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Low latitude airglow*

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Abstract. Tropical airglow work during the last few years is reviewed. Airglow instrumentation is becoming more complex. Some of these sophisticated airglow experiments giving important information about the upper atmosphere such as ionospheric F region electron density, height of maximum electron density, dynamics of and irregularities in the F region, mesospheric neutral temperature and its variation, dynamics of mesospheric, etc. are mentioned. At the end some problems which could be tackled in near future with airglow techniques have been suggested.

Keywords. Airglow; earth's atmosphere; F region; irregularities and dynamics; mesospheric temperatures.

1. Introduction

We shall review only a few areas of interest in the studies of the upper atmosphere where airglow techniques are used. The tropical region and the magnetic equator are of particular interest for some special phenomena occurring exclusively in these latitudes and we shall, by and large, confine our attention to this region. An earlier review (Kulkarni 1974) on tropical airglow may be noted. We shall examine the use of airglow emission to study the F region of the ionosphere and the mesosphere.

2. Night time F region of the ionosphere and the airglow

During the last 10 years or so equatorial ionosphere has been extensively studied and the use of airglow techniques for such studies is showing great promise. While the importance of forbidden 6300 A OI emission and its association with the F region of the ionosphere was recognised in early sixties or even before, the association of the F_2 ionosphere with the airglow due to forbidden 1356 A line and permitted lines such as 1304 A, 4368 A and 7774 A all due to atomic oxygen is only during the last decade.

Around 1960s it was Daniel Barbier who observed the enhancement of 6300 A airglow emissions on the equator in the tropical latitudes on the African continent and called these enhancements as the "intertropical arc" and the "western sheet". This was quite different from the Stable Auroral Arcs (SAR) discovered by Barbier (1957) in the mid-latitudes. While the equatorial/tropical enhancements are related to the local ionosphere the SARs are due to the different mechanism. SARs last for several hours and are rather infrequent. Their morphology is described by Roach and Roach (1963). The equatorial enhancements of 6300 A, however, are quite dynamic.

A semi-empirical relation given by Barbier (1959) to estimate the 6300 A emission from ionospheric parameters was extensively used for many years and was a good approximation for the physical mechanism emitting 6300 A radiation in the F region of the ionosphere. The expression for emission was later derived by Peterson *et al*

* Invited Review paper, Commission 21, IAU, Patras, Greece, August, 1982.

(1966). It is very interesting to note that results calculated with the above formulae and compared with the 6300 A observation on a typical night at a tropical station show that the observations are in better agreement with Barbier's formula than that with Peterson's.

From Barbier's observations, King (1968) pointed out the similarity in the night time movement of the *F* layer anomaly crests and the 6300 A airglow emission in the low latitudes. With certain exceptions normally the 6300 A in the mid-latitudes is quiet, showing a fast decay after the evening twilight, remaining steady during the night for several hours and showing enhancement before the morning twilight. On the other hand, the 6300 A emission in the tropics is quite lively and its manifestation has been reported in the forms of (i) intertropical arcs (Barbier 1961); (ii) gradients (Steiger *et al* 1966; (iii) fingers (Steiger 1967); (iv) pair of humps (Kulkarni and Rao 1972) showing the above mentioned features in the geomagnetic latitudes $\pm$ 15° and in some cases tracing the movement of such features towards the equator in the early hours of the night.

2.1 *Satellite studies*

With satellite observations it was possible to monitor the 1304 A and 1356 A ultraviolet oxygen airglow lines and enhanced emissions were reported around $\pm$ 15° geomagnetic latitude (Hicks and Chubb 1970; Barth and Schaffner 1970). They further predicted that the 7774 A and 4368 A oxygen permitted lines also should accompany the above emission. Weill and Joseph (1970) reported preliminary ground-based observations of 7774 A. Under the Appleton anomaly, in Brazil, Tinsley (1972) observed 7774 A emission and found that its intensity decreases from end of twilight to well after mid-night (from ~ 100 R to a few R). Later Tinsley *et al* (1973) reported variation of intensity of 7774 A from 10 to 30 R at Agulhas Negras.

