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MESOPAUSE TEMPERATURES AT 23°S

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Abstract. Observations of the OH(9,4) and $O_2A(0,1)$ atmospheric band emissions at 7750Å and 8645Å, respectively, made between 1983 and 1986, have been analyzed to give atmospheric temperatures for the corresponding emission heights. The annual mean temperatures are found to be 193 K and 198 K for the OH and O_2 emissions, respectively. The OH rotational temperature shows an annual oscillation of 2.3 K amplitude with a maximum in late March, and the semiannual component shows equinoctial maxima with an amplitude of 3.0 K. The O_2-derived temperature shows a 2.5 K annual component maximizing in May.

Introduction

Measurements of the band structure of nightglow emissions were first used to determine mesospheric temperature by *Meinel* [1950], who applied the technique to the OH(6,2) band at 8342 Å and the O_2 atmospheric band emission $O_2A(0,1)$ at 8645 Å. A number of workers have subsequently made systematic measurements of this sort to determine the nocturnal and seasonal variations of temperature at the emission height [see, e.g., *Wallace*, 1961; *Noxon*, 1978; *Takahashi and Batista*, 1981; *Offermann et al.*, 1983]. Observations of the OH(8,3) band were made at Cachoeira Paulista (22°S, 46°W) between 1972 and 1982, and the OH(9,4) band has been observed at the same location from 1983 to the present. Observations of the $O_2A(0,1)$ band have been made since 1983. Some of the results of these measurements have been presented by *Takahashi et al.* [1986]. In this report we present the seasonal variations determined from four years of measurement made between 1983 and 1986 and compare these results with other measurements of temperature in the mesopause region.

The Measurements

The observations were made using tilting filter type photometers. Details of the instrumentation are given by *Takahashi et al.* [1986]. Synthetic spectra for the $O_2A(0,1)$ emission were calculated using the molecular constants given by *Babcock and Herzberg* [1948] and the intensity factors from *Krassovsky et al.* [1962]. For the OH emission the Einstein coefficients from *Mies* [1974] were used. The OH(9,4) band rotational temperatures were derived from the ratio between the Q and R branch intensities. In the case of the O_2 emission the temperature was determined from the slope of the P branch. Details of the techniques used to derive the rotational temperatures are given by *Takahashi and Batista* [1981] and *Takahashi et al.* [1986]. As described in the above referenced papers, the instrumental error in the determination of the OH rotational temperature is approximately ±5 K, and for the O_2 band emission an error of ±10 K is estimated. These values refer to a single measurement, normally repeated at 3-min intervals, so that a typical nightly mean is the average of about 200 such measurements. The analysis which we will present is based on a total of about 40,000 individual measurements, involving more than 200 nights of observations.

When discussing temperatures derived from the rotational spectra of airglow emissions, the question arises as to whether or not the emitting molecule is in local thermodynamic equilibrium (LTE) with the ambient atmospheric molecules. In the case of the O_2 emission there can be no doubt that LTE exists, because the lifetime of the upper level is in excess of 100 s. For the OH emission the lifetime is much shorter, and the emitting molecules are not necessarily in equilibrium with the ambient gas. *Pendleton et al.* [1989] have examined this problem in detail. On the basis of their observations of the (7,4) band emission they conclude that rotational levels 1-5 are in almost complete LTE. Our OH rotational temperatures are derived from Q and R branch ratios. Our filter transmission factors are such that only levels 1 and 2 contribute to the measured Q branch intensity, and levels above 5 contribute less than 1% to the R branch. As a result of this, we believe that the measured rotational temperatures do not diverge significantly from the ambient gas temperature.

