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### Title

Hans E. Suess (1909-1993): Radiocarbon, Sun and Climate Pioneer

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# HANS E. SUESS (1909-1993)

## RADIOCARBON, SUN AND CLIMATE

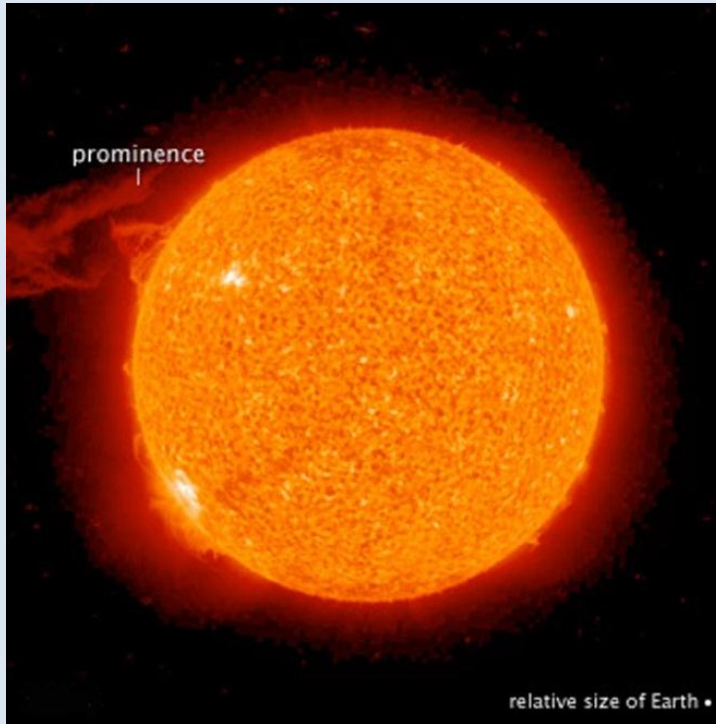


*Hans Suess*

### PIONEER

Hans E. Suess, a distinguished physical chemist, co-founder of the Department of Chemistry at UCSD in the late 1950s, worked on the abundance of elements in the solar system, and on the abundance distribution of radiocarbon through time.

H.E. Suess, S.I.O., UCSD Library

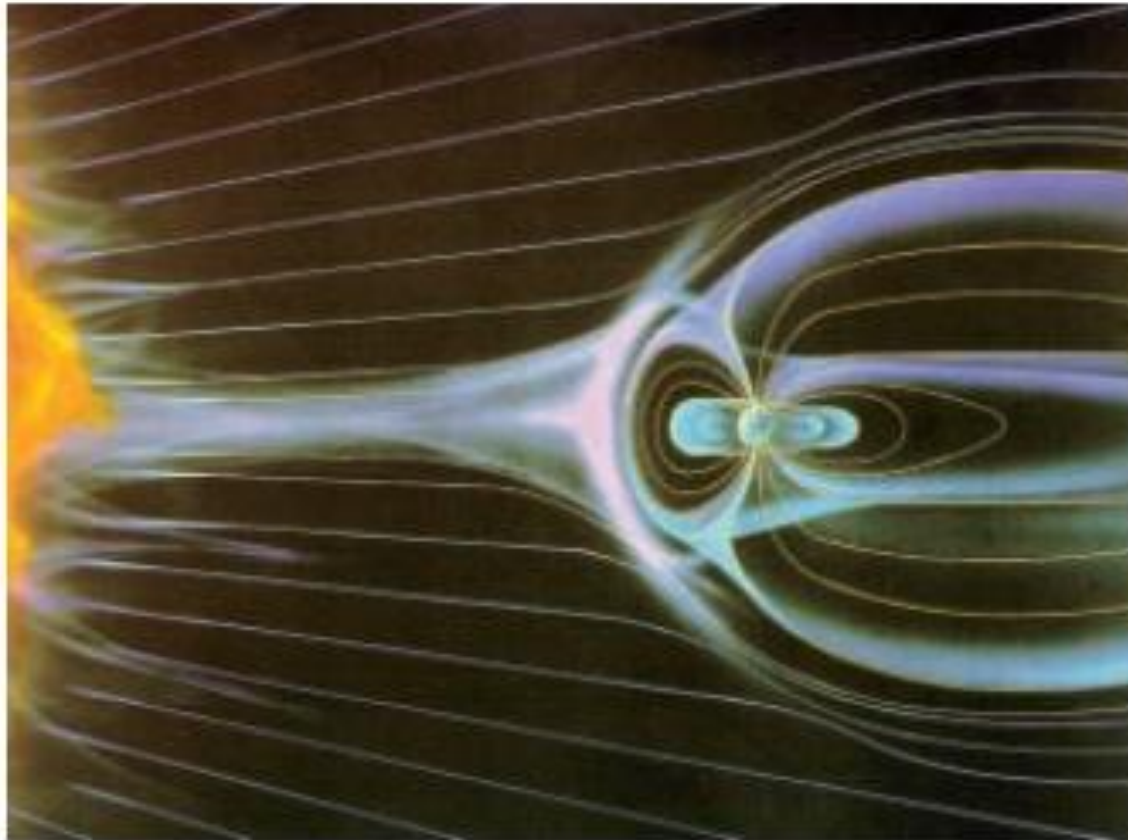


NASA

## SOL

**Suess was interested in the question of how the sun's activity changes through time, and whether the variations in activity can be recognized in climate proxy records.**

Suess thought that the  $^{14}\text{C}$  activity in well-dated tree-rings would solve the question of how the sun's activity changed through time, on a previously unavailable scale (that is, thousands of years back in time, and with resolution on decades or better).



from Beer 2001

**Figure 2**

*In this cartoon the Sun's atmosphere continually expands from the left into interplanetary space. The flow of ionised gas, called solar wind, carries frozen-in magnetic fields from the Sun into space. When sweeping by the Earth, it deforms the geomagnetic field. Explosive eruptions lead to sudden "space storms" which can seriously affect the Earth. The solar wind fills a space larger than 100 times the distance from Sun to Earth. The magnetic field deflects the charged cosmic ray particles. Therefore, the cosmic ray flux is reduced considerably within the solar system during periods of high solar activity. (Credit: ESA).*

**Basic idea: Sol modifies access of cosmic rays to Earth**

# BRISTLECONE PINE

To reconstruct the history of radiocarbon production, he needed well-dated carbon samples for the Holocene and earlier times .

He found this material in the rings of ancient trees.

His favorite source were bristlecone pines, whose great age had been established by A.E. Douglass and E.P. Schulman. Suess worked with the tree-ring specialist C.W. Ferguson of Arizona University to be sure to get the calendar ages right.



Bristlecone pine, White Mountains, California.

Suess analyzed the wood samples using the acetylene method he had invented and found that he could fit a sine wave to the resulting data (after correcting for exponential decay, for the half-life of radiocarbon, which is roughly 6000 years). Suess assumed 5730 years for the half-life, when making the correction for the figure shown. The sine wave had a length of 10,350 y. Suess noted the deviations from the best-fit sine curve and opined that they represented variation in solar output.

## RADIOCARBON

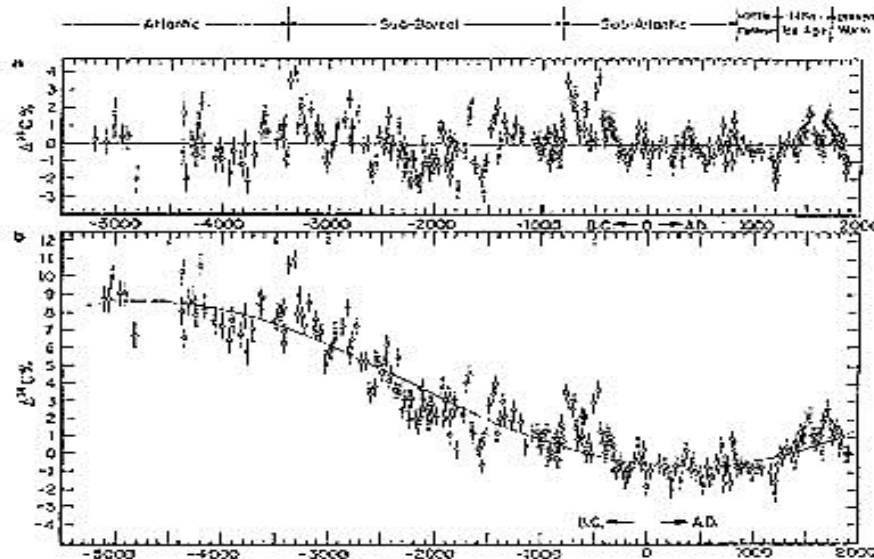


Fig. 1a. Deviations of  $\Delta^{14}\text{C}$  (‰) from the sine wave shown in Fig. 1b plotted versus wood age. The deviations are probably caused by the sun. b. Plotted are deviations  $\Delta^{14}\text{C}$  in per mil of measured  $^{14}\text{C}$  content of tree-ring-dated wood from age-corrected  $^{14}\text{C}$  (assuming 5,730 years for the  $^{14}\text{C}$  half-life) relative to the  $^{14}\text{C}$  in fir wood from Oregon, grown between A.D. 1870 and 1890 versus dendrochronological wood age. The curve drawn through the points is a best-fit sine wave (period 10,350 years, amplitude 99‰), corresponding approximately to the  $\Delta^{14}\text{C}$  change caused by the change of the geomagnetic field. The data are preliminary and obtained by the La Jolla Radiocarbon Laboratory. A tentative possible correlation with climatic epochs is indicated at the top of the figure.

By 1980, Suess presented information on reconstructed radiocarbon anomalies for the last 8000 years in considerable detail.

## “WIGGLES”

Two questions immediately arise, as follows:

- (1) What exactly are the periodicities contained in the record.
- (2) Is there evidence that the “wiggles” are caused by solar activity, or is there a possibility that they are of environmental origin (e.g., changes in the intensity of upwelling, with its low radiocarbon content). After all, radiocarbon is part of the carbon cycle.

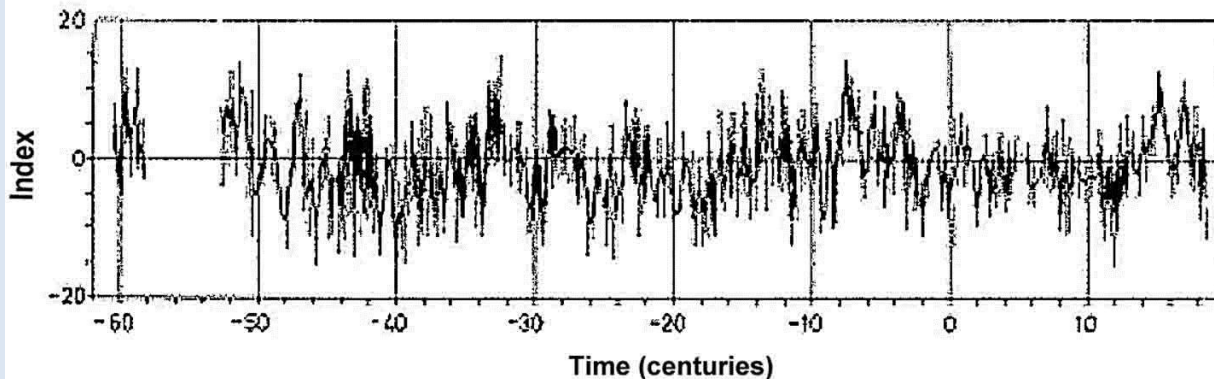


Fig 1. Variations of the atmospheric  $^{14}\text{C}$  level during the past 8000 years as derived from La Jolla  $^{14}\text{C}$  measurements (calculated with a  $^{14}\text{C}$  half-life of 5730 years). Error bars denote standard counting error of each measurement. The line through the data points is a computer drawn spline function.

**WHAT ABOUT HESSEL DE VRIES (1916-1959) OF THE UNIVERSITY OF GRONINGEN?**

**DIDN'T HE SHOW EARLIER THAT RADIOCARBON VARIED THROUGH TIME?**

**YES, HE DID, IN 1958. PAUL DAMON (1921-2005) AT THE UNIVERSITY OF ARIZONA CALLED IT THE "DE VRIES EFFECT." HOWEVER, DE VRIES DID NOT NECESSARILY FAVOR SOLAR ACTIVITY AS THE MAIN REASON FOR THE VARIATION BUT EARLY ON EMPHASIZED CHANGES IN THE OPERATION OF THE CARBON CYCLE.**

Suess's first paper on the subject of radiocarbon variation was published in 1965.



The first question, regarding cyclicity, was readily answered by Suess, early in his studies. He found several periods in the record of deviations, with one near 200 years rather prominent. A solar period of slightly more than 200 y has been reported, it is known as the “Suess” cycle, or also as the “de Vries” cycle (although de Vries did not report periodicity in his radiocarbon data).

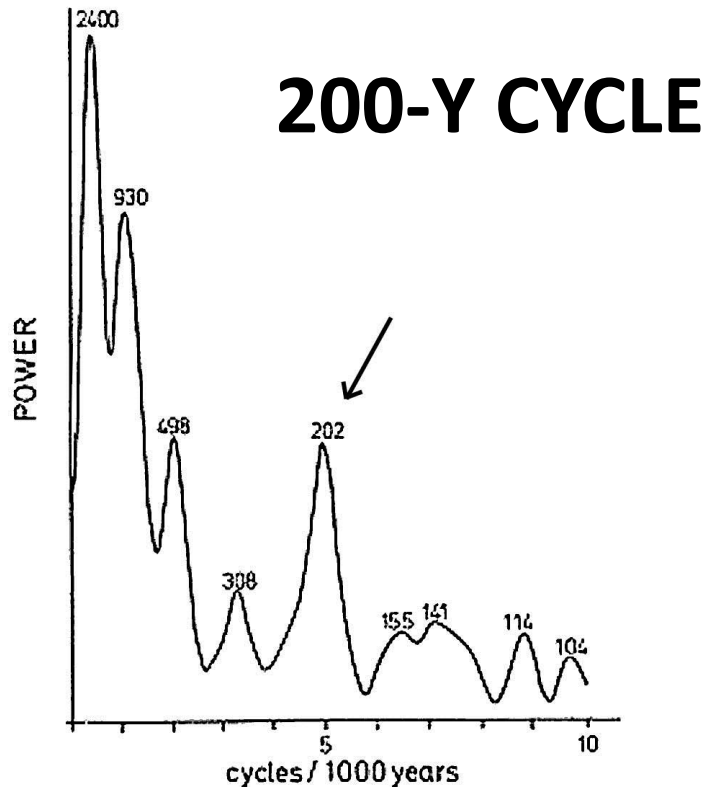


Fig 2. Typical Fourier spectrum of a  $\Delta^{14}\text{C}$  function as shown in figure 1.

Suess found the 200-y cycle, by Fourier analysis (verified by A. Kruse), at 202 y. (I have marked it with an arrow on the figure from Suess’s 1971 paper.) The period analyzed is 5300 B.C. to 1500 A.D.

The marked periods are 2400, **930**, 498, **308**, 202, **155**, 141, 114, and **104**.

