Solar Dynamo modelled with a variable speed inner core.

P.G. Vejde

pgvejde@gmail.com

Abstract

Sunspot patterns and motions observed in the photosphere are modelled here by assuming the more solid inner core of the sun rotates at a variable speed. In a solar cycle with a periodicity where the inner core alternates between rotating faster than the outer convection zone every 11 years. And then rotates slower than the convection zone for the next 11 years. For a total of a 22 year solar cycle. This physical mechanism creates a 22 year cycle in the rotational velocity gradient in the plasma of the convection zone across its radius. Which drives the N-S solar dynamo and creates both the motion of sunspots and induces the observed variations and reversals in polarity of sunspots. And in turn induces the overall Polarity of the dipole solar magnetic field.

Introduction

The sun is composed of a gaseous plasma that has a rotation period length at the photosphere which varies with latitude. The equatorial rotation period is the fastest at 25.6 days and higher latitudes have longer periods. With a 36.4 day rotation period observed at 70 degrees latitude. Which creates differential rotation in the varying rotation rates of the plasma of the convection zone. To date various theories of how to explain observations of sunspot rotations on the photosphere and their overall magnetic polarity have been proposed. (Hale,Babcock). All of these models rely in one way or another on the assumption that it is heat convection flows from the suns interior and the differential rotation of the sun at different latitudes, which drives the dynamo mechanism. And in turn this dynamo dictates the observed variations in polarity of the sunspots and the solar magnetic field. Some theorists suggest that a dynamo driven mechanism between the tachocline and the solar surface is what creates the observed solar and sunspot helicity (1). And more recently others propose this dynamo mechanism is occuring only at the surface of the convection zone (2).

This paper takes a novel approach and models the motion and rotation of the sunspots as a result of a physical mechanism where there is a cycle of a periodic variable rotational speed between the more dense inner core and the plasma of the outer convection zone at equatorial latitudes. Where the suns rotation is observed to be the fastest at a 25.6 day period. A concept inspired by induction theory where reversing the electric current reverses the polarity of the induced magnetic field. This physical mechanism of a variable speed inner core creates a variable velocity gradient across the suns radius between the tachocline and the outer edge of the convection zone. With the maximum velocity gradient between core and photosphere being at the equator. This variable speed gradient across the solar radius not only supplies the dynamo mechanism which induces the overall solar dipole magnetic field and facilitates the observed north - south solar polarity reversals. It also creates turbulence andassociated eddy currents/vortices in the convection zone plasma. The helicity or direction of rotation of these vortices, or sunspots, in each hemisphere also defines each sunspots individual magnetic polarity depending on the sunspots vortices direction of rotation.

