Digital elevations from ICESat: Effects of dynamic terrain

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1. INTRODUCTION

Substantial problems arise from the sand movement in civilian and industrial cities in arid and semiarid countries. Problems are caused by the encroachment of sand on roads and railway tracks, farm-lands, towns and villages, industrial installations, airports, etc. Sand movement is highly affected by geomorphology such as vegetation, shapes and heights of terrains, and grain sizes of the sand [1]. However, wind direction and speed are the most important factors that affect sand movement. A minimum wind speed of 6 – 8 m/s is needed for sand to transport. With increasing wind speed there is an exponential increase in potential sand movement [2]. One of the most active areas regarding sand and dunes movement is the area of Arabian Peninsula. Approximately one-third of the Arabian Peninsula is covered by sand dune areas (Fig. 1). Different wind regimes that cause sand dune movements occur in the deserts of the Arabian Peninsula. Winds capable of moving sand have a northerly component 75 percent of the time and a southerly component 17.4 percent of the time; the remainder is from the east or the west [3]. The frequency of northerly winds is highest in April, May, and June and lowest in February and March. The frequency of southerly winds is relatively high in February and March but extremely low during May and June [3]. Thus, the amount of sand blown from north to south is highest in spring and summer and lowest in winter. In contrast, the amount of sand blown from south to north is highest in winter and lowest in spring and summer.

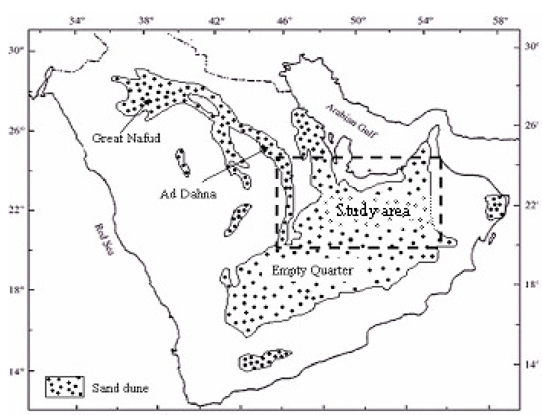

Fig. 1. Sand dune areas in the Arabian Peninsula.

The purpose of this study is to evaluate the elevations differences caused because of the sand dunes movement and to estimate the movement vector by computing the movement distance and direction. The selected study area is located in the eastern part of the Arabian Peninsula and extends between 20 to 25 degrees in latitude and 45 to 55 degrees in longitude (Fig. 1). The altimetry satellite data used are ICESat land surface altimetry data level 2. These data are good enough for this study since ICESat samples every 175 m along-track with a footprint size of only 65 m in diameter.

2. DATA PREPARATION

The available ICESat observations, were found for our specific study area, are in the years 2003, 2004, 2005, and 2006. ICESat tracks were plotted together in order to extract those closed to each other. As the footprint size is approximately 65 meters on the earth's surface, a limit of maximum 50 meters in between is considered in order two tracks to be covering the same dunes. Thus, two ICESat track sets are used in this study, the first set as well as the second contains two tracks the first one acquired in November 2005 and the second in March 2006 (five months in between).

3. ELEVATION DIFFERENCES CALCULATION

Elevation differences caused by sand movement can be calculated. In the first set as well as in the second one, the footprints of the first track (Nov. 2005) are projected in the second track (Mar. 2006). Thus, there elevations in Mar. 2006 can be interpolated using the available elevations of the footprints in the Mar. 2006 track. Each footprint in the first track will have two elevations, one measured elevation in Nov. 2005 and another interpolated one in Mar. 2006. Now, the elevations of Nov. 2005 are subtracted from the elevations of Mar. 2006 to calculate the change in elevations between these two time periods because of sand movement. The maximum and the minimum difference in elevations are 24.57 m and -18 m for the first set and 24.44 m and -43.58 m for the second set, respectively. The mean difference and the standard deviation for the first set are -0.07 m and 3.06 m while for the second set are -0.03 m and 4.58 m, respectively.

