FIELD CAMPAIGNS DAY 1 (01-03-2016): measurements of bulk density, depth and SWE with different devices

Field campaigns were organized in two sites close to Erzurum in Turkey. Sites located in mountainous area close to automatic weather stations which measured e.g. snow depth and SWE. In Figure 1 is presented a map and photos from the sites. Air temperature was positive during the measurements and soil was not frost. Guzelyayla (2065 m) site had no wind and Senyurt (2250 m) was slightly windy while it was upper in the mountain. Guzelyayla site had grass covered ground with some vegetation and small pine trees. Senyurt site had grass and gravel covered ground without trees. Instrumentation used for SWE observations is described in Appendix 1.

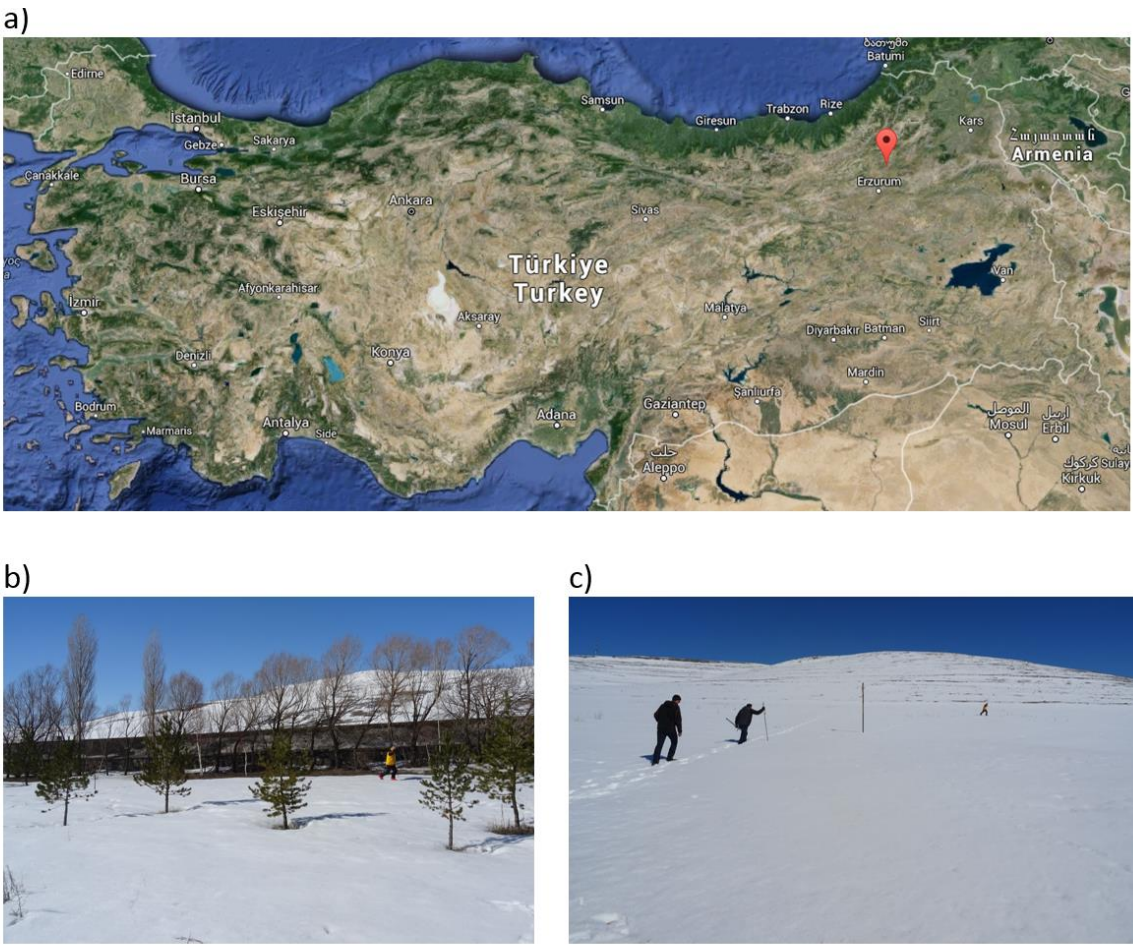

Figure 1. a) Location of measurement sites, b) Guzelyayla site, and c) Senyurt site.

STOP 1: Guzelyayla

Snow measurements were taken in a flat area (approximately 20x8 meters) with a shallow snowpack near of an automatic weather station (AWOS, Guzelyayla). Different teams measured snow depth, density and SWE with different SWE tubes, following parallel lines separated approximately 2 meters each other. Figure 2 shows a summary of the collected information. Snow depth varied between 10 and 34 cm (average 22.5 cm), whereas snow density varied from 260 to 431 kg m^{-3} (average 351.2 kg m^{-3}). Such variability in density seems to be very high considering the small sampled area and its homogeneity. It is very likely that some uncertainty is associated to the measurement acquisition such as observer and instrument related bias. Average SWE of the 8 measured profiles was 78.9 mm with a relative standard deviation of 21 %. Snow depth measured at the AWOS was 20 cm.

