Mathematical analysis of temperature results of the total solar eclipse on 29.03.2006.

T. Pintér, Slovak Central Observatory, Hurbanovo, pinter @suh.sk
K. Péntek, NYME, Savaria Campus, Szombathely, pentek @nyme.ttmk.hu
Z. Mitre, NYME, Savaria Campus, Szombathely, plomet @freemail.hu

Abstract
In the paper we present the mathematical analysis of the measured temperature values of the total solar eclipse in Turkey (Antalya Bay). A research group of the Slovak Central Observatory (SUH) observed this eclipse on the 29th of March 2006, very close to the central line of the eclipse. We present a new way of processing of the measured values, and draw new, supervising conclusions from it. We also present the theory of the used special examination method.

1. INTRODUCTION

The research group of the Slovak Central Observatory performed a successfull observation in Turkey, in March, 2006. The group made a complex, scientific observation of the total solar eclipse, which appeared above the area. The expedition paid a special attention to observe the temperature decrease, as a result of the total solar eclipse, in addition the astronomical and photographical observations. (Littman et al., 1999*;* Espenak, 2004).

This paper describes the mathematical analysis of the measured temperature values, and it is the result of a cooperation between the University of West Hungary, Savaria Campus, Mathematical and Phisical Institution - NYME-SEK, and the Slovak Central Observatory - SUH.

Observable radiation from the Sun stops for a couple of minutes, during a total solar eclipse. One can only observe the thread-like structure of the suncrown in the sky from the covered area by the Moon’s shadow. At this time, the Moon’s body seems visibly black, and fully covers the Sun. Brightest stars, planets appears, because of the significant decrease of the intensity of the scattered light in the atmosphere. We can experience on our own skin the decrease of temperature and the grow of the force of the wind. In such a case, the Moon accurately crosses the imaginary line between the observer and the center of the Sun. The Moon’s center almost touches this imaginary line.

The Earth and the Moon revolve around the Sun on ellipse-shaped orbit. That is why (close to certain extreme positions) the appear angular diameter of the Moon becomes sometimes less, than the appear angular diameter of the Sun. In this case, we can observe an annular total solar eclipse. When the appear angular diameter of the Moon becomes larger, than the appear angular diameter of the Sun (this is the favourable case for the examination below), the diameter of the moonshadow - projected on the surface of the Earth - can be between 1 and 250 kilometers. It depends on the distance of those from the Earth in case of a given total solar eclipse. The length of the total phase in time – visible from the central line of the given eclipse - can be between 1 second and 7,5 minutes. The Moon‘s shadow induces changes in the eclpise covered atmosphere: because of decrease of the sunlight, twilight like conditions are present, we can notice many biological, social, meteorological, and other phenomena.

The shadow of the Moon darted across in Central Europe on the 11th of August 1999. One of the best observation places was Hungary, where experts made many analyses from the observed data of that eclipse. (Makra et al., 1999; Nowinszky et al., 2000; Péntek, 2002).

We tried to collect further observed data from other eclipses for a detailed analysis. The partial solar eclipse on the 31st of May in 2003, covered the 85 percent of the Sun. We could do only simple observations, because it appeared in an unfavourable time – early in the morning in Hungary.

Then, we examined the ways of the Moon’s shadow on the surface of the Earth during some total solar eclipses in the close future. We took the ones close to Central Europe and easily approachable into a special consideration. The total solar eclipse on the 29th of March in 2006 seemed a perfect goal from this point of view. Central line of the Moon’s shadow darted across in several countries, such as Turkey, which is easily approachable from Central Europe. Research group of the Slovak Central Observatory made perfect temperature, visual, photographic observations in

Turkey, the Hungarian research group observed the social, etological, biological, botanic phenomena, during the total solar eclipse. (Vértes et al., 2006; Pintér et al., 2007).

This paper presents the analysis of measured datalines of the research group of SUH.
We introduce the process and preferences of the eclipse in *section 2*. We use the method of Péntek (2002) for the analysis in *section 3.*, and draw the conclusions from the results of the examination in *section 4*. Application of the results obviously give useful information and data to the experts, who are occupied in similar researches.

2. DESCRIPTION OF THE TOTAL SOLAR ECLIPSE, SURROUNDINGS OF OBSERVATION

The eclipse began early in the morning, over East-Brasilia, where the central star of our Solar System rose, and appeared above the horizon as a black Sun. The shadow of the Moon moved in the direction of The Atlantic Ocean with significant speed, reached West-Africa, swept through Central-Africa, touched lightly Egypt, then moved toward the direction of Mediterraean See and entered Turkey. Then the shadow moved in the direction of the Caspian See, and leaved the surface of the Earth in Central Asia (Mongolia), where the Sun appeared and set under the horizon as a black disc.

