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Scientific Report for COST Action ES1404

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Introduction

Over the course of the 2nd Annual Winter Snow School, held in Preda, Switzerland from Feb. 14-20, 2016, multiple snowpits were dug and data collected for the purpose of obtaining a snapshot of the current state of the snowpack and potentially also its history (Figure 1.). To provide adequate spatial coverage, three distinct locations were selected as study sites:

1. **Meadow Site**: open to broad array of incident solar angles in flat field with no trees in immediate vicinity.
2. **Forest Site**: many trees (deciduous and coniferous) close by to study plots
3. **Alpine Site**: site near or above treeline, approximately 500 m above open site.

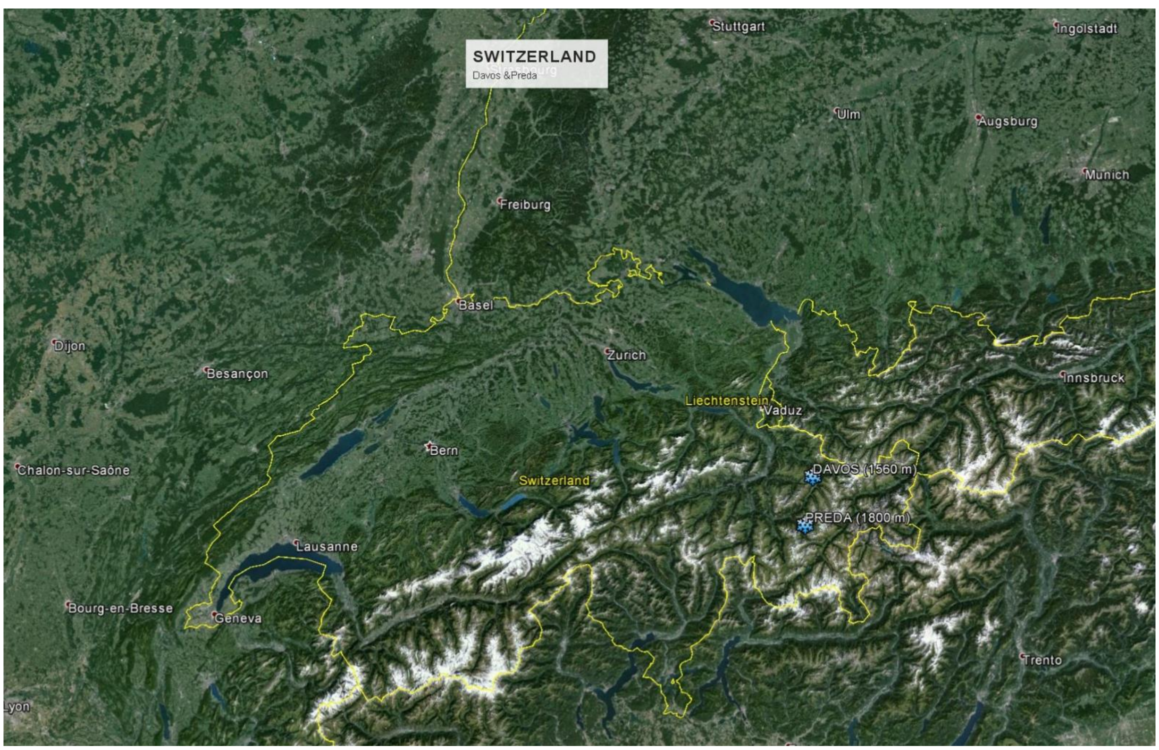

Figure 1. Location and altitude of Preda and Davos

Typical data collected included snowpack depth, stratigraphy, grain size, grain type, and density. In addition to these measurements, many specialized field instruments were also introduced for the quantification of some additional variables such as specific surface area (SSA), albedo, and hardness using IRIS, IceCUBE, SMP, and pyrometers. With these instruments, more insight could be gained into the current state of the snowpack, such that the data provided could also be related to the thermodynamic energy balance of the snowpack and its potential for remote sensing applications. For a detailed study of the microstructural characteristics of the snowpack, snow samples were collected and later scanned via micro-CT at the SLF laboratories in Davos, Switzerland.

General Observations

During the course of our daily investigations into the various snowpack properties at the various sites, one unique feature that stood out was an ice crust that was perceived to be due to a recent rain event (per Martin Schneebeli). This crust was unique in that it varied so dramatically from one site to the next. At the Alpine site, this crust may not have been present, but there was a very thick (1 cm) hard lens of ice observed, at the Forest site it was only a few millimeters thick but still visible, while at the Meadow site the crust was no longer visible, but was distinguishable via a density change in a seemingly uniform layer of snow. Visual examples of the rain crust are shown in Figure. 2.

