Solar Cycle Evolution of Filaments over a Century: Investigations with the Meudon and McIntosh Hand-drawn Archives

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Received 2021 April 18; revised 2021 June 4; accepted 2021 June 6; published 2021 October 1

Abstract

Hand-drawn synoptic maps from the Meudon Observatory (1919 onwards) and the McIntosh archive (1967 onwards) are two important sources of long-term, manually recorded filament observations. In this study, we calibrate the Meudon maps and subsequently identify filaments through an automated method. We extract physical parameters from this filament database and perform a comparative study of their long-term evolution focusing on the cotemporal period of the McIntosh and Meudon observations. The spatiotemporal evolution of filaments manifests in the form of a filament butterfly diagram, further indicating that they are intimately related to the large-scale solar cycle. Physical descriptors such as the number and length of filaments, which are tracers of the solar surface magnetic field, have cycles which are phase locked with the ∼11 yr sunspot cycle. The tilt-angle distribution of filaments—both near to or distant from active region locations—indicates that their origin is due to either large-scale surface magnetic field or inter-active-region field evolution. This study paves the way for constructing a composite series of hand-drawn filament data with minimal gaps stretching over the time span of solar filament observations up to a century. On the one hand, this would serve as a useful constraint for models of magnetic field emergence and evolution on the Sun’s surface over multiple solar cycles, and on the other hand, this filament database may be used to guide the reconstruction of filament/prominence associated eruptive events before the space age.

Unified Astronomy Thesaurus concepts: Solar cycle (1487); Solar filaments (1495); Solar activity (1475)

1. Introduction

Filaments are dark, thin, elongated structures on the solar disk. The same structures appear bright when seen above the limb and are called prominences for historical reasons. Filaments are dense, cool, plasma structures suspended in the solar corona. Filament eruptions often produce coronal mass ejection (CMEs) which create hazardous space weather (Gilbert et al. 2000; Gopalswamy et al. 2003; Jing et al. 2004; Sinha et al. 2019). So, the theoretical and observational study of filaments is important for space weather. Though filaments form in the lower solar atmosphere, they are related to magnetic flux emergence and evolution on the solar surface and hence reveal valuable information about the large-scale evolution of solar magnetic fields and the sunspot cycle. Filaments always form over polarity inversion lines (PILs; McIntosh 1972; Makarov et al. 1983; Martin 1998), the line separating two oppositely signed magnetic patches on the solar surface. Karachik & Pevtsov (2014) studied the criteria for the formation of the filaments over a PIL. Depending on the position of the filaments in the solar disk they are divided into different categories (D’Azambuja 1923, 1928, 1948) namely active region filaments, quiescent region filaments, and polar filaments. Martin et al. (1994) categorized filaments as dextral and sinistral by their chiral properties. They reported that the northern hemisphere was dominated by dextral filaments whereas the southern hemisphere was dominated by sinistral filaments (Priest et al. 1996; Pevtsov et al. 2003; Bernasconi et al. 2005).

Different features on the Sun are manifestations of solar magnetic field distribution and are crucial in gauging solar magnetic field evolution in the past, before direct measurement of the large-scale solar magnetic fields became possible following the invention of the magnetograph. Solar filaments are special as they appear across latitudes depending on the phase of the solar cycle, and studies indicate the importance of their long-term evolution for illuminating the polar field buildup process (Chatterjee et al. 2017, 2020; Mazumder et al. 2018; Xu et al. 2021). There are several studies of the automated and semiautomated detection of filaments from solar images (Bernasconi et al. 2005; Fuller et al. 2005; Aboudarham et al. 2007; Yuan et al. 2011; Hao et al. 2013; Schuh et al. 2014; Hao et al. 2015) and synoptic maps (Chatterjee et al. 2017; Webb et al. 2017). However, a historically significant effort has been made to detect and produce catalogs of solar features such as sunspots, plages, and filaments with the manual intervention of experienced human operators (Ravindra et al. 2020). Careful evaluation of these enables us to extract useful information and make a composite of different manual catalogs through the comparison of results at the overlapping period.

