# *Solar Bulletin*

THE AMERICAN ASSOCIATION OF VARIABLE STAR OBSERVERS
SOLAR SECTION

Rodney Howe, Kristine Larsen, Co-Chairs
c/o AAVSO, 185 Alewife Brook Parkway,
Cambridge, MA 02138 USA

Web: https://www.aavso.org/solar-bulletin
Email: solar@aavso.org
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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 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 Hidden Markov Model (HMM) reveals zero sunspot days

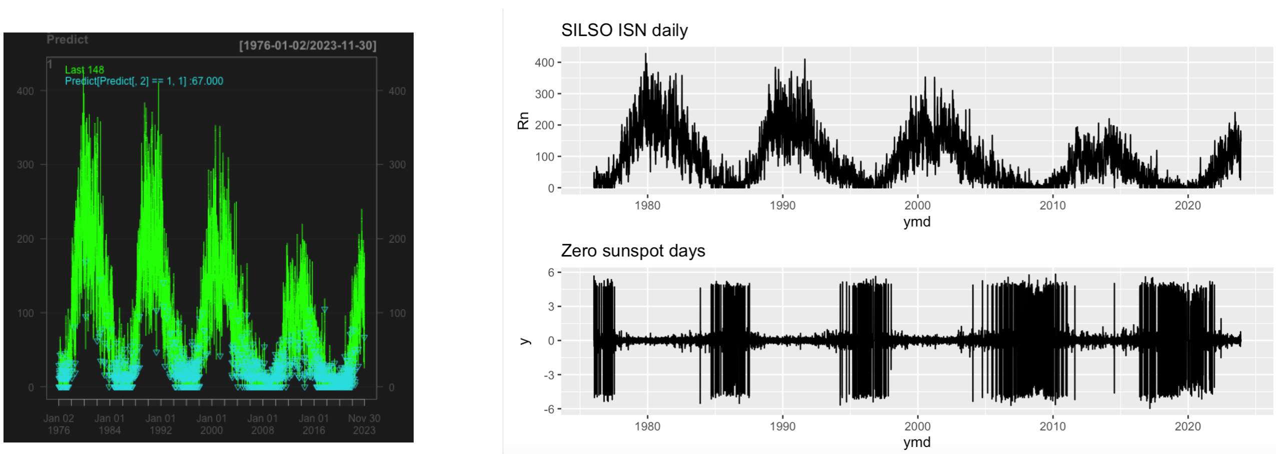


Figure 1: SIDC daily ISN, back to 1976 using the HMM shows zero sunspots as blue (left), and HMM back to 1976 shows sunspot minimum's zero sunspot days, right bottom panel (Dr. Jamie Riggs).

Using a Hidden Markov Model shows the solar cycles back to 1976 and zero sunspot days during solar minimums. The zero sunspot days show an increase in the length of the solar cycles for 24 and 25. However, there are other models we can use to validate how the frequency of zero sunspot days is increasing.

Getting the solar cycle periods from the sunspot number of monthly average of $R_a$ data from (LISIRD https://lasp.colorado.edu/lisird/data/american_relative_sunspot_number_daily) we can then find a good model to fit for the last 4 full solar cycles, using routines for doing Fast Fourier Transform (FFT). The following table shows the top periods from (R Statistical Software, 2010, TSA::periodogram). The highest power period is 129 months, which is 10.8 years. The next closest period that matches this is 100 months, or 8.3 years. However, this period has a significantly lower statistical power.

Table 1: The highest power period is 129 months, which is 10.8 years.

| period | power |
|---|---|
| 129 | 7209.9068 |
| 100 | 591.5095 |
| 450 | 335.6277 |
| 64 | 185.4779 |
| 900 | 183.3674 |
| 180 | 181.0576 |

Table 2: This table shows 4 cycle start and cycle peak dates with number of groups for those days. (SIDC https://www.sidc.be/SILSO/groupnumberv3) Cycle start and end dates with total number of days in each cycle, and zero sunspot days for each cycle.

