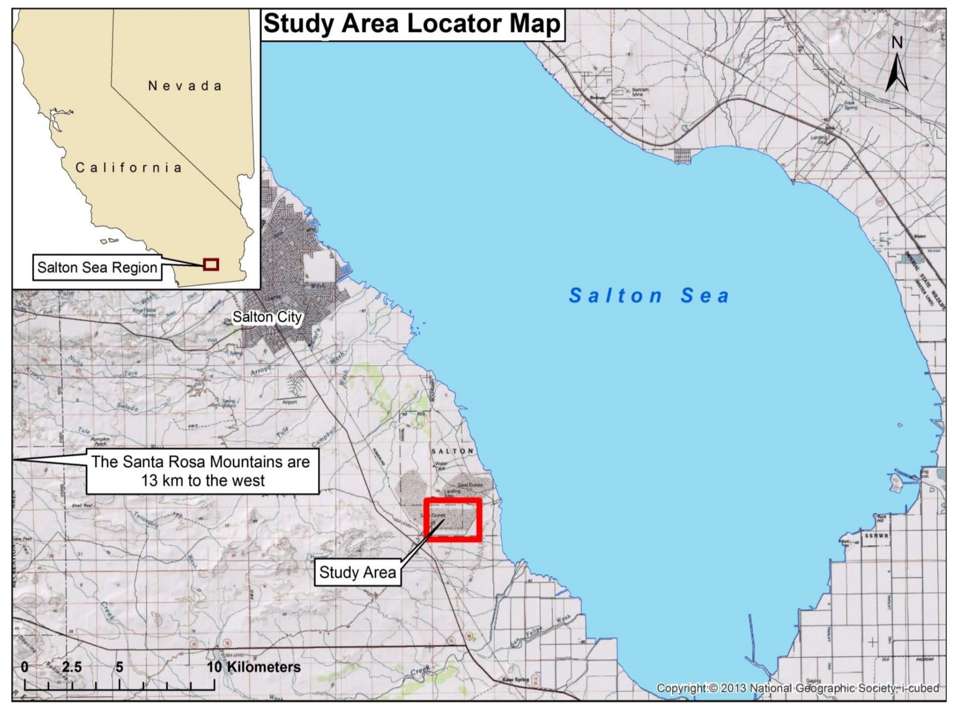
Quantification of Barchan Dune Evolution over Daily to Interannual Time Scales Using Airborne LIDAR and Terrestrial Laser Scanning

Michael P. Hoose[1], Jon D. Pelletier[2], Jacob Napieralski[1]
[1]Earth Sciences, University of Michigan – Dearborn, [2]Department of Geosciences, University of Arizona

