SIMULATING URBAN SURFACE ENERGY AND WATER BALANCES ABOVE DIFFERENT SURFACE COVERS IN VANCOUVER, BC

UNIVERSITY OF HELSINKI
FACULTY OF SCIENCE

Tom Kokkonen[1], Sue Grimmond[2], Helen Ward[2], Andreas Christen[3], Tim Oke[3], Manuela Hayn[3], Olle Räty[1], Leena Järvi[1]

tom.kokkonen@helsinki.fi

[1]Department of Physics, University of Helsinki, Finland; [2]Department of Meteorology, University of Reading, UK; [3]Department of Geography, University of British Columbia, Canada

INTRODUCTION

Urbanization and further densification influences the energy and water balances of an area. Lack of observations makes modeling a useful tool to explore these changes.

The objectives of this study:

- To examine temporal changes in energy and water balances due to the densification at two suburban sites in Vancouver, BC, Canada
- To evaluate how well the new model version (V2015a, Figure 1) of the Surface Urban Energy and Water Balance Scheme (SUEWS, Järvi et al., 2011; 2014) performs at the study sites

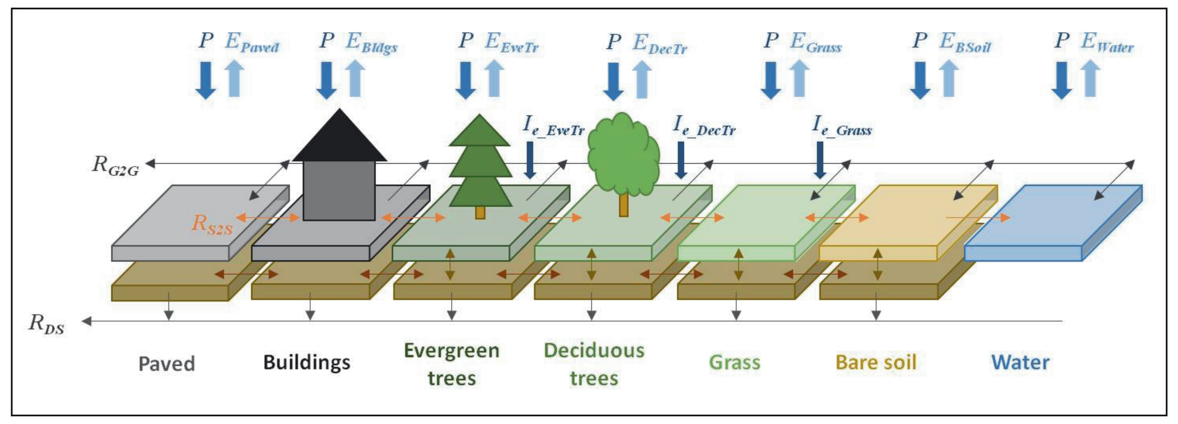

Figure 1. Overview of the seven parallel surface types with the vertical and horizontal flow of water. *E* is evapotranspiration, *P* precipitation, I_e external irrigation and *R* runoff within SUEWS (Ward et al., 2015).

STUDY SITES

Vancouver (Figure 2) general climate is influenced by it's location on the coast and mountain chains parallel to coast. Detailed climatology of the area is a response to local topography and urban development.

Focus here is two suburban sites Oakridge and Sunset (49°23'N, 123°1'W), which differ in land cover fractions (Table 1).

- Oakridge more prosperous with bigger houses and lots, and more automatic irrigation systems (61% vs 1%)
- Sunset smaller lots and houses, more paved surfaces (45% vs 29%)

Figure 2. Aerial image of Vancouver showing locations of Oakridge and Sunset (Google Earth, 2015).

Table 1. The characteristics of the sites. *A* is area, f_{bldg}, f_{pav}, f_{evergr}, f_{dec}, f_{grass}, $f_{irrgrass}$, f_{aut} are fractions of buildings, paved surfaces, evergreen trees and shrubs, deciduous trees and shrubs, grass, fraction of irrgated grass of grass surfaces and automatic irrigation, *p* is population density, z_h is mean building height and z_{hv} is mean tree height.

