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Impacts of the solar eclipse of 29 March 2006 on the surface ozone and nitrogen dioxide concentrations at Athens, Greece

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Abstract

The behavior of surface ozone and nitrogen dioxide concentration as well as the variations in various meteorological parameters before, during and after the total solar eclipse of 29 March 2006 has been examined. This analysis is based on measurements performed at four stations located in the greater Athens basin in Greece. The experimental data demonstrated that the solar eclipse phenomenon affects the surface ozone and nitrogen dioxide concentrations as well as the temperature, the relative humidity and the wind speed near the ground. The reduction of the solar ultraviolet radiation at 312 and 365 nm reached 97% and 93% respectively, while the air temperature dropped, the relative humidity increased and the wind speed decreased. The percentage change (decrease) of surface ozone concentration was maximized one hour after the maximum phase of the eclipse due to the decreased efficiency of the photochemical ozone formation. The surface nitrogen dioxide concentration increased and the time lag of the nitrogen dioxide response to the solar eclipse was found to be different for each station. A plausible cause for the increase in NO_2 concentration may be the conversion of NO to NO_2 through reaction with pre-existing O_3 along with the low photolysis rates of NO_2 as a consequence of the decreased solar radiation during the solar eclipse event. In general, the time response to the eclipse phenomenon was different for each of the aforementioned parameters.

1 Introduction

The solar eclipse being a rare natural phenomenon gives an opportunity to investigate how the photochemical processes react to the comparatively fast solar radiation changes.

The plausible variations in the stratospheric composition caused by natural processes like a solar eclipse have been among the most attractive issues for many workers (Bojkov, 1968; Wuebbles and Chang, 1979; Elansky et al., 1983; Burnett and

Burnett, 1985; Mims and Mims, 1993; Zerefos et al., 2000, Gogosheva et al., 2002; Tzanis, 2005). In particular, the variation in total ozone (TOZ) content during a solar eclipse event has been attributed mainly to the cooling of the atmosphere and, therefore, the generation of internal gravity waves (Chimonas and Hines 1970; Chimonas and Hines, 1971; Zerefos et al., 2007) as well as the alteration of the photochemical balance.

However the number of studies exploring the effects of solar eclipse on surface temperature and surface winds as well as on surface ozone (SOZ) and its precursors is relatively small (Srivastava et al., 1982; Fernadez et al., 1993; Zerefos et al., 2001; Kolev et al., 2005; Tzanis, 2005).

The experimental data obtained from different observational sites in Bulgaria during the solar eclipse of 11 August 1999, demonstrated that the influence of the phenomenon was manifested with a certain delay and the maximal impact of the eclipse on the meteorological parameters (temperature, humidity and wind speed and direction) and the ground ozone concentration was revealed to be 7 and 10 min after the maximal eclipse, respectively (Kolev et al., 2005).

A decrease of around 10–15 ppbv in SOZ concentration has been observed at Thessaloniki, Greece, during the solar eclipse of 11 August 1999 (Zerefos et al., 2001), while the percentage change of SOZ concentration at Athens, Greece was maximized one hour after the solar eclipse maximum and the greater values of SOZ percentage change were observed at the Patision station, an urban station located in the central part of the Athens basin (Tzanis, 2005). The ozone profile measurements over Thessaloniki during the solar eclipse of 11 August 1999 indicated also an ozone decrease up to 2 km with a lag-time between the maximum of the eclipse and the maximum of the induced ozone decrease (Zerefos et al., 2001).

The effect of various meteorological parameters on the variability of the surface ozone and its precursors in the Greater Athens area (a site in the Mediterranean region, where very frequent photochemical pollution episodes occur), has been discussed in a number of recent publications (Cartalis and Varotsos 1994; Kondratyev and Varotsos 2001a,b; Varotsos and Kondratyev, 1995; Ziomas et al., 1998; Varotsos et al., 2001a,b;Varotsos et al., 2003). Although the most important chemical mechanisms involved in photochemical pollution have been already identified and studied, further investigation is necessary because this atmospheric phenomenon is a very complex process involving meteorological, topographic, emission and chemical parameters (Varotsos et al., 2004).

