Solar Bulletin

THE AMERICAN ASSOCIATION OF VARIABLE STAR OBSERVERS
SOLAR SECTION

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ISSN 0271-8480

Volume 82 Number 1 January 2026

The Solar Bulletin of the AAVSO is a summary of each month's solar activity recorded by visual solar observers' counts of group and sunspots, and the very low frequency (VLF) radio recordings of SID Events in the ionosphere. The sudden ionospheric disturbance report is in Section 2. The relative sunspot numbers are in Section 3. Section 4 has endnotes.

1 Constructing a Generalized Linear Mixed Model for Sunspot Number Estimation, by Jamie D. Riggs, Ph.D.

Sunspot count data, provided by solar observers who contribute to the American Association of Variable Star Observers Solar Section, are used to estimate monthly sunspot numbers. The data include sunspot counts for the sunspot cycles 23, 24, and partially 25, each beginning with a minimum and progressing toward the next minimum. The counts from each observer are checked for consistency and completeness, and then are blended via a Generalized Linear Mixed Model (GLMM) such that the resulting sunspot numbers derive the best linear unbiased estimate that minimizes observational error. The individual observer's monthly sunspot counts is combined to form an overall, weighted monthly average of all the qualifying numbers. As such, the overall weighted monthly averages determined from the daily counts have unbiased estimates of the true monthly sunspot numbers under the assumptions of accurate data and an appropriate statistical model. As no sunspot number standard is available for this study, the adjustments are therefore relative to the data provided. The result is that, during model construction, tuning may be required for each month, as well as each successive month. This tuning is consistent with historical [Shapley, 1949, Taylor, 1985, Schaefer, 1993], and current [Clette et al., 2007] treatments. Analyzing sunspot data must account for several sources of variation which comprise the total amount of variability in the sunspot data. The statistical literature defines two overall types of variability other than inherent randomness: the variability due to fixed effects, and the variability due to random effects (Figure 1). Milliken and Johnson [2009] define these two types of variability as:

> **Fixed Effects:** A variable (feature) is considered to be a fixed effect if the levels of a variable are selected by a nonrandom process or if its levels consist of the entire population of possible levels. The fixed effects variables in the GLMM are:
>
> – Seeing condition (Excellent, Good, Fair, Poor, Missing)
> – Observing method (projection, direct, CCD, unknown)
> – Instrument used (refractor, SCT/Maksutov, SCT, reflector, SDO-HMI, unknown)
> – Filter type (glass, herschel, mylar, unknown, wl)

- Observer submits to both AAVSO and SIDC (0 = AAVSO only, 1 = both AAVSO and SIDC)

Random Effects: A variable is considered to be a random effect if its levels consist of a random selection of the levels from a population of possible levels. The GLMM random effect is observer. Observer is a random effect as in any given month, not all observers submit sunspot counts on any given day, i.e., the number of submitting observers differs month to month.

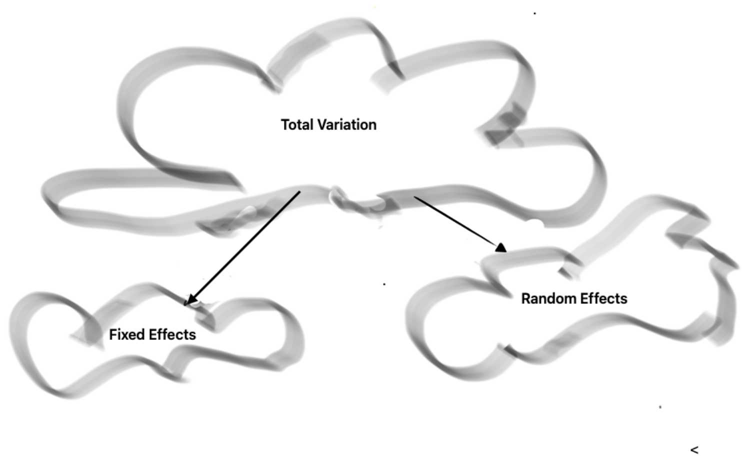

Figure 1: A "cloud" of total variation split into a cloud of fixed effects variation and a cloud of random effects variation. The total variation includes completely random variation not associated with either the fixed or the random effects.

