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# Study of Long Term Variations in Night Time Thermospheric Airglow Emission At 6300 Å Over Mid Latitude Japanese Station i.e., KISO ($35.79^{o}$N, $137.63^{o}$E)

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**ABSTRACT**

*The long-term behaviour of Pre-midnight and Midnight airglow intensity of deep red colour at 6300 Å concerned to thermospheric layers are described in the present paper. This paper also shows a close look of airglow intensity with solar flux. The airglow intensity shows the positive decadal change between 12 to 20R per decade during July and August month, and 15 to 18R in October-November months, whereas March and June months show the declining trend with the significance of only about 50% and magnitude of about 7.5 to 8.5R per decade during pre-midnight period. Similar types of results are also shown by their MARVs. However during Midnight hours, the maximum significant value (about 90%) is observed in the month of January with the deviation in increasing trend of 5.5R per decade, April and October months show, 8.5 to 9R deviation per decade, whereas March, May and November months provides the increasing trend with variation 6-7R per decade. September month also showing the increasing behaviour but its level of significance is not upto the mark, so its behaviour may not be predicted. The decreasing behaviour in deviation value of airglow intensity is shown in February and June to August months. Airglow intensity also has dependence with solar flux, which also described the present paper.*

**Keywords : airglow 6300Å, long-term changes, F - region PACS Nos.- 92.60.hw; 92.05.Ek**

## INTRODUCTION

It is well known fact that the Earth's ionosphere emits continuously, electromagnetic radiations ranging from the visible to the near infra-red region during different hours. Such radiation depends on neutral & electron density, temperature, rate of the recombination and photochemical reactions between the numerous chemical species, which occur at different altitudes of the upper and lower ionosphere (Rees, 1989; Chattopadhyay and Midya, 2006). It is found that about 40% of the light in a dark moonless night, beyond the city comes not only from the stars or zodiacal belt or galaxies. In addition to these astronomical sources there is an overall uniform luminosity originating from the Earth's own atmosphere. This light scattered by atmospheric particles and is produced by a natural chemi-luminescence's process in the presence of numerous types of atmospheric atoms and molecules present in the earth's ionosphere (Jana et al., 2006; 2011). This self-luminescence activity observed on the ground is known as airglow (Midya and Midya, 1993) or glowing of air is known as airglow. Thus, the night sky has an overall background luminosity. Therefore, the luminosity of the sky is due to the combination of astronomical and an airglow source that allows us to see the shadow of an object held against the dark sky on a clear moonless night. The brightest region of airglow is about 10 to 20 km thick zone at an altitude of about 100 km. Sodium layer is one of the contributors to airglow.

The airglows are mainly of three types named as day, twilight and night airglow. Such airglows are categorized according to their time of occurrences (Midya and Chattopadhyay, 2006).

During daytime, various atmospheric atoms, molecules and ions get excited by absorbing incidental solar energy fluxes. Subsequently, they come down to the ground state and emit energy as light and it is termed as Day Airglow (Chamberlain, 1961; Hunt, 1970; Rees, 1989). However, in night hours, the radiation emitted by atmospheric atoms, molecules and ions in transition between excited to ground state or excited to meta-stable state are known as Night Airglow. Besides this, collision also plays a vital role for night airglow emission. During twilight hours, the ions, atoms and molecules are partly or completely getting excited by absorbing solar energy and by different collision phenomena. There are various types of night airglow spectrums, such spectrum are lines, band and continuum, ranging from ultraviolet to near infrared region. The primary emission lines, accessible on the ground are known as Oxygen airglow (OI 5577 Å, OI 6300 Å), Hydroxyl airglow and Sodium airglow lines (5893 Å).

The night airglows are of several lines of wavelengths concerned to different ionospheric region. Generally night airglow of Sodium D line (5893 Å) is found to be linked with mesospheric-lower thermospheric (MLT) region i.e., 90 to 100 km (peak emission altitude ~92 km), whereas the night airglow of deep red emission at 6300 Å attributes to ionospheric F-region and is representative of thermospheric behavior in the neighborhood of 300 km altitude (peak emission altitude ~245 km) (Herrero and Meriwether, 1981; Bates, 1982). However, the nocturnal airglow intensity at 5577 Å is mainly linked with the mesospheric region in different night hours (Bangia et al., 2010). Thus, nocturnal airglow intensity Na-D 5893 Å and OI 5577 Å are to be called as Mesospheric airglow and OI 6300 Å is known as Thermospheric airglow.

