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Short communication

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Influence of Solar Dipole Field on Earthquake Occurrence

Aysegul Yilmaz*

Retired Physicist, Yukari Bahcelievler Mahallesi, Cankaya-Turkiye

***Corresponding Author**
Aysegul Yilmaz, Retired Physicist, Yukari Bahcelievler Mahallesi, Cankaya-Turkiye.

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Abstract

According to elastic rebound theory, a tectonic earthquake occurs often along faults, narrow zones where rock masses move in relation to one another. Then strains accumulated in these rock masses cause the stresses exceeding the strength of the rocks, a sudden fracturing results in an earthquake. The major fault lines of the Earth are located at the fringes of the huge tectonic plates that make up Earth's crust.

As a new aspect of Earth-Planetary Science, our study investigates influence of solar magnetic field on triggering earthquake by comparing variations in Number of World's Earthquakes (NEQKs) and Solar Equatorial Dipole Field (SEDF) [1].

In the following sections, to investigate the connection between solar magnetic field and earthquake occurrence we introduce an model for the outer core of Earth and consider the contributions from centripetal and cenrifugal foce applied by axial and equatorial dipole field of Earth, respectively coupling to axial and dipole fields of Sun throughout the interplanetary magnetic field during a solar cycle.

1. Introduction

Large-Scale Magnetic Field of Sun (LSMFS) is a mixture of closed and open magnetic fields [2].

• In the closed field region, the hot and bright arcs of magnetism and superheated plasma are known as coronal loops of flux upwelling from the solar interior [3]. On the Sun's surface, ARs, which are large long-lived bipolar magnetic structures, appear as an ensemble of coronal loops in two bands (magnetic conveyer) parallel to solar equator. Part of the solar magnetic field that emerges in the ARs drags outward together with solar field. Sunspots appear as bipolar pairs oriented in east-west direction in northern hemisphere with opposite polarity in southern hemisphere of the Sun in relation with the ARs when LSMFS is positive. Sunspots, regions of toroidal magnetism in solar photosphere, are carried up to solar surface by Bouncy force.

• In the open field regions, coronal holes at North and South magnetic poles of sun are funnel-like regions where the magnetic field is unipolar and opens the interplanetary medium, i.e., North and South poles of LSMFS are extensive regions of unipolar field [4]. The positive and negative polarities of Sun correspond to conditions when the field in the northern hemisphere is directed toward and away from the sun, respectively.

Plasma motion in solar interior provides a dynamo-action to generate Large-Scale Magnetic Field of Sun (LSMFS) oscillating between a poloidal and a toroidal state and re-organizing itself throughout [5]. The ~22-year Solar Cycle, so-called the Hale Cycle which includes even number Sunspot Cycle and the following odd number. Sunspot Cycle. Each Sunspot Cycle with exhibits fluctuations from a period of minimum solar activity (i.e., Solar Minimum) to a period of maximum solar activity (Solar Maximum) [5].

• During the Solar Minimum period, the number of sunspots of served on the solar surface decreases as the number of coronal loops decreases, in turn, the solar activities decreases. During the period of Active Sun, solar Corona is more or less confined to equatorial region of Sun with coronal holes covering the polar region. The solar minimum is designated by the lowest number of the sunspots.

• As approaching Solar Maximum, the coronal holes are closed. In addition, the increasing number of coronal loops leads to increasing number of Solar Storms such associated with Active Regions ARs [6]. Solar storms are related to Coronal Mass Ejections (CMEs) as a cloud of plasma and magnetic field erupted from the Sun and Solar Flare (SFs) as releasing of electromagnetic energy from the

Sun in the form of light and X-rays.

• During the Solar Maximum period, as the number of sunspots increases, the solar activity occurrence goes up. During the period of Active Sun, the Corona is evenly distributed over the equatorial and polar regions of the Sun.

As the sunspots spread out and cause the solar magnetic field to immigrate from the sun's equator to one of the Sun's poles, the average Sun's magnetic field soon became zero before the North and South poles changes place,i.e., the polarity of LSMGS reverses at the Solar Maximum. The polar fields of the sun are re-established with the opposite polarity as the same polarity of leading west portion of the bipolar sunspot group around the same hemisphere, in turn, after two Sunspot Cycles the same pattern of Solar field returns. The Solar Maximum is designated by the largest number of sunspots.

The Sun's magnetic field is not confined to the immediate vicinity of our star. Since the top most layer of solar corona is hot enough to escape from the Sun's gravity, a stream of high-energy charged particles, so-called solar wind, releases from the corona. Solar wind has two components. Slow stream solar wind is originated from coronal loops, whereas high stream solar wind arises mainly from coronal holes. Slow one wraps more around the sun, while the fast one moves directly and tends to overtake the slow one. As the solar wind leaves the corona through low density regions, it picks up the local magnetic field contributed by sunspots and the sun's magnetic field poles and drags its field lines into interplanetary medium, so- called "Interplanetary Magnetic Field" or "IMF". Because the Sun rotates (once every 27 days), the IMF has a spiral shape [7].

