The Giga Revolution in Geomorphometry: Gigabytes of RAM, Gigabyte-Sized Data Sets, and Gigabit Internet Access

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Abstract—**Recent advances in computer technology herald a revolution in geomorphometry. Desktop computers and 64 bit operating systems can access massive data sets like the entire SRTM DEM from RAM. Multi-temporal lidar topography, with 1 m or 0.5 m grid spacing, can require gigabytes of data for relatively small project areas, but repeated surveys allow monitoring geomorphometric changes over time. As gigabit internet access reaches greater audiences, the need to download data before beginning analysis might be replaced with just-in-time delivery over the internet, or analysis as a service with downloading data. Traditional DEMs like SRTM could be viewed as almost all signal—they might be smoothed or filtered, but there was no way to remove whatever vegetation noise was present, and the user basically had to accept the dataset. With lidar the user can process the point cloud to remove vegetation, and can consider further removing boulders and similar features to get a generalized and more representative view of the landscapes.**

Views of desert dune landscapes at three scales (1 km—100 m—1m) illustrate these changes. The half gigabyte global data set ETOPO1 easily loads into RAM. The largest dune fields appear at this scale, but few characteristics of the dunes appear and some suffer from aliasing. SRTM and ASTER GDEM have very similar 100 m real point spacing, and allow automated extraction of dune heights, spacing, and orientation for most dunes, although smaller dunes like many of those in Australia are at the limits for these elevations models. SRTM's collection over a short period captured a virtually instantaneous snapshot, whereas the ASTER GDEM's long temporal averaging smears out dune changes. The smallest dunes, such as those at White Sands, New Mexico, only appear well defined in lidar grids with 1 m resolution which can track dune migration and reveal spatial patterns.

I. INTRODUCTION

Increases in computer power, cloud delivery of both huge data sets and geospatial services, and increasing bandwidth all make this an exciting time for geomorphometry. This paper will look at three scales of data to show the increasing capabilities.

II. GLOBAL DEMs: ETOPO1 AND SRTM30

Global DEMs have come a long way from ETOPO5, which covered the entire globe, oceans and continents, in under 20 MB. Currently two data sets, ETOPO1 and SRTM30, cover the globe with about 500 MB and 2 GB respectively. ETOPO1 can load entirely into RAM, while SRTM30 must be subset or loaded into 64 bit software. For the purposes of geomorphometry, these data sets perform similarly, with data spacing of about 1 km.

The large linear dune fields of the world appear in these data sets, but at the limit for detection and quantitative geomorphometric analysis. Figure 1 shows the terrain classification of Iwahashi and Pike [1, 2] next to the SRTM30 for a region in the western Sahara. The dunes show up as noisy, alternating pixels in two categories. Attempts to use fabric analysis [3] on the dunes cannot differentiate them from linear tectonic ridges.

III. SRTM AND ASTER GDEM

The SRTM and ASTER GDEM have very similar effective resolutions. GDEM covers more the earth, although generally with more noise and other artifacts, but can improve on SRTM where the radar was shadowed or did not get returns in dry sand. With a 64 bit operating system, a desktop PC with 64 GB of RAM and clever indexing, could load the entire SRTM DEM into memory for rapid, random access.
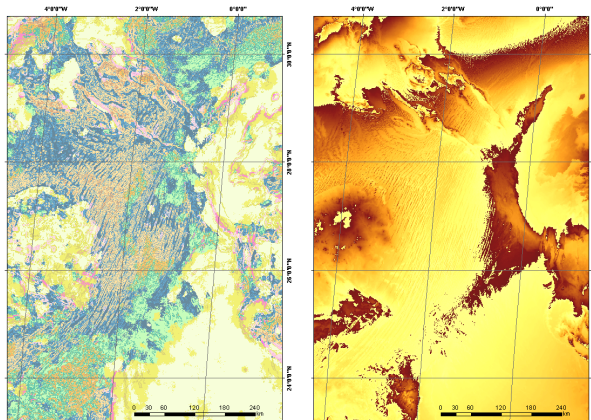
Figure 1. Classification of western Sahara from Iwahashi and Pike, compared to SRTM30 topography.

