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Diurnal and Seasonal Variations of Equivalent Slab thickness over Low and Mid Latitude Regions

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Abstract

The equivalent slab-thickness (τ) is very important in the study of the complex dynamics of the ionosphere as a result of its ability to determine the skewness of the ionospheric electron density profile. This study involves the day to day and monthly variations of τ. Ionosonde (FoF2) and Total electron content (TEC) data at the low latitude station of Sao Luis (Glat 2.60° S, Glong 315.80° E and Mlat 6.05° N and Mlong 28.40° E), Brazil and mid latitude station of Chilton (Glat 51.50° N, Glong 359.40° E and Mlat 53.35° N and Mlong 84.34° E), United Kingdom from January 2013 to December 2015 were used in the study of τ . For Sao Luis station, the diurnal pattern for the different days are characterized by day time (08:00 – 16:00 UT) high values and nighttime (20:00 – 04:00 UT) low values; however, Chilton shows signatures, such as day time low values and nighttime high values. Also, the daytime values (~600 km) of τ for the low latitude station (Sao Luis) is more than double the mid latitude station (Chilton) maximum value (~235 km) over the years considered. The monthly variation of τ also indicate a seasonal variation with highest daytime values (400 km) during winter months and lowest (below 300 km) during summer months for the low latitude station (Sao Luis). However, the nighttime values are of the same order (about 200 km) for the low latitude station (Sao Luis). Also, highest daytime values (above 250 km) are observed during summer months and the nighttime values are below 200 km over the years for the mid latitude station (Chilton).

Keyword: Ionosphere; Total electron content; Critical frequency (FoF2); equivalent slab thickness.

1. Introduction

Ionospheric slab thickness (τ) is an essential ionospheric parameter which provides information on both the top and bottom sides of the ionosphere. The study of this parameter provides information about the nature of the distribution of ionization in the study locations. Information about the neutral temperature and an assumed electron density profile has made the study of slab thickness significant. It can be related directly to the scale height of the ionizable constituents [1] . τ is basically the ratio of the total electron content (TEC) to the F- region peak electron density (NmF2). This could also be calculated through various ionospheric models [1, 3, 6, 8]. Slab thickness is a vital parameter because it allows conversion between FoF2 and TEC. NmF2 is proportional to the square of the F2 – layer critical frequency (FoF2). The combination of NmF2 with TEC is useful for the estimation of equivalent ionospheric slab thickness [e.g. 2, 4, 5, 7, 9]; this is represented in equation (1) as follows:

$$\mathrm{NmF2} = 1.24(\mathrm{foF2})^2 \times 10^{10}\ \mathrm{el.m^{-3}} \quad (1)$$

Where foF2 is in MHz

$$\tau = \frac{\mathrm{TEC}}{\mathrm{NmF2}} \quad (2)$$

The slab thickness τ is in km.

The study of ionospheric slab thickness is essential due to the fact that it provides information on the shape of the electron density profile, the neutral and ionospheric temperature gradient as well as the ionospheric composition and dynamics [11, 1, 3].

Some workers have revealed the relationship between slab thickness and the vertical scale height [13, 12, 14].

[3] studied the equivalent ionospheric slab-thickness (τ) at the low latitude station of India during low (1964-1966) and high (1967-1969) solar activity periods. They observed a higher magnitude of (τ) around noon compared to the night values. Their study further revealed the highest mid-day value of (τ) during the equinoctial season, followed by summer season and the least during winter season. It was also observed in their study that (τ) increases with solar activity. [15] worked on the ionospheric slab thickness (τ) in the Brazilian sector during one year (March 2009-February 2010) of low solar activity period. They noticed a lower magnitudes of night time (τ) compared to the day time magnitudes in all the seasons considered in the sector. Their study further revealed a higher magnitude of (τ) during summer and equinoctial seasons compared to winter season. [16] studied the behaviour of the equivalent slab thickness (τ) over three European stations during the solar maximum (2001) and solar minimum (2007) periods. They noticed that the diurnal variation of (τ) is characterized by day time values lower than the night time values during summer of high solar activity period. Their study further showed a double peak at dusk and at dawn during winter at low solar activity period. They also observe an increase in the day time values of (τ) from winter to summer while the nigh time values of (τ) experienced a decrease correspondingly. [17] worked on the comparison of ionospheric slab thickness (τ) at two mid-latitude locations in the Northern and Southern hemisphere during high, moderate and low solar activity (2000, 2003 and 2007) periods. They observed peak values of (τ) at the pre-sunrise and post-sunset periods during the local winter at the two stations considered. Their study further revealed that the winter nights registered the highest value of (τ), followed by summer season and least during equinoctial season. In addition, the observed pre-sunrise peaks were attributed to lowering of the ionospheric F-layer into the areas of denser atmosphere where ionization losses are higher while the post-sunset peaks were attributed to field-aligned plasma flow from the plasmasphere to the ionosphere.

