# Evaluating the recovery of beach-dune systems from the 2016 El Niño using unmanned aerial systems (UAS) and terrestrial laser scanning (TLS)

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**Abstract**

This paper compares and contrasts UAS-based Structure from Motion (SfM) and TLS survey methods as applied to evaluate the impacts of, and recovery from, the extreme El Niño 2015-16 on the seasonal geomorphic and sediment budget responses of an embayed, high-energy beach-dune system on the central coast of British Columbia, Canada. TLS and UAS mapping campaigns over a two-year period provided seasonal bare-earth digital terrain models (DTMs) and orthophoto mosaics. Spatial-temporal change detection methods were used to quantify volumes of significant erosion and deposition within the beach-dune system. The frequency and magnitude of erosive events and aeolian activity were also estimated from oblique, time-lapse photography. During the 2015-16 El Niño season, elevated water levels and storm waves eroded the foredune and lowered the beach surface by ˜ 1m. Erosion was greatest in the middle of the beach with dune scarping of over 2m where wave energy was focused. Minor accretion occurred during the summer of 2016 on the upper beach, and ramp rebuilding was observed mostly from slumping and avalanching of existing dune sands. The following winter 2017 storm season led to minor erosion on the beach and extensive incipient dune development and sand ramp recovery fronting the foredune to an extent close to pre-El Niño elevations. Comparison of change surfaces between methods revealed limitations in the SfM method, namely due to vegetation effects on DTM generation, which limit its ability to detect change in the coastal environment. The costs, time, logistics, and accuracy for both SfM and TLS survey methodologies for coastal geomorphic change detection analysis is also evaluated. Combined, the UAS and SfM workflow provides a competitive solution to more expensive and time-consuming survey methods, such as TLS and aerial LiDAR, but its utility and accuracy is highly dependent on research objectives and post-processing techniques.

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**Figure 1.** West Beach, NW Calvert Island (red star) on the central coast of British Columbia, Canada, 600km north of Vancouver. The beach is macrotidal, and exposed to high energy wind & wave regimes. Blue polygon shows study area. Black box shows time-lapse camera from Fig 3. (credit: K. Holmes – Hakai Geospatial, M. Grilliot)

## Research Context

- Emerging 'near field' remote sensing geospatial technologies have increased the efficiency and accuracy of topographic surveys.[1,2,3,4,5]
- Lidar and Structure from Motion Multi-View Stereo (SfM) methods provide cm-scale 3-D surface models of coastal environments.[1,2,6,7]
- Coastal sand ecosystems are rare and important in British Columbia[8,9]:
  - ✓ supports rare & endangered species
  - ✓ offers recreation opportunities
  - ✓ provide a protective buffer from large storms

## Objectives

1. Evaluate the erosion-recovery cycle of a beach-dune system to a large storm occurring during the El Niño 2016 season (9 March 2016).
2. Examine the performance of TLS & SfM methods for quantifying morphological change on a high energy beach-dune system on Calvert Island, BC, Canada.
3. Provide recommendations for applying TLS and SfM methodologies to examine different scales of change in beach-dune systems.

