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GEOMAGNETIC AP INDEX AND WORLDWIDE EARTHQUAKE OCCURRENCES

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CONTENTS

Introduction

The advanced research in sensors and understanding on how the Sun and Earth interact, encouraged the researchers to investigate this relationship further. (Herdiwijaya, Arif, Nurzaman, & Astuti, 2015; Sukma & Abidin, 2016; Urata,Duma, & Freund, 2018).

The correlation between solar activity and earthquake events remains unclear, as there are no testable correlations that can be used to predict future earthquakes (Love & Thomas, 2013).

The relationship between solar activity and earthquake occurrences should be investigated in a more specific way to understand the phenomenon.

In this study, the relationship is further investigated by using the information of the natural geomagnetic field of Earth which may temporarily be disturbed by solar events, that caused the geomagnetic storm.

INTRODUCTION

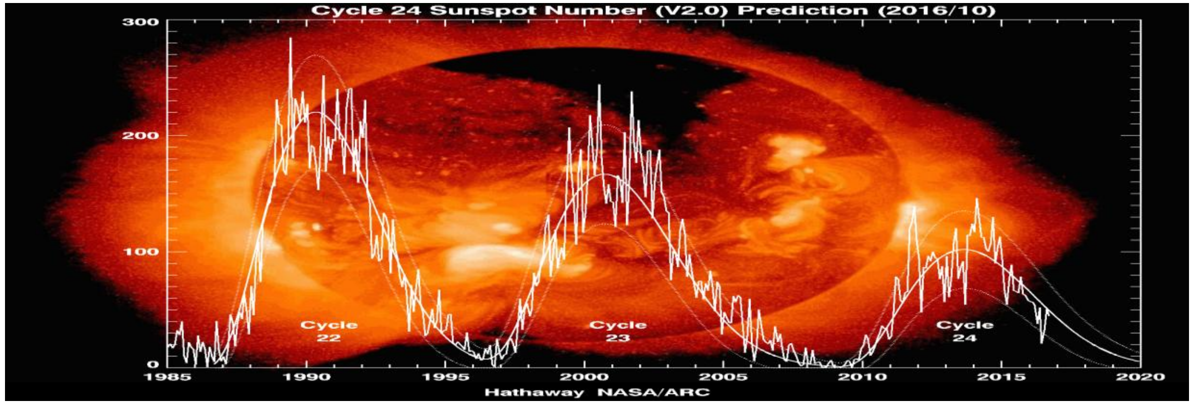
UNDERSTAND THE SOLAR TERMS

Solar cycle

- Solar cycles have an average duration of about 11 years.
- Solar maximum and solar minimum refer to periods of maximum and minimum counts of the sunspot.

Coronal Mass Ejection (CME)

- The solar magnetic field structures the corona, giving it its characteristic shape visible at times of solar eclipses.
- The occurrence frequency of coronal mass ejections and flares is strongly modulated by the cycle.



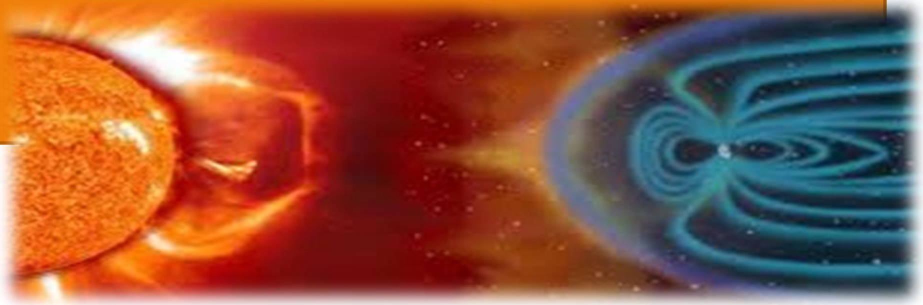
INTRODUCTION

UNDERSTAND THE SOLAR TERMS

Geomagnetic storm

- These disturbances are usually triggered by the high-speed solar wind (HSSW) and the coronal mass ejections (CMEs).
- The weak-to-moderate geomagnetic disturbances are due to the HSSW, while CME drives the intense disturbances

The A_p index is used as an indicator of geoeffective solar events.



