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LONG-TERM STUDIES OF WATER VAPOR ABSORPTION BAND IN TWILIGHT

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Abstract. Measurements of water vapor absorption band (1-3-1) in 650 nm spectral range in the framework of twilight spectrographic observations in 1960-2002 at Abastumani astrophysical observatory (41.8° N; 42.8° E) are given for the solar depression angle $\Delta\chi_{\odot}$ of 4°- 10°. Vertical distribution, averaged seasonal variations and long-term trends of the contents of water vapor at heights from 15 up to 100 km are investigated. It is shown that at heights of the mesosphere the water vapor content is mainly controlled by the solar cycle and mesospheric dynamics, while at the stratosphere the long-term trend of H_2O is influenced by the contents of methane in the atmosphere.

Introduction

Investigation of the mean vertical profile of humidity in the stratosphere and mesosphere along with its spatial and temporal variations is of great theoretical and practical importance in calculating the atmosphere energy and thermal balance as well as in developing numerical methods of the climate forecast [1].

Measurements

The present study deals with registration of water vapor at heights of 15-100 km, based on absorption band H_2O (1-3-1) measurements in the spectral range of 650 nm by the twilight spectrographic observations over the recent 40 years at Abastumani astrophysical observatory (41.8° N, 42.8° E) [2]. The twilight observations were performed from 1961 up to 1990 simultaneously in two directions– towards the north and in vertical of the Sun with spectrographs SP-48 (dispersion 8 nm/mm, spectral resolution about 0.25 nm) in the spectral range of 550-700 nm. During a twilight period each spectrograph registered six spectra for the solar depression angles $\Delta\chi_{\odot}$ from 7 to 18 degrees with the exposure time from a few seconds to 40-60 minutes. The H_2O (1-3-1) band, very weak at daytime observations, becomes distinct during the twilight, when optical mass, crossing by solar beams, strongly grows. The choice of this absorption band for measurements is related to the fact that the photo-films used in our spectrographic observations have maximum sensitivity in 600-700 nm spectral range, which provides the registration of the water vapor till late twilight. The intensity of water vapor absorption band (A, %) measured in twilight characterizes the absorption mass on the trace of the sunbeams and variation of the optical trajectory minimum distance from the Earth's surface [3]. In case of twilight observations from the Earth's surface, the mass of the water vapor $Q=Q_1 + Q_2$, where Q_1 is the mass of water vapor before the perigee and Q_2 – after the perigee. Both right terms should be multiplied by the function $F(\Delta\chi_{\odot})$, describing the dependence of absorbing gas mass on the twilight phase.

Absorption (in per cent) of the H_2O band deepest branch with the wavelength of 650 nm (A%) was measured in the twilight sky microspectrograms. It is known that the water vapor absorption from 2% up to 20% corresponds to 1 through 10 g/cm^2 content in the atmosphere [4].

In 1960 and from 1996 to 2002, twilight spectrographic observations at Abastumani, because of deficiency of high-sensitive photo film, were performed only toward the north at an angle of 40-45° to the horizon, with the solar depression angles $\Delta\chi_{\odot}$ changing from 4 to 8°. In Table 1 the measured values of water vapor absorption (A, %), averaged over 1960 and 1996-2002, for different solar depression angles $\Delta\chi_{\odot}$ and corresponding heights Z (km) of the Earth's shadow, as well as the H_2O content in the atmospheric column (Cont. H_2O g/cm^2) are given. The data (A, %) were corrected for the absorbing air mass growth factor – $F(\Delta\chi_{\odot})$ function.

The data in Table 1 show that within 40 years the water vapor absorption (A%) and consequently the H_2O content in the stratosphere above Transcaucasus increased on average by 17%, i.e. 0.4% per year. At altitudes of 15 to 50 km the water vapor was observed to decrease according to the formula $C = Co\ 10^{-\alpha Z}$, where Z is the height in km and α is the coefficient of the order of 0.16, changing slightly with the height.

Twilight observations in 1961-1990 were performed for $\Delta\chi_{\odot}$ from 7 to 12°, in the northward direction and in the solar vertical simultaneously. Table 2 presents the values (A, %) averaged over this observational period, for the four seasons of the year with allowance for the increase in water vapor absorbing mass with $\Delta\chi_{\odot}$ separately for the morning and evening twilight.

Table 1

1960				1996-2002	
$\Delta\chi_{\odot}$	Z, km	A, %	Cont,g/cm^2	A, %	Cont, /cm^2
4	15	-	-	9.8	5.1
5	22	8.1	3.9	8.8	4.4
6	31	6.4	3.2	7.3	3.7
6.5	36	6.1	3.0	7.1	3.5
7	42	5.8	2.9	6.9	3.4
7.5	50	5.6	2.8	6.5	3.3
average		6.4	3.2	7.7	3.9

Table 2

Absorption of the water vapor (A, %). The solar vertical.

