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## **THREE-DIMENSIONAL EARTH MODELLING PERFORMANCE ANALYSIS OF GOKTURK-2 SATELLITE**

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### **ABSTRACT**

Following RASAT, Göktürk-2, placed into its orbit as Turkey's second domestic production of earth observation, has three times higher spatial resolution (2.5 m) than RASAT and has much more advanced stereo vision capability. However, like all-optical imaging satellites, Göktürk-2 has problems in data quality due to reasons such as sensor geometry, contrast, dense forest cover in the field of view and topographic slope. In this study, it is aimed to evaluate the horizontal and vertical geolocation accuracy performance of three-dimensional Digital Surface Models (DSM) derived from Göktürk-2 stereo images in comparison with a reference DSM obtained by traditional photogrammetry method in Derik district of Mardin province with high slope and variable topographic conditions. The results demonstrated that the three dimensional topographic representation capability of Göktürk-2 is quite successful despite offering a medium spatial resolution. The Göktürk-2 DSM has an absolute horizontal geolocation accuracy of  $\leq 0.1$  pixels (25 cm) both for X and Y directions. On the height, it provides accuracy as standard deviation of 7.3 m and normalized median absolute deviation of about 5.7 m.

**Keywords:** *Göktürk-2, Digital Surface Model, Performance, Quality*

## 1. INTRODUCTION

Remote Sensing (RS), the technology of acquiring airborne or space-borne information from target objects on earth without making direct contact with them, has become a modern method that is increasingly used worldwide with rapidly developing optical, radar and lidar technologies. Countries have been working hard for many years to integrate this technology.

In Turkey, space-borne RS activities started in the 1990s under the leadership of Scientific and Technological Research Council of Turkey (TUBITAK), and BILSAT, which emerged as a product of collaboration with Surrey University in the UK, was orbit in September 2003 as the first Turkish satellite mission. Through BILSAT, Turkey had the chance to acquire 12.6 m panchromatic and 26.7 m multispectral own satellite imageries (Yüksel *et al.*, 2016). BILSAT mission, which worked until 2006, was terminated in August 2006 as a result of technical failures in communication links. After BILSAT, Turkey's first domestic production of earth observation satellite RASAT was successfully placed into orbit in August, 2011. RASAT is a satellite mission with an optical principle capable of 7.5 m panchromatic and 15 m multispectral image acquisition. Despite some technical failures in the positioning systems immediately after its launch, RASAT continues its duty successfully. RASAT, which does not have infrared vision, could not provide the expected performance in stereo imaging due to the very slow stereo-vision camera. Turkey, learning more from each mission and developing, planned a new developed domestic satellite mission which corrected all deficiencies and the third earth observation satellite Göktürk-2 was placed into the orbit in December 2012. Göktürk-2, which is the first high-resolution earth observation satellite developed by our country, was not only designed, produced, but also the engineering activities in the test stages were utterly national.

In optical satellite missions, because of solar dependence, high-altitude imaging geometry, contrast and sensor characteristics, some limitations exist in product quality. Due to this fact, it is an indispensable requirement to determine the quality loss experienced by each satellite mission and determine the quality level of the satellite data and the resulting products (Aguilar *et al.* 2010; Zhao *et al.* 2011; Hladik and Alber 2012; Hobby and Ginzler 2012). Likewise, it is revealed that the satellite data whose quality is determined may be the reason of choice in such studies. In this study, it is aimed to evaluate the planimetric and vertical quality of three dimensional Digital Surface Models (DSM) obtained from Göktürk-2 stereo images. As it is known, DSMs, which represent the earth in three dimensions including all natural and man-made objects, are indispensable products for many disciplines such as forestry, archeology, hydrology and city planning (Fraser, 2003; Navalgund *et al.*, 2007; Font *et al.*, 2010; Sterenczak and Kozak, 2011; Sefercik *et al.* 2013; Yılmaz and Uysal, 2017).

The study is divided into five sections. In the second section, the study area and the properties of the materials used are presented. In the third section, the methodology of the study is given. In the fourth section, the results are presented, and in the fifth and final section, the conclusions and future targets are given.

## 2. STUDY AREA AND MATERIALS USED

Derik District is located in South-eastern Anatolia Region and is 42 km from Mardin City centre. The district is located between 40° 16 '5' East longitude and 37° 21' 53 " North parallel and has a surface area of 1,381 km<sup>2</sup>. An area of 1.35 × 3.45 km including Derik District Centre and its surrounding area was determined as the study area. Fig. 1 presents the location of the study area in Turkey and shows a close-up image. Derik was selected as the study area because of its variable and steep topography which enables a better interpretation of Göktürk-2 DSM performance.