Objectives

The primary purpose of this research is to understand the impact and characteristics of geoeffective solar events on the occurrences of earthquakes from a statistical point of view.

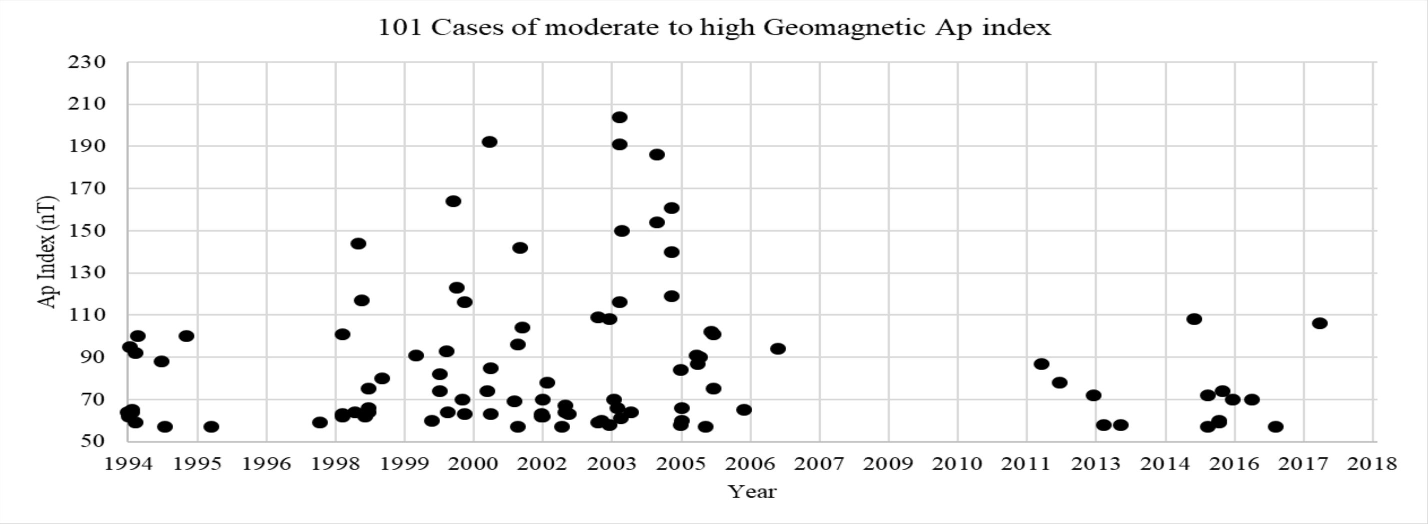
DATA

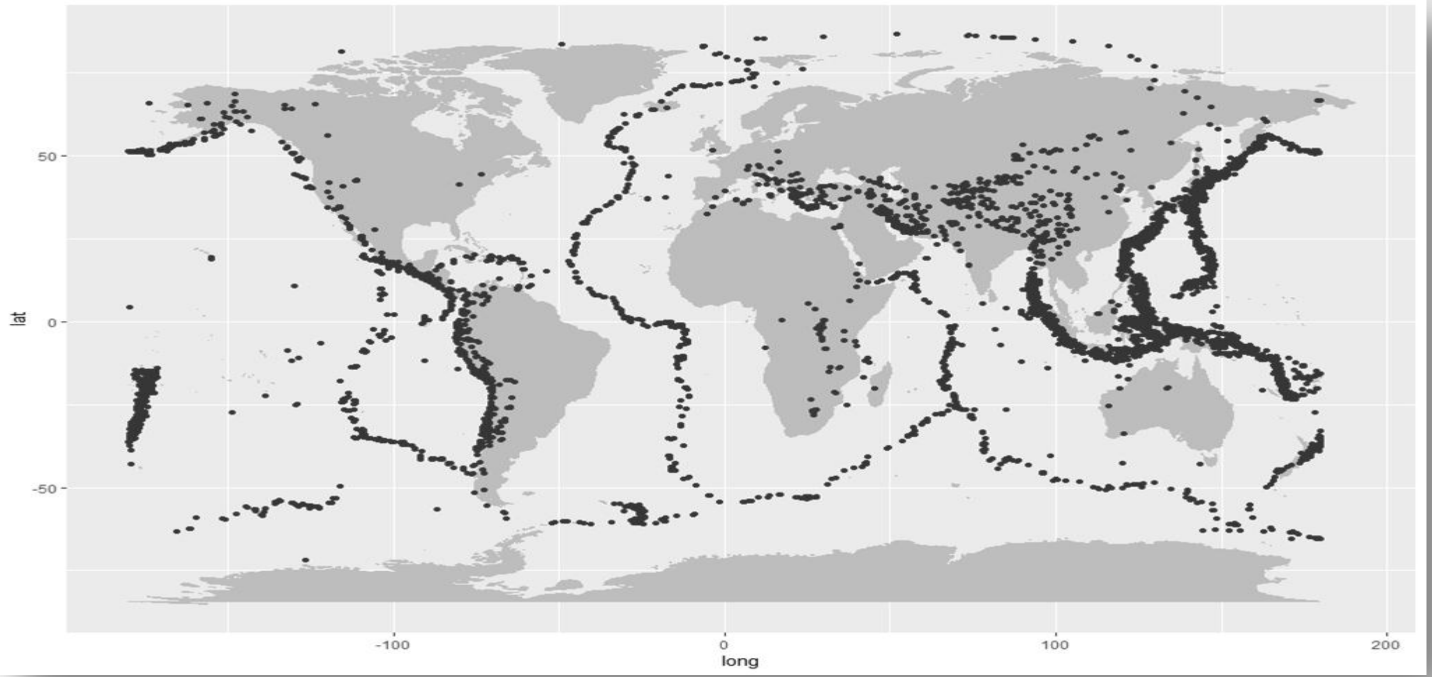
We investigate the data of the geomagnetic index and the frequency of the earthquakes from 1994 to 2017.

This geomagnetic A_p index is provided by Helmholtz-Centre Postdam – GFZ German Research Centre for Geosciences provides a good indicator for the geoeffective solar activity.

A total of 101 storms where the observation corresponds to the value of the Ap index from moderate to an extreme geomagnetic disturbance (Bartels, 1957) where the A_p is more than or equal to 57 nT ($A_p \geq 57$ nT).

The gap between 2007 until 2011 is due to the A_p index is below the selected threshold value, which is $A_p \geq 57$ nT, and this also corresponds to an interval with minimum solar activity.