$\Delta\chi_{\odot}$	Z,	Winter		Spring		Summer		Autumn		Average	
degr	km	I	M	I	M	I	M	I	M	I	M
7	40	6.6	9.5	9.4	7.0	10.1	8.9	10.6	10.8	9.2	9.5
7.5-8	46	7.2	7.4	6.7	6.8	7.9	8.5	7.8	7.4	7.4	7.5
8-9	57	6.3	7.6	7.0	7.1	7.5	6.7	8.1	6.3	7.2	7.0
9-10	70	8.9	9.3	9.5	7.2	10.4	9.0	9.2	8.1	9.5	7.9
10-12	88	11.1	9.8	10.7	9.6	12.7	11.1	12.5	10.8	11.8	10.8
Average		8.02	8.12	8.66	7.54	9.72	8.8	9.6	8.8	9.0	8.5
Ratio I/M		0.99		1.15		1.10		1.09		1.08	

Note: I- evening twilight, M – morning twilight.

The data in Table 2 indicate that the value of (A, %) above the Caucasus is maximum in the summer-autumn period, being higher in the evening twilight than in the morning one at all heights (except for the winter period). This feature could be associated with the trace of the sunbeams with the perigee passing over the terminator zone above the Black Sea water area (that of high humidity) in the evening, and over “drier” continental area of the Caucasus in the morning. Comparison of the data in Table 1 and 2 enables to estimate the vertical distribution of water vapor at heights from 15 to 100 km, i.e. slow dropping with the height from 15 to 50 km and then growth up to the maximum value (82-116 km). According to the photochemical theory, in result of H_2O photodissociation higher than 60-70 km, the humidity should sharply decrease, however, vertical motions of the air connected with cyclones break through the tropopause and transfer significant quantities of H_2O into the upper stratosphere and mesosphere [4].

To study long-term trends in water vapor absorption, mean annual values of A (in %) for a given $\Delta\chi_{\odot}$ were calculated. They are plotted in the Figure. For the solar depression angles of 9-10^o and 10-12^o two maxima in A are revealed: the early one in 1960-s and the late one in 1970-s, overlapped by a quasi five-year variation well distinct in the period of 1970-1990. Approximations for the long-term trends (A, %) were calculated by linear regression technique with the regression coefficient Re, relative errors err_n and standard deviation σ [5]. Table 3 lists the data separately for the periods 1991-1970, 1971-1980, 1981 –1990 as well as for the whole 30-year (1961-1990) observational period under different values of $\Delta\chi_{\odot}$.

It follows from Table 3 that the long-term trend of the water vapor absorption (within 1961 - 1990) is vague, as it is less than the relative error. For late twilight the trend is obviously negative in the period of 1961 - 1970 and positive within 1971 -1980. It is necessary to note a small positive trend of A for the whole period within 1961 - 1990 for $\Delta\chi_{\odot}=7^0$ (heights of 45-50 km).

Consequently, tracing of water vapor absorption for lower heights according to twilight observations of 1996-2002 is meaningful. The mean annual data (A, %) are listed in Table 4.

The present study is important for verification of the idea that the water vapor is formed in the stratosphere basically as a result of methane (CH_4) oxidation, the content of CH_4 in the circumterrestrial layer rising from 0.7 to 1.0 % per year. According to existing models the annual increase in methane by 0.8 % causes the growth of the H_2O content in the stratosphere by ~0.4 % per year [6,7}. At large heights the effect of CH_4 is difficult to distinguish because of a strong dependence of H_2O content on Lyman α variation in the solar cycle and on mesospheric dynamics [8]. This point is evident from the Figure by comparison the curves (A, %) for $\Delta\chi_{\odot}$ of 12-9^o and 9-7^o.

