Latitude migration of solar filaments

K. J. Li

1 National Astronomical Observatories/Yunnan Observatory, CAS, Kunming 650011, China
2 Key Laboratory of Solar Activity, National Astronomical Observatories, Chinese Academy of Sciences

ABSTRACT
The Carte Synoptique catalogue of solar filaments from March 1919 to December 1989, corresponding to complete cycles 16 to 21 is utilized to show latitudinal migration of filaments at low latitudes (less than 50°), and the latitudinal drift of solar filaments in each hemisphere in each cycle of the time interval is compared with the corresponding drift of sunspot groups. The latitudinal drift of filaments obviously differ from that of sunspot groups. At the beginning of a cycle filaments (sunspot groups) migrate from latitudes of about 40° (28°) with a drift velocity of about 2.4 m/s (1.2 m/s) toward the solar equator, reach latitudes of about 25° (20°) 4 years later at the cycle maximum with a drift velocity of about 1.0 m/s (1.0 m/s), and halt at about 8° (8°) at the end of the cycle. When solar activity is programming into a solar cycle, the difference between the appearing latitudes of filaments and sunspot groups becomes smaller and smaller. The difference rapidly decrease in the first and last ~ 4 years of a cycle, but almost does not decrease in the ~ 4 years after the maximum time of the cycle. For filaments, the latitudinal drift velocity decreases in the first ~ 7.5 years of a cycle, but it increases in the last ~ 3.5 years of the cycle. However, for sunspot groups the drift velocity always decreases in a whole cycle. The different between the latitude drift of filaments in the northern and southern hemispheres is found not to be obvious. The latitudinal drift velocity of filaments slightly differs from each other in the northern and southern hemispheres in a cycle. The physical implication behind the latitudinal drift of filaments is explored.

Key words: Sun: activity– Sun: filaments – Methods: data analysis

1 INTRODUCTION
It is widely believed that the Sun’s magnetic field is generated by a magnetic dynamo within the Sun. Solar dynamo models demonstrate that the solar activity cycle displays a recycling of the two main components of the Sun’s magnetic field (Parker 1955): the poloidal and toroidal components. The solar meridional flow, the flow of material in the meridional plane from the solar Equator towards the Sun’s poles at the surface and from the poles towards the Equator deep inside the Sun to carry the dynamo wave towards the Equator, should play an important role in the Sun’s magnetic dynamo (Parker 1987; Choudhuri, Schussler, & Dikpati 1995; Durney 1995; Hathaway et al. 2003; Charbonneau 2007). Propagation of the toroidal field wave at the base of the solar convection zone is believed to manifest itself on the surface as the migration of the sunspot activity belt toward the Equator (the so-called butterfly diagrams), (Hathaway et al. 2003). It is helpful to investigate the latitude migration of sunspot activity for understanding the Sun’s magnetic dynamo. Hathaway et al. (2003) examined the drift of the centroid of the sunspot area toward the Equator in each hemisphere from 1874 to 2002 and found that the drift rate slows as the centroid approaches the equator, which was also found early by Li, Yun, & Gu (2001) and Li et al. (2002). Hathaway et al. (2003) compared the drift rate at sunspot cycle maximum with the period of each cycle for each hemisphere and found a highly significant anti-correlation: hemispheres with faster drift rates have shorter periods. These observations are consistent with a meridional counterflow deep within the Sun as the primary driver of the migration toward the Equator and the period associated with the sunspot cycle (Hathaway et al. 2003).