The McIntosh archive is one such hand-drawn archive that contains spatial information about sunspots, plages, filaments, PILs, and coronal holes. Mazumder et al. (2018) performed a detailed analysis of the filaments’ properties from McIntosh hand-drawn archive and found that the filaments are uniformly distributed in longitude in the Sun. However, they are not uniform in latitude. The latitudinal distribution of filaments shows a bimodal nature with two peaks between 10° and 30° (Hao et al. 2015; Mazumder et al. 2018). The temporal variation of the latitudinal distribution of filaments renders a butterfly pattern (D’Azambuja 1948; Mouradian & Soru-Escaut 1994; Hao et al. 2015; Tlatov et al. 2016; Mazumder et al. 2018) with a much wider distribution in latitude (−80° to 80°).
corroborate hand-drawn observational records by different observers, and on the other hand, allows us to check for consistency in the long-term spatiotemporal evolution of filament properties. We describe the data sets used for this study in Section 2 and illustrate the calibration and detection methods in Sections 3 and 4, respectively. We present and discuss the results in Section 7 and conclude in Section 9.

2. Hand-drawn Data Sources

2.1. Meudon Synoptic Maps

Meudon Observatory in France has archived a large set of hand-drawn synoptic maps spanning the period 1919–2003 (Mouradian & Soru-Escart 1994; Mouradian 1998; Aboudarham & Renié 2020). They depict different magnetic structures such as sunspots, plages, and filaments. This data set currently stands as among one of the largest and oldest historical filament archives. Though a filament catalog containing filament locations and labels is available from the Observatory, a detailed study of filament morphological parameters requires segmentation of the filaments. The upper-left panel of Figure 1 shows a representative Carrington map from the Meudon database. The rightmost panel of Figure 1 is the histogram of available observation days in Meudon data.

2.2. McIntosh Synoptic Maps

Patrick McIntosh, from NOAA’s Space Environment Center at Boulder, created an archive of hand-drawn Carrington maps from 1967 April to 2009 July using both satellite- and ground-based observations available at that time. These maps were then scanned, digitized, and archived by NOAA/NCEI and made available both as images and in “fits” format by the McIntosh Archive project (a Boston College/NOAA/NCAR collaboration, funded by the NSF). The Carrington maps in this archive contain filaments, PILs, sunspots, plages, and coronal holes. The data cover solar cycles 20–23 (from 1967 April to 2009 July) with three data gaps: one from 1974 June to 1978 July, another from 1991 October to 1994 January, and the last one from 1994 April to 1996 May. We have used level 3 “fits” files from this archive for our study. The bottom-left panel of Figure 1 shows a representative Carrington map from the McIntosh Archive. The middle panel of Figure 1 is the histogram of available observation days in the McIntosh data.

3. Data Calibration

Scanned, hand-drawn, synoptic maps (Tlatov et al. 2016) from Meudon Observatory come in different sizes, origins, and orientations. Thus, before filament detection the maps need to be brought to the same origin, orientation, and pixel scale. The calibration procedure is described in detail below:

1. We convert all the scanned Meudon maps (Figure 2(a)) in jpeg format to binary maps converting all the pixels lying below intensity 200 to 1’s and rest to 0’s. The 1’s include the grids, filaments, and plages present in original maps.
2. To separate the grids from the rest of the regions, we morphologically erode the binary images (Sonka et al. 2014) three times and subsequently dilate them three times.

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6. Available at http://bass2000.obspm.fr/lastsynmap.php.
7. https://www2.hao.ucar.edu/mcintosh-archive/four-cycles-solar-synoptic-maps
with horizontal and vertical structure functions having sizes $1/80$ times the image $x$-dimension. The repeated erosion and dilation with the horizontal and vertical structure functions separates the horizontal and vertical grids, respectively, from the rest of the images. A combined map of vertical and horizontal grids is shown in Figure 2(b).

3. From one of the horizontal grids we calculate the tilts of the maps and subsequently derotate the maps to make the equator horizontal.

4. After rotation correction, we calculate the median $x$-coordinates from the leftmost and rightmost vertical grids. We also calculate the median $y$-coordinates from the bottom-most and top-most horizontal grids. Through these $x$- and $y$-coordinates, we crop a rectangular region of all the maps and rebin them to the same size of 400 pixels ($y$) $\times$ 800 pixels ($x$) as depicted in Figure 2(c).

We have made all the gray-scale and colored calibrated images publicly available on GitHub$^8$ and Zenodo: doi:10.5281/zenodo.4919528.