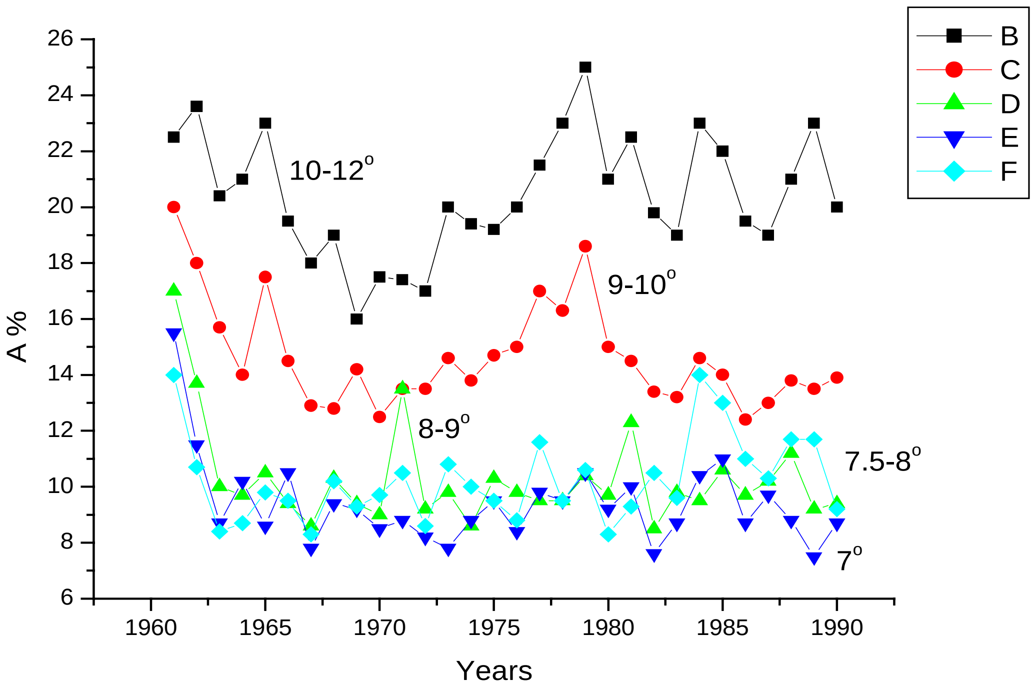

Figure. Mean annual absorption values of the water vapor band (1-3-1) in the range of 650 nm (A, %) for different $\Delta\chi_{\odot}$.

Table 3

$\Delta\chi_{\odot}$, Degr.	Years															
	1961-1970				1971-1980				1981-1990				1961-1990			
	Re	σ	A,%	σ	Re	σ	A,%	σ	Re	σ	A,%	σ	Re	σ	A,%	σ
12-10	-0.86	0.16	19.8	2.3	0.63	0.37	20	2.53	-0.033	0.026	20.9	2.0	0.04	0.27	20.4	2.25
10-9	-0.96	0.34	15.2	2.5	0.33	0.30	15	1.50	-0.20	0.08	13.5	0.7	-0.06	0.07	14.5	19
9-8	-0.79	0.66	11.0	3.4	0.19	0.18	10	1.2	-0.06	0.30	9.9	1.1	-0.09	0.085	10.3	2.2
8-7.5	-0.57	0.66	10.2	2.75	0.17	0.16	9	0.84	-0.04	0.36	8.9	2.0	-0.07	0.071	9.3	1.86
7	-0.38	0.4	10.0	2.4	0.18	0.16	8.9	0.84	-0.15	0.31	8.92	1.3	0.03	0.102	10.4	2.02
Aver.	-0.71	0.50			0.30	0.23			-0.10	0.26			-0.03	0.12		

The data in Table 4 show that, on the whole, for heights from 15 to 48 km the water vapor content increased by 3.5 % within 1996-2002, i.e. by 0.5 % per year. This result is quite consistent with the model calculation [6]. It should be noted that, according to our measurements, this increase for lower heights seems to grow, on the average, from 0.4 % per year within 1960-1990 up to 0.5% per year from 1996 to 2002, perhaps, pointing to anthropogenic growth of the methane content in the atmosphere.

Table 4
Absorption of water vapor (A, %) with allowance for the increase in absorbing mass with increase in $\Delta\chi_{\odot}$.

$\Delta\chi_{\odot}$	Z, km	Years				
		1996	1997	1998	2001	2002
4	15	9.0	9.4	6.0	9.2	12.0
5	24	6.9	8.8	7.2	8.6	9.9
6	35	5.1	6.2	6.3	7.3	7.4
6.5	41	4.8	4.8	4.3	4.5	7.8
7	48	5.9	5.8	7.9	7.3	10.3
average		6.3	6.9	6.4	7.4	9.5

Conclusion

Thus, the results of investigation on long-term variations of the water vapor absorption at twilight are basically consistent, with the finding of the present paper on modulation of the H_2O content in the middle atmosphere up to 40% during the solar cycle [8]. Our data also show not identical modulation of the water vapor from one solar cycle to another at heights of the mesosphere, which is apparently associated with a different level of solar activity and cyclic variations of the atmospheric dynamics. In the stratosphere the contents and long-term variations of H_2O are influenced by the abundance of methane in the atmosphere.

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