Modeling regional climate change and urban planning scenarios and their impacts on the urban environment in two cities with WRF-ACASA

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ABSTRACT

The number of urban metabolism studies has increased in recent years, due to the important impact that energy, water and carbon exchange over urban areas have on climate change. Urban modeling is therefore crucial in the future design and management of cities. This study presents the ACASA model coupled to the Weather Research and Forecasting (WRF-ARW) mesoscale model to simulate urban fluxes at a horizontal resolution of 200 meters for urban areas of roughly 5 by 5 km, 8 by 8 km and 20 by 20 km. As part of the European Project "**BRIDGE**", these regional simulations were used in combination with remotely sensed data to provide constraints on the land surface types and the exchange of carbon and energy fluxes from urban centers. Surface-atmosphere exchanges of mass and energy were simulated using the Advanced Canopy Atmosphere Soil Algorithm (ACASA).

ACASA is a multi-layer high-order closure model, recently modified to work over natural, agricultural as well as urban environments. In particular, improvements were made to account for the anthropogenic contribution to heat and carbon production. Two different modelling strategies were applied.

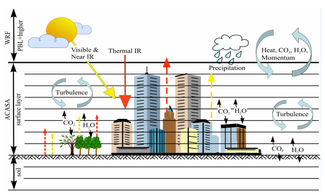
Using dynamically downscaled input data provided by **BRIDGE** two cities with four climate change and four urban planning scenarios were simulated: The climate change scenarios include a base scenario (Sc0) corresponding to the 2008 Commit in IPCC, a first climate change scenario (sc1) corresponding to the A2 IPCC scenario (medium emission scenario), the second climate change scenario (Sce2) corresponding to the A1F1 IPCC scenario (worst emission scenario) and finally Sce3 corresponding to the B1 IPCC scenario (best emission scenario).

A different approach was used to simulate larger regional domain that allow for better evolution of the urban atmosphere exchange at regional scale: we used a sequence of 6 nested domains with feedback for WRF-ACASA (Δx = 48.6, 16.4, 5.2, 1.8, 0.6 and 0.2 km) using NNRP reanalysis data in combination with CLC land cover data. The two highest resolution maps of the results are shown here. While more computationally expensive better spatial cohesion of the results is observed across the entire domain.

MODELLING

The off-line multilayer model ACASA (Pyles et al., 2000; Marras et al., 2011) (Fig. 2) has been applied by CMCC at Helsinki and Florence case studies, at local scale (Marras et al., in prep), and at regional scale using the coupled model WRF-ACASA (Figs. on the right) to estimate the exchanges of moisture, carbon dioxide, radiation, heat, momentum, and other quantities.

Figure 1 (below) is a cartoon schematic showing this coupling & its main physical aspects



Regional urban metabolism

WRF-ACASA simulations of urban mass and energy fluxes were conducted over two different urban regions: a high latitude city, Helsinki (Finland) and an historic European city, Florence (Italy). Helsinki is characterized by recent, rapid urbanization that requires a substantial amount of energy for heating, while Florence has far older, thicker buildings, with higher amounts of thermal inertia in the walls. Domains for Helsinki are shown on the left and center, Florence on the right hand side:

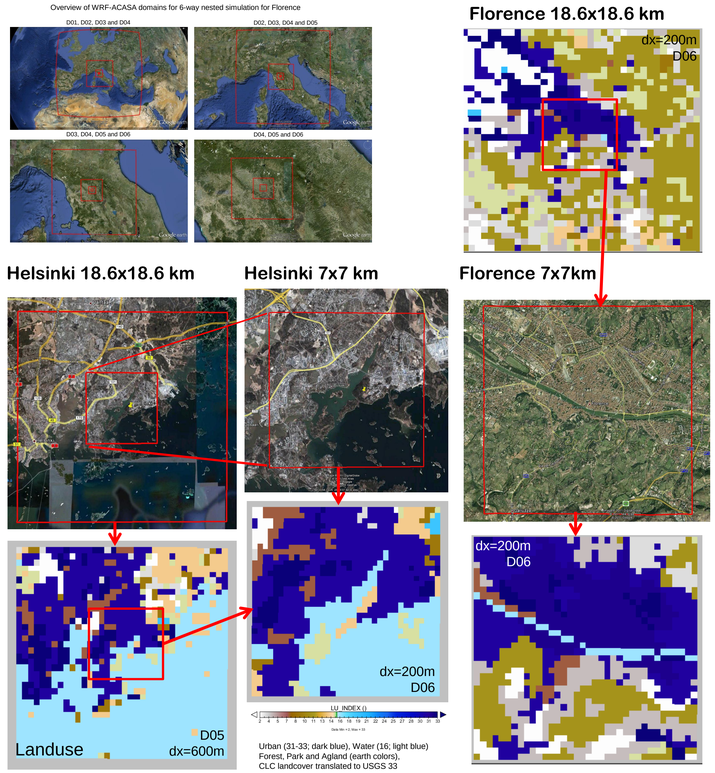


Fig. 2: High resolution domains d05 (Helsinki) and d06 (Helsinki and Florence) for the fully nested WRF-ACASA simulations using 100 meter resolution Corine Land Cover (CLC 2000)

