Measuring sand dune migration using multi-temporal LiDAR data in White Sands Dune Field, New Mexico, USA

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1. Introduction

Understanding how sand dunes form and change has long been a research topic in Earth and planetary surface processes, yet few methods have been developed for automated detection and measurement of dune migration directions and migration rates in large dune fields. In comparison with traditional remote sensing techniques, LiDAR has provided unprecedented datasets for sand dune studies. Using the angle of repose (AOR) as a sensitive movement indicator of barchan (crescent-shaped) and transverse dunes, Dong (2015) proposed a PSTP (pairs of source and target points) method to automatically match before and after points on dune slip faces revealed by LiDAR data. The flowchart of the PSTP method is shown in Figure 6.4, and an ArcGIS add-in was created using the Python programming language to automate the whole process in Figure 6.4. The objective of this project is to use the add-in for calculating sand dune migration rates from multi-temporal LiDAR data in a study area in the White Sands Dune Field (WSDF), New Mexico, USA. Before using the add-in, users will work through several steps to better understand the processes of extracting slip faces from the DEMs, and converting the centerlines of the slip faces into vector polylines.

2. Data

An area of 401 m by 802 m in WSDF is selected for this project. LiDAR data for the study area was acquired on January 24, 2009 and June 6, 2010. The LiDAR point density is about 4.19 points/m^2 (for January 24, 2009) and 4.62 points/m^2 (for June 6, 2010). The horizontal coordinate system is UTM Z13N NAD83 (CORS96) [EPSG: 26913], and the vertical coordinate system NAVD88 (Geoid 03) [EPSG: 5703]. LiDAR data acquisition and processing was completed by the National Center for Airborne Laser Mapping (NCALM). NCALM funding was provided by National Science Foundation's Division of Earth Sciences, Instrumentation and Facilities Program, EAR-1043051.

3. Project Steps

(1) Open an empty Word document so that you can copy any results from the following steps to the document. To copy the whole screen to your Word document, press the PrtSc (print screen) key on your keyboard, then open your Word document and click the "Paste" button or press Ctrl+v to paste the content into your document. To copy an active window to your Word document, press Alt+PrtSc, then paste the content into your document.

(2) Open ArcMap, load the Spatial Analyst Extension and 3D Analyst Extension, then add "d20090124.tif" and "d20100606.tif" to ArcMap (Figure 6.30 and Figure 6.31).

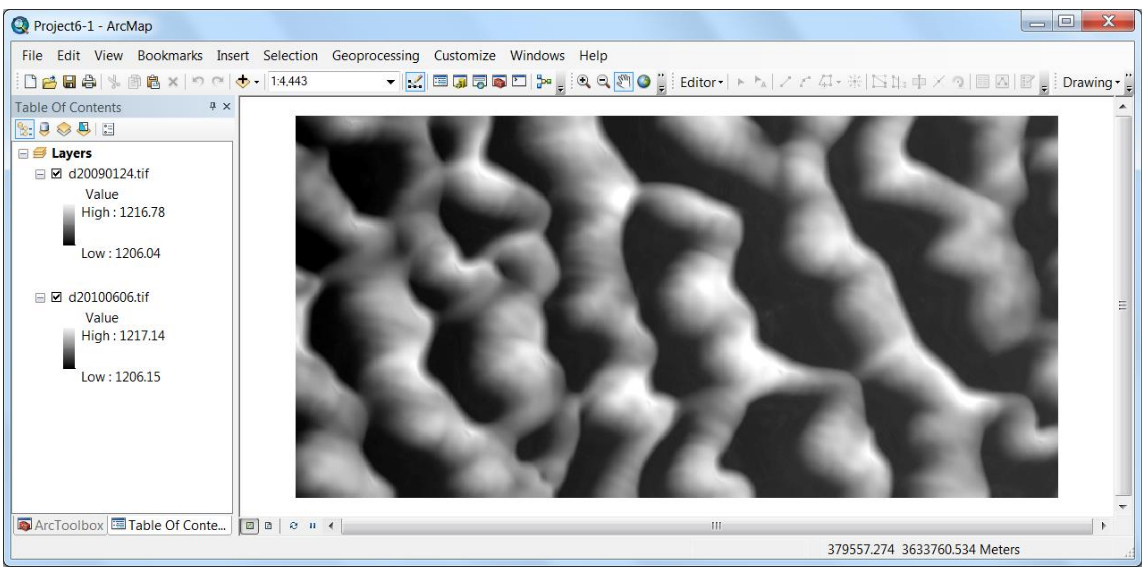

Figure 6.30. LiDAR-derived DEM (1-m resolution) of January 24, 2009 for the 401 m by 802 m test area.