Consequently, this paper reports the day to day and monthly variations of equivalent slab thickness at low latitude station of Sao Luis (Glat 2.60° S, Glong 315.80° E and Mlat 6.05° N and Mlong 28.40° E), Brazil and mid latitude station of Chilton (Glat 51.50° N, Glong 359.40° E and Mlat 53.35° N and Mlong 84.34° E), United Kingdom from January 2013 to December 2015.

2. Data and method of analysis

For this paper we have used the Ionosonde (FoF2) and TEC data, obtained at GIRO website (available at http://giro.uml.edu). The Ionosonde data was separated into different days and months and reduced to hourly average using MATLAB scripts. The electron density at the F2 layer (NmF2) was computed from the critical frequency of the F2 layer (FoF2) obtained from GIRO website as expressed in equation 1 and the equivalent slab thickness which is the ratio of the NmF2 to the TEC as shown in equation 2 was computed using MATLAB script. This process was used to compute the estimated slab thickness for the low latitude station of Sao Luis and the mid latitude station of Chilton and their coordinates are given in Table 1

Table 1 List of ionosonde stations

Location	Code	Geographic		Geomagnetic		Difference between LT and UT
		Lat	Long (°E)	Lat (°N)	Long (°E)	
Sao Luis, Brazil	Bjco	2.60° S	315.80	6.05	28.40	1 h
Chilton, United Kingdom	Mars	51.50° N	359.40	53.35	84.34	2 h

3 Results and discussion

3.1 Variation of Slab Thickness Approximations at Low- Latitude

The typical plots for low – latitude station of Sao Luis are shown in figure 1 for the year 2013, 2014 and 2015. The diurnal pattern for the different days are characterized by day time (08:00 – 16:00 UT) high values and nighttime (20:00 – 04:00 UT) low values.

On 17 December 2013, during daytime, the values of estimated slab thickness (τ) ranges from 200 kilometres to 600 kilometers. And the maximum value (600 km) was observed at about 16:00 UT. However, the nighttime values of estimated slab thickness ranges from 60 kilometers to 350 kilometers. In addition, the diurnal variation indicates two pre – sunrise τ maximum of about 90 km and 140 km at about 02:00 UT and 05:00 UT respectively.

On 02 December 2014, a similar result to that in 2013 was observed, except that, the daytime maximum value is about 580 kilometers at about 14:00 UT. Additionally, two pre sunrise τ maximum of about 110 km and 170km was observed at about 02:00 UT and 05:00 UT respectively.