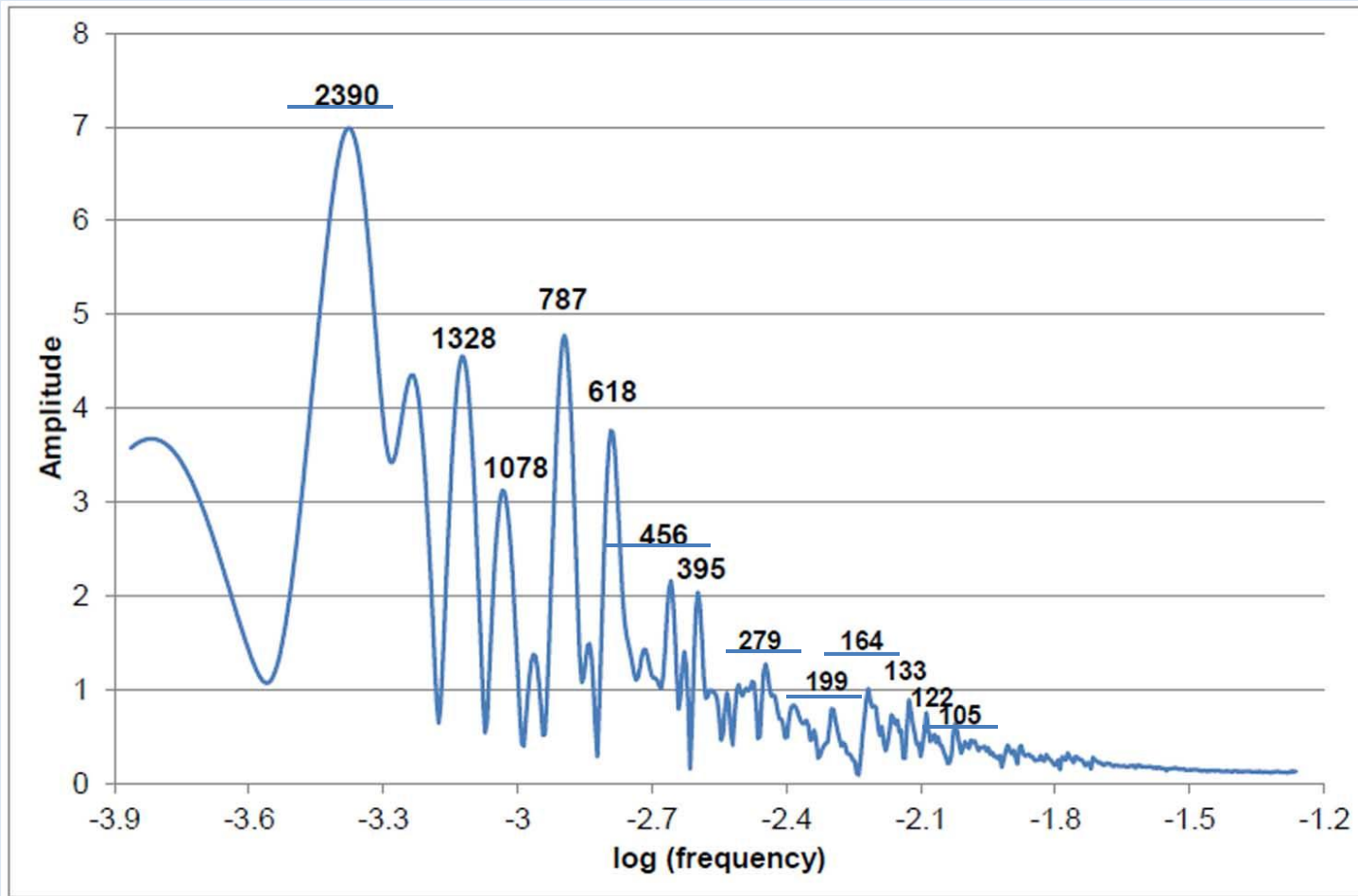
Note that several of these are obviously mutually supportive harmonics (marked bold above):

$104 \times 1.5 \sim 155$ ;  $155 \times 2 \sim 308$ ;  $155 \times 6 = 930$ ;  
 $308 \times 3 \sim 930$ .

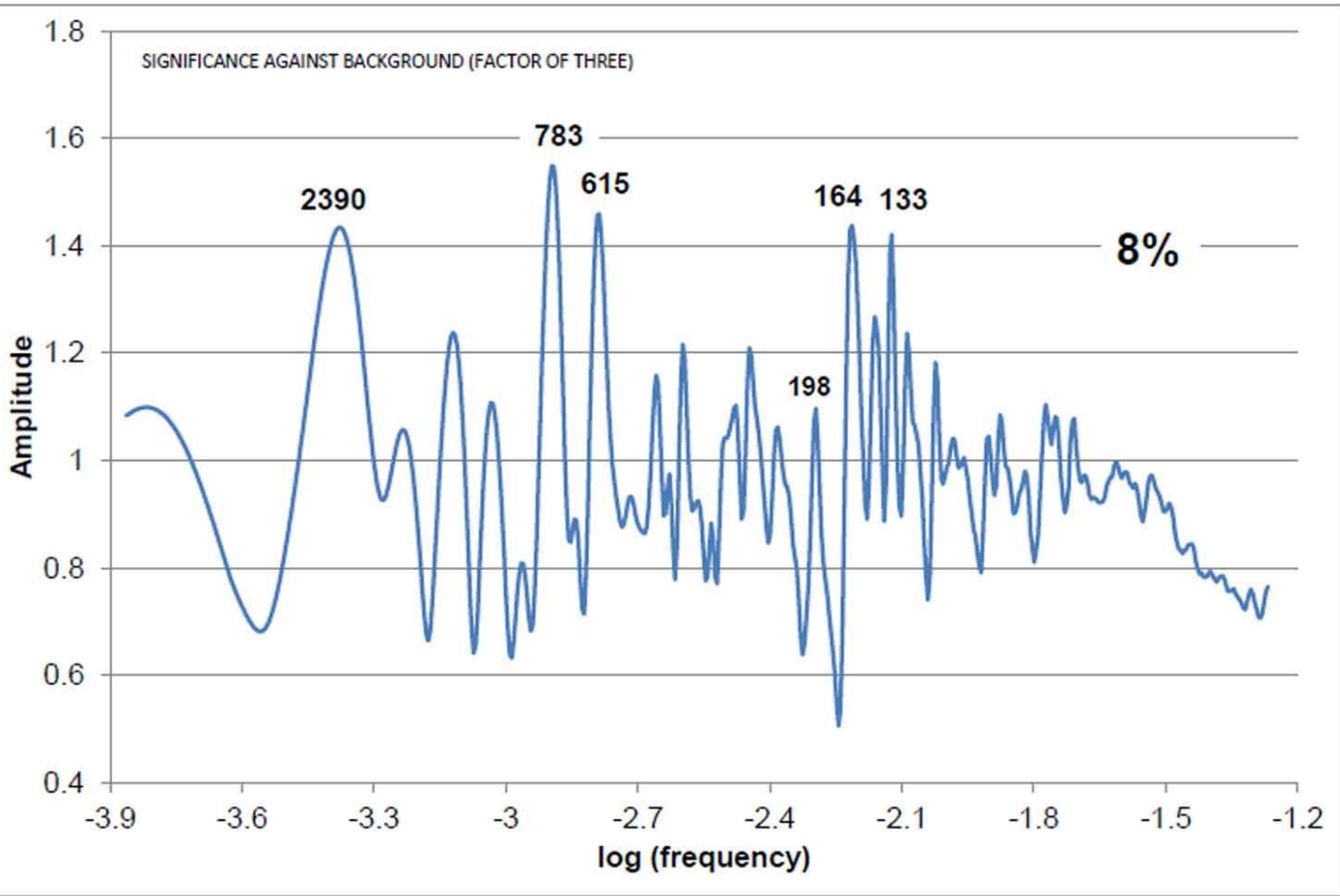
In each case, the error is less than one percent.

From Suess, 1971.

200 ?



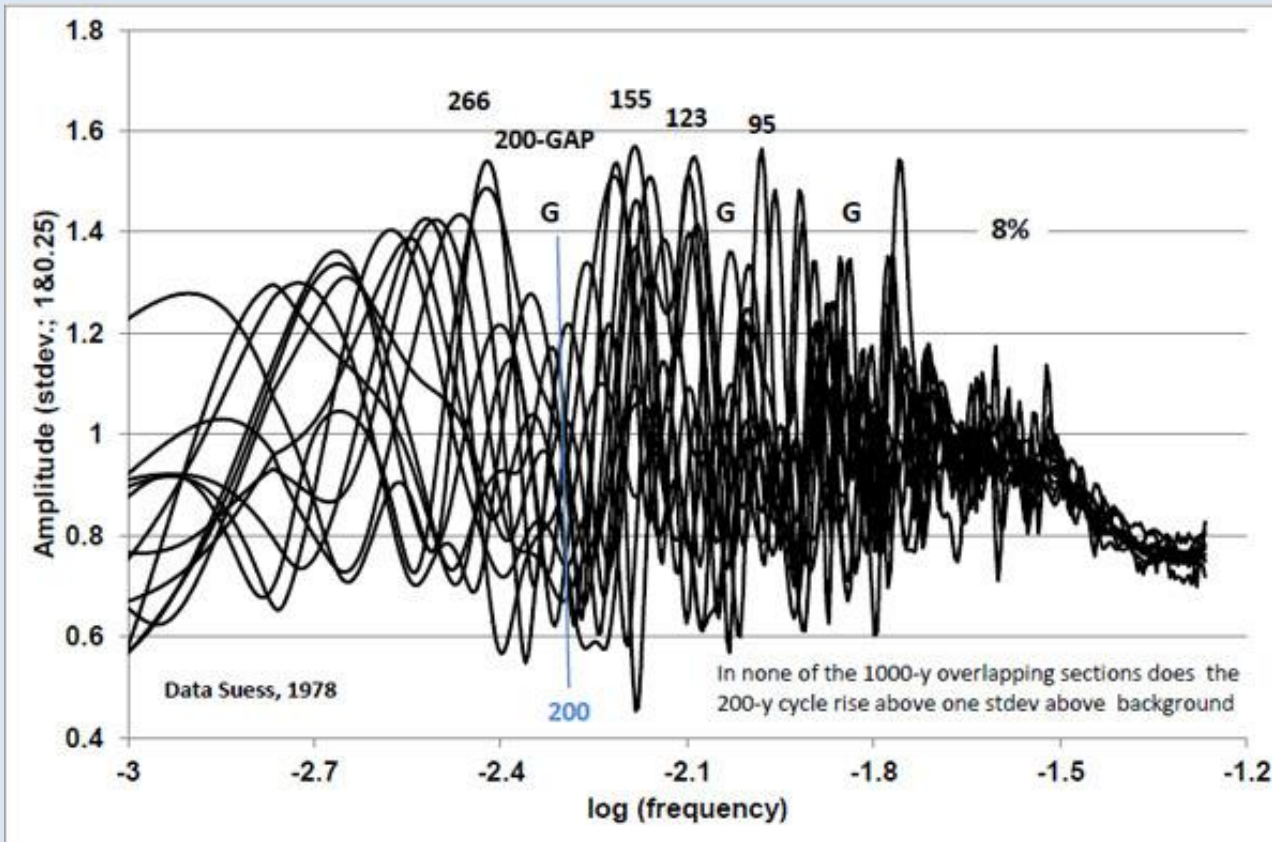
An analysis of data published by Suess (in 1978) yielded cycles reminiscent of many of the ones he found in the earlier data set, but with the 200-year “Suess Cycle” hardly in evidence at all.



**783 !**  
**p < 0.03**

The subdued nature of the 200-y cycle is confirmed when plotting the cycles against background in a window of a factor of three, to ascertain significance of peaks. The most prominent turns out to be a peak near 783 (suggesting a relationship to the much-quoted ~1500-y cycle of Heinrich layers and the 1470-y climate oscillation of Schulz et al., 1999). Other important periods are 615, 164, and 133 years.

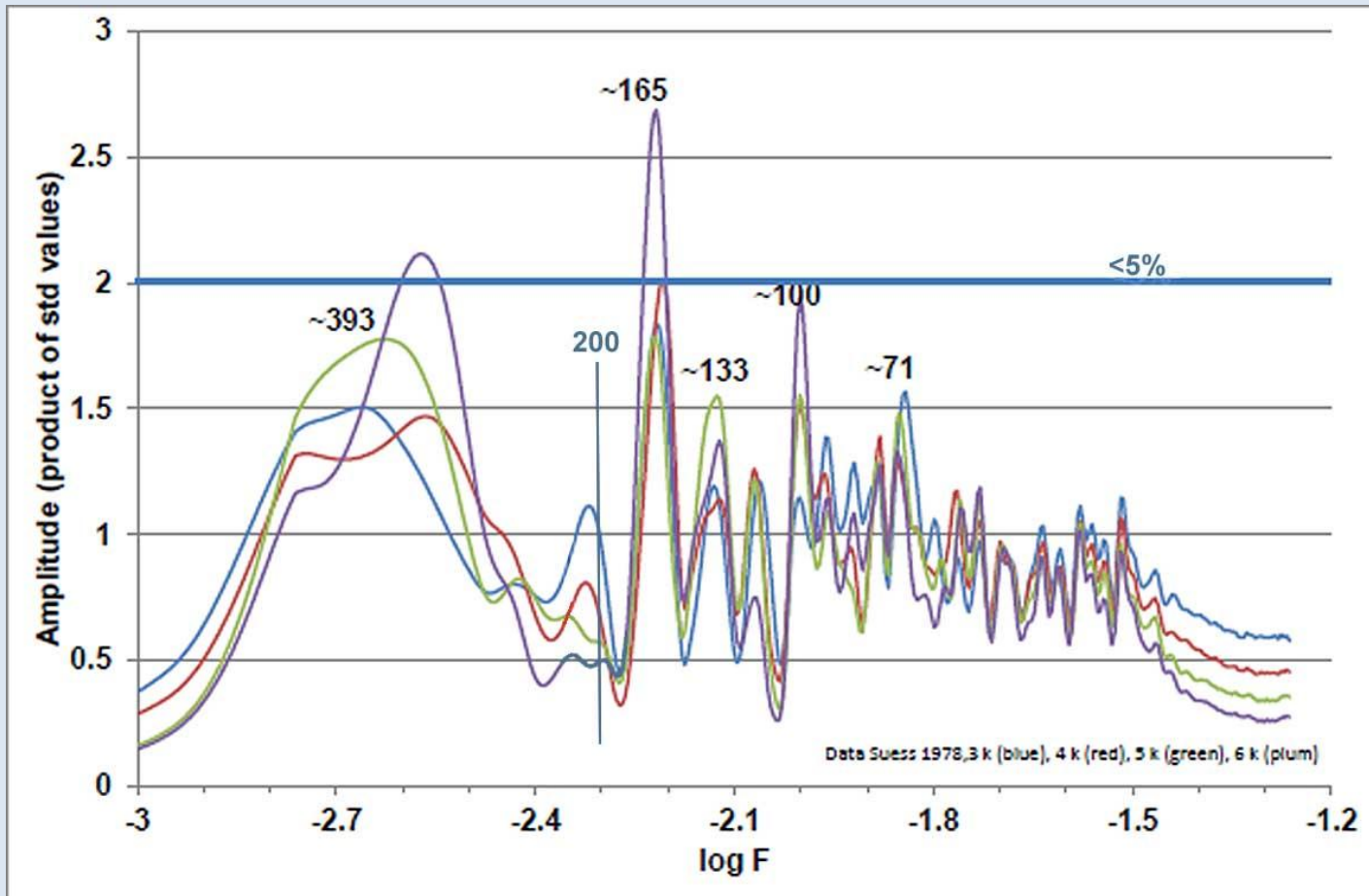
# The 200 gap



**An attempt to locate the 200-year cycle, by analyzing overlapping 1000-year sequences of the bristlecone series published in 1978, failed to find the 200-year cycle. The analysis did, however, suggest the existence of a gap of power at this period.**

At places in the Suess (1978) series, artifices were introduced by adding data from European trees, depending on calendar-year dating by the appropriate European dendrochronologists. The European radiocarbon values are distinctly off-scale with regard to those from the Ferguson bristlecone pine samples. They are here ignored.

# Could not find 200-y cycle



Using consecutively longer series portions, going back in the Suess 1978 series, one notes that some periods do not change much. All do change amplitude, however. A cycle near 200 years is not in evidence at a significant level.