### 4. Filament Detection

Filaments in Meudon maps are recorded with and without color for the rotations after and before 1823, respectively. We apply four different automated techniques to detect the filaments from four different ranges of Carrington rotations (CRs) as described below.

#### 4.1. Rotations 876–1823

1. We perform smoothing on the grid regions (detected from calibration steps) with a $5 \times 5$ median filter and replace all pixels lying above an intensity of 160 in the calibrated maps (Figure 3(a)) with value of 255. This step retains regions with a low-enough intensity, including filaments (Figure 3(b)).

2. We perform a gray-scale morphological opening on the Step 1 image to join the hatched patterns inside filaments and create continuous structures (Figure 3(c)).

3. We apply an intensity threshold of $(\text{median} - 1.5\sigma)$ producing a segmented image of filaments and plages (Figure 3(d)). $\sigma$ stands for the standard deviation of the entire Step 2 image (Figure 3(c)).

4. We perform morphological opening to remove all the elongated regions (i.e., filaments) with a kernel width of the typical filament thickness. This step results in an image containing plages (Figure 3(e)).

5. Subtracting the Step 4 image from the Step 3 image, and subsequently retaining the connected regions of an area greater than 20 pixels and regions within plage regions with an intensity less than $(\text{median} - \sigma)$ produces the final filament-segmented image (Figure 3(f)). Here the median

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$^8$ Available at https://github.com/rakesh-mazumder/calibrated-meudon-maps.
and standard deviation ($\sigma$) are calculated over individual plage regions in the Step 2 image (Figure 3(c)).

Through the above detection method we detect a total 66,253 filaments from 948 Carrington maps (rotations 876–1823) available as black and white images in the Meudon database during the period 1919–1989.

4.2. Rotations 1824–1853

To detect the filaments in this rotation regime, we extract the pixels having intensity 4 (Figure 4(a)). Subsequently, we fill those filaments found through morphological closing with a 5 × 5 kernel to produce the final filament-segmented image (Figure 4(b)).

4.3. Rotations 1931–1992

Filament information for this range of rotations is presented in three different pixel values, 1, 2, and 3. By equating the calibrated image (Figure 4(c)) to values of 2 and 3 we find most of the filament pixels. We extract the rest of the filament pixels by equating the calibrated image to a value of 1 and filtering out areas less than or equal to 5 pixels. This step is necessary as filtering with just the intensity value also results in grid locations. We subsequently fill those filament structures through morphological closing with a 5 × 5 kernel to produce a final filament-segmented image (Figure 4(d)).

4.4. Rotations 1993–2008

The extraction of filaments in this rotation regime is quite straightforward. We extract the green color plane from the calibrated image (Figure 4(e)). From the green color plane, we extract pixel locations having an intensity value of 153. We then fill those regions through morphological closing with a 5 × 5 kernel to produce the final filament-segmented image (Figure 4(f)).

We extract a total of 22,065 filaments from 105 Carrington maps (rotations 1824–2008) available as color images in the Meudon database during the time period 1989–2003. Thus we extract 83,318 filaments in total from 1053 Carrington maps (rotations 867–2008).

All Carrington maps in the McIntosh archive, being digitally color coded, provide a straightforward way to extract filaments, as presented in Mazumder et al. (2018).

In Figure 5 we plot a Carrington map with a detected filament from Meudon CR 1831 and overlay the filaments of the same rotation from the McIntosh database. One can observe the visual match of individual filaments indicating consistent information from the two presented archives and also validating our methods of detection. Using the detected filaments, we extract different filament parameters, perform the statistical analysis, and study corroboration of the two hand-drawn data sets as depicted in the following sections.
5. Estimating Length and Tilt of the Filaments

We calculate filament length using the following formula from Mazumder et al. (2018):

\[ L = \sum_{n} \left( R_\odot^2 \delta \theta^2 + R_\odot^2 \cos^2 \theta \delta \phi^2 \right) \]

where \( L \) is the filament’s length, \( R_\odot \) is the solar radius, the symbols \( \theta \) and \( \phi \) represent the latitude and longitude of a particular pixel, respectively, and \( n \) is the total number of pixels associated with the filament’s structure. The quantities \( \delta \theta \) and \( \delta \phi \) are the latitudinal and longitudinal differences between two adjacent pixels, respectively. We then add together the lengths of all filaments in a Carrington map to get a total length for that map.