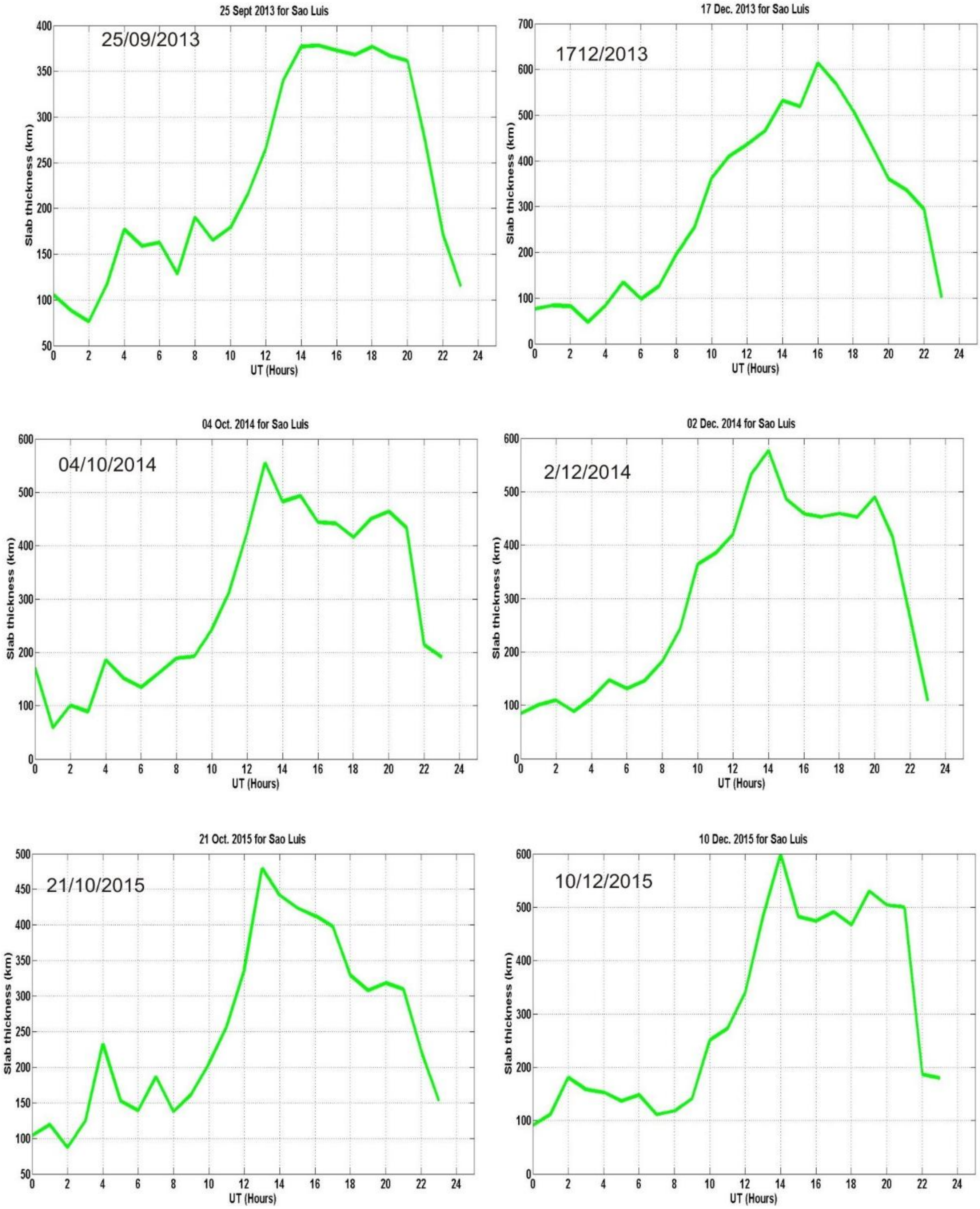


Fig. 1: The typical diurnal patterns for estimated slab thickness (τ) variation at Sao Louis station in 2013, 2014 and 2015

On 10 December 2015, the pattern is similar to that in 2013 and 2014, except that the daytime maximum value is about 600 kilometers at about 14:00 UT. Additionally, the two pre sunrise τ maximum was about 180 km and 140km at about 02:00 UT and 06:00 UT correspondingly. Essentially, at low latitude station of Sao Louis, τ value is maximum (~600 km) at 14:00 UT over the years considered. The maximum value of estimated slab thickness (τ) during the day time is in agreement with electrodynamic drift (fountain effect), which increases the content of the topside [18]. Nevertheless, the reduction in the magnitude of estimated slab thickness (τ) at about 22:00 UT may be attributed to the movement of the equatorial ionosphere to lower altitude during this period.

3.2 Variation of Slab Thickness Approximations at Mid- Latitude

The typical plots for mid – latitude station of Chilton are shown in figure 2 for the year 2013, 2014 and 2015. The diurnal pattern for the different days shows signatures, such as day time (08:00 – 16:00 UT) low values and nighttime (20:00 – 04:00 UT) high values.

On 25 December 2013, during daytime, the values of estimated slab thickness (τ) ranges from 50 kilometers to about 145 kilometers. And the maximum daytime value (145 km) was observed at about 14:00 UT. However, the nighttime values of τ ranges from about 155 kilometers to 200 kilometers. In addition, the diurnal variation indicates two pre – sunrise τ maximum of about 200 km and 190 km at about 01:00 UT and 04:00 UT respectively. Also, a depression in the value of τ was observed at about 17:00 UT.

On 02 December 2014, a similar result to that in 2013 was observed, except that, the daytime maximum value is about 175 kilometers at about 13:00 UT. Additionally, during the nighttime, two pre sunrise τ maximum of about 210 km and 220 km was observed at about 01:00 UT and 04:00 UT respectively.

