POSSIBLE EVIDENCE OF THE DE VRIES, GLEISSBERG AND HALE CYCLES IN THE SUN'S BARYCENTRIC MOTION

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Abstract

We find that there is substantial correlation between the dominant periodicities that are seen in the long-term solar activity cycle and the periodicities in a carrier suppressed amplitude modulated signal with frequencies related to the Sun's Barycentric motion. Both quantities show periodicities at the de Vries (210 years), Gleissberg (90 years), and Hale (22.3 years) cycles. As yet, there is no reasonable model to explain why there might be a link between the level of solar activity and the Sun's Barycentric motion. However, we believe that the topic warrants further investigation because of the good agreement between the observed periodicities.

Introduction

Direct instrumental observations of the Sun since 1610 have shown that the level of sunspot activity on the Sun has a mean periodicity of 22.3 years, known as the Hale cycle. In addition, these observations of the Sun have shown that there are longer-term periodicities present in the level of solar activity. The most prominent long-term cycles that have been identified so far are the 90 year Gleissberg cycle and the 210 year de Vries (Suess) cycle. However, because of the limited time over which instrumental observations have been available, the confirmation of the latter two cycles has required the use of proxies to study the variation in the level of solar activity over much longer periods of time. Tables 1 and 2 show the sources in the literature that confirm the existence of the Gleissberg and De Vries cycles in the level of solar activity.

Table 1. Observational evidence for the Gleissberg cycle

Method	Period (yrs)	Time frame	Reference
1. De-trended δC^{14} from tree rings	87.8	0 – 11 854 BP	1
2. Sunspot number	87 ± 13	1700 – 2005 A.D.	2
3. Modulation of the length & symmetry of Schwabe cycle	~ 90	1853 – 2000 A.D.	3
4. Reconstructed Solar Irradiance	~ 80	1600 – 2000 A.D.	4
5. Solar proton events (ice-core & satellite observations)	80 – 90	1561 – 1994 A.D.	5
6. Ti^{44} levels in stony meteorites	~100	1750 – 2000 A.D.	6
7. Dust profiles in the GISP2 ice cores	~ 91	13 900 – 91 555 BP	7

1. Peristykh & Damon (2003); 2. Rodgers et al. (2005); 3. Pelt et al. (2000); 4. Lohmann et al. (2004);
5. McCracken et al. (2001); 6. Taricco et al. (2005); 7 Ram & Stolz (1999).

Table 2. Observational evidence for the deVries (Suess) cycle

Method	Period (yrs)	Time frame	Reference
1. De-trended δC^{14} from tree rings	208	0 – 11 854 BP	1
2. De-trended δC^{14} from tree rings	206	~ 11,000 period	2
3. Be^{10} levels in the GRIP ice cores	205 ± 5	25 000 – 50 000 BP	3
4. Sunspot number	188 ± 38	1700 – 2005 A.D.	4
5. Dust profiles in the GISP2 ice cores	~ 197	13 900 – 91 555 BP	5

1. Peristykh & Damon (2003); 2. Stuiver & Braziunas (1993); 3. Wagner et al. (2001); 4. Rodgers et al (2005);
5. Ram & Stolz (1999).

Periodicities in the Solar Motion about the Barycentre of the Solar System

Given that the Sun is over 1000 times the mass of Jupiter, most people assume the centre of mass (CM) of the Solar System is located at the centre of the Sun. In fact, the centre of the Sun moves about the CM is a series of complex loops, with the distance between the two varying from 0.01 to 2.19 solar radii (Jose 1965). Studies of this motion show that it is characterized by four main long-term periodicities.

The Jupiter/Saturn Synodic Cycle = 19.86 years
The first and most prominent cycle, is the time required for the Sun to move through one loop about the Barycentre. This is when it moves from it furthest distance from the Barycentre, in towards its closest approach to the Barycentre and then back out again to its furthest distance. The length of this cycle is set by the time between consecutive oppositions of Jupiter and Saturn, which is equal to the synodic period of 19.86 years.

