VULNERABILITY OF ECONOMIC SECTORS TO GEOMAGNETIC STORMS AND MITIGATION STRATEGIES

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ABSTRACT:

Solar storms and CMEs increase the amount of radiation that reaches the Earth and can perturb the magnetic shielding of the Earth. K and Kp indices quantify this perturbation by using magnetometers calibrated accordingly to the latitude of the geomagnetic observatory It is possible to contribute this measurement by establishing an observatory specialized in space weather studies. Many basic sectors are vulnerable against a strong solar storm unless necessary mitigation strategies are applied. Moreover, failure in taking an immediate precaution may have long-term effects which include economic destruction, irreversible health problems and weaknesses in national defence. In this work, the requirement such an observatory should have, the most 11 vulnerable sectors and corresponding mitigation strategies are discussed in detail. Turkey's seven geographical regions are examined to find the optimal location for the foundation of such a probable observatory. It is found that Central Anatolia is the ideal region and districts Konya/Karapinar and Konya/Çeltik are the possible candidates for such a location.

1. INTRODUCTION

The activity of the Sun increases and decreases over a period of 11 years. During a solar maximum, the activity of the Sun becomes its highest. In the solar maximum, the number of sunspots and coronal mass ejections (CMEs) gets stronger and more often; therefore, extreme ultraviolet and X-ray emissions occur. Consequently, their impact on the upper atmosphere and surface of the Earth becomes more prominent. Entrance of these high energetic accelerated particles into Earth's atmosphere results in plenty of outcomes. The first one of these is atmospheric heating due to mentioned energy emissions. By the increasing heat, the temperature and the density of the atmosphere also increase in the altitudes that many spacecrafts are confined to. Increasing drag force in Low Earth Orbit (LEO) may result in a substantial decrease in the orbital lifetime of the satellites. Simultaneously, the increase in the number of high energetic accelerated particles boosts the likelihood of an instrument being damaged. The astronauts in these space stations and people who travel in high altitudes and polar routes are also threatened by the radiation emerge from CMEs and solar flares. Even the terrestrial climate of the Earth gets affected by these changes. It is found that the heat on the surface of the Earth maximizes and minimizes in correspondence to Sun's maxima and minima (Hathaway, 2015). Astoundingly, these particles may cause a formation of radiocarbon in the atmosphere of the Earth (Zhang, 2022). Solar storms also affect the total electron content (TEC) in the ionosphere which might result in erroneous positioning of GNSS satellites. These storms may even affect the electronic components and radio control signals of a GNSS satellite (Shprits et al, 2019). Today, electricity is widely used in many sectors therefore economic, health-related and defence sector consequences of such a storm will be disastrous.

The change in the magnetic field of the Earth due to solar storms and CMEs are expressed by K and Kp indices (Bartels, 1957), (Elliot et al, 2013). Kp index is also called the "planetary K index". These indices are calculated from the data collected by geomagnetic observatories all around the world. For a geomagnetic observatory to be able to join this calculation process, it must satisfy the requirements determined by "International Real-time Magnetic Observatory Network (INTERMAGNET)". Any observatory that meets these requirements can be a part of K index calculation; however, since Kp is the planetary K index, observatories in extreme altitudes cannot contribute Kp index calculation. Therefore, any observatory which can collect the data would be used to calculate Kp index must be located in between the limits of sub auroral altitudes (Matzka et al, 2021). In order to obtain the data for K&Kp index calculation, ground-based magnetometers are used. These devices measure the change in the magnetic field of the Earth and record it. In addition to the INTERMAGNET requirements on magnetometers, there are additional scientific requirements, which will be detailed in the following sections, that need to be satisfied for a geomagnetic observatory.

Even though SOHO provides an early-warning system to such a solar storm, it is vital to understand ground-based consequences of a geomagnetic disturbance and analyse it carefully to take ground-based precautions because the mitigation strategies will be different than in the space (Brekke,2005).

