WRF parameterization updates based on recent and long-term satellite observations

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Abstract Recent satellite-derived products are analyzed and processed in order to update input parameters of the meso-scale model WRF (Weather Research and Forecasting), used for the study and prediction of extreme weather events in Greece, in the framework of the AKAIPRO project. Updated input parameters included the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) derived GDEM (Global Digital Elevation Model), which substantially improves the original WRF elevation spatial resolution; surface emissivity and albedo derived from MODIS (Moderate Resolution Imaging Spectroradiometer) multi-year observations. These emissivity and albedo timeseries, covering Europe, northern Africa and the Middle East, after statistical processing were used to update corresponding WRF input tables based on land cover classification. Updated input parameters also included land cover maps extracted from ESA's GlobCOVER product, based on MERIS (Medium Resolution Imaging Spectrometer) data. The processing and implementation procedures for updating the WRF input parameters are described in this study. WRF numerical simulations results and comparisons with data from meteorological stations are also presented, in order to assess the impact of the performed updates on the effectiveness of WRF in severe weather predictions.

1 Introduction

Severe weather events are expected to change under changing climatic conditions, in terms of both their frequency and intensity. Among the most susceptible regions, the wider area of Greece is already witnessing such changes. The IPCC report on extreme events (IPCC 2012) concludes that there have been major increases in warm temperature extremes across the Mediterranean, while Trenberth 2011 found an increase in convective storm intensity over the same region. Extreme rainfall events are also increasing, according to Kioutsioukis et al. 2010 and Nastos and Zerefos 2007.

Mesoscale numerical weather prediction models, such as the Weather Research and Forecasting (WRF) model, are essential for simulating and studying extreme events. In the framework of the AKAIPRO project, the WRF model is used for the study of extreme weather events in Greece during the last years, and their short-term prediction.

In the present study, recent satellite-derived products were analyzed and processed, in order to update important input parameters of the WRF. These parameters include topography, land cover, land surface emissivity (LSE) and land surface albedo (LSA). Topography, and especially its spatial resolution, is crucial for the accuracy of WRF simulations and predictions. Land surface variability, which determines the microclimate of a region but also affects local scale and mesoscale atmospheric circulation (e.g. Hartmann 1994), requires continuous updates. LSE and LSA, on the other hand, are needed for the computation of both shortwave and longwave radiation fluxes, which play a key role in surface-atmosphere interactions.

In the next section, the satellite products and the methodology for the corresponding WRF inputs update are described. A case study, evaluating the WRF results using the updated data, is presented in Section 3.

2 Data and Methodology

WRF represents topography using a Digital Elevation Model (DEM), derived from global observations of the Shuttle Radar Topography Mission (SRTM). The SRTM product is available at 30 arcsec ($\approx$900 m × 900 m) posting. This data set was replaced by recently available data from a Global DEM (GDEM), generated from data collected from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), using photogrammetry and stereoscopy (Abrams et al. 2010, Toutin 2008). GDEM posting is 30 m × 30 m, having the potential to substantially improve the topography representation in the WRF.

The original WRF land cover data come from the US Geological Survey (USGS) Global Land Cover Characteristics (GLCC) database, whereby land is divided in 24 categories, with 900 m × 900 m spatial resolution. The data set was derived from AVHRR (Advanced Very High Resolution Radiometer) data, spanning April 1992 through March 1993 (Loveland et al. 2000). These data were replaced by corresponding data from ESA's GlobCOVER product (2009), based on MERIS (Medium Resolution Imaging Spectrometer) data.

LSE and LSA in WRF are based on land cover types; two values of LSA (and similarly LSE) are assigned in each land cover category, for summer (16th April–15th October) and winter, respectively. These data were derived from measurements by AVHRR (Csiszar and Gutman 1999), and were updated by data from MODIS, spanning the period 2000–2012.

