DATA ANALYSIS OF THE SNOW PACK ANALYZING SYSTEM TESTED BY UCAR

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ABSTRACT

Snow pack measurements can be costly to perform and generally provide only snow water equivalent (SWE) and snow depth from which density can be calculated and the onset of snow melt can be estimated. A new automatic snow pack analyzing system designed by Sommer Systemtechnik in Koblach, Austria has developed new technology to measure snow pack characteristics. The instrument is an automatic in-situ measurement system that determines the percentage of liquid water and ice by measuring the "complex" impedance from which SWE is determined. However, the liquid water content as a percentage is a value that has never been able to be measured before.

This Snow Pack Analyzing system or SPA system, as it is referred to, was installed at the (University Corporation for Atmospheric Research (UCAR) Test Field site in March of 2012 where it could be collocated and compared to conventional snow tube and snow pillow measurements. This manuscript will describe the measurement principal of the SPA system as well as the parameters that can be derived, including indicators to help improve the prediction of snow melt. Preliminary results from the UCAR Test Field site installation comparing the SPA system to both the snow tube and snow pillow measurement will also be presented. It is reasonable to conclude the SPA system can be a valuable addition to existing snow melt forecasting schemes. (KEYWORDS: snow pack, snow water equivalent, SWE, liquid water)

INTRODUCTION

While the science in achieving accurate snow water equivalent (SWE) measurements has been improving with new technologies, achieving an accurate prediction of when snow pack runoff will begin has typically been an estimate. Additionally, there are existing concerns when measuring SWE with a snow pillow because of the use of environmentally unfriendly liquids and the possible formation of ice bridging. Retrieving data from within the snow pack has generally been a manual and periodic measurement.

This paper will discuss a new technology called the Snow Pack Analyzing System (SPA System) that can actually look within the snow pack to measure the percentage of liquid water, percentage of ice and snow depth from which SWE and snow density is calculated. Having the sensor living in the snow pack, measuring throughout the snow pack, also eliminates the loss of data caused by ice bridging. Additionally, an accurate measurement of liquid water content as a percentage in conjunction with meteorological forecasting can increase the accuracy in the prediction of runoff.

In order to validate the accuracy of the data gathered by the SPA System locally in the United States, the National Center for Atmospheric Research (NCAR) purchased and installed a complete SPA System in their test field in Boulder, Colorado. In order to analyze and validate the data, it was compared to the nearest National Resource Conservation Service SNOTEL site, which is located at Niwot Ridge. The sites along with the data retrieved from each site will be analyzed and compared.

This paper will discuss the measuring principal of the SPA System, analyze the comparison of data between the test site in Boulder, Colorado by NCAR to the Niwot SNOTEL site and discuss the advantages and disadvantages of the SPA System.

MEASURING PRINCIPAL

The SPA System was designed and began to be developed during the international EU-funded research project SNOWPOWER which took place from 2001 to 2004 at FZK Karlsruhe (Germany), SLF Davos

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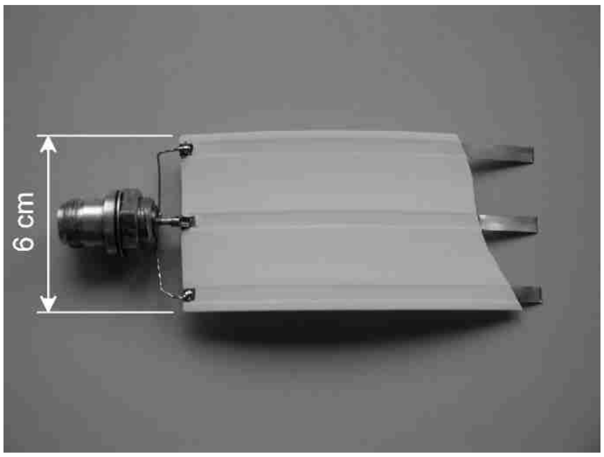
(Switzerland), KTH Stockholm (Sweden), Hydro-Quebec (Canada), INRS (Canda), and Sommer's office in Austria. From 2004 to 2008 the system continued to be developed and refined by Sommer Systemtechnik who reengineered its installation and mounting, improved the algorithm for calculating measurements and designed the device to measure in-situ. The system was finally completed in 2009.