Observers could examine the total phase of the eclipse at the Turkish Riviera inside a 160 km wide shadow stripe. Here the Moon appeared as a black body in front of the Sun, and fully covered it. Observers could examine the eclipse between 1 second and 3 minutes 47 seconds long, it depended on the geographical place of the observation. The central line of the shadow stripe reached the Turkish Riviera close to the area of Side. Place of measurement laid a few kilometers from this line, in a park of Selimiye, on grass covered soil, at *φ=36° 49‘ 03“ (N), λ=31° 18‘ 14“ (E)* coordinates.

The Slovak research group measured and stored the temperature values by a MicroStep-MIS AMS 111 data-logger type instrument. This instrument uses a microprocessor to collect the data from its small measuring apparatus. The research group placed this sensor 1,5 meters above the level of ground during the observation. They preserved it from direct sunlight, so the sensor could collect only valid values. The working instrument collected the data on the 29th of March in 2006, between 00:00:01 and 23:59:31, included both of the mentioned time points. The instrument stored the observed values in a memory unit, in datalines. It produced a mass of facts with 2880 lines from this observation. Phases of the total solar eclipse ensued in the following times. We calculated these times to the geographical position of the instrument (in Universal Time, local time equals with UT + 3 hours):

Contact: U1
Time: 09:38:18,8, Height: +56°, Azimuth: 170°, Position angle: 227°.

Contact: U2
Time: 10:54:54,8, Height: +54°, Azimuth: 204°, Position angle: 045°.

Contact: Uk
Time: 10:56:47,4, Height: +54°, Azimuth: 205°, Position angle: 138°.

Contact: U3
Time: 10:58:39,7, Height: +54°, Azimuth: 206°, Position angle: 231°.

Contact: U4
Time: 12:13:29,9, Height: +45°, Azimuth: 231°, Position angle: 049°.

Figure 1: Total Solar Eclipse visible from Antalya.

3. MATHEMATICAL ANALYSIS OF THE TEMPERATURE VALUES

3.1. Temperature – Time function

We examine the measured T temperature, as the function of t time. We assume, the t independent variable of the $T(t)$ function, is not a probability variable. It means, that we determined the t_0, t_1, t_2, ... time points of every single measurements without mistake. However, T_0, T_1, T_2, ... temperature values of T dependent variable charged by inaccuracy of measurment. That is why instead of the theoretical value of the function, we observe such a probability variable, which distribution is approximately normal. Its dispersion in the time intervall of measurement equals approximately.

We examine the temperature data of the derived function at first, based on the values measured close to the eclipse. We can experience temperature decrease during a partial solar eclipse with significant covering or during a total solar eclipse. We can observe the same temperature values after the last phase of the eclipse, like the daily normal temperature values. Péntek (2002) offered two different measurements during the

examination of the total solar eclipse in 1999, to examine and prove the measure of temperature decrease. At first, they measured temperature values during the day of total solar eclipse, and in the same time interval, a few days after. Then they determined linear functions, based on the measured values for each observed days. They ignored the decreasing temperature values on the day of eclipse, which depends on the total solar eclipse. Then they interpolated a linear function, based on the the temperature values of times, before and after – not dependent on - the total solar eclipse. The interpolated function of measured values of the day after the eclipse showed almost the same, like the interpolated function of measured values of the day of total solar eclipse, which does not dependen on the total solar eclipse. It follows from that, if the total solar eclipse had not appear, changing of temperature would have showed similar values in the same time interval.
By the reason of the former results, we examine the changing of temperature of the day of the eclipse compared with interpolated linear functions of data of the days before and after the day of eclipse.

We can consider the parts of the functions of temperature values *T(t)* before and after the phenomenon as one pointset, which queued along a straight line. Now we include only the temperature data, which does not depend on the eclipse, based on the values measured on the 29th of March in 2006. Equation of the regression straight, based on this parts:

$$Y_1 = 12{,}844 \cdot t + 12{,}868 \qquad (1)$$

We can persume according to the conclusions from the analysis of the temperature values measured in the August of 1999, that the temperature values during the total solar eclipse on the 29th of March in 2006 in the bay of Antalya would have changed along the $Y_1(t)$ function, if the total solar eclipse had not appeared. We can see this function as well in *Figure 3*.

