Estimating Naples' urban heat island effects using the March 20, 2015 partial solar eclipse

Adriano Mazzarella*, **Nicola Scafetta**
Osservatorio Meteorologico, Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse, Università di Napoli, Federico II, Italy
* adriano.mazzarella@unina.it

Abstract

During the partial (~50%) solar eclipse occurred on March 20, 2015, we monitored the time evolution of air temperature and of incoming solar radiation above the historical center of Naples and of Casamicciola town, on the island of Ischia. These measurements were useful to determine the radiative emissivity ε of the two different locations. The experimental conditions were optimal because of the clear sky situation over Italy. The eclipse lasted about 2 hours between 9:25:06 (UT+1, local Italian time) and 11:43:09 (UT+1, local Italian time). We obtained an emissivity of ε=0.86 for the historical center of Naples and ε=0.96 for Casamicciola town. We used these emissivity estimates, the surface air temperature and solar radiance records to characterize the urban heat island of Naples as due to an additional source of heat of about W/m2 at maximum in respect to Casamicciola.

1. Introduction

Urban heat island (UHI) influences all metropolitan areas (Environmental Protection Agency, 2008; Bottyan, et al., 2005; Fortelli et al. 2016). UHI is a significant warming excess occurring in urban areas relative to the surrounding countryside ones. In densely urbanized areas, UHI can reduce or improve the human comfort according to the season. For example, enhanced heat waves could lead to emergency conditions during summer times (Di Cristo et al., 2007; Li and Bou-Zeid, 2013). Moreover, the specific temperature areal variation inside a city determines also the demand of energy for cooling or heating buildings in the summer or winter times, respectively (Scafetta et al., 2017).

An important issue is to characterize UHI for a specific city (e.g., Naples) and better understanding its causes. Fortelli et al. (2016) showed that the historical center of Naples is about 2.1 °C warmer than the surrounding countryside areas (e.g. relative to Bacoli town). In order to better characterize the phenomenon, we propose to apply the Stefan-Boltzman equation to determine the different emissivities between the historical center of Naples and the island of Ischia located at about 20 km from Naples. This information can then be used to evaluate the hypothetical energy flux addition explaining the UHI of Naples.

We hypothesize that this emissivity measurement can be obtained when the outgoing radiation from the surface is known. This can happen when the system is in thermal equilibrium with the incoming solar radiation. Scafetta and Mazzarella (2016) observed that, during the solar eclipse of March 20, 2015, the air temperature in Naples remained constant from about 10:00 to 11:00 am. We hypothesize that such a temperature constancy could be due to a transient equilibrium between the incoming and outgoing radiations. Therefore, the direct measurement of the incoming solar radiation during that period could be assumed to be a valid estimate of the outgoing radiation in that same moment. We understand that our hypothesis is an approximation based on the assumption that the physical properties of the system remain constant: e.g., the wind and other processes of heat transport are assumed to be stationary during the analyzed period and, therefore, their action negligible.

An eclipse constitutes a rapid, profound and widespread perturbation of the solar radiation received by the Earth's surface and its atmosphere at a given location. The occurrence of an eclipse provides an occasion to measure a set of atmospheric parameters (such as surface air temperature, atmospheric pressure and incoming solar radiation) useful to measure the emissivity of the site on which the observation is made. We use the eclipse occurred on March 20, 2015 whose peak occurred around 9:46 UT on the ocean between Iceland and Norway (lat. 64°25'54"N, long. 6°38'48"W).

The meteorological data were collected from two observatories:

1) The Meteorological Observatory of San Marcellino is attached to the Department of Earth Sciences, Environment and Resources and is located in the historical center of Naples. It is the highest institution regarding the knowledge of meteorological events of the city of Naples and one of the oldest meteorological centers in Italy.
2) The Casamicciola Geophysical Observatory was established shortly after the earthquake of July 28, 1883, which

dramatically hit Casamicciola. The seismic event prompted the Italian Government to establish a network of geophysical observatories in Italy.