In this work we examine the behavior of surface ozone and nitrogen dioxide concentration as well as the variations in various meteorological parameters (temperature, relative humidity and wind speed and direction) during the solar eclipse that took place on 29 March 2006 over Athens, Greece (38° N, 23° E).

2 Data

We have used the measurements of SOZ and nitrogen dioxide concentration along with meteorological measurements, taken at four monitoring stations (Patision, Smyrni, Geoponiki and Zografou) of the local air pollution monitoring network (National Service for Air Pollution Monitoring). The four sites are located into the greater area of the Athens basin as follows: Patission site in a street of heavy traffic in the centre of the city, Smyrni site at about 5 Km SE of the centre of the city in an area of low traffic, Geoponiki site at about 2 Km SW from the centre of the city in an area of low traffic and light industrial activities and Zografou site at about 3 Km NE of the centre of the city in an area of low traffic inside the campus of the Athens University. SOZ and nitrogen dioxide measurements were made by employing conventional analyzers (chemiluminescence and UV absorption, respectively) with time resolution 30 s and accuracy ±1 ppb. The selection of the above mentioned monitoring stations was made on the basis that their respective locations give a representative picture of the urban area since they cover four opposite sections.

Solar ultraviolet radiation (SUVR) measurements at 312 and 365 nm were carried out during the eclipse event by using a VLX-3W (Vilber-Lourmat, France) radiometer equipped with two sensors (CX-312 and CX-365).

In addition, the MICROTOPS II sun-photometer (Solar Light Co., Inc.) was used for measurements of SUVR-B at 312 nm. This filter instrument is a continuation of a series of hand-held ozonometers with TOPS at the beginning. The new generation of those instruments is MICROTOPS II, that is a 5-channel sun-photometer with centre wavelengths of 300, 305, 312, 940, and 1020 nm for measurements of TOZ, total water vapour and aerosol optical thickness measurements (Kondratyev and Varotsos, 2000). With this instrument TOZ is derived from measurements for three wavelengths in the UV region, given the site's latitude and longitude, universal time, altitude and pressure. As in Dobson instrument, the measurement at an additional third wavelength enables a correction for particulate scattering and stray light (Varotsos et al., 1995). The total water vapour is determined through the measurements at 940 nm and 1020 nm. The angle of view of each of optical channels is 2.5° and the resolution is 0.001 μWcm^{-2}. The typical agreement between various MICROTOPS II instruments (accuracy) is within 1–2%. The repeatability of consecutive ozone measurements is better than 0.5%. A 21-months intercomparison of the MICROTOPS II filter ozonometer with the Dobson and Brewer spectrometers resulted that Mtops can measure TOZ with an accuracy comparable to the conventional spectrometers (agreement is better than ±1%), over a reasonable range of μ. Adverse conditions (clouds, haze, and low sun) result in deviations of more than ±2% or even ±3% (Kondratyev and Varotsos, 2000).

3 Discussion and results

The solar eclipse of 29 March 2006 at Athens, Greece (38° N, 23° E) started at 12:31 LT, reached the maximum solar coverage (84%) at 13:48 LT and ended at 15:04 LT.

Figure 1 presents the SOZ measurements and the expected SOZ values as derived from the fitted curve of the measurements, before, during and after the solar eclipse of 29 March 2006, at four stations (Patision, Smyrni, Geoponiki and Zografou) in the

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Athens basin. The expected values were calculated by applying a 6th degree polynomial fit (best fit) to the observed SOZ concentrations when the eclipse event was absent. All percents in Table 1 were calculated by subtracting the observed SOZ concentrations just before, during and just after the eclipse event from the expected ones. According to Fig. 1 and Table 1, the percentage change of SOZ is maximized one hour after the solar eclipse maximum at each of the stations. The greater values of SOZ percentage change are observed at the Patision station, an urban station located in the central part of the Athens basin. This is in perfect agreement with SOZ measurements before, during and after the solar eclipse of 11 August 1999 at Patision, Geoponiki and Smyrni stations as it shown in Fig. 2 and Table 2 (Tzanis, 2005). The above mentioned behavior of SOZ during the solar eclipse may be related to photochemical processes due to the fact that the gradual decrease in the solar radiation affects the photochemical reactions within the planetary boundary layer. The decrease in SOZ concentration started a few minutes after the beginning of the eclipse and maximized after the solar eclipse maximum as a consequence of the further fall in sunlight intensity that decreased the efficiency of the photochemical ozone formation (decrease in the net ozone production rate). The solar radiation started to increase after the eclipse totality while the SOZ concentration started to increase about one hour later and returned to its ordinary behavior several minutes after the end of the solar eclipse. The SOZ variations detected at Athens, before, during and after the solar eclipse of 29 March 2006 demonstrated that the influence of the phenomenon was manifested with a certain delay.