Several researchers have reported the short-term variation such as nocturnal hourly variation, seasonal dependence of night time airglow intensities since last decades and excellent review work on the airglow studies have been discussed in details by Chattopadhyay and Midya, 2006.

In this direction, some typical investigations were reported on the thermospheric airglow studies, concerned with the correlation among several F-region ionospheric parameters such as the maximum electron density of F-region ($N_mF_2$), Critical Frequency ($f_0F_2$), Virtual height (h'F), Total Electron Content variables as well as precursors of Spread-F with the airglows emitting at 6300 Å (Ogawa et al., 2002; Sobral et al., 2002; Bangia et al., 2010). In this way we can say that the optical emissions of the night airglow intensity investigation plays a vital role in understanding the short- and long-term changes in neutral and thermal properties of different ionospheric regions through the collision, quenching and photochemical reactions in the upper and lower ionosphere. Thus, airglow emissions are an important and useful tool for investigation and understanding about the chemical and dynamical processes controlling the state of the upper mesosphere and lower thermosphere about short as well as long-term variations in neutral density and thermal properties of the ionosphere during different space weather phenomena and in normal environment (Chakrabarti, 1998).

In this direction the long-term variation study specifically based on computed long-term night airglow intensity at Na 5893 Å and Li 6708 Å at some of Indian stations were carried by Jana & Nandi (2005a, b, c; 2006) and Jana et al, (2006, 2011). They reported the close association of long-term change in mesospheric airglow intensities with depletion of long-term trend in ozone. Similarly Vyas & Saraswat (2013a) and Saraswat (2013) on the basis of observed data of Na-D airglow of the present study site i.e., Kiso (Japan) reported a declining long-term trend in ozone value and mesospheric temperature or ozone depletion and mesospheric cooling phenomena. Vyas & Saraswat (2013b) also showed a long term trend between ozone and solar flux (10.7cm). The first critical review work on long-term change, depending on atmospheric data set carried by ground, satellite and rocket based experiments of the multi decade period of mesospheric temperature trend and on earlier reported observations were summarized and discussed by Beig et al., (2003). They established primary fact about the evidences of long-term mesospheric cooling. Rajesh et al., (2007) have reported the ionospheric plasma depletion phenomenon over Kavalur i.e., Indian low latitude station using the nighttime airglow intensity measurements at 5577 Å. Effect of seasonal, solar cycle variation and determination of different range of periodicities from a few days to less than one solar cycle on nighttime airglow intensity of 5577 Å over Kiso, was described by Das et al., (2008, 2011). But they didn't attempt the long-term accept of such study and this problem was carried by Vyas & Saraswat (2012) and Saraswat (2013), they conclude that there is a positive increasing decadal change in Midnight and Pre-midnight mesospheric airglow intensity of the range 25 - 88 R. This range is the order of 10 to 30% of the observed MARV and average night airglow intensity of 250 R. They also report on their findings that the positive decadal change in night time mesospheric airglow intensity has been further linked to the reduction of mesospheric electron densities and temperature or shrinking and cooling of the lower ionosphere. Apart from the above two intensities of airglow, OI 6300 Å have also their own importance because it is associated with the F - region. This airglow is an ideal tracer of ionospheric variations and thermospheric-ionospheric interaction. The atomic oxygen emission at 6300 Å is one of the most prominent lines in the airglow spectrum that has been extensively studied using ground based photometers (Greenspan, 1966; Nelson and Cogger, 1971; Herrero and Meriwether, 1981; Chu et al., 2005) and all sky cameras (Weber et al., 1978; Sahai et al., 2001; Sinha et al., 2003; Martinis et al., 2003; Mukherjee, 2003; Pimenta et al., 2003; Mendillo et al., 2005; Rajesh et al., 2007). The atomic oxygen emissions at 6300, 6364 and 6392 Å, arising from the 3P −1D transition (Hays et al., 1978, 1988).

Early studies of the atmospheric excitation of O($^1$D) have been reviewed by Chamberlain (1961), Noxon (1968), Bates (1978, 1982) and Torr and Torr (1982). Bates and Dalgarno (1953, 1954) showed that the 6300 Å emission should be one of the strongest features of the dayglow but also suggested that chemical deactivation was important at lower altitudes.

