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RESEARCH ARTICLE

IONOSPHERIC SLAB THICKNESS OVER HIGH LATITUDE ANTARCTICA DURING THE MAXIMA OF SOLAR CYCLE 23RD

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ABSTRACT

The ionosphericSlab thickness is a very important parameter for the study of the neutral temperature and electron density profile; it can be related directly to the scale height of the ionizable constituents. The variability of ionospheric slab thickness at high latitudes during the high solar activity period 2005, we have selected a high latitude station Casey (66.3^0 S, 110.6^0 E) in the southern polar region. The results show that the diurnal variability of slab thickness shows that the night time values are higher than the day time values. A significant difference is observed between the day time and night time values during equinoxial months. The diurnal variability at Casey during the high solar activity period is also characterized by a pre sunrise peak in some months which does not occur around the same time as well as is not pronounced during the other months of year. The monthly variability of slab thickness at high latitude follows the semi-annual type of variability with two peaks during the month of March and September. The value of slab thickness is highest during the equinox while least in the summer season. We also notice that the night time values of slab thickness are higher than the day time during all the seasons. The pre sunrise peak is much pronounced during the summer and equinox seasons. The monthly variability of slab thickness follows a very good association with X-ray flux (1-8Å) and EUV flux (26-34nm) and very weak association with the F10.7cm. The correlation coefficients of slab thickness with F 10.7 cm, X-ray Flux (1-8Å) and EUV Flux (26-34nm) are 0.28, 0.58 and 0.60 respectively.

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INTRODUCTION

The slab thickness (τ) is a very important parameter for the study of both the top and bottom sides of the ionosphere; further, it indicates the electron density versus height profile. Ionospheric slab thickness may also be regarded as the depth of an imaginary ionosphere that has the same total electron content (TEC) and uniform electron density as the actual ionosphere. Slab thickness study useful for the shape of the electron density profile.(Titheride, J. E., 1973; Davies, K. and X. M. Liu., 1991, Bhuyan, P. K, 1986) Previously a number of studies have outlined the relevance of ionospheric slab thickness to the vertical scale height (Stankov, S. M and N. Jakowski., 2006) and (Haris Haralambous, 2011., Lui, 2014; Owolubi, 2019). The τ parameter has renewed popularity by virtue of abundant TEC monitoring by GPS satellite.

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The study of this parameter provides information about the nature of the distribution of ionization at that location. Besides from the point of view of satellite to ground radio communication, the equivalent slab thickness is very useful parameter since it contains all the new information from TEC measurements, which is not readily available in foF2. For α-Chapman layer, the value of τ is shown to be equal to 4.13 H, where H is the scale height of the ionosphere (Wright, 1960). Titheridge (1973) has developed a relationship between τ and natural temperature. Furman and Prasad (1973) found that τ in general depends upon the plasma scale height but is not a good indicator of either electron or ion temperature and (B. Jayachandran, T .N. krishnakutty, and T.L. Gulyaeva., 2004). The slab thickness exhibits a pronounced pre-dawn enhancement (PDE).the magnitude of this increase is larger in low latitude than in middle latitude (Bhonsle et al., 1965; Davies and Liu, 1991, Amayenc, P., 1971). It is attributed to low value of NmF2 rather than Ne an increase in TEC. The pre-dawn increases closely related to the maintenance of the night time F layer and can sufficiently well be explained by the lowering of the ionospheric F layer immediately before sunrise to regions of grater natural density, leading to the increased ion loss due to recombination.

