Report by UWI doctoral researcher Kyle Pipkins (N2)

Project number: N2

First and last name of doctoral researcher: **Kyle Pipkins**

(Working) title of doctoral project: **Heat and vapor transport at the soil-atmosphere interface in urban areas**

Name of supervisors: Prof. Dr. rer. forest. Birgit Kleinschmit (TUB), Prof. Dr. rer. agr. Gerd Wessolek (TUB), Hon.-Prof. Dr.-Ing. Heiko Sieker (Ingenieurgesellschaft Prof. Dr. Sieker mbH, Hoppegarten)

2. Description of doctoral project and research results achieved to date:

Motivation

Globally, the effects of a warming climate on human health are being compounded by increasing rates of urbanization. Urbanization can lead to a conversion of land from permeable to surfaces with differing degrees of impermeability (e.g. from bare soil to pavement). This leads to changes in both surface water and heat dynamics, which have subsequent environmental and human health impacts [1]. Therefore, it can be useful to recognize such surfaces in urban areas and characterize their hydrothermal properties. There are many methods for characterizing such surfaces, including approaches which create parameterized simulations of urban areas, as well as empirical methods which use physical models at different scales of observation. This project aims to assess these empirical-based approaches in order to determine the most important factors in assessing surfaces with different degrees of impermeability, both in recognizing these surface types from remote sensing as well as characterizing their thermal dynamics.
The thermal dynamics on the earth's surface can be described by the surface energy balance, in which net radiation is partitioned into component heat fluxes at the soil-atmosphere interface (Figure 1). Urban areas, which are typically comprised of high amounts of sealed surfaces, generally have greater sensible heat fluxes both in the day-time and night-time in comparison to rural areas, due to reduced cooling due to evapotranspiration as well as greater heat storage during the day (which is then released at night) [2]. This phenomenon is generally referred to as the urban heat island effect.

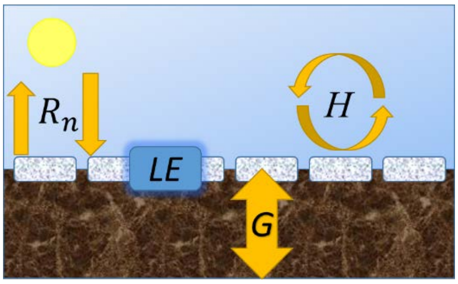

Figure 1: Surface energy balance, where R_n is net radiation, H is sensible heat flux, G is ground heat flux, and LE is the latent energy used for evaporation

The surface energy balances of urban surfaces are strongly influenced by such factors as albedo and permeability [3]. A number of authors have determined that partially impermeable surfaces such as cobblestone and permeable concrete have differing thermal dynamics from fully impermeable surfaces [4]. However, the majority of these studies have only been performed using in-situ measurement methods, such as through the use of embedded temperature sensors in the paving material. These surfaces are typically excluded from simulation-modelling approaches due to their high heterogeneity and difficult parameterization. Instead, these models typically rely on large scale estimations of sealing degree of percentages of asphalt and concrete [5]. Remote sensing-based analyses also tend to exclude these surface types, since the most common thermal sensors have ground resolutions of 90 meters to kilometre scales. Therefore, this project aims to consider ways in which partially-sealed surface types can be included in large scale analyses, by characterizing their thermal dynamics using spatially-explicit approaches and improving methods for their detection at large scales.

Methods

This project is divided into two main components. The first is the detection of the thermal dynamics of partially-sealed surfaces using remote sensing methodologies. This involves using a fixed platform (Figure 2) to collect a time series of thermal imagery (Figure 3) over two different types of partially sealed surfaces, as well as multispectral imagery for the determination of shortwave albedo. Meteorological data is collected at an adjacent tower. This data is then used to determine ground heat fluxes using a variety of methods, including surface energy balance residual, linear modelling, and thermal inertia approaches based on the Fourier transform of surface temperature data. Temperature and moisture profiles from embedded sensors in the partially-sealed surfaces are used to determine validation ground heat fluxes.

