Study Of Atmospheric Boundary Layer Thermodynamics During Total Solar Eclipse On The Basis Of Microwave Radiometers Data

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Abstract—**Results of temperature profile measurements at altitude range 0÷600 m and total water content measurements during total (Kislovodsk, 2006; Novosibirsk, 2008) and partial (Moscow, 2011) solar eclipse by the using of microwave radiometer data presented in the report. Terrestrial consequences of solar eclipse (especially the total ones) are noticeable and important. Eclipses support unique, specific conditions which give the opportunity to numerous varied meteorological researches. The most important indicator of thermodynamical processes during solar eclipse is air temperature in the different altitudes in the atmospheric boundary layer (ABL). The ABL air temperature depends in general on the flux of solar radiation and on some features of the ground (albedo, absorptivity and emissivity) and the features of the air (mainly humidity).**

Keywords; Total solar eclipse, microwave radiometer, atmospheric boundary layer thermodynamics.

I. INTRODUCTION

This paper compares the results of the complex experiment during three solar eclipses: total (Kislovodsk, 2006; Novosibirsk, 2008) and partial (Moscow, 2011). Both of them in Kislovodsk and Novosibirsk had been analyzed earlier [1, 2] and such reactions as reduction of air temperature, increase of stability of the layer, and suppression of turbulence on the atmospheric boundary layer were found. Solar eclipses effects had been used as influence to thermal vertical stratification and by use simultaneous remote measurement of the dynamic reactions of the boundary layer had been studied. The values of the temperature gradients as functions of the height, time delay and distances had been calculated. The specifics of the thermodynamical effects in boundary layer and quantitative reactions of the thermal regime as results of solar eclipse had been represent in this work.

II. DISRIPTION OF THE COMPLEX EXPERIMENTS TO STUDY THERMODYNAMICS EFFECTS DURING SOLAR ECLIPSES

A. *Instruments for complex experiment to study effects of the eclipse on the atmospheric boundary layer*

As instrument for the measuring the dynamic of the vertical temperature stratification microwave temperature profilers MTP-5 an-angular scanning single-channel radiometers with the central frequency 60 GHz were used [3, 4, 6-8]. To measure the difference in thermal spatial reaction of the atmospheric boundary layer two units of the modern version of the MTP-5 had been installed in distance during each of experiments. The specification of this type of temperature profiler is shown on Tabl. I.

TABLE I. SPECIFICATION OF THE MTP-5

Parameter	Value
Radiometer with the central frequency	60 GHz
Altitude range	600 m
Displayed height interval	50 m
Measurement interval, minimum	2 minutes
Accuracy of temperature profile RMS error T[C] for 0÷600 m (depend on type of temperature profile)	less than 0.25÷0.90
Error in determination of the height	25%
Calibration	self calibrating

For measuring of the total water vapor content each 4 seconds the dual-channel radiometer with frequencies 22.23GHz and 20.73GHz was used. Such type of the radiometer is allowed to eliminate the effect of clouds during measurements [5]. And the second radiometer for water vapor was near other line of absorption on 140GHz. The signal of the water vapor fluctuations on this line is 3 or 4 times powerful in front of previous. For registrations of the solar radiation we used net radiometer CNR-1 instrument from Kipp&Zonen and ultrasonic anemometer as meteorological station [2].

B. *The specifics of the experiments in Kislovodsk, Novosibirsk and Moscow*

The first experiment with solar eclipse observation was in Kislovodsk on the 29 March, 2006, at the South part of Russia (Caucas Region). The total eclipse phase of the Sun started at 3.15 p.m. local time and with the duration 2 min 32 sec - for city Kislovodsk. One temperature profiler MTP-5 and additional equipment (net-radiometer CNR-1 and ultrasonic anemometer) were installed in the center of Kislovodsk city (altitude 890 m above sea level), second profiler was installed at about 18 km from Kislovodsk city (at altitude 2070 above

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sea level) on Station Shad-Hgatmaz (43.43 N; 42.66 E). Fortunately weather was excellent for observations during anticyclone conditions. We have a few clouds before eclipse.