2. SOLAR FACTORS AND ITS CONSEQUENCES

2.1 Solar Cycle and Solar Storms

The change in the activity of the Sun causes a disturbance in the magnetosphere-ionosphere of the Earth and this activity is called "geoeffective processes". 11 years and 22 years of solar cycles are the well-known effects of this change. The Earth-Sun system has two main movements, which are called "sideral motion" and "synodic motion", which may cause other repetitions, namely 27-days, 13.5-days and 9-days of periodicities. The incoming flux from the Sun also exhibits

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changes depending on these features. Understanding the magnetic field components of such changes increases the chance of foreseeing flux variations. The dynamics of one or multiple coronal holes are thought to be one of the reasons for these periodicities since coronal holes are usually the plasma arcs that connect sunspots. As the number of sunspots increases, the number of coronal holes and, therefore, the activity of the Sun increases, which occurs more often while the Sun is at its maximum in the cycle (Richardson, 2018).
The Sun's temporal variability affects space weather and climate on time spans ranging from millennia to minutes. We refer to the disturbances as "storms" if they are powerful enough. The magnetosphere, in other words, the Earth's magnetic environment, is shaken by these fluctuations in the solar wind. The magnetosphere of the Earth creates a shield against the high energetic charged particles that emerge from the solar wind. The magnetic force deflects these solar wind particles before they reach the surface of the Earth. For a high energetic charged particle to reach a particular altitude, it should exceed a certain threshold which is specified for that particular location. This threshold is called "geomagnetic cut-off" (Chu et al, 2016). The geomagnetic cut-off value decreases towards the poles since the strength of the magnetic field decreases. This allows particles with lower energy being able to penetrate through the magnetosphere and have a higher chance of reaching the surface of the Earth. Therefore, during a potential solar storm, poles are exposed to more radiation than the rest. A solar storm is capable of disturbing this magnetic protection and as a consequence, since the magnetic field becomes weaker than before, particles with lower energy will be able to reach the surface of the Earth. On the ground, there will be an accumulation of charged particles and, therefore, more electromagnetic radiation. Additionally, due to the tilt angle between the Earth's rotation axis and the magnetic field, there is an inhomogeneity which results in South Atlantic Anomaly (SAA). In SAA, the charged particles accumulate, which results in a higher flux than in other locations in the same latitude.

When the ionosphere of the Earth is considered, solar storms also have an impact. Changes in the ionospheric currents can cause rapid time variations on the surface of the Earth, according to Faraday's law. In any conductive system, electric currents due to this electric field will be driven. Moreover, if this electric field penetrates through soil or water, undersea communication cables and gas pipelines will also be affected by this induction current.

SOHO (the Solar and Heliospheric Observatory) is an international project conducted by ESA and NASA to study the dynamics of Sun (Fleck, 1997). It provides unique information about the Sun, its inner and outer dynamics. Since it is in a halo orbit around L1 Lagrangian point, it is positioned outside the magnetosphere of the Earth and therefore is deprived of the magnetic shielding provided by it. SOHO monitors the Sun 24 hours in a day and due to its proximity to the Sun, SOHO has a leading role in the early-warning system for the space weather extremeness (Brekke,2005).