Figure 2: Tripod with thermal camera over a lysimeter with a paved surface

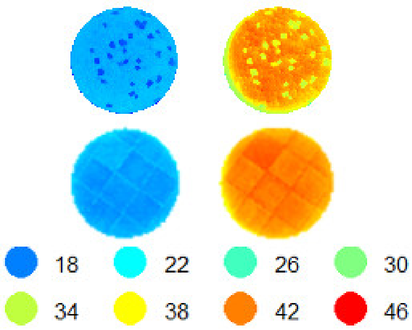

Figure 3: Morning and afternoon paved lysimeter thermal images, in degrees Celsius

The second component of this project is the detection of the spatial patterns of thermal behaviour of partially-sealed surfaces at large scales of observation. This work involves the sub-pixel classification of time series satellite thermal imagery in order to detect different types of urban surfaces based on their thermal behaviours. The thermal imagery is freely available and provided by the MODIS, Landsat, and Sentinel satellite programs, and surface cover data for different intensities of pavement sealing (also freely available) is provided by the city of Berlin.

Current State of Work

The first work of this project was to produce a review paper on the remote sensing of thermal dynamics of urban sealed surfaces, which is currently in the final review stages. For the remote sensing of the thermal dynamics of partially sealed surfaces, all test and validation methods have been incorporated into the R programming language. An example of some of the first results (comparing mean surface heat fluxes between methods) can be seen in Figure 4. The first test results will be orally presented at the 5th EARSeL joint workshop (Bochum, Germany), and the final results will be presented in a journal paper. The final component of this project, the remote sensing-based detection of partially sealed surfaces, will be submitted to present at the 2nd Mapping Urban Areas from Space conference (Frascati, Italy), and will have a corresponding journal paper.

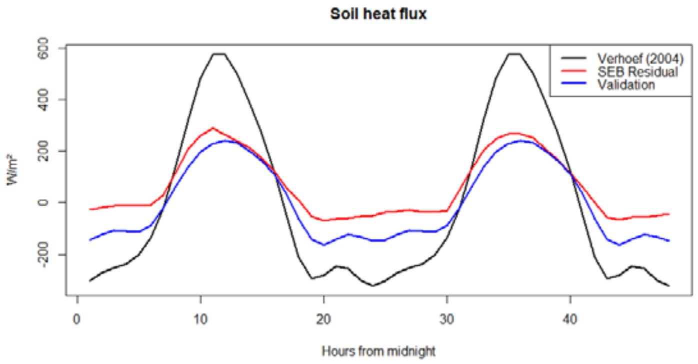

Figure 4: A comparison of surface heat fluxes using remote sensing methods, compared to embedded sensors

Collaboration

This project has closely collaborated with research project T1 (Anne Timm) with regards to the partially sealed lysimeters. There are expected collaborations with projects N3 (Sonia Herrero) and N4 (Clara Romero) regarding geospatial analysis of urban surface waters. The research project is part of the common topic groups "Modelling" and "Urban Soil - Atmosphere Interface". Access to the study site and meteorological data was provided by the Umweltbundesamt, Station in Berlin-Marienfelde. The work was also supported by a student assistant, Rafael Camargo, who provided field work and image processing assistance.

References

1. Tan,J. *et al.* (2010): The urban heat island and its impact on heat waves and human health in Shanghai. (eng), *International journal of biometeorology*, 54(1): 75–84
2. Oke,T.R. (1988): The urban energy balance. *Progress in Physical Geography*, 12 (4), 471–508
3. Qin,Y. and Hiller,J.E. (2014): Understanding pavement-surface energy balance and its implications on cool pavement development. *Energy and Buildings*, 85: 389–399
4. Mohajerani,A., Bakaric,J., and Jeffrey-Bailey,T. (2017): The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete, (eng). *Journal of environmental management*, 197: 522–538
5. Grimmond,C.S.B. *et al.* (2009): Urban Surface Energy Balance Models: Model Characteristics and Methodology for a Comparison Study, in *Meteorological and Air Quality Models for Urban Areas*, Baklanov,A., Grimmond,C.S.B., Alexander,M., and Athanassiadou,M., Eds.: Springer Berlin Heidelberg, 97–123

3. Comments on the qualification programme and supervision strategy:

I came into this program with no background in water-related sciences, so the core courses were very helpful in obtaining a beginning understanding of the fields of research of my colleagues. Consequently, this understanding allowed me gain a greater appreciation of the lecture series. The summer schools and interim workshop were excellent opportunities to gain further appreciation for the work of my colleagues, as well as to explore potential collaborations.

