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Effect of Twilight Airglow on The Vertical Profiles of Aerosols

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ABSTRACT

Aerosol measurements have been carried out at Kolhapur (16°42'N, 74°14'E) by using newly designed Semiautomatic Twilight Photometer, which now yields a reasonable qualitative picture of the day-to-day variability of the vertical distribution of the aerosols from about 6 km to a maximum of 350 km. The basic principle of this technique is that, if more number of aerosols exists in the atmosphere then more scattering takes place. The main aim of this study is to demonstrate the measurement capabilities offered by semiautomatic twilight photometer and it is the first attempt in India made by the authors to study the twilight airglow emission lines by twilight sounding method (TSM).

KEYWORDS : airglow, aerosols, twilight photometer, TSM, ionosphere

1. INTRODUCTION

Twilight scattering method (TSM) is extensively used by varies workers in all over the world to study the vertical distribution of aerosol particles which is a strong function of their sources, sinks and their residence times. All this study is reviewed by Jadhav et al. (2000). In the present work aerosol measurements have been carried out at Kolhapur (16°42'N, 74°14'E) by using newly designed Semiautomatic Twilight Photometer during the period 1 January 2009 to 30 December 2011 to study the vertical distribution of the atmospheric aerosols.

Kolhapur city, a location in the south-waste Maharashtra is selected for this study because this station is free from any large scale industrial and urban activities or biomass burning and also surrounded by agricultural land mainly. It has an elevation of 569 meters. Kolhapur's climate is a blend of coastal and inland climate of Maharashtra.

The TSM yields a reasonable qualitative picture of the vertical distribution of aerosols from about 6 km to a maximum of 350 km. This being a passive technique, clear sky conditions are preferable for obtaining the vertical profiles of aerosols. In this study an attempt has made to examine the effect of twilight airglow on the vertical profiles of aerosols. The rate of change of red light due to the twilight airglow would show a large intense peak at this time about 80 km or above altitude. In semiautomatic twilight photometer a red glass filter peaking at 670nm with half bandwidth of about 50 nm is used. Therefore the lines due to twilight airglow having wavelengths in between 620 nm and 720nm were detected by this photometer.

The twilight airglow is the light of electronically and/or vibration-rotationally excited atoms and molecules existing at 80 km or higher altitudes in the earth's atmosphere. Sunlight shining upon the high atmosphere during twilight gives energy to the atoms and molecules of the air, causing them to directly reemit some of this energy in the form of light. The resulting twilight airglow emissions can be quite bright. Twilight glow exists when only the upper atmosphere is illuminated. It is the most voluntarily observable airglow from the ground since the observer is in darkness and Rayleigh scattering of sunlight by the dense lower atmosphere is absent, while the airglow region of upper atmosphere is still illuminated. 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. As high energy particles from the Sun are accelerated by the Earth's magnetic field, they smash into atoms in Earth's atmosphere and cause them to glow.

2. INSTRUMENTATION AND METHODOLOGY

The instrument semiautomatic twilight photometer is simple and inexpensive based on passive remote sensing technique and hence can be operated continuously for monitoring the day-to-day variability of the aerosols. The more details regarding the instrument are given elsewhere, (Mane et al., July-2012).

The twilight sounding method is analogous to the method of rocket sounding. When the sun is within 0-18° below the horizon, the lower part of the atmosphere comes under the Earth's shadow while the upper part is sunlit. The boundary between the illuminated and shadowed parts is monotonously shifting up during the evening twilight and down during the morning twilight. In this method , the solar radiation scans the Earth's atmosphere during the enhancement of the twilight, and the light received from any part of the sky is due primarily to the light scattered by illuminated by molecules and the particles of interest. It is assumed that bulk of the scattered light comes to an observer from the lowest, and therefore densest, layer in the sunlit atmosphere at the time of measurement. The contribution of the rest of the atmosphere above this layer can be neglected due to an exponential decrease of air density with increasing altitude. The height of this lowest layer (twilight layer) increases with increasing earth's shadow height. The lower atmospheric layers now submerged in shadow, no longer contribute to the sky brightness, and the scattered light comes more and more from the higher altitudes, which are still illuminated by direct sunlight.