DATA PROCUREMENT AND METHODOLOGY

In order to study the variability of ionospheric slab thickness at high latitudes during the high solar activity period, we have selected a high latitude station namely Casey (66.3^0 S, 110.6^0 E) in the southern polar region. For conducting this study we have collected the data of the year 2005. The year 2005 was the period of high solar activity when the solar cycle 23 was in the declining phase. The ionospheric slab thickness is not directly provided by the observation but instead can be derived by using direct observations as input. It is derived from the simultaneous observations of ground based ionosonde system and Global Positioning System. Therefore for conducting the study, two data sets from the southern polar region were used to examine the variation in slab thickness in the year 2005 during the transition phase from high solar activity to low solar activity. From the ionsonde observation we have taken the cricitical frequency of F2 layer, foF. The foF2 datasets for this study were collected from the huge database of National Geophysical Data Center (NGDC) under URL: https://ngdc.noaa.gov/ionosonde/data/. We have taken the values of foF2 from the database derived from the ionogram records at 15 min intervals. However for calculating slab thickness we require the peak or maximum electron density of F2 layer (NmF2). The NmF2 parameter is not provided by the ionosonde or cannot be derived from ionograms by scaling procedures. It rather can be calculated from the values of foF2 by using the relation:

$$NmF\ 2 = 1.24 \times (foF\ 2) \times 10^{10}\ el\ /\ m^3$$

Where, foF2 is the ordinary critical frequency of the F2 region in MHz. For calculating slabthickness we also require the Total Electron Content, apart from NmF2 over the same station. The TEC data was taken from the International GPS Service (IGS) station Casey. The data recorded at all the stations which form part of the IGS is collected and a huge database has been maintained. This data can be freely accessed and download from the IGS website data archive. For our study we have download the data of Casey station from the URL: http://sopac.ucsd.edu/dataArchive/.

The vertical TEC (VTEC) is derived from the GPS signals. In the GPS system, every satellite transmits signals using two frequencies (f1=1575.42MHz and f2=227.60 MHz). By using the recorded broadcast ephemeris data and the given sub-ionospheric height of 325 km, the slant TEC (STEC) along the ray path can be converted into the VTEC at its associated longitude and latitude. Hence, STEC between a GPS satellite, Tx, and a ground based receiver, Rx, can be written as:

$$STEC = \int_{Rx}^{Tx} Ndl = \frac{f^2}{40.3}\int_{Rx}^{Tx}(1/n - 1)dl$$

$$= \frac{f^2}{40.3}\int_{Rx}^{Tx}\left(\frac{1}{\sqrt{1 - f_N{}^2/f^2}} - 1\right)dl$$

$$VTEC = STEC \times Cos\,\chi$$

Where, N denotes the electron density in el/m3, n denotes the refractive index, and f and $f_N$represent the radio wave and plasma frequencies in Hz, respectively. 'χ' is the angle of indication at the sub-ionospheric point of a ray from the satellite to the ground receiver. The ionospheric slab thickness (τ) is defined by the ratio of Total Electron Content (TEC) to maximum electron density of F-region (NmF2), and is calculated by the following formula:

$$Slabthickness(\tau) = \frac{TEC}{NmF2}$$

Or

$$\tau = \alpha \times TEC/(foF\,2)^2$$

α =80.645

Where, TEC is Total Electron Content in TEC units i.e. 10^{16} el/m^2, foF2 critical frequency of F2 layer in MHz, NmF2 is peak electron density of F2 layer in 10^{10} el/m^3 and τ is slab thickness in km. After calculating the slab thickness we investigated its diurnal, monthly and seasonal variability. For examination purpose, we categorized the months into three seasons: Equinox (March, April, September, and October), Summer (May, June, July, and August), and Winter (November, December, January, and February) months to examine.

Solar Radiation Flux: An investigation was also conducted in order to understand the solar activity variations of the ionospheric slab thickness at high latitude station Casey. In order to present the solar activity variations of the slab thickness we have considered radiation flux parameter in different wavelengths. We have taken the solar radio flux at 2800MHz i.e F10.7cm. The F10.7cm has been extensively used in previous studies concerning the solar activity variations of ionosphere as well as ionospheric slab thickness (Chou, 2007). The hourly values of F10.7cm were taken from Space Physics Interactive Data Resource (SPIDR) server of National Geophysical Data Centre (NGDC) on website. http://spidr.ngdc.noaa.gov/spidr/dataset.do

