MEASURING SNOW COMPONENTS WITH NEW METHODS AND VALIDATION USING SATELLITE IMAGES IN TURKEY

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Snow is an important aspect at mountainous areas and high latitudes in terms of water resources, agriculture, energy, tourism and indication of climate change. Turkey, with an average elevation of around 1130 meters, is the 4th highest country in Europe after Andorra, Georgia and Switzerland. Therefore in winter, large amount of snowfall takes place which may stay on the ground for more than half of the year at high elevations. As a result, governmental institutions measure snow on the ground since the late 1960's using manual methods. Recently, manual measurements are assisted by automatic stations that collect more detailed data. With time, the number and type of automatic stations in the network have increased providing comprehensive data for analysis and modeling.

In this study, snow component measurements of 11 Snow Pack Analyzer (SPA) stations in Turkey are evaluated and compared with satellite images. During the snow season, performance and representativity of the stations are evaluated and satellite image consistency is validated. In addition, consistency of the measurements is also examined by snow pit analysis performed near some of the selected automatic stations. According to results, some of the stations show no deposition of snow hence bringing the idea of station relocation. Among the stations that lay under the snow for a long time, Palandöken station displayed the best performance value in terms of snow water equivalent (20-57 mm error rate) compared to satellite images while Nemrut station gave the worst result (429-552 mm error rate).

Keywords: snow components, satellite images, Snow Pack Analyzer (SPA), snow pit

INTRODUCTION

Water, which is continuously circulated under the effect of temperature in the earth; is essential for climate, agriculture, tourism and therefore living life. Along with the importance of water on human life, when the climatic characteristics of high regions are considered, snow has an important place in the hydrological cycle. Especially in countries with high average elevation such as Turkey, it is necessary to determine the precipitation events that occur in the form of snow for the majority of the year and the resultant snow accumulation.

During the snow season intermittent snowfall events cause snow cover to have a layered structure. The meteorological variables such as air temperature, wind and humidity during snowfall are the main reasons for metamorphism, which affect the intensity and depth of falling snow. For these reasons, snow layers forming snow cover can show different physical properties according to time and place (elevation, area, etc.). This variability of snow cover and the challenging terrain conditions can be shown as the reason for the diversity of measurement methods.

One of the most important parts of snow hydrology is ground measurements mainly carried out at high altitudes. Studies on data collection techniques and profile measurements based on different applications are very valuable. In the last decades; guidelines have been published for national institutions that make profile measurements by the National Oceanic and Atmospheric Administration (NOAA, 2013) and studies have focused on the measurement of snow components and their physical properties (depth, density water equivalent, crystal type and size etc.) with different equipment (Kinar and Pomeroy, 2015; Krajci et al., 2016; Proksch et al., 2016).

Considering the difficulties experienced in measuring the snowpack on land and the problem of spatial representation of point measurement, satellite products have an important role in remote monitoring of snow cover. In addition to the real-time point data obtained from the ground measurements, it is also possible to follow near real-time changes as satellite images have wider spatial representations. Because snow is one of the brightest objects in the spectral band range, it can be detected in different forms by various satellites and used in many studies conducted in the field of snow hydrology.

Earth Observation (EO) data began to be applied in snow hydrology during 1970's. As pioneering studies Rango et al. (1977) implemented snowmelt based streamflow forecasting using EO data and Rott (1978) applied different sensors in monitoring the snow-covered area of the Alps. Further mapping of EO snow and ice data are summarized in Hall and Martinec (1985). Tekeli et al. (2005) and Tekeli (2008) evaluated snow cover and snow water equivalent data in the eastern region of Turkey. Strum et al., (2010), Şorman and Beşer (2013) studied algorithms to estimate snow density and then determine snow water equivalent.

The main objective of this study is to analyze the data collected from 11 newly set up automatic snow stations in Turkey and compare their results with satellite images produced in the EUMETSAT H-SAF Project. In addition, snow components at some of these stations are validated using manual snow tube and snow pit measurements.

MATERIALS AND METHODS

Study Area

Turkey is the 4th highest country in Europe, after Andorra, Georgia and Switzerland, with an average elevation of 1130 m.a.s.l. Therefore, snow frequently occurs and may stay on the ground more than half of the year especially in the north, east and central regions. Snow measurements are conducted by governmental organizations since 1960's using manual methods as well as automatic stations from the beginning of 2000's. In the beginning of 2015 snow season, Turkish Meteorological Service set up 11 automatic Snow Pack Analyzer (SPA) stations at certain high elevated locations throughout Turkey (Figure 1).