3.2. Area of the visible arc of the Sun – Time function

Now, we examine the experienced changes in luminosity, which decreases first, then increases during the total solar eclipse, as the function of time. We can recognize the decrease and increase of temperature from the temperature data in *Figure 2*. This change obviously depepnds on the total solar eclipse. The area of the Sun not covered by the Moon (so-called Area of the visible arc of the Sun) decreases at first and increases after the total phase of the total solar eclipse. It follows from this, that the area of the Sun covered by the Moon increases at first, no direct sunlight touches the ground during the total phase of the eclipse, then the size of the covered area of the Sun decreases till the end of the eclipse. By reason of this, we examine the decrease and increase of the visible arc of the Sun as the function of time.

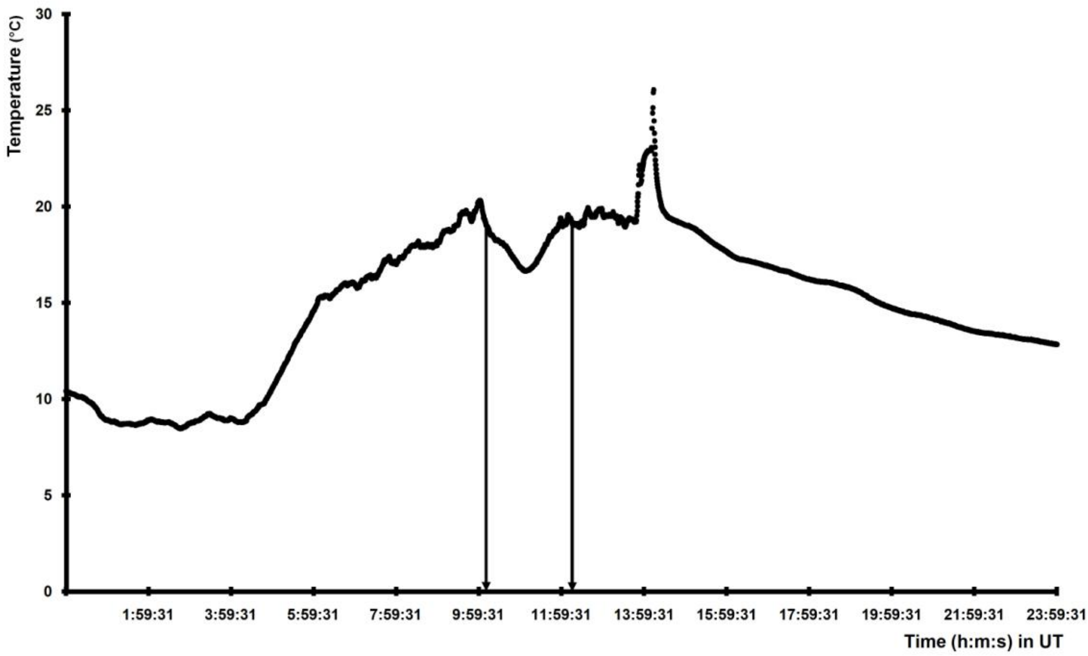

Figure 2: Measured temperature values at the signed times in Selimiye, on 29th of March 2006.

