Meridional Flow Variations in Cycles 23 and 24: Active Latitude Control of Sunspot Cycle Amplitudes

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ABSTRACT

We have measured the meridional motions of magnetic elements observed in the photosphere over sunspot cycles 23 and 24 using magnetograms from SOHO/MDI and SDO/HMI. Our measurements confirm the finding of Komm, Howard, and Harvey (1993) that the poleward meridional flow weakens at cycle maxima. Our high spatial and temporal resolution analyses show that this variation is in the form of a superimposed inflow toward the active latitudes. This inflow is weaker in cycle 24 when compared to the inflow in 23, the stronger cycle. This systematic modulation of the meridional flow can modulate the amplitude of the following sunspot cycle through its influence on the Sun's polar fields.

Introduction

The origin of the sunspot cycle is the oldest unsolved problem in solar physics. Sunspot cycle maxima vary in amplitude from virtually no sunspots per day during the Maunder minimum to more than 200 per day at the peak of Cycle 19 in 1957 – nearly twice the average of 113. The source of this variability is still uncertain.

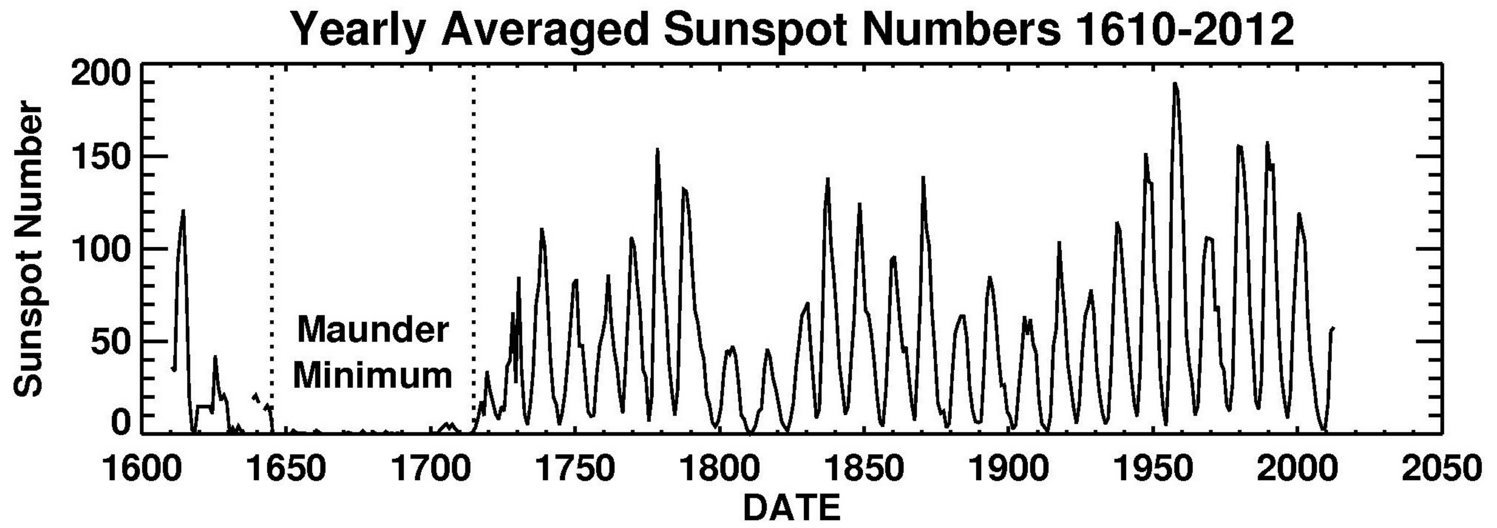

Figure 1. Yearly averages of the daily sunspot number show the wide variation in sunspot cycle amplitudes..

The sunspot cycle is magnetic in nature. The magnetic field changes are controlled by the fluid motions within the Sun's convection zone – differential rotation, meridional flow, and the non-axisymmetric convective motions. The strength of the Sun's polar fields at the start of a sunspot cycle is the best indicator for the ultimate strength of the sunspot cycle itself (Ref. 1). These polar fields are produced by the transport of magnetic flux that emerges in active regions (Ref. 2 and Figure 2).

