Abstract
In the paper we present the analysis of the temperature data of the total solar eclipse in China, close to Shanghai, on the 22nd of July, 2009. We examine the relation between the change of the visible arc of the Sun and the temperature decrease. We also examine the relation between the height of the measurement points above the ground and the value of the lowest decrease of temperature. We estimate the minimum height, where the decrease of the temperature is not remarkable. We present some new idea for further measurements, based on the results of the analysis. This work is the productum of the co-operation of the Slovak Central Observatory and the University of West Hungary, Department of Mathematics and Physics.

1. INTRODUCTION

In 2008 we presented a special way of the analysis of the temperature decrease during a total solar eclipse, compared with the function of the visible arc of the Sun. We used this method to examine the observed temperature data of the total solar eclipse in Turkey, on the 29th March 2006. (P. PINTER, K. PENTEK, Z. MITRE, 2008)

We applied this analysis method to former total eclipses as well, and we confronted the results and drew the conclusions from these details (PENTEK K., MITRE Z., 2009).

We recommended doing observations of the temperature values in different heights and areas, in the track of the total phase. We chose the total solar eclipse in China, on the 22nd of July, 2009, to do detailed measurements of temperature data, in several points.

2. METHOD AND SURROUNDINGS OF THE MEASUREMENT

Unfortunately the total phase of the solar eclipse on the 22nd July in 2009 moved across mainly the Pacific Ocean. One could observe the total solar eclipse on dry land from East India, Bangladesh, and South-east China. The shadow of the Moon moved across these countries before noon (local time), earliest (in the morning, around sunrise) in India, latest (around 11 AM) in China. (fig. 1.)

We can observe the most valuable data close to the highest position of the Sun (close to noon), that is why we recommended the area of Shanghai for the observation of the phenomena. The observation groups registered the temperature data during the eclipse in the territory of Tianhuangping, 130 km south-west from Shanghai. (We call the observation place as Shanghai in the following part of the paper.) We experienced 5min 50sec as total phase from the eclipse in the observation points.

The observation groups used the same measurement unit and apparatus, as in 2006 in Turkey: MiscroStep-IMS AMS 111. This unit collects the measured temperature data into a database; user can set the time difference between two measurements.

The geographical coordinates of the observation points are 30°43’ 46” North, 121°23’ 49” East. The groups recorded the temperature data in different heights and observed the humidity as well. We have seven databases from three measurement places from this territory.

We can see the details of the eclipse, number of data and time interval of the measurement in the table 1.

We experienced more measurement errors in China, than during the former eclipses, due to weather circumstances, which influenced the measurements and decreased the sharpness of the data. The weather was mainly sunny, but during the second part of the eclipse some clouds covered the sky (around 03:00 UT ≈ 11000 sec). This caused the significant and disturbing decrease
fig 1:
Track of total phase of the total solar eclipse on the 22nd July 2009, in China by F. Espenak & J. Anderson

Table 1:

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Number of datalines</th>
<th>Time interval (UT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (-10 cm)</td>
<td>21360</td>
<td>21:49:22 – 03:45:21</td>
</tr>
<tr>
<td>Temperature (10 cm)</td>
<td>21360</td>
<td>21:49:22 – 03:45:21</td>
</tr>
<tr>
<td>Temperature (50 cm)</td>
<td>21360</td>
<td>21:49:22 – 03:45:21</td>
</tr>
<tr>
<td>Temperature (150 cm)</td>
<td>680</td>
<td>22:09:31 – 03:49:01</td>
</tr>
<tr>
<td>Temperature t (200 cm)</td>
<td>21360</td>
<td>21:49:22 – 03:45:21</td>
</tr>
<tr>
<td>Humidity (%)</td>
<td>17</td>
<td>21:49:22 – 03:45:21</td>
</tr>
</tbody>
</table>