The complete SPA System consists of two (2) SPA sensing bands with one installed horizontally 10 centimeters above the ground and the other installed at an angle (referred to as the sloping band), an impedance analyzer, an ultra-sonic snow depth sensor and mounting accessories to assure proper tension of the SPA bands (Figure 1). Each of the SPA bands sends frequencies into the snow pack and measures the complex impedance. Snow consists of ice, air and water. Each of these elements have different dielectric constants and when the band sends out the measuring frequencies it is able to read the returned value to determine the percentage of liquid water, ice and the remaining value as air (Figure 2).



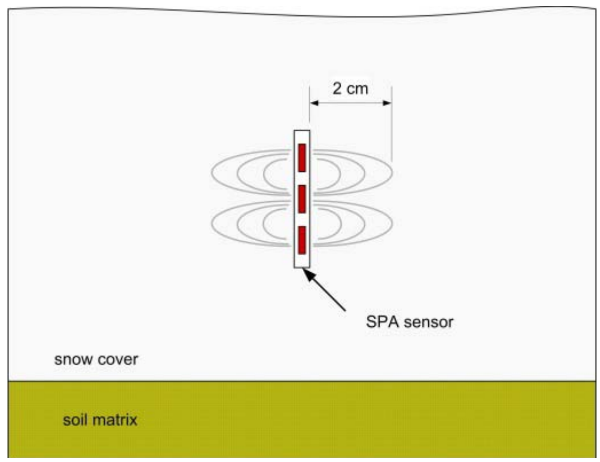


Figure 1. A. Example of the SPA Band B. Diagram of the frequency sent into the snow pack

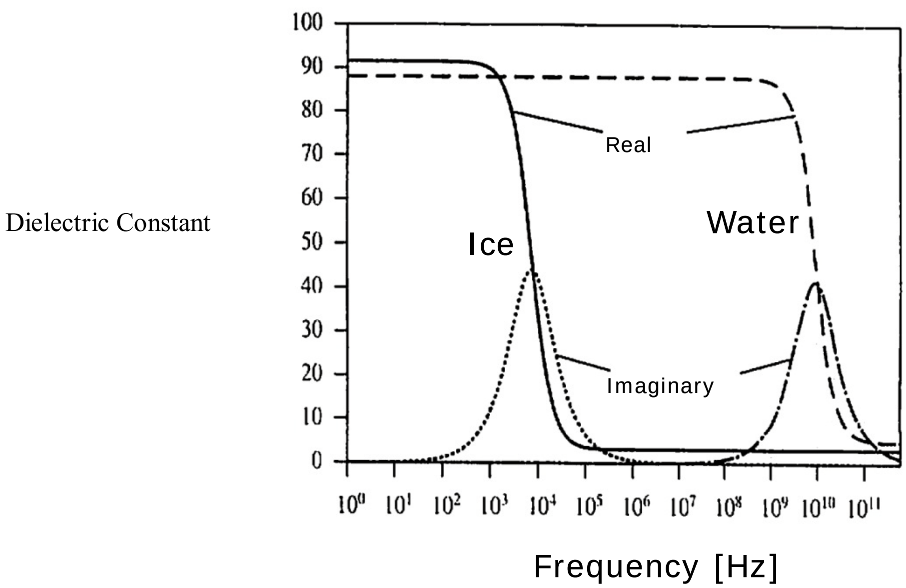


Figure 2. Example of the frequency and dielectric constant relationship

Measurements in Snow with Ice Bridging

This measurement from the sloping band can give us the SWE values from throughout the entire snow pack and when used in conjunction with the ultra-sonic snow depth sensor will calculate the density of the entire snow pack. The sloping band replaces the function of the snow pillow but eliminates the errors or loss of data caused by ice bridging. It also gives additional values of liquid water and ice as a percentage throughout the snow pack. Since the SPA band is installed at an angle through the entire snow pack, it is able to measure the part that is ice regardless of the weight distribution of the snow pack.

