

# Global Survey of Organized Landforms: Recognizing Linear Sand Dunes

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## 1. Introduction

The Shuttle Radar Topography Mission (SRTM) provided an unrivalled view of Earth's topography and a rich data set for geomorphometry (Farr et al. 2007). The 30" overview data set shows regional trends and can fit on a single CD-ROM, and the 3" local data set shows an incredible amount of detail with required storage of about 35 GB. The increasing availability of 1 meter Lidar topography highlights the possibility of looking at landscapes at a wide range of scales; SRTM provides the big and medium pictures for looking at the entire world or individual continents.

Guth (2007) described the creation of a geomorphometric atlas from the 3" data. This paper will use that atlas to look at terrain organization, focusing on the identification of linear dune fields (Lancaster 1995).

## 2. Geomorphometric Atlas

The earth's land surface between 60°N and 56°S contains about 7.4 million blocks 2.5' (arc minutes) on a side. The blocks range in size from 4.6 x 4.6 km at the equator, to 4.0 x 4.6 km at 30° latitude, and 3.0 x 4.6 km at 60° latitude. The atlas contains grids for 37 parameters (Evans 1998; Pike 2001), computed from 2601 points in each block, sufficient for robust statistics describing terrain. Each data grid contains 8640x2784 values, about 70% of which are voids covering the oceans. The atlas allows color coding each parameter on a map, as well as the creation of filters based on selected values for any parameter, and rapidly combining filter results.

Terrain organization (Guth 2003) provides a key characteristic to identify several categories of terrain, including drumlin fields, folded mountains, fault block mountains, and linear dune fields (Guth 2007). Organization measures the tendency for ridges and valleys to share the same spatial orientation. Drumlin fields may not have a large enough spatial scale for identification in the geomorphometric atlas, but this study will use to the atlas to locate and identify large linear dune fields.

## 3. Linear Dunes

Lancaster (1995) described three categories of linear dunes (Table 1). Despite some overlap in size measures, the three types generally reflect an increase in all three size measures. Figure 1 shows an SRTM shaded relief map and a topographic profile across complex dunes in Saudi Arabia. While simple dunes clearly show up in the SRTM 3 second data, they may be difficult to discriminate because the smaller wavelengths include only a few 90 m grid postings, and the dune height approaches the inherent radar speckle in flat regions. This work therefore seeks to investigate the geomorphometry of compound and complex linear dunes.

Linear Dune Type	Spacing (m)	Width (m)	Height (m)
Simple	430-2346	220-290	4-21
Compound	990-2080	650-940	24-48
Complex	1500-3300	900-1500	40-200

Table 1. Linear dune statistics (after Lancaster 1995).