T1 (first contact) 00:23:08.3 1388.3s
T2 (second contact) 01:36:14.4 5774.4s
Tk (middle of the eclipse) 01:39:10.6 5950.6s
T3 (third contact) 01:42:07.8 6127.8s
T4 (fourth contact) 03:01:48.0 10908s

Visible angle diameter of the Moon: 33.2’
Visible angle diameter of the Sun: 31.5’

Position of the Moon and Sun in the sky, at the time of the middle of the eclipse:
Rectascension: 8h 05m 40s Declination: +20° 18’ 08.3”
Distance of Moon - Sun = 353 813.7 km
Distance Sun – Earth = 1.0160 AU ≈ 151 991 400 km
of the temperature; we can clearly recognize this run-down in the temperature graphs (Fig. 2/b, 2/c, 2/d, 2/e). The middle-forced wind also caused errors during the measurements, because the temperature always changed a bit up and down in a very short time interval. This caused a remarkable spread of the measured data and decreased its sharpness.

We will pay attention to these mistakes during the analysis, especially when we fit a function to the data.

3. EXAMINATION AND FUNCTIONS

We use the data of the measuring points at heights of 0.1, 0.5, 2.0 metres from the Observation Place 1. (Fig. 2/b, 2/c, 2/e) (From this place Bulgarian experts observed the eclipse.)

From the Observation Place 2. we use the data of the one measuring apparatus at a height of 1.5 metres. (Fig. 2/d) (From this place the experts of the Slovak Central Observatory observed the eclipse.)

The distance between the two observation groups is approximately 100 meters. This distance did not influence the measured data; we will see this during the analysis.

At the third measure point we recorded the humidity of the air during the total solar eclipse. We examined these data as well, to find any relation between the other measured data and time.

We will examine the measured values and fit an appropriate function to these data, using the method of Pentek. (PÉNTEK K., 2002., PINTER P. et al. 2007., PINTER P. et al., 2008a.)

We will represent these data in one coordinate system as well to examine the values of each function. We will try to find mathematical relations between the decrease of temperature and delay in time from the process of the eclipse and the height of the measurement above the ground.

We will draw the conclusions from the results, and give remarks to apply for the future observations to reach more sharpness.

In the first step, we represent the recorded temperature data as the function of time. We determine a time interval, which includes all temperature data of the eclipse, and also data before and after the phenomena, not dependent on the solar eclipse. During our analysis we choose the borders of this interval approximately 23 minutes before and after the solar eclipse.

Fig 2/a:
Graphs of temperature data from measuring apparatuses at different heights. Numbers on the “t” axis of the coordinate system represents the time from the 0h UT in seconds.
Fig. 2/b, 2/c: Graphs of temperature data from measuring apparatuses at different heights. Numbers on the “t” axis of the coordinate system represents the time from the 0h UT in seconds.
Fig. 2/d, 2/e: Graphs of temperature data from measuring apparatuses at different heights. Numbers on the “t” axis of the coordinate system represent the time from the 0h UT in seconds.
Fig 3.: Linear function, fit on the temperature data independent from the solar eclipse at a height of 10 cm.
We can represent with this linear function the process of the change of the temperature without the solar eclipse.

Then, we put out the data not dependent on the solar eclipse from this time interval, and represent as the function of time. Obviously this pointset does not contain “solar eclipse influenced” temperature values. We fit a linear $Y(t)$ function to these independent data. This function describes the process of the temperature change in the selected interval, approximately on the same way like on a normal day without the total solar eclipse. (fig. 3.)

In the next step we describe the change of the area of the visible arc of the Sun as the function of time. (fig. 4.) We use the same method, like the analysis of the data from the 1999 and 2006 solar eclipses (PÉNTEK K. et al., 2009.)

Then we subtract every recorded temperature values during the solar eclipse from the values of the $Y(t)$ function at the same times. Now we receive the real values of the temperature decrease from the approximately temperature values of a normal day.

