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THE ALTITUDE REGION SAMPLED BY GROUND-BASED DOPPLER TEMPERATURE MEASUREMENTS OF THE OI 15867 K EMISSION LINE IN AURORAE

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Abstract—Measurements of atmospheric optical emissions with ground-based spectrometers give column-integrated line profiles. Therefore, measurements from a single station are insufficient to infer the height of emission and, thus, the height of temperature and wind determinations. In aurorae the temperature measured by a ground-based spectrometer can be lower than similar measurements in the nightglow because the 15867 K (630.0 nm; 1 K = 1 cm^{-1}) emitting region may occur at lower altitudes. Temperature measurements obtained on an individual night from College, Alaska, illustrate this effect.

1. INTRODUCTION

Single-station ground-based spectroscopic measurements of atmospheric emissions do not typically determine the height of the observed emitting region. For many purposes, measurements of column intensities provide sufficient information for analysis. However, for ground-based measurements of dynamics, this inability to determine height leads to ambiguities in the interpretation of the measurements. This note will address the height problem in the region of the thermosphere sampled by Fabry–Perot spectrometer measurements of the OI 15867 K emission line in aurorae.

The height range sampled by ground-based measurements at low- and mid-latitudes of the OI 15867 K emission during geomagnetically quiet periods has been the subject of several studies. Roble *et al.* (1968) compared monthly averages of the exospheric temperature estimated from radar electron densities and ion temperatures with calculated neutral temperatures, as would be observed by a Fabry–Perot spectrometer. Their findings show that the calculated neutral temperature was 25–50 K lower than the radar-derived exospheric temperature, but showed similar variations. The corresponding height of the calculated effective temperature was about 240 km for an assumed temperature profile and O(^{1}D) production rate. Hays *et al.* (1970) obtained and compared Fabry–Perot spectrometer-derived temperatures with radar-derived exospheric temperatures. This study supported the earlier theoretical results. Cogger *et al.* (1970) also performed the same type of experiment from Arecibo, Puerto Rico. The electron, ion, and neutral temperatures were found to be equal at about 250 km. Further low-latitude comparisons were made using radar-derived electron temperatures and neutral temperatures by Hernandez *et al.* (1975), who also concluded that the Fabry–Perot spectrometer measures a neutral temperature close to, but lower than, that of the exosphere.

There exist a limited number of temperature studies in the auroral zone. Wark (1956) measured three temperatures in the spring twilight and suggested these measurements were consistent with 15867 K emission from a height of 150–200 km. Shepherd and collaborators (Nilson and Shepherd, 1961; Turgeon and Shepherd, 1962) made a large group of measurements, primarily using the OI 17925 K (557.7 nm) emission. Four sets of measurements were obtained scanning the spectrometer across stable auroral forms. Assuming a height of 105 km for the lower border of the aurora, they obtained temperatures up to 160 km. These temperatures were consistent with theoretically derived profiles.

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Hernandez and Roble (1976) presented temperature, wind, and intensity measurements of the OI 15867 K emission during geomagnetic storm periods at mid-latitudes. The temperature measurements reported by these authors for 6 July 1974, from Fritz Peak Observatory were significantly lower than those temperatures predicted by the OGO-6 semi-empirical neutral atmospheric model. Hernandez and Roble (1976) suggested that these lower temperatures reflected a lowering of the 15867 K emission profile due to electron precipitation.

Sica (1984) compared ion temperatures determined by an incoherent scatter radar with neutral temperatures obtained from measurements of the OI 15867 K line profile in the auroral zone. However, uncertainties in the density ratio $[O^+]/\{[NO^+]+[O_2^+]\}$ during periods of particle precipitation prevented any conclusive statement about the height of the emitting region.

In this study we show that, due to the decrease of the centroid of the emission-height profile of the 15867 K radiation to lower heights, the observed Doppler temperature of the neutral gas decreases during typical nighttime aurora. Measurements obtained on an individual night are used to illustrate this effect.

