# Summary of Doctoral Thesis

Enrollment year: 2017 y 10 m
UGAS Specialty: Plant Production
Name BRANDT, Alexander Christian

| Title | Influence of snow dynamics on mountainous forest soil hydrology cycle |
| --- | --- |

**Introduction and purpose**

The overall objective of this study was the analysis of the hydrological cycle in the Yamagata University Research Forest (YURF), representing the Asahi Mountains, and the understanding of recent changes. The region has high precipitation and especially heavy snowfall in winter. Precipitation in spring is lowest within one year and therefore snowmelt is of great importance for forest ecosystems and agricultural areas. Snow depth of more than 3 m and air temperatures around 0 °C result in high snow densities and a high snow water equivalent (SWE). Changes in precipitation and air temperature from one year to another result in significant changes of SWE. Furthermore, soil moisture reacts first to water input and is an indicator for rain-on-snow events in warm winters, snowmelt and changes in water supply. Hence, the understanding of soil moisture and snow dynamics in YURF is essential to characterise the influences of decreased snowmelt in warm winters on the water supply to forests and agricultural areas in Shonai. Understanding the mechanisms is followed by predictions and estimations, hence, SWE models and snowmelt models are becoming important for the region. Effective models are able to predict the volume of water stored in snow in the mountains and can estimate the amount of snowmelt produced and distributed to the lowlands on every day. For Shonai, where precipitation in spring is low, those models will be able to improve irrigation processes and water management in general.

**Materials and methods**

Soil samples were taken at three spots along a Japanese cedar forested slope. Soil texture, hydraulic conductivity and maximum water content were measured using the HYPROP system and soil moisture data was monitored continuously at all three spots. Bedrock runoff and surface runoff have been measured in the summer season 2019. Simultaneously, precipitation, air and soil temperature, relative humidity, snow depth and solar radiation have been recorded by a measuring tower automatically every hour since November 2011. Meteorological data and soil physical properties have been applied to a numerical simulation in the software HYDRUS 1D in order to model soil moisture dynamics for the three spots at the slope. Modelled soil moisture was

compared with recorded soil water content in order to optimize the modelling process.
Furthermore, snow density and snow depth have been measured manually in the winter seasons 2018/2019 and 2019/2020. Obtained snow density values were used to calculate SWE and to characterise melting and refreezing processes within the snowpack. The data of the winter 2018/2019 was used to develop a model for SWE estimations based on meteorological parameters and snow depth. Two models were developed, one for the snow accumulation and one for the snowmelt period. Furthermore, Degree-Day Factors (DDF) were calculated for every snowmelt season from 2012 to 2020 using the modelled SWE and measured snow density values of the winter 2018/2019.
Additionally, the effect of rain-on-snow events on soil moisture under a deep snowpack was analysed. Soil moisture was measured during the winter seasons and peaks in the soil moisture curves were analysed regarding water increase rate and abundance. The intensity of rain-on-snow events and their abundance was compared for the last ten years and discussed with regards to climate change.

**Results**

Soils in YURF were with usually less than one meter depth shallow and characterised by a coarse texture. Sand as the major fraction of the soil resulted in high water retention and hydraulic conductivity. However, water storage capacity was low due to high air capacities of the pores. The amount of water being stored in the soils was therefore limited.
The recent winter (2019/2020), with high air temperature and without heavy precipitation events, resulted in the shallowest snow cover in YURF which was measured. Snow depth was combined with snow density, which was higher in years with greater snow depth, because snow was compacted more in those years. Furthermore, snow at the surface melted on days with temperatures of more than 0°C and moved downwards in the snowpack. Water refroze in deeper layers of the snowpack, where it changed the snow crystal structure and increased the snow density. The same process was observed after rain-on-snow events. Knowing the snow density after those events means knowing the amount of water which will be supplied to the Shōnai plains in spring. Modelling of snow density for the snow accumulation period and also for the snowmelt period was performed for every winter starting in the year 2011. Using precipitation data and degree-day factors (DDFs), accurate models for the snow water equivalent (SWE) of the snowpack were carried out.
Rain-on-snow events were not only causing increases in snow density, but were also found to affect soil moisture under the snowpack. In order to measure these effects, soil moisture was monitored at three spots of a slope, vegetated with Japanese cedar (*Cryptomeria japonica*). Two winters with significantly different snow depth were measured and analysed in this thesis in order to understand the relation between snow cover and rainwater infiltration. Soil moisture was also affected by numerous small rain events of less than 10 mm in the winter