In Figures 1 and 2 we show mass plots of the nightly average rotational temperatures, derived from the OH(9,4) and $O_2A(0,1)$ emissions, respectively, together with least mean squares fitted seasonal trends. The latter are constituted by annual and semiannual oscillations about the annual mean. The OH measurements correspond to an average temperature of 193 K with an annual component having an amplitude of 2.3 K, maximizing toward the end of March, and a semiannual component of amplitude 3.0 K, maximizing at the beginning of April and October. The O_2 measurements correspond to an average temperature of 198 K with an annual component having an amplitude of 2.5 K, maximizing in May, and a semiannual component of amplitude 2.2 K, maximizing in February and August. Despite the very large scatter in the experimental data, the regression curves fitted to the OH rotational temperatures give correlations significant at better than the 1% level for both the annual and semiannual components. For the $O_2A(0,1)$ emission the annual variation is just significant at the 5% level, but the semiannual variation is not. The greater dispersion in the O_2 temperatures is probably due, at least in part, to the larger experimental error involved in this measurement.

Discussion

In order to compare our rotational temperature with atmospheric models we must estimate the relevant emis-

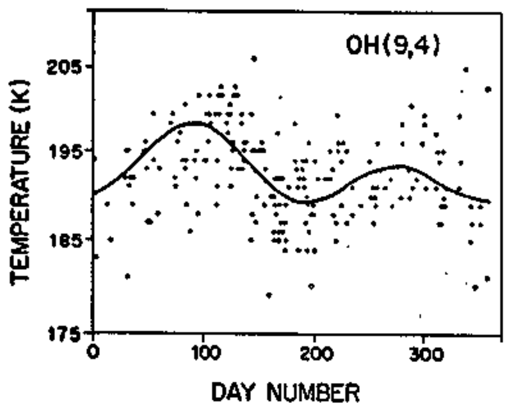

Fig. 1. Mass plot of nightly average OH(9,4) band rotational temperatures obtained between February 1983 and May 1986. The continuous curve is a least mean squares fit of the annual and semiannual oscillations.

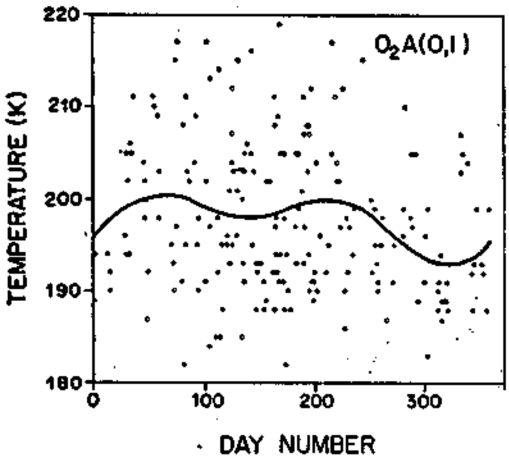

Fig. 2. As Figure 1, but for the $O_2A(0,1)$ emission.

sion heights. The height distribution of the OH emission has been determined in many rocket experiments and the O_2 bands have been measured in a rather smaller number of flights. A very complete compendium of the OH measurements has been published by *Baker and Stair* [1988]. Many of the measurements suffer from high noise levels and contamination. We have tried to select the more reliable published data, and in Figure 3 we show average emission profiles derived from work by *Witt et al* [1979], *Thomas and Young* [1981], *Harris* [1983], *Greer et al.* [1986], and *Ogawa et al.* [1987]. Figure 3 shows that the OH emission typically peaks at 88 km and that the O_2 emission should be expected to peak at 94 km. The average OH emission profile is skewed toward greater heights, so the effective temperature for the integrated emission measured on the ground may refer to a height as great as 90 km. Many measurements of mesospheric and

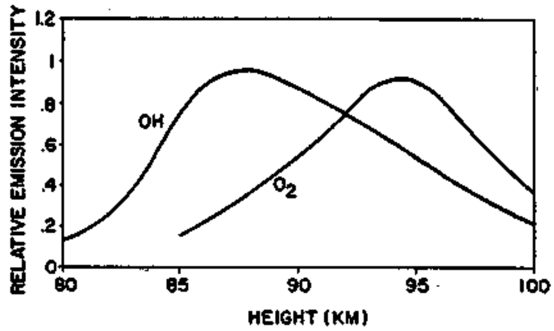

Fig. 3. Average vertical profiles for the OH and O_2A emissions.