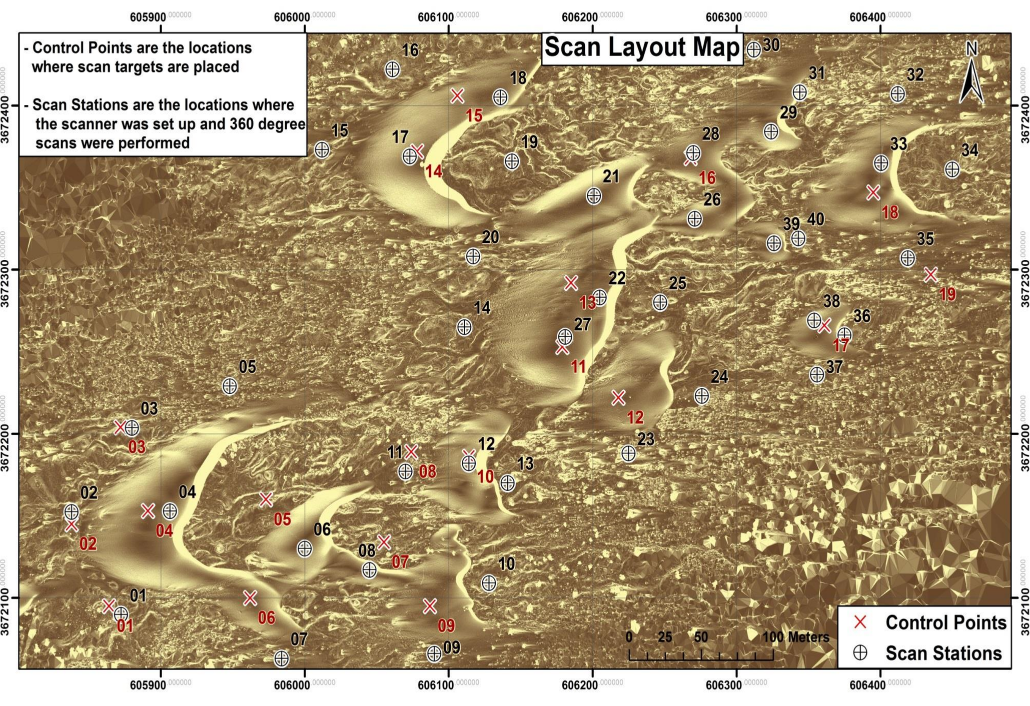
I Introduction and Study Area

- This project was undertaken as part of a 10-week NSF-funded REU at the University of Arizona's Biosphere 2 research facility.
- A combination of airborne and terrestrial LIDAR scanning (TLS) was used to analyze a 400m x 700m barchan dune cluster on 3-year, 3-month, 1-month, and 2-day intervals.
- The variety of time scales allows change to be analyzed for both dominant and subdominant wind regimes.
- The cluster is situated on lake bed deposits laid down by the adjacent Salton Sea.
- The sand supply is produced by wind erosion of the Santa Rosa Mountains that have been rising at 5cm/yr for the last 1myr.
- Historical lake level data suggests that the area was flooded as recently as 300 years ago, making this the upper limit for the dune field's age.



II Methods

- Bare-earth airborne LIDAR DEM was produced by the USGS with 5.1 returns per m² with a vertical accuracy of +/- 9.25 cm and was downloaded from opentopography.org.
- TLS data was collected using a Leica C10 laser scanner (top pic on right) capable of collecting 50,000 data points/sec with < 3cm horizontal accuracy and < 1 cm vertically.
- Forty full 360° scan stations were required to produce a seamless, shadow-less DEM of the dune cluster.
- The stations were mosaiced together using common control points (bottom pic on right) using the Leica Cyclone software suite.
- Five of the control points were surveyed to < 1cm accuracy with a Leica RTK GPS to allow the mosaiced scan to be georeferenced.
- Arcmap was used to produce the change maps (Figs 1-4) and to calculate the tabulated symmetry data (Table).
- PHOENICS Computational Fluid Dynamics Solver was used to produce Figs 5, 6, and 7.