| Cycle No. | Start | Peak | days | groups: | Start | End | days | zero days |
|---|---|---|---|---|---|---|---|---|
| 21 | 197603 | 197912 | 1365 | 1177 | 197603 | 198609 | 3830 | 985 |
| 22 | 198609 | 198911 | 1155 | 923 | 198609 | 199608 | 3620 | 845 |
| 23 | 199608 | 200111 | 1915 | 1654 | 199608 | 200812 | 4500 | 1322 |
| 24 | 200812 | 201404 | 1855 | 1595 | 200812 | 202003 | 4110 | 1781 |

As explained by Y. Natsume,"Out of the several models available for modelling discrete sequential data, hidden Markov models are one of the more simple but powerful ones. The first order Markov process makes a very important simplification to observed sequential data, the current system state depends only on the previous system state." (Hidden Markov Models with Python, 2022) https://medium.com/@natsunoyuki/hidden-markov-models-with-python-c026f778dfa7

Sunspot activity is assumed to be around the 11 year cycles from solar minimum to solar minimum, but when we fit an HMM, we can see the hidden state (2nd state) of zero sunspot days increasing, making the solar cycle length variable (see Figure 1).

# 2 Sudden Ionospheric Disturbance (SID) Report

## 2.1 SID Records

December 2023 (Figure 2): there were 266 XRA flares: two X class, 18 M class, 246 C class. This is about the same flaring as last month, however, with a X5.0 flare on December 31st. (U.S. Dept. of Commerce–NOAA, 2023).

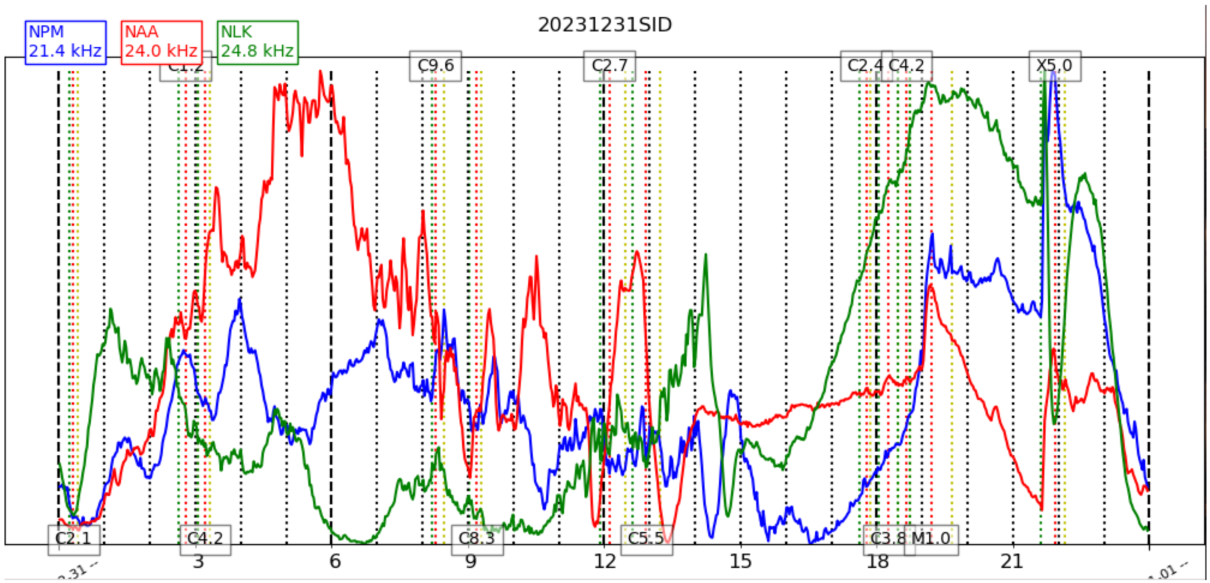


Figure 2: VLF recording from Fort Collins, Colorado for the 31st of December.

## 2.2 SID Observers

In December 2023 we had 14 AAVSO SID observers who submitted VLF data, as listed in Table 3.

Table 3: 202312 VLF Observers

| Observer | Code | Stations |
|---|---|---|
| R Battaiola | A96 | HWU |
| J Wallace | A97 | NAA |
| A Son | A112 | DHO |
| L Loudet | A118 | DHO GQD |
| J Godet | A119 | GBZ GQD ICV |
| F Adamson | A122 | NWC |
| J Karlovsky | A131 | TBB |
| R Mrllak | A136 | GQD NSY |
| S Aguirre | A138 | NAA |
| G Silvis | A141 | NAA NML NPM |
| L Pina | A148 | NAA NLK |
| J Wendler | A150 | NAA |
| H Krumnow | A152 | DHO FTA GBZ |
| 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.

