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Research Paper

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Semiannual Variation of Total Ion Density of Topside Ionosphere Over Indian Equatorial and Low Latitudes

S. Bora

Dept. of Physics, Lakhimpur Telahi Kamalabaria College, N Lakhimpur, Assam, India

Author's Mail Id: saradi.bc.bora@gmail.com, Tel.: +91-9864678656

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Abstract – The total ion density measured by the Retarding potential analyzer (RPA) onboard the satellite FORMOSAT-1 have been analyzed to study the periodicity of the total ion density in the Indian equatorial and low latitude topside ionosphere during peak of the solar cycle 23 (1999 – 2003). The observation reveals the existence of an equinoctial asymmetry. The density is higher in the equinoxes than in the other seasons. This asymmetry is hemisphere dependent. The total ion density is maximum in the March equinox than that in the September equinox in the northern hemisphere. In the southern hemisphere, this pattern is seen in 2000 and 2002. But the March equinoctial density in 2001 is higher than that in the September equinox in the southern hemisphere. An annual and semiannual variation in density during the daytime (10:00-14:00 hrs LT) and nighttime (22:00-02:00 hrs LT) hours is observed. The spectral analysis shows that the power of the annual component is higher in the southern hemisphere while the semiannual component is higher in the northern hemisphere during daytime. But during the nighttime the power of the annual component is higher than that of the semiannual component.

Keywords- Ionosphere, ionospheric total ion density, annual and semiannual variation, periodicity.

I. INTRODUCTION

The main source of plasma density in the ionosphere is the photoionization and is controlled by the production and loss mechanisms. The production and loss rate of plasma in the ionosphere is controlled by atomic and molecular gases respectively. So the atomic to molecular ratio affects the variation of ion density in the ionosphere. Many ionospheric parameters exhibit a periodicity which is represented by an annual and semiannual component. The annual component has a cycle with maximum in summer solstice, and the semiannual component has a cycle with maxima near equinoxes. It has been found that there exists a regular annual and semiannual variation in peak electron density of the F_2 layer, NmF_2 [1, 2, 3, 4, 5, 6] and the height of the F_2 layer peak, hmF_2 [7]. A semiannual variation is also noticed in case of geomagnetic indices such as K_p and A_p [8, 9]. Annual and semiannual variation in Total Electron Content (TEC) also has been reported in several earlier works [10, 11].

Hitherto there is no single agreement over the main reason for the observed periodicity or annual/semiannual variation. These ionospheric variations are studied with the help of satellite observed plasma density by many earlier workers [11, 12, 13, 6]. In this paper the equinoctial asymmetry or semiannual variation of total ion density is analyzed as observed by the satellite ROCSAT – 1 during the period 1999 – 2003 over Indian longitude sector.

II. RELATED WORK

To explain the semiannual variations a mechanism named 'thermospheric spoon' has been proposed [14]. They suggested that due to global thermospheric circulation during solstices the density of the molecular nitrogen (N_2) and oxygen (O_2) rises thereby reducing the density than that in equinoxes. Using the electron density observed by Hinotori satellite an annual asymmetry by 100% during daytime and 30% during nighttime has been found [11]. They used the Sheffield University Plasmaphere Ionosphere Model (SUPIM) to study the annual and semiannual variations in the low latitude topside ionosphere and the model calculations showed that annual variations exist in the neutral gas densities. They proposed that the transequatorial neutral winds are responsible for these variations. The global annual and semiannual variation of NmF_2 and hmF_2 are tried to be explained by the atomic to molecular ratio [O/N2] in many earlier works [4, 10, 6]. It has been suggested that the semiannual variation of the diurnal tide in the lower thermosphere modulates the semiannual variation of the Equatorial Electrojet via the wind dynamo process, and this affects the ionospheric variations through fountain effect [3]. Similar annual asymmetry in the MSIS model of the thermosphere has also been found [5]. They also reported difference of the asymmetry between the two hemispheres.

III. MATERIALS AND METHOD

In this study the ion density as measured by the satellite ROCSAT – 1 (later renamed as FORMOSAT 1) has been used. It is a Low Earth Orbiting satellite at a mean altitude of 600 km with an inclination of 35^o. The onboard Ionospheric Plasma and Electrodynamics Instrument (IPEI) made in situ measurements of ion density, temperature, ion composition and drift velocity. It had started its measurement from March 1, 1999 and ended on June 14, 2004. Details of the IPEI can be found in [15]. At a fixed longitude and in low latitudes the satellite took about 25 days for full coverage. In the present study the ion density data have been divided into sets of ±2.5^o in latitudes from -40^o to +20^o geomagnetic latitudes (±30^o geographic latitudes) in 5^o interval for geomagnetic quiet condition (Kp≤ 3). The longitudinal extent of the data has been restricted to 65^{o}E to 100^{o}E.