The observed SUVR measurements at 312 and 365 nm as derived from the MICROTOPS II sun-photometer and the VLX-3W radiometer, before, during and after the solar eclipse of 29 March 2006 at Athens are shown in Figs. 3 and 4. As can be seen, the percentage decrease of SUVR-B (312 nm) which was measured by the MICROTOPS II and VLX-3W instruments reached the value of 97% and 93% respectively, during the solar eclipse maximum while the change in SUVR at 365 nm was about 93%. This is in close agreement with the observed reduction in the incoming solar radiation as derived from measurements conducted at Thission station (center of Athens) by Founda et al. (2007).

Figure 5 presents the march of surface nitrogen dioxide concentration before, during and after the solar eclipse as well as the nitrogen dioxide variations observed on 28 March 2006, a day with similar meteorological conditions, for the stations of Patision, Smyrni, Geoponiki and Zografou. The data presented in Fig. 5 show that in site of the similar diurnal variability the levels of NO_2 are different, which may be an impact of emission changes due to “eclipse show”. The main conclusion from this figure is that NO_2 concentrations start to increase after the beginning of the eclipse event at Patision, Geoponiki and Zografou stations, while at the station of Smyrni NO_2 starts to increase just after the maximum of the solar coverage. After the solar eclipse event NO_2 started to decrease reaching the values observed on 28 March 2006. From Fig. 5 it is evident that the solar eclipse affected the nitrogen dioxide concentration and the time lag of the NO_2 response with respect to the first contact was different for each station. A possible explanation for the above mentioned behavior of NO_2 concentration during the solar eclipse may be the conversion of NO to NO_2 through reaction with pre-existing O_3 along with the low photolysis rates of NO_2 as a consequence of the decreased solar radiation. Comparison of Figs. 1 and 5 shows that the observed reduction of SOZ concentration after the beginning of the solar eclipse is accompanied by an increase of NO_2 concentration at each station. Furthermore, the low photolysis rates of NO_2 may be the most possible reason for the reduced surface ozone values during the eclipse event due to the fact that the primary photochemical source of ozone in the troposphere is photolysis of NO_2 in the presence of molecular oxygen (Kondratyev and Varotsos, 2000). It is worth noting that the same conclusions for NO_2 were derived, when applying the analytical method described above for ozone.

Figure 6 shows the temporal variation of the relative humidity, temperature and wind velocity during the eclipse at Patision station. Air temperature near the ground decreased from 20.1°C to 19.4°C during the eclipse event and after that it began to increase abruptly. Relative humidity started to increase at 13:00 (55%) as a result of the

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temperature decrease reaching a maximum (58%) at the end of the solar eclipse. The fact that the wind speed started to decrease after the solar eclipse maximum, may be attributed to the cooling and the stabilization of the atmospheric boundary layer. The wind speed continued to decrease for two hours after the eclipse event without any significant change in direction. Kolev et al. (2005) observed similar changes in the wind speed in Bulgaria during the solar eclipse of 11 August 1999. The temporal variation of the above mentioned meteorological parameters during the solar eclipse of 29 March 2006 is in close agreement with observations at three other stations (Thission, Penteli, Markopoulo) in the Athens basin reported by Founda et al. (2007).

4 Conclusions

During the solar eclipse of 29 March 2006 measurements of surface ozone and nitrogen dioxide concentration, solar ultraviolet radiation and meteorological parameters (relative humidity, temperature and wind velocity) were performed at four sites (Patision, Smyrni, Geoponiki and Zografou) into the greater area of the Athens basin in Greece.