An automated algorithm can find dune spacing (crest separation), dune height, and crest orientation. Terrain fabric identifies the orientation of the dunes, and analysis of profiles perpendicular to the crests and pick out the crests and troughs and compute the spacing. Figure 2 shows crests picked in Niger, in a region with perpendicular dune orientations. Figure 3 shows dune heights in part of the Xianjang Desert of China.
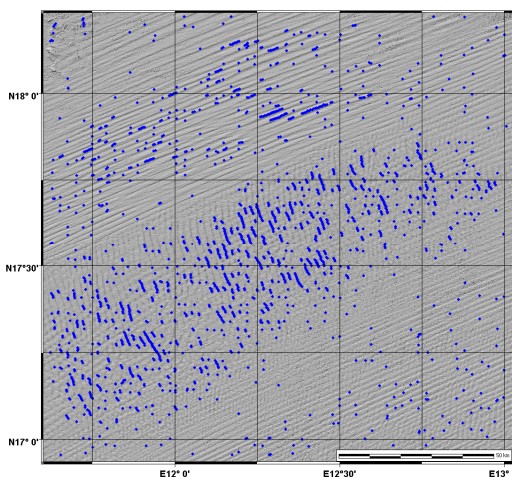

Figure 2. Dune crests identified in central Niger, with orthogonal trends.

IV. LIDAR DEMs AND DUNE MIGRATION

The real power released by current developments shows up with lidar data sets. Three lidar collections cover the White Sands dune field in New Mexico, in January 2009, September 2009, and June 2010. As point clouds in LAS format these require 5-9 GB of data storage each, with point densities of 4-6 points/m². Converted to gridded DTMs they require about 400 MB each.

Three methods were developed to track dune migration: (1) tracking the migration of dune crests; (2) assessing the shifts that provide the best correlation for subsets of the grids; and (3) identify slip face objects, and track their migration. All methods used a gridded DEM, and two require identification of the dune slip faces by locating slopes > 50%.
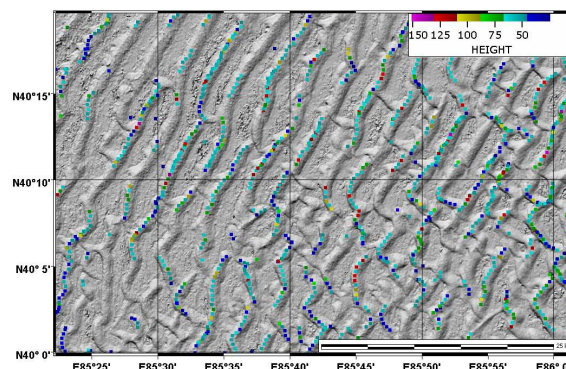

Figure 3. Dune heights computed along crests in Xinjiang Desert, China.

A. Migration from Identified Crests

The algorithm starts with the slip faces identified by slope, and picks the expected migration direction from the 8 principle cardinal directions, and then pick points on the opposite edge of the dunes as the dune crests of the dunes. It looks along profiles in the candidate direction starting from each crest point in the first DEM. If there is a crest in the other DEM within a maximum search distance, it will be the migrated crest. Positive numbers will be in the northerly or easterly direction.

B. Migration from Grid Correlations

This algorithm requires three parameters: the interval between computation points; the size of the regions, which can overlap; and the maximum distance to consider for shifting the two grids. Regions must be large enough to contain a significant proportion of dunes, as this will not work in flat interdune regions. The algorithm shifts one grid relative to the other, and computes the correlation coefficient between the elevation in the stationary grid and the shifted grid. The offsets for the highest correlation define the computed migration.