Similarly, we have also taken the solar EUV flux and solar X-ray to investigate solar activity variations of slab thickness. These two parameters have not been used in the past in such studies. The Solar EUV Monitor (SEM) instrument on board the SOHO spacecraft has been measuring solar EUV flux since 2002 in two wavelengths ranges viz. 24-36 nm and 0.1-50 nm ranges with pa very high resolution in Seconds. However in our study we have used the 24-36 nm EUV flux, because it is considered to be more specific for ionospheric studies. The data of EUV flux in the range 26-34 nm with 10 minute resolution was downloaded at http://www.usc.edu/dept/space_science/semdatafolder/. The solar X-Ray flux is another important parameter for investigating the solar activity variations of ionosphere. The solar X-Ray is being continuously monitored by Geostationary Operational Environmental Satellite (GOES) series from last number of decades. GOES measures the solar X-Ray in two energy channels namely 0.5 - 4.0 Å and 1 – 8 Å. However, in our study we have used the 5min values of solar X-Ray flux in the range 1 – 8 Å. The GOES X-Ray flux data was taken from NOAA's Space Environment Center (NOAA-SEC) website http://www.ngdc.noaa.gov/stp/GOES/. The hourly, daily and monthly values of these fluxes were also constructed and used in the study.

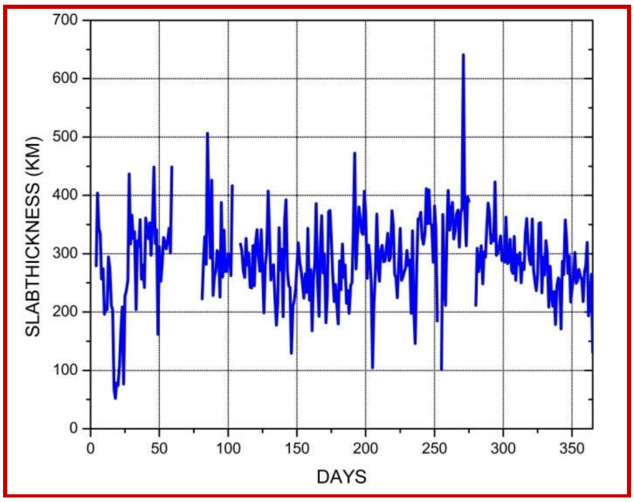

Figure 1. The diurnal variability of the slab thickness over Casey during each months of the year 2005