As expected, all the parameters mentioned above were affected by the solar eclipse.

The percentage decrease of the SUVR at 312 and 365 nm reached 97% and 93% respectively at the maximum phase of the eclipse.

The SOZ concentration decreased during the eclipse event and the maximum percentage change observed one hour after the maximum of the solar eclipse at all stations. The greater values of SOZ percentage change were observed at Patision station (urban station) located in the center of Athens. The decrease in SOZ concentration was attributed to the dramatic reduction of the solar radiation that affects the photochemical reactions.

The surface nitrogen dioxide concentration increased at all stations as the solar eclipse phenomenon progressed while the time lag of the NO_2 response to the eclipse was different for each station. This increase in NO_2 concentration may primarily be attributed to the low photolysis rates of NO_2 as a result of the decrease in solar radiation along with the conversion of NO to NO_2. The influence of the solar eclipse on surface ozone and nitrogen dioxide was manifested with a certain delay.

The near-ground air temperature dropped about 0.7°C during the eclipse event at the center of Athens while the relative humidity increased reaching a maximum at the end of the solar eclipse. The wind speed decreased after the solar eclipse maximum without any significant change in direction.

After the end of the solar eclipse of 29 March 2006, all the aforementioned parameters exhibited a tendency to regain their ordinary behavior.

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Table 1. Calculated percentage change of surface ozone (at four stations, separately) throughout the eclipse event of 29 March 2006 at Athens, Greece.

Time	Patision	Geoponiki	Smyrni	Zografou
13:00	−21.0	−14.4	−3.5	−1.4
14:00	−57.4	−21.0	−8.4	−15.3
15:00	−69.3	−23.5	−23.8	−24.8
16:00	−38.8	0.0	−3.9	−14.1

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Table 2. Calculated percentage change of surface ozone (at three stations, separately) throughout the eclipse event of 11 August 1999 at Athens, Greece.

Time	Patision	Geoponiki	Smyrni
13:00	−19.3	−20.2	−6.1
14:00	−14.2	0.0	0.0
15:00	−32.7	−24.4	−12.7
16:00	−11.3	−2.3	−1.1

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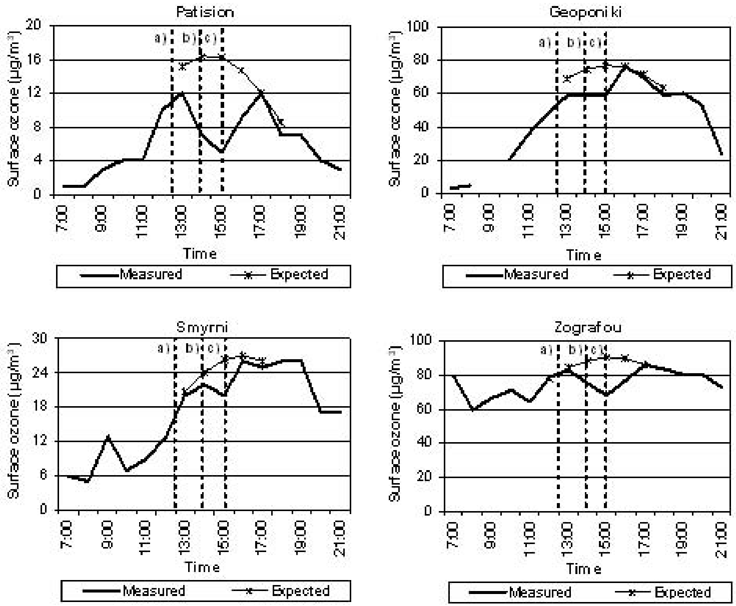

Fig. 1. Surface ozone measurements and the expected surface ozone values as derived from the fitted curve of the measurements before, during and after the eclipse event of 29 March 2006 at four stations (Patision, Smyrni, Geoponiki and Zografou) in the Athens basin, **(a)** beginning of the solar eclipse, **(b)** solar eclipse maximum, **(c)** end of the solar eclipse.

