The cyclic behavior of solar full-disk activity

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Abstract. In order to describe the cyclic behavior of solar full-disk activity (the surface magnetic fields, filaments, the green (Fe XIV, 5303Å) corona local maxima intensities, and torsional oscillations), we propose a new concept, a 'full-disk activity cycle', which consists of two successive normal cycles: a high-latitude activity cycle following a low-latitude activity cycle. When solar activity begins to progress into a full-disk activity cycle, it latitudinally rushes to the poles, starting from middle latitudes (about 40^0) at about a normal cycle minimum. At the solar poles, magnetic polarity reversal takes place on both the solar hemispheres, and opposite reversals occur on the opposite hemispheres, resultingly, the new appearing magnetic polarity at high latitudes on a hemisphere will become the leading magnetic polarity of regions at low latitudes on the same hemisphere in the following normal cycle. After that the latitudinal drift of solar activity reaches the solar poles at about the maximum time of the normal cycle, solar activity begins to latitudinally migrate in a reverse direction; it moves toward the equator continually till almost arriving at the solar equator and lasting for about 1.5 normal cycles. When a full-disk activity cycle progresses from a high-latitude activity cycle into a low-latitude activity cycle, the next full-disk activity cycle begins. Two successive full-disk activity cycles have a normal cycle overlapped in time, but are spatially separated. The characteristics of full-disk activity cycles are summarized as well. At present we do not know why a full-disk activity cycle begins at mid-latitudes, it is perhaps related with solar differential rotation, further work is required to uncover the physical mechanisms behind the concept.
keyword: Solar filaments – Solar activity – Solar cycle

1. Introduction

Sunspots are the earliest and easiest observational phenomenon of solar activity. The most fundamental characteristic of solar activity is found, based on observations of sunspots, to be its cyclic behavior, such as the 11-year Schwabe period and the latitudinal drift of sunspots shown as butterfly diagrams. Considering the magnetic polarity of sunspots, the so-called magnetic activity cycle is proposed. During a given cycle, regions on opposite hemispheres have opposite leading magnetic polarities alternating between successive sunspot cycles. The period of a magnetic activity cycle is twice that of the sunspot cycle, that is, about 22 years on average. A magnetic activity cycle, namely the Hale cycle (Hale et al., 1919), consists of two successive normal low-latitude cycles. However, the traditional concept of the magnetic activity cycle does not precisely tell how, when, and where the magnetic polarity reversal takes place, because the concept describes solar magnetic activity at low latitudes while the magnetic polarity reversal occurs at high latitudes. Sunspots appear only at middle and low latitudes. They do not reveal solar activity at high latitudes; that is to say, the cyclic behavior of solar activity at the full disk, from the poles to the equator of the Sun, has not been told by the magnetic activity cycle.

The accepted length of the sunspot activity cycle has been fixed at approximately 11 years for more than a century. Theoretical and empirical models have been developed to explain the latitudinal drift of sunspots in each solar hemisphere, running from approximately 30^0 latitude to the equator, shown as butterfly diagrams (Li, Yun, and Gu, 2001). However, Howard and LaBonte (1980) and Legrand and Simon (1981) demonstrated that solar magnetic active patterns (high-latitude ephemeral regions and low-latitude small sunspots) belonging to two successive cycles can be observed at the same time on the Sun, it means that the total duration of a cycle must be longer than the interval of 11 years between two successive cycles. Based on observations of solar active phenomena other than sunspots, such as ephemeral regions, the Ca^+ plage area and so on, the extended activity cycle is proposed (Harvey 1992). An inspection of 'butterfly diagrams' of sunspots reveals that an overlap of up to three years may exist between adjacent sunspot cycles (Altrock, 1997): sunspots of a normal cycle begin to appear as much as approximately 1.6 years before the defined conventional sunspot minimum and continue to emerge as much as 1.8 years after the following minimum. Thus the duration of the sunspot activity belonging to a given cycle is about $2-3$ years longer than the time interval between successive minima. This extended period during which activity of a sunspot cycle occurs is called the extended activity cycle (or overlapping activity cycle) (Wilson et al. 1988; Li et al 2002c). Recent observations increase the evidence for an 'extended' solar cycle that begins every 11 years but lasts for approximately 19-20 years, starting from the maximum time of a normal cycle and ending soon after the minimum time of the next normal cycle (Altrock, 1997).