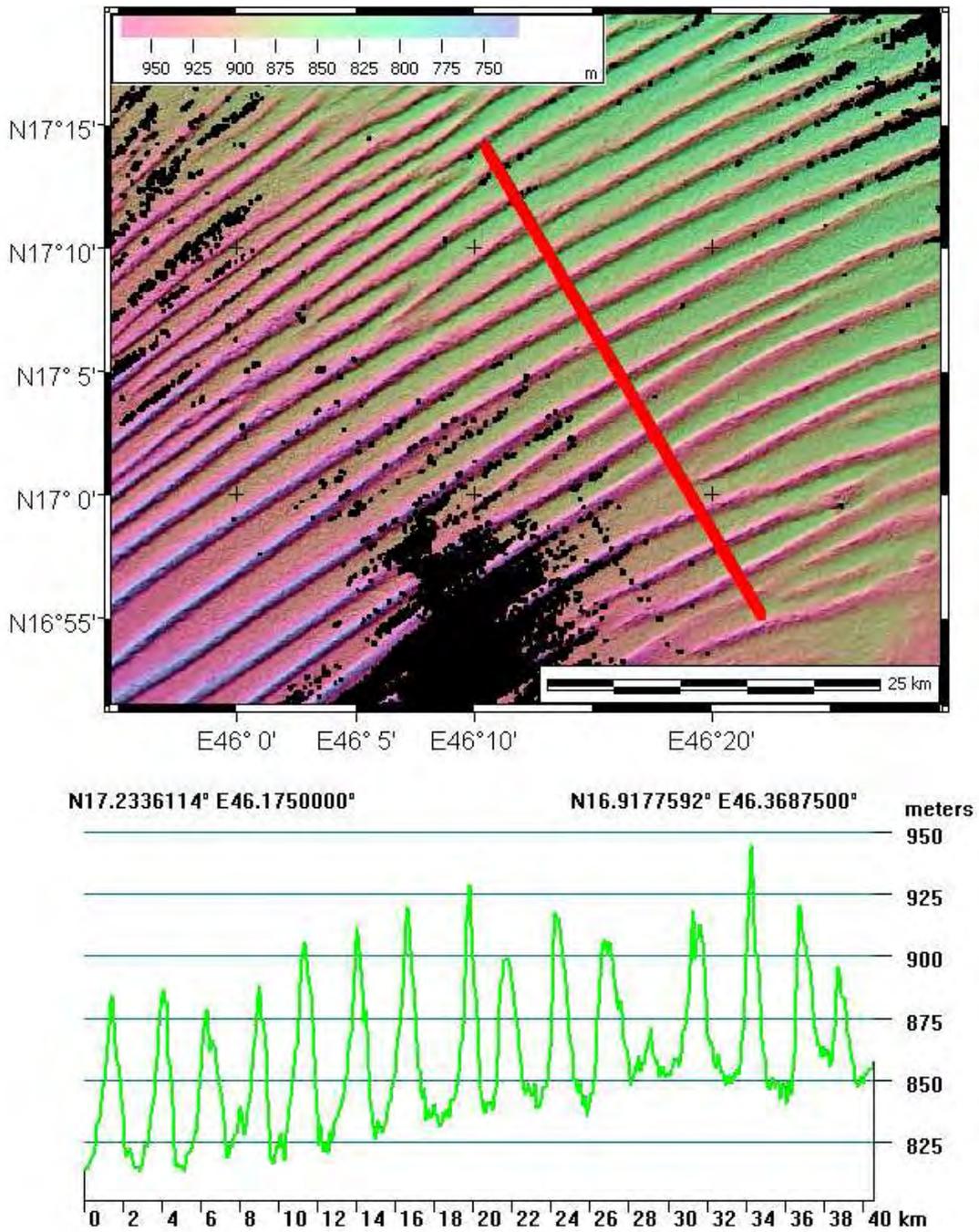


Figure 1. Complex dunes in southwestern Saudi Arabia in map view and profile. The tallest dunes are about 100 m high.

## 4. Methods

Geomorphometric parameter maps can be viewed in conjunction with maps derived from SRTM-30 and SRTM-3, with colored symbols from the atlas overlaid on grayscale shaded relief to provide context, or on satellite imagery. Where necessary, Google Earth provides rapid access to high quality imagery to verify interpretations. Initial examination of the global terrain organization map, focusing on the high values, shows that large linear dune fields are among the features that stand out.

An initial classification identified dune regions, and Figure 2 shows bivariate scatter plots for 25 geomorphometric parameters from the atlas. Each parameter appears in a column and a row, with the principal diagonal showing the parameter plotted against itself. The gray color indicates the entire data set, and the red the linear dune fields. Parameters that do a good job discriminating linear dunes should show a tight distribution of the red points. Similar graphs with univariate histograms show how the linear dunes compare with other landforms for values of a single parameter.

