D6.2 Research results of on-site monitoring

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Project coordinator name, title and organization
TechnischeUniversität Graz
Institute for Computer Graphics and Vision
Dr. Ernst Kruijff
phone: +43 316 873-5055
fax: +43 316 873-5050
mail: kruijff@icg.tugraz.at

Project website http://www.hydrosysonline.eu

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Workpackage leader: Megan Daniels
Contributors: Megan Daniels, Silvia Simoni, Thomas Gruenewald, Ioan Ferencik, Viivi Moll

1 Introduction

This report includes the research results of on-site monitoring. These results are presented within the context of two main scenarios which will be referred to as the Swiss and the Nordic Scenarios. The scenarios are described in section 2 and results of field monitoring and analysis are presented in section 3.

For the Swiss scenario, wireless sensor networks were used as part of a ongoing field campaigns to monitor the hydrologic and meteorological conditions in an alpine environment. The Swiss Scenario consists of Dorfberg, Gemsstock, Alpine3D, and La Fouly.

In Dorfberg, Mitterer et al. 2009 analysed two wet-snow avalanche cycles and modelled the snow-cover with SNOWPACK and Appine3D to deduce factors which might have caused the wet-snow avalanches. Feick et al. (2011) developed and tested two methods (classification from time-lapse photography and from satellite images) to automatically detect glide cracks of glide snow avalanches (a special type of wet-snow avalanche), shedding light on triggering mechanisms.

At Gemsstock, permafrost was monitored using a terrestrial laser scanner. A massive rock fall was observed, likely due to thawing of ground ice in the rock walls near the cable car station. Permafrost degradation is a phenomenon associated with global climate change, thus its observation is both critical and of relatively recent importance.

Alpine3D was coupled to a mesoscale atmospheric model to model snow deposition and to identify the processes that cause snow distribution in the accumulation season. Mott et al. 2011 applied Alpine3D to simulate the snow depletion in melting conditions.

In La Fouly, the campaign was focused on understanding the sources of stream flow generation in an alpine catchment. In addition to the sensor network for field monitoring, with realtime data feedback, two different hydrologic modeling approaches were taken in order to better understand the physical processes observed in the field. In particular, it was discovered that a relatively simple lumped model was able to accurately capture daily and monthly variations in stream flow according to changes in snowmelt and precipitation, while a more complicated distributed model was unable to more accurately predict these phenomena.

For the Nordic scenario, the focus was on monitoring the hydrology of semi-urban catchments. Developing a method for deriving vector based stream geometry from point clouds was the main result of the data processing tasks. An existing 1D environmental hydraulics model was further developed and tested successfully in predicting the cross-section water height of a branching channel system using channel cross-section geometry. The results of this work can be used to predict the fate of pollutants in such systems, or to aid in stream restoration projects where new channel cross-sections may be proposed and the potential flow behavior in the new channel is not known.

This report summarizes the main findings of the field campaigns and describes the role of the physical model / simulation research. The report takes the stance of depending much on research results reported in publications: as such, we summarize the results and provide an overview of the published publications and presentations that can be referred to for further details.

2 Description of field sites

2.1 Swiss Scenarios

Further reading
This section introduces the various scenarios that have been deployed in HYDROSYS. A detailed overview of the scenarios canscenarios can be found in report D6.3.

The Alpine (Swiss) scenario consists of three applications, Dorfberg, Gemsstock and La Fouly. They were chosen as they represent a diversified set of natural environments, applications and sensors with complexity on different levels. The chosen environmental processes are of high importance as they are currently poorly understood, frequent and have a significant potential for damage.

The task is of major importance as it provides multiple sets of data which are needed for testing, applying and adapting the handheld setup developed under real on-site conditions. This will give significant results whether the technologies are working well in natural environments and whether they hit the end-user requirements. Moreover the collected data are of interest for the end-users, e.g. for environmental research purposes.

The tasks of the reported period of the project were to carry on the Alpine deployments in order to generate data and to set up new sensors. Field campaigns took place at La Fouly and Gemsstock in summer and autumn 2009 and 2010 and at Dorfberg sensor stations were prepared for the winter field season.

2.1.1 Dorfberg (WSL) -- Wet-snow avalanches

Wet-snow avalanches are hazards which are frequently occurring in mountain regions. They are characterized by a large degree of potential damage to infrastructure and people. So far the processes which cause the formation and triggering of wet snow avalanches are poorly investigated. The Dorfberg (Davos, Switzerland) has been established as the preliminary field site for wet-snow avalanche research in the last years. Many different types of sensors have been installed and manual measurements were obtained regularly.

The data which have been collected in the last three years have been and are currently analysed to investigate the triggering of wet-snow avalanches. Several scientific publications have been submitted and significant advance can be reported even if it will - if ever possible - require much more efforts to get a full understanding of this highly complex topic.

2.1.2 Gemsstock (WSL) -- Monitoring infrastructure stability

It is a well known fact that alpine permafrost has retreated in the last decades and it is expected that this trend is continuing in future. This retreat has a significant effect on human activities, especially in regions where infrastructures such as buildings, power lines or cable car pylons are located on permafrost: Thawing of ground ice can destabilize the ground and result in settling or tilting of infrastructure. The “Gemsstock- scenario” is a case study for this impact of thawing permafrost in alpine areas. The study site is the Andermatt (Switzerland) skiing resort. Parts of the cable car infrastructure are built on frozen ground. Therefore different sensors and methods have been used to analyse the possible changes in the permafrost on the one hand, and to directly monitor the infrastructure on the other hand.

2.1.3 Alpine3D (WSL) -- Improvement of physical process model

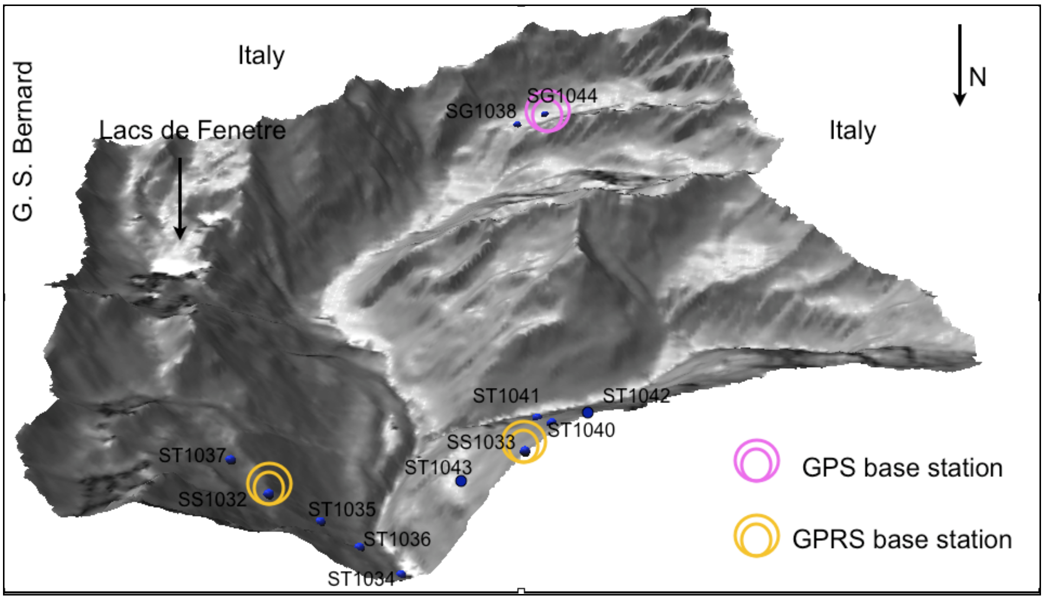
For addressing complex environmental processes the use of physical process models can be of high benefit. These models are used to simulate environmental processes and to gain a deeper understanding of the interrelation and the effects of different parameters. ALPINE3D is a physically based process model which description processes acting in alpine regions in three dimensions. The model is mainly used to simulate the interaction energy balance, snow distribution and hydrology of mountain regions.

As these models are highly complex and computational expensive, using Alpine3D was restricted to modelling experts. It was a major purpose of the project to improve the user-friendliness, reduce computational requirements and therefore allow to model to be applied in an operational context. Additionally the model was tested and applied for several research studies which helped to improve the understanding of snow depth distribution and the interaction of different processes like wind drift or radiation balance on the snow cover. Such studies help to develop important background knowledge for improving the understanding of all types of avalanches.

2.1.4 La Fouly (EPFL) – Understanding sources of streamflow generation

La Fouly deployment focus on the **understanding and managing natural hazards such as debris flows**, **landslides and floods** because they are fairly frequent, poorly understood and could have serious economic, environmental and social impacts.

The 2009 and 2010 field campaigns carried out at La Fouly took place from June to October. In October 2009 all 12 stations were removed and transferred to the EFLUM laboratory, taking care of keeping together sensors belonging to the same station to be able to reproduce the same sensor configuration for the next year campaign. During 2010 two stations were left at the field site during the winter months; the harsh winter conditions made their operation a challenge, but some data was successfully collected.



3D view of La Fouly catchment and localization of the 12 SensorScope stations.

The entire data-set collected was validated by applying a procedure consisting in:

- data filtering: i.e. cleaning the dataset from NA and out-of-range values;

- interpolation of missing data using appropriate techniques [Liston et al. 2006];

- data averaging over an appropriate time interval (depending on the type of analysis);
- data accumulation over an appropriate time interval (depending on the type of analysis).

The goal of the analysis focused on **understanding whether the spatial variability of the data was significant** across the study area and whether it had an **impact on the catchment hydrology**. Among the several hydrological processes that take place in a catchment, the analysis was focused on the flow generation mechanisms and on the role played by snow and ice melt, rainfall-run off and deep drainage. In order to investigate this aspect, continuous measures of water level were taken using a pressure transducer installed in the river and measurements of river discharge were taken weekly with the aim of building a relationship linking the water level in the river and the discharge. Both distributed and lumped hydrologic models were used to investigate stream flow generation in the catchment. Results are presented in a later section of this report.

2.2 Nordic Scenarios

For the Nordic scenario, the focus was on studying the hydrology and stormwater management of semi-urban catchments. Stormwater is runoff water from built-up areas. Development of the urban areas, covering ground with an artificial hard surface like asphalt, buildings and other, has a significant effect on the natural water cycle and water quality. The artificial covers on water permeable surfaces decrease infiltration, and therefore the total volume of surface runoff is substantially higher in the covered areas, than in the natural environment. Added to this surface waters flow much faster on a hard cover and channels, compared with a natural cover, and therefore the flow both arrive and pass faster. As a result peak flows grow, and the receiving water body becomes sensitive for flooding. Also the groundwater recharge becomes poorer, as the surface waters move away from the originating area through sewers, channels and artificial surfaces.

Stormwater can be heavily contaminated with a range of polluting substances. These substances consist of a complex mixture of natural organic and inorganic materials, with a small proportion of man-made substances derived from transport, commercial and industrial practices. These materials are originated partly from atmosphere and as a result of being washed off or eroded from surfaces. Stormwater quality is therefore influenced by rainfall and, especially, by the catchment. The activities on and landuse of the catchment plays the most important role. The quality is highly variable from place to place and time to time and may in certain circumstances be as polluted as wastewater. Urban erosion produces particles of brick, concrete, asphalt and glass, as well as roof, gutter and exterior paint particles. Corrosion of metallic structures, such as fences and benches, releases toxic substances such as chromium.

One source of pollutants is derived by street debris, litter, organic materials like dead vegetation, fallen leaves, cut grass. They generate one more oxygen demanding pollutant group. Households may by accident or illegally pollute the ground, and therefore storm water with cleaning solutions, motor fluids or lubricants or other chemicals. Domestic sources of chemical pollutants are, however, usually minor comparing with industrial spills or illicit toxic waste disposal.

Stormwater management requires understanding of the processes contributing to stormwater quantity and quality. Semi-urban catchments are complex and thus their hydrological characteristics are challenging to quantify. Pollution enters channels and eventually are transported away to downstream entities lake lakes and seas. Water is the transporting agent, thus environmental hydraulics of streams is an important object of study.

One of the major goals of the Nordic instance of HYDROSYS was to conduct a detailed investigation into the nature of semi-urban watersheds hydrology using the two sites as examples. This investigation had a twofold nature: to employ the HYDROSYS system one hand and to improve the understanding of environmental hydrology in the Nordic instance, on the other side. A task based, sequential approach was closely followed with dependencies among other work packages of the HYDROSYS project.

Open channel flow and transport of substances are some of the most complex and least understood processes in nature (Wu, 2008). Bends, hydraulic structures, vegetation, rapid changes in cross-sectional geometry are few of the issues complicating environmental hydraulics modeling (Syme 2001, Tullis 2008). After a review of existing environmental hydraulics models (see for example Zoppou 2001), existing models and model codes available within the research group (Blomfeldt 2008, Helmiö 2004), we went on and developed a suitable environmental hydraulics model and model code (Niemi 2010). The requirements were set broadly according to the needs of the HYDROSYS system in development.

2.2.1 Description of the field sites

The Nordic scenario focused on urbanizing areas of varying sizes in southern Finland. Three sites were examined: a patch of land in Korkeasaari Zoo (in Helsinki), along Ridalinpuro creek (in the Nummela neighborhood of Vihti municipality), and Kylmäoja catchment (mostly in Vantaa municipality). The patch in Korkeasaari is a micro site, interesting from the point of view of heavy wear by strollers and occasional heavy showers. Ridalinpuro creek is a site of environmentally sensitive hydraulic engineering and it exhibits the impact of typical sub-urbanizing neighborhood and construction. The main focus in Ridalinpuro was a stretch of the channel. The Kylmäoja site is a 20.84 sq-km more complex semi-urban catchment and channel system exhibiting pressures from increasing imperviousness, construction, chemical use on Helsinki-Vantaa airport, traffic and others.

The relatively large amount of impervious areas increases the sharpness of hydrograph. Both Ridalinpuro and Kylmäoja catchments are situated in southern Finland near coastal area and therefore have same basic climatic conditions. Finland's location between 60th and 70th latitude on the edge of Eurasian continent explains its mid-term climate with both maritime and continental features. Weather depends on from which direction air flow and low and high pressure fronts come. Weather types change rapidly especially in winter. The annual mean temperature in study areas (in 1971-2000) is +4...5 degrees celsius and the daily mean temperature varies from -10 degrees celsius in winter to +14 degrees celsius in summer. There are on average 161...180 rainy days a year and mean annual precipitation is between 600 and 700 mm. In winter, there are more rainy days than during other seasons, but the amount of precipitation is the largest in autumn. However, precipiation is in general rather evenly distributed throughout the year. In winter, the temperature is mostly below zero and rainfall comes as snow.

The Nordic scenario comprised several (one in Ridalinpuro, four in Kylmäoja) event-based campaigns, which each lasted approximately a month. Luode provided, installed and maintained the sensors in the campaigns. The monitoring campaigns provided quantitative and qualitative hydrological data. The quantitative data consisted of indirect discharge measurements (measured variable was water level) while the qualitative data consisted of temperature, dissolved oxygen, conductivity, and turbidity measurements. The data was used for an assessment of environmental state and response of the hydrological systems as well as modeling.

The research goals for the deployments of on-site monitoring tools on the sites was to collect data about environmental characteristics of the water systems during selected conditions. The hypothesis was and is that this data gives us new information about how land use and various activities affect peri-urban environment. The data was also assumed to be of great value to model development, specifically to our further development of the environmental hydraulics model. That assumption was correct. The data collection effort itself and all things related to it was foreseen to provide also valuable information about such event-driven campaigns: the planning, placement of sensors, the sensor management, the value of information etc. An important goal of our research associated with the development of the HYDROSYS on-site monitoring system was to test and see how it improves the capability to do environmentally sensitive storm water engineering in our conditions. Detailed topographic data of the sites (in Ridalinpuro case only the downstream section) was a available from National Land Survey of Finland as a result of airborne lidar mapping conducted in 2008.

The end-users in the Nordic scenario have been environmental engineering contractors, environmental authorities, non-governmental groups and water utility representatives.

2.2.2 Ridalinpuro (Nummela)

The catchment of Ridalinpuro is partly urbanized and therefore subject to anthropic pressure (Figure 1 at the end of results section). The creek has been heavily modified due to agriculture use and urbanization. The stream suffers from flooding and heavy foreign matter loading. The source of its nutrient, sediment and pollutant loading is the surrounding fields and sub-urban area of Nummela.

The Nummela watershed is a clayey area neighboring Lohjanharju ridge marginal deposit in the northwest, and rocky moraine ridges in south (Figure 2 at the end of results section). Ridalinpuro stream drains into southwestern part of Enäjärvi lake. Excluding Lohjanharju ridge, the majority of the soils within the watershed are poorly permeable. The rocky moraine ridges are covered by forest and bog, while Lohjanharju ridge is mostly a built-up area. The clayey soils are prone to erosion and are may have a acidic characteristic due to sulphates deposited after the last ice age. Lohjanharju is a part of an important groundwater source. The altitude of the catchment varies between 50 m and 110 m above sea level.

The creek has been heavily modified in its history due to agriculture and urbanization. Enäjärvi is a small, eutrophic lake. The stream suffers from flooding and heavy foreign matter loading. The source of its nutrient, sediment and pollutant loading is the surrounding fields and sub-urban area of Nummela.

The goals of the measurement campaign of HYDROSYS-project on Ridalinpuro ware the impact of land-use on water quality in the stream, the impact of stream restoration projects, and development of the physical modeling of environmental hydraulics.

2.2.3 Kylmäoja

Kylmäoja stream has three main branches, eastern, central and western, which all unites to the main stream in the middle of the catchment area (Figure 3). Characteristic for the area are wide clayey plains and washed rocky moraine ridges (Figure 4). Proportion of clay soil in the Kylmäoja catchment is remarkable, especially in river valleys, and clay has filled even the smallest depressions. Prevailing frictional soil is moraine, which mostly occur as shallow layers on rocky hills. The area is dominated by impermeable soils, but as an exception the Ruskeasanta ridge marginal deposit is located on the area and is an important groundwater area. Mainly due to its proximity to the airport the Kylmäoja watershed is much more urbanized and as a result the land use is more diverse in comparison with Nummela.