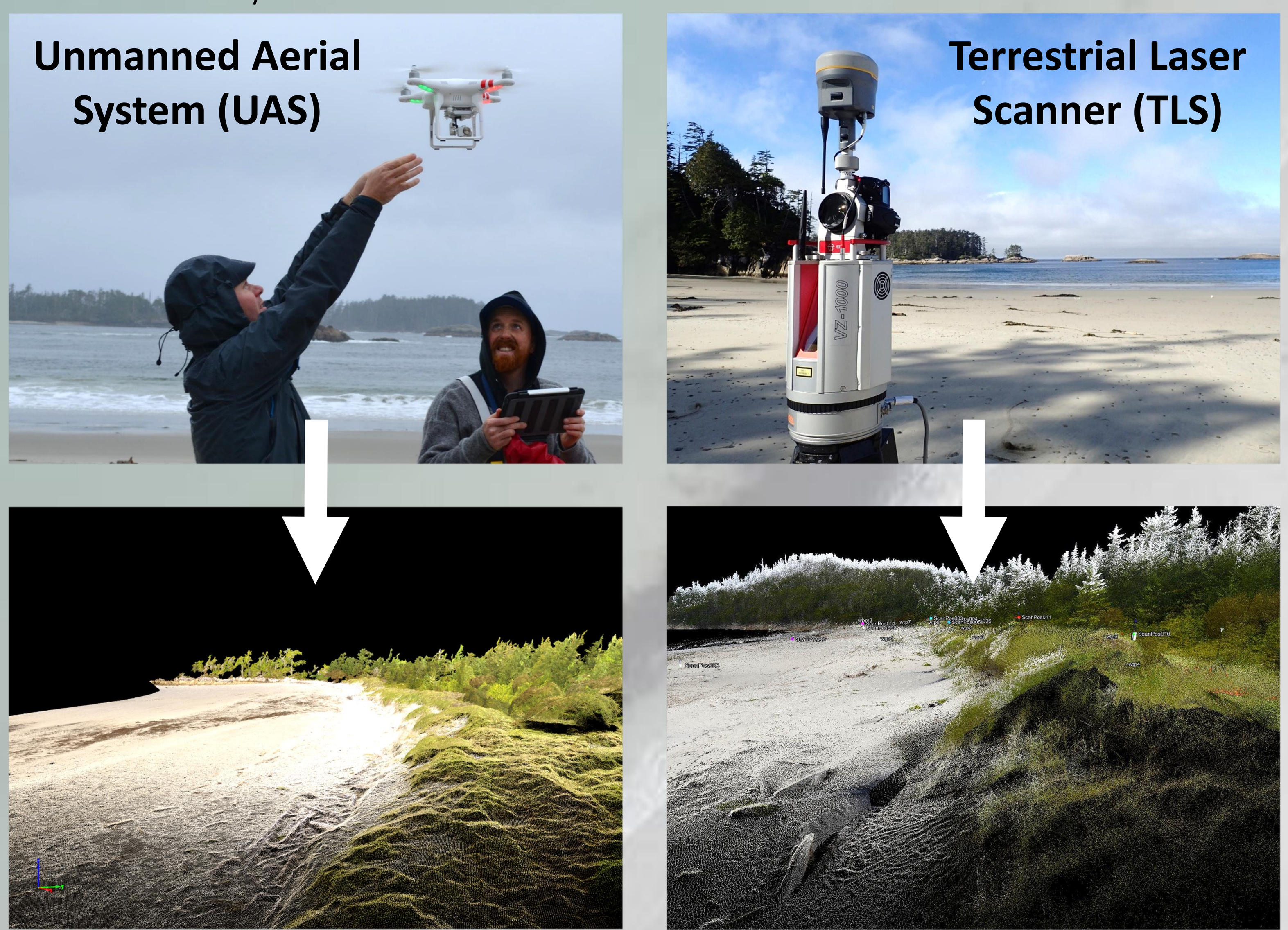



**Figure 2.** Examples of UAS (Left) and TLS (Right) deployment and resulting 3D point clouds.


**Figure 3.** West Beach Dune, looking East, showing pre-event, post-event, and recovery conditions. Position of scarp crown on March 10, 2016 shown as red dashed line in all panels. Camera location is shown on Figure 1.

## Data & Methods

- TLS data:
  - → Rigel VZ-1000 scanner w/ GNSS positioning via Trimble R-10 RTK-GPS.
  - → Registered using Ri-SCAN PRO©'s & Multi-station adjustment (RMSE < 1 cm). Validated via erosion pins & GNSS (RMSE < 2 cm)
- SfM data:
  - → DJI Phantom 3 Pro. GCPs via Trimble R-10 RTK-GPS.
  - → SfM-MVS processing – Photoscan Pro© 1.3. [4,5,11]
  - → Systemic Error Validation – SfMgeoref [12,13]
- Timelapse data:
  - → Harbortronics mounts, 15-min interval.
- 5cm DTMs generated for each of coincident TLS and SfM datasets. Inverse distance weighted (IDW) interpolation.
- Geomorphic Change Detection (GCD) method[10] examines spatial distribution of surface elevation changes between repeat surveys. Sediment volume changes quantified for distinct geomorphic units (beach, incipient dune, foredune) (Fig. 4)
  - → uncertainty accounted for in GCD model by a t-test & confidence interval (p=0.05) based on TLS & SfM vertical uncertainty (±0.02 m & ±0.05 m, respectively).