Solar filaments have been observed since the invention of the spectrohelioscope (Tandberg-Hanssen 1995; Heinzel 2007). They are prominences projected against the solar disk, displaying themselves as cool and dense “clouds in the solar corona” (Kippenheuer 1953; Tandberg-Hanssen 1995, 1998). The shape, fine structure, dynamics, and physical properties of solar filaments vary one to another in the wide range of values (Hundhausen, Hansen, & Hansen 1981; Illing & Hundhausen 1986; Heinzel 2007; Lin, Martin, & Engvold 2007).
It is always interesting to study the general trend of the solar activity by using statistical data such as the “Cartes synoptiques” of solar filaments (dAzambuja 1923; Mouradian 1998a, 1998b). Mein and Ribes (1990) used the “Cartes synoptiques” and evidenced the meridional circulation and the existence of convective giant cells by following the filaments used as indicators of magnetic tracers, and it is very important to understand how the solar dynamo works and therefore the existence of magnetic solar cycles. The phenomenon “rush to the pole” has been confirmed through studying the migration of polar filaments towards the pole at the beginning of solar cycles by many authors (Topka et al. 1982; Makarov & Sivaraman 1989; Mouradian & Soru-Escaut 1994; Shimojo et al. 2006; Li et al. 2008). Solar filaments are distributed on the whole solar surface, from the solar equator to the poles, and during the whole period of a sunspot cycle (Li et al. 2007). Such a distribution is not random due to that solar filaments are closely connected with sites of magnetic fields on the solar disk (Martin 1990). The north-south asymmetry of filaments in solar cycles 16–21 is investigated with the use of the “Cartes synoptiques” (Li et al. 2010), and filament activity is found regularly dominated in each of cycles 16–21 in the same hemisphere as that inferred by sunspot activity (Li, Schmieder, & Li 1998; Li et al. 2002).

Filaments’ feature to occur in all heliospheric latitudes and to outline the boundary between magnetic fields with different polarities makes themselves suitable tracers for the large-scale pattern of the weak background magnetic field of the Sun (McIntosh 1972; Low 1982; Minarovjech et al. 1998a, 1998b). On the other hand, study of the occurrence of filaments can help us to better understand distribution of these fields on the solar disk, their development within a solar cycle, and especially, provide useful insights into the nature of the Sun’s magnetic field (Rusin et al. 1998, 2000; Mouradian & Soru-Escaut 1994). Study on filaments (prominences) through both individual events and statistical analyses are of importance, and some progresses on the knowledge of filaments have been achieved up to now, including both the morphological aspects and theoretical scenarios of filaments (Anzer 2002; Engvold 2004; Heinzel 2007; Schmieder et al. 2007, 2009; Labrosse et al. 2010; Mackay et al. 2010; and references therein). In this paper, we will investigate the latitude migration of solar filaments, focusing on their statistical properties, and further compare with that of sunspots.

2 OBSERVATIONS, ANALYSES, AND RESULTS

The different solar activity time series analyzed in our study are:

- The first one: the Carte Synoptique solar filaments archive, namely the catalogue of solar filaments, observed at Meudon from March 1919 to December 1989, corresponding to Carrington solar rotation numbers 876 to 1823, which can be accessed via the NOAA’s web site. The observations of filaments were mainly shown in maps drawn at Meudon, which were a synthetic representation of solar active regions and filaments (dAzambuja 1923), and the Meudon maps were complemented with tables of solar active regions and filaments (for details, see Mouradian 1998a, 1998b). The World Data Center A (WDC-A) for Solar-Terrestrial Physics has digitized the Carte Synoptiques (Coffey & Hanchett 1998).

- The second: the observational data of sunspot groups, which come from the augmented Royal Greenwich Observatory (RGO) data set (the RGO data set extends from 1874 to 1976; thereafter, the observations are from NOAA) and are available at NASA’s Web site. The data set comprises sunspot groups during the period of May 1874 to March 2009 and will be updated monthly.