The Hale cycle, the solar magnetic activity cycle (Hale et al., 1919; Hale and Nicholson, 1938), and the extended activity cycle, the overlapping activity cycle (Harvey, 1992; Wilson et al., 1988), are two of the most important findings in solar physics. One extended activity cycle shows a spatially successive cyclical evolution of solar activity from the solar poles to the solar equator in a time interval of about 20 years, which is 2-3 years shorter than a magnetic activity cycle. One magnetic activity cycle shows a temporally successive cyclical evolution of solar activity in a longer time

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interval of about 22 years, but at solar low latitudes without solar activity at high latitudes considered. In the evolution of the magnetic activity cycle there is a spatial jump from the equator region at the end of a normal cycle to the mid-latitude region at the start of the following cycle. Therefore, a question emerges: can an extended activity cycle be theoretically combined with a solar magnetic activity cycle into one cycle? That is to say, is there a solar cycle whose periodical length is as long as a magnetic activity cycle and whose spatially cyclical evolution is as successive as an extended activity cycle does? Here our paper proposes a new concept, a 'full-disk activity cycle' to address this issue and to describe the cyclic behavior of solar full-disk activity.

2. The solar full-disk activity cycle

2.1. Latitudinal migration of filament activity over the solar full disk

The spatial distribution of solar activity that varies with time can be represented by the latitudinal migration of solar activity, the new concept, a 'full-disk activity cycle' will be given through studying latitudinal migration of solar activity. Filaments can provide the possibility for investigation of global properties of large-scale magnetic fields, especially when magnetographic observations are unavailable or unreliable. Their property of appearing in all heliospheric latitudes and outlining the border between magnetic fields with different polarities makes them suitable tracers for the large-scale pattern of the weak background magnetic field (McIntosh, 1972; Minarovjech, Rybansky, and Rusin, 1998a). In contrast, the study of the occurrence of filaments can help us better understand the distribution of these fields on the solar surface, their development with a cycle activity, and they especially provide useful insights into the nature of the Sun's magnetic field (Mouradian and Soru-Escaut, 1994; Rusin, Rybansky, and Minarovjech, 1998). Our paper uses the Carte Synoptique solar filament archive (d'Azambuja and d'Azambuja, 1948; Mouradian, 1998), namely the catalogue of solar filaments from March 1919 to December 1989 that corresponds to solar rotation numbers 876 to 1823. The Care Synoptique can be accessed via *ftp : //ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_FILAMENTS*.

A criterion for how a solar activity event can be assigned to an extended activity cycle was proposed by Li, Yun, and Gu (2001). The normal solar activity is usually applied to solar active events whose latitudes are lower than 50^0 (Sakurai, 1998). Here, according to the criterion and with the use of the Carte Synoptique solar filament archive, filaments with their unsigned latitudes lower than 50^0 are divided into individual butterflies, namely their normal cycles of low-latitude activity. Filaments with their unsigned latitudes larger than 50^0 are also divided into normal sunspot cycles according to minimum times of normal cycles of sunspot activity. Next the quarterly mean latitudes of filaments with their unsigned latitudes lower than 50^0 are calculated and plotted in Figure 1, and the quarterly mean latitudes of filaments with their unsigned latitudes larger than 50^0 are also calculated and

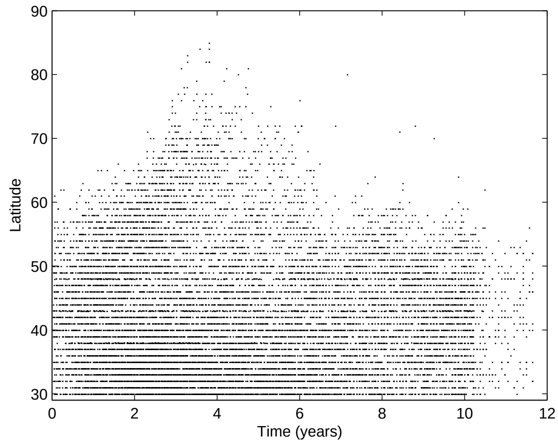

Figure 2. The superimposed epoch pattern when all filaments in different cycles are superimposed in a normal cycle with their individual minimal beginning times overlapped.

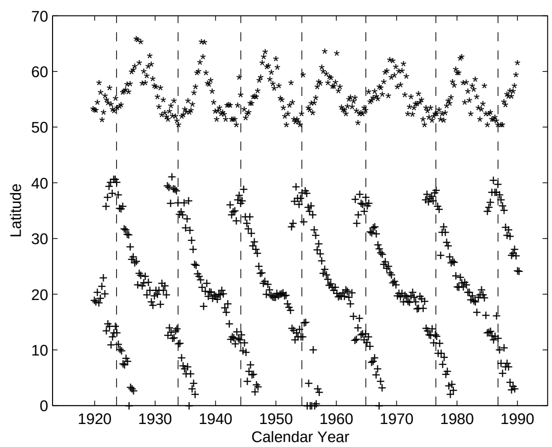

Figure 1. The quarterly mean latitudes of filaments with their unsigned latitudes lower than 50^0 (marked with plus signs) and larger than 50^0 (marked with asterisks), respectively. The dashed vertical lines mark minimum times of sunspot cycles.