The Tri-Synodic Cycle = 59.58 years
The second cycle in the Sun's motion is set by the fact that, in a reference frame that is fixed with respect to the stars, the line-of-opposition joining Jupiter, Saturn and the Sun rotates by approximately 117^{O} between each consecutive opposition. Seen from above the Sun's pole, the direction of this motion is in the opposite (or retrograde) direction to the motion of the planets. This means that after three synodic periods of Jupiter/Saturn, equivalent to 59.58 years, the line-of-opposition rotates back to a point that is shifted, on average, by $8.93\ ^{O}$ in a prograde direction, from its starting point. Stated another way, the Sun takes three loops about the Barycentre before it completes roughly one orbit with respect to the stars.

The Jose Cycle = 178.7 years
The third cycle in the Sun's motion results from the fact that line-of-opposition of Jupiter, Saturn and the Sun almost precisely returns to the same configuration with Uranus after seven Jupiter/Saturn synodic periods (i.e. 139.0 years) and with Neptune after 11 synodic periods (i.e. 218.5 years). This means that Jovian planets roughly return to the same configuration with respect to each other, and with respect to the stars, after three lots of three = 9 Jupiter/Saturn synodic periods (i.e. 178.7 years). This leads to the pattern in the looping motion of the Sun about the CM of the Solar system repeating itself roughly every 178.7 years (Jose 1965). We will call this 178.7 year period the Jose cycle.

The Hallstatt-Like Cycle ~ 2400 years
The fourth cycle in the Sun's motion is the result of $8.93\ ^{O}$ prograde shift that happens to the line-opposition of Jupiter, Saturn and the Sun between successive oppositions of Jupiter and Saturn. This means that it takes 40.3135 Jupiter/Saturn synodic periods for the line-of-opposition to complete one orbit with respect to the stars. However, it takes three of these orbits (i.e. 3 x 40.3135 = 120.9405 ~ 121 Jupiter/Saturn synodic periods = 2 402.94 years) for an opposition of Jupiter and Saturn to return to roughly the same point with respect to the stars. This period almost matches the ~ 2300 year Hallstatt Cycle that is seen in the de-trended δC14 tree ring data (Peristykh and Damon 2003) here on Earth.

Suppressed carrier amplitude modulation

If we have a carrier wave with an amplitude C and frequency ω that is amplitude modulating by a lower frequency wave with an amplitude M and frequency ω_m, the resulting combined wave is given by:

$$\mathbf{y(t) = C \sin(\omega\ t) + (M/2) [\cos((\omega_m - \omega)\ t) - \cos((\omega_m + \omega)\ t)]}$$

The resultant signal is made up of a carrier wave plus two sidebands, locate at $\omega + \omega_m$ (positive side-band) and $\omega - \omega_m$.(negative side-band). When the modulation of the carrier wave exceeds 100 % (i.e. M/C > 1), the side bands are emphasized at the expense of the carrier wave, with substantial suppression occurring for values of M/C ≥ 5.

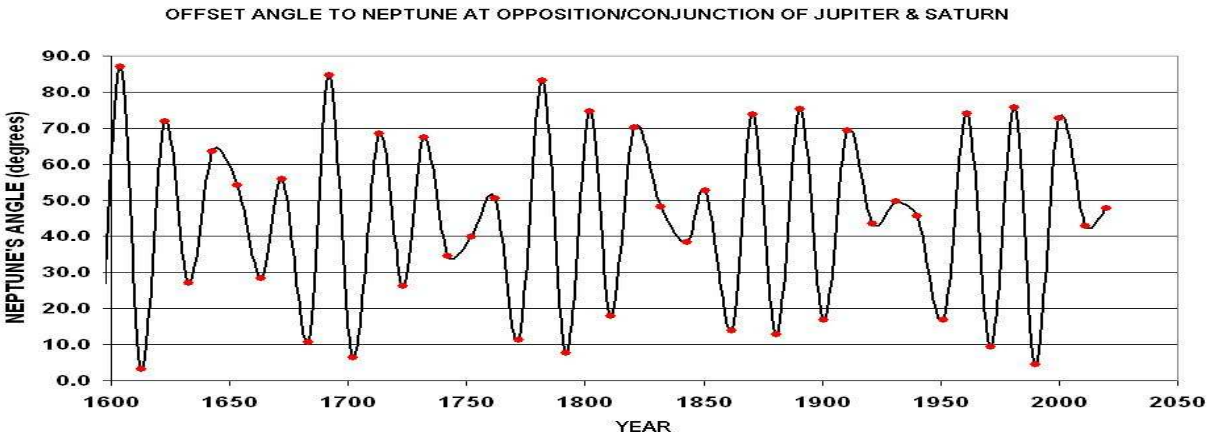
If you apply this concept to periodicities that are seen in the solar motion, Table 3 shows that the periodicities that are observed in the level of solar activity are naturally produced by a process of carrier suppressed amplitude modulation. The Hale and Gleissberg cycles are just the frequencies of the negative side-bands that are produced when the Jose cycle amplitude modulates the Jupiter/Saturn synodic and tri-synodic cycles, respectively. Similarly, de Vries cycle is the frequency of the negative side-band that is produced when a signal varying at half the Hallstatt cycle amplitude modulates the Jose cycle. (**Note**: The δC^{14} data of Peristykh and Damon (2003) also shows significant periodicities at 150 and 44.9 years, closely matching those of the positive side-bands at ~156 and 44.7 years. In addition, Javaraiah (2005) finds a statistically significant ~17 year periodicity in the equatorial rotation rate of the Sun that may be related to the positive side-band at 17.9 years.)