Generally accepting that the 7774 A emission is due to the radiative recombination reaction

$$O^+ + e = O^* + h\nu,$$

to which ion–ion recombination could be added but shown to be not very significant and the 6300 A emission due to the dissociative recombination

$$O^+ + O_2 = O_2^+ + O$$

and $$O_2^+ + e = O + O^*\,(^1D) \quad \text{(and other branchings)}$$

it has been shown by Chandra *et al* (1975) that monitoring of these two radiations could be used to understand the tropical *F* region of the ionosphere. Tropical *F* region shows spread *F* activity usually during early evening hours and from the Jicamarca radar extensive *F* region work has been reported. *F* region irregularities have been named as holes, bubbles, bite-outs, plumes to describe various shapes and sizes which are basically due to the depletions in the electron density in the night-time ionosphere mainly at the *F* layer heights. It has been observed that monitoring of airglow radiations even from ground-based station provides a lot of high resolution information for better understanding of the phenomenon.

2.2 *Ground-based studies*

It was shown by Tinsley and Bittencourt (1975) that height and peak electron density of F region of the ionosphere could be determined by calculating column rate emission, J of 1356 A and 6300 A from the intensity measurements I_{1356} and I_{6300}.

J_{1356} and J_{6300} being proportional to the square root of the electron density and the electron density respectively, Tinsley *et al* (1975) showed that peak electron density $n_m(e)$ is proportional to $(J_{1356})^{1/2}$ and to a good approximation the ratio $(J_{1356})^{1/2}/J_{6300}$ is a single-valued function of the layer height h_mF_2. While the value of $n_m(e)$ thus derived is little affected by the assumed exospheric temperature, h_mF is strongly affected. However, it must be remembered that 1356 A observation must be taken from a space-borne vehicle due to its strong absorption by the atmospheric ozone. It was further shown (Tinsley and Bittencourt 1975) that 7774 A is also mainly emitted due to radiative dissociation thus making $(J_{7774})^{1/2}$ proportional to the electron density and $(J_{7774})^{1/2}/J_{6300}$ can be used to estimate h_mF. It should be remembered that 7774 A emission can be monitored by a ground-based instrument. The intensity I_{7774} and I_{6300} has been actually measured and used for the above purpose.

Recently, Sahai *et al* (1981) have reported from a ground-based station airglow observations of 6300 A and 7774 A under the southern F region anomaly (22.7° S) in Brazil. They find good correlation between the column density $(J_{7774})^{1/2}$ and the F layer peak electron density $n_m(e)$. They also find good correlation between $(J_{7774})^{1/2}/J_{6300}$ and the maximum height h_mF_2 of the F layer. They have concluded that simultaneous measurements of these two emissions would be a very useful technique for remote sensing the ionospheric F layer dynamics.

2.3 *Spread F and neutral temperature*

From Doppler width temperatures observed with FP interferometer Rajaraman *et al* (1979) found interesting correlation at Mt Abu (Geographic Latitude 24.6° N, Geomag. Lat. 15°, Long. 72.7° E) between the emission layer temperature of the 6300 A night airglow emission and the spread F phenomenon. It was observed that the F region temperature increased by as much as 200° K over its usual night-time value, when spread F is present on the magnetic equator and without spread F occurring on the magnetic equator there was no increase in the temperature at Mt Abu. F layer temperature at Mt Abu increases after 15–30 min following the occurrence of spread F at the magnetic equator. The basic heating mechanism is suggested to be the Joule dissipation of the electric currents associated with turbulent electric fields during the equatorial spread F.

2.4 *Aircraft studies*

In 1972 from a jet aircraft simultaneous observations of 6300 A airglow and F region plasma structures with an ionosonde were made by Markham *et al* (1975). The conclusion was that no anomalies in either atmospheric composition or reaction rates are associated with the regions of unusually strong emission (400 R), the entire complicated structure of 6300 A emission over an extended range of latitude seems entirely to reflect corresponding changes in F region plasma structure.