2. MODEL RESULTS

Model production rates for both nightglow and auroral conditions for the 15867 K emission are shown in Fig. 1. These production rates have been generated by a time-dependent, one-dimensional numerical model. The model and the detailed chemistry used in the derivation of the figure have been described by Roble and Rees (1977) and Rees and Roble (1979). The production of the OI 15867 K emission in aurorae is treated in detail in a recent work by Rees and Roble (1986). The model run used in this study was performed for 65° latitude at solar maximum during winter solstice. The mass spectrometer and incoherent scatter (MSIS) empirical atmosphere (Hedin *et al.*, 1977a, b) was adopted with an exospheric temperature of 1100 K. The auroral case assumed a Maxwellian incident electron spectrum peaked at 2 keV that precipitates into the atmosphere at local midnight. The volume emission rates are then integrated to give the column emission rate. For the nightglow profile, the emission rate of OI 15867 K radiation is 93 Rayleighs (R). The auroral case has a column emission rate of 2514 R.

The MSIS temperature profile is shown in Fig. 2. When weighted by the 15867 K nightglow emission profile of Fig. 1, the nightglow case yields a centroid for the emission at 203 km. The temperature corresponding to this height is 1026 K. The precipitating electrons in the auroral example lower the centroid of the emission to 161 km, where the corresponding temperature is 874 K. The purpose of these calculations is to quantitatively describe the decrease in height of the emission layer centroid as the excitation process changes; hence, a ground-based spectrometer would measure a lower temperature in the auroral example. However, in the real atmosphere, changes in the incident particle spectrum as well as local ionospheric

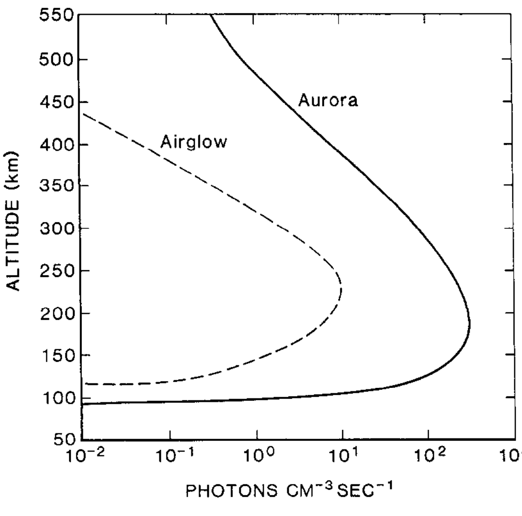

FIG. 1. COMPARISON OF MODEL 15867 K EMISSION-HEIGHT PROFILES WITH AND WITHOUT AURORAL ELECTRON PRECIPITATION.
Details of the model are given by Rees and Roble (1986).

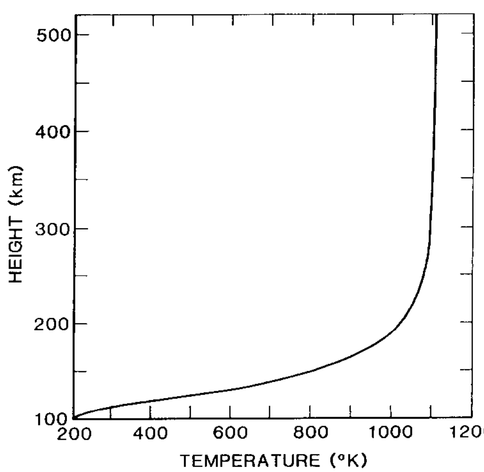

FIG. 2. TEMPERATURE PROFILE FROM THE MSIS EMPIRICAL ATMOSPHERE.
The exospheric temperature is 1100 K.

and atmospheric perturbations can modify the structure of the assumed temperature profile, also affecting the height region sampled by the spectrometer.

3. A COMPARISON WITH OBSERVATIONS

Measurements of nighttime thermospheric wind and temperature using the 15867 K OI emission line have been made at College, Alaska, since 1981 (Sica, 1984). Sica *et al.* (1986a) have described the instrument used to obtain the measurements, the data acquisition system, and reduction techniques. Figure 3 shows the neutral temperature and emission rate obtained with the Fabry–Perot spectrometer in the geographic zenith on 23 February 1982 U.T. (magnetic midnight is about 11:20 U.T.). The intensity measurements are accurate to about $\pm 12\%$. The figure shows that temperatures measured after 09:00 U.T. are significantly lower than those measured prior to this time. This observed decrease in the measured temperature can then be interpreted to be due to a decrease in the emission centroid of the 15867 K emission.

