Human health response to geomagnetic disturbances

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Abstract—**The relationship between human health and variations in the Sun and in the Earth's magnetic field could potentially have global implications. However, conflicting information exists regarding this issue because the solar activity has both positive and negative effects on human health. For example, solar activity provides a protective shield to the earth from cosmic rays and prevents our atmosphere from being eroded by solar wind. This work attempts to measure the impact of solar activity on human health, and to identify whether this impact on human health is positive (beneficial) or negative (detrimental).**

We used data on the daily number of calls to the ambulance service at Nagoya city in Japan, between 1955 and 2017. The patients were first taken to hospital by ambulance where an appropriate diagnosis was made. This data contained the number of patients with different diagnoses e.g., myocardial infarction, cerebral infarction etc.

To identify the impacts of geomagnetic storms on human health (short-term effects), an informational analysis was conducted using the Kullback-Leibler information index and Jeffrey index, which measures the distance between distributions. We extended these notions to have a plus and a minus sign, the "signed Jeffrey index", to indicate positive or negative effects due to solar activity respectively. We compared two groups of distributions of patients, one week before and after geomagnetic storms.

The minus sign of the "signed Jeffrey index" was observed with incidences of myocardial infarctions and acute heart failures whereas the positive sign was observed with incidences of cerebral infarctions.

These results suggest that geomagnetic storms and solar activity have both positive and negative short-term effects on human health that vary based on the type of diseases. Our informational methods could potentially contribute to illustrate the impact of geomagnetic storms against human health.

Index Terms—**geomagnetic storm, Kullback-Leibler, Jeffrey, myocardial infarction, acute heart failure, cerebral infarction.**

I. Introduction

In the literature, there are studies on the relationship between yearly fluctuations in solar activity and human health [1,2,3]. However, conflicting information exists regarding this relationship. There is both an increase and a decrease in the incidence of some diseases with increasing geomagnetic activity. The Earth's magnetic field acts as a protective shield against cosmic rays. A decrease in the incidence of sudden cardiac deaths has been observed following geomagnetic storms [4]. The Earth's magnetic field is known to act as a protective shield against cosmic rays. Therefore, this decrease in disease incidences may be due to a protective shield against cosmic rays.

Since the fluctuation of solar activity is characterized on a long-term scale (e.g. yearly scale), there have been studies on long-term effects of solar activity and human health with lugs of several years (cf [1,3]). However geomagnetic storms may have short-term (e.g. weekly scale) effects on human health. Thus it is crucial to assess the study of short-term effects of geomagnetic activity, for instance, addressing the daily geomagnetic effect on human health.

In this paper, we propose a new method to identify the short-term effects of an impulse of geomagnetic storms. Kullback-Leibler divergence measures the distance between probabilistic distributions. The Jeffrey divergence is a symmetric version of Kullback-Leibler divergence. We wish to extend Jeffrey's divergence to address both positive and negative effects of solar activity.

In our previous work [3], geomagnetic storms were classified into two groups; storm of sudden commencement (ssc) and storms of gradual commencement (sgc). We examined, on a yearly scale, the effects of both types of storms on yearly death rates from a range of diseases in Japan. The ssc index was significantly positively/negatively correlated with the yearly death rates. Therefore, in this paper, we focus on daily changes (or other frequency) in incidences of diseases following ssc type of storms.

For a given ssc event, we assessed the changes in distributions of numbers of patients, one week before and after a given ssc event. For this purpose, we introduced the notion, signed Jeffrey, to measure both positive and negative changes in distributions from a human health point of view.

We explored the database of ambulance calls in Nagoya city to identify disease to which a significant change in the signed Jeffrey index could be attributed.

II. Methods

The data on ambulance service calls were provided by the city of Nagoya in Japan. This included the daily number of patients between 2002 and 2017. The data of patients, regardless of age, who were first transported by ambulance to a hospital and then diagnosed at the hospital. Nagoya has a standard subtropical climate with four characteristic annual seasons and its climate is characterized by one month's rainy period.

The Kullback–Leibler divergence (KLD) is a method of measuring the fit of two probabilistic distributions [5,6]. For two different continuous distributions P, Q, KLD is defined as follows.

$$KLD(P,Q) = \int_{-\infty}^{\infty} P(x)\log\frac{P(x)}{Q(x)}dx$$

For discrete distributions, the integral is replaced by summation. In this paper, we use KLD as a measure of how a probability distribution of patients before a geomagnetic storms is different from a distribution of patients after a

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geomagnetic storms. KLD is not a distribution-wise symmetric measure and it always has positive sign or it is zero.

