NPHY 3rd Year Practicle

Solar Telescope

Determining differential Solar speeds

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Contents

1 Abstract

The objective of this report is verify the validity of the rotation speed equation found in Snodgrass (1983). The data compared to the Snodgrass function was 12 active regions observed between 15 August 2022 and 5 September 2022. From these active regions the average rotational speed between latitudes -30° and 30° was calculated and graphed. Afterwards Snodgrass's function was plotted on the same graph, however the graphs did not fit since the observed data had an equatiorial rotation speed of $2.75\mu rad$ per second. whereas Snodgrass had a rotation speed of $2.9\mu rad$ per second. However, there was a relationship observed between the two, therefore there is a possibility that the data fill fit better if more observations were given. In conclusion Snodgrass's function not a valid approximation for our data.

2 Introduction

The name of our Sun is Sol and is estimated to be 4.6 billion years old, making it a yellow Dwarf star. It is the largest object in our solar system with a radius of about 695 000 km and a mass of $1.9885x10^{30}$ kg. The Sun is 109.2 times larger than Earth and needs about 1.3 million Earths to fill the Sun's volume (NASA, 2022). The distance to the Sun is 150 million kilometers away, however the scientific distance is 1 Au. The main elements of any star is Hydrogen and Helium that's responsible for nuclear fission, however stars have other elements that are heavier than H and He, we call this a stars metallicity. Our Sun mass consist of 92.1% H and 7.9% He whereas the remaining 0.1% is heavier elements (Space, 2012).

A synodic period is the time it takes an celestial body to return to approximately the same position relative to another celestial body, whereas sidereal periods is the time a celestial body takes to return to its original position relative to fixed stars (Ford, 2020). When an object has varying sidereal periods along its latitude it's considered that it has a differential rotation rate. The period at the equator is 24.47 days, whereas the period at the poles are 35 days. This means that the objects rotates the fastest at the equator than the poles (Stanford.edu, 2022).

We can measure the rotation by observing how a solar active region changes, these active regions are places where the Sun's magnetic fields are disturbed and can easily be seen by locating sunspots. These regions can spawn various types of solar activity such as solar flares and coronal mass ejections (Ucar.edu, 2022).

We observe can observe the Sun through various Sun-exploring observatories such as Solar Dynamics Observatory (SDO) or SOLO. These observatories can have multiple instruments that can help observe specific solar activities. The Atmospheric Imaging Assembly (AIA) instrument can view certain active regions depending on the wavelength measurement.

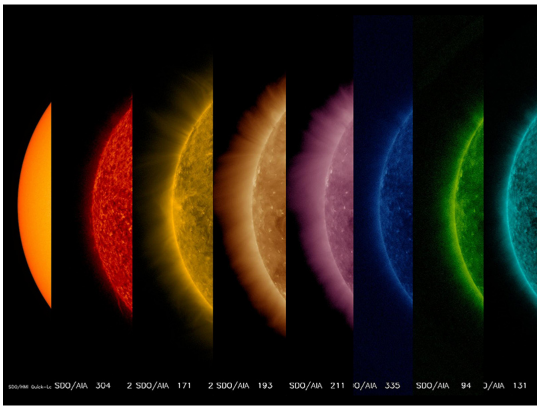

Figure 1: *Images captured by SDO with various wavelengths in the AIA instrument. Each wavelength gives some specific solar activity*

The SDO observatory with the AIA 171 instrument is best used for viewing flares or active regions(Helen, 2014). The image below visualizes some solar activities, more specifically a filament and prominence. Filaments are huge plasma arcs that appear above sunspots, they are usually held up by strong magnetic fields. Filaments can remain for several days, they travel along the longitude at different rates depending on its latitude.