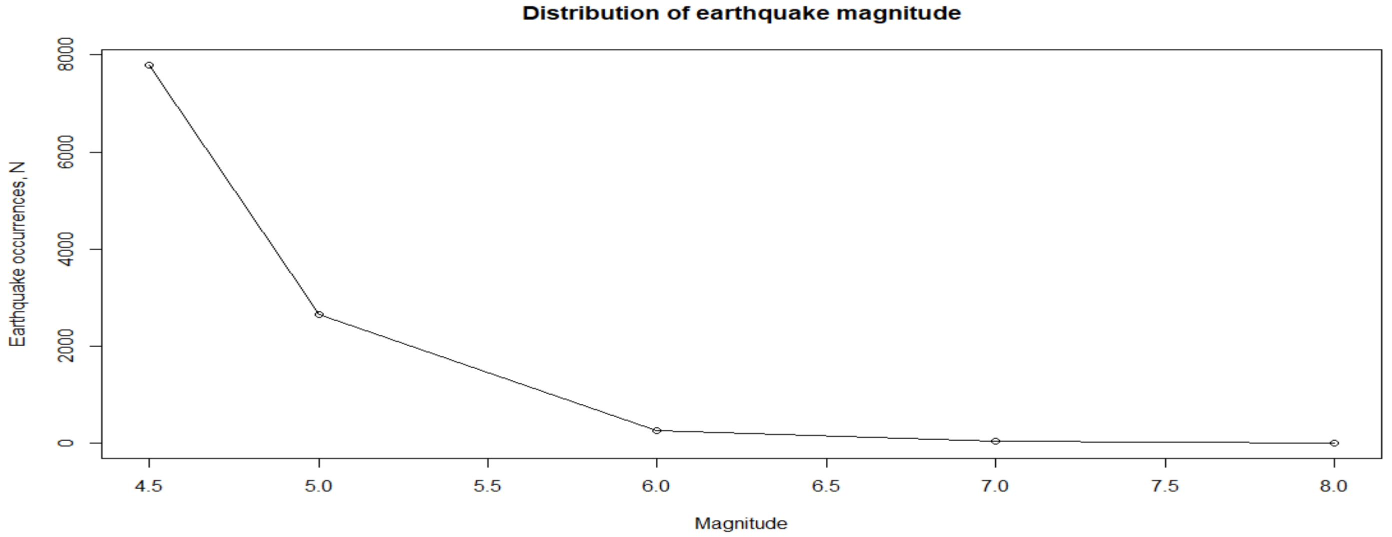


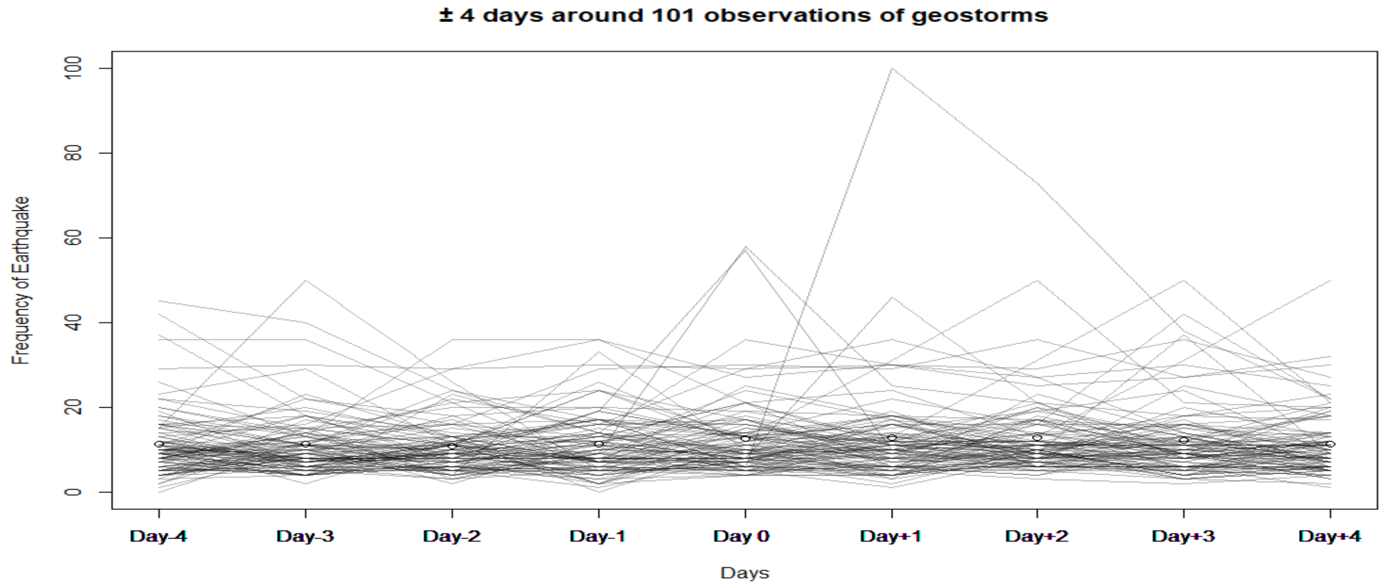
DATA

The earthquake frequencies are counted for each of the days of the geostorm occurrences.