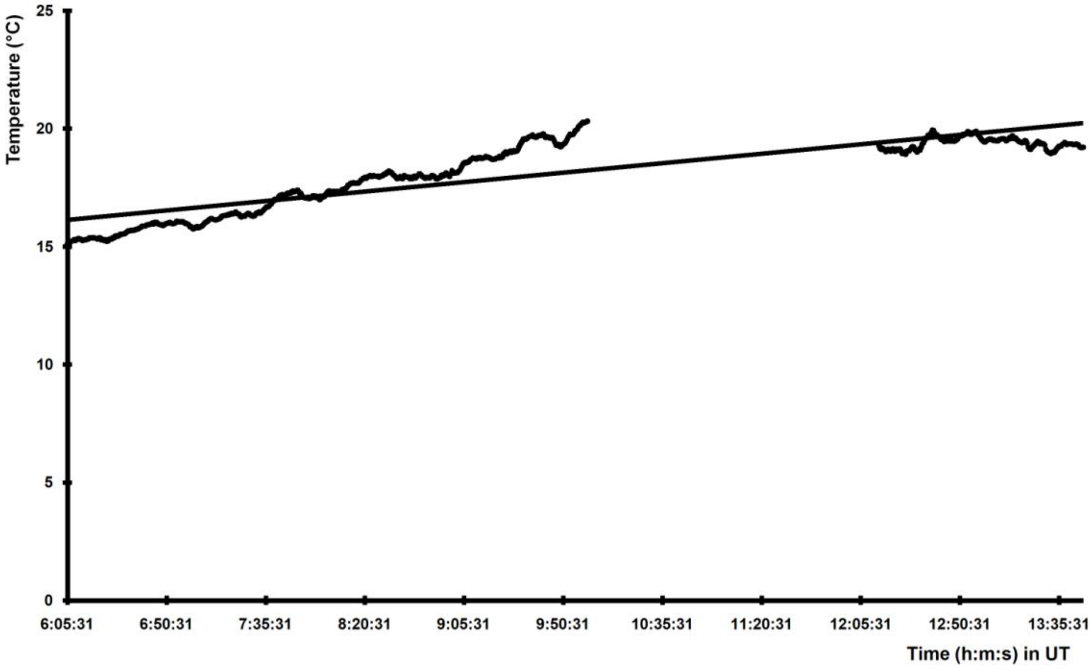

***Figure 3.: Measured temperature data, not dependent on solar eclipse in Selimiye, and its trendline*.**

We use some reduce premise, close to the real circumstances:

- Visible angular diameter of the Sun was D_O = 32,0‘ at 11h 00m on the 29th of March in 2006. Visible angular diameter of the Moon was D_M = 33,5‘ in the same time. We persume that the visible size of the two celestial bodies perfectly equals, that is why we can work with two geometric coincident roundplates.

- We suppose, that both of the coincident roundplates of the Moon and the Sun moves and covers each other along their central line. (This is a rational premise, close to the real cicumstances, because the research group of SUH executed the observation close to the central line of the total solar eclipse). In other words, the Moon moved smoothly along a straight line in front of the Sun, which links the center of the Moon and that of the Sun in the beginging of the partial eclipse.

- We suppose, that the position of the observation during the $U_2 - U_1$ = 4596 s time interval the Moon covers an equal distance with its appear angular diameter on the sky, as compared to the Sun, with ω = = 32,0’ · 4696^{-1} s^{-1} = 6,962576 · 10^{-3}’s^{-1} relative angular speed. Coincident plates of the two celestial bodies remains still to each other, during the interval of total phase $U_3 - U_2$ = 224,9 s. Then during the $U_4 - U_3$ = = 4490,2 s time interval the Moon covers an equal distance with its appear angular diameter again, as compared to the Sun, with ω= 32,0’ · $4490{,}2^{-1}$ s^{-1} = = 7,126631 · 10^{-3}’s^{-1} angular speed.

- We use the unit of the radius of the coincident plate of the Moon and the Sun as one, to make the calculations easier. We examine only the rates and tempo of decrease of luminosity as the function of time.

We apply the simplifications above, and use two coincident plates, which covers each other at first, then slip down from each other. We examine the uncovered area of the Sun by the Moon, during the time intervall of the eclipse (Péntek, 2002).

We use a fixed Cartesian coordinate system to describe the geometry of the process of the total solar eclipse. The origo of the coordinate system is joined to the O_1 center of the plate of the Sun. The *x*-axis is placed in such a way, that the O_2 center of the plate of the Moon moves along on this axis from right to left, in other words from the positive section of the axis in the direction of negative.

We can describe every phase of the total solar eclipse unambiguously by an angular ($0° < \alpha < 180°$, $\alpha \neq 90°$). We determine this angular by the positive section of the *x*-axis, and the semi-straight, which links the origo and the *M* point of intersection of plates of the Moon and of the Sun, in the upper semi-plane of the coordinate system.

The $\alpha \to 0°$ describes the beginning of the partial eclipse in U_1 time, acute angles describe the first partial part of the eclipse, $\alpha \to 90°$ describes the begining of the total phase in U_2 time. The $\alpha \to 90°$ describes the ending of the total phase in U_3 time, obtuse angles describe the second partial part of the eclipse, $\alpha \to 180°$ describes the end of the partial eclipse in U_4 time. We can see the sequence of phases of the eclipse and definition of the angle alpha in *Figure 4*.

