Tropical He I 10830-A Observations

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In a recent publication, Christensen *et al.* [1971, here called CPT] discussed ground-based twilight observations of the resonance-scattered He I 10830-A radiation in connection with model calculations. During the past year, the grille spectrometer used for that study was moved to Agulhas Negras, a mountain peak in the state of Rio de Janeiro, Brazil (altitude, 2.4 km; latitude, 22.38°; longitude, 44.68°). Observations of several atmospheric emissions have been carried out. In this paper, we report the results of twilight He I 10830 A for the period December 1970 to May 1971. The data indicate a seasonal variation of the upper-atmospheric helium density at tropical latitudes, in agreement with a winter-helium-bulge model determined by geomagnetic rather than geographic latitude. The increased photoelectron loss rates of Schunk and Hays [1971] should improve the agreement with model calculations. The description of the grille spectrometer and the data reduction techniques, given by CPT, and the references cited therein will not be repeated here.

Table 1 is a summary of the observations. The intensities were measured at a solar zenith angle of 105° ($\chi_z = 105^\circ$) looking east (90°) in the morning and west (270°) in the evening (exceptions are indicated) at a zenith angle of 60°. The errors listed are random errors and do not include an estimate of systematic error. Figure 1A shows more clearly the seasonal variation of the data given in Table 1. The morning intensities for the vernal equinox and

early winter (day 75–150) average about 1400 rayleighs. In December, the only complete morning twilight observation gave a 600-rayleigh intensity. Thus a ratio of 2:1 is a rather rough estimate of the morning seasonal variation.

The greater emission in local winter is related to the helium distribution, which tends to maximize near 50–60° latitude in the winter hemisphere [Reber, 1971; Keating and Prior, 1968]. However, the measured seasonal variation cannot be attributed entirely to motion of the helium bulge, since other factors, such as conjugate photoelectrons, changes in *F*-region electron density, and solar activity, can affect the emission rate.

Conjugate photoelectrons are capable of exciting the helium atoms, as well as other atmospheric species [Meier, 1970], but generally the effects are only observed when the solar zenith angle at the conjugate point (χ_c) is less than 105°. Using this criterion, it is expected that conjugate excitation would not occur until after day 120 in the morning in Brazil. Therefore, the morning observations near equinox were not significantly influenced by conjugate photoelectron excitation. This cannot be said for the evening, however, since $\chi_c < 105^\circ$ is true for all evening observations at $\chi_z = 105^\circ$ obtained after day 50.

A second factor that determines to some extent the emission intensity is the ambient *F*-region electron density. An increase in the ambient density enhances the deactivation of the metastable helium atoms and, more important, increases the photoelectron energy loss to electrons, decreasing the number of photoelectrons of energy sufficient to produce excitation. For the present observations, measurements of the relevant ionospheric parameters

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TABLE 1. Observed 10830-Angstrom Intensities,* December 1970 to June 1971

Date	Day	Morning Intensity, Rayleigh	Evening Intensity, Rayleigh	A_p	$S_{10.7}$	T_{ex}
Dec. 7, 1970	341	600 $\pm$ 100†	200 $\pm$ 200‡	8	171.7	1012
Dec. 8	342		600 $\pm$ 200‡	19	172.5	1142
March 15, 1971	74	1350 $\pm$ 100	850 $\pm$ 150	22	111.5	1002
March 16	75	1400 $\pm$ 200		14	115.7	988
March 17	76	1050 $\pm$ 150	700 $\pm$ 200	9	117.3	969
March 18	77	1300 $\pm$ 200		6	115.2	948
March 19	78	1400 $\pm$ 150		16	110.0	981
April 4	94	1500 $\pm$ 100		27	107.6	1017
April 6	96	1400 $\pm$ 100		14	107.1	980
April 15	105		760 $\pm$ 100	36	138.2	1090
April 28	118	1350 $\pm$ 200		21	96.2	972
April 30	120		750 $\pm$ 200	8	93.4	918
May 1	121		620 $\pm$ 150	7	93.8	911
May 19	139		650 $\pm$ 150	10	107.2	934
May 21	141	950 $\pm$ 300		5	99.5	883
May 22	142	1300 $\pm$ 100		5	91.1	861
May 24	144		400 $\pm$ 150	7	86.6	857
June 1	152	1450 $\pm$ 100	440 $\pm$ 100	22	110.	981
June 2	153	1750 $\pm$ 150	640 $\pm$ 150	31	108.	993
June 4	155	1700 $\pm$ 100	660 $\pm$ 200	9	100.	925

* Intensities observed at 15° solar depression looking east at dawn and west at dusk at zenith distance 60°, except as noted.

† Azimuth 120°.