Regarding having a child, I was fully supported by all the staff regarding time management and contractual issues, which made the transition into parenthood and back to work as trouble-free as possible.

Participation in the following Research Training Group events: 1. Core courses • I – Urban interface processes – fluxes, transport, interactions (3 ECTS) • II – Modelling and measuring concepts of interface processes (3 ECTS) • III – Urban freshwater ecology (3 ECTS) 2. Elective courses • Proposal writing workshop (TU Berlin, 16.03.2018) 3. UWI lectures: Participated in all UWI lectures 4. Other UWI events • Orientation Seminar and UWI Opening Ceremony (08. – 09.09.2015) • Exposé Talks (08.12.2015) • Summer School (13. - 14.09.2016) • Kollegiate Seminar (22.09.2016) • UWI Workshop 'Collaborative Working' • Student Research Council (17. – 18.03.2017) • Interim Meeting (19.05.2017) • Summer school (19. – 20.09.2018)
Research stays or internships at other research institutions both at home and abroad.
Participation in conferences, congresses, etc., at home and abroad: 2015: - Water Research Horizon Conference (17. –18.06.2015, Berlin, Germany) - SPIE Remote Sensing (21. –24.09.2015, Toulouse, France) - Course on temporal and spatial analysis (FEM) (26. – 29.10.2015, Michele all'Adige, Italy) 2016: - BioMove GIS workshop (IZW) (01. – 04.11.2016, Berlin, Germany) 2017: - 37^{th} Symposium on Remote Sensing of the Environment (08. – 12.05.2017, Tshwana, South Africa) - Course on multicopter aeronautics and safety (Handwerkskammer) (29. – 30.05.2017, Berlin, Germany) 2018: - Google Earth Engine Workshop (Google) (05.02.2018, Berlin, Germany) - An Introduction to Scientific Computing and Reproducible Research (GFZ) (25. – 26.04.2018, Potsdam, Germany) - 5^{th} EARseL Joint Workshop (24. –26.9.2018, Bochum, Germany) - 2^{nd} Mapping Urban Areas from Space Conference (20 –31.10.2018, Frascati, Italy)

4. Individual publications:

I. Articles:

- Clasen,A., Somers,B., Pipkins,K., Tits,L., Segl,K., Brell,M., Kleinschmit,B., Spengler,D., Lausch,A., Förster,M. (2015): Spectral Unmixing of Forest Crown Components at Close Range, Airborne and Simulated Sentinel-2 and EnMAP Spectral Imaging Scale. *Remote Sensing* 7: 15361-15387
- Lang,S., Corbane,C., Blonda,P., Pipkins,K., Förster,M., (2015): Multiscale Habitat Mapping and Monitoring Using Satellite Data and Advanced Image Analysis Techniques. Remote Sensing Handbook - Three Volume Set. Ed. Thenkabail,P.S. Boca Raton: CRC Press

II. Conference, poster presentations etc.:

- Pipkins,K., Kleinschmit,B., Wessolek,G. (2017): A spatial-temporal method for assessing the energy balance dynamics of partially sealed surfaces. *37^{th} International Symposium on Remote Sensing of Environment* (8. –12.5.2017, Tshwane, South Africa), poster presentation
- Pipkins,K., Kleinschmit,B., Förster,M. (2018): Determine Storage Heat Fluxes For Two Different Urban Pavement Types Using Remote Sensing. *5^{th} Joint Workshop of the European Association of Remote Sensing Laboratories* (24. –26.9.2018, Bochum, Germany), oral presentation