LONG TERM TREND IN NOCTURNAL AIRGLOW EMISSION OF 589.3 nm OVER MID LATITUDE JAPANESE STATION *i.e.*, KISO (35.79°N, 137.63°E)

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The paper describes long-term changes in monthly Pre-midnight and Midnight time mesospheric airglow emission on Na-D 589.3 nm over Kiso, Tokyo Astronomical Observatory, University of Tokyo (35.79°N, 137.63°E; 1130 m), Japan. The higher reductions in long-term change in the Pre-midnight airglow intensity values are observed in the range of 12 to 24R per decade during November, January and February months only with best statistical significant level above 90%. However in Midnight hours, its corresponding reduction value per decade is found only 11-12R with good significance level of above 80% in January and October, while in May and November, its values occur in 5-6R per decade. These variations are in the order of 10 to 30% of the observed MARV. An attempt has been made to interpret the present findings in view of similarities observed between negative decadal change in night time mesospheric airglow intensity with earlier reported works on declining long term trend in ozone value and mesospheric temperature or ozone depletion and mesospheric cooling phenomena.

Key words: Airglow, Long Term Changes and Ionosphere.

1. INTRODUCTION

The Earth's ionosphere emits continuously, its electromagnetic radiation spectrum ranging from the visible to near infrared wavelength during different hours. It depends on neutral & electron density, temperature, rate of the recombination and photo-chemical reactions that take place among the numerous chemical species present at different layers of the Earth’s ionosphere [1–2]. It has been well recognized fact that about 40% of the light in a dark moonless night, beyond the city comes not from the stars or zodiacal belt or galaxies. But, it is scattered by atmospheric particles. This light is produced by a natural chemi-luminescence's processes in the presence of numerous types of atmospheric atoms and molecular species of the Earth's ionosphere [3]. This self-luminescence activity observed on the ground is known as Airglow [4]. Thus, airglow emissions are an outcome of chemi-luminescence property of ambient atomic molecular species in the middle and the upper atmosphere. The airglows are mainly of three types like day, twilight and night airglow. Therefore, they are categorized according to their times of occurrences [5].

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 [1, 6 & 7]. However, in night hours, when they come down to ground state or meta-stable lower energy state, they emit the electromagnetic radiation light; these transitions 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 not only by absorbing solar energy but also by different collision phenomena. There are also various types of night airglow spectrum, according to their natures, such as lines, band and continuum types emission ranging from ultraviolet to near infrared. The primary emission lines, accessible on the ground are known as Oxygen airglow (OI 557.7 nm (Green), OI 630 nm (Red)), Hydroxyl airglow and Sodium D-airglow lines (Na-D 589.3 nm (Yellow)) [8].

The night airglows of several lines of wavelengths are concerned to different ionospheric regions. Generally night airglow of Na-D line (589.3 nm) 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 630 nm (peak emission altitude ~250 km) attributes to ionospheric F-region [9–10]. However, the nocturnal airglow intensity at 557.7 nm is mainly concerned with the upper thermospheric region at different night hours [11]. Thus, nocturnal airglow intensity Na-D 589.3 nm is called as mesospheric or MLT airglow and both OI 557.7 nm and 630 nm are known as Thermospheric airglow.

Na nightglow involves the complex catalytic chemical process, which combines with O to make NaO and ozone (O_3) to make Na + O_2. O_3 is produced by recombination involving O, and consequently the brightness is related to the Na and O densities. More details of chemical kinetics and excitation mechanisms are already discussed by Jana *et al.* [3] and Jana & Nandi [12 – 15].