To investigate the *F* region irregularities experiments on board an aircraft were conducted in 1977 and 1978 (Weber *et al* 1980). The 6300 A imaging photometer, ionosonde and receiver for satellite amplitude scintillation measurements were used. They measured 6300 A depletions, spread *F*, and scintillation producing irregularities all associated with low density plasma features in early night equatorial ionosphere. With the above instruments they have estimated the electron densities inside and outside the depletion and find that on a typical night during early hours electron density inside a typical depletion is 66% near the magnetic equator as well as near the southern Appleton anomaly. These results agree very well with those obtained from the ionosonde and satellite data.

Continuing their air-borne experiments in 1979 Moore and Weber (1981) found that within 15° magnetic latitude between Africa and South America plasma depletions existed and on 14–15 December 1979 peak electron density varied from $3.3 \times 10^6\ cm^{-3}$ outside the depletion to $1.1 \times 10^6\ cm^{-3}$ inside the depletion. The depletion on another night produced even larger variations. These inferences are drawn from airglow observations of 6300 A and 7774 A. They conclude that 6300 A depletions, spread *F*, and scintillations are associated with low density bubbles in the post-sunset equatorial ionosphere. 6300 A airglow depletions are bottom-side signatures of *F* layer plumes of very small size (metre size) irregularities as measured by 50 MHz back scatter radar.

3. Suggested studies

Tinsley and Bittencourt (1982) have pointed out the possibility of "imaging" *F* region bubbles, plumes and depletions at night-time through airglow measurements from ground by taking advantage of the plasma flow from over the equator towards the tropical latitudes. Again 7774 A and 6300 A airglow emissions arising at the peak of the F_2 and at the bottom-side of F_2 layer respectively are proposed to be used to advantage. On the magnetic equator the plasma is lifted to various heights (upto or more than 1000 km altitude) depending on the magnitude and direction of the electric field. This plasma rolls down along the earth's magnetic lines of force and at appropriate height and density manifests itself as airglow emission at various latitudes depending on at what altitude on the equator it starts flowing along the magnetic lines of force. Tinsley and Bittencourt (1982) have shown that from a chosen station say at about 18° dip latitude if airglow observations are taken at zenith angles 60, 70, 80, 85°, etc. towards the magnetic equator, they intercept the airglow emissions layer at various latitudes thus allowing the study of bubbles at various stages of developments. The emission layer being relatively narrow, the scanning or imaging of airglow structures will be without much blurring and a sort of cross-section at that height.

The observations will have maximum accuracy when the line of sight having airglow emission layer intercepts tangentially to the magnetic lines of force. They have also estimated the blurring due to misalignment with respect to the magnetic lines of force. The technique can also be used for studying the morphology of the artificial bubbles or ionospheric holes produced by chemical releases. Problem of background due to OH (9–4) band which must be properly eliminated to get the correct 7774 A intensities must be seriously considered.

High resolution Fabry-Perot spectrometer can be conveniently used in pressure scanning mode (or any other technique) to determine the Doppler broadening and the Doppler shift of the airglow lines convenient for such purpose. The temperature and the neutral wind velocity at the emission altitude can be estimated from such measurements. Emissions such as 6300 A from the *F* region of the ionosphere and 5577 A from about 100 km altitude are quite useful for such purposes. Such measurements on the magnetic equator and at low latitudes will be quite useful.

3.1 *OH studies*

Two ground-based techniques recently used for studying (i) temperature and (ii) dynamics of the mesosphere will be discussed.