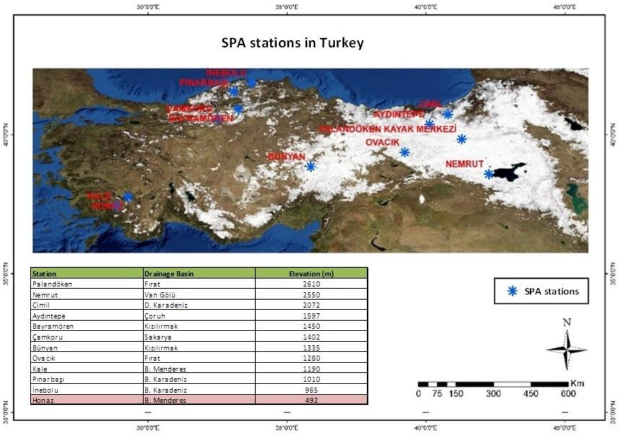
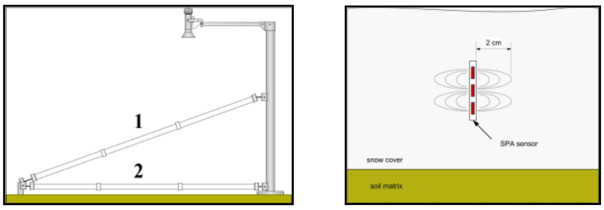


Figure 1. SPA station locations in Turkey

Snow Measurements

Snow Pack Analyzer (SPA) is a measurement system in order to determine snow components such as snow depth, snow water equivalent, snow density and water content. There are different station installation positions according to ground situation and planned measurement. At the station there is a SPA sensor, a control unit, an ultrasonic snow depth sensor and springs to maintain the required tension of the system. Tension springs can be flat or inclined to hold the frequency sensors at different levels (Figure 2-a). While the sensors on the straight tension spring represent measurements of snow for the same depth, the inclined one measures overall average snow components from different layers.

The SPA strips conduct measurements with different frequency sensors for the level they are positioned (Figure 2-b). With these sensors, snow density is determined according to the state of the water, air and ice components in the snowpack. The determined snow density together with the measured snow depth enables the calculation of snow water equivalent. Figure 3 depicts some SPA station examples established in Turkey.



(a) (b)

Figure 2. SPA station example and working principle

Figure 3. Examples of SPA stations in Turkey

When appropriate atmospheric conditions prevail, precipitation events below the freezing temperature occur in the form of snow and accumulate in layers. Snow pit analyses are conducted to determine the physical properties (such as depth, density, temperature, and crystal type) of snow layers in detail (Figure 4).

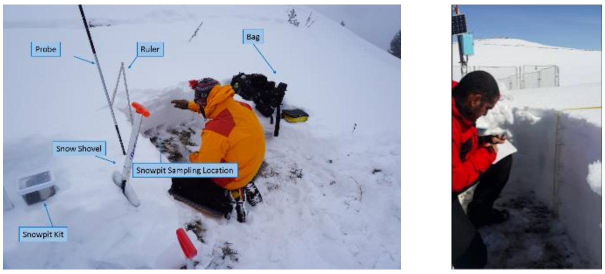


Figure 4. A view of snowpit area and measurement equipment

Satellite Images

The harsh weather and difficult topographic conditions impedes monitoring of snow during winter. At such times the most efficient way to detect snow properties can be the use of satellite remote sensing. In this study, satellite images of snow water equivalent (SWE) values having 25 km spatial and 1-2 day temporal resolution are utilized (Figure 5). These products are obtained from the SSMI/S passive microwave sensor within the EUMETSAT H-SAF Project (H-SAF, 2012).

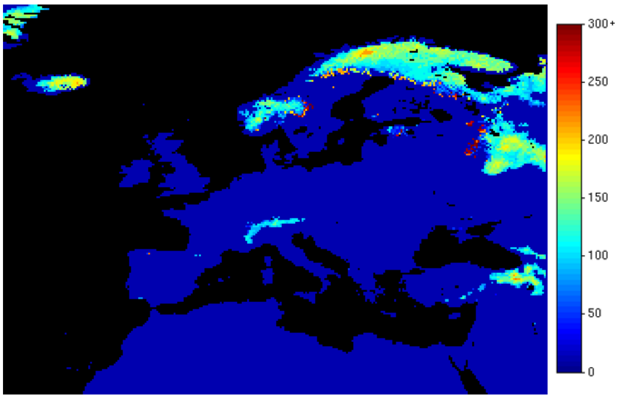


Figure 5. SWE (mm) image of 17 March 2016

RESULTS

10 minute interval data collected at each SPA station is filtered and converted into daily format for further analysis. Then pixels on the SWE image corresponding to SPA stations are determined and extracted for 2015 snow season. An example of SPA and satellite snow data are plotted for Palandöken station in Figure 6. Each satellite pixel value is compared with the inclined (SWE-1) and flat (SWE-2) SPA strip measurement based on Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) statistics. The comparison results are presented in Table 1. Satellite SWE images between December and March snow period are used when there is deep and dry snow on the ground. Otherwise it is know that passive microwave has difficulty for shallow and wet snow. Hence, the number of SWE pixels present for each station differs due to either satellite passage or other topographic factors.