The residential areas of Ilola and Kylmäoja in central section of the catchment are dominated by row- and detached houses. Trend in those areas is, however, towards denser housing, as a consequence of continuously rising estate prices. In central sub-catchment the railway will pass through the area on the ground. In the northern part of the catchment in Tuusula municipality, a new business park is constructed substituting a former forested area. The business center covers the area only partly but may still have an effect on stormwaters of the central branch of the Kylmäoja stream.

The eastern section of the catchment offers a variety of land uses. In the northern part, in Tuusula municipality, the above mentioned business park is affecting the eastern branch the most. The area of Kulomäki, south from business park, is dominated by logistical centers. Right after the logistic area the stream flows into a nature conservation area. New residential area with a train station of the new railway line are under constructions in Leinelä, which will be located partly on the catchment area. All three branches of Kylmäoja unite as one, main stream in the middle of the watershed. The land-use on the sub-catchment area of the main stream differs from dense-low rise housing areas of Ruskeasanta to dense housing, industrial and commercial area of Tikkurila.

Kylmäoja is experiencing anthropic pressure, including development of the urban areas, e.g. construction of a logistic center in Tuusula in the upper part of the catchment. Also new railway line is under construction, crossing the catchment in east-west direction. The Helsinki–Vantaa international airport is partially located in the catchment area, and it is the main source of deicing chemicals released specially in the cold season.

Specific goals in the Kylmäoja site was modeling (the application of the physical model in a complex system), and specific impact of airport and the logistics area in water quantity and quality and the interaction with a natural site downstream.

3 Research results

3.1 Swiss Scenarios

3.1.1 Dorfberg -- *Wet-snow avalanches*

Results

Wet-snow avalanches have – due to their frequent occurrence and their large potential damage – high social impact. Nevertheless the processes causing these hazards are currently only poorly understood. Within the Alpine scenarios of Hydrosys it was one aim to improve the understanding of these hazards.

The Dorfberg (Davos, Swizerland) has been developed as a field site for wet-snow avalanche research. The site was therefore equipped with numerous sensors (e.g. fully equipped weather station, sensorscope stations, time-lapse photography...). and regular manual monitoring campaigns were obtained in the winter season. Such it was possible to create a large and unique dataset. Additionally data collected by the long-term monitoring systems of the SLF (e.g. IFKIS automatic weather station network, avalanche database…) were analysed and the physical models Alpine3D and snowpack were used to simulate the snow-cover. Several peer reviewed papers and conference contributions could be released.

Mitterer et al. 2009 analysed two wet-snow avalanche cycles and modelled the snow-cover with SNOWPACK and Appine3D. They were able to detect some of the factors which might have caused the wet-snow avalanches. Figure 1 illustrates the wetting of the snowpack and the occurrence of the avalanches. (for more details see abstract in Appendix).

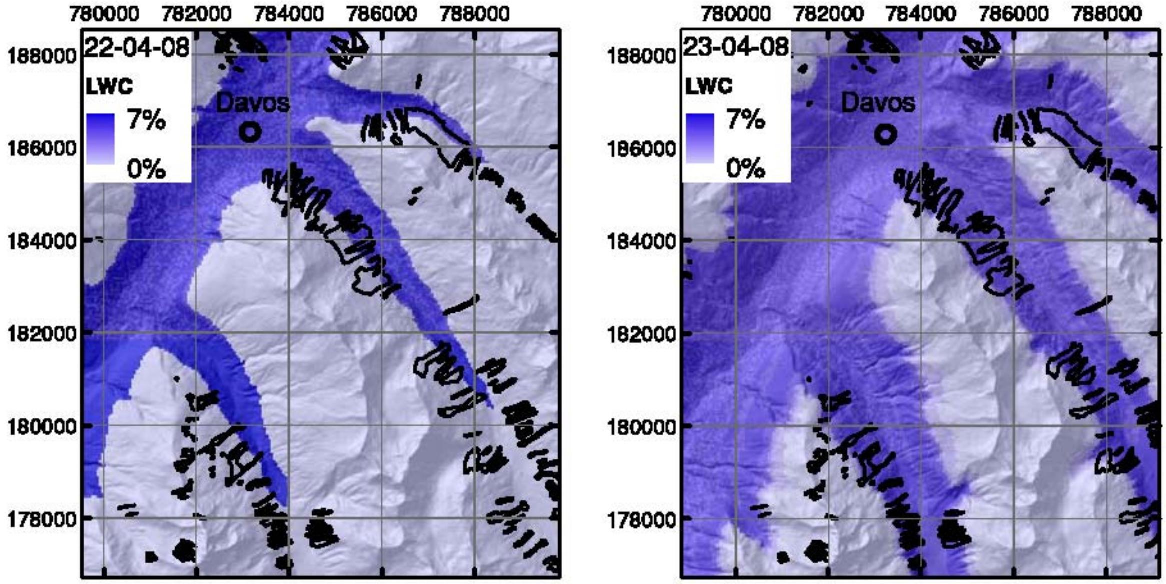


Figure 1. Amount of liquid water content for one day before (left) and after (right) the wet-snow avalanche cycle in April 2008. The black lines mark the avalanches.

Feick et al. (2011) developed and tested two methods (classification from time-lapse photography and from satellite images) to automatically detect glide cracks of glide snow avalanches (a special type of wet-snow avalanche). Additionally they gathered information on triggering factors and tried to relate the occurrence of the glide cracks to meteorological conditions (for more details see abstract in Appendix).

Mitterer et al. 2010a; 2011a compared modelled (SNOWPACK) and measured liquid water content and snow stratigraphy of the snowpack during periods of wet-snow instabilities. Details are given in Appendix.

For monitoring the wetting and the stratigraphy of the snowpack an upwards looking radar system was successfully tested and applied by Mitterer et al 2010b and Mitterer et al. 2011b. They showed that it was possible to detect possible weak layers with the radar (for more details see abstract in Appendix).

Usefulness

Wet snow avalanches claim lives every year in Switzerland and across the world. Thus a better understanding of the mechanisms which govern avalanche formation can directly save lives when applied to avalanche forecasting. The dataset collected at Gemsstock is one of the largest of its kind in the world and allowed Feick et al. (2011), for example, to shed light on trigger factors for wet snow avalanches.

Future directions

A two-dimensional model for water infiltration and wetting of the snowpack is currently developed and first promising results have been presented by Reinweger et al. 2011. (see Appendix).

3.1.2 Gemsstock – Degradation of the cryosphere

Results

The main scientific outcome of the cyrosphere-degradation scenario was the development of a new monitoring system to observe possible affects of permafrost retreat on infrastructure built on frozen ground. Such a system has been developed and first tests have shown large potential to simplify such observations for the end-users. The userinterface is shown in Figure 2.. Nevertheless the system is still a prototype as shortcoming in sensor accuracy limit the application. Further efforts and tests are ongoing. The measurement device has been presented to the scientific community at the European Geosciene Union gernarl assembly 2011 (Grünewald et al. 2011, abstract and details see below).

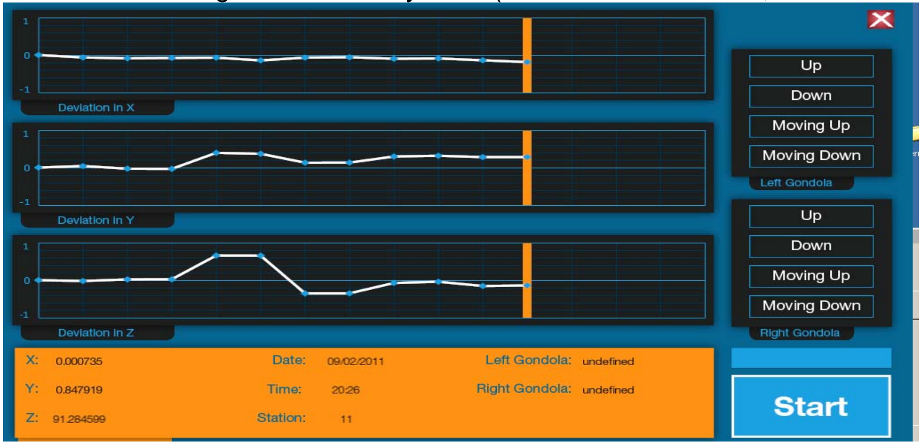


Figure 2: Userinteface for the Gemsstock-scenario.

Additionally cryospheric monitoring campaigns were performed at the Gemsstock site: The site has been equipped with numerous sensors like borehole temperature chains or a fully equipped automatic weather station for several years. Additionally monitoring campaigns using terrestrial laser scanning were performed in regular intervals.

Usefulness
Such measurements and monitoring campaigns are highly important to improve the understanding of the processes which cause permafrost degradation. In the campaigns it was possible to monitor a massive rock fall probably caused by thawing ground ice in the rock walls near the cable car station. A detailed assessment on the methods and the results of the campaign is currently submitted for publications to “Cols regions science and technology” (Kenner et al. 2011, abstract see below).

3.1.3 Model development and improvements Alpine3D

Results
In order to be able to apply the high level physical based models Alpine3D and SNOWPACK within the Hydrosys project significant amount of work had to be performed to enable the models to run in such an operational environment. Large efforts have been made to improve the performance and the user-friendlyness of the model. Kounen et al. 201o applied and tested the concept of distributed parallel computation (POP-C++) for Alpine3D and such enabled a much higher computational performance.

The main focus of the model improvements was on the development of a robust and easy to handle input-output management. Therefore MeteoIO, a data pre-processing library for numerical models has been developed by Bavey et al. (2010; 2011), and was presented to the scientific community in several conference papers. Additionally MeteoIO has been released as open source on http://slfsmm.indefero.net/p/meteoio . More detaild are given in the abstracts in the Appendix.

Application of Alpine3D for modelling alpine surface processes

In addition to the large technical improvements described above Alpine3D has been tested and applied to address diverent very significant scientific questions in relation to alpine snow covers. Mott and Lehning (2010) and Mott et al. 2010a,b,c combined Alpine3D and the meteorological model ARPS to simulate the snow distribution in an alpine catchment and to identify the processes that cause snow distribution in the accumulation season. Mott et al. 2011 applied Alpine3D to simulate the snow depletion in melting conditions. For details and references see abstracts in the Appendix.

Usefulness
These efforts helped to improve the performance and user-friendlyness of the model significantly. More non-experts and scientific partners of the SLF are now able to run the model for their studies and an operational application of the model is now possible.

Future directions
Work on Alpine3D is ongoing at WSL, with the aim of improving avalanche prediction capabilities. In particular, work is underway to connect Alpine3D to the MeteoSwiss COSMO database for near-realtime high-resolution (2 km) meteorological forcing and more accurate avalanche prediction.

3.1.4 La Fouly

Results

Presented here are the summarized results of a thorough analysis of the data collected during the 2009 field campaign, aimed at understanding sources of stream flow in the alpine catchment at La Fouly. It was found that snowmelt dominated stream flow while precipitation often had little effect, even when soil was near saturation, due to evaporation. Detailed descriptions and results of this study can be obtained from the author: silvia.simoni@epfl.ch, Simoni et. al. (submitted to Water Resources Research). Preliminary analysis of 2010 data is presented at the end of this section.

A field measurement campaign was conducted from June to October 2009 in La Fouly, a 20 km2 alpine catchment of the Swiss Alps with a wireless network of 12 stations. The objective was to study mechanisms of stream-flow generation and the spatial variability of meteorological forcings. The analysis of the runoff dynamics highlighted the important contribution of snowmelt from spring to early summer. During the entire experimental period, the stream-flow discharge was dominated by base flow contributions with temporal variations due to occasional rainfall-runoff events and glacier melt. Given the importance of snow and ice melt runoff in this catchment, patterns of near surface air temperatures were studied in detail. Air temperatures were highly influenced by topographic effects such as slope, aspect and elevation. Rainfall was also found to be spatially variable inside the catchment. The hydrology of the watershed was simulated with a simple lumped degree-day model to quantify the different contributions to stream flow. A spatial 3D model (GEOtop) was also used to check its capacity to provide soil moisture fields. Despite the important variability present in the watershed (morphological features, meteorological forcings, etc.), relatively good results with respect to total stream-flow discharge were obtained with the lumped model. The GEOtop model provided reliable estimates of soil moisture content throughout the watershed, based on comparisons with local soil moisture measurements. Given the major role of snow in the watershed response, future deployments should include snow distribution measurements.

The runoff generation of most elevated mountainous basins is dominated by snow and glacier melt. Changes in the timing and magnitude of mountainous stream flows are expected as a result of climatic change. For instance, increasing air temperatures should lead to an earlier spring snowmelt and a reduced snow accumulation in winter [Barnett et al., 2005]. These changes will have important consequences at the global scale, especially since a sixth of the world's population rely on snow or ice melt for their water supply [Barnett et al., 2005]. Schaefli et al. [2007] have also shown that a warming climate would result in a reduced performance of hydropower production in regions like the Swiss Alps where large reservoirs are filled annually with glacier and snow melt.

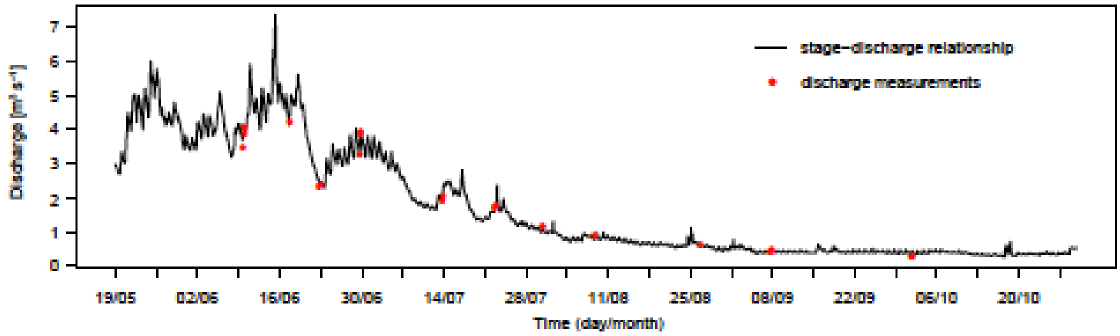


Figure 1. Time series of river flow for the study period. The black curve is the stage-discharge relationship (see (3)) and the red dots are discharge measurements obtained with the salt-dilution method.

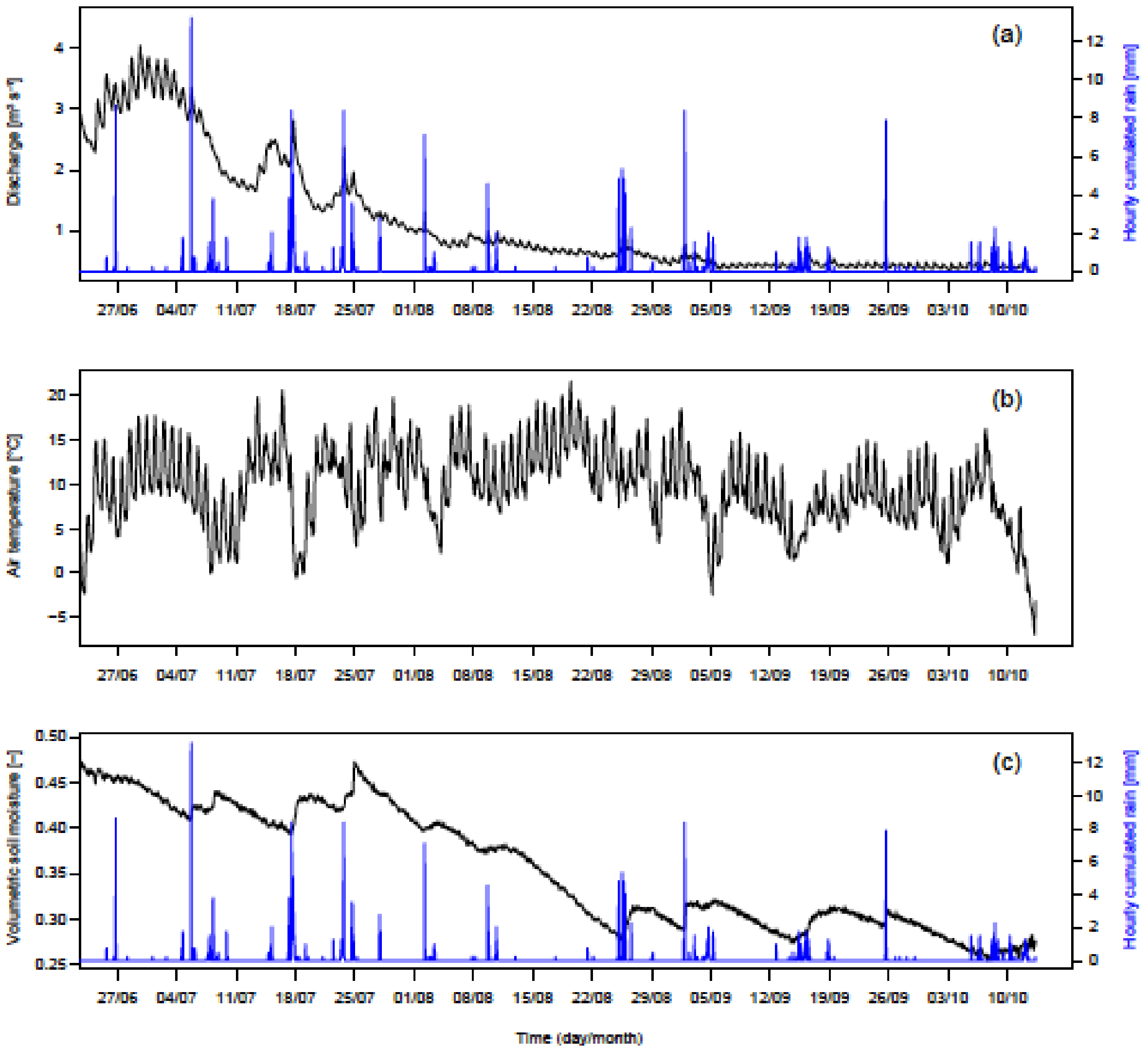


Figure 2. (a) Time series of river discharge for the study period. The black curve is the stagedischarge relationship (see (3)). Four main components are evident: snow and glacier melt, rainfall-runo_ and deep drainage decay. Rainfall measurements from station 1043 are shown in blue. (b) Near-surface air temperatures measured at station 1043. (c) Soil moisture 20 cm below the surface measured at station 1043. Rainfall measurements from station 1043 are shown in blue.