2.2 Consequences of Solar Storms

2.2.1 Space Mission Consequences

As mentioned in section 1, there are several consequences of a solar storm, one of which is atmospheric changes. When a solar storm penetrates through the atmosphere, it heats the environment which results in a density increase that causes drag force to decrease. Engines that cannot overcome this drag force become insufficient to keep the satellite at a particular altitude therefore, it starts falling down, which ends up burning the satellite in the atmosphere of the Earth. Also, solar storms have a large impact on the electronic subsystems of satellites. It may cause single-event effects and cause the computer to reset itself. When the space environment is concerned, most of the failures are due to solar storms (Tafazoli, 2009). In figure 1, it can be seen that the predominant reason for spacecraft failures due to the space environment is solar storms.
Since astronauts cannot benefit from the shielding of the magnetic field, they should protect themselves from solar flares. For example, astronauts protected by the Mir station during the time of the solar storm at the end of 1989 absorbed their yearly radiation dose limit in a matter of hours. During solar storm events, astronauts have reported seeing light flashes in their eyes. They are produced by radioactive particles that enter the bulkhead of the shuttle and generate streaks or flashes in the astronauts' eyes that are comet-like (Marusek, 2007). One can be affected by solar storms even without leaving the atmosphere. Depending on the strength of the storm, air travellers will also be affected by these high energetic charged particles. For example, more than a hundred people were injured in the Qantas plane crash in 2008 (Australian Government, 2008). In the research, it has been revealed that the weather data may be affected by the cosmic ray radiation that the inertial reference unit is exposed to during the flight. As a result of the interaction of cosmic rays with the atmosphere, secondary neutrons formed, which can affect aircraft avionics systems (Australian Government, 2008).

2.2.2 Consequences on GNSS Signals

Solar storms affect the TEC of the atmosphere, which can cause a wrong positioning of GNSS (GPS, GALILEO, GLONASS, BEIDOU, QZSS, IRNSS) satellites. Solar storms may corrupt the radio control signals of a satellite or even its electronic components (Shprits et al, 2019). The change in the ionosphere's total electron content density may change the speed at which the radio waves propagate and therefore, the GNSS signal which will be used to determine the positioning of the satellite will be wrong. Rapid changes in electron density from space weather fluctuations can cause a loop shift in carrier phase tracking. As an example, studies during two successive geomagnetic storms that occurred during the period from 8 to 12 November 2004 clearly demonstrated adverse effects on GPS range latency, as evidenced by Total Electron Content (TEC) measurements from seven dual-frequency GPS chains (Sreeja, 2016). The delay in the ionosphere can be explained by the Fermat principle. It is understood that the sum of the refractive indices along the beam from the satellite to the receiver gives the ionospheric delay in meters. The rapid changes in storm time that occur in the TEC cause a series of phase shifts in the GPS signal compared to those on quiet days. These phase shifts are due to the loss of locking of GPS receivers which results and negatively affects GPS-based navigation (Rao et al, 2009).

2.2.3 Vulnerability and Mitigation Strategies

When we consider the ground-based effects of a solar storm, one can see that the spectrum gets a lot wider. There will be both vital and economic effects which can be either an instant or a long-term one. An example of this situation is the "Carrington solar storm", which occurred during the solar cycle 10 in 1859. It is the strongest solar storm recorded in the history and the probability of such a solar storm repeating again is quite possible. The Carrington solar storm destroyed telegraph lines

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and electrical networks at the time of its occurrence. During a solar storm, electronic devices are affected due to the induced current. Today, when electricity is used much more widely, such an event will cause a great disaster. There are 11 fundamental sectors that will be affected enormously by such a solar storm.

i. Civil Aviation Industry: The amount of radiation exposed by an aircraft depends on the solar activity, space weather, geomagnetic latitude and altitude. When the electronic components in spacecrafts are exposed to high radiation, high energetic particle produces an unnatural pulse in the circuit. This pulse may result in temporal or permanent effects in the circuit (Both, 2012). Single Event Upset (SEU) occurs when such a particle hits in a cell in a digital circuit it can flip the logic gate and therefore the stored information. It can take place in a cell or in multiple cells (Multiple Bit Upset). In SEU, by using an error correcting code it is easier to fix a software issue however when MBU is considered, it is not as straight forward as SEU. For full recovery, the system needs to be restarted (Prado, 2013) (Maniatakos, 2012). While SEU and MBU are reversible corruptions, various types of Single Event Effects (SEE) such as Single Event Latch-Up (SEL) and Single Event Burnout (SEB) are irreversible corruptions. Qantas plane incident mentioned in section 2.2.1 is one of the recent examples of an SEE (Australian Transport Safety Bureau, 2008) that is reported. In the report, SEE is given as the most probable reason for such a damage. Reference unit of the Qantas airplane is thought to send a false signal due to a SEE which resulted in flight control failure causing the airplane to sudden ascent and descent with the passengers inside. According to SKYTRAX, Turkish Airlines is the 7th biggest company around the world (World's Top 100 Airlines 2022, SKYTRAX) and it will be greatly affected by such a radiation exposure. During such a solar storm, one way of protecting from the radiation is to decrease the amount of time spent in high radiation zone therefore delaying non-urgent flights until the effect of solar storm passes is a solution. Due to the latitude and altitude effects, a change in flight route is another option. Altitude change might cause more fuel consumption however it can be atoned by adapting the flight speed depending on the altitude (Meier,2020).