We focused on four days before and four days after the event and defined Day-0 as the day of the geostorm with the condition, $A_p \geq 57$ nT.

For one case with high A_p index (geostorm), we record the frequency of nine days, i.e., Day-4, Day-3, Day-2, Day-1, Day-0, Day+1, Day+2, Day+3, Day+4, and a total of 10743 earthquakes occurrences were recorded for all the 101 observations of high A_p index.





STATISTICAL METHODS

Hierarchical clustering method

- Generally, the motivation for clustering is the analysis of data and pattern recognition, storage, search, and retrieval.
- In this study, one of the objectives is to see the clustering of the earthquake frequency in nine days (Day-0 and Day$\pm$4) that would probably give a hint on which days are affected significantly by the intense geomagnetic disturbance and which days are not affected.

GENERALIZED LINEAR MIXED MODEL (GLMM)

Extension of General Linear Model (GLM): There is only one source of random variation, assuming fixed effects

Whenever a factor is considered to be *random*, it is a sample from a distribution of levels, and now the factor or variable brings a new source of random variation to the model

The general linear mixed model is the most flexible approach for incorporating random effects

$$\mathbf{Y}_i = \mathbf{X}_i \boldsymbol{\beta} + \mathbf{Z}_i \mathbf{b} + \boldsymbol{\varepsilon}_i$$

GENERALIZED LINEAR MIXED MODEL (GLMM)

$$\mathbf{Y}_i = \mathbf{X}_i \boldsymbol{\beta} + \mathbf{Z}_i \mathbf{b} + \boldsymbol{\varepsilon}_i$$

$\mathbf{X}_i$ is the usual design matrix of fixed effects for the i-th subject

$\boldsymbol{\beta}$ is a vector (i.e., a k×1 matrix) of regression coefficients

$\mathbf{Z}_i$ is a design matrix of random effects for the i-th subject

$\mathbf{b}$ is (another) vector of regression coefficients

(more on **Z** and **b** later)

$\boldsymbol{\varepsilon}_i$ is a variance-covariance matrix

RESULTS

We classify the variables into the days that have been affected by the geomagnetic storm events (before and after the storm).

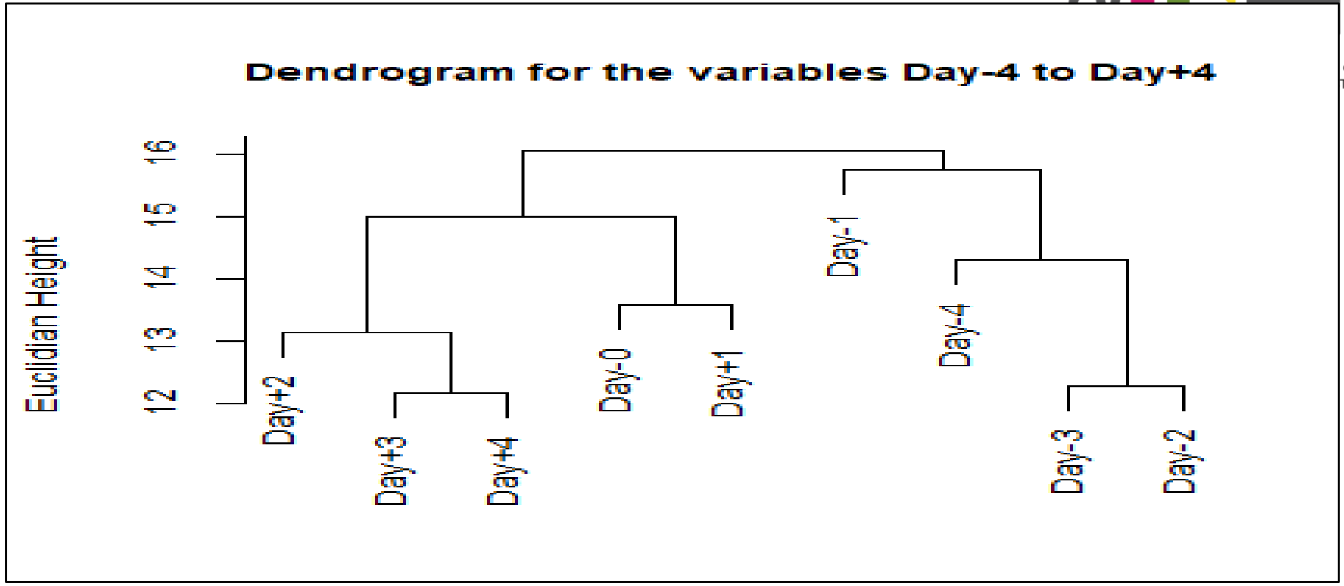
Our dataset was divided into nine variables.

