UMEP - An integrated tool for urban climatology and climate sensitive planning applications

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1. Introduction

The urban climate is influenced by processes taking place at a range of different scales. Based on application (e.g. land surface or thermal comfort modelling), the appropriate scale has to be considered to make accurate estimation of the phenomena examined. Furthermore, the interaction of processes taking place at different scales makes it important to accurately couple and understand the different scale dependent processes controlling the urban climate and thus outdoor thermal comfort. In this paper, UMEP (Urban Multi-scale Environmental Predictor), an integrated tool for urban climatology and climate sensitive planning applications is presented. The tool can be used for a variety of applications related to outdoor thermal comfort, urban energy consumption, climate change mitigation etc. The tool consists of a coupled modelling system which combines "state of the art" 1D and 2D models related to the processes essential for scale independent urban climate estimations. UMEP will be delivered as an open source alternative where users will be able to contribute as well as extend the tool to improve modelling capabilities.

2. Modelling concepts

The modelling system contained within UMEP is designed to run from the street canyon to city scale (10^0-10^5 m) depending on the application. This is the range of scales that need to be understood in most urban climate, architectural and urban planning projects. The model is able to estimate a number of variables that relate to, for example, spatial variations of urban surface energy exchanges, boundary layer developments. Currently, the following main models that are to be coupled in UMEP are (Fig. 1):

1. The SOLWEIG-model (SOlar and LongWave Environmental Irradiance Geometry model) which simulates spatial variations of 3D radiation fluxes and mean radiant temperature (T_{mrt}) in complex urban settings. The model requires a limited number of inputs, such as shortwave radiation, ambient air temperature, humidity, urban geometry and vegetation cover (e.g. Lindberg et al. 2008; Lindberg and Grimmond 2011). SOLWEIG is also able to model shadow patterns which is important information requested by urban planners and architects. A solar energy model, SEBE (Solar Energy on Building Envelopes) (Lindberg et al. 2015) will also be incorporated in the modelling system.
2. SUEWS (Surface Urban Energy and Water Balance Scheme), a model able to simulate the urban radiation, energy and water balances using only commonly meteorological variables and information about the surface cover (e.g. Grimmond and Oke 2002; Järvi et al. 2011) and snowmelt (Järvi et al. 2014).
3. BLUEWS (Boundary Layer Urban Energy Water Scheme) is a daytime Convective Boundary Layer (CBL) model (Cleugh and Grimmond 2001) that has been previously coupled to SUEWS (Onomura et al. 2014). From the coupling of the two models it is possible to generate the site-specific input data needed for the calculations made in SOLWEIG i.e. air temperature, radiation and humidity. BLUEWS operates on the local to meso scale (Onomura et al. 2014). Furthermore, a night time cooling rate model, NOCRAM (NOcturnal Cooling RAte Model), will also be included to simulate intra urban, local scale, temperature variations.
4. LUCY (Large scale Urban Consumption of energY model) simulates all the components of anthropogenic heat flux (Q_F) on a global scale which is often ignored or roughly estimated in other energy balance models (Allen et al. 2011; Lindberg et al. 2013). SUÈWS/BLUEWS includes options for this estimation but including LUCY provides a third robust system taking Q_F to account for any urban area on Earth.