A large number of nocturnal hourly variations and seasonal dependence of night time airglow intensities have been reported since last decades and their works are summarized in an excellent review paper on the airglow aspects in more detail by Chattopadhyay & Midya [2]. They reported that nocturnal intensity of airglow emission of Na-D line was founded more in equinoxes and less in summer and winter with an average value of 120R over high latitude. As far as, its latitudinal dependence concerned that its intensity was found the least over the equator and intermediate magnitude over mid latitude. It is worthwhile to add here that MLT region along with nocturnal intensity of airglow emission of Na-D line is the least explored topic due to its very low level of brightness as compared to other airglow emission lines like OI-630 nm [16 – 17]. So, there are scarcities of long-term change studies on the nighttime airglow intensity of Na 589.3 nm or MLT airglow due to rare availability of such type of long series of datasets of any particular station. However, such available fourteen years continuous nighttime sodium airglow intensity at 589.3 nm over Kiso, Tokyo Astronomical Observatory (TAO), University of Tokyo (35.79°N, 137.63°E; 1130m), Japan are the unique data set, which provide the opportunity to study the long-term change in nighttime sodium airglow intensity.

Since the beginning of the last three decades, considerable attention has been given to detecting the long-term change in various direct and indirect measured parameters *i.e.*, thermal structure of the several regions of Earth's atmosphere extending from troposphere to ionosphere on the basis of experimental observations and modeling works [18–20]. The first excellent review work on long-term change in stratospheric temperature in term of stratospheric cooling was summarized by Ramaswamy *et al.* [21]. Later on, extended critical review work on the long-term in mesospheric temperature trend on the basis of earlier reported works during past decades observations was summarized and discussed by Beig *et al.* [22]. They established primary fact about the evidences of long-term mesospheric cooling from the analysis of multi-years atmospheric datasets retrieved from ground, satellite and rocket based experiments. Such findings have been linked to global earth-climate impact *i.e.*, continuous enhancement of trace gas emission in the earth's atmosphere in past decades by anthropogenic activities. In this context, the first pioneering modeling work of Roble & Dickinson [23] using global model of meso-thermosphere and ionosphere has estimated that the reduction of the mesosphere and thermosphere to be about 10K and 80K respectively, assuming the doubling mixing ratio of CO_2 and CH_4 at 60 km altitude. Further detailed investigations on long-term change in mesospheric electron density and Long radio waves reflection height were also reported the decreases of mesospheric electron density, *Lower Frequency* (LF) reflection height etc., by Bremer & Berger [24]. In these perspectives of long-term trends in mesospheric region, Jana *et al.* [3] and Jana & Nandi [12 – 15] have performed the analysis specifically based on computed long-term night airglow intensity at Na 589.3 nm at some of Indian stations. They have attempted to establish the close association of long-term change in mesospheric airglow intensities with depletion of long-term trend in ozone. Besides these, Semenov & Shefov [25] also discussed the long-term variation in middle atmospheric temperature from mid latitude night time mesospheric airglow measurements of 50 years.

The present work is also an attempt in this direction to extend the study of long-term change on the basis of experimentally measured MLT airglow intensities at 589.3 nm, which were recorded over mid latitude Japanese station Kiso, TAO, Japan.

2. DATA ANALYSIS

The basis of the present analysis is regular observations of sodium (Na-D) airglows brightness at zenith (3degrees diameter) on moonless clear night days. The present investigation is carried out from the analysis of collecting such raw datasets of hourly values of night airglow emission at 589.3 nm for fourteen year period over Kiso, TAO, Japan. Such airglows daily hourly data have been downloaded from the Solar Activity World Data Center, TAO Japan using the web site <http://solarwww.mtk.nao.ac.jp/wdc.html> for the period of 1979-1994. Such extensive long-term data encompass more than one solar activity period and therefore provide an opportunity to describe the long-term characteristics of the night time mid latitude airglow emission at 589.3 nm, which primarily refers to the MLT region [2].

To ascertain above such long-term change, it is necessary to remove hourly, seasonal and solar cycle variation of the airglows intensity from the available raw time series data. For this purpose, following method has been used in the present investigation.