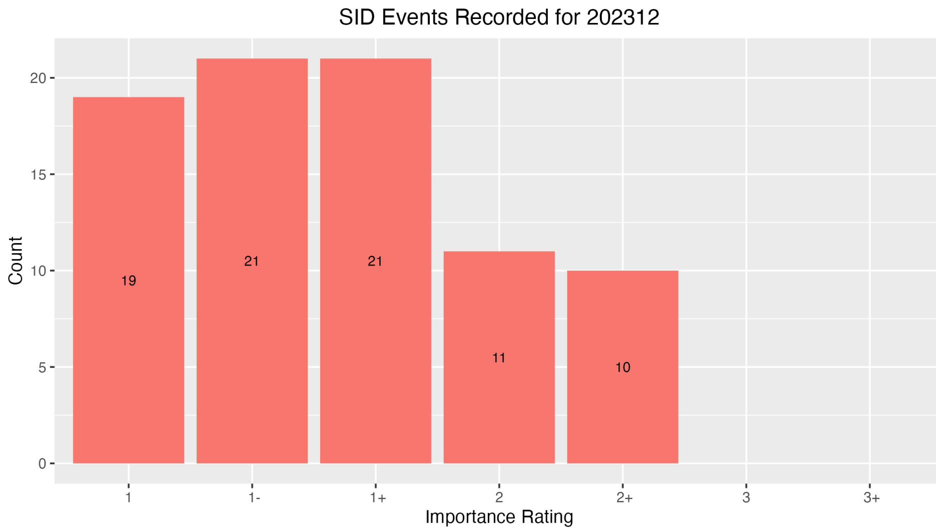


Figure 3: VLF SID Events.

### 2.3 Solar Flare Summary from GOES-16 Data

In December 2023, there were 266 XRA flares: two X class, 18 M class, 246 C class. There were 5 days of no data from the U.S. Dept. of Commerce-NOAA (see Figure 4).

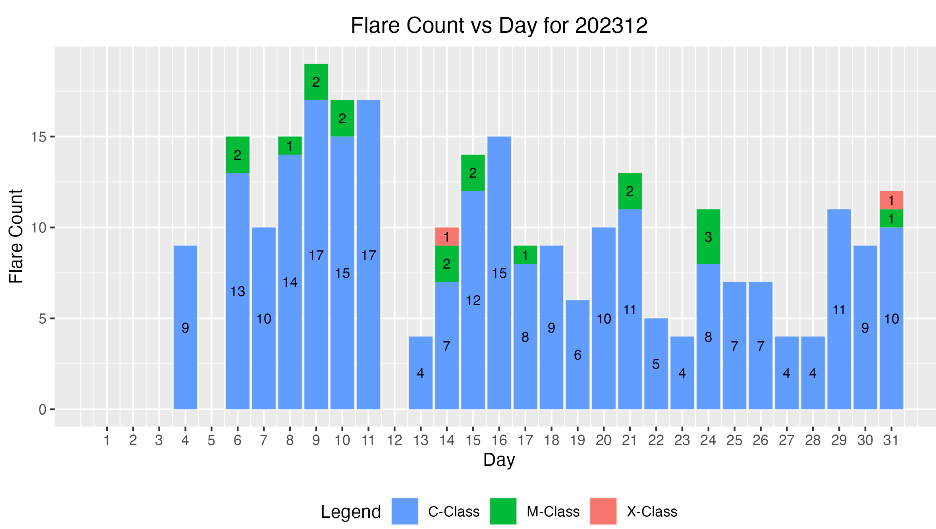


Figure 4: GOES-16 XRA flares (U.S. Dept. of Commerce–NOAA, 2023).

# 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 then are 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 December 2023. 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.

