



ESTIMATION OF IONOSPHERIC ENERGY DISSIPATION FOR THE YEAR 2012 USING ØSTGAARD'S EMPIRICAL RELATION

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ABSTRACT

The energy dissipation in the ionosphere resulting from the geomagnetic activity have caused an increasing number of major disruptions of important power and communication services, malfunctions and loss of expensive equipment. In this paper, data for the electron precipitation energy (ep) and joule heating energy (jh) have been used in the computation of both mean daily and hourly ionospheric energy dissipation using Østgaard's empirical relation. The computation has been done for the year 2012. Hourly provisional values of geomagnetic indices obtained at International Service for Geomagnetic Indices from World Data Centre for Geomagnetism, Kyoto, Japan were used in the computation. International Association for Geomagnetism and Aeronomy (IAGA)-2002 format was adopted in the analysis. Under the assumption that the magnetosphere does not store any energy, the beginning of the event is taken as $t_1=0$ and ending at $t_2=24$ hours. This is the duration used for the estimation. The estimated amount of energy dissipated through the ionosphere within this interval was found to be $1.414393E+07 \pm 824,154.1$ GJ with 90% confidence level, which indicates that ionospheric energy dissipation is the dominant channel of energy transfer in that year from the solar wind. This is consistent with many results found by other researchers.

Keywords: Østgaard's Empirical Relation, Ionospheric Energy Dissipation, Electron Precipitation, Joule Heating

INTRODUCTION

In the Earth's magnetosphere, the solar wind energy is dissipated into various sinks during magnetic storms and substorms. The main energy dissipation channels are Joule heating, Auroral precipitation in the ionosphere, ring current encircling the earth at the equatorial plane, plasma sheet heating in the night side magnetosphere and the release of plasmoids from the magnetospheric tail. Plasma erupted from the Sun, carrying the interplanetary magnetic field, can penetrate the magnetic shielding of the Earth through a reconnection process. This merging of field lines and penetration of particles represent an energy transfer into the magnetosphere. The energy can then either be deposited "directly" into the ionosphere with a typical delay of 20 minutes or be stored in the magnetosphere and with a typical delay time of 60 minutes and then dissipated during Substorms (Liou *et al.*, 1998).

The primary dissipation mechanisms in the ionosphere are Joule heating and particle precipitation. A number of empirical relations are used to estimate the energy dissipated via these mechanisms (Østgaard *et al.*, 2002). The most commonly used of these formulae give the energy dissipated as a function of an Auroral

index (typically AE or AL)

In this work we consider both the two ionospheric energy sinks (Joule Heating and particle precipitation) and used geomagnetic indices irrespective of the event. The data obtained at International Service for Geomagnetic Indices (ISGI) from World Data Center (WDC) Kyoto, were used as input in the relation developed by Østgaard *et al.*, (2002) to estimate the ionospheric energy dissipation.

Ionospheric Dissipation

Here, we consider only two important modes of energy dissipation from the magnetosphere to ionosphere which are joule heating $w(jh)$ and electron precipitation $w(ep)$ while all other energy sinks, upward ion acceleration and kilometric radiation are much weaker, therefore total ionospheric energy dissipation is estimated as;

$$W_i = w(jh) + w(ep) \quad (1)$$

Where W_i is the ionospheric dissipation energy $w(jh)$ is joule heating energy and $w(ep)$ represents the energy via electron precipitation. The different ionospheric dissipation channels are not totally independent of each other; for example, the electron precipitation affects

ionospheric deposition energy indirectly through joule heating by increasing the ionospheric Pederson conductance (Østgaard *et al.*, 2002). However, these two channels are different processes and thus cannot be estimated using the same parameter (Eija, 2002)