lower thermospheric emissions have suffered from noise and contamination. We have used what we believe to be the more reliable profiles, but it is quite possible that the skewness of the average profile is partly the result of contamination emissions. It should be noted that the measurements on which Figure 3 are based were all made at middle and high latitudes, but there is no reason to believe that the emission heights should be greatly different at 23°S. It is possible, of course, that the emission heights suffer a systematic seasonal variation. If this is the case, part of our observed seasonal variation in temperature could result from the seasonal emission height variation. The maximum excursion in our OH rotational temperature is about 10 K. This corresponds to a height variation of about 7 km for the SME winter profile, or just over 10 km for the CIRA 20°N annual mean. It seems unlikely that such large excursions should occur in the emission height, particularly at low latitudes, so it is improbable that height variations make a major contribution to the seasonal variations in rotational temperature.

Until recently our knowledge of atmospheric temperature structure in the mesopause region has been poor, especially in the southern hemisphere. The CIRA 1972 [*COSPAR*, 1972] temperature profiles are based mainly on northern hemisphere data, and even these are rather sparse in the appropriate height range. The MAP Draft Reference Atmosphere [*Middle Atmosphere Program (MAP)*, 1985] adds little to the CIRA model above 80 km. Recently, however, *Clancy and Rusch* [1989] have published a very complete climatology of mesospheric temperatures derived from the ultraviolet limb radiances measured by the SME satellite. The measurements, which extend from 58 to 90 km, were made between January 1982 and September 1986 and thus refer to the same solar epoch as our rotational temperature measurements. It is interesting to compare our rotational temperatures with the Clancy and Rusch climatology and with the CIRA 1972 standard atmosphere.

Clancy and Rusch [1989] present their seasonal variations at 3.5 km height intervals, the two highest of which are 86.5 and 90 km. Our OH temperatures should be expected to be somewhere between the 86.5 km and 90 km values, and our O_2 temperatures should be closest to the 90 km SME values, although the former are expected to come from about 4 km higher. In Figure 4 we show vertical temperature profiles for summer, winter and equinox periods, plotted from the 20°S data of *Clancy and Rusch* [1989]. It is clear from Figure 4 that the satellite data indicate no pronounced seasonal change in the mesopause height, which is always close to 80 km, except in summer, when the temperature is still decreasing at 90 km, so that the mesopause height is not determined. An extrapolation of the curves of Figure 4 suggests that the O_2-derived temperatures should be about 5 K higher than Clancy and Rusch's 90-km values, except in summer, when the temperature gradient seems to be much smaller. In Figure 5 we show our annual trends together with CIRA 1972 temperatures for 20°N, shifted by 6 months, and Clancy and Rusch's 86.5 and 90 km variations for 20°S. Both the CIRA model and the satellite data have been treated in the same way as our rotational temperatures, in that the curves shown represent a two-harmonic least mean squares fit to the published data points. For the satellite data the annual mean temperatures are 208 and 211 K at 86.5 and 90 km, respectively, and the amplitudes of the annual oscillations are 4.4 and 3.0 K with maxima in October and September. The corresponding semiannual amplitudes are 4.6 and 6.4 K with maxima in May and April, respectively. The CIRA 1972 mean annual temperatures are 195.7, 190.9, and 194.4 K at 85, 90, and 95 km, respectively, and the amplitudes of the annual oscillations at these heights are 1.9, 2.0 and 5.5 K, with maxima in May, April and April, respectively. The corresponding semiannual oscillations have amplitudes of 3.5, 4.5, and 6.2 K, with maxima in May, March and April, respectively. These values are summarized in Table 1.