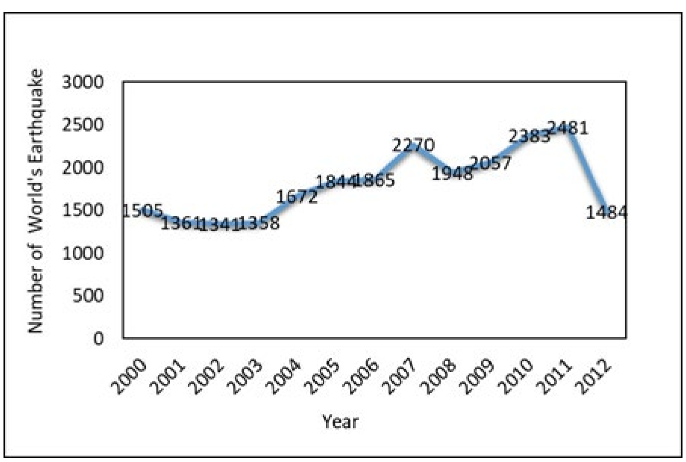
When the IMF comes to contact with the Earth's magnetosphere at its magnetopause, the Earth's magnetosphere contracts or expands depending on the solar wind's pressure. Solar activities such as solar storms and high-stream solar wind lead to not only high solar wind flux, but also, to distorted IMF during the Solar Maximum period. Moreover, geomagneticstorm occurswhen the plasma inside the earth's magnetosphere becomes sufficiently large to inflate and thereby to distort the geomagnetic field, because of sudden strong variations in density, speed, density and magnetic properties of solar wind due to solar storms

Earth's magnetosphere is created by the main magnetic field of Earth composed of poloidal fields and toroidal fields. A poloidal field is one, which has a radial component. This is the type of field with which we are all familiar since dipole fields are poloidal. A toroidal field, on the other hand, is ring or donut shaped, with no radial component. In the Earth, toroidal fields are are confined to the core and are not detectible at the Earth's surface [8].

• The main magnetic field of Earth is in a permanent state of flux and generated by the movement of molten iron in the Earth's outer core. Since iron, weather liquid or solid, is conductor of electricity. Electrical current would therefore flow in molten iron. Bouncy force due to thermal and compositional effects leads to convectional electrical current as the molten outer core convicts by means of rising heat and conductive liquid of outer core rises up. This convective motion would display the flowing electrical current. Moving a flowing electrical current generated a magnetic field at right angle to the electrical current direction. The magnetic field is oriented around the axis of Earth's rotation because of Coriolis force acting on the moving fluid. Coriolis force causes to spiral the flow, in turn, to organize the electrical currents with the same direction into columns aligned with the rotational axis.

• The remaining 6% of Earth's field is partly due to electrical currents in space near Earth (i.e., magnetosphere and ionosphere of Earth), partly due to magnetized rocks in lithosphere (i.e., crust plus upper mantle of Earth).

Moreover, Plate tectonic said that the Earth's stronger layer, called lithosphere which includes the brittle upper portion of the mantle and the crust, the outermost layer of Earth's interior varying in depth from earth's surface to 60 km, is made of large segments, tectonic plates, Formation of earthquake is due to physical movement of the tectonic plates, but depends on to stress loading and accumulation on the tectonic plates. The strain developed in rocks of lithosphere deforms the rocks to lead sudden release of energy stored in them. Faulting is a basic mechanism by which rocks deform.



2. Modeling

First, we plotted Number of World Earthquakes (NWEQKs) with magnitude from 5.0 to 9.9 versus Yearto compare the changes in Interplanetary Magnetic Field (IMF) from 2000 to 2012 [9].

In addition, we apply a model of outer core as spherical shell built by infinitesimal number of co-axial circular areas with infinitesimal thickness around Earth's rotational axial and with sizes getting larger from boundary with inner core to the boundary with mantle. These co-axial circular areas with infinitesimal thickness, altogether, builds up the bulk of the outer core.

According to our model, to describe diverging and converging of the outer core, we focus on total contributions from $\vec{v}_{\varnothing} \times \vec{B}_z$ -force and $\vec{v}_z \times \vec{B}_{\varnothing}$ -force applied by Axial and Equatorial Dipole Fields, ($\vec{B}_z$ and $\vec{B}_{\varnothing}$) of Earth (A-EDF and E-EDF), along the radial distance.

Then, we refer to graphs of Equatorial and Axial Sun's dipole fields(E-SDF and A-SDF) per Year and variations of the IMF versus Year for the period of interest, 2000 to 2012 [7,10].

Moreover, we consider plotting of Number of Geomagnetic Storms (N-GMS) per Year and Rate of Change of Angle for Declination, D, (RC-AD) of Earth Magnetic Field per Year from 2000 to 2012 [11,12].