The normal solar activity is usually applied to solar active events whose latitudes are lower than 50° (Sakurai 1998; Li et al. 2008), thus used here are filaments whose latitudes are lower than 50°. Fig. 1 shows both filaments’ and sunspot groups’ positions versus time, namely the familiar butterfly diagrams. The figure indicates how the bands of filaments (sunspot groups) drift toward the equator and how successive cycles overlap during the minimum time of a sunspot cycle. As the figure displays, filaments are distributed themselves at higher latitudes and within a wider latitude band at a certain time epoch than sunspot groups do. It is difficult to accurately divide sunspot groups into solar cycles to which they really belong (Harvey 1992) and even more difficult to divide filaments into solar cycles. A criterion for how a solar activity event can be assigned to an active cycle was once proposed by Li, Yun, & Gu (2001). Here, according to the criterion and with the use of the Carte Synoptique solar filament archive, filaments are divided into individual butterflies. Then monthly mean latitudes of filaments in the northern and southern hemispheres are calculated and plotted in Figs. 2 and 3, respectively. For sunspot activity (sunspot groups or sunspot areas), a second-order polynomial curve could give a satisfactory fit to the monthly mean latitudes of sunspot activity (Li Yun, & Gu 2001; Hathaway et al. 2003), but for filament activity, it is a third-order not second-order polynomial curve that can give a satisfactory fit to the monthly mean latitudes of filaments respectively in the northern and southern hemispheres, and the fitting curves are also given in Figs. 2 and 3. In order to compare the latitude drift of filaments with that of sunspot groups, the best fit to the monthly mean latitudes of sunspot groups respectively in the northern and southern hemispheres at each month of a cycle, but the difference between the two becomes smaller and smaller with solar activity of a cycle programming into the cycle.

In order to compare the latitude drift of filaments re-
respectively in the northern and southern hemispheres, the unsigned monthly mean latitude of filaments is plotted in Fig. 4. As the figure shows, the difference between the two is not obvious in a cycle for cycles 16 to 21 except cycle 19.

The unsigned monthly mean latitudes of filaments for all of the 6 solar cycles are plotted together in a cycle in Fig. 5 by using the time measured relative to the maximum times of their corresponding cycles. Also given in the figure is a third-order polynomial fit to these points. As the figure shows, in a statistical view filaments appear at latitudes of about 40$^\circ$ at the beginning of a cycle, move toward the equator, reaching 25$^\circ$ some 4 years later at the cycle maximum, and then halting at about 8$^\circ$ at the end of the cycle.

Similarly, the unsigned monthly mean latitudes of sunspot groups in the 6 solar cycles are plotted together in a cycle in Fig. 5 using the time measured relative to the maximum times of their corresponding cycles. A second-order polynomial is used to fit these points, which is also given in the figure. Then we know the difference between the two fits varying with the time measured relative to cycle maximum time, which is shown in the bottom panel of the figure as well. Filaments appear at much higher latitudes than sunspot groups do at the beginning of a cycle; when solar activity is programming into the cycle, the difference between the appearing latitudes of filaments and sunspot groups becomes smaller and smaller. The difference rapidly decrease in both the first and last ~4 years of a cycle, but hardly decrease in the ~4 years after the maximum time of the cycle.

Shown in Figs. 6 and 7 are the latitudinal drift velocity of filaments varying with time in a cycle in the northern and southern hemispheres, respectively. The latitudinal drift velocity ranges within about 1.5 to 3.5 m/s in a cycle, and it slightly differs from each other in the northern and southern hemispheres in a cycle. Also displayed in the two figures is the latitudinal drift velocity of sunspot groups varying with time in each of cycles 16 to 21 and in the northern and southern hemispheres, respectively. As the two figures show, the drift velocity linearly decreases with time for sunspot groups in both the northern and southern hemispheres in each of cycles 16 to 21, but for filaments it firstly decreases and then increases in a cycle. Hathaway et al. (2003) investigated the drift of the centroid of the sunspot area toward the equator in each of the northern and southern hemispheres from 1874 to 2002 and found that the drift rate slows as the centroid approaches the equator except cycle 21 in the northern hemisphere. Fig. 8 shows the general feature of the latitudinal drift velocity in a cycle for each hemisphere and for each cycle is plotted together by using the time measured relative to the maximum time of that cycle (see Fig. 5). At the beginning of a cycle filaments (sunspot groups) migrate from latitudes of about 40$^\circ$ with a drift velocity of about 2.4 m/s (1.2 m/s) toward the solar equator, reaching latitudes of about 25$^\circ$ (20$^\circ$) 4 years later at the cycle maximum with a drift velocity of about 1.0 m/s (1.0 m/s), and halting at about 8$^\circ$ at the end of the cycle. For filaments the latitudinal drift velocity decreases in the first ∼7.5 years of a cycle, but it surprisingly increases in the last ∼3.5 years of the cycle.