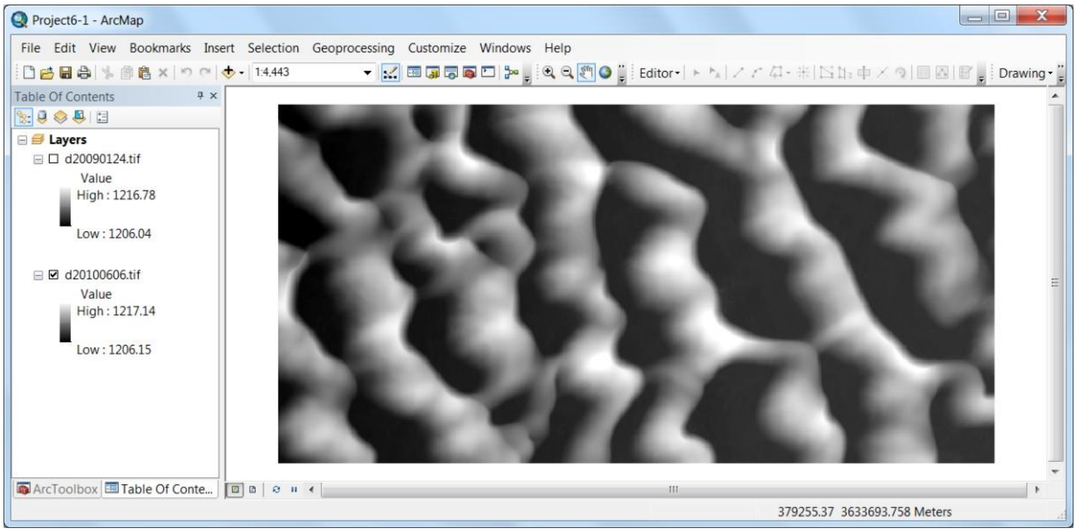

Figure 6.31. LiDAR-derived DEM (1-m resolution) of June 6, 2010 for the 401 m by 802 m test area.

(3) Create DEM profile. To better understand the concepts of slip face and angle of repose for sand dunes, open the Customize menu of ArcMap and select Toolbars → 3D Analyst to open the 3D Analyst toolbar. Select d20090124.tif as the 3D Analyst Layer on the toolbar, click the Interpolate Line tool, draw a straight line from left to right in the central part of the DEM for January 24, 2009, and click the Profile Graph icon on the 3D Analyst Toolbar to display the DEM profile (see Figure 6.32 for a sample).

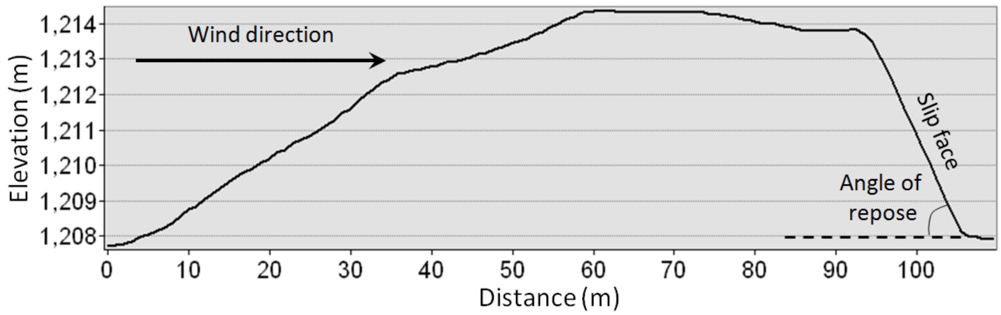

Figure 6.32. Sample profile for a single dune in the 2009 DEM. Note the vertical exaggeration.