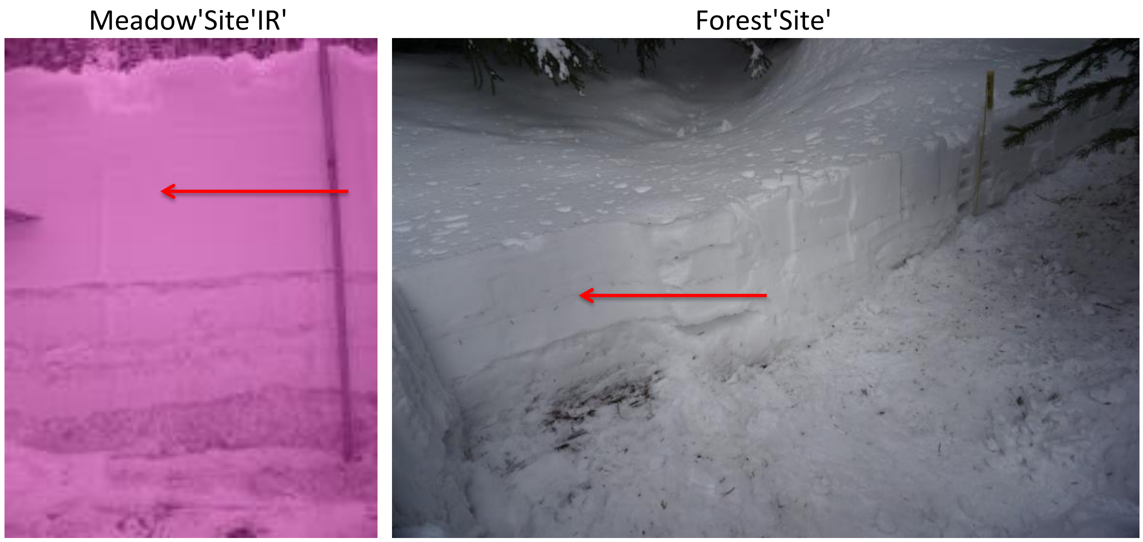

Figure. 2. Images from Meadow Site and Forest Site showing location of rain crust/density change in snow slab with red arrow.

In this figure, the difference between images taken with an infrared (IR) camera and a normal camera is also demonstrated, as the layering of the snowpack stratigraphy is somewhat more perceptible with the IR camera. The red arrows point out the actual rain crust (right) and density change where it is presumed the rain crust once existed (left).

At the Alpine site, it was more difficult to tell if there was still any trace of the rain crust. It is possible that, similar to the Meadow site, the crust was eroded by the sun and wind that would have prevailed out in the open space above treeline, but it seems more likely that the snowpack was thinner and more barren in this wind and sun exposed area. An image of the stratigraphy via the IR camera of the Alpine site is shown in Figure. 3.

Figure 3. IR image from Alpine site showing no signs of the rain crust but a much thicker ice crust above old snow layer near ground.

In this image, a well-defined ice crust can be observed near the bottom of the snowpit above the old snow layer, made up predominantly of depth hoar and faceted crystals. One possibility for explaining this thick ice lens (1 cm), is that it is due to the percolation of the rain event that caused the rain crust in the Forest site, or that there was no snow on this layer when the rain event occurred, such that the ice lens created became much thicker than anywhere else observed. Without more data analysis of recent weather events and field observations, this is hard to determine, but it is possible that the snow on this exposed face could have been sublimated or been wind transported prior to the rain event. In any case, it is interesting to compare the three sites as all having a somewhat different signature of the same event.

Forest Site Observations

Of the three sites studied over the course of the snow school, the Forest site proved to be the most interesting. To begin, it was impossible to tell how deep the snow cover was under the tree canopy without first probing. For instance, the location, where from a distance we had visually selected to begin digging our pit, turned out to be only a few centimeters deep. Thus, we chose to dig a transect from directly under the tree canopy towards a more open area, approximately 4 m in distance away. We measured temperature, density, and SMP data along this transect and found some interesting results. Figure 4 shows a plot of temperature vs. distance and depth, as the transect moved from a shallow region of the snowpack to a much deeper region of the snowpack. In this plot, it can be observed that the shallower region had a ground temperature nearly the same as the ambient air temperature (-1.9°C), but warmed significantly under a deeper and more insulating snowpack. This is an interesting observation in that it is normally assumed that the temperature of the base of a snowpack is near that of the ground, typically close to 0.0°C, but our data shows that this may actually be a function of the depth of the snowpack and should not necessarily be assumed a priori.