Figure 3 is a graph of the data that was collected at a test site in Hindelang, Germany at 980 meters (3,215 feet) elevation during the winter of 2008 to 2009.

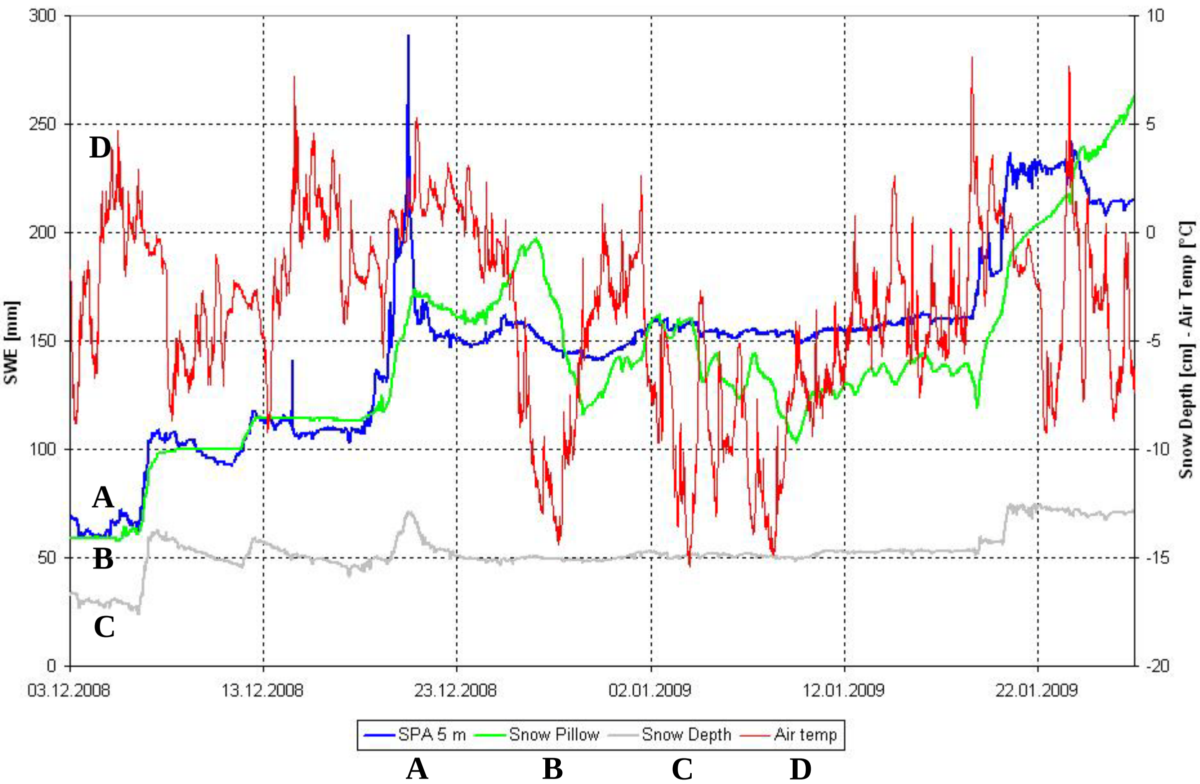


Figure 3. Comparison of SWE from the SPA with a snow pillow SWE over 2 months, along with snow depth and air temperature (Snow Pack Analyzers Paper November 2009 V1.0.0)

Figure 3 shows a comparison of SWE in millimeters as measured by a 5 meter SPA band (A) and by a snow pillow (B). It also measures snow depth in centimeters (C) and air temperature in ºC (D). At the beginning of the season the air temperature rises and falls around 0 ºC with the snowfall events occurring when the temperature is below 0ºC. From the beginning of December to about the 19th of December the SPA and snow pillow follow each other very closely.