	Oakridge	Oakridge	Sunset	Sunset
Year	1982	2009	1987	2009
Code	Vo82	Vo09	Vs87	Vs09
A (ha)	21	21	21	78
f_{bldg}	0.19	0.24	0.26	0.23
f_{pav}	0.25	0.29	0.27	0.45
f_{evergr}	0.04	0.05	0.02	0.03
f_{dec}	0.08	0.10	0.07	0.09
f_{grass}	0.44	0.32	0.38	0.20
$f_{irrgrass}$	0.75	0.97	0.56	0.90
f_{aut}	0.05	0.61	0.01	0.01
p (in ha^{-1})	20.5	29.3	21.4	64.1
z_h (m)	7	5.8	5.2	5.5
z_{hv} (m)	7	8	6.0	7.1

Changes with time

- Between 1982 and 2009 in Oakridge
  - Surface cover fraction of buildings increased from 19% to 24%
  - Paved surfaces from 25% to 29%
- Between 1987 and 2009 in Sunset
  - Surface cover fraction of buildings decreased from 26% to 23%
  - Paved surfaces increased from 27% to 45%

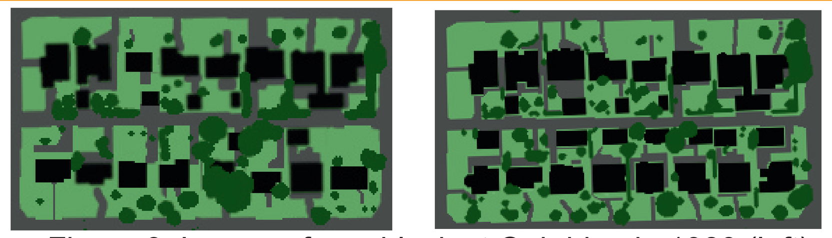

Figure 3. Layers of one block at Oakridge in 1989 (left) and 2009 (right). Light green is grass, dark green is trees and shrubs, gray is paved surface and black is buildings.

Land cover fractions for Oakridge analyzed from historical aerial photographs using image manipulation (Figure 3). Different layers of buildings, trees and shrubs, grass and impervious surface cover fractions were calculated separately. Surface cover fractions for Sunset were taken from Grimmond and Oke (1991) and Järvi et al. (2011).

Measurements at these sites are turbulent fluxes of sensible and latent heat using the eddy covariance net technique, precipitation, temperature, wind speed, relative humidity, air pressure, short- and long-wave components of the new all wave radiation (Q^*).

MODEL AND REANALYSIS DATA

- SUEWS was used (Ward et al., 2015) to model surface energy and water balance exchanges
- Surface cover is divided in to seven parallel surface types (Figure 1)
- Net all-wave radiation simulated using the net all -wave radiation scheme (NARP; Offerle et al., 2013; Loridan et al., 2011)
- Storage heat flux is simulated using the Objective Hysteresis Model (OHM; Grimmond et al., 1991)
  - Version V2015a improves description of surface conductances when compared to version V2014b. Model time step is shorter (5 min) and some known bugs fixed
  - Versions V2014b and V2015a were compared against measurements (Figure 4)

- To force SUEWS, Watch Forcing Data WFD (Weedon et al., 2011) and WFDEI (Weedon et al., 2014) were used
  - Derived for hydrological modeling purposes from ERA-40 and ERA-Interim reanalysis products
  - Grid size WFD and WFDEI datasets is 0.5°
  - Grid height in WFD and WFDEI is the mean height of the 50x50 km grid, which is higher than the height of the study sites
  - Temperature and pressure had to be scaled to surface values using fundamental equations
  - WFD and WFDEI data are in 3 or 6 hour resolution and the model uses hourly data, so data had to be interpolated to one hour resolution
  - We used the GPCC precipitation model for Watch Forcing Data which overestimates the precipitation compared to the measurements because of the higher grid height (Figure 5)
  - For long term modeling both WFD and WFDEI datasets are needed because WFD is available for 1901 - 2001, and WFDEI 1979 - 2012

