

Estimation of Ionospheric Joule Heating Energy Rate Using Some Empirical Relations

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Abstract- In the process of Solar wind Magnetosphere Ionosphere (SW-M-I) system there is a resulting energy rate being dissipated in the ionosphere. One of this is joule heating which causes some thermal expansion in the ionosphere. Here the joule heating was computed using some empirical relations, Auroral electrojet indices are used as input to the relation. Hourly provisional data values were obtain for the year 2010, 2011,2012,and 2013 were obtain at ISGI from world date center Kyoto and International Association for Geomagnetism and Aeronomy (IAGA) 2002 format was adopted during the computation under the assumption that the magnetosphere those not store any power. The coefficient of determination of this relations where compared and it was found the Baumjohann and Kamide relation has a better coefficient of determination which shows that they accurately estimate this energy rate compare to other relations.

Keywords: Solar wind, Magnetosphere, Ionosphere, Auroral Electrojets, Joule heating, Geomagnetism, Aeronomy.

I. INTRODUCTION

The Atmosphere is the gaseous layers that surround the earth, it is composed of mixture of gases including nitrogen, oxygen, carbon dioxide and water vapor the temperature of the atmosphere decreases with increasing altitude and the pressure also decreases with increasing altitude. The atmosphere plays an important role in regulating earth climate and protecting life on Earth from harmful radiation. The atmosphere has different layers with the troposphere being the lowest and closest to the earth surface.

The study of atmospheric layers began with phenomenon known as radio propagation. In 1990s scientist began to used radio wave to study the upper Atmosphere and they discover that the radio wave does not travel in straight line but instead were bend or refracted by the Atmosphere today scientist used different method to study the Atmosphere including balloons satellite and radar. Sound waves are used to study structure of the lower atmosphere while satellite are used to study the upper atmosphere. Radar is the strongest tool used to study the entire atmosphere.

In the process of solar magnetosphere system a stream of charge particles emitting from the sun

called solar wind. This charged particles interact with earth magnetic field in the ionosphere and transfer energy to ions, causing disturbance and malfunctions of satellite and loss expensive therefore monitoring the energy in the ionosphere can minimized this effect [1][2][10][11]. Ionospheric joule heating energy is one of the causes of energy dissipation in the ionosphere, is the process by which energy from the sun is transferred in to heat.

This occur when the earth magnetosphere is disturbed and energy provided by the solar wind is consumed in the magnetosphere –ionosphere system by three main process[3];injection of particles into inner magnetosphere and there subsequent loss mainly by charge exchange ,therefore in order to understand the energy transfer or coupling between the solar wind and the magnetosphere – ionosphere system it is important to deduce good estimate global joule heating rate which is second most important energy sink after ring current [3] or even sometimes the most important one [8]. However this important quantity has been very difficult to monitor continuously over the entire polar region .measurement of ionospheric field and conductivities with rocket borne and instrumentation or with the incoherent scatter Chatanika radar can only provide joule heating rate integrated over small area .Therefore a geomagnetic

index such as AE has been used and will probably be used in the future too as first approximation measure of the global joule heating rates.

The joule heating rate can be calculated using the equation [5][6][7]

$$U_{JH} = J.E \quad (1.1)$$

Where J is the current density and E is the electric field in the ionosphere

There are many empirical relations used in ionospheric joule heating energy rate estimates due to lack of direct measurement in J and E. Baumjohann and Kamide (1984) provide a relation which is based on combination of satellite and observation and theoretical calculations. The model is used to calculate the Joule heating power, which is the amount of energy deposited the atmosphere by particle precipitation and electromagnetic field space weather and it has been a reliable tool for estimating ionospheric Joule heating energy. Some researchers used observations from incoherent scatter radar in Chatanika, Alaska to create a similar regression equation. They found that the joule heating power can be represented by a law function of the solar radio flux. And finally they obtain a an equation