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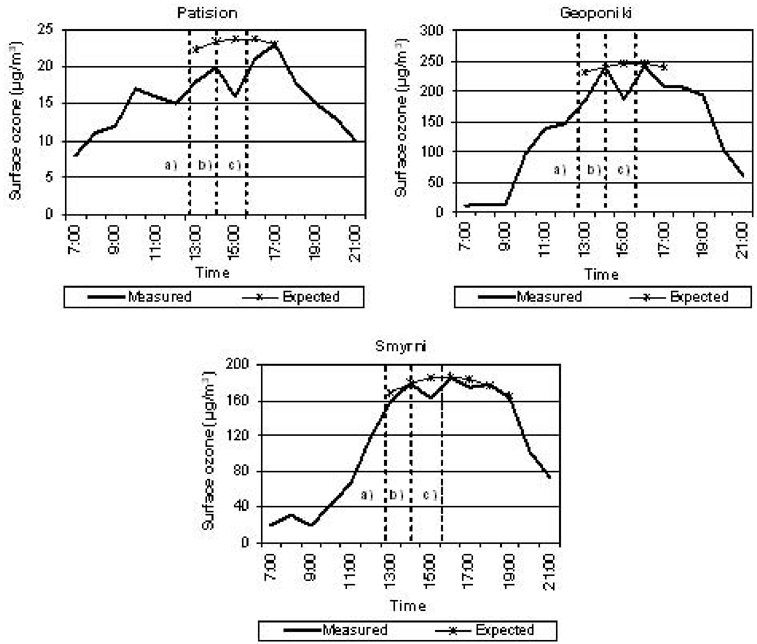

Fig. 2. Surface ozone measurements and the expected surface ozone values as derived from the fitted curve of the measurements before, during and after the solar eclipse of 11 August 1999 at three stations (Patision, Geoponiki and Smyrni) in the Athens basin, **(a)** beginning of the solar eclipse, **(b)** solar eclipse maximum, **(c)** end of the solar eclipse.

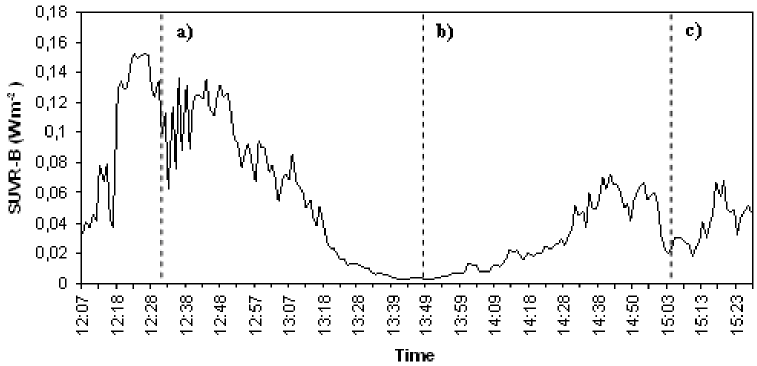

Fig. 3. SUVR-B (312 nm) measurements derived from the MICROTOPS II sun-photometer (Solar Light Co., Inc.), before, during and after the solar eclipse of 29 March 2006, at Athens, **(a)** beginning of the solar eclipse, **(b)** solar eclipse maximum, **(c)** end of the solar eclipse.

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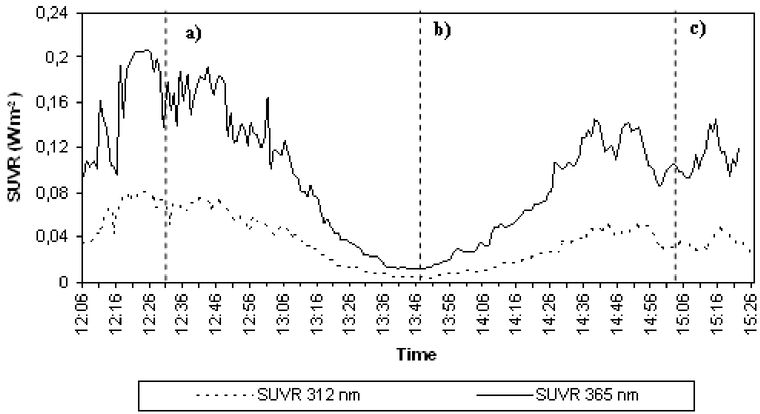

Fig. 4. SUVR (312 and 365 nm) measurements derived from the VLX-3W radiometer (Vilber-Lourmat, France), before, during and after the solar eclipse of 29 March 2006, at Athens, **(a)** beginning of the solar eclipse, **(b)** solar eclipse maximum, **(c)** end of the solar eclipse.