C. Migration from Slip Face Objects

This algorithm first detects the slip face objects, finding all connected regions on the map of slip faces from 50% slopes. The algorithm creates a grid with an ID for each object, and a database with the data about the object. The user selects a box region to search for the migrated slip face. The computer finds the shift with the largest percentage of the slip face matching a slip face in the second time period. The output notes the number of objects within this shift, as a dune can fragment as it migrates Figure 5). The algorithm also performs a reverse analysis, from

the later DEM back to the original DEM. This provides similar results, but there are different numbers of slip faces in the two time periods, and some of the earlier slip faces may merge (Figure 5).
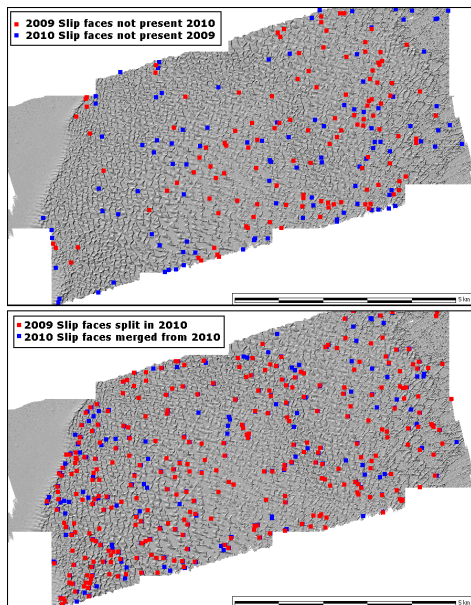

Figure 4. Slip faces without a simple 1:1 correspondence from January 2009 to June 2010.

V. RESULTS

Tables I and II summarizes the results. Figure 6 shows map depictions of the motion for all three methods. The grid correlation and slip face object methods produce very similar results, with a vector average rate of 5.1 to 5.4 m/year toward N70E, slightly more than the crest migration which only provides a component of the total motion. This is on the high end of reported figures (1-4-m/yr [4]). The most interesting result is the spatial pattern of migration shown in Figure 6, which shows the largest rates, approaching and some cases exceeding 10 m/yr along the western edge of the dune field, and a region in the center with lower rates than occur either to the east or west.

TABLE I.   MIGRATION RATES FROM FIRST TWO METHODS

Method	Number	Average m/yr	Median m/yr	Vector Average m/yr
Grid Correlations	152	5.16	5.33	5.13 toward 68.9°
Crests, Motion E	59026	3.58	2.93	3.58 toward 90°
Crests, Motion NE	36181	4.73	4.17	4.73 toward 45°

TABLE II.   SLIP FACE OBJECT ANALYSIS

Survey Date	Category	Number	Percentage	Vector Average m/yr
1/24/09	Total slip faces	2568		
	Trace forward	2446	95.25%	5.40 toward 72.2°
	Unique matches	2141	83.37%	5.22 toward 73.1°
	No match 2010	122	4.75%	
	Split forward	239	9.31%	
6/6/10	Total slip faces	2486		
	Trace backward	2381	95.78%	5.36 toward 72.2°
	Unique matches	2086	83.91%	5.16 toward 73.1°
	No match 2009	105	4.22%	
	Merge forward	271	10.90%	

VI. CONCLUSION

Huge data sets, large amounts of RAM on desktop computers, and large bandwidth for data downloads promise to change the practice of Geomorphometry: larger data sets, more details, and multi-temporal views. The rise of smartphones and tablets may drive analysis onto the web as a service, leaving visualization and data manipulation onto small clients.

