SATELLITE BASED SNOW COVER VALIDATION AND LONG TERM TREND ANALYSIS OVER TURKEY

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ABSTRACT

The trend analysis of the daily snow cover data, covering 2004-2012 period, from interactive multisensor snow and ice mapping system (IMS) by National Oceanic and Atmospheric Administration's National Environmental Satellite Data and Information Service (NOAA/NESDIS) is introduced for Turkey. Daily IMS product is validated using daily ground truth snow depth measurements from 219 (climatological and synoptic) sites as the first step of the study. The probility of detection (POD) and false alarm rates (FAR) statistics are provided for Turkey and geographical subregions respectively. The POD amount considering whole Turkey is obtained to be 73.55% while the FAR amount is obtained to be 25.11%. The snow covered area percentages for Turkey and subregions are used for the trend analysis using the non-parametric Mann-Kendal test in the second part of the study. Test results with significance level of α=0.05 indicated *negative trend* for the snow-covered area percentage variation for the study period considered. Varying test results are obtained when the same test is applied with respect to seasonal snow-covered area percentage variation.

1. Introduction

The snow cover extent and variability is important from various perspectives such as large-scale climate and hydrologic systems (Udnaes *et al.*, 2007). The direct and indirect effect of snow cover in river discharge requires snow cover extent monitoring for the water resources management and climate change studies (Brubaker *et al.*, 2005).

Snow monitoring over Turkey is limited with ground observation sites in association with the complex topography (Akyürek *et al*., 2011; Tekeli, 2008). Ground based observations and snow field observations indeed are performed over limited areas and are mentioned not to be adequate both in temporal and spatial terms for snow extend monitoring (Tekeli and Tekeli, 2012). On the other hand, Satellite remote sensing provides extensive and continuous snow cover monitoring at regional and global scales (Hall *et al*., 2005). Various snow cover products are introduced in the literature from geostationary and polar orbiting sensors for the end users (e.g., Hall *et al*., 2010; Parajka and Bloschl, 2008; Romanov *et al*., 2003).

The main objective of this study is to analyze the snow-covered area trends over Turkey and introduce the results in seasonal and regional perspective. Among the various available snow cover products, daily snow cover data from interactive multisensor snow and ice mapping system (IMS) by National Oceanic and Atmospheric Administration's National

Environmental Satellite Data and Information Service (NOAA/NESDIS) is used for the study. Owning being the longest satellite-derived environmental data for hemispheric snow cover monitoring dataset, made IMS to be the first preference among the other snow cover products. As the first step of the study, the daily IMS data is validated by using daily ground truth snow depth observations over 219 synoptic and climatological stations. The POD and FAR statistics are introduced for Turkey and subregions to present the IMS product validity. Non-parametric Mann-Kendall test is used in the second part of the study to present the trend results over Turkey and with respect to geographical subregions in seasonal basis as well.

2. IMS Data

IMS data is provided by NOAA/NESDIS since 1966 and is considered to be the longest satellite-derived snow cover dataset for the northern hemisphere (Robinson *et al*., 1993). The advanced very high resolution radiometer (AVHRR) onboard NOAA satellites are the primary data source for IMS product. The geostationary satellite imagery and surface observations are taken into account as secondary data source in IMS product generation (IMS, 2013). In 1966, the product started to be produced in weekly basis with spatial resolution of 190 km. The spatial resolution of the product is reduced to 25 km and the product became an operational in daily basis in 1997 (Helfrich *et al*., 2007). Since 2004, the IMS poroduct is provided in daily basis with 4 km spatioal resolution for the user community. For the IMS product, each pixel is labeled as *sea/lake*, *land*, *sea/lake ice or snow* according to the classification test thresholds.

3. Ground Observation

The synoptic and climatological stations in Turkey are used for the validation of the IMS snow product. The daily snow depth (SD) observations from 219 sites, considering SD>=1 cm threshold, is used as ground truth data. The site layout with respect to seven official geographical subregions is provided in Figure 1. Among them, 87 are operated as synoptic sites only while 87 are operated as climatological sites only and 45 sites are operated as both synoptic and climatological sites.