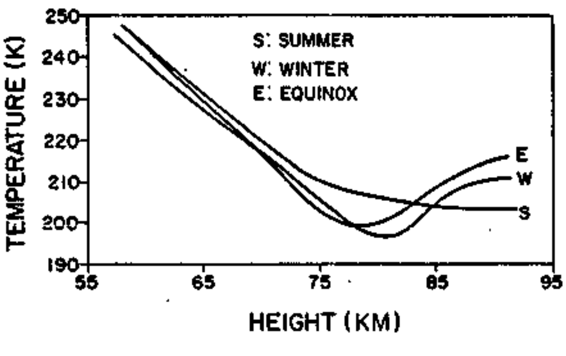

Fig. 4. Vertical temperature profiles for 20°S from *Clancy and Rusch* [1989].

The agreement between our rotational temperature measurements and the satellite data of *Clancy and Rusch* [1989] is not good, especially in respect of the annual mean temperature. Our OH rotational temperatures are

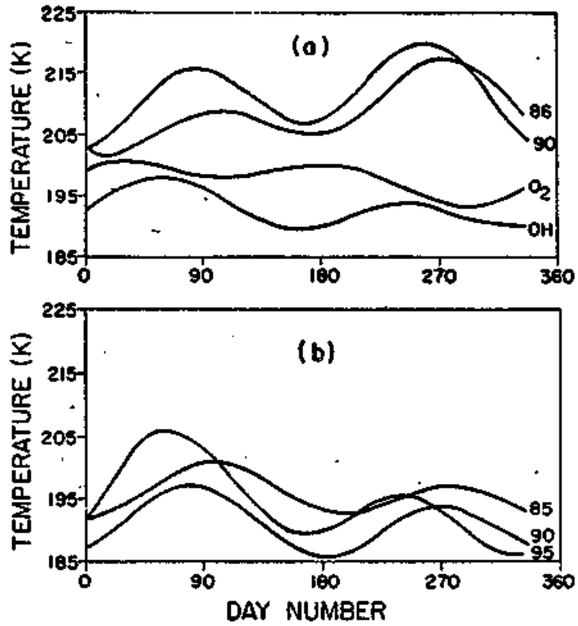

Fig. 5. Seasonal variations in rotational temperature compared with (a) SME measurements, (b) CIRA 72 model atmosphere.

about 15 K lower than those derived from the SME measurements at 86.5 km, and almost 20 K less than the 90 K values. This difference is 3-4 times our estimated experimental error for single measurements. The difference between our annual mean O_2 rotational temperature and the 90 km SME temperature is of the same order of magnitude. Estimating that the temperature at the $O_2A(0,1)$ emission height should be about 15 K higher than the 90 km SME values the difference between our O_2 temperatures and the satellite data is about 18 K.

With respect to the seasonal variations only the phase of the semiannual variation in OH rotational temperature is in good agreement with the satellite data. The amplitude of our semiannual variation is about 60% of that derived from the satellite data. In the case of the annual variation, our OH rotational temperature is almost 180° out of phase with the 86.5 km satellite measurement, and the amplitude is about one half. The annual variation in the $O_2A(0,1)$ rotational temperature is in slightly better agreement with that derived from the SME data but, on the other hand, the annual variation in our $O_2A(0,1)$ temperatures is only just significant at the 5% level, and not too much weight can be given to the comparison. Our measurements agree much better with the CIRA 1972 model. The annual mean for the OH rotational temperature is about half way between the 85 and 90 km CIRA values, the amplitude of the annual oscillation is about 15% greater, and its phase is within 30°. The amplitude of the semiannual oscillation is about 75% of the corresponding CIRA value, and its phase is very similar. Our annual mean O_2 rotational temperature is only 3.3 K

TABLE 1. Temperature Variations Derived From Airglow Observations Compared With Satellite Measurements and CIRA 72

	Annual Mean, K	Annual Oscillation		Semiannual Oscillation	
		Amplitude, K	Day of Maximum	Amplitude, K	Day of Maximum
			This Work		
OH	192.8	2.3	84	3.0	91
O_2	197.7	2.5	131	2.2	47
			Clancy and Rusch [1989]		
86.5 km	208.4	4.4	289	4.6	127
90 km	211.4	3.0	248	6.4	111
			CIRA 72		
85 km	195.7	1.9	136	3.5	126
90 km	190.9	2.0	97	4.5	70
95 km	194.4	5.5	112	6.2	93

higher than the 95 km CIRA value, and only the amplitude of the annual oscillation shows a marked difference, the CIRA amplitude being a little more than twice the value determined from the $O_2A(0,1)$ measurements. The phases of the annual oscillations differ by only 19°.