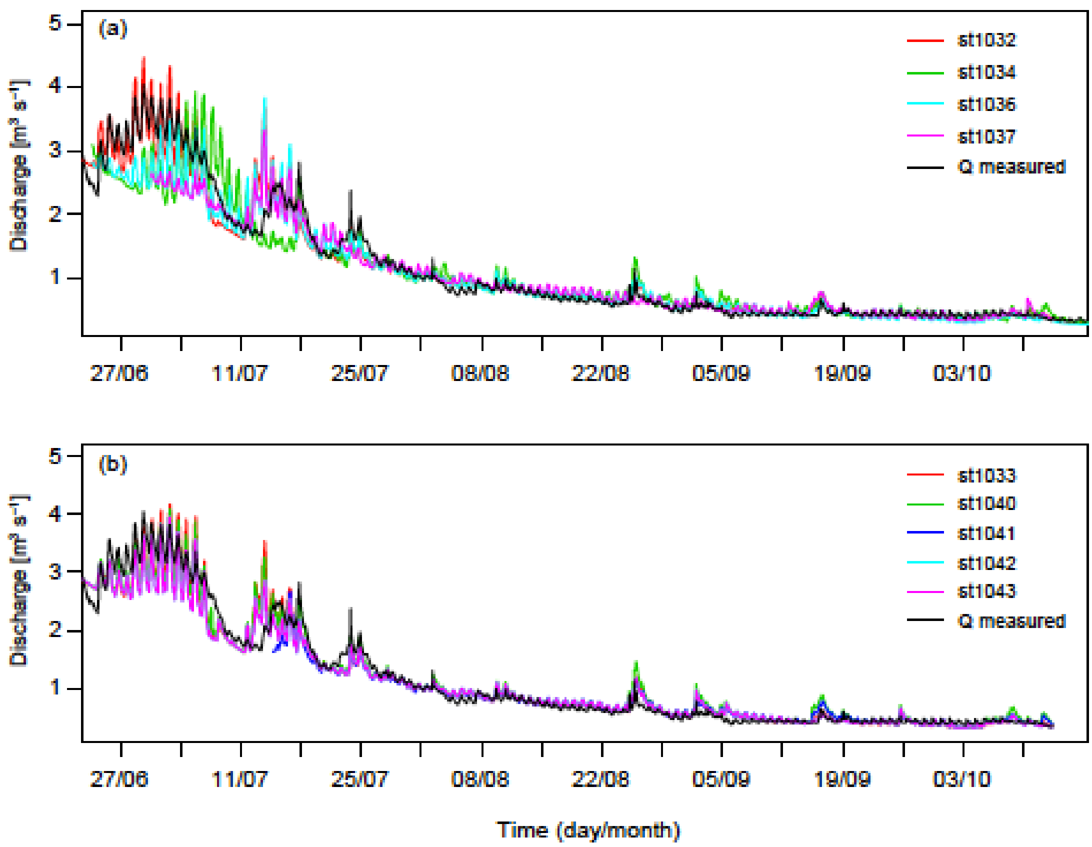


Figure 3. Simulated streamflow obtained with the lumped model using nine di_erent meteorological datasets. (a) Results obtained using data from stations located on the orographic right side of the catchment (1032, 1034, 1036 and 1037) versus the measured discharge. (b) Results obtained using data from stations located on the orographic left side of the catchment (1033,1040, 1041, 1042 and 1043) versus the measured discharge.

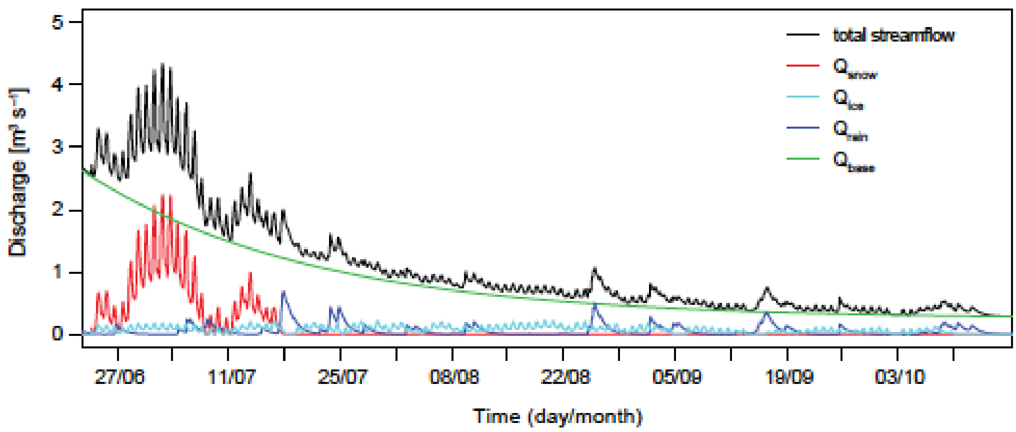


Figure 4. The four components contributing to the modeled stream flow (in black) with the lumped model using spatially averaged air temperatures (see Figure 11): the snowmelt runoff in red), the ice melt runoff (in light blue, see (3)), the rainfall runoff (in dark blue) and the base flow (in green).

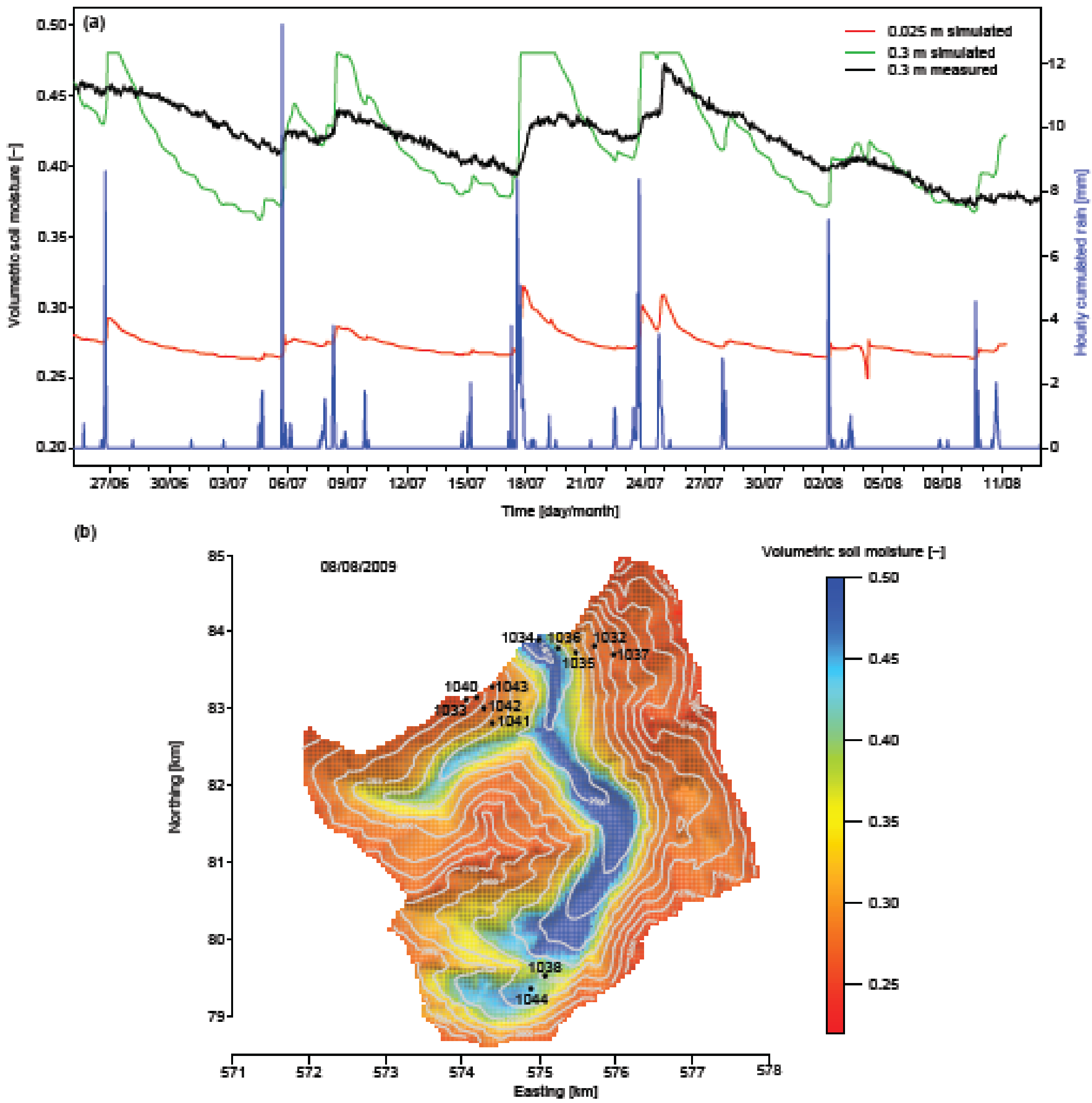


Figure 5. (a) Time series of soil moisture profiles measured at station 1043 (black) and simulated at two different depths. Rainfall measurements from station 1043 are also displayed (in blue). The run was validated using the soil moisture measured at 30 cm below the surface. (b) Soil moisture map calculated by GEOtop on 8 August 2009.

The spatial variability of air temperature and rainfall data collected during a four-month field deployment in the Swiss Alps was quantified. The variability of these variables was studied through the analysis of variance, which highlighted that data were sampled from different statistical populations. The variation in air temperature and rainfall is partly due to the varying morphological features of the catchment, such as the elevation and the aspect of the surface. Two models with varying levels of complexity were used: a simple lumped linear model and a 3D, distributed, physically-based model (GEOtop). This choice was not driven by the objective of comparing the performances of the models, but rather to highlight that the hydrological processes governing stream flow, such as ice melt, base flow and in part snowmelt, can be captured and eventually reproduced using a lumped model over complex topography. On the other hand, processes driven by meteorological forcings that vary significantly in space (e.g. soil moisture fields) can be better captured through distributed modeling and wireless sensor networks.

Usefulness
This study supports previous studies which show that reliable results can sometimes be achieved more easily with relatively simple lumped models depending on the question being asked (e.g. [Jakeman and Hornberger , 1993]). This study serves as an important reminder that increasing the number of physical processes directly calculated by a model is useful only if sufficient resolution and boundary conditions are available. To support the 2009 findings, analysis of the 2010 dataset is ongoing. Results were presented at the American Geophysical Union Meeting in December 2010. (See abstract by Fernandez-Vidal in the Appendix).

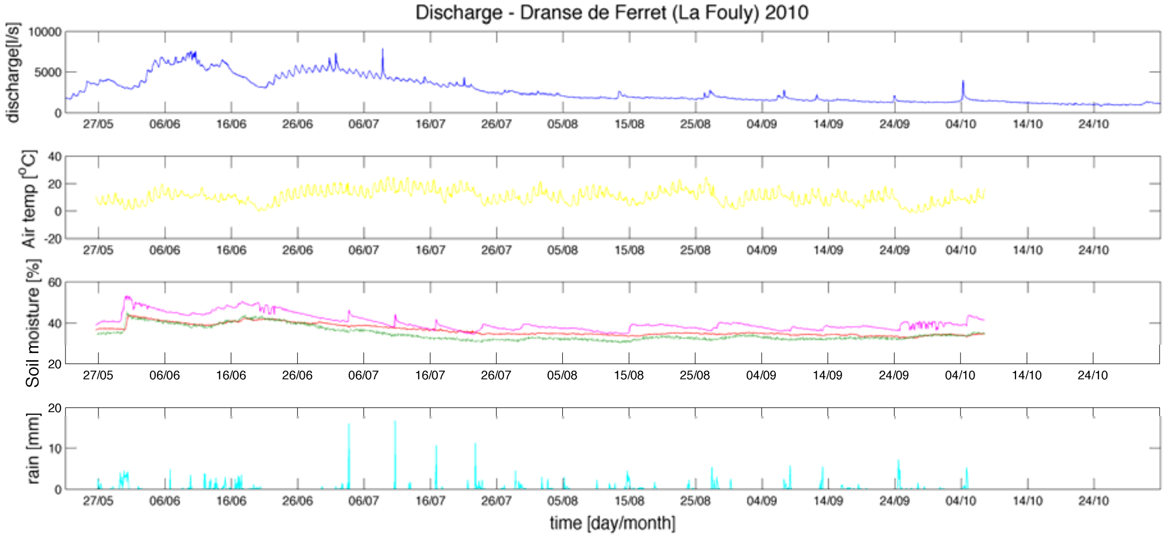


Figure 6. Time series of stream discharge (at Dranse de Ferret), air temperature, soil moisture, and precipitation from La Fouly during the 2010 field campaign. Data shown (besides discharge) was collected at a nearby sensorscope station.

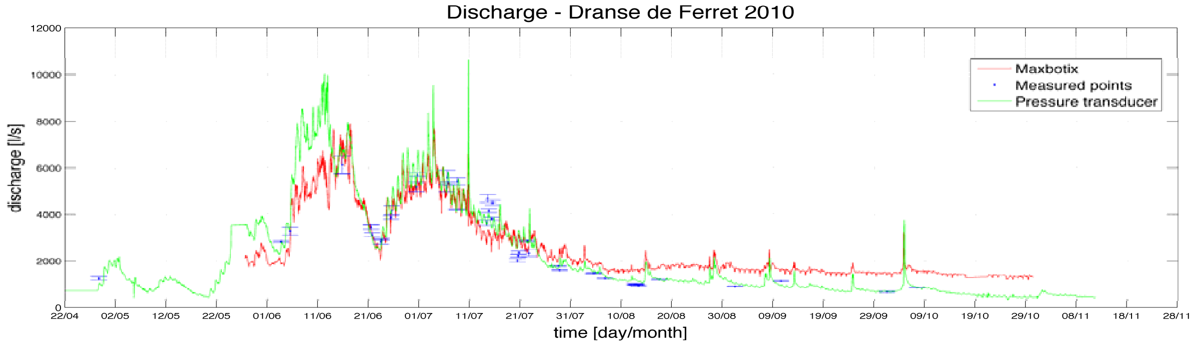


Figure 7. Time series of stream discharge (at Dranse de Ferret) from La Fouly during the 2010 field campaign. Maxbotix measures water level using ultrsound, the pressure transducer was installed at the streambed, and measured points correspond to the manual measurements using a salt slug.

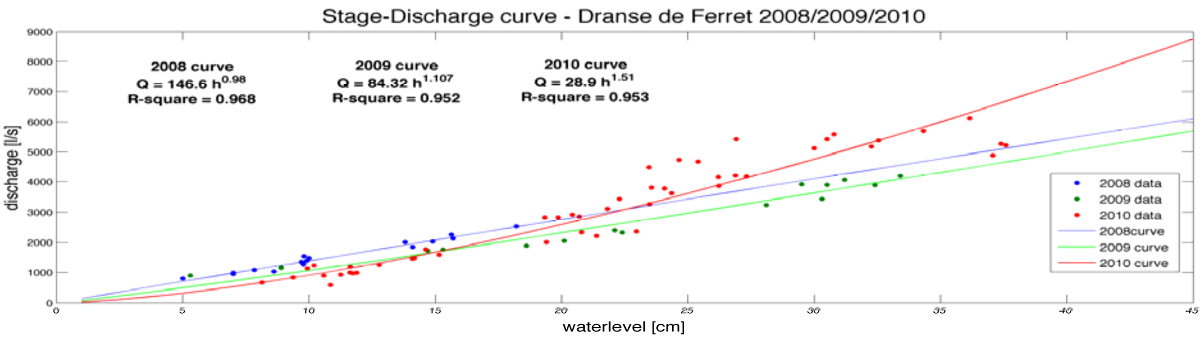


Figure 8. Different stage-discharge curves for 2008, 2009, and 2010 due to changes in the cross section of the river

Future directions

Future work planned for the 2011 field campaign will focus on field campaigns involving a larger number of stations being deployed in the catchment along with additional sensors (e.g. snow height) with the objective of further improving the performance and physical basis of hydrologic models. As such, the 2011 field campaign is aimed directly at obtaining higher resolution boundary conditions for the distributed model. Additional goals for the 2011 campaign include quantifying hydrologic impacts on the atmospheric boundary layer and the coupled physical processes involved.

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3.2 Nordic Scenarios

Monitoring campaigns of Nordic scenario were carried out with sensor stations provided by project partner Luode Consulting Ltd. Sensor stations consisted of data logger, battery and combination of sensors depending of parameters to be measured. Water quality parameters, such as turbidity, conductivity and temperature, were measured with YSI 600-series water quality probe. Oxygen concentration was measured with Marvet oxygen probe, and in Kylmäoja with YSI 6600-series optical oxygen sensor to avoid sensor fouling that occurred in western branch that is influenced by runoff from airport. Water level, which can be linked to flow and discharge functions, was measured with Keller pressure gauge.

Sensors were installed to the stream channel by anchoring them with heavy weights in order to resist storm water flow conditions. Sensors were connected to the Luode-data logger that was stored together with battery in a weather proof box on the stream bank. Datalogger was operating the sensors, storing the data and transmitting data to data server over GSM-network. Measured parameters were sampled every 10 minutes.