The method for calculating the earth's geometrical shadow height (h) is given by Shah (1970). Thus the earth's geometrical shadow height (h) is defined as the vertical height from the surface of the earth, of a point where the solar ray grazing the surface of the earth meets the line of slight. Therefore,

$$h = R(\sec[\delta] - 1) \qquad \ldots\ldots (1)$$

Where, R is radius of earth and δ is sun's depression.

In following the method of Shah (1970), it is assumed that the red twilight comes from a distance of 6 Km. The shadow heights were computed for zenith sky observations, and the raw data were utilized for the analysis of '1/I (dI/dh)' curve, where 'I' is the observed intensity, 'dI' and 'dh' are the differences in intensities and shadow heights respectively observed at time't' and't+dt'.

As the sun sinks below the horizon, the effective height of the Earth's shadow rises and scattering takes place to higher levels. Most of the light received at the ground will be the primary scattered light by the particles for the solar depression less than 6-7 deg. Therefore,

$$\frac{1}{I}\frac{dI}{dh} = \frac{d\log I}{dh} \qquad \ldots\ldots (2)$$

The effect of the Rayleigh scattering component on the value of '1/I (dI/dh)' has been studied by Bigg (1956). Variations in the vertical profiles of the molecular density were very small and their effect on the observed intensity was nearly constant, hence the variations in the value of – (1/I) (dI/dh) can be assumed to be mainly due to changes in aerosols density. Thus,

$$\frac{1}{I}\frac{dI}{dh} = \frac{d\log(\text{aerosol number density})}{dh} \qquad \ldots\ldots (3)$$

3. RESULTS AND DISCUSSION

Following emissions of twilight airglow lines were detected by semi-automatic twilight photometer:

I. Oxygen emission:

Figure-1 shows twilight airglow emission due to excited oxygen atoms. When oxygen atoms are excited, they emit light of various colors, but the brightest are the red and green emissions. Oxygen atoms emit 630 nm (peak emission altitude ~ 250 km) "auroral red line" light only at very high altitudes because these atoms are de-excited by collisions with nitrogen molecules below about 150 kilometers. Thus Red oxygen aurorae are 150 km upwards to 250 km and more rarely to 600 km plus.

II. Nitrogen emission:

Figure-2 shows twilight airglow emission of nitrogen. Excited nitrogen molecules and nitrogen molecular ions produce pink and red lines at the altitudes about 100 km.

III. OH emission:

Figure-3 shows OH twilight airglow layer. Vibrationally and rotationally excited OH radicals emit red (image) and infrared in a narrow layer (6-10 km FWHM) centered at ~ 86-87 km. The O_2 and OH emissions are bands of many closely spaced wavelengths because the transitions involve changes in vibrational energy together with smaller changes in rotational energy. The excited OH source is the Bates-Nicolet reaction between ozone and hydrogen atoms. The OH airglow is limited at higher altitudes by the rapid fall off in ozone concentration with height and at lower levels by the onset of rapid quenching of the excited products by collisions more frequent at the higher atmospheric pressures. The balance between the two limiting processes creates the narrow OH twilight airglow layer.

IV. Lithium emission:

Figure-4 shows light emissions in the upper atmosphere from elemental lithium. This alkali metal is present in the upper atmosphere at altitudes from about 80 to 100 km and is very efficient in resonant scattering of sunlight. The lithium emission at 671 nm has been observed at twilight.

V. H-alpha (Hα) emission:

Figure-5 shows twilight airglow emission of H-alpha (Hα). It is a specific red visible spectral line created by hydrogen with a wavelength of 656.28 nm, which occurs when a hydrogen electron falls from its third to second lowest energy level.

