HYDRO-CSI

CLUSTER 3 –
REMOTE SENSING APPLIED TO HYDROLOGY

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Summary of Hydro-CSI research clusters

INTRODUCTION

The doctoral Education Unit in Hydrological Sciences (Hydro-CSI) is contributing to the exploration of new and interdisciplinary research avenues to overcome limitations in our current understanding of catchment functioning.

Hydro-CSI is led by LIST in partnership with the University of Luxembourg (LU), Vienna University of Technology (AT), Wageningen UR (NL), Karlsruher Institute of Technology (DE) and is supported by the FNR.

Hydro-CSI is composed of four research clusters:

- Cluster 1 – Innovative field-deployable instruments for high-frequency monitoring
- Cluster 2 – New tracers and approaches for investigating hydrological processes
- **Cluster 3 – Remote sensing applied to hydrology**
- Cluster 4 – Hydrological forecasts and projections under global change

In this document, please find the presentation of Cluster 3.

3.1 PHD PROJECT OF ANNE HOEK VAN DIJKE

Topic: **Remote sensing and eco-hydrological modelling**

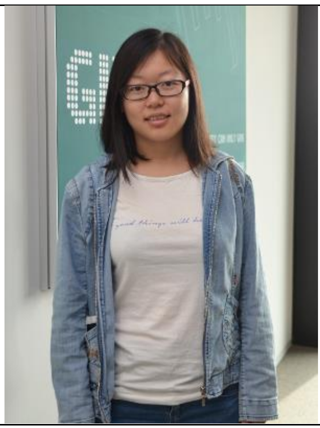
Project objectives:

1) Study how soil moisture and remote sensing derived catchment scale variability in vegetation functional traits control transpiration in the Attert River basin (L);
2) Multiscale mapping of evapotranspiration by integrating land surface temperature from airborne acquisition, Landsat and MODIS sensors into a surface energy balance model to study the controlling factors of evapotranspiration at different scales;
3) Identify the effect of vegetation functional traits on evapotranspiration and evapotranspiration partitioning across a range of climatic conditions;
4) Investigate the effects of deforestation on the local water balance and climate, via the controlling effects of leaf area index on the latent heat flux.

Abstract:
Evapotranspiration is the second largest component of the terrestrial water cycle and is influenced by vegetation physiology and hydrometeorological parameters. In order to predict the influence of climate or land use change on evapotranspiration, it is important to understand its controls. The aim of this project is to study the interaction between vegetation functional traits and evapotranspiration and its components on both catchment- and global scale. The first objective is to study tree transpiration in combination with satellite-derived vegetation characteristics in the Attert catchment in Luxembourg. A second objective is to analyse how the effect of vegetation characteristics on evapotranspiration differs within and between ecosystems and climate zones, by using FLUXNET research sites. A third objective is to map evapotranspiration using a surface energy balance model with land surface temperature as input from three different measurement scales (airborne, Landsat and MODIS). Using this, the controlling factors of evapotranspiration will be studied at different scales. The last objective will assess the impact of land use change on ecosystem water fluxes via the influence of leaf area index on the surface energy balance.

3.2 PHD PROJECT OF JIE ZHAO

Topic: **Remote sensing**



Project objectives:

Through her PhD project, Jie Zhao aims at developing an algorithm for producing a record of binary flood maps at global scale with high accuracy from Synthetic Aperture Radar (SAR) data. Special emphasis is put on characterizing the uncertainties of the flood maps and to identify areas where SAR is not sensitive (e.g. densely vegetated areas or shadow areas).

Abstract:

Floods are the most frequent and costly weather disasters in the world and mapping their extension is fundamental for emergency management. A large number of algorithms has been published in the literature to produce flood maps in near real-time.
However, the detection of floodwater under vegetated canopies and in built-up environments still represents a critical issue, since the Synthetic Aperture Radar (SAR) backscattering of floodwater in such target areas are often not clearly identifiable and different land covers (snow, dry soil, ice, road and airport) can have the water-like backscatter. But most of the algorithms proposed in the literature only focused on a specific area and those methods cannot be applied at large scale to produce a global scale flood map.

