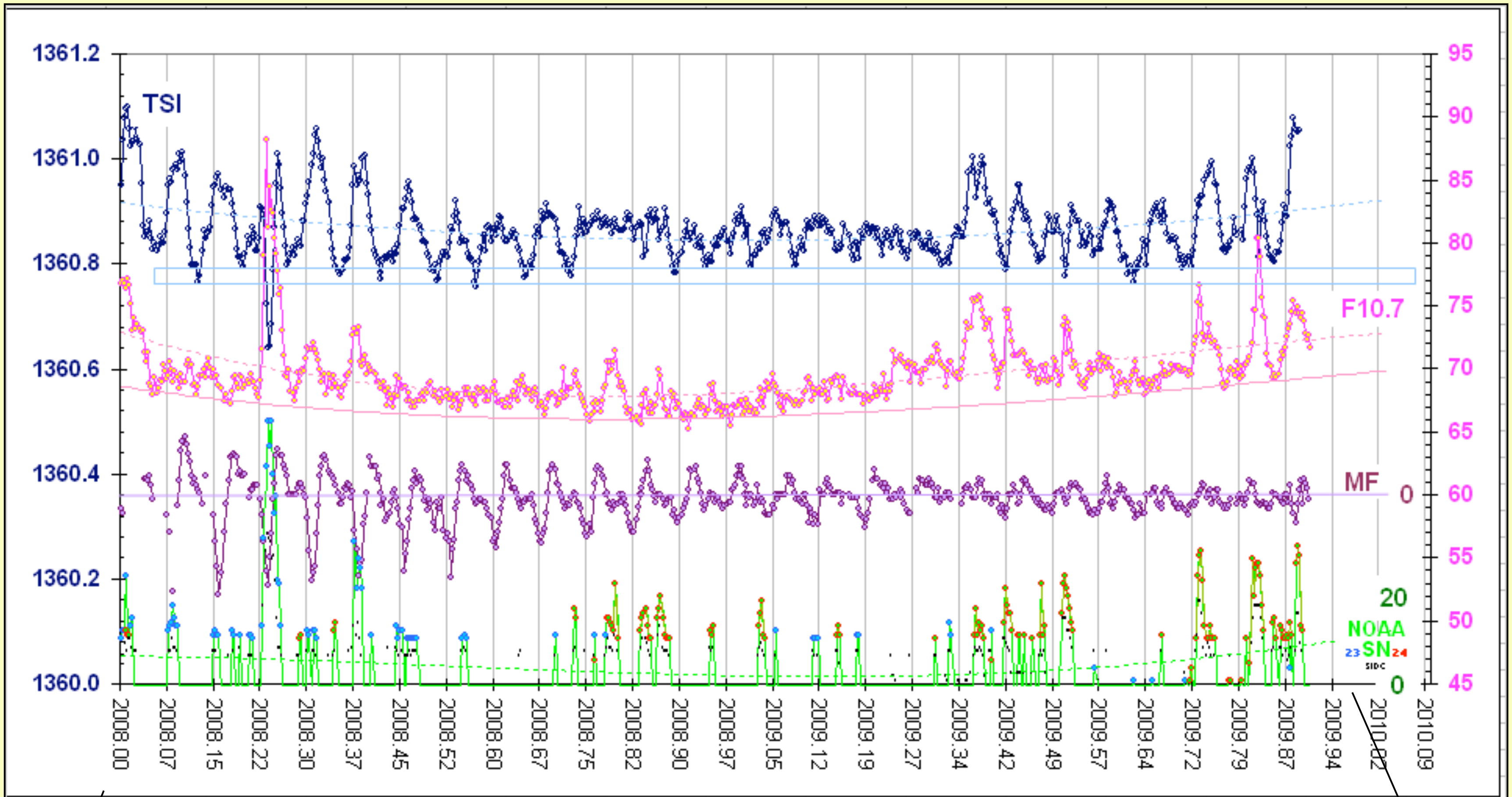
Sunspot variations - 2



Routine IR photometry and Zeeman measurements from KPNO by W. Livingston and M. Penn at 1564.8 nm

- There is an apparent *secular decrease* of umbral contrast, referred to quiet photosphere
- There is an apparent *secular decrease* of umbral field strength
- Livingston & Penn suggest that a dearth of sunspots is arriving

Indices during recent minimum



The TSI variations don't follow standard models

2008

2010

TSI model non-compliance

- The TSI data have excellent precision, and show systematic variations during the 23/24 minimum
- The normal 4-component* models of TSI can't explain what we see in the Cycle 23/24 minimum

  - Since early 2008, the sunspots have not produced TSI dips

  - Uncorrelated TSI minima appear

  - An isolated F10.7 peak has no TSI counterpart

*Base, sunspots, plage, active network

Conclusions

- The change in F10.7/SSN seen in Cycle 23 suggests an unprecedented phenomenon
- The Livingston-Penn IR observations of umbral field intensity also suggest a secular change
- F10.7 shows interesting behavior in the Cycle 23/24 minimum that we don't know the causes of
- The normal 4-component models of TSI can't explain what we see in the Cycle 23/24 minimum

Speculations

- There appears to be a general secular change in sunspot behavior
- F10.7, supported by the Japanese fixed-frequency observations, is consistent with this pattern
- Sunspots do not appear to form as expected
- The Cycle 23/24 anomalous minimum may be a part of a change in the state of solar activity