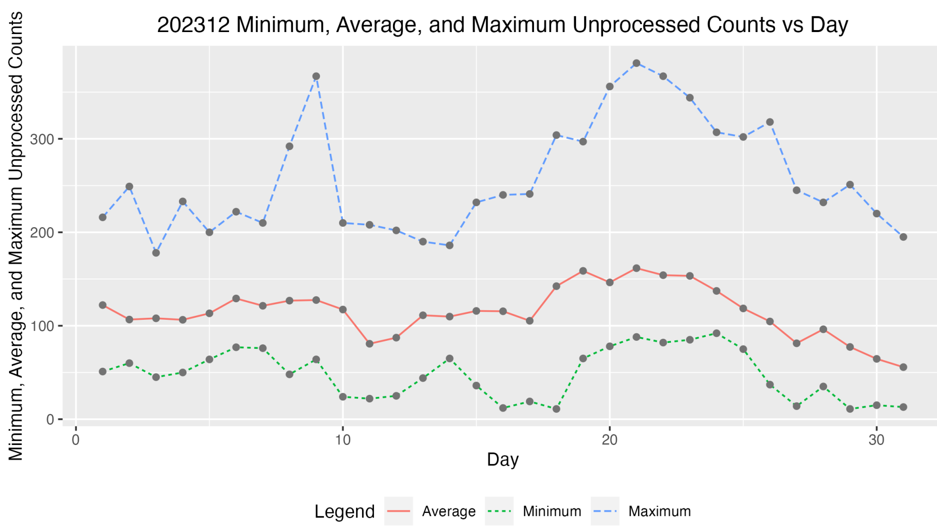


Figure 5: Raw Wolf number average, minimum and maximum by day of the month for all observers.

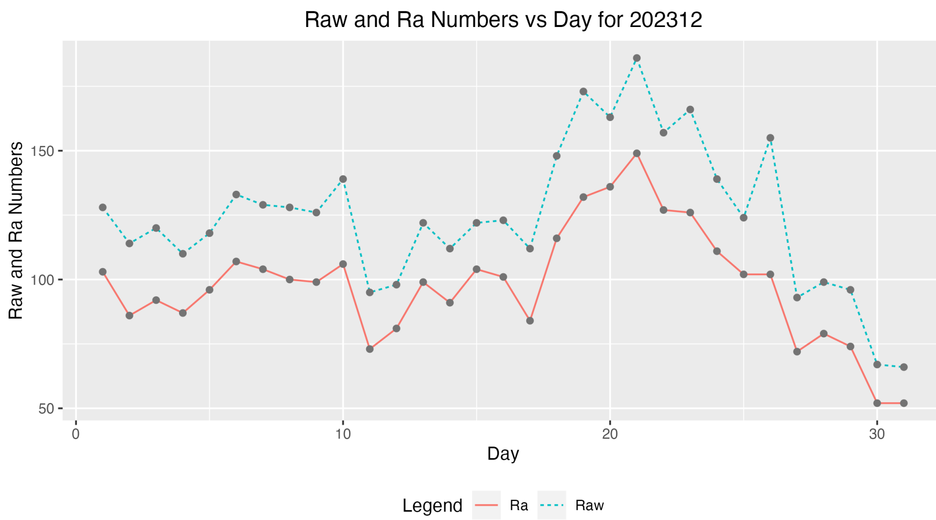


Figure 6: Raw Wolf average and $R_a$ numbers by day of the month for all observers.

### 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 4 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 4: 202312 American Relative Sunspot Numbers ($R_a$).

| Day | Number of Observers | Raw | $R_a$ |
|---|---|---|---|
| 1 | 22 | 128 | 103 |
| 2 | 19 | 114 | 86 |
| 3 | 29 | 120 | 92 |
| 4 | 25 | 110 | 87 |
| 5 | 21 | 118 | 96 |
| 6 | 31 | 133 | 107 |
| 7 | 28 | 129 | 104 |
| 8 | 23 | 128 | 100 |
| 9 | 22 | 126 | 99 |
| 10 | 26 | 139 | 106 |
| 11 | 31 | 95 | 73 |
| 12 | 30 | 98 | 81 |
| 13 | 25 | 122 | 99 |
| 14 | 29 | 112 | 91 |
| 15 | 34 | 122 | 104 |
| 16 | 36 | 123 | 101 |

Continued

Table 4: 202312 American Relative Sunspot Numbers ($R_a$).