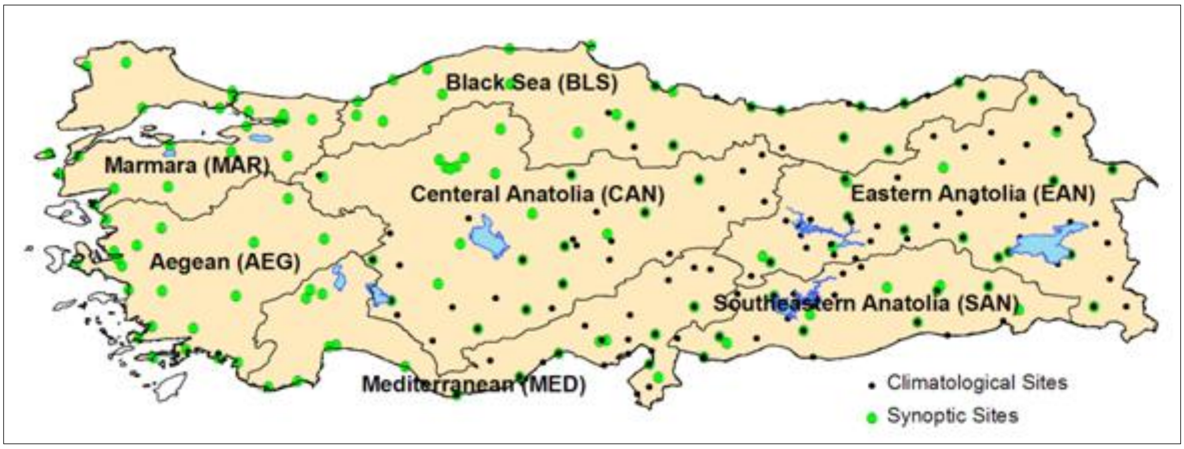

Fig.1. The ground truth site layout with respect to seven geographical subregions over Turkey.

4. IMS product Validation

Contingency tables and associate statistics (POD and FAR) are used to introduce the validation of the IMS products. For the February 2004 - December 2012 period, the contingency tables are constructed in daily basis using the daily IMS product data and ground truth observations. Then the contingency tables' elements are cumulated element wise where POD and FAR statistics are estimated for Turkey, subregions and with respect to seasons as well as provided in Table 1 and Table 2.

Table 1. Seasonal POD variation with respect to subregions.

Region	Autumn(%)	Winter(%)	Spring(%)	Summer(%)
MED	38.71	65.50	40.43	NaN
EAN	64.53	87.72	75.62	NaN
AEG	34.48	69.60	39.22	NaN
SAN	24.32	55.42	38.89	NaN
CAN	61.80	85.63	53.86	NaN
BLS	36.60	73.57	45.77	NaN
MAR	61.50	80.22	67.08	NaN
TUR	58.73	83.67	66.83	NaN

Table 2. Seasonal FAR variation with respect to subregions.

Region	Autumn(%)	Winter(%)	Spring(%)	Summer(%)
MED	60.00	37.56	79.01	NaN
EAN	38.82	17.43	45.81	NaN
AEG	41.18	27.49	39.39	NaN
SAN	66.67	51.91	84.44	NaN
CAN	26.17	23.21	52.17	NaN
BLS	43.05	33.71	60.51	NaN
MAR	16.89	33.02	21.83	NaN
TUR	35.11	22.97	47.32	NaN

For the summer seasons, the POD and FAR amounts are mentioned to be NaN in Table 1 and 2 since no snow exist on the ground and IMS product does not declare snow in this season. Other than that, highest POD amounts are observed in winter season where the second highest POD amounts are obtained to be in the spring season. On the other hand, the lowest FAR amounts are observed in winter season as expected.

5. Snow-covered Area Trend Analysis

The IMS snow product is used for the trend analysis of the of snow cover extend in Turkey. First of all, the snow-covered area percentage (SCA) is defined as the area fraction of a region covered by snow and formulated as follows for the area considered.

$$SCA = \frac{Sum\ of\ the\ IMS\ pixel\ indicating\ snow}{Total\ number\ of\ IMS\ pixels\ within\ the\ polygon} * 100$$

The SCA for Turkey and subregions are estimated in daily basis covering the study period of February 2004–December 2012.

Owning to the non-parametric character and being applicable to the non-normally distributed data sets, Mann-Kendall (MK) trend test (Kendall, 1938; Mann, 1945) is run to examine the SCA trends. The MK test examines the null hypothesis of H_0, no trend exists. The alternative hypothesis of H_1 indicates that monotonic trend is present in the dataset. The estimated *p* value, the probability of obtaining a test statistic as large as the observed value under the assumption of null hypothesis is true, is used to test the null hypothesis by choosing the significance level of $\alpha=0.05$. So, for the *p* value is less than 0.05, H_0 is rejected and it is concluded that dataset contains a trend under the statistical significance level of 0.95. The trend sign is determined by the estimated test statistics either being positive or negative. Alternatively, H_0 is accepted and hypothesis of trend presence (H_1) is rejected. The MK test results in yearly basis with respect to subregions and seasons are provided in Table 3. For each column (year), the MK test is applied considering the data from 2004 to the corresponding year.

