



# Comparisons Between The Mesopause Temperature Profiles Measured With A Sodium Temperature Lidar And The OH(6,2) And O<sub>2</sub> A(0,1) Rotational Temperatures at 23° S

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## ABSTRACT

The mesopause temperature profile has been measured at São José dos Campos (23.2° S, 45.9° W) for a total of 15 nights from July to October 1998. The technique used is the measurement of the Doppler temperature of the sodium atoms present in the atmospheric sodium layer with a Lidar. During 7 of the 15 days of Lidar temperature data, simultaneous measurements of the rotational temperature of the OH(6,2) band at 843.0 nm and the O<sub>2</sub> (0,1) Atmospheric band at 864.5 nm were obtained at a nearby station, Cachoeira Paulista (22.7° S, 45.2° W), with a tilting filter photometer. There is a fair agreement between the OH temperature and the Gaussian weighted temperature calculated using the Lidar temperatures centered on 84.7 km and with a half-width of 4.5 km, consistent with rocket measurements for the OH emission profile, for most of the days. But no consistent combination of height and half-width can reproduce the absolute value and variation of the O<sub>2</sub> (0,1) temperature for most of the days, suggesting that the transition probabilities used for determining the latter may need to be revised.

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## INTRODUCTION

The temperature structure in the region of the upper mesosphere and lower thermosphere (MLT) was first measured by means of in situ rocket measurements carried out since the sixties (e.g Craig, 1965). Although having good height resolution these measurements had the disadvantage of being simple snapshots of the momentary temperature profile. Time variation of the profile was difficult to measure by this method because it required a large number of rocket launches. It is only a few years ago that the measurement of the Doppler temperature of the metals in the 80-105 km region using lidars became available (She and von Zahn, 1991; Yu and She, 1995; von Zahn et al., 1996). For measuring the Doppler-broadened hyperfine structure of sodium, potassium and iron, all of these workers used sophisticated laser systems to generate a single line output. Recently, our group, (Clemesha et al., (1997)), used a much simpler and cheaper method to obtain the mesospheric temperature profile. Results of these measurements are presented by Clemesha et al., (1999). Our lidar measurements can provide a sequence of temperature profiles from ~80-100 km with time resolution as good as 10 minutes and height resolution of 1 km.

At the same time, the brightness weighted rotational temperature of the excited OH and O<sub>2</sub> molecules present in the upper atmosphere, which can be easily measured by ground-based photometers, provides the weighted mean temperatures at the altitude of around 87 and 96 km, respectively. Although useful for studying the relative time variation of temperature during the night, the absolute value of the rotational temperature depends on uncertain spectroscopic parameters and may have a systematic error. The comparison of these values with other temperature measurements is therefore highly desirable.

During 7 of the 15 nights of lidar measurement campaign in São José dos Campos (23.2° S, 45.9° W), the rotational temperatures of the OH(6,2) band and of the O<sub>2</sub>(0,1) atmospheric band were measured in Cachoeira Paulista (22.7° S, 45.2° W), a nearby station. In this work, we report the comparison between the two.

## SUMMARY OF THE EXPERIMENTAL TECHNIQUES

### Sodium Lidar:

INPE's lidar, used normally to measure the sodium density from 80-105 km (Clemesha, 1984), was slightly modified by putting a pressure-controlled Fabry-Perot interferometer inside the laser cavity. This Fabry-Perot produces a multi-line output consisting of a comb of narrow lines spaced by 1.98 pm, which is exactly equal to the separation of the two groups of hyperfine lines in the sodium D<sub>2</sub> line spectrum. By appropriate change in the gas pressure it is possible to tune the laser output for the situation where the lines exactly coincide in wavelength with the NaD<sub>2</sub> hyperfine lines and where the central line is exactly equidistant from the D<sub>2</sub> lines. Sodium profiles are obtained alternately for a certain

number of shots with the laser off-line and on-line. At a determined height, the ratio of the signal on-line and off-line is obtained. This ratio varies from 2.3 to 3.9 as the temperature of the sodium atoms, in equilibrium with the atmosphere, varies between 230 K and 170 K. For this campaign the measurements were carried out in a 3 min cycle, with 200 shots on-line and 500 shots off-line. The data were interpolated at constant and coincident intervals and low-pass filtered in time and height in order to remove rapid variations in sodium density due to short-period gravity waves and poor signal to noise ratio. Clemesha et al., (1999), estimate the error to be  $\pm 7K$  in absolute temperature and  $\pm 2K$  in the relative temperature.