4. MOVEMENT VECTORS ESTIMATION

In order to calculate movement vectors, dune shifts in latitude and longitude are computed by correlating the different elevation profiles (Nov. 2005 and Mar. 2006) for each set. Having the two elevation profiles (Nov. 2005 and Mar. 2006) of the footprints, elevations are interpolated along the track latitude on the track points with 1 m distance. The elevation of each new point in Nov. 2005 and Mar. 2006 is calculated using the two elevation profiles of the footprints. In addition, the longitude of each point is interpolated using the longitude of the footprints. The same process is repeated by interpolating the elevations along the track longitude on points on the track with 1 m distance. The latitude of the new points is interpolated using the footprints latitude. Thus, new elevation profiles for each set are produced, in which elevations are known not only in footprints but also in points with 1 m distance in between along the track latitude/longitude. These profiles are used in calculating the distance and the direction of the moved dunes.

In order to find both, the distance and the direction of the moved dunes, the highest correlation coefficient between the two new elevation profiles (Nov. 2005 and Mar. 2006) should be evaluated. A moving window by fixed shift distance is defined. In each window step, the elevation curves inside the window are correlated. Analytically, one curve moves over the other with steps of one meter. The movement is performed to the right and to the left where the correlation coefficient is calculated for each step. Since dunes are moved by the wind with a certain distance, highest correlation is expected at this specific distance. For the highest correlation coefficient, the corresponding movement distance of the curve is calculated and the direction in which the curve moved (right or left) is determined. Thus, the resulted distance corresponds to the shift in latitude of the sand dunes inside the window. Moreover, the related direction of the movement (right or left) corresponds to the direction of the sand movement. The output of each window step is the maximum calculated correlation, the corresponding shift distance in latitude, the shift direction in latitude, and the latitude and longitude of the window center point. The same steps are repeated for longitude. Having the shift distance and direction in latitude and longitude, the length of the movement vector as well as its azimuth angle for each window center point can be calculated.

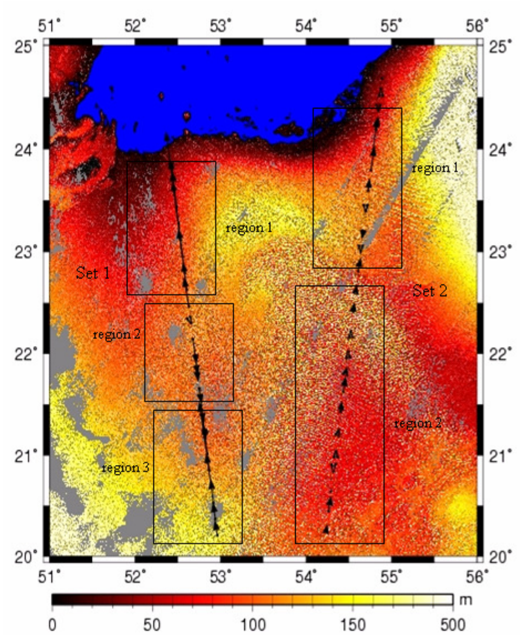

Fig. 2. Movement vectors plotted on SRTM DEM of the study area.

Fig. 2 shows the movement vectors of the two data sets plotted on SRTM Digital Elevation Model (DEM) of the study area. The length and the direction of the each vector are proportional to the dunes movement distance and direction. Four dune types can be discriminated in the areas of interest where the tracks of the two sets pass. In the first set, the area where the track passes can be divided into three regions. The first and the third regions contain complex linear dunes while the second region contains star dunes. The main movement direction in the first and third regions is from the south to the north. This direction agrees with the main wind direction in winter. On the other hand, the main movement direction in the second region is from the north to the south. This opposite direction should be related to winds in this region that had direction from the north to the south. The mean movement distance of the dunes is 22.87 m. In the second set, the area where the track passes can be divided into two regions. The first region contains longitudinal dunes while the second region contains complex crescentic dunes. The main movement direction in the two regions along the track is from the south to the north which agrees with the main winds direction in winter. The mean movement distance of the dunes is 6.40 m.

5. CONCLUSIONS

Elevation profiles from ICESat data can be used in a correlation analysis to find direction and distance of movement. The direction of the movement depends on the main direction of the winds. In the period between November and March the movement has main direction from the south to the north. This is because the main direction of the winds in this period is from the south to the north. However, some northern winds exist in this period and cause a movement of sand in some areas towards the south.

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