One of the disadvantages of the SPA system occurs in the beginning of the winter if there is a wet snowfall event. A wet snowfall event will cause snow and ice to stick on the band that is not covered by the snow pack. This data is easy to identify. For example, this graph shows around the 19th of December there is a warmer snowfall event and the SWE measured by the SPA (A) spikes. Within 24 to 48 hours the wet snow or ice will fall off the SPA bands and the measurements will regulate. These spikes only occur at the beginning of the season.

Just after the wet snowfall even where the temperatures are hovering above and around 0ºC the air temperature (D) dramatically drops to about -13ºC. It is here the formation of ice bridging occurs. As the season progresses the SWE from the snow pillow (B) is not stable and all measurements are lost for the rest of the season. However, the SWE measurements from the sloping SPA band remain stable following the fluctuations in snow depth as it should.

Increased Runoff Prediction

The band installed horizontally at 10 centimeters above the ground gives new and valuable information to increase the accuracy in predicting when runoff will begin. The graph below is an example of data from a test site at Korsvattnet, Sweden from the winter of 2008 to 2009.

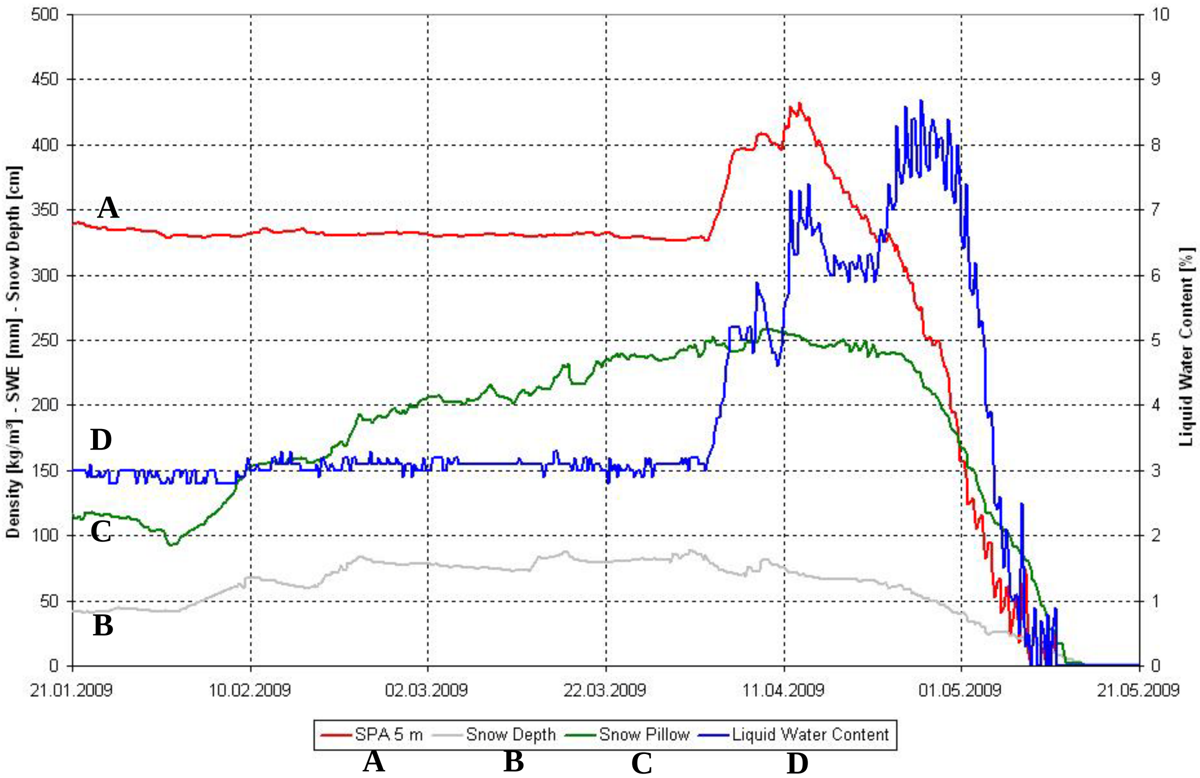


Figure 4. Comparison of SWE from the 5-m horizontal SPA with a snow pillow SWE over 2 months, along with snow depth and liquid water content (Snow Pack Analyzers Paper November 2009 V1.0.0)