# SPACING OF SUNSPOT MINIMA

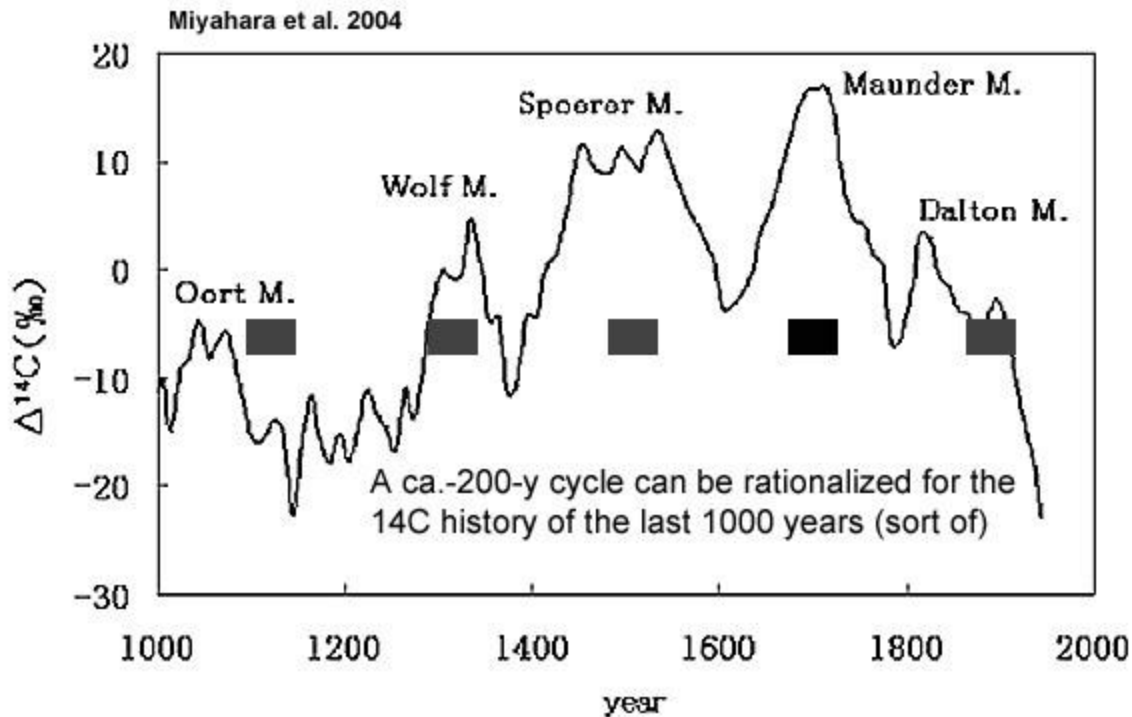


Figure 2 Decadal variation of  $^{14}\text{C}$  content in tree rings (Stuiver et al. 1998)

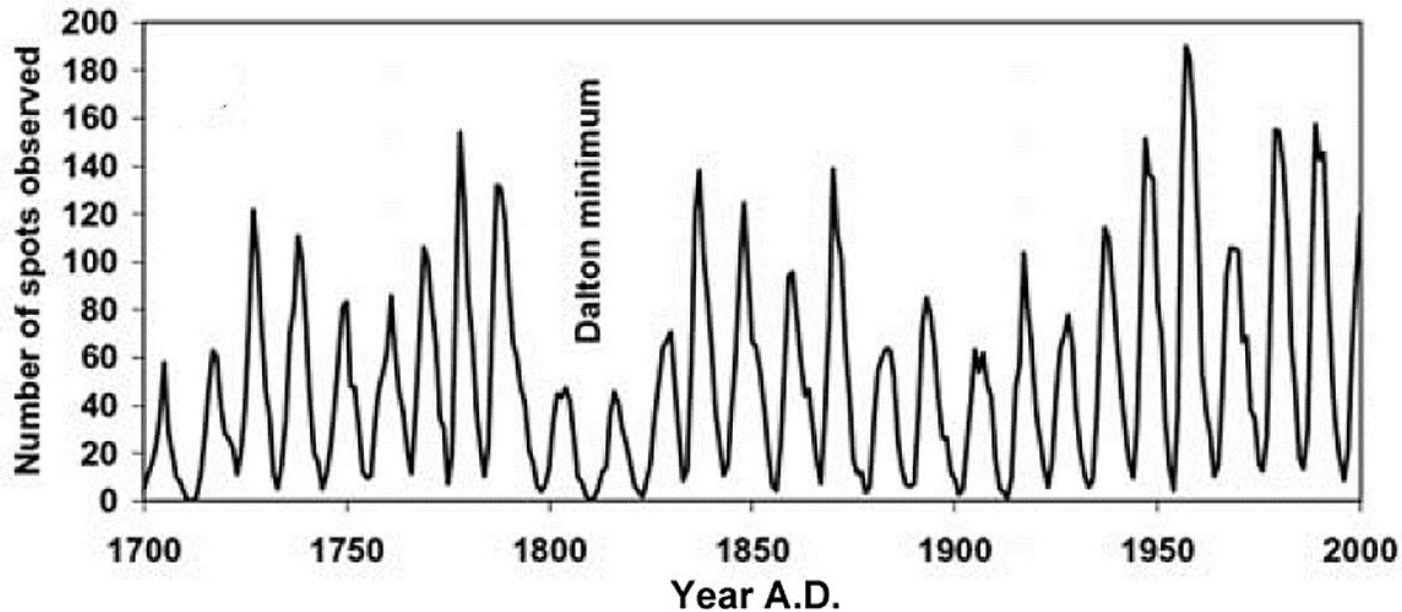
Finding a gap in power near 200-y in the spectrum is very puzzling. The spacing of the sunspot minima of the last 1000 years (based on radiocarbon in tree rings) is suggestive of a cycle close to but somewhat larger than 200 y in the sequence Wolf Minimum – Spoerer Minimum – Maunder Minimum. It is true, nevertheless, that the Oort and Dalton Minima are not lining up properly in such a scheme.

# **IS THE SEARCH FOR THE 200-Y CYCLE ADDRESSING A CRUCIAL QUESTION?**

**The important thing is NOT whether Suess had the cycles right (as a pioneer, he defined questions, while the answers are open to discussion).**

**The important thing is whether there are cycles in solar activity and whether those cycles can be found in the climate data.**

**For this complex of question, we turn to more modern studies.**

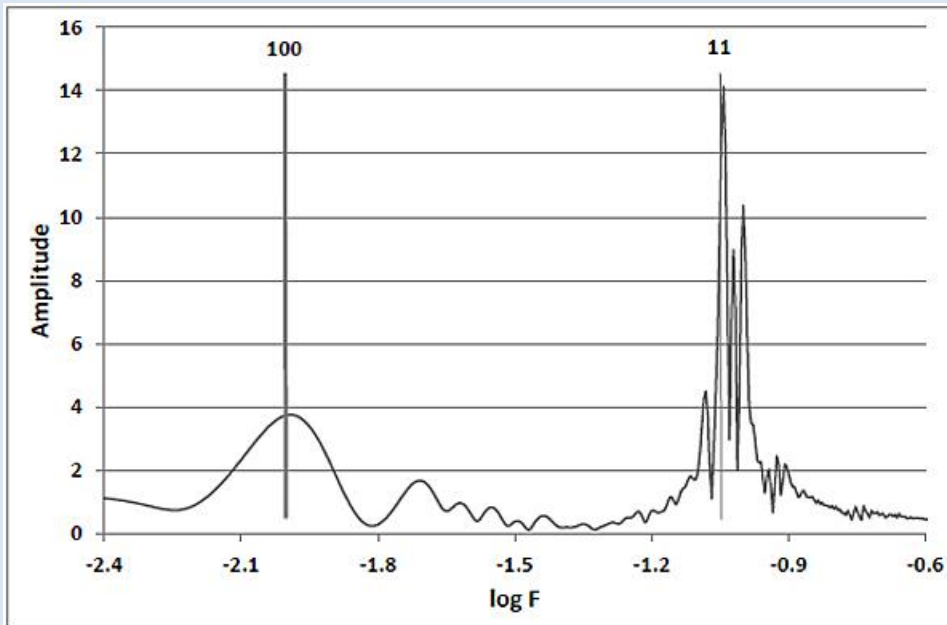


**SOLAR OUTPUT IS VARIABLE, AND THERE IS  
AT LEAST ONE WELL-DEFINED CYCLE,  
ALTHOUGH IT COMES AND GOES**

There is no disagreement about the presence of ca-11-y sunspot cycles, which have been known and studied for many decades. (Source: Belgium Observatory. Also see Miyahara et al., 2004.)



True, the 11-y cycle is complicated, with nearby cycles identified by Fourier analysis. These cycles interfere. They produce a 100-y cycle (also seen by Suess, albeit less prominently than his 200-y cycle).



The cycles adjacent to 11 y are: 11.03, 10.45, and 9.97.

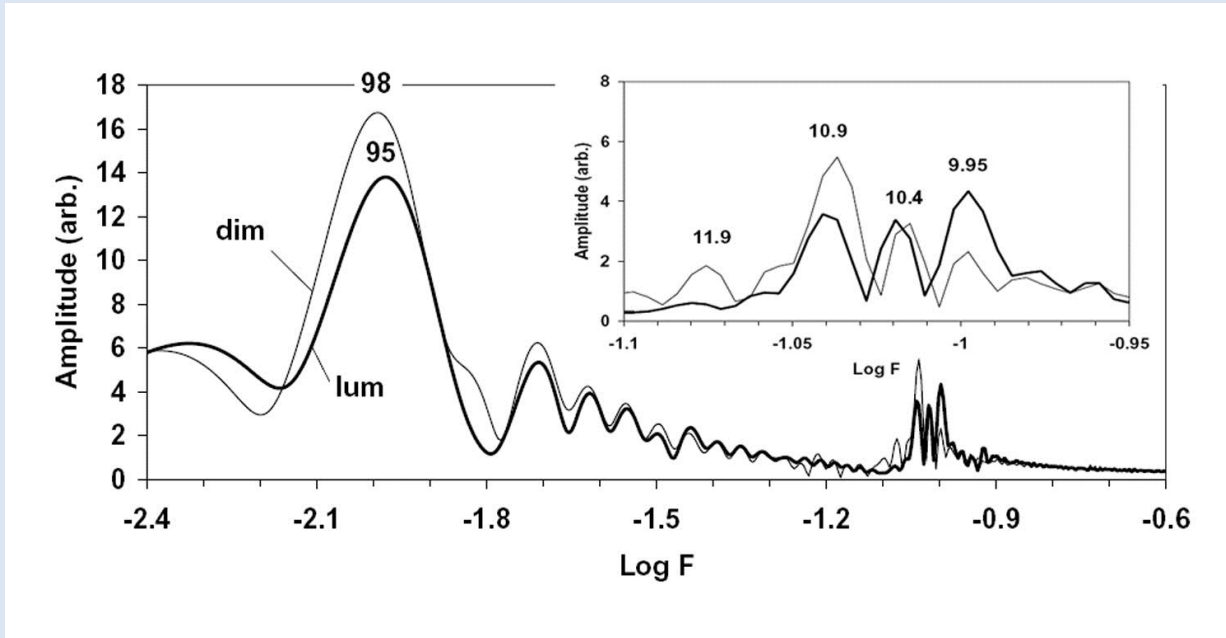
The resulting difference tones are 199, 104, and 217.

Data mainly Hoyt and Schatten, 1997.

**Fourier-type analysis (1% steps, not 1/n) yields the mixture of cycles on a fine scale.**

**THERE ALSO IS A 100-Y CYCLE AND OTHER DIFFERENCE TONES FOR SUNSPOT CYCLES OF THE LAST 3 CENTURIES**

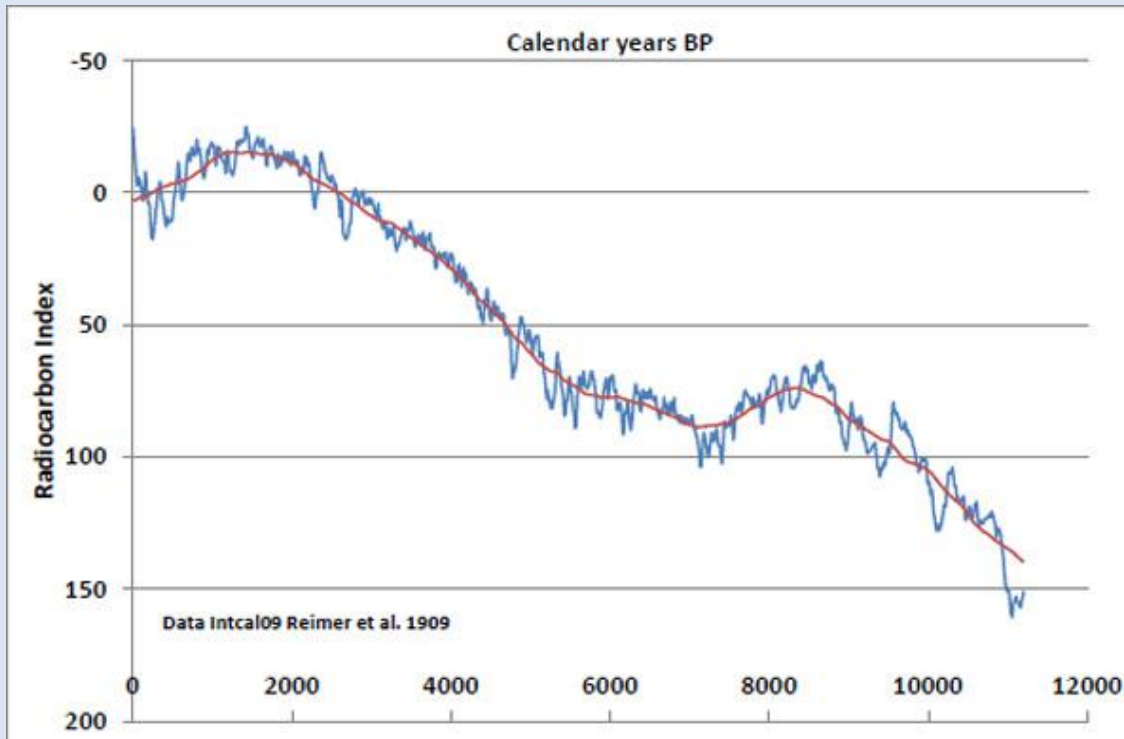
It is quite certain that the “11-year” cycles are not in steady state. They vary for the documented period (the last 300 years) as a function of the brightness of the sun (itself linked to the typical number of spots over a cycle).



However, the case for a 200-y cycle is not weakened by these observations. Also, a doubling of the 100-y cycle seems not unlikely.

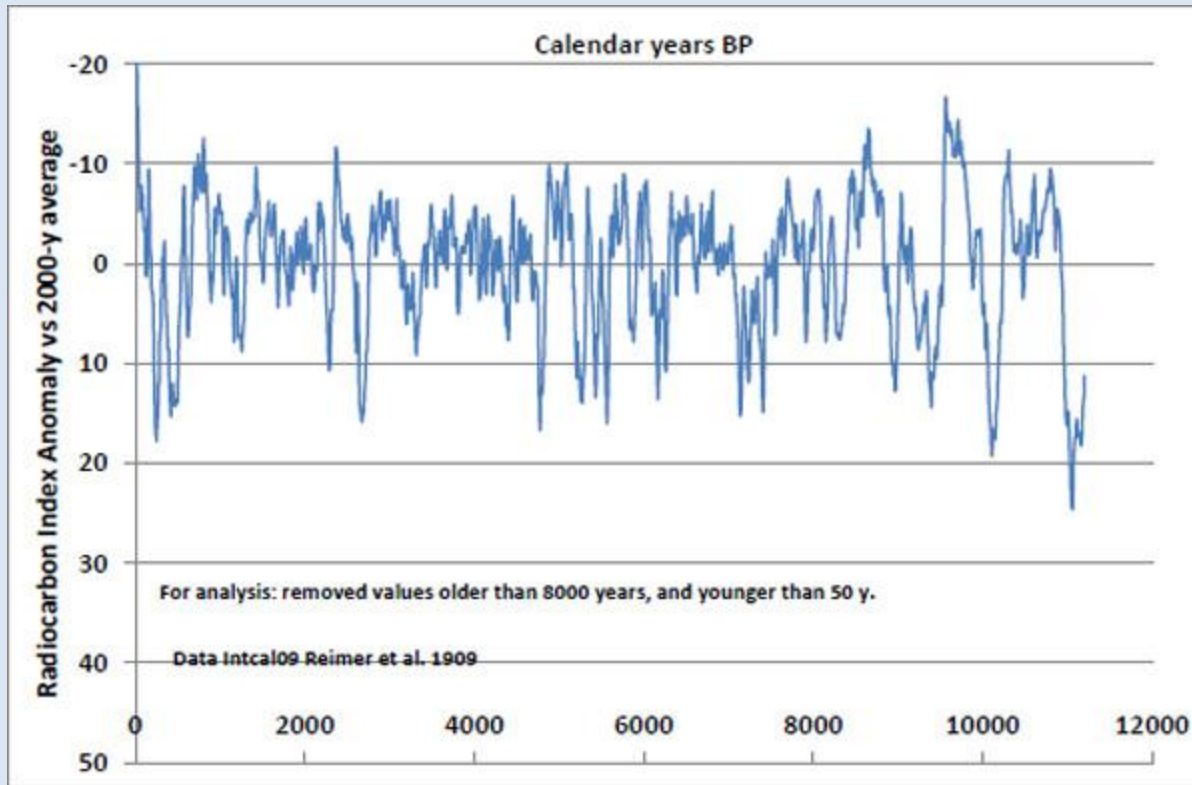
**RESULTS APPLY TO THE LAST 300 YEARS ONLY**

To check further on the existence of a 200-y cycle, we use the several-thousand year series of the Intercalibration Project, Reimer et al., 2009.