The GLMM model differs in the treatment of the counts data distribution assumptions of the existing linear model developed by Shapley [1949] from Waldmeier [1961], which model sunspot numbers by variance-stabilizing transformations prior to forming a weighted average of the monthly counts. The GLMM log-linear time series model methodology does not assume a linear model, and statistically meets or exceeds the performance criteria set by Shapley. The GLMM provides an unbiased method for determining the relative sunspot number reported monthly by the American Association of Variable Star Observers Solar Section.

The steps for statistically modeling the fixed and random sources of variation (GLMM) in the submitted sunspot numbers involve considering not just the fixed and random sources of variation, but also considering the sunspot counts as a time series. Time series modeling considers that the data have an autocorrelation structure, i.e., the counts may be time dependent within each observer and from one observer to another. The steps are:

1. Test for linear trends in the time series data. Use the KPSS test (linear trend and/or random walk, Fuller [1976]) and the ADF test (linear trend and/or drift, Fuller [1976]). A trend either upward or downward or both can add to the variability in the data relative to the time series aspect of the total variability, i.e., a trend can confound the autocorrelation structure.

2. Remove any trends using a first difference on the time series (there will be one less observation than with the original time series). If a first difference series tests as NOT trend stationary,

a more complex method may be required such as fitting a polynomial or using exponential smoothing, e.g. This makes the time series linearly stationary.

3. Identify cyclical components on the trend stationary time sequence using Fourier analysis. This works on a first difference, but if a more complex fitting method was used (e.g., smoothing), the Fourier analysis will be on the residuals of this more complex fitted method.

4. First assemble a matrix of fixed effects from the fixed effects matrices of each observer and the Fourier analysis coefficients. The matrix then is used by the GLMM to estimate the "weight" of each fixed effect on the changes in sunspot number.

5. Use the GLMM residuals to obtain the within- and across-observer auto-correlation and cross-correlation ARMA(p, q)) time series model coefficient orders of p and q for each time t of the random effect of observers. These coefficients measure the levels of autocorrelation and cross correlation among the observers. The estimated coefficients in these matrices have values for each observer within autocorrelation and values for the cross-correlation among the observers. The residuals are obtained from fitting the multivariate time series ARMA model.

6. Test the ARMA residuals for volatility (changes in the time series due to time dependent variation). A volatility model component can be added to the ARMA component of the time series model. This is a step that is for future incorporation.

7. Reshape the matrices based on the time series coefficients then refit a sunspot count GLMM model from the fixed effects, cyclical components, random effects, and the time series model. Test for stationarity, undetected cyclical components, and for white noise in the residuals. If all the tests pass, this model then gives fitted monthly sunspot numbers, and can be used to forecast future month's numbers. If not all the tests pass, repeat steps 1 through 7 as needed.

References

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M. Waldmeier. *The sunspot-activity in the years 1610-1960.* Verlag Schulthess u. Co. AG., Zurich, 1961.

2 Sudden Ionospheric Disturbance (SID) Report

2.1 SID Records

January 2026 (Figure 2): there was an M-class, 12 C-class flares on the 17th of January; the M2.1 shows a nice SID with a "shark's tail" lasting about an hour. This VLF scan was recorded in southern France by Lionel Laudet (A118). (U.S. Dept. of Commerce–NOAA, 2022).