The OI 6300 Å airglow emission line is produced as specific emission line in combination with 6364 Å lines, conjugately known as Red Doublet (Peterson et al., 1966). The reactions involve in it are as

$$O\,(^1D_2) \rightarrow O\,(^3P_2) + h\nu\ (6300\text{Å})$$

$$O\,(^1D_2) \rightarrow O\,(^3P_1) + h\nu\ (6364\text{Å})$$

O$^1$D may be produced in three different ways as follows:

(i) Dissociative Recombination (Unstable)

$$O_2^+ + e \rightarrow O_2 \rightarrow O^* + O^*$$

(ii) Photo-dissociation (Schuman Runge dissociation) (Carovillano and Forbes, 1983)

$$O_2 + h\nu\ (\lambda < 1750\ \text{Å}) \rightarrow O\,(^1S) + O^*$$

(iii) Photo-detachment

$$O^- + h\nu \rightarrow O\,(^1D) + e.$$

Amongst the above three processes, the dissociative recombination is the most significant process to contribute to the production of OI 6300Å emission (airglow). It is found that the 6300 Å region also has a spectral contribution from the mesospheric heights from the OH(9–3) vibrational transitions at 6287, 6298, and 6306 Å (Burnside et al., 1977; Mende et al., 1993) in addition to atomic oxygen emission.

Sobral et al, 2002 has investigated the ionospheric plasma bubbles climatology based on 22 years of 6300 Å airglow observations over Brazil. The long-term analysis of OI 6300 Å airglow emission was also done by Mukherjee et al., 2000 over an Indian site Kolhapur (16.8ºN, 74.2ºE, dip lat 10.6ºN) with the help of tilting filter photometers and a comparison has been made between the simultaneous nightglow and the ionospheric parameters of virtual F-layer height and critical frequency of the F-layer at Ahmedabad (23.02ºN, 72.6ºE). They showed a good correlation between the measured airglow emission and F-region peak electron densities during quiet periods. And for intense magnetic disturbances, the airglow fluctuations are mainly controlled by sharp changes in height variations of the h′F layer. The period of airglow variation generally corresponds to periods of F-region height variation during magnetic disturbances. But most of the researchers work on the short-term variations of airglow specially related to F-region or thermospheric region. Thus, studies of long-term variation on thermospheric airglow specifically based on experimentally observed data and its possible causes are either rare or few.

Realizing these facts in mind, an attempt has been made in the present paper to study the long-term variations on the basis of experimentally measured nighttime airglow intensities 6300 Å, which were recorded for the period 1979-1994 over mid latitude Japanese stations Kiso, Tokyo Astronomical Observatory (TAO), University of Tokyo (35.79ºN, 137.63ºE; 1130 m), Japan. This particular station has been taken for the present work because the long-time series data are available only on the study site.