(4) Create empty polyline shapefile in ArcCatalog, which will be used for storing polylines for slip face centers later in the project. Open ArcCatalog and select the project folder for Project6-1, then right click the ArcCatalog window and select “New” → “Shapefile…” to create a polyline shapefile “polyline20090124.shp”. To define the spatial reference of polyline20090124.shp, click the “Edit” button and import the spatial reference properties of the DEM raster “d20090124.tif”. Add polyline20090124.shp to ArcMap.

(5) Create a slope raster from the 2009 DEM. Open ArcToolbox → Spatial Analyst Tools →Surface → Slope, use “d20090124.tif” as the input raster to create the output slope raster “slp20090124” (Figure 6.33). The maximum slope is 35.604° in the slope raster. However, if raster cells with a slope value over 34.8 °are selected using the Raster Calculator, it can be seen that only several isolated cells are selected. These isolated cells with slope values greater than 34.8 °are probably caused by bushes or other objects in the desert, and can be easily removed in the next steps.

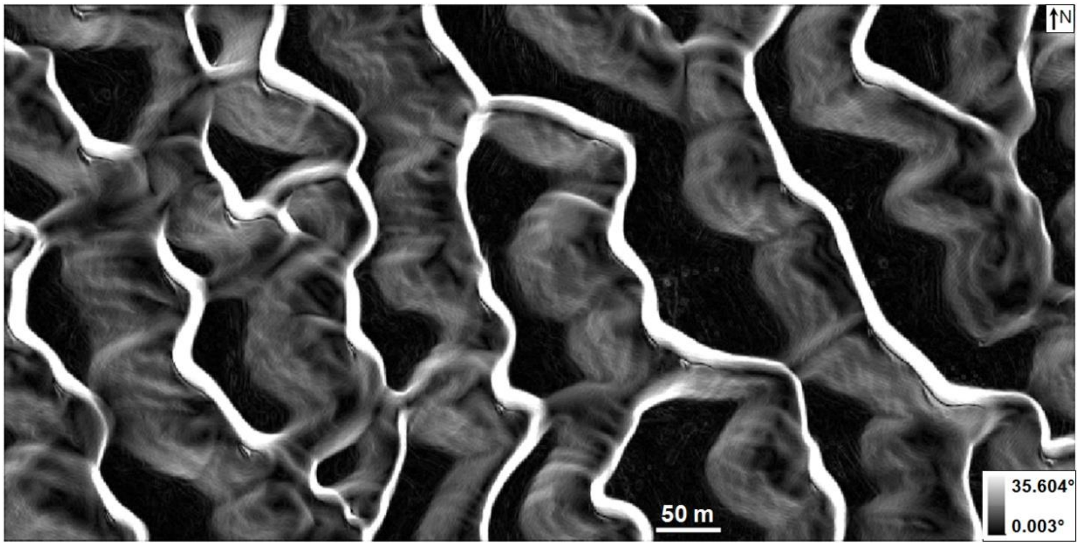

Figure 6.33. Slope raster derived from the DEM for January 24, 2009.

(6) Extract slip faces from the slope raster. In this project, slip faces are identified by selecting slopes greater than 30 ° and less than 35 °. Open ArcToolbox → Spatial analyst Tools → Map Algebra → Raster Calculator, use Con((("slp20090124" > 30) & ("slp20090124" < 35)), 1, 0) as the expression to create binary raster "face20090124" where 1's are for slip faces (black cells in Figure 6.34), and 0's for other cells.