Figure 4 shows a comparison of density at the base of the snow pack as measured by the 5 meter horizontal SPA band in kg/m^3 (A), snow depth from the ultra-sonic snow depth sensor in centimeters (B), SWE as measured by the snow pillow in millimeters (C), and liquid water content as a percentage as measured by the 5 meter horizontal SPA band (D). As we follow line D designating liquid water content as a percentage, one can see that this particular snow pack maintains a liquid water content of about 3%. Through the numerous tests and trials the SPA system has shown between 7% and 8% of the snow pack becomes saturated which is when runoff begins. This graph shows at the end of March and beginning of April the liquid water content dramatically increases and the melting process has begun. This graph simultaneously shows the density (A) of the snow pack increasing with liquid water content during the melting process.

In April, the SWE (C) levels have plateaued and during the last week of April the SWE finally begins to taper off designating the start of runoff. The increase in density has generally been the measurement used to predict runoff. However, being able to view the percentage of liquid water and ice in the snow pack gives additional data regarding the freezing and melting of the snow. This graph also shows there must have been a cold spell that froze the snow that had begun to melt, delaying the runoff. Right after this cold spell, the weather appears to have warmed and started the runoff process.

Depending on ambient temperatures and meteorological forecasts, the prediction of runoff once the melting process starts can be further refined. Monitoring only SWE will not be sufficient because by the time the SWE levels begin to drop, runoff has already begun, the water is coming and it is too late. Maximizing reservoir levels without wasting water is important for hydro-electric power generation, maintaining potable water supplies, irrigation and preventing floods.

The configuration of the SPA System can vary depending on the necessary data required. The standard installation is with one horizontal band and one sloping band to measure SWE. However, up to 4 bands can be used with each impedance analyzer and each band installed horizontally to actually look at what is happening at each layer within the snow pack.

STUDY SITE

Site Description and Comparison

The purpose of this paper is to analyze the installation of UCAR's SPA System. To help analyze this system, we have compared it to the NRCS SNOTEL Niwot site.(capitol or lower case, you have capitol below and lower case on the first page) In order to properly analyze the data received, it is important to understand the differences between the two sites.

The NRCS Niwot SNOTEL site (capitol or lower case, you have lower case above and lower case on first page) is located in a sub-alpine, lodgepole forest at around 10,000 feet elevation. The equipment has been installed in a clearing of about 10 meters by 20 meters and is measuring snow depth through and ultra-sonic snow depth sensor, ambient temperature, precipitation and SWE from a snow pillow from which density is calculated.

The UCAR site selected in install the SPA system is in the same general location, about 50 meters away. However, the SPA System was installed under the canopy of the trees where there is only a clearing of about 5 meters by 10 meters (Figure 5). The site was installed in late 2011 at a different location but was dug out in March and moved to the current location where they reburied the sensor in the snow pack. The pictures below show the first site and the process of digging out and burying the sensor at the new location (Figures 6 and 7) and the reconstruction of the snow pack.