3. METHOD OF ANALYSIS

First, monthly average airglow intensity values are calculated for three hours intervals between 20:00 to 22:00 hours as Pre-midnight period and 23:00 to 01:00 hours as the Midnight period from their respective daily values of each particular month of the years from 1979 to 1994. Such groupings of particular average monthly values of Pre-midnight and Midnight hours are made to remove the hour, month to month as well as seasonal dependence factors from the raw airglow data. Subsequently, *Monthly Average Reference Value* (MARV) has also calculated separately from the average monthly values of Pre-midnight and Midnight hours for each specific month of the entire study period. Such MARV of individual monthly value of airglow intensity is evaluated to eliminate the solar cycle variations of entire specified period and are shown in Table 1 and Figures 1 & 2.

Therefore, MARV has treated as base monthly value for the specific month of the chosen study period. The deviation of the individual average monthly values from corresponding MARV of the similar months have computed and plotted as a function of years. The average values of such deviations are also depicted as red dotted lines to visualize the overall long-term trend in MLT airglow intensities or departure from the normal level.

Table 1

Monthly Average Reference Values of the airglow intensity of Na 589.3 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	34.5 ± 2.96	35.77 ± 3.10
February	28.95 ± 2.28	29.61 ± 2.67
March	39.40 ± 3.87	35.05 ± 2.82
April	41.52 ± 3.42	36.62 ± 3.30
May	31.41 ± 2.24	23.69 ± 1.15
June	23.97 ± 2.07	16.75 ± 1.25
July	19.61 ± 1.64	14.66 ± 0.97
August	22.96 ± 2.22	16.95 ± 1.21
September	41.78 ± 3.80	40.49 ± 3.93
October	58.17 ± 3.86	60.59 ± 3.86
November	54.73 ± 4.81	57.16 ± 5.65
December	41.35 ± 4.27	43.94 ± 4.68

Furthermore, such time series of deviation value of MARV are subjected to statistical linear regression analysis to obtain the slope or yearly change and correlation coefficient (R′) etc., of the linearly fitted line. The statistically linearly regression fitted lines are shown by green inclined lines along with their observed trend exhibited by dark black lines in the respective figures. The slope, R′ and probability (P) values are also displayed in each figure, giving the inference about the changing of airglow intensity per year with its statistical significance level, respectively. Figures 1 and 2 show a graphical representation of the long-term change in airglow intensity 589.3 nm in each individual month of years from 1979 to 1994 in the case of Pre-midnight and Midnight hours, separately. The salient features obtained from the above mentioned analysis have given and discussed in the next section.

4. RESULTS

4.1. MID LATITUDE PRE-MIDNIGHT AIRGLOW INTENSITIES

Figure 1 shows the yearly variations in deviation value from MARV of Pre-midnight airglow emission line intensity of the individual particular monthly mean value. It has been observed from the slope and R′ values that the maximum reduction trend in the deviation airglow intensity is found in a range of 11-24R per