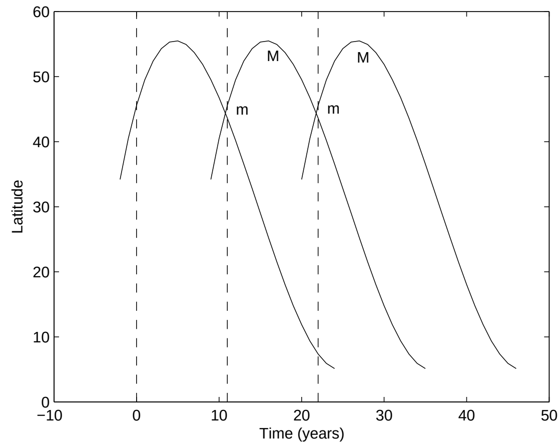

Figure 3. Skeleton of the latitudinal distribution of solar filament activity progressing in a full-disk activity cycle. Three successive cycles of such a full-disk activity cycle are plotted (three solid lines). The minimum times of normal cycles are denoted with the symbols m and marked with the dashed vertical lines while the symbols M are denoted the maximum times of normal cycles.

plotted in the figure. The figure clearly shows an equatorward migration at low latitudes and a poleward migration at high latitudes (Waldmeier, 1981; Song and Wang, 2006), namely the so-called 'rush to the poles' (Altrock, 1997; Coffey, 1998), appearing within a normal cycle. However, an equatorward migration is found from the solar poles toward middle latitudes (about 50^0) appearing in a normal cycle, which was once reported by Altrock (1997), although his report received less attention in the literature and seemingly even ignored in solar dynamo models.

In the figure, there is a gap at the middle latitudes of about 40^0 to 53^0 where no shift appears. When a quarterly mean latitude of filaments with their unsigned latitudes less than 50^0 is calculated, it should be less than 50^0. Similarly, when a quarterly mean latitude of filaments with their unsigned latitudes larger than 50^0 is calculated, it should be larger than 50^0. Therefore, the calculated quarterly mean latitudes are all away from the middle latitude of about 50^0, and thus the gap produced due to the 50^0 used as a latitude separator.

Next we use a superimposed epoch analysis to explain the production of the gap. We divide all the filaments into their normal cycles according to the minimum times of normal cycles of sunspot activity and then move them into a normal cycle with their individual minimal beginning times overlapped. Figure 2 shows the unsigned latitude distribution of the filaments varying with time in such a cycle; that is the superimposed epoch pattern. The figure clearly indicates that filaments are continually distributed at the latitudes of the gap and continually distributed from the solar pole region to the solar equator after high-latitude filaments rush to the poles; thus the gap should be artificial due to the division of the high and low latitudes by the latitude of 50^0.

We also repeat the above procedure, but with latitudes larger than 60^0 regarded as high latitudes and latitudes less than 40^0 as low latitudes, and the three kinds of latitudinal migrations mentioned above all appear too: (i) a poleward drift at high latitudes, (ii) a equatorward drift from poles to middle latitudes (about 50^0), and (iii) an equatorward drift at low latitudes. Therefore, the three kinds of latitudinal migrations always appear regardless of any division of the high and the low latitudes. Here, based on Figure 1, our new concept, a full-disk activity cycle is proposed consisting of two successive normal cycles: a high-latitude activity cycle following a low-latitude activity cycle, which is illustrated in detail in Figure 3. When solar activity begins to progress into a full-disk activity cycle, it latitudinally rushes to the poles, starting from middle latitudes (about 40^0) at about a normal cycle minimum. After a latitudinal drift of solar activity reaching the solar poles at about the maximum time of the normal cycle, solar activity begins to latitudinally migrate in a reverse direction, toward the equator continually till almost arriving at the solar equator and last for about 1.5 normal cycles. During the $\sim$1.5 normal cycles of the equatorward migration, solar activity latitudinally migrates to the middle latitudes at about the minimum beginning time of the following normal cycle to complete a normal cycle, but at high latitudes, Then it continues to latitudinally migrate almost to the solar equator at about the minimum ending time of the following cycle to complete the next normal cycle but at low latitudes. When a full-disk activity cycleprogresses from a high-latitude activity cycle into a low-latitude activity cycle, the next full-disk activity cycle begins. Two successive full-disk activity cycles have a normal cycle overlapped in time, but are spatially separated.

The full-disk activity cycle is a good description for the cyclic behavior of the full-disk filament activity. Due to less solar active phenomena appearing at high latitudes, we have to search some other examples in the literature to demonstrate the validity of the new concept. We used the following observations which were once used to illustrate extended activity cycles, to show full-disk activity cycles.