Rotational temperatures:

OH(6,2) Band - A multi-channel tilting filter photometer (Multi-2) has been operated regularly at Cachoeira Paulista, SP (22.7° S, 45.2° W) since 1977. The general characteristics of the photometer can be found elsewhere (Takahashi and Batista, 1981). The photometer can measure the intensity of the line emissions OI557.7 nm, OI630.0 nm and NaD(589.3 nm); and the OH(6,2) and O2(0,1) band intensities and rotational temperatures. The total cycle is repeated at every 3 min. Until 1994 the OH(9,4) was measured, but from 1994 to now the OH(6,2) is being measured. The photometer measures the background and the P<sub>1</sub>(4), P<sub>1</sub>(3) and P<sub>1</sub>(2) lines of the OH(6,2) band and the rotational temperature is calculated from the ratio between P<sub>1</sub>(4) and P<sub>1</sub>(2). Estimated error for the temperature is of 12%. It is assumed that the excited OH molecules are in local thermodynamical equilibrium with the atmosphere. Pendleton et al., (1989) show that it is true for the rotational levels 1-5. Our temperature is determined from the 1 and 4 rotational P<sub>1</sub> lines, so it is true for our case. The rotational temperature then represents the weighted average temperature of the atmosphere, where the weight is the emission volume profile.

O2(0,1) Band - The O2(0,1) temperature is determined from the slope of the P branch of the O2(0,1) spectra. This slope is determined from the ratio between two consecutive tilted positions of the filter. A synthetic spectrum which uses molecular constants given by Babcock and Herzberg (1948) and the intensity factors from Krassovsky et al., (1962) is used to convert the ratio to rotational temperature. The filter used has a linewidth of 1.2 nm and the estimated error in temperature is about 10% (Takahashi et al., 1986). Since the lifetime of the excited O2 molecules is very high, there is no doubt that the rotational temperature represents the atmospheric temperature. A more detailed description of the instrument and technique used to measure the O2(0,1) rotational temperature in Cachoeira Paulista is presented by Takahashi et al., (1986).

OBSERVATIONS

The lidar measurements of the mesopause temperature profiles for this study were carried out from July to October, 1998. Table 1 shows the days when simultaneous lidar/airglow temperature measurements were obtained, together with the duration of the measurements.

For making our comparison the airglow rotational temperature measurements obtained at 3-min time intervals were first filtered with a 5-point running mean. The results for July, 24, 1998 are shown in Figure 1 as a thick line for the OH and a thin line for the O2. For a direct comparison, a weighted temperature is calculated from the lidar temperature data. The height and thickness of the emission layers are not known precisely, so we assume a Gaussian shaped emission profile to calculate the weighted average temperature. The height and thickness (half-width) of the OH emission layer as measured by rocket photometry is reviewed by Baker and Stair, (1986). The average height and thickness is given as  $86 \pm 2.6$  km and  $8.6 \pm 3.1$  km, respectively. For the O2 emission height, Tarassic and Evans, (1993) give an average height of  $94 \pm 1$  km and thickness from 8 to 10 km. The profiles refer to the (0,0) band, but the (0,1) band should be similar. Starting with these values, we assumed a Gaussian shape

$$V(h_i) = \exp[-(h_i - h_0)/\sigma]^2$$

for different h<sub>0</sub>'s and σ's (note that the half-width  $\Gamma=1.6645 \sigma$ ). The measured lidar temperatures are assembled in a height × time matrix (T<sub>Na</sub>(t<sub>i</sub>,h<sub>i</sub>)) at each 1 km and constant time interval (generally 3 min), then we calculate the Gaussian weighted temperature for each time.

$$T(t_i) = \sum_j T_{Na}(t_i, h_j) V(h_j) / \sum_j V(h_j)$$

The calculation starts with the average parameters for OH and O2. The results are compared in absolute values and time variation with the OH and O2 rotational temperatures. We search for the values of h<sub>0</sub> and σ which best fit the OH

Table 1. Days of measurements

	Lidar	Airglow
Date : 1998	Start-end (duration)	Start-end
July 24	18:31-20:45 (2:14)	18:45-03:00
August 18	18:45-02:00 (7:15)	18:45-04:40
August 19	22:32-03:52 (4:20)	22:00-05:00
August 26	20:03-01:28 (5:20)	20:15-04:50
September 17	19:00-22:13 (3:13)	19:00-04:20
October 15	18:47-20:43 (2:04)	19:00-23:00
October 21	19:09-21:49 (2:40)	19:15-28:00

