Longitudinal Variation of ion temperature of topside ionosphere over Indian low latitudes

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Abstract: The ion temperature of topside ionosphere shows significant variation with respect to daytime and season. The longitudinal variation of ion temperature of topside ionosphere has been studied using satellite data for the the period of 1999 to 2003 over Indian subcontinent. The study showed a longitudinal drift of ion temperature along 95^{o}E longitude sector as compared to the 75^0 E longitude sector.

Keywords: Ionosphere, Ion temperature, Longitudinal asymmetry.

1. Introduction:

The atmosphere of a planet is the gaseous envelop that surrounds the planet and protects it from the Sun’s extreme radiation. The Earth’s atmosphere may be subdivided into the lower atmosphere (troposphere), middle atmosphere (stratosphere and mesosphere) and upper atmosphere (ionosphere and thermosphere). The solar radiations in the wavelength range of extreme ultra violate (EUV) and X-rays ionize the upper atmosphere mainly at low and equatorial latitudes. This process is known as the photoionization. At high latitudes in addition to photoionization, the collisional ionization due to particle precipitation from the magnetosphere is another source of ionization. The ionosphere is a part of the upper atmosphere where there are enough electrons and ions to effectively interact with electromagnetic fields. The existence of a conducting layer in the upper atmosphere was first inferred by Balfour Stewart based on the observed daily changes in the geomagnetic field. In 1889 Schuster demonstrated the presence of an electric current flowing overhead. On Dec 12, 1901 Marconi transmitted radio waves across the Atlantic. The very discovery of the ionosphere came from this radio wave observations and the recognition that only a reflecting layer composed of electrons and positive ions could explain the characteristics of the data. Kennelley and Heaviside in 1902 independently invoked that an overhead conducting layer is present which is responsible for transmitting the radio wave. Kennelley placed the layer at 80 km, much higher than thought by Stewart and Schuster and it was called the Kennelley- Heaviside layer. Direct evidence of the existence of the Kennelley- Heaviside layer was obtained by comparing the fading characteristics of signals received on two types of directional antennas by Appleton and Barnett (1925) and called E layer by Appleton. It plays an important role in atmospheric electricity and forms the inner edge of the magnetosphere. The most important property of ionosphere is its ability to reflect under suitable conditions the long medium and short waves used for broadcasting and radio communications.

The ionosphere has no upper boundary but merges into the Heliosphere. Above the Mesopause, the temperature increases to above 1000^{o}K. This region is termed as Thermosphere. The shorter ultraviolet radiations are absorbed in the thermosphere and are responsible for the high temperatures existing there. At heights of about 80 km in the thermosphere, the atmosphere is so thin that free electrons can exist for a short period of time before they are captured by a nearby positive ion. So the atmospheric constituents at this height are in the plasma state due to absorption of solar radiation. In addition to the photo ionization process another source of ionization is the collisional ionization due to particle precipitation from the magnetosphere in particular in the high latitude regions. The strength and form of the magnetospheric effect is primarily determined by the solar wind dynamic pressure, and the orientation of the Inter-planetary Magnetic Field (IMF). The neutral densities in the lower thermosphere is effected by gravity waves and tides propagated from the stratosphere. These variations also affect the plasma densities of the ionosphere. So, different external driving mechanisms and their relations to the ionospheric parameters are studied to determine the global distribution of plasma densities, temperature and drifts.

The ionosphere is vertically stratified in to D, E and F layers depending on the different physical processes and different dominating ions. In the D and E regions the main ions are O_2^+, N^+_2, NO^+ and dominant by photochemistry. The ionization is caused mainly by the UV and X-rays in the D region and solar radiation of EUV wavelength is responsible for E region. The F layer is usually subdivided into three layers. The lowest region (F_1) is produced by photoionization and loss process take place by recombination with electrons. The next layer is the F_2 layer where maximum electron density occurs. The uppermost part of the ionosphere above F_2 layer is usually termed as topside ionosphere where ionization is dominant by diffusion. These processes occur during the daytime that is in the sunlit side of the earth. During nighttime, ionization occurs in the E region only due to the resonantly scattered sunlight and star light.