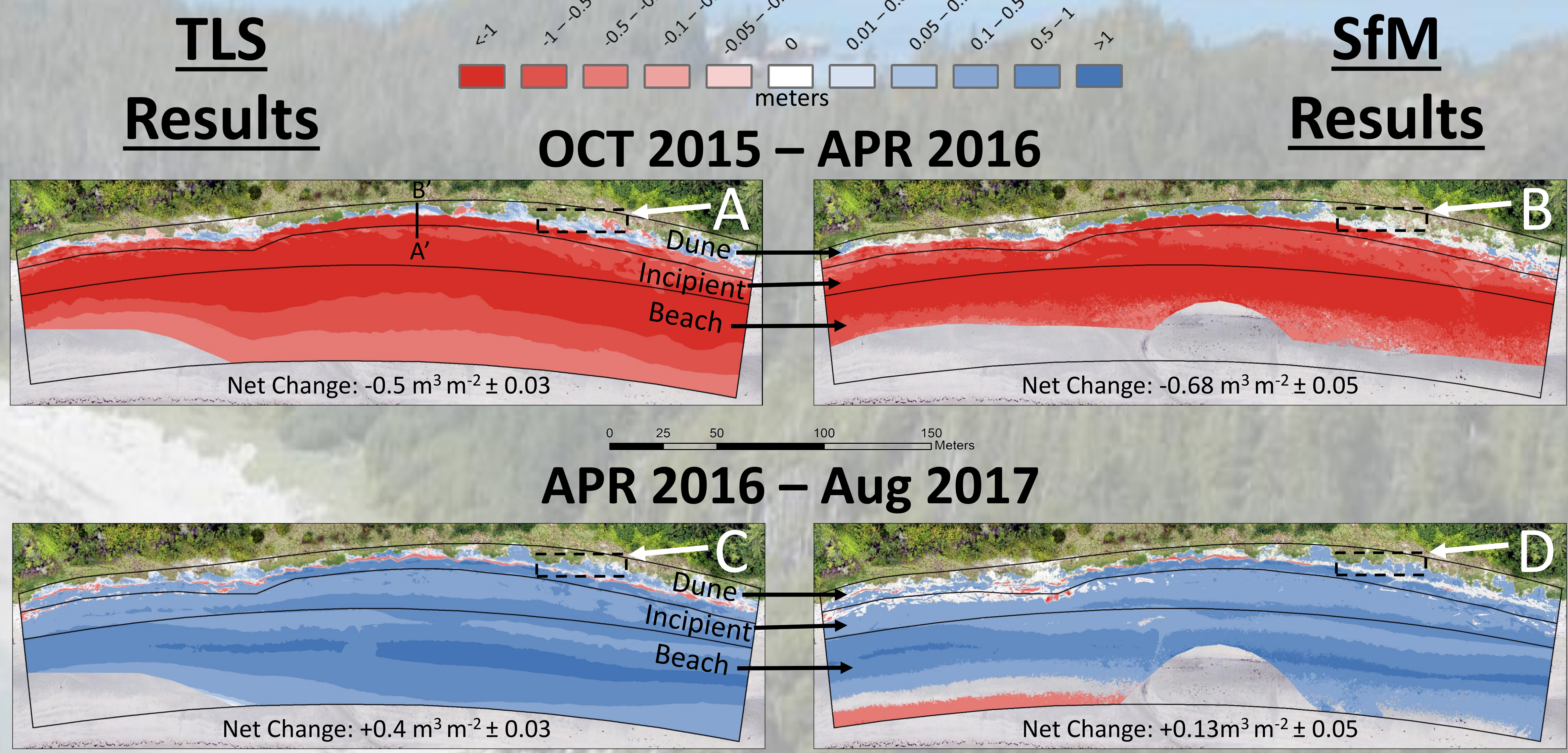



**Figure 4.** (Above) TLS (left) & SfM (right) derived change maps showing statistically significant patterns in surface erosion (red) or deposition (blue) for October 2015 to April 2016 (top) and April 2016 to August 2017 (bottom). Only pixels with significant change (p > 0.05) are shown. Dashed boxes represent locations of detail presented in figure 5, below. Line A'B' in upper left panel shows the profile in Figure 7.