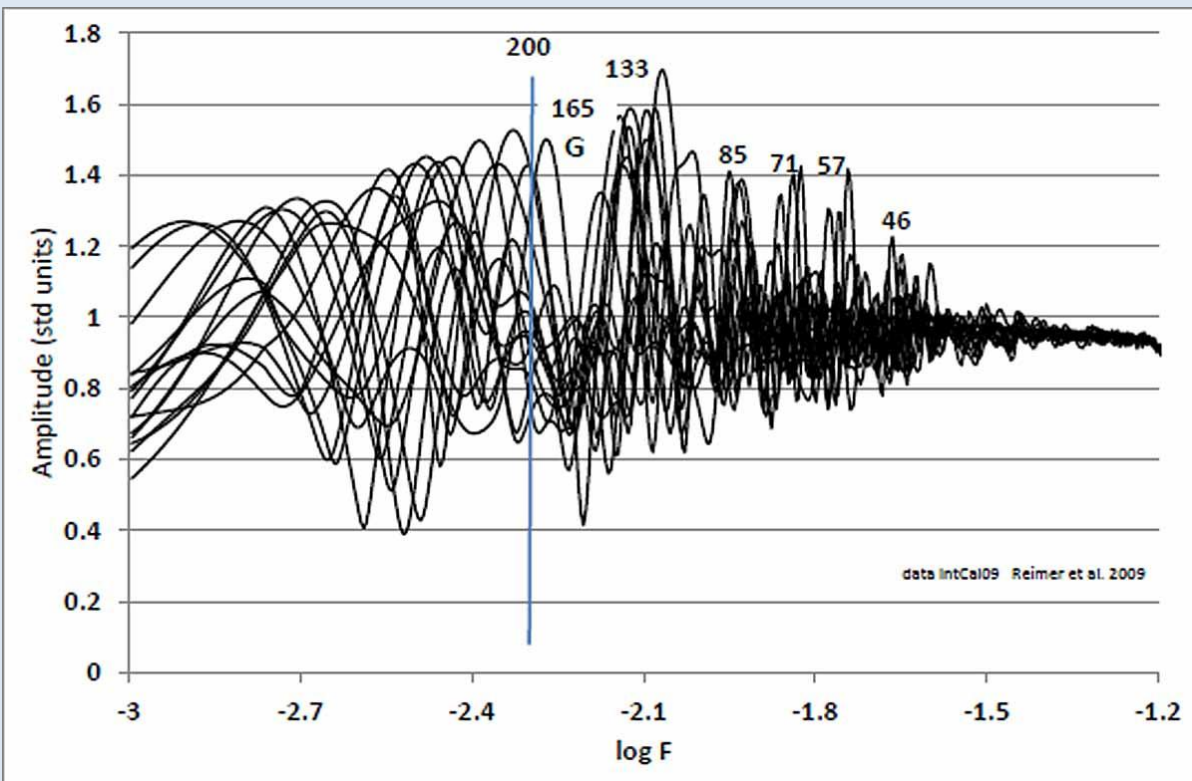
For detrending the C14 data, I use a smoothed version, rather than a calculated expectation.

**FOR INFORMATION FURTHER BACK, WE NEED  
MUCH LONGER SERIES THAN OFFERED BY  
SUNSPOT OBSERVATIONS**



The anomalies show up nicely. To avoid complications from the industrial Suess effect (burning of dead carbon) and to stay well within the Holocene, I restrict the width of the series analyzed, avoiding the most recent decades.

**14C ANOMALIES ARE OBVIOUS ALL THROUGH  
THE HOLOCENE: SUESS WIGGLES ARE REAL**



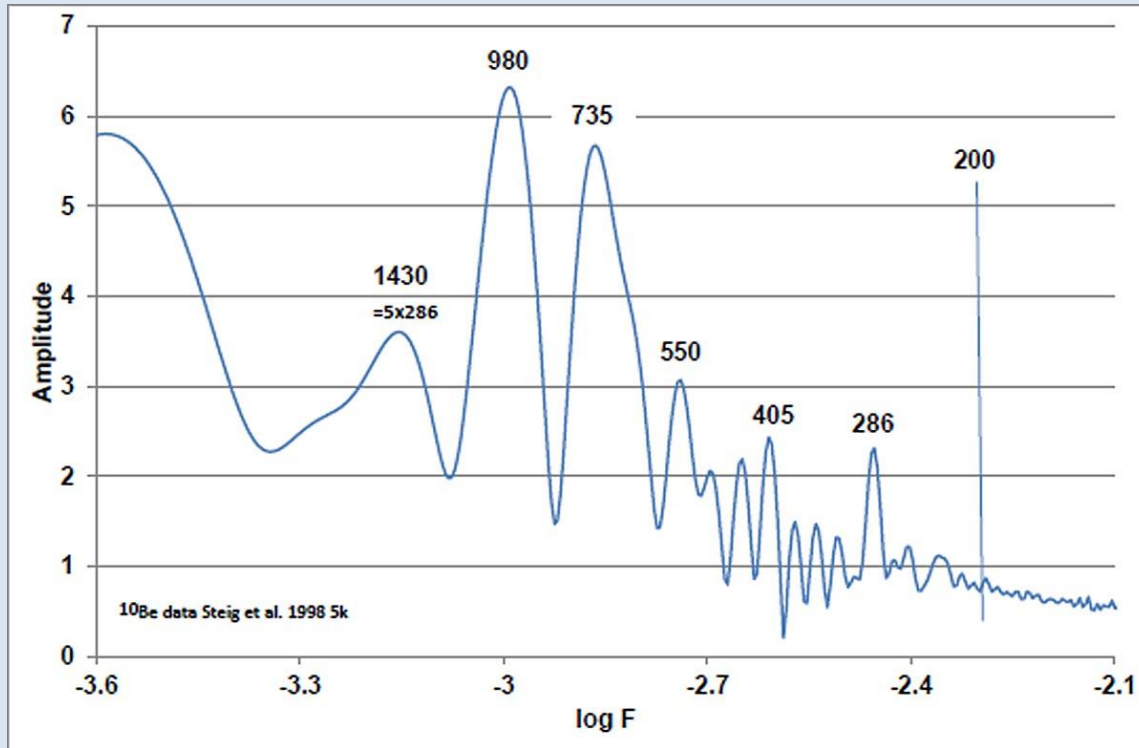
**BUT THE 200-Y  
PERIOD IS NOT  
ALWAYS THERE**

**EACH  
MILLENNIUM IS  
DIFFERENT**

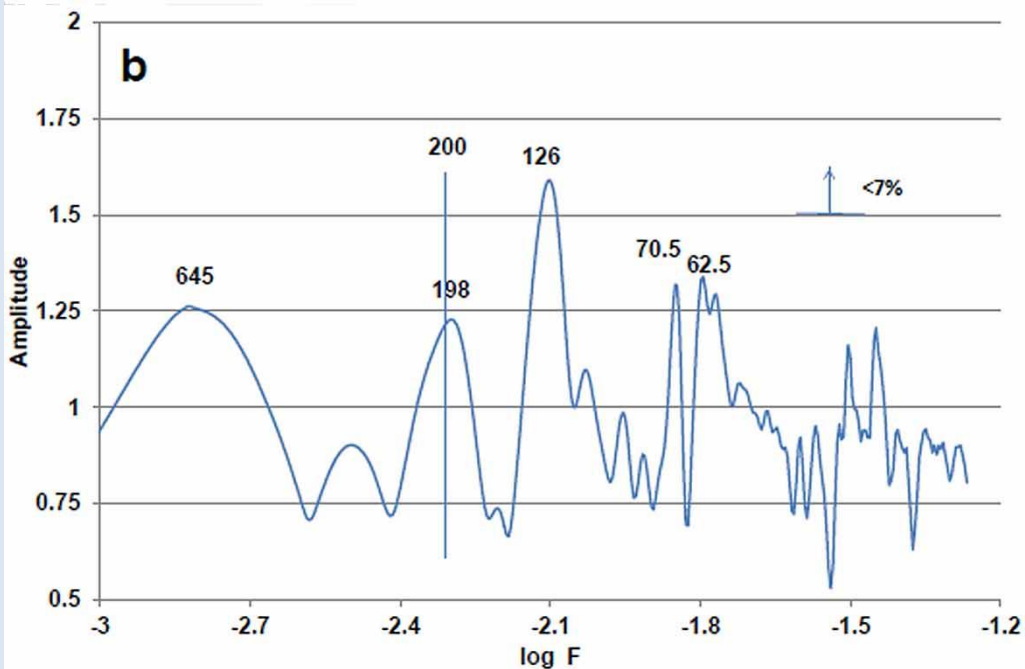
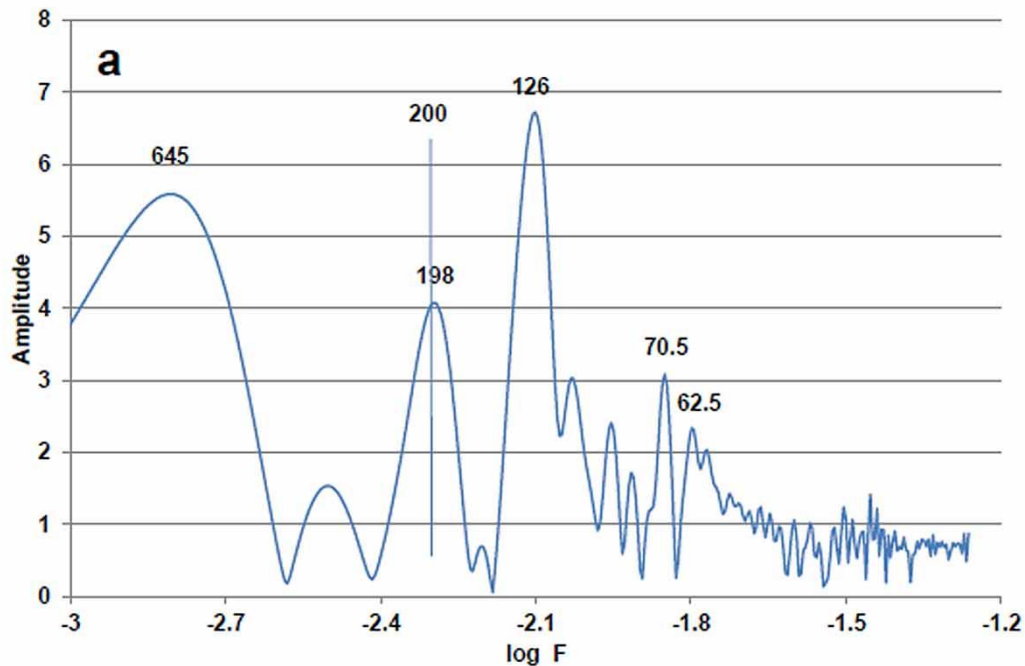
The result of the analysis (evolutionary spectrum, Fourier scan of 1000-y sections, with 500 y overlap) suggests that there is no special activity at a period of 200 years, and there is a gap nearby, centered on 165 years. Below and above this gap, there are some examples of frequencies with a power close to or exceeding two standard deviations above the variation in a window (within the spectrum considered) of width factor-of-three. The pattern found suggests that solar variation is linked to preferred band widths within the spectrum between 20 y and 1000 y (marked), but that realized periods come and go.

**A GAP NEAR 165 Y**

Beryllium-10, presumed to be mainly representing solar activity. 50-year step resolution, Holocene



**10Be 5k RECORD: LONG CYCLES,  
1000-Y PERIOD IS STRONGEST  
note harmonics**



Further on 10Be: In the 1200-y record listed by Bard et al. 2000, there is a 200-y cycle, but it is weak relative to several others, the main one being at 126 y (peak well over 2 stdev. over background (factor of 3 window; lower graph)).

**STRONGEST CYCLE  
IN 10Be RECORD  
LAST 1k: 126 Y**

# TO CHECK FOR SOLAR EFFECT ON CLIMATE WE NEED TO RECONSTRUCT THE HISTORY OF IRRADIATION AND COMPARE WITH CLIMATE HISTORY

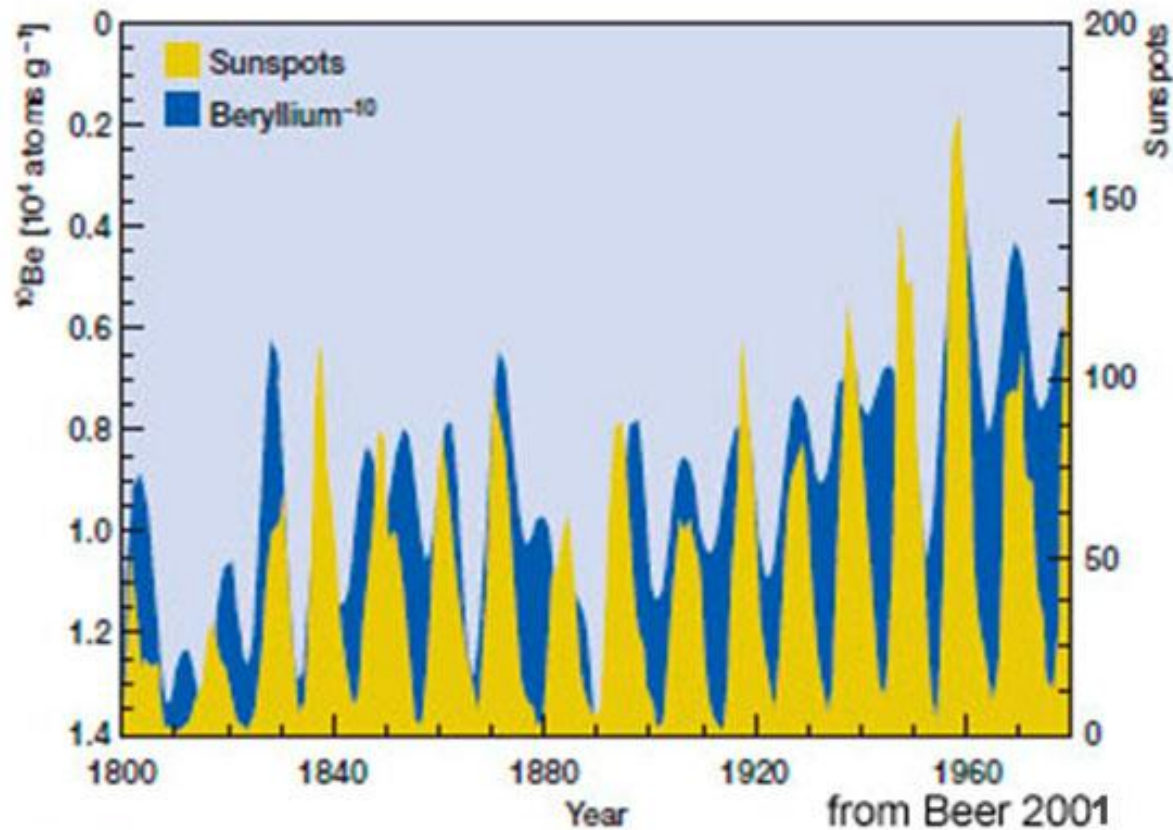
There is no question that solar activity varies through time, as seen in the sunspot observations of the last 400 years, and also in aurora reports.

The question is, how can the changing solar activity level be reconstructed.

Bard et al. (2000) think they can do this, using both  $^{10}\text{Be}$  and  $^{14}\text{C}$ , radioactive isotopes whose production is controlled by solar activity, but which have entirely different environmental pathways.