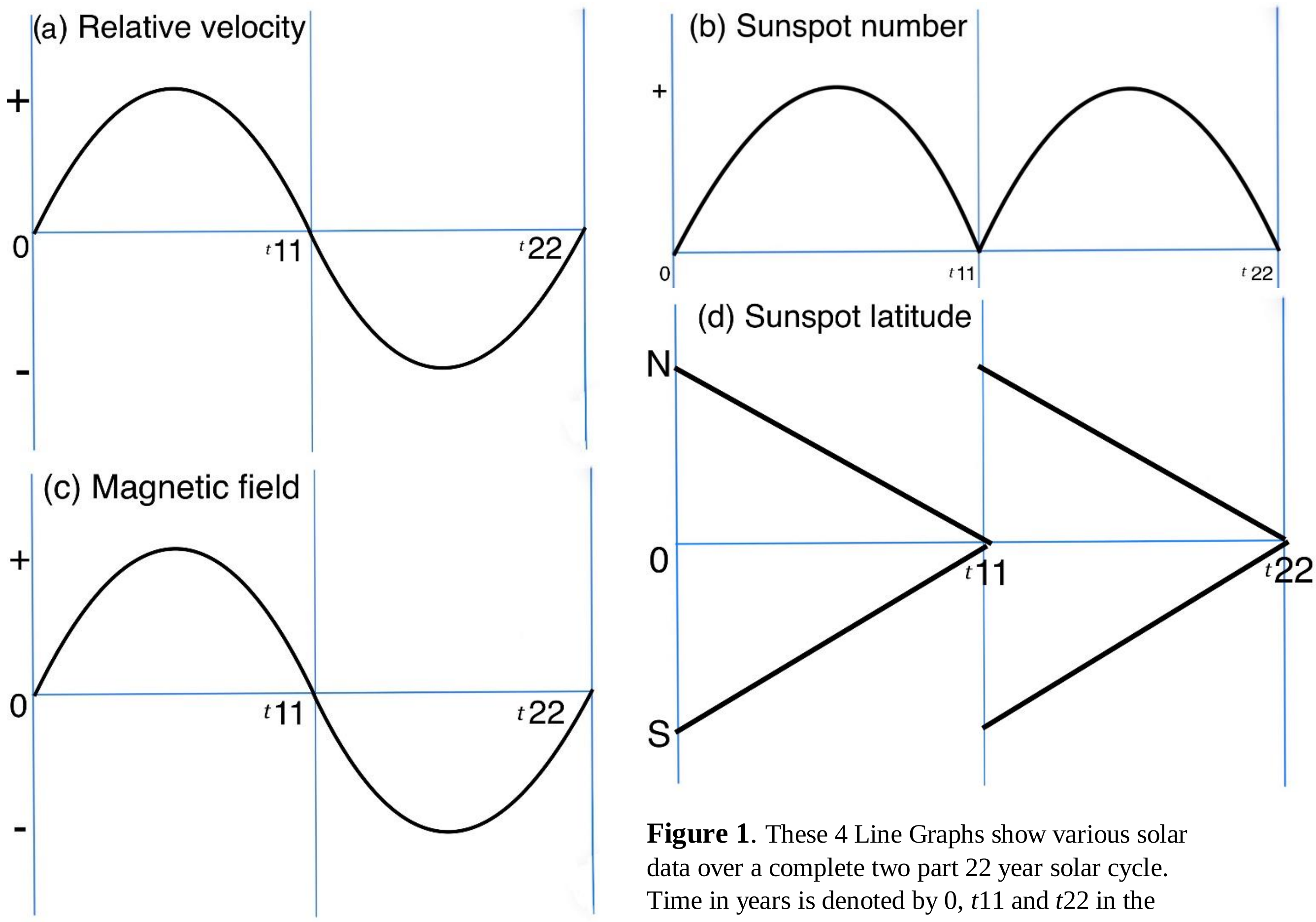

Figure 1. These 4 Line Graphs show various solar data over a complete two part 22 year solar cycle. Time in years is denoted by 0, *t*11 and *t*22 in the horizontal axis.

1(a) Velocity difference in the y axis between the inner core and the outer convection zone. For the first 11 years of the cycle the inner core rotation velocity speeds up relative to the the outer convection layer at the photosphere in the heliocentric frame. And then in the second 11 years the inner core slows down its rotation velocity relative to the observed rotation velocity of the sun at the photosphere. The peak difference in relative speeds between the core and photosphere occurs at the mid point of each 11 year cycle.
1(b) Sunspot number on the vertical axis. As the difference in relative velocity between the core and the photosphere increases every 11 years, so too does the frequency of sunspots observed.
1(c) The overall solar magnetic field generated by the variable speed dynamo, increases to peak strength every mid 11 year cycle. Then decreases to zero and flips polarity between positive and negative every 11 years.
1(d) The average latitude of sunspots decreases as the 11 year cycle progresses. With solar maxima occurring roughly mid cycle coincidental to maximum sunspot activity and maximum rotational velocity difference between the inner core and photosphere. Not shown here on this graph is the fact that some overlap of sunspots between cycles does occur. In that due to turbulence, sunspots from one cycle will start or finish in previous or subsequent cycles. Turbulence in fluid mechanics is never perfect and indeed the length of solar cycles themselves and other data indicate considerable variability occurs between solar cycles.