VI. Sodium emission:

Figure-6 shows twilight airglow emission of sodium. Sodium layer refers to a layer within the mesosphere (the third layer of the Earth's atmosphere). This layer is made up of unbound, non-ionized atoms of sodium. The altitude of sodium layer is usually located between 80–105 kms and has a depth of about 5 km. Atmospheric sodium below this layer is normally chemically bound in compounds such as sodium oxide, while above the layer the atoms tend to be ionized. There are four red lines between 650 and 670 nm belonging to ionized (missing 1 electron) sodium.

VII. Nitric oxide (NO) formation emission:

Figure-7 shows twilight airglow emission caused by formation of a molecule of nitric oxide (NO). One another twilight airglow mechanism is when an atom of nitrogen combines with an atom of oxygen to form a molecule of nitric oxide (NO). In this process a photon is emitted. This photon may have any of several different wavelengths characteristic of nitric oxide molecules. The free atoms are available for this process because molecules of nitrogen (N_2) and oxygen (O_2) are dissociated by solar energy in the upper part of the atmosphere, and may encounter each other to form NO.

VIII. Sprite emission:

A sprite is a very brief, luminous glow that occurs in the middle atmosphere. Sprites often start around 45 miles (72 km) high (in the mesosphere) and extend upwards to the edge of the ionosphere (88-96 km) and sometimes downwards into the stratosphere below (to as low as 24-32 km). They are primarily red in color, except for some bluish tinge in the downward extending tendrils (Figure-8).

The airglow normally occurs in layers at varying altitudes above the earth's surface. The heights and the thickness of the layers depends on the production mechanism and therefore on such factors as the composition. Twilight offers an opportunity to observe resonant scattering of sunlight on layers. As the Earth's shadow scans through the layers, the changes of intensity allow their heights to be measured. All the above mentioned twilight airglow emission lines were detected by semiautomatic twilight photometer used for this study. However it is not sufficient to study altitudinal separation of these lines only, which are strong functions of their wavelengths. Filters peaking at different wavelengths and having very narrow bandwidths ~2-5 nm required to use for detail study of twilight airglow.

5. SUMMERY AND CONCLUSION

Semiautomatic twilight photometer is capable to study the twilight airglow emission lines. However it is not sufficient to study altitudinal separation of these lines only, which are strong functions of their wavelengths. Filters peaking at different wavelengths and having very narrow bandwidths ~2-5 nm required to use for detail study of twilight airglow. An attempt made to study the twilight airglow emission lines by twilight sounding method (TSM), for the first time in India.

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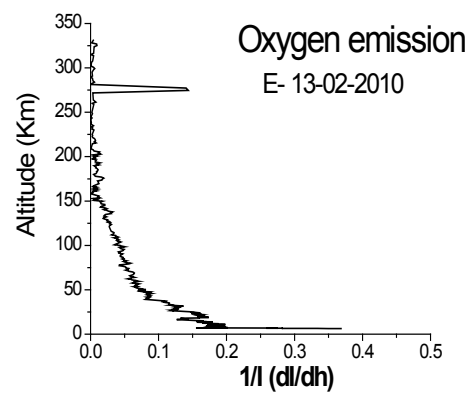