3.2 *Mesospheric temperatures*

It is generally accepted that OH emission in the mesosphere is due to hydrogen-ozone reaction. In the 85–90 km region of the upper atmosphere, before radiative de-excitation, OH radical undergoes about 250 collisions and attains the ambient neutral temperature. The OH radical emits the rotational vibrational band system and the intensity of a rotational line is linked to the temperature by the following relation.

$$I_J = C\nu^4 S_J \exp(-F(J)hc/kT),$$

where I_J is the intensity of a rotational line and T the neutral ambient temperature. Spectroscopically it is possible to determine the temperature from the relative intensities of the rotational lines in a given OH band by photographing or by photoelectrically scanning the OH bands. However, by selecting a proper band, say OH (7–2) where rotational lines are well separated and no other emissions overlap it is possible to isolate a single rotational line with a moderately broad filter ($\sim$ 10 A) and monitor its intensity. Majmudar and Kulkarni (1975) used photoelectric photometer and measured intensities of $P_1(3)$ line and ΣR branch of the OH (7–2) band. From the above relation it is possible to associate a unique temperature for one value of ratio of intensities of $P_1(3)$ and ΣR. With usual background elimination when the ratio is taken it eliminates problems of absolute calibration to some extent.

Mesospheric temperatures by the above method have been measured at Mt Abu for a few years. The nocturnal pattern of temperature shows that the mesosphere has variations in temperatures even during night. Atmospheric models show a minimum between 84 and 94 km. Any variation in temperature in this part of the atmosphere is quite important for *D* region chemistry. Its coupling with higher altitude, if any, could be very important.

The study over a number of nights reveals that about a fifth of nights show that the temperature is steady during these nights, while a third of the nights individually show temperature fluctuations during those nights. There are some nights on which the temperature increases by as much as 40° K within a few hours in the night. A few nights also show decrease in temperature. While the constant temperature conditions can be attributed to the static conditions in the mesosphere, fluctuations or changes are difficult to interpret. In his work on internal gravity waves Hines (1960, 1965) has shown that in the 90 km region of the earth's atmosphere reversible adiabatic heating is produced due to the gravity waves and the heating could manifest itself as fluctuations in the temperature and the periods of such fluctuations could be between 10 and 200 min. On many nights fluctuation in temperature was observed by Majmudar and Kulkarni (1980) at Mt Abu showing some order of periodicity as predicted. Very likely these fluctuations in temperature could be attributed to the internal gravity waves.

With other techniques temperatures in this region have been measured (Rai and Fejer 1971; Krassovsky 1972; Shagev 1974; Meriwether 1975; Armstrong 1975). Some of these authors have detected fluctuations. Manson and Meek (1976) from radiometer data have reported the periodicity of IG waves greater than 2 hr in this region.

It is also possible to estimate wave-induced horizontal component, U_x, of the neutral wind from the temperature fluctuations $\Delta T/T$ from the following relation given by Hines (1965);

$$\Delta T/T = \pm i(\gamma - 1)^{1/2} C^{-1} U_x,$$

where i indicates the phase quadrature between the time and place of maximum in T and U_x. Unless additional information on phase is available it is not possible to decide the direction, that is + or − sign in the above equation. In its absence only the dominant periodic component would give the magnitude of U_x. The magnitude of neutral winds from the above relation was estimated at 10 to 25 $\mathrm{m\,sec^{-1}}$ from Mt Abu data.

3.3 *Mesospheric wavy structures*

Moreels and Herse (1977) in the past few years have used the technique of photographing airglow emission in the very near infrared (7580 to 9850 A) which is dominated by strong OH emissions. In about 10 to 15 min exposure they take a picture. On a number of photographs they have seen wave-like patterns. By triangulation they could determine the height of the emission layer at 85 km with an accuracy of ± 2 km. The wavelength of such waves is not very constant but varies. The approximate value is estimated at a few tens of kilometers. The wave velocity is of the order of 15 $\mathrm{ms^{-1}}$ and a period of 50 min is estimated from such photographs. This period fits into that derived theoretically for the gravity waves.

The structure shown in the near infrared photographs due to OH emission supports independently the possible presence of gravity waves in the atmosphere in the 80 to 90 km region. These observations are taken at mid-latitudes. A sophisticated experiment proposed by Service d'Aeronomy, CNRS, France and Physical Research Laboratory, Ahmedabad, India, for photographing these structures from Sky-Lab has been accepted by NASA. This would reveal the global structure of OH waves.

It might be very interesting to measure simultaneously temperatures in the F region and the D region of the atmosphere to investigate if there is any coupling between the two.

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