2.1 Methodology for Topography, Land Cover, LSE and LSA Update

For the GDEM incorporation in the WRF, a large number of GDEM tiles was initially retrieved, covering the wider Balkan and Central Mediterranean regions. These tiles were used to create a mosaic image in GeoTIFF format, and in Geographic/WGS84 and EGM96 horizontal and vertical geodetic datums, respectively, as described in Chrysoulakis et al. 2011. The next step involved modification of this product into binary file format, compatible with the *geogrid* program of the WRF Preprocessing System (WPS), in order to be exploitable by the WRF, as well as changes in corresponding WPS input files. For this purpose, the methodology and software described in Beezley et al. 2011 were used. In the new topography, the GLCC land cover classification and topography interpolation method remained unchanged. Due to limitations in the number of WRF topography input files, the spatial resolution of the GDEM data set was upscaled to 60 m × 60 m, from the initial 30 m × 30 m posting, using bilinear interpolation.

The number of land cover types differs between the USGS GLCC data set, used by the WRF, and GlobCOVER, which was used for updating these input data. Due to this difference, and in order to maintain the GLCC classification while updating its spatial distribution, land cover types of GlobCOVER were assigned corresponding values of GLCC, based on their similarity.

In order to update the land cover types in the wider area of WRF simulations, 32 GLCC land cover tiles were converted from generic binary to GeoTIFF format and used for the creation of a mosaic image, which was then collocated with the corresponding GlobCOVER data. Furthermore, since the two data sets differ in their spatial resolution, which is about 900 m × 900 m in GLCC and 300 m × 300 m in GlobCOVER, creating a correspondence of 9 GlobCOVER pixels for each GLCC pixel, the updated value of each pixel was assigned based on the GlobCOVER land cover type which occupied the majority of these 9 pixels. Finally, the new data set was divided into 32 tiles, which replaced the initial GLCC WRF input.

WRF input LSE and LSA values were replaced by corresponding more recently available data from Terra MODIS Level 3, 8–day mean products, available at 1 km × 1 km spatial resolution. For this purpose, 23 MODIS tiles, covering Europe, Northern Africa and the Middle East, were downloaded for each 8–day for the entire available time series (2000–2012), and processed accordingly (format conversion, data extraction and descaling).

LSE was initially calculated on a pixel basis, as the average of LSE in MODIS bands 31 (10.78–11.28 μm) and 32 (11.77–12.27 μm). Temporally average LSE values were then computed for the entire area, corresponding to summer and winter means. For the assignment of summer/winter value in each WRF land cover type, these seasonal mean LSE data were collocated with the corresponding land cover spatial distribution data, and the average LSE value for each land cover type was calculated.

LSA values were computed as a linear combination of black and white sky albedo values (BSA and WSA, respectively), as described in Schaaf et al. 2002. Specifically, 8–day mean BSA, which is a function of solar zenith angle (SZA), was first calculated on a pixel basis by averaging corresponding BSA values calculated at 9:00, 12:00, 15:00 and 18:00 local time SZAs, according to equation (2) in Schaaf et al. 2002. LSA was then calculated based on equation (3) in Schaaf et al. 2002, whereby it is a function of the fraction of diffuse skylight, which, in turn, is a function of aerosol optical thickness (AOT). For this purpose, AOT data from the corresponding MODIS Level 3 8–day product were used, covering the entire region, and LSA was computed by averaging results acquired using different SZAs, as previously described. The assignment of LSA values in each land cover type was performed with the same procedure described for LSE.

3 Case Study

The case study focused on a heat wave event in Athens, in July 15th, 2012. Two WRF runs were performed, both with the new GDEM, and with the old and new land cover data, respectively. To represent the thermal and dynamic effects of urban surfaces, a single-layer Urban Canopy Model (UCM, Kusaka et al. 2001) was coupled in Noah Land Surface Model (LSM, Chen and Dudhia 2001).

Figure 1 shows the differences in the obtained WRF results for near surface air temperature, evaluated with the two land covers, at 2012-07-15 and 23:00 local time. The simulation based on the new land cover gave higher temperatures in the northern and southern peri-urban areas of Athens, as well as in the eastern Attica (Mesogeia area), which was affected by substantial urban sprawl during the last decades (Chrysoulakis et al. 2013).