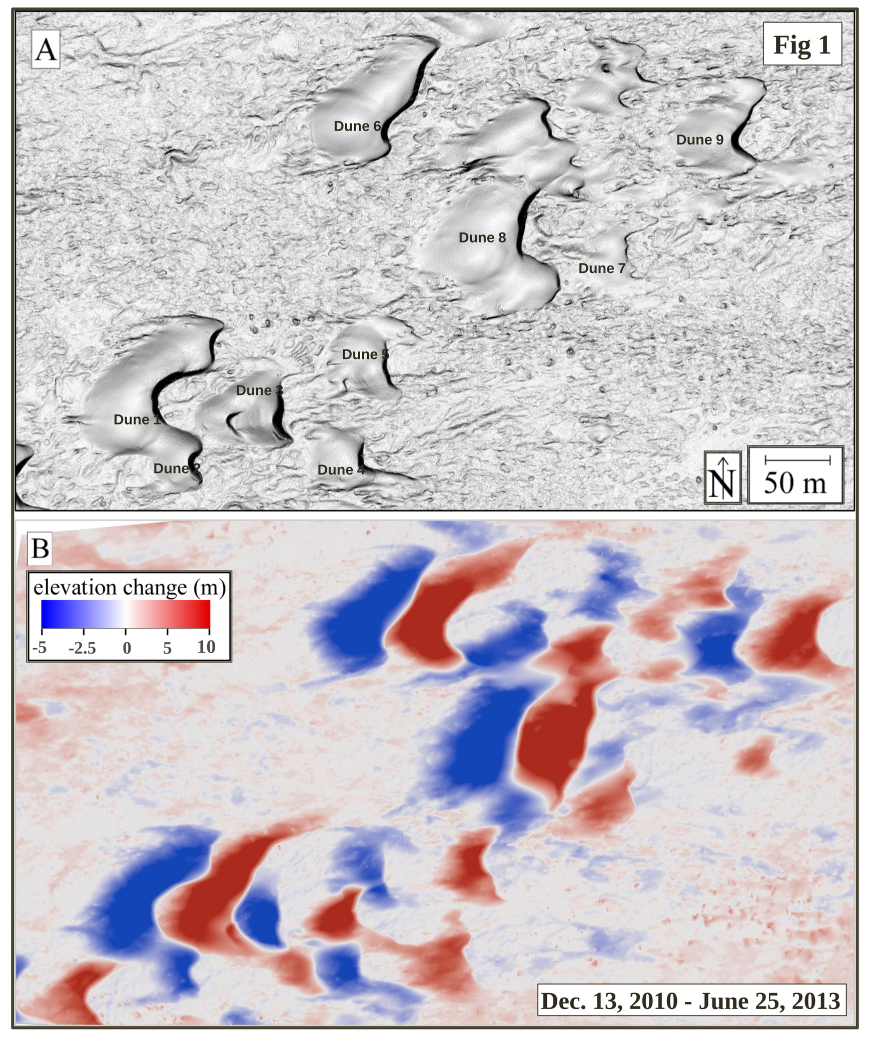


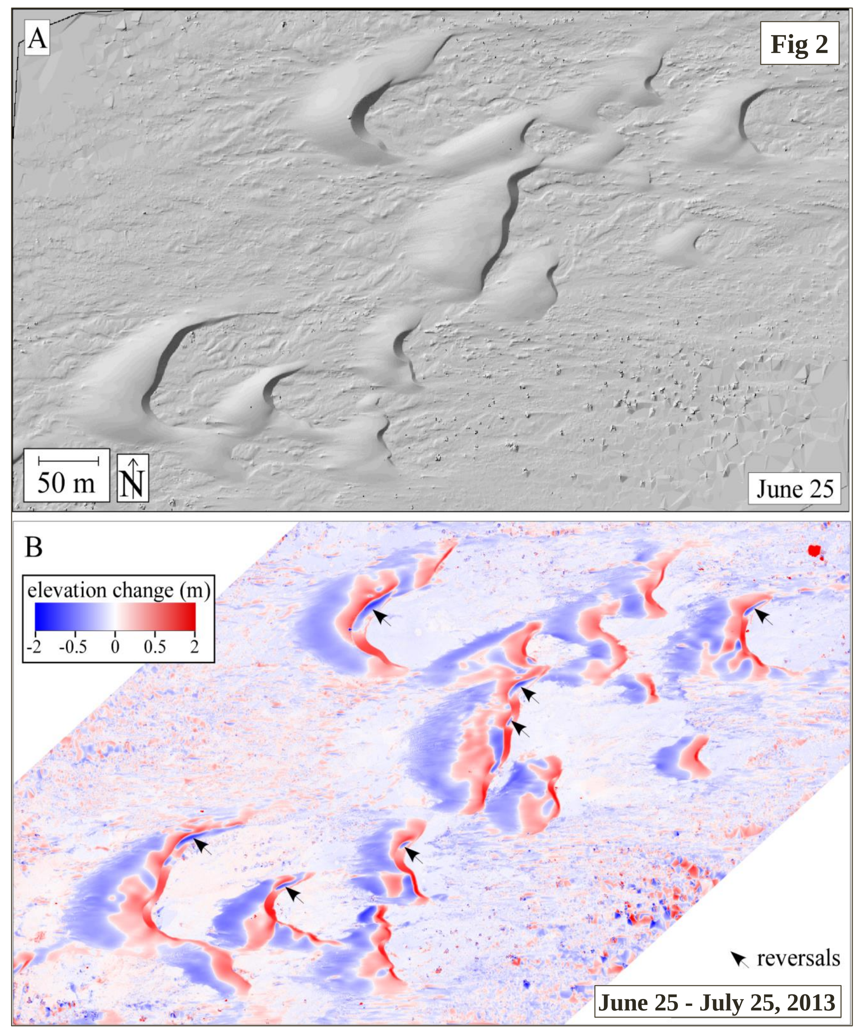
III Results

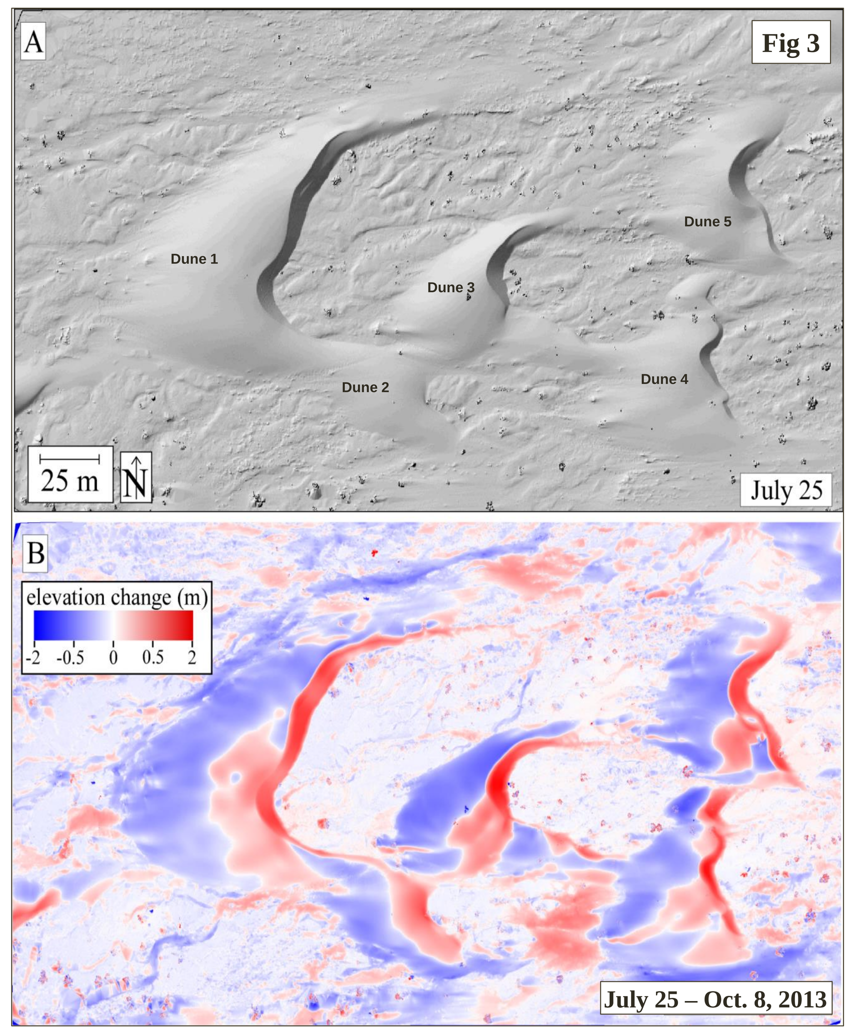
a) Over the 3-year period (Fig 1) the 9 study dunes show a pattern of pure erosion on their stoss sides and deposition along their slip faces, resulting in uniform movement within +/- 1° of due west (vectors calculated in Arcmap).
   i. Winds were predominately W/WSW (Fig 5A).
   ii. Symmetry decreased in 8 of the 9 dunes as the N sides gained in% volume (Table).