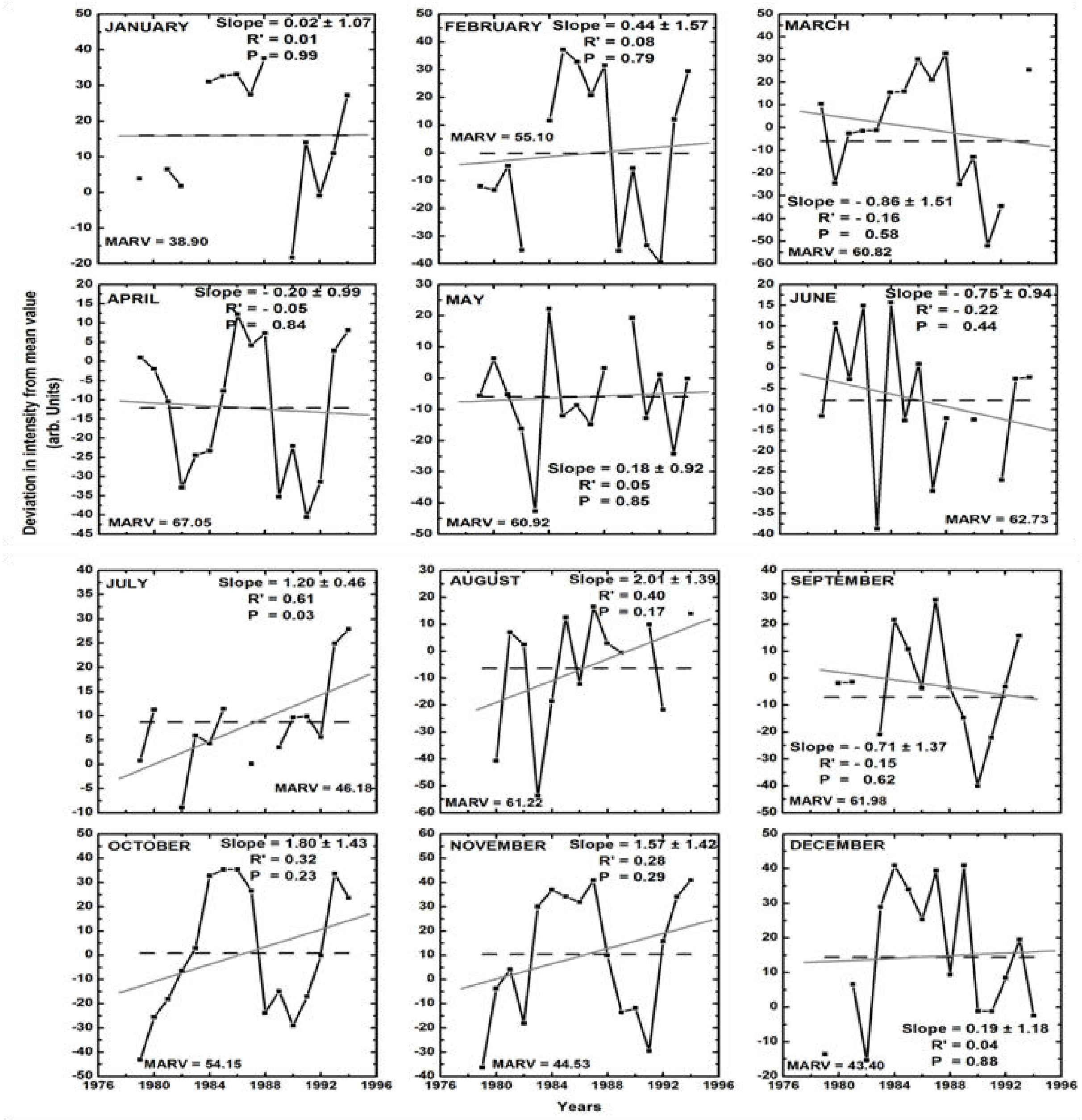


**Figure 1: Long-term change in Pre-midnight Airglow intensity at 6300Å for different months**

## DATA ANALYSIS

The basis of the present analysis is regular observations of oxygen red (OI) airglow line at zenith (3 degrees diameter) on moonless clear night days. The present investigation is carried out from the analysis of a data set of hourly values of night airglow intensity at 6300 Å, which were recorded over Kiso, TAO, Japan and are downloaded from the Solar Activity World Data Center, Japan using the website (http://solarwww.mtk.nao.ac.jp/wdc.html) during the period 1979-1994. Such extensive data cover one and half decade and hence provide an opportunity to carry out long-term trend study analysis over mid latitude thermospheric airglow emission at 6300 Å (Mukherjee et al., 2000).

To ascertain the long-term trend first, it is necessary to remove hourly, seasonal and solar cycle variations of the airglows intensities from the available raw time series data. In this connection, following method has adopted in the present course of work.

## METHOD OF ANALYSIS

In this work, the monthly mean values are computed for the airglow intensity at 6300 Å separately. The mean values obtained for the three hour interval are from 8:00 to 10:00 P.M. (Pre-midnight period) and 11:00 P.M. to 1:00 A.M. (Midnight period) from their respective daily values of each particular month of the present study period (1979 to 1994). The main reason for adopting this method is to eliminate the seasonal and diurnal variations, because this long study period contains several seasons and activity period. Using above computed monthly mean values, Monthly Average Reference Value (MARV) are calculated for each month of the entire selected study period, separately. This value removes the solar cycle dependence for the same study period and is shown in **Table 1** and **Figures 1** and **2**. Therefore, MARV has treated as reference value for the specific month of observations of the chosen study period. This value is considered as a baseline for the specific month of observations of the entire study period.

These MARV are shown by dotted line in each figure. After computing the MARV of each particular month, the deviation of individual monthly mean values of thermospheric airglow intensity at 6300 Å of the specified study period is computed from corresponding MARV to extract the decadal change in respective parameters. These deviations are then plotted to demonstrate the long-term variation in thermospheric airglow emission intensity against the years for each month separately.