Herein, we propose the following methodology: 1) we measured the incoming solar radiation during the eclipse of March 20, 2015, both at the Meteorological Observatory of San Marcellino in the historical center of Naples and at the Geophysical Observatory of the town of Casamicciola on the island of Ischia; 2) we measured the surface air temperature at the same observatories during the same eclipse; 3) finally, we used the Stefan-Boltzman equation to determine the different emissivities.

This study is relevant because the two chosen sites are characteristic of two alternative environments and experience a different response to a sudden variation to radiative forcing. In fact, the historical center urban area of Naples, where the Meteorological Observatory of San Marcellino is located, is heavily built, densely populated and characterized by tall buildings made mostly of concrete and clay tiles, and by asphalt and lave rocks streets. On the contrary, the Geophysical Observatory of Casamicciola is located on an island that is poorly populated and it is surrounded by a green park and a large wood.

2. Meteorological data during the eclipse

Figure 1 depicts the eclipse path map. It was mostly visible from the North Sea, the Faeroe Islands and Svalbard, but partially visible throughout Europe. The response of the atmosphere to an eclipse event strongly depends on the local coordinates, geography and meteorological conditions. Studying total and partial eclipses is equally important for a better understanding of its effects on the environment (Muraleedharan, 1998; Kazadzis, 2007; Zerefos, 2007).

In Italy, the Sun was obscured by 39% to 67% depending on the latitude and longitude of the observation: see Figure 2. Herein, we study how a sudden decrease of solar radiation during an eclipse can provide a different response in surface air temperature in two different locations few kilometers apart: the historical center of Naples and the town of Casamicciola, on Ischia island. The eclipse lasted from 9:25 to 11:43 am and the Sun was obscured up to about 50% in both locations (Scafetta and Mazarella, 2016).

The solar eclipse of March 20, 2015 was quasi total in the United Kingdom (98% at Edinburgh) but the meteorological conditions were of cloudy sky for the presence of an high pressure over the British Islands and of numerous cold fronts and instability lines on their North-Western coasts (Figure 3) (Hanna et al., 2016). On the contrary, a stable area of high pressure over Italy determined a weather sunny and cloud-free sky (Scafetta and Mazzarella, 2016) (Figure 3). Most Italy benefited meteorological conditions favorable to study the meteorological consequences of the eclipse.

We collected surface air temperature and solar radiation data at the Meteorological Observatory of the University of Naples Federico II, (lat. 40°50’50.2”N, long. 14°15’28.7”E, altitude 50 m) and at the Geophysical Observatory of Casamicciola town on Ischia Island (lat. 40° 44’ 48.7” N, long. 13°54’ 5.6” E, altitude 125 m).

Figures 4 and 5 show the total solar irradiance records measured at the two observatories on the eclipse day. The data are 10-minute averages. The colored area in Figure 4 highlights the period of the eclipse’s occurrence from 9:25 to 11:43 local time. The dimming of the surface solar radiation records during the eclipse is evident in both observatories. Until noon the solar radiation record is very smooth, a fact that confirms that the sky was cloud free during the entire eclipse period.

In Naples, at the eclipse’s beginning (9:25 am, local time), the total solar irradiance was 552 W/m^2. It reached a minimum of 334 W/m^2 at the eclipse’s apex at 10:32 am, local time, and it increased to 760 W/m^2 when the eclipse ended at 11:43 am, local time.

In Casamicciola, at the eclipse’s beginning (9:25 am, local time), the total solar irradiance was 600 W/m^2. It reached a minimum of 368 W/m^2 at the eclipse’s apex at 10:32 am, local time, and it increased to 840 W/m^2 when the eclipse ended at 11:43 am, local time.

The air temperature remained stationary during the eclipse both at Naples, with a value equal to T=14.8 °C + 273.15 °C = 287.95 K, and at Casamicciola, with a value equal to T=13.6 °C+273.15 °C = 286.75 K.

3. Evaluation of the radiative emissivity in the historical center of Naples and in Casamicciola town

The emissivity ε varies from 0 to 1 and measures the effectiveness of a surface in emitting energy as thermal radiation. It is the ratio of the thermal radiation J from a surface to the radiation from an ideal black surface at the same temperature according to the Stefan-Boltzmann law:

$$J = \varepsilon \sigma T^4 , \quad (1)$$

where the Stefan’s constant is $\sigma = 5.67 * 10^{-8}\ Wm^{-2}K^{-4}$.