The latitudinal drift velocity varying with latitude is plotted in Fig. 9 respectively for filaments and sunspot groups in each hemisphere in each cycle. For filaments, the drift velocity decreases in a cycle with latitudes until that they reach latitudes of about 20$^\circ$, after then it increases with latitudes until the ending of the cycle. For sunspot groups, drift velocity decreases with latitudes in each hemisphere in each of cycles 16 to 21 without any exception.

The latitudinal drift acceleration varying with time is plotted in Fig. 10 respectively for filaments and sunspot groups when the unsigned monthly mean latitude of filaments and sunspot groups for each hemisphere and for each cycle is plotted together by using the time measured relative to the maximum time of that cycle (see Fig. 5). For sunspot groups, the acceleration is a constant, about -0.2 (degrees/s$^2$) in a cycle, but for filaments, the acceleration linearly increase from about -1.2 (degrees/s$^2$) at the beginning of a cycle to about 0.4 (degrees/s$^2$) at the ending of the cycle.

3 CONCLUSIONS AND DISCUSSIONS

Shimojo et al. (2006) showed well the comparison of prominence activities and the butterfly diagram obtained from synoptic Carrington maps of Kitt Peak magnetograms. The drift of prominences follows the polar ward motion of the magnetic flux until the reversal of the polar polarity. This is well visible for latitudes 30$^\circ$ to 90$^\circ$. Latitudinal migration of filament activity over the solar full disk was qualitatively introduced by Li et al. (2008). In the present study, the catalogue of solar filaments from Carrington solar rotation numbers 876 to 1823, corresponding to complete cycles 16 to 21 is used to investigate latitudinal migration of filaments at low latitudes (less than 50$^\circ$), and the latitudinal drift of solar filaments in each hemisphere in each cycle of the time interval is compared with that of sunspot groups in the same time interval. The latitudinal drift of filaments obviously differ from that of sunspot groups: for sunspot groups a second-order polynomial can give a satisfactory description of the latitudinal drift in a cycle, but for filaments it is a third-order not second-order polynomial curve that can give a satisfactory description. At the beginning of a cycle filaments migrate from latitudes of about 40$^\circ$ with a drift velocity of about 2.4 m/s toward the solar equator, reaching latitudes of about 25$^\circ$ 4 year later at the cycle maximum with a drift velocity of about 1.0 m/s, and halting at about 8$^\circ$ at the end of the cycle. Compared with filaments, sunspot groups appear at much lower latitudes at the beginning of a cycle; when solar activity is programming into a cycle, the difference between the appearing latitudes of filaments and sunspot groups becomes smaller and smaller. The difference rapidly decrease in the first and last ~4 years of a cycle, but almost does not decrease in the ~4 years after the maximum time of the cycle.

The reasons why filaments statistically appear at higher latitudes than sunspot groups are suggested: (1) The decay of old sunspots usually diffuses towards the solar poles (the so-called “rush to the pole”), an emergence of new sunspots at a certain latitude acts with the decay component of old sunspots, which should form a filament (or filaments) at a higher latitude. (2) The emergences of the magnetic field
usually form sunspots, but sometimes they form ephemeral regions (tiny “pores”), do not form sunspots. Ephemeral regions statistically locate at higher latitudes than sunspots (Harvey 1992). Filaments, relating with these ephemeral regions should thus appear at higher latitudes. And (3) the background poloidal magnetic field should be more easily observed at high latitudes. The toroidal magnetic field of sunspot groups at a latitude should act with the background poloidal magnetic field to form filaments at a higher latitude.