$$U_{JH}(GW)=0.32AE \quad (1.2)$$

Where U_{JH} is the Joule heating rate in Gig watts and the AE is the difference between the auroral electroject i.e difference between Eastward and westward AU and AL respectivel, Ostgaard et al., (2002) also provide a relation which is based on geomagnetic indices of KP and AE index. The KP index is a measure of the global activity of the earth's magnetic field. While the AE index is a measure of the auroral zones. These indices are used to represent the level of geomagnetic activity and its influence on the ionosphere In the Ostgaard et al., (2002) relation KP and AE are ussed to estimate the strength of the electric field and the different geomagnetic indices .The Ostgard et al., (2002) used observation from millstones Hill incoherent scatter radar, which is a radar facility in Massachussets that is used to study the ionosphere. He analyzed the data from this facility for a period several years and he found that the joule heating power can be represented by power law function flux. This function was used to create a regression equation that could

be used to predict the joule heating power. Finally he obtain an equation but inform of regression equation.

$$P(jh)(GW)=aAE+b \quad (1.3)$$

Where P (jh) is the Joule heating energy rate, AE is the difference between Westward and Eastward electrojet AU and AL respectively, while a and b are the scaling factors.

Now the Ostgaard et al., (2002) equation is given as

$$U_{JH}(GW)=0.28AE+0.9 \quad (1.4)$$

Where U_{JH} (GW) is the Joule heating rate in Gigawatts, while AE is the difference between the AU and AE electroject, 0.28 and 0.9 are the scaling factors.

The value of auroral electroject AE is obtain by the formula

$$AE =AU -AL \quad (1.5)$$

Recall that all the values of Al are negative therefore equation. (1.5) becomes

$$AE=AU +AL \quad (1.6)$$

Kalafatoglu Eyingiler (2018) provide a that relation used ionospheric observations to estimate the energy input into the ionosphere and it also takes into account the effect of earth magnetic field and solar wind.

The model is assigned to be used in real time and it is able to provide estimated of heating energy for specific location .In this model the satellite based FORMOSAT-3S/COMIC data was used to analyzed the joule heating power .He found that the observed power can be represented by a law function of the solar radio flux. Similar to Ostgard et al., (2002) and [4]. He finally obtain an equation which is inform of regression equation

$$U_{JH}(GW)= 0.23AE \quad (1.7)$$

Where U_{JH} is the Joule heating rate in gigawatts, AE is the difference between the auroral electroject. (i.e difference between AU and AL) and 0.23 is the scaling factor. Ostgard et al., (2002) model and Baunjohann and Kamide (1984) model have some similarities both models used similar method to analyze the incoherent scatter radar data, they both used statistical techniques to find a regression equation that best represented the data. Additionally

both model found that a power law function was good fit for the data, they also used similar assumptions about the physics of the ionosphere in their analysis .While [9] used FORMSAT- 3/COSMIC data to analyzed joule heating rate.

The Ostgard et al., (2002) model and Baumjohann and Kamide [1984] model have some few difference. One of the difference between [12], [4] is the location of the incoherentscatter radar used in the analysis, where the [12] used the millstone Hill radar which is located in the Massachsetts, while Baunjohann 1984 used the Chatanika radar which is located in Alaska.this difference very because the structure o f the ionosphere can vary greatly from one location to another.

The Ostgard et al., 2002 model used data from 1981 to 1986 while [4] model use data from 1975 to 1979, this difference is also important because it can affect the statistical properties of the data which in turn can affect the regression equation.

In general the [4] model used a longer data set which can lead to a more robust regression equation. Another difference is the used of power law function in the analysis, both models used power law function to analyze data. Having understand how the three models used their data and finally obtain a regression equation for estimating ionospheric joule heating rate.

Here we employed three empirical model in order to compare and find out the most accurate regression equation that established the relationship between joule heating energy rate and any of the geomagnetic index

II. MATERIALS AND METHOD

The hourly provisional data values of AU and AL was obtain from International Service for Geomagnetic Indices(ISGI) from World Data Center Kyoto Japan, was used to estimate the joule heating rate using different empirical relation under the assumption that the magnetosphere ionosphere does not store any energy .