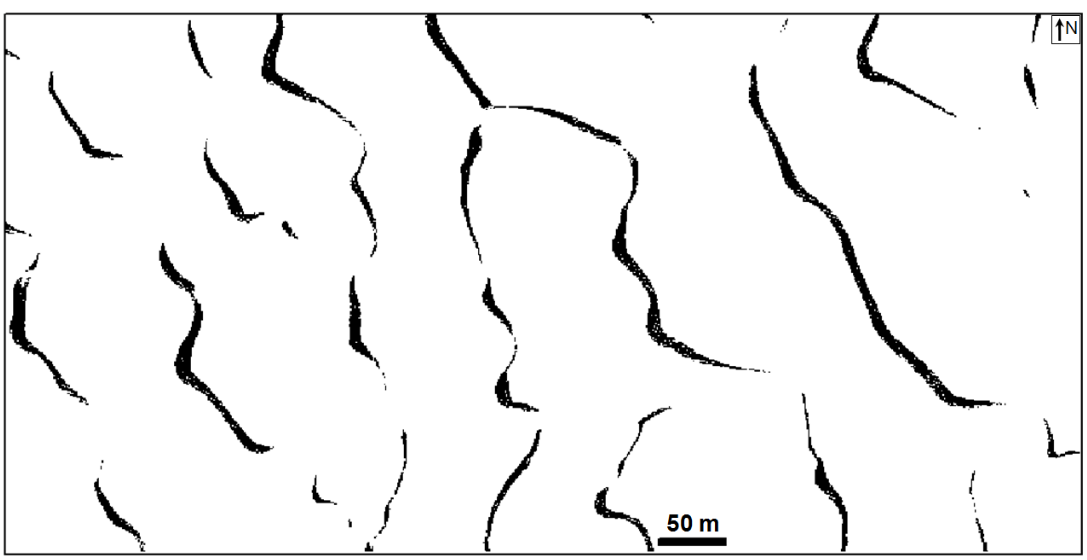

Figure 6.34. Binary raster "face20090124" for slip faces.

(7) Edit binary raster for slip faces. Open the “Customize” menu of ArcMap and select Toolbars → Editor. Right-click the binary raster layer “face20090124” in the ArcMap table of contents, then select Editing Features → Start Editing. Then open the Customize menu in ArcMap and select Toolbars → ArcScan. Select “face20090124” as the ArcScan Raster Layer for the ArcScan Toolbar (Figure 6.35).

Figure 6.35. ArcScan Toolbar in ArcMap.

Open the Raster Cleanup menu on the ArcScan Toolbar (Figure 6.35) and select “Start Cleanup” to enable the tools under the Raster Cleanup menu. Select the mathematical morphological operation “Closing…” under the Raster Cleanup menu, put 1 as the number of pixels, and click OK remove noises in the binary raster.

(8) Create polylines from slip face centerlines through vectorization. Open the Vectorization menu on the ArcScan Toolbar (Figure 6.35) and use the default settings and options, then click “Show Preview” under the Vectorization menu to see the preview. In this project, the default settings work fine, so you do not need to make any changes. Right-click the empty polyline shapefile “polyline20090124.shp” on the ArcMap table of contents, and select Editing Features → Start Editing. You will be asked if you want to save the edits to the raster “face20090124”. Click “Yes” to save the edits. Now select “Generate Features…” under the Vectorization menu of the ArcScan Toolbar, use “polyline20090124” as the template, and click OK to generate polyline features for slip face centerlines derived from the 2009 DEM. On the Editor toolbar, select Edit → Stopping Editing to save the edits to slip face centerlines. Figure 6.36 shows the slip face centerlines (polyline20090124.shp) over the 2009 DEM (d20090124.tif).