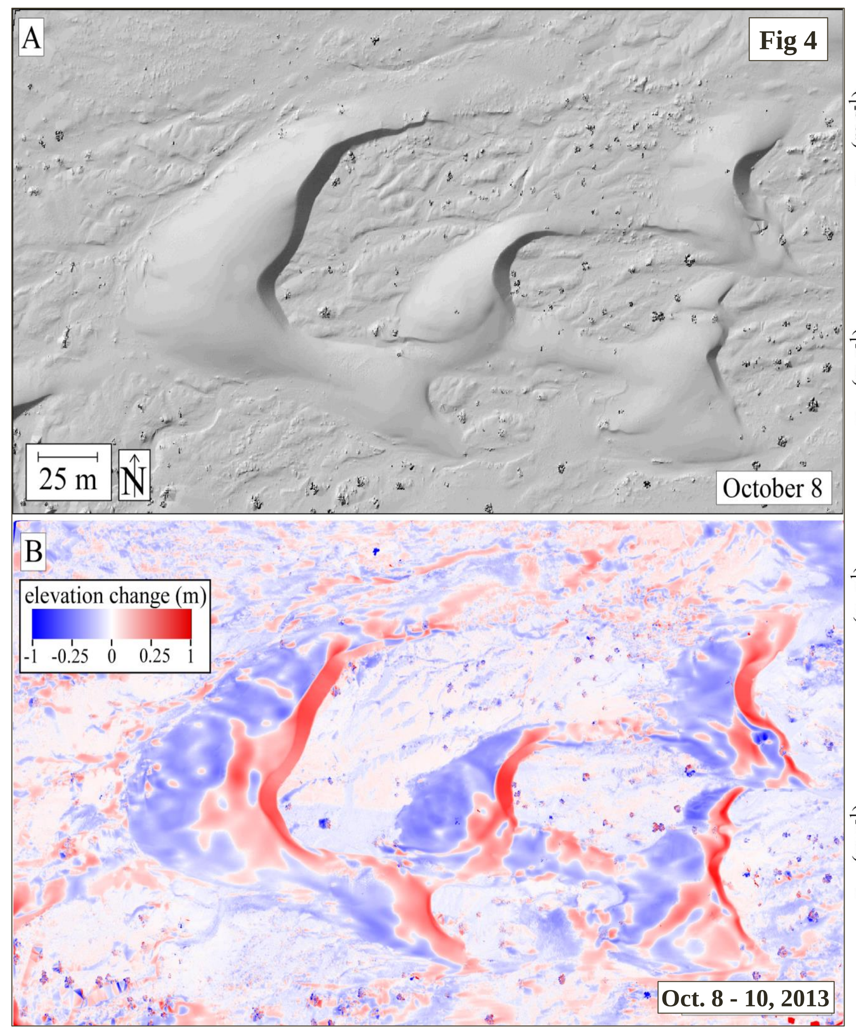
b) Over the 1-month period (Fig 2) erosional wedges formed on the SE-facing portions of dunes 1, 3, 5, 6, 9 and along the central barchanoid ridge while symmetry increased in dunes 2, 3, 4, 5, and 7 (Table).
   i. All 9 dunes also show deposition along their crests and upper stoss sides.

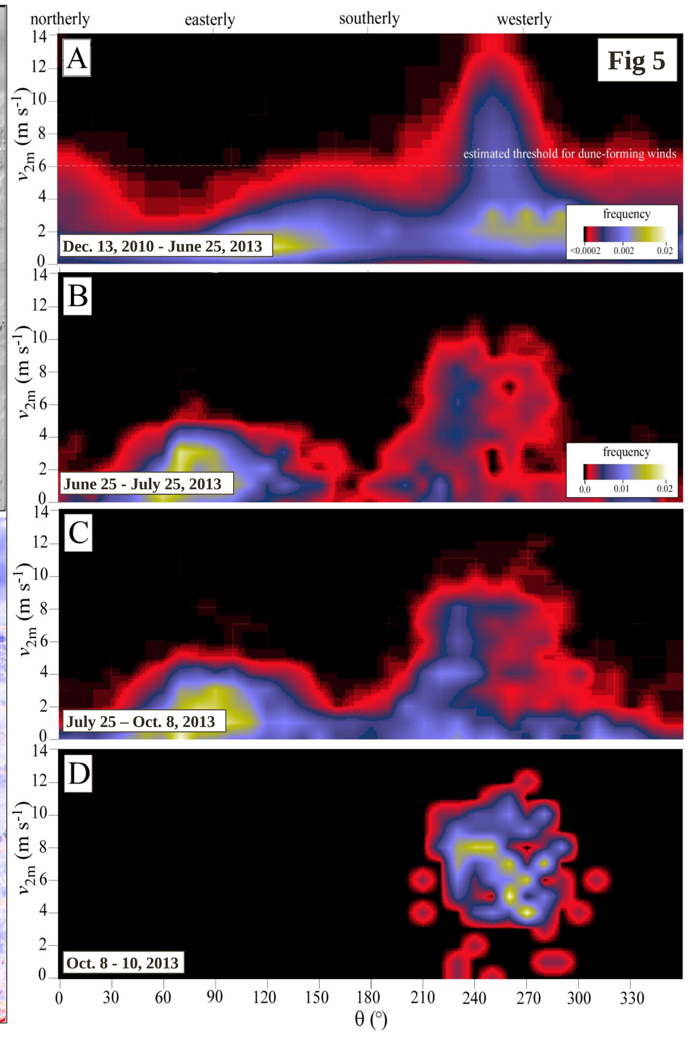
c) Over the 3-month and 2-day periods (Figs 3/4) the 9 study dunes show mainly stoss-side erosion and slip-face deposition with some deposition on their S stoss sides.
   i. Winds for both periods were largely W/WSW with the 3-month period seeing scarce easterly wind events (Figs 5C/5D).