On 10 December 2015, the pattern of estimated slab thickness (τ) is similar to that in 2013 and 2014, except that the daytime maximum value is about 180 kilometers at about 12:00 UT. And the pre sunrise τ maximum of about 160 km was observed at about 04:00 UT. Essentially, at mid latitude station of Chilton, τ value is maximum (~235 km) during the nighttime at about 07:00 UT over the years considered. The maximum value of estimated slab thickness (τ) during the night time is in agreement with [6]. This may be due to the propagation of field aligned plasma from the protonosphere to the ionosphere.

In general, the variation in estimated slab thickness (τ) exhibit a day to day variation over the years considered. The low latitude station of Sao Louis maximum τ value (~600 km) during the daytime (14:00 UT) is more than double the mid latitude station of Chilton maximum τ value (~235 km) over the years considered. This is an indication that the F region is thicker near the equator/ low latitude and can be attributed to the electrodynamic drift as well as diffusion in the equatorial ionosphere [19]. The pre- sunrise peak in τ value observed in the two station may be attributed to the downward movement of the ionosphere [1]. Additionally, it may also be the resultant of the rapid ionization of the top side ionosphere, which increases the TEC while the peak electron density (NmF2) was lagging behind [20, 6, 22, 3].

3.3 Monthly Estimated Slab Thickness (τ)

The hourly estimated slab thickness for each of the months at Sao Luis (low latitude) and Chilton (mid latitude) were calculated for the years considered.

Table 3.1 shows the monthly mean daytime (08:00 –16:00 UT) and nighttime (20:00 – 04:00 UT) value of estimated slab thickness at Sao Luis for the year 2013 to 2015. It can be seen that the mean daytime value of τ are higher than the mean nighttime value for all the months considered though there were no data (ND) for some months.

Fig. 2: The typical diurnal patterns for estimated slab thickness (τ) variation at Chilton station in 2013, 2014 and 2015

Table 3.1: Monthly mean daytime (08:00 – 16:00 UT) and nighttime (20:00 – 04:00 UT) values of Estimated Slab thickness (τ) for Sao Luis station in 2013, 2014 and 2015

Months	2013		2014		2015	
	Daytime (km)	Nighttime (km)	Daytime (km)	Nighttime (km)	Daytime (km)	Nighttime (km)
January	ND	ND	408.0283	195.2998	409.3732	201.7564
February	ND	ND	319.7739	194.2532	351.4573	214.0781
March	ND	ND	ND	ND	316.2251	223.0263
April	ND	ND	ND	ND	341.9005	226.3891
May	320.7525	194.0245	ND	ND	327.3578	198.7505
June	290.8974	206.7357	ND	ND	287.3575	196.1383
July	299.2966	197.9232	ND	ND	280.6631	188.2206
August	297.7125	188.2134	ND	ND	265.7566	181.0933
September	289.0673	163.8774	ND	ND	299.7893	167.4075
October	341.6742	169.4542	327.8521	195.6077	335.2617	175.3283
November	362.0331	179.2005	357.0656	207.5432	351.5619	187.0541
December	407.0271	184.0443	411.0475	220.6876	407.4016	193.0957

ND: No data

For the years considered, highest mean daytime values of 407, 411 and 407 km respectively for 2013, 2014 and 2015 were observed during the winter months. However, lowest mean daytime values of 265 and 289 km are observed for 2013 and 2015 respectively during the equinoctial months. For the monthly mean nighttime values, in 2013 this range between 163 and 206 km, in 2014 this range between 194 and 220 km and in 2015 this range between 167 and 226 km. The range of daytime and nighttime values of slab thickness as observed in Sao Luis compared favourably to what was observed by 22 & 8.

Table 3.2 shows the monthly mean daytime and nighttime value of estimated slab thickness at Chilton for the year 2013 to 2015. It can be seen that the mean daytime value of τ are higher than the mean nighttime value except during winter months for all the months considered. For the years considered, highest mean daytime values of 275, 271 and 274 km respectively for 2013, 2014 and 2015 were observed during the summer months. However, lowest mean daytime values of 106 and 117 and 155 km are observed for 2013, 2014 and 2015 respectively during the winter months. For the monthly mean nighttime values, in 2013 this range between 142 and 192 km, in 2014 this range between 173 and 207 km and in 2015 this range between

