Low Latitude Observations of Airglow

Walter R. Steiger

I Introduction

The low latitude observations of airglow to be discussed in this paper have been made at the Haleakala Observatory of the Hawaii Institute of Geophysics, University of Hawaii, during the period from June 1961 to December 1965. Although this is not a survey of low latitude observations in general, we believe that what we have observed is probably fairly representative of the phenomena found at this latitude.

The Haleakala Observatory is exceedingly well situated for airglow studies because at an elevation of 3080 meters above sea level it is generally above the cumulus clouds suppressed by the trade wind inversion and enjoys an exceptionally transparent atmosphere [see Steiger and Little, 1958], well away from artificial lights. The zenith observations at 300 km correspond to a dip latitude of 19°N and at 80° from the zenith in the South the photometer reaches about 1000 km towards the equator, or about 10° in latitude.

The photometric equipment includes (a) a scanning, birefringent filter photometer for the emissions of [OI] 5577A, [OI] 6300A, and Na I 5890A-5896A doublet [Roach, Megill, Rees, and Marovich, 1958] and (b) a fixed, zenith photometer employing interference filters for the same three emissions as well as a fourth centered near 5300A to record the background continuum [Purdy, Megill, and Roach, 1961].

The scanning photometer covers the sky in a series of almucantar sweeps at zenith angles 80°, 75°, 70°, 60°, 40°, and zenith. Five minutes are required for a complete survey in each of the three colors so that the time interval between successive surveys for a given color is 15 minutes.

The zenith photometer makes a complete series of observations every 5 minutes. The sky observation through each filter is followed by an observation of a carbon 14 - phosphor standard light source. Reduction of the observations by the two-color method [Roach and Meinel, 1955] then leads to absolute integrated emission rates in rayleighs. The birefringent photometer observations at the zenith are calibrated by comparison with the zenith photometer. The carbon 14 light source is periodically calibrated against a secondary standard carbon filament lamp. We estimate an absolute error of ±20 rayleighs at most in our results.

II The Nature of the Phenomena

In this section we shall discuss the temporal and spatial variations of the emissions studied.

A. Diurnal variations. In figure 1 is shown an example of the variation of the three emissions during a particular night. This is not necessarily a "typical" night but it is a classic example of the completely independent variations among the three lines. The average diurnal variations, shown in figures 2, 3, and 4 for the years 1962 to 1965, show that, in general terms, the 5577A emission reaches a maximum during the night, the 6300A emission is a maximum at the begining of the night but decreases rapidly and levels off at a fairly low level for the remainder of the night, and the 5893A emission (as we shall refer to the Na doublet) has no significant diurnal variation. We also note that the 5577A and 6300A emissions seem to show a decline towards the minimum of the solar cycle, 1963, and a rise thereafter. The 5893A emission shows no significant variations from year to year.

Figure 5 illustrates that the diurnal variation can differ dramatically from the "typical" or average behavior. This is a classic example of 6300A tropieal enhancements with covariant 5577A enhancements. Note that again the 5893A emission behaves quite independently of the other two. The temporal and spacial variations of these enhancements and their physical interpretation constitute some of the most fascinating and perplexing problems of the tropical airglow. These shall be discussed at greater length later on.

In figures 12, 13, and 14 are presented the monthly-diurnal variations of the south-to-north ratios of the emissions of the three wavelengths. In the case of the 5577A and 5893A emissions there seems to be a weak summer maximum in the north, but aside from this effect it is difficult to describe any systematic pattern to these variations. For this reason only one or two of these plots have been shown. The 6300A emission, however, shows quite a clear-cut pattern and variation from year to year. A consistent feature is the summertime maximum in the north in the evening hours before midnight. Spring and autumn maxima in the south are features that appear to alter during the solar cycle, diminishing from 1961 to 1964 and apparently beginning to rise again in 1965. The autumn of 1963 is a notable departure from this pattern. The large ratios observed here may be related to the high level of solar activity and magnetic disturbance that occurred during September and October.