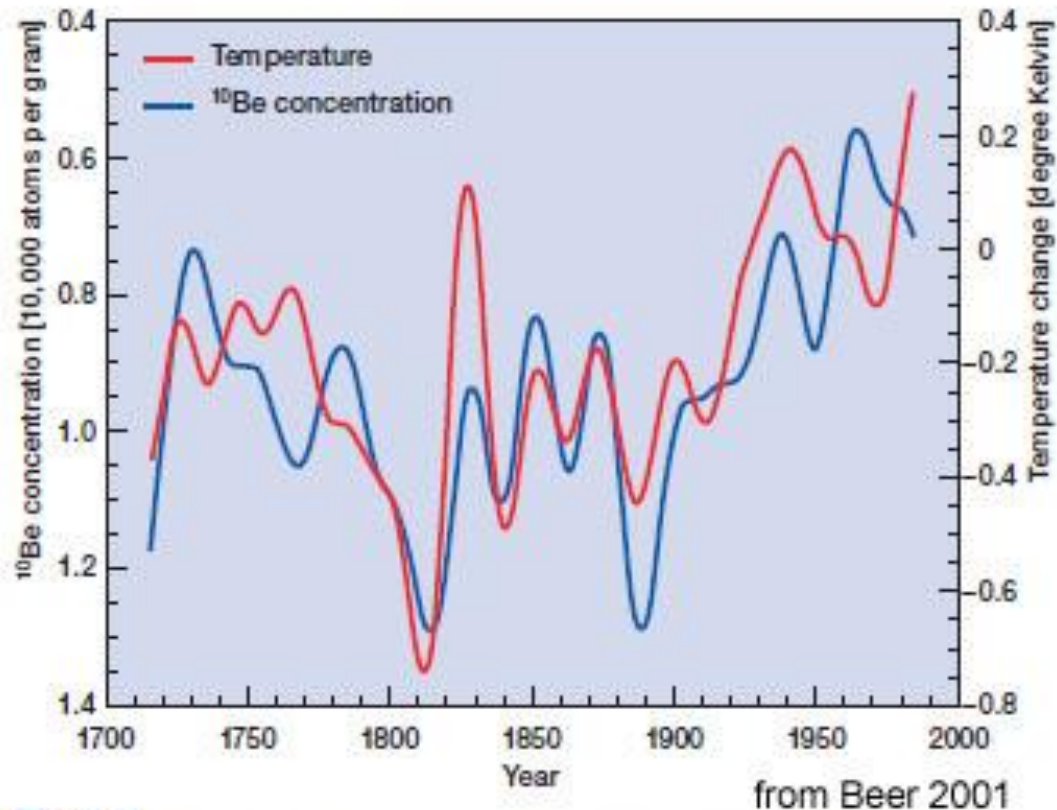
**HOW GOOD ARE THE RECONSTRUCTIONS?**



**Figure 9**

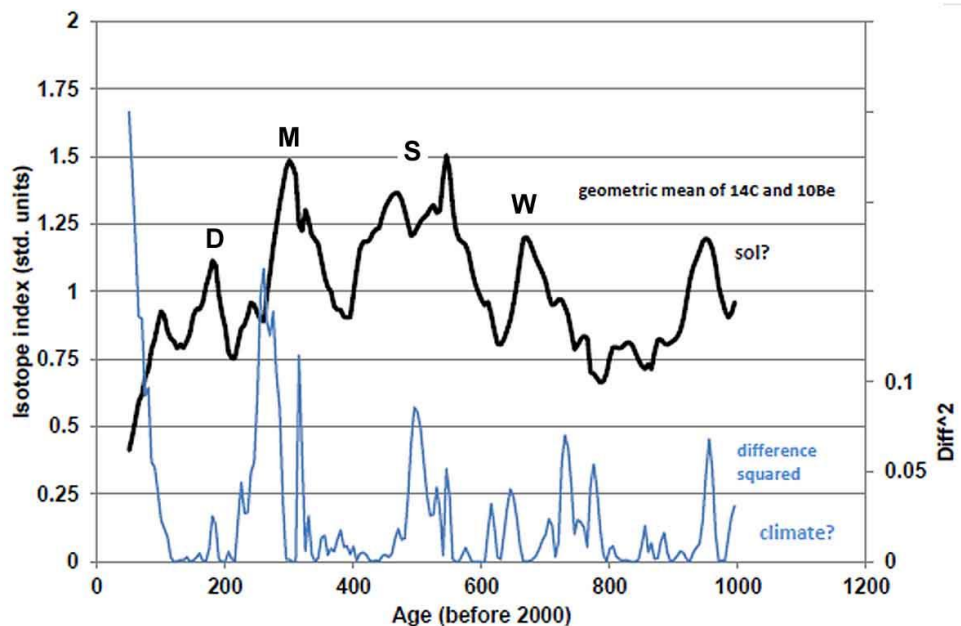
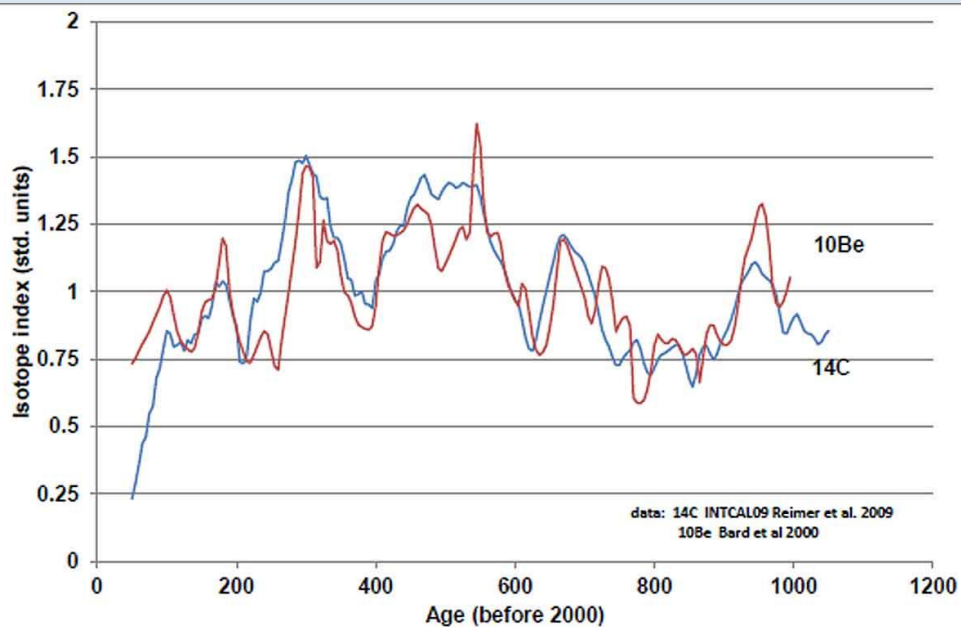
**Comparison** between the observed mean annual number of sunspots with the concentration of  $^{10}\text{Be}$  atoms in the ice-core from Dye 3 (Figure 7). A large number of sunspots correspond to higher solar activity, more solar wind, fewer cosmic rays, lower production rates of  $^{10}\text{Be}$  and therefore a lower  $^{10}\text{Be}$  concentration. Both records show a clear 11-year Schwabe cycle and a long-term trend interrupted by short periods of reduced solar activity around 1815 and 1900.

**Sunspot cycles seem to be well mirrored by  $^{10}\text{Be}$  variation in polar ice**



**Figure 12**  
**Comparison** of the  $^{10}\text{Be}$  concentration measured in an ice core from Dye 3 (Figure 7) reflecting the solar activity with a reconstruction of the northern hemispheric temperature. Both records were filtered to only show changes on time scales longer than 20 years. Note the solar minima (high  $^{10}\text{Be}$  concentrations) around 1815 and 1890 which coincide with cold periods (Figure 5) and the rapid temperature increase during the first half of the 20<sup>th</sup> century.

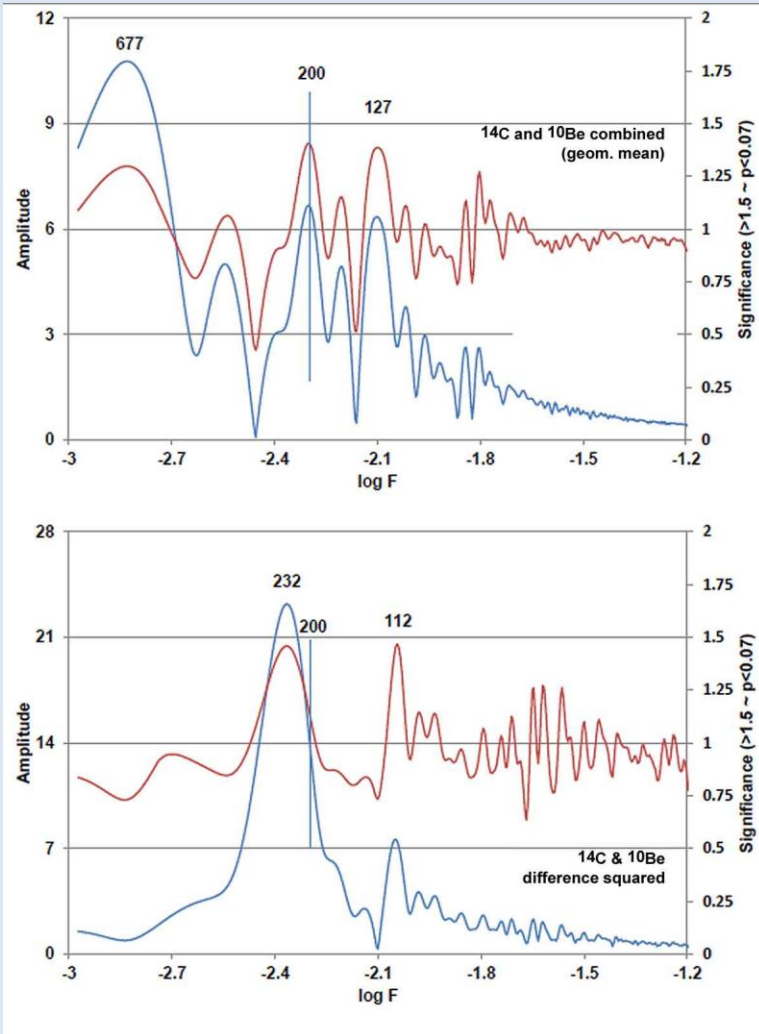
**NH temperature seems to follow  $^{10}\text{Be}$**



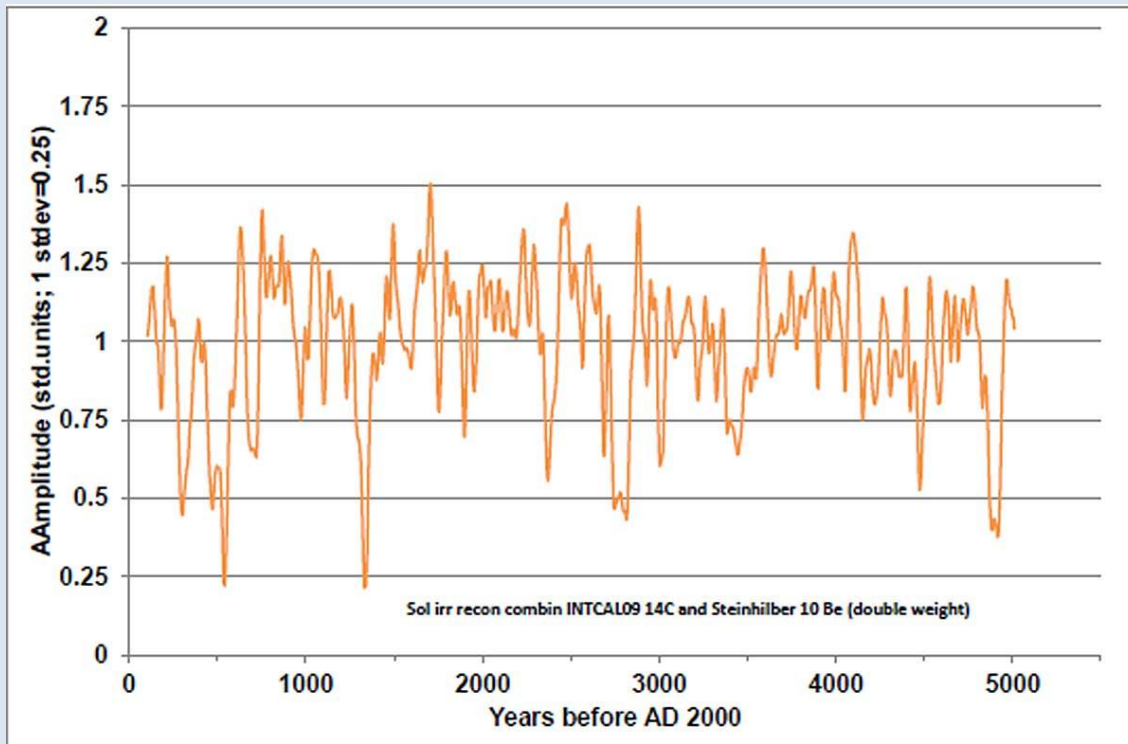
The Point in making the reconstruction is that  $^{10}\text{Be}$  and  $^{14}\text{C}$  series are very similar, despite their different pathways in the environment. Hence the suggestion that their production rates must be the crucial factor in producing the series. (Cautionary note: even dissimilar environmental pathways may be correlated.) Following the source hypothesis, one finds that **agreement** (geometric mean; black line) produces a reasonable representation of probable solar activity, with maximum production during solar minima (Dalton, Maunder, Sporer, Wolf).

**RECONSTRUCTION  
SEEMS TO WORK FOR  
AT LEAST THE LAST 1 K**

Spectra of combination and of differences of C14 and Be10 series, last 1k, suggest the presence of the 200-y cycle within solar activity of the last millennium. However, significance is below  $p \sim 0.07$ . Equally strong are 677 and 127. In the “environmental” series (differences squared) a cycle near a period of 232 y is quite strong, as is one near 112 y (note near-harmonics).



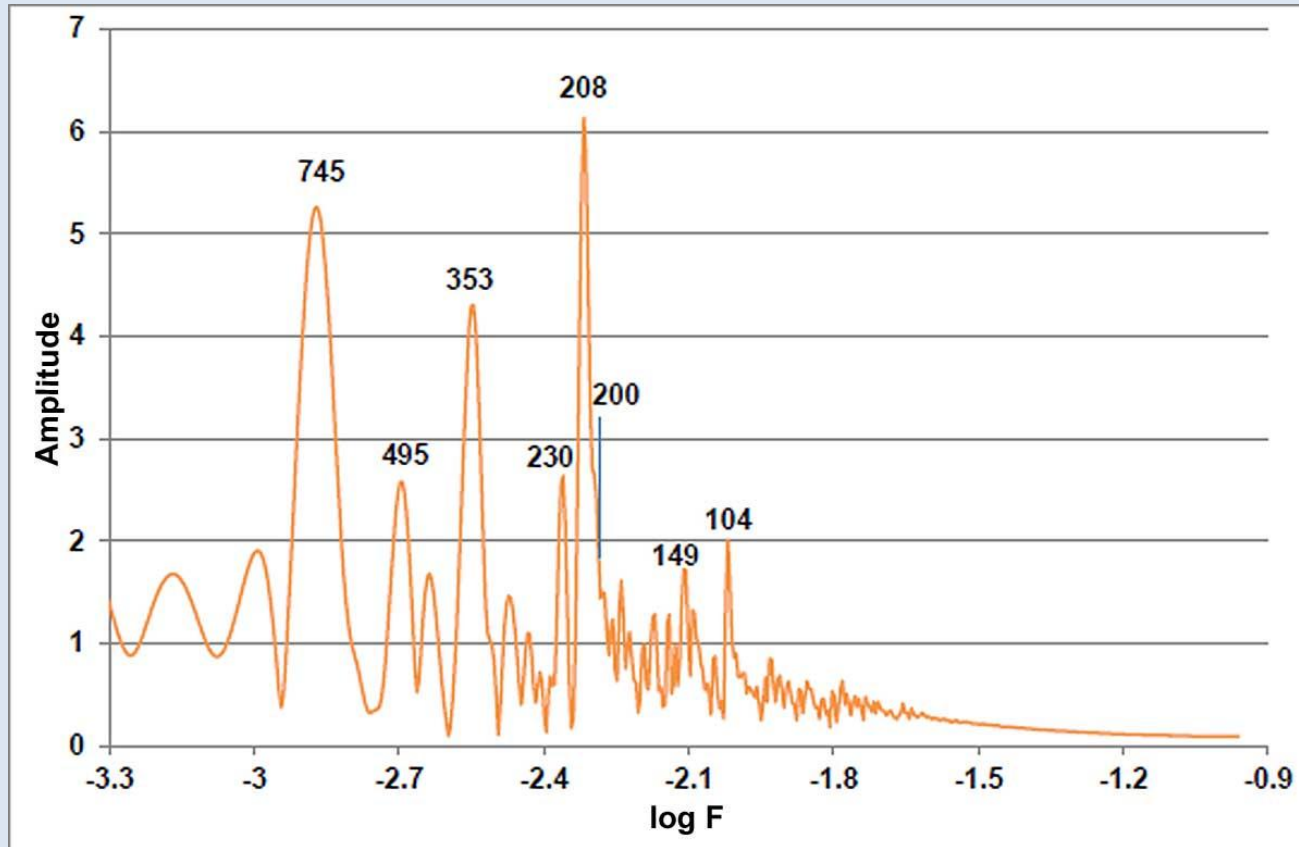
**CYCLES APPEAR IN THE COMBINATION AND DIFFERENCE SERIES, BUT THEY BARELY REACH SIGNIFICANCE**



While the reconstruction of solar activity (from published radiocarbon and  $^{10}\text{Be}$  data) for the last 5000 years cannot be checked against sunspot information, chances are, it is not far off the truth. It gives us a tool to check for impact on climate variation.