The first objective of the PhD is to produce a binary flood map at the global scale with high accuracy from SAR observation data. The backscatter analysis in the vegetated areas will be studied, and the urban flood will be taken into consideration because it has most severe impacts in comparison to floods in rural areas. The second objective is to characterize the uncertainties of the flood map and produce a global probabilistic flood map. The third objective is to produce a map where the SAR is not sensitive, e.g. very dense vegetated areas where the SAR signal might not reach the flood under the canopy or the shadow areas from SAR observations.
In this thesis, a methodology to detect floods at global scale will be developed, combining approaches which rely on the statistics of a single SAR image and the ones which take advantage of long SAR temporal series analysis. The uncertainties of resulting maps will be also characterized taking advantage of a Bayesian framework. To validate the resulting maps, optical data will be used.

3.3 PHD PROJECT OF TESSA VAN HATEREN

Topic: **Hydrology-related fluxes & microwave measurements**

Project objectives:

The soil water balance equation describes the water balance in any soil profile. It is based on the conservation of mass, indicating that all inputs and outputs in a soil profile are balanced on long time scales. Knowledge on the size of all the terms in the soil water balance equation leads to a deep understanding of the hydrological processes playing a role in the local soil profile. However, measuring each of the terms is not as straightforward as it may seem, due to e.g. spatial heterogeneity and temporal variation. In this PhD project, different state-of-the-art microwave measurement techniques will be combined to estimate the different terms of the soil water balance equation.

Abstract:

Estimation of different terms of the soil water balance equation by interpreting and combining remote sensing-based microwave measurements.

The soil water balance equation (Equation (1)) describes the water balance in any soil profile. It is based on the conservation of mass, indicating that all inputs and outputs in a soil profile are balanced on long time scales. Knowledge on the size of all the terms in the soil water balance equation leads to a deep understanding of the hydrological processes playing a role in the local soil profile. However, measuring each of the terms is not as straightforward as it may seem, due to e.g. spatial heterogeneity and temporal variation.

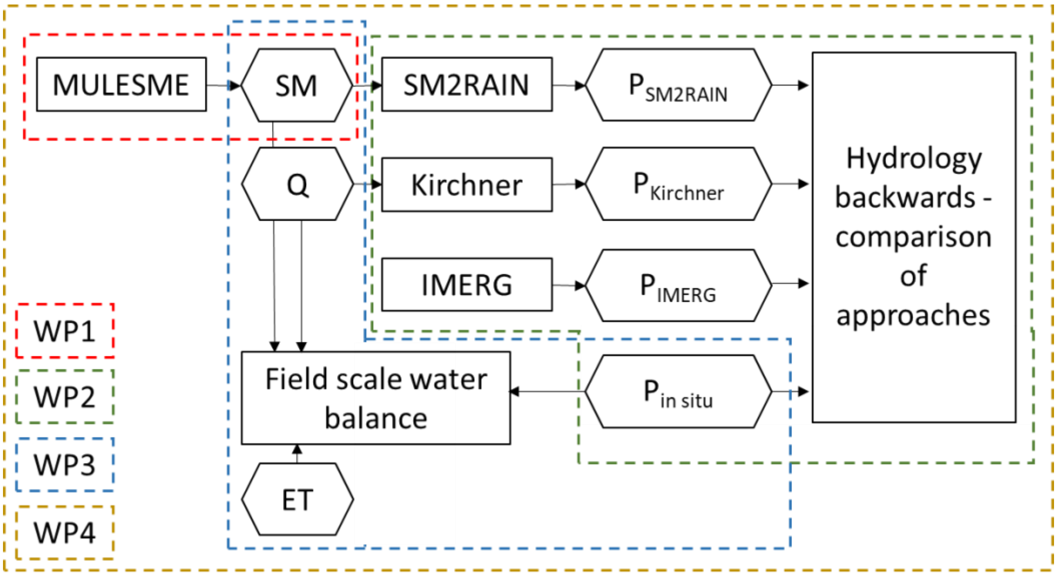
$$\textbf{Storage change} = \textbf{precipitation} - \textbf{evapotranspiration} - \textbf{drainage} - \textbf{surface runoff} \qquad (1)$$