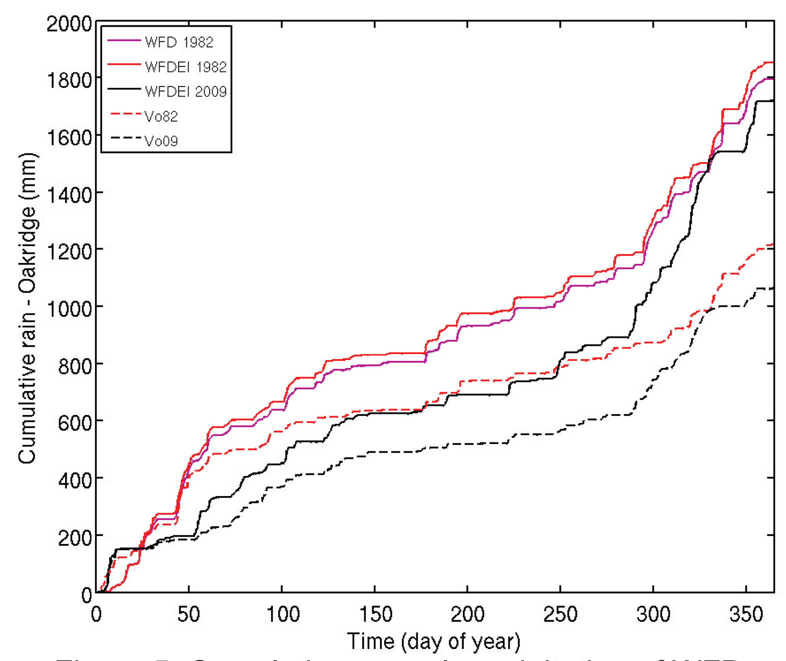

Figure 5. Cumulative annual precipitation of WFD, WFDEI and measurements for Vo82 and Vo09. WFD reanalysis data only for 1982 because it is not available for 2009.