KLD was revised to make it symmetric as shown below; this was then referred to as the Jeffrey divergence [7].

$$J(P,Q) = KLD(P,Q)+KLD(P,Q)$$

Again, J(P,Q) was still positive or zero.

In this paper, we extended J(P,Q) so as to have both positive and minus signs for Poisson distributions P, Q. We defined signed J as follows:

$$signed\ J(P,Q) = |\lambda - \lambda'| \log \frac{\lambda}{\lambda'}$$

where λ, λ' are mean values of Poissson distribution P, Q respectively. If λ is larger than λ', then signed J has positive sign. Similarly, if λ is smaller than λ', then signed J has negative sign.

In this paper, Q represents the Poisson distribution of the number of patients before the ssc (storm with sudden increase) event. P represents the distribution after the ssc event.

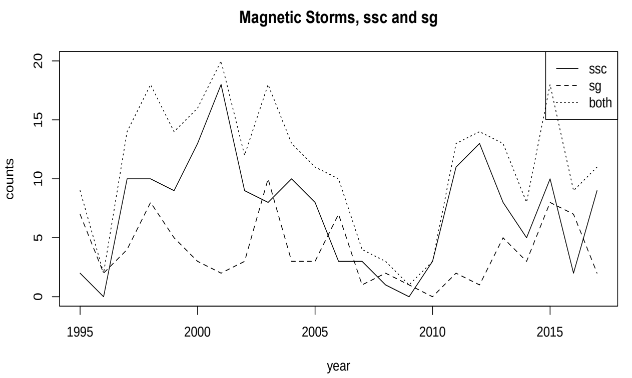
Therefore, if the mean value increases after ssc event, then signed J will have positive sign. Similarly, if the mean value decreases after ssc event, then signed J will have negative sign. Thus we can numerically measure both positive and negative effects of geomagnetic storms on human health.

III. Results

We examined, using chi-square tests, whether the daily distributions of patients could be described using Poisson distribution. These distributions fitted the Poisson distribution with 95% statistical significance level for most of diseases including cerebral infarction, myocardial infarction and acute heart failure.

Data on geomagnetic storm events were obtained from the Kakioka Magnetic Observatory in Japan. The data were classified into two categories, storms of sudden incidence (ssc) and storms of gradual incidence (sg). The storm level was expressed using the K-index (0 to 10). We selected only the type of ssc with K-index more than or equal to 5 as our storm events. The total numbers of storm events each year was formulated yearly time series, which were named "SSC INDEX" in [3]. Fig.1 shows the variability of this index from 1955 to 2017.

Figure 1. Variability of geomagnetic index, including "SSC INDEX".



Note: The straight line represents yearly changes of storms with sudden increase of fluctuations (ssc). The dashed line corresponds to storms with gradual increase of fluctuations. The dotted line is for the sum of both storms.

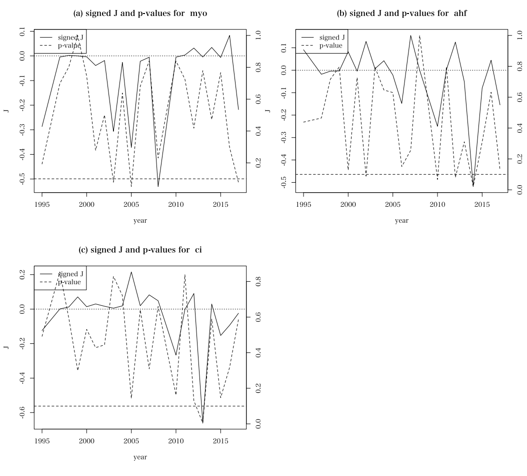
Here, we used our new index, the signed Jeffrey (signed J) to assess the relationship between magnetic storms and human health. This informative index is an extension of the Kullback-Leibler Information (see methods section). We restricted the usage of this index (the signed J) for "short-term" (i.e. weekly scale) periods. We calculated the signed J to compare the patients' distributions one week before and after the storm event. This is because our results were focused on the short-term impact of storm events on human health. The differences between the two patients' distributions of, (before and after the event) were measured by the signed J.

The calculation process was as follows: We first selected ssc-events with 5-level of K-index or more during each calendar year. Based on the calendar year (between 1955 and 2017), we defined two groups of distributions. We then collected number of patients one week before storm events in the same year. This formed one group of data of patients. The other group of patients was drawn from patients reported one week after the storm events. The distribution of each group followed a Poisson distribution. We estimated the distance between the two distributions by calculating the signed J (singed Jeffrey index) for these two distributions. We called these two distributions, "pre-distribution" and "post-distribution" respectively. If the mean of post distribution exceeded the mean of pre-distribution, then signed J had a plus sign. If the mean of post distribution fell below the mean of pre-distribution, then signed J had a minus sign.