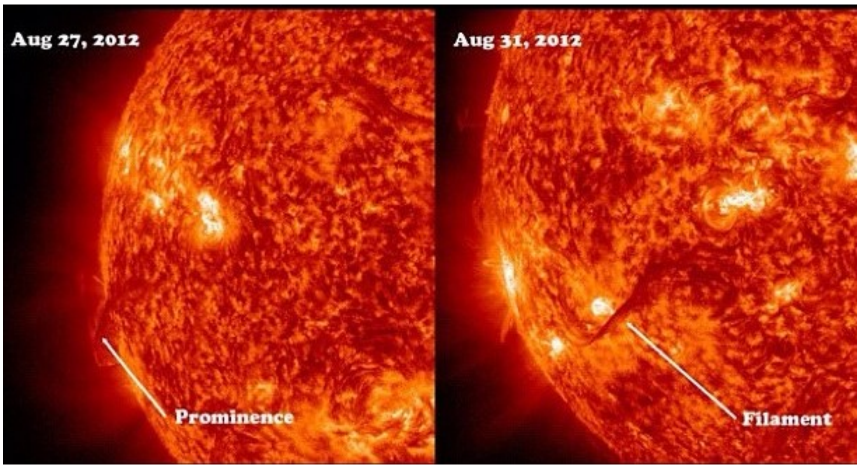

Figure 2: *The left image shows an example of a prominence, since the plasma arc is visible over the Sun's horizon, whereas the right image shows the arc over the Sun's surface*

The following figure shows examples of how the AIA SDO with three different wavelength filters captured the same solar events on 27 October 2022. The AIA 171 filter shows the strong magnetic fields whereas the AIA 211 shows dark spots which are cool dense plasma spots on the surface known as the coronal holes (Ucar.edu, 2014).

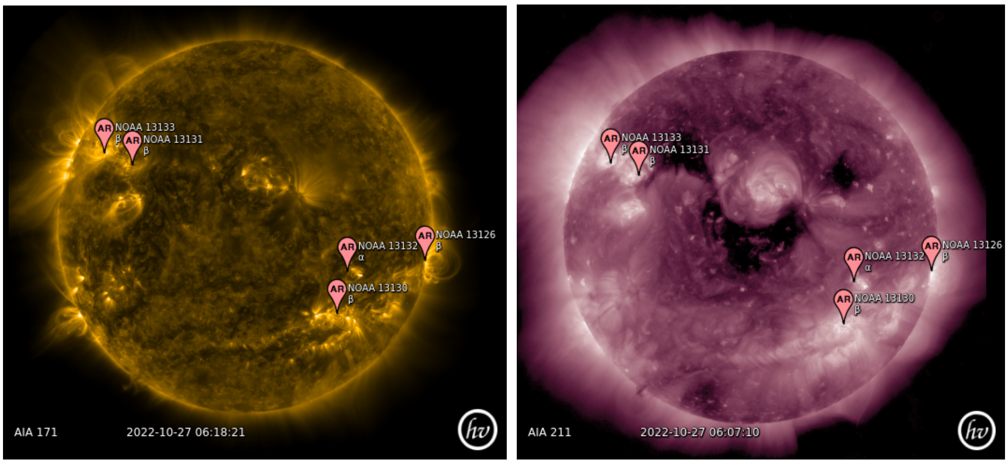

Figure 3: *This figure captured the same solar activities in wavelength 17.1 nm and 21.1 nm, which are used to study magnetic fields and coronal holes. Image credit: NASA*

The AIA 304 filter shows filaments and prominences like the arc of plasma above solar activity NOAA 13133, and the last usefull instrument is SDO Helioseismic and Magnetic Imager (HMI) instument that measures ripples and the magnetic fields ans show us sunspots.

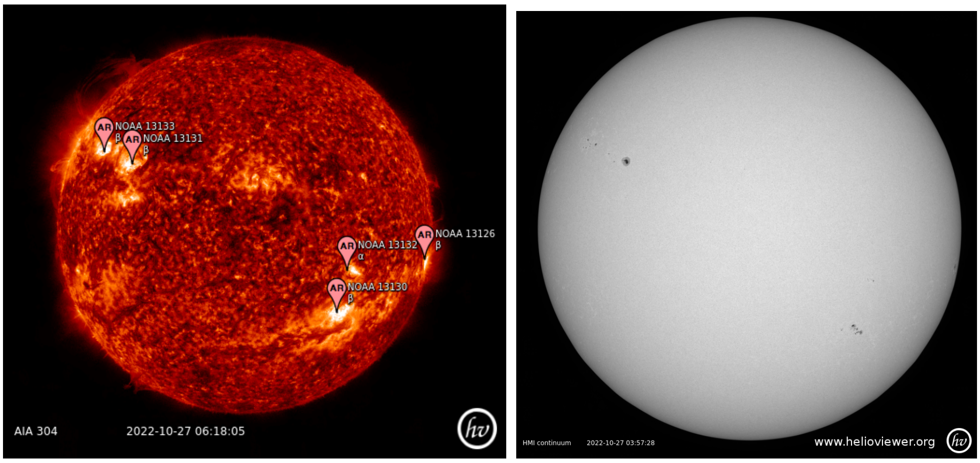

Figure 4: *This figure captured the same solar activities in different wavelength filters. Image credit: NASA*

