Solar Cycle: Relationship between sunspots, solar magnetic field, and solar corona

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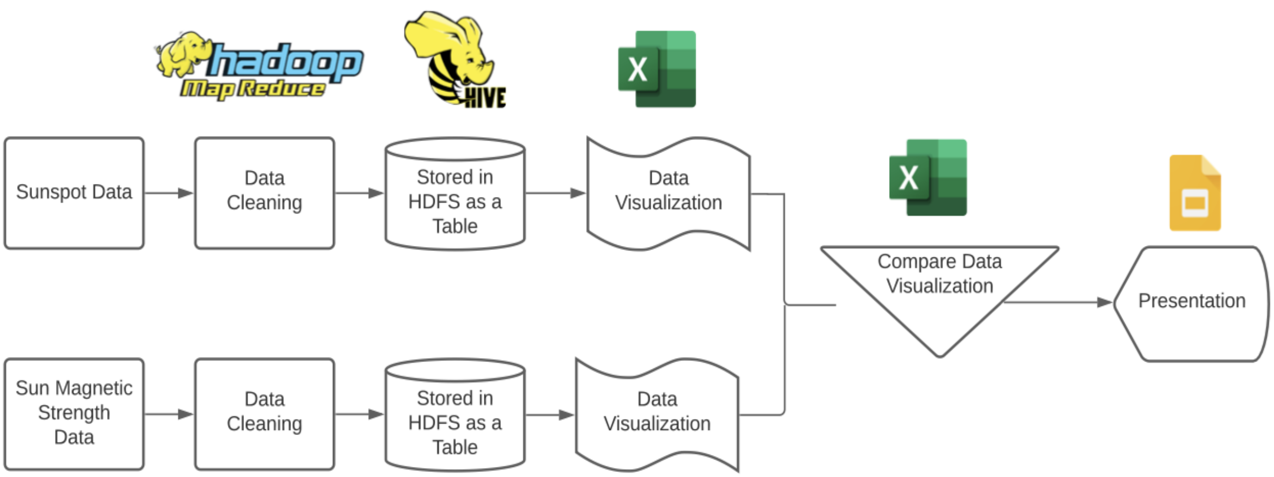
Abstract

The Solar Cycle, namely the 11-year polar reversal cycle, is a characteristic of the sun, while sunspots are cooled regions caused by solar magnetic field influxes of the Solar Cycle against solar irradiances. Sunspot data are important not only because they comprehend scientists' understanding of the solar phase, but also provide a possible way to classify stars that are similar to the sun. In this project, we proved the existence of the Solar Cycle by showing the correspondence between solar magnetic field strength, sunspot number, and the sun's luminosity. We performed data normalization and calculation using MapReduce and Hive in NYU Peel, and data visualization in Excel. Our results show the existence of that cycle.

Keywords
Solar Cycle, Sunspot, Solar Magnetic Field, Solar Corona

Introduction

Solar Cycle is a term used to describe the polar reversal cycle or a cycle of solar minimum and solar maximum. It is often used to study the sun or stars that are similar to the sun. Before going into our project, it is crucial to understand what sunspot is, and how it is formed and diminished. Like earth, the sun is sustained through its inner core. Yet much more powerful than our earth's core, the solar core is made up of hydrogens and plasmas that generate nuclei fusions (similar to hydrogen bombs) that eject flames out to the surface. The ejection is called the Coronal Mass Ejection (CME). It is the reason why the sun releases radiation and heat to its orbiting planets. CME also determines the shape of the sun as either liking a regular sphere or a distorted fireball. Though CME is powerful, solar magnetic fluxes are stronger. They sometimes push the CME down below the surface. As mentioned in the abstract, sunspot is a dark cool region with relatively lower temperature — this is because solar magnetic fluxes prevent ejections from heating up the photosphere. On top of that, the solar magnetic field is unstable — there is no rule to predict where solar fluxes go, and no way to calculate the locations, appearances, and the number of sunspots. For instance, a half-ring magnetic field flux can create two sunspots (one on the left, another on the right) while a straight line flux can create only one. With the above information, we have already noticed a positive relationship between the strength of the solar magnetic field and the number of sunspots. Furthermore, as polar reversal impacts the strength of the solar magnetic field, sunspots and sunspot numbers are also changing along with the reversal. Keep in mind that it costs less to find a dark spot than detecting magnetic waves, so observing sunspots becomes a trend for scientists to study the solar cycle. Even the first systematic discovery is through changes in sunspots. Since the sun provides enough energy to allow habitats, studying this characteristic of the sun may help scientists to quickly identify stars that are similar to the sun, and locate the planets where life is possible to exist. This is important because it helps to answer interesting questions like "is earth the only planet with civilizations" and "can humans immigrate to another planet?" Statistical information of the solar cycle can also detect the status of the sun as a check to our current understanding of this star and the "normality" of it. Back to the project, as shown in the data-flow diagram below, in order for us to detect the existence of solar cycles, we would use Hadoop MapReduce to clean related data and Hive to store them. We would also use Excel to visualize their trends separately and combine them to construct our proof that there is a cycle.