IV. RESULTS AND DISCUSSION

Figure 1 shows the 2D surface plot of monthly average daytime (10:00-14:00 hrs LT) ion density over ±30^o geographic latitudes. The same is plotted for nighttime (22:00-02:00 hrs LT) ion density in Figure 2. Due to the formation of Equatorial Ionization Anomaly (EIA), double humped structure of density on either side of the equator has been observed. The total ion density is greater in the equinoxes than that in the winter or summer. The annual asymmetry has been found in many previous works [12, 5, 11, 6]. But its proper explanation is still an open question in ionospheric physics [6]. It has been proposed that the annual asymmetry may be contributed from the geomagnetic field configuration, the sun earth distance, and forcing from the lower atmospheric tides [17]. The observed annual asymmetry in ion densities at 840 km may be attributed to the changes of neutral oxygen and thermospheric winds [13]. They found similar annual and hemispheric asymmetries in O as provided by the NRLMSISE-00 model [18] and neutral winds from the HWM (Hedin Wind Model) model [19]. Since transport plays an important role in the dynamics of the topside ionosphere besides neutral compositions, the seasonal variations of neutral winds may play an important role in annual variations of ion density [13]. Figure 1 also shows an inter-hemispheric asymmetry. It is seen during daytime that, the density is maximum in the northern hemisphere than in the southern hemisphere. In 2000, the density is greater in the March equinox than that in the September equinox in both the hemispheres. In 2001, the density is greater in the March equinox in the northern hemisphere, but in the southern hemisphere, it is greater in the September equinox. In 2002, a different pattern is observed. In the September equinox the density is higher in the southern hemisphere, but in the March equinox it is higher in the northern hemisphere. Also in the northern hemisphere the density is higher during the winter (January) in 2002. In 2003, the density is higher in the March equinox than that in the September equinox. During nighttime the density is higher in the March equinox in 2000, 2002 and 2003. But in 1999 and 2001 it is higher in the September equinox.

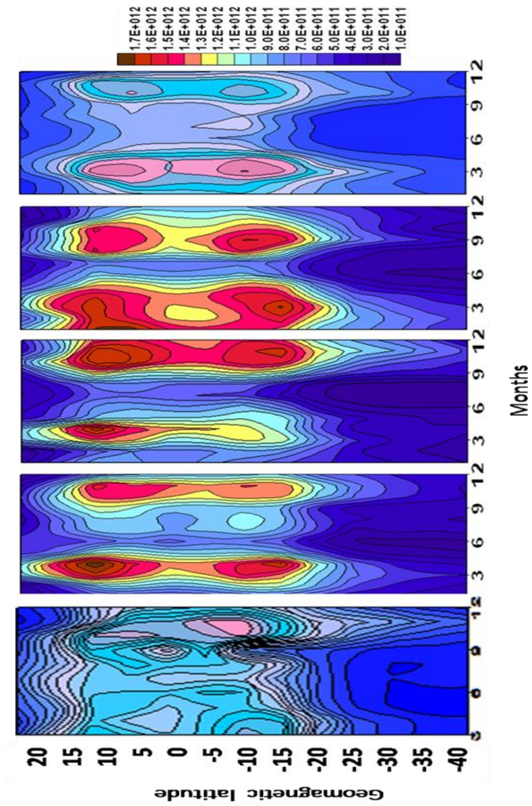

Figure 1: Month to month variation of daytime average (1000 LT – 1400 LT) total ion density from 1999 (March) to 2003 (December).

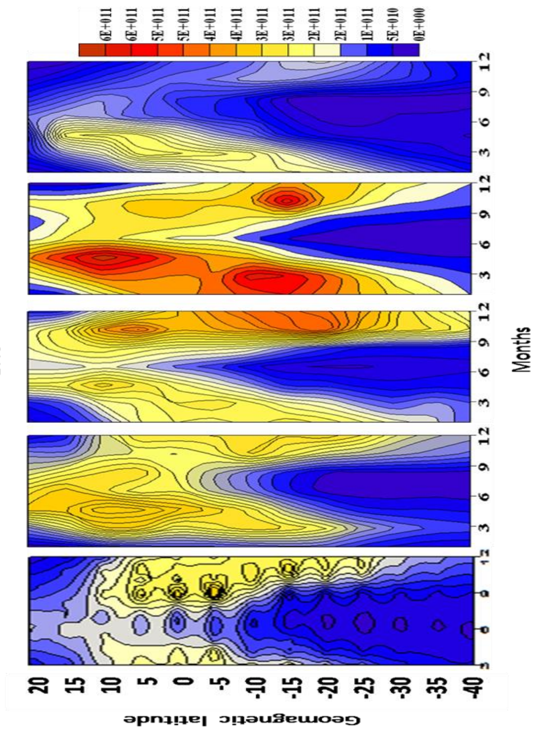

Figure 2: Month to month variation of nighttime average (2200 LT – 0200 LT) total ion density from 1999 (March) to 2003 (December).