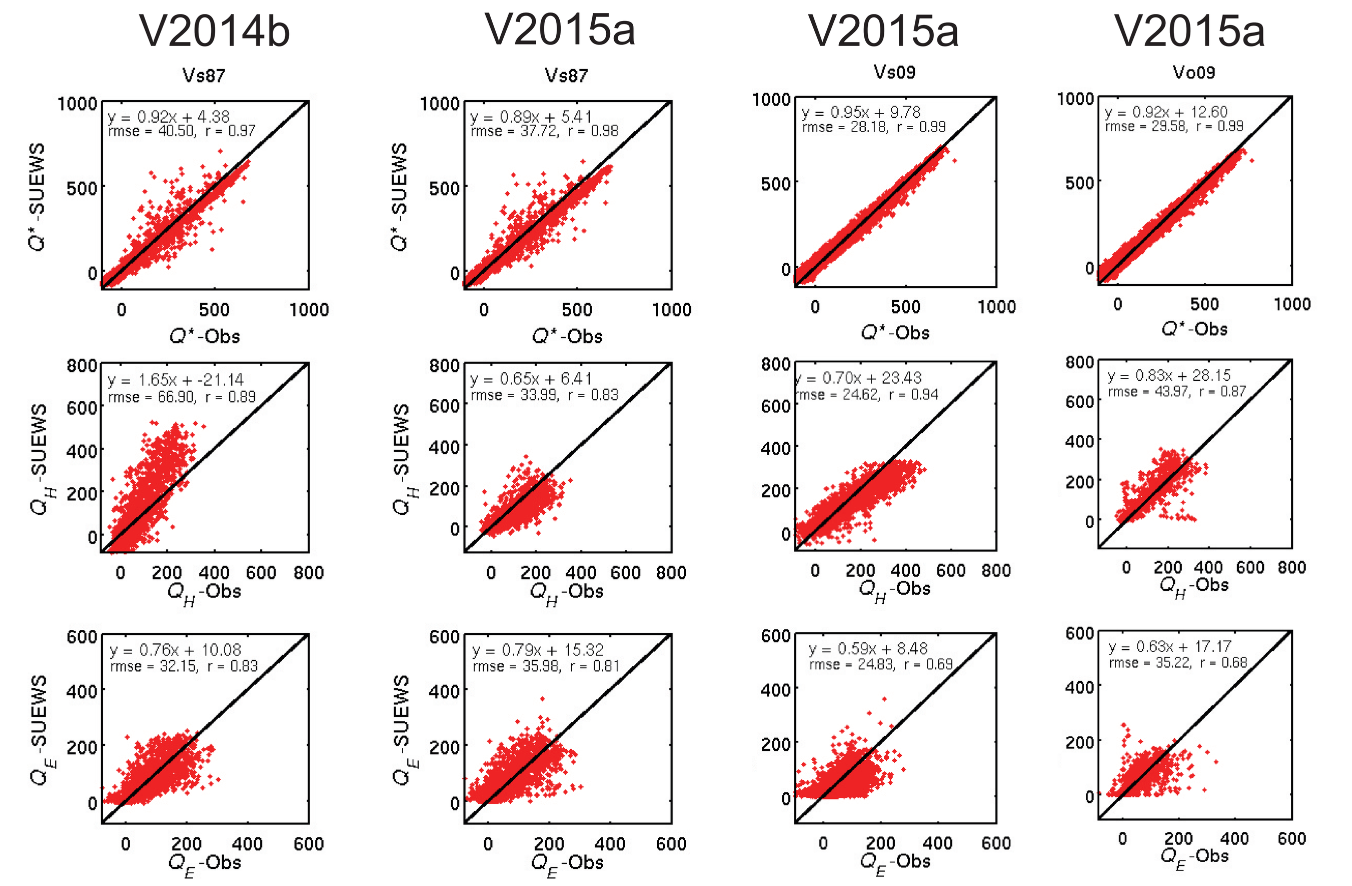

Figure 4. Statistics of measured and modeled hourly net all-wave radiation Q^* and turbulent heat fluxes Q_H and Q_E for Vs87 with model versions V2014b and V2015a (2 Feb - 28 Jun) and with model version V2015a for Vs09 (1 Jan - 31 Dec) and Vo09 (27 Jun - 30 Aug).

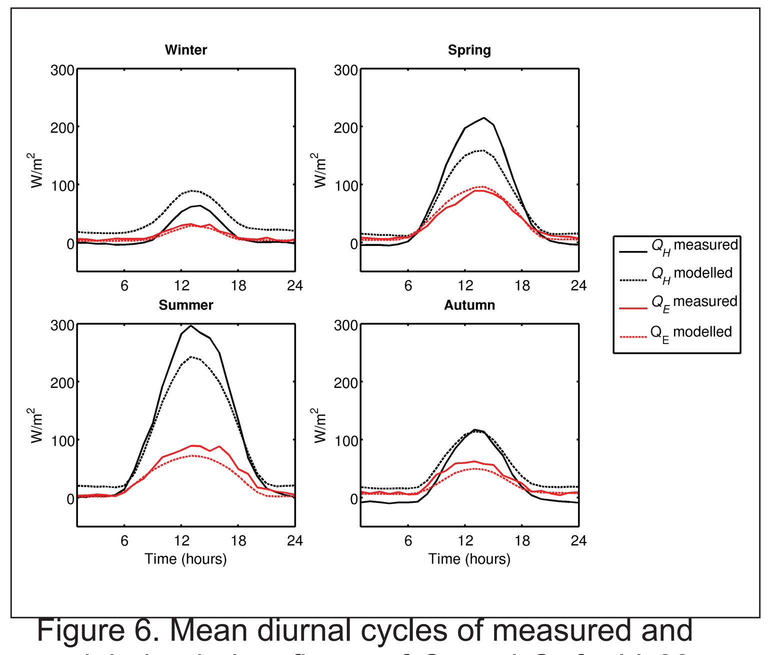

Figure 6. Mean diurnal cycles of measured and modeled turbulent fluxes of Q_H and Q_E for Vs09. Winter is Dec, Jan, Feb. Spring is Mar, Apr, May. Summer is Jun, Jul, Aug. Autumn is Sep, Oct, Nov.