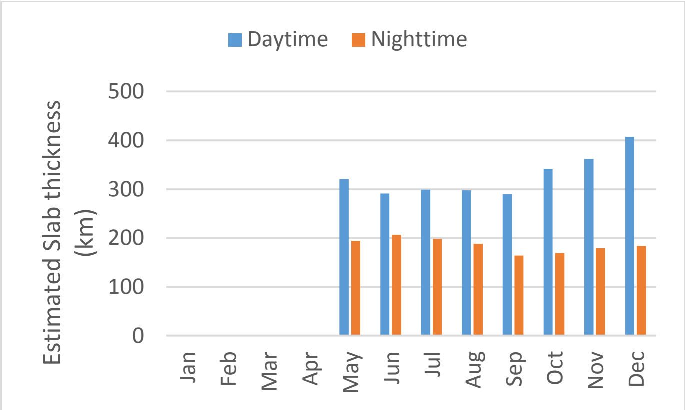
171 and 202 km. The range of daytime and nighttime values of slab thickness as observed in Chilton compared favorably to what was observed by 6 & 16.

From Table 3.1 and 3.2, histogram plots obtained are as shown in figure 3 and 4 for Sao Luis and Chilton respectively. For Sao Luis and in particular for year 2015 for which there is a complete data set, daytime values are highest (400 km) during winter months and lowest (below 300 km) during summer months. Whereas nighttime values are of the same order of magnitude (about 200 km). However, for Chilton (mid latitude station), highest daytime values (about 250 km) are observed during summer months for the years considered. The nighttime values are below 200 km for all the years considered.

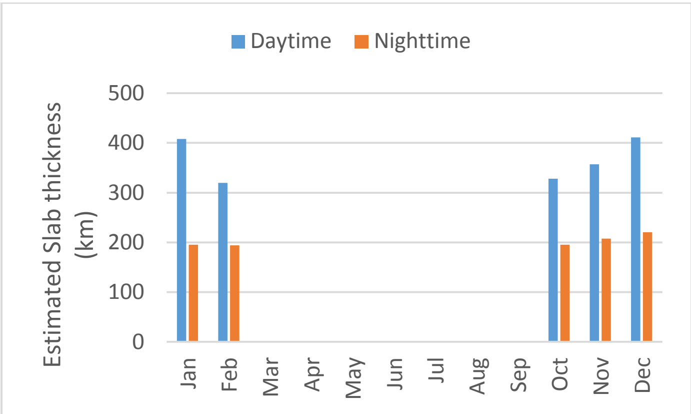
Table 3.2: Monthly mean daytime (08:00 – 16:00 UT) and nighttime (20:00 – 04:00 UT) values of Estimated Slab thickness (τ) for Chilton station in 2013, 2014 and 2015

Months	**2013**		**2014**		**2015**	
	Daytime (km)	Nighttime (km)	Daytime (km)	Nighttime (km)	Daytime (km)	Nighttime (km)
January	131.0009	163.3899	117.0712	179.5969	165.9904	202.0432
February	143.0286	170.9931	179.3955	189.3637	188.5662	200.0028
March	169.2699	161.7111	221.4122	190.9403	222.0071	200.1377
April	194.4256	142.7863	261.4883	191.4143	256.6328	193.9684
May	258.4189	172.0098	263.9834	186.2121	262.5375	187.3077
June	275.3723	192.1806	261.9814	181.0367	274.7638	193.5005
July	274.0046	189.4357	271.9839	183.1988	268.7541	182.0238
August	253.7016	178.6718	253.4836	173.1387	257.2822	182.8023
September	192.8738	162.9755	228.0814	183.1737	214.4169	172.1912
October	141.9142	176.3671	196.3089	192.3994	192.9639	171.3297
November	106.8346	177.4054	172.1439	202.3325	164.0114	178.0821
December	111.8215	190.7117	169.7029	207.2455	155.9261	175.3253