**PUBLISHED DATA ARE AVAILABLE FOR THE ENTIRE HOLOCENE. HERE WE GO BACK 5 K, IN (EFFECTIVE) STEPS OF  $\sim 10$  Y.**

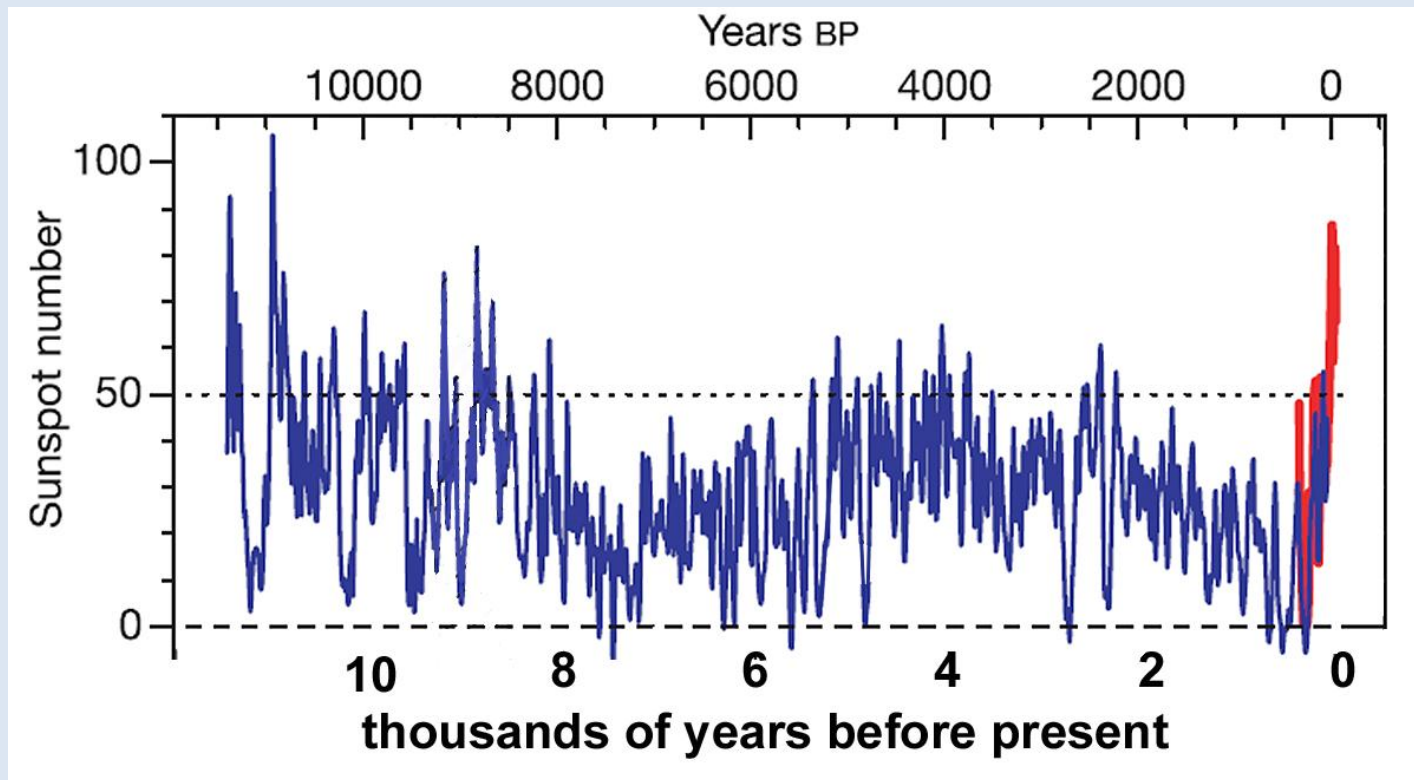
Spectral analysis of the 5 k reconstruction suggests cycles near 745, 353, 208, and 104 years (shorter sunspot cycles are not prominent on the resolution adopted). The strength of the ca.-200-y cycle is remarkable, as is that of the one-half Bond cycle (near 1500 years).



**CYCLES ARE PRESENT, SEVERAL QUITE STRONG.  
THERE IS DEFINITELY EVIDENCE OF A SUESS CYCLE.**

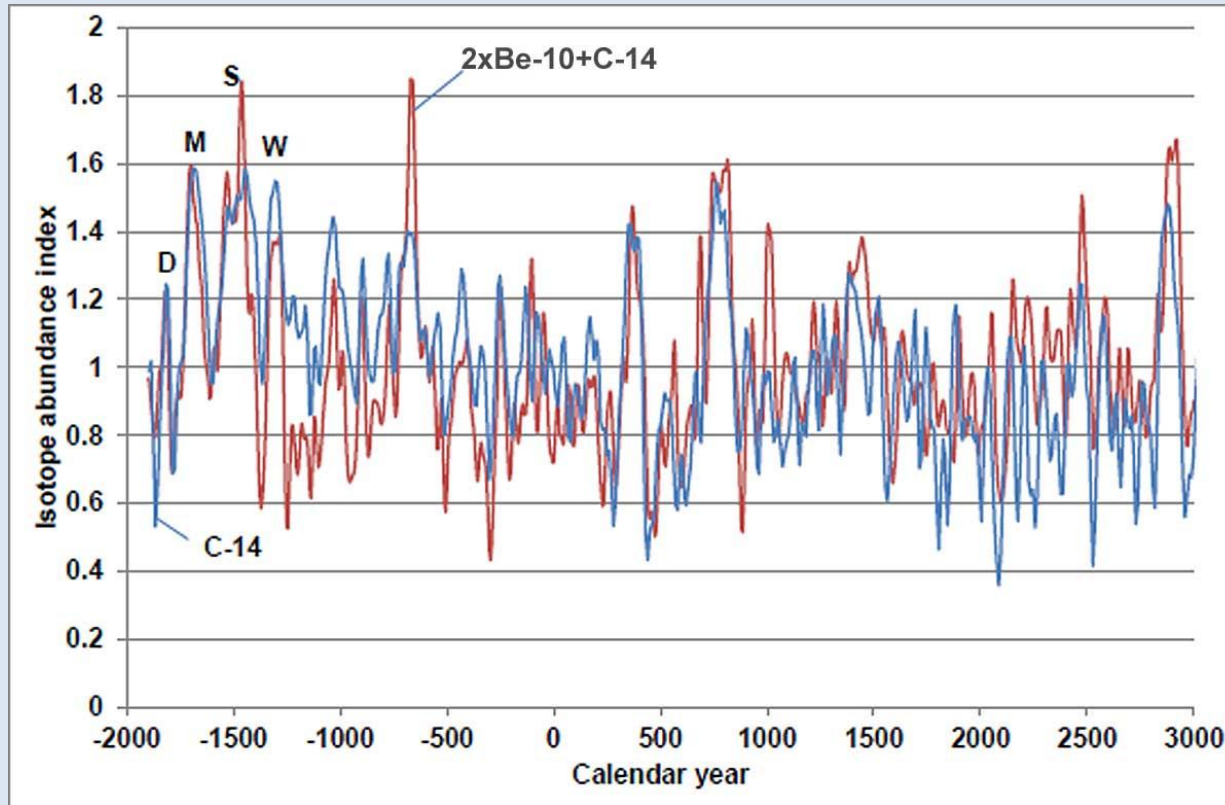
# How good is the reconstruction?

For comparison with the solar irradiation reconstruction adopted here, there is the reconstruction of Solanki et al. (2004), based entirely on radiocarbon (see below). These authors were sufficiently confident of the accuracy of their reconstruction to suggest that the sun has recently been brighter (red line) than for the past eight thousand years. (If true, this could explain the warming and shrinking of mountain glaciers at the end of the Little Ice Age, which happens too early to be assigned to human impact. Also, the reconstruction has implications for the end of the Younger Dryas, some 12,000 years ago.)



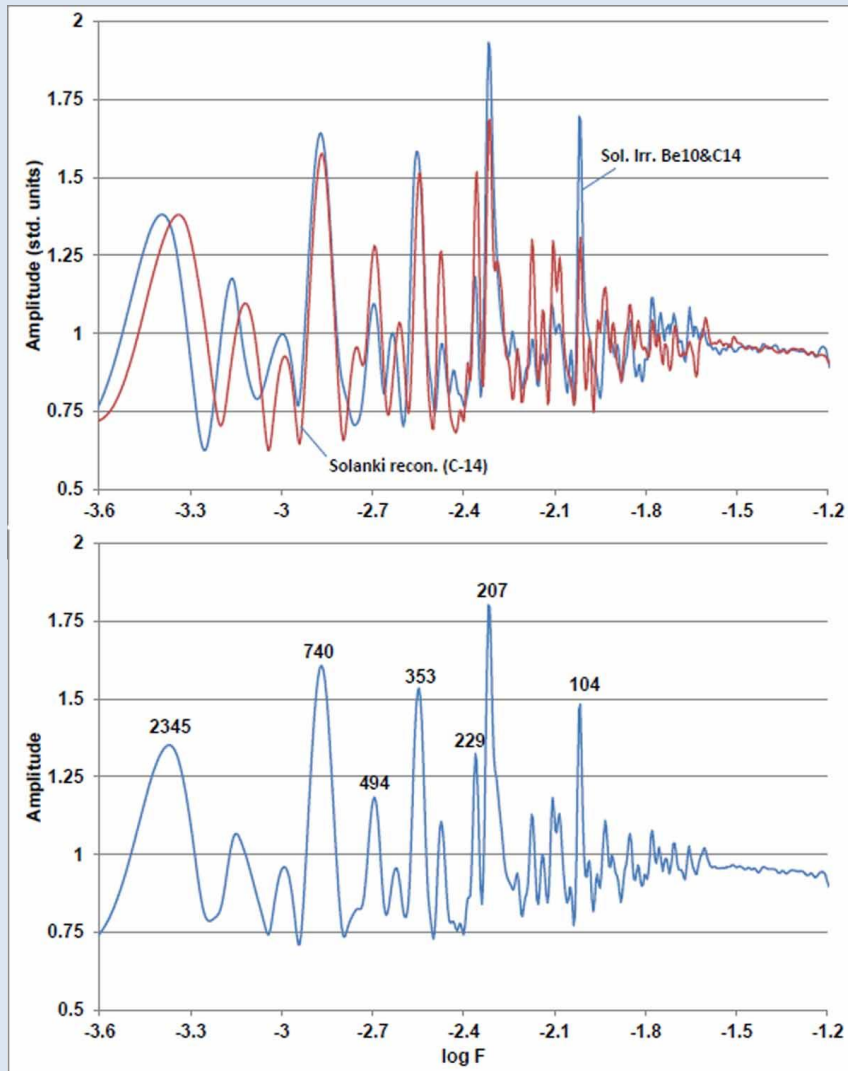


# ENCOURAGING BUT NOT PERFECT



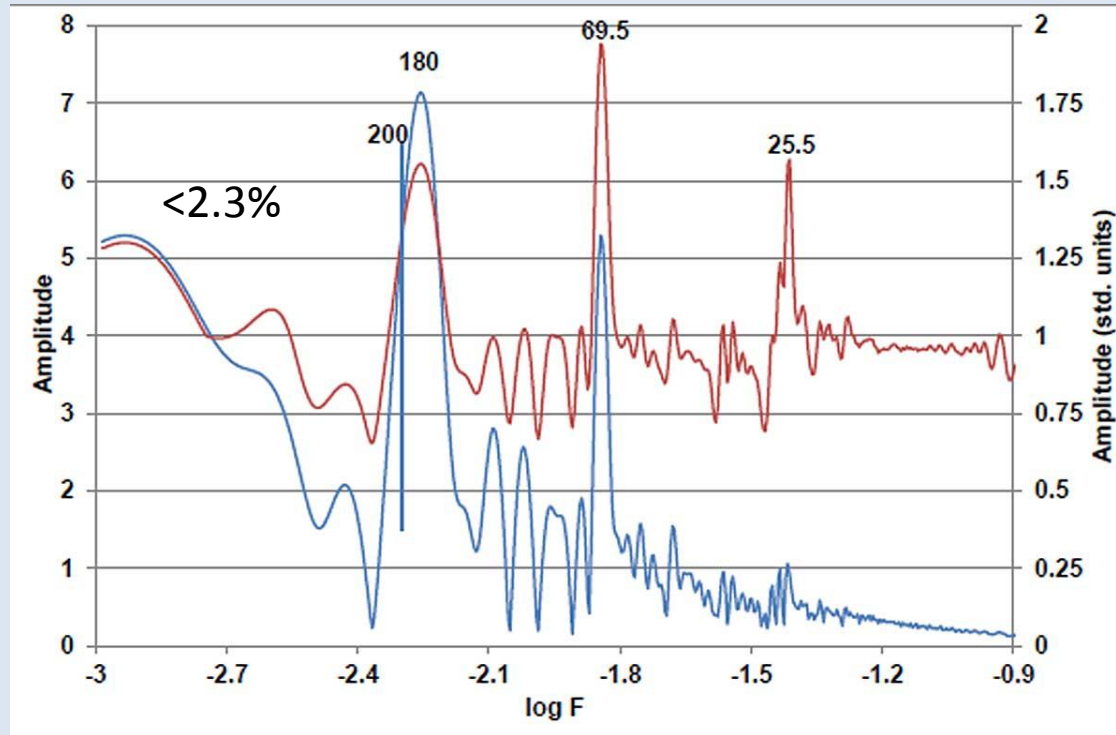
A simple comparison of the two long-term solar reconstructions is instructive. Large excursions are similar, but this is not necessarily true for lesser excursions from the average. Be-10 is more heavily weighted (factor of two) than C-14 in this graph. Dalton, Maunder, Spörer, and Wolf minima are marked. Years since zero shown negative.

# WHICH CYCLES, IF ANY, DO THE RECONSTRUCTIONS AGREE ON?



Comparison of the spectra of the two reconstructions of solar irradiation for the last 5000 years shows striking similarities. Agreement is shown by making a spectrum of geometric averages of the standardized amplitudes (lower graph). The three peaks that exceed two standard deviations, in aggregate, are 207, 740, and 353. A peak near 104 comes close, but does not reach that criterion. There is no useful information about periods shorter than 40 years, presumably owing to sampling and smoothing procedures.