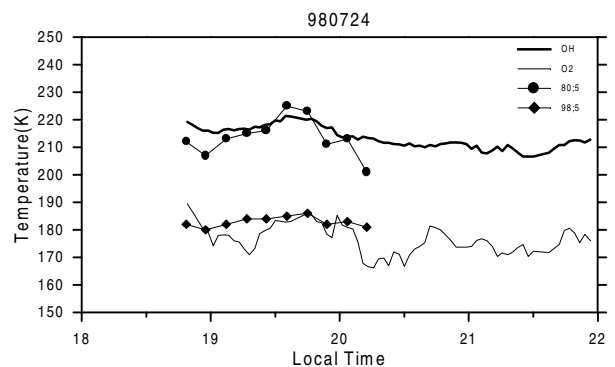


Fig. 1. Rotational temperatures for the OH(6,2) (thick line) and for the O2(0,1) (thin line). Gaussian fitted temperatures with the (h<sub>0</sub>; σ) parameters showed in the legend.

and O<sub>2</sub> temperatures. The full circles and diamonds in Figure 1 show these Gaussian weighted temperatures with the fitting parameters ( $h_0$ ;  $\sigma$ ) shown in the legend. Figure 2 (a-f) shows the results for the other days.

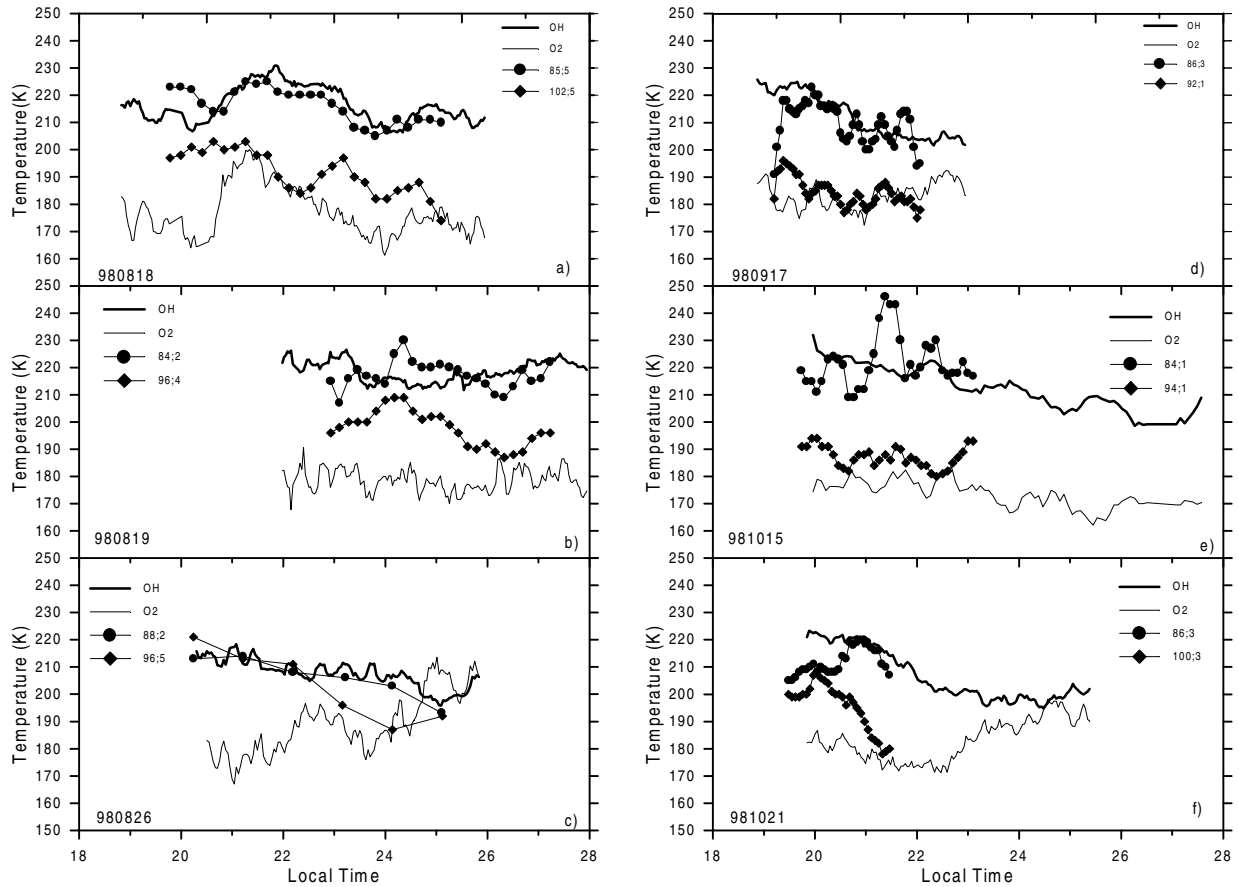


Fig. 2. As in Figure 1 but for August 18, 1998 (a); August 19, 1998 (b); August 26, 1998 (c); September 17, 1998 (d); October 15, 1998 (e); and October 21, 1998 (f).

### DISCUSSION

For the July 24 night, good agreement is apparent. For OH the agreement is good in absolute value as well as in time variation. For O<sub>2</sub> the agreement is good for the absolute value but not for the time variation. Better agreement is obtained for the OH temperature when  $h_0$  is 80 km, in the lower limit of the measured lidar temperatures.

Nevertheless, this good agreement is not a verified for the other 6 days. In Figure 2(a) for the night of August 18, 1998 time variations of the rotational temperatures are very similar for OH and O<sub>2</sub>, but with the O<sub>2</sub> temperatures around 40 K lower than OH. A good agreement is obtained for the OH and the (85;5) Gaussian fit, but the best fit for the O<sub>2</sub> has a higher temperature value and the time variations are also not very good. Similar results are obtained for the August 19, 1998 night (Figure 2(b)). For the night of August 26, 1998, a good agreement can be obtained only for OH. For this night, the time variation of the O<sub>2</sub> rotational temperature is completely different from the OH, but all the Gaussian fits give a similar variation. Our lidar measurements for the other three nights cover a smaller period but some conclusions can be drawn. For the September 17, 1998 night, except for the first three points that can be in error, the agreement is good. For the night of October 15, 1998 (Figure 2(e)) a reasonable agreement is obtained, but with a small bandwidth, meaning good agreement at only one height. For the October 21, 1998 night, a poor agreement is obtained for both the OH and O<sub>2</sub>.