In comparing our rotational temperatures with the SME measurements we have ignored any possible effects of systematic diurnal variations. Such variations could result from atmospheric tides, especially the diurnal component. A systematic diurnal variation could influence the comparison because our rotational temperatures typically represent a nocturnal average, while the SME results refer to 1500 hours local time. Oscillations in the OH rotational temperature have been studied by *Takahashi et al.* [1984], who found regular nocturnal variations which they interpreted as being caused by tidal effects. It is difficult to estimate the effect of such variations on the relationship between the satellite temperatures and the airglow rotational temperature because of the time difference. From *Takahashi et al.* [1984]'s Figure 2, however, it is possible to estimate that the nocturnal mean rotational temperatures should not, on the average, differ by more than about 5 K from the sunset values. Atmospheric tidal models can also be used to estimate any possible bias. *Forbes and Gillete* [1982] have published model results for 24°S which show amplitudes for the diurnal tide of about 5 K at 90 km. The phase, which varies little throughout the year, is such that the temperature difference between 1500 hours and the nocturnal average would be less than 2 K. Remembering that the diurnal tide typically shows very large day-to-day phase variations it is likely that the average temperature difference would be even less. On the basis of the above discussion we conclude that diurnal variations in atmospheric temperature are very unlikely to be responsible for the difference between the SME climatology and our rotational temperatures. It should be noted that *Clancy and Rusch* [1989] arrive at a similar conclusion with respect to the comparison between the SME temperatures and CIRA 72.

It is interesting to note that the discrepancy between measured rotational temperatures and the SME results does not necessarily extend to higher latitudes. *Offermann et al.* [1983] have published OH rotational temperature measurements for 51°N, showing an annual mean value of 202 K, as compared with 204 K for the annual mean of the 86.5 km SME measurements at 50°N. Thus the agreement of the mid-latitude OH rotational temperatures with the satellite measurements is better than with CIRA, for which the annual mean is about 15 K lower.

Conclusions

Rotational temperatures derived from measurements of the band structure of the OH(9,4) and $O_2A(0,1)$ emissions at 23°S are in good agreement with the CIRA 1972 model atmosphere but do not agree well with the SME satellite results published by *Clancy and Rusch* [1989]. Annual mean rotational temperatures are 15-20 K cooler than those indicated by the satellite measurements. Only the phase of the semiannual variation in the OH(9,4) rotational temperature, with equinoctial maxima, is in good agreement. The difference between the annual means is 3-4 times the estimated accuracy of the rotational temperature measurements in the case of OH(9,4), for which the comparison is most valid. In view of the fact that our results are in good agreement with the earlier measurements on which the CIRA model is based, the discrepancy with the satellite results suggests that for heights above 80 km at low latitudes the latter must be treated with caution. It should be noted that this discrepancy does not necessarily extend to higher latitudes, where the SME temperatures are in fairly good agreement with the *Offermann et al.* [1983] OH rotational temperatures for 51°N and show a seasonal variation similar to CIRA 72.

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References

Babcock, H. D., and L. Herzberg, Fine structure of the red system of the atmospheric oxygen bands, *Astrophys. J., 108*, 167-190, 1948.

Baker, J. B., and A. T. Stair, Rocket measurements of the altitude distribution of the hydroxyl airglow, *Phys. Scri., 37*, 611-622, 1988.

Clancy, T. R., and D. W. Rusch, Climatology and trends of mesospheric (58-90 km) temperatures based upon 1982-1986 SME limb scattering profiles, *J. Geophys. Res., 94*, 3377-3394, 1989.