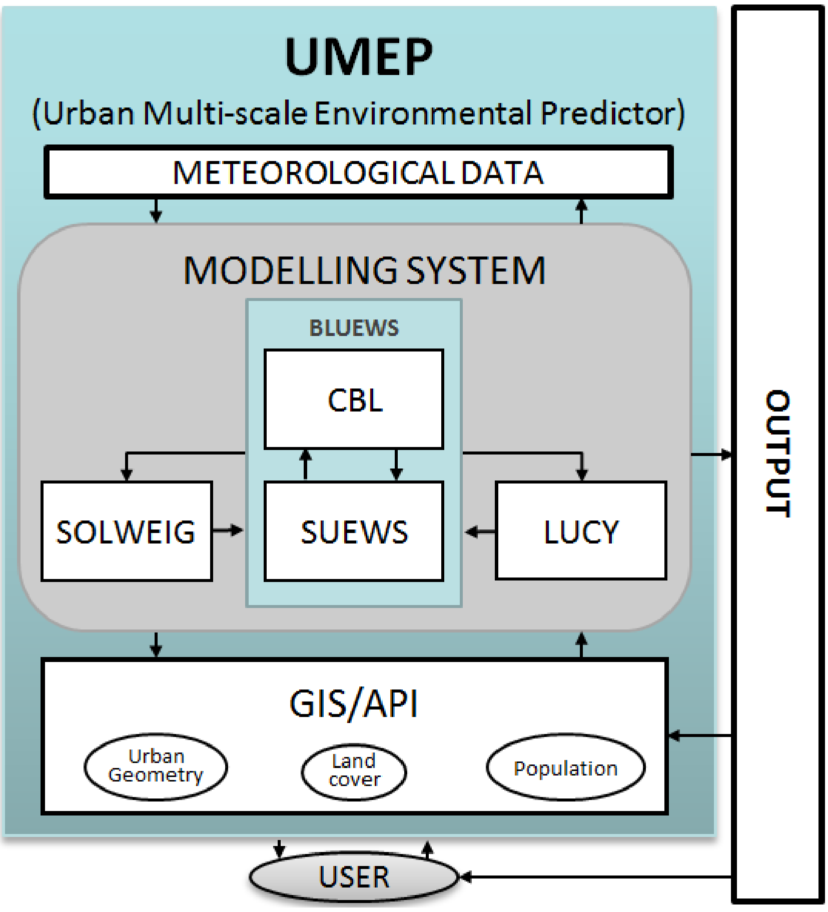

Figure 1: Schematic flowchart of the coupled modelling system in UMEP. See text for abbreviations.

3. Initial results and further model developments

All parts of the modelling system are active and the individual models have continued ongoing development. The first part of the coupling (SUEWS and CBL (BLUEWS)) has already been accomplished. BLUEWS allows routine observations from distant sites (e.g. rural, airport) to be used to predict daytime air temperature and relative humidity in an urban area of interest. It will also be possible to generate site specific air temperature and humidity values using only a few meteorological variables for input (e.g. solar radiation, wind etc.). As mentioned, further developments are currently taking place where a nocturnal cooling rate model is being developed to capture the diurnal cycle of essential meteorological parameters. The LUCY-model has recently been made spatial dynamic and are able to model Q_F down to 30 arc-seconds for any location of the world. SOLWEIG is currently being coupled with BLUEWS. Exchange of input data for SOLWEIG as well as input to BLUEWS in from of e.g. surface characteristics and radiative fluxes will take place. Also, very promising work on evaluating pedestrian wind speed patterns in the urban canopy layer will be included based on Johansson et al. (2015). UMEP will be designed so it could be exploited in both a simple mode using default configurations as well as an advanced mode. Thus, both practitioners as well as researchers could make use of the tool.

Other sub-models are also in the planning process of being incorporated in the modelling system such as the ESTM-scheme (Element Surface Temperature Model) which is able to estimate storage heat flux and an agent-based modelling approach for deriving local scale anthropogenic heat flux in urban areas.

5. User interface and application programming interface (API)

In order to easily use UMEP a major characteristic is the ability for a user to interact with spatial information to determine model parameters. This requires a dynamic approach where spatial data at different scales and sources are needed. This is accomplished by using an existing API for spatial data. UMEP make use of QGIS - a cross-platform, free, open source desktop geographic information systems (GIS) application - that provides data viewing, editing, and analysis capabilities. QGIS is both extendable by plugins plus reducible to only essential core feature needed. QGIS is written in C++ but have bindings to the Python language that will be exploited in the development of the tool. Furthermore, bindings between Python and Fortran will be used where intensive calculation are required. The QGIS community is very active and developments within the core software as well as plugin developments are impressive. A wide range of advantages are obtained from having a GIS-software and the model tightly coupled. This includes the ability to read and write a variety of geodata formats, ease of combining geodatasets so issues such as coordinate systems and scale are natively dealt with, visualization of inputs and output are combined, pre-processing of geodata for model parameters are directly calculated, thus are consistent between models and unnecessary additional preparation reduced.

The tool will be designed to include a pre-processor, a processor and a post-processor. The pre-processor is needed to prepare spatial and meteorological data as inputs to the modelling system. Tools such as a Sky View Factor Calculator (Fig 3) and tools for calculating morphology parameters such as frontal area index etc. will also be included. The processor includes all the main models for the main calculations. To provide initial “quick looks” the post-processor will be enable results to be plotted, statistics calculated etc. based on the model output.