# ARE THESE CYCLES PRESENT IN CLIMATE PROXY SERIES?

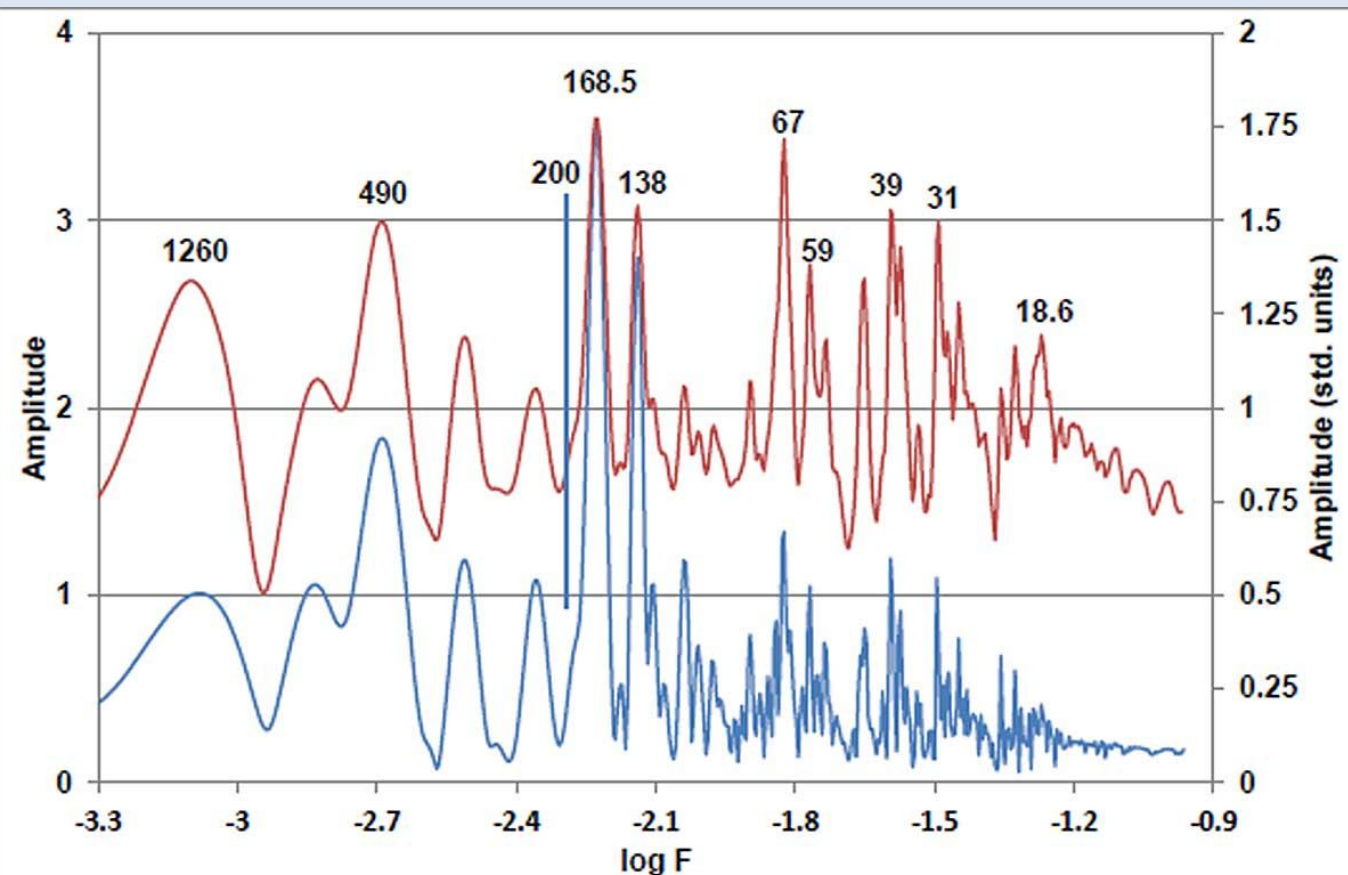


Perhaps. Hard to say in the case of northern hemisphere temperature by Crowley and Lowery (2000), since the dominant cycle near 70 y is not readily seen in the forcing series (where useful information stops near 100 y) and the Suess Cycle may be represented, but offset by 10%.

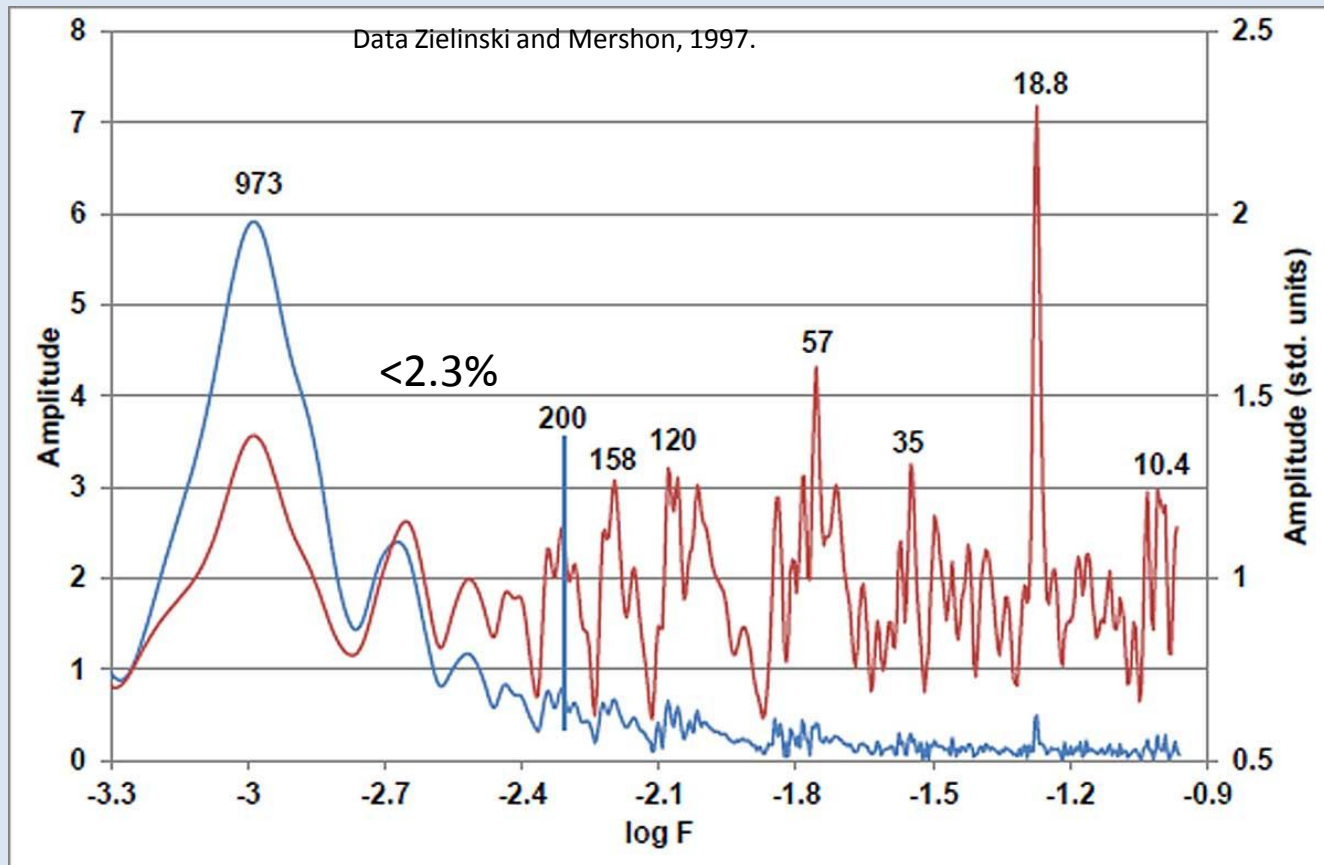
Blue line: Fourier scan of autocorrelation. Red line: standardized for normal distribution across a factor of three in timing (gliding window along the log series).

In the case of the GISP ice core series of Grootes and Stuiver (Grootes et al., 1993; Stuiver et al., 1995), some 25 centuries into the past, the Suess cycle is missing altogether (instead there is a prominent cycle near 170 y) and the information regarding cycles shorter than 100 y is difficult to interpret. For once, there seems to be contamination with tidal information (as suggested by the period near 18.6 years, which is a main lunar period).

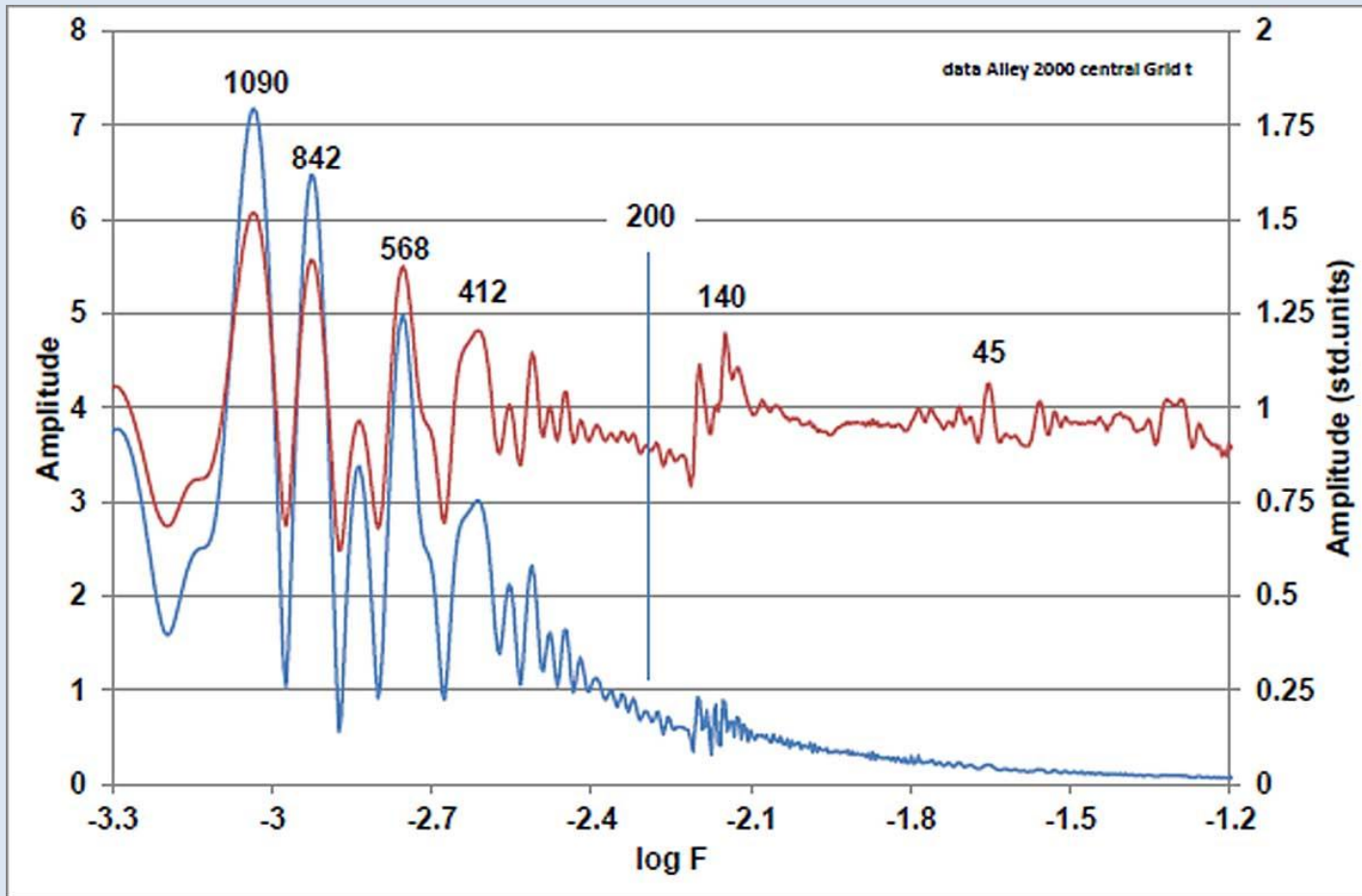
## GISP DELTA 0-18 NEGATIVE



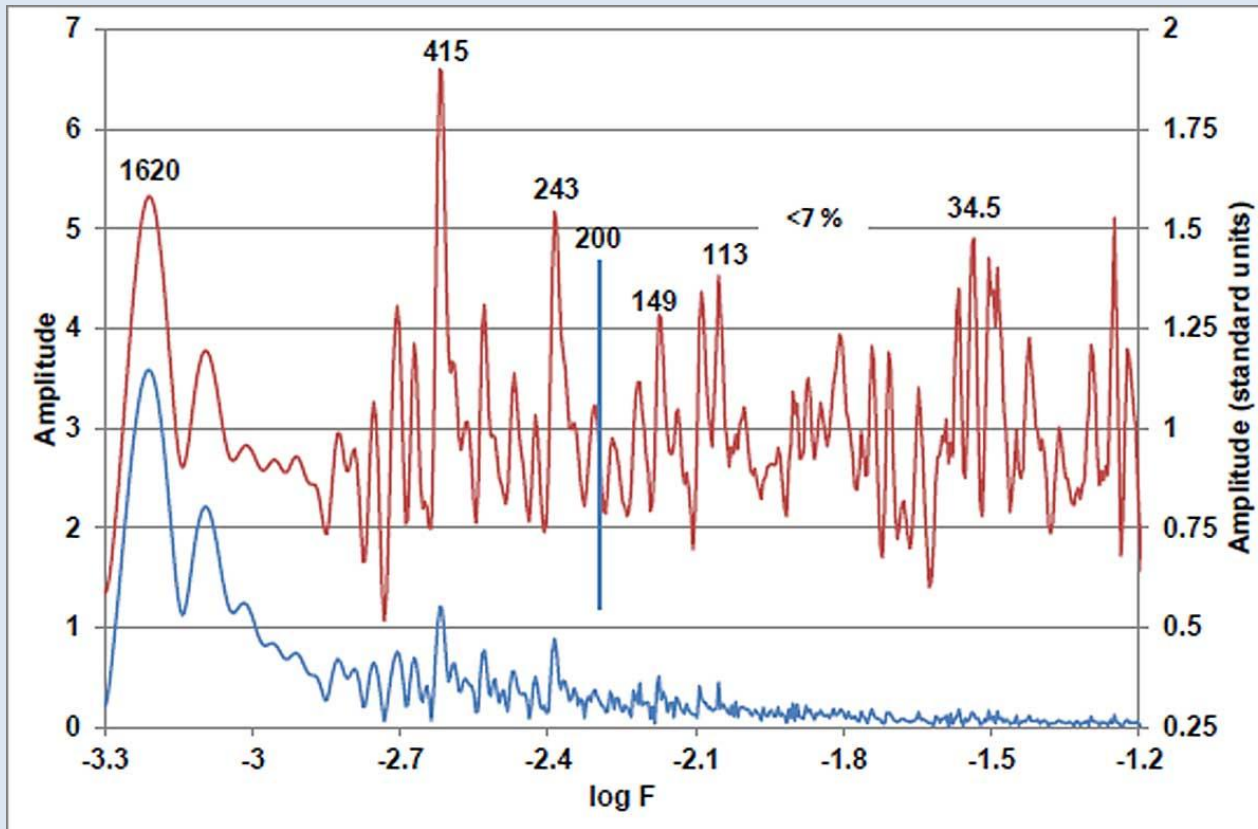
For the variation of particles within the GISP2 ice series, a link to burning has been claimed, and is likely. Again, any solar influence on the environment seems tenuous in the context, although clearly there is some evidence of the 10-11-y sunspot cycles. Again, it seems that there is contamination from lunar information (18.8; also 57 is close to 3 times the major lunar cycle at 18.6). The origin of the Brueckner cycle (near 35) is not known. I suspect a link into tides.