The ionosphere shows significant variations with time of the day, latitude, longitude, altitude, seasons, solar activity, geomagnetic activity and eclipses. Owing to the geometry of the earth's dipolar magnetic field lines a distinctive latitudinal characteristics is found in the ionosphere. So the ionosphere is classified into three latitude regions, low (equatorial), middle and high (auroral) latitude regions. Each latitudinal region is controlled by different physical processes. In this chapter I am going to discuss some spatial and temporal variations of ion temperature observed over Indian low latitude topside ionosphere.

2. The equatorial and low latitude ionosphere:

The equatorial and low latitude ionosphere has been the venue of many ground and space based experiments as it has many unique features which are not found elsewhere. The ionospheric electric field plays a dominant role in low-latitude electrodynamics. The effect of neutral winds together with diurnal and semi-diurnal tidal components in the atmosphere causes currents at an altitude of 100 to 130 km, which is known as the Sq current system in the E region. This current system results in an eastward electric field at low latitudes. In the equatorial E-region the east-west electric field drives the equatorial electrojet which is a narrowband of enhanced eastward current flowing in 100 to 120 km altitude region within $\pm 3^o$ latitude of magnetic equator during daytime. During the daytime one of the most prominent features seen at the equatorial low latitude ionosphere, is the Equatorial Ionization Anomaly (EIA) or the Appleton anomaly. It is distinguished as a depression in plasma density or trough at the geomagnetic equator and two peaks at about $\pm 10^o$ to $\pm 15^o$ magnetic latitudes. The EIA is formed as a consequence of E×B upward plasma drifts associated with the eastward electric field (E) and a northward horizontal magnetic field (B). As the plasma is lifted to greater heights, it diffuses downward along the geomagnetic field lines due to the gravitational force and plasma pressure gradient. And this results in ionization enhancements on both sides of the magnetic equator. This physical phenomenon is generally termed as the plasma fountain. The fountain rises to several hundred kilometers at the magnetic equator and the crests become weaker with increasing altitudes. At higher altitudes a single peak appears over the magnetic equator. In situ measurement of plasma density in the F region ionosphere provides useful information about the location of the EIA, its spatial and temporal extent and variability with season and solar cycle. Besides these Equatorial Temperature and wind Anomaly (ETWA), Equatorial Spread F, plasma bubble etc. are the common features of the equatorial low latitude region.

3. Plasma temperature variation:

The study of ion/electron temperature of low latitude ionosphere has been done using satellite, radars and incoherent scatter radars. The lack of thermal equilibrium is a normal feature of the equatorial F region ionosphere. The energy carried by ionizing photons or charged particles generally exceeds the energy required for ionization. The time taken by these fast super thermal photoelectrons to lose the excess energy to the neutral gas is very much shorter than their lifetime before recombination. Therefore, the average electron energy exceeds that of other particles and hence electron temperature (Te) is higher than that of neutral temperature (Tn). The ion temperature (Ti) lies in between the electron and neutral temperatures. Some interesting features seen at the low latitude ionosphere and studied extensively are the morning and afternoon enhancement, the temperature and wind anomaly, latitudinal/longitudinal asymmetry and short and long term periodicity (Balan et al., 1997; Bhuyan et al., 2002 (a, b), 2004; Prabhakaran Nayar et al., 2004; Borgohain et al., 2012) etc. The diurnal variations of ion temperature show an increase of temperature during morning hours after a nighttime minimum, followed by a daytime plateau and a secondary evening enhancement. Oyama et al. (1996) showed that the structure of the equatorial ionospheric F region plasma density and plasma temperature are strongly controlled by the ionospheric electric field, neutral wind, exospheric temperature and intensity of solar flux variations. Bhuyan et al., (2002c) reported that Te at 500 km rises sharply during sunrise to reach a peak within a couple of hours and then falls to a daytime average level. Watanabe (1995) theoretically investigated morning and afternoon enhancements of the electron temperature and found that the morning Te enhancement is due to photoelectron heating while afternoon enhancement is controlled by meridional wind and downward E×B drift at afternoon. At sunrise, photoelectrons are produced through photoionization and they share their high energy with the ambient electrons. So the plasma temperature increases and the process is rapid in the early morning hours due to low plasma density. The intense morning enhancement of electron temperature observed over the equator is due to the reduction in electron density caused by the downward drift of plasma occurred in morning hours. After sunrise, as the plasma density increases and energy is shared between more electrons/ ions, the plasma temperature decreases. The daytime valley of plasma temperature as reported so far is the result of the balance between electron heating and cooling processes. Though electron heating by solar EUV is maximum near noon, it is compensated by electron cooling, resulting from the higher noontime electron density.