Joule Heating Energy

This is the energy which simply arises as a result of stream of highly charged particles (electrons) emitting from the sun current into the ionosphere which is responsible for geomagnetic disturbances. To estimate the joule heating rate there are many empirical relations using different geomagnetic indices as input to the results, but in the form of regression equation (Østgaard *et al.*, 2002) :

$$P(jh)(GW) = aAE + b \quad 2$$

Where $P(jh)$ is the joule heating rate, AE corresponds to the difference between the west-ward(AU) and east-ward (AL) auroral electrojets while a and b are scaling factors Depending on the values of a and b , we consider the following: we choose AE index, whose values are derived from the same stations. We note also that using more stations provides greater accuracy; as an example, the AE indices from 68 stations is on average 35% higher in accuracy than that of AE from 12 stations(Lu *et al.*, 1998), which implies that the scaling factor a obtained when a large number of stations are used should be smaller when ≤ 10 . We need a rough seasonal dependence of a and b , which is estimated by the work of Østgaard, *et al.*, (2002) based on a linear fit to an estimate of the height-integrated energy dissipation and high correlation coefficient given by:

$$P(jh)(GW) = 0.54AE + 1.8 \quad 3$$

Where $P(jh)(GW)$ is the total hemispherical Joule heating rate in both the two hemispheres. Integrating equation (3) from the beginning of the event t_1 to its end t_2 with time, will give the corresponding energy in Giga joules (GJ)(Østgaard *et al.*, 2002).

$$w(jh) = \int_{t_1}^{t_2} P(jh)(W) dt \quad 4$$

Electron Precipitation

Electron precipitation energy occurs when electrons energized by solar winds, which are normally trapped in the magnetosphere, are pulled into the ionosphere by waves. To obtain the power via electron precipitation in GW we used Østgaard empirical relation obtained from UV and X-ray emissions converting westward electrojet into the northern hemispherical power which is then doubled to obtain global value (Østgaard *et al.*, 2002).

$$P(ep)(GW) = 2[4.4(AL)^{1/2} - 7.6] \quad 5$$

This is then integrated to obtain the total energy via electron precipitation $w(ep)$, from beginning t_1 to the end of the event t_2 in GJ (Østgaard *et al.*, 2002) .

$$w(ep) = \int_{t_1}^{t_2} P(ep)(GW) dt \quad 6$$

MATERIALS AND METHODS

The AE, AL in equations (7) and (8) were used to obtain joule heating rate and power via electron precipitation. The hourly provisional Auroral Electrojet indices (AE) for 2012 were converted to mean hourly-daily geomagnetic index as follows to reduce the clusters of data. To minimize error in dealing with a cluster of 1h-cadre of data we centralized them to a source K , such that : If $x_0, x_1, x_2, x_3, \dots, x_{23}$, are the hourly geomagnetic indices for a day, then

$$K = \frac{\sum_{i=0}^{23} X_i}{n} \quad 9$$

If X 's Geomagnetic indices are grouped into N intervals, with midpoints m_1, m_2, \dots, m_N and frequencies f_1, f_2, \dots, f_N , respectively, the simple arithmetic average is given by

$$K = \frac{\sum_{i=0}^{23} f_i m_i}{\sum_{i=0}^{23} f_i} \quad 10$$

The mean geomagnetic index obtained from either equation (9) or (10) was used as an input to equations 2 and 6, which we integrated to obtain an estimated energy value.