2.2. Coronal activity cycle

To study the coronal activity at low altitudes ($\sim$ 50000 Km), it is customary to follow the intensity of the emission line $\lambda = 5303 Å$, which is known to be a reliable parameter describing activity in the lower corona (Leroy and Noens, 1983). Leroy and Noens (1983) once analyzed the data of coronal $\lambda 5303 Å$ emissivity obtained at Pic du Midi through the years 1944 to 1974, searching for the latitude variation of coronal activity. According to their Figure 1, which is plotted again here as Figure 4, they inferred the main features of coronal activity cycles as follows: starting from the epoch of a sunspot maximum M (-6 years in Figure 4), a high latitude active zone is found near 60^0. At the time of the minimum of the next sunspot cycle it branches toward a polar band and, at least in the southern part of the figure, towards the first active regions of the new cycle, near 40^0. Later on, the polar active band drifts towards the poles which are reached near the maximum of the cycle, while the main, low latitude, active band follows approximately the latitude evolution of sunspots. They concluded that a complete cyclical development of activity in the corona covers a time lapse of about 17 years, spanning from the maximum

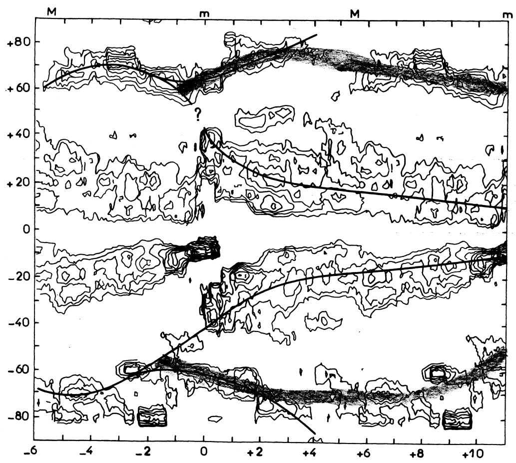

Figure 4. Time-latitudinal distribution of isovalues of the quantity $(\sigma_{5303} - \bar{\sigma}_{5303})$ varying with time in years with the minimum (m) and maximum (M) epochs of the cycle specified, where $\bar{\sigma}_{5303}$ is the latitude average of σ_{5303} over 20^0 intervals. This figure is originally come from Leroy and Noens (1983), but with two hand-drawn uneven wide-belt lines added here to illustrate the new concept.

Figure 5. (a) Time-latitudinal distribution of the green corona local maxima intensities for averages of 27 days as derived from the homogeneous coronal data set, (b) Time-latitudinal distribution of values of 'prominence index'. This figure is originally come from Minarovjech, Rybansky, and Rusin (1998a), but with uneven lines added here to illustrate the new concept.

of a cycle to the minimum of the next cycle. It is the other kind of the description for the full-disk activity, which is named a coronal activity cycle here to distinguish from the above full-disk activity cycle. A full disk filament activity can also be described within the way shown in Figure 4 by Leroy and Noens (1983). However, in such a coronal activity cycle, the poleward branch should seemingly be connected with the high-latitude equatorward branch of the next coronal activity cycle in each hemisphere, and the concept of a full-disk activity cycle can give a better description of the coronal activity at low altitudes, which is illustrated with two hand-drawn uneven wide-belt lines in Figure 4. When a coronal activity event (for example the 5303$\AA$ emission) begins to progress into a full-disk activity cycle, it latitudinally 'rushes to the poles', starting from middle latitudes at about a normal cycle minimum. After the latitudinal drift of coronal activity reaching the solar poles at about the maximum time of the normal cycle, coronal activity begins to latitudinally migrate in a reverse direction, toward the equator continually till almost arriving at the solar equator, lasting for about 1.5 normal cycles. A full-disk activity cycle for coronal activity is proposed to consist of two successive normal cycles: a high-latitude activity cycle following a low-latitude activity cycle. Thus, based on observations, we prefer to the above full-disk activity cycle.

In order to study coronal activity, a time-latitudinal distribution was once shown for the green corona (Fe XIV, 5303$\AA$) by Minarovjech, Rybansky, and Rusin (1998a) in their Figure 2. Based on the figure, shown here in Figure 5 is the time-latitudinal distribution of the green corona local maxima intensities for averages of 27 days (Minarovjech, Rybansky, and Rusin, 1998a), as derived from homogeneous coronal data set (Rybansky et al., 1994). As the butterfly diagrams of sunspots obviously show the 11-year Schwabe cycles, the green corona activity clearly shows full-disk activity cycles. Based on the observations of the green corona, we prefer to the above full-disk activity cycle.

As the figure shows, a polar branch of the green corona local maxima intensities begins to appear at latitude of about 50^0 at a normal cycle minimum, migrates to latitudes of $70^0 - 80^0$, and reaches the poles at the normal cycle maximum, then it reverses to equatorward migration, reaching the equator at the end of the next solar cycle. It ends very abruptly at latitudes around $5^0 - 10^0$. Thus, a full-disk activity cycle for coronal activity is proposed to consist of two successive normal cycles: a high-latitude activity cycle following a low-latitude activity cycle, which is illustrated with two hand-drawn uneven wide-belt lines in the figure. The green corona activity obviously shows the exist of a full-disk activity cycle.