ii. International Health Sector: An electromagnetic pulse (EMP) is a temporary electromagnetic disturbance which can also stem from solar storms. A high altitude EMP is capable of producing an electric field strength of 20-50 kV/m (Vandre, 1993). Modern electric systems with highly complex circuits are very sensitive to EMP. Any wire that is attached to the electronic equipment can serve as an antenna, such as power cords, patient leads, or metal chassis, transfers energy from the EMP electric field. An EMP deposits energy that is enough to burnout semiconductors and damage the circuit components. Burnout in the junction in the transistor or an integrated circuit results in permanent damage. Any medical technological equipment facing with this consequence stops at that instant and cannot be made functional again. To prevent damage due to high electromagnetic voltage induced by an EMP, unused equipment should be unplugged, life support units and MR devices in intensive care units should be turned off during a solar storm. Designing medical equipment with a wire as short as possible. Wiring should be close to the ground as much as possible since the higher the wire gets more voltage is generated. Finally, sensitive equipments can be placed to ISO (International Organization for Standardization) shelter (Vandre,1993). These precautions can be taken by Turkish Ministry of Health to prevent damages in hospitals and health sector.

iii. Telecommunication Sector: Ionosphere of the Earth acts as a shielding and protects the Earth from solar storms. However, depending on the strength of the geomagnetic disturbance, this shielding might weaken due to the change in the total electron content (TEC) density in ionosphere (McManus,2021). The increase in the background noise due to the storm will result in a signal loss. Today, most of the communication is done via phones or internet. Maintain the telecommunication sector operational is crucial during a disaster to call for emergency services and organizing purposes.

iv. Defence Sector: In addition to communication sector, ionospheric disturbances also affect radio signals up to 10 GHz. A first-order propagation delay stems from the interaction between radio waves and plasma and this delay is proportional to $1/f^2$. Because of the change in the ionospheric refraction index, satellite mis-positioning might occur which cause an error in the navigation signals. GNSS signal disturbances can also cause communication breakdowns in the defence and military industries. In such a case, for example, it will not be possible to detect a potential air attack. Preventing such a vulnerability is possible with using a dual frequency receiver (Kuusisto, 2013). The Republic of Türkiye and The Republic of Türkiye Ministry of National Defence General Staff may highly benefit from such a precaution.

v. Pharmaceutical and Medical Equipment Sector: Power outages caused by solar storms will also endanger the storage of medicines that must be kept in the cold chain. The effects will be great in areas where extreme care is required during transport such as organ transplantation and tissue samples. In this case, if measures are not taken, the loss that will occur in the pharmaceutical sector will be large-scale economically.

vi. Financial Technologies Sector: When a solar storm hits the Earth, facing regions with the shock will be affected more. While this solar storm may cause electrical and technical problems in one region particularly, others may continue to operate. This will make these regions vulnerable towards to a cyber attack and moreover they will not be able to establish the security back before this problem is solved. All transactions (money transfer, investments etc.) may be disrupted and cyber-attacks may occur due to both internet outages and system shutdowns.