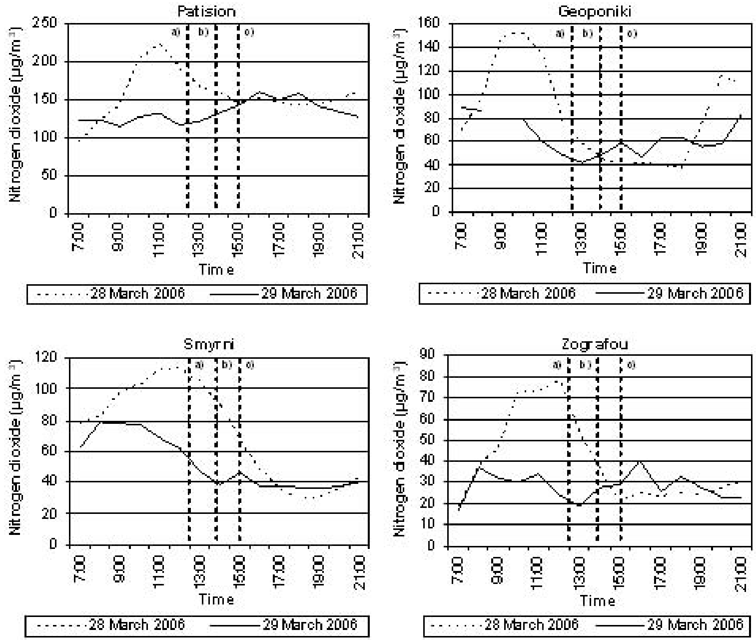

Fig. 5. Nitrogen dioxide measurements before, during and after the solar eclipse of 29 March 2006 at four stations (Patision, Smyrni, Geoponiki and Zografou) in the Athens basin, **(a)** beginning of the solar eclipse, **(b)** solar eclipse maximum, **(c)** end of the solar eclipse. The dashed line presents the nitrogen dioxide variations observed on 28 March 2006 (a day with similar meteorological conditions).

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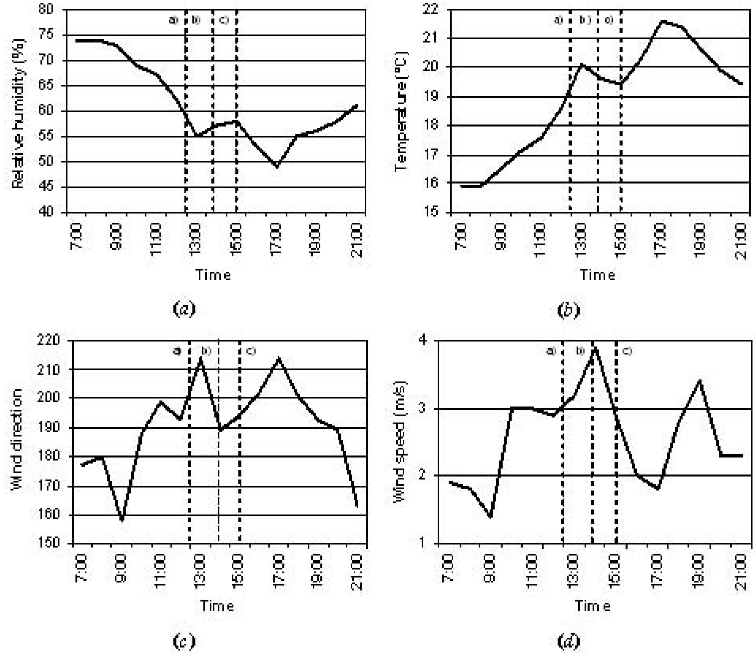

Fig. 6. Meteorological data obtained at Patision station before, during and after the solar eclipse of 29 March 2006, **(a)** beginning of the solar eclipse, **(b)** solar eclipse maximum, **(c)** end of the solar eclipse.

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