Table 3. Mann-Kendall test results variation (with significance level of α=0.05) in yearly basis. ('+', '-' and '0' signs are referring to positive trend, negative trend no trend respectively).

Season	Region	2004	2005	2006	2007	2008	2009	2010	2011	2012
Autumn	MED	+	+	+	+	**0**	**0**	**0**	**0**	**0**
	EAN	+	+	+	+	+	+	+	+	+
	AEG	+	+	+	+	**0**	**0**	**0**	**0**	**0**
	SAN	+	+	+	+	**0**	**0**	**0**	**0**	**0**
	CAN	+	+	+	+	+	+	**0**	**0**	**0**
	BLS	+	+	+	+	+	+	+	+	**0**
	MAR	+	+	+	+	**0**	**0**	**0**	**0**	**0**
	TUR	+	+	+	+	+	+	+	+	+
Winter	MED	-	**0**	-	**0**	**0**	**0**	**0**	**0**	+
	EAN	-	-	-	**0**	**0**	-	-	-	-
	AEG	-	**0**	**0**	**0**	**0**	**0**	**0**	**0**	+
	SAN	-	-	-	**0**	-	-	-	-	-
	CAN	-	-	-	**0**	**0**	**0**	-	-	**0**
	BLS	-	-	**0**	**0**	**0**	-	-	-	-
	MAR	**0**	+	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	TUR	-	-	**0**	**0**	**0**	-	-	-	**0**
Spring	MED	-	-	-	-	-	-	-	-	-
	EAN	-	-	-	-	-	-	-	-	-
	AEG	-	-	-	-	-	-	-	-	-
	SAN	-	-	-	-	-	-	-	-	-
	CAN	-	-	-	-	-	-	-	-	-
	BLS	-	-	-	-	-	-	-	-	-
	MAR	-	-	**0**	-	-	-	-	-	-

	TUR	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Summer	MED	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	EAN	**-**	**-**	**-**	**-**	**-**	**-**	**0**	**0**	**0**
	AEG	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	SAN	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	CAN	**-**	**-**	**-**	**0**	**-**	**0**	**-**	**-**	**-**
	BLS	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	MAR	**0**	**0**	**0**	+	+	**0**	**0**	**0**	**0**
	TUR	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
All Season	MED	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0**
	EAN	**-**	**-**	**-**	**0**	**-**	**-**	**-**	**-**	**-**
	AEG	**-**	**-**	**-**	**0**	**-**	**-**	**-**	**-**	**0**
	SAN	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	CAN	**-**	**-**	**-**	**0**	**-**	**-**	**-**	**-**	**-**
	BLS	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	MAR	**-**	**0**	**0**	**0**	**-**	**-**	**-**	**-**	**0**
	TUR	**-**	**-**	**-**	**0**	**-**	**-**	**-**	**-**	**-**

6. Results and Conclusions

For the whole Turkey area, dominantly *negative trend* is observed when all season data is considered. In seasonal perspective, *positive trend* is observed in autumn season while *negative trend* is dominant in spring and summer seasons and mixture of *negative* and *no trends* are observed in winter season.

From the seasonal standpoint, varying trend behaviors are observed. For instance, dominantly a clear *negative trend* is observed in spring season for each subregion. The winter season results on the other hand, dominantly showed mixture of *negative* and *no trends* where a few *positive trends* are observed as well. The autumn season results indicated *positive trend* for the half of the study period for all regions while the *no trend* is observed for the MED, AEG, SAN and MAR regions hereafter. The results for summer season indicated *no trend* for the MED and AEG regions through the study period while totally *negative trend* is observed for the SAN and BLS regions.

Despite the varying trend results in Table 3, test result of *negative trend* is the most significant result for the MK test. Among the other possible reasons, global warming seems to be the first reason for such results since Intergovernmental Panel on Climate Change (IPCC) already report a 0.8^{o}C annual average surface temperature increase for the last 100 years (IPCC, 2007). Similar findings are also expressed in Erlat and Türkeş (2012) Erlat and Yavaşlı (2009) reporting the increase in the daytime temperatures. Another study by by Kuglitsch *et al*. (2010) indicated summer daytime temperatures increase by 0.38 ± 0.04 °C/decade and summer nighttime temperatures increase by 0.30 ± 0.02 °C/decade when 206 stations are used in the Eastern Mediterranean region. Alternatively, variations in the atmospheric oscillation patterns might be the other possible source of snowfall variations over Turkey as their possible effects on precipitation variability are already discussed by many studies. (e.g, Yurdanur *et al*., 2012; Türkeş and Erlat 2006; Krichak and Alpert 2005).

7. References

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