COSPAR, *CIRA 1972 Standard Atmosphere*, Akademie, Berlin, 1972.

Forbes, J. M., and D. F. Gillette, A compendium of theoretical atmospheric tidal structures. Part 1: Model description and explicit structures due to realistic thermal and gravitational excitation, Air Force Geophys. Lab., *Tech. Rep. AFGL-TR-82-0173(1)*, Hanscom AFB, Mass., June 1982.

Greer, R. G. H., D. P. Murtagh, I. C. McDade, P. H. G. Dickinson, L. Thomas, D. B. Jenkins, J. Stegman, E. J. Llewellyn, G. Witt, D. J. Mackinnon, and E. R. Williams, ETON 1: A data base pertinent to the study of energy transfer in the oxygen nightglow, *Planet. Space Sci., 34*, 771-788, 1986.

Harris, F. R., The atmospheric system of O_2 in the nightglow, *Trans. AGU, 64*(45), 779, 1983.

Krassovsky, V. I., N. N. Shefov, and V. I. Yarin, Atlas of the airglow spectrum 3000-12400 Å, *Planet. Space. Sci., 9*, 883-915, 1962.

Middle Atmosphere Program, *Handbook for MAP*, vol. 16, edited by K. Labitzke, J .J. Barnett and B. Edwards, Scientific Committee for Solar-Terrestrial Physics, University of Illinois, 1985.

Meinel, A. B., OH emission bands in the spectrum of the night sky II, *Astrophys. J., 112*, 120-130, 1950.

Mies, F. H., Calculated vibrational transition probabilities of OH($X^2\Pi$), *J. Mol. Spectrosc., 53*, 150-188, 1974.

Noxon, J. F., Effect of internal gravity waves upon night airglow temperatures, *Geophys. Res. Lett., 5*, 25, 1978.

Offermann, D., R. Gerndt, G. Lange, and H. Trinks, Variations of mesopause temperatures in Europe, *Adv. Space Res., 3*, 21-23, 1983.

Ogawa, T., N. Iwagami, M. Nakamura, M. Takano, H. Tanabe, A. Takechi, A. Miyashita, and K. Suzuki, A simultaneous observation of the height profiles of the night airglow OI 5577 Å, O_2 Herzberg and atmospheric bands, *J. Geomagn. Geoelectr., 39*, 211-228, 1987.

Pendleton, W., P. Epsy, D. Baker, A. Steed, M. Fetrow, and K. Henriksen, Observation of the Meinel (7,4) P(N''=13) transitions in the night airglow, *J. Geophys. Res., 94*, 505-510, 1989.

Takahashi, H., and P. P. Batista, Simultaneous measurements of OH(9,4), (8,3), (7,2), (6,2) and (5,1) bands in the airglow, *J. Geophys. Res., 86*, 5632-5642, 1981.

Takahashi, H., Y. Sahai, and P. P. Batista, Tidal and solar cycle effects on the OI 5577 Å, NaD and OH(8,3) airglow emissions observed at 23°S, *Planet. Space. Sci., 32*, 897-902, 1984.

Takahashi, H., Y. Sahai, and P. P. Batista, Airglow $O_2A(0,1)$ atmospheric band at 8645 Å and the rotational temperature observed at 23°S, *Planet. Space. Sci., 34*, 301-306, 1986.

Thomas, R. J., and R. A. Young, Measurement of atomic oxygen and related airglows in the lower thermosphere, *J. Geophys. Res., 86*, 7389-7393, 1981.

Wallace, A. B., Seasonal variation and interpretation of the OH rotational temperature of the airglow, *J. Atmos. Terr. Phys., 20*, 85-93, 1961.

Witt, G., J. Stegman, B. H. Solheim, and E. J. Llewellyn, A measurement of the $O_2(b^1\Sigma_g^+ - X^3\Sigma_g^-)$ Atmospheric band and the OI(^{1}S) green Line in the nightglow, *Planet. Space Sci., 27*, 341-350, 1979.

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