The stationary meteorological condition observed during the eclipse, from about 10:00 to 11:00 am, were used to conclude that during that time the mean incoming radiation was likely in balance with the emitted one. Thus, we assume that

the J value in Eq. 1 is equal to the measured incoming solar radiation at the eclipse apex, that is, we assume that the heat conduction (e.g. with the material under the surface) is negligible during the eclipse. In such a condition, the average emissivity ε of the historical center of Naples and of the town of Casamicciola could be calculated using Eq. 1.
Under the above hypothesis, we obtained ε=0.86, typical of concrete, for Naples (see Google map in Figure 4) and ε=0.96, typical of a green park, for Casamicciola town (see Google map in Figure 5).

4. UHI in Naples relative to Casamicciola

Figure 6A shows the incoming solar radiation reaching the surface in the historical center of Naples and in Casamicciola as measured at the two observatories. We found that for the month of July 2015 the maximum of the incoming solar radiation in Naples was about 900 W/m^2 while in Casamicciola was about 1200 W/m^2. Thus, the historical center of Naples receives about 75% of the solar radiation received in Casamicciola. Probably, this difference is due to the fact that the Observatory in Casamicciola is about 75 m higher than that in San Marcellino and that the air in Ischia is significantly clearer than in the urban center of Naples.
Figure 7B shows the surface air temperature measured in the two observatories in July 2015. We found that the mean maximum diurnal temperature during July measured in San Marcellino is about 2.5 °C higher than in Casamicciola. In the hottest day, on July 18, 2015, the maximum air temperature in San Marcellino was about 37.0 °C while in Casamicciola was 33.5 °C, which is 3.5 °C lower.
Because the Observatory of Casamicciola is located about 75 m higher than in that in San Marcellino, it accounts for about 0.6 °C cooling due to the lapse rate. It is noteworthy that the normalization process of different air masses is done through potential temperature θ. This is the temperature that an air mass assumes when it is lowered adiabatically from its altitude (characterized by a determined atmospheric pressure P and air temperature T_0) to sea level atmospheric pressure of 1013 hpa. The potential temperature is governed by the adiabatic Poisson equation:

$$\theta = T_0(1013/P)^{0.287} \qquad (2)$$

that implies a mean lapse rate of about 0.8 °C for each 100 m of altitude (Holton, 2004). Thus, San Marcellino which is 75 m lower than Casamicciola was, on July 18, 2015, effectively about (2.5+0.6) °C = 3.1 °C warmer than Casamicciola during the maximum diurnal temperature. This result evidences the UHI effects of the historical center of Naples.

We used the Stefan-Boltzmann law, Eq. 1, to calculate the thermal radiation J associated to the two measured maximum air temperatures on July 18, 2015. We found that for San Marcellino J=450 W/m^2, while in Casamicciola J=480 W/m^2.
Considering that San Marcellino received an amount of solar radiation equal to 75% of that received in Casamicciola, if San Marcellino environment were similar to that of Casamicciola, we would had to obtain J=480*0.75=360 W/m^2. Thus, it is like as if in summer the air in San Marcellino received about 90 W/m^2 at maximum more than what expected. This amount will decrease by a certain fraction if, for example, during the eclipse the emitted radiation was the same fraction of the incoming radiation due, for example, to heat conduction, that above was neglected.