Data quality control was done both automatically and manually, by robot in the data server after data transmissions and manually by Luode staff twice per day. GSN was installed to Luode data server for delivering the data to project partners. Virtual sensors were created in the GSN for every sensor connected to the sensor stations. Wrappers were programmed to connect the virtual sensors to data files of Luode data server. Virtual sensors in the GSN were collecting the recent data from the data server and delivering it automatically to the project partners. In addition to GSN data delivery, the data was also delivered to end users with Luode web based data service, where the data can be read in graphical and table format or downloaded for further analysis.

Maintenance of sensor stations was carried out both automatically and manually by Luode staff to avoid sensor fouling. Optical sensors (turbidity and oxygen) were cleaned automatically with wipers before each measurement. All sensors were cleaned manually in weekly maintenance routine and also every time when automatic or manual data quality control alarmed.

The quantitative investigation aimed at predicting water level and discharge at intermediate points on the main streams. An analysis and processing of baseline topographic data was carried out first. The goal of the topographic processing tasks was to generate stream geometry that will form the base of routing water inside the hydraulic model. A second type of data necessary for hydraulic modeling are friction coefficients inside the stream channels and these ware obtained from the land use geospatial layers and literature. As data was processed and made available for modeling.

3.2.1 Ridalinpuro (Nummela)

On Ridalinpuro a goal of the campaign was to study the impacts of a project, in which 200 m of the creek was restored to improve water quality and reduce stormwater amount. Main focus of the campaign was monitoring impacts caused by an excavator working in the channel on sediment transportation from the rehabilitation area to downstream. The results are utilized as a background data for simulations and visualizations of the HYDROSYS-project.

The campaign began on 2.9.2008, week before the restorations started. The period of the rehabilitation was 8.-25.9. Water quality parameters, turbidity, conductivity and also temperature were measured at all sensor stations (figures 5a and 5b). Sediment transportation from rehabilitation area to downstream was recorded as turbidity values. To the sensor stations Field and Lower dam, a Thompson weir was installed on 15.9 to monitor discharge as a function of water level, which was measured by pressure gauge. Lower dam sensor station was removed to the new weir on 17.9. Campaign ended on 15.10.2008.

Hydrological findings

Discharge at sensor stations Field and Lower dam was calculated by water level recordings and created discharge curves and is presented in figure 5. During the period of recording the water level values, 15.9-15.10.2008, rain occurred in the turn of the month. At Field station the discharge increased 2 l/s up to the maximum of 132 l/s. At Lower dam station from discharge goes from 6 l/s up to 334 l/s.

Figure 5 depicts how precipitation causes rapid increase in discharge at Lower dam cross-section. The effect is milder at Field station. The explanation is, that water to Field station originates mostly from arable land and is therefore better infiltrated and detained on the catchment area. To Lower dam -sensor station water is gathered from all over the watershed, which includes urban areas.

The watershed of Ridalinpuro is relatively small and it can be assumed, that rain occurs the same time at all sensor stations. The effect of urbanization can be noted also in reaction time. At the Field -sensor station the time from the beginning of the rain till the discharge peak is noticeable longer than at the Lower dam -station.

The nearest public weather station of Finnish Meteorological Institute (FMI) was at the time of the campaign situated in Palojärvi, about 6 km from the watershed. The rain events at the Palojärvi -weather station are illustrated in figure 6. As stated, the affect of rain is mild at the head of the Ridalinpuro stream. An exception make the rain event late 5.10, which is heavy and can be noticed as a rapid increase in discharge at both sensor stations.

The excavator was working in the rehabilitation area on 8.-25.9 and the causes were clearly seen in turbidity values downstream. Sediments were released from rehabilitation area, turbidity values increased from background level around 20 NTU reaching maximum level of 650 NTU during the work. Clear daily rhythm could be observed from turbidity time series, values increased during the day when excavator was working and decreased during the night. The work was carried out only on weekdays, therefore turbidity values decreased to background level during the weekends.

Sediment transportation along the stream followed typical function, impact is strong and short close to the source but further downstream it is milder and longer. Part of the sediments released from the rehabilitation area were trapped along the stream with low discharges. About 10 % of released sediments were trapped between Reservoir and Lower dam stations (distance 250 m) on 18.9.

Impacts of rain events on stream water quality could be recognized as a rapid increase in turbidity values occuring same time with rapid decrease in conductivity values. Increased discharge in the stream caused erosion from the channel bed and catchment area which is increasing turbidity values. Conductivity values decrease when stream water becomes diluted with rain water. Major rain events occurred before the rehabilitation work, once during the work and a week after the work was finished. Impacts of rain events could be seen in stations located both upstream (Field and Pipe) and downstream (Reservoir and Lower dam) of rehabilitation area.

The size, shape and location of the catchment governs its hydrological regime. The time of concentration is controlled mainly by the spatial distribution of land use throughout the catchment with three distinct areas: shallow concentrated flow in the northern part due to urbanization, channel flow in the stream and surface overland flow in the rest of the catchment. The most important component contributing to surface runoff is surface precipitation and it drains through surface overland flow for more than a half of the catchment area. These proportions are in agreement with previous research (Blomfeldt 2008). The channel flow plays a major role only in the case of high rainfall rates through the stream geometry. The Manning's coefficients values used in the hydraulic modeling had to be increased in comparison to standard literature for all the land use classes in order to account for the contextual conditions and successfully simulate the flow.

Modeling

In general, small streams do not receive much attention in hydrological literature. However, in case such a stream is located in a urban area its importance increases significantly as its has potential to affect the built environment end eventually produce damage. The small peri-urban streams are characterized by small slopes and high frequency of artificial flow structures like bridges and culverts. In addition, various domain specific parameters and conditions necessary in hydraulic modeling do not apply to these streams as they derived i under different circumstances (eg. no dry bed situations, average to high flow rates). This calls for customized models able to handle the specific context based modeling as well as improved methods for input generation from laser scanning data collection campaigns.

We developed a method for extracting stream cross-section data from LiDAR data obtained in low flow situations. The method analyzes the LiDAR data and provides the geometry and topology of the streams in the area of interest. In addition it provides the cross-section data and roughness estimates. The results of this work are best described in the HYDROSYS report D6.1 and in manuscripts to be submitted. The method is based on the regularized spline with tension method developed by Mitasova and Mitas (1999). The source of LiDAR data was the Finnish National Land Survey which carried out airborne LiDAR data collection campaigns prior to start of HYDROSYS (2007).

In order to leverage the precision and accuracy of LiDAR derived input we developed a hydraulic model in Fortran 95. The model is capable of computing water level and discharge at the hydraulic cross-section of a maximum three branched channel system. It uses as input the channel geomtries consisting of cross-sections and hydraulic structures, boundary conditions derived form sensor measurements and a series of domain specific parameters like Manning's coefficients as well as solver specific coefficients. The input data is read from PostgreSQL database tables. The output consists of water level and discharge for each cross-section in the computational spatial 1D as well as temporal domain. The input data is read and converted from Python list into Numpy array structure aligned in Fortran order. The model is exposed as a standard Python function through Python C API. For computational and optimization reasons the Python model behaves like a routine more than a function meaning it merely fills an input array with the proper values rather than allocating memory outside Python memory stack. Once the function returns the results can be displayed as graphs for each cross section as a function of time or for each time step for all cross-sections (Figure 11).

The model was successfully validated with on-site campaign data obtained early from the Ridalinpuro site. Thus the model was deemed fit for the HYDROSYS system from the point of being a state-of-the-art environmental hydraulics model.

Discussion (significance, usefulness, future directions)

Monitoring the impacts of the rehabilitation work was successful. Besides collecting general hydrological and water quality data, the system can be used for monitoring the amount of released sediments, size of impacted area and processes along the stream. The system can also be used as a tool to control impacts of e.g. rehabilitation work on stream water quality in order to follow certain water quality values given by authority or to protect sensitive aquatic ecosystem. Monitoring functionality and environmental improvement of rehabilitated area requires long term monitoring with same sensor station technology.

Role of end users was very important and valuable during the project, especially in the monitoring activities. Opinions of the Advisory board members, environmental specialists from public and private organizations, municipalities and also from local children were listened carefully when specifying needs of hydrological and water quality monitoring actions in urban environment. Their knowledge of special environmental issues in the project study sites created the grounds for monitoring campaigns. Goal of the campaigns were collecting environmental information from the study sites to fill the needs of end users as well as developing simulation and visualization components of the project.

Sensor stations and recorded hydrological and water quality data were presented to several end user groups. The HYDROSYS- system, including monitoring, simulation and visualization components, was presented in demonstration events. The event consisted of a presentation on the state of the project including a general overview of the project, a brief on the conducted measurement campaigns in the area, an overlook of the simulation work and an introduction to the mobile phone user interface.

An important new element in data collection for environmental hydraulics modeling is the use of LiDAR terrain data (see for example Straatsma and Baptist 2008). Most of the times the end product of such research is the Digital Terrain Model/Digital Surface Model. These type of products are used as input for spatially distributed surface hydrology models or simplified mixed 1D/2D hydraulic models like Lisflood FP (Bates & de Roo, 2000). In our case, the data processing went further, to extract cross-sections and generate vector geometries with the main difference being the extremely high requirements in data accuracy and precision (25 cm DEM). The solver used in the model allows little flexibility in terms of lack of accuracy. As the model validation and calibratin showed in small stream with relatively flat terrain the channel flow is dominated by roughness and frictional forces. As a result the domain specific parameters hasd to be adjusted to reflect these conditions.

3.2.2 Kylmäoja

A primary goal of the measurement campaigns in Kylmäoja catchment was to collect general hydrological and water quality data for research purposes. The collected data was utilized in development of simulation models and in visualization activities. Impacts of land use on water quality and hydrology were studied in the branches of Kylmäoja.

Monitoring campaigns were carried out in Kylmäoja on 1.-30.10.2009, 22.3-22.4.2010 and 6.10.-19.11.2010. The first campaign in autumn 2009 focused on collecting water quality and hydrological data during autumn rain period. Four sensor stations were deployed to the stream, one to the main stream (Kylma 7) and three to the western branch (Kylma 1, 2 and 3) for two weeks and then to the eastern branch (Kylma 4, 5 and 6) for another two weeks (figure 12). The second campaign in the spring 2010 focused on collecting data with two sensor stations from western branch (Kylma 1) and from the main stream (Kylma 7) during the snow melt period. The third campaign focused on, like the first one, collecting data from branches during the autumn rain period. Four sensor stations were deployed to the stream, two in the western branch (Kylma 1 and 3) and two in the eastern branch (Kylma 4 and 5).

Hydrological findings

Discharge increases rapidly in western and central branches of Kylmäoja (Kylma 1, Kylma 2, Kylma 3 and in main stream Kylma 7, figure 6) due to highly covered urban areas. The effect is slightly milder in western branch, with airport in the sub-catchment area. That is probably because of the non-covered area next to the runways, which slows down the surface flow.

Flow to the main stream (Kylma 7) seems to be generated mostly by waters from western and central branches. The sub-catchment of the eastern branch is less built and in addition there is a nature conservation area between Kylma 4 and Kylma 5. Figure 8 shows how water from precipitation is detained and infiltrated in that area.

Dissolved oxygen results from the western branch didn’t indicate any major impacts of glycol during the measurement periods. Major oxygen losses were not recorded, slight decreases in oxygen level were related to increased discharge of the stream during the rain events. Decreased oxygen concentration might be caused by both glycol and other suspended organic matter flushed from the surfaces to the water. Different method, e.g. sensor stations equipped with automatic water sampling system, should be considered to monitor impacts of glycol on stream water quality more precisely.

High peaks in conductivity values were observed during autumn rain period and high conductivity level in the beginning of snow melt period. They indicate effluent of other de-icing chemicals or waste water coming from the airport branch. Highest conductivity values were recorded right after the airport at Kylma 1 sensor station during the autumn rain events and values were lower downstream. Conductivity level was anyway slightly higher in the main stream compared to the airport branch during the snow melt period, which means that there are also other pollution sources in the catchment area, most probably salt used for road maintenance and other urban sources.

Turbidity results indicate that most significant solid matter load to the main stream come from the western branch. Values were high especially in the northern part of the branch (Kylma 2) during precipiation events. High turbidity peaks observed in the western branch probably originated from railway construction work area that crosses the stream between the Kylma 1 and Kylma 3 sensor stations.

Results from eastern branch indicate clear improvement of water quality in the nature conservation area when comparing data from inlet (Kylma 4) and outlet (Kylma 5). A significant part of solid matter was trapped to the area between the sensor stations (turbidity values decreased), conductivity was lower at the outlet and oxygen concentration increased significantly.

The flow regime in the Kylmaoja catchment is influenced by the high impervious coefficients (Krebs 2010) which sharpens the hydrological response. The main stream is relatively flat with and average slope of 5 degrees. This further complicated the flow simulation using the in house developed model as it increased the role of the vegetation and anthropic changes (bridges, culverts) in the channel flow. The main effect was that the coefficients controlling the type and stability of the Preismann solver had to be adjusted. A collateral conclusion is that for small flat streams 2D raster based hydraulic modeling might be more suitable because the accuracy and precision of geo-spatial datasets are often not met.

Modeling

The modeling study at Kylmäoja focused on modeling application, where a more complex system is first semi automatically mapped, then its geometry and topology is described into the database, and in the third phase the cross-sections and roughness coefficients are obtained from LiDAR data. As this is achieved, the model is made available to the HYDROSYS system using new GSN extensions developed for simulation.

GSN extensions for simulation were developed in HYDROSYS work package 4 task 6. The extension was proof-of-concepted with 2D hydrological models, which are quite different computationally than 1D hydraulic model that was used and developed in the Nordic scenario. The technology transfer and required modifications is still taking place as of this writing. In the Nordic scenario another, perhaps a more standardized web service was proof-of-concept for the environmental hydraulics model. The Open Geospatial Consortium published 2007 a Web Processing Service (WPS), which defines a standardized interface that facilitates the publishing of geospatial processes, and the discovery of and binding to those processes by clients. A processes include any algorithm, calculation or model that operates on spatially referenced data. Publishing means making available machine-readable binding information as well as human- readable metadata that allows service discovery and use (Open Geospatial Consortium 2007). The interoperability test between GSN simulation web service as OGC WPS is currently being carried out. It should be noted that these technological advances go beyond the HYDROSYS description of work, as task 6.3.4 requires only that implications for requirements to modeling be analyzed.

Discussion (significance, usefulness, future directions)

General hydrological and water quality information was collected successfully from the site. The impacts on water quality and hydrology of different land uses in the catchment area were clearly observed from the collected data. Also the pollution sources were recorded and followed downstream. The impacts of railway construction works on water quality were recorded as increased turbidity values. Monitoring the effluents of glycol coming from the airport requires other sensors or automatic water sampling system connected to the sensor stations.

Local specialists were consulted when planning the exact locations of sensor stations. Their knowledge of hydrological characteristics of the locations was important when choosing installation method in order to ensure data quality and to avoid damages caused by storm water. Recorded hydrological and water quality data was delivered to end users using Luode data service during the campaigns. Data service enables end users to observe recent data and for to download whole data set for further analysis.

End user meetings were held both indoor and outdoor on the site during the project to get information and feedback from end users and to present progress of the project (figure 9). Sensor stations and recorded hydrological and water quality data were presented to several end user groups on the sites. The HYDROSYS- system, including monitoring, simulation and visualization components, was presented in demonstration events. The functional prototype was shown running on the mobile phone first via a projector before end users tested it on the site.

The state-of-the-art environmental hydraulics models are typically developed for the batch execution mode, i.e., they use text formatted input data files and produce text formatted output data files. Our requirement was to use partly a standard relational database and middle-ware and partly web services. The state-of-the-art models have not been developed for the HYDROSYS use case, i.e., on-site modeling with interaction among modelers, users, data collectors and so on. This use case implies flexible data structures and data models, which we developed into the model.

The main higlights of the modeling are the following. A physically based hydraulic model was developed for web services usage. The focus here was on integrating state of the art computational libraries like Numeric Python for facilitating the reduction of computational times. Without these refinements a hydraulic model would hardly be usable in a on line system. The model was exposed as and online standardized (OGC WPS) web service.

Future directions

A key future direction for research is environmentally sensitive stormwater engineering. This is continued within the hydrology and water engineering research group at Aalto University. Within HYDROSYS this line of research was enhanced by modeling and environmental informatics aspects.

Future directions regarding physical modeling may include considering lateral inflow and obtaining its physical parameters from lidar data. The results obtained implementing the model on Kylmaoja catchment imply that describing some physical features (junctions, culverts, cross-sections) as well as some physical phenomena (local supercritical flow, local drying) require more work in modeling. However, improving the description of the physical processes is only one of several possible directions for future research.

A key future direction for the environmental informatics aspect of the research is development of standards-based information infrastructures for data and modeling.