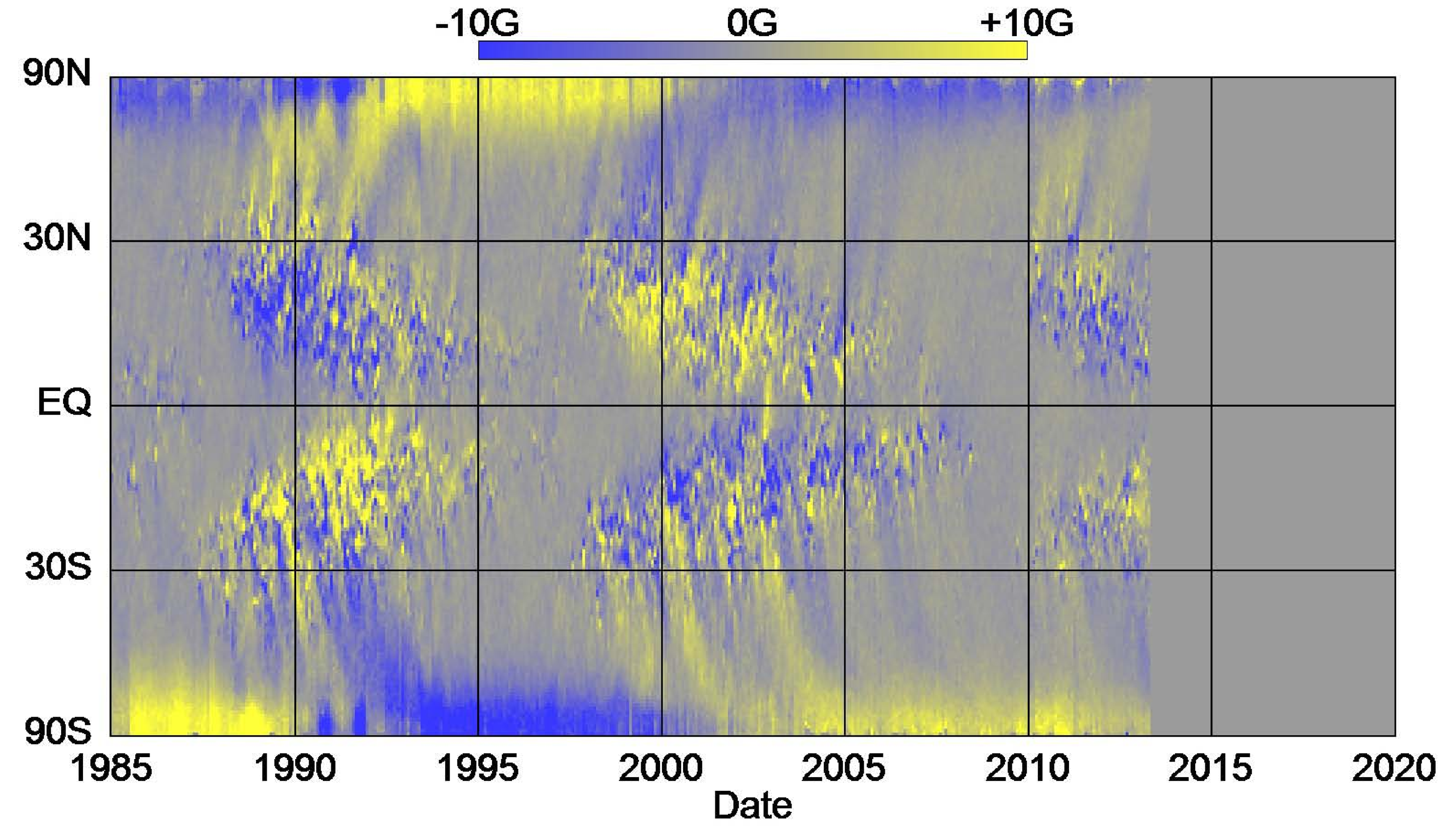

Figure 2. The longitudinal averages of the Sun's radial magnetic field as functions of latitude and time show the magnetic nature of the sunspot cycle.

Variations in the strength of the polar fields produced during each sunspot cycle depends upon variations in the sources (active region flux and Joy's Law tilt) and variations the transport (primarily the meridional flow). Here we find that the meridional flow varies systematically from cycle to cycle and that these changes can be shown to modulate (and moderate) sunspot cycle amplitudes.

Meridional Flow Measurements

We have measured the axisymmetric motions of the small magnetic elements by cross-correlating data strips from magnetograms obtained with SOHO/MDI and SDO/HMI (Ref. 3-5). We fit the differential rotation and meridional flow profiles to polynomials in sin*B* multiplied by cos*B* where *B* is the heliographic latitude. A similar analysis was done earlier using blocks of data from Kitt Peak/NSO magnetograms (Ref. 6). These analyses show that the meridional flow is strong at cycle minima and weak at cycle maxima as shown in Figure 3.