5. Discussion and conclusion

Surface air temperature and solar irradiance were measured in historical center of Naples and in the town of Casamicciola on Ischia Island, in Central Italy, during the partial (~50%) equinoctial solar eclipse occurred on March 20, 2015. This information was useful to determine the radiative emissivity ε of the two places. We found an emissivity ε=0.96 in Casamicciola town but a lower value ε=0.86 in the historical center of Naples. This difference was expected because Casamicciola's environment is comparable to that of a green wood park while the historical center of Naples is made mostly of concrete, asphalt and bricks (cf. Sobrino et al., 2012). In fact, Ischia is called the Green Island (Mennella, 1958).
Moreover, we found that despite the historical center of Naples receives 75% of the solar radiation received in Casamicciola, its maximum daily air temperature in summer is about 3.1 °C warmer than in Casamicciola. This evidences that the historical center of Naples is influenced by a strong urban heat island effect.
We calculated the different heat flux associated to the two sites and we concluded that, relative to a wood green park, the historical center of Naples is like as if it is warmed by an additional source of heat of about 90 W/m^2 at maximum.
We conclude that in order to mitigate the urban heat island effect of Naples, it would be opportune to make the city greener (Lee et al., 2014; O'Malley et al., 2015). Moreover, it would be useful to create a detailed emissivity map of the city to better determine and understand the local patterns of the UHI effect in Naples (Palumbo and Mazzarella, 1984; Di Cristo et al., 2007; Mazzarella and Giuliacci, 2011).

Figure 1 – Path of the solar eclipse of 20 March 2015,showing fractional obscuration of the Sun at maximum eclipse. Image courtesy of http://www.greatamericaneclipse.com;copyrightMichaelZeilerandreproducedwithpermission

