Seeing Spots!

Exploring the variability of sunspot tilt angles of sunspot cycles in observations and a supercomputer model

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Introduction

Scientists have observed the irregularities of the sunspot cycle for centuries. Though the reasons for this variability are not yet understood, we do know that sunspots are an observable result of the solar dynamo, or the process by which the sun generates its magnetic field. Specifically, in the widely accepted Babcock-Leighton model of the solar dynamo, the flip from the toroidal magnetic field and the poloidal magnetic field is dependent upon the orientation of sunspot tilt angles, an irregular portion of the sunspot cycle (Babcock 1961, Leighton 1964).

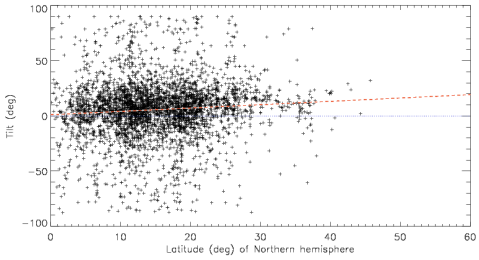
There are two key patterns to sunspot tilt angles. The first is Joy's law, which states that sunspot tilt angles are dependent upon the latitude of the sunspot. Specifically, the Joy's law equation is: tilt angle = 31.2 * sin(theta), where theta is a sunspot's latitudinal location (Li, Jing, Ulrich 2012, Stenflo & Kosovichev 2012). The second pattern is that sunspot tilt angles in either hemisphere fall under a Gaussian distribution curve.

The equation used to calculate tilt angles in the computer model is: **tilt angle = $31.2^{o} * \sin\theta$ + random**. The first part of this equation is Joy's law, and the random variable follows a Gaussian distribution curve with a mean of 0 and a code-defined **σ** value, which controls the level of variability in the sunspot tilt angles. In this way, the equation encompasses both major patterns observed in sunspot tilt angles.

Tilt angles in observation

Sunspot data was calculated using the NOAA/USAF solar region summaries from May of 1997 to May of 2010 of greater than 500 gauss (Upton, L., Hathaway, D. H., 2013). I calculated sunspot tilt as shown below.

Figure 1: tilt angle by latitude of observation data



tilt angle calculation: tangent(θ) = opposite/ adjacent

- opposite = difference in latitudes between the two sunspots
- Adjacent = difference in longitudes between the two sunspots.

Tilt angles in computer modeling

This project included three different runs of the computer model, STABLE, (Miesch, Teweldebirhan, 2016) with different **σ** values: 0, 10 and 20. The surface flux of the sigma 20 run is shown in Figure 2.

Figure 2: surface radial field of computer model when **σ** =20

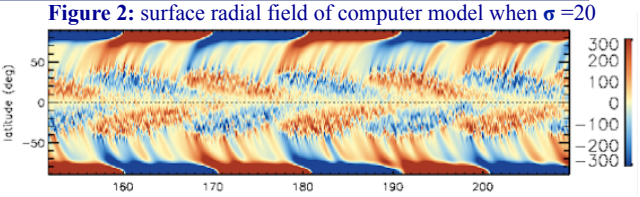
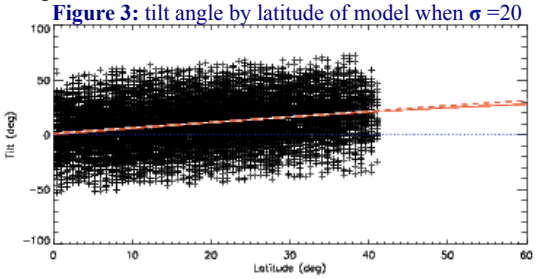


Figure 3: tilt angle by latitude of model when **σ** =20



- Although we expected the high level of variability in the **σ** = 20 run to cause a death of the solar dynamo, the model continued re-generating the solar dynamo (as seen is Figure 2) as well as for runs when **σ** = 20 and **σ** = 0.

Conclusion

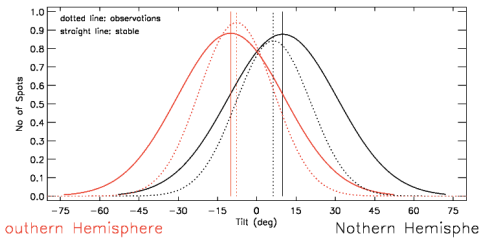


Figure 4: gaussian curves of tilt angle distribution of observational data and computer modeling data.

- By comparing tilt angle distributions in Figures 1 and 3, we see first that the computer model is densely populated up to 30° while observations are only densely populated up to 40°, and second that observational data has a higher level of randomness in tilt angle and latitude.
- BUT in Figures 3 and 4 we see we see the computer model is successfully generating accurate solar cycles.
- Therefore, we conclude that scatter in tilt angle is not responsible for solar cycle irregularity.

References

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