(a) for 2013



(b) for 2014



(c) for 2015

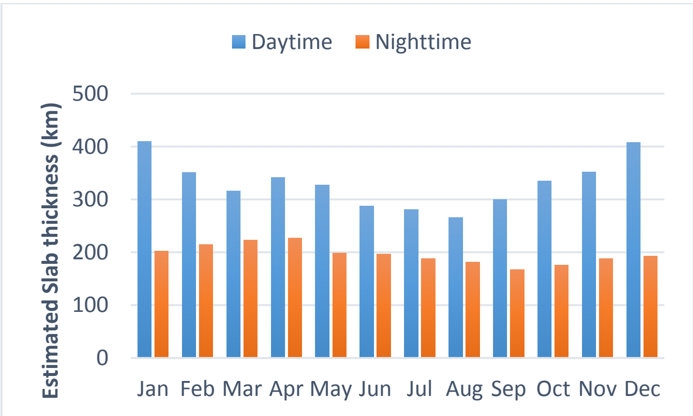
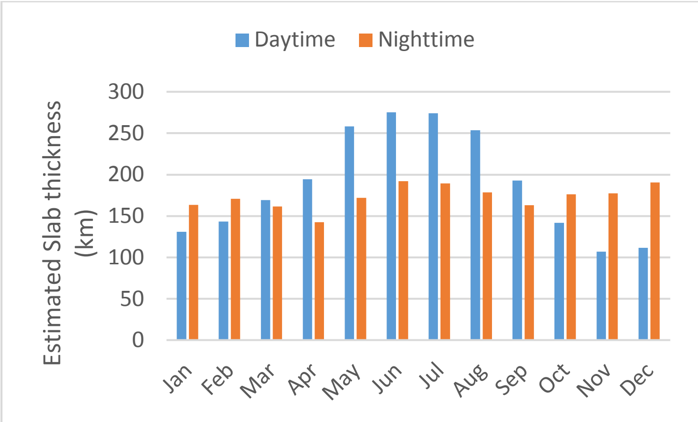
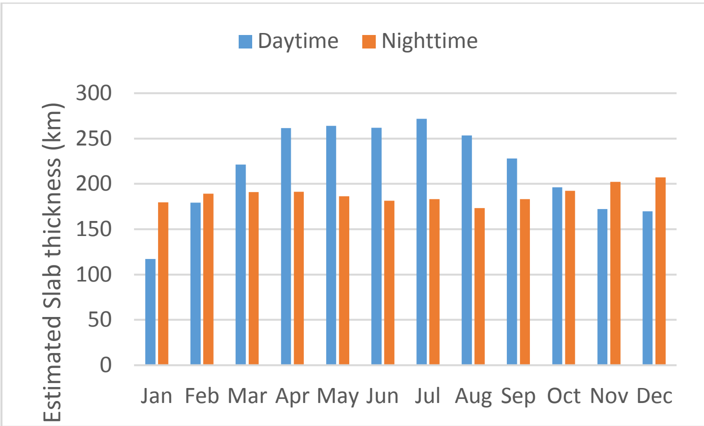


Fig. 3: Monthly Mean (τ) Variation at Sao Luis station for the Period of (a) 2013 (b) 2014 (c) 2015

(a) for 2013



(b) for 2014



(c) for 2015

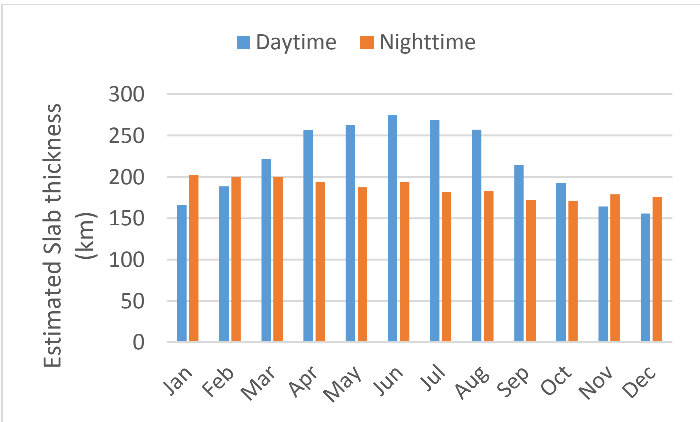


Fig. 4 : Monthly Mean (τ) Variation at Chilton station for the Period of (a) 2013 (b) 2014 (c) 2015

Figure 5 shows the monthly estimated slab thickness for each month for Sao Luis for the years considered. Generally, the pre – sunrise values are small (below 200 km) when compared to daytime/ sunset values (peak at 500 km) for all seasons.

For Chilton (mid latitude station), as shown in Fig. 6, the sunrise values are essentially below 200 km while daytime values are also below 300 km. The slab thickness for the years considered are well correlated during summer month for the period considered.

It should be noted that there is a differential in the daytime peaks for the two regions (low and mid latitude). This might be due to complex ionospheric conditions at low latitude resulting from the EXB drifts originating from the equator [24, 6, 5].