| Day | Number of Observers | Raw | $R_a$ |
|---|---|---|---|
| 17 | 33 | 112 | 84 |
| 18 | 29 | 148 | 116 |
| 19 | 28 | 173 | 132 |
| 20 | 28 | 163 | 136 |
| 21 | 23 | 186 | 149 |
| 22 | 26 | 157 | 127 |
| 23 | 26 | 166 | 126 |
| 24 | 26 | 139 | 111 |
| 25 | 34 | 124 | 102 |
| 26 | 28 | 155 | 102 |
| 27 | 30 | 93 | 72 |
| 28 | 27 | 99 | 79 |
| 29 | 29 | 96 | 74 |
| 30 | 30 | 67 | 52 |
| 31 | 25 | 66 | 52 |
| Averages | 27.5 | 124.5 | 98.2 |

### 3.3 Sunspot Observers

Table 5 lists the Observer Code (column 1), the Number of Observations (column 2) submitted for December 2023, and the Observer Name (column 3). The final row gives the total number of observers who submitted sunspot counts (68), and total number of observations submitted (853).

Table 5: 202312 Number of observations by observer.

| Observer Code | Number of Observations | Observer Name |
|---|---|---|
| AAX | 23 | Alexandre Amorim |
| AJV | 10 | J. Alonso |
| ARAG | 29 | Gema Araujo |
| ASA | 2 | Salvador Aguirre |
| BATR | 7 | Roberto Battaiola |
| BKL | 1 | John A. Blackwell |
| BMF | 14 | Michael Boschat |
| BMIG | 16 | Michel Besson |
| BROB | 26 | Robert Brown |
| BXZ | 24 | Jose Alberto Berdejo |
| BZX | 15 | A. Gonzalo Vargas |
| CIOA | 5 | Ioannis Chouinavas |
| CKB | 17 | Brian Cudnik |
| CLDB | 12 | Laurent Cambon |
| CMAB | 8 | Maurizio Cervoni |

Continued

Table 5: 202312 Number of observations by observer.

| Observer Code | Number of Observations | Observer Name |
|---|---|---|
| CNT | 30 | Dean Chantiles |
| CPAD | 3 | Panagiotis Chatzistamatiou |
| CVJ | 2 | Jose Carvajal |
| DARB | 14 | Aritra Das |
| DAT | 1 | Adam Derdzikowski |
| DELS | 2 | Susan Delaney |
| DGIA | 13 | Giuseppe di Tommasco |
| DJOB | 9 | Jorge del Rosario |
| DJSA | 4 | Jeff DeVries |
| DJVA | 14 | Jacques van Delft |
| DMIB | 21 | Michel Deconinck |
| DUBF | 14 | Franky Dubois |
| EHOA | 13 | Howard Eskildsen |
| ERB | 6 | Bob Eramia |
| FALB | 10 | Allen Frohardt |
| FERA | 1 | Eric Fabrigat |
| FLET | 16 | Tom Fleming |
| GIGA | 19 | Igor Grageda Mendez |
| HALB | 1 | Brian Halls |
| HKY | 9 | Kim Hay |
| HOWR | 13 | Rodney Howe |
| HSR | 4 | Serge Hoste |
| IEWA | 16 | Ernest W. Iverson |
| ILUB | 4 | Luigi Iapichino |
| JGE | 10 | Gerardo Jimenez Lopez |
| KAND | 17 | Kandilli Observatory |
| KAPJ | 4 | John Kaplan |
| KNJS | 30 | James & Shirley Knight |
| KTOC | 9 | Tom Karnuta |
| LKR | 10 | Kristine Larsen |
| LRRA | 9 | Robert Little |
| LVY | 29 | David Levy |
| MARC | 5 | Arnaud Mengus |
| MARE | 12 | Enrico Mariani |
| MCE | 26 | Etsuiku Mochizuki |
| MJHA | 25 | John McCammon |
| MLL | 2 | Jay Miller |
| MMI | 31 | Michael Moeller |
| MWU | 26 | Walter Maluf |
| ONJ | 5 | John O'Neill |
| PLUD | 9 | Ludovic Perbet |
| RJV | 11 | Javier Ruiz Fernandez |
| RMW | 3 | Michael Rapp |

Continued

Table 5: 202312 Number of observations by observer.