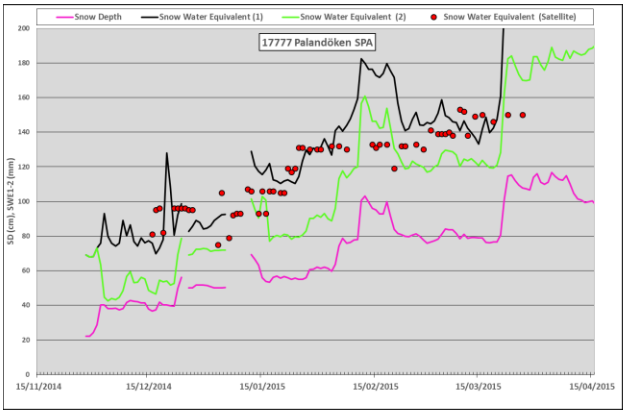


Figure 6. Palandöken SPA vs. corresponding satellite SWE data

Table 1. SPA vs. Satellite SWE results for 2015 snow season

	Elev (m)	Obs. No.	RMSE (mm)		MAE (mm)	
			SWE-1	SWE-2	SWE-1	SWE-2
Palandöken	2610	59	30.0	57.3	20.4	37.5
Nemrut	2550	19	484.0	552.4	429.0	533.2
Cimil	2072	46	78.9	95.7	73.4	88.7
Aydıntepe	1597	28	103.0	113.2	96.6	113.2
Bayramören	1450	36	99.5	70.4	91.3	66.1
Çamkoru	1402	10	40.7	62.1	33.3	59.6
Bünyan	1335	27	84.7	83.1	83.1	81.4
Ovacık	1280	11	123.5	129.4	121.5	111.1
Kale	1190	0	0.0	0.0	0.0	0.0
Pınarbaşı	1010	0	0.0	0.0	0.0	0.0
Honaz	492	0	0.0	0.0	0.0	0.0

During 2017 snow season, a snow campaign is held whereby manual snow tube and snow pit measurements are conducted near some of the SPA stations. As an example, Figure 7 depicts different snow properties at automatic Palandöken SPA station along with four snow tube and two snow pit measurements. In addition, Figure 8 shows one of the snow pit analysis at the same station organized on 7 March 2017.

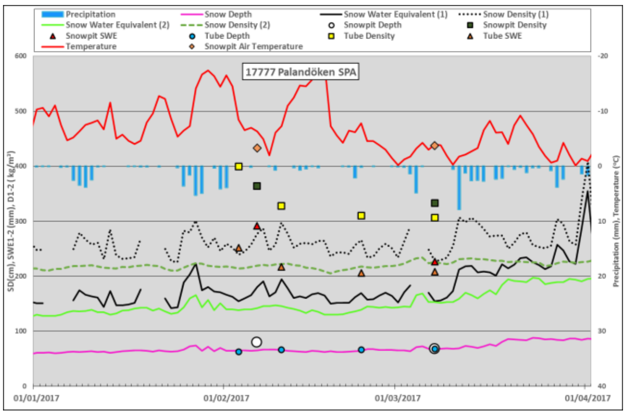


Figure 7. Snow properties measured at Palandöken SPA

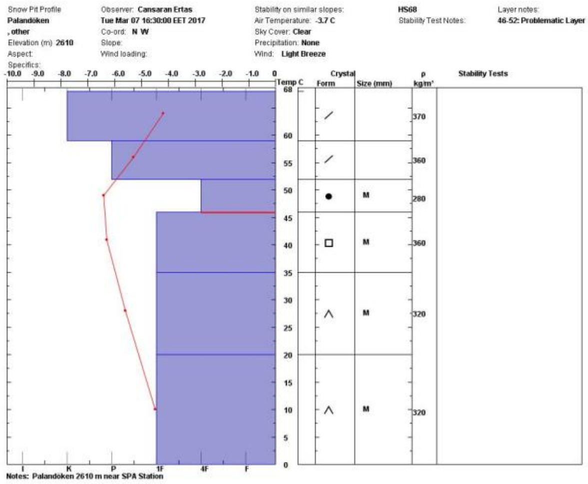


Figure 8. Snow pit analysis at Palandöken SPA

CONCLUSION

Snowmelt runoff in the mountainous eastern part of Turkey constitutes almost 2/3 in volume of the total yearly runoff during spring and early summer months. Therefore, it is of utmost importance to monitor snow spatially and temporally in order to use the water resources of the country most efficiently.

In this study, 11 automatic snow measuring stations (SPA) are tested along with manual measuments and validated using satellite images. From the analysis, it is noted that not all SPA stations collected data of similar quality due to location and maintanence problems. Also the SPA station data showed high variability with satellite values mainly because of topographic reasons as well as satellite resolution. Palandöken station indicated the best SWE relation with satellite data (20-57 mm error rate) and Nemrut (429-552 mm error rate) the worst. As a result, SPA stations located in the vicinity of urban, forest or water areas did not show a good relation when compared to satellite data. This gives an idea for relocating some of the SPA stations for a better representativity. Another important conclusion of the study is that periodical manual measurements are still of vital importance besides automatic and remote data collection as these data validate overall or layered ground snow properties.

As a conclusion, different methods for measuring snow properties will enrich the spatio-temporal snow data over the years in Turkey and can well assist hydrological modeling in the mountainous regions.

Acknowledgement

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