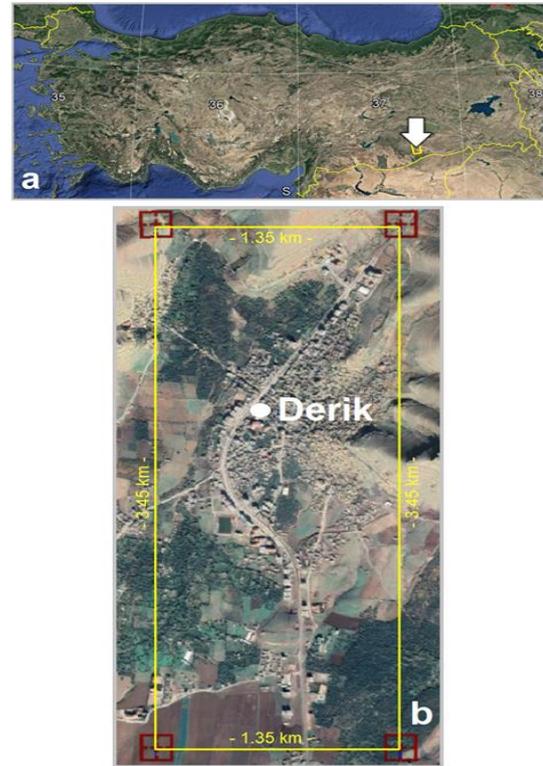


Fig. 1. Study area: (a) the location on the map of Turkey, (b) Derik district study area boundaries

The three-dimensional coverage and characteristics of the Göktürk-2 satellite images used in the study are presented in Fig. 2 and Table 1. As shown in Fig. 2, the study area is located in a steep region in the approximate middle portion of the stereo images.

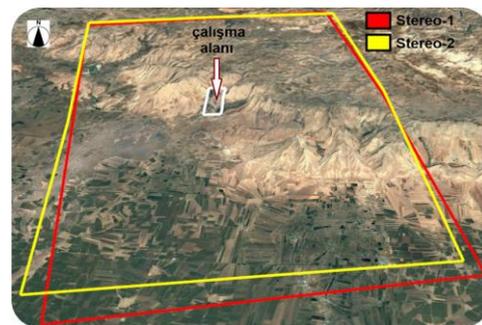


Fig. 2. Göktürk-2 stereo image boundaries

Table 1. Characteristics of Göktürk-2 stereo images

Characteristics	Göktürk-2 Stereo-1	Göktürk-2 Stereo-2
Reception Date (y/m/d)	2018-09-16	2018-09-16
Reception Time (h/m/s)	07:15:17.63	07:17:10.21
Stereo reception mode	Along-track	
Spatial resolution (m)	2.5 PAN / 5 MS	
Sun azimuth angle (°)	134.80406	135.36513
Sun height angle (°)	45.90185	46.15824
Coordinate reference system	WGS84	
Dimensions (width × length) (km)	~24×40	

### 3. METHODOLOGY

In this study, Göktürk-2 images were oriented by three-dimensional affine transformation. In the process, 18 Ground Control Points (GCP) collected from Google Earth images with a resolution higher than the spatial resolution of 2.5 m PAN of Göktürk-2 satellite were used. All of them were utilized for the orientation of stereo image 1 and 16 of them were used for the orientation of stereo image 2. The distribution of the GCPs used in the orientation process is shown in Fig. 3.



Fig. 3. GCP distribution

After the completion of the orientation process, 5 m grid DSM was produced from Göktürk-2 stereo images with DPLX software. The performance of the produced DSM is demonstrated visually and statistically using a reference photogrammetric DSM which have ~8 cm horizontal and ~12 cm absolute vertical accuracy. The 0.5 m grid reference DSM was derived from aerial photos taken by a Phase One 80 megapixel digital aerial camera at 800 m flight altitude. In the visual evaluations, the height error map produced from the differential model of Göktürk-2 DSM with reference photogrammetric DSM was interpreted. In height error map generation, the grid intervals of the DSMs were balanced by re-sampling. In statistical analyses, Göktürk-2 DSM geolocation accuracy was calculated

using standard deviation (SZ) (equation 1) and normalized median absolute deviation (NMAD) (equation 2) metrics.