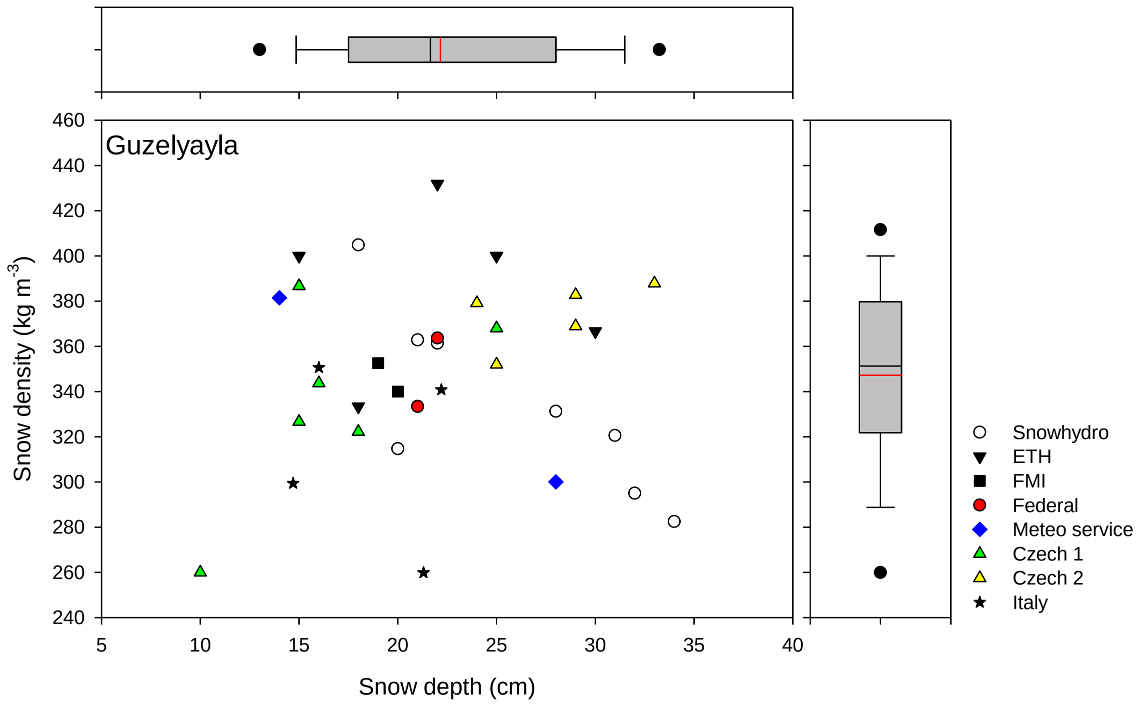

Figure 2. Snow depth and snow density measurements with different SWE tubes. Boxplots inform of the variability measured for each variable. Red line is the average, black line the mean, boxes inform of the 25th and 75th percentiles, bars inform of the 10th and 90th percentiles and points inform of 5th and 95th percentiles.

Figure 2 also shows that clear relation between snow depth and snow density did not existed. It is not fully explained with compaction by overburden in the shallow snowpack.

In general, there is not an obvious relation between the used snow sampler and measured density; however, there are significant differences between some profiles summarized in Table 1. For instance, the density measurements taken with ETH sampler are generally higher than those conducted by the Italian team with a narrower Plexiglas tube. Such differences are probably caused by variating density in different parts of the studied plot (spatial variability), observer related bias or the different characteristics of SWE tubes. In this particular case, there is not enough data to conclude which is the most plausible explanation.

It is interesting to note that the Czech sampler (Slovakian team) data was collected from two different profiles. Profile 1 showed lower densities than profile 2, suggesting that different parts of the studied area may present different densities instead of differences due to instrumental issues. Some profiles exhibited large differences among the measurements (e.g. Snowhydro) which again could be explained by changing snow density during a profile, or due to the uncertainty associated to the data acquisition. The Italian and Snowhydro profiles made replications of each measurement and revealed that differences between replicates are in average below 5%, and they do not exceed 10%, which suggest that the errors in data acquisition should be a secondary reason to explain the observed differences in snow density.

Table 1. Average snow depth, snow density and SWE in the different profiles (using different SWE samplers)

	Snow density (kgm^{-3})	**Snow depth (cm)**	**SWE (mm)**
ETH	383.3	22	78.5
Czech profile 2	374.1	28	105
Federal	348.5	21.5	75
FMI	346.3	19.5	67.5
Meteoservice	340.7	21	68.7
Italy	338	19	63
Czech profile 1	334.5	16.5	56.3
Snowhydro	334	25.75	80.6

STOP 2: Senyurt

The second exercise was done in Senyurt close to Senyurt AWOS, which is in a wider (approximately 40 x 40 meters) and slightly steep area. There were conducted three density profiles and distributed snow depth survey with 18 measurements. Figure 3 shows a summary of the collected information. In this area was deeper and denser snowpack with an average depth of 55 cm (maximum and minimum of 64 and 40 cm respectively) and an average density of 399 kg m^{-3} (maximum and minimum of 373.4 and 446.6 kg m^{-3} respectively). At this site variability of snow density was lower than recorded in the first Guzelyayla site. Average SWE was 216.6 mm with a relative standard deviation of 12%.