4. Longitudinal asymmetry in ion temperature over Indian low latitudes

The data from topside F region measurements over equatorial and low latitudes are sparse especially over the Indian subcontinent both in the temporal and spatial extent. The Japanese Hinotori satellite which had a near circular orbit at ~600 km provided a good database for study of the temporal and spatial variation of electron density and temperature in the topside ionosphere [*Watanabe and Oyama*, 1995, 1996; *Su et al*., 1996]. But the Hinotori data were limited to a period of medium and high solar activity (150≤ F10.7 ≤ 220). The Indian satellite SROSS C2, launched in 1994 into an orbit of 630 km by 430 km, had two Retarding Potential Analyzers (RPA), on board for measurement of electrons and ions separately. The satellite provided an extended database, for the first time over the Indian longitude sector, for study of electron density and temperature variations for a period extending from solar minimum (1995) to solar maximum (2000) during solar cycle 23. Later in 1999, the first Republic of China Satellite (ROCSAT – 1) was launched which provides the global data of total ion density, temperature, ion composition and drift velocity with 1- s resolution. In this work, the ion temperature measured by the ROCSAT – 1 from 1999 to 2003 over the Indian longitude sector has been used to investigate the temporal and spatial variation. Particular emphasis is given to the delineation of the effect of longitudinal gradient of ion temperature. These data have been divided into bins of ±2.5^{o} in latitudes from -20^{o} to +20^{o} geomagnetic latitudes in 5^{o} interval for geomagnetic quiet condition (Kp≤ 3). The longitudinal extent of the data is restricted to ± 10° of 75°E and 95°E to avoid superposition of data from one longitude to another. For studying seasonal variations, three seasons are considered: June solstice (May, June, July, Aug) December solstice (Nov, Dec, Jan, Feb) Equinox (Mar, Apr, Sept, Oct). The annual mean F10.7 solar flux is ~153,~181,~184,~180 and ~130 for 1999,2000,2001,2002 and 2003 respectively.

5. Results and discussion:

a) Diurnal and seasonal variation of ion temperature:

Figure 1 and figure 2 shows the 2D plots for diurnal variation of ion temperature in three seasons along 75^{o}E and 95^{o}E longitude sectors respectively. From the two figures it is seen that the magnitude of ion temperature (Ti) is slightly higher along 75^{o}E than that along 95^{o}E during the daytime hours in all the seasons accept in 2000 June solstice. The peak value of Ti during the period is observed in June solstice 2001. During the period of observation (1999 to 2003) in all the seasons Ti starts to increase its value at around 0600LT and attains it's maximum at around 0800 LT. After attaining maximum value it spreads for a longer period till the noon or afternoon hours and then starts to decrease slowly over ±15^{o} latitudes. But over the geomagnetic equator the Ti after attaining its maximum value decreases quickly. The maximum value of Ti over equator exists for a period of about two hours, but over off equatorial latitudes it exists for a longer period. The minimum Ti is found during nighttime and before sunrise. After sunrise, the ion temperature falls as the electron temperature also falls due to sharing of energy with more electrons. The daytime ion temperature is the result of balance between ion heating and cooling processes. The daytime electron temperature also shows a plateau. The diurnal maximum and minimum ion temperature for each season from 1999 to 2003 is given in Table 1 and 2 along 75^{o} E and 95^{o} E longitude sectors respectively.