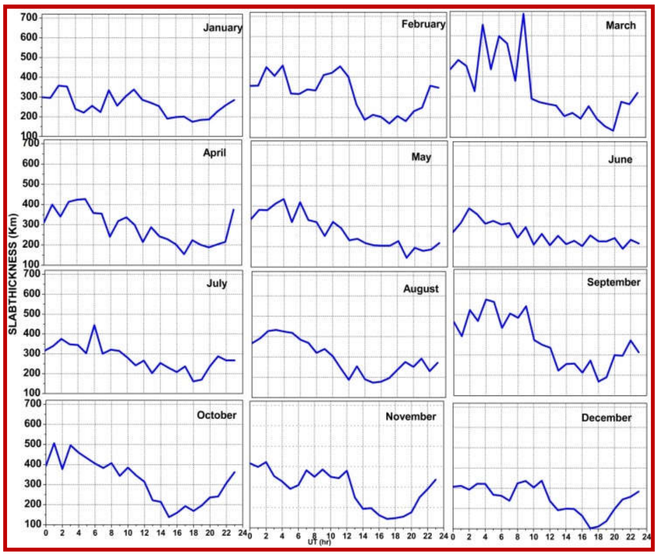

Figure 2. The daily profile of slab thickness at Casey during year 2005

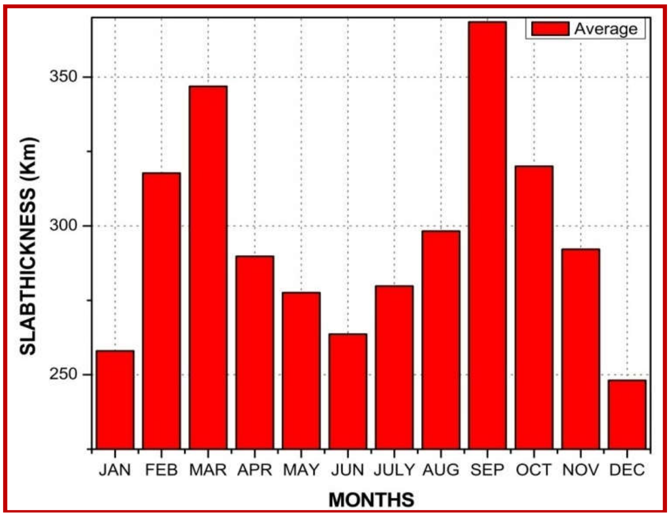

Figure 3. The monthly variability of slab thickness in the year 2005

The variability of ionospheric slab thickness was investigated with the variability of these solar fluxes at the high latitude station, Casey.

RESULTS AND DISCUSSION

The ionospheric slab thickness is an important and significant parameter which measures the skewness of the electron density profile of ionosphere since it includes information regarding both the top and bottom sides of the ionosphere. It gives a first order measure of ionospheric ionization or electron density.The majority of studies conducted to study the climatology of slab thickness have been performed using single station observations under limited solar activity variations. From these studies, it has been found that slab thickness shows appreciable diurnal, day-to-day, seasonal, solar and magnetic activity variations with considerable dependence on the location of the observing station. We have studied the diurnal, monthly, seasonal and solar activity variations of the slab thickness during the high to low transition period of the solar cycle 23 i.e 2005. First we will present the diurnal, monthly and seasonal variability of the slab thickness and then we will describe the variability of slab thickness with solar radiations fluxes namely F10.7 cm, X-ray Flux (1-8Å) and EUV Flux (26-34nm).

DIURNAL VARIABILITY OF SLAB THICKNESS

First we examine the behaviour of slab thickness from hour to hour during all the days of each month and then from day to day during all the days of year 2005. The diurnal variability of the slab thickness over Casey during the months of the year 2005 is shown in figure 2. In this plot we have shown the variation of hourly values of monthly median in each instead of showing the variation of all the 30 days of the month. From the figure we find that the slab thickness at high latitude station Casey follows a diurnal variability. The nigh time values are comparatively higher than the day time values. The day and night time values are also not the same in all the months. There is considerable variation in the day and night time values in different month as well. A considerable difference can be observed in the day and night time values during the equinoxial months. While during the summer months the difference between the day and night time values is very small. According to figure 1, where the diurnal profile of monthly median hourly values of slab thickness for each month is shown, the diurnal variation of slab thicknessover Casey is characterised by a pre sunrise peak. The pre sun rise peak is pronounced during the months of January, March, May, July and September. However, in other months the peak is not pronounced. The time of occurrence of the pre sunrise peak is not same during different months. The time of occurrence of the peak varies from month to month. The pre-sunrise peak is a phenomenon closely related to the maintenance of the night-time F layer and can be sufficiently attributed by the lowering of the ionospheric F layer immediately before sunrise to regions of greater neutral density, leading to increased ion loss due to recombination (Davies and Liu, 1991). The effect is considered to be particularly evident in the bottomside ionosphere that encompasses the density peak. As a result, the decrease in NmF2 and the bottomside density is much faster than the topside ionosphere where the loss rate is lower and thus, an enhancement occurs. We also investigated the daily variability of the slab thickness during the 2005. The daily profile of slab thickness at Casey during year 2005 is shown in figure 2. From the figure we notice that there is not a considerable change in the daily values of the slab thickness during year 2005. The daily values usually vary in the range 200-400 km, during majority of the days.