2019/2020, where the maximum snow depth was 1.3 m. In contrast to the highly variable soil moisture in this winter, water infiltrated the soil only a few times in the winter 2018/2019, when the snow cover was 3 meters at its maximum. Further it was found that different parts of the slope receive different amounts of water. While most water reached the soil surface at the top and at the bottom of the slope, soil at the slope was less affected by rain-on-snow events. Consequently lateral flow of water in the snowpack downwards the slope was of higher rate than vertical flow into soil.

Infiltration of the snowpack by water resulted in a constant soil moisture level at the matric potential of the soil. High precipitation in autumn filled most pores of the soil, and the last pores to reach field capacity were filled in early winter. Rain-on-snow events and partial snowmelt supplied water to fill quickly draining pores. However, due to high sand contents and high hydraulic conductivity, soil never became saturated. Soil moisture increased insignificantly in spring during snowmelt, which caused higher surface runoff of snowmelt water and less subsurface runoff. Soil moisture decreased significantly shortly before snowmelt ended. Trees started to transpire, and increasing soil temperature caused evaporation. Soil moisture reacted immediately to rain events in summer and autumn. However, soils in YURF had high water repellency, resulting in higher surface runoff when the soil was dry. Runoff measurements confirmed that surface runoff was higher after dry periods and when the rain event was heavy.

The results revealed that winter precipitation had positive as well as negative impacts on forests in Tōhoku region. On the one hand, water saturated soils due to infiltration of water from rain-on-snow or snowmelt events supply plants with sufficient moisture for transpiration in spring. Melting processes in spring last longer in forested areas than in clear cut sites, resulting in longer snow cover. Unfrozen soil determines the connection between water in the soil surface and the rhizosphere, as was found in YURF.

On the other hand, drastic decrease in snowfall results in a smaller SWE and shorter melting periods in spring. Water running off in winter was not available for vegetation in spring, which had negative effects on forests due to low precipitation during the initial growing stage. Forests in mountainous areas might be subject to water shortages in spring, as the snowmelt water supply decreases, and subsurface runoff in mid-winter increases as a result of warmer winters and increase in the number of rain-on-snow events. Thus, it is expected that an increase in the rain/snow ratio will have a strong effect on subsurface water runoff, groundwater levels and stream water discharge in the future, which will probably affect the forest ecosystems.

**Conclusion and consideration**

In conclusion, this study demonstrated water storage and movement in soil, and the potential for using models for the calculation of hydrological processes. Increases of rain-on-snow

events in winter resulted in higher influences on soil moisture and snowmelt, since a decrease in the amount of snowfall was followed by smaller SWE in the Asahi Mountains. More runoff in winter and smaller SWE results then in shorter snowmelt periods and less water available for plants during the growing season. SWE models delivered accurate estimations for snow accumulation and snowmelt period, while DDFs indicated that snowmelt rates did not change during the snowmelt season.

As already found in the significantly small amount of snow in the recent winter (2019/2020), the effect of climate change might have a large impact on forest water supply and on agriculture, since the amount of snowmelt water may decrease significantly over the next years. Combined with changes in the amount of precipitation, the meteorological conditions may change more in future. Detailed monitoring and analysis in different locations will be needed in order to determine whether the warm and dry winter 2019/2020 was a unique winter or the start of a change in winter climate of Tōhoku and other regions of Japan.

DDF and SWE calculations are a basis for snowmelt runoff models on large scale for the whole heavy snowfall area of the Asahi Mountains. The use of HYDRUS 1D was useful for the summer season, but improvements need to be done for the winter season. Future research on snow and soil moisture in YURF will improve the understanding of the interaction of all connecting processes. Overall, the results of this thesis improve the understanding of hydrological processes in Japanese mountain forests, especially in winter, and introduced modelling approaches adjusted to the study region in the heavy snowfall area.

Note 1 The summary will be published online. Please confirm that UGAS has your permission to do so.

Note 2 In the summary, please do not include any content beyond your control (e.g. patents or intellectual assets) which will make online publication impossible.

Note 3 The summary should be four or five pages in total.