Solar Cycle modelled by a Variable speed core

This solar cycle alternates every 11 years between the inner core rotating for 11 years at a faster velocity relative to the 25.6 day rotation rate of the sun at outer edge of the convection zone in the equatorial regions. And then slowing down to a slower rotational velocity than the 25.6 day period relative to the plasma at outer part of convection zone for the next 11 years. The total time for these two phases has an average of 22 years and is referred to as the Hale cycle. When the maximum speed difference at the equator between the inner core and the outer part of the convection zone occurs, this is the point in this model in each 11 year cycle where the N-S solar dipole magnetic field is assumed to be the strongest. And where the sunspot activity also reaches maximum. When the relative rotational velocity between the inner core and outer convection zone at the equator is equal, this corresponds to the weakest point in the dynamo cycle. This point in the sunspot cycle is referred to as the sunspot minima part of the 11 year cycle. It is also the point in the solar cycle at which the model proposes the overall solar dipole N-S field flips.The sun, like the earth is considered to be rotating west to east or counter clockwise in the heliocentric frame. Whether the inner core rotates slower or faster than the 25.6 day equatorial rotation period of outer part of the convection zone this can still be considered to be a counter clockwise rotation of the core, if one is in the heliocentric frame and looking down at the suns northern hemisphere. However the important distinction to note for this model is that in the sunspot frame (the observer or frame that rotates with the sunspot), the inner core will appear to rotate *clockwise* or east to west relative to the sunspot when the inner core is rotating slower than the convection zone. And when the inner core is rotating faster than the convection zone, in this model the inner core will reverse apparent direction in this sunspot frame and appear to move west to east or clockwise relative to the sunspot's frame. It is a combination of this variable 'slowing down-speeding up' velocity gradient vertically across the suns radius between tachocline and photosphere coupled with the differential rotation of the convection zone decreasing at higher latitudes that this model uses to explain the appearance of vortices or eddy currents in the convection zone. And in turn the alternating rotational direction of these eddy currents/sunspots in each hemisphere. A physical mechanism which becomes a dynamo that induces the various different magnetic polarity of sunspots and the overall solar dipole field

Sunspot mechanisms

This alternating cycle of a speeding up and then slowing down of the rotation of the inner core relative to the convection zone creates a vertical velocity gradient in the plasma medium of the convection zone between the inner core and the outer edge of the convection zone. A gradient which is greatest at the solar equator and least at the poles. This is the gradient which creates the rotating vortices or 'sunspots' in the convection zone plasma. Generally vortices of both clockwise and counter clockwise rotations of sunspots can be found in both north and south hemispheres of the sun. Although there is a slight statistical bias for opposing helicity preferences for sunspots in each hemisphere. Sunspots usually come in groups or 'pairs'. The main leading sunspots always tend to have the same helicity in one hemisphere and the opposite in the other hemisphere. With secondary or trailing sunspots usually having opposing helicity to its leading pair (3,4). These in turn usually follow the rule that a Clockwise rotating sunspot will have negative polarity and a counter clockwise rotating sunspot positive polarity (5). It is no accident that sunspots, like rotating water eddies, are also observed to be depressions in the convection zone at the photosphere. And that vortices in water can be both CW and CCW adjacent to each other. Confirming that sunspots are indeed physically rotating vortices or eddies in the plasma of the convection zone.

The angle between leading and trailing sunspots is observed to increase at higher latitudes (Joy's law). This can be explained in this model by the differential rotation of the convection zone at different latitudes. Where rotation velocities of the sun at the photosphere decreases at greater latitudes from a 25 to a 34 day rotation period. At higher latitudes this velocity differential between the leading and its trailing spot is less than a sunspot pair nearer the equator. This equates to a smaller Longitudinal distance covered in the same amount of time between leading and trailing spot's at higher latitudes.

The preference for sunspot pairs with the leading spot always having an opposite rotational helicity to a leading sunspot in the opposite solar hemisphere can also be accounted for by the fact that the velocity gradient differential in the plasma of the convection zone is always greatest at the equator. On either side of the equator the velocity gradient between core and convection zone decreases with increased latitude . Creating opposing differential rotation directions of the convection zone plasma in either hemisphere. Thus at any one point in the 11 year cycle, leading sunspots north of the solar equator will always rotate in opposite directions to a sunspot south of the solar equator due to differential rotation in the plasma. Much in the same way as low pressure weather systems are observed to be cyclone or anticyclone in earths atmosphere due to opposing differential rotation of the atmospheric medium in each hemisphere.

Opposing directions of rotation between leading and trailing sunspots in the same hemisphere is explained with a similar mechanism due to differential rotation of the local medium between each adjacent sunspot. A clockwise rotating leading sunspot will usually induce counter clockwise rotation in an adjacent trailing sunspot. Much in the same way that air in terrestrial low pressure areas will induce opposing rotation of the air in adjacent high pressure zones in the same hemisphere. Vortices and eddies in moving water also display this opposing clockwise or counter clockwise rotation between adjacent rotating vortices.