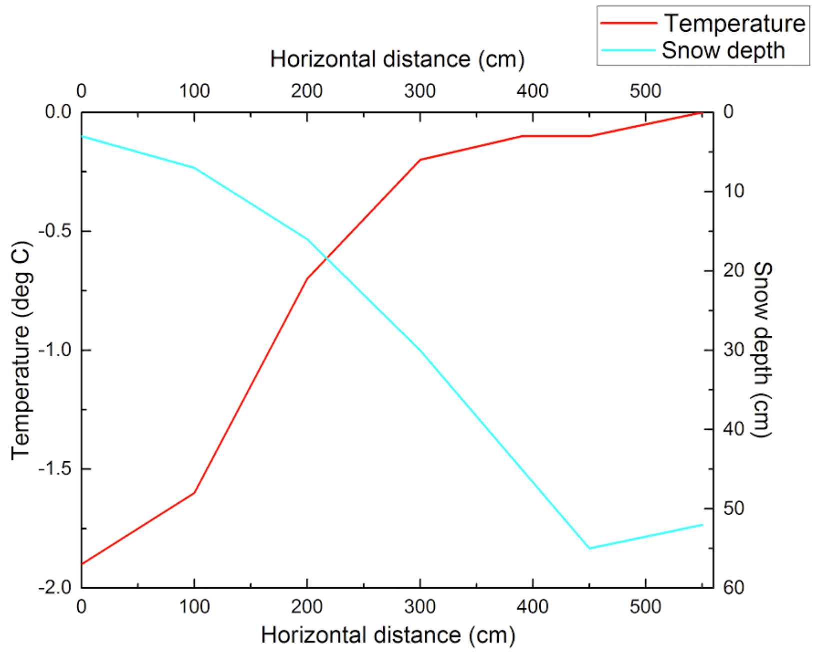

Figure 4. Temperature and Snow Depth vs. Horizontal Distance of snowpit transect in Forest site.

To further illustrate the effects of sky cover and how the layers varied spatially from one end of the transect to another, we also plotted the snow pit stratigraphy as a cross section, as shown in Figure 5. In this figure, it can be observed that not all layers were present all the way across the transect, which is sensible since the snowpack was only a few centimeters deep at the shallow end. The observed rain crust (yellow line), however, was seemingly preserved all the way across the transect.

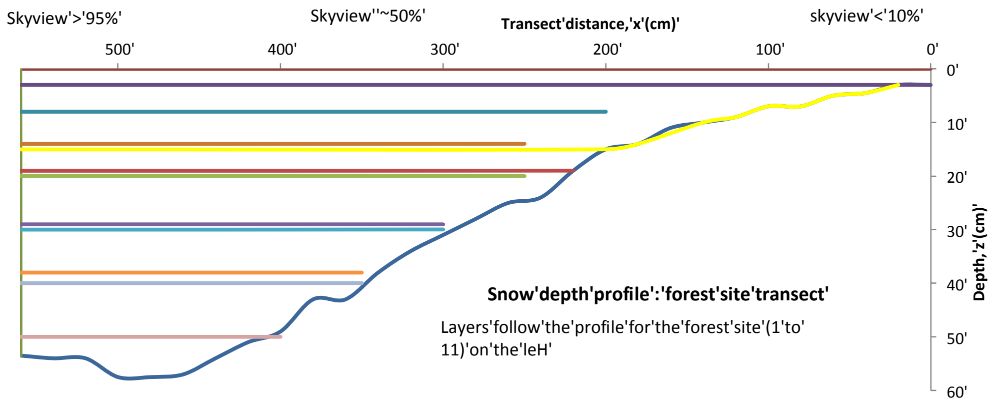

Figure. 5. Snow Depth/Transect Profile. Colored lines correspond to interfaces observed in stratigraphy.

When compared with density measurments made with the density cutter, as shown in Figure 6., the region containing the rain crust appears to have nearly the same density (8-14 cm).