Motivation

The sun is the closest star to our Earth. It is one of the main factors why Earth is a suitable environment for organisms to thrive. This means that astronomers can even detect a "second Earth" if they can prove the correspondence between the sun and the star that the planet is orbiting. So, studying the characteristics of the sun is important, and examining the polar reversal (the solar cycle) of the sun is crucial. This is not only for scientists who wish to study and classify stars, but also for people who look to immigrate or to collect more resources from other planets similar to that of our earth.

Related Work

The Solar Flux and Sunspot Number; A Long-Trend Analysis by Babu Ram Tiwari and Mukul Kumar

Researchers investigated the monthly sunspot number reports and solar flux F10.7 (noise generated by the Sun at 10.7 cm wavelength that can be used to model solar emission) by employing the linear and multiple regression techniques. They correlated the monthly mean sunspot number with solar flux F10.7 and observed that even in deep solar minimums exist some magnetic activities. They extended the modeling of solar flux F10.7 back to the year 1700 and proved a good correspondence between the modeled and observed solar activity result using solar flux F10.7. They estimated the correlation coefficient for sunspot number and solar flux F10.7 to be a high 0.97.

On Polar Magnetic Field Reversal in Solar Cycles 21, 22, 23, and 24 by Mykola I. Pishkalo

Researcher Pishkalo analyzed the Sun's polar magnetic field activity near the maximum of sunspot activity, and proved that the polar reversal took place near the peak of solar magnetic field strength. He used data of the Solar Cycles 21 to 24, and observed the abnormality of Solar Cycle 24 of having triple polar reversals (in recognition that different reports of Solar Cycle 24 generate different conclusions). His data showed not only was Solar Cycle 24 indeed unusual, but also the solar magnetic field strength was decreasing over cycles with Solar Cycle 24 occurring at the minimum of the average solar magnetic strength (of Cycle 21 - 24). Also, the polar reversal in Solar Cycle 24 happened years later than that of the other cycles (under the same scale). Lastly, Pishkalo predicted based on the current data that Solar Cycle 25 would be similar to Solar Cycle 24.

What will the Solar Eclipse of 2017 look like? A Coronal Prediction by Stanford Solar Center

In this article, researchers explained the mechanism of forming a sunspot region. Specifically, a solar magnetic flux behaves like a suppressor that pushes the solar irradiation down from its surface, which results in several spot-like "blaken" regions that are observable from earth. The stronger the solar magnetic flux, the deeper and greater the number of sunspots. And since solar irradiation contributes to our perception of the appearance of the sun, there also exists a relation between the solar magnetic field and the shape of the sun. Generally, the stronger the solar magnetic flux suppression, the clearer for us to see the sun is round.

Description of Datasets

The first dataset is collected by the Royal Observatory of Belgium that records the sunspots number. It consists of year, month, day, date, number, standard deviation, and number of observations. It shows the number of sunspots each day. We used data from 1992 to 2020 and observed only the year, month, day and sunspot number since 1992 is a year when all data we used existed, and 2021 was not over yet when we determined our project's topic, and we only needed those fields in our project.

1992	1	01	1992.001	186	14.3	19
1992	1	02	1992.004	190	8.2	21
1992	1	03	1992.007	234	18.3	21
1992	1	04	1992.010	243	14.8	20
1992	1	05	1992.012	242	13.8	18
1992	1	06	1992.015	245	18.7	14
1992	1	07	1992.018	251	20.9	14
1992	1	08	1992.020	270	19.2	20
1992	1	09	1992.023	255	18.2	10
1992	1	10	1992.026	242	12.4	18
1992	1	11	1992.029	205	9.5	20
1992	1	12	1992.031	189	11.0	16
1992	1	13	1992.034	188	8.9	18
1992	1	14	1992.037	143	7.6	17
1992	1	15	1992.040	141	7.3	17
1992	1	16	1992.042	115	4.8	14
1992	1	17	1992.045	100	7.0	22
1992	1	18	1992.048	94	10.8	24
1992	1	19	1992.051	116	7.9	15
1992	1	20	1992.053	152	8.7	18
1992	1	21	1992.056	188	6.8	22

The second dataset comes from the Wilcox Solar Observatory, which is solar magnetic field strength data. The column of data is presenting the month of that date, and the row presents the day of that date, the value is the magnetic field strength of that date. Here we took advantage of the values in the form of year, month, date, and solar magnetic strength to infer the change of magnetic field strength of the sun.