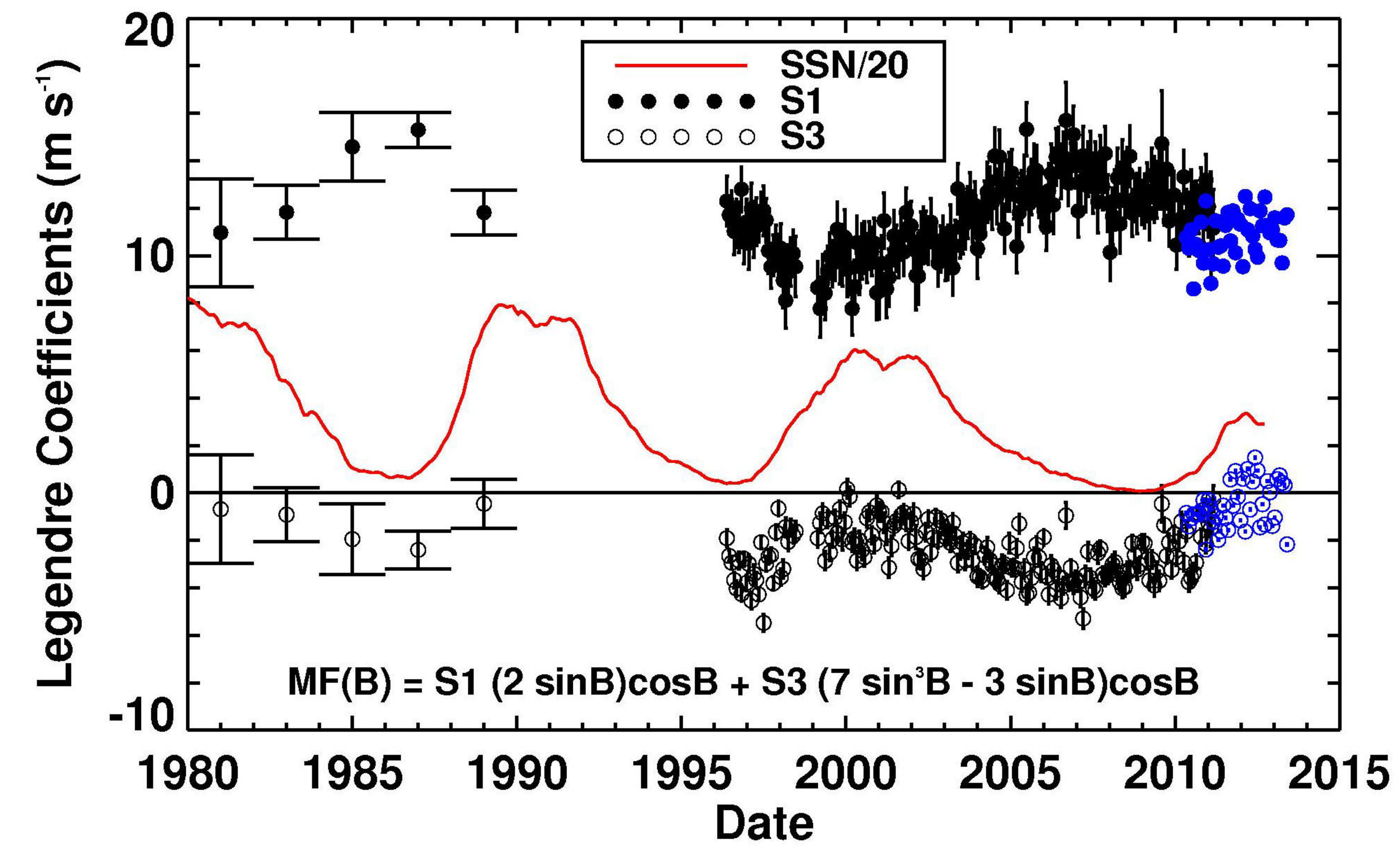

Figure 3. Meridional flow variations from 1980 to 2013 as given by Legendre polynomial fit coefficients. The earlier data (with 1-sigma error bars) are from the analysis of Komm, Howard, and Harvey (1993). The data in black from 1996 to 2010 (with 2-sigma error bars) are from our analysis of SOHO/MDI magnetograms. The data in blue from 2010 to 2013 (with 2-sigma error bars) are from our analysis of SDO/HMI magnetograms. The dominant component, of the meridional flow is characterized by the S1 coefficient,. It gives faster meridional flow at cycle minima and slower meridional flow at cycle maxima.

Cycle Maximum Variations

We previously noted that one important variation in the meridional flow is the difference in flow speed from Cycle 23 minimum in 1996 to Cycle 24 minimum in 2008 – slower at the start of Cycle 23 and faster at the start of Cycle 24. Here we note the difference in the meridional flow at the cycle maxima – slower at Cycle 23 maximum in 2000 and faster at Cycle 24 maximum in 2013. This is attributed to the systematic weakening of the meridional flow at cycle maxima and its association with sunspots themselves.

Active Latitude Inflows

The nature of this weakening of the meridional flow at cycle maxima is revealed by the full meridional flow profiles shown in Figure 4 below. The weakening of the poleward flow is primarily on the poleward side of the activity zones and is consistent with a superimposed inflow toward the sunspot zones. This inflow was pronounced during Cycle 23 (1996-2008) but substantially weaker during Cycle 24 (2009-present).