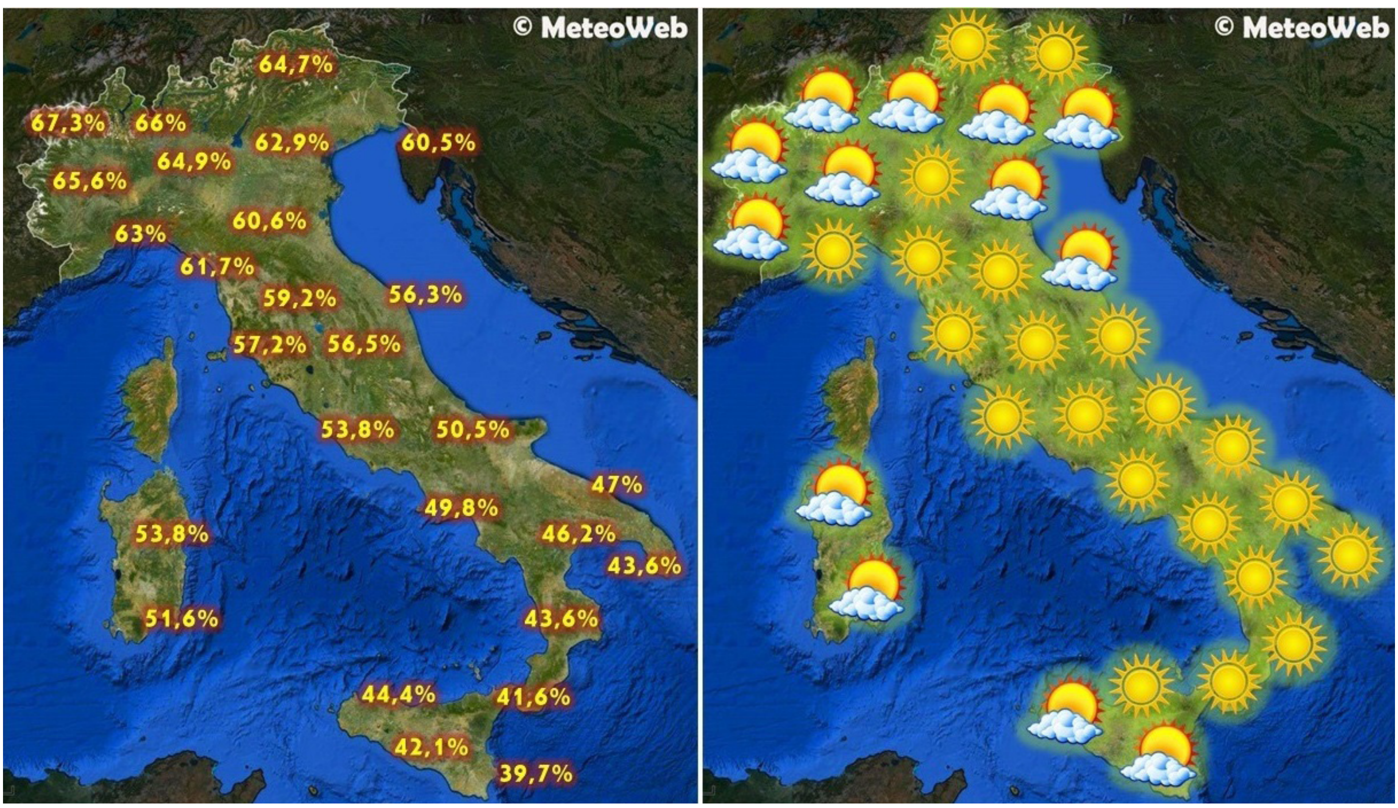

Figure 2 – Eclipse of 20 March 2015: percent of the Sun's dimming and meteorological conditions in Italy.

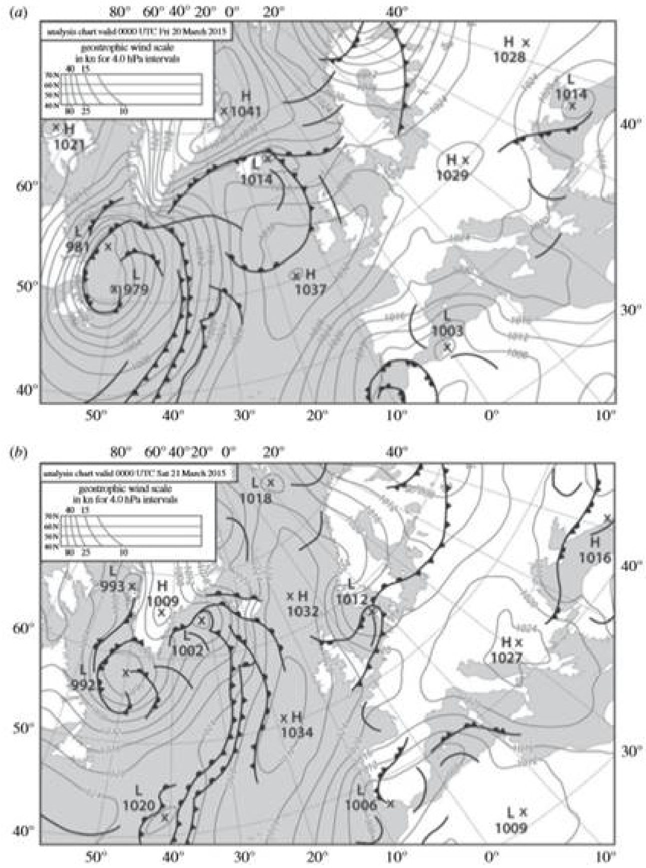

Figure 3 – Met Office mean sea-level pressure chart for (a) 00:00 UTC on 20 March 2015 and (b) 00:00 UTC on 21 March 2015 (redrawn). Original charts obtained from the Wetterzentrale Topkarten website (http://www.wetterzentrale.de/).