For filaments, the drift velocity decreases in the first ∼ 7.5 years of a cycle, but it surprisingly increases in the last ∼ 3.5 years of the cycle. However, for sunspot groups the drift velocity always decreases in a whole cycle. The increase of the latitudinal drift velocity of filaments at low latitudes should possibly imply the existence of interaction between the paired wings of a butterfly, such as cross-hemispheric coupling (Charbonneau 2007). In fact, for filaments the paired wings of a butterfly are hardly distinguished from each other near the equator (see Fig. 1). Although sunspots are hardly observed near the equator, filaments can be observed to cross the equator, known as transequatorial filaments (Wang 2002), also supporting the implication. The latitudinal drift acceleration of filaments changes from the negative sign during the first about 7.5 years of a cycle to the positive sign during the last about 3.5 years of the cycle, implying that the mechanism driving filaments to drift should be different in the two time intervals of a cycle.

The different between the latitude drift of filaments in the northern and southern hemispheres is found not obvious in a cycle for cycles 16 to 21 except cycle 19. The latitudinal drift velocity of filaments slightly differs from each other in the northern and southern hemispheres in a cycle.

Filaments are large magnetic structures in the corona, but sunspots are the emergence of strong magnetic field from the Sun’s interior to the photosphere and chromosphere. The difference between the latitudinal drift of filaments and sunspots implies that: (1) filaments should be related with weak background magnetic field sometimes; (2) to what extent does the latitudinal drift of sunspots reflect the meridional flow below the solar atmosphere? it is an open issue.

In this study, latitudinal drifts are determined from the tabulated heliocentric positions of the centroids of sunspots and filaments. Centroids from sunspot images are a good measure of sunspot position because the dark spots are compact and clearly visible in white light images. In contrast, filaments are long sinuous structures on the disk, their heliocentric positions are thus less accurately determined than sunspots’ positions. Filaments are known to tend to be aligned more east-west on the disk, this should reduce the contest of the determinations of their latitudes. Average of filaments’ and sunspots’ latitudes over one month is used in this study, this should further reduce the contest coming from the determinations of filaments’ latitudes. In this study, we investigate the latitudinal drift of filaments in a whole solar cycle, not focusing on individual monthly averages of filaments’ latitudes, the effect of the contest on our findings should be reduce further again. Thus, the influence of the contest in the determinations of filaments’ positions should be very small and can be neglected.

One point should be emphasized. We concentrate on the behaviour of a particular class of filament. We study only the active region (AR) or intermediate class filaments (see the classification by MacKay et al. 2010). The fact that filament gravity centers are located higher than the AR means that filaments are preferentially located at the periphery of AR. Therefore, the large drift of filaments located at latitudes around 40º possibly compared to the drift of sunspots at the beginning of the solar cycle could in fact reflects the fact that there is still a mixture of polar crown filaments migrating towards the pole and low latitude filaments following AR.

ACKNOWLEDGMENTS

We thank the referee for his/her careful reading of the manuscript and constructive comments, which improved the original version. Data used here are all downloaded from web sites. The authors would like to express their deep thanks to the staffs of these web site. The work is supported by the NSFC under Grants 10583032, 10921303, and 40636031, the National Key Research Science Foundation (2006CB806303), and the Chinese Academy of Sciences.