Figures

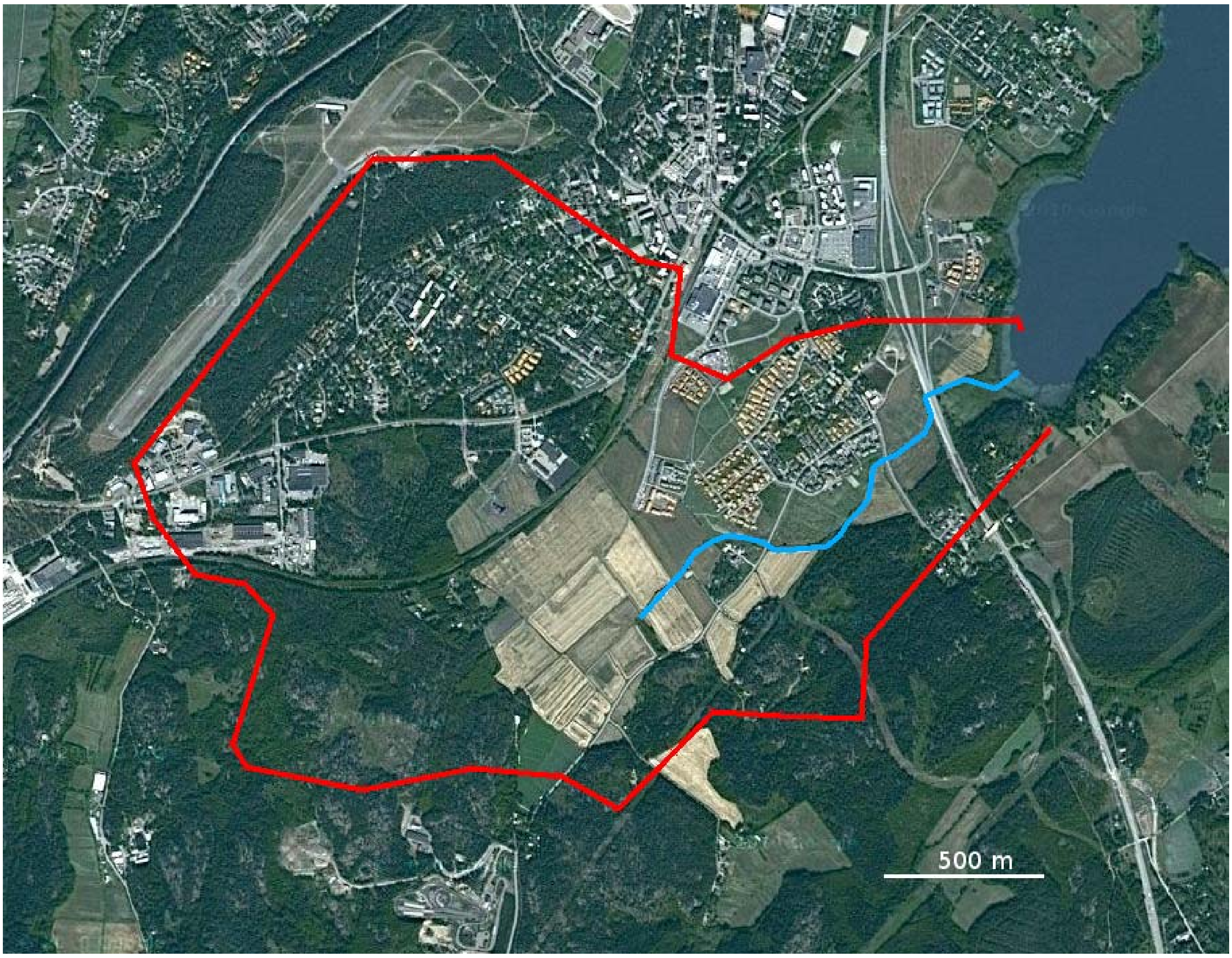

Figure 1. Ridalinpuro and its catchment

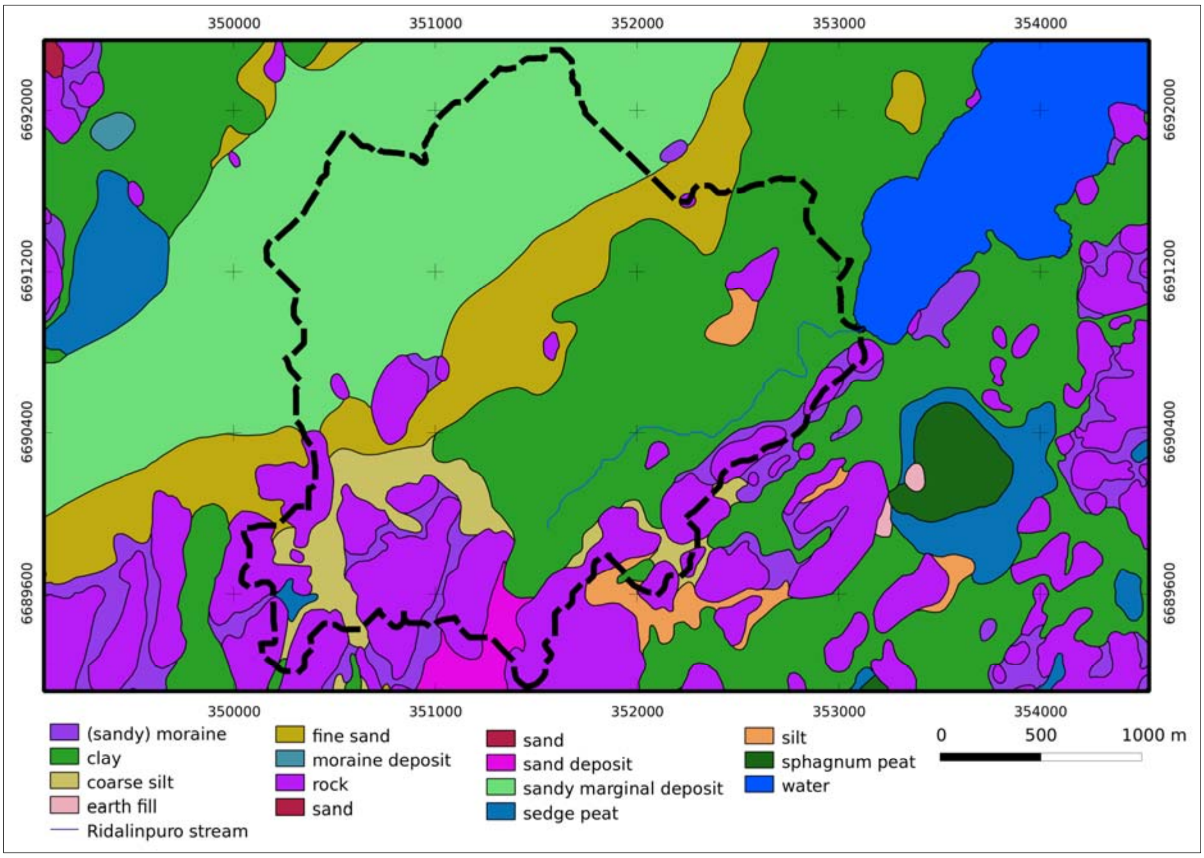

Figure 2. The geological map of the Ridalinpuro catchment

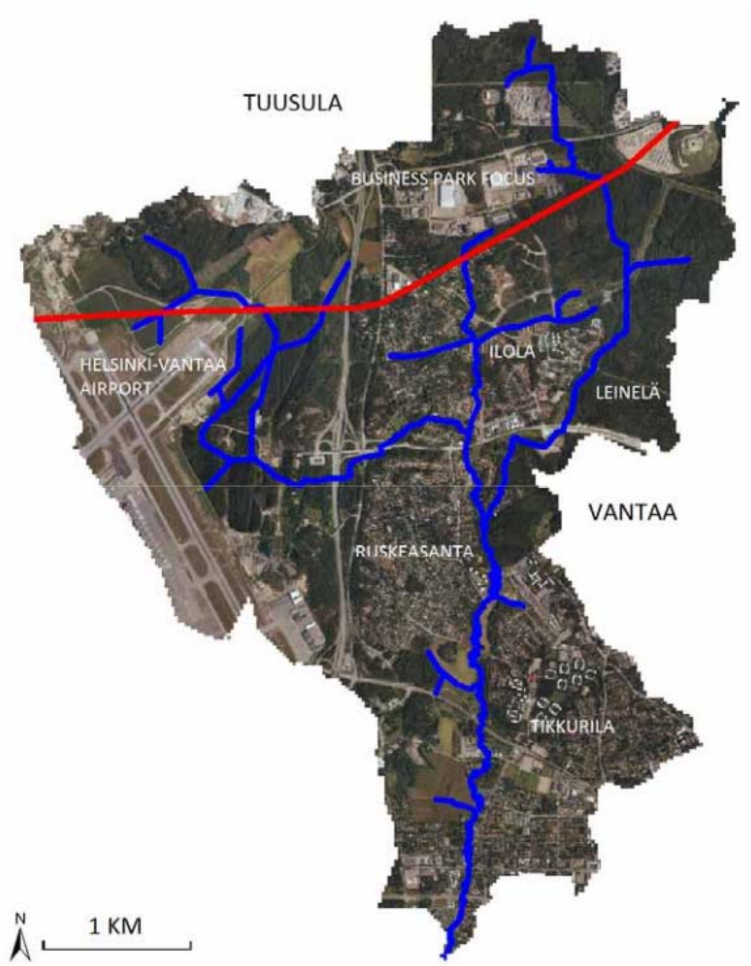

Figure 3. Kylmäoja and its catchment

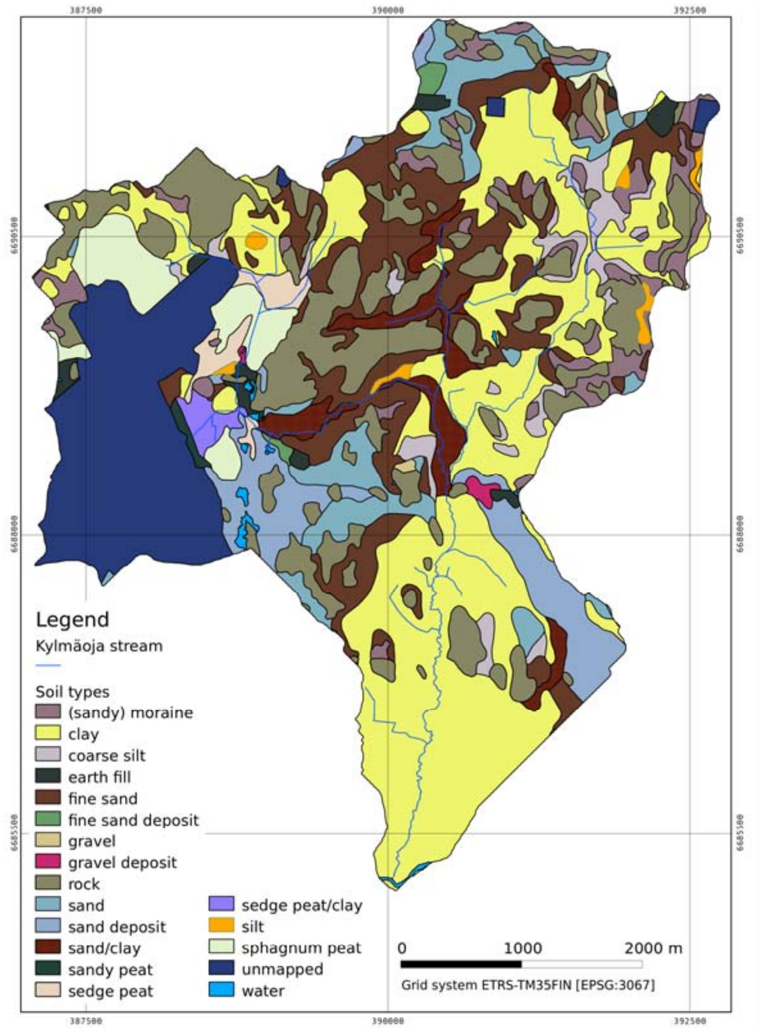

Figure 4. The geological map of the Kylmäoja catchment

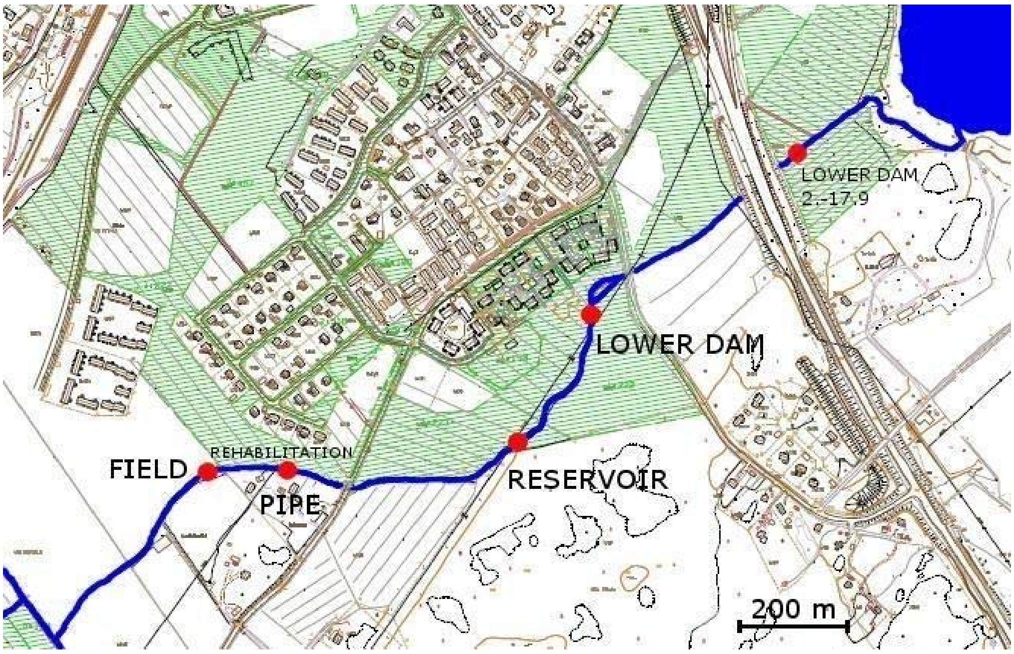

Figure 5a. Locations of sensor stations on Ridalinpuro during the campaign 2.9-15.10.2009. Rehabilitation area is between stations Field and road downstream right after Pipe station.

Figure 5b. Sensor station installations at Ridalinpuro. YSI 600-sensor (left) is mesuring water quality from a storm water drain (right).

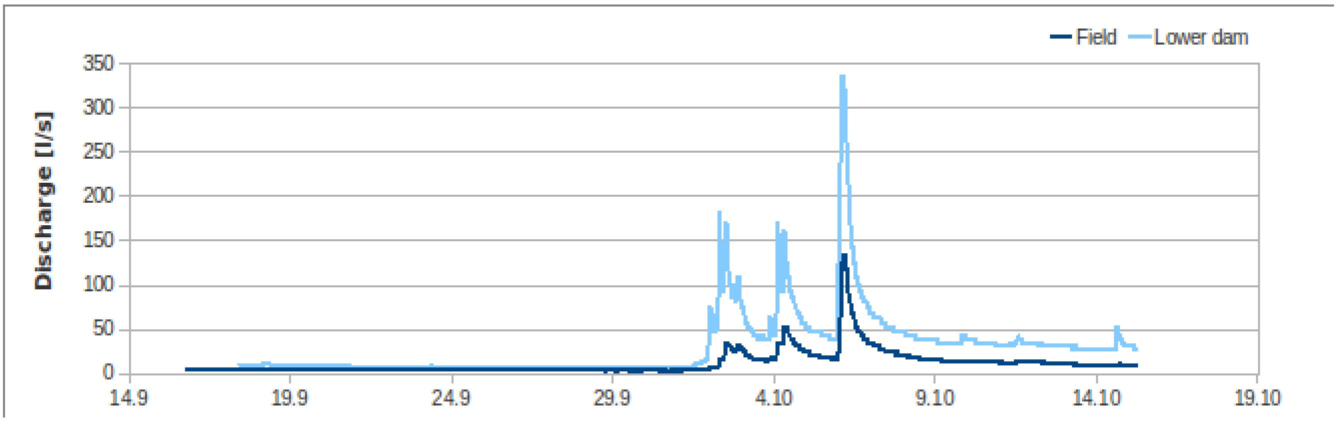

Figure 5. Discharge at stations ”field” and ”lower dam” 15.9. - 15.10.2008

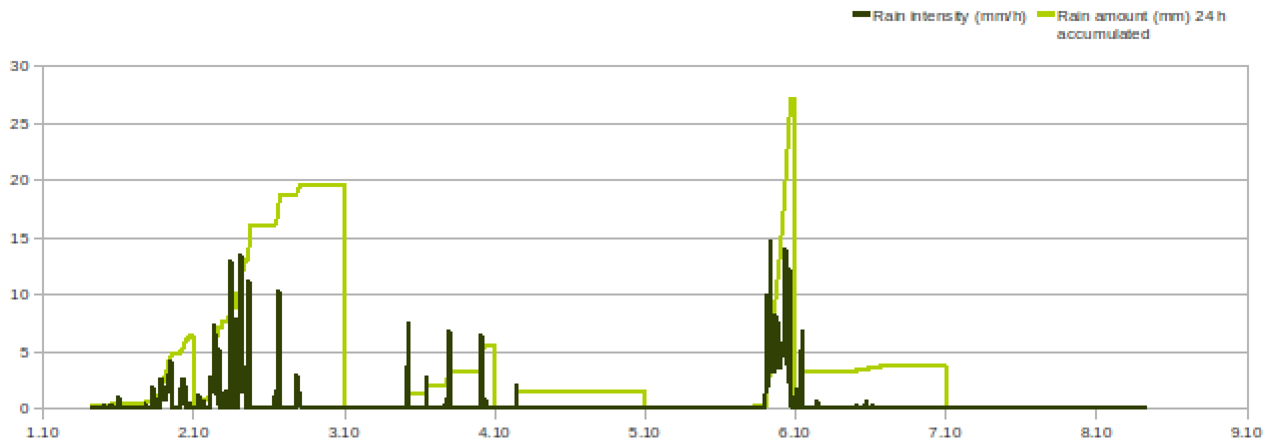

Figure 6. Rain intensity and amount at Palojärvi weather station.