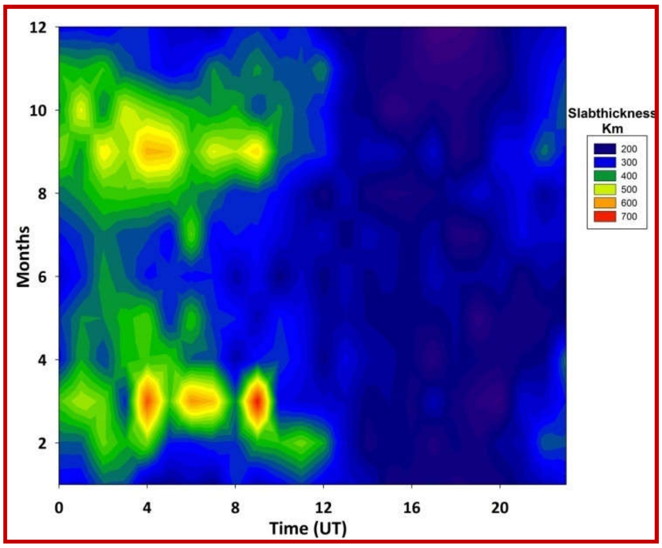

Figure 4. **The contour graph of the hourly variability of the slab thickness during the months**

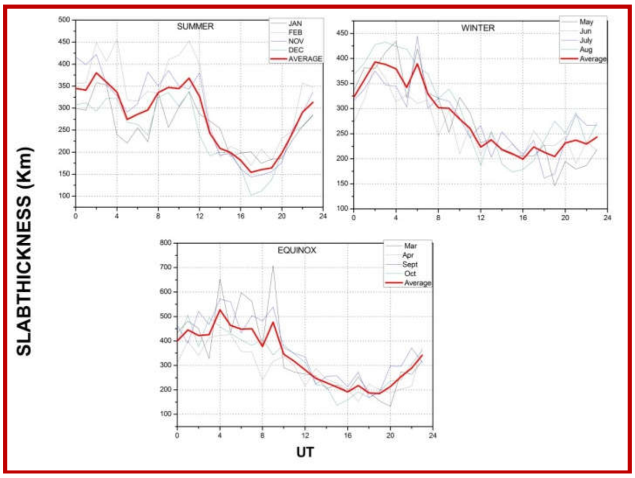

Figure 5. The seasonal variability of slab thickness at Casey during the year 2005

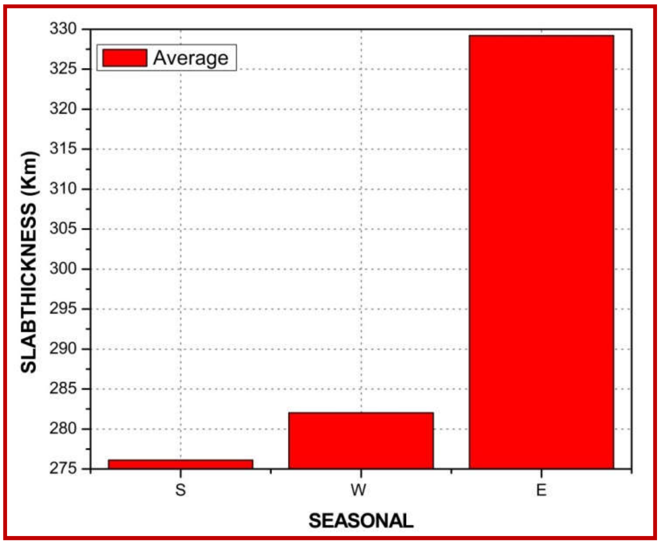

Figure 6. The seasonal variability of the slab thickness at during the year 2005

The highest value of 643 km is observed on the 271rd day and the lowest value of 52 km is observed on the 18th day of the year 2005.

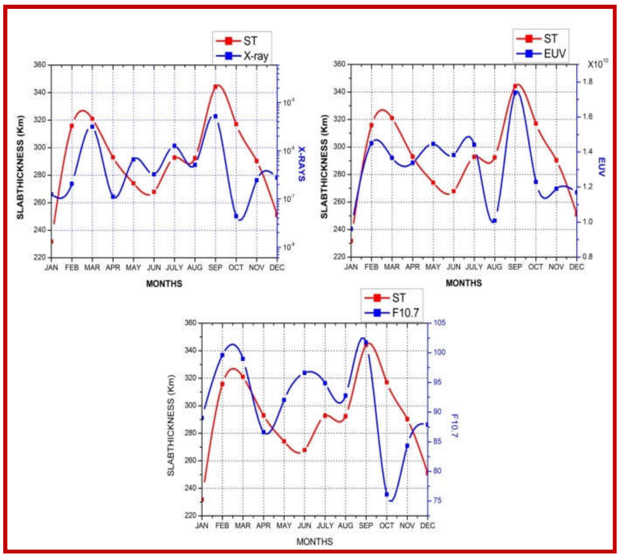

Figure 7. The monthly variability of the slab thickness with the monthly changes in the F10.7 cm, X-ray Flux (1-8Å) and EUV Flux (26-34nm)

