Toward an urban water and energy budget model as an evaluation tool of urban planning: greening scenarios evaluation over the City of Nantes, in France.

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INTRODUCTION

Urban population has growing fast these last decades and is expected to still increase during the future decades (United-Nations, 2011). Urban areas, due to artificial materials, impacts both urban climate and hydrology: heat island, more frequent floods, longer droughts (Leopold, 1968). Furthemore, these disturbances related to urbanization go together with those due to climate change (GIEC, 2013). City planning evaluation in both hydrological and climate terms becomes crucial. Numerical models are useful tools for such evaluations. Nevertheless, even if numerous models dedicated to urban areas are used, very few models are able to simulate both detailed energy and water budgets. Most of them are specialized in one topic and simulate roughly the other one (URBS, Rodriguez et al (2008); PUMMA, Jankowfsky et al (2010); TEB (Masson, 2000); Martilli et al (2002)).

Introduction of vegetation in cities is supposed to be one of the solutions to limit urbanization impacts as urban heat island, floods, by increasing water infiltration and favoring evapotranspiration. The VegDUD research project (Musy et al, 2012), funded by the Research French Agency, aimed to evaluate urban greening solutions by grouping teams of different disciplines (urban climate, hydrology, acoustics, building energy, …) at different scales (street, district and city). At the city scale, the model TEB (Masson et al, 2000; Lemonsu et al, 2012) is able to evaluate urban climate impacts of urban development scenarios thanks to a detailed energy budget while the water budget is quite rough. Introduction of specific urban hydrological processes were introduced to allow hydrological evaluation of urban planning and also a better evaluation of climate impacts as energy and water budgets are linked through the evapotranspiration process. As applications, greening devices were specifically studied: greenroof, trees vs grass land and vegetation density variation, over a large area of the city of Nantes, in northwestern of France.

This paper briefly describes the hydrological processes introduced in the TEB model. The study domain and the scenarios are presented. Preliminary results are discussed before to conclude.

THE TEB-HYDRO MODEL

The model Town Energy Balance (Masson, 2000; Hamdi and Masson, 2008) was developed to simulate the radiative, energy and hydrological processes between the built surfaces and the atmosphere. It discretizes space thanks to a regular meshed grid. In each mesh, urban areas are represented by a simplified geometry using the urban canyon concept: flat roof, two identical walls and a street. Further developments allowed to improve the model: the introduction of urban vegetation into the canyon structure (Lemonsu et al, 2012), the greenroof structure (de Munck et al, 2014). To improve the water budget, the soil with heat and water transfers, under streets and buildings have been implemented. All these developments use the coupling with the soil-vegetation-atmosphere-transfer model ISBA-DF (Boone et al, 1999).

Without any soil under built surfaces (streets and buildings), water transfer is limited to surface transfer in TEB (Masson, 2000). Moreover, all the surface runoff is lost for the model. The introduction of urban vegetation in the model (Lemonsu et al, 2012) allowed water transfer between ground, garden type surface and atmosphere. To complete the urban water cycle:

- an infiltration rate through the streets has been added, as urban impervious surfaces are never totally impervious;
- ground water vertical transfers are resolved by ISBA-DF, for under building ground and under street ground, separately, in the same way as for garden ground but with different upper boundary conditions;
- groundwater infiltrations into the sewer network (Dupasquier, 1999), have been taken into account as in Furusho et al. (2013) to decrease the near ground water content and simulates a kind of base discharge in the sewer networks during wet periods;
- surface runoff as the sum of all the surface type runoff is calculated and available to be routed to an identified outlet.

These developments have been evaluated thanks to a 10-years database over a little urban catchment (Rezé, 13ha) near Nantes (Berthier et al, 1999).

THE STUDY SITE AND THE SCENARIOS DESCRIPTION

In order to illustrate the applications of such numerical modeling, it has been applied to a large area (46 km^2) of the City of Nantes, a growing city in northwestern France. The simulation period lasts 2 years and 5 months, from the 1st of May 2010, with the first year used as a warm-up period for the model. Only the last 17 months are analysed. Atmosphere forcing data are homogeneous over the simulation domain. Land use data are extracted from satellite data (SPOT5), urban database and French database (BDTOPO® (2008)). This constitutes the reference (REF) scenario. In order to evaluate the impact of greening strategies, five scenarios have been built and compared to REF scenario and to each other. As the study site has already a high natural surface fraction, the greening scenarios focus on a reduction of vegetation rather than an increase: NOTREE (all the trees are replaced by low vegetation), GRD* (vegetation fraction is reduced by *=10, 20, 30 %). Except in the GREENROOF scenario, where some buildings (commercial, public services, collective) are transformed with greenroof, increasing the average natural surface fraction by 8%.

RESULTS AND DISCUSSION

The REF simulation has been evaluated thanks to observed data (Mestayer, 2013) at the grid mesh scale corresponding to the observed data location and at both catchment scales: Gohards (513ha) and Pin Sec (31ha, a subcatchment of Gohards). Both catchments belong to French long term urban observatory ONEVU (Ruban et al., 2007). The comparison of simulated discharges with observed ones shows a model tendency to overestimate but a realistic dynamic at a daily scale.

The runoff volume and latent heat, from each scenario are integrated over the analysis period and over the simulation domain and both catchments. Their comparison to REF scenario and to each other highlights two main results. As expected, the more natural surface fractions are reduced, the more total runoff volume increases and latent heat decreases (GDR** and GREENROOF scenarios but not for NOTREE scenario). As a second result, the type of vegetation (high vs low vegetation) seems to have a weaker impact on runoff volumes than the natural surface fraction while it has a stronger impact on latent heat. These results are verified at the domain scale and at the both catchments scales as well, considering the relative natural surface fractions.

CONCLUSIONS

Considering the urban population growth and the expected climate change impacts for the futures decades, the development of models assessing the hydrological and micro climate impacts of urban planning scenarios is a crucial issue. Indeed, supposed mitigation strategies using vegetation are more and more used by urban planners. Numerical models are needed to evaluate such strategies impacts in an integrated approach, at city scale. The enrichment of the TEB model with typical urban hydrological processes offers a first step to such tools by being able to evaluate both hydrological and climate impacts of mitigation strategies. Nevertheless, the model needs some more improvements. The transfer function allowing water routing from each grid mesh to defined outlets is under development (Allard, 2014). Other sustainable and mitigation strategies will also be developed: greenwalls, swales, … To go further in the integrated approach, the introduction or the coupling with other topics is needed. For instance, improving the model with social and human sciences topics as economy, stakeholders policy could improve the analysis.

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