2.3. Torsional oscillations

The sun's differential rotation has a cyclic pattern of change that is tightly correlated with the sunspot, or magnetic activity, cycle. This pattern can be described as a torsional oscillation, in which the solar rotation is periodically speeded up or slowed down in certain zones of latitude while elsewhere the rotation remains essentially steady. The zones of anomalous rotation move on the sun in wavelike fashion, keeping pace with and flanking the zones of magnetic activity. It may be an important link in the connection between the rotation and the cycle (LaBonte and Howard, 1982; Snodgrass and Howard 1985). The surface torsional pattern, and perhaps the magnetic activity as well, are only the shadows of a more potent phenomenon occurring within the convection zone (Snodgrass, 1987).

The so-called torsional oscillations, discovered by Howard and LaBonte (1980) are familiar to solar physicists as a pattern of azimuthal wind bands that appear at high latitudes a few years before the solar minimum of a normal cycle and migrating to the poles, reach the poles at the normal cycle maximum. Then they reverse to migrate toward lower latitudes to meet the zone of emerging activity of the next cycle, and continue along this zone until reaching the equator at the end of the next solar cycle (Brown and Snodgrass, 2003). Thus, a full-disk activity cycle for the solar torsional oscillations is also proposed to consist of two successive normal cycles: a high-latitude activity cycle following a low-latitude activity cycle, which is illustrated with shallow-grey uneven lines in Figure 6. The figure is originally come from the Figure 1 of Brown and Snodgrass (2003).

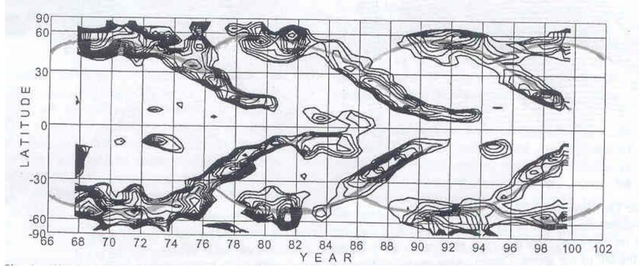

Figure 6. The positive-velocity wind band of the torsional pattern, plotted in standard form as a function of latitude and time. The contour interval is 1m/s. This figure is originally come from Brown and Snodgrass (2003), but with thick uneven lines added here to illustrate the new concept.

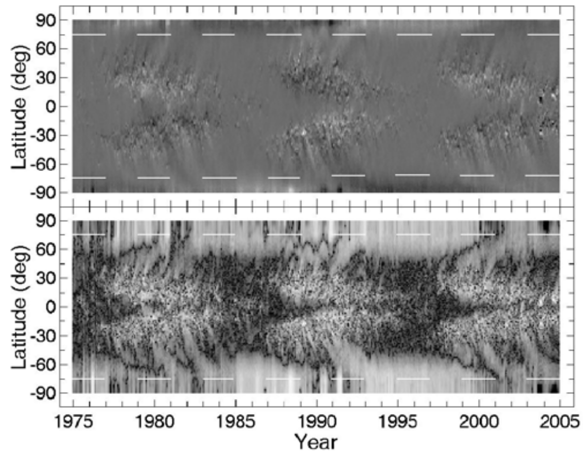

Figure 7. Longitudinally-averaged meridional migration for magnetic fields based on the original data (top) and the data after processing (bottom). In the upper figure, the white/dark areas correspond to positive/ negative polarities of the azimuthally averaged magnetic flux (adopting the same terminology as used by NSO/Kitt Peak). In the bottom figure, the white/dark areas represent high/low strengths of the absolute values of the averaged magnetic fields. The dashed lines correspond to 75^0, above which the values of the magnetic field may be unreliable, because they are radial values inferred from a longitudinal magnetograph. This figure is originally come from Minarovjech, Rusin, and Saniga (2007).

2.4. Solar surface magnetic fields

The time-latitudinal distributions of the surface magnetic fields and green corona ($FeXIV 5303\AA$) have been analyzed together by Minarovjech, Rusin, and Saniga (2007). They prepare a new synoptic chart - the processed longitudinally averaged magnetic flux - as shown in the lower part of their Figure 1, and it is shown here again as Figure 7. It can be easily seen from the figure that the boundaries (branches) between the opposite polarities of the magnetic field split off the 'longitudinally averaged magnetic field' butterfly pattern at mid-latitudes and migrate from there toward the poles (Minarovjech, Rusin, and Saniga, 2007). Comparison between the absolute values of magnetic field intensities and the green corona local maxima is shown in their Figure 3 and here again in Figure 8, and the time-varying component of the green corona and its meriodional migration correlate well with the magnetic-field distribution and their flows, as indicated in the figure. The green corona intensities are very intimately connected with the distribution of solar local magnetic flux and mimic its development over a solar cycle, and further, a direct physical coupling the photospheric magnetic fields and the green corona, discovered in the middle and low heliographic latitudes, applies well also to polar regions (Minarovjech, Rusin, and Saniga, 2007). Thus, a full-disk activity cycle for the solar surface magnetic fields is proposed to consist of two successive normal cycles as well: a high-latitude activity cycle following a low-latitude activity cycle.