In Novosibirsk, the solar eclipse started at 16:41 and ended at 18:45 Local Time (LT). The phase of the total solar eclipse lasted for about 3 min, from 17:43 to 17:46 LT. The meteorological conditions on August 1, 2008, in Novosibirsk were quite favorable for observing the solar eclipse and its effects in the atmosphere. On that day, the city was in a small gradient baric field and was relatively far away from the centers of the nearest cyclones and anticyclones. Partial cloudiness was present during the day. The clouds markedly decreased during the eclipse. During this experiment two of MTP-5 had been installed in distance 25 km on the way of shadow. One of them has been installed in the center of the city and the other one on territory of the Academy village of Russian Academy of Science. The total water vapour content Q was measured in the centre of Novosibirsk by using of a microwave spectral radiometer at the frequency of resonance transition for the water vapour line, 22.2 GHz and additional single-channel radiometer with frequencies 140 GHz. The net-radiometer CNR-1 was used also.

A partial solar eclipse (the total phase 0.813) occurred in Moscow, January 4, 2011 The beginning of the eclipse, 10h 38m, mid-12ch.04 m, the end of 30m -13 h (Moscow time). The beginning of the eclipse took place in conditions of almost continuous cloud cover, middle and end - with the breaking clouds, and the maximum phase of the eclipse was observed in almost cloudless atmosphere. Two temperature profilers (MTP-5) had been used in distance 18 km for observations. One of them was in the centre of the city and other in suburb.

III. RESULTS OF THE MEASUREMENTS

On Fig.1 the dynamics of the temperature profiles during day of solar eclipse in Kislovodsk region are shown with time interval 5 minutes.

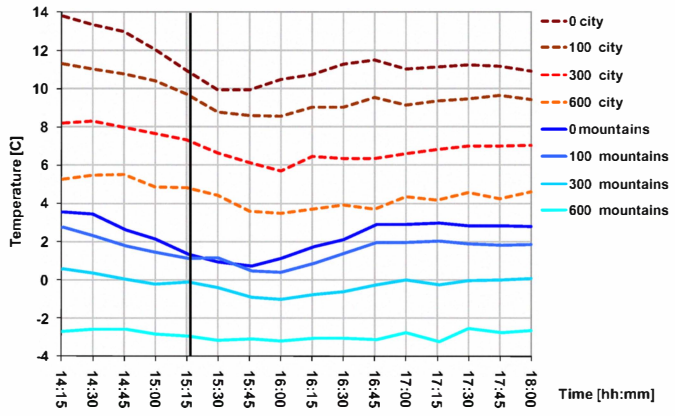

Figure 1. The dynamics of the temperatures profiles during solar eclipce period are shown for Kislovodsk city at altitude 890 m (0-600 city) and for Kislovodsk mountains Station Shad-Hgatmaz at altitude 2070 m above sea level (0-600 mountains)

The maximum decreasing of the temperature during eclipse was in Kislovodsk city (at 0 m 3.9°C, at 600 m 2.0°C) than on the Station Shad-Hgatmaz (0 m 2.8°C, at 600 m 0.7°C). At the Station Shad-Hgatmaz decreasing of temperature was started simultaneously for different altitudes (from the beginning the eclipse), but in the Kislovodsk city it was delay about 30 minute at the altitude 600 m relative to the surface layer.

The temperature profiles on mountain Station Shad-Hgatmaz and in Kislovodsk city at the moment total phase are shown on Fig. 2. We have a small inversion on mountain station.