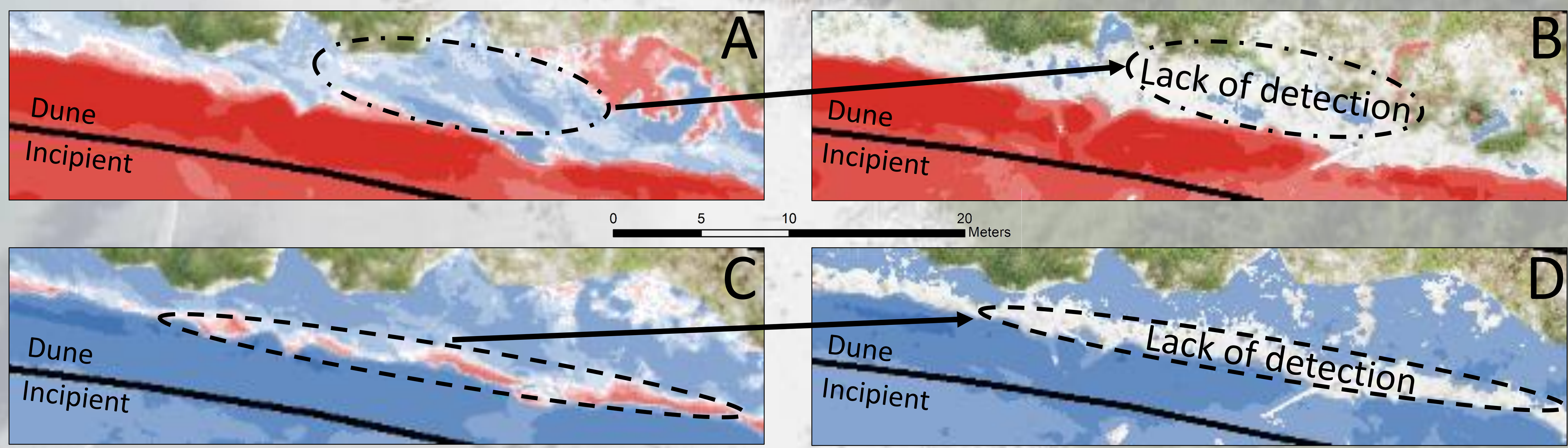



**Figure 5.** Detail of TLS (A & C) & SfM (B & D) derived change maps from figure 4. Note the inability of SfM to detect less than 10 cm of deposition on the dune from Oct 15' to Apr 16' and the erosion of the scarp crown from Apr 16' to Aug 17'

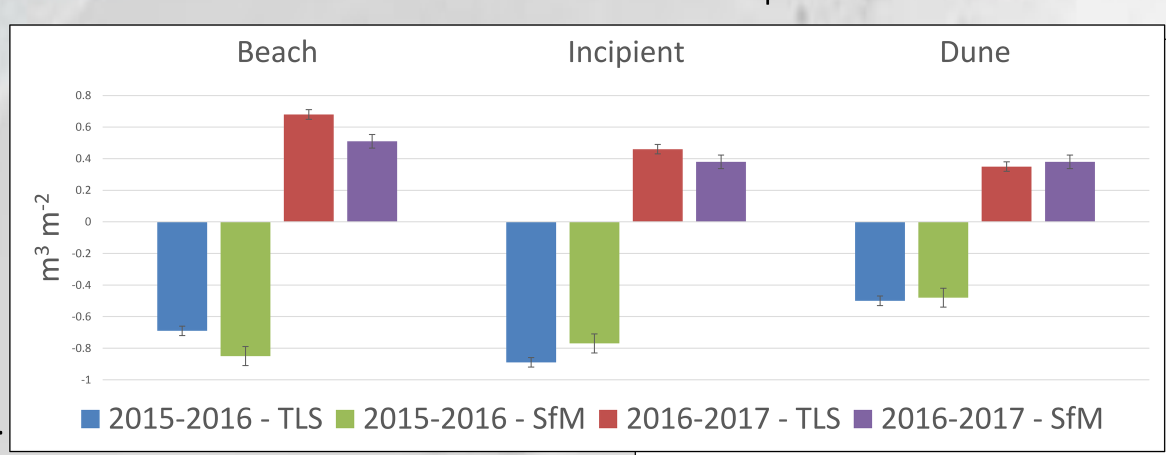
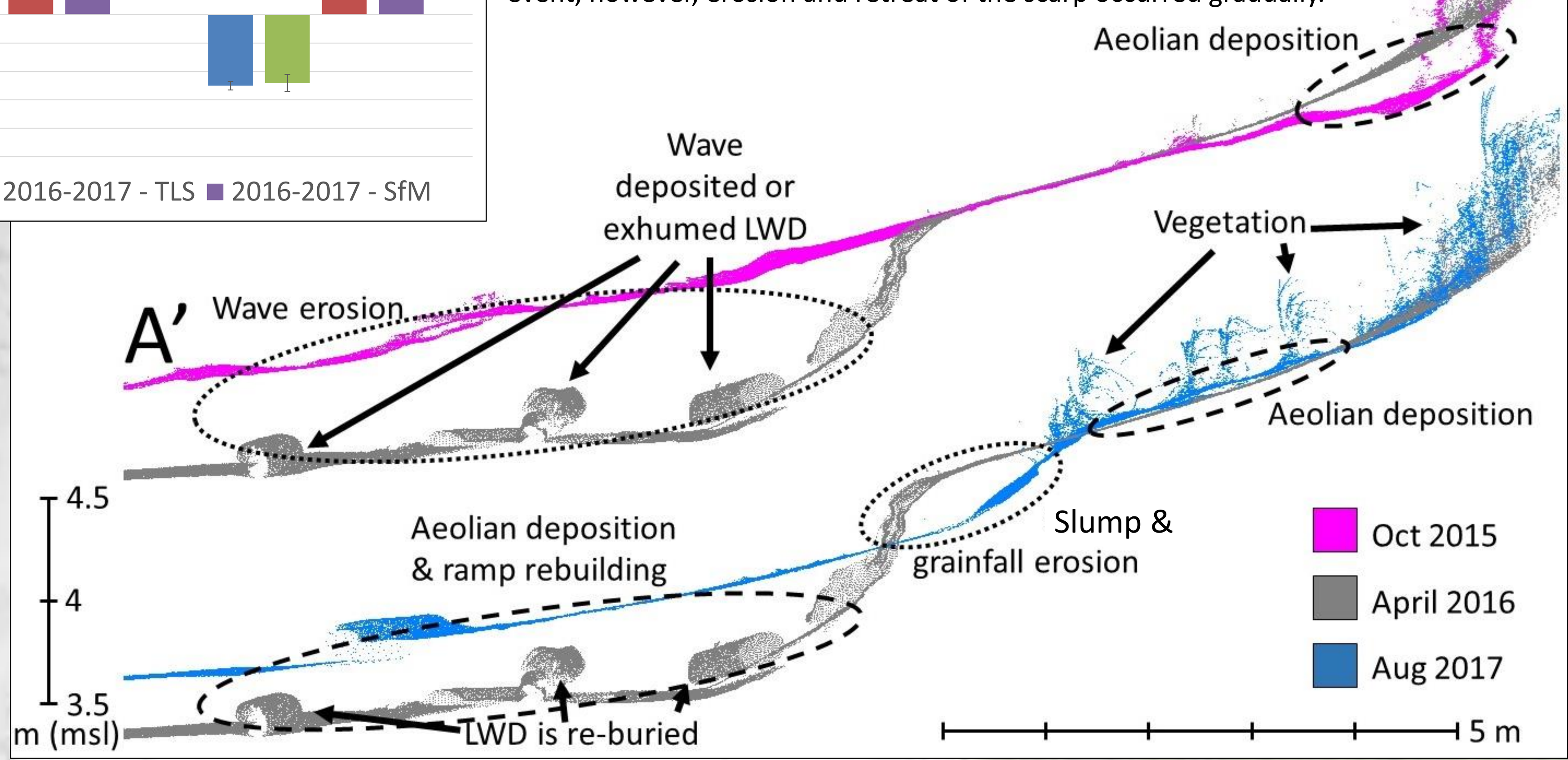