To display the decadal change in theses parameters, the linearly fitted line is also plotted by its statistical regression analysis along with observed trend. Such statistical linear regression fitted line is shown by an inclined line along with their observed trend exhibited by dark black line in the respective figures (Figure 1 and 2). The slope, correlation coefficient value (R′) and probability (P) values are shown in each figure, giving the inference about the changing of airglow intensity per year and its statistical significance respectively. In this study only three hour values are used for grouping as Pre-midnight and Midnight, so it is not superior to display the error bars in the respective figure hence error bars are not displayed. Figure 1 and 2 show the long-term change in thermospheric airglow intensity 6300 Å in each individual month of years from 1979 to 1994 during Pre-midnight and Midnight hours separately. The results obtained from the figures are presented and discussed in the next section.

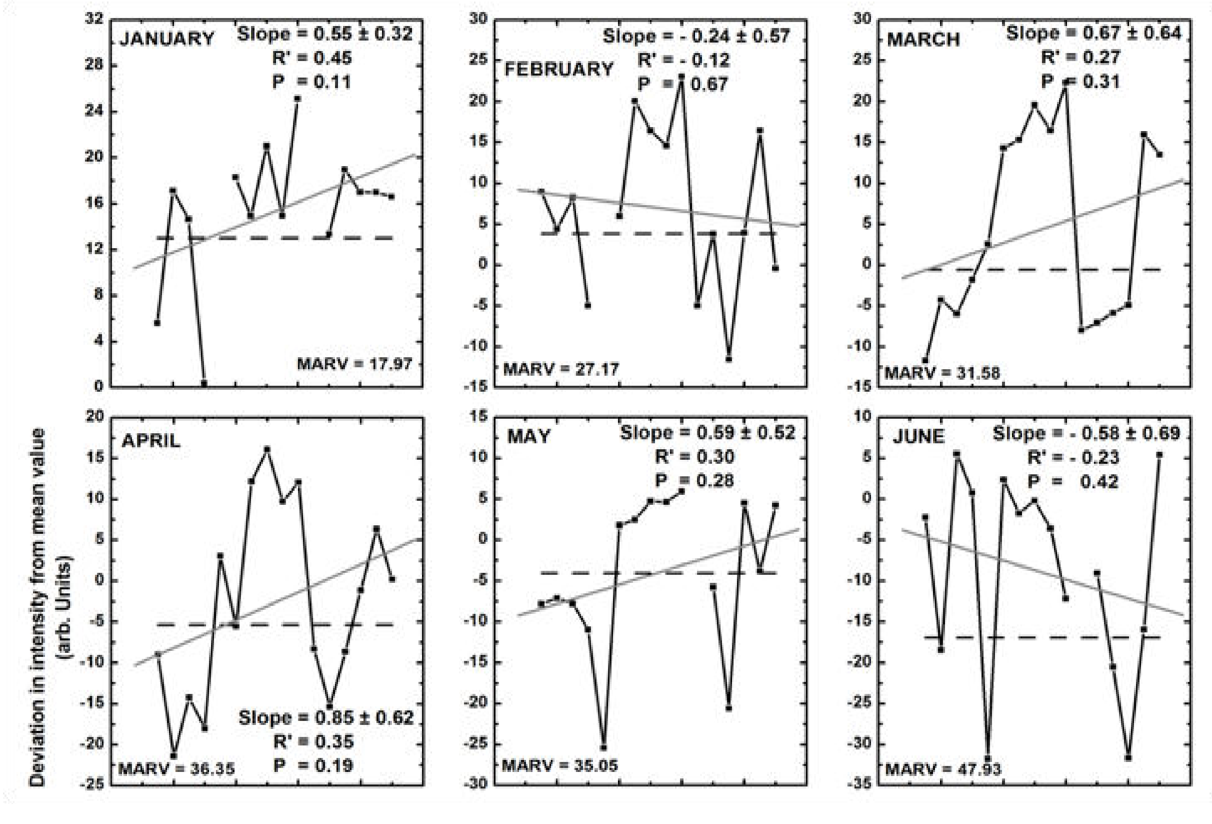
## RESULTS

### Mid Latitude Pre-Midnight Airglow Intensity

The year to year variation in deviation values from MARV to its individual average monthly value of Pre-midnight red airglow emission of Oxygen at wavelength 6300 Å are shown in Figure 1. It is conspicuous from Figures and calculated values of slope, R′ and P that deviation from the MARV airglow intensity shows the positive decadal change between 12 to 20R per decade during July and August month with the significance level above 80%. The intermediate significance level above 70% is found in the month of October and November with the increasing trend between 15 to 18R per decade and in the rest of the month there is no significant long-term increasing trend, however in the month of March and June the decreasing trend in deviation value is seen with the significance of about 50% and magnitude of about 7.5 to 8.5R per decade. On the basis of MARV the decreasing trend of about 62 to 39R is observed from September to January months and increasing trend from February to April month with the value of 55 to 67R (Table 1), which agrees with the result that the nightglow intensity maximum occurs in autumn and minimum in summer months (Chattopadhyay and Midya, 2006). During May to August there is no systematic trend observed.

### Mid Latitude Midnight Airglow Intensity

In **Figure 2** the Midnight yearly behaviour of deviation values from the MARV to each specific monthly mean value are plotted with years for the same period. It is pragmatic from the figure that in most of the month the deviation value shows the increasing trend but in case of certain month negative trend has also observed but their level of significance is very small, except in the month of August. The maximum significant value about 90% is observed in the month of January with the deviation in increasing trend of 5.5R per decade. In the month of April and October the deviation has 8.5 to 9R per decade with the significance of greater than 80% and in March, May and November months 6-7R per decade increasing trend has been observed but their level of significant is around 70%. In the month of December, the increasing trend in deviation value of airglow intensity is also shown with the significance of about 70% but their rate of change is very small, about 2.5R per decade only. September month also showing the increasing behaviour but its level of significance is not upto the mark, so its behaviour may not be predicted.