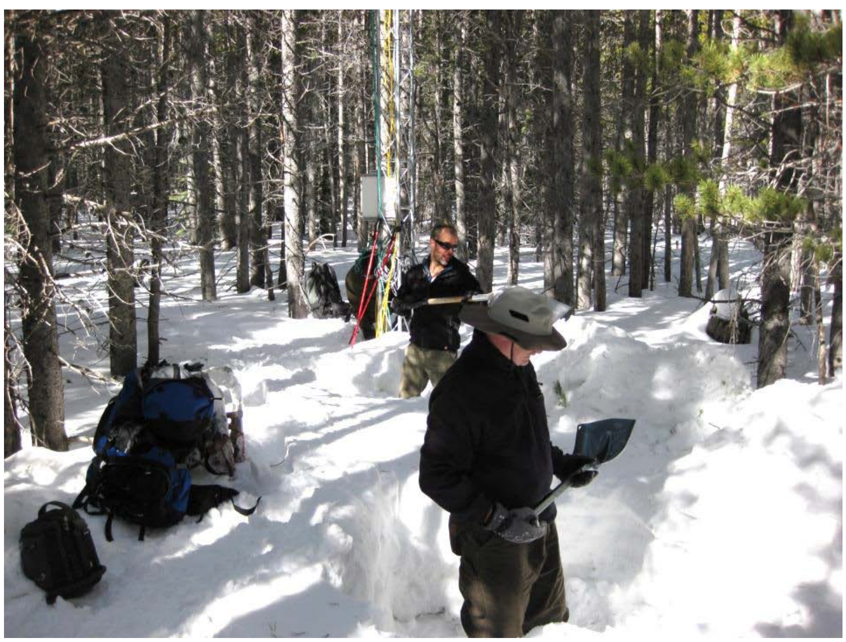


Figure 5. The initial SPA installation was dug out from this forested location.

Figure 6. A new site was selected and a clearing in the snow pack was dug out to install the SPA System

Figure 7. The snow pack was filled back in (left), and this view is of the final snow pack (right), with the SPA system operating from the 23rd of March 2012 through the winter.

Good data were collected from the first winter, but the snow pack was not natural and therefor is not considered a good representation of the melting and runoff process in this region. In the winter of 2012-2013 the sloping band gave data that showed extremely low frequencies. It is thought this band has been damaged and it is being sent back to manufacturing to perform an analysis. Since the data from the sloping band was invalid, it is not been taking into account in this paper.

<u>Results and Comparison of Data</u>

Figures 8 and 9 are graphs that compare the data received from each site. In the middle of May of 2013 there was a power failure at the SPA site. The graph below compares the snow depth data received by each ultra-sonic snow depth sensor. We can see the data from each site follows very closely. The SNOTEL site receives more snowfall and experiences a quicker depletion of snow at its site due to the open canopy and greater exposure to the elements. The manual core measurements taken at the UCAR SPA site follow the measurements of the ultra-sonic snow depth sensor except as the snow depth increases. It was expressed that core measurements were more difficult to make due to the depth and very light and dry snow pack.