SUMMARY AND CONCLUSIONS

The study of the variation of equivalent slab thickness over low and mid latitude region using Ionosonde (foF2) and TEC data at Sao Louis, Brazil (low-latitude) and Chilton, United Kingdom (Mid- latitude) for the period of January 2013 to December 2015 has been carried out. The variation in estimated slab thickness (τ) exhibit a day to day variation over the years considered. The low latitude station of Sao Louis maximum τ value (~600 km) during the daytime (14:00 UT) is more than double the mid latitude station of Chilton maximum τ value (~235 km) over the years considered. Additionally, from the computed monthly values of τ, a seasonal variation of τ was observed. This has a highest daytime values (400 km) during winter months and lowest (below 300 km) during summer months for the low latitude station (Sao Luis). However, the nighttime values are of the same order (about 200 km) for the low latitude station (Sao Luis). Also, highest daytime values (above 250 km) are observed during summer months and the nighttime values are below 200 km over the years for the mid latitude station (Chilton).

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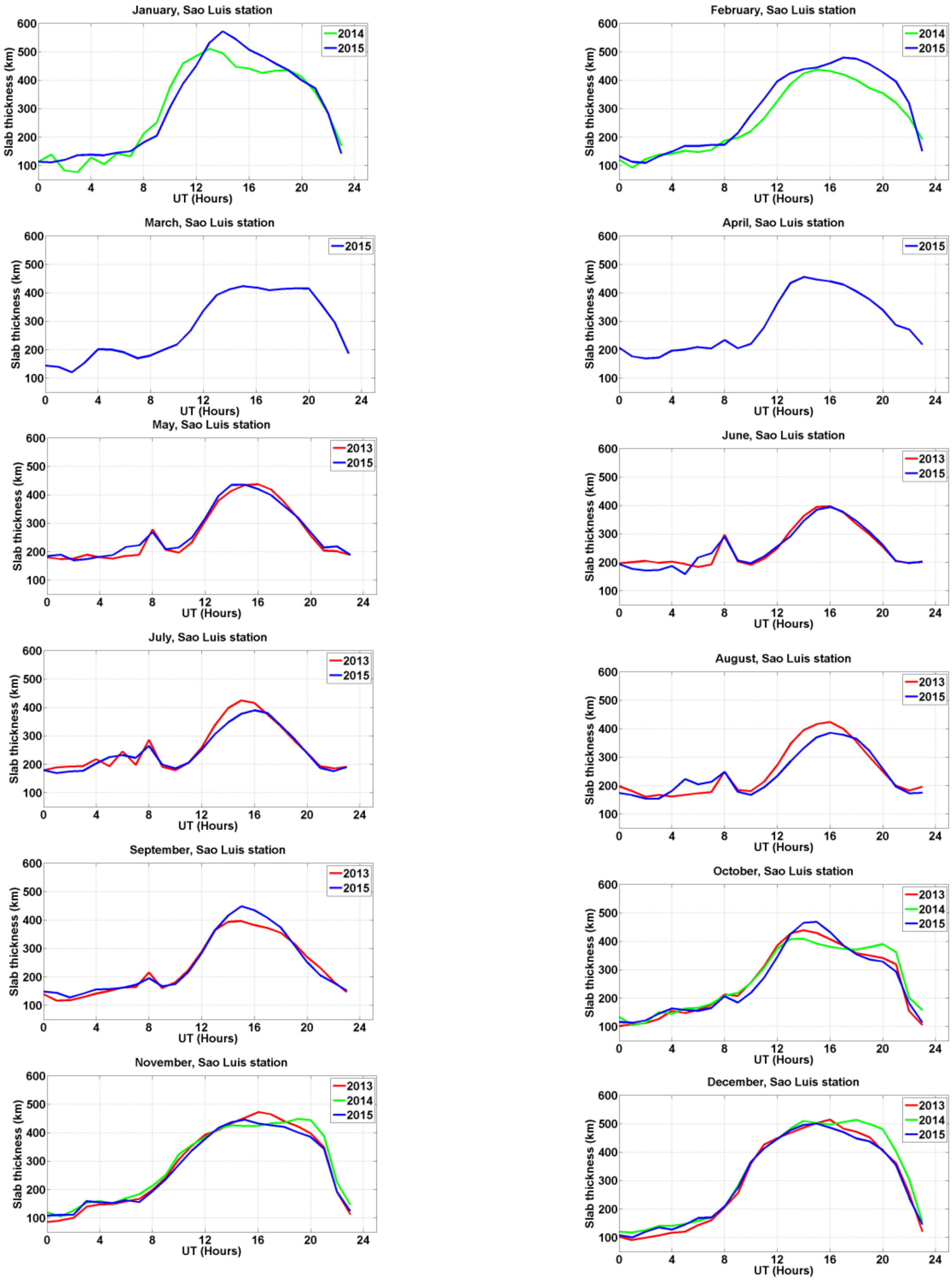

