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COMPUTATIONAL STUDY OF THE EFFECTS OF INDUCED LAND USE CHANGES ON METEOROLOGICAL PATTERNS DURING HOT WEATHER EVENTS IN AN URBAN ENVIRONMENT

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Abstract: The heavy urbanisation of great cities has caused immense concern to societies due to air quality degradation and adverse changes in local climates such as abnormally high temperatures. Due to the growing demand for renewable energy resources and electrical power generation, the installation of photovoltaic (PV) panels on building roofs and other available open spaces has advanced in the recent years. Such applications are translated to land use and land cover modifications with respect to the existing situation. This work attempts to investigate the application of PVs in the city of Athens (Greece) and estimate computationally the subsequent results in maximum temperatures and wind velocities mainly during hot weather events. Those events were identified using meteorological data available from the National Centres for Environmental Prediction (NCEP) Global Forecasting System (GFS). Land use changes due to photovoltaic canopies have been translated into changes in surface albedo and roughness, specific heat capacities, thermal properties and evapo-transpiration in the input files of the domain of Athens (1x1 km^2) of the modelling system (Mesoscale Model 5, MM5). The model results revealed noticeable changes in the temperature and wind fields when applying the scenario of installing PV panels in the urban canopy of the city.

Key words: *urban environment, hot weather events, land use changes.*

INTRODUCTION

The continuously growing needs in electricity production, using renewable energy sources thus, reducing CO_2 emissions to the environment, has increased the spatial installation and use of Photovoltaic (PV) panels globally. In urban regions, PV arrays are most often retrofitted into existing buildings, usually mounted on top of the existing roof structure or on the existing walls. Alternatively, in the case of available space, an array can be located separately from the building but connected by cable to supply power for the building. PV installations can operate for many years with little and low-cost maintenance or intervention after their initial set-up.

A few studies so far have focused on investigating the effects of PV installed systems to the regional climate of various parts of the world. The effects of extensive deployment of PV panels on global scale was discussed in Nemet, G. F. (2009), where it was shown that the climate benefits resulting from the CO_2 emissions reduction (radiative forcing decreased by 30 times) were much more important than the increase in radiative forcing due to the albedo changes. Millstein, D. and S. Menon, (2011) found that large-scale adoption of PV panels on simulated desert grid cells (USA case study) caused temperature increases of 0.4 °C and changes in wind patterns.

Schemes partly funded by European and national sources have been running during the last few years in Greece for promoting and supporting the installation of PVs (with maximum power up to 10 kW_p) in the residential sector and small enterprises (interconnected electricity network). Due to this financial incentive, the installation of PV systems has become more attractive and thus, the coverage of urban areas with PV panels has increased. In particular, in the city of Athens (Greece), which bears 40% of the Greek population, the energy demands are the highest compared to other urban regions of the country. Taking into consideration that the interest to install PVs on buildings is constantly growing in the city of Athens, the main aim of this study is to estimate the impact of the enhanced coverage with PVs on the meteorological patterns of the region. The induced changes in the land cover and land use parameters due to PVs have been simulated using the 3-dimensional Mesoscale Model 5 (MM5, Penn State University version 3.7.2).

DESCRIPTION OF THE STUDY AREA

The region of interest is depicted in Figure 1. The Attica peninsula is characterised by a complex topography. The urban region of approximately 4.5 million inhabitants is mainly lying on a basin surrounded by a high altitude mountain range in the north (Partnitha mountain of 1413 m height), in the northeast (Penteli mountain of 1109 m) and in the east (Hymettus mountain 1026 m). The weather conditions result mainly from the interaction of large and local scale circulation systems. Typically, the region has a hot-summer Mediterranean climate with wet mild winters and extremely long periods of sunshine throughout the year while the highest precipitation occurs mainly from mid-October to mid-April. According to the Hellenic National Meteorological Service, the average annual temperature is 19°C with highest summer temperatures occurring in the range between 35° -39°C. The winds blow mostly along the N–NE/S–SW axis with the prevailing wind direction being NNE in late summer, fall and winter and SSW in spring and early summer. Low wind speed conditions (less than 3m/s) predominate in the area, while winds exceeding 8 m/s are not common. Atmospheric stability is mainly neutral; however, in late autumn, winter and early spring the frequency of stable conditions increases. In summer, unstable conditions prevail in association with northeasterly flow (Kassomenos, P.A. and I.G. Koletsis, 2005). Various studies have identified the frequent occurring 'heat island' phenomenon in Athens during the summer season, causing comfort problems to the population (e.g. Mihalakakou, G. et al., 2004).