$$SZ = \sqrt{\frac{\sum_{i=1}^n (\Delta Z_i - \mu)^2}{n-1}} \quad (1)$$

$$NMAD = 1.4826 \times \bar{X}_i [|\Delta Z_i - \bar{X}_j(\Delta Z_j)|] \quad (2)$$

In Equation 1, n is the number of pixels compared,  $\Delta Z$  is the height difference of the compared pixels, and  $\mu$  is the arithmetic mean of these differences. In Equation 2,  $\bar{X}_j$  is the median of the univariate data set of height differences, and  $\bar{X}_i$  is the median value of the height differences from  $\bar{X}_j$ . While NMAD stands out as a value very close to SZ in normal error distribution, if there is a structure that causes random error distribution in DSM, NMAD value is higher than SZ which is an undesirable situation indicating that DSM tested in absolute vertical accuracy analysis is in structural difficulty. Although NMAD is a robust accuracy metric for detecting significant structural errors, it does not perform as well as SZ in terms of revealing minor height differences (Hellerstein, 2008).

After the Göktürk-2 horizontal geolocation accuracy determination, the error amounts occurring in X and Y directions were eliminated by horizontal shifting by area-based cross-correlation method and Göktürk-2 DSM and reference DSM were fully overlapped horizontally before vertical geolocation accuracy analysis. Likewise, the basic condition of correct vertical accuracy evaluations is %100 horizontal overlap of analyzed DSMs. If horizontal overlap is not achieved, it is indisputable that vertical error detection in different parts of the models will lead to misleading results.

### 4. RESULTS

The horizontal geolocation accuracy of Göktürk-2 DSM obtained based on the standard deviation metric according to the reference photogrammetric DSM, as well as the horizontal offset amounts performed before the vertical accuracy are presented in Table 2. As can be seen from the Table 2, Göktürk-2 DSM's horizontal geolocation accuracy is 0.1 pixels in the X direction and 0.01 pixels in the Y direction. This also clearly demonstrates the performance of the GCPs used in the image orientation process.

Table 2. Absolute horizontal accuracy of Göktürk-2 stereo images

Reference DSM	Tested DSM	$\Delta X$ (m)	$\Delta Y$ (m)
Photogrammetric (0.5m)	Göktürk-2 (5m)	0.26	-0.03

DSMs obtained from photogrammetric reference data, and Göktürk-2 stereo images are shown in Fig. 4. When DSMs are examined, it can be mentioned that the topographic description performance of the 5 m grid DSM obtained from Göktürk-2 images with 2.5 m medium spatial resolution is quite successful. When the coloured height scale is considered, it can be seen that the correlation of topographic elevation zones with photogrammetric reference is quite high and even some narrow linear lines can be represented. Besides, the

minimum and maximum elevation values appear to be equal on the colour elevation scales, which is not typical for DSMs from medium resolution satellite data.

Table 3 shows the absolute vertical geolocation accuracy results of Göktürk-2 DSM. In the Table, the performances of DSM in the whole area and only the uninclined topography are presented separately. Inclination expression was used for plots with slope  $< \tan^{-1}0.1$  ( $\sim 6^\circ$ ) as usual in DSM quality researches (Jacobsen, 2016).

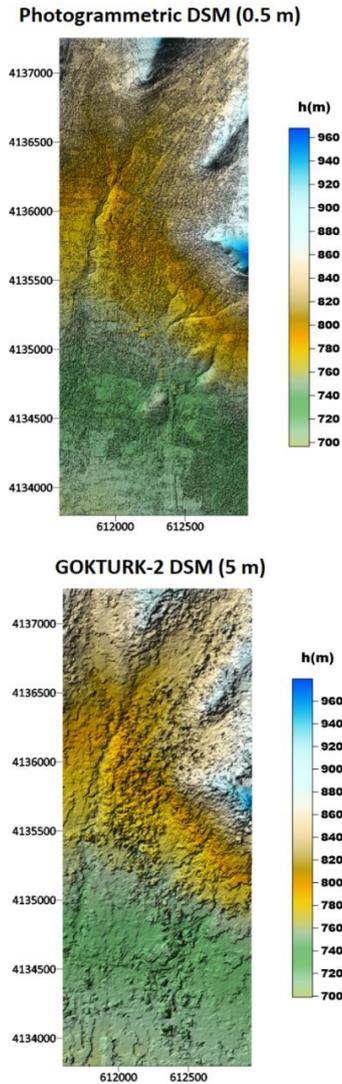


Fig. 4. Göktürk-2 and reference photogrammetric DSM

Table 3. Absolute vertical geolocation accuracy of Göktürk-2 DSM

Reference DSM	Tested DSM	Class	SZ (m)	NMAD (m)
Photogrammetric (0.5m)	Göktürk-2 (5m)	All terrain	7.37	5.77
		Slope	5.88	4.32