Stanford Mean Solar Magnetic Field (microTesla)

1992

day	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
01	-97	-6	73	53	7	14	8	39	88	.	19	-16
02	-78	25	.	25	0	17	17	60	67	.	-5	.
03	-45	72	61	10	-1	23	13	58	43	.	-24	.
04	.	8	78	0	21	47	.	58	-22	.	-41	-39
05	53	28	.	-14	25	52	33	46	-27	.	-57	-38
06	.	.	.	-13	32	17	39	38	-18	.	-47	.
07	.	.	27	11	43	-5	21	37	13	4	-48	-20
08	104	.	19	21	43	-12	18	-4	24	-17	.	.
09	101	.	-3	1	33	-18	29	-45	19	-40	-29	.
10	125	.	15	-7	15	-18	39	-44	29	-68	-7	.
11	145	.	17	.	-13	-2	.	-10	-18	-57	-1	.
12	126	7	8	.	-19	20	.	-2	-25	-31	-5	-50
13	102	.	28	-34	-30	20	-55	10	-53	-38	-16	-41
14	54	.	.	-61	-44	18	-46	9	-46	-29	-24	-15
15	37	.	.	4	-50	6	-16	34	-33	-33	-23	8
16	12	.	.	-81	-14	-18	2	14	-30	-14	-19	11
17	-21	.	-31	-138	25	-13	8	-19	-26	-5	20	.
18	-43	.	-54	-121	.	-19	24	-4	-26	-13	57	6
19	-46	.	.	-59	21	12	25	11	-9	.	.	-9
20	-20	-33	.	-42	28	35	-31	-14	-13	-5	.	.
21	.	.	.	-19	39	23	-56	-12	-22	24	-2	-3
22	-6	-34	.	-9	35	10	-55	-17	-23	34	.	11
23	-16	-75	-50	3	62	-21	-59	-3	-1	66	-9	42
24	0	-64	13	20	88	-50	-55	-6	17	65	.	57
25	-46	-11	40	46	85	-45	-42	1	54	47	.	49
26	-36	75	40	70	50	-36	-26	4	79	20	.	40
27	-113	58	39	72	-64	-11	-5	25	85	-7	60	.
28	-126	63	55	49	-51	.	1	55	60	.	62	.
29	-115	.	.	42	-27	.	4	.	39	.	55	.
30	-74		.	27	-13	17	-1	101	7	-14	11	-59
31	.		82		8		-5	97		22		.

The third dataset is Solar Coronal Index Data with the data format itself similar to that of the solar magnetic field data. Since the solar coronal index accounts for the green corona emitted by the sun's visible hemisphere (to earth), we drew a parallel line between it and the sun's luminosity. This data is provided by the National Centers for Environmental Information.