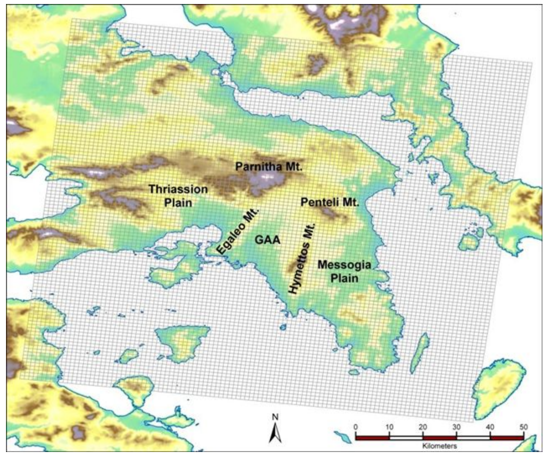


Figure 1. Topography of the region and gridded domain of the computational simulations.

METHODOLOGY

The study involved the application of the MM5 meteorological model in the region of Athens (Fig. 1) during an identified hot summer event (19-20, July 2011). The 25-category of 30-seconds resolution vegetation / land use data have been updated using recent information for the region by applying a Geographical Information System (ARC.GIS). The MM5 model runs were performed with the Grell option (simple cloud scheme), the Rapid Radiative Transfer Model (RRTM) longwave scheme and the Five-Layer Soil model option. The MM5 simulations were performed in two-way nesting. The outer computational domain was set with a spatial resolution of 3×3 km^2. The inner and final domain covered an area of 103×103 km^2 with a grid of 1×1 km^2 horizontal resolution (Fig. 1). In the vertical, the MM5 domain was based on 29 full σ levels to the top at 100 mb.

Initial and boundary conditions for all model runs were based on 6-hours re-analysis meteorological data available from the National Centres for Environmental Prediction (NCEP) Global Forecasting System (GFS) for the period of interest. First of all, a base run was performed for the two dates. The simulated days were characterised by high temperatures up to 36°C and low to moderate north to north-easterly winds (Fig. 2 and Fig. 3). The highest temperatures were found in the city centre.

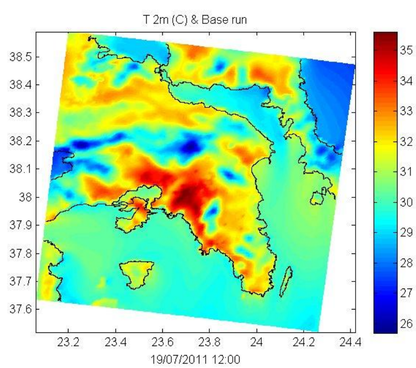


Figure 2. MM5 simulated near-surface (2 m) temperature fields on July 19, 2011, at 12:00 hours (base run).

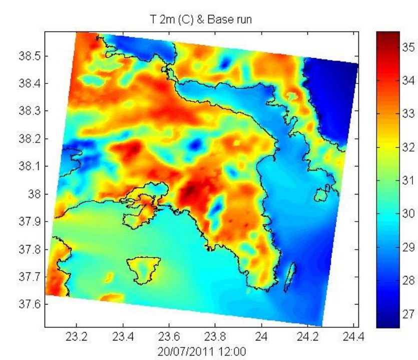


Figure 3. MM5 simulated near-surface (2 m) temperature fields on July 20, 2011, at 12:00 hours (base run).