We fit straight lines to each filament to estimate the filament tilt angle. For a particular filament, the inclination angle the fitted straight line makes to the equator gives the measure of the tilt angle of that filament. We assume that the angle is positive in a counterclockwise direction from the equator and negative in a clockwise direction from the equator.

6. Identification of the Association of Filaments with an Active Region

To ascertain the association of the filaments with an active region we use the plages as identified in the Meudon maps. We define active-region-associated filaments to be those which are within a 5° distance from any plage. Likewise, we define active-region-unassociated filaments to be those which have a greater than 5° distance from all the plages present in the map. To demonstrate this we show Carrington map 1831 with detected plages (represented by black patches) and filaments (with red or green lines) in Figure 6. The red lines represent the active-region-associated filaments, whereas the green lines represent the active-region-unassociated filaments. This method of defining active-region-associated and -unassociated filaments is an improvement on that of Mazumder et al. (2018), in which association was defined only by latitude criterion. They defined active-region-associated filaments to be the filaments that are within the active region belt defined only by latitude extension (see the butterfly diagram in Figure 4 in Mazumder et al. 2018) and thus overestimated the active-region-associated filaments that are within the active region belt.
Figure 4. Detection of filaments from Meudon maps for rotation 1824 onward. (a) Calibrated maps for rotation 1824; (b) detected filaments from (a); (c) calibrated maps for rotation 1931; (d) detected filaments from (c); (e) calibrated maps for rotation 1993; (f) detected filaments from (e).

Figure 5. Filament detected from Meudon CR 1831 (black) overplotted on those from McIntosh (red) for the same rotation.
but are separated by longitude. Thus, in addition to a longer time length of the Meudon data set, our improved method of estimating the active region association of filaments gives better confidence to the statistical results that crucially depend on the number of active-region-associated and -unassociated filaments.

9 http://www.sidc.be/silso/home
7. Results and Discussion

7.1. Total Filament Number and Total Filament Length

Solar activity varies periodically with a period of 11 yr. The number of filaments also varies periodically (Hao et al. 2015; Tlatov et al. 2016; Mazumder 2019). The total filament length gleaned from Carrington maps is also known to vary with an 11 yr periodicity (Tlatov et al. 2016; Mazumder et al. 2018).

We count all the filaments in each Carrington map and define it as the total filament number corresponding to that Carrington map ($N_{\text{tot}}$), so as to study the variation of filament numbers with time. The middle panel of Figure 7 depicts the variation of $N_{\text{tot}}$ with time. The brown line represents the variation of $N_{\text{tot}}$ with time from the Meudon data and the blue line represents the variation of $N_{\text{tot}}$ with time from the McIntosh data. We find that for the overlapping period (1967 July–2003 October) the variation of $N_{\text{tot}}$ in the Meudon data is correlated with the variation of $N_{\text{tot}}$ in the McIntosh data with a Spearman’s rank correlation coefficient of 0.66 and confidence of 99.99%. We add the lengths of all filaments in a Carrington map and define it as total filament length ($L_{\text{tot}}$) for that map, so as to study the variation of the total filament length with time. The top panel of Figure 7 depicts the variation of $L_{\text{tot}}$ with time. The brown curve represents the variation of $L_{\text{tot}}$ from the Meudon data and the blue curve represents the variation of $L_{\text{tot}}$ from the McIntosh data. There is an overlap of data in cycles 20–23. We found a good match in the variation of filament length between the Meudon and McIntosh databases in the overlapping period. We find that for the overlapping period the variation of $L_{\text{tot}}$ from the Meudon data is correlated with the variation of $L_{\text{tot}}$ of the McIntosh data with a Spearman’s rank correlation coefficient of 0.81 and confidence of 99.99%. We find that the sunspot number variation is correlated with the variation in the Meudon $N_{\text{tot}}$ with a Spearman’s rank correlation coefficient of 0.81 and confidence of 99.99%. The sunspot number variation is correlated with the variation in the Meudon $L_{\text{tot}}$ with a Spearman’s rank correlation coefficient of 0.76 and confidence of 99.99% (Figure 7).

7.2. Latitudinal and Longitudinal Distribution of Filaments

The longitudinal distribution of filaments is uniform (Mazumder et al. 2018) across the solar disk (see Figure 8). However, the latitudinal distribution of filaments is not uniform. The left panels in Figure 9 depict histograms of the latitudinal distribution of filaments from the McIntosh database (top-left panel) and the Meudon database (bottom-left panel). We find a bimodal distribution with a peak between 10° and 30°, which is similar to the observation by Mazumder et al. (2018) from the McIntosh database and Hao et al. (2015) from the Notional Solar Observatory (NSO), and Global Oscillation Network Group (GONG) database.