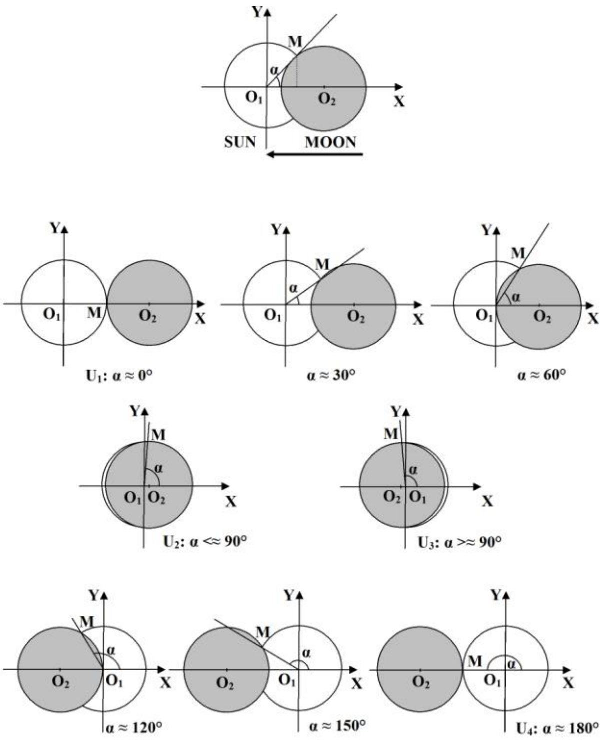

Figure 4.: Explanation of the angle α, which characterizes the partial phase of the total solar eclipse.

We can easily see that we can determine the distance of the $d\ (O_1\, O_2)$ centres of plates of the two celestial bodies by the

$$d(O_1O_2) = |2 \cdot \cos\alpha| \qquad (2)$$

equation. The amount of the distance decreases smoothly during U_2 - U_1 time intervall from 2 to 0, because we used the unit of the radius of the two celestial bodies as one. That is why, we use the

$$\cos\alpha = 1 - \frac{\omega}{D_M} \cdot \Delta t = 1 - \frac{\omega}{D_M} \cdot (t - t_0) \qquad (3)$$

equation in the U_2 - U_1 time interval, to describe the changing of the values of *cos α*, using the metric of *t* time in seconds. Then we can determine the A_C area of the visible arc of the Sun. We substract the double values of the $A_S\ (2\alpha)$ area of the segment of the 2α central angle, from the area of the plate of the Sun. We apply the following

$$\begin{aligned} A_C &= A_\Theta - 2 \cdot A_S \cdot (2\alpha) = \\ &= r^2 \cdot \pi - 2 \cdot (\frac{1}{2} \cdot r^2 \cdot (2\alpha - \sin 2\alpha)) \end{aligned} \qquad (4)$$

equation, using the unit of *r* radius as 1.

We determine the areas by the same method in the time interval of U_3 and U_4. We can calculate the area of the visible arc of the Sun by using the equation (4), for every times of temperature measurement during the total solar eclipse. The value of the area decreases at first, then increases, using the radius of the Moon and of the Sun as one. We sign this function with *S(t)* symbol in the following procedures. We sign the *S(t)* function with solid line in the *Figure 5.* as the result of our calculations.