Figure-1

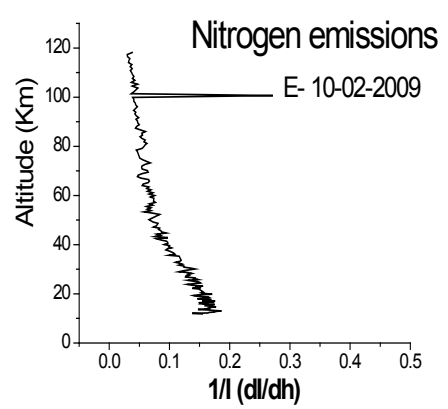


Figure-2

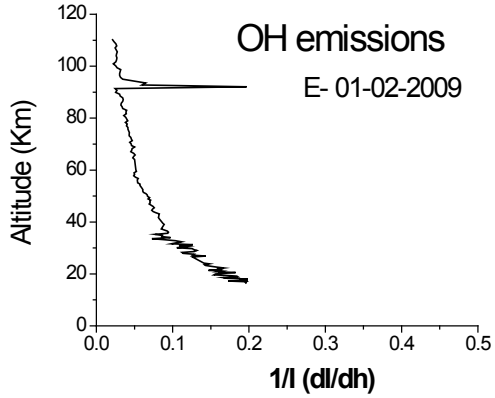


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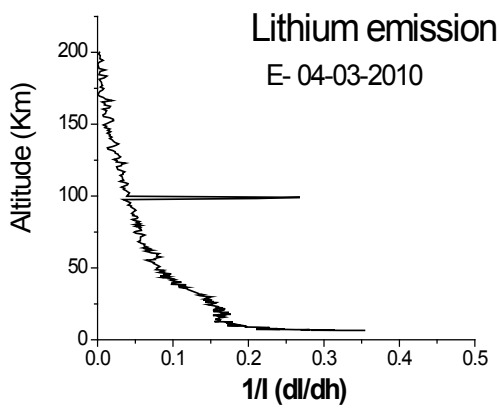


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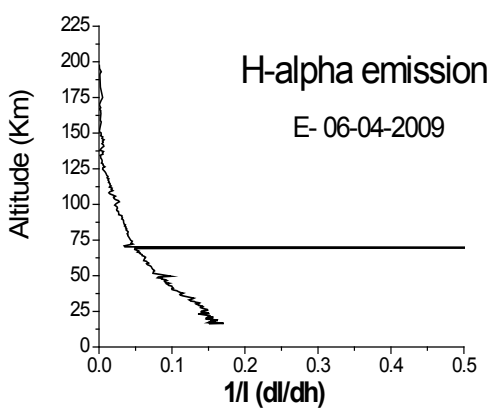


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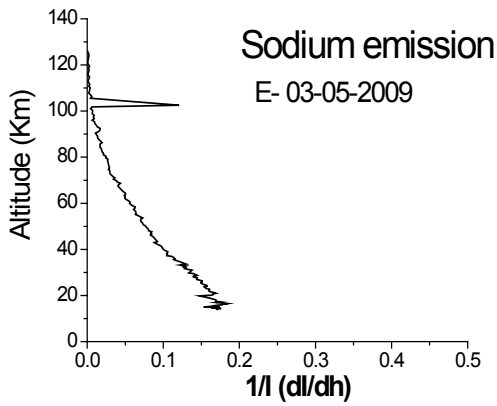


Figure-6

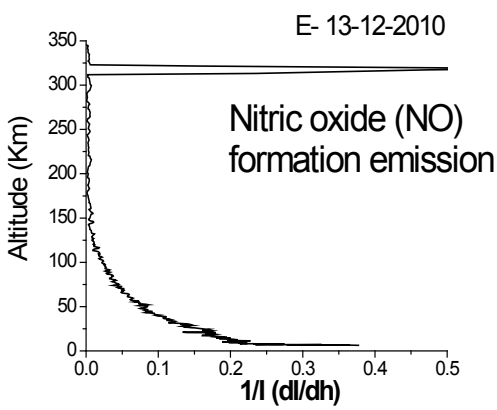


Figure-7

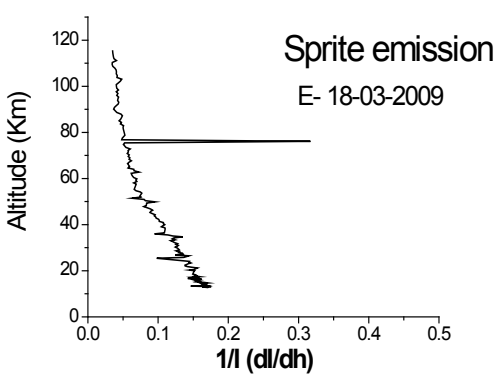


Figure-8

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