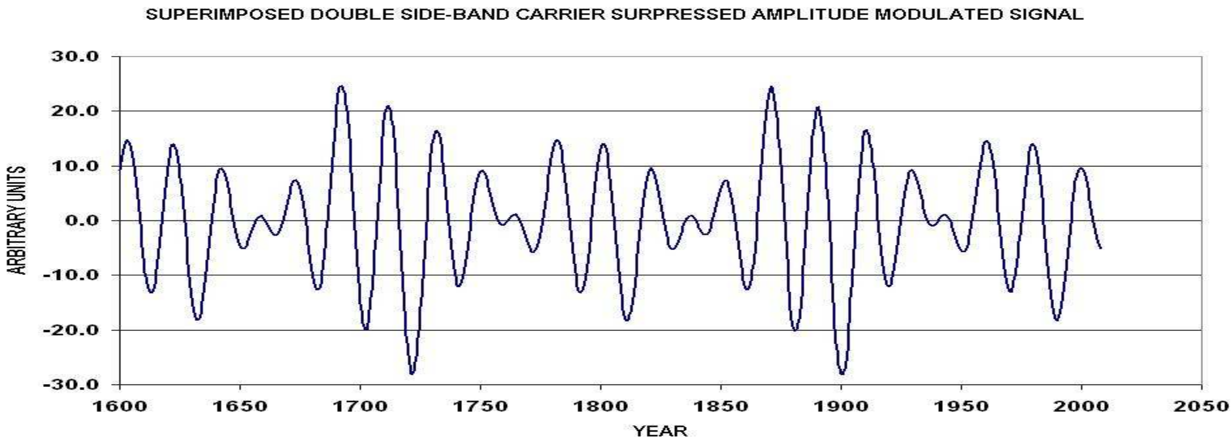
Another application of this concept is shown in figure 1a. This figure is a plot of the angle of Neptune to the line-of-opposition of Jupiter/Saturn at the times of syzygy, over the period from 1600 to 2020 A.D. This parameter is an indicator of the maximum torque that is applied to the Sun by Neptune as the Sun moves about the CM of the Solar

Table 3. Amplitude Modulated Cycles.

Solar Motion Cycle	Period (years)	Modulating Cycle	Period (years)	Positive Side-Band	Negative Side-Band	Solar Activity Cycle	Period (years)
Synodic	19.86	Jose Cycle	178.7	17.87	22.34	Hale	22.3
Tri-Synodic	59.58	Jose Cycle	178.7	44.68	89.37	Gleissberg	~90
Jose Cycle	178.7	Half-Hallstatt	~1200	~156	~210	De Vries	~ 205 – 210