These forces act on azimuthal electrical flow, $\vec{v}_{\emptyset}$, due to rotational motion and convectional electrical flows, $\vec{v}_z$, due to thermal motion along rotational axis being against the gravity, $\vec{g}$, to suppress Coriolis Force, $\vec{F}_C$, respectively.

Case 1: Decreasing NWEQKs

Influence of Coriolis force, $\vec{F}_C$ increases, as outer core converges toward inner core due to being pushed by centripetal $\vec{v}_{\emptyset} \times \vec{B}_z$ -force along radial distance inward direction to center of Earth as rotational speed of outer core increases. Consequently, the outer core liquid along the boundary with solid inner core could squeezed to lead super jets observed in magnetosphere (ESA SWARM Mission).

Case 2: Increasing NWEQKs

Influence of Coriolis force, $\vec{F}_C$ decreases as the outer core diverges toward mantle due to being pushed by centrifugal $\vec{v}_z \times \vec{B}_{\emptyset}$ -force along radial distance outward direction from center of Earth as rotational speed of outer core decreases to cause increase in pressure gradient through lower mantle.

Eventually, stress loading leads to release huge energy through lithosphere, in turn, to form faulting, which is typical deformation causing to earthquake.-.

3. Results

When we refer to our modeling, for the period form the year 2000 to the year 2012 including solar cycle 23 (SC23) and ascending period of Solar Cycle 24 (SC24) the following results are obtained:

➢ During descending phase of SC 23 from 2000 to 2009, the variations for A-SDF, E-SDF and IMF are found as the following:

• From 2000 to 2001, as strength of A-SDF increases.
• In addition, from 2000 to 2003, the strength of E-SDF and IMF increase up to its highest value.
• From 2001 to 2009, the strength of the A-SDF smoothly decreases.
• From 2003 to 2009, the strengths of the E-SDP and the IMF sharply decrease up to a minimum value at 2009, with a local peak value at 2008 between 2007 and 2009.

➢ During rising phase of SC24 from 2009 to 2012, both E-SDP and IMF go up to a small maximum at 2012, as the A-SDF goes to zero.
➢ During descending phase of SC23 from 2000 to 2009, the NWEQKs changes as the following:

• From 2000 to 2003, the NWEQKs decreases.
• From 2003 the N-WEQKs increases to 2009 with a local deep value at 2008 between 2007 and 2009.

➢ During rising phase of SC24 from 2000 to 2009, the variations in NWEQKs are like in the followings:

• From 2009 to 2011, the NWEQKs increases up to the highest value at 2011.
• From 2011 to 2012 the NWEQKs sharply decreases.

➢ During the period of interest, 2000 to 2012, the variations in N-GMSand RC-AD are connected with the variations in the strengths of NWEQKs, A-SDF and E-SDF, throughout the solar storms.

4. Discussion and Conclusion

The results found by means of our modeling can be explained as written in the following items:

➢ During rising phase from 2000 to 20003, as the strength of SDF with dominant components of west to east oriented (WE) E-SDF, which contributes mainly to IMF, increases, the strength of WE IMF increases. The number of solar storms leads to increase in RC-AD.

• As the number of solar storms increases, N-GMS goes up.
• The increasing number of solar storms, which distort the EDF with components of EW E-EDF and northward (NW) Axial EDF (A-EDF), results in descending NWEQKs.

➢ During rising phase from 2003 to 2009, as the strength of SDF with dominant components of west to east oriented (WE) E-SDF, which contributes mainly to IMF, decreases, the strength of WE IMF decreases.
• As the number of solar storms decreases, RC-AD descends.
• As the number of solar storms descends, N-GMS reduces.
• The decreasing number of solar storms leads to increase in N-WEQKs.

➢ During rising phase from 2009 to 2011, as the strength of SDF with dominant components of southward (SW) A-SDF, which contributes mainly to IMF, decreases, the strength of SW IMF decreases, too.

• In addition to solar storms, the interaction of SW IMF with the EDF with the NW A-EDF leads to GMS.
• Therefore, the N-GMS increases.
• As the strength of SW IMF decreases, NW A-EDF becomes more effective to result in ascending NWEQKs
• As the number of solar storms increases, RC-AD increases.

➢ During rising phase from 2011 to 2012, as the strength of SDF with dominant east to west oriented (EW) E-SDF, which contributes mainly to IMF, increases, the strength of EW IMF increases, too.
• As the strength of in the number of solar storms increases, RC-AD ascends.
• As the strength of SW IMF goes to zero, N-GMS decreases, but not too much due to increasing the number of solar storms.
• The increasing strength of EW IMF leads to less effective NW A-EDF. Hence, NWEQKs is reduced.

In conclusion, our study shows that better modeling and forecasting of earthquakes could be done throughout the conditions in Earth-Sun system, instead of conditions just on Earth [13,14].

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