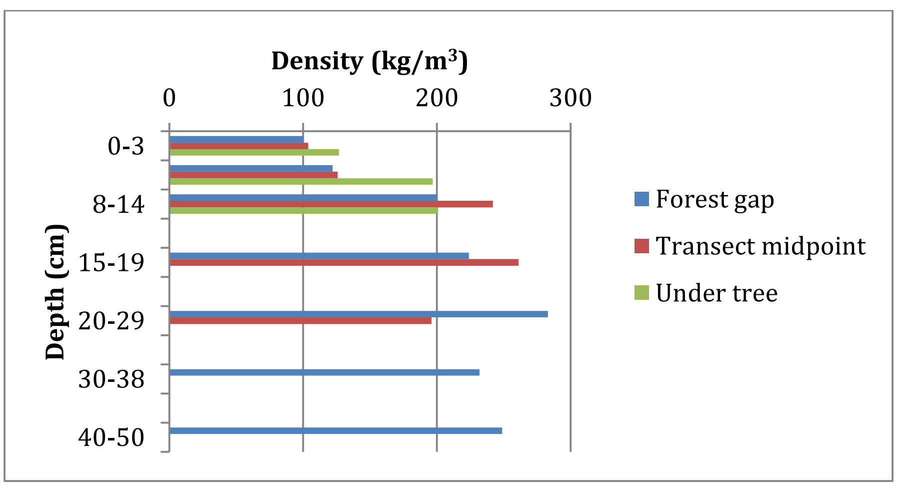

Figure 6. Density measurements from three locations along the Forest site transect snowpit.

As a point of comparison between instrumentation and locations, this density is also compared to the density derived from SMP data for the Meadow site, shown in Figure 7, where the red arrow is the approximate location of the same layer as that measured in the open area of the Forest site. Notice that the density is approximately the same, around 220-240 kg m^{-3}.

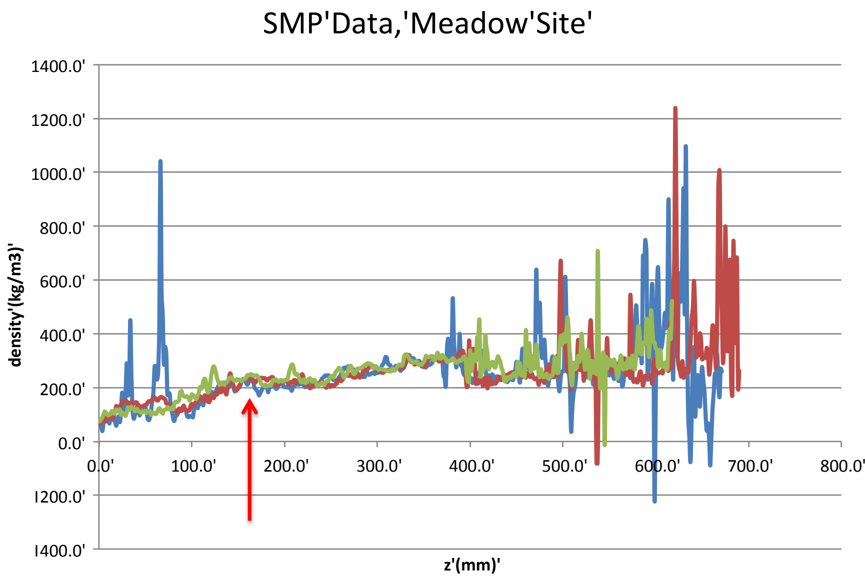

Figure 7. Density as a function of snowpit depth as derived from SMP for Meadow Site.

This is an interesting point of comparison in that it shows that the SMP is quite accurate in measuring density when compared to the manual method of measurement using a density cutter, and that the same layer has the same density in the two different locations, even though one has a prevalent ice crust and one does not. This would suggest that in the Meadow site, the rain crust must have been dissolved by wind, sun, or a combination of the two. Because the presence of such an ice lens can cause differences in the local metamorphism of nearby snow grains, this is an important feature to study.

Microstructure

To further investigate the microstructure of the snowpack near the ice crusts caused by the rain event in the Forest site, a sample of snow was taken to the SLF in Davos to be scanned via micro-CT. Using the micro-CT, a 5-um resolution can be obtained over a large portion of the profile containing the ice crust and reconstructed in 3-D. Figure 8. Shows an IR image of the snow sample that was scanned (left) and the micro-CT image (right).