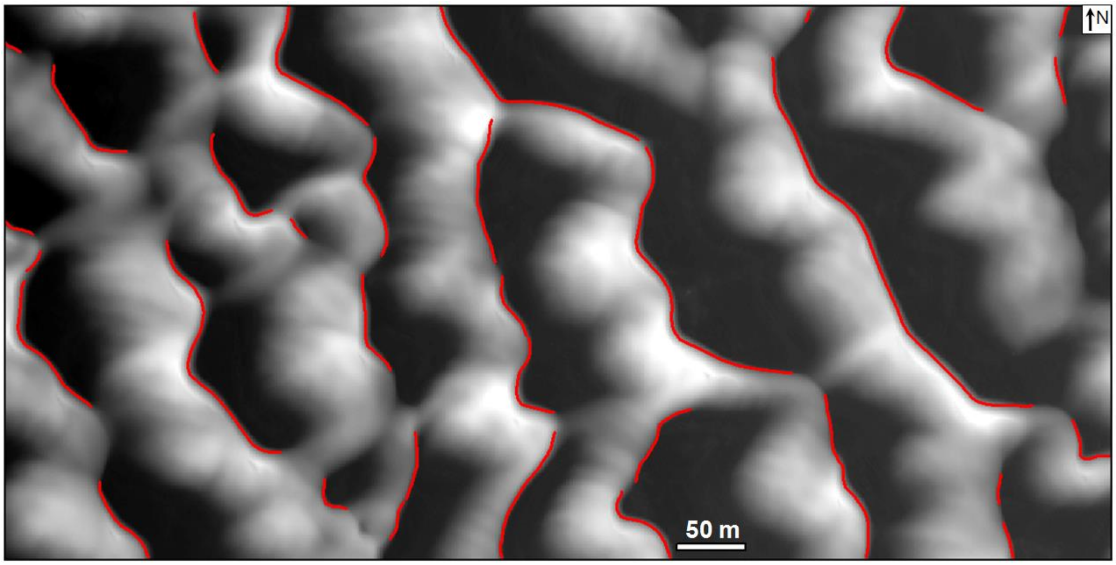

Figure 6.36. Extracted slip face centerlines over 2009 DEM.

As can be seen from Steps (4) – (8), it would be time-consuming to repeat the process using the DEM for June 6, 2010 (d20100606.tif) and follow the flowchart in Figure 6.4 to obtain the final results. Therefore, an ArcGIS add-in has been created by the author using the Python programming language to automate the whole process. The ArcGIS add-in "DuneMigration.esriaddin" is at the folder "project 8". In the following steps, the add-in will be installed, and source directions and dune migration rates will be calculated using the add-in toolbar.

(9) Install the "Dune Migration" add-in. Double click the file "DuneMigration.esriaddin" in the project folder to open the add-in Installation Utility window (Figure 6.37). Click the "Install add-in" button, and you should see a pop-up message: "Installation Succeeded."

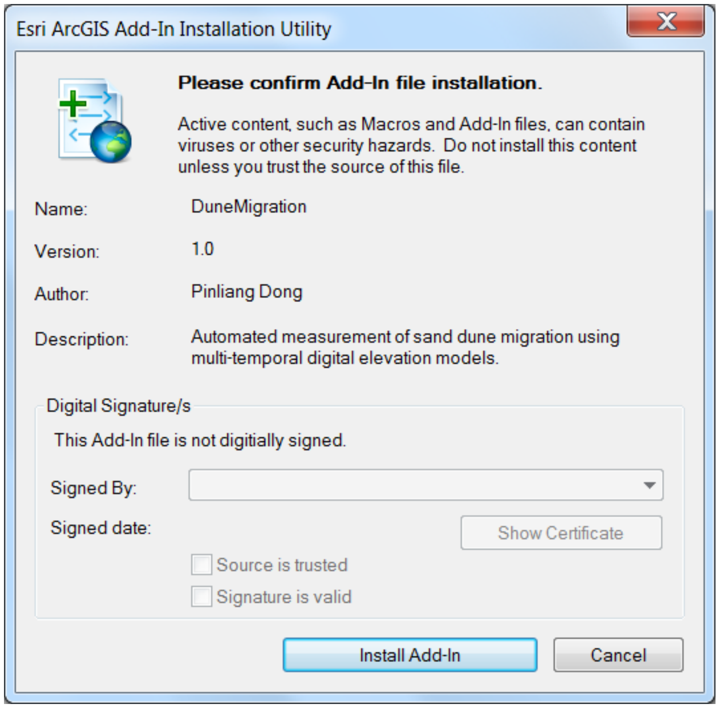

Figure 6.37. ArcGIS add-in installation utility.

(10) Load the Dune Migration add-in toolbar. Open the “Customize…” menu in ArcMap and select “Add-in Manager…”. Then select the “DuneMigration” add-in and click “Customize…” (Figure 6.38). In the Customize window, check the Dune Migration toolbar, then click “Close”. The Dune Migration toolbar should appear (Figure 6.39).