REFERENCES

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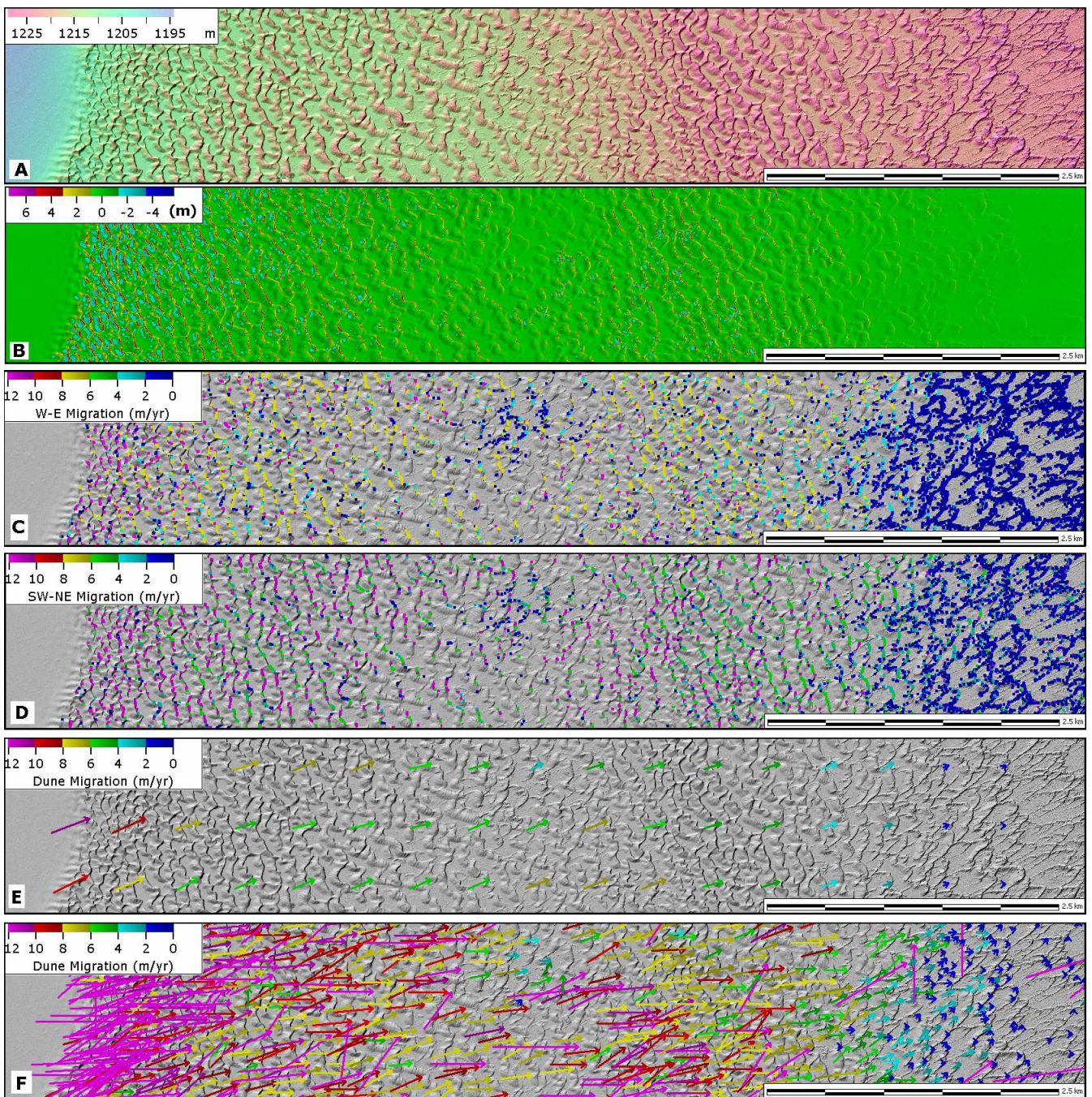
White Sands, New Mexico. A shows the dune elevations and morphology in January 2009; B the elevation difference between January 2009 and June 2010; C the computed east west component of dune migration of dune crests in 18 months; D the SW-NE migration over 18 months; E the migration using elevation correlations; and F the migration tracking features.

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