By using these various filters we can observe almost everything that happens with the Sun, the area at which these events happen is known as active regions. The aim of this report is to determine the differential rotation rates at various latitudes, by observing the behaviour of active regions on the sun, over a period of a month. As well as validating an differential rotation rate equation.

3 Method

The data used throughout this report was the behaviour of 12 active regions over a period of 21 days, 15 August to 5 September. To make calculations easier I sorted the data by their active region name, afterwards the average differences between the the same active region were calculated and tabulated in table 2.

The differential rotation rate of each active region was then calculated in degrees per day, through the following equation:

$$\omega = \frac{Distance}{\Delta Time} \tag{1}$$

where the distance was the average difference in longitude, and the time was the difference in decimal hours. However we need also the speed in terms of in terms of μrad per second:

$$\omega = \frac{Distance}{Time} \frac{1}{(180 * 3600) * (10 * 10^6)} \tag{2}$$

The final calculation made was determining the period of at each latitude:

$$Period = \frac{360 \ \ degrees}{speed} \tag{3}$$

,where the speed is from equation 1. An summary of these data points can be found in table 2. Afterwards both differential rotation rates were plotted on the same figure against the latitude. A curve was then predicted by using a python library and compared to an differential rotation rate equation obtained from Snodgrass (1983),

$$\omega(\phi) = 2.902 - 0.464 * sin(\phi)^2 - 0.328 * sin(\phi)^4 \tag{4}$$

,where ϕ is the latitude of the active region. Lastly we checked if Snodgrass's approximation was valid.

4 Results

The following table contains a sample of the given data, sorted by their name. The given data includes the date and time recorded, as well as its position on the sun.

AR Name	Date	Time	Latitude	Longitude
AR3074	2022-08-15	11:07:36	-16.0	125.0
AR3074	2022-08-16	10:56:56	-17.0	112.0
AR3076	2022-08-15	11:07:36	17.0	155.0
AR3076	2022-08-16	10:56:56	16.0	142.0
AR3078	2022-08-15	11:07:36	-23.0	184.0
AR3078	2022-08-16	10:56:56	-23.0	171.0
AR3078	2022-08-17	11:31:30	-24.0	159.0

Table 1: *This is an sample of the orginized given data, indicating the date and time of record, aswell as the position of the of active region. The full table can found in the addendum*

From the given data we can construct a figure that shows the position of all the recorded solar activities:

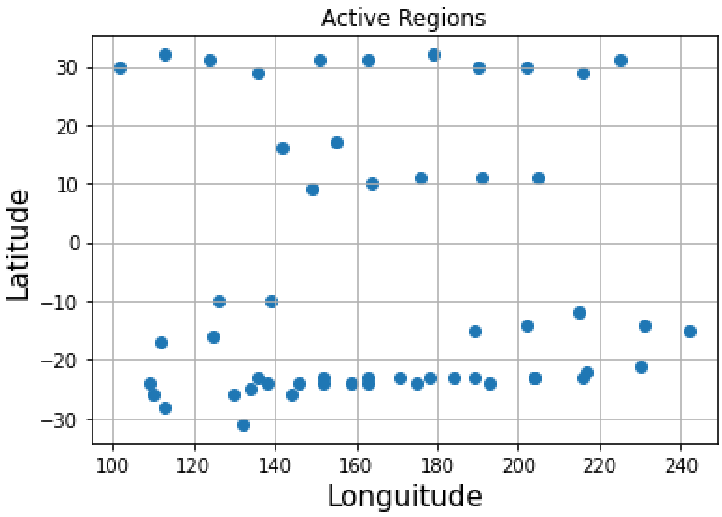

Figure 5: *A rough view of each active region and how it moves*

From the above graph we visualize the paths of the active regions, however since we want to calculate the speed of each active region, we need to know the distance it traveled. This can be done by the calculating the difference between the longitude and latitude for each active region,aswell as the difference between the times recorded. These differences can be seen in table 2.

