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Terrestrial O_2 Lines Used as Wavelength References: Comparison of Measurements and Model Computations[*]

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Summary. High-precision spectral measurements of the wavelength of terrestrial O_2 lines within solar spectra using the Kitt Peak 1 m Vacuum Fourier Transform Spectrometer are compared with model computations of the shifts of these lines due to wind up to 20 km. Although the wind data available existed only from radio sonde measurements about 65 km away and only from two launches per day, the shifts observed during two days could be explained well. Maximum shifts of terrestrial O_2 lines of ± 0.3 mÅ at about 6300 Å were observed. It is shown that it may be possible to correct a general trend of the observed shifts with a precision of ± 3 m s^{-1} during a day.

Key words: terrestrial oxygen lines – wavelength reference – wind model

1. Introduction

For many solar and stellar spectral investigations a reference wavelength system of better than 1 mÅ accuracy is needed. Within the red part of the visible spectrum and the infrared spectral region terrestrial O_2 lines serve since many decades as acceptable wavelength standards. Although Doppler shifts of these lines are expected due to wind speeds of up to several dozen m s^{-1} permanently existing within the terrestrial atmosphere, it is generally believed, that the stability of O_2 lines equals to about ± 10 m s^{-1}.

The aim of this work was to prove this hypothesis by comparing spectral measurements and model computations using wind measurements from radio sondes. Finally it should be checked, whether it might be possible to correct the wavelengths of terrestrial O_2 lines by these data.

2. Spectral Data

29 solar spectra averaging over $5 \cdot 25$ (arc s)^2 at different positions on the disk and about 30 min in time were obtained using the $1\overset{\mathrm{m}}{.}5$ McMath telescope and the 1 m Vacuum Fourier Transform Spectrometer (Brault, 1979) at Kitt Peak. The useful spectral region is from about 4800 Å to 6600 Å with a spectral resolution of about 600,000 and a signal-to-noise ratio in the wavelength region of 6300 Å of about 1000. The spectra were obtained on consecutive days from August 25 until August 29, 1980. Several interruptions were caused mainly by clouds and some technical problems, therefore only the 9 spectra covering the local times from 8:00 to 16:00 on August 26 and the 7 spectra obtained from 7:30 until 12:00 on August 28 could be used for this investigation. During these days the wavelength stability of the spectrometer, which is controlled by a LASER reference beam, was better than 0.1 mÅ/day.

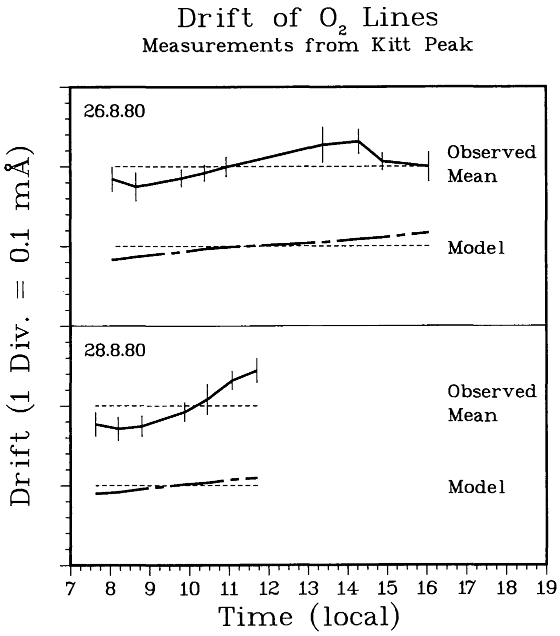

Fig. 1. Observed mean (——) and computed model (—-—) shifts of all terrestrial O_2 lines selected for August 26, 1980, and August 28, 1980, depending on the local time

11 terrestrial O_2 lines which are almost unblended were selected within the region of 6300 Å to investigate possible shifts caused by the wind. The census of data for these lines is given in Table 1. The wavelength positions of the lines were determined by 4th order polynomial fits through the lower third part of the lines. Shifts of the lines during the day were determined relative to an average position of the lines. The averaged shifts for all 11 lines and their r.m.s. errors depending on the local time are given in Fig. 1 for both days.

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Table 1. Census of data for the terrestrial O_2 lines used

Wavelength (Å)	Central intensity		Equivalent width		r.m.s. position stability (mÅ)
	Minimum	Maximum	Minimum	Maximum	
	(continuum = 1)		(mÅ)		
6277.30	0.082	0.419	62.6	122.9	0.089
6278.86	0.089	0.434	24.2	54.9	0.060
6279.09	0.041	0.357	29.2	78.1	0.079
6279.88	0.078	0.422	55.3	69.2	0.077
6281.16	0.117	0.472	20.7	43.5	0.093
6292.94	0.081	0.420	28.1	57.0	0.059
6295.16	0.099	0.447	23.1	48.1	0.058
6295.95	0.063	0.387	26.7	52.6	0.080
6298.44	0.111	0.447	23.6	47.3	0.049
6302.00	0.142	0.505	20.4	43.9	0.081
6302.75	0.117	0.469	31.1	45.5	0.095