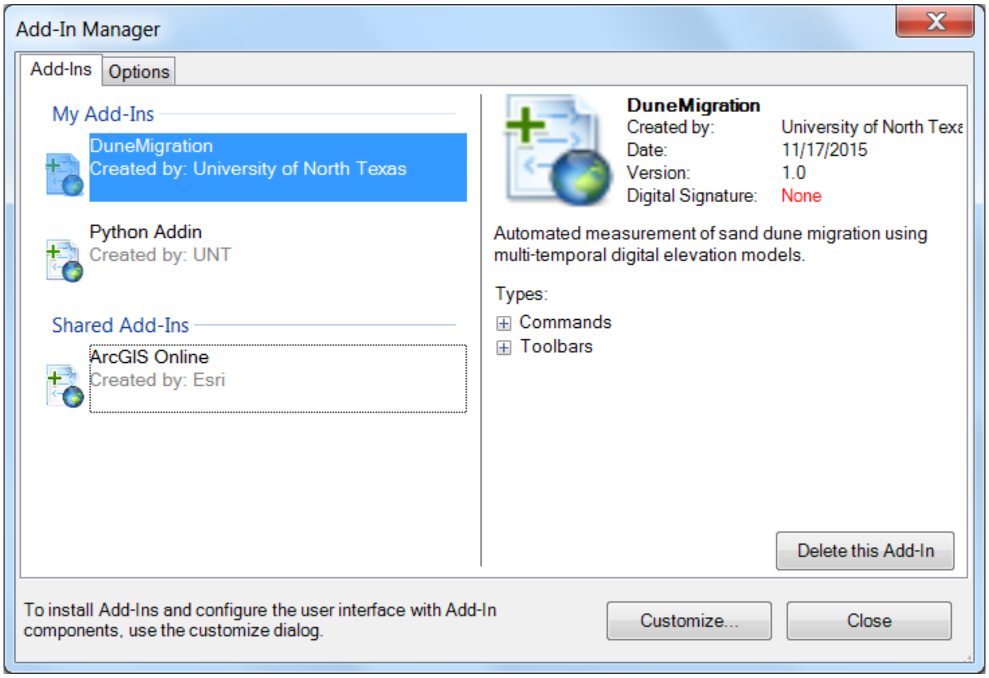

Figure 6.38. Add-in Manager for ArcMap.

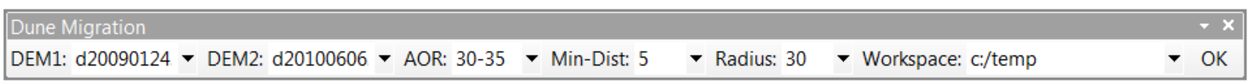

Figure 6.39. Dune Migration Toolbar for ArcMap.

(11) The parameters for the Dune Migration Toolbar in Figure 6.58 are explained below, and the results are shown in Figures 6.40 – 6.42.

(a) DEM1: The first DEM raster which can be created from LiDAR data or other data sources. The data acquisition date is contained in the DEM layer name in the format of YYYYMMDD, and the YYYYMMDD string can be any where in the DEM name as long as it is the first eight numbers, for example, A20090124DEM1. The DEM layer name can be changed by the user in ArcMap, and can be different from the actual file name.

(b) DEM2: The second DEM raster (similar to DEM1). The dates for DEM1 and DEM2 are used for calculating the time interval (number of days) between DEM1 and DEM2, which will be used to convert dune migration distance into migration rate at each sampling point.

(c) AOR: Angle of repose for sand dune slip faces. AOR is usually around 34°, depending on the sand grain size, shape and moisture content. Users can select/input a range, such as 30-35, as AOR values.

(d) Min-Dist: The minimum distance between two random points. The unit of distance is the same as the linear unit of the DEM layers.

(e) Radius: The search radius used to identify the nearest source point around a random target point. The unit of radius is the same as the linear unit of the DEM layers.

(f) Workspace: The folder for output rasters and shapefile. To ensure the geoprocessing steps are not affected by any existing files, there should be no existing files or folders in the workspace before a users clicks the OK button; otherwise a warning message will pop up.

(g) OK: Click OK to run the program. If there are any errors in the parameters on the toolbar, error messages will pop up. Results from the test data are shown in the following figures.