| Observer Code | Number of Observations | Observer Name |
|---|---|---|
| SDOH | 31 | Solar Dynamics Obs - HMI |
| SNE | 5 | Neil Simmons |
| SQN | 17 | Lance Shaw |
| SRIE | 15 | Rick St. Hilaire |
| TDE | 22 | David Teske |
| TPJB | 3 | Patrick Thibault |
| TST | 8 | Steven Toothman |
| URBP | 9 | Piotr Urbanski |
| VIDD | 7 | Dan Vidican |
| WWM | 15 | William M. Wilson |
| Totals | 853 | 68 |

### 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.

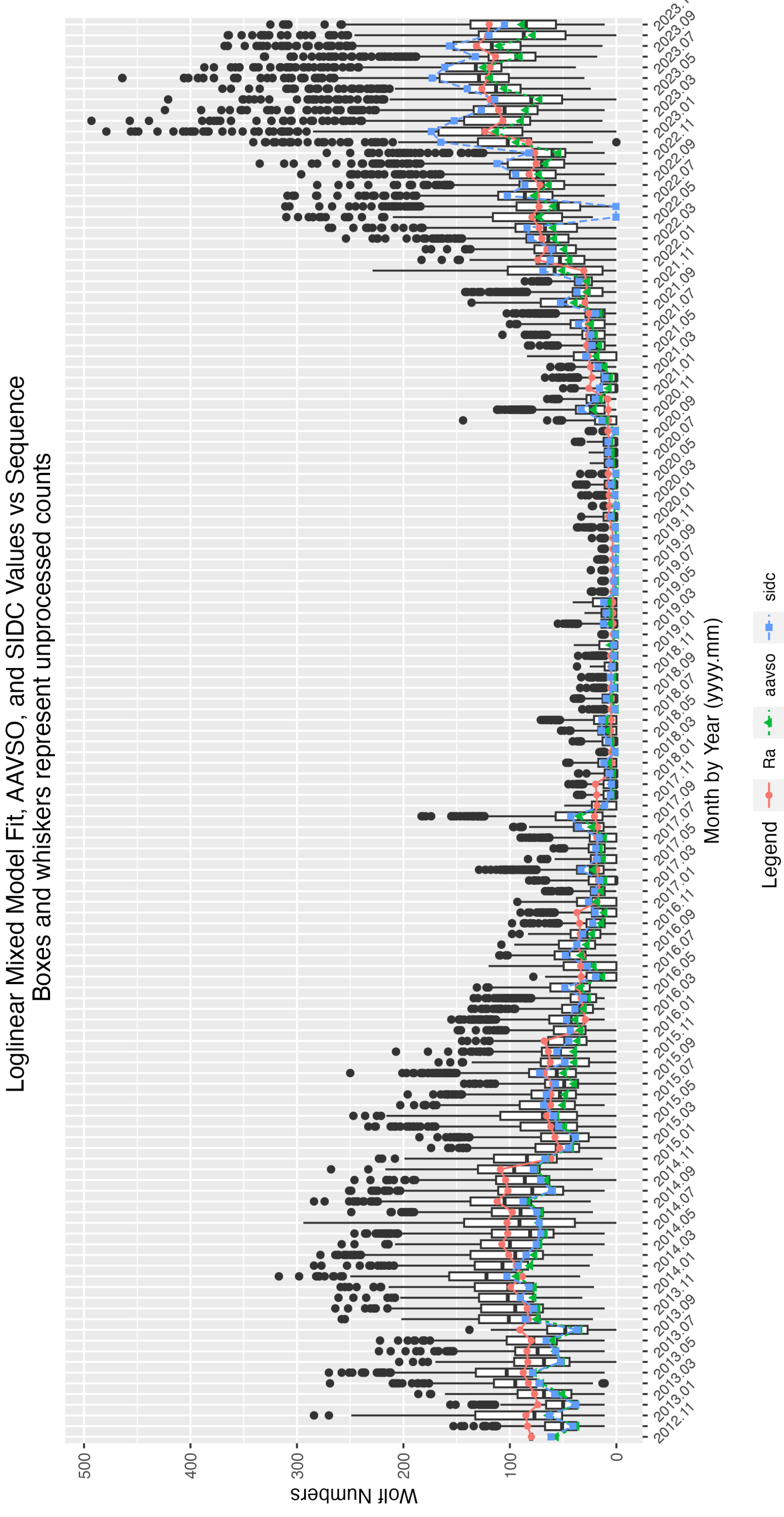


Figure 7: GLMM fitted data for $R_a$. AAVSO data: https://www.aavso.org/category/tags/solar-bulletin. SIDC data: WDC-SILSO, Royal Observatory of Belgium, Brussels