REFERENCES

Anzer, U., 2002, in Proc. 10th Solar Physics Meeting, ESA SP-506, 389
Charbonneau P., 2007, Advances in Space Research, 40, 899
Choudhuri A. R., Schussler M., Dikpati M., 1995, &A, 303, L29
Colley H. E., Hanchett C. D., 1998, ASP Conference Series, 150, 488
dAzambuja L., 1923, Comptes Rendus, 176, 950
Durney B. R., 1995, Sol. Phys., 160, 213
Engvold O., 2004, in Proc. IAU Symp. No. 223, A.V. Stepanov & E. Benevolenskaya (eds.), Cambridge Univ. Press, Cambridge, UK, 187
Harvey K. L., 1992, ASP Conf. Ser., 27, 335
Hathaway D. H., Nandy D., Wilson R. M., Reichmann E. J., 2003, ApJ, 589, 665
Hundhausen A. J., Hansen R. T., Hansen S. F., 1981, Journal of Geophysical Research, 86, 2079
Illing R. M. E., Hundhausen A. J., 1986, Journal of Geophysical Research 91, 10951
Kiepenheuer K. O., 1953, in G. P. Kuiper (ed.), The Sun, University of Chicago Press, Chicago, 322
Labrosse N., Heinzel P., Vial J. C., Kucera T., Parenti S., Gunar S., Schmieder B., Kilper G, 2010, Space Science Reviews, in press
Li K. J., Li Q. X., Gao P. X., Mu J., Chen H. D., Su T. W., 2007, J. Astrophys. Astr., 28, 147
Li K. J., Li Q. X., Gao P. X., Shi X. J., 2008, J. Geophys. Res., 113, A11108, doi:10.1029/2007JA012846
Li K. J., Liang H. F., Yun H. S., Gu X. M., 2002, Sol. Phys., 205, 361
Li K. J., Liu X. H., Gao P. X., Zhan L.S., 2010, New Astronomy, 15, 346
Li K. J., Schmieder, B., Li, Q. S., 1998, &A Suppl. Ser., 131, 99
Li K. J., Wang, J. X., Xiong S. Y., Liang H. F., Yun H. S., Gu X. M., 2002, &A 383, 648
Li K. J., Yun H. S., Gu X. M., 2001, AJ, 122, 2115
Lin Y., Martin S. F., Engvold O., 2008, ASP Conference Series, 383, 235
Lopez Ariste A., Aulanier G., 2007, in P. Heinzel, I. Dorotovic, R. J. Rutten (eds.), The Physics of Chromospheric Plasmas, ASP Conf. Ser. 368, 291
Latitude migration of solar filaments

Low B. C., 1982, Solar Phys., 75, 119
Mackay D. H., Karpen J. T., Ballester J. L., Schmieder, B., Aulanier G., 2010, Space Science Reviews, in press
Makarov V. I., Sivaraman K. R., 1989, Sol. Phys., 123, 367
Martin S. F., 1990, IAUS, 138, 129
McIntosh P. S., 1972, Rev. Geophys. Space Sci., 10, 837
Mein P., Ribes E., 1990, A&A, 227, 577
Minarovjech M., Rybansky M., Rusin V., 1998a, Solar Phys., 177, 357
Minarovjech M., Rybansky M., Rusin V., 1998b, ASP Conference Series, 150, 484
Mouradian Z., 1998a, in K. S. Balasubramaniam, J. W. Harvey, and D. M. Rabin (eds.), Synoptic solar physics, ASP Conf. Ser. 140, 181
Mouradian Z., 1998b, in K. S. Balasubramaniam, J. W. Harvey, and D. M. Rabin (eds.), Synoptic solar physics, ASP Conf. Ser. 140, 197
Mouradian Z., Soru-Escaut I., 1994, A&A, 290, 279
Parker, E. N. 1955, ApJ, 122, 293
Parker E. N., 1987, Sol. Phys., 110, 11
Rusin V., Minarovjech M., Rybansky M., 2000, J. Astrophys. Astr., 21, 201
Rusin V., Rybansky M., Minarovjech M., 1998, ASP Conference Series, 140, 353
Sakurai T., 1998, ASP Conf. Ser., 140, 483
Schmeider B., Aulanier G., Lopez Ariste A., 2007, ASP Conference Series, K. Shibata, S. Nagata, T. Sakurai (eds.), 369, 137
Schmeider B., Aulanier G., Torok T., 2009, IAU Symposium, 257, 223
Shimojo M., Yokoyama T., Asai A., Nakajima H., Shibasaki K., 2006, Publ. Astron. Soc. Japan, 58, 85
Tandberg-hanssen E., 1995, The nature of solar prominences, Kluwer Acad. Publ., Dordrecht, Holland.
Tandberg-hanssen E., 1998, ASP Conference Series, 150, 11
Topka K., Moore R., La Bonte B. J., Howard R., 1982, Sol. Phys., 79, 231
Wang J., 2002, In Henoux, J.C., Fang, C., Vilmer, N. (eds.) Understanding active phenomena: progress and perspectives the 2nd French-Chinese Meeting on Solar Physics, International Scientific Publishers and World Publishing Corporation Press, Beijing, 145