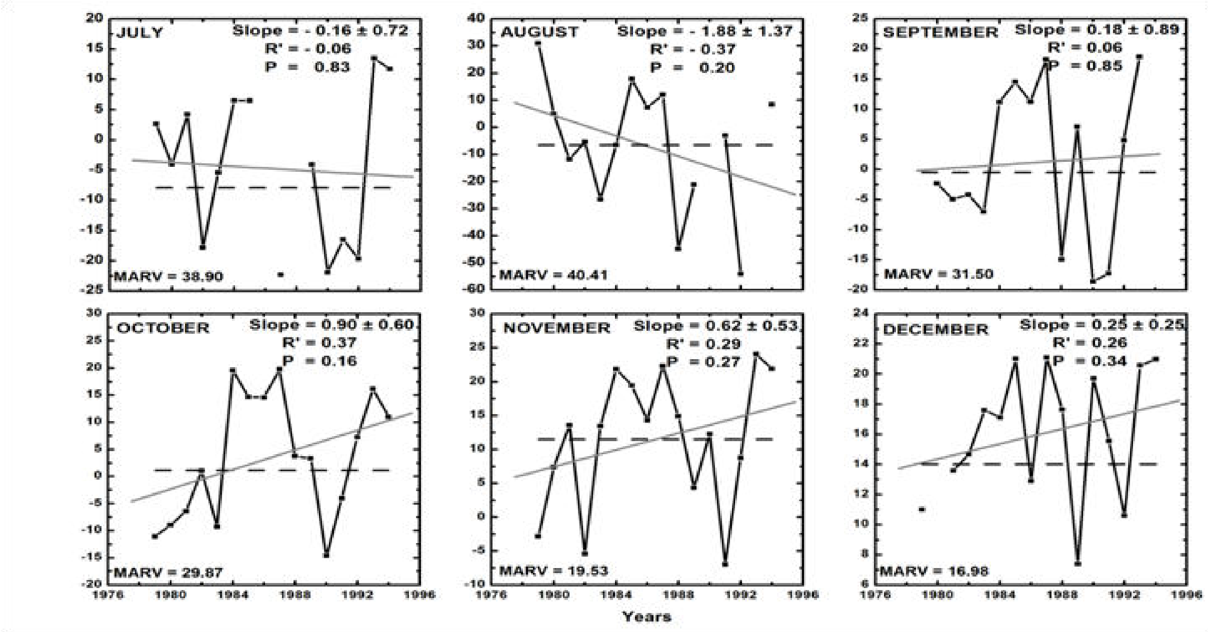


**Figure 2: Long-term changes in Midnight Airglow intensity at 6300Å for different months**

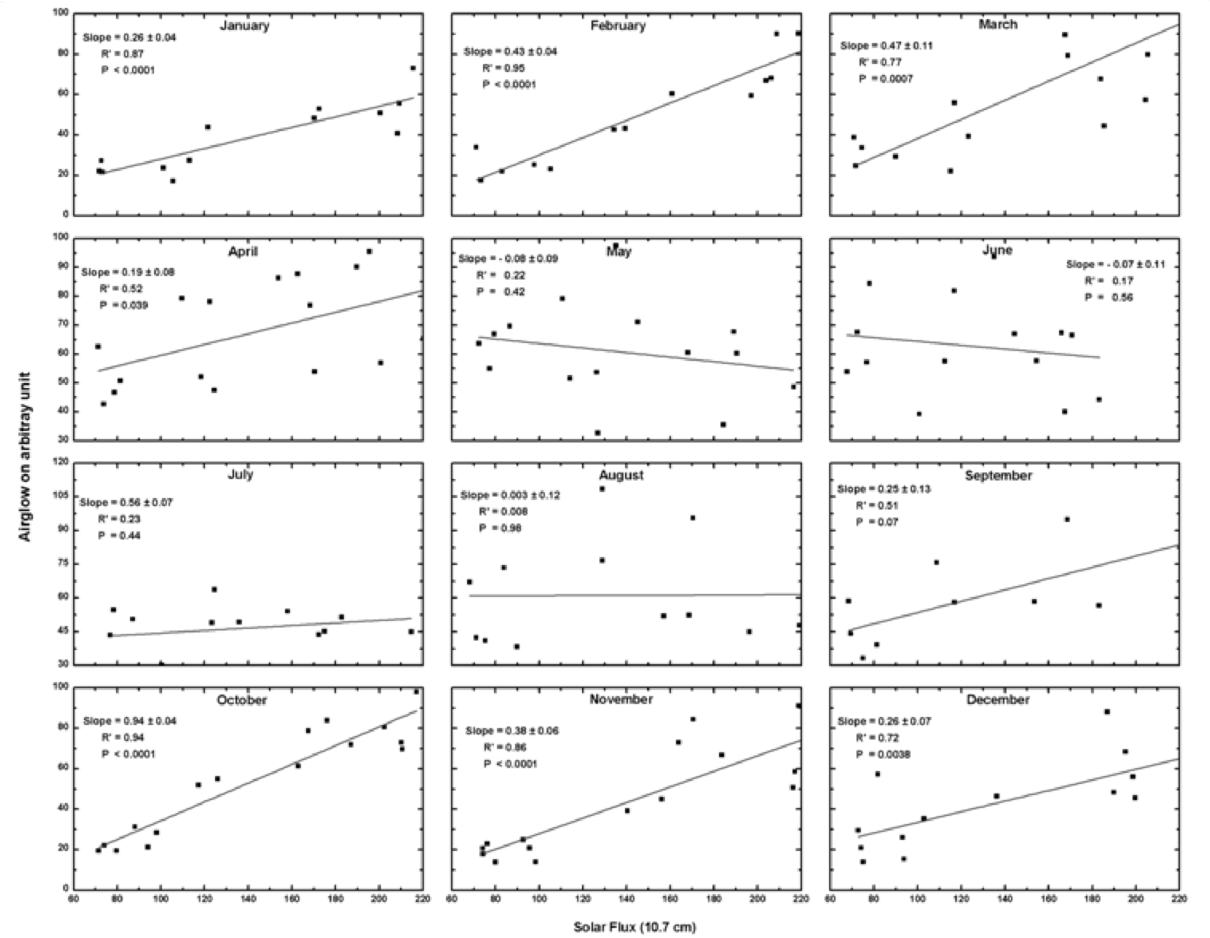


**Figure 3: The variation of airglow intensity at 6300Å with solar flux (10.7 cm)**

The decreasing behaviour in deviation value of airglow intensity is shown by the rest of the month i.e., in the months of February and June to August. The most significant decreasing trend on the basis of characteristic diagram shown in Figure 2 is observed in the month of August with the level of significancy about 80% and having value 19R per decade, which is highest in comparison to all the observed months. The less significance level is observed in June (about 60%) with the variation of −5.8R per decade and in February & July months no significant variation is observed in deviation values.