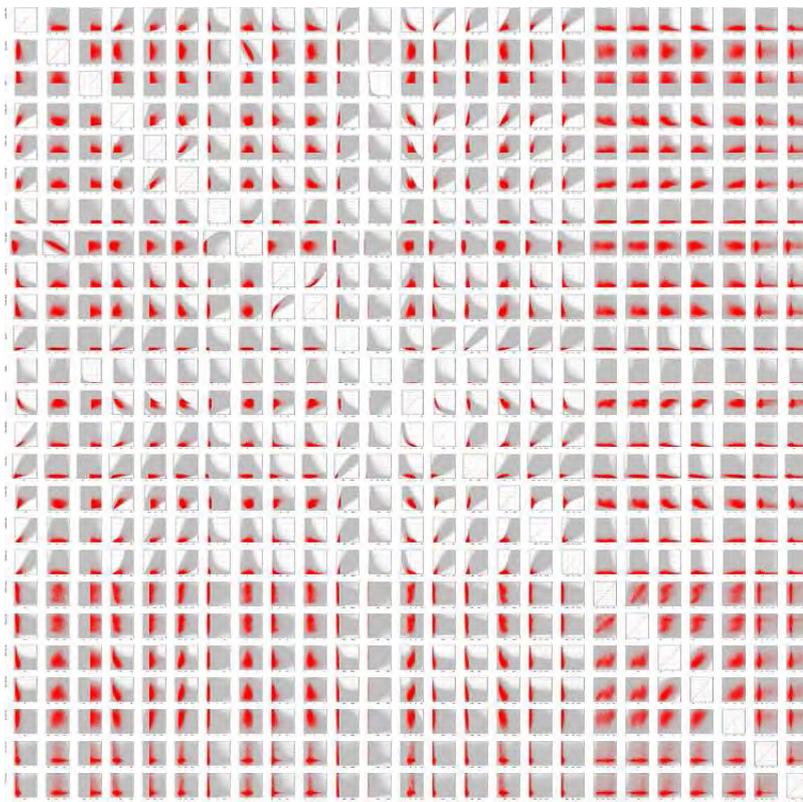


Figure 2. Bivariate scatter plots for 25 parameters, with linear dunes in red and all SRTM data in gray.

Selection of parameter values can use either the absolute value, or the percentile range which avoids problems with some extreme values in the data set related to SRTM holes and other statistical anomalies. Figure 3 shows the approximately highest 10% of cells in terms of terrain organization, and three other parameters selected because they appear to discriminate dunes from other features. Homogeneity, the kurtosis of the elevation distribution, easily differentiates linear dunes from star or isolated dunes. Curvature in profile, the standard deviation of the profile curvature distribution, and relief, further appear to differentiate linear dunes. Table 2 shows the parameters selected for dune discrimination.