From this table we can calculate the rotation speed of each active region, however we first need to calculate the average differences between the time, latitude and longitude. The average time

AR3074 is 0.993 days or 23 hours 49 minutes and the difference traveled was 13 degrees. With these values we can calculate the rotational speed by using equation 1 first then use that value to calculate the wanted rad/sec speed:

$$\omega = \frac{13 \quad degree}{0.993 \quad days}$$
$$= 13.097 \quad \frac{deg}{day}$$

However we want the rotational speed in $\frac{\mu rad}{s}$ by using equation 2,

$$\omega = 2.646\frac{\mu rad}{sec}$$

To determine the period of a certain longitude we use equation 3. All the calculated values are tabulated below, it contains all the important information about the given Active Region.

Name	$\Delta Time$ [Day]	Latitude [Degree]	Longitude [Degree]	speed $[\frac{deg}{day}]$	speed $[\frac{rad}{s}]$	Period [Days]
AR3074	0.993	-16.5	-13.0	13.097	2.646	27.487
AR3076	0.993	16.5	-13.0	13.097	2.646	27.487
AR3078	0.995	-23.8	-12.5	12.566	2.538	28.649
AR3079	0.993	-10.0	-13.0	13.097	2.646	27.487
AR3081	0.995	10.4	-14.0	14.074	2.843	25.58
AR3082	0.981	30.0	-11.5	11.72	2.367	30.717
AR3083	0.922	-26.0	-14.0	15.178	3.066	23.719
AR3085	0.988	30.75	-12.571	12.721	2.57	28.3
AR3086	1.004	-23.286	-13.333	13.277	2.682	27.114
AR3087	1.01	-14.0	-13.25	13.116	2.649	27.447
AR3088	0.954	-28.333	-11.0	11.525	2.328	31.237
AR3089	1.242	-23.111	-15.125	12.175	2.459	29.569

Table 2: *This table contains the average differences in active regions*

From the above table we can graph the differential rotation of the Sun in both rate units (figure 6), as well as a graph that visualizes the period at each latitude (figure 7).

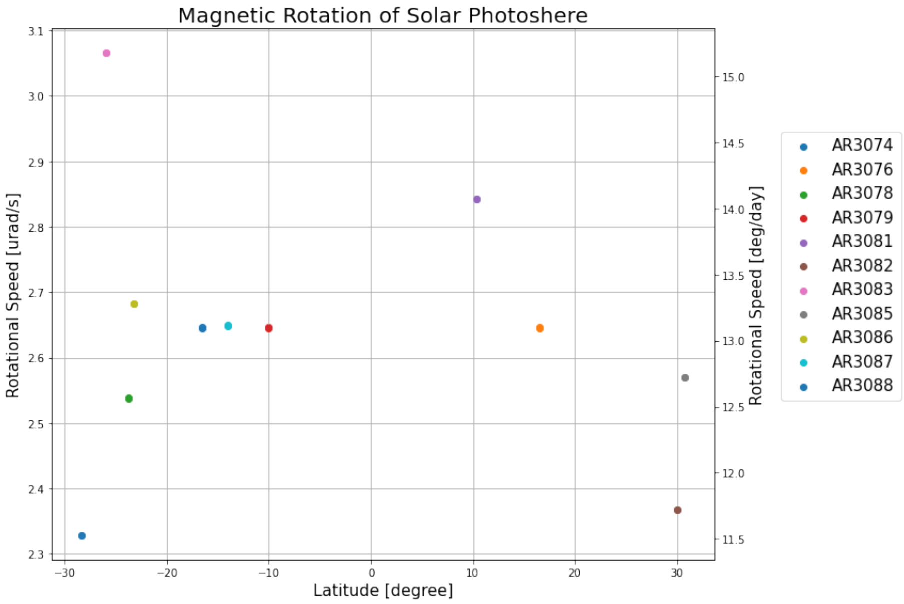

Figure 6: *This figure indicates the calculated period of the active regions. From this figure we observe that the further away a active region is from the equator, the longer its period is.*