vii. IT Sector: Even though the IT equipment does not affected by a solar storm directly, signal loss, communication interruptions and data transfer & storage will be affected by the electrical outages. Since solar storms may be powerful enough to affect a whole hemisphere and has long-term effects, any sector based on IT will suffer from this corruption. A back-up data or software centre in a different

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geographical region may make it easier to overcome such a problem(Sergeant, 2012).

viii. Maritime Sector: After a shockwave hits the Earth it disturbs the geomagnetic field followed by a geoelectric field which can penetrate through the conducting interior of the Earth. In grounded lines, a Geomagnetically Induced Current (GIC) is produced as a response. Subsea communication cables are designed to operate at 1A current, in case of a burnout it takes 2-3 years to construct the submarine cables. Due to the loss of signal in the automatic identification system (AIS), which is mentioned in section 2.1, vessel tracking traffic will not be possible, and the probability of loss of route and accident will also increase (Castellanos, 2022).

ix. Livestock Sector: Animals may need to be transported to closed areas depending on the strength of the storm.

x. Beverage and Food Sector: Foods that need to be kept intact in the cold chain may also be wasted, as in medicines. It will have a negative economic impact.

xi. Automotive Sector: The ignition of vehicle batteries is a serious threat. As awareness arises from such a storm, all batteries should be disconnected and especially electric vehicles should not be used for transportation. Additionally, software using GPS signal to determine the route of the car will also be disturbed and therefore may cause the car to move in routes that do not exist or even worse dangerous.

Solar storms affect other industries apart from these ones. However, as a result of the research has been done, the damage in these industries is more than the rest and taking precaution for the damage in these industries is much more important. Otherwise, in the case of a strong solar storm, global possibilities that may progress to major disasters such as loss of life, mass extinctions, and the onset of famine may be triggered.

3. MEASURING THE STREGTH OF SPACE STORMS

As mentioned previously, even though the ground is much more protected by the magnetic shielding of the Earth, the effects of solar storms can be seen from the ground. There are many ways to indicate the strength of a solar storm, all of which are specified according to its purpose. In this work, the “K” and planetary K index “Kp” are focused on. Various ground-based instruments are used to measure different solar storm indices, one of which is magnetometers.

3.1 Solar Strom Indices: K and Kp Index

In order to describe the strength of solar storms, most of the time, sunspot numbers are widely used; however, they do not give any clue for the strength of individual storm; instead, it indicates an extended time range. Solar storms are classified into classes which can be seen in table 1:

A	$10^{-8} – 10^{-7}$ Wm^{-2}
B	$10^{-7} – 10^{-6}$ Wm^{-2}
C	$10^{-6} – 10^{-5}$ Wm^{-2}
M	$10^{-5} – 10^{-4}$ Wm^{-2}
X	$\geq 10^{-4}$ Wm^{-2}

Table 1. Solar X-ray emission classes (Koskinen, 2011).

To characterize solar storms in the magnetosphere, many activity indices have been used to measure the amount of magnetic deviation. For many years, these indices have been obtained by using the Mayaud rules. Indices are specified for features such as latitudes, time scales and decay current. Examples of widely used indices are “Dst” index and “K” index for global storm levels and AE (auroral electrojet) index for auroral regions (Koskinen, 2011).

K and Kp indices are used to indicate the deviations in the horizontal component of the magnetic field of the Earth (Bartels, 1957), (Elliot et al, 2013). Measurement of K and Kp indices is made by 3 hours of data obtained by the geomagnetic observatories. K index can be measured by any geomagnetic observation station at any latitude. Unlike the K index, the Kp index is called the planetary K index; therefore, the geomagnetic observatory which contributes to the measurement should be in the sub-auroral latitude region (Matzka et al, 2021). By doing this, it will be possible to avoid extreme conditions in polar regions since the magnetic field is weaker in that regions and therefore, the optimum measurement can be performed. K and Kp indices have values ranging from 0 to 9 depending on the strength of the solar storm. Values between 0-3 are calm, 4 is perturbed and 5-9 are called geomagnetic storm regions which can be seen in table 2:

K and Kp Indices	Meaning
0	Calm Region
1	
2	
3	
4	Perturbed Region
5	Geomagnetic Storm
6	
7	
8	
9	

Table 2. Values of K&Kp indices and their meaning.