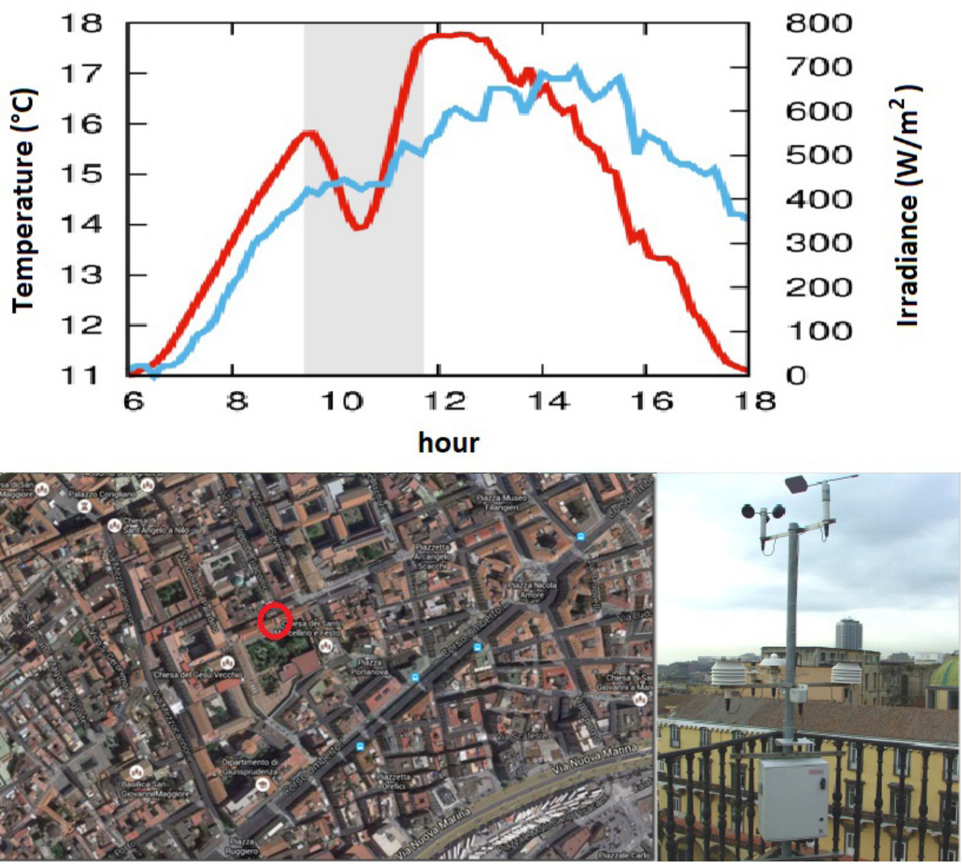

Figure 4 – (Top) Temperature and solar irradiance measured in the historical center of Naples. (Bottom) Photographs of the Meteorological Observatory of San Marcellino indicated by the red circle.