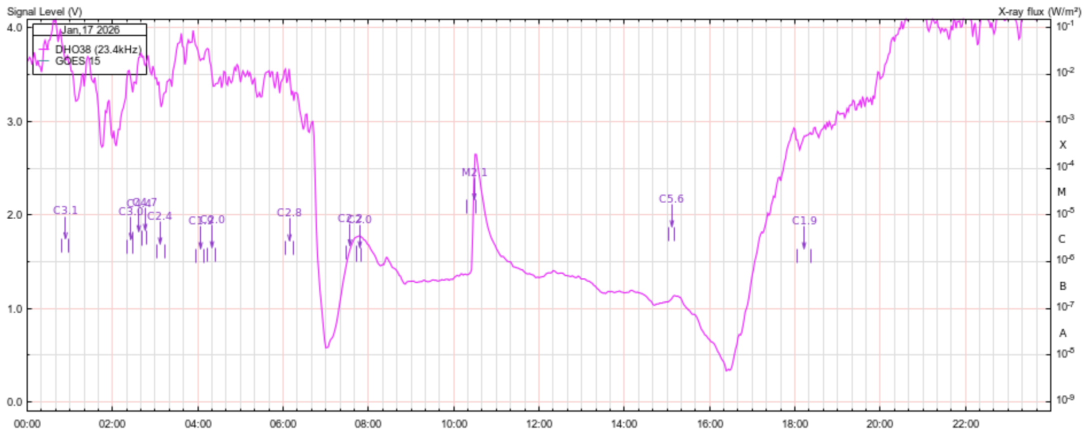

Figure 2: VLF recording from southern France.

2.2 SID Observers

In January 2026 we had 10 AAVSO SID observers who submitted VLF data, as listed in Table 1.

Table 1: 202601 VLF Observers

Observer	Code	Stations
R Battaiola	A96	ICV
L Loudet	A118	DHO GBZ
J Godet	A119	DHO GBZ GQD
R Mrllak	A136	NSY
S Aguirre	A138	NPM
G Silvis	A141	NAU NPM NLK
L Pina	A148	NAA NML
J Wendler	A150	NAA
H Krumnow	A152	DHO GBZ HWU
J DeVries	A153	NLK

Figure 3 depicts the importance rating of the solar events. The duration in minutes are -1: LT 19, 1: 19-25, 1+: 26-32, 2: 33-45, 2+: 46-85, 3: 86-125, and 3+: GT 125.

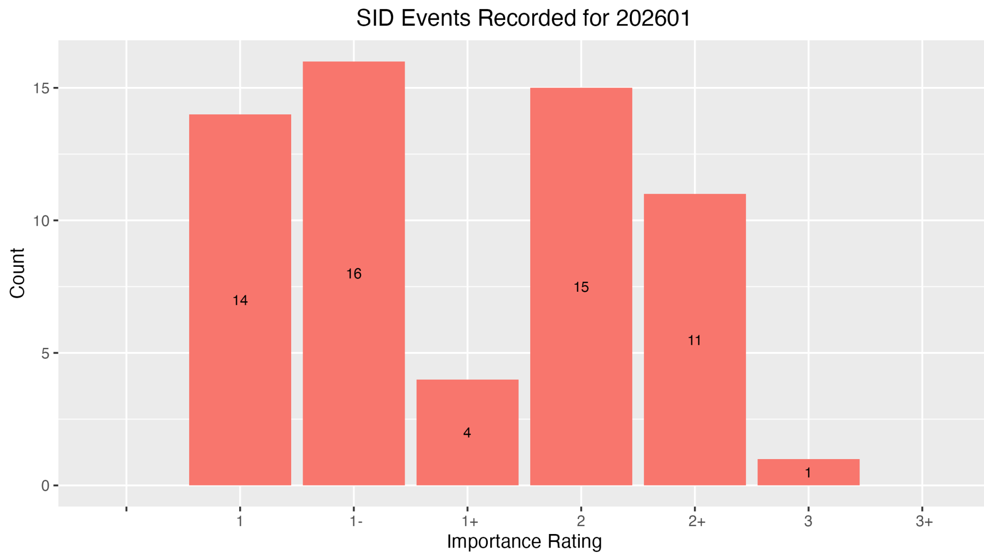

Figure 3: VLF SID Events.