The second run involved the application of PV panels on the urban canopy. Our interest was to simulate a maximum effect of PV panels on the meteorological patterns of the area and therefore, we assumed that 10% of the urban cells were covered with photovoltaics. Installing dark-coloured PV panels on top of land or structures, results in reducing or even minimising the albedo effect. Certain land use parameters (thermophysical properties) were modified in the MM5 pre-processor to simulate the PV surface properties. The albedo value was assumed to be 5% while the surface emissivity and the thermal inertia were set at 0.9 and 0.2, respectively (Nemet, G. 2009; Millstein, D. and S. Menon, 2011). The surface roughness was not modified in the case of PV panels and it was kept the same as that of the urban class.

RESULTS

The results from the MM5 meteorological model are discussed in this section. The temperature differences due to the installation of PV panels (BASE run - PV run) for July, 19, 2011 and for 06:00, 12:00, 15:00 and 21:00 hours are depicted in Figure 4. The changes in the temperature values can be seen in the urban cells where the application of the PVs has taken place. During daytime, more shortwave radiation is absorbed by the PV panels and hence, less (longwave) radiation is reflected back. The radiative forcing thus increases as the outgoing radiation is smaller. This effect causes higher air temperatures due to the PVs which is seen in the figures as negative values. The effect is stronger later at noon (15:00), when significant changes in temperatures up to -1.2°C can be deduced (Fig.4 (b) and (d)). At night, the situation reverses. The absence of solar heating causes the atmospheric convection to decrease, and the urban boundary layer begins to stabilize keeping surface air warm from the still-warm urban surfaces. The urban land cover cells have higher nighttime temperatures due to their higher thermal inertia as compared to the PV land cover class and therefore, the differences in temperatures (Base run - PV run) become positive (Fig. 4 (a)).

The temperature profiles obtained with and without the installation of PV panels are shown in Figure 5 for two different locations in the domain, in the city centre and at a suburban site in the north (Thrakomakedones). Overall, the differences in the temperature fields between the two simulated days were negligible and therefore, to save efficiently space in this paper, the results are presented mostly for the first date (July 19, 2011). It is mentioned however, that a noteworthy increase of 0.6°C is found in the city centre during daytime due to the PV panels.