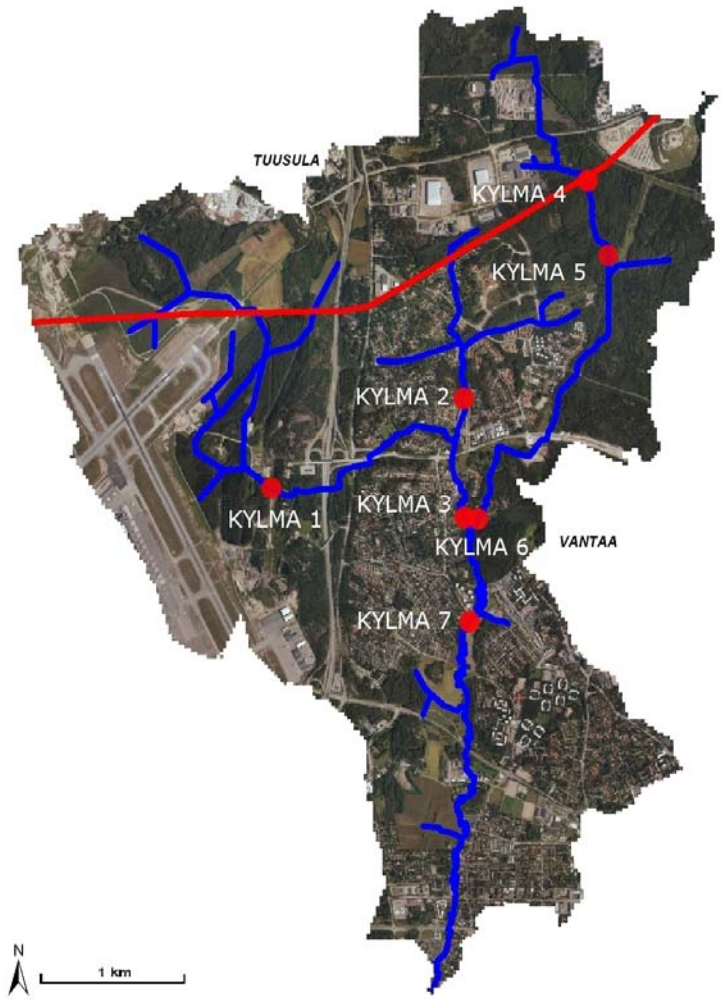

Figure 7a. Locations of sensorstations in Kylmäoja during the campaigns.

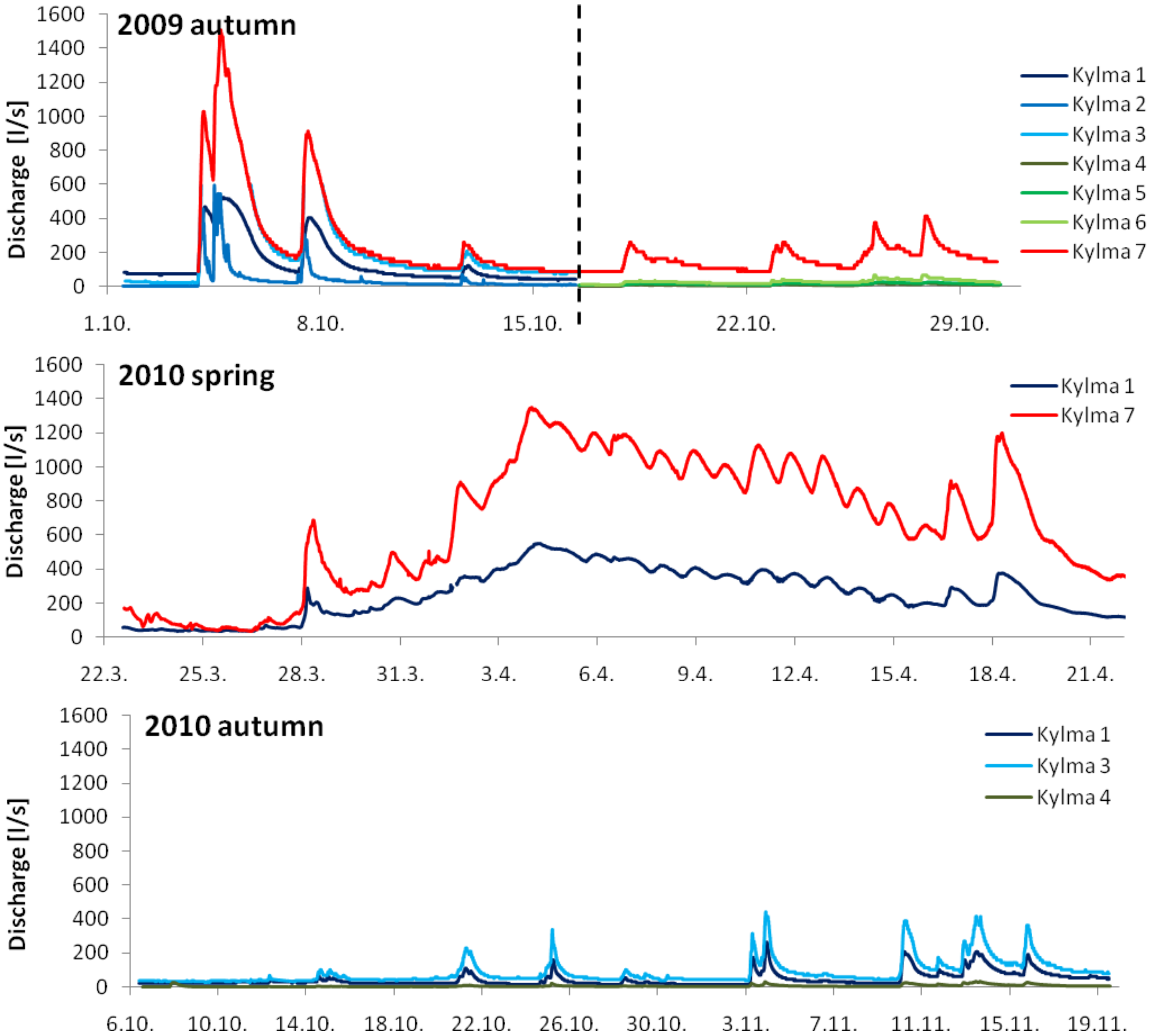

Figure 7. Discharge data from three monitoring campaigns in Kylmäoja from various sensor stations.

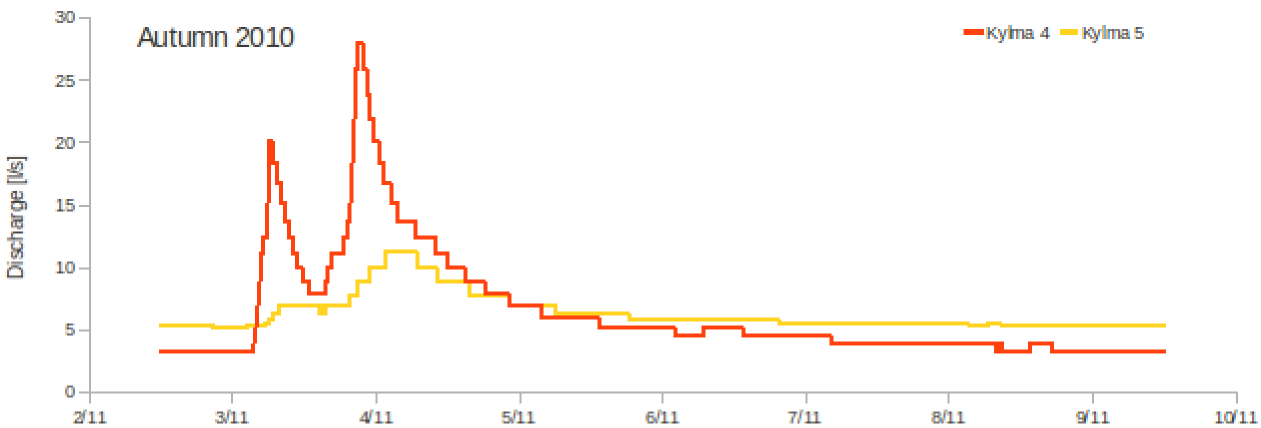

Figure 8. The effect of the nature conservation area, located between Kylma 4 and Kylma 5, to the stream discharge.

Figure 9. End users, environmental specialists observing recorded water quality data using the 3D-model in mobile phone user interface in demonstration event at Kylmäoja in the spring 2010.

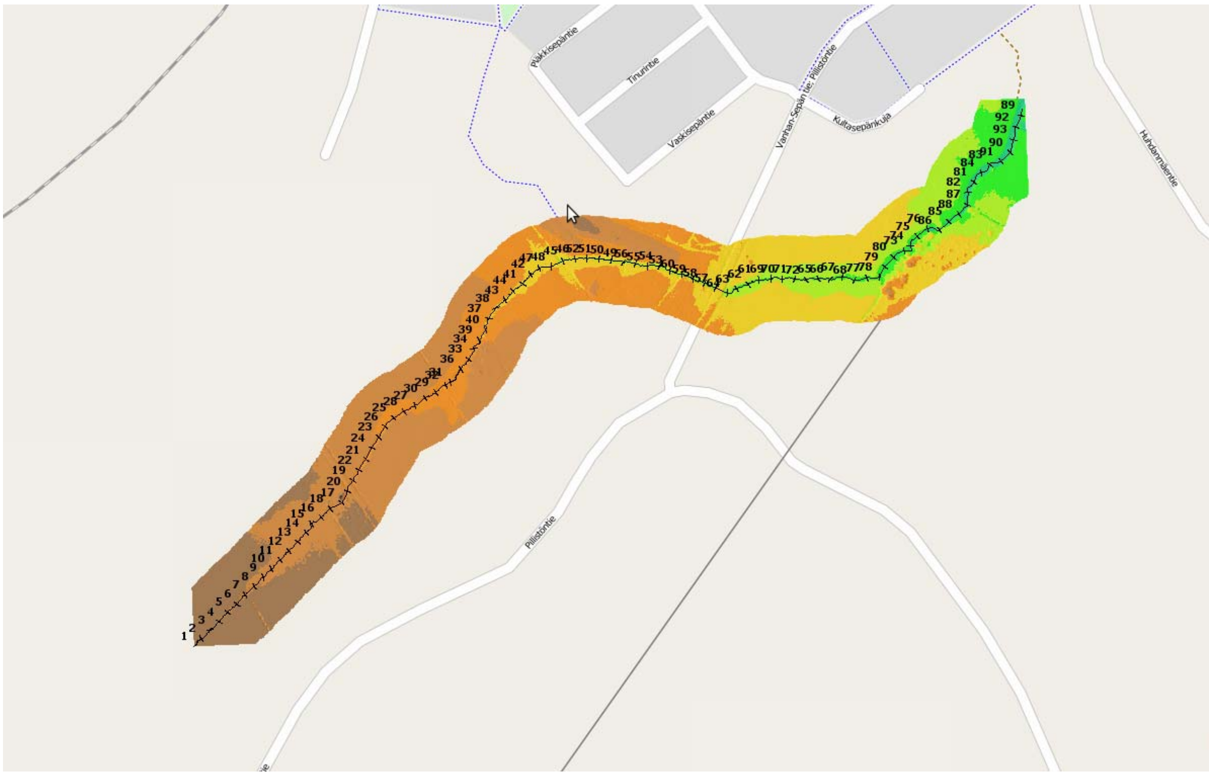

Figure 11. A visualization of cross-section data obtained from LiDAR data of Ridalinpuro.

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Appendix: selected abstracts

1 Dorfberg:

Observations and analysis of two wet-snow avalanche cycles

CHRISTOPH MITTERER, REBECCA MOTT AND JÜRG SCHWEIZER

Wet-snow avalanches threaten mountain communities and communication lines. Their formation as well as the snowpack processes leading to wet-snow instability are poorly understood. Forecasting wet-snow avalanches is a great challenge and poses great difficulties for local authorities. Better knowledge about the processes leading to wet-snow instabilities is therefore very important. During the winters of 2007-2008 and 2008-2009 two distinct wet-snow avalanche cycles occurred in the surroundings of Davos, Switzerland. We analyzed meteorological data, in-situ snowpack information and mapped avalanche extent. In addition, the snow cover model SNOWPACK was used to fill the gap where snowpack data, such as volumetric water or snow temperature, were not available. The analysis focused on the causes of instability: loading and/or weakening due to water infiltration. The full energy balance was calculated using meteorological data and extrapolated to the investigation area using the model ALPINE3D. Both avalanche cycles occurred in a short period of time. Precipitation amounts and the type of precipitation, i.e. rain or snow, played an important role during the first avalanche cycle, while terrain parameters such as aspect and slope angle combined with liquid water infiltration patterns were crucial during the second wet-snow avalanche cycle. Although different meteorological conditions prevailed during these two avalanche cycles, it appears that wet-snow instabilities were mostly influenced by snow stratigraphy, rapid increase in air temperature and water infiltration patterns.

Mitterer, C.; Mott, R.; Schweizer, J., 2009: Observations and analysis of two large wet-snow avalanche cycles. Presentation at the International Snow Science Workshop 27 September to 2 October 2009, Davos, Switzerland – Proceedings of the ISSW

Automated detection and analysis of gliding snow

SEBASTIAN FEICK, STEFAN BRUNNER, CHRISTOPH MITTERER AND JÜRG SCHWEIZER

Full-depth avalanches caused by snow gliding are a particular type of wet-snow avalanches. Many observations have shown that a thin wet layer reduces friction between the snow-soil interface before a glide crack or complete failure occurs. The occurrence, however, of glide cracks and their evolution to a full-depth glide avalanche are still poorly understood. Permanent monitoring of glide cracks is an essential step towards glide avalanche risk assessment. The aims of the presented work are (1) to develop an algorithm for automated glide crack detection and mapping, and (2) to gather more information about the main triggering factors leading to glide avalanches. We tested two approaches for automated detection of glide cracks using very high spatial resolution satellite images (WorldView-1). The first approach combined GIS and statistical modelling techniques; the second one included an object-based image analysis. In addition, we installed two automatic weather stations nearby two slopes which are known to often produce gliding-snow events. The stations recorded meteorological parameters, but also volumetric liquid water content and water potential at the snow-soil interface. Two automated cameras were installed to monitor glide-snow avalanche occurrence. The panchromatic WorldView-1 images with a spatial resolution of 0.5 m were suited to identify glide cracks, however, with coarser spatial resolution (>1 m) detection was not possible. The object-based image analysis approach worked as well and seems to be the more practicable approach in terms of computation rate and general applicability. Some problems with misclassifications existed, in particular in snowfree areas and open forest stands. Gliding-snow activity was weakly related with air temperature, especially during events early in the winter when large parts of the snowpack can still be dry and well below 0_C. In most cases, only the layer above the soil was wet. The water potential decreased rapidly shortly before high gliding-snow activity, while the water content increased towards the events suggesting a ponding of water due to different percolation characteristics at the snow-soil interface. The evolution in water potential and water content, however, cannot be related with a failure below the open crack. Here other properties such as terrain roughness or terrain breaks may play a major role.

FEICK, S., BRUNNER, S., MITTERER, C. AND JÜRG SCHWEIZER, J., 2011. AUTOMATED DETECTION AND ANALYSIS OF GLIDING SNOW. POSTER PRESENTED AT THE EUROPEAN GEOSCIENCE UNITION GENERAL

ASSEMBLY 2011, APRIL 3-8. VIEANNA, AUSTRIA. GEOPHYSICAL RESEARCH ABSTRACTS VOL. 13, EGU2011-13923, 2011.

Wet-snow instabilities: Comparison of measured and modelled liquid water content and snow stratigraphy

CHRISTOPH MITTERER, HIROYUKI HIRASHIMA, JÜRG SCHWEIZER

Wet-snow avalanches are difficult to forecast, 1 as the change from stable to unstable snow conditions occurs rapidly in a wet snowpack, often in response to water production and movement. Snow stratigraphy plays a vital role in determining flux behaviour. Capillary barriers or melt-freeze crusts can impede and divert water horizontally over large areas and thus may act as a failure layer for wet snow avalanches. We will present a comparison of measured and modelled liquid water content (θw) and snow stratigraphy during periods of wet-snow instabilities. Special attention is given to the reproducibility of capillary barriers, ponding of water on melt-freeze crusts and the timing of first wetting and of water arrival at the bottom of the snowpack, because these factors are believed to play a major role in the formation of wet-snow avalanches. In-situ measurements were performed in the vicinity of automatic weather stations or close to recent wet-snow avalanches in order to compare them to model results. The simulations are based on two different water flux models incorporated within the 1-D snow cover model SNOWPACK. The comparison of the two model runs with observed liquid water content and stratigraphy revealed that both water transport models reproduced the ponding ofwater on melt-freeze crusts. However, in both models melt-freeze crusts were transformed to normal melt forms earlier than observed in nature and thus still existing ponding was not captured by the models. Only one of the models was able to reproduce capillary barriers in agreement with observations. The time of the first wetting at the surface was well predicted, but the simulated arrival time of the wetting front at the bottom of the snowpack differed between the simulations; it was either too early or too late compared with the observation.

MITTERER, C., HIRASHIMA, H. AND SCHWEIZER, J., 2011A. WET-SNOW INSTABILITIES: COMPARISON OF MEASURED AND MODELLED LIQUID WATER CONTENT AND SNOW STRATIGRAPHY. ANNALS OF GLACIOLOGY, ACCEPTED.

MITTERER, C., HIRASHIMA, H. AND SCHWEIZER, J., 2010A. WET-SNOW INSTABILITIES: COMPARISON OF MEASURED AND MODELLED LIQUID WATER CONTENT AND SNOW STRATIGRAPHY. PRESENTATION GIVEN AT THE INTERNATIONAL SYMPOSIUM ON SNOW, ICE AND HUMANITY IN A CHANGING CLIMATE, 21-25 JUNE 2010, SAPPORO, JAPAN.

2-D modelling of water flow in snow

INGRID REIWEGER, CHRISTOPH MITTERER, AND JÜRG SCHWEIZER

The amount of liquid water and its interaction with snow stratigraphy is related to wet-snow instability. Layers with a high amount of liquid water show reduced shear strength. Observations have shown that a large amount of water reaching the bottom of the snowpack causes instability and can be associated with wet-snow avalanche activity. Quantifying liquid water content in snow under field conditions is difficult, time consuming and prone to errors as most measurement devices do not allow capturing the evolution over time and even may influence the water flow itself. Modelling of water flow in snow is an alternative, but complicated by the fact that water flow in snow is a highly transient phenomenon with direct feedbacks on the surrounding ice matrix and thus the water flow itself. Therefore, only very few attempts were made to model water flow in snow. We model water flow through a snowpack with an adapted cellular automaton model in 2 D. Within our model we use a randomly generated snowpack with a certain density, grain size, and layering. Water flows into the snowpack from the top, as it may happen due to melting of the uppermost layer or during rain-on-snow events. During the flow process water may refreeze and parts of the ice matrix may melt according to stochastic cellular automaton rules. We studied the flow patterns for different amounts of water, various grain sizes and layering of the snowpack. First results indicate that the model well reproduced general flow characteristics in porous media. With small grain size water tended to flow in a uniform wetting front, while with large grain size preferential flow fingers were more often triggered. With coarse-grained snow water flow was fast with few, but large preferential flow channels routing large amounts of water deep into the snowpack.