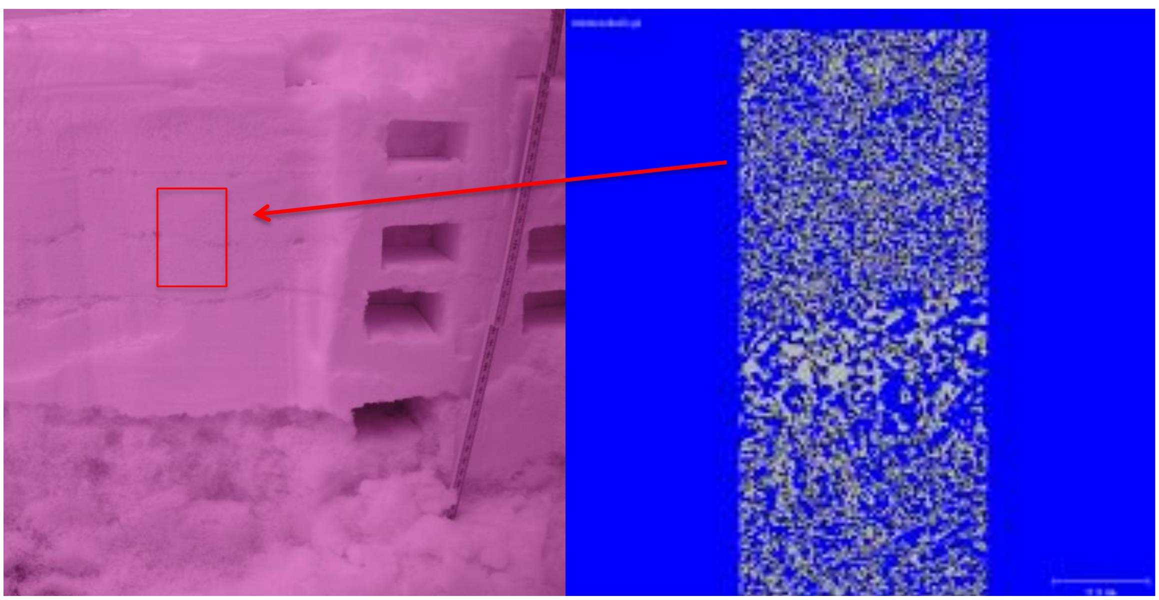

Figure 8. Region of snowpack sampled (left) for micro-CT analysis (right).

Interestingly, the micro-CT imagery shows the discontinuous nature of the ice crust. In Figure 8 right, the region of the sample with the much larger grains is the ice crust.

These grains appear to have a character similar to melt-freeze grains, but are more likely a combination of melt-freeze grains and a semi-dissolved ice layer from the rain event. This observation somewhat supports the hypothesis that the same layer had already completely dissolved from the Meadow site before the next layer of snow had accumulated, such that it was only detectable by a density change in the snow slab. Table 1 shows the differences in mean density and mean specific surface area (SSA), above and below the ice crust, as calculated from micro-CT data.

Table 1. Micro-CT calculations of Density and SSA over 3 regions of snow profile from Forest site.

	Mean Density (kg m^{-3})	**Mean SSA (m^{-1})**
Above Ice Crust	165.5	557.3
Ice Crust	178.0	350.1
Below Ice Crust	168.8	487.4

From this data, a signature of the ice crust can be observed in a dramatic decrease in the SSA. There is also an increase in the density, but this is less pronounced and could perhaps be easily missed via course resolution density measurements. It should also be noted htat the density calculated via micro-CT was slightly less than that calculated in the field via density cutter measurements or with the SMP.

Conclusions

During the week of the 2nd Annual Winter Snow School, a wide variety of data was collected from an equally wide variety of site locations and snowpits. From these observations, an ice crust was found to exist in the Forest site, under heavy tree cover, that was not observed to exist in the Meadow site, which had no tree cover. There was, however, an obvious density change found at the same snow depth in the snow cover from the Meadow site, suggesting that the same ice crust may have been present in this location but had since eroded away due to either large temperature gradients in the snowpit or a long period of exposure to the elements atop the surface of the snowpack. It is thought that this observed ice crust (in the Forest site) and density change (in the Meadow site) is due to a rain event that had occurred earlier in the winter. In this study, it has been shown that the presence of this ice crust could be detected via changes in density, but more so by decreases in SSA. At the Alpine site, it was less clear if a signature of this ice crust or rain event was present, as the snowpack was much thinner and it seemed likely that the rain event occurred only on the older layer of snow, where a very thick ice crust was observed.

It was also shown that, in the Forest site, there is an opposing trend in temperature and snow depth. This finding would suggest that it should not always be assumed that the bottom of a snowpack is at or near 0.0 degrees C, without further verification. This is thought to be an important point when calculating temperature gradients in thin snowpacks.