2.3 Solar Flare Summary from GOES-16 Data

In January 2026, There were 249 GOES-19 XRA flares: one X-class, 7 M-class, 236 C-class and 5 B-class flares. Far less flaring this month compared to last. (U.S. Dept. of Commerce–NOAA, 2022). (see Figure 4).

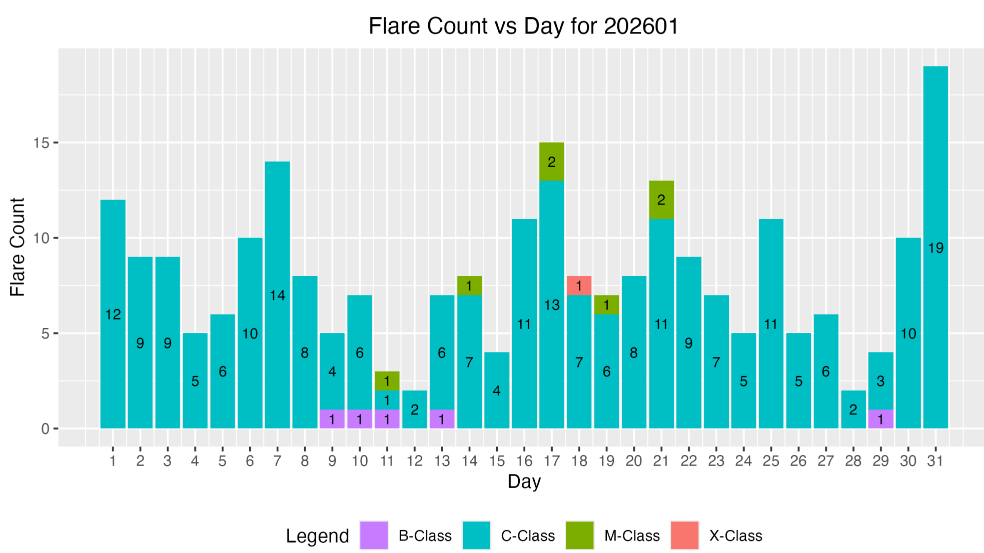

Figure 4: GOES-16 XRA flares (U.S. Dept. of Commerce–NOAA, 2022).

3 Relative Sunspot Numbers (R_a)

Reporting monthly sunspot numbers consists of submitting an individual observer's daily counts for a specific month to the AAVSO Solar Section. These data are maintained in a Structured Query Language (SQL) database. The monthly data are then extracted for analysis. This section is the portion of the analysis concerned with both the raw and daily average counts for a particular month. Scrubbing and filtering the data assure error-free data are used to determine the monthly sunspot numbers.

3.1 Raw Sunspot Counts

The raw daily sunspot counts consist of submitted counts from all observers who provided data in January 2026. These counts are reported by the day of the month. The reported raw daily average counts have been checked for errors and inconsistencies, and no known errors are present. All observers whose submissions qualify through this month's scrubbing process are represented in Figure 5.