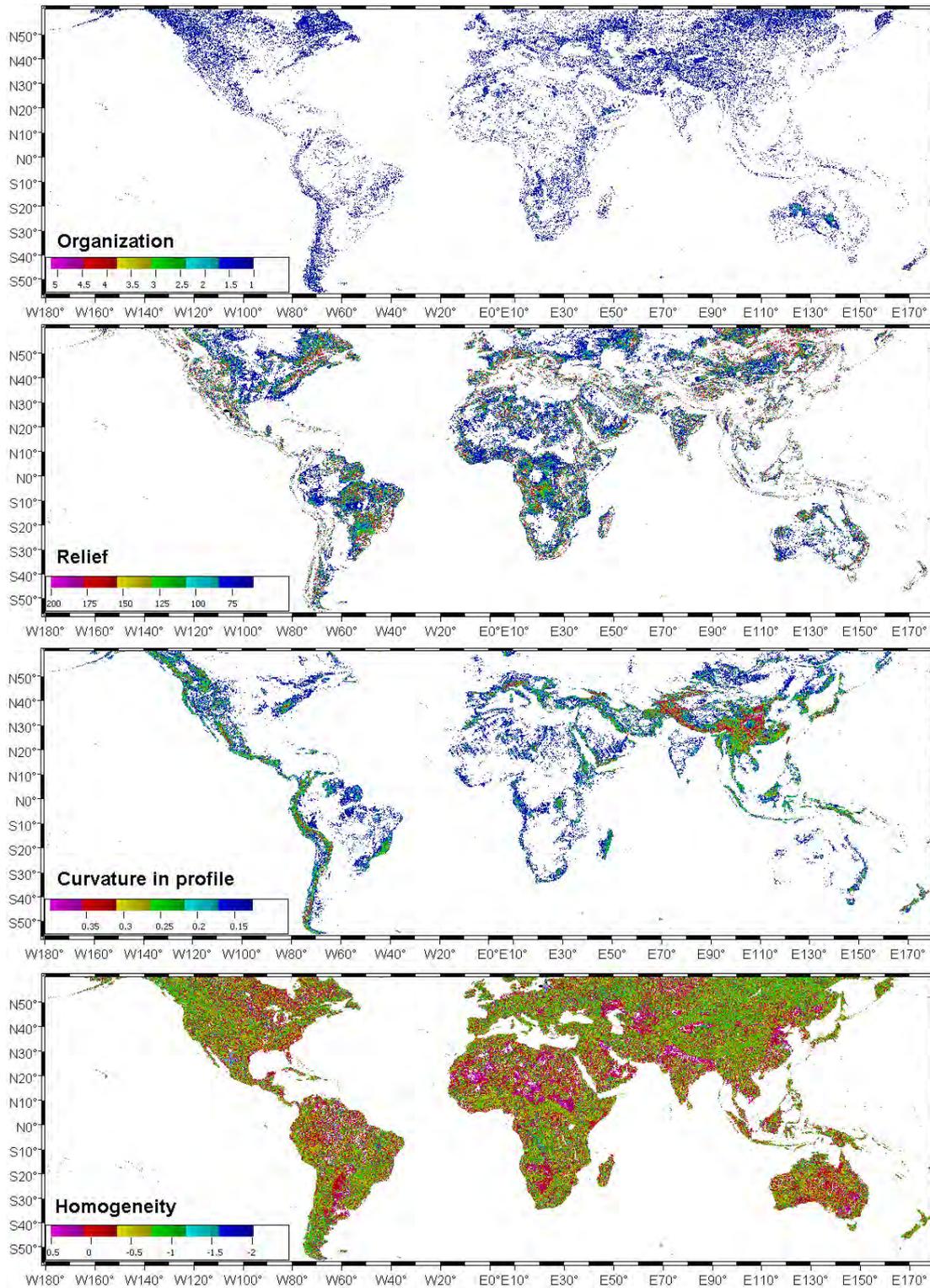


Figure 3. Four of the parameters used to identify linear dune fields. Colored points show locations that match the individual criteria; the map display exaggerates the proportion of the earth's surface actually matching each criterion.

We created masks for each parameter for the cells that matched the criteria, and then combined masks to find candidate regions. Because of the noise in the resulting maps, we filtered the data to find all cells that had at least 65 neighbours within an 11x11 neighbourhood (54% of the region) that met the criteria. This meant that we

were looking for dune fields covering 50 x 50 km at the equator, 44 x 50 km at 30° latitude, and 33 x 50 km at 60° latitude

Parameter	Range	Percentile Range
Organization	1 to 5.15	88.8 to 99.9
Relief	60 to 200	41.4 to 71.8
Steepness (Average slope)	3 to 25	45.2 to 89.8
Homogeneity (elevation kurtosis)	-2.02 to 0.5	0.1 to 75.1
Massiveness (elevation skewness)	0.1 to 50.94	41.9 to 99.9%
Curvature in profile (standard deviation)	0.12 to 0.4	73.1 to 99.6

Table 2. Parameters used to classify dunes.

## 5. Results

Table 3 shows the results of using 4 combination of parameters. All cases use organization, average slope, and relief. The raw matches show the number of cells meeting the criteria out of the 4.7 million in the world covered by the SRTM, and the region matches show the number that belong to a region, typically about 10% of the raw matches. Figure 5 shows the results for the three parameter solution, and regional matches clearly remove a great deal of noise with isolated cells (so that they appear on the map, the size of the matches are exaggerated for display). While the three parameter model located a number of dune fields in the northern hemisphere desert belt, it also identified a large region east of Hudson Bay (Figure 6) and a number of regions along the coasts of the Black Sea, Caspian Sea, and similar latitudes farther east in central Asia. Table 3 and Figure 6 show that adding the standard deviation of profile curvature does the best job of removing these non-dune regions.

Figure 6 shows the dune fields identified with this algorithm. Google Earth imagery confirms that all regions shown in green represent large linear dune fields.

Parameters	Raw Matches	Region Matches
Organization, average slope, and relief	223,566	21,323
Organization, average slope, relief, and <b>elevation kurtosis</b>	171,357	13,650
Organization, average slope, relief, and <b>elevation skewness</b>	133,211	9103
Organization, average slope, relief, and <b>standard deviation of profile curvature</b>	32,379	4464

Table 3. Classification results with 4 combinations of parameters.