Higher electron energy results in higher ion temperature. Photoelectron productions begin at sunrise through the ionization of neutral particles. As the photoelectrons share their high energy with ambient electrons, the electron temperature increases rapidly in the early morning hours as the electron density is minimum during this period. After sunrise, temperature decreases as electron density increases and energy is shared between more and more electrons. The daytime valley results out of the competition between electron heating and cooling processes. An evening enhancement of ion temperature is also noticed. This may be attributed to the E×B drift and the neutral wind effects (Oyama et al., 1996). In the equatorial anomaly region, downward E×B drift near sunset can carry the high altitude dayside hot plasma into the topside F region which results in the observed enhancement of ion temperature.

b) Longitudinal variation of ion temperature:

The hourly average ion temperature (Ti) at four hour interval from 0400 LT to midnight over ± 15^o latitude and over the equator along 75^oE and 95^oE longitudes are compared to study the longitudinal difference of Ti and shown in figure 3(a) and 3(b). The figure 3(a) shows that the data points are lying along the zero line showing there is no difference in Ti along the two longitude sectors at midnight, 0400 LT and 2000 LT. But at 0800 LT which is the time of occurrence of maximum Ti, it is greater along 75^oE longitude over the equator. Over ± 15^o latitudes the Ti along the two longitudes remains same. In figure 3(b) at 1200 LT ion temperature is greater along 75^oE over 15^oS and equator. But no difference is seen over 15^oN. At 1600 LT the ion temperature is greater along 75^oE than that along 95^oE over ± 15^o latitude. But over the equator, there is no difference of ion temperature along the two longitude sectors.

The ionospheric plasma temperature depends on plasma density and neutral atmosphere. It has been established that the ion/electron density is negatively correlated with the ion/electron temperature. (Mahajan 1977. 1996; Brace and Theis.,1978; Bhuyan et al., 2002,2004). Bhuyan et al. (2002) had observed that electron temperature measured by the SROSS C2 satellite at 500 km altitude in the 75°E longitude sector from 10°S to 15°N geomagnetic latitudes during 1995 - 1996 decreases with increase in electron density in all seasons for temperature above the level of 1000 K. Nighttime electron temperature, which is generally around 900 K, remains independent of density. Further Bhuyan et al. (2004) have observed that the ion temperature measured by the SROSS C2 satellite during 1995 - 1996 over the Indian subcontinent decreases with increase in ion density in all seasons for daytime and the nighttime ion temperature has no correlation with ion density. Further Borgohain and Bhuyan (2012) found that the daytime ion temperature and ion density are negatively correlated during solar minimum, while the nighttime ion temperature does not exhibit any correlation. But during high solar activity density exhibits negative correlation with temperature at $\pm 10^o$ latitude while positive correlation over the equator.

In the topside ionosphere, the electron heating rate is proportional to electron density, while the electron cooling rate is proportional to the square of electron density. The electron cooling takes place due to coulomb collisions with the ions (Otuska et al., 1998). Studying the longitudinal variation of electron temperature from 1995 to 2005 at an average altitude of 850 km Ren et. al., (2008) found that the longitudinal variations of electron temperature are almost opposite that of ion density. The maxima of electron temperature locate near the minima of ion density and vice- versa. Kakoty et al., 2019 reported that during the midday and afternoon hours when the EIA is fully grown a longitudinal gradient in ion density higher towards 95^oE develop irrespective of seasons or years of observation along the anomaly crest latitudes. They attributed the longitudinal asymmetry of drift velocity along these two longitude sectors. It can be said from the above results that the longitudinal difference of ion temperature is a reverse effect of longitudinal gradient of ion density along 75^oE and 95^oE longitudes. As the ion density is greater along the 95^oE longitude during the daytime hours the ion temperature is greater along 75^oE longitude during daytime hours. In addition this gradient of Ti is also noticed at 0800 LT when diurnal maximum of Ti occurs.

6. Conclusion:

The ion temperatures measured by ROCSAT 1 over 75^o E and 95^o E in the Indian sector from 1999 to 2003 were examined for longitudinal and interhemispheric asymmetries. From the study it has been seen that the plasma temperature is higher along 75^oEthan that along 95^oE during the time of occurrence of diurnal maximum temperature. It can be attributed to the reverse effect of longitudinal gradient of plasma density along the two longitudinal zones.