We define our first variable as the frequency of earthquakes on the day of the most intense geostorm denoted as Day-0.

The other variables are defined as the frequency of earthquakes on days before and after the event of a geomagnetic storm (“Day-1 and Day+1, respectively)

Based on the dendrogram, we can see that four days before the geostorm (Cluster 2) and four days after the geostorm (Cluster 1) are nicely separated into two clusters if we set the distance of 15.9.

Based on the corrplot, we can see two groups that have a correlation above 0.5 between the variables inside of each group, which gives similar information by the clustering analysis



	Day-4	Day-3	Day-2	Day-1	Day 0	Day+1	Day+2	Day+3	Day+4
Day-4	1	0.59	0.45	0.41	0.36	0.19	0.15	0.29	0.41
Day-3	0.59	1	0.51	0.31	0.29	0.13	0.16	0.17	0.24
Day-2	0.45	0.51	1	0.5	0.25	0.49	0.44	0.35	0.38
Day-1	0.41	0.31	0.5	1	0.37	0.31	0.36	0.36	0.46
Day 0	0.36	0.29	0.25	0.37	1	0.25	0.23	0.25	0.41
Day+1	0.19	0.13	0.49	0.31	0.25	1	0.78	0.51	0.43
Day+2	0.15	0.16	0.44	0.36	0.23	0.78	1	0.57	0.47
Day+3	0.29	0.17	0.35	0.36	0.25	0.51	0.57	1	0.65
Day+4	0.41	0.24	0.38	0.46	0.41	0.43	0.47	0.65	1

RESULTS

For our dataset, we built two models with no fixed effect, where Model 1 only focused on Day as the random effect, while Model 2 has cross-random effects, which were Day and observation.

The inclusion of the observation variable does means that the inclusion of geostorms information.

We considered the number of earthquakes that occurred as the response variable then, found Poisson distribution is suitable in GLMM and Laplace approximation for estimation.

In this case, we have no fixed effect only intercept, which makes the output, only gives the estimated intercepts to explain the importance of the effects (McCulloch & Neuhaus, 2005).

The cross-random effects Model 2 obtained the lower AIC value which shows that the model is better for an explanation of the phenomenon.