Although not obvious at the scale of Figure 3, the curvature map shows anomalies in the SRTM processing that follow the shuttle orbital pattern (Guth 2006). Figure 8 shows 3 arc second SRTM elevation data, overlaid with regional atlas data for organization and profile curvature. Large square symbols meet the criteria for linear dunes, and small triangles do not; the colors show the value of the parameter. The diagonal patterns of SRTM holes repeat at about 60 km spacing, which match the

width of the four portions of the 225 km SRTM swath width. Particularly for the curvature in profile parameter, alternating bands have low values (which do not meet the dune field criteria) and higher values (which do meet the criteria).

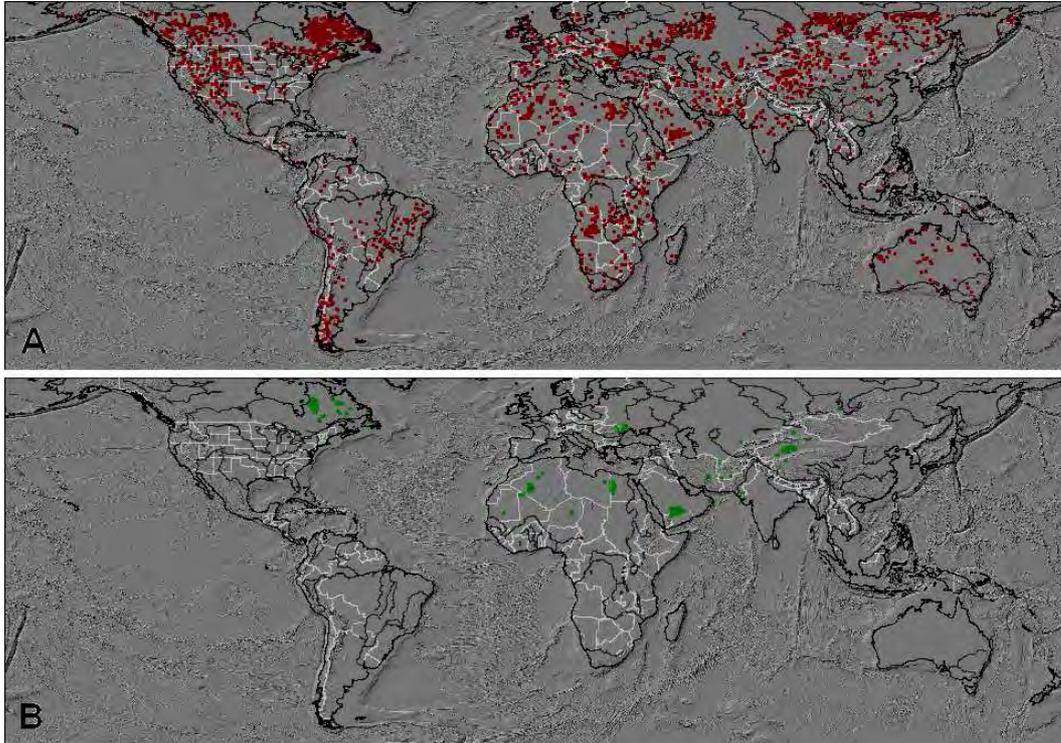


Figure 4. Classification using organization, average slope, and relief. Figure 4A shows the raw matches, and Figure 4B the filtered regional matches.