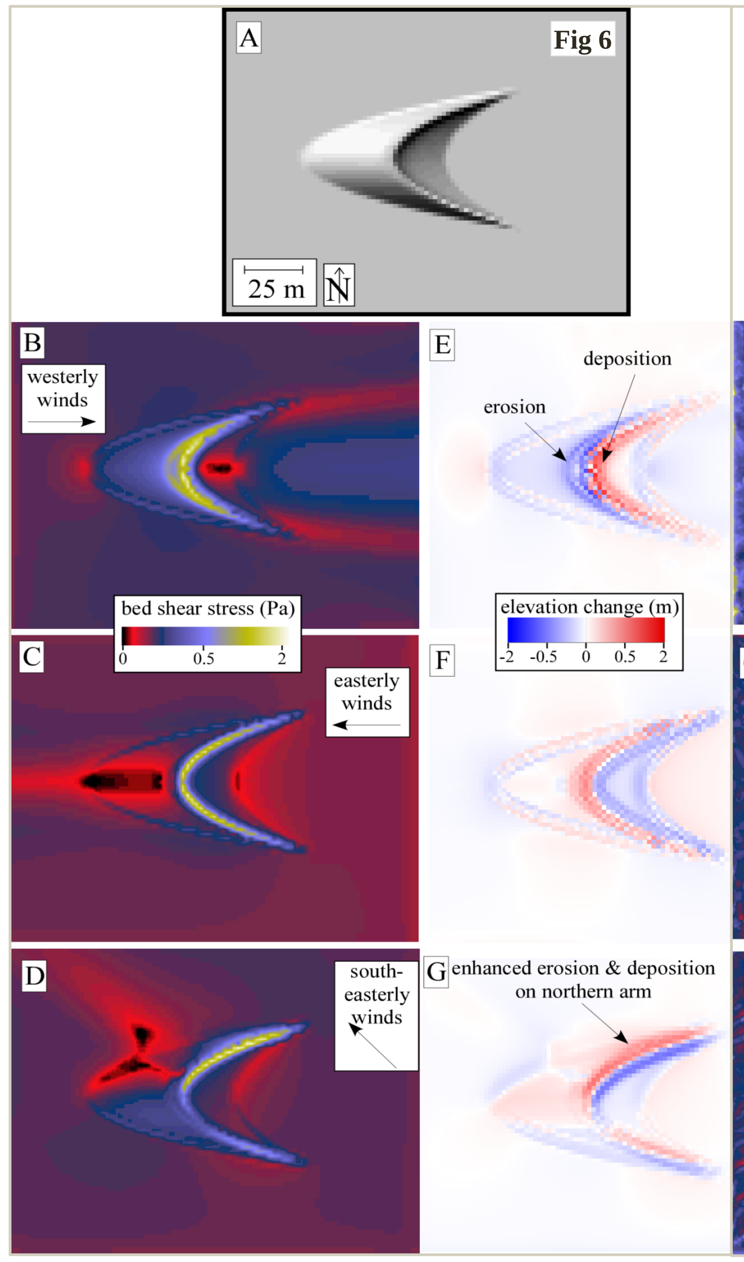


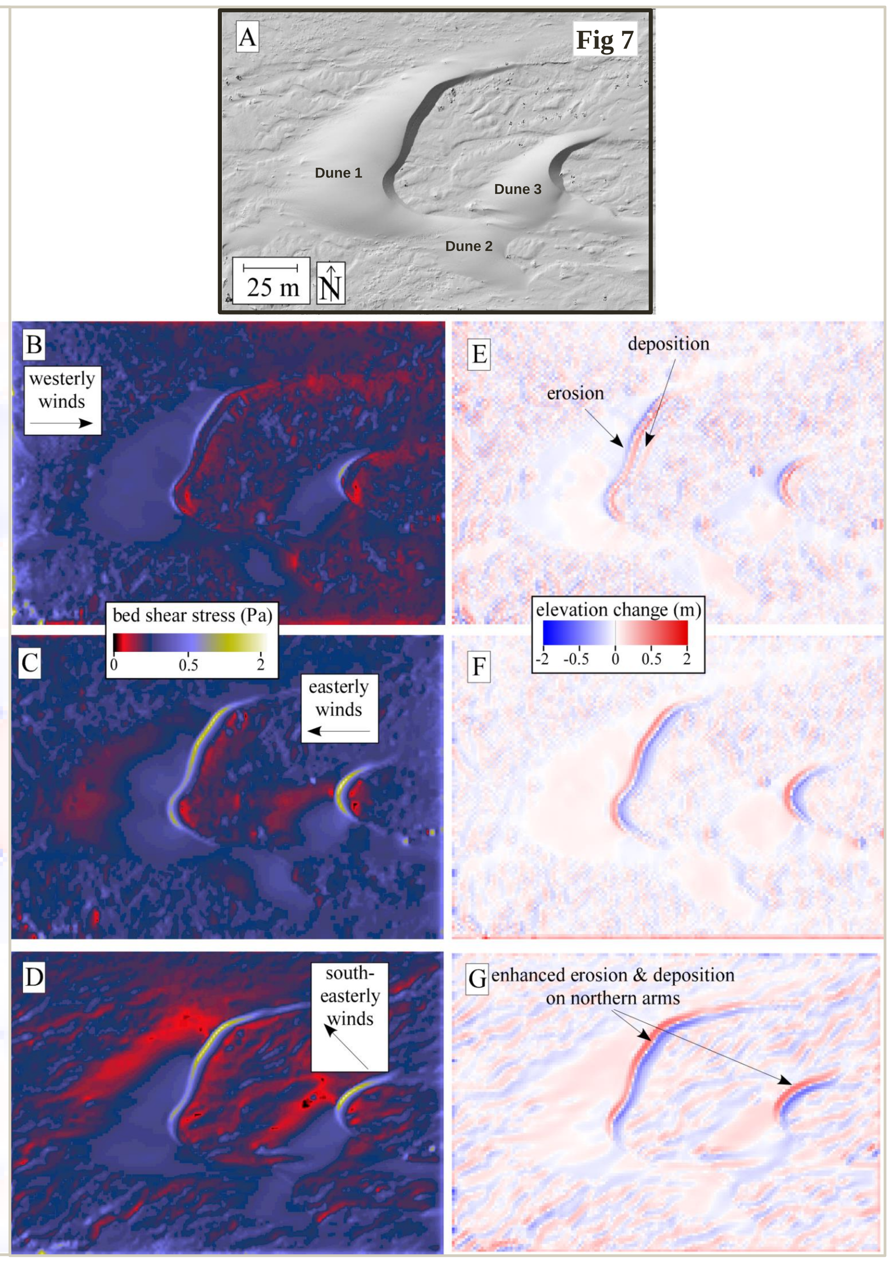












Dune Name	11/13/10 Volumes (N%/S%)	06/25/13 Volumes (N%/S%)	07/30/13 Volumes (N %/S %)
Dune 1	50.40 / 49.60	62.61 / 37.39	62.62 / 37.38
Dune 2	56.58 / 43.42	61.45 / 38.55	52.82 / 47.18
Dune 3	44.91 / 55.09	49.59 / 50.41	46.69 / 53.31
Dune 4	39.76 / 60.24	41.70 / 58.30	39.88 / 60.12
Dune 5	46.83 / 53.17	48.23 / 51.77	47.49 / 52.51
Dune 6	44.89 / 55.11	62.77 / 37.23	62.94 / 37.06
Dune 7	52.02 /47.98	55.07 / 44.93	53.75 / 46.25
Dune 8	50.86 / 49.14	49.15 / 50.85	54.22 / 45.78
Dune 9	42.88 / 57.12	45.87 / 54.13	47.77 / 52.23