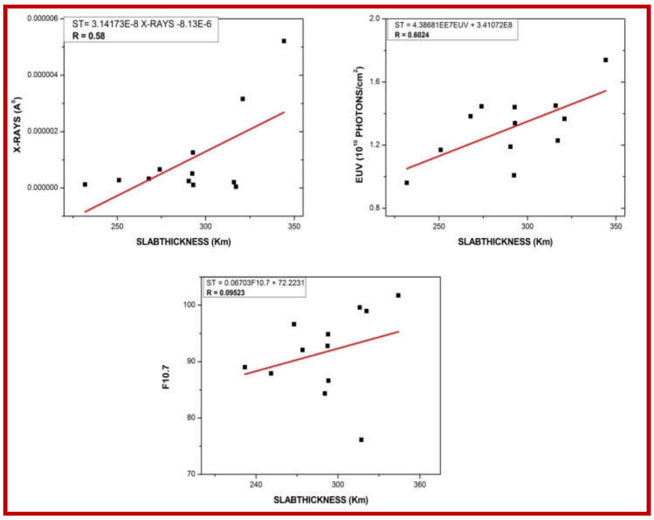

Figure 8. Scatter plots and Correlation of slab thickness with F10.7 cm, X-ray Flux (1-8Å) and EUV Flux (26-34nm)

The large changes in the value of slab thickness can be observed only during the 1-50th day as well during the 200-255th day of the year 2005, while during the other days of the year there is not large change in the value of slab thickness.

MONTHLY VARIABILITY OF SLAB THICKNESS

We also investigated the monthly variability of slab thickness at Casey during 2005. The monthly variability of slab thickness is presented in figure 3. To make this plot we have taken the average value of monthly median of each month. From the figure we notice that the slab thickness is highest during the month of September, March, October and February with peak values 368 km, 346 km, 320 km and 317 km respectively. The lowest values of slab thickness are recorded during the months of December and January with peak values 248 km and 258 km respectively. While during other months like November, August, July and April moderate values of slab thickness are observed. From the figure we also notice that the monthly variability of slab thickness at high latitude station Casey follows well known semi-annual variation. In other words the monthly variability follows a periodic variability with period of six months.

We also plotted the hourly variability of the slab thickness during all the months. This represented by a contour map shown in figure 4. In order to make this contour map we have used the hourly values of monthly median during all the 12 months. On the x-Axis we have shown the universal time in hours and on the y-axis we have represented the months of the year 2005. The colour represents the variation in slab thickness. The colour code is provided on the left side of contour map. This shows that the monthly variability of slab thickness apart from observing the semi- annual type of variability also follows the day night variability during all the twelve months. The values of slab thickness are higher in the night time while these are low during the day time.

SEASONAL VARIABILITY OF SLAB THICKNESS

We also studied the seasonal changes that occurred in the slab thickness at Casey during 2005. Four months comprise the one season in this way we get three seasons namely Summer (May, June, July and August), Winter Season (January, February, November and December) and the Equinox Season (March, April, September and October). The seasonal variability of slab thickness at Casey during the year 2005 is shown in figure 5. In the figure we plotted the hourly median the values of month during all the four months of the season along with the average. The four unbold solid curves in each panel represent the median of hourly value of each month and the solid bold (red) curve represents the average of the hourly value of four months. From the figure we find that the highest values of slab thickness are observed during the equinox season followed by winter season and least in the summer season. We also notice that the night time values of slab thickness are higher than the day time values during all the three seasons. The pre-sunrise peak is much pronounced during the summer and equinox seasons. Although a pre sunrise peak is also observed during the winter season but is not clearly pronounced like in summer and equinox. We then took the average of the four months of each season to construct an average value of each season. The seasonal variability of the slab thickness is then shown in figure 6. From the figure we find that the highest value of slab thickness is observed during the equinox season with peak value of 329 km while the least value of slab thickness is observed during the summer season with peak value of 276 km. The peak value of slab thickness during the winter season was observed to be 282 km.