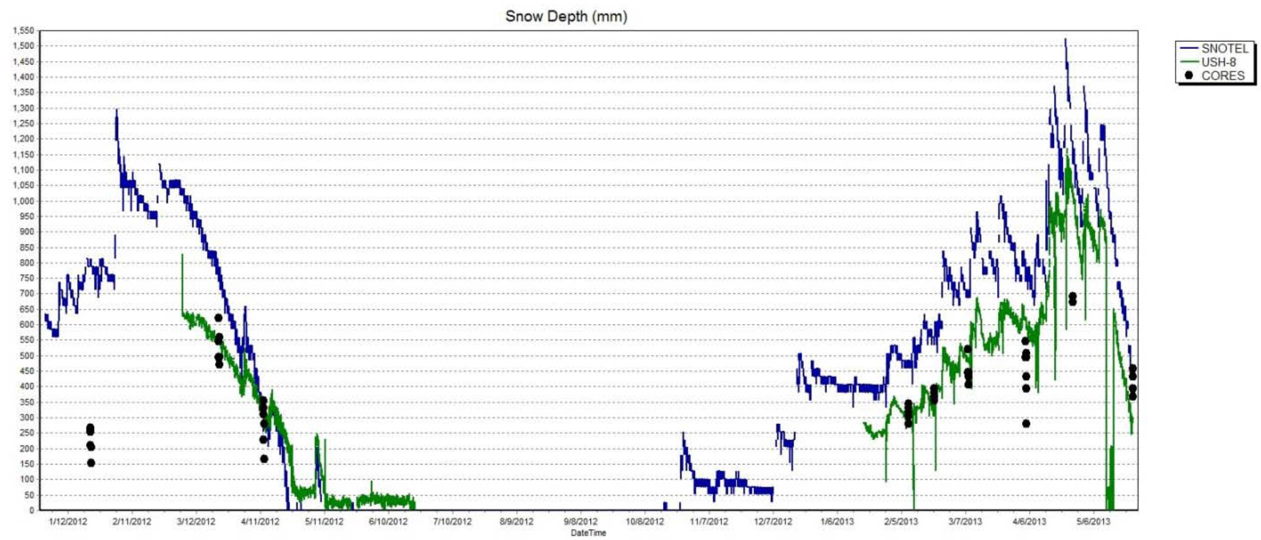


Figure 8. Comparisons of snow depth for the 2013 winter between the SNOTEL and UCAR sites

Figure 9 compares the measured value on the 10 centimeter band at the base of the snow pack used for runoff prediction. We cannot confirm the ‘dryness’ of the snow pack in Colorado this year and the increase in liquid water content until runoff begins. Runoff is shown by the dramatic drop off of SWE. There still needs to be more research on how the liquid water content and ice interact in the ‘dry’ snow pack encountered in Colorado. It is also important to note the SWE measurement is the SWE at the base of the snow pack where the 10 centimeter band is located. The total SWE measurement would have been measured by the sloping back which encountered problems at the beginning of the 2012-2013 winter.

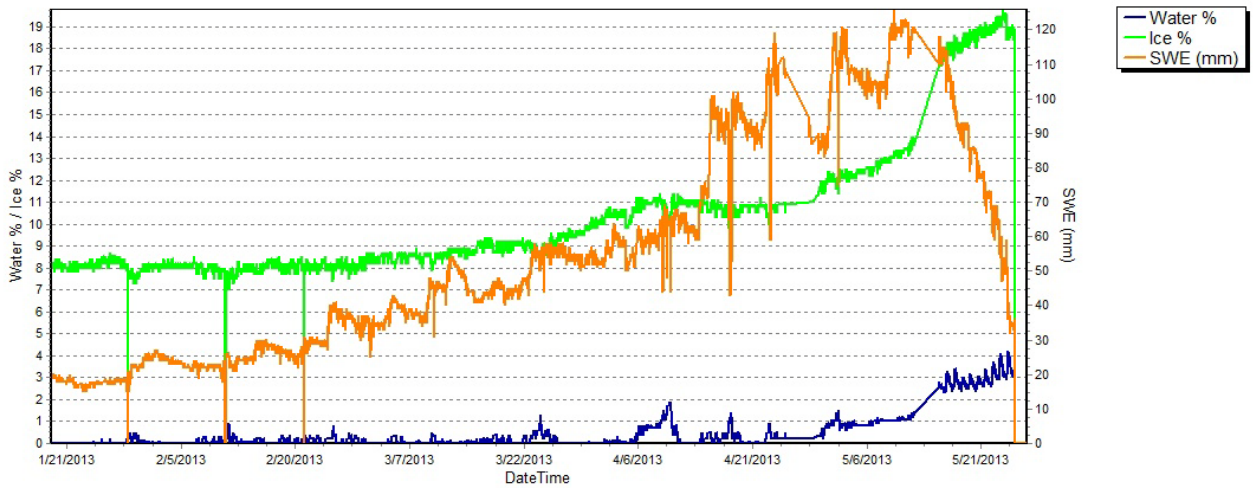


Figure 9. Comparison of winter 2013 trends in water, ice, and SWE for the lower horizontal band

CONCLUSIONS

To conclude, the SPA band produced good correlating information in the 10 centimeter band at the base of the snowpack. Unfortunately, the sloping band was damaged and did not receive accurate frequency returns to calculate SWE and liquid water content values throughout the entire snowpack. The ultra-sonic snow depth sensors functioned accurately. Values from the winter from 2011-2012 are much higher due to the reconstruction of the snow pack. Further testing and investigation of the SPA system in the 'dry' snow pack encountered in Colorado would be beneficial in order to better understand how the snow pack is really formed and how compression and metamorphism throughout the winter occurs. The SPA might then be used to improve the prediction of when run off would occur in this location.

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