V References

- Pelletier, J. D. "Deviations from self-similarity in barchan dune form and migration rates: The case of the Salton Sea dunes, Imperial County, California." *Department of Geosciences, University of Arizona, Tucson, Arizona* (2013)
- Jerolmack, D. J., et al. "Internal boundary layer model for the evolution of desert dune fields." *Nature Geoscience* Vol. 5 (March 2012): 206-209.
- Airborne LIDAR data produced by USGS and downloaded from opentopography.org
- Wind data downloaded from the Citizen's Wx Observation Project (http://wxqa.com) (Station DW1021)

QR code links to a downloadable e-version of this poster

IV Discussion

Over interannual time periods the dune field sees mainly westerlies with occasional SW winds (Fig 5A). Using PHOENICS, these winds were modeled flowing over both a geometrically perfect barchan (Fig 6) and dunes 1-3 of the study cluster (Fig 7). In both cases the shear stress rises going up the stoss side as the wind is forced to converge (Figs 6B/7B), reaching a maximum at the crest before the dropping suddenly when the flow becomes diffuse and separated with the abrupt removal of the rising topography. Erosion and deposition (Figs 6E/7E) follow the same pattern as convergence and high shear at and near the crest causes transport (erosion) and the sudden flow separation and formation of a turbulent internal boundary layer (IBL) allows the sand to immediately be deposited upon encountering the slip face. Thru this mechanism the dune continuously migrates along the path of the predominant wind direction. Changes in symmetry over this period are hypothesized to be caused by steering from the occasional SW winds (Table).

The erosional wedges formed from frequent SE wind reversals during the month from late-June to July (Fig 5B) also occurred in both the idealized and real-world dune models. In the models, shear stress spikes due to rapid convergence when the air flow encounters the dune's SE-facing arms, causing erosion along that portion of the crest and upper slip face (Figs 6D/6G/7D/7G). Unlike in the case of predominant westerlies, when the wind tops the crest going "backwards," the gradual stoss slope causes less abrupt diffusion and a thinner IBL to develop. The sand is still deposited, but it takes place over a longer distance, creating a large zone of deposition along the N stoss side that grades out gradually (Fig 5B). It is unclear whether all of the sand transported during wedge creation is deposited on the stoss slope, but the increase in symmetry observed in 5 of the 9 study dunes hints that some material may be removed from the N arm (Table). Also evident over this period is a shortening of the dunes along their path of movement as material is eroded from the slip face and deposited along the upper reaches of the stoss sides (Fig 5B). It is possible that the spattering of E winds had the same effects as SE winds, only distributed more evenly along the dune (Fig 6C/6F/7C/7F). In the control point photo (above) the small gullies cut into the crest of dune 6 were the first observed responses as the wind suddenly shifted to the east and material was carried down the stoss slope.

The winds during both the 2-day and 3-month periods were largely out of W/WSW with a few E winds occurring during the latter (Figs 5C/5D). Despite this, the change maps are very similar with small areas of deposition along the dune's S stoss slopes; a configuration which is essentially a majority of W wind boundary conditions (Figs 6B/6E/7B/7E) with a minority of E wind conditions superimposed on top (Figs 6C/6F/7C/7F). The fact that this occurred during the 2-day period with no east winds may mean that even minor reversals that take place in between the CWOP's (Citizen's Wx Observation Program's) 10-minute data intervals are enough to produce stoss side deposition.

This research suggests that the classical view of pure stoss side erosion/slip face deposition is only emergent for interannual time scales when the palimsestic features created by short-term variability are overwritten by the area's aggregate conditions.