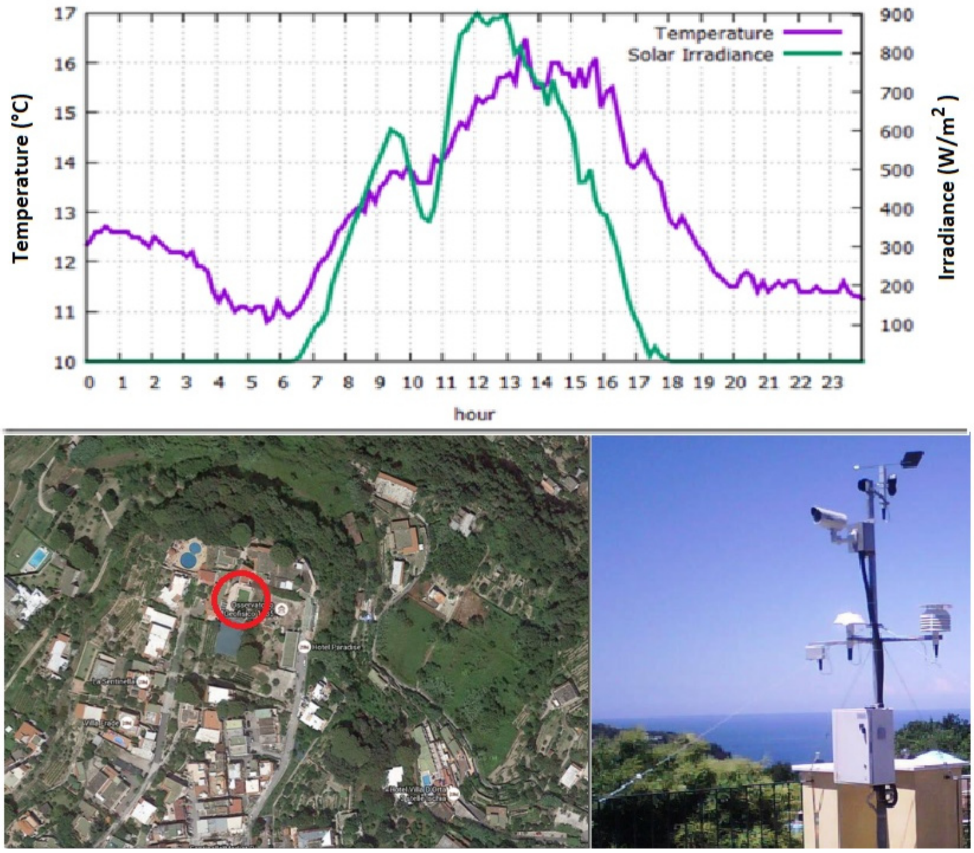

Figure 5 – (Top) Temperature and solar irradiance measured in Casamicciola. (Bottom) Photographs of the Geophysical Observatory in Casamicciola indicated by the red circle.

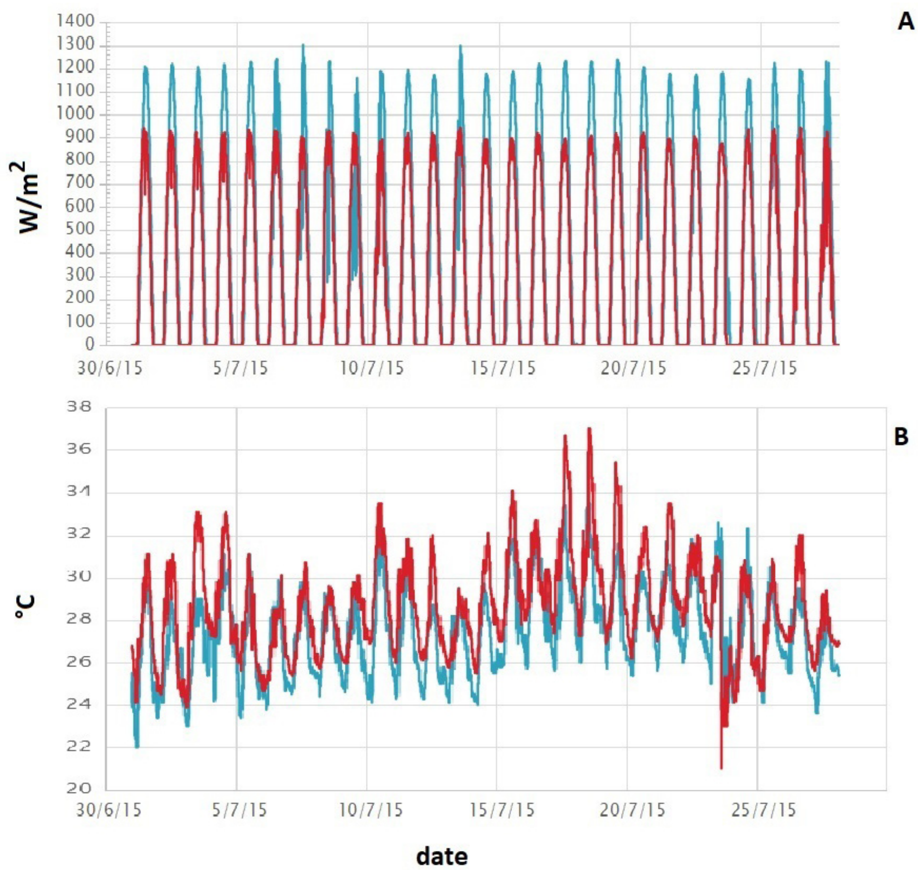

Figure 6 – (A) Solar irradiance measured in the meteorological observatory of San Marcellino Temperature (red) and in the geophysical observatory in Casamicciola (blue). (B) The air temperature measured in the two observatories, respectively.

References

Bottyan, Z., Kircsi, A., Szegedi, S., Unger, J., "The relationship between built-up areas and the spatial development of the mean maximum urban heat island in Debrecen, Hungary". *Int. J. Climatology,* vol. 25, pp. 405-418, 2005. DOI: 10.1002/joc.1138

Di Cristo, R., Mazzarella, A., Viola R. (2007). *An analysis of heat index over Naples (Southern Italy) in the context of European heat wave of 2003*. Nat. Hazards, 40, 373-379. doi: 10.107/s11069-006-0033-7

Environmental Protection Agency (2008). Reducing urban heat islands: Compendium of strategies. https://www.epa.gov/heat-islands/heat-island-compendium

Fortelli A., Mazzarella A., Scafetta N.: Local warming in the historical center of Naples, International Journal of Heat and Technology, 34, Special Issue, S569-S572, 2016, https://doi.org/10.18280/ijht.34S252.