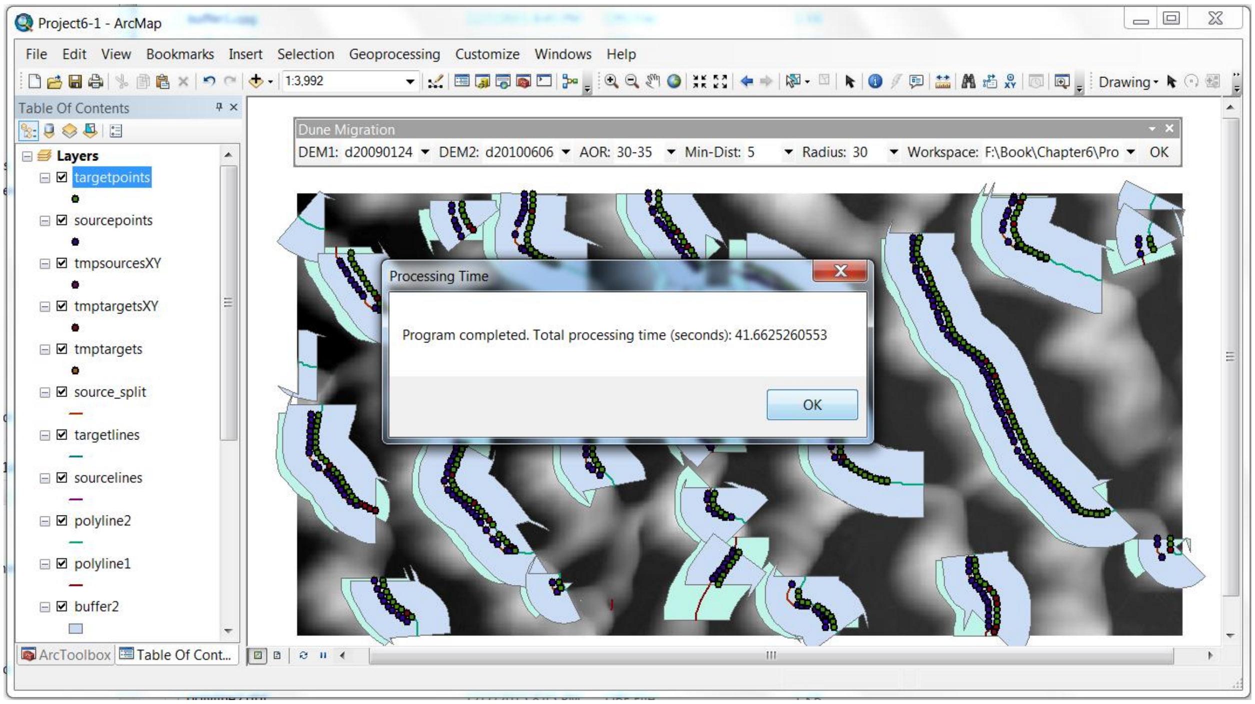

Figure 6.40. The test datasets were processed in less than 42 seconds.