‡ Azimuth 240°.

are not yet available. In lieu of more direct data, we have listed in Table 2 average $(f_oF_2)^2$ values for months of similar sunspot number for the magnetic latitude and season of the site using the data of Sanatani [1966]. For the morning observations, we note a significant decline in the electron density from December to June, which is related to the decline in solar activity during this period (see Figures 1B, 1C).

The intensity of the solar XUV flux tends to follow solar activity [Timothy and Timothy, 1970; Hall et al., 1969]. The 10.7-cm flux ($S_{10.7}$) was 170 for the December measurements and 110 for the equinox. Judging from the data of Hall et al. [1969], the XUV flux is expected to have decreased only by about 15% during this time.

The helium emission is also dependent on exospheric temperature. Table 1 lists the exospheric temperature calculated by the Jacchia [1966] method for the observation days. The temperatures reflect the general decline of solar activity (Figure 1B) during the period of interest. It has been found from a computer model of the excitation process (see CPT) that

lower exospheric temperatures result in less helium emission, provided that the electron density is not affected. However, with declining solar activity, both the exospheric temperature and the F_2 -region electron density diminish, and their effects on the helium emission tend to cancel.

Therefore, since the effects due to the sun do not appear to be dominant, the major factor in seasonal variation is probably the upper atmospheric helium density.

The magnitude of the observed variation is in good agreement with the Ogo 6 data reported by Reber et al. [1971]. They provided evidence that the location of the helium bulge is determined by geomagnetic latitude rather than geographic latitude. For a number of passes in June 1967, the peak was found also to follow the -53° south magnetic dipole latitude, rather than remain at constant geographic latitude. For the satellite pass reported at 0740 LT, June 7, 1969, the peak helium density was near -52° geographic latitude. Hence for this pass the geographic and magnetic latitudes are very nearly the same, and winter-to-summer density ratios at a given magnetic latitude can be taken

Fig. 1. (A) Dawn and dusk helium 10830-A intensity for a solar depression angle of 15° on observation days in 1970-1971. Azimuth is east at dawn and west at dusk except as noted in Table 1. (B) Sunspot number for the same period, (C) 10.7-cm radio flux for the same period.

from their Figure 2. The winter-to-summer helium abundance ratio for Agulhas Negras corresponds to the ratio at $\pm 13^\circ$, which is approximately 2:1. The ratio for $\pm 23^\circ$ (corresponding to the geographic latitude of Agulhas Negras) is 3:1, which does not fit the observations.

In addition to the seasonal variation, another

TABLE 2. Values of f_oF_2 (in MHz^2)*

Month	Morning	Evening
December ($R_z = 114$)	36	121
March ($R_z = 69$)	16	144
June ($R_z = 49$)	16	100

* From Sanatani [1966]. Values for solar depression of 10° , since the observed helium emission region is approximately 5° closer to the terminator for the observation at 60° zenith distance.

obvious aspect of the data is the greater morning emission in the pre-winter period. Reference to the data given in Table 1 shows that the dawn-to-dusk ratio is in the range of 1.5 to 3. The largest ratio applies to the early June observations. This is consistent with the onset of morning conjugate photoelectron excitation, which should commence after day 120, but not conclusive evidence that this is responsible. In addition, the F_2 region electron density is greater in the evening. Using the data of Table 2, it is reasonable to expect, on the average, the electron density to be some 3 to 6 times greater in the evening than in the morning.

Computations identical to those described by CPT have been carried out using an electron density model with a density of $2 \times 10^6 \text{ cm}^{-3}$ at the F_2 peak. The results indicate that a tenfold decrease of the electron density is required to enhance the total 10830-A emission about threefold.

The lower morning exospheric temperature

tends to diminish the morning intensity, so that the mechanism responsible for the higher morning intensity must overcome the temperature effect. In this regard, the conclusion of CPT was that the electron densities measured by ionosonde were insufficient to account for the dawn-to-dusk ratio when the temperature effect was included. This same result is apparent here in the Brazilian data.

An explanation of these discrepancies may be that the photoelectron energy loss rate to ambient electrons that has been used in the calculations is too low. Recently Schunk and Hays [1971] have pointed out that the Butler and Buckingham loss rates that have been used in previous photoelectron spectrum calculations, including those of CPT, are too small. They indicate that the correct loss term for 20-eV photoelectrons capable of producing He(2^1S) is about 50% greater than the Butler and Buckingham expression. This correction is the proper direction to bring the calculations in better accord with the observations. Further calculations are planned with revised loss rates when ionospheric data concurrent with the observations become available.

Acknowledgments. We wish to thank Drs. F. de Mendonca and G. Meira for their encouragement in this work. We thank Dr. T. N. L. Patterson for the use of the computer program. We also appreciate the data reduction work of Miss Jane Broadt.

Financial support for this work was provided by NSF grant GA-18767 and internal INPE funds.

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(Received October 26, 1971;
accepted November 29, 1971.)
Communicated by D. M. Hunten