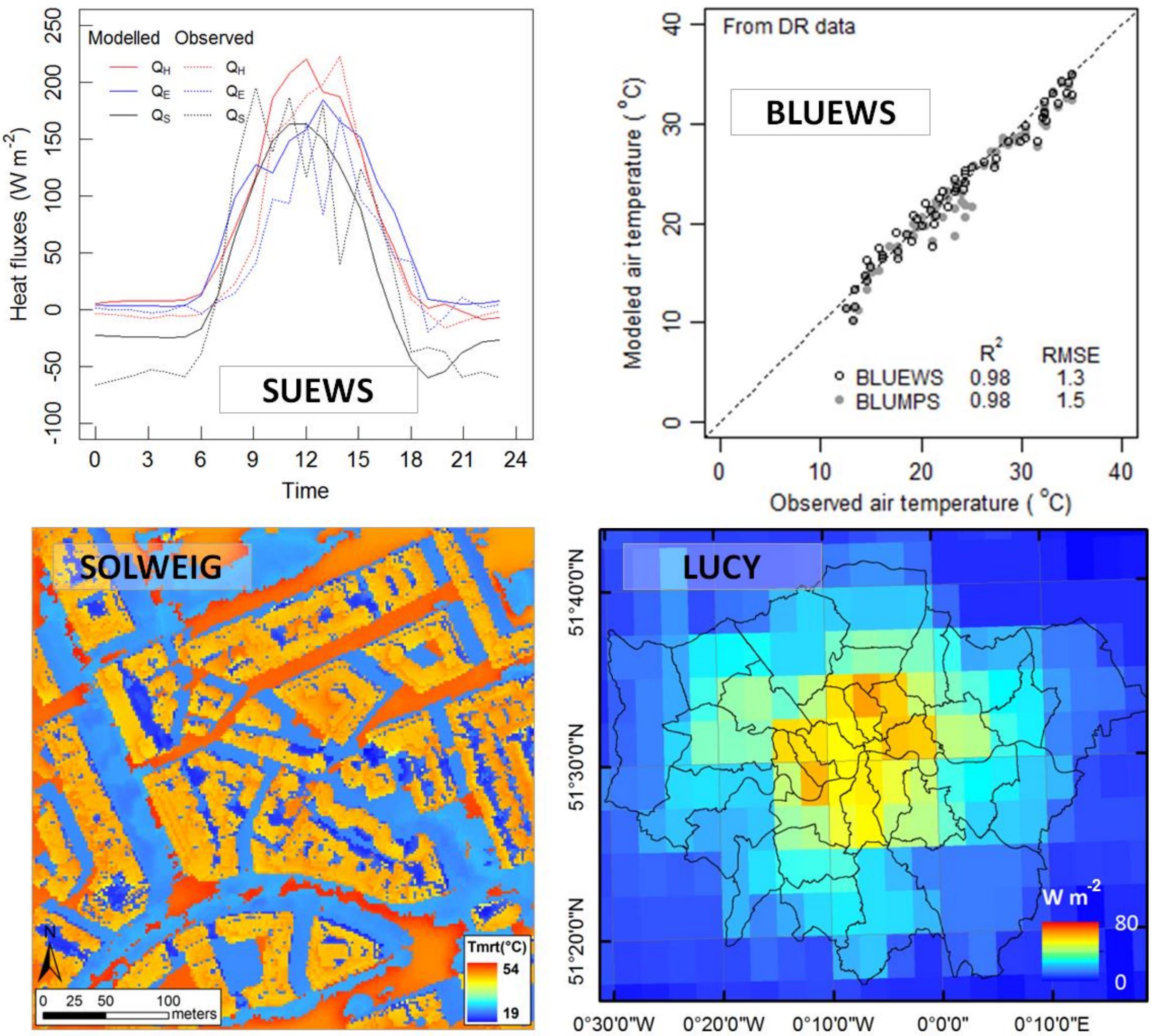

*Figure 2. Outputs from single and coupled models included in UMEP. **SUEWS**: Modelled and observed energy fluxes in Sacramento (US) 22nd August 1991. **BLUEWS**: Modelled and observed air temperature for a suburban site in Sacramento (US) using observed data at a dry rural site (DR). **SOLWEIG**: Tmrt in central of London (UK), 3 pm 3 June 2010. **LUCY**: Annual average Q_F for 2000 for London.*