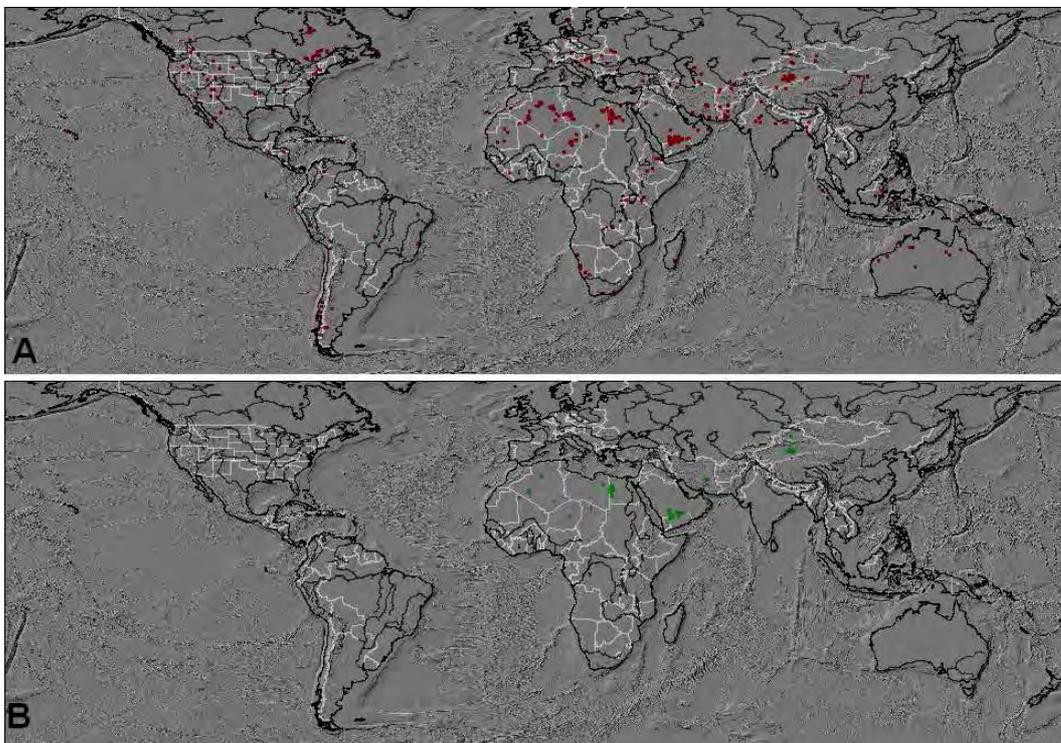


Figure 5. Classification using organization, average slope, relief, and standard deviation of profile curvature. Figure 5A shows the raw matches, and Figure 5B the filtered regional matches.

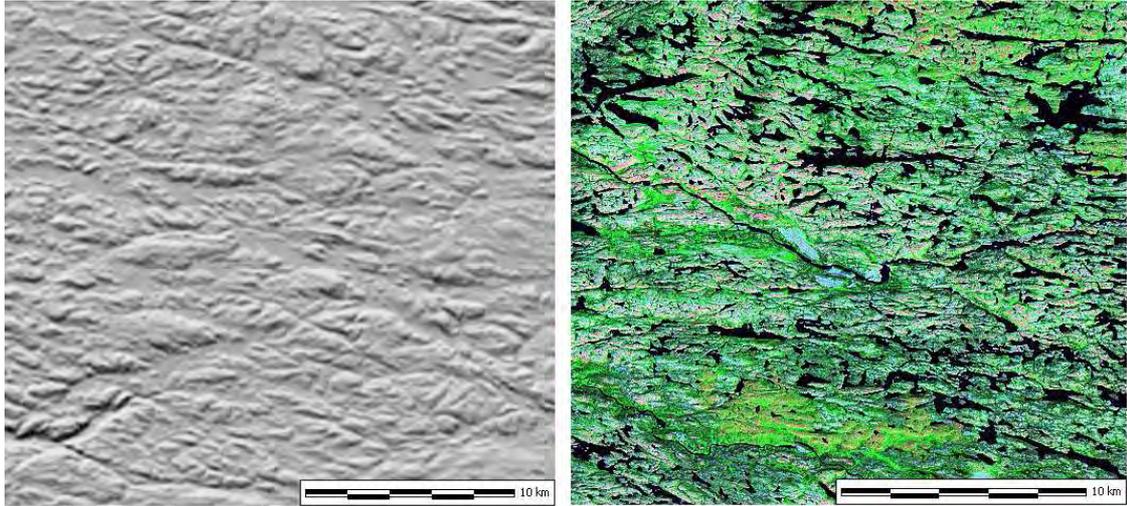


Figure 6. Glacial topography east of Hudson Bay, in shaded relief from the SRTM 3'' dataset on the left and the Geocover 2000 Landsat imagery on the right.