RESULTS

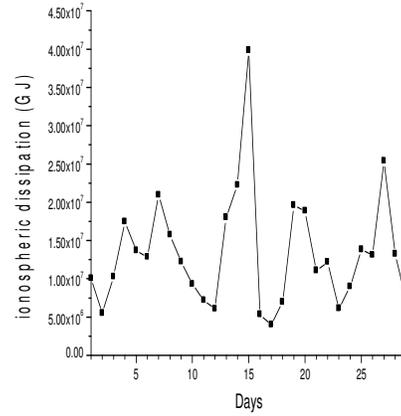
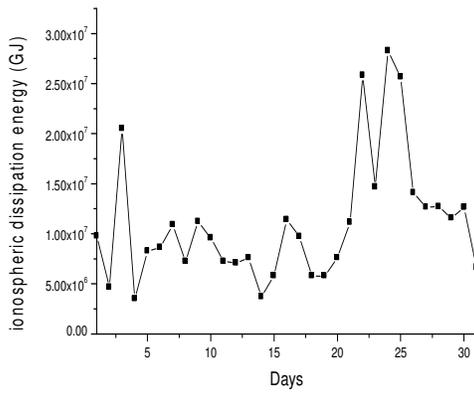
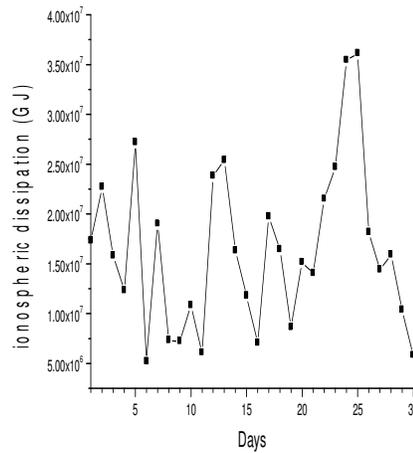
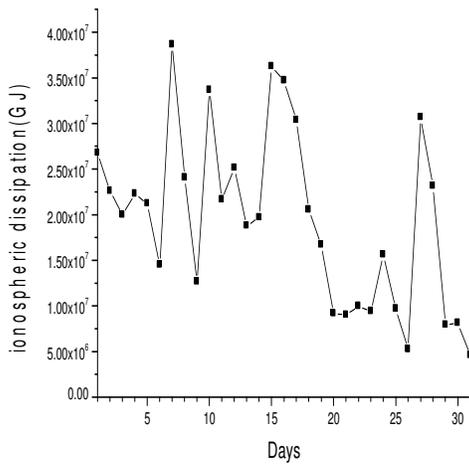
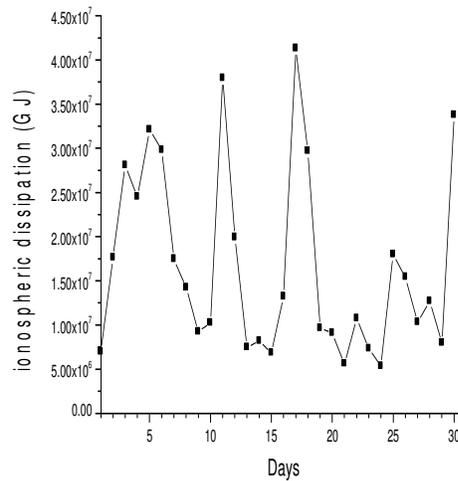
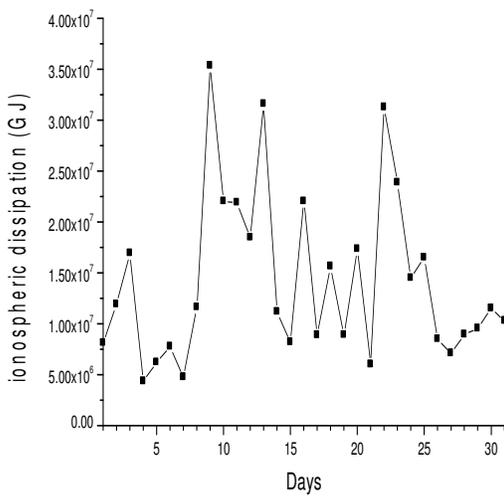


Figure1 & 2: Mean Daily Ionospheric Dissipation Energy (January & February, 2012)



Figures 3&4: Mean Daily Ionospheric Dissipation Energy (March & April, 2012)



Figures 5 and 6: Mean Daily Ionospheric Dissipation Energy (May&June, 2012)