We represent the received data in separate coordinate systems, and search the most suitable polinom functions on them. During the former analyses we fit sixth degree polinom functions. These functions had appropriate accuracy to these examinations. But now - due to the effect of weather - we recognize many errors in the data from Shanghai that is why we need to fit such polinom functions, which have more accuracy.

Fig. 4.: Visible arc of the Sun as the function of time during the total solar eclipse in Shanghai, calculated to the observation place.
We fit ninth degree polinom functions on these data, using the help of a computer. By this step, we have appropriate accuracy for our analysis, and we can determine the lowest value and time of the temperature decrease. (fig. 5/a, 5/b, 5/c.)

In the next step we transform the area of the visible arc of the Sun as the function of time to compare with the decreases of the temperatures. We represent this function between the interval of \([0;10]\). We project the time interval of the total phase with weak lines to the graphs of the temperature decreases, to compare the times of the phases of the total solar eclipse with the times of the lowest values of temperature decreases. (fig. 6.)

**Fig. 5/a:** Graph of the temperature decrease and the fit polinom function at the observation point 1. (Bulgar), at 10 cm height.

**Fig. 5/b:** Graphs of the temperature decreases at the three measurement heights at the observation point 1., and the fit polinom functions.
Fig. 5(c): Graph of the temperature decrease at the observation point 2. (Slovak) and the fit polinom function.

Fig. 6.

Graphs of the temperature decreases as the function of time, contains data from all observation points in one coordinate system. We also represent the transformed area of the visible arc of the Sun as the function of time.

We represent the change of the humidity (in percents) as the function of time, where we transform the area of the visible arc of the Sun between the interval of [0;100]. (fig. 7.)

Then, we do the analysis and examinations of the temperature results. We calculate the time differences between the same values of the area of the visible arc of the Sun as the function of time and the temperature decrease as the function of time. In this way, we can recognize the time delay of the temperature values at the main phases of the eclipse. (table 2.)

We examine – as a new field of our research – the relation between the lowest temperature decrease and the measurement position above the level of the ground. We determine the height, where the decrease of the temperature during the solar eclipse reaches the value of the error of the measurement, so we cannot recognize any decrease in the temperature.
Fig 7. Humidity in percents as the function of time. We also represent in this coordinate system the transformed area of the visible arc of the Sun as function of time.

4. NEW RESULTS AND CONCLUSIONS

At the Observation Point 1. (Bulgarian group) the experts made an observation 10 cm deep under the ground (fig. 1/a). The temperature data do not show any remarkable changes, that is why we do not use these data for further examinations during our analysis. But we can recognize in these data that the temperature of the soil stay almost at the same value during the eclipse, and this process turned into increase close to the end of the eclipse. We cannot recognize here any temperature decrease during the time of the total solar eclipse.

We can see, that the temperature data of the Observation Point 2. (Slovak group), - in contrast to the distance of this observation point 100 meters away from the Observation Point 1. - do not show any difference from the data of the Bulgarian group. That is why we can represent these data together with the data of the Bulgarian group. (fig. 6.)

In the joined graphs we can easily separate the temperature decrease functions in different heights, and we can experience, that the higher we measure, the smaller the decrease.

We can see the results of the calculations in the table 2.

<table>
<thead>
<tr>
<th>P</th>
<th>E</th>
<th>A10 cm</th>
<th>D10cm</th>
<th>A50cm</th>
<th>D50cm</th>
<th>A150cm</th>
<th>D150cm</th>
<th>A200cm</th>
<th>D200cm</th>
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<tbody>
<tr>
<td>0</td>
<td>→0</td>
<td>1388,3</td>
<td></td>
<td>1867</td>
<td>478,7</td>
<td>1879</td>
<td>490,7</td>
<td>1981</td>
<td>592,7</td>
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<tr>
<td>Min</td>
<td>→0</td>
<td>5950,6</td>
<td>6046,3</td>
<td>95,7</td>
<td>6023,45</td>
<td>72,85</td>
<td>6105,98</td>
<td>155,38</td>
<td>6045</td>
</tr>
<tr>
<td></td>
<td>→0</td>
<td>10908</td>
<td>9621</td>
<td>-1287</td>
<td>9569</td>
<td>-1339</td>
<td>9901</td>
<td>-1007</td>
<td>9656</td>
</tr>
</tbody>
</table>