It is noted that for most of the nights the OH and O<sub>2</sub> variations are well correlated, differing only by the absolute values. However, for the nights of August 26 and October 21 the time variations for the OH and O<sub>2</sub> are very different.

Table 2. Summary of the results

Date	OH $h_0$	OH $\sigma$		O <sub>2</sub> $h_0$	O <sub>2</sub> $\sigma$	
980724	80	3	f	98	5	g
980818	85	5	g	102	5	b
980819	84	2	f	96	4	b
980826	88	2	g	96	5	b
980917	86	3	f	92	1	g
981015	84	1	g	94	1	g
981021	86	3	b	100	3	b
	84.7	2.7		96.8	3.4	

g: good agreement; f: fair agreement; b: bad agreement

One interpretation for this is that the altitude of the emitting layer and probably the width is varying considerably during the night. Our calculation of the Gaussian fit assumes that during the night the average altitude and bandwidth of the layer is constant.

Table 2 shows the determined  $(h_0, \sigma)$  parameters as well as the 7-day average. The letters classify the agreements as good, fair and bad. It is seen that for the OH only one fitting is bad, but for the O<sub>2</sub> in 4 out of 7 the agreement is poor. The average values of 84.7 km for the OH layer and 96.8 km for the O<sub>2</sub> layer are within the high variation range expected, but the widths are smaller.

## CONCLUSIONS

For the OH rotational temperature, a good agreement can be obtained for the absolute temperature value as well as for the time variation for most of the nights. Disagreement for the time variation on a few nights can be explained by the large variation of the altitude of the emission layer along the night. For the O<sub>2</sub> rotational temperature the time variation may be in a fair agreement but not the absolute value, which is always lower than the lidar temperature. On a few occasions, mainly when the time variation of the OH and O<sub>2</sub> rotational temperatures are very different no agreement can be found with the Gaussian fit. The rotational temperature calculation for the OH emission is well established, and there is good agreement between the absolute values determined by different workers. For the O<sub>2</sub> emission there is great discrepancy between the few published values. It is concluded that the transition probabilities or other parameters used to calculate the O<sub>2</sub> rotational temperature should be reconsidered.

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