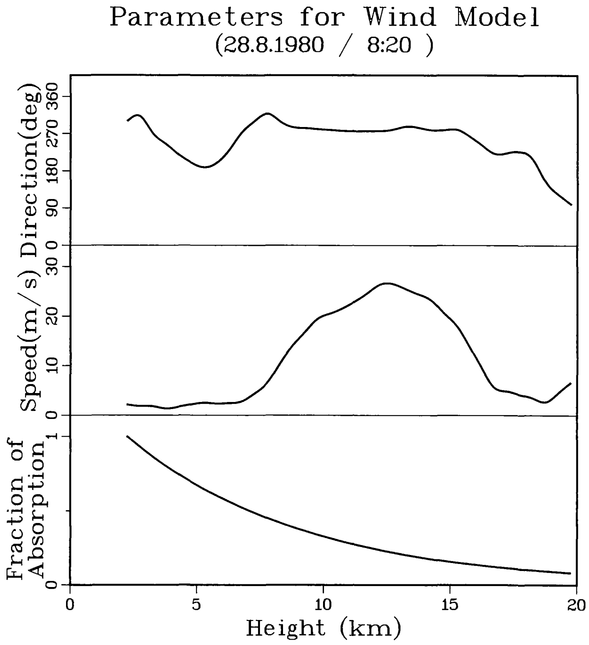

Fig. 2. Typical parameters of wind direction (0 deg $\hat{=}$ wind from the south), wind speed and fraction of absorption for the wind model used

3. Wind Model

Two times a day, at 5:00 and at 17:00 local time, radio sonde balloons are launched at the municipal airport of Tucson (about 65 km NE of Kitt Peak) to obtain data of the windspeed, the wind direction, and the temperature within the atmosphere. These data in steps of 50 mb in pressure were used to compute components of velocities of the wind within a model which serves to determine theoretically the shifts of an averaged terrestrial O_2 line taken from Table 1. In addition contribution functions depending on the air pressure and the rotation quantum number of the lines and including their dependence on the temperature were computed to determine the fraction of absorption for a special O_2 line depending on the height in the Earth's atmosphere. The artificial O_2 lines were then computed by adding up VOIGT profiles which resulted in about the same equivalent widths like those from the observed lines. The wavelength positions of these artificial lines were also determined by 4th order polynomial fits. The results are given in Fig. 1. A typical model of the atmosphere giving the wind speed, the wind direction, and the fraction of absorption is given in Fig. 2.

Details of the computations of the wind model are given in the german Diplomarbeit of Thiele (1982).

4. Results, Discussion, and Conclusions

The observed and computed shifts of terrestrial O_2 lines given in Fig. 1 are similar. It is concluded that the observed shifts in these cases are mainly caused by the Doppler shifts due to the wind.

In general the observed shifts are bigger than those computed. The mean value of the absolute differences between observed and computed shifts is 0.05 mÅ during the first and 0.09 mÅ during the second day. The maxima are 0.11 mÅ and 0.17 mÅ, respectively. Since 0.1 mÅ equals to a velocity of about 4.8 $\mathrm{m\,s^{-1}}$ at the wavelength used, a limit of $\pm 8\ \mathrm{m\,s^{-1}}$ is the maximum error for an individual correction of determined velocities by this method. Similar data existing from another observing run in November 1981 give in principle the same results, but with more noise, because the interferograms were transformed to spectra with less points.

There are two main limitations which have to be considered: The wind data were only available from measurements about 65 km distant. In most of the cases the wind data were not available for the exact times of observation of the spectra, therefore averaged data were used for the model for most of the times. It is concluded that the group of 11 terrestrial O_2 lines investigated are useful as a reference for velocity measurements to about $\pm 15\ \mathrm{m\,s^{-1}}$ without corrections (from Fig. 1). If the wind direction and wind speed for the entire atmosphere at the time of the observation of the spectra are available, the corrections should be possible to less than ± 3 $\mathrm{m\,s^{-1}}$. The limit we expect is the r.m.s. value for the positions of the lines (Table 1). In a realistic case it must be expected that there can be some changes of the wind speed during the launch of the radio

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sonde and therefore the corrections may only be possible to $\pm 5\,\mathrm{m\,s^{-1}}$.

New methods to determine wind speeds in the atmosphere by VHF radars may overcome the problems of radio sondes. The vertical oscillations of some $\mathrm{m\,s^{-1}}$ observed with these techniques e. g. by Balsley and Gage (1980) and Röttger (1980) do not change our results, because the spectra are averaged over 30 min, while the periods of the velocity oscillations are about 10 min.

The information about the temperature in the atmosphere are not really needed, because the dependence on the temperature is very small.

In the case that only a fraction of the O_2 lines is available, the most useful lines are those at 6292.94 Å, 6295.16 Å, and 6298.44 Å.

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