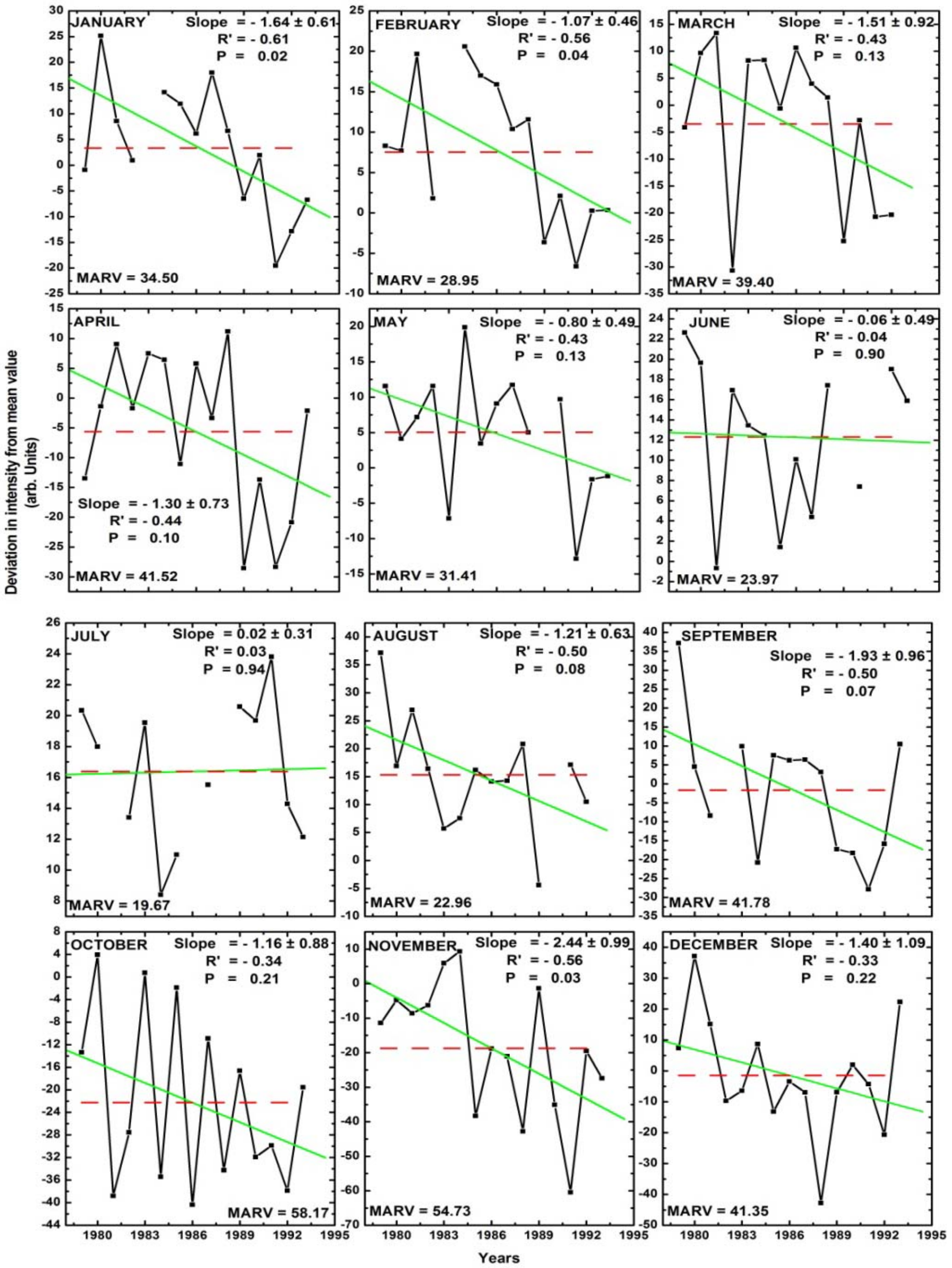

Fig. 1 – Long-term change in Pre-midnight Airglow intensity at 589.3 nm for different months.

decade (Unit of airglow intensity, Rayleigh (R) = 10^6 photons/cm^2/sec) during November, January and February months with the good confidence about the significance level above 95% and the intermediate value of 12 to 19R per decade in April, August and September (the significance level between 90 to 95%). While in rest of the month, there is insignificant statistical variation in their values.

It is also observed from Table 1 that MARV have been observed to the highest of the order of 58 to 55R in October and November, intermediate values in the range of 41 to 31R during December to April and lower values (23 to 19R) in the rest of the month. Thus, it refers to the monthly and seasonal dependence, which are quite similar to earlier reported works by Jana *et al.* [3] and Jana & Nandi [12–15].

On the basis of the average deviation value of a particular month from their MARV, several statistical parameters, it is obvious that there is a significant decreasing decadal change in the Pre-midnight airglow intensity from 11 to 24R, which is of the order of 25–40% of their MARV and showing the statistically significant variation. Furthermore, such year to year fluctuations in the deviation value of the airglow intensity also attributes to the inter-annual monthly nature as well as monthly variation as seen from the linear regressive fitted line, monthly average deviation value line and Table 1.