A full-disk activity cycle includes the high-latitude solar activity, where the so-called magnetic polarity reversal takes place. Thus, it is easy to lead the magnetic polarity reversal into a full-disk activity cycle. Details are given as follows for a full-disk activity cycle of the surface magnetic fields.

In a full-disk activity cycle, solar magnetic activity latitudinally 'rushes to the poles', beginning from middle latitudes (about 40^0) at about a normal cycle minimum. Then during the solar low-latitude maximum phase, the polar regions are populated by magnetic elements of positive and negative polarity of almost equal numbers and of equal field strengths rendering the net fields at the poles close to zero (Lin, Varsik, Zirin, 1994). This presumably represents the polar-field reversal epoch (Sivaraman, Antia, Chitre, Makarova, 2008). With the progress of the sunspot cycle towards the minimum, the elements of one polarity outnumber those of the opposite polarity in terms of the field strengths and numbers rendering the fields at the poles predominantly of one polarity (Sivaraman, Antia, Chitre, Makarova, 2008). At the solar poles, magnetic polarity reversal takes place on both the solar hemispheres, and opposite reversals occur on the opposite hemispheres, resultingly, the new appearing magnetic polarity on a hemisphere will become the leading magnetic polarity of regions at low latitudes on the same hemisphere in the following normal cycle. For example, magnetic polarity reversal took place from the positive polarity to the negative on the north hemisphere in November 1958, and from the negative polarity to the positive on the south hemisphere during March to July 1957 (Babcock 1959), then the leading magnetic polarity is negative on the north hemisphere and positive on the south hemisphere in cycle 20. The magnetic field reversals at the northern and southern poles of the Sun are the phenomenon in the polar zones that imparts the cyclic nature on the solar activity (Makarov, Tlatov, and Callebaut, 2005). With the use of H_α synoptic charts, Makarov and Sivaraman (1989), Makarov, Tlatov, and Callebaut (2005), and Makarov, Tlatov, and Sivaraman (2001) worked out the epochs of polar field reversal over a period of 12 solar cycles from 1872 to 2001, showing that after polar field reversal, the new appearing magnetic polarity on a hemisphere will become the leading magnetic polarity of regions at low latitudes on the same hemisphere in the following normal cycle. During the course of a sunspot cycle, namely a normal low-latitude cycle, the trailing polarity field first cancels the field of opposite polarity left over from the previous sunspot cycle. After about half a sunspot cycle, the residual field has been canceled entirely and a reservoir of the new polarity begins to build up. During the next sunspot cycle the process repeats with opposite polarities, thereby completing a 22-year Hale magnetic cycle (Schrijver, DeRosa, and Title, 2002; Snodgrass, Kress, and Wilson, 2000).

It is well-known that, the polar field reversal is caused through the solar surface meridional flow (Kuker, Ruediger, and Schultz, 2001; Schrijver, 2001; Nandy and Choudhuri, 2002; Wang and Sheeley, 2003). Wang, Lean, and Sheeley (2005) used a flux transport model to simulate the evolution of the Sun's total and open magnetic flux over the last 26 solar cycles (1713-1996). In the model, polar field reversals are maintained by varying the meridional flow speed between 11 and 20 m s^{-1}, with the poleward-directed surface flow being slower during low-amplitude cycle. With the use of the National Solar Observatory (NSO)/Kitt Peak magnetic synoptic charts during Carrington rotations 1666-2007, we estimate the poleward-directed drift speeds of the magnetic flux in high-latitude region during solar maximums, which are indeed of 7-20 m s^{-1}, in agreement with the meridional flow speeds used by Wang, Lean, and Sheeley (2005).

After reaching the solar poles at about the maximum time of a normal cycle, solar magnetic activity begins to latitudinally migrate in a reverse direction, toward the equator continually till almost arriving at the solar equator, lasting for about 1.5 normal cycles. During the ~1.5 normal cycles of the equatorward migrating, solar activity latitudinally migrates to the middle latitudes at about the minimum beginning time of the following normal cycle to complete a normal cycle, but at high latitudes, and then it continues to latitudinally drift almost to the solar equator at about the minimum beginning time of the following second cycle to complete another normal cycle but at low latitudes.

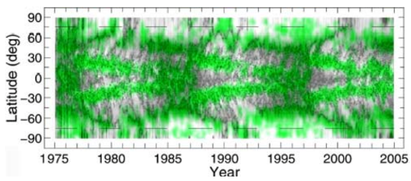

Figure 8. Meridional migrations for the magnetic fields from the bottom of Figure 7 (gray color scale) and the green corona (green color). This figure is originally come from Minarovjech, Rusin, and Saniga (2007).