As seen in Table 3, it is determined that Göktürk-2 has higher performance in uninclined areas as in all DSMs obtained from space-borne optical RS data. In the

analyses made on the whole area; The absolute vertical geolocation accuracy of Göktürk-2 is around 7.3 m as SZ and around 5.7 m as NMAD. In uninclined areas, both values are about 1.5 m higher. The height error maps reflecting the grid-by-grid height differences between Göktürk-2 and reference photogrammetric DSM are shown in Fig. 5. To facilitate visual interpretation, the maps were prepared in different versions to reflect height errors of  $\pm 20$  m,  $\pm 10$  m,  $\pm 5$  m and  $\pm 1$  m. It was evident from the height error maps that the biggest problem of Göktürk-2 DSM is the topographical slope. In regions where the topographic slope is high, the correlation with photogrammetric DSM decreases significantly. Another problem stands out in the narrow streets of Derik town centre. Some of narrow streets could not be represented at the required level. However, considering the spatial resolution of Göktürk-2, this is a natural result. On the other hand, it was concluded that the performance of Göktürk-2 was quite successful in areas other than over-sloping topography. Particularly, the performance of Göktürk-2 stereo images at an altitude of 684 km is admirable when examining the bounded zones with an error of  $\pm 1$  m. In these zones, the photogrammetric reference obtained at an altitude of 800 m, the vertical topographic difference between DSM and Göktürk-2 is  $\leq 1$  m.

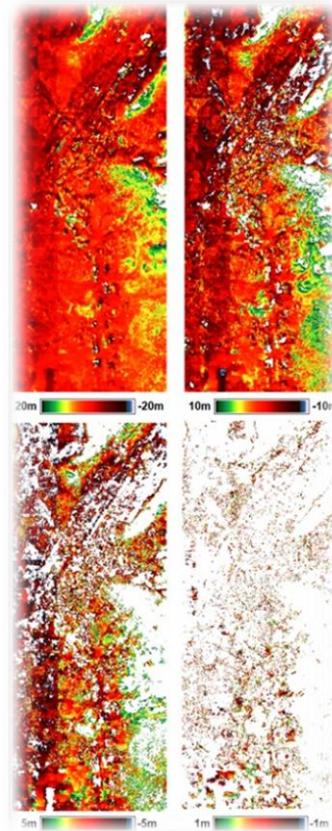


Fig. 5. Height error maps at different scales

## 5. CONCLUSIONS

The study carried out by Turkey's second domestic production Göktürk-2 earth observation satellite was evaluated with its horizontal and vertical absolute

geolocation accuracy performance of 5 m grid DSM produced from 2.5 m spatial resolution stereo satellite images. Evaluations were conducted by using visual and statistical methods with reference to photogrammetric DSM in Derik District of Mardin Province, where topographic slope is highly variable.

As a result of statistical accuracy, the analysis was performed based on standard deviation — also, normalized median absolute deviation metrics. Besides, visual interpretations in the light of height error maps, it was concluded that despite the medium spatial resolution of Göktürk-2 satellite at 2.5 m levels, the three-dimensional topographic representation capability was quite successful. The Göktürk-2 DSM has an absolute geolocation accuracy of  $\leq 0.1$  pixels in both directions horizontally. On the vertical, it provides accuracy as standard deviation of 7.3 m and normalized median absolute deviation of about 5.7 m. The biggest problem of the satellite is in the regions where the topographic slope is hardened. Likewise, the vertical accuracy level in the uninclined areas was found as 1.5 m better in both standard deviation and normalized median absolute deviation. Influence of the slope was clearly visualized in the generated height error maps. Height error maps revealed that Göktürk-2 satellite data also had problems in narrow streets in the town centres. The next target of our study team will be to find the primary sources of these problems detected in the narrow streets and improve image performance by filtering algorithms and improve the topographic description performance of the satellite.

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