To investigate this hypothesis, data from the Poker Flat Meridian Scanning Photometer (MSP) were examined. Details of the Poker Flat MSP are given by Romick (1976). Figure 4 shows stack plots of the intensity of the auroral green line. In the figure the northern horizon is to the left and the College zenith is just to the South of the Poker geographic zenith. Aside from a small disturbance in the far North at about 06:30 U.T., there is no visible auroral activity until about 08:30 U.T. After some arc brightenings, a breakup and subsequent poleward contraction of the oval occurs. This activity is followed by a larger breakup around 11:30 U.T. (near local magnetic midnight) over College. The 17925 K intensity before 09:00 U.T. in the College zenith is relatively low (<1 kR) but still above the nominal nightglow level measured from 05:45 to 06:30 U.T. (250 R). This suggests that the change from nightglow to auroral particle precipitation was not sudden. Intensity measurements of other auroral emissions are necessary to determine if a distinct change in the energy of the precipitating particles has occurred.

Figure 5 displays the intensities of the OI 15867 K and 17925 K emissions, the N_2^+ 1N(0, 1) emission at 23368 K (427.8 nm), and the hydrogen beta (Hβ) emission (20566 K; 486.1 nm) in the College zenith as measured by the MSP. The data have been corrected for atmospheric scattering and continuum background, then smoothed with a running triangle average. The smoothing employs three points at 17925 K, five points at 23368 K and 15867 K, and nine points

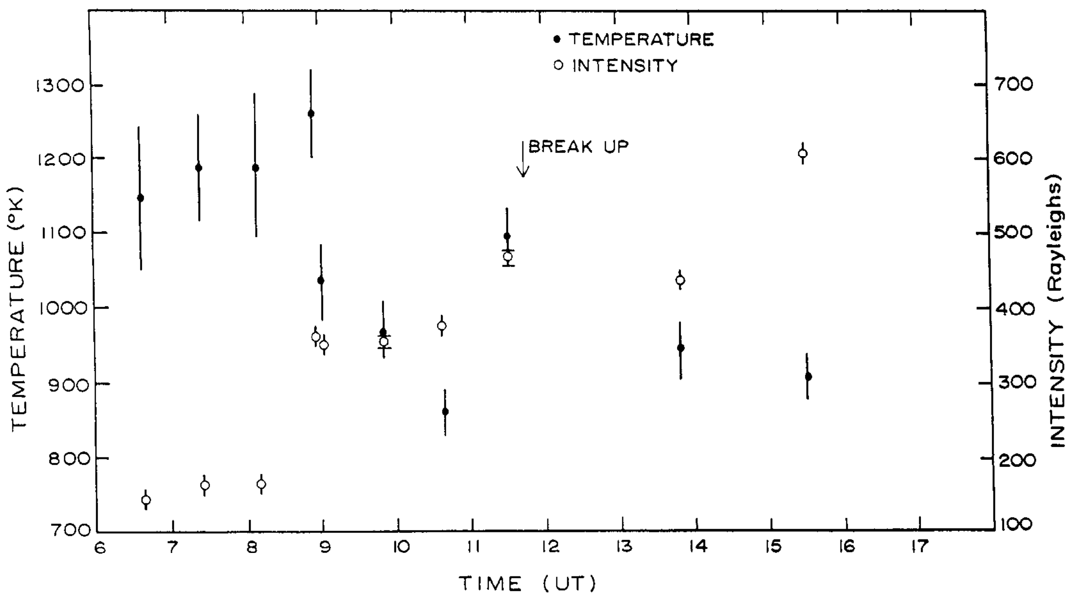

FIG. 3. FABRY–PEROT SPECTROMETER MEASUREMENTS OF TEMPERATURE AND INTENSITY IN THE GEOGRAPHIC ZENITH.

The bars through the points are plus and minus one standard deviation. The intensity uncertainty is the statistical error of the measurement.