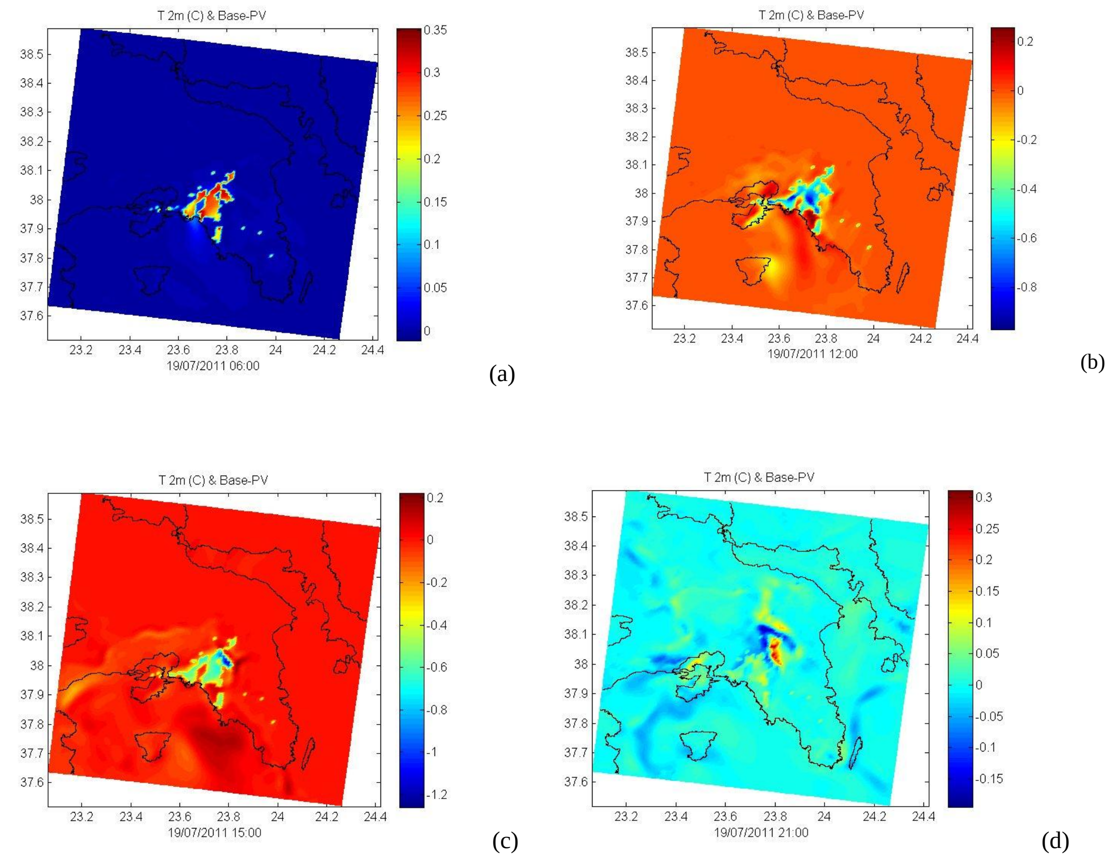
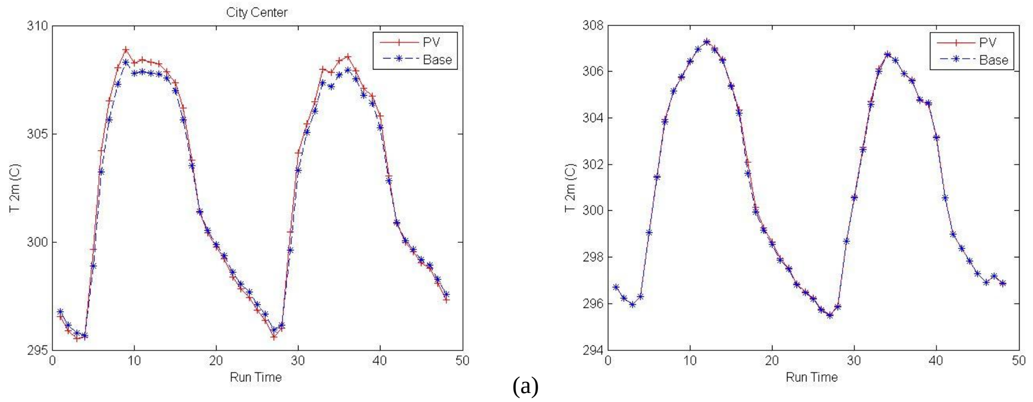


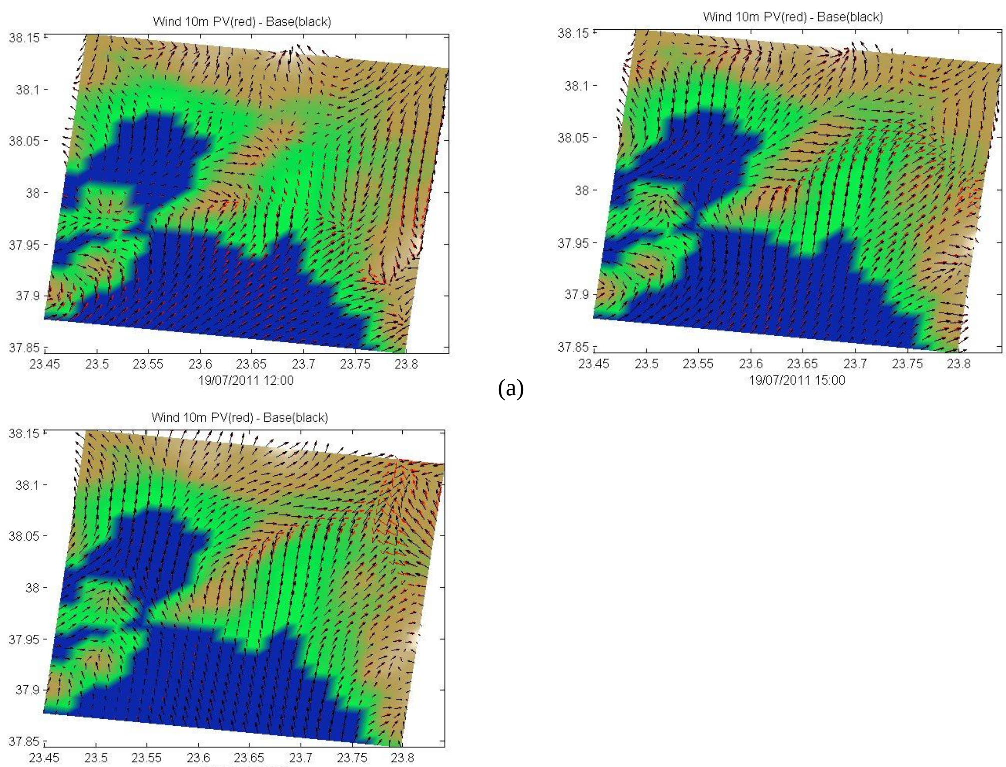
Figure 4. MM5 simulated differences in near-surface (2 m) temperature fields due to PV panels at: (a) 06:00, (b) 12:00, (c) 15:00 and (d) 21:00, on July 19, 2011 (Base run- PV run).