In this PhD project, different state-of-the-art microwave measurement techniques will be combined to estimate the different terms of the soil water balance equation. First, Sentinel-1 soil moisture data will be derived on a field scale, using image segmentation. The project will then evolve around two types of doing hydrology backwards, i.e. (i) inferring rainfall and evapotranspiration from discharge, using the method developed by Kirchner (2009)), and applied in Luxembourg by Krier *et al.* (2012); and (ii) inferring rainfall from soil moisture, using SM2RAIN [Brocca et al. (2014)]. These methods will be applied in a catchment in Luxembourg, and subsequently used to determine the most optimal approach to infer precipitation. This will be done by comparing the results both to a global precipitation dataset and in situ measurements of precipitation.
Additionally, a field experiment in the same Luxembourgish catchment will be set up, enabling a comparison between different field-scale microwave measurements of evapotranspiration (using eddy

covariance measurements), soil moisture (Sentinel-1 and TDR probes) and precipitation (GNSS and rain gauges). This will lead to the determination of the suitability of SAR remotely sensed field-scale soil moisture for field-scale water balance studies. Finally, a synthesis of the obtained results in a hydrological model will lead to a more rich understanding of the soil water balance equation.

The project is completed upon finishing four parts of the project (see figure below):

1. Increasing the spatial resolution of SAR measurements, by image segmentation on the field scale;
2. Application of the resulting soil moisture measurements in the SM2RAIN algorithm, and comparing these with other (inferred) precipitation estimates;
3. Comparison of field-scale microwave measurements of evapotranspiration, soil moisture, and precipitation, and application on a field-scale water balance study; and
4. A synthesis of obtained results to enrich understanding of the soil water balance equation.



[Brocca et al. (2014)] Brocca, L., Ciabatta, L., Massari, C., Moramarco, T., Hahn, S., Hasenauer, S., Kidd, R., Dorigo, W., Wagner, W., Levizzani, V., 2014. Soil as a natural rain gauge: estimating global rainfall from satellite soil moisture data. Journal of Geophysical Research: Atmospheres 119 (9), 5128–5141.

[Kirchner (2009)] Kirchner, J. W., 2009. Catchments as simple dynamical systems: Catchment characterization, rainfall-runoff modeling, and doing hydrology backward. Water Resources Research 45 (2).

[Krier et al. (2012)] Krier, R., Matgen, P., Goergen, K., Pfister, L., Hoffmann, L., Kirchner, J. W., Uhlenbrook, S., Savenije, H. H. G., 2012. Inferring catchment precipitation by doing hydrology backward: a test in 24 small and mesoscale catchments in Luxembourg. Water Resources Research 48 (10).

The storage change can be measured in terms of changes in soil moisture (SM). A useful tool for measuring surface SM changes is the change-detection method, used by Synthetic Aperture Radar (SAR) satellite systems. Active microwave measurements have several advantages. They provide the difference in soil moisture between the current and previous overpass, and additionally, have a very high spatial resolution and large spatial extent. This provides rather accurate estimations of the first term of the soil water equation on a global scale, also in poorly gauged basins. Other microwave measurements can also be used to estimate terms of the equation. For instance, the GNSS global satellite system can measure precipitation, and it was recently shown that it can also be used to measure surface soil moisture. Eddy covariance measurements can be used to measure evapotranspiration. Drainage and surface runoff are estimated from field measurements.