4.2. MID LATITUDE MIDNIGHT AIRGLOW INTENSITIES

Similarly, year to year variation in the deviation values of the Midnight MLT airglow intensities is illustrated in Figure 2. It is appearing from the figure as well as derived several statistical parameters that the corresponding deviation values also exhibit the declining behaviours with lower magnitude order of 5 to 12R as compared to observed values of 12 to 24R per decade in Pre-midnight case hours. Such change in Midnight airglow intensity per decade is found to be higher in order of 11-12R in January and October with a significance level of above 80% and 5-6R in May and November with good significance level of above 90%. However, in the remaining months, there is insignificant long-term variation in the same period of the Midnight airglow intensity. As far as concerned to its monthly dependence, it is also again observed the similar features as observed in the case of the monthly variation of Pre-midnight airglow *i.e.*, it is observed to highest in October and November, intermediate values in December to April and lower value in the remaining months.

Hence, it is quite clear from the above discussed result that during some of the months, the deviation value of MLT airglow intensity revealed the reducing behaviour 12 to 24R in Pre-midnight hours and 5 to 12R in Midnight hours. However, by computation of night airglow intensities at 589.3 nm from the excitation mechanism and chemical kinetics of Na 589.3 nm, Jana *et al.* [3] and Jana & Nandi [12–15] have also demonstrated the similar fluctuation of 4 to 6R per