**TABLE – 1**
**Monthly Average Reference Values of the airglow intensity of OI 630 nm and their standard error values in Pre-midnight and Midnight hours of different months during study period**

| Month | MARV during | |
|---|---|---|
| | Pre-Midnight | Midnight |
| January | 38.90 ± 4.70 | 17.97 ± 2.61 |
| February | 55.10 ± 7.09 | 27.17 ± 4.21 |
| March | 60.82 ± 8.75 | 31.58 ± 5.15 |
| April | 67.05 ± 4.42 | 36.35 ± 4.29 |
| May | 60.92 ± 4.20 | 35.05 ± 2.48 |
| June | 62.73 ± 4.35 | 47.93 ± 9.42 |
| July | 46.18 ± 3.08 | 38.90 ± 4.68 |
| August | 61.22 ± 6.08 | 40.41 ± 6.08 |
| September | 61.98 ± 7.90 | 31.50 ± 4.44 |
| October | 54.15 ± 6.70 | 29.87 ± 4.10 |
| November | 44.53 ± 6.61 | 19.53 ± 2.49 |
| December | 43.40 ± 5.69 | 16.98 ± 2.46 |

If we conclude the result on the basis of MARV then it is observed that the maximum value of MARV is found in the month of June, which is about 48R, and decreasing trend is observed from August to December months having values from 40 to 17R and then increasing behaviour is shown from January to the month of April with MARV from 18 to 36R. It is also found that the value of correlation coefficient R′ in all the month is found to be very small about 0.3 to 0.4 only.

As discussed earlier, night Oxygen airglow intensity at 6300 Å deals to ionospheric F-region altitude and directly concerns to thermospheric condition, thus observed augmentation in appreciable amount in Pre-midnight and Midnight hours airglow intensity at 6300 Å in the present work provide the confirmation of fact about the perturbation in physical and chemical condition like critical frequency, virtual height, electron density and thermal condition of airglow emission region of the ionospheric F- layer during selected study period. For confirmation that the airglow intensity at 6300 Å is directly related to solar flux, a graphical treatment between solar flux (F 10.7cm) and variation in airglow is shown in **Figure 3**. It is evident from the figure that airglow and solar flux follow the same trend in most of the month, during October to March the trend follows with the significance level above 99%, April to September with significance level above 90%, while during May and June months the negative correlation followed between airglow intensity at 6300 Å and solar flux with the significance about 45 to 60%. In the month of August, there is no significance level between airglow and F10.7.

## SUMMARY AND DISCUSSIONS

The long-term behaviour of Pre-midnight and Midnight airglow intensity of deep red colour at 6300 Å concerned to thermospheric layers are described in the present paper. It is observed that positive decadal change in night time thermospheric airglow is seen with higher range of 10 to 20R per decade for the airglow emission of 6300 Å during Pre-midnight period and lower range of 2 to 9R during Midnight period respectively. It is also clear from the above discussion that the deviation of Midnight airglow intensity shows a negative trend in some of the month but their significance level is very small. The direct correlation between airglow and solar flux shows that solar flux plays a vital role in airglow emission. It has been well recognized and well established fact that airglow emission intensity and its width primarily depend on the large number of factors like electron density and temperature profile, the nature of chemical species, chemical kinetics etc., of the concerned height range of airglow emission lines where it takes place. Furthermore, the electron density and temperature both are higher in the thermospheric region in comparison to mesospheric region. Thus, such large changes in thermospheric airglow intensity as compared to mesospheric night airglow intensities might be due to coincidence of available higher electron density value in thermosphere and lower electron density in the mesosphere.

However, the observed varying nature of its decadal change in thermospheric and mesospheric airglow intensity can be interpreted on earlier reported findings about the long-term behaviour of critical frequency, height etc., of concerned ionospheric E and F- region such as critical frequency $f_0E$, $f_0F_2$, $h'F_2$ etc. On the basis of earlier findings, it is well established fact that long-term changes in atmospheric parameters concerning to different atmospheric layers respond differently in both natures as well as the overall change in their magnitude per decade (Lastovicka et al., 2006; Beig, 2008). They reported varying nature of change like negative at mesospheric height and positive in thermospheric altitude, which is supported to present observed findings about the long-term behaviour at night time mesospheric and thermospheric airglow intensity. Aburjania et al., (2000) showed that OI6300 Å line intensity had been observed to increase 2-3 hour before the start of local twilight and increase within an hour up to twice its original value. Also it is found by them experimentally that about 65% of 6300 Å line intensity can be explained by the direct collision of oxygen atom with photoelectrons that are produced by in the magneto-conjugate ionosphere. Since this study is only based on six hours duration of night time, so it cannot say anything about local twilight hours.

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