# 4 Endnotes

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

## 4.1 Antique telescope project

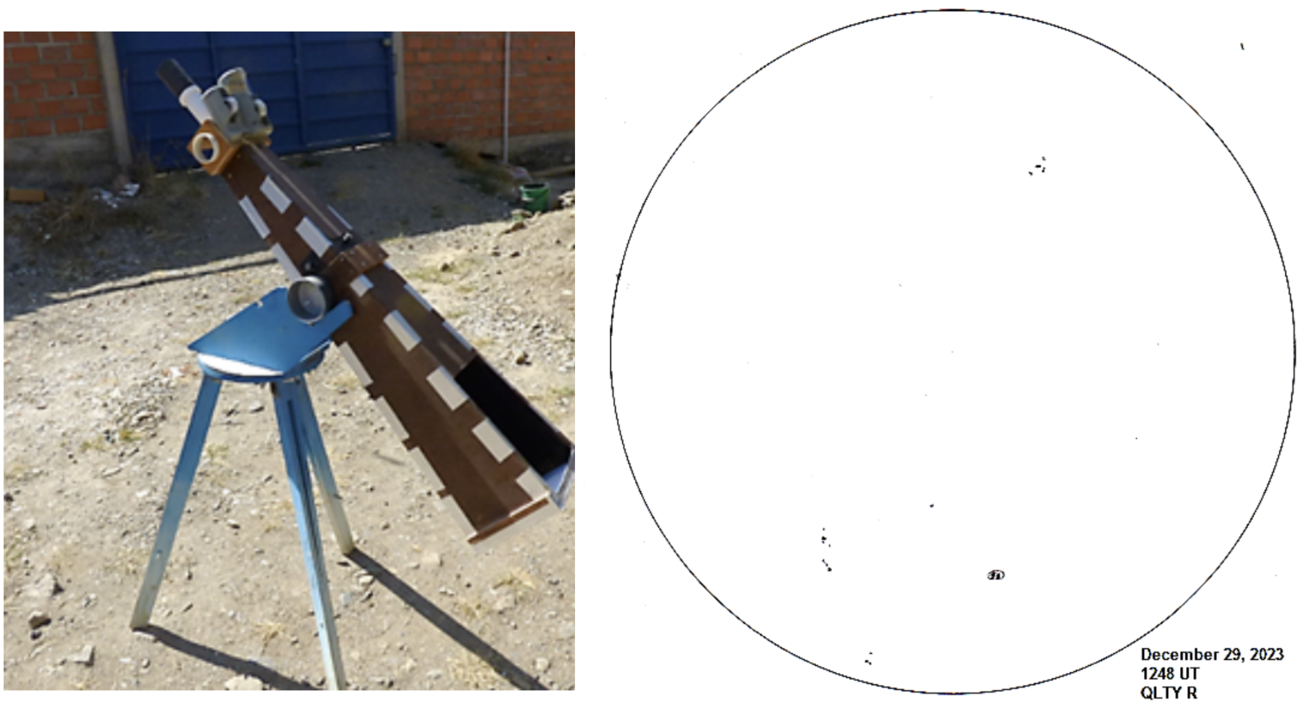


Figure 8: An antique telescope built by Gonzalo Vargas (BZX) (left). Drawing for the 29th of December, from Cochabamba, Bolivia (right).

# 5 References

Y. Natsume, Hidden Markov Models with Python, 2022, *Modelling Sequential Data Stochastically* `https://medium.com/@natsunoyuki/hidden-markov-models-with-python-c026f778dfa7`

Dr. Jamie Riggs, Solar System Science Section Head, International Astrostatistics R Statistical Software (2023), TSA Libraries: `https://cran.r-project.org`

SIDC data (2023), WDC-SILSO, Royal Observatory of Belgium, Brussels `https://www.sidc.be/silso/datafiles`

U.S. Dept. of Commerce–NOAA, Space Weather Prediction Center (2023), *GOES-16 XRA data.* `ftp://ftp.swpc.noaa.gov/pub/indices/events/`