From the observation of the scanning photometer it is possible to obtain a rather detailed map of the entire sky down to a zenith angle of 80°. For any one of the three wavelengths such a map is available every 15 minutes, as explained earlier. These are normally obtained by reading the records every $22^{1}/_{2}°$ in azimuth at each zenith angle and from the local zenith intensities deduced for each one of these 81 points, an isosphote map is produced. The maps are plotted so as to have a uniform scale of distance along any radius, assuming a height of 300 km for 6300A, 100 km for 5577A, and 85 km for 5893A. These maps are useful for studying the detailed spacial variation of the airglow. In figure 15(a) is a single map for the same night, September 11/12, 1961, as used earlier in figure 5. A series of such maps for the night of September 11/12 give a detailed picture of the morphology of the three enhancements which occurred on this night. We find that these enhancements do not extend over the entire sky but in fact are rather limited in area, having a diameter of roughly 500 km or so. Also, they do not necessarily occur at the zenith but generally, though not always, to the south of Haleakala. This accounts for the peaks in the south-north ratio seen in figure 13. A careful analysis [Peterson et al., 1966] of two such nights has shown a gradual motion of the enhancement pattern in a south-easterly direction at a speed of about 200 km/hr.

It was mentioned earlier that the 6300A tropical enhancements are frequently accompanied by similar variations in the 5577A emission. This has also been seen in the maps of enhancements where the 6300A structure has been quite closely duplicated in the 5577A structure. An example of such a situation is shown in figure 15(b) which is a map of the 5577A observed emission reduced and plotted as though it were entirely at a height of 300 km. Perhaps 100 rayleighs or so actually originates from a height of 100 km with the remainder originating at the same height as the 6300A emission and hence showing a similar pattern.

There have been a number of occasions when the structure in the 6300A airglow has been so precipitous that much of its detail is lost when reading the records only every $22\frac{1}{2}°$ in azimuth, as is customary. On a few of these we have re-read the records at smaller intervals so as to show the photometric peaks and valleys as observed. An example of such structure is shown in figure 16. Such structure is always associated with a much enhanced emission and is generally in the form of narrow, parallel ridges or fingers running approximately north-south.

The tendency of the fingers to converge towards the meridian, as noted in the figure, is no doubt an observational distortion caused by the fact that the bright regions are at a significantly lower altitude than the fainter regions, as we shall discuss a little later. Hence, they will tend to appear further away than they actually are when they are plotted as though they were at 300 km. Since the south ends of the fingers are brighter and hence lower than the north ends, their locations will be more distorted than the north ends, resulting in the converging appearance.

Actually, the majority of isophote maps do not show any significant structure and, in fact, a great many show a rather uniform emission over the sky with often a gradual gradient towards the south. These maps have the appearance of more-or-less straight and parallel isophotes. It has been found [Steiger et at., 1966] that during the hours from 22 hrs to 03 hrs, during which we are free from twilight effects, a large majority of those 6300A maps on which the isophotes are aligned show a preferred direction of alignment such that the gradient of the radiance is anti-parallel to the horizontal component of the earth's magnetic field. This again suggests some sort of magnetic control in the formation of the 6300A emission.

III Relationships with the Ionosphere

The relationship of the 6300A emission to the F-region ionosphere was proposed by Barbier in terms of a semi-empirical formula now known to all in the field simply as "Barbier's Equation", which is

$$Q = A + B(f_oF2)^2 \, e^{-\frac{h'F - 200}{H}} \quad .$$

Here Q is the 6300A integrated emission rate, f_oF2 is the F-region critical frequency in M hertz (the square of this quantity is proportional to the electron number density at the F2 peak), h'F is the virtual height in km of the base of the F region, and H is the molecular scale height at 200 km and is about 40 km. The constants A and B are determined empirically from comparison with observed 6300A emissions. The significance of B has been interpreted theoretically by Peterson, Van Zandt, and Norton [1966] in terms of ion exchange-dissociative recombination reactions. But the constant A does not come out of the theory and is not yet fully understood. It has been suggested by Peterson and Steiger [1966] that it may be due to contamination of OH emissions entering the optical system. It is also possible that some other mechanism, as yet undiscovered, may be producing a 6300A emission. For any given night, constants A and B can be found such that this formula gives a surprisingly good fit to the observations, as seen in figure 17.