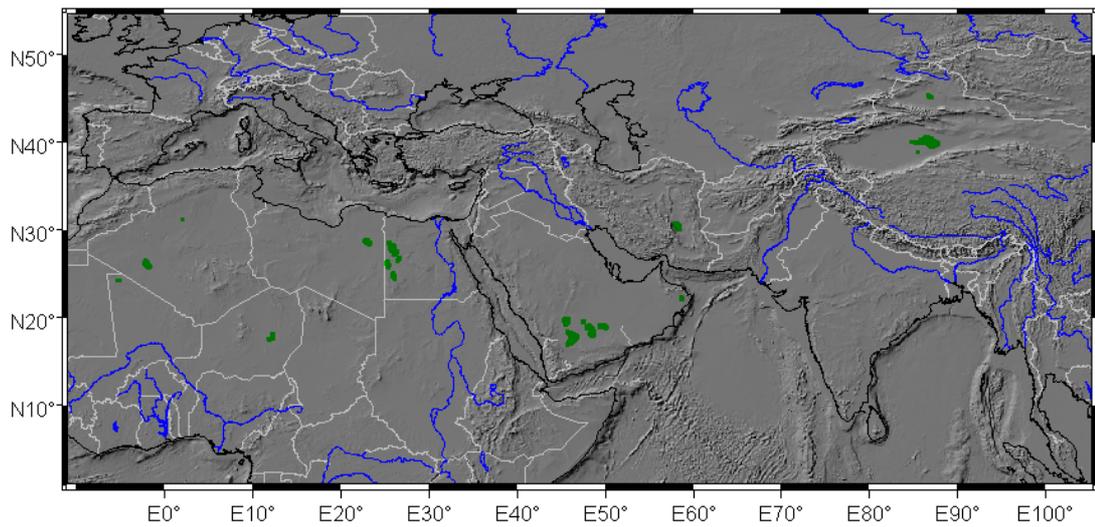


Figure 7. Blowup of Figure 5B, showing the large linear dune fields identified using geomorphometric criteria.