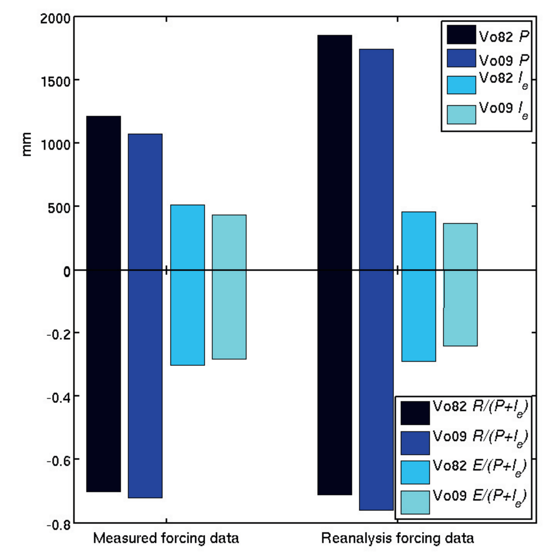

Figure 7. Annual precipitation, irrigation and normalized runoff and evaporation for Vo82 and Vo09 with measured forcing data and reanalysis forcing data from WFDEI.

RESULTS

SUEWS was originally applied to the Sunset suburban site using Vs87 data (Grimmond and Oke 1991, Järvi et al. 2011).

- New model version (V2015a) was first tested for Vs87
  - New version improved the simulation of Q^* and Q_H and the Root Mean Square Errors (RMSE) decreased from 40.50 to 37.72 W m^{-2} and from 66.90 to 33.99 W m^{-2}, respectively (Figure 4)
  - Simulation of Q_E on the other hand was slightly decreased (RMSE increased from 32.15 to 35.98 W m^{-2}

SUEWS run for Vs09 (whole year) and Vo09 (summer months) for seasonal mean diurnal cycles of turbulent heat fluxes.

- Q_E is simulated well compared to the measurements although it underestimates daytime values in summer (Figure 6)
- Daytime Q_H underestimated in spring and summer
- In winter systematic overestimation throughout the day. Probably due to overestimation in anthropogenic heat flux

Water balance for Oakridge 1982 and 2009

- Increase in runoff normalized with (precipitation+irrigation) as expected as the impervious surface cover increased 16% (Figure 7)
- Normalized runoff increased 0.70 to 0.72 (3%)
- Normalized evaporation decreased 0.30 to 0.28 (7%)
- SUEWS indicates changes in densification of urban areas in agreement with observations

CONCLUSIONS

- SUEWS evaluated and found to perform well compared to measurements of net all-wave radiation and turbulent heat fluxes
- Watch Forcing Data needs to be downscaled to match the daily statistics of local observations using methods described in Räty et al. (2014)

FUTURE WORK

- Surface cover fractions will be analyzed from aerial photographs for Oakridge and Sunset
- Same methods will be used to analyze the energy and water balances for 1920-2009

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REFERENCES

Grimmond and Oke (1991). Water Resour. Res. 27: 1739–1755.
Järvi et al. (2011). J. Hydrol. 411, 219–237.
Järvi et al. (2014). Geosci. Model Dev. 7: 1691 - 1711.
Loridan et al. (2011). J. Appl. Meteorol. Clim. 50: 185 - 202.
Offerle et al. (2003). J. Appl. Meteorol. 42: 1157 - 1173.
Räty et al. (2014). Climate Dynamics, 42, 2287–2303.
Ward et al. (2015). SUEWS Manual : Version 2015a. 16 July 2015.
Weedon et al. (2011). J. of Hydrometeor., 12, 823–848.
Weedon et al. (2014) Water Resources Research, 50, 7505–7514.

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