The Global Ultraviolet Imager (GUVI) is one of the four instruments that constitute the TIMED spacecraft, the first mission of the NASA Solar Connections program. The values of [O/N_2] refers to the column density ratios above levels of the fixed N_2 column content (10^{21} m^{-2} or 10^{17} m^{-2}), derived from air glow observations in the 140 – 250 km height range [20]. The thermosphere has a greater O/N2 ratio in the low latitudes and maximizes during the equinoxes as compared to solstices [7] which is supported by the maps of GUVI O/N2 [10]. So the equinoctial asymmetry in the ROCSAT 1 total ion density may be due to the variation in the thermospheric atomic to molecular density ratio. The thermospheric O/N_2 ratio images of GUVI for the year 2002 and 2003 on 15th of every month is shown in figure 3 and 4.

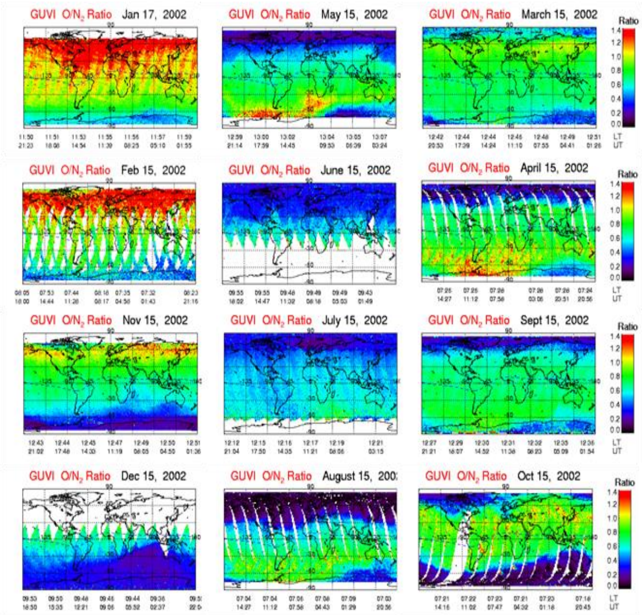

Figure 3: Thermospheric O/N_2 ratio given by GUVI for 2002.

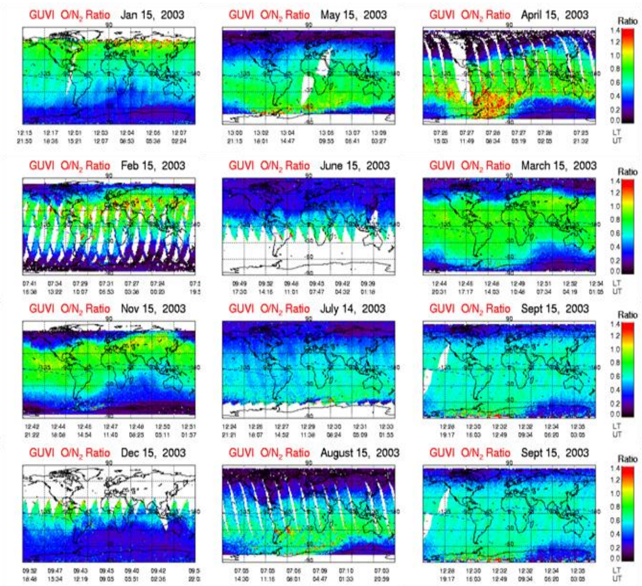

Figure 4: Thermospheric O/N_2 ratio given by GUVI for 2003.

It is seen from the figures that the O/N_2 ratio is greater in the equinoctial months (March, Apr, Sept, Oct) than that in the other periods. However in 2002 a higher ratio is found during January and February. It is reflected in case of total ion density that a broad maximum is found in winter to March equinoctial period in 2002. The observed equinoctial maximum in total ion density may be attributed to the observed behavior of O/N_2 ratio.