1992 CORONAL INDEX OF SOLAR ACTIVITY 1992

Slovak Academy Fill-Disk Fe Emission (530.3 nm) Units=10**16 W/sr

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	16.04	14.26	14.23	13.62	12.18	9.58	8.45	8.48	8.79	8.36	8.88	10.68
2	15.91	13.08	14.33	12.60	12.06	9.58	8.39	9.18	9.00	8.91	8.33	8.88
3	16.99	12.76	14.26	13.28	11.63	9.94	8.81	9.17	8.93	9.17	8.49	9.84
4	17.90	13.02	14.12	12.97	11.19	9.98	8.86	10.10	8.79	9.03	8.13	9.61
5	17.22	12.74	14.25	12.62	10.94	9.75	9.51	10.36	8.55	8.85	8.43	9.49
6	16.18	12.82	14.32	12.38	10.41	10.20	11.20	10.15	8.75	9.03	8.33	9.63
7	15.46	12.87	13.88	12.11	11.19	11.12	11.57	10.95	8.41	9.18	8.31	10.20
8	14.96	13.25	13.86	11.45	11.55	9.91	11.63	11.16	8.47	9.38	8.22	9.45
9	14.92	14.08	13.77	11.86	12.00	11.21	10.66	9.92	8.43	8.86	9.49	9.53
10	14.78	14.64	13.92	11.53	12.43	11.86	11.44	10.38	8.69	8.57	8.50	9.04
11	14.02	13.64	13.81	11.53	12.98	11.32	11.41	10.36	9.03	8.44	9.71	10.20
12	13.34	12.66	13.40	12.08	12.83	11.63	11.41	10.17	8.63	8.59	8.66	10.66
13	12.98	12.85	12.65	12.68	13.65	12.06	10.93	10.89	8.26	8.42	8.81	10.69
14	12.71	13.01	12.80	12.77	14.02	11.56	10.65	11.28	8.55	8.21	8.94	11.20
15	11.93	12.81	13.00	13.08	14.30	11.24	10.30	10.26	8.59	8.28	8.91	11.10
16	11.98	12.24	13.68	13.26	13.22	10.50	10.38	9.84	9.04	7.99	8.91	9.69
17	11.60	11.66	13.91	13.77	14.07	10.49	9.97	9.42	9.64	7.89	9.21	12.00
18	12.00	12.02	14.26	14.11	13.51	10.47	10.14	9.10	9.49	7.80	9.69	11.86
19	11.98	12.76	13.79	15.23	13.83	10.54	10.08	9.61	9.32	7.79	9.31	11.35
20	11.93	13.22	14.65	14.49	13.45	10.21	9.08	8.40	9.53	7.65	9.11	11.28

Analysis

We first wrote MapReduce functions to normalize all of our data into one format.

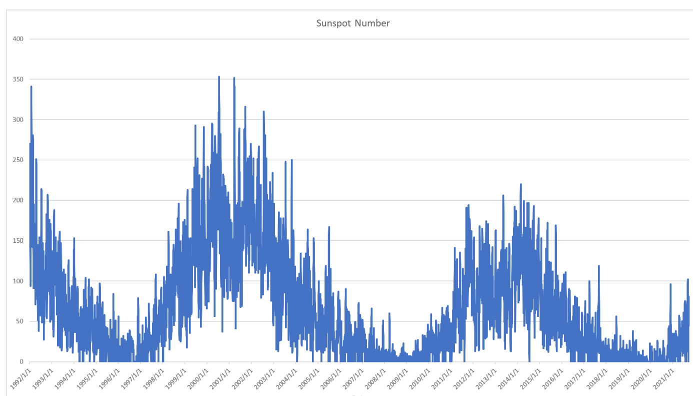
It is worth mentioning that we used different methods to concatenate solar magnetic and luminosity files. Due to each row in solar magnetic data containing multiple unusual delimiters like a mix of tabs and blanks, our MapReduce function was performed individually to each file and was updated when a new pattern was detected. On the other hand solar luminosity data is much more organized, so a single Python function was enough. After concatenation, we loaded our data into three Hive tables and changed all fields of year, month, day, and numeric values to type integer using update query. We used this data type because it is

```
1992,1,1,-97
1992,1,10,125
1992,1,11,145
1992,1,12,126
1992,1,13,102
1992,1,14,54
1992,1,15,37
1992,1,16,12
1992,1,17,-21
1992,1,18,-43
1992,1,19,-46
1992,1,2,-78
1992,1,20,-20
1992,1,21,.
1992,1,22,-6
1992,1,23,-16
1992,1,24,0
1992,1,25,-46
1992,1,26,-36
1992,1,27,-113
1992,1,28,-126
1992,1,29,-115
1992,1,3,-45
1992,1,30,-74
1992,1,31,.
1992,1,4,.
1992,1,5,53
1992,1,6,.
1992,1,7,.
1992,1,8,104
```

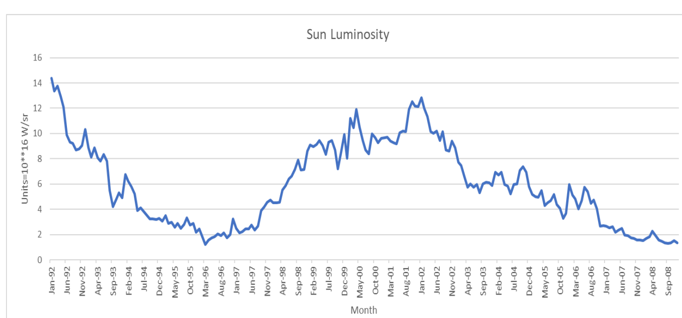
easier to sort values in ascending or descending order without distorting the original meaning of the data. We allowed number 0 to exist in sunspot, magnetic strength and luminosity field, because it is logical to have none of the sunspot or magnetic flux or luminosity. However, we did not allow negative numbers to exist in sunspot and luminosity, because it is illogical to have a non-positive number of a spot and negative luminosity as we assumed that a luminosity of 0 means to “not be seen”. In addition, we dropped all data with missing values using delete query. Note that the downside of dropping data is that the portion of each year’s data is unevenly distributed, which may result in bias. Also, we did recognize the move of observing solar data from 1992 to 2020 could be unsmart because 1992 is not the standard starting year of Solar Cycle 23 nor is 2020 the ending of the cycle. Yet the intention of this project is to prove the existence of the Solar Cycle, not the accuracy of an exact year of the beginning of the cycle. So, it is acceptable to not disinclude year 1992 to 1995 even if we knew that 1996 is the actual beginning year of Cycle 23, because it traded us with more available data. After cleaning our tables, we used average, maximum, and minimum queries of Hive to gain statistical insights of Cycle 23, 24, and 25.