Two indicative comparative time series plots for selected stations are also presented. It should be noted, however, that comparisons with surface point measurements at specific locations can be misleading, given the specific local environment characteristics. In Fig. 2 (left, Gkazi station of the National Observatory of Athens), the new land cover slightly improves the simulated temperature. At Ano Liosia station, operated by the Hydrological Observatory of Athens (Fig. 2 right), WRF simulation with the new land cover, overestimates air temperature during the night of 15-07-2012. It follows, however, the exact temperature pattern the following night. Similar comparisons with other stations showed minor differences when the land cover type remained unchanged between the two data sets, while an overestimation of air temperature by the new land cover was found in a recently built-up area, with the specific station, however, operating inside a park environment.

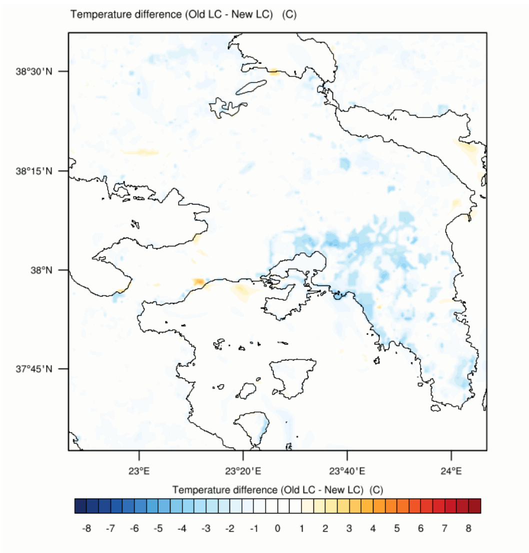

Fig. 1. Spatial distribution of the difference in near surface temperature (2m a.g.l.), between the two WRF runs, in July 15th, 2012, 23:00 local time.

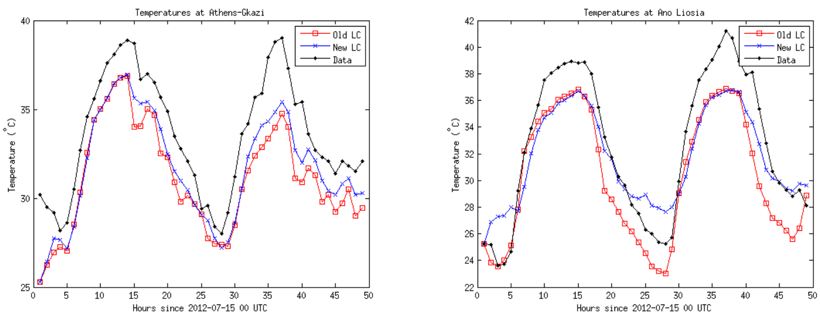

Fig. 2. Intercomparison of the near surface temperature between the two WRF runs and Gkazi (left) and Ano Liosia (right) stations.

4 Conclusions

Important input parameters of the meso-scale WRF model were updated based on recently derived satellite products, in the framework of the AKAIPRO project, aiming to study extreme weather events in Greece. These parameters included topography, land cover types distribution, LSE and LSA.

ASTER GDEM data were used for the topography update, improving its spatial resolution by two orders of magnitude. Recent land cover data from ESA's GlobCOVER product (2009) were also used to update the original, outdated WRF data set. For the LSE and LSA, MODIS data were used, covering a wide area (including Europe, Northern Africa and the Middle East), and spanning the period 2000-2012.

WRF simulations with the new land cover capture correctly the tendency for a stronger UHI effect in the Athens Great Area, where extensive urbanization took place in the last decade. However, comparison of the simulated surface temperature with surface measurements at specific locations can be misleading given the specific local environment the measuring stations operate in.

These preliminary results highlight the importance of up to date input parameters in WRF simulations, concerning regional climatic and environmental changes, which can lead to significant ecological and social consequences.

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