To study the annual and semiannual variation, a spectral analysis was carried out. Figure 5 and 6 shows periodograms for the daytime and nighttime ion density respectively. It is seen that the relative strength of the semiannual and annual components is quite different between day and nighttime and also between the two hemispheres. During the daytime the semiannual component is stronger than the annual component in the low latitude and equatorial regions. Over the ± 20° magnetic latitudes, the annual component starts to increase and prominent in the southern hemisphere than the semiannual component. This latitudinal variation of annual and semiannual components is consistent with the previous works [21, 22, 13]. The observed north – south asymmetry as seen in figure 5 and 6 may be attributed to the difference of O/N_2 ratio in the two hemispheres during June and December solstices. The ratio is higher in the northern hemisphere in December solstice while it is higher in the southern hemisphere in June solstice with a symmetrical pattern in the equinox.

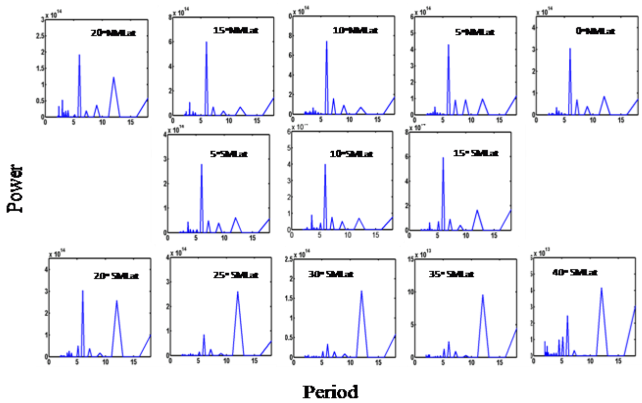

Figure 5: Periodogram for daytime (1000 LT – 1400 LT) total ion density.

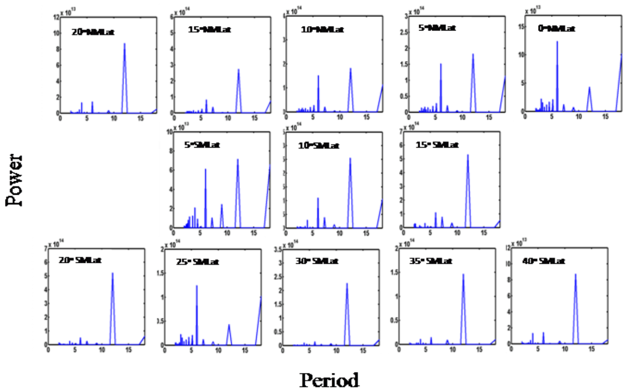

Figure 6: Periodogram for nighttime (2200 LT – 0200 LT) total ion density.

A hemispheric asymmetry in NmF2 and high altitude electron density has been found from FORMOSAT3/COSMIC IRO observations [22]. From total electron content (TEC) measurements a decreasing trend from low to high latitudes in semiannual component has also been found [21]. The north-south asymmetry of ion density of topside ionosphere may be influenced by the neutral winds. Thermospheric winds push the plasma to higher altitudes and the plasma is transported from one hemisphere to the other through modulation of the field aligned flows, which in turn influences the latitudinal variation of ion density of topside ionosphere. As reported earlier that the hemispheric asymmetry is accentuated by the neutral winds, which lift the F region upward/downward in the summer/winter hemisphere and thus electron density tends to increase/decrease in the summer/winter hemisphere [16] the study of neutral winds in the two hemispheres may be helpful for further study. In this study it has also been found that during nighttime, the amplitude of the annual component in both the hemispheres is pronounced in the high latitudes.

V. CONCLUSION AND FUTURE SCOPE

The semiannual variations of total ion density of topside ionosphere are studied with the help of satellite data. The results show that the ion density is greater during the equinoxes indicating the presence of strong semiannual component in the low latitudes. Also there exists an interhemispheric asymmetry during March and September equinoxes between the two hemispheres. To study the variations more precisely a spectral analysis has been done with the help of periodogram. The amplitude of the annual component is more prominent at low and high latitudes of southern hemisphere whereas the amplitude of the semiannual component highest in the northern equatorial region. The semiannual component on the other hand is confined to the low latitudes only and peaks at the magnetic equator. The combined effect of neutral winds and drift along the magnetic flow and production during the daytime might left residual ionization thus affecting the seasonal variation even in the absence of production. The variation in the amplitudes of the annual/semiannual component as well as position with respect to the magnetic equator needs further investigation.

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AUTHORS PROFILE

Dr. Saradi Bora pursed her PhD from Dibrugarh University, Assam in Ionospheric research. She is currently teaching physics in Lakhimpur Telahi Kamalabaria College, North Lakhimpur, Assam.