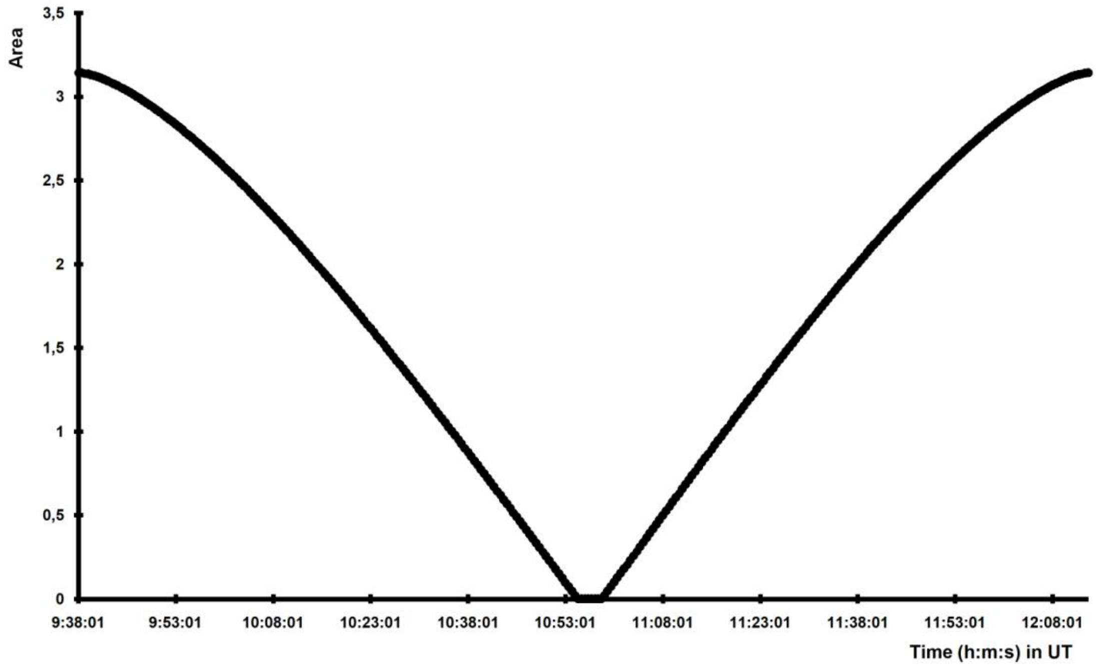

Figure 5.: Area of the visible arc of the Sun, under partial solar eclipse as the function of time S(t) on 29th March 2006 in Turkey in the signed times, using the unit of Moon's and the Sun's radius as one.

Péntek (2002) compared the area of the visible arc of the Sun as function of time with the measured results with light meter at the analysis of the total solar eclipse on the 11th of August 1999 in Szombathely (Vértes, 2000). He found the two graphs almost equal, used the appropriate scale for the two graphs. We can experience the same results from the analisys of various total solar eclipses from other countries.

3.3. Comparison of the Temperature – Time and the Area of the visible arc of the Sun – Time functions.

We try to compare the changing of area of the visible arc of the Sun as function of time, which obviously indicates the changing of the intensity of sunlit, with the decrease of temperature, as the function of time.

We compose the

$$D(t) := T(t) - Y_1(t) \tag{5}$$

function, for the whole observation time, to get rid of the mistake of the temperature difference before and after the eclipse. The decrease of temperature during the eclipse began from a lower value, and rised up a higher value after the eclipse, and stabilized the process.

There are several ways to interpolate a function to the pointset of the *D(t)* function (Péntek, 2002). We seek the *D'(t)* function in a sixth ordered polinom function form, with the help of a computer. We can describe this function by the

$$D'(t) = a \cdot t^6 + b \cdot t^5 + c \cdot t^4 + d \cdot t^3 + e \cdot t^2 + f \cdot t + g \tag{6}$$

equation.

We can see the *D(t)* and the interpolated *D'(t)* functions in *Figure 6*. We can determine the lowest value of the temperature (the maximum value of the temperature decrease) by the analisys of the *D'(t)* function, $\Delta T = -2{,}22$ °C, ensued at t_{min} = 11h 09m 01s.

In the interest of compare the *D(t)* function with the *S(t)* function, we transform the values of *S(t)* with a suitable horizontal elongation and shift to the representation, so its width in this direction equals with absolute value of *T*. It means, in other words, that transformed values of *S(t)* changes between [–2,22°,0] instead of the [0,π].

We represent the transformed

$$S'(t) := \lambda \cdot S(t) - \pi \tag{7}$$

function together in a joined coordinate system with *D(t)* and *D'(t)* functions. We can see the *S(n)* function with solid line, and the *D'(t)* function with with broken line in *Figure 7*. We can ascertain by the analisys of graphs, that the *D'(t)* function delays from the *S'(t)* function in time. It means, that decrease of temperature follows the tempo of decrease and increase of radiation of the Sun with delay in time.

Value of this decrease changes during the solar eclipse. That is why we represent the value of the delay as the function of time using the graphs of *Figure 7*. We can see the result *τ(t)* function in *Figure 8*. We can notice, that the value of the delay decreases by time, we can consider it almost linear. We interpolate a linear function into the section, using the regression calculation based on the method of least squares. We can describe the interpolated linear function by the