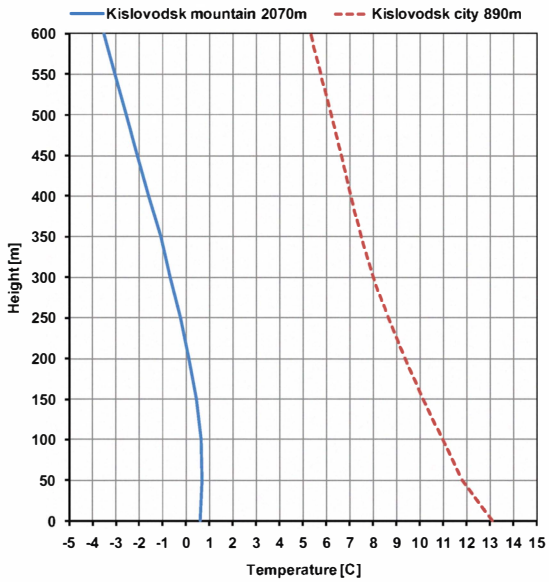

Figure 2. The temperature profiles on mountain Station Shad-Hgatmaz and in Kislovodsk city at the moment total phase are shown

In Novosibirsk, as well for Kislovodsk we had a small inversion abroad of the cities Fig.3. The town is inhibits the inversions development.

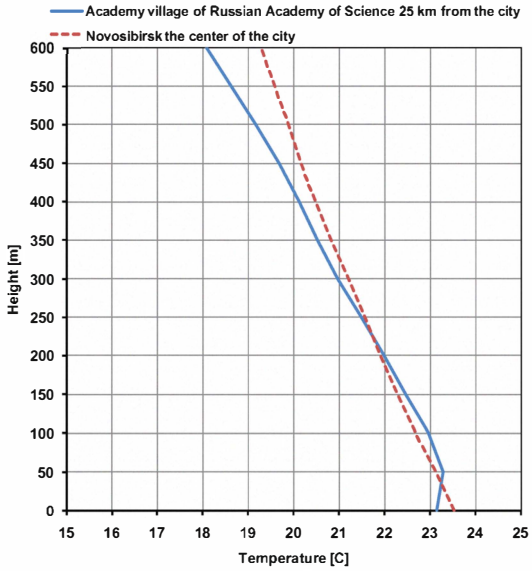

Figure 3. The results of measuring of the temperature profile during eclipse in Novosibirsk city and abroad are shown.

The minimum of the total water vapor content, equaling about 0.65 g/cm2, was observed approximately 40 min before the total eclipse phase. On the day of eclipse, starting from 13:00 local time until the total phase of the solar eclipse, there were considerably turbulent water vapor pulsations as large as from 0.1 to 0.25 g/cm2 more than 8%. Usually, the value of this fluctuation is not more than 0.02 g/cm2 and equal about 1%. The amplitude of these pulsations monotonically decreased during and after the eclipse, correlating well with the temporal pattern of the intensity of the temperature pulsations and pulsations of the vertical wind velocity component. This indicates that the convection was weakened not only in the near ground layer, but also in the boundary layer (up to about 2 km).

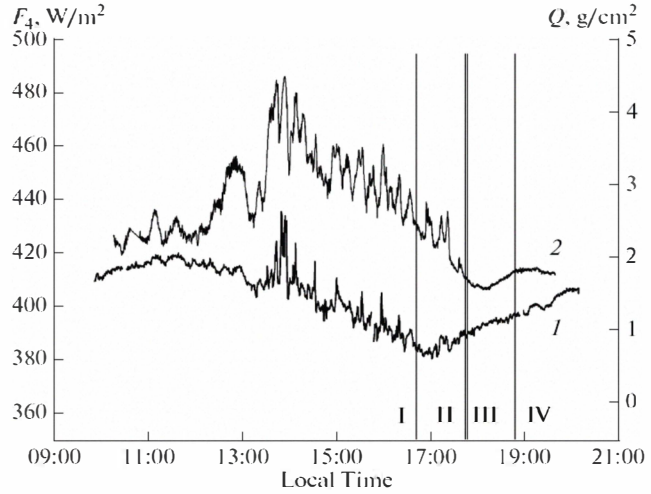

Figure 4. Total water vapor content Q (curve 1) and counterradiation F4 (curve 2) on August 1, 2008, in Novosibirsk. I and IV indicate the times of the eclipse start and end, and numbers II and III indicate the times of beginning and finish of the total eclipse phase.