**GISP2 PARTICLES: NEGATIVE**

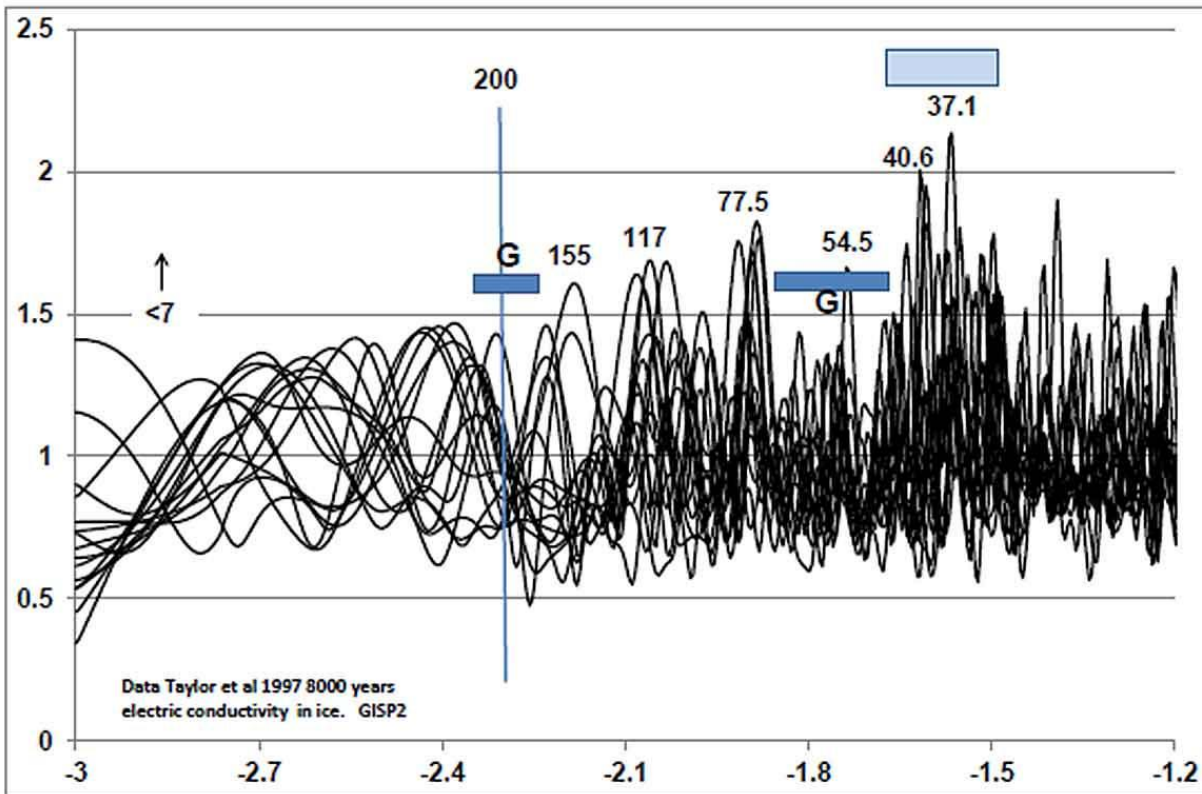


**Greenland temperature (5k): Negative**



## No indication of a 200-y cycle in GISP 2

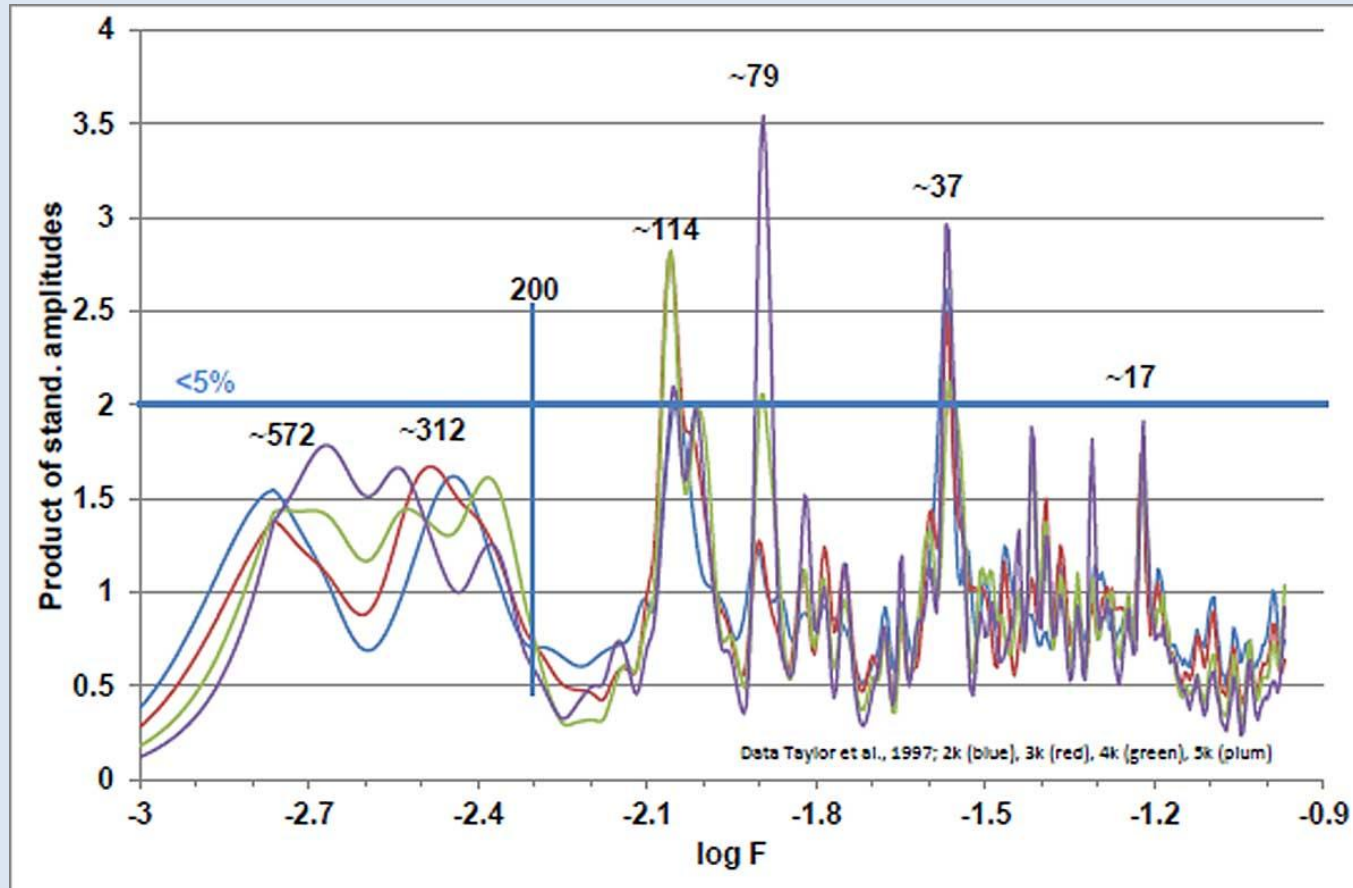
A continuous record of electric conductance in the GISP2 site (back 8,000 years) has no indication of a 200-year Suess cycle (data from Taylor et al., 1997). Possibly, 200-y energy has been captured by the 415-y cycle.



**ENVIRONMENTAL INFO, AA (IN ICE):  
200-Y GAP. ALSO GAP CENTERED NEAR 60 Y  
PERIOD**

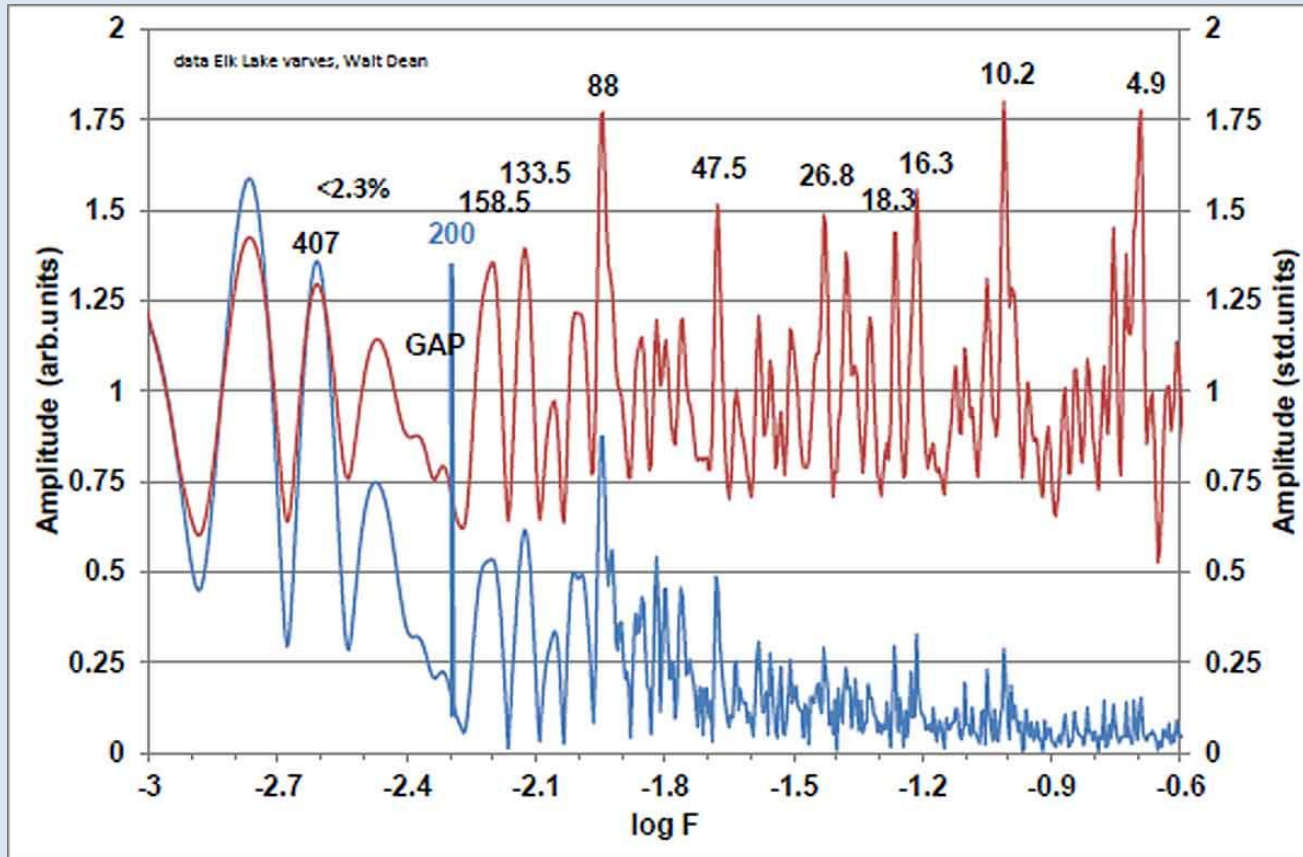


# No 200-y cycle in high northern latitudes



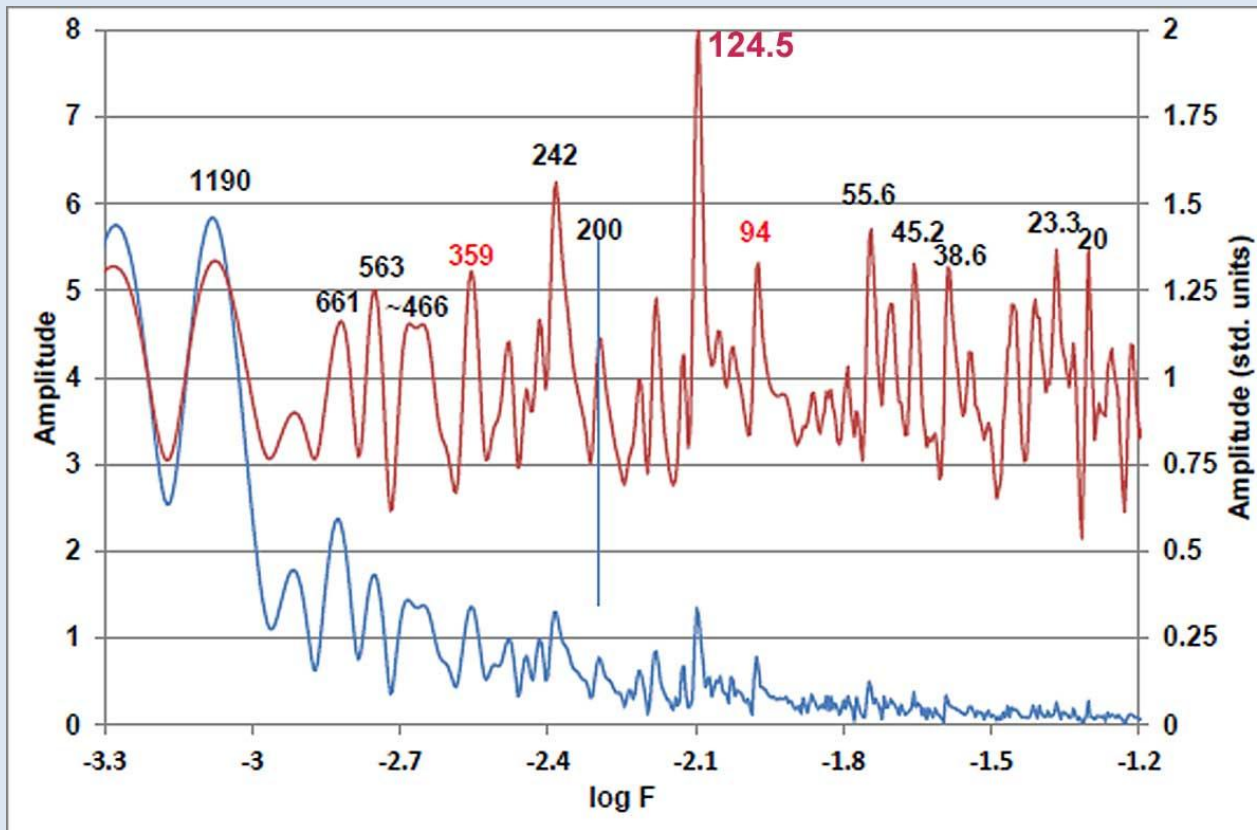
The Taylor-et-al series describes electric conductivity in GISP2 ice; this is definitely an environmental signal in high northern latitudes. There is no evidence for a 200-year cycle. The strongest periodicity is near 79 years, and also near 37 years. The second of these is likely linked to tides (twice 18.6). A gap centered near 170 y is conspicuous. It is bordered on the long side by the 200-y period (here missing).

# NO SUESS CYCLE IN THE VARVES OF ELK LAKE



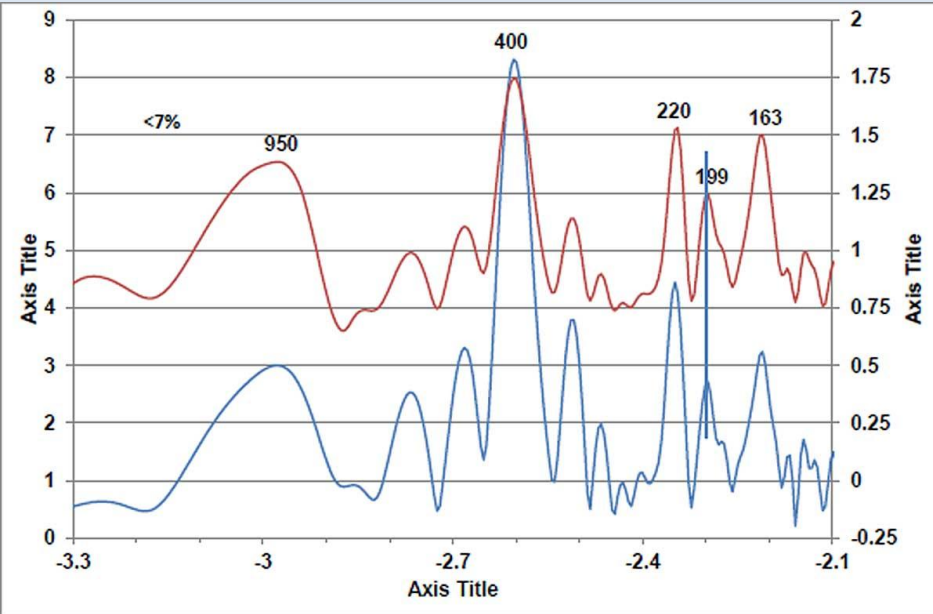
Varve thicknesses in Elk Lake, Minnesota, have interesting periodicities, but none near 200 y. In fact, there is a gap there, presumably any energy in this period has been transferred to a 400-y cycle. The cycle near 18.3 (presumably should be 18.6) suggests that a 1.5% shortage of varves, either missing layers, or miscounted. If true, the 10.2-y cycle is actually 10.35.

The dominant cycle in a core from off Pakistan has a period near 125 years.



Data from Bundesanstalt f. Bodenforschung, Hannover, courtesy of Ulrich von Rad. Vertical scale on right: standardized Fourier scan values for window of factor of three. Mean is unity, one standard deviation is 0.25. The line near 125 is four standard deviations above the mean.

**Varves off Pakistan: Mostly negative (but some outside forcing likely: shown as red numbers)**



Data Thompson et al., 2002. Oxygen isotopes from ice on Kilimanjaro (Holocene). The main period is near 400 years. Possibly the Sues cycle appears cryptically in this harmonic position.

## Kilimanjaro: 400-year period

## Conclusions

The “Suess wiggles” are real, and they appear to contain evidence for cyclicity in solar activity, although mainly the periods seem to change through the millennia. The “Suess cycle” of 200-year length, prominently displayed in a spectrum of radiocarbon anomalies in Suess (1971) was not found in a long series of bristlecone data published by Suess in 1978. Subsequent studies of radiocarbon history and of 10-Be history suggest important solar cycles near **1000, 500, 200, 126, 100, and 71**. Many of these were identified in Suess (1971) (as 930, 498, 202, 104).

**These cycles do not necessarily show up in environmental proxy records of the Holocene, although some of them do, in various circumstances.**

For example, northern hemisphere temperature of the last millennium (Crowley and Lowery, 2000) has a cycle near 70; the GISP  $\delta^{18}O$  record of Grootes and Stuiver has periods near 490 and 67; the GISP2 particle record (Zielinski and Mershon, 1997) shows periods near 970 and 120. However, the GISP2 conductance record (Taylor et al., 1997) has a list of periods that do not match the solar template. In low latitudes, the varves of Pakistan (presumably related to the Asian monsoon) show a strong line near 125. The ice on top of Kilimanjaro (Thompson et al., 2002) has a cycle near 1000 (950) and a weak one near 200 (199). But its strongest spectral line is near 400 years. Perhaps this is where the energy provided by the Suess cycle has moved.

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