International Association for Geomagnetic and Aeronomy (IAGA 2002) format was adopted

If $x_1, x_2, x_3, x_4, \dots, x_{30}$ represent the auroral electrojet for the month of the year, then the total auroral electrojet is given as

$$AE = \sum_{i=1}^{30} xi \tag{3.1}$$

The above equation was used to compute the AE for each month of the year and it was input to the empirical relation which is used as input to empirical relations.

III. RESULT AND DISCUSSION

Result

TABLE 1.Joule heating energy rate for the year 2010

S/N	MONTHS	Baunjohann and Kamide (1984)(GW)	Ostgard et al (2002) (GW)	Kalafatoglu Eyigiler (2018) (GW)
1	January	454118.4	41753.6	3263957.4
2	February	42889.6	375278.4	308264.4
3	March	496166.4	434143.6	356619.6
4	April	599884.8	524899.2	431167.2
5	May	356006.4	311505.6	255879.5
6	June	31673.63	27714.4	22765.4
7	July	364416	318864	261924
8	August	339187.2	296788.8	243790.8
9	September	322368	282072	231702
10	October	260697.6	228110.4	26394.8
11	November	36723.2	32132.8	225657.6
12	December	313958.4	274713.6	23437.2

TABLE 2. Joule heating rate for the year 2011

S/N	MONTHS	Baunjohann and Kamide (1984) (GW)	Ostgard et al., (2002) (GW)	Kalafatoglu Eyigiler(2018) (GW)
1	January	94279.68	82494.72	67763.52
2	February	61286.4	536225.6	44049.6
3	March	48806.4	427056	35079.6
4	April	36864	32256	26496

5	May	22617.6	1970.4	16256.4
6	June	20736	18144	14076
7	July	249984	21873.6	18823.2
8	August	321408	30240	22245.6
9	September	34560	39580.8	24012
10	October	45235.2	5844	31657.2
11	November	66816	65082.8	48852
12	December	86899.2	76036.8	63314.4

TABLE 3. Joule heating energy rate for the year 2012

S/N	MONTHS	Baunjohann and Kamide (1984)(GW)	Ostgard et al (2002) (GW)	Kalafatoglu Eyigiler (2018) (GW)
1	January	9525112	83328.9	68448
2	February	6021.12	526848.9	4327.68
3	March	499996.8	437472.9	3593.2
4	April	40320	3528.9	2898
5	May	23808	20832.9	17112
6	June	19584	22916.1	14076
7	July	2618828	270816.9	18823.2
8	August	30950.4	29232.9	22245.6
9	September	33408	3850.1	2392
10	October	440448	59472.9	31657.2
11	November	67968	6732.9	4882
12	December	880896	7639.3	63314.4

TABLE 4. Joule heating rate for the year 2013

S/N	MONTHS	Baunjohann and Kamide (1984) (GW)	Ostgard et al (2002) (GW)	Kalafatoglu Eyigiler (2018) (GW)
1	January	904704	79162.5	65025.6
2	February	62361.6	54567.3	44822.4
3	March	47616	4166.9	3422.4
4	April	3801.6	33264.9	27324
5	May	21427.2	18748.7	154008
6	June	18432	16128.9	13248
7	July	26.8	2084.1	17112
8	August	29760	26040.9	21390
9	September	32256	28224.9	23184
10	October	42854.4	37498.5	30801.6
11	November	645312	56448.9	46368
12	December	88089.6	770784.9	63314.4