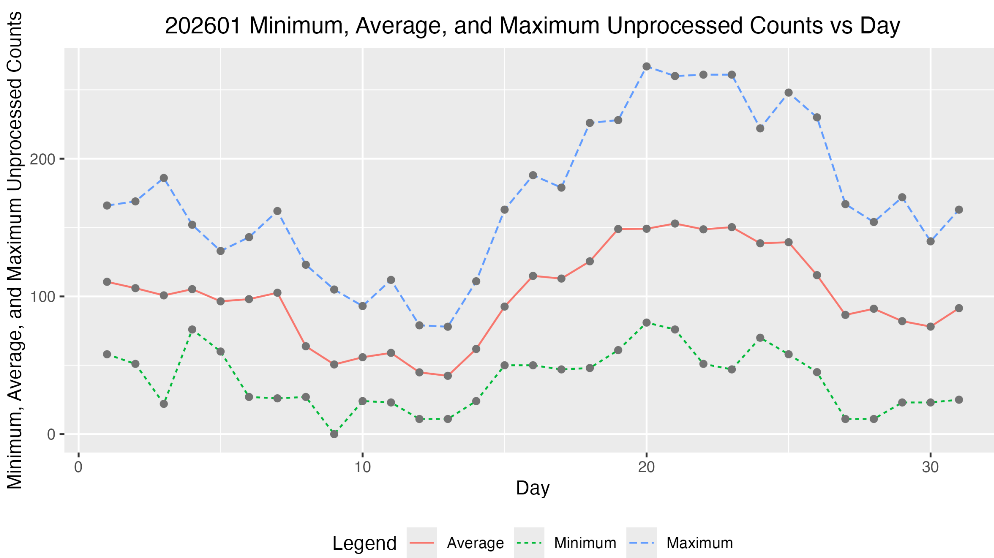

Figure 5: Raw Wolf number average, minimum and maximum by day of the month for all observers.

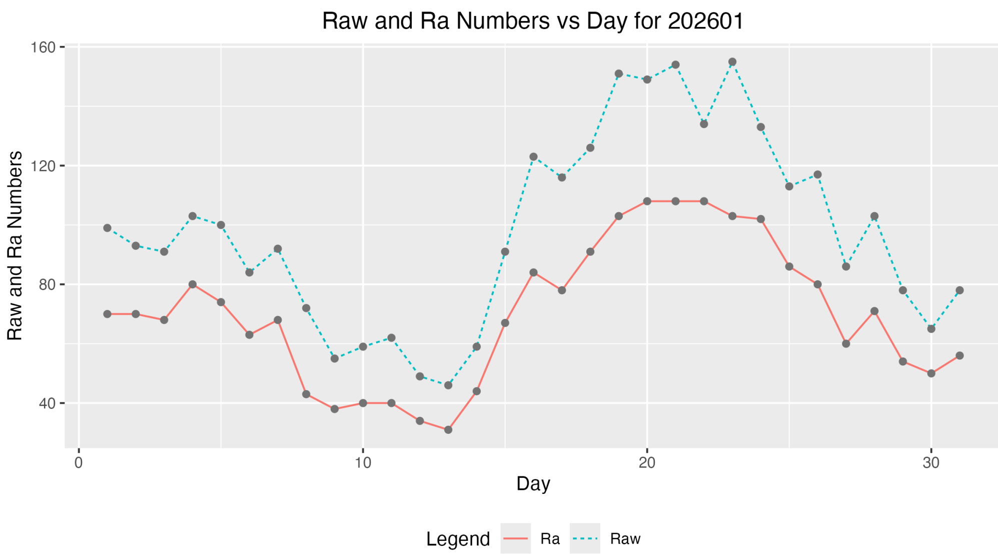

Figure 6: Raw Wolf average and R_a numbers by day of the month for all observers.

3.2 American Relative Sunspot Numbers

The relative sunspot numbers, R_a, contain the sunspot numbers after the submitted data are scrubbed and modeled by Shapley's method with k-factors (`http://iopscience.iop.org/article/10.1086/126109/pdf`). The Shapley method is a statistical model that agglomerates variation due to random effects, such as observer group selection, and fixed effects, such as seeing condition. The raw Wolf averages and calculated R_a are seen in Figure 6, and Table 2 shows the Day of the observation (column 1), the Number of Observers recording that day (column 2), the raw Wolf number (column 3), and the Shapley Correction (R_a) (column 4).

Table 2: 202601 American Relative Sunspot Numbers (R_a).

Day	Number of Observers	Raw	R_a
1	20	99	70
2	26	93	70
3	20	91	68
4	23	103	80
5	25	100	74
6	28	84	63
7	26	92	68
8	16	72	43
9	27	55	38
10	24	59	40
11	28	62	40
12	29	49	34
13	23	46	31
14	26	59	44
15	23	91	67

Continued

Table 2: 202601 American Relative Sunspot Numbers (R_a).