The right panels in Figure 9 show the temporal variation of latitudinal distribution of the centers of filaments. We see a butterfly structure similar to the sunspot butterfly diagram. However, the latitudinal extent of the sunspot butterfly diagram is spread over ±40°, whereas for the filaments we see a larger latitudinal spread. We observe a poleward migration during solar cycle maxima. This poleward migration is popularly known as the “rush to the pole” phenomenon. These results are in agreement with earlier studies (Tlatov et al. 2016; Mazumder et al. 2018). Hao et al. (2015) have reported similar butterfly patterns in the temporal variation of the latitudinal distribution of filament centers from the Big Bear Solar Observatory archive. Chatterjee et al. (2017) have also reported a similar pattern by analyzing the Kodaikanal archive. Mazumder et al. (2018) observed that the poleward migration of filaments coincides with the polar field reversal. The timing of the polar...
field reversal is crucial information necessary for predicting the next solar cycle. However, observations of the polar field are challenging due to debilitating projection effects. So the timing of the poleward migration of filaments can be used as a proxy for polar field reversal, setting a crucial constraint on solar cycle evolution.

7.3. Tilt-angle Analysis of Filaments

We analyze the tilt angle of the filaments to find their origin. We segregate the filaments into active-region-associated filaments and active-region-unassociated filaments, depending on their distance from plages.

Figure 10(a) depicts the latitudinal distribution of all positive tilt-angle filaments. The southern hemisphere filaments tend to have excess positive tilt in comparison to the northern hemisphere ones. Figure 10(b) depicts the latitudinal distribution of all negative tilt-angle filaments. Northern hemisphere filaments have an excess negative tilt in comparison to the southern hemisphere ones. Figure 12 depicts a cartoon of an active region and its associated PIL. We follow the convention that the tilt angle of active regions in the northern (southern) hemisphere is negative (positive) according to Hale’s polarity law (Hale et al. 1919). Now the PILs and their tilts are perpendicular to active region tilts. Hence the tilt angles of PIL-associated filaments should be positive in the northern hemisphere and negative in the southern hemisphere. The yellow lines joining the opposite polarities (positive polarities represented by red circles and negatives by black) in Figure 12 represent the tilt of active regions, which is evidently positive in the northern hemisphere and negative in the southern hemisphere. However, active region PILs are depicted by green lines, which being perpendicular to the active region tilt (depicted by the yellow lines) follow the exact opposite behavior to those of the active region tilt. So PIL tilts (represented by green lines) are expected to be positive in the northern hemisphere and negative in the southern hemisphere. Filaments usually form along the PILs (McIntosh 1972; Makarov et al. 1983; Martin 1998). Thus, active-region-associated filaments should follow the same tilt-angle pattern as active region PILs, so we should expect a positive tilt for active-region-associated filaments in the northern hemisphere and a negative tilt in the southern hemisphere. However, the active-region-unassociated filaments may or may not follow this pattern since they are known to be formed along PILs of the large-scale magnetic field in the solar disk and are not constrained within active regions. Figure 10(a) shows southern hemisphere filaments having an excess positive tilt in comparison to the northern hemisphere ones. In contrast, Figure 10(b) depicts northern hemisphere filaments having an excess negative tilt in comparison to the southern hemisphere ones; exactly the opposite pattern to that expected from active-region-associated filaments. However, since the complete filament distribution includes active-region-unassociated filaments, we segregate the filaments into active-region-associated filaments and active-region-unassociated filaments (the methods of segregation are described in Section 6) to see whether contribution from active-region-unassociated filaments produces this anomaly in the overall filament tilt-angle distribution.

Figure 10(c) represents the histogram of the latitude of all positive tilt angles of active-region-associated filaments. Even in this set, we notice that the southern hemisphere dominates a
positive tilt angle. Figure 10(d) represents the histogram of latitudes of all negative tilt-angle filaments located near the active region belt. We notice that the northern hemisphere has a dominance of negative tilt-angle filaments even in this set. Figure 10(e) represents the histogram of the latitudes of all positive tilt-angle filaments that are not associated with active regions. In this sample, the southern hemisphere dominates positive tilt-angle filaments. Figure 10(f) represents the histogram of latitudes of all negative tilt-angle filaments not associated with active regions. The northern hemisphere dominates negative tilt-angle filaments.