Kazadzis, S., Bais, A.F., Blumthaler, M., Webb, A., Kouremeti, N., Kift, R., Schallhart, B., Kazantzidis, A. (2007). *Effects of total solar eclipse of 29 March 2006 on surface radiation.* Atmos. Chem. Phys., 7, 5775-5783. doi: 10.5194/acp-7-5775-2007

Hanna, E., Penman, J., Jónsson, T., Bigg, G.R., Björnsson, H., Sjúrðarson, S., Hansen, M.A., Cappelen, J., Bryant, R.G. (2016). *Meteorological effects of the solar eclipse of 20 March 2015: analysis of UK Met Office automatic weather station data and comparison with automatic weather station data from the Faroes and Iceland.* Phil.Trans.R. Soc. A 374: 20150212. doi: 10.1098/rsta.2015.0212

Holton, J.R., 2004. "An Introduction to Dynamic Meteorology", International Geophysical Series, Vol 48 Academic Press.

Li, D., Bou-Zeid, E., "Synergistic interactions between urban heat islands and heat waves: the impact in cities is larger than the sum of its parts". *J. of Applied Meteorology and Climatology*, vol. 52, pp. 2051-2064, 2013. DOI: 10.1175/JAMC-D-13-02.1

Lee J.S., Kim, J.T., Lee, M.G. (2014). *Mitigation of urban heat island effect and greenroofs.* Indoor and Built Environment, 23, 62-69. doi: 10.1177/1420326X12474483

Mazzarella, A., Giuliacci, A. (2011). *Urbanization induced variations in air temperature and rainfall in Naples - Southern Italy.* Romanian Journal of Climatology, 2, 67-77.

Mennella C. (1958). *L'isola d'Ischia gemma d'Italia.* I quaderni dell'isola verde, 201 pp.

Muraleedharan, P.M., Nisha, P.G.,Mohankumar, K. (2010). *Effect of January 15, 2010 annular solar eclipse on meteorological parameters over Goa, India.* J. Atmos. Sol.-Terr. Phy., 73, 1988-1998. doi: 10.1016/j.jastp.2011.06.003

O'Malley, C.,Piroozfar, P., Farr, E.R.P.,Pomponi, F. (2015). *Urban Heat Island (UHI) mitigating strategies: A case-based comparative analysis.* Sustainable Cities and Society, 19, 222-235. doi: 10.1016/j.scs.2015.05.009

Palumbo, A., Mazzarella, A. (1984). *Local recent changes in extreme air temperatures.* Clim. Change, 6, 303-309. doi: 10.1007/BF00142478

Scafetta, N. , Mazzarella, A. (2016). *Effects of March 20, 2015, partial (~50%) solar eclipse on meteorological parameters in the urban area of Naples (Italy).* Annals of Geophysics, 59, 1, A0106. doi: 10.4401/ag-6899

Scafetta,N., Fortelli A., Mazzarella A.: Meteo-climatic characterization of Naples and its heating-cooling degree day areal distribution, International Journal of Heat and Technology, 35, Special Issue, S137-S144, 2017, DOI: 10.18280/ijht.35Sp0119

Sobrino, J. A., Oltra-Carrió, R., Jiménez-Munoz, J. C., Julien, Y.,Sòria, G., Franch, B.,Mattar, C. (2012). Emissivity mapping over urban areas using a classification-based approach: Application to the Dualuse European Security IR Experiment (DESIREX). Int. J. Appl. Earth Obs., 18, 141-147. doi: 10.1016/j.jag.2012.01.022

Zerefos, C., Mihalopoulos, N., Monks, P. eds. (2007). The total solar eclipse of 2006 and its effects on the environment, Atmos. Chem. Phys., Special issue.