Fig. 5 : Monthly Mean (τ) Variation at Sao Luis station for the Period of January to December 2013, 2014 and 2015 (Red Plot: 2013, Green Plot: 2014 and Blue Plot: 2015

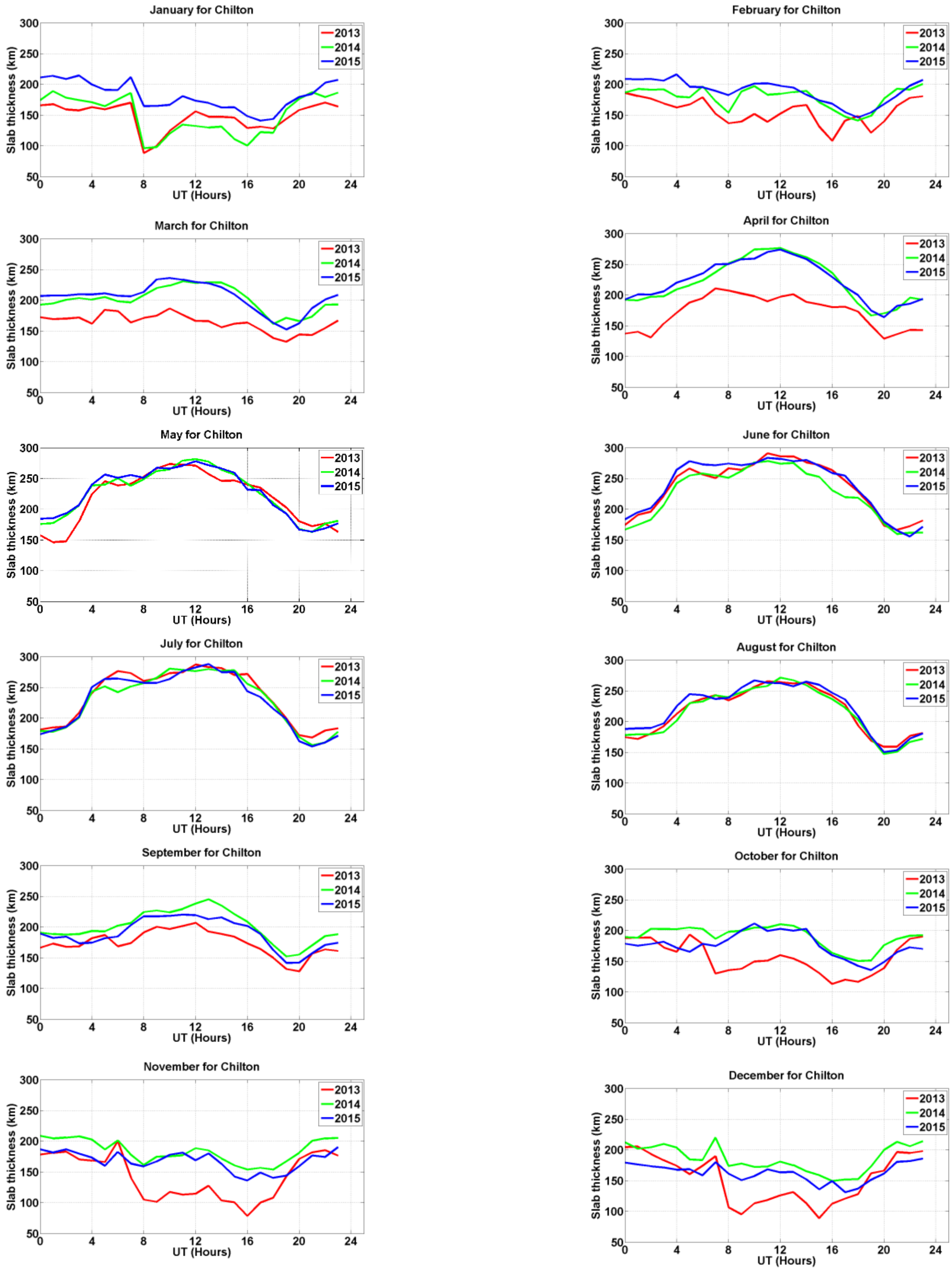

Fig. 6: Monthly Mean (τ) Variation at Chilton station for the Period of January to December 2013, 2014 and 2015 (Red Plot: 2013, Green Plot: 2014 and Blue Plot: 2015

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