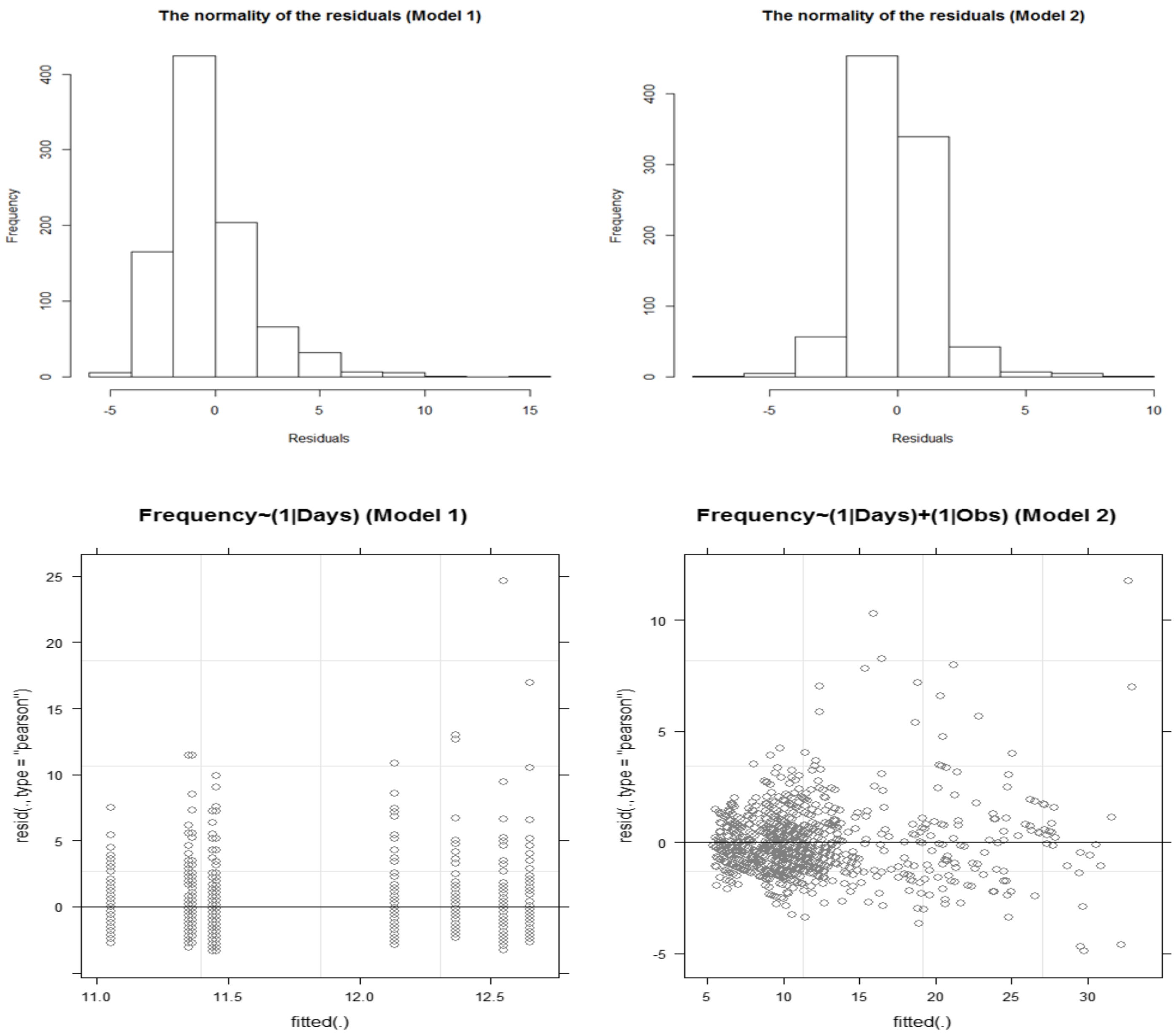
	Fixed effect	Random effects		AIC
	Intercept	Variable	Standard Deviation	
Model 1	2.47	Days	0.05	7994.3
Model 2	2.38	Days	0.05	6294.1
		Obs	0.40	

RESULTS

In GLMM, we assumed the errors are normally distributed and from the comparison of histogram shows that the errors in Model 2 is symmetric than Model 1 which slightly skewed to the right.

Model 1 shows the random effect fitted by Day, and clearly, the fitted model is for single link between the variables, while most of the points in Model 2 were scattered around zero, which indicate Model 2 is better than Model 1.

Therefore, we can conclude that the earthquake occurrences might significantly influenced from the observation variable which related to the geostorms information.



CONCLUSION

The present findings are significant in an aspect:

- Geostorm changes the pattern of earthquake occurrences:
  - HCA – clearly shows differences between the days before and after the geostorm (producing 2 major clusters).
  - GLMM – to investigate a dynamic relationship between high geomagnetic storms with earthquake frequency across time. The models suggest that geostorm is an important variable to study the earthquake activity.

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