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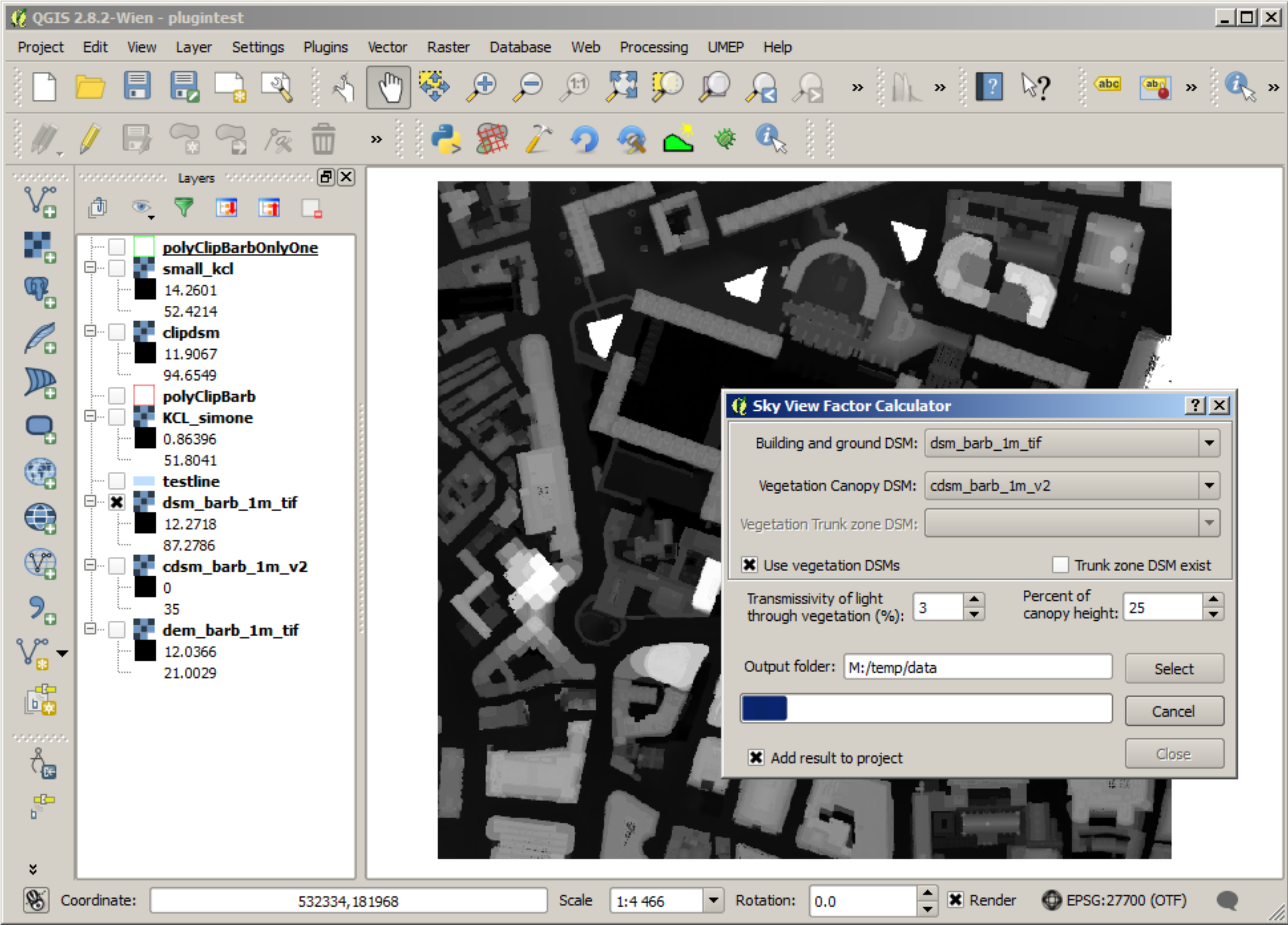

Figure 3. The QGIS (2.8.2) interface using the Sky View Factor Calculator.

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