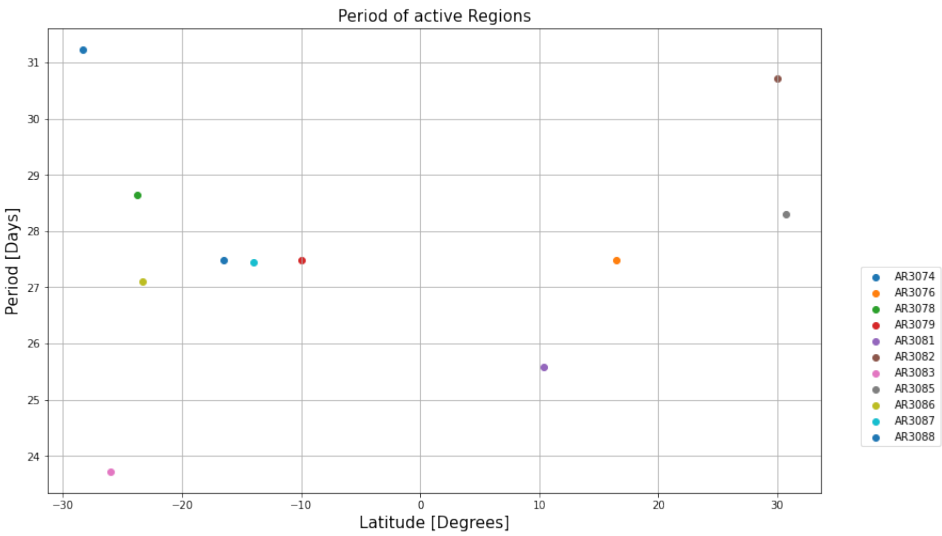

Figure 7: *This figure indicates the calculated period of the active regions. From this figure we observe that the further away a active region is from the equator, the longer its period is.*

The last graph in this report is the calculated rotational speed plotted alongside the Snodgrass's equation (4). An Python code generated an possible sinusoidal function that fits our observed data, however python refused to generate a possible fit.