3. Fine-scale characteristics of full-disk activity cycles

1. There are some small fine migration structures (subsidiary migration branches) in a full-disk activity cycle:

– Both the original magnetic field synoptic charts, provided by NSO/Kitt Peak for Carrington rotations 1625 to 2006 (years 1975-2003), and the magnetic data from the SOHO/MDI have been used to give the distribution of the longitudinally averaged magnetic flux by Minarovjech, Rusin, and Saniga (2007). They find that the "butterfly" pattern of the magnetic flux moves as a whole to the equator, with individual strips of different polarities (branches) moving to the poles at different heliographic latitudes, note that this pattern is relatively wide, being about 30^0.

– As shown in Figure 5, there is a second separation in the green-corona intensities, occurring three to four years after the appearance of the first poleward migration branch and at heliographic latitudes around 30^0-40^0 (Minarovjech, Rusin, and Saniga, 2007).

– The time-latitude distribution of the "prominence index" in the period of May 1967 to May 1996 was given to compare with the distribution of the emission in the green corona by Minarovjech, Rybansky, and Rusin (1998b). As shown in their Figure 1 (Figure 5 in this paper), there are some "small chains" in the distribution of prominences. At high latitudes, it should be quite possible that the "small chains" are subsidiary polar branches, observed for the first time by Waldmeier (1973). In the middle and low equatorial zones, "small chains" have a tendency to move towards the equator.

–There are some segments (fine structure) in the sunspot zone (Butterfly Diagram) in each of cycles 20, 21, and 22, and in both hemispheres (Ternullo, 2007).

2. When solar activity progresses into a full-disk activity cycle, it is not always in phase in the hemispheres.

– At the beginning of a full-disk activity cycle, solar activity migrates toward the poles and reaches the northern and southern poles at different times.

– The maximum time of solar activity in a normal cycle is usually different in the two hemispheres (Li et al, 2002a).

3. Solar activity is not symmetrically or evenly distributed in the northern and southern hemispheres in a full-disk activity cycle.

– Solar activity indices (sunspot number, sunspot area, flare index, and etc.) vary over the solar disk, and various activity parameters are not considered to be symmetric between the northern and southern hemispheres in a normal solar cycle (Li et al 2002b; Temmer et al., 2006).

– A north-south asymmetry for torsional oscillations is found both in the emergence of the mid-latitude traveling torsional zones for cycle 22 and in the higher contours of the traveling zones near the start of cycle 21, and the greater overall continuity of the torsional pattern can be seen for cycle 21 in the northern hemisphere (Snodgrass, 1987).

4. The velocity of the poleward migration of solar activity is in range of several to tens meters per second. It is 10 to 25 ms^{-1} for filament activity (Minarovjech, Rybansky, and Rusin, 1998b) or 4 to 29 ms^{-1} (Makarov and Sivaraman, 1989), several meters per second for the green-corona intensities (Minarovjech, Rusin, and Saniga 2007), 7 to 20 m s^{-1} for the surface magnetic fields.

4. Conclusions and Discussions

The spatial distribution of solar activity varying with time can be represented by the latitudinal migration of solar activity. With the use of the Carte Synoptique solar filament archive, the latitudinal migration of solar activity at the solar full disk is found as follows: solar activity latitudinally 'rushes to the poles' , beginning from middle latitudes (about 40^0) at about a normal cycle minimum. At the solar poles, magnetic polarity reversal takes place on both the solar hemispheres, and opposite reversals occur on the opposite hemispheres, resultingly, the new appearing magnetic polarity at high latitudes on a hemisphere will become the leading magnetic polarity of regions at low latitudes on the same hemisphere in the following normal cycle. After latitudinal drift of magnetic activity reaching the solar poles at about the maximum time of a normal cycle, solar activity begins to latitudinally migrate in a reverse direction, toward the equator continually till almost arriving at the solar equator, lasting for about 1.5 normal cycles. During the ∼1.5 normal cycles of the equatorward migrating, solar activity latitudinally migrates to the middle latitudes at about the minimum beginning time of the following normal cycle to complete a normal cycle, but at high latitudes, and then it continues to latitudinally drift almost to the solar equator at about the minimum beginning time of the following second cycle to complete the other one normal cycle but at low latitudes. Based on these latitudinal migration characteristics, a new concept, full-disk activity cycle is proposed to consist of two successive normal cycles: a high-latitude activity cycle following a low-latitude activity cycle. When a full-disk activity cycle progresses from a normal high-latitude activity cycle into a normal low-latitude activity cycle, the next full-disk one begins. Two successive full-disk magnetic activity cycles have a normal cycle overlapped in time, but are spatially separated.