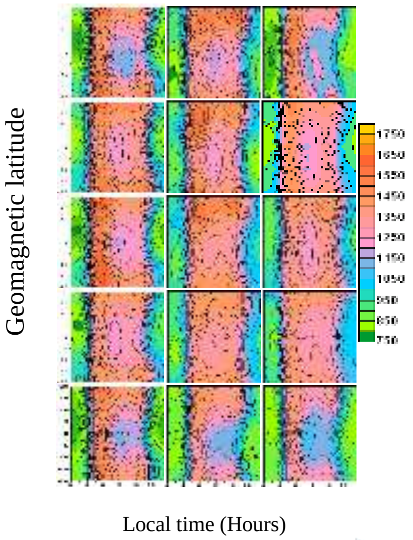

Figure 1: 2D plot for diurnal and seasonal variation of ion temperature along 70ºE longitude over ±20 GLAT measured by ROCSAT -1 at 600 km from 1999 to 2003.

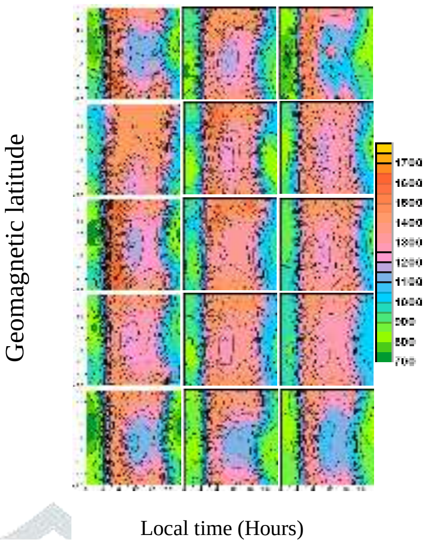

Figure 2: 2D plot for diurnal and seasonal variation of ion temperature along 90ºE longitude over ±20 GLAT measured by ROCSAT -1 at 600 km from 1999 to 2003.

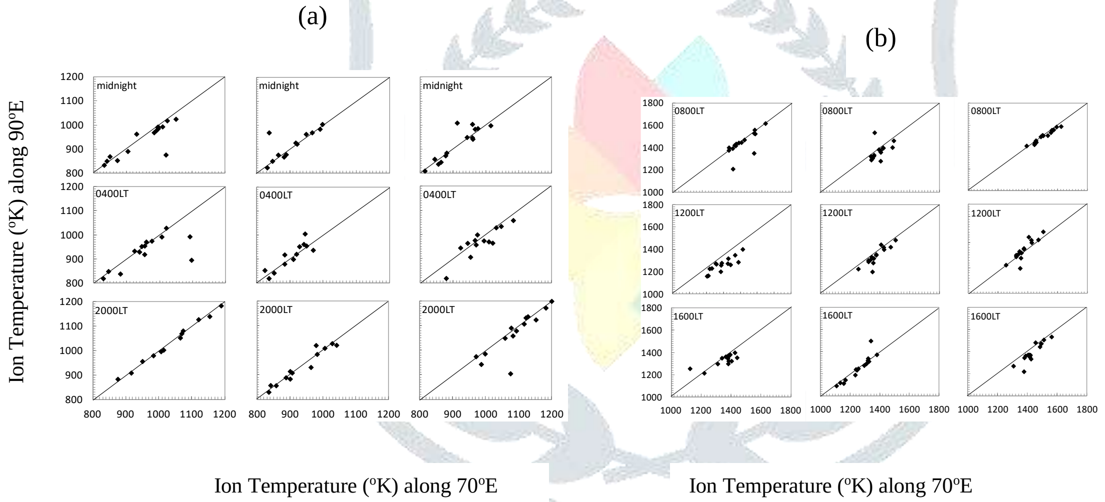

Figure 3: Ion Temperature comparison along 70ºE and 90ºE over 15ºS (left), equator and 15ºN (right)

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