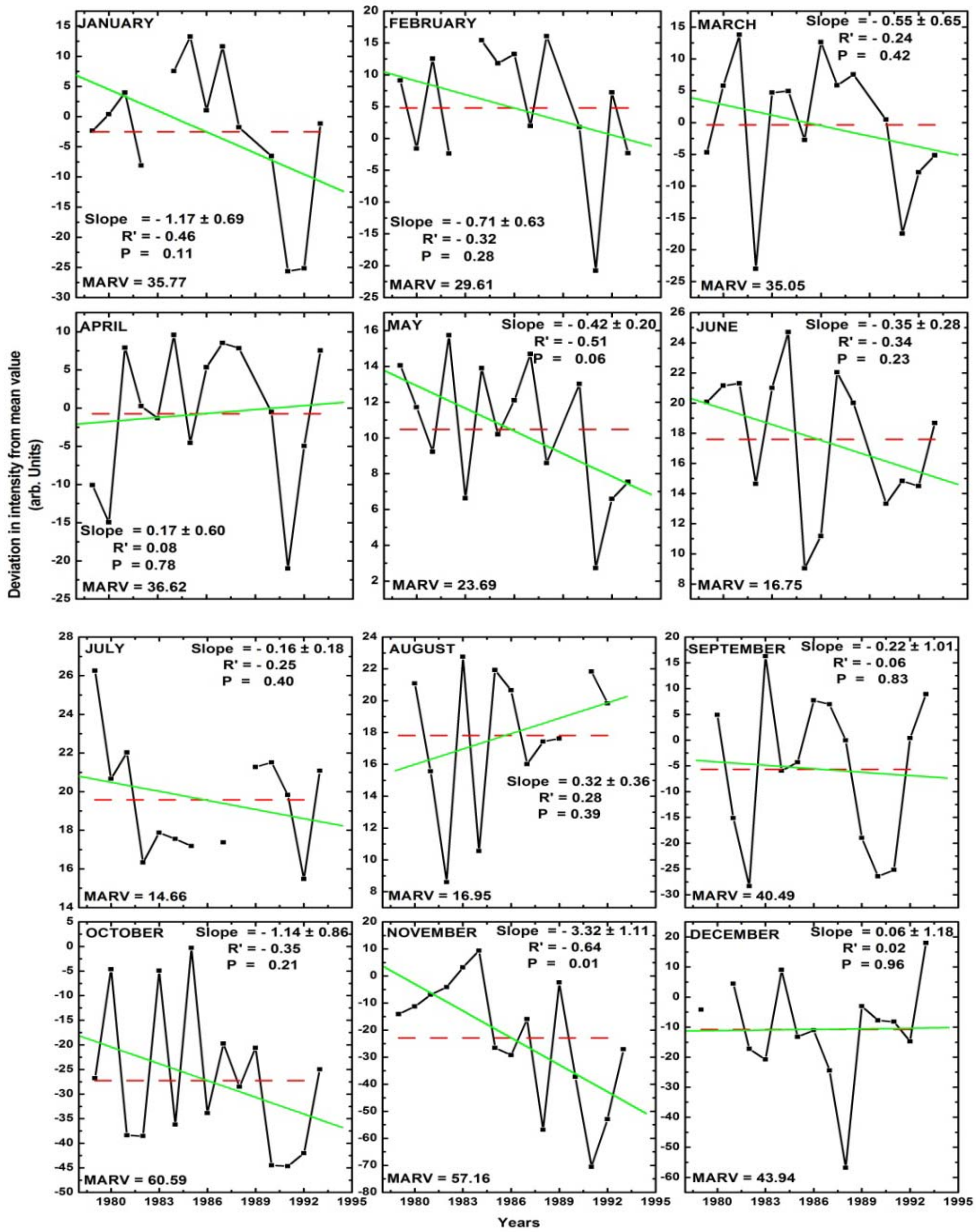

Fig. 2 -–Long-term change in Midnight Airglow intensity at 589.3 nm for different months.

decade in reducing characteristics in night airglow intensity of Na 589.3 nm over Indian Stations like Sri-Nagar, New-Delhi, Trivandrum and Varanasi. However, in this work, the such deviation in intensity from monthly mean value is found to be the highest range *i.e.*, of order of 12 to 24R per decade in Pre-midnight hours and the lowest value of 5R in Midnight hours, which is comparable values and confirm the earlier reported findings to present work. Thus, overall changes in night time MLT airglow intensity is in magnitude of 9% with respect to particular MARV.

Thus, the present findings demonstrate the negative change in deviation values from the mean values of night time MLT airglow intensity between 12 to 24R and 5 to 12R in Pre-midnight and Midnight hours, respectively. Earlier workers have proposed a possible explanation of the long-term change in mesospheric airglow intensity in terms of long-term declining trend in ozone concentration or ozone depletion. Furthermore, long-term data from 1955-2005 about hydroxyl and atomic oxygen emissions, Semenov & Shefov [25] and Bittner *et al.* [26] have also demonstrated the declining trend in night time mesospheric airglow emission and suggested another cause due to decrease in mesospheric temperature computed from the airglow emission. Thus, on above reported results and present observed findings, the most plausible causes of the observed reduction in year to year night time MLT airglow intensity observed in the present investigation might be due to either ozone declining or mesospheric cooling effect phenomenon as suggested by Jana *et al.* [3], Beig *et al.* [22], Semenov & Shefov [25] and Bittner *et al.* [26].

5. SUMMARY AND DISCUSSIONS

The long-term trends in Pre-midnight and Midnight airglow intensities relevant to MLT region are described in the present investigation. The observed results suggest that there is a negative decadal change in Midnight and Pre-midnight MLT airglow intensity of the higher magnitude in the range of 12 to 24R in Pre-midnight and the slightly lower range of 5 to 12R in Midnight hours, which is the order of 10 to 30% of the observed MARV and average night airglow intensity values of Na 589.3 nm. It has been well recognised and well established fact that airglow emission intensity and its width primarily depends 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 [1, 4]. Hence, such observed reducing decadal change in mesospheric height airglow intensity can be interpreted on the of basis of earlier reported findings in terms of linking the reduction in mesospheric temperature or cooling effect on concerned height of the airglow emission.

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