The stochastic significance was verified using the following mathematical facts: If X obeys Poisson distribution of mean r, then n-samples X1, X2, ..., Xn obeys Poisson distribution of mean nr.

Fig. 2 (a,b,c) shows the yearly changes of the signed J and p-values for myocardial infarction, acute heart failure and cerebral infarction. The level of 90% confidence level is shown by the horizontal dotted line.

Figure 2. Variability of signed Jeffrey (signed J) for myocardial infarction, acute heart failure and cerebral infarction from 1955 to 2017



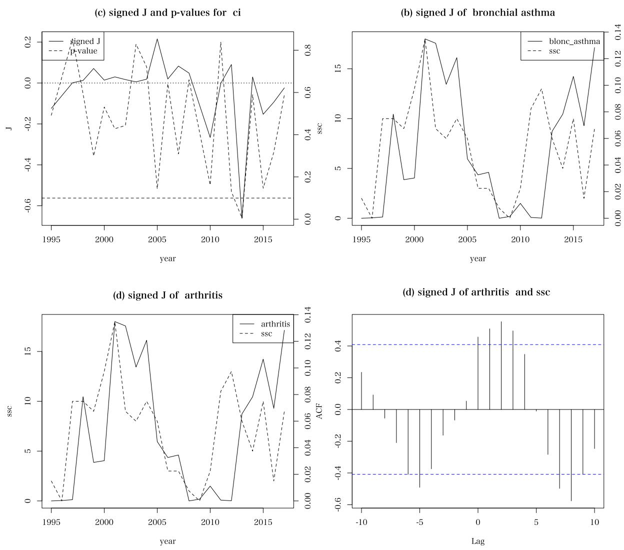
Note: (a) myocardial infarction, (b) acute heart failure, (c) cerebral infarction. The dashed horizontal line indicate p-value less than 10 %.

Regarding myocardial infarction and acute heart failure, the index signed J generally had a negative sign. This implies that the means of the post-distribution decreased after the ssc event. Since cosmic radiation is known to be negatively correlated with solar storms, it is possible these diseases maybe be influenced by cosmic rays. Conversely, for cerebral infarction, the general sign of the signed J was positive, except during the year 2013.

To further investigate the effect of storm events on cerebral infarction, we examined the "long-term effects" of geomagnetic storms. Because geomagnetic storms were very weak and rare in 1995, we used the patients' distribution ci in 1995 as the basic distribution, i.e., Q in signed J(P,Q) s out "pre-distribution". We calculated the signed J(P,Q) computing P the distribution of each year (excluding 1995) between 1955 and 2017. Thus we explored the differences in the distribution between the basic year 1995 and other years. The first picture of Fig.3 shows that the incidences of cerebral infarctions after the ssc with the lags of several years.

Similar methods of assessing long-term effects of geomagnetic storms were applied to various diseases. Among these diseases, a significant difference was observed with only athritis. Fig.3 shows the time series of the signed J and the ssc index. The figure shows that the variability in these two indices was similar and that the ssc index precedes the signed J index.

Figure 3. Long-term effects of geomagentic storms against cerebral infarction, arthritis and asthma.



Note: (a) cerebral infarction, (b) bronchial asthma, (c) arthritis, (d) ccf of signed J of arthritis and ssc-index

To further clarify this feature, we calculated the cross correlation function (ccf) of these two indexes, the signed J of arthritis and the ssc-index. The last picture of Fig.3 shows that the signed J preceded the increase/decrease in incidences of arthritis for 0~3 years with 95% significance level.

IV. Discussion

This study explored the effects of fluctuations in geomagnetic activity on the incidence of various diseases. For this research study, the distributions of incidences of diseases were compared before and after an event of geomagnetic storms. By extending informatics measurements, we developed a new method, the signed Jeffrey, based on the Kullback-Leibler informatics.

We examined changes in distributions of patient calls to the ambulance service one week before and after events of geomagnetic storms, especially storms with sudden increase in fluctuations (called ssc). We identified a stochastically significant decrease in the incidences of myocardial infarction and acute heart failure following these events (see Fig.2). The changes in Poisson distributions of incidences before and after the event of geomagnetic storms (ssc) were observed by measuring their signed Jeffrey index.