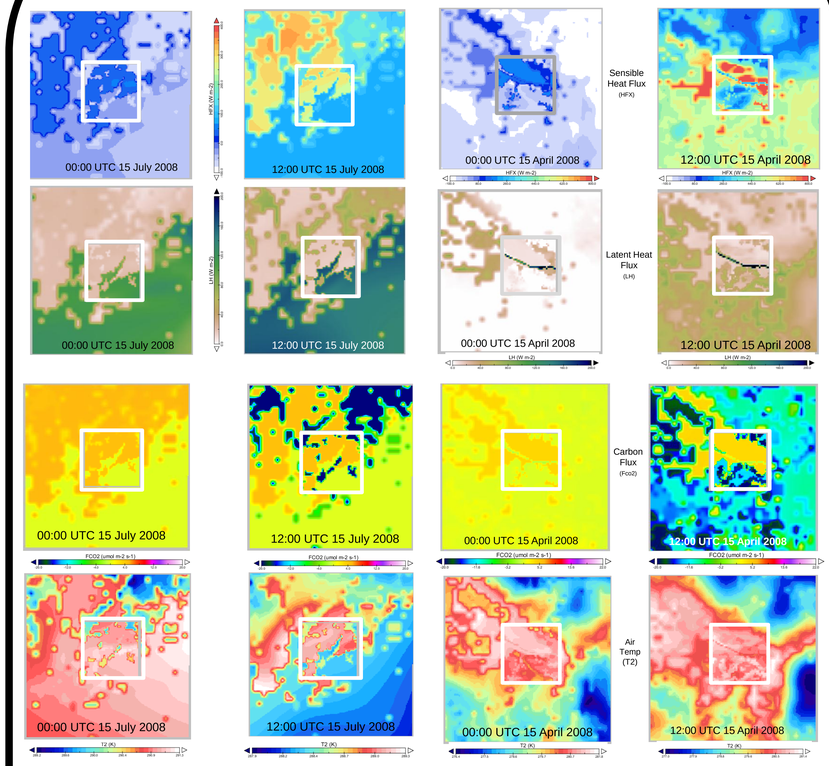
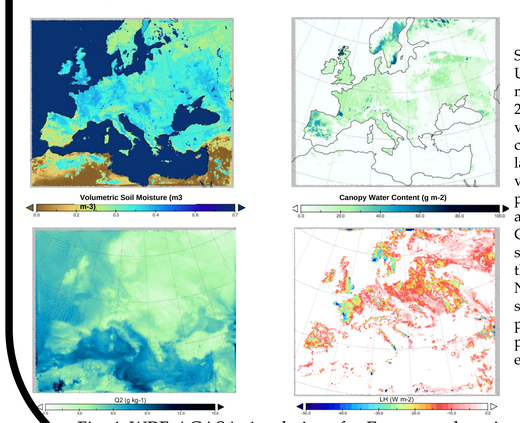


Fig. 3: Fully nested WRF-ACASA simulations (2008) using 100 meter resolution Corine Land Cover (CLC 2000), shown are results for July (Helsinki) and April (Florence) respectively.

Left hand side: Surface fluxes and temperature fields for Helsinki (eight panels total). Left column represents 00:00 UTC (night), and the right column represents 12:00 UTC (midday) values. From top to bottom: Sensible heat flux density (HFX) , latent heat flux density (LH), CO2 flux density (FCO2), and 2-meter air temperature (T2). White rectangle indicates approximate boundary between the innermost (200m gridded) domain and the adjacent outer domain (600m grid). The simulation invoked six nested concentric domains, the outermost domain encompassing the European continent on 48km grid . Urban heat island effects are apparent in the temperature field, while H and LE vary widely both day and night within each domain, depending on land use & local meteorological effects. Values are within range of observations (full analyses pending).

Right hand side: Surface fluxes and temperature fields for Florence (eight panels total). Left column represents 00:00 UTC (night), and the right column represents 12:00 UTC (midday) values. From top to bottom: Sensible heat flux density (HFX) , latent heat flux density (LH), CO2 flux density (FCO2), and 2-meter air temperature (T2). fields here as well indicate high dependence on WRF forcings and microenvironment on land use. The stippled feature with high value for LH are points representing enhanced evaporation over the Arno river, 200m gridded from city air (relatively dry) moving over the water. Values of T2 can vary by several degrees C within the areas.



Selected results for most of Europe, 00:00 UTC 30 April 2008 on a 24 km grid. The model was initialized on 00:00 UTC 1 April 2008. From left to right, top to bottom: volumetric soil moisture, canopy water content, 2m specific humidity (Q2), and latent heat flux density (LH). Note wide variations in soil moisture indicating realistic precipitation & evaporation effects accumulated over the 30 day simulation. Canopy moisture content fields indicate successful creation of additional variables in the WRF memory core and output regime. Negative values of LH (lower right) indicate successful inclusion of condensation processes, which is an essential physical process that influences specific humidity estimations (lower left).