REIWEGER,I., MITTERER, C. AND SCHWEIZER, J. 2011. 2-D MODELLING OF WATER flOW IN SNOW. . PRESENTATION AT THE EUROPEAN GEOSCIENCE UNION GENERAL ASSEMBLY, APRIL, 3RD TO 8TH 2011, VIENNA, AUSTRIA. GEOPHYSICAL RESEARCH ABSTRACTS VOL. 13, EGU2011-13920

Upward-looking ground-penetrating radar for measuring wet-snow properties

CHRISTOPH MITTERER; ACHIM HEILIG; JÜRG SCHWEIZER; OLAF EISEN

Snow stratigraphy information is among other sources the key data for assessing avalanche danger - not only for dry-snow but also for wet-snow situations. Until now this information is obtained by traditional snow pit observations or more recently by using more quantitative methods such as the snow-micro penetrometer or dielectric devices. All these methods are destructive and only provide a snap shot in time of snowpack evolution. We used an upward-looking ground-penetrating radar system (upGPR) to monitor snowpack evolution on a daily or whenever necessary hourly basis to obtain information on wet-snow properties. We focused on determining the volumetric liquid water content (θw) by calculating the permittivity of the wet snow above the radar antennas, the advance of a wetting front and the wet snow stratigraphy. Results were compared to in-situ measured permittivity, modelled wetting front advance and measured outflow at the bottom of the snowpack. The upGPR system clearly showed the advance of a wetting front and the arrival time was similar to that recorded with a nearby lysimeter. Possibly weak wet layers with a high liquid water content (θw > 6%) were detected within the radar signal by multiple reflections. However, determining the exact amount of liquid water for each layer separately was not possible.

MITTERER, C., HEILIG, A., SCHWEIZER, J., EISEN, O. 2010B. UPWARD-LOOKING GROUND-PENETRATING RADAR FOR MEASURING WET-SNOW PROPERTIES. COLD REGIONS SCIENCE AND TECHNOLOGY.

Measuring wet-snow properties with ground-penetrating radar technology

CHRISTOPH MITTERER, ACHIM HEILIG, LINO SCHMID , JÜRG SCHWEIZER, OLAF EISEN

Snow stratigraphy and its interaction with percolating water play a vital role in determining periods with wetsnow instability. So far, research on wet-snow avalanches mostly focused on linking meteorological parameters with periods of avalanche activity, so that information on snowpack properties prior and during times of high avalanche activity is rare. Characteristics of percolating water within the snow cover were estimated by traditional snow pit observations or more recently measured with dielectric devices. Both methods are destructive and highly influence the snow stratigraphy and thereby the percolation behaviour. In the present study, we used an upwardlooking ground-penetrating radar system (upGPR) to monitor snowpack evolution on a daily or whenever necessary hourly basis to obtain information on wet-snow properties without disturbing the snowpack above the antennae.We focused on (1) determining the volumetric liquid water content by calculating the relative permittivity of the wet snow above the radar antennae, and (2) on the advance of a wetting front and the wet-snow stratigraphy. Results were compared to in-situ measured permittivity, modelled wetting front advance and measured outflow at the bottom of the snowpack. The upGPR system allowed monitoring the advance of a wetting front and the arrival time at the bottom was similar to the time recorded with a nearby lysimeter. Potentially weak wet layers with a high liquid water content (>6%) were detected within the radar signals by multiple reflections. However, determining the exact amount of liquid water for each layer separately was not yet possible.

MITTERER, C., HEILIG, A., SCHMID, L., SCHWEIZER, J., EISEN, O. 2011B. MEASURING WET-SNOW PROPERTIES WITH GROUND-PENETRATING RADAR. PRESENTATION AT THE EUROPEAN GEOSCIENCE UNION GENERAL ASSEMBLY, APRIL, 3RD TO 8TH 2011, VIENNA, AUSTRIA. GEOPHYSICAL RESEARCH ABSTRACTS VOL. 13, EGU2011-13916

2 Gemsstock:

Monitoring infrastructure stability in alpine permafrost

THOMAS GRÜNEWALD, ERICK MENDEZ, URS ROOS , CARLO DANIOTH AND MARCIA PHILLIPS

The retreat of permafrost is a highly important issue in many arctic and alpine regions. Especially infrastructures such as buildings, power lines or cable car pylons are affected by the consequences of permafrost degradation. Thawing of ground ice can destabilize the ground and result in settling or tilting of infrastructure. Parts of the cable car infrastructure of the Gemsstock skiing resort in Andermatt (Swiss Alps) are built in alpine permafrost. Thawing permafrost could potentially cause tilting of building walls and therefore affect rope guidance and structure stability. The infrastructure is therefore *carefully monitored at regular intervals. Wall inclinations are measured manually at selected points of interest using fixed benchmarks. This is a time-consuming task which requires bulky measurement tools, manual recordings and manual post-processing of the data. We present a first concept for a new monitoring system for infrastructure located in permafrost areas. The system is currently being tested at Gemsstock where eleven points of interest have been selected. At these points located on a pylon and inside the top station of the cable car, plastic markers have been installed as benchmarks. The measurement system consists of a small handheld computer with a user friendly software interface and a high precision inertia orientation sensor. The orientation sensor is a small box which directly monitors inclination angles in three perpendicular directions. It is placed at the markers and a measurement is started from the computer user interface. The three measured angles are directly transmitted and displayed on the handheld. In addition, the inclination deviations in comparison to a reference measurement are visualized in a time series plot. The position of the cable car cabins, which might affect the inclinations, can be recorded via pre-defined buttons on the interface. The combination of the simple setup and short measurement times of only a few seconds allows immediate on-site visualization and analysis of the results. Critical situations can be identified directly and possible measurement errors can be assessed by a repeated measurement. Post processing and in-office analysis is therefore dispensable. First tests of the system have shown that inclination monitoring is simplified and accelerated in comparison to the previously used method. Nevertheless, we also recorded that external factors like the position and the movement of the cable cars have a discernable effect on the wall inclinations. The first tests also indicate that initial challenges of the system, including repeatability and stability issues might affect the accuracy of the measurements. These disturbing factors need to be quantified before the system can be used in an operational manner by practitioners.*

GRÜNEWALD, T., MENDEZ, E., ROOS, U., DANIOTH, C., AND PHILLIPS, M. 2011. MONITORING INFRASTRUCTURE STABILITY IN ALPINE PERMAFROST. PRESENTATION AT THE EUROPEAN GEOSCIENCE UNION GENERAL ASSEMBLY, APRIL, 3RD TO 8TH 2011, VIENNA, AUSTRIA. GEOPHYSICAL RESEARCH ABSTRACTS VOL. 13, EGU2011-5636-1, 2011 EGU GENERAL ASSEMBLY 2011

Investigation of rock and ice loss in a recently deglaciated mountain rock wall using terrestrial laser scanning: Gemsstock, Swiss Alps

R. KENNER, M. PHILLIPS, C. DANIOTH, C. DENIER, P. THEE, A. ZGRAGGEN

Monitoring of permafrost phenomena is an integral part of the investigation of Alpine natural environments. The sensitivity of permafrost to climate change and the resulting destabilization of slopes are of particular interest at present. Rock walls react rapidly to changing climate conditions and the consequences can be hazardous. Temporally and spatially resolved monitoring of the terrain surface using terrestrial laser scanning can contribute towards improved process understanding and the prevention and management of natural hazards. The advantages and disadvantages of two scan systems used to monitor a recently deglaciated permafrost rock wall at Gemsstock in the central Swiss Alps are analyzed here and the optimisation of referencing methods and accuracy analyses discussed. Mass movements of around 1800 m3 were detected and quantified over a period of 4 years and mean erosion rates of 6.5 mm yr-1 determined. Volumetric changes caused by rock fall and melting ice could be defined with an accuracy of 4 – 10% of their surface area in cubic metres in the direction of projection.

KENNER, R., PHILLIPS, M., DANIOTH, C., DENIER, C., THEE, P., ZGRAGGEN, A. (UNDER REVISION). INVESTIGATION OF ROCK AND ICE LOSS IN A RECENTLY DEGLACIATED MOUNTAIN ROCK WALL USING TERRESTRIAL LASER SCANNING: GEMSSTOCK,SWISS ALPS. SUBMITTED TO COLD REGIONS SCIENCE AND TECHNOLOGY.

3 Alpine3D:

POP-C++ and Alpine3D: petition for a new HPC approach

PIERRE KUONEN, MATHIAS BAVAY AND MICHAEL LEHNING

Current numerical models used for research on and forecasting of natural hazards benefit from the steady increase in computational power and are getting more and more complex. Very often, they now *consist of various sub-process models, each with different numerical characteristics. The traditional approach to High Performance Computing (HPC) can hardly face this challenge without rethinking its paradigms. Here we suggest leveraging on the well known Object Oriented approach and introduce the programming model POP-C++, which distributes sub-processes onto a heterogeneous computing environment for parallel execution.*

The first part of this contribution describes a complex, multi-physics numerical model, Alpine3D as an example of such a complex model.

The second part gives a description of the POP-C++ concept as well as its semantics and shows that a small extension of C++ is able to cater to the needs of complex numerical models in a way that appears natural to the developers.

KUONEN, P., BAVAY, M., LEHNING, M., 2010. POP-C++ AND ALPINE3D: PETITION FOR A NEW HPC APPROACH. IN: ASIMAKOPOULOU, E. AND BESSIS, N.: ADVANCED ICTS FOR DISASTER MANAGEMENT AND THREAT DETECTION: COLLABORATIVE AND DISTRIBUTED FRAMEWORKS. DOI: 10.4018/978-1-61520-987-3

MeteoIO: A Meteorological Data Pre-Processing Library for Numerical Models

MATHIAS BAVAY , THOMAS. EGGER, AND LAURENT. WINKLER

While using numerical models, which require large meteorological data sets, the majority of the problems encountered by the operators can be traced back to the Input/Output functionality. Complex models are usually developed by the environmental sciences community with a focus on the core modeling issues. As a consequence, the I/O routines are often primitive, unreliable, error-prone, lacking flexibility and robustness. With the (operational) use of the physical models, this situation ceases to be simply uncomfortable and becomes a major issue. In parallel, the added requirements (in term of robustness and flexibility) increase tremendously the cost of dealing with the I/O. In order to address these needs and contain the costs of new adaptations, a new I/O library has been designed for the specific needs of numerical models consuming meteorological data. The whole task of data pre-processing has been delegated to this library, namely retrieving, filtering and re-sampling the data if necessary as well as providing spatial interpolations. The focus has been to design an Application Programming Interface (API) that would provide a uniform interface to meteorological data in the models; hide the complexity of the processing taking place; guarantee a robust behavior dealing with formats or transmissions errors, erroneous or missing data. Moreover, for an operational context, this error handling should avoid interrupting the simulation as much as possible. A strong emphasis has been put on simplicity and modularity in order to make it extremely easy to support new data formats or protocols and to allow contributors not familiar with the environmental sciences and/or a particular model to painlessly participate. This library can also be used in the context of High Performance Computing in a parallel environment. Finally, the "MeteoIO" library is released under an Open Source license and is available at http://slfsmm.indefero.net/p/meteoio .

BAVAY, M., EGGER, T., WINKLER, L. 2010. METEOIO: A METEOROLOGICAL DATA PRE-PROCESSING LIBRARY FOR NUMERICAL MODELS. PRESENTATION AT THE EUROPEAN GEOPHYSICAL UNION GENERAL ASSEMBLY, MAI, 2ND TO MAI 7TH 2010, VIENNA, AUSTRIA.

MeteoIO: A Meteorological Data Pre-Processing Library for Numerical Models

MATHIAS BAVAY AND THOMAS EGGER

While using numerical models, which require large meteorological data sets, the majority of the problems encountered by the operators can be traced back to the Input/Output functionality. Complex models are usually developed by the environmental sciences community with a focus on the core modeling issues. As a consequence, the I/O routines are often primitive, unreliable, error-prone, lacking flexibility and robustness. With the (operational) use of the physical models, this situation ceases to be simply uncomfortable and becomes a major issue. In parallel, the added requirements (in term of robustness and flexibility) increase tremendously the cost of dealing with the I/O. In order to address these needs and contain the costs of new adaptations, a specific I/O library has been designed for the specific needs of numerical models consuming meteorological data. The whole task of data pre-processing has been delegated to this library, namely retrieving, filtering and re-sampling the data if necessary as well as providing spatial interpolations. The focus has been to design an Application Programming Interface (API) that would provide a uniform interface to meteorological data

in the models; hide the complexity of the processing taking place; guarantee a robust behavior dealing with formats or transmissions errors, erroneous or missing data. This library is currently used by the Alpine3D alpine surface processes model, the SNOWPACK snow column model, the GeoTop hydrological model and some web applications. A new design of the API and of the core infrastructure that has been envisioned in order to better deal with filtering performance issues as well as provide more flexibility for spatial interpolations will be presented alongside new challenges introduced by some new applications. New challenges brought by the integration of kriging will also be exposed. The "MeteoIO" library is released under an Open Source license and is available at http://slfsmm.indefero.net/p/meteoio .

BAVAY, M. AND EGGER, T., 2011. METEOIO: A METEOROLOGICAL DATA PRE-PROCESSING LIBRARY FOR NUMERICAL MODELS. PRESENTATION AT THE EUROPEAN GEOSCIENCE UNION GENERAL ASSEMBLY, APRIL, 3RD TO 8TH 2011, VIENNA, AUSTRIA. GEOPHYSICAL RESEARCH ABSTRACTS VOL. 13, EGU2011-11653, 2011 EGU GENERAL ASSEMBLY 2011.

Meteorological Modeling of Very High-Resolution Wind Fields and Snow Deposition for Mountains

REBECCA MOTT AND MICHAEL LEHNING

The inhomogeneous snow distribution found in alpine terrain is the result of wind and precipitation interacting with the snow surface. During major snowfall events, preferential deposition of snow and transport of previously deposited snow often takes place simultaneously. Both processes, however, are driven by the local wind field, which is influenced by the local topography. In this study, the meteorological model Advanced Regional Prediction System (ARPS) was used to compute mean flow fields of 50-m, 25-m-, 10-m-, and 5-m grid spacing to investigate snow deposition patterns resulting from two snowfall events on a mountain ridge in the Swiss Alps. Only the initial adaptation of the flow field to the topography is calculated with artificial boundary conditions. The flow fields then drive the snow deposition and transport module of Alpine3D, a model of mountain surface processes. The authors compare the simulations with partly new measurements of snow deposition on the Gaudergrat ridge. On the basis of these four grid resolutions, it was possible to investigate the effects of numerical resolution in the calculation of wind fields and in the calculation of the associated snow deposition. The most realistic wind field and deposition patterns were obtained with the highest resolution of 5 m. These high-resolution simulations confirm the earlier hypothesis that preferential deposition is active at the ridge scale and true redistribution—mainly via saltation—forms smaller-scale deposition patterns, such as dunes and cornices.

MOTT, R. AND LEHNING, M. 2010. METEOROLOGICAL MODELLING OF VERY HIGH RESOLUTION WIND FIELDS AND SNOW DEPOSITION FOR MOUNTAINS, J. HYDROMET. 11, 934–949, DOI:10.1175/2010JHM1216.1.

Understanding snow-transport processes shaping the mountain snow-cover

R. MOTT, M. SCHIRMER, M. BAVAY, T. GRÜNEWALD, AND M. LEHNING

Mountain snow-cover is normally heterogeneously distributed due to wind and precipitation interacting with the snow cover on various scales. The aim of this study was to investigate snow deposition and wind-induced snow-transport processes on different scales and to analyze some major drift events caused by north-west storms during two consecutive accumulation periods. In particular, we distinguish between the individual processes that cause specific drifts using a physically based model approach. Very high resolution wind fields (5 m) were computed with the atmospheric model Advanced Regional Prediction System (ARPS) and used as input for a model of snow-surface processes (Alpine3D) to calculate saltation, suspension and preferential deposition of precipitation. Several flow features during north-west storms were identified with input from a high-density network of permanent and mobile weather stations and indirect estimations of wind directions from snowsurface structures, such as snow dunes and sastrugis. We also used Terrestrial and Airborne Laser Scanning measurements to investigate snow-deposition patterns and to validate the model. The model results suggest that the in-slope deposition patterns, particularly two huge cross-slope cornicelike drifts, developed only when the prevailing wind direction was northwesterly and were formed mainly due to snow redistribution processes (saltation-driven). In contrast, more homogeneous deposition patterns on a ridge scale were formed during the same periods mainly due to preferential

deposition of precipitation. The numerical analysis showed that snow-transport processes were sensitive to the changing topography due to the smoothing effect of the snow cover.
MOTT, R., SCHIRMER, M., BAVEY, M., GRÜNEWALD, T., AND LEHNING, M. 2010A. UNDERSTANDING SNOW-TRANSPORT PROCESSES SHAPING THE MOUNTAIN SNOW-COVER, THE CRYOPSHERE, 4, 545-559.