The Kp network is oriented to Western Europe and North America, with seven of the thirteen stations, respectively". There are only two stations in the Southern hemisphere and none in East Europe and Asia. Besides two Europe stations (Brorfelde/Denmark and Uppsala/Sweden), data coming from two stations in the Southern hemisphere (Eyrewell/New Zealand and Canberra/Australia) are combined and involved in the calculation with their mean value. Therefore, the Southern hemisphere contributes to indices as one.

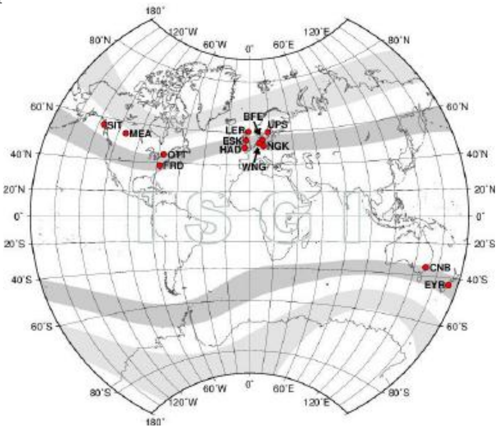

Figure 1. Distribution of Kp observatories (ISGI - International Service of Geomagnetic Indices, n.d.).

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3.2 INTERMAGNET and Magnetometers

INTERMAGNET (International Real-time Magnetic Observatory Network) is a programme that serves as a near-real-time data collector to monitor and predict the response of the Earth to solar activity changes. Magnetic observatories all around the world are encouraged to share real-time data with INTERMAGNET. Its foundation was determined at the "Workshop on Magnetic Observatory Instruments" in Ottawa in August 1986 (Kerridge, 2001). Its purpose is defined as "The INTERMAGNET objective is to establish a global network of co-operating digital magnetic observatories adopting modern standard specifications for measuring and recording equipment in order to facilitate data exchange and the production of geomagnetic data products in close to real-time." (Louis et al, 1999).

The Kp index is measured by ground-based magnetometers in the corresponding geomagnetic observatory. These magnetometers must meet the requirements and standards that are determined by INTERMAGNET. After that, these observatories can be a member of the INTERMAGNET network and can contribute with their data. The standards of a magnetometer that an observatory should have in order to become an INTERMAGNET member are given in table 3:

Magnetometer	Vector	Scalar
Resolution	0.1 nT	0.1 nT
Dynamic Range	8000 nT for Auroral and Equatorial Latitude	-
	6000 nT Mid-latitude	
Bandpass	Dc 0.1 Hz	-
Sampling Rate	1 Hz (1s)	0.033 Hz (30s)
Thermal Stability	0.25 nT/Celcius	-
Long Term Stability	5 nT/year	-
Accuracy	-	1 nT

Table 3. Minimum magnetometer standards determined by INTERMAGNET

Observatory that meets all the requirements can start to operate after its magnetometer is calibrated according to the latitude that the observatory is founded. After becoming a member of the INTERMAGNET network, it can start to contribute to K index data. Moreover, it can compare its own results with the others. In Turkey, the measurement of the K index was started with the geomagnetic observatory that is located at Kandilli/Istanbul in 1947. This centre became a member of the INTERMAGNET network in 1997 and started to share its own data. However, due to the rapidly increasing city growth, the observatory remained in the city noise, and then the studies continued to be calculated with the data taken from the Iznik Magnetic Observatory affiliated to Boğaziçi University Kandilli Observatory and Earthquake Research Institute since 2005.