Fig. 4: WRF-ACASA simulations for European domain

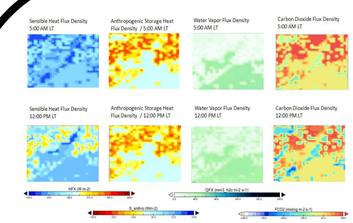


Fig. 6 Seasonally-averaged (July through September) local noon conditions for future climate scenarios (2030) for each case study, specifically water vapor flux and 2m air temperatures at Helsinki (top 8 panels) and Florence (bottom 8 panels): C0 = "2008-Commit"; C1 = IPCC "medium"; C2 = IPCC "worst"; C3 = IPCC "best". All 4 panels in the leftmost column are averages for C0, while average differences between C0 and each of C1, C2, C3 are shown to the right.

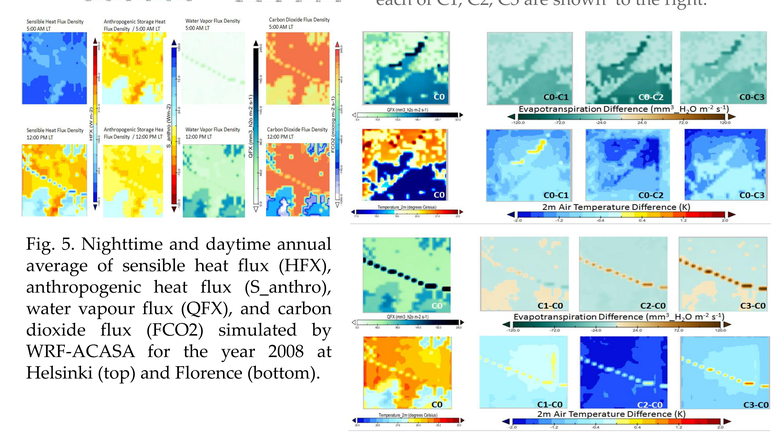
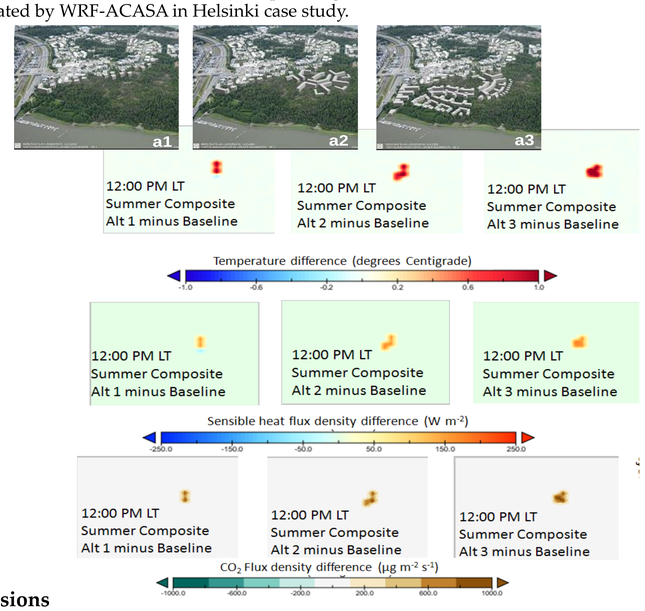


Fig. 5. Nighttime and daytime annual average of sensible heat flux (HFX), anthropogenic heat flux (S_anthro), water vapour flux (QFX), and carbon dioxide flux (FCO2) simulated by WRF-ACASA for the year 2008 at Helsinki (top) and Florence (bottom).

The impact of three alternatives planning an increased building surface has been simulated by WRF-ACASA for Helsinki case study (Fig. 7). Increased air temperature (and related urban heat island), less evpotranspiration, and increased CO_2 emissions are the main effects detected by the model simulation as consequences of the increased urbanized area.

Fig. 7. Differences between the three planning alternatives and the baseline scenario, simulated by WRF-ACASA in Helsinki case study.



Conclusions

We successfully ran WRF-ACASA simulations for the entire month of April 2008 (Florence) and July 2008 (Helsinki) using six nested grids, scaling from 48 km (continental) to 200m (local) were performed successfully using 16-node multiprocessor array. Simulations for Florence and Helsinki were done separately. Preliminary examination of all fields indicate the simulations to be realistic, with values of surface fluxes and near-surface air temperatures nearly continuous at the boundaries between the domains, indicating a "seamless" union with little distortion. The domains were chosen to maximize the amount of higher-resolution points in the interior (37 x 37) with each adjacent nest concentric to the last. We believe this configuration to generate more realistic results than those generated using fewer nests, less concentricity, and fewer points at the highest resolution.

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