Thus the subset filaments located either near to or away from active regions have a tilt angle that is opposite (a similar anomaly has been reported by Mazumder et al. (2018) and Mazumder (2019) from the McIntosh database) to what would be expected if they are formed on the PILs between the two spots of an individual active region.

7.4. Toward a Composite Uniform Long-term Data Set of Filaments

Figure 11 depicts a histogram of the latitude of positive and negative tilt-angle filaments, similar to Figure 5 but only for the cotemporal data where both data sources, Meudon and McIntosh, have records. Together with Figure 5, which shows a one-to-one cospatial relation between filaments, these similar tilt-angle distributions from both data sets evidence the robustness of our method of the detection of filaments from hand-drawn Meudon data and pave a way toward building a composite data set of solar filaments. This will work as a unique resource to solar physicists for the study of long-term variation in solar filaments.

8. Asymmetry

The generation of a magnetic field in the Sun is not symmetric in the two hemispheres, and this introduces an asymmetry in observed solar magnetic features. Earlier studies (Hao et al. 2015; Mazumder et al. 2018; Mazumder 2019) have found that the generation of filaments is not symmetric in the two hemispheres. We define the asymmetry in filament numbers $A_f$ to be

$$A_f = \frac{N_f - S_f}{(N_f + S_f)}$$

where $N_f$ and $S_f$ are the total number of filaments in the northern and southern hemispheres, respectively. So, if $A_f > 0$ this implies that the total number of filaments in the northern hemisphere is greater than in the southern hemisphere, and if $A_f < 0$ this implies that total number of filaments in the southern hemisphere is greater than in the northern hemisphere. The brown line in Figure 13 represents the variation of asymmetry in the number of filaments from the Meudon database. The blue line in Figure 13 represents the variation of asymmetry in filament numbers from the McIntosh database. The filament number asymmetry, $A_f$, fluctuates over the time of observation with a prominent inclination toward the northern hemisphere.

Figure 10. Histogram of the latitude of filaments with either only a positive tilt or only a negative tilt. (a) Histogram of the latitude of all filaments with a positive tilt; (b) histogram of the latitude of all filaments with a negative tilt; (c) histogram of the active-region-associated filaments with a positive tilt; (d) histogram of the active-region-associated filaments with a negative tilt; (e) histogram of active-region-unassociated filaments with a positive tilt; (f) histogram of active-region-unassociated filaments with a negative tilt.
hemisphere during 1919–1966 (which is covered by the Meudon data only). After 1966 the $A_r$ again fluctuates, but this time with a preference toward the southern hemisphere, which is in agreement with an earlier report by Mazumder et al. (2018). We find that the north–south asymmetry of filament numbers from the Meudon data is correlated with the north–south asymmetry of filament numbers from the McIntosh data during overlapping periods, with a Spearman’s rank correlation coefficient of 0.50 with confidence of 99.99%.

9. Summary and Conclusions

We develop an automated method to calibrate and detect filaments from Meudon hand-drawn Carrington maps both in black/white and colored formats. We extract 83,318 filaments from the Meudon database during the period 1919–2003 using our detection method. We compare our prior results of filament detection from the McIntosh database (Mazumder et al. 2018) during the overlapping period (1967 April–2003 October) and find a good agreement. We determine the tilt angle of the filaments to explore their origin. We perform a detailed analysis of the properties of filaments and their evolution with time over solar cycles 15–23.
Solar activity varies periodically. Similar to the number of sunspots and their area, the number of filaments (Li et al. 2010; Hao et al. 2015; Tlatov et al. 2016; Mazumder 2019) and total filament length (Hao et al. 2015; Tlatov et al. 2016; Mazumder et al. 2018) also vary periodically. From the Meudon observations, currently the longest available baseline of hand-drawn filaments, we confirm that the number of filaments and the total filament length vary periodically in phases with the variation in the number of sunspots. We find the sunspot number variation is correlated with the Meudon total filament number variation with a Spearman’s rank correlation coefficient of 0.81 with a confidence of 99.99%. We find the variation of total filament number and length in the overlapping period (solar cycle 20–23) using the McIntosh data to be consistent. We find that in the overlapping period the variation of total filament length from the Meudon data is correlated with the variation of the same from the McIntosh data, producing a Spearman’s rank correlation coefficient of 0.80 with a confidence of 99.99%. We also find the sunspot number variation to be correlated with the Meudon total filament length variation with a Spearman’s rank correlation coefficient 0.76 and a confidence of 99.99%.