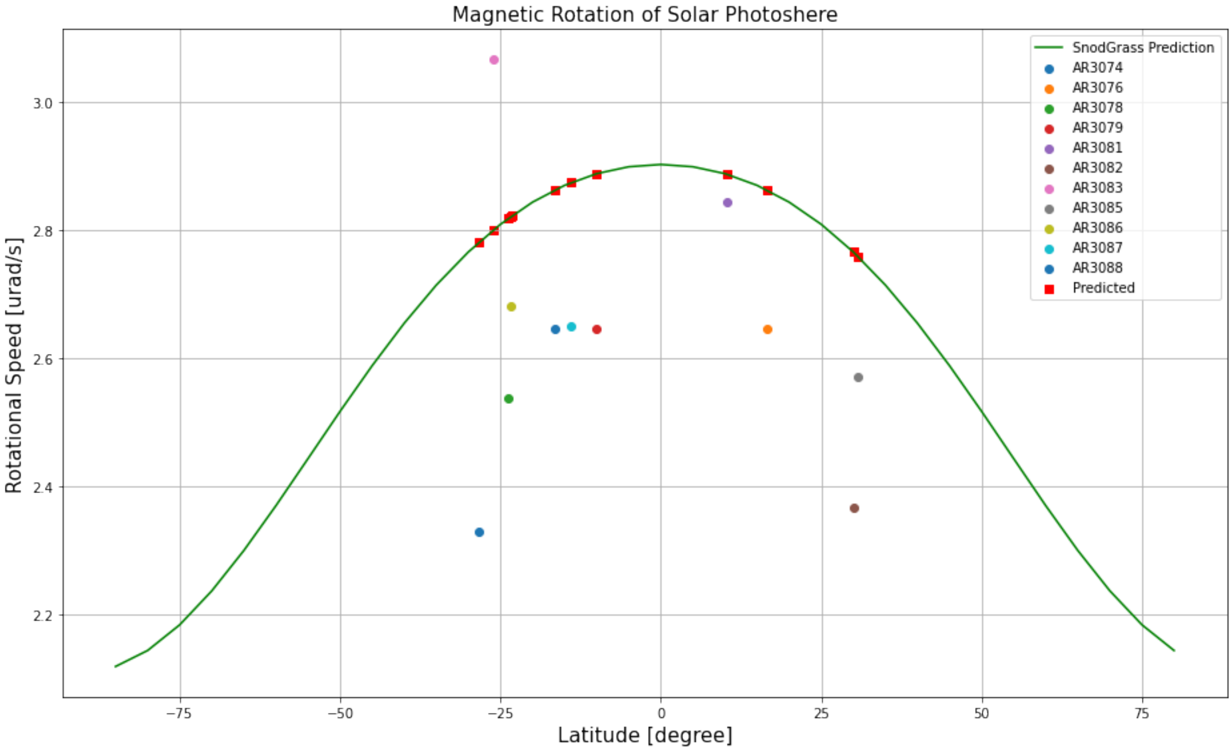

Figure 8: *This figure compares the observed data throughout the report against Snodgrass's rotational speed equation. The observational data has an equatorial speed of approximately* 2.75 *μrad per second, whereas Snodgrass has* 2.9 *μrad per seconds*

5 Discussion and Conclusion

As mentioned in the introduction the aim of this report is to calculate the different differential rotations of the sun and compare the result to a predicted model. This was done by observing several active regions for a period of 18 days, 15 August to 5 September, and a total of 12 active regions. This observed data can be found in table (3), however this data is visualized in figure 5.

The average differences of each active region can be found in table 2, and is visualized in figure 6. From this figure we observe that the active region that is nearest to the equator is AR3079 with has a latitude of -10 degrees and a rotational speed of 2.646 rad/s, with a period of 27.487 days. Whereas the active region furthest away from the equator was AR3085 with a latitude of 30.75 degrees and a rotational speed of 2.57 rad per second, with a period of 28.3 days. Since there is a difference in rotational speed between two latitudes, hence differential rotation is valid here, it is certain that the Sun is a non-solid celestial body.

By observing figure 7 we can visually see that the further away an active region is from the equator, the longer period it has. From this figure differential rotation is proven, however except for active region 3083. According to table 2 AR3083 has the highest value rotation rate, and the shortest period even though it is located at a latitude of -26 degrees. This is either an observational error or the Sun has a shorter radius at latitude value -26 degrees. But since only have 2 data points for AR3083, its more plausible that its an observational error.

The aim of this report was to calculate the differential rotation rate at various latitudes by observing solar activities, and then comparing these rates to a theoretical rates obtained from Snodgrass's equation, therefore the final graph. However the python curve fitting software couldn't compute an fit, nonetheless we can see an sinusoidal wave peak that has is smaller than Snodgrass's. The estimated equatorial speed of our observations are around $2.75\mu rad$ per second, where as Snodgrass's equatorial speed is $2.9\mu rad$ per second.

An possible reason that our peak is smaller (a slower equatorial differential rotational rate), could be because we have less than one month's solar activity behaviour, whereas Snodgrass uses 15 years worth of observational data. Therefore if we had more observational data we could have fitted a more accurate rotational speed graph. In conclusion, Snodgrass's equation (4) is a not an valid approximation for our data since it gives an faster equatorial rotational speed than our observed data.