It can be concluded as a result of the consultations that have been done, The Scientific and Technological Research Council of Turkey National Metrology Institute (TÜBİTAK UME) is capable of producing such a magnetometer locally. High-sensitive (nT) magnetometer research have been begun approximately ten years ago in TÜBİTAK UME. As a sensor element, a superconductive material is used in the first magnetometer produced and a resolution level of less than 1 nT is reached (Topal, 2013). Since superconducting materials need to be cooled with liquid nitrogen or liquid helium, the usage area of this type of sensor is very limited. However, this study showed us that superconducting materials are also very sensitive to the magnetic field. In later developed devices, soft magnetic alloys were used as sensor material, as in similar commercial products. The resolution level is reached up to pT magnitude (Topal et al, 2021), (Can et al, 2017). At the same time, software and electronic cards that control these sensors are also produced in TÜBİTAK UME. The last device produced at TÜBİTAK UME has been prepared with space qualification and has passed all tests successfully.

4. DETERMINING A SUITABLE LOCATION FOR KP INDEX CALCULATION

A geomagnetic observatory should avoid certain features to be able to take correct measurements. Since a magnetometer detects the anomalies in the magnetic field of the Earth, it should be away from any fault zone to take pure space-based magnetic field effects (Gao et al, 2014), (Johnston, 2002), (Robbes, 2006). Another feature is the DC electrified railways. The observatory should be away from the railways for a similar reason (Pirjola, 2011), (Love, 2009). The soil must be free of elements that can cause geomagnetic disturbance (Girdler, 1971). Due to its conductivity, it should be away from salty and soda water and should be protected from the effect of lightning and strike (Grant, 2006), (Čop, 2014). Requirements that a geomagnetic observatory for Kp index measurements are given in table 4 as a summary:

Requirements	Reasons	Reference
An observatory should be away from fault lines.	Magnetometers in these observatories measure the change in the magnetic field and earthquakes produce magnetic field. This feature should be satisfied in order to avoid false signals.	Gao et al, 2014 Johnston, 2002 Robbes, 2006
An observatory	For observatory to	Pirjola, 2011

should be away from railways.	be far away from the electromagnetic effect of the railways it should be at least 20km away from a DC electrified railways and tram ways.	Love, 2009
Soil must be free of elements that can cause geomagnetic disturbance.	It should be far away from the element sources, such as iron, which have magnetic properties, in order to be protected from magnetism.	Girdler, 1971
An observatory should be away from salty and soda water.	The amount of salt and soda in the water source changes the conductivity of the water. For this reason, it is necessary to stay away from this feature in order to keep the conductivity at a minimum.	Grant, 2006
An observatory should be protected from the effect of lightning and strike.	Weather events such as strikes and lightnings are fast-moving electric currents and therefore they create an electromagnetic field.	Čop, 2014

Table 4. Requirements for a geomagnetic observatory which will be founded with the purpose of space-weather study.

4.1 Potential Locations in Turkey

To determine the location of a potential geomagnetic observatory, elimination method is used. In this research, where all seven geographic regions of Turkey are examined, related maps are studied in order to satisfy the requirements given in table 4.

i. An observatory should be away from fault lines: EM wave emissions due to earthquakes are one of the most important features for a geomagnetic observatory to avoid from. Any geomagnetic observatory that is located near an active fault line would not reach a pure enough space weather sample to analyse because of the frequent EM wave signals coming from the earth crust and its signal would be contaminated by those signals. While this is a necessity for a geomagnetic observatory which searches for earthquakes, it should be avoided for an observatory which is specified to study space weather. The Iznik geomagnetic observatory, which was established for earthquake research, cannot be used for calculating the Kp index due to its proximity to the North Anatolian Fault, and for the same reason, the Marmara and Western Black Sea Regions are not suitable for hosting such an observatory due to the North Anatolian Fault Line. The East Anatolian Fault Line has caused the elimination of a large part of the East and Southeast. The West Anatolian Fault Line, which exhibits a large number of graben and horst structures, has been concluded that the Aegean is not suitable for a geomagnetic observatory for space weather purposes, since it affects the entire Aegean Region. The structure of Turkey was determined by examining the geological and tectonic aspects in order to establish the appropriate observatory for the calculation of the Kp index. According to this, when an area is far from the active earthquake fault line, away from an iron deposit formed as a result of any magmatic intrusion or their influence, and especially away from saline solutions due to the lacustrine sequence and evaporitic rock deposits due to them, the Konya plain was determined as the most suitable region. In case of the start of the project, on-site sampling will be performed for the selection of the exact location and geochemical analyzes will be made, and at the same time, the location of the appropriate observatory will be determined for the calculation of the Kp index by selecting the areas away from the buried faults by taking geophysical measurements.