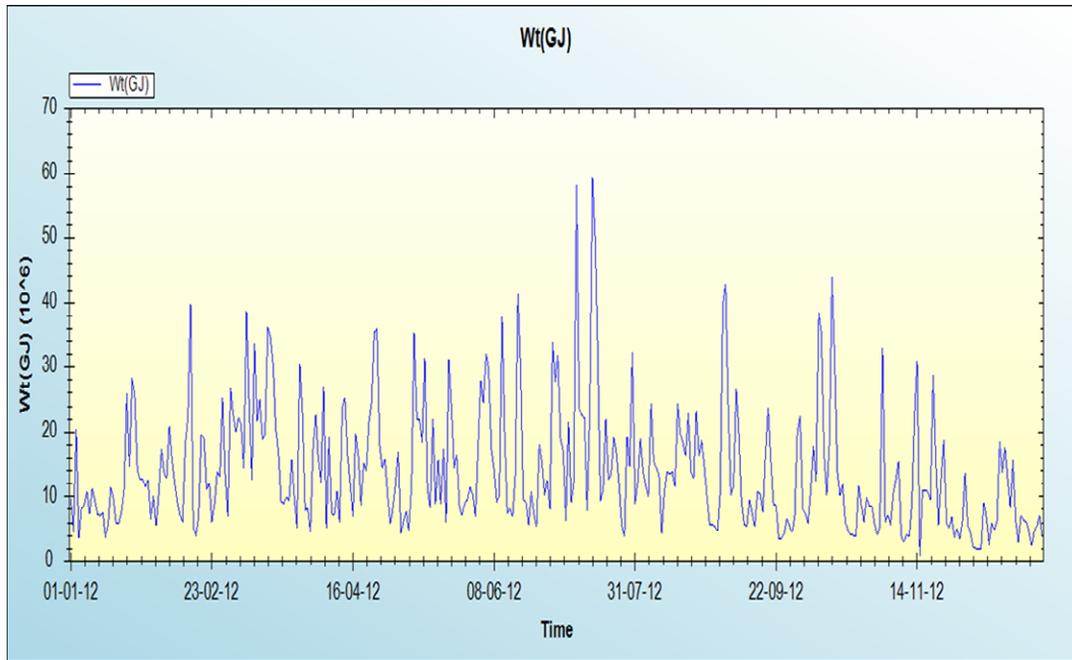


Figure7: Daily plot for Ionospheric dissipation 2012

DISCUSSION

In Figure1, during the first day of the year the dissipation energy was found to be moderate compared to other remaining days, high on 22nd but is maximum or very high on 24th followed by 22nd after which it started to decrease towards the minimum value. This means that the geomagnetic activity is almost stable for the month of the year.

On the 15th day of February, 2012, ionospheric dissipation was high, followed by average values during the 7th, 19th, 20th and 26th day of the month and least on the 17th, which means that the electric conductivity within the ionosphere begins to increase during these days.

From Figure3, we see that on 1st day of the month, the dissipation is of the order of 10^7 GJ with the peak value on the 7th, 15th and average values on 12th and 28th. Such orders of magnitude indicate the charged particles only drift to each other without collisions with neutral particles within the ionosphere (Ahn, *et. al*, 1998) thereby having both high thermal and drift energy.

The highest value of energy in Figure 4 occurs on 24th and 25th. The peak value of dissipation and their minimum values for both Figure 5 and 6 are in the range of 10^7 GJ and 10^6 GJ respectively.

The dissipation is very high compared to the other days of the year on the 9th, and 15th of July, 2012 with energy 5.81×10^7 GJ and 5.94×10^7 GJ respectively. This trend shows that

the solar wind current has imposed electric field in the ionosphere, thus dissipating huge amount of energy (Candrescu, *et. al* 1995).

On the 6th and 16th of August, 2012, the dissipation energy is almost the same. This is also true for the 19th and 22nd with least values on the 10th and 31st. within the same month and also ionospheric dissipation is high on 2nd followed by sudden increase on the 3rd before it starts decreasing towards an average value on the 4th, 7th and 19th of September, 2012. For these months, the concentration of neutral particles within the ionosphere seems to dominate the charged particles.

The charged particles drift relative to each other and neutral particles such that only some part of the particles velocities will be converted to thermal energy for dissipation in the ionosphere (Kallio, *et al*, 2000).

Figure7 gives the summary of the results and it is clear from the figure that the estimated daily ionospheric Dissipation Energy is $1.414393E+07 \pm 824154.1$ GJ. This means that in a year this amount of energy is dissipated in the ionosphere daily, which is greater than the solar wind energy input estimated by Akasofu in 1981. His estimate was 1.7×10^6 GJ. This clearly indicates that there are possibly other sources of energy dissipation in the ionosphere and not only the energy deposition by solar wind. The collisions between imposed electric field and neutral particles may possibly account for this energy increase.

CONCLUSION

The estimated value for ionospheric energy dissipation was found to be $1.414393E+07 \pm 824154.1GJ$ which is greater than the estimated energy input by Akasofu in 1981. This clearly indicates that there are other

sources possibly the collisions between imposed electric field and neutral particles may account for this energy increase and not only the energy deposition in the ionosphere as the sun constantly release energy, which is carried via the solar wind into the interplanetary space.

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