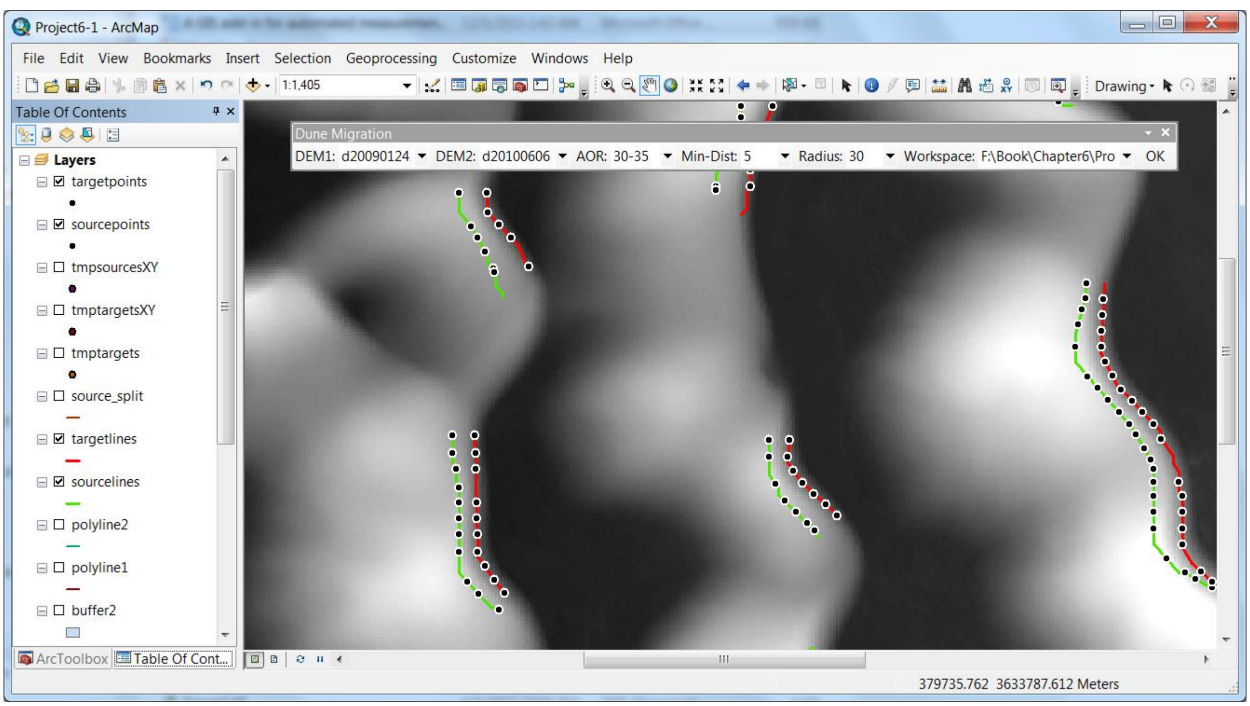

Figure 6.41. Target points on target lines (red, for June 6, 2010), and source points for source lines (Green, for January 24, 2009).

Table

targetpoints

FID	Shape *	NEAR_DIST	NEAR_X	NEAR_Y	NEAR_ANGLE	Azimuth0	Azimuth1	Diff_Azi	m_Rate
0	Point	10.045656	379426.9799	3634010.15506	-174.289407	264.289	174.289	90	7.36278
1	Point	9.590955	379427.487759	3634005.07647	-174.289407	264.289	174.289	90	7.02952
2	Point	10.108606	379429.487476	3633996.87115	-155.556045	245.556	155.556	90	7.40892
3	Point	10.168364	379431.583568	3633992.25974	-155.556045	245.556	155.556	90	7.45272
4	Point	10	380049.975701	3633979.95514	180	270	0	270	7.32932
5	Point	11.455775	380049.975701	3633975.2855	180	270	0	270	8.3963
6	Point	12.587863	380051.840124	3633966.60378	-161.565051	251.565	161.565	90	9.22604
7	Point	9	379605.975701	3634021.16765	180	270	0	270	6.59639
8	Point	9	379605.975701	3634015.97633	180	270	0	270	6.59639
9	Point	7.111591	379608.801112	3634007.25258	-150.255119	240.255	150.255	90	5.21231
10	Point	7.025692	379610.143614	3634004.5254	-165.963757	255.964	165.964	90	5.14935
11	Point	7.781547	379614.339523	3633997.31572	-139.085617	229.086	139.086	90	5.70334
12	Point	7.65866	379617.628123	3633993.52118	-139.085617	229.086	139.086	90	5.61328
13	Point	6.019416	379620.667891	3633990.01376	-139.085617	229.086	139.086	90	4.41182
14	Point	6.37817	379623.957318	3633986.21826	-139.085617	229.086	139.086	90	4.67476
15	Point	7.602758	379629.069294	3633977.41599	-140.710593	230.711	140.711	90	5.5723
16	Point	7.08949	379632.384508	3633973.36407	-140.710593	230.711	140.711	90	5.19611
17	Point	7.972901	379638.737329	3633964.16674	-136.974934	226.975	136.975	90	5.84359
18	Point	6.66975	379642.188065	3633960.46952	-136.974934	226.975	136.975	90	4.88847
19	Point	5.233663	379645.504543	3633956.91615	-136.974934	226.975	136.975	90	3.83592

0 (0 out of 282 Selected)

targetpoints

Figure 6.42. Attributes of target points. NEAR_DIST – migration distance, Azimuth0 – source direction, and m_Rate – migration rate (meters/year).

(12) Save your ArcMap project.

(13) Questions: (a) How can you show histograms of source directions and migration rates? (b) How can you create a continuous raster in ArcGIS to show dune migration rates in the study area?