Geophysical Research Abstracts
Vol. 16, EGU2014-2797, 2014
EGU General Assembly 2014

Measurement of surface moisture using infra-red terrestrial laser scanning

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The measured aeolian supply of sand from the beach to the foredune is generally less than the potential supply because the wetness of the beach surface limits sand entrainment and supply. The strong spatial and temporal variability in surface moisture is, however, notoriously difficult to determine, which has prevented the development of quantitatively more realistic sand-supply models. Here we test the possibility of deriving surface moisture content from the reflectance signal of an infra-red terrestrial laser scanner (TLS) in a large area ($\sim 100 \times 100$ m) with high spatial ($\sim 0.25 \times 0.25$ m) and temporal (~ 30 minutes) resolution.

We deployed a RIEGL VZ-400 3D laser scanner (short-wave infra-red, wavelength = 1550 nm) from a tripod at Egmond Beach, The Netherlands, with the instrument about 2 m above beach level. The TLS collected data through 360° in the horizontal plane and 100° in the vertical, with a rate of 122,000 points/s. A full 360°/100° (panorama) scan with a 0.02° resolution in the horizontal and vertical took about 12 minutes to complete. Nine panorama scans were performed over a single tidal cycle, during which also 69 surface scrapings (thickness of a few millimetres) were taken. After each panorama scan, a cross-shore profile from the dunefoot to the shoreline was scanned 10 times per second for 2 minutes to explore the repeatability of the TLS data. The nine scans were processed into 0.25×0.25 m reflectance maps, while the scrapings were processed into moisture estimates using standard laboratory techniques. The RIEGL VZ-400 expresses reflectance in decibels, with a $1/R^2$ correction to account for the reduction of returned intensity with range R.

We found that reflectance does not change for $R = 15 - 60$ m over beach sand with spatially invariant moisture content. Apparently, the returned reflectance is then indeed proportional to $1