Visualization

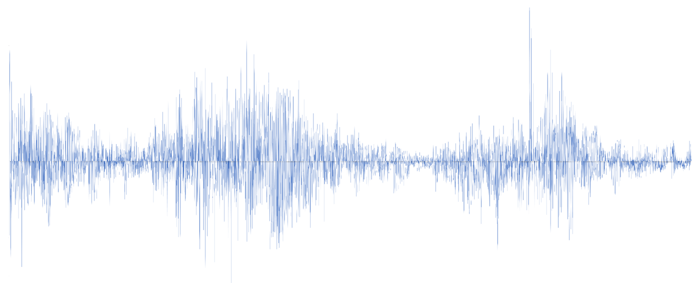
After our analysis, we put the data into Excel to get the graphs of these indexes. The first graph shows the number of sunspot numbers by date. We can see here that the number of sunspots follows a cycle of around 10 to 11 years. The first cycle ends in 1997, the second ends in 2008, and the third ends in 2019. In these cycles, the sunspot number change (parabolas) follows a similar rise and fall. And based on what we found in the analysis process, the max, min, and mean sunspot number are all very similar.



The second graph is the average luminosity of each month from 1992 to 2008. Due to the limitation of data, we cannot strictly fit the graph to the other two, but we still find a similar curve: the first cycle ends in August 1996 and the second cycle ends in 2008. Despite the similar cycle time, the trend of the rise and fall of the luminosity index is also close to



the sunspots number data.
The last graph is the analysis of solar magnetic field strength from 1992 till now. The x axis is the date and the y axis is the strength index. Again, like the two parts above, the number of magnetic field indexes also shows three cycles which matches the result of the early two's. However, we can see that the trend of it is not the same as the two above. Instead of simply rising and falling, here the number that fits the early two graphs' trend is the absolute value of the magnetic index. Again the absolute average of the magnetic field in each cycle is nearly the same, but here the second cycle's average is the negative value while the first and the third is positive value.



Conclusion
The first and the most important one is that we found that there exists a solar cycle for every 10-11 years. Inside the solar cycle we can see a trend of rising for about five years and then falling to a low level within the next five years. Aside from the cycle, there are also relationships between the three indexes. There exists a positive relationship between sunspot number and solar magnetic field strength, and a negative relationship between sunspot number and solar luminosity. Specifically, the stronger the magnetic field force, the weaker the solar influx, therefore the more possible that there is a sunspot (or "cool region") present. Specifically, the number of solar influx has a negative relationship with the sunspot number while having a positive relationship with the luminosity, we may also deduce that the greater the sunspot number, the "darker" the Sun's surface (the weaker the Sun's luminosity).

The study of the Solar Cycle can have significant meaning on knowing our Earth, as the essay from NASA demonstrates that this "activity can have effects on Earth. For example, eruptions can cause lights in the sky, called aurora, or impact radio communications. Extreme eruptions can even affect electricity grids on Earth.(NASA)"

During the research process we notice that even though there's a clear trend of cycling for these indexes, the average of these cycles is not the same. In the future we are going to explore other indexes that could affect these changes. Also, like the article said above, the change of Solar Cycle can have a huge impact on Earth, so the impact of Solar Cycle on Earth is also a part that we are going to explore in the future.

Acknowledgment

We would like to express our greatest gratitude to Professor Malavet for her teaching of Big Data tools and giving us this opportunity to work on our interest and NYU HPC Peel platform administrators for providing us a convenient way for data analysis. We would also like to thank the Royal Observatory of Belgium for publishing sunspot number data, the Wilcox Solar Observatory for solar magnetic field data, and the National Centers for Environmental Information for solar coronal index data.

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