The basis of the earlier statement that the brighter regions are generated at lower altitudes than fainter regions can now be understood in terms of the Barbier equation. Q is related to h'F exponentially but to f_oF2 quadratically. It turns out that f_oF2 usually varies by a factor of less than 2 during an enhancement, but the height may change by 100 km or more, resulting in a factor of 10 or more change in Q. Thus, Q is more sensitive to h'F than f_oF2 and, as a first approximation, large changes in observed Q can be associated with large changes in the height of the emission. It follows then that, at times when the 6300A emission is enhanced and highly structured, the F-region ionosphere will present a "corrugated" bottom side. This is borne out in the ionogram for the night of September 11/12, 1961, shown in figure 18. The oblique and spread reflections from these corrugations makes the ionogram extremely difficult to interpret. Indeed, before the establishment of this airglow-ionosphere relationship, the interpretation was impossible in any detailed way.

Earlier we suggested the possibility of a solar-cycle variation in the behaviour of the 6300A emission. Unfortunately our observations started in 1961 when solar activity was rapidly declining towards the minimum, and it will be several years yet until the next maximum. However, with the aid of Barbier's equation and a catalogue of ionospheric data, it is possible to go back in time and estimate what the 6300A emission might have been. This has been done by Walter Brown of this observatory and the results are shown in figure 19. According to these calculations the general level of 6300A emission should reach a very large peak at solar maximum.

Acknowledgements. The author wishes to acknowledge the assistance of Dr. V. L. Peterson, W. E. Brown, and L. L. Smith in the preparation of certain parts of the data presented here. This work was supported in part by NASA Grant NsG-135-61 and NASA contract R-18.

Bibliography

Barbier, D., F.E. Roach, and W.R. Steiger, The summer intensity variations of [OI] 6300A in the tropics, J. Res. NBS, 66D, 145-152, 1962.

Peterson, V.L., T.E. VanZandt, and R.B. Norton, F-region nightglow emissions of atomic oxygen, 1. Theory, J. Geophys. Res., 71, 2255-2265 (1966).

Peterson, V.L., and W.R. Steiger, F-region nightglow emissions of atomic oxygen 2. Analysis of 6300A and electron density data, J. Geophys. Res. 71, 2267-2277, 1966.

Peterson, V.L., T.E. VanZandt, F.E. Roach, and W.R. Steiger, Detailed maps of the tropical F-region atomic oxygen nightglow enhancements, to be submitted to Annales de Geophysique.

Purdy, C.M., L.R. Megill, and F.E. Roach, A new airglow photometer, J. Res. NBS, 65C, 213-216, 1961.

Roach, F.E., and A.B. Meinel, The height of the nightglow by the VanRhijn method, Astrophys. J. 122, 530-553, 1955.

Roach, F.E., L.R. Megill, M.H. Rees, and E. Marovich, The height of the nightglow 5577. J. Atm. and Terr. Phys. 12, 171-186, 1958.

Smith, L.L., and R.W. Owen, The seasonal variation of nightglow NaI 5890-96A, [OI] 5577A, and [OI] 6300A in the tropics, NBS Technical Note 329, January 10, 1966.

Steiger, W.R., and J.W. Little, On the feasibility of a solar observatory in the Hawaiian Islands, Publ. of the Astronomical Soc. of the Pacific, 70, 556-560, 1958.

Steiger, W.R., W.E. Brown, and F.E. Roach, The alignment of 6300A airglow isophotes in the tropics, J. Geophys. Res. 71, 2846-2849, 1966.

List of Figures

Figure 18. Maui ionogram for September 11, 1961, corresponding closely in time to figure 15.

Figure 19. Monthly-diurnal variations of 6300A emission as calculated by the Barbier equation from Maui ionospheric data.

Paper presented at NATO Advanced Study Institute on Aurora and Airglow, University of Keele, Keele, England. August 15-26, 1966.