**Figure 6.** (Right) Volumetric change in each sub-region as erosion (-) or deposition (+) for TLS and SfM sampling methods.

**Figure 7.** TLS profiles (shown in Fig. 4 above, top left) of the dune for each interval. Erosion and deposition from Oct 15' to Apr 16' result from a single event. Deposition from Apr 16' to Aug 17' is also from a single event, however, erosion and retreat of the scarp occurred gradually.




## Summary & Conclusions

- Sediment loss in foredune & incipient dune from Oct 15' to Apr 16' from direct wave erosion and storm surge. Deposition on dune caused by the same storm, a few days before the scarp event.
- Deposition from Apr 16' to Aug 17' from onshore littoral transport and significant aeolian delivery of sand from the beach to incipient and foredune zones during winter storms.
- Time lapse shows ramp rebuilding occurred over two short, intensive transport events. Additional data from as early as 2012 suggests major dune scarping events (>1 m scarp) occur frequently (2-3 yrs).
- Dune ramp re-established one year after erosion event (i.e. < erosion occurrence interval) suggesting long-term dune resilience. Ramp rebuilt by a combination of aeolian deposition & scarp slumping. Slumping not sufficient to rebuild ramp, rather aeolian rebuilding is most significant.

## Summary & Conclusions, continued

- On dissipative sandy beaches, SfM most suitable for landscape scale analysis, while TLS can provide insight to finer scale geomorphic change and on vegetated surfaces (foredunes).
  - i) SfM showed similar overall change to TLS (Fig. 6) yet unable to resolve minor dune changes detected by TLS, possibly leading to inaccurate regime assessment of the frequency and magnitude of events.
  - ii) UAS easier to deploy on remote beaches: portable (~20Kg), cost (<$5K) & time effective (2 hrs for 0.08 km²) vs TLS (~80kg), ($145,000+), (8 hrs for 0.08 km²), but accuracy suffers on flat featureless beach due to lack of feature matching.

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