Fig 1. Graph of Joule heating energy rate for the year 2010



Fig. 2. Graph of Joule heating energy rate for the year 2011

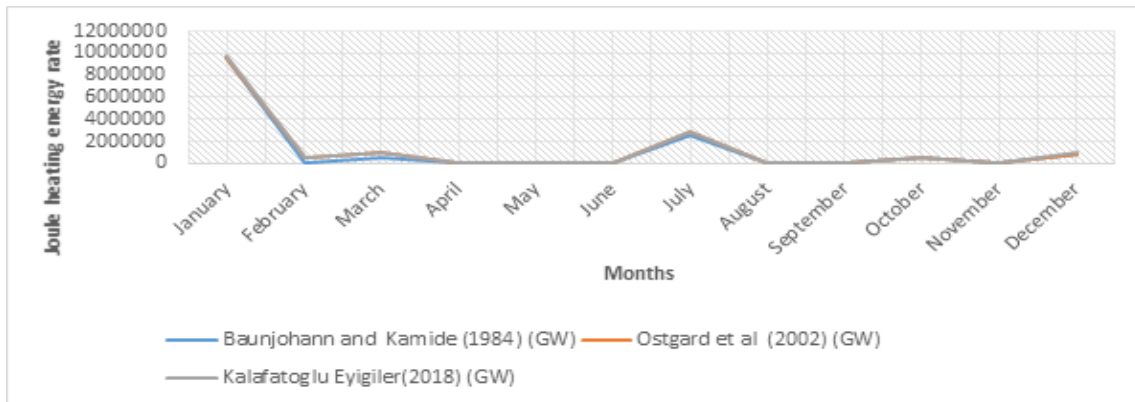


Fig.3. Graph of Joule heating energy rate for the year 2012

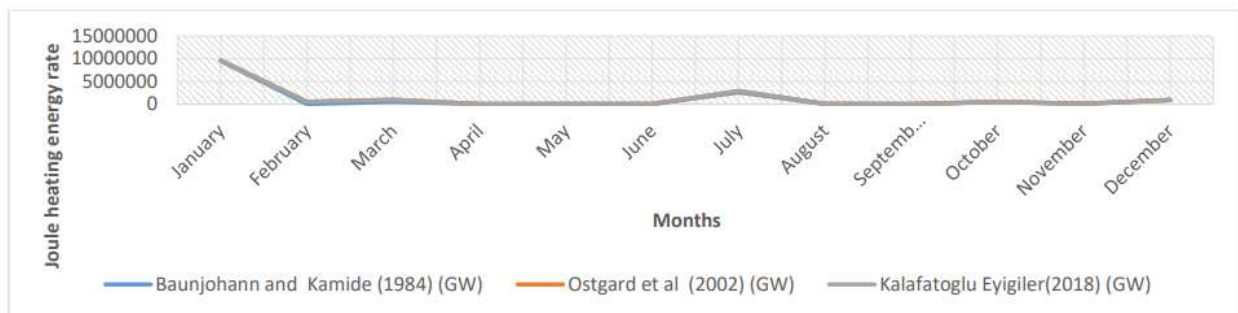


Fig.4. Graph of Joule heating energy rate for the year 2013

Table 5. COEFFICIENT OF DETERMINATION OF THE EMPIRICAL RELATIONS

S/N	Year	Ostgard et al 2002	Baunjohann and Kamide 1984	Kalafatoglu eyingiler 2018
1	2010	0.54	0.32	0.04
2	2011	0.06	0.412	0.65
3	2012	0.52	0.832	0.61
4	2013	0.32	0.91	0.561

Mean

0.36

0.62

0.47

IV. DISCUSSION

In table 5. the Baunjohann and Kamide 1984 relation was found to have the highest mean determination coefficient of 0.62 compare to Kalafatoglu eyingiler 2018 relation which is the moderate with the mean determination coefficient of 0.47 followed by Ostgard et al 2002 which has the minimum mean determination coefficient of 0.36 this implies that the Baunjohann and Kamide 1984 relation provide accurate energy rate estimate.

V. CONCLUSION

Result obtained during the period of study indicate that Baumjohann and Kamide (1984) provide accurate estimate, with 0.62 as mean determination coefficient for the duration of the study.

Recommendation

Further research is needed to use other empirical relations or other geomagnetic indexes in order to estimate ionospheric joule heating energy rate which will increase a better understanding of upper atmosphere.

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