The values of the temperatures gradients on different heights had been calculated for all three eclipses. The maximum was in Kislocvodsk city at 0 m and decreased with the heights. On mountains station we had much more bright reaction in temperature, it was 2.1 decrees in comparison for the same time in Kislovodsk city Tabl. II.

TABLE II. THE VALUES OF THE TEMPERATURES GRADIENTS ON DIFFERENT HEIGHTS DURING SOLAR ECLIPSES

Points of the measurements	0 м	100 м	300 м	600 м
Kislovodsk city 29/03/2006	3.9	2.8	2.6	2.0
Station Shad-Hgatmaz 29/03/2006	2.8	2.4	1.6	0.7
Novosibirsk the center of the city 01/08/2008	2.5	1.2	1	0.9
Academy village of Russian Academy of Science 25 km from the city 01/08/2008	1.7	1	0.7	0.7
Dolgoprudny (18 km from center of Moscow) 2011/01/04	0.9	0.7	0.6	0.6

The ground-based temperature changing is similar with previous publications [9-12].

The time shifting for the temperature minimum on the different heights are shown on Tabl. III. We had delay in heights reactions for Kislovodsk city about 30 minutes. It was for different heights in different time. And the same reaction we had on mountains station for all heights above 100 m but simultaneously. In Novosibirsk city the minimum was after one hour for all heights at the same time. And abroad of the city is like the same with small 5 minutes delay for each of the heights.

TABLE III. THE ILLUSTRATIONS OF THE TIME SHIFTING OF THE TEMPERATURE'S REACTIONS ON DIFFERENT HEIGHTS DURING SOLAR ECLIPSES ARE REPRESENT

Point of the measurements and time solar eclipses started	The shifting of the temperature's minimum on layer			
	0 м	*100 м*	*300 м*	*600 м*
Kislovodsk city 29/03/2006 14:00	01:35	01:50	02:00	
Station Shad-Hgatmaz 29/03/2006 14:00	01:37	02:00		
Novosibirsk the center of the city 01/08/2008 16:45	00:55			
Academy village of Russian Academy of Science 25 km from the city 01/08/2008 16:45	01:10	01:15		01:20
Dolgoprudny (18 km from center of Moscow) 2011/01/04 11:30	00:52		01:14	

IV. MAIN RESULTS

The comparison of the temperature reaction during three solar eclipses are shown maximum decreasing of the temperature was in Kislovodsk city (3.9°C at 0 m and 2.0°C at 600 m above surface) than in the station (2.8°C at 0 m and 0.7°C at 600 m above surface). The difference in temperature reaction for town area and abroad were the same as for mountains region (Kislovodsk) and for West Siberia territory (Novosibirsk) and for Kislovodsk it was about 1 degree and 0.6 in Novosibirsk.

The eclipse not only was accompanied by a decrease of turbulence intensity due to an increase in the stability of the atmospheric boundary layer. In Novosibirsk, as well for Kislovodsk we had a small inversion abroad of the town and the town is inhibits the inversions development.

The time delay in temperature reaction was about 30 minutes at the altitude 600 m relative to the surface layer in Kislovodsk town and correspondent to each of the height. The observational results of this study will contribute to detailed model calculations for clarifying the meteorological effects of total eclipse of the sun.

The minimum of the total water vapor content, equaling about 0.65 g/cm2, was observed approximately 40 min before the total eclipse phase in front the average value about 1.75g/cm2 as usually.

The observed quasi-periodic pulsations of water vapor content indirectly indicate the possible formation of a vertical circulation cell in the shadow area. The much more moist air has been removed from this band of boundary layer due to

increased pressure and a dry air enters from the middle troposphere. Such type of the circulation may give rise to internal atmospheric waves, which, in turn, cause the quasi-periodic fluctuations in water vapor content in the atmospheric column.

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