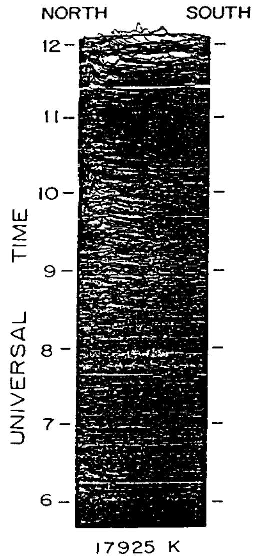

FIG. 4. MERIDIAN SCANNING PHOTOMETER STACK PLOTS OF OI 17925 K INTENSITY FROM POKER FLAT, ALASKA.
The North horizon is to the left, the southern horizon is to the right, and the College zenith is just to the right of center. The separation between lines is 1 kR.

at 20566 K. The times at which Fabry–Perot spectrometer measurements were taken are also indicated in the figure. In the period before 09:00 U.T. there are small, but significant, N_2^+1N emissions ranging from 30 to 100 R.

The variation of the Hβ intensity in the evening is strikingly similar to the variation of the N_2^+1N emission. Proton bombardment can excite the N_2^+1N system by electron capture and ionization reactions. Rees (1982) has computed the amount of N_2^+1N emission as a function of incident proton energy. Assuming typical incident proton energies of 5–10 keV, the ratio of Hβ to N_2^+1N intensity is about 0.3. Therefore virtually none of the N_2^+1N emission measured in the zenith until the initial breakup at 09:30 U.T. is due to precipitating electrons. This result is consistent with the observed auroral morphology, since the proton oval typically lies equatorward of the electron oval in the evening (Rees *et al.*, 1961).

Any electron precipitation in the College zenith before 09:00 U.T. would then be of low energy, since the electrons did not penetrate sufficiently far enough into the atmosphere to significantly excite the N_2^+1N

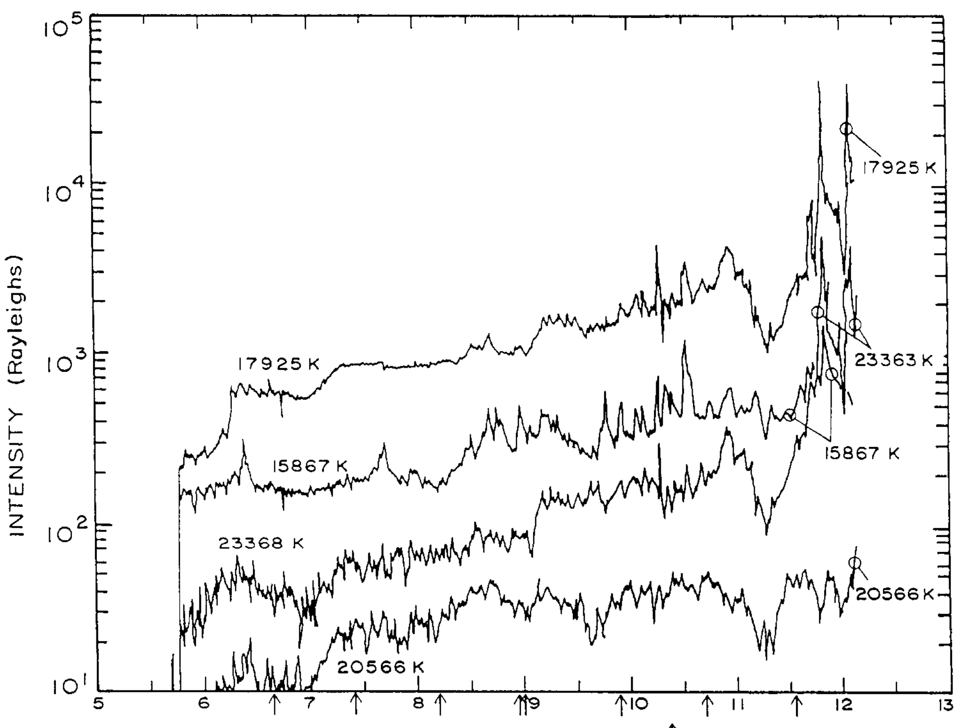

FIG. 5. INTENSITIES OF OI 15867 K AND 17925 K, N_2^+ 1N(0, 1) (23368 K), AND Hβ (20566 K) EMISSIONS IN THE COLLEGE GEOGRAPHIC ZENITH AS MEASURED BY THE MSP.
The data are corrected for atmospheric scattering and background continuum, then smoothed with a running triangle average.