6 Bibliography

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7 Addendum

Name	Date	Day	Month	Time	Latitude	Longitude
AR3074	2022-08-15 11:07:36	15	8	11:07:36	-16.0	125.0
AR3074	2022-08-16 10:56:56	16	8	10:56:56	-17.0	112.0
AR3076	2022-08-15 11:07:36	15	8	11:07:36	17.0	155.0
AR3076	2022-08-16 10:56:56	16	8	10:56:56	16.0	142.0
AR3078	2022-08-15 11:07:36	15	8	11:07:36	-23.0	184.0
AR3078	2022-08-16 10:56:56	16	8	10:56:56	-23.0	171.0
AR3078	2022-08-17 11:31:30	17	8	11:31:30	-24.0	159.0
AR3078	2022-08-18 09:39:46	18	8	09:39:46	-24.0	146.0
AR3078	2022-08-19 10:37:27	19	8	10:37:27	-25.0	134.0
AR3079	2022-08-15 11:07:36	15	8	11:07:36	-10.0	139.0
AR3079	2022-08-16 10:56:56	16	8	10:56:56	-10.0	126.0
AR3081	2022-08-15 11:07:36	15	8	11:07:36	11.0	205.0
AR3081	2022-08-16 10:56:56	16	8	10:56:56	11.0	191.0
AR3081	2022-08-17 11:31:30	17	8	11:31:30	11.0	176.0
AR3081	2022-08-18 09:39:46	18	8	09:39:46	10.0	164.0
AR3081	2022-08-19 10:37:27	19	8	10:37:27	9.0	149.0
AR3082	2022-08-17 11:31:30	17	8	11:31:30	31.0	225.0
AR3082	2022-08-18 09:39:46	18	8	09:39:46	29.0	216.0
AR3082	2022-08-19 10:37:27	19	8	10:37:27	30.0	202.0
AR3083	2022-08-17 11:31:30	17	8	11:31:30	-26.0	144.0
AR3083	2022-08-18 09:39:46	18	8	09:39:46	-26.0	130.0
AR3085	2022-08-22 09:56:32	22	8	09:56:32	30.0	190.0
AR3085	2022-08-23 10:26:06	23	8	10:26:06	32.0	179.0
AR3085	2022-08-24 09:22:15	24	8	09:22:15	31.0	163.0
AR3085	2022-08-25 07:57:55	25	8	07:57:55	31.0	151.0
AR3085	2022-08-26 12:32:13	26	8	12:32:13	29.0	136.0
AR3085	2022-08-27 11:55:50	27	8	11:55:50	31.0	124.0
AR3085	2022-08-28 10:21:07	28	8	10:21:07	32.0	113.0
AR3085	2022-08-29 07:58:12	29	8	07:58:12	30.0	102.0
AR3086	2022-08-24 09:22:15	24	8	09:22:15	-23.0	216.0
AR3086	2022-08-25 07:57:55	25	8	07:57:55	-23.0	204.0
AR3086	2022-08-26 12:32:13	26	8	12:32:13	-23.0	189.0
AR3086	2022-08-27 11:55:50	27	8	11:55:50	-24.0	175.0
AR3086	2022-08-28 10:21:07	28	8	10:21:07	-23.0	163.0
AR3086	2022-08-29 07:58:12	29	8	07:58:12	-24.0	152.0
AR3086	2022-08-30 09:58:40	30	8	09:58:40	-23.0	136.0
AR3087	2022-08-24 09:22:15	24	8	09:22:15	-15.0	242.0
AR3087	2022-08-25 07:57:55	25	8	07:57:55	-14.0	231.0
AR3087	2022-08-26 12:32:13	26	8	12:32:13	-12.0	215.0

Table 3: *All given data sorted by active region name. The data includes Date and time recorded as well as the location on the Sun it was observed.*

Name	Date	Day	Month	Time	Latitude	Longitude
AR3087	2022-08-27 11:55:50	27	8	11:55:50	-14.0	202.0
AR3087	2022-08-28 10:21:07	28	8	10:21:07	-15.0	189.0
AR3088	2022-08-26 12:32:13	26	8	12:32:13	-31.0	132.0
AR3088	2022-08-27 11:55:50	27	8	11:55:50	-28.0	113.0
AR3088	2022-08-28 10:21:07	28	8	10:21:07	-26.0	110.0
AR3089	2022-08-26 12:32:13	26	8	12:32:13	-21.0	230.0
AR3089	2022-08-27 11:55:50	27	8	11:55:50	-22.0	217.0
AR3089	2022-08-28 10:21:07	28	8	10:21:07	-23.0	204.0
AR3089	2022-08-29 07:58:12	29	8	07:58:12	-24.0	193.0
AR3089	2022-08-30 09:58:40	30	8	09:58:40	-23.0	178.0
AR3089	2022-08-31 13:07:16	31	8	13:07:16	-24.0	163.0
AR3089	2022-09-01 09:17:59	1	9	09:17:59	-23.0	152.0
AR3089	2022-09-02 10:26:51	2	9	10:26:51	-24.0	138.0
AR3089	2022-09-05 11:03:29	5	9	11:03:29	-24.0	109.0

Table 4: *All given data sorted by active region name. The data includes Date and time recorded as well as the location on the Sun it was observed.*