The filament distribution in longitude is uniform (Mazumder et al. 2018) but the latitudinal distribution of filaments shows a bimodal nature (Hao et al. 2015; Mazumder et al. 2018). We reconfirm from the Meudon database that the longitudinal distribution of filaments is indeed uniform and the latitudinal distribution shows a bimodal distribution with peaks between 20° and 30°. The temporal variation of the latitudinal distribution of filaments shows a butterfly structure similar to earlier reports (D’Azambuja 1948; Mouradian & Soroush-Escaut 1994; Hao et al. 2015; Tlatov et al. 2016; Mazumder et al. 2018). The spread of the latitude of the filaments is larger in comparison to the latitudinal spread of sunspots in the butterfly diagram. Similar to the results of the earlier reports (Hao et al. 2015; Tlatov et al. 2016; Mazumder et al. 2018) we also observe a migration of the filaments to the pole during cycle maxima in the Meudon database. According to Hale’s polarity law (Hale et al. 1919), the tilt angle of the bipolar active region is negative in the northern hemisphere (with respect to the equator) and positive in the southern hemisphere. Since the tilt angle of a PIL is perpendicular to the active region tilt, the tilt angle of an active region PIL carrying filaments is expected to be positive in the northern hemisphere and negative in the southern hemisphere. However, our study of Meudon data reveals the tilt angle of filaments—both near to and away from active regions—follows an opposite trend. The tilt is predominantly negative in the northern hemisphere and positive in the south. This indicates that filaments predominantly originate not within active regions PILs but outside of them in the large-scale inter-active-region fields or even larger-scale surface magnetic field distributions. Our finding confirms the result by Mazumder et al. (2018) from the McIntosh database. Thus our work puts the finding of the anomalous behavior of filaments by Mazumder et al. (2018) from the McIntosh database on firmer ground, suggesting that filaments originate in the large-scale field distributions beyond individual active regions. This result is now confirmed from the longest filament database and needed to be addressed to aid understanding of the evolution of the large-scale field on the Sun.

Furthermore, like other magnetic features in the Sun, filaments are not symmetric in the two hemispheres and this asymmetry also varies with time (Hao et al. 2015; Mazumder et al. 2018). We find the north–south asymmetry of filament numbers from the Meudon database is correlated with the north–south asymmetry of filament numbers from the McIntosh data during the overlapping period with a Spearman’s rank correlation coefficient 0.50 and a confidence of 99.99%. This asymmetry in filament distribution may arise from the underlying asymmetry of magnetic field emergence associated with the solar dynamo mechanism (Passos et al. 2014; Bhowmik 2019; Hazra & Nandy 2019) and/or it might be related to hemispheric asymmetries in large-scale plasma flows (Lekshmi et al. 2018, 2019); these merit further theoretical investigations.

Solar filament and prominence structures often get destabilized and cause eruptive events such as CMEs—which can generate severe space weather (Sinha et al. 2019). However, direct observations of CMEs have existed only from the Solar and Heliospheric Observatory—Large Angle Spectroscopic Coronagraph era since 1996. In this context, century-scale filament time series such as ours may be utilized to reconstruct plausible eruptive space weather events in earlier times, well before the space age.

In summary, our work establishes the consistency of the properties and long-term evolution of filaments gleaned from two major, hand-drawn filament archives. We would like to extend our analysis to other long-term archives such as the Kodaikanal Solar Observatory data in the future. These archives may act as foundations of independent long-term filament studies, constrain models of solar magnetic field evolution, and act as an indicator of eruptive space weather events before direct CME observations associated with filament eruptions were possible.

The Center of Excellence in Space Sciences India (CESSI) is funded by the Ministry of Education, Government of India under the Frontier Areas of Science and Technology (FAST) scheme. D.B. acknowledges support from the Department of Science and Technology (DST), Government of India through the Cluster Project titled “Preservation and analysis of the century long solar data from Kodaikanal Solar Observatory.”

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