Figures 1a and 1b



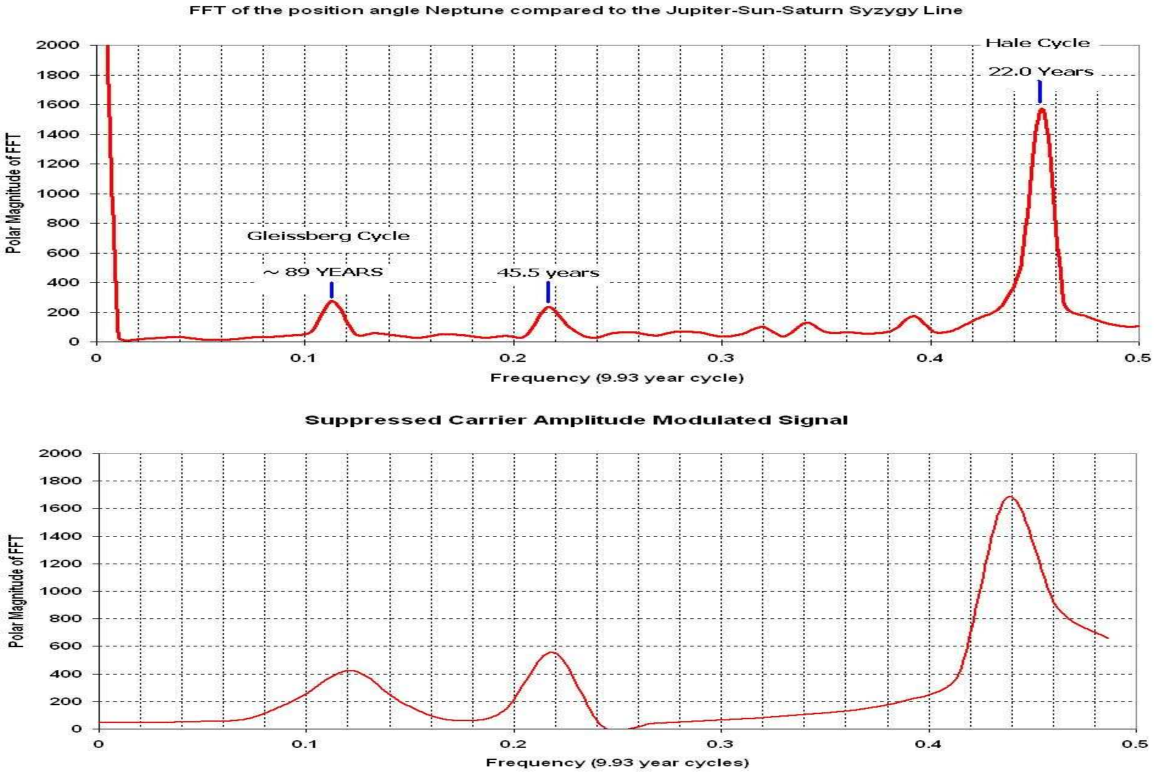


System. A comparison between figures 1a and 1b shows that we are able to successfully reproduce the variations in Neptune's position angle that are displayed in figure 1a by using the following carrier suppressed amplitude modulated signal that is plotted in figure 1b:

$$y(t) = \{[1 + 5\cos(2\pi(t-1890)/178.7)]\cos(2\pi(t-1990)/59.58)\} + 4\{[1 + 5\cos(2\pi(t-1890)/178.7)]\cos(2\pi(t-1990)/19.86)\}$$

This equation is just a simple superposition of two signals with carrier frequencies at the Synodic (1/19.86 years^{-1}) and the Tri-Synodic (1/59.58 years^{-1}) cycles of Jupiter and Saturn, that have undergone carrier suppressed amplitude modulation by the 178.7 year Jose cycle. The ratio used to weight the contributions from the Synodic to Tri-Synodic cycles is 4:1. The level of agreement between the data in figures 1a and 1b is further reinforced by the spectral data shown in figures 2a and 2b. Figure 2a shows the polar form of the FFT (Fast Fourier Transform) of the position angle of Neptune from figure 1a. The spectrum is dominated by three frequencies, the 22.0 year Hale cycle, the 90 years Gleissberg cycle and the 45 year Half-Gleissberg

Figures 2a and 2b



cycle. Figure 2b shows the corresponding plot for the carrier suppressed amplitude modulated signal seen in figure 1b.

Conclusions

The good agreement between the data plotted in figures 1a, 2a and that plotted in figures 1b, 2b raises the possibility that the dominant periodicities that are seen in the long-term level of solar activity i.e. the de Vries (210 years), Gleissberg (90 years), and Hale (22.3 years) cycles, may be related to the periodicities that are observed in the Sun's Barycentric motion. As yet, no one has provided a reasonable explanation as to why there might be a link between the level of solar activity and the Sun's Barycentric motion. However, we believe that the topic warrants further investigation because of the excellent agreement between the observed periodicities.

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