Understanding snow deposition on mountain slopes

REBECCA MOTT, THOMAS GRÜNEWALD, MICHAEL SCHIRMER, VANESSA WIRZ, AND MICHAEL LEHNING
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Snow water storage in the mountains is vital for summer water supply in many areas of the world and snow deposition determines the avalanche danger. While mountain snow covers have been investigated for many decades, we only now have the technology to measure high resolution snow distribution in steep terrain. High resolution airborne and terrestrial LASER scanner data are used in this contribution to assess snow distributions in two high Alpine catchments. For the first time, multiple measurements during the accumulation phase are analyzed. The measurements show that sub-areas in the investigation have persistent inter- and intra-annual accumulation patterns, which differ from area to area. These observations motivate the use of simple parameters of terrain exposure to predict accumulation patterns. The Winstral parameter showed a locally high predictive skill, provided a good knowledge on local wind direction is available, which can be found from measurements or simple parameterizations. For a more detailed investigation of physical processes, three-dimensional flow fields are needed. Detailed wind fields are created with an atmospheric numerical model (ARPS) and used to drive the physical process description of snow deposition in the numerical model Alpine3D. The numerical simulations with a grid resolution of 5 m show that snow redistribution (in particular saltation) lead to the formation of inhomogeneous snow distributions in a particular slope in the form of drifts, while homogeneous deposition of snow is achieved through preferential deposition in other slopes. These results help to understand that typical assumptions on altitudinal precipitation gradients appear to poorly represent real snow distribution.

MOTT, R, GRÜNEWALD,T., SCHIRMER,M., WIRZ, V. AND LEHNING, M. 2010B. UNDERSTANDING SNOW DEPOSITION ON MOUNTAIN SLOPES PRESENTATION AT THE EUROPEAN GEOPHYSICAL UNION GENERAL ASSEMBLY, MAI, 2ND TO MAI 7TH 2010, VIENNA, AUSTRIA. GEOPHYSICAL RESEARCH ABSTRACTS VOL. 12, EGU2010-12248, 2010

Understanding small scale variability of a mountain snow cover

REBECCA MOTT, MICHAEL SCHIRMER, MATHIAS BAVAY, MICHAEL LEHNING
The mountain snow cover is known to be heterogeneously distributed. Especially in very complex Alpine terrain the inhomogeneous snow distribution is the result of wind and precipitation interacting with the snow cover and the local energy balance at the snow surface. This variability is known to influence snow avalanche formation, snow water storage and local ecology. The aim of our work is to achieve a better understanding of the spatial varying deposition and ablation processes which are acting together to cause the spatial and temporal variability of the mountain snow cover of the Wannengrat area, Switzerland. For the accumulation period we investigate snow deposition and drifting and blowing snow at different scales, analyzing major drift events of two accumulation periods. We examine snow deposition features on the ridge scale as well as on smaller scales. For the ablation period we address the influence of the spatially distributed wind speed and the patchiness of the snow cover on the local energy balance and therefore on the ablation processes. Accumulation and ablation periods are both investigated experimentally and using numerical modelling. New technologies like terrestrial laser scanning enable the survey of snow depth variability in a very high spatial and temporal resolution. Meteorological forcing is measured by a dense network of permanent and mobile automatic weather stations. High resolution (5 m) wind fields are computed with the atmospheric model ARPS (Advanced Regional Prediction System) and used as input for a model of surface processes in alpine terrain (Alpine3D). From the model, preferential deposition on the one hand and redistribution of snow via saltation and suspension on the other hand as well as the local energy balance at the snow surface can be quantified. Results suggest that small scale deposition patterns, particularly two huge cross-slope cornice-like features, developed only during prevailing wind direction north-west and are formed mainly due to snow redistribution processes (saltation). In contrast, more homogeneous deposition patterns on ridge scale are formed during the same periods mainly due to preferential deposition of precipitation. Further results show that the spatial distribution of wind speed as well as the patchiness of the snow, which lead to strong lateral gradients of surface temperature can explain observed variations of melt rates during the ablation period.

MOTT, R., SCHIRMER, M., BAVEY, M., AND LEHNING, M., 2010C. UNDERSTANDING SMALL SCALE VARIABILITY OF THE MOUNTAIN SNOW COVER. PRESENTATION GIVEN AT THE INTERNATIONAL SYMPOSIUM ON SNOW, ICE AND HUMANITY IN A CHANGING CLIMATE, 21-25 JUNE 2010, SAPPORO, JAPAN.

Typical errors when calculating snow ablation in mountains

REBECCA MOTT, MATHIAS BAVAY, AND MICHAEL LEHNING

The mountain snow-cover gets patchy in the course of the melting season. The patchiness of a snow cover is caused by the spatially variable snow-depth distribution at the time of peak accumulation and by the spatially variable energy balance. The local energy balance is driven by net radiation and turbulent exchange of sensible and latent heat. As turbulent heat fluxes are linearly dependent on the local wind speed, the topographically induced air flow is crucial for modelling turbulent heat fluxes. Once the snow cover is patchy, thermal boundary layers develop and advection of warm air from adjacent bare ground to the snow surface provides an additional source of energy possibly contributing to snow melt. The objective of this study is to demonstrate the capability and the limits of a state of the art physically-based energy-balance model to capture the diverse small-scale processes driving melt of a patchy snow cover. We investigate snow melt in an Alpine catchment by combining a three-dimensional meteorological model with a fully distributed energy balance model. To account for the spatial variability of turbulent fluxes as a function of the local flow conditions, we drive the energy balance model of Alpine3D with high-resolution atmospheric flow-fields, calculated with the non-hydrostatic and atmospheric prediction model Advanced Regional Prediction model (ARPS). We also consider the snow-depth distribution at the start of the ablation period by initializing the Alpine3D model with snow depths measured by an airborne laser scan at the time of peak accumulation. Modelled ablation patterns are compared to measured ablation rates obtained from six terrestrial Laser scanning campaigns covering the complete ablation season 2009. Measured and modelled results demonstrate that areas of high wind velocities are characterized by high ablation rates mainly driven by increased turbulent fluxes. Areas affected by wind-induced snow erosion and deposition become patchy first. The measured ablation rates indicate that the advection of sensible heat causes locally increased ablation rates at the upwind edges of the snow patches. Nevertheless, the effect of local-scale advection appears to be dominant only over rather short distances. Neglecting the local advection in the energy balance calculations, we are able to model the mean ablation rates for the early ablation periods with a fractional snow cover above 0.6. Once the fractional snow cover is below 0.6 the model starts to strongly overestimate melting. Although the model considers stable conditions suppressing turbulence over snow patches, the air temperature appears to be strongly overestimated by the model. Similar to most energy balance models, the air temperature driving the Alpine3D model is obtained from single weather stations in the surrounding area, with sensors located several meters above ground. The measured air temperatures seem to overestimate the local air temperature above snow patches, where stable internal boundaries layers have started to develop. Modelled and measured results suggest that the over-prediction of melt energy results from overestimations of the local air temperature causing very high turbulent fluxes of sensible heat towards the snow surface when the fractional snow-cover is below a critical value. We conclude that for snow-melt calculations the development of stable internal boundary-layers above snow patches and its influence on melt energy fluxes needs to be investigated in detail.

MOTT, R., BAVAY, B. AND LEHNING, M. 2011. TYPICAL ERRORS WHEN CALCULATING SNOW ABLATION IN MOUNTAINS. PRESENTATION AT THE EUROPEAN GEOSCIENCE UNION GENERAL ASSEMBLY, APRIL, 3RD TO 8TH 2011, VIENNA, AUSTRIA. GEOPHYSICAL RESEARCH ABSTRACTS VOL. 13, EGU2011-5543, 2011 EGU GENERAL ASSEMBLY 2011

4 La Fouly:

Sensitivity of streamflow components to spatial variability of meteoreological forcing in high alpine watershed: application of a wireless sensor network

Silvia Simoni, Simone Padoan, Amilcare Porporato, Martin Vetterli, Guillermo Barrenetxea, and Marc

Brendan Parlange EPFL, Lausanne, Switzerland (silvia.simoni@epfl.ch, +41 21 693 6391)
A field campaign was conducted in a 20 km_2 high alpine catchment in the Swiss Alps, with a distributed sensor network, to investigate the impact of the catchment spatial variability and forcing parameters on stream flow gener- ation and soil moisture. Twelve sensorscope weather and soil moisture stations were installed over a wide range of elevations and aspects to capture some aspects of the spatial variability of different hydrological parameters includ- ing: soil moisture, precipitation, air temperature, relative humidity, wind speed and direction, solar radiation and land-surface skin temperature. Streamflow discharge at the outlet of the catchment was monitored with high tempo- ral resolution. Rainfall and air temperature were both influenced by spatial location where temperature was found to be related to morphological features of the catchment. Snow and ice melt streamflow components, which are particularly important in the Alps, display a diurnal trend of different amplitudes and duration declining throughout the summer. The long-term seasonal decreasing trend of the baseflow contribution to streamflow appeared to not be affected by catchment spatial variability. Summer and fall rainfall-runoff events were dominated by the highly spatial occurrence of convective rainfall events. To support the data analysis, streamflow was modeled using two models of different complexity: a 3D-spatially distributed model (GEOtop) and a lumped degree-day model. The GEOtop model proved to be more suitable for reproducing rainfall-runoff response, and the lumped model was at least as accurate to describe the snow melt. Initial conditions on snow depth over the catchment are necessary for spatially explicit models to simulate snow melt; however the lumped approach worked well simply knowing the average daily air temperature. The spatialy explicit model was successful in reproducing spatial and temporal soil moisture patterns, which are important in slope stability analysis. Spatially distributed models, though conceptu- ally more appealing than the lumped, require a substantial amount of meteorological input which is typically not available in Alpine environments.

Silvia Simoni, Simone Padoan, Amilcare Porporato, Martin Vetterli, Guillermo Barrenetxea, and Marc Brendan Parlange, Sensitivity of streamflow components to spatial variability of meteoreological forcing in high alpine watershed: application of a wireless sensor network, Abstract 4577, presented at 2011 General Meeting, EGU, Vienna, Austria, 4-8 April

Observed effects of soil moisture on surface fluxes and slope winds in an alpine valley

Megan Daniels (1), Eric Pardyjak (2), Wilfried Brutsaert (3), Daniel Nadeau (1), Susana Fernandez-Vidal (1),Gillermo Barrenetxea (1), and Marc Parlange (1)
(1) École Polytechnique Fédérale de Lausanne, Switzerland (megan.daniels@epfl.ch), (2) University of Utah, Salt Lake City, UT, United States, (3) Cornell University, Ithaca, NY, United States
Soil moisture affects flow in the atmospheric boundary layer through the relative partitioning of energy into the surface sensible and latent heat fluxes. While this effect has been well-studied over flat terrain through both field experiments and simulations, in complex terrain it has previously only been investigated through simulations. In the current study, we use observations to investigate effects of surface soil moisture on the strength and onset of buoyancy-driven slope winds following the diurnal cycle in an alpine valley. In the summers of 2009 and 2010, the Val Ferret catchment (□20 km2) in southern Switzerland was instrumented with surface weather stations measuring wind speed and direction (2 m), soil moisture, surface skin temperature, air temperature (2 m), humidity (2 m), incoming solar radiation, and precipitation. Results indicate that on calm, cloudless days, increased soil moisture leads to weaker up-slope and up-valley winds. This is corroborated through the calculation of surface sensible and latent heat fluxes using Monin-Obukov similarity theory, which shows that increased soil moisture leads to increased latent heat fluxes and correspondingly decreased sensible heat fluxes at stations within the valley.

Megan Daniels, Eric Pardyjak, Wilfried Brutsaert, Daniel Nadeau, Susana Fernandez-Vidal, Gillermo Barrenetxea, and Marc Parlange, Observed effects of soil moisture on surface fluxes and slope winds in an alpine valley, Abstract 8531, presented at 2011 General Meeting, EGU, Vienna, Austria, 4-8 April

Spatially distributed hydrologic response in a small catchment in the Swiss Alps

**Fernandez-Vidal, S, Simoni, S, Rinaldo, A, Daniels, M H, and Parlange, M B*

A continuous field campaign since 2008 was designed in order to understand the spatial heterogeneity of hydrologic and meteorological variables over a complex terrain and the consequences for river flow generation. The study area is located in the Swiss Alps, close to the Gd-St-Bernard, in the upper part of the Val de Ferret. The catchment has a total area of 20 km2 and the altitudes ranges from 1777 m to 3206 m. Steep complex terrain, entirely covered with snow from November to May and deep gullies are the main features of the study area. A system of 15 meteorological stations equipped with standard meteorological and soil sensors (moisture, suction and temperature) were deployed in a network spread over the study area to capture the heterogeneity of the meteorological forcing relevant to micrometeorological processes and its impact on snow melt, soil moisture distribution and stream runoff. Stream discharge from the cat

Fernandez, S, Simoni, S, Rinaldo, A, Daniels, M H, and Parlange, M B (2010), Spatially distributed hydrologic response in a small catchment in the Swiss Alps, Abstract H11G-0895 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec.

Distributed landsurface skin temperature sensing in Swiss Alps

**Van De Giesen, N, Baerenbold, F, Nadeau, D F, Pardyjak, E, and Parlange, M B*

The ZyTemp TN9 is a mass-produced thermal infrared (TIR) sensor that is normally used to build handheld non-contact thermometers. The measurement principle of the TN9 is similar to that of very costly meteorological pyrgeometers. The costs of the TN9 are less than $10. The output of the TN9 consists of observed thermal radiation, the temperature of the measurement instrument, and the emissivity used. The output is provided through a Serial Peripheral Interface protocol. The TN9 was combined with an Arduino board that registered data onto a USB memory stick. A solar cell, lead acid battery, housing and stand completed the meausrement set up. Total costs per set was in the order of $200 Land surface atmosphere interactions in mountainous areas, such as the Swiss Alps, are spatially heterogeneous. Shading, multi-layer cloud formation, and up- and downdrafts make for a very dynamic exchange of mass and energy along and across slopes. In order to better understand these exchanges, the Swiss Slope Experiment at La Fouly (SELF) has built a distributed sensing network consisting of eight micro-met stations and two flux towers in the "La Fouly" watershed in the upper Alps. To obtain a better handle on surface temperature, fifteen TIR sensing stations were installed that made observations during the 2010 Summer. Methods and results will be presented.

Van De Giesen, N, Baerenbold, F, Nadeau, D F, Pardyjak, E, and Parlange, M B (2010), Distributed landsurface skin temperature sensing in Swiss Alps, Abstract H11A-0790 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec.

The Effect of Energy Flux Partitioning on the Atmospheric Boundary Layer Height

*Higgins, C W, Mimouni, T, Nadeau, D F, Pardyjak, E, and Parlange, M B

The growth and extent of the atmospheric boundary layer during the diurnal cycle is difficult to predict or assess from local ground based measurements. Oftentimes it is necessary to use airborne methods (such as radiosondes), or remote sensing methods (such as Lidar) to obtain an appropriate measurement. In this paper we revisit Deardorf's scaling for the w* parameter and use a new approach to estimate the daytime boundary layer depth using simple evaporation and sensible heat flux measurements. The approach is validated against three separate datasets: arid desert, forest, and agricultural fields, and show that evaporation has a significant influence on the resulting boundary layer development.

Higgins, C W, Mimouni, T, Nadeau, D F, Pardyjak, E, and Parlange, M B (2010), The Effect of Energy Flux Partitioning on the Atmospheric Boundary Layer Height*, Abstract H21J-03 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec.*

5 Ridalinpuro (Nummela), Kylmäoja:

On site environmental modeling and monitoring: the Nordic Scenario in HYDROSYS project

Ferencik, I., Niemi, T. & Jolma, A. 2010. On site environmental modeling and monitoring: the Nordic Scenario in HYDROSYS project. To appear in: Swayne, D. A., Wanhong, Y., Voinov, A. A., Rizzoli, A. & Filatova, T. (eds.). Modelling for Environment's Sake: proceedings of the International Congress on Environmental Modelling and Software. Ottawa, Ontario, Canada, July 5 - 8 2010.

Environmental modeling represents a common method for improving the understanding of environmental phenomena and most of the times is carried out off site. The high computational requirements of environmental models coupled with large amounts of spatial data are the main causes for this situation. Conducting environmental simulations by means of environmental models on-site represents a challenge but with recent advances in Wireless Sensor Networks (WSN) and development of affordable smart hand-held devices new possibilities are opening. The work presented in this paper is related to the HYDROSYS project and is linked to the Nordic scenario located in south of Finland. The goal of the project is to provide end-users with advanced on-site and on-line spatial analysis tools for the purpose of environmental modeling. Thus, we have integrated a 1D hydraulic model with WSN and environmental modeling. This allows end users to carry out environmental simulation on-site almost in real time using smart clients improving their understanding in respect to environmental phenomena. The setup has a big potential for environmental management and decision support and could be highly exploited by environmental managers and specialists.

Development of a hydraulic model and its application to a small urban stream

Niemi,T. 2010. Development of a hydraulic model and its application to a small urban stream . Master’s thesis. Helsinki University of Technology, Department of Civil and Environmental Engineering. Espoo, Finland. 74 p.

In this thesis a one-dimensional hydraulic model to simulate gradually varied subcritical steady or unsteady open channel flow in a small urban stream or a branched stream network was developed, implemented and tested . The model was implemented using Fortran 95 programming language and it was connected to a PostgreSQL/PostGIS spatial database using a middleware program implemented in Perl. The database stores the input data and the simulation results of the model, whereas the middleware program enables the interaction between these components and provides a user interface for the system. It was observed that simulating flow in a small urban stream is challenging for many reasons. In small streams estimation of flow resistance is difficult, since the flow varies on a large scale and the variations are usually rapid, the methods commonly used to determine resistance are not suitable for small streams, and local energy losses have a significant impact. Lateral inflow to the stream might also be so significant that is should be taken account in modeling, but quantifying its amount is difficult. Furthermore, low flows are rather common in small streams from the computational point of view, and these may cause numerical difficulties in simulation. The developed model was tested with data from a small Ridalinpuro stream in

Nummela, Southern Finland. The model provides a tool that can be used to simulate flow in single reaches of open channel, and which can easily be modified and extended to suit further needs.

In addition to these there are three manuscripts:

Ferencik, I. Terrain modeling with LiDAR data for environmental hydraulics applications.
Ferencik, I. A distributed modeling system for peri-urban water environment.
Moll, V. Intensive measurement campaigns in a small suburban catchment in South Finland.