Day	Number of Observers	Raw	R_a
16	30	123	84
17	23	116	78
18	23	126	91
19	23	151	103
20	25	149	108
21	22	154	108
22	23	134	108
23	21	155	103
24	21	133	102
25	20	113	86
26	24	117	80
27	23	86	60
28	21	103	71
29	24	78	54
30	28	65	50
31	33	78	56
Averages	24.1	97.9	70.1

3.3 Sunspot Observers

Table 3 lists the Observer Code (column 1), the Number of Observations (column 2) submitted for January 2026, and the Observer Name (column 3). The final row gives the total number of observers who submitted sunspot counts (57), and total number of observations submitted (748).

Table 3: 202601 Number of observations by observer.

Observer Code	Number of Observations	Observer Name
AAX	27	Alexandre Amorim
AJV	6	J. Alonso
ARAG	30	Gema Araujo
BATR	3	Roberto Battaiola
BMIG	22	Michel Besson
BTB	7	Thomas Bretl
BVZ	7	Jesus E. Blanco
BXZ	18	Jose Alberto Berdejo
CIOA	1	Ioannis Chouinavas
CKB	20	Brian Cudnik
CMAB	1	Maurizio Cervoni
CNT	22	Dean Chantiles
CPAD	2	Panagiotis Chatzistamatiou
DARB	26	Aritra Das

Continued

Table 3: 202601 Number of observations by observer.

Observer Code	Number of Observations	Observer Name
DELS	4	Susan Delaney
DFR	8	Frank Dempsey
DGIA	6	Giuseppe di Tommasco
DIL	21	Bill Dillon
DJOB	7	Jorge del Rosario
DJSA	4	Jeff DeVries
DJVA	31	Jacques van Delft
DMIB	12	Michel Deconinck
DUBF	14	Franky Dubois
EHOA	6	Howard Eskildsen
FALB	15	Allen Frohardt
FERA	9	Eric Fabrigat
GCNA	1	Candido Gomez
HKY	13	Kim Hay
HOWR	17	Rodney Howe
HRUT	21	Timothy Hrutkay
ILUB	9	Luigi Iapichino
JGE	1	Gerardo Jimenez Lopez
KAMB	31	Amoli Kakkar
KAND	4	Kandilli Observatory
KAPJ	13	John Kaplan
KNJS	31	James & Shirley Knight
KTOC	21	Tom Karnuta
LKR	2	Kristine Larsen
LLEC	28	Leroy Leonard
LRRA	12	Robert Little
MARC	2	Arnaud Mengus
MARE	10	Enrico Mariani
MJHA	28	John McCammon
MMI	31	Michael Moeller
MUDG	2	George Mudry
MWMB	1	William McShan
MWU	23	Walter Maluf
PLUD	17	Ludovic Perbet
RJV	9	Javier Ruiz Fernandez
SDOH	31	Solar Dynamics Obs - HMI
SNE	1	Neil Simmons
SRIE	8	Rick St. Hilaire
TDE	17	David Teske
TPJB	3	Patrick Thibault
TST	12	Steven Toothman
URBP	19	Piotr Urbanski

Continued

Table 3: 202601 Number of observations by observer.

Observer Code	Number of Observations	Observer Name
WGI	1	Guido Wollenhaupt
Totals	748	57

3.4 Generalized Linear Model of Sunspot Numbers

Dr. Jamie Riggs, Solar System Science Section Head, International Astrostatistics Association, maintains a relative sunspot number (R_a) model containing the sunspot numbers after the submitted data are scrubbed and modeled by a Generalized Linear Mixed Model (GLMM), which is a different model method from the Shapley method of calculating R_a in Section 3 above. The GLMM is a statistical model that accounts for variation due to random effects and fixed effects. For the GLMM R_a model, random effects include the AAVSO observer, as these observers are a selection from all possible observers, and the fixed effects include seeing conditions at one of four possible levels. More details on GLMM are available in the paper, *A Generalized Linear Mixed Model for Enumerated Sunspots* (see 'GLMM06' in the sunspot counts research page at http://www.spesi.org/?page_id=65).