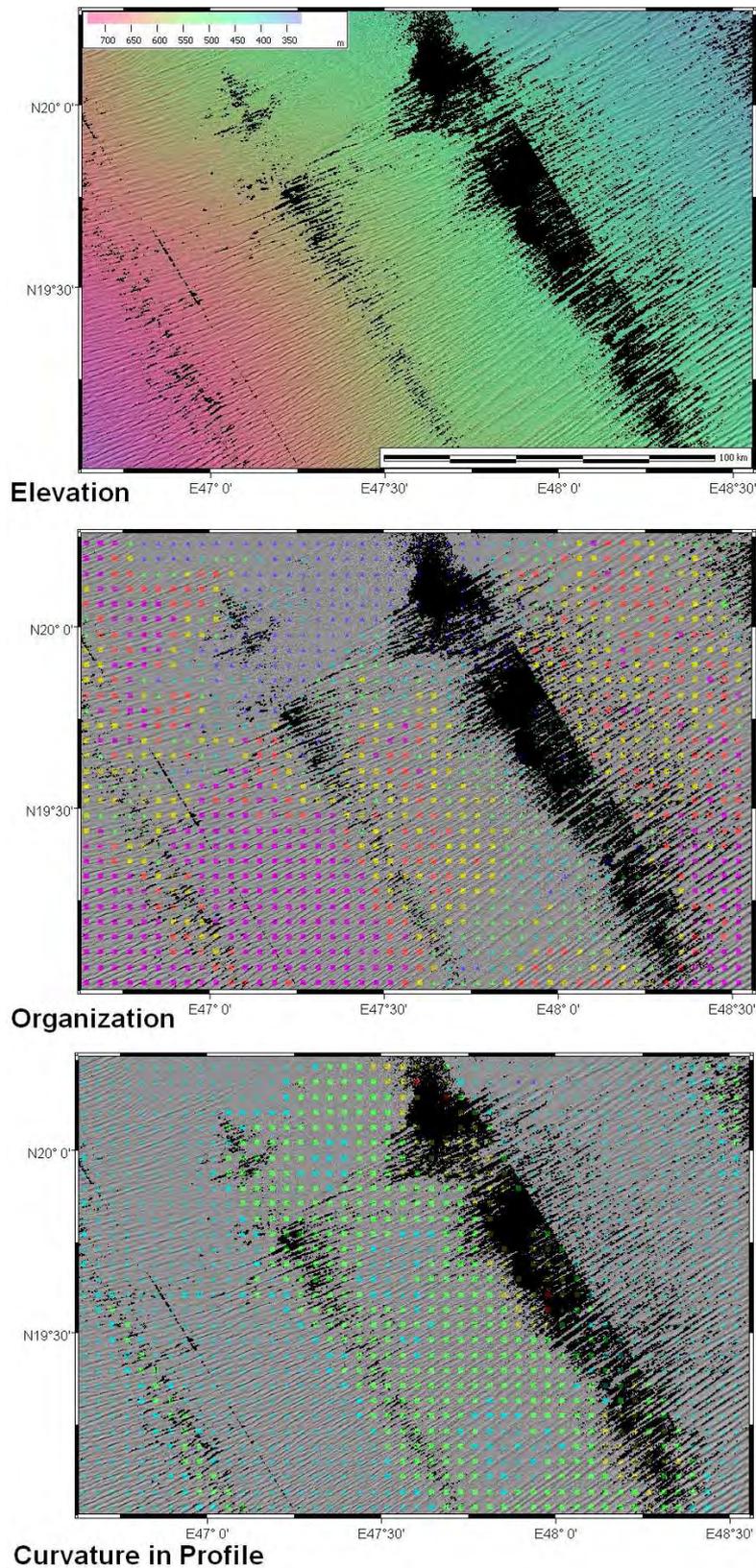


Figure 8. Map of a region in southwestern Saudi Arabia that includes Figure 1. The elevation map shows SRTM-3" data, and the bottom two maps overlay organization and curvature in profile.

## 6. Future Work

Figure 9 shows complex dunes in the Rub' al Khali region in southeastern Saudi Arabia. These are taller, and less linear than those shown in Figures 1 and 8, and in fact the algorithm does not identify much of this area as being composed of linear dunes. Additional work will focus on (1) better identifying large complex dunes and small simple dunes; (2) adjusting the criteria ranges, or adding additional criteria to reliably identify smaller regions of linear sand dunes; and (3) extending the work to additional categories of landforms, such as drumlins and folded mountains. Finally, we would like to quantify the results, which will require an independent digital data set with the locations of specific landforms.

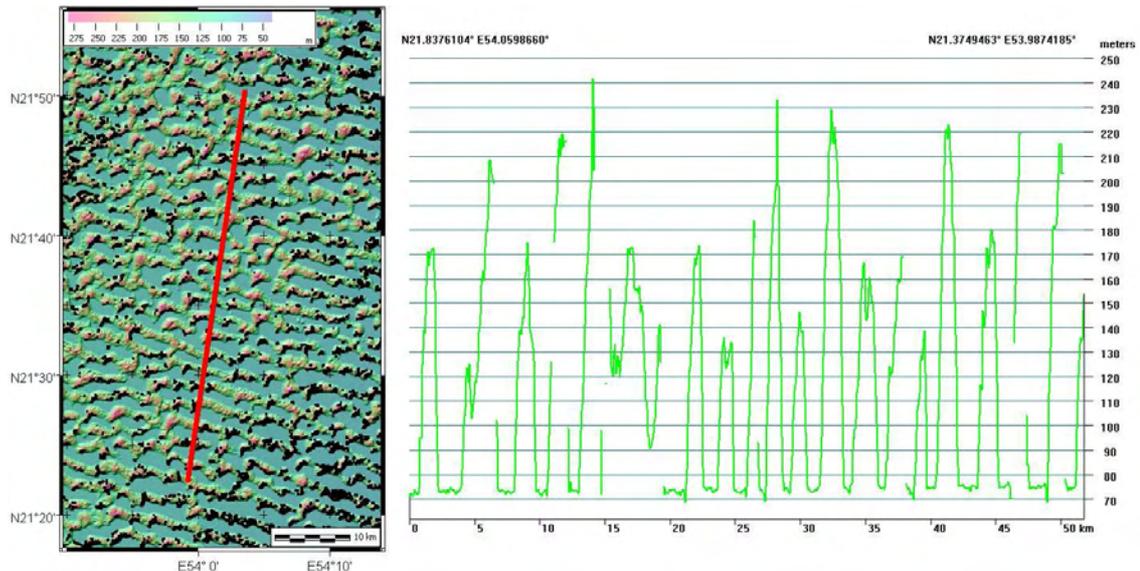


Figure 9. Complex dunes in the Rub' al Khali region in southeastern Saudi Arabia. These dunes are much taller and less linear than those successfully identified by the current algorithm.

## Acknowledgements

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