VARIABILITY OF SLAB THICKNESS WITH SOLAR RADIATION FLUXES

We then took the three types of solar radiation fluxes namely F10.7 cm, X-ray Flux (1-8Å) and EUV Flux (26-34nm) and investigated the variability of slab thickness with these solar radiation fluxes. These radiation fluxes are usually used to characterize the changes in the solar activity. The monthly variability of the slab thickness with the monthly changes in the F10.7 cm, X-ray Flux (1-8Å) and EUV Flux (26-34nm) is drawn in figure 4.8. In the figure red line shows the monthly variability of slab thickness while the blue line shows the three types of radiation fluxes in the three panels of figure 7. From the figure we find there is good agreement between the changes in the radiation fluxes and the corresponding changes in the slab thickness. We know the monthly variability of slab thickness exhibits the semi-annual variation with two peaks one in the month of March and other in the month of September. Although, F 10.7 cm, X-ray Flux (1-8Å) and EUV Flux (26-34nm) does not exhibit the semi-annual pattern of monthly variability, but we can clearly find that there two peaks one in the month of March and other in the month of September as discussed above. Therefore the two peaks of the three radiation fluxes agree exactly with the corresponding peaks in the slab thickness. Apart from these peaks in the month of March and September, the variability of the slab thickness with three radiation fluxes in other months also has a remarkable agreement. The variability of the slab thickness with F10.7 cm in months of May, June and July are in disagreement with each other. Amongst all the three fluxes, the highest agreement of slab thickness is observed to be with X-ray flux, and the least with F10.7 cm. In order to access the nature and magnitude of association of slab thickness with F10.7 cm, X-ray Flux (1-8Å) and EUV Flux (26-34nm) we have also performed the correlation analysis and derived the correlation between them. The scatter plots and correlation of slab thickness with F10.7 cm, X-ray Flux (1-8Å) and EUV Flux (26-34 nm) is shown in figure 8. The top two panels show the correlation of slab thickness with X-ray Flux (1-8Å) and EUV Flux (26-34nm) while the bottom panel shows the correlation of slab thickness with F10.7 cm. To construct this scatter plot we have used the monthly values of radiation fluxes and slab thickness. From the graph we find that slab thickness exhibits a good correlation with X-ray flux and EUV flux with correlation coefficients 0.58 and 0.60 respectively. At the same time slab thickness exhibits a very weak correlation with F10.7 cm with correlation coefficient of 0.28. Which means slab thickness follows 58% and 60% correlation or association with X-ray flux and EUV flux while only 28% association is found to exist with the F10.7cm. So, we conclude X-ray Flux and EUV flux play the dominant role solar activity variations of slab thickness as compared to F10.7 cm which have been used in some previous studies.

Conclusion

The diurnal variability of slab thickness shows that the night time values are higher than the day time values. A significant difference is observed between the day time and night time values during equinoxial months. The diurnal variability at Casery during the high solar activity period 2005 is also characterized by a pre sunrise peak in some months which does not occur around the same time as well as is not pronounced during the other months of year 2005. The monthly variability of slab thickness at high latitude station Casey follows the well-known semi-annual type of variability with two peaks during the month of March and September 2005. The value of slab thickness is highest during the equinox season while least in the summer season. We also notice that the night time values of slab thickness are higher than the day time values during all the three seasons. The pre sunrise peak is much pronounced during the summer and equinox seasons. The monthly variability of slab thickness follows a very good association with X-ray flux (1-8Å) and EUV flux (26-34nm) and very weak association with the F10.7cm. The correlation coefficients of slab thickness with F 10.7 cm, X-ray Flux (1-8Å) and EUV Flux (26-34nm) are 0.28, 0.58 and 0.60 respectively.

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