The spatial variability of snow depth, measured when snow density was calculated, (coefficient of variation 12% with an average of 55cm) was lower than that estimated from the distributed survey (21% with an average of 50 centimeters), as the latter covered a larger area than the one in which SWE measurements were carried out.

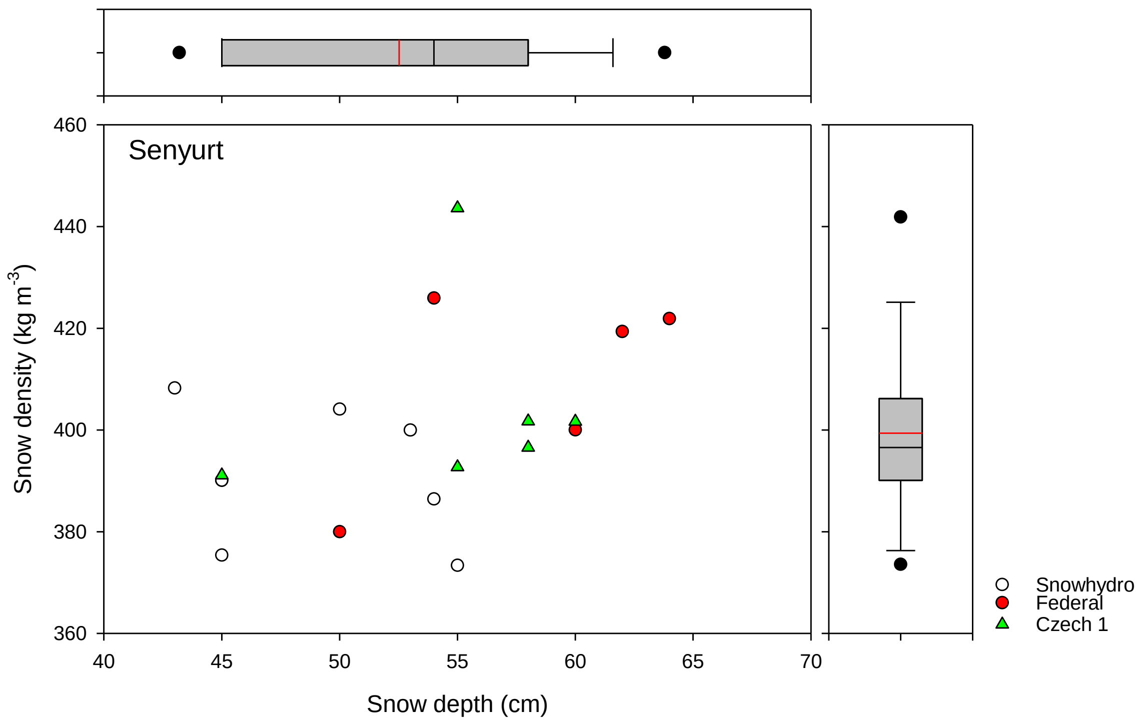

Figure 3. Snow depth and snow density measurements with different SWE tubes. Boxplots inform of the variability measured for each variable. Red line is the average, black line the mean, boxes inform of the 25th and 75th percentiles, bars inform of the 10th and 90th percentiles and points inform of 5th and 95th percentiles.

Conclusions from the field campaigns

- There are different devices to measure SWE and snow density. Their main differences are length, the diameter of the tube and the possibility (or not) to be directly weighted (and in some cases converted to SWE) from the tube.

- It is difficult to establish which devices are better or worse, it mainly depends on the snow depth and snow characteristics (hardness, wetness, sticky snow, etc). In this particular case (shallow and soft snow), short and wide tubes were easier to use. Long tubes and those that need to be emptied into a bag were the less useful at that day (i.e. Snowhydro).

- Electronic scales are much more accurate compared to mechanical ones. The first ones depend on the batteries and may be problematic under very cold conditions.

- The skill of the person who is measuring and wind (that affects the weighting) may affect the accuracy of the obtained variables.

-The experimental design of the field campaign does not allow to properly distinguishing to which extent the differences in snow density and SWE are due to the variability of snow characteristics or to the used device or human errors.

Appendix 1. SWE measurement instruments in field campaign in Erzurum Turkey in 1 March 2016

									
Excel num.	**101**	**102**	**103**	**104**	**105**	**106**	**107**	**108**	**109**
Country	Turkey	Turkey	Switzerland	Italy	Italy	Spain	Spain	Finland	Slovakia
Name	Federal Snow Sampler (USA)	TSMS tube	CRREL tube	CRREL tube		ETH-Sonde	Snowhydro	FMI	Czech 1 and 2
Pit	No	no	yes	yes	no	yes	no	yes	no
Method	Weighting	Melting	Weighting	Weighting	Weighting	Weighting	Weighting	Weighting	Weighting
Bag	no	yes	No	Yes	Yes	no	yes	no	no
Unit	kg	mm	mm	kg	Kg	kg	kg	mm	mm