(a) (b)

Figure 5. Near-surface temperature temporal profiles for the two days of simulation (July 19-20, 2011) at: (a) the city centre and (b) Thrakomakedones (suburban/background location).

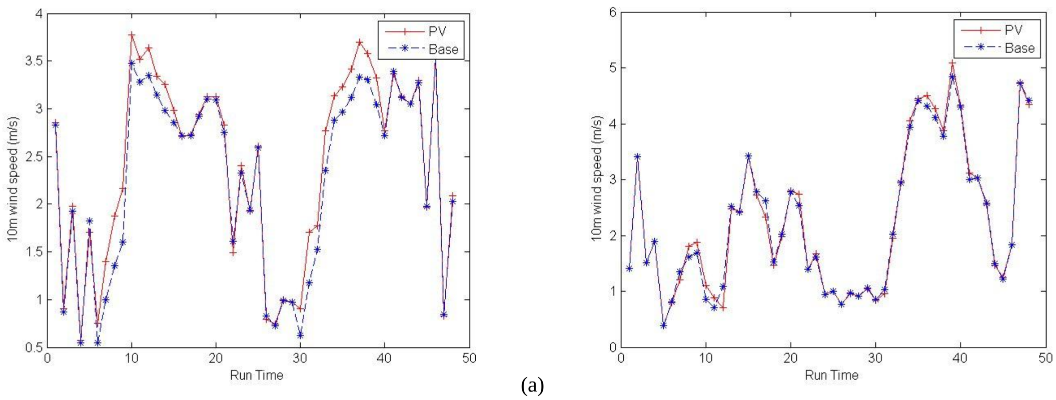
Figure 6 depicts the MM5 simulated wind fields for July 19, 2011. Variations in the direction of the wind vectors are detectable, but not important, as a consequence of the modified temperature fields.



(c)

Figure 6. MM5 simulated wind fields (at 10 m above surface) due to PV panels at: (a) 12:00, (b) 15:00 and (d) 18:00, on July 19, 2011 (PV run with red; Base run in black).

Investigation of the effects of PV panels in the near-surface wind speed during the two days of the simulation yielded that the highest changes occur at noon and during afternoon hours in the city centre (Figure 7 (a)). However, these changes are of the order of 0.5 m/s and not important. In addition, the impact of the PV panels on the wind speed in the suburban areas is even smaller and insignificant (Figure 7 (b)).



(a) (b)

Figure 7. Temporal profiles of MM5 calculated wind speed during the July 19-20, 2011, at: (a) the city centre and (b) Thrakomakedones (suburban/background site).

CONCLUSIONS

Here we have examined using the MM5 model, the local effects of the installation of photovoltaic panels on the meteorology patterns of the area of Athens, during a summer period. We have found at the urban cells with 10% assumed installed PV panels, increases in air temperature values up to 1.2°C during daytime hours. The effect is deduced to be important but it is counter balanced at night, when cooling increases. Similar findings have been reported in Millstein, D. and S. Menon, (2011), where local temperature increases of 0.4°C were calculated (with the Weather Research and Forecasting, WRF, model) due to the installations of PVs in desert areas of California. It is interesting to study the induced effects of PV panels in local climates when these are added in rural surfaces and other land cover classes with varying albedo and thermal properties in the future.

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