Although in some studies (6) the authors suggest a clockwise rotating sunspot can have either a positive or a negative magnetic polarity. Although their study is not clear if individual sunspot rotations directions were correlated to that individuals helicity. Or if statistically as a whole, each hemispheres' total amount of helicity percentages and rotation rates were compared. This statistical approach needs further study where the individual sunspots direction of rotation would be compared with that same sunspots polarity (3).

Summary and Conclusions

In the Heliocentric frame in the first part of the 22 year cycle when the inner core is rotating faster than the plasma of the convection zone this creates an overall greater anti clockwise rotation velocity (positive polarity). When the rotation velocity of the inner core slows relative to the outer convection zone rotation period in the second half of this 22 year cycle, the dynamo reverses. It is this alternating reversal in the flow of the plasma of the convection zone relative to the photosphere which creates a reversal in direction of rotation of the solar dynamo and induces a reversal of the solar dipole magnetic field. This 11 year flow reversal cycle also accounts for the reversal in sunspot rotations in each hemisphere between cycles.

For example it has been noted that during solar cycle 23 in 1999-2002 it was observed that leading sunspots rotated anti clockwise in the northern hemisphere and clockwise in the Southern Hemisphere. Using the model proposed in this paper this would indicate that the core was rotating faster than the outer convection zone during this period. And as the convection zone at the photosphere is considered to always rotate in a counterclockwise direction in the heliocentric frame, than the assumption here is that the core was also rotating counterclockwise but even faster than the convection zone during this same period. And in turn if one follows the rules of helicity direction vs polarity in dynamos, this model assumes that the North Pole of the solar magnetic dipole field was positive during cycle 23. (3,4). It is important to note here that this model's predicted reversal of rotation direction of the inner core relative to the convection zone at the photosphere from clockwise to counterclockwise is frame relative.

Examples: In the heliocentric frame the sun rotates counter clockwise or east to west in the observers frame. In this frame when the inner core rotates faster or slower than a spot on the photosphere the observer in the heliocentric frame would see the inner core increasing or decreasing its CCW or west to east rotational velocity. The core would always rotate eastwards throughout the full 22 year cycle. But only slow down or speed up this eastward rotation between cycle. However, for an observer in the frame which rotates above or "with" a spot on the equator at surface of the sun, the inner core beneath the sunspot would appear to rotate first to the east, or counter clockwise, for 11 years. And then to the west or clockwise every other 11 years. It is in this frame that one can best appreciate and understand the motions and polarities of sunspots on the photosphere. Essentially the sunspots in this frame wouldn't move significantly. Just grow and fade and disappear as the cycles progresses. But as the inner core rotates back and forth in this particular frame beneath the sunspot it physically "fans" the convection zone plasma medium beneath the sunspot(s). This back and forth rotation of the inner core creates rotating vortices in the convection zone which manifest at the photosphere as sunspots. As the velocity of the inner core relative to the observer at the surface increases, the dynamo strength increases and in turn the volumes, numbers and sizes of sunspots also increases at the photosphere surface.

In conclusion it must be noted this model only explains the mechanism of the solar dynamo . But can only speculate on the reasons behind the theoretical variable speeds of the inner core. Various possibilities can be invoked. The core could be changing size, density, temperature or shape between the cycles which could affect its own spinning rate. Their could be a topological deformity to the inner core as it spins. In that it could be an asymmetric shape and wobbles or precesses at different period rates as it rotates every 22 years.

A similar variable speed off centred inner core dynamo mechanism can also be used to model the variations of polarity observed in earths magnetic field. Including the earths magnetic field reversing or "flipping" periodically. And the 'wandering' North magnetic pole.

References:

1)Choudhuri & Chatterjee 2004, Helicity of Solar active regions from a dynamo model

2)Vasil et al, 2024, The solar dynamo begins near the surface, Nature

3)Brown et al, Observations of Rotating Sunspots from TRACE 2003

4)Bao et al, 2002, The Sources of Magnetic Field Twist in Solar Active Regions

5)Jianchuan Zhen, 2016 On the Rotation of Sunspots and their magnetic polarity The Astrophysical Journal

6)Yan et al 2008, A Statistical study on rotating sunspots: Polarities, Rotating directions and Helicities.