There have been studies on long-term effects of geomagnetic storms with lugs of several years (cf [1,3]). However, limited research addresses short-term impulses with daily lugs. We used the signed Jeffrey to address this gap and to identify the impact of geomagnetic storms. We found that the signed Jeffrey was an effective index in identifying impact response

This negative effect (the decrease of incidences) of short-term impulses of geomagnetic storms on human health may be explained by the nature of cosmic rays. Solar activity usually provides a protective shield against cosmic rays and prevents our atmosphere from being eroded by solar wind. An increase in the incidence of Sudden Cardiac Death (related to Ventricular Tachycardia and Ventricular Fibrillation) (VT,VF) is often accompanied by higher Cosmic Ray (Neutron) activity [4]. A decrease in sudden cardiac deaths after the geomagnetic storms may therefore be due to the protective shield against cosmic rays. Our results as regards myocardial infarction and acute heart failure concur with this observations documented by Wing and sto (2019) [1,3,4].

Regarding cerebral infarction, we identified positive response (see Fig.2) using the same method (signed Jeffrey). This finding is aligned to that of Ghi et al (2019) [3, 8]. Ghione et al. (1998) reported a positive correlation between geomagnetic activity and blood pressure in humans. However, systolic blood pressure had a higher correlated with geomagnetic activity when compared to diastolic pressure. The maximum correlation was obtained after a delay of 3 days (to the nearest whole day); this corresponds to the time required for solar wind from an active region on the sun to reach the earth's surface.

Although cerebral infarction was mainly positively correlated with the sign of signed J, there was a year with negative correlation, i.e., 2013. To further investigate this, we looked into the "long-term effects" of geomagnetic storms on human health. Since geomagnetic storms were very weak and rare in 1995, we calculated the signed J(P,Q) the distribution of patients of ci in 1995 as basic distribution, Q. We calculated the signed J(P,Q) where P was taken the distribution of each year between 1955 and 2017 (excluding 1995). Fig.3 shows the long-term positive correlation between geomagnetic storms and human health with the lags of several years. In Fig.3, we used (for comparison purposes), the ssc-index as the index of fluctuations in geomagnetic activity. The ssc-index counts the frequency of ssc storms with a high level of K-index (for example, level 5) [3].

We found a good cross correlation of our index with the ssc-index with arthritis and bronchial asthma. Wing reported that the incidence of rheumatoid arthritis (RA) varied based on the solar cycle with lags of 3 years following the solar maximum [1].

Our results, in Fig.3, showed that the incidences of RA peaked 2 years after the ssc-index. Fig.3 also shows that the increase in incidence of RA had a delay of 1 or 3 years also had stochastic confidence.

Following a 3-year survey, the largest number of calls to the ambulance service due to bronchial asthma and their fatal outcome coincided with long periods when high-frequency geomagnetic pulsation were absent [9]. Their results concur with our results on bronchial asthma.

There are mechanisms that explain the effects of geomagnetic storms on human health. For example, melatonin synthesis is known to play an important role in human circadian rhythms. Phase advance in pineal circadian rhythms is believed to be the underlying biochemical mechanism behind the geomagnetic effects on human health [10]. Geomagnetic disturbances reduce the nocturnal excretion of a melatonin metabolite in humans [11]. Abnormal melatonin levels have been observed in patients with non-SAD (seasonal affective disorder) depression. This may be due to the hydrophobic character of the cell membrane and changes in permeability that may lead to phase advance in non-SAD depressive illness [10]. The variability in heart rate (HRV) is usually a reflection of the state of the human nervous system. This link between geomagnetic activity and nervous system has been shown by continuously monitoring the HRV [12]. These findings suggest a background mechanism may partly explain our results.

In the literature, an increase in the levels of IL-6 (interleukin-6) among other cytokines has been known to active major depression [13]. Because IL-6 plays an important role in the human's immune system, a study on the network of cytokines may identify a new aspect as regards the effects of geomagnetic activity on the human's immune system.

V. Conclusion

We identified the existence of the immediate (short-term) effects on human health due to solar fluctuations. We extended informatics methods to create a new index signed Jeffrey. Using this, we found that solar fluctuations decrease the incidence of myocardial infarction and acute heart failure, and increase the incidence of cerebral infarction. We further explored the long-term effects of solar fluctuations (i.e. yearly variations) using the ssc-index and the signed Jeffrey. We found a signficant positive/negative correlation between ssc-index and several diseases, such as cerebral infarction, arthritis and bronchial asthma. All these results indicate that our novel method the “signed Jeffrey index” could potentially be useful method in identifying the effect of solar on human health.

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