Figure 7 shows the monthly GLMM R_a numbers for a rolling eleven-year (132-month) window beginning within the 24th solar cycle and ending with last month's sunspot numbers. The solid cyan curve that connects the red *X's* is the GLMM model R_a estimates of excellent seeing conditions, which in part explains why these R_a estimates often are higher than the Shapley R_a values. The dotted black curves on either side of the cyan curve depict a 99% confidence band about the GLMM estimates. The green dotted curve connecting the green triangles is the Shapley method R_a numbers. The dashed blue curve connecting the blue *O's* is the SILSO values for the monthly sunspot numbers.

The tan box plots for each month are the actual observations submitted by the AAVSO observers. The heavy solid lines approximately midway in the boxes represent the count medians. The box plot represents the InterQuartile Range (IQR), which depicts from the 25^{th} through the 75^{th} quartiles. The lower and upper whiskers extend 1.5 times the IQR below the 25^{th} quartile, and 1.5 times the IQR above the 75^{th} quartile. The black dots below and above the whiskers traditionally are considered outliers, but with GLMM modeling, they are observations that are accounted for by the GLMM model.

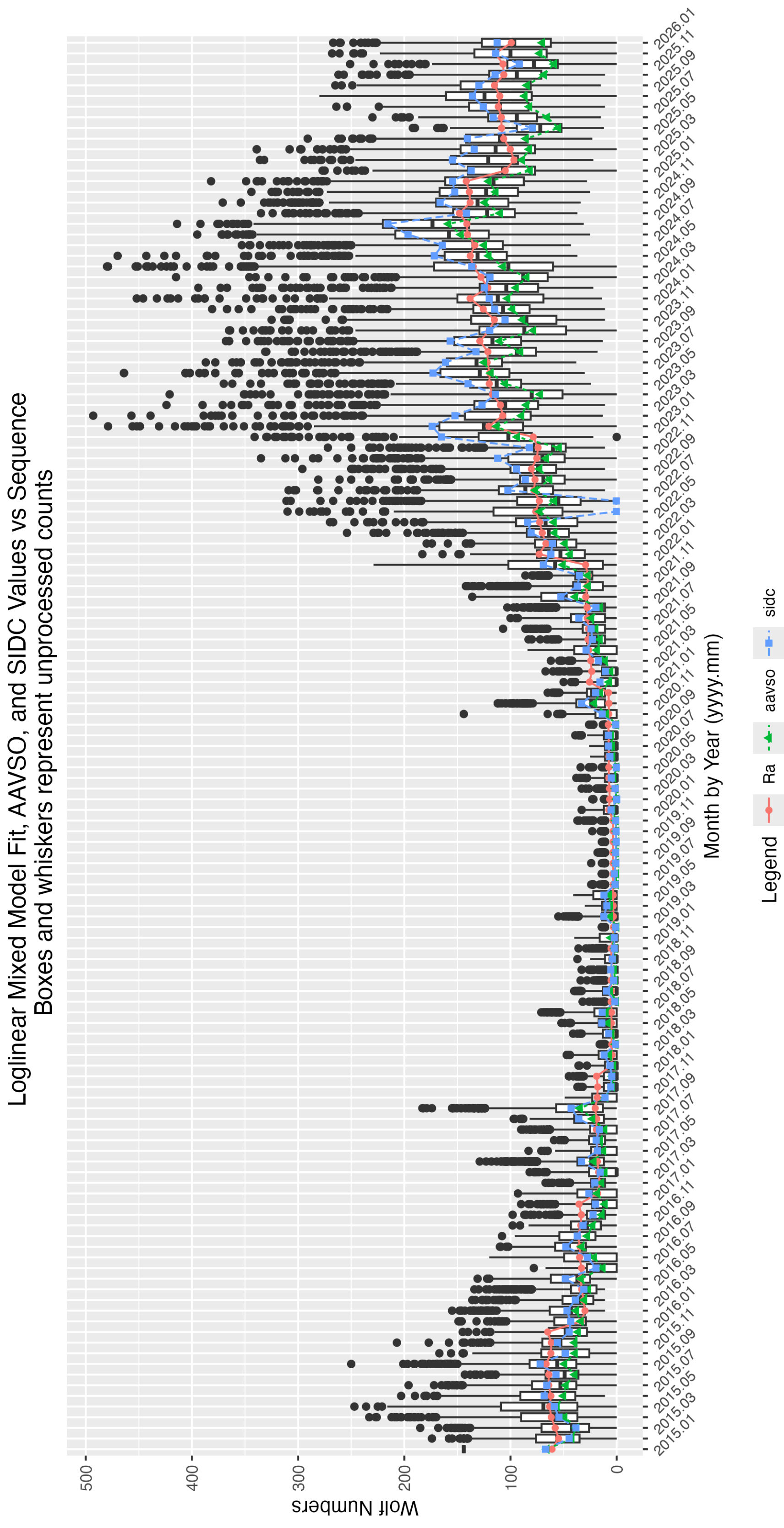

Figure 7: GLMM fitted data for R_a. AAVSO data: https://www.aavso.org/category/tags/solar-bulletin. SIDC data: WDC-SILSO, Royal Observatory of Belgium, Brussels

4 Endnotes

- Sunspot Reports: Kim Hay solar@aavso.org
- SID Solar Flare Reports: Rodney Howe rhowe137@icloud.com

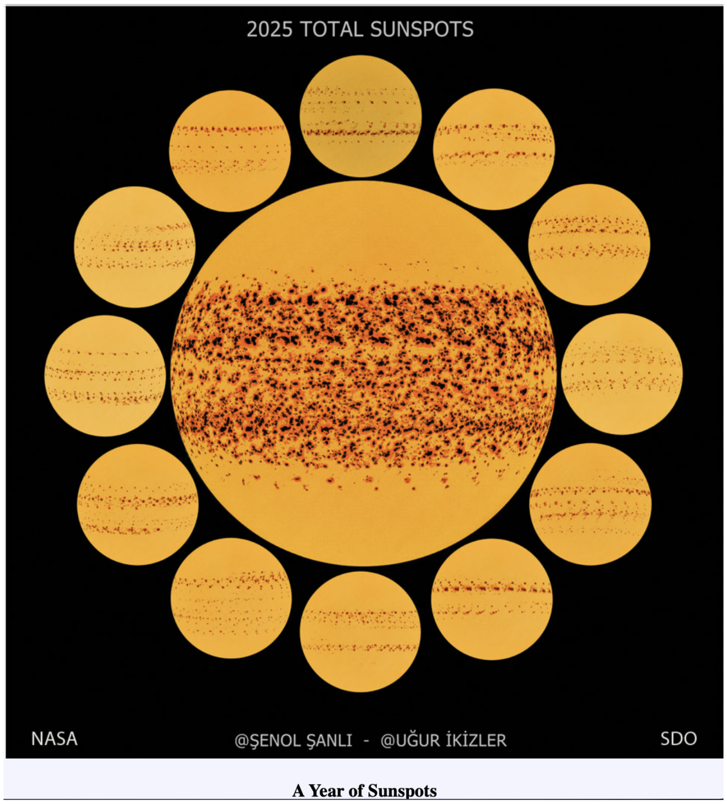

Figure 8: A full year of monthly sunspot counts and their distribution over the north and south hemispheres. Courtesy of NASA and SDO satellite. February 11, 2026 image from APOD (Archive): (https://apod.nasa.gov/apod/ap260211.html)

5 References

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Shapley, (1949), method with k-factors (http://iopscience.iop.org/article/10.1086/126109/pdf).

U.S. Dept. of Commerce–NOAA, Space Weather Prediction Center, 2022. *GOES-16 XRA data.* ftp://ftp.swpc.noaa.gov/pub/indices/events/