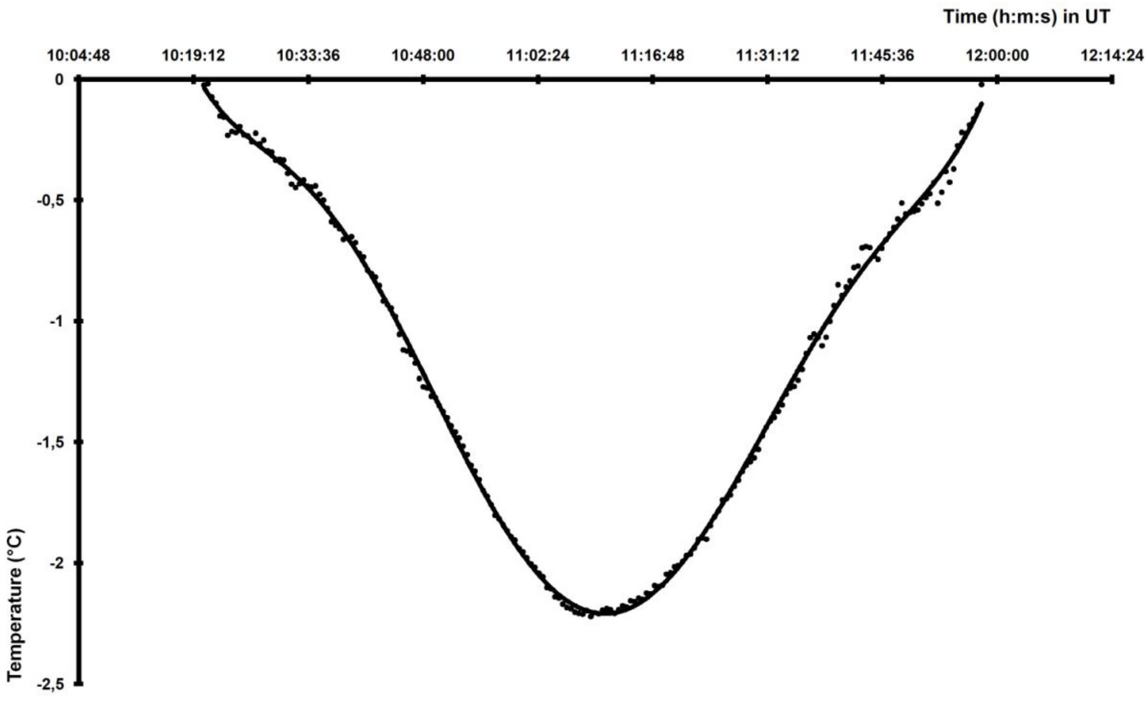

Figure 6.: The D(t) and the conjured D'(t) function based on the measured datas in Selimiye.

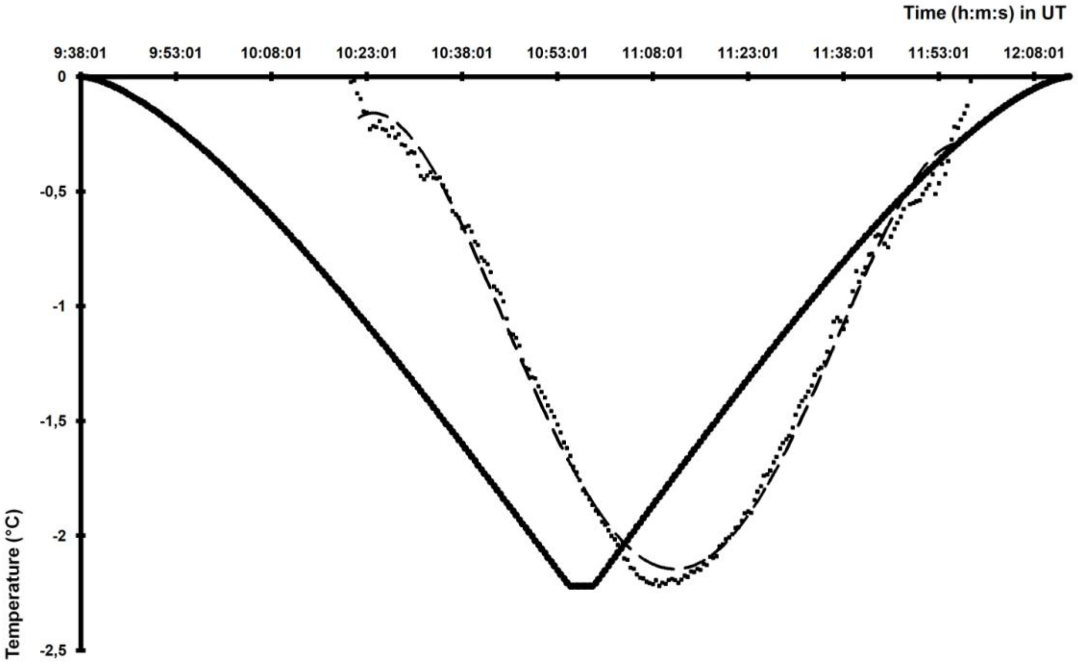

Figure 7.: Transformed S'(t) function and Temperature - Time D'(t) function based on the measured datas in Selimiye