Table 2:

<table>
<thead>
<tr>
<th>H</th>
<th>Tmin</th>
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<tbody>
<tr>
<td>10 cm</td>
<td>-8.0161</td>
</tr>
<tr>
<td>50 cm</td>
<td>-6.0852</td>
</tr>
<tr>
<td>150 cm</td>
<td>-4.9582</td>
</tr>
<tr>
<td>200 cm</td>
<td>-4.4022</td>
</tr>
</tbody>
</table>

P: Temperature value (°C)
E: Contacts of the total solar eclipse (SEC)
A: Time of the P temperature value at the signed height (SEC)
D: Delay of the A time value from E value. (SEC)
H: Height above the ground (CM)
Tmin: Minimum value of the temperature (°C)
Based on the lowest values of these functions, we can determine the minimum height where we cannot experience temperature decrease. We represent the lowest temperature data from the table as the function of the height from the level of the ground. Regarding, that we can describe almost all of the natural phenomena by exponential function, that is why we fit an exponential function as the most suitable function to these data points. We can see the graph and the fit function in the (fig. 8.).

We can recognize from the fit function that the temperature decrease above the heights of 18–20 meters almost equal with the error of the measurement. Above this height we cannot experience any temperature decrease during the total solar eclipse in China, Shanghai, in 2009.

We presume that the height of disappearance of the temperature decrease is similar in other total solar eclipses as well. We also presume that the type of soil and the environment also influence the height, where the temperature decrease disappears.

We presumed before the analysis, that the higher we measure, the latest the lowest value of the temperature will occur after the interval of the total phase. So, we presumed, that the slighter the decrease of the temperature, the more the functions will shift to the right of the coordinate system. Despite of these expectations of ours we cannot recognize this phenomenon in the functions in the (fig. 6).

We can see in the graphs of (fig 6.), that the lowest values of the temperatures are in an approximately 1.5 – 2.5 minutes delay from the middle of the eclipse in every height. The process of the decrease started 8-10 minutes later than the beginning of the phenomenon, and the increase stops 20-22 minutes before the end of the eclipse.

So we just experience similar time delay of the process of the temperature change from the phases of the solar eclipse in every height like during the former examined total solar eclipses. (Pintér P. et al., 2008b.)

![Graph of the lowest temperature decreases as a function of height.](image)

**Fig. 8. Lowest temperature decreases as the function of height. We can see the fit exponential function to the lowest temperature decreases.**

### 5. FINAL CONCLUSIONS

We experienced every phenomena during the total solar eclipse in China like during the total solar eclipses what we examined before. (Péntek K. et al., 2009.)

But during the measurements in Shanghai we noticed more errors, due to the weather circumstances like the wind, which caused the disturbing change of temperatures in a short time interval. We tried to moderate the error with the help of a polinom function with more coefficients – ninth degree polinom -, than before. Most part of the total solar eclipse occurred before the highest position of the Sun in the sky – before noon – but this situation did not influence our measurement.

From the measurement in 2009 we received data from different heights, which we used for detailed examinations. That is why we can say approximately the height, where we can not experience the temperature decrease.

But – despite of our presumption – we can not recognize such delay of the functions, what we wanted to use to demonstrate of the process of the warm up of the air, after the end of the total phase of the solar eclipse.

In the future we need to pay attention to collect data from more measuring points in different heights, up to 20 meter high level. We need to collect data above different type of soils. We need send groups to the different points of the moon shadow ellipse, to examine the temperature change during different length of total phases.
Acknowledgements

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REFERENCES