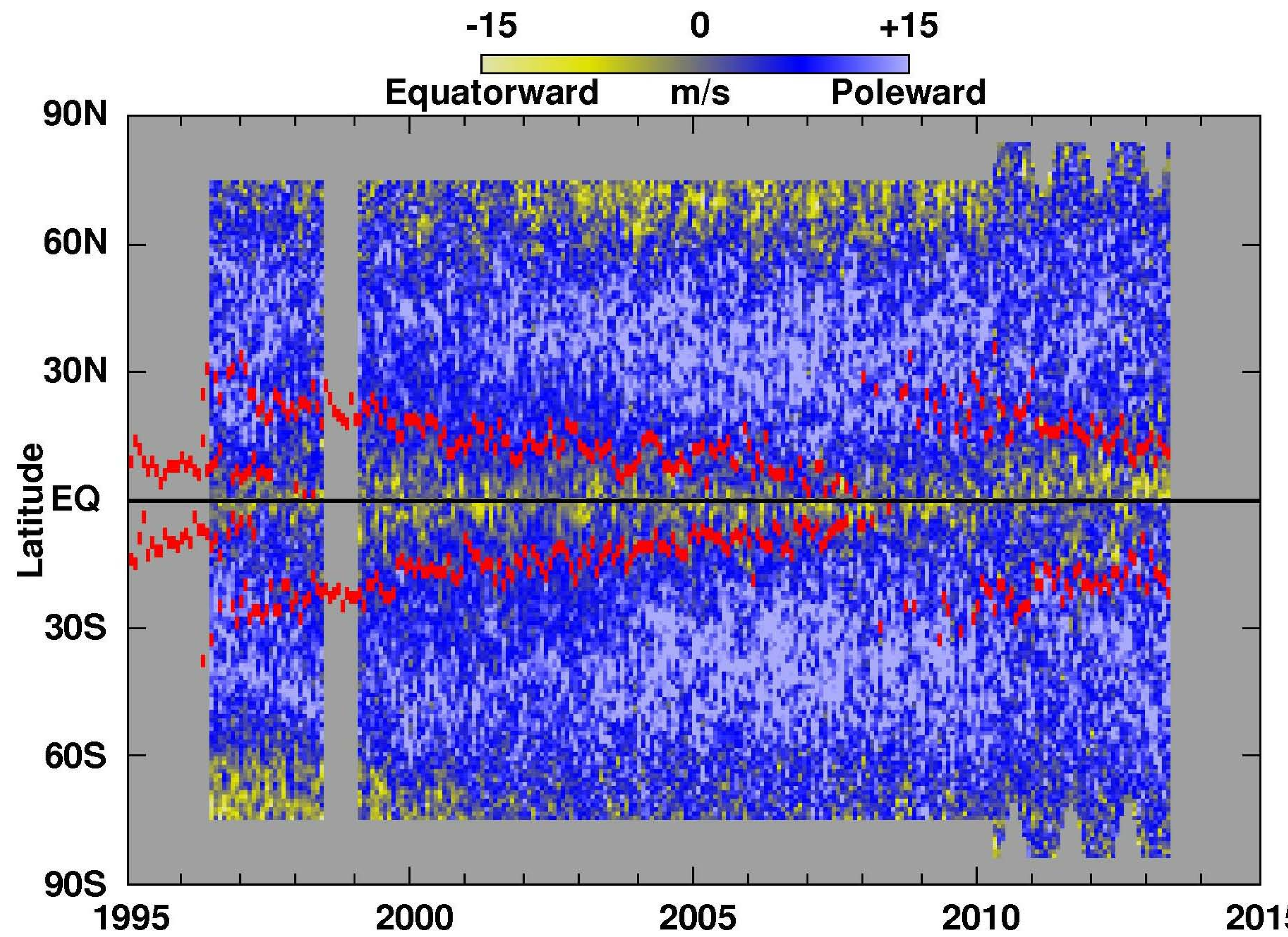

Figure 4. The full, individual meridional flow profiles for each Carrington Rotation are shown in shades of blue and yellow with red dots indicating the centroid positions of the sunspot area. The weakening of the meridional flow at cycle maximum (darker blues) is clearly evident and consistent with a superimposed inflow toward the sunspot zones.

Conclusions for Polar Fields

This active region induced inflow toward the active latitudes has a direct impact on the flux transported to the poles. During strong cycles the faster poleward flow near the equator decreases the cross-equator cancelation of leading polarity flux while the slower poleward flow at the higher latitudes transports less following polarity flux to higher latitudes. Both effects produce weaker polar fields during strong cycles than would be obtained without these meridional flow variations (Ref. 7).

These observed, cycle strength dependent inflows present one promising mechanism for modulating sunspot cycle amplitudes.

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