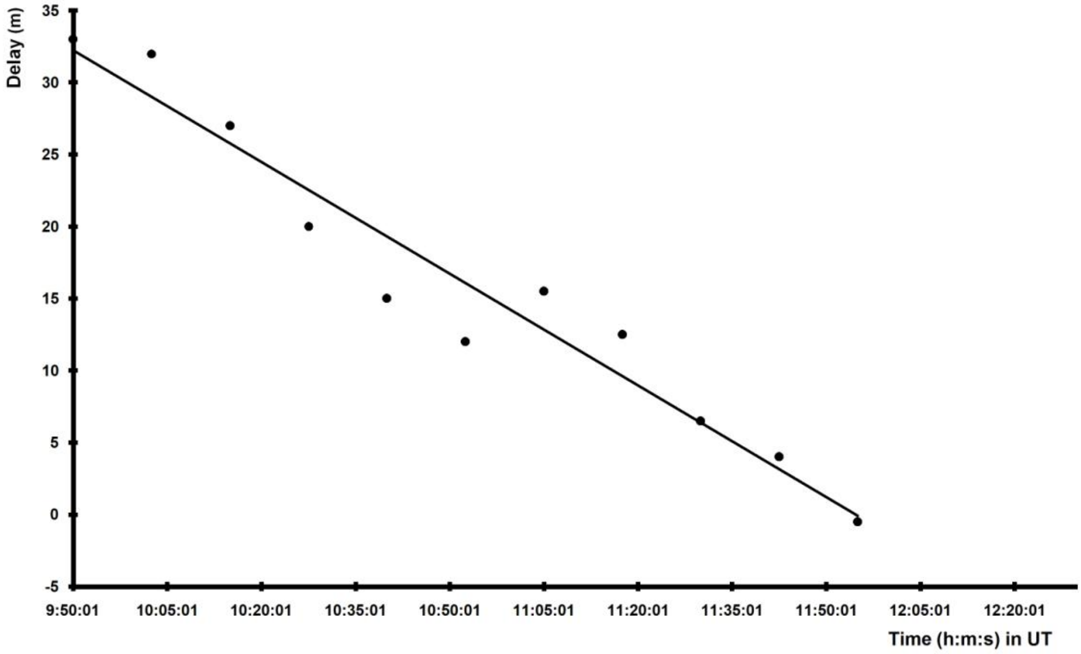

Figure 8.: The Delay - Time τ(t) function.

following formula:

$$Y_2(t) = -372{,}31 \cdot t + 184{,}8 \qquad (8)$$

We can also find this function in *Figure 8*.

4. CONCLUSIONS

We can draw the following conclusions from the analisys of the measured temperature results of the total solar eclipse in Turkey, on the 29th of March, in 2006.

1. Temperature of the air decreased during the total solar eclipse, lowest value of the decrease is approximately $\Delta T = -2{,}22$°C.
2. Minimal value of the temperature of air during the solar eclipse ensued somwhere around at 11h 09m time.
3. We can ascertain by the analisys of measured temperature values of other total solar eclipses (for example in Hungary, in 1999.), that the temperature would have been changed almost smoothly, during the time of the total solar eclipse, but without the eclipse.

4. Decrease of temperature, reaction of the atmosphere ensued with phase delay from the changing of radiation of the Sun during the total solar eclipse.
5. Value of the delay is 33 minutes at the time of begining of the first partial phase, 15,5 minutes in the middle of the total phase, and ends 18 minutes before the end of the eclipse.

Several astronomical and meterological factors can influence the phenomenon, what we discussed in this paper. The examined total solar eclipse was ideal to draw this consequences from it. A favourable surrounding of this eclipse, that the sky was cloudless, another favourable factor was the position of the Sun in the sky, close to the point of meridian.
By the analisys of other temprature values from other total solar eclipses – their precision lower, than this measurement of SUH -, we can presume, that the type of soil, plants, and the microclimate of the place of the observation influences the value of changing of the temperature during the eclipse. Temperature values from total solar eclipses from several places, over different type of soils, in different surroundings, can perhaps help to describe the changing of temperature of the air, as the result of the decreasing radiation over different type of soils.

Results of this examinations, can perhaps help to forecast the microclimate of a given area, territory after the change of plant or soil type. This examination can be significant for agricultural purposes too.

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