This paper has been typeset from a \TeX/\LaTeX file prepared by the author.
Figure 1: Butterfly diagrams of filaments (green dots) and sunspot groups (red dots) from March 1919 to December 1989.
Figure 2 The monthly mean latitudes (crosses) of filaments in the northern hemisphere in cycles 16 to 21 and their corresponding third-order polynomial fits (the thick solid lines). The thick dashed lines are the second-order polynomial fits of the monthly mean latitudes of sunspot groups in the northern hemisphere.
Figure 3 The monthly mean latitudes (crosses) of filaments in the southern hemisphere in cycles 16 to 21 and their corresponding third-order polynomial fits (the thick solid lines). The thick dashed lines are the second-order polynomial fits of the monthly mean latitudes of sunspot groups in the southern hemisphere.
Figure 4 The unsigned monthly mean latitude of filaments respectively in the northern (the solid lines) and southern (the dashed lines) hemispheres in a cycle for cycles 16 to 21.
Figure 5 The top panel: latitude of filaments vs. time relative to the time of sunspot cycle maximum. The unsigned monthly mean latitude of filaments for each hemisphere and for each cycle is plotted as an individual dot by using the time measured relative to the maximum time of that cycle. A third-order polynomial fit to these points is shown by the thick solid line. Similarly, the unsigned monthly mean latitude of sunspot groups for each hemisphere and for each cycle is plotted as an individual dot by using the time measured relative to the maximum time of that cycle, and a second-order polynomial (the thick dashed line) is used to fit these points. The bottom panel: the different between the thick solid and dashed lines.
Figure 6. The latitudinal drift velocity respectively for filaments (the thick solid lines) and sunspot groups (the thick dashed lines) varying with time in the northern hemisphere in each of cycles 16 to 21. The vertical thin dashed and solid lines mark the minimum and maximum times, respectively.
Figure 7 The latitudinal drift velocity respectively for filaments (the thick solid lines) and sunspot groups (the thick dashed lines) varying with time in the southern hemisphere in each of cycles 16 to 21. The vertical thin dashed and solid lines mark the minimum and maximum times, respectively.
Figure 8 The general feature of the latitudinal drift velocity in a cycle respectively for filaments (the thick solid line) and sunspot groups (the thick dashed line) when the unsigned monthly mean latitude of filaments and sunspot groups for each hemisphere and for each cycle is plotted together by using the time measured relative to the maximum time of that cycle (see Figure 5).
Figure 9 Drift velocity varying with latitude respectively for filaments (the top panel) and sunspot groups (the bottom panel) in each hemisphere in each cycle. The dashed lines is for sunspot groups in the northern hemisphere in cycle 21.
Figure 10 Latitudinal drift acceleration varying with time respectively for filaments (the thick solid line) and sunspot groups (the thick dashed line) when the unsigned monthly mean latitude of filaments and sunspot groups for each hemisphere and for each cycle is plotted together by using the time measured relative to the maximum time of that cycle (see Figure 5).