Although the new concept is given through analyzing latitudinal migration of filament activity, and it is plausible to describe the cyclic behaviors of the green (Fe XIV, 5303$\AA$) corona local maxima intensities, the surface magnetic fields, and the torsional oscillations with the new concept. In the present study, some characteristics of a full-disk activity cycle are given as well: there are some small fine migration structures (subsidiary migration branches) in a full-disk activity cycle; when solar activity progresses into a full-disk activity cycle, it is not always in phase in the two hemispheres; solar activity is not symmetrically distributed in the northern and southern hemispheres in a full-disk activity cycle.

Martin and Harvey (1979) analyzed the global distribution of 'ephemeral' active regions, which live for less than a day and are approximately 10 Mm across. They demonstrate the existence of high-latitude ephemeral regions having the polarity characteristics of solar-cycle-21 active regions, but occurring as early as the maximum of cycle 20. Thus, they speculated that two solar cycles might exist on the Sun at all times, which is in agreement with the idea of the new concept.

Compared with the traditional concept of magnetic activity cycle, the new concept of full-disk activity cycle tells the cyclical evolution of the solar full-disk magnetic activity, showing how, when, and where magnetic polarity reversal takes place. Meanwhile, the new concept clearly indicates how the extended activity cycle is completely extended, and obviously, the so-called extended activity cycle is actually a part of a full-disk activity cycle.

The most prominent feature of the global circulation of the Sun is its differential rotation. Helioseismology has now revealed much more detail about rotation below the photosphere, and a summary about it was once given by Gilman (2000). As displayed in the Figure 1 of Gilman (2000), the differential rotation is essentially independent of radius through the bulk of the convection zone, from 0.74 $R_\odot$ to 0.96 $R_\odot$. Both above and below there are sharp radial shear layers, in both of which the radial gradient changes sign at *mid-latitudes* (Schou et al., 1998; Gilman, 2000; Jiang and Wang, 2005). We do not know why a new cycle proposed here begins at *mid-latitudes*, it is perhaps related with solar differential rotation. As mentioned above, at *mid-latitudes*, the radial gradient of solar differential rotation changes sign in the sharp radial shear layers. In the future, further work is required to uncover the physical mechanisms behind the concept

Based on the new concept, a preceding high-latitude cycle continually evolves into the following normal low-latitude cycle, and the latter is closely related with the former, thus, the new concept may give some clues to or offer a way for a prediction of solar activity in a normal low-latitude cycle. For example, the amplitude of each normal low-latitude cycle is found to be positively correlated with the polar field strength (averaged between the two hemispheres) at the start of the solar normal cycle (Wang, 2004), reflecting the evolution of solar activity in such a new cycle.

In summary, a full-disk activity cycle may reflect cyclic evolution of the full-disk solar activity, it unites the Hale magnetic activity cycle with the extended solar activity cycle, and cyclic behavior of the high-latitude solar activity is well connected with that of the low-latitude solar activity, which may offer a way for predictions of the low-latitude solar activity. In such a full-disk activity cycle, both the magnetic field and the flow field are evolved in a similar way, showing a close coupling of the both.

There appear to be compelling reasons for reconsidering the theoretical basis of a full-disk solar activity cycle, in order to allow two normal cycles to be in progress at all times, and it seems more suitable for a dynamo model to represent solar activity in such a full-disk magnetic cycle than that in a traditional magnetic activity cycle, because considered in the new concept are solar activity at the *whole* disk and its complete latitude migrations. In the future, the migration from the poles toward middle latitudes of the Sun should be paid more attentions in a dynamo model, besides the essential migration in 'butterfly diagrams, and the absolutely necessary 'rush to the poles'.

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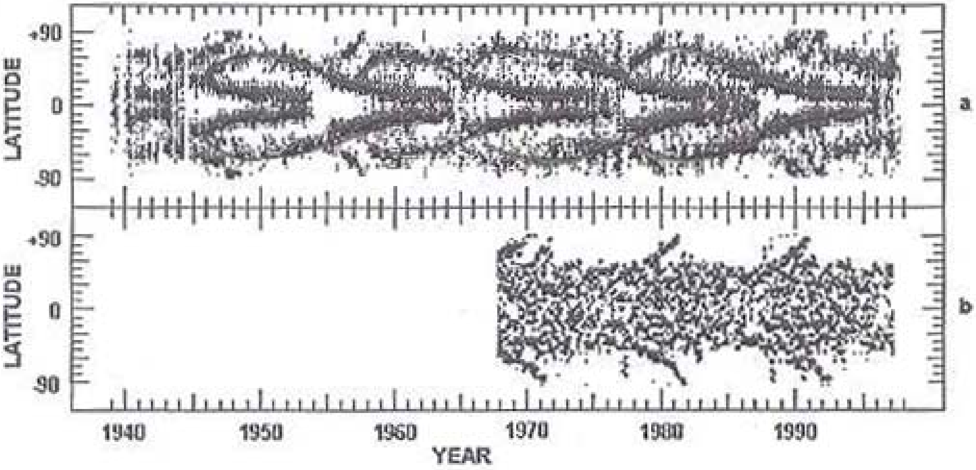

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