ii. An observatory should be away from railways: In order not to be affected by electromagnetic fluctuations, geomagnetic observatories need to be located far from railways and should be at least 20 km away from DC electric railways and tram lines. It is seen that the Marmara and Aegean Regions do not meet this requirement, while some of the regions in Central Anatolia and Eastern Anatolia may be away from these effects. The lower parts of the South-eastern Anatolia region do not meet this requirement either.

iii. The soil must be free of elements that can cause geomagnetic disturbance: The geomagnetic observatory should be away from the soil structure where the geological elements with magnetic properties are located. It is seen that the Eastern Black Sea region does not meet the requirement due to magnetic anomalies. Likewise, although not spread in the Central Anatolia region, there is some anomaly.

iv. An observatory should be away from salty and soda water: The change in pH level changes the ionization rate of the soil. The conductivity level of a region closes to salty or soda water will increase due to the ionization rate. Since electrical disturbances may occur due to the increase in conductivity, the observatory should be away from this factor. For this reason, the coastlines of our country, which is surrounded by seas on 3 sides, especially the Eastern Black Sea region, which are far from fault lines, are eliminated. Since most of the lakes in our country (Van, Eğridir, Beyşehir, etc.) are soda, most of the Central Anatolia and Eastern Anatolia regions are eliminated.

v. An observatory should be protected from the effect of lightning and strike: The station should also be far from areas where lightning and strikes are common due to electromagnetic effects. Lightning and strikes are caused by fast-moving charged particles, which cause the electromagnetic effect.

After examining all the requirements in detail, Central Anatolia and the Mediterranean regions seem to be the most appropriate candidates for such an observatory. However, because of the mountain formations and the requirement of being away from salty water, the Mediterranean region is also eliminated. While Central Anatolia meets all the requirements for a potential geomagnetic observatory, Konya province, which has a flat geography and provides an easy-to-reach area, is mainly focused. A magnetic anomaly is spotted; however, as a result of the discussions with the experts, it is seen that avoiding this magnetic anomaly is possible. Districts Konya/Karapınar (37° 42‘K, 33° 33‘D) and Konya/Çeltik (39° 1′ K, 31° 47′ D) are determined to be the most suitable candidates for a potential location in order to establish such a geomagnetic observatory which will be specified for space weather research.

5. CONCLUSION

The atmosphere and the surface of the Earth are affected by the flux changes caused by our Sun, which has a solar cycle that repeats itself every 11 years. The Sun reaches its maximum and minimum in this interval and when it is at its maximum, solar activity also reaches its maximum, which results in frequent solar flares and CMEs. High energetic charged particles mediated by these solar storms may affect space missions by changing the density of the atmosphere and interfering with the electronics of the satellites. Moreover, by changing the TEC of the ionosphere, they can contaminate GNSS signals which cause delays in communications. On the ground, vital and economic consequences may occur and their negative impact might be long-term. By using K and Kp indices, these changes can be studied and understood in detail and therefore taking precautions becomes easier. Approaching the solar maximum expected in 2024, by becoming a member of INTERMAGNET, Turkey might become a partner in this research and by producing its own magnetometer, even trade of such an instrument would be possible in the future. For these benefits, requirements for such an observatory have been studied in this research and it is decided that the ideal locations are Konya/Karapınar and Konya/Çeltik.

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