bands. As was shown in Section 2, the airglow 15867 K emission calculations yielded an effective temperature corresponding to the MSIS temperature at about 203 km. Rees and Roble (1986, in preparation) have shown that the centroid of the OI 15867 K emission-height profile would also be at this level for low-energy precipitating electrons (below 1 keV). However, after 09:00 U.T. the Hβ emission levels off and the 15867 K and N_2^+ 1N intensities continue to increase as the electron oval expands over College. It is at this time that the temperatures measured by the Fabry–Perot spectrometer decrease. This temperature decrease is primarily due to the extension of the 15867 K emission profile to lower altitudes.

It is also interesting to note the rapid change in the temperatures measured around 09:00 U.T. The 15867 K intensity measured by the MSP increased 30% between measurements obtained 3.5 min apart, while the temperature decreased about 200 K. Such a rapid variation in the neutral kinetic gas temperature cannot be attributed to local heating.

Rapid temperature variations occurred in 14 other pairs of fringes during the night. The Doppler shifts between each pair of fringes and a simultaneously scanned laser was identical. The sky measurements are normalized with the emission measurements from a co-aligned, 15867 K photometer, when the variation between fringes is greater than 5%, as described by Sica (1984). Of these 14 measurements, nine pairs were normalized, including the zenith measurements near 09:00 U.T. The temperature change is not induced by the normalized technique. These rapid temperature changes are observed almost every night from College. When a fixed signal-to-noise scanning technique, as described by Hernandez *et al.* (1984), was employed for later measurements, these temperature changes were still observable. It is likely these variations are of geophysical origin, often due to particle precipitation as in the above case. At other times they may be caused by intensity fluctuations induced by atmospheric gravity waves.

The previous discussion has ignored the effect of neutral winds on the determination of temperature from emission line profiles. Neutral winds can, for instance, alter the line shape of the emission as has been shown by Hays and Atreya (1971). However, this should not affect the temperature measurements we used in this study, since only those line profiles that are Gaussian in shape have been analyzed for temperature. Of the 114 measurements obtained in the geographic zenith and the four cardinal directions (magnetic North, South, East and West), 22 measurements did not meet the analysis criteria (Sica, 1984). These 22 rejected measurements were randomly scattered throughout the night. No measurements between ± 30 min of 09:00 U.T. were rejected, and only two measurements between ± 30 min of 11.30 U.T. were rejected.

Neutral winds can also affect the relation between auroral particle heating and broadening of the emission-height profile. The wind system can transport locally heated air parcels out of a region of particle bombardment. In addition, large vertical winds, often observed during periods of auroral activity, could transport air from the lower to the upper thermosphere (and vice versa; see Sica *et al.*, 1986b, in preparation). To further complicate the situation, hotter (or colder) air can be transported into the local region by horizontal winds. Though the data presented in this paper are relatively easy to interpret, this is not generally the case. The interplay between the thermospheric wind system and the auroral particle heating is often quite complex.

The effect of a changing 15867 K emission-height profile should be taken into account in the interpretation of wind measurements. When a ground-based instrument samples the 160 km region of the thermosphere, the assumption of a wind system uniform in height (as is typically assumed in the upper thermosphere) may no longer be valid. In this region of the atmosphere wind shear is often observed (Edwards *et al.*, 1956; Mikkelsen *et al.*, 1981). The temperature information present in the measurements is then essential for the interpretation of neutral wind determinations. In addition, under conditions of uniform particle precipitation, magnetic zenith ratios of various optical emissions can be used to estimate the altitude of the emitting region to further assist in the interpretation of the Doppler measurements.

4. CONCLUSIONS

The theoretical calculation, given in Fig. 1, predicts an altitude profile of 15867 K volume emission rate that extends substantially below the level of airglow radiation, so that the effective temperature will also be lower. The above results are for "typical" auroral primary electron energies of a few kilo-electron volts. If the precipitating electrons were in the energy range of a few hundred electron volts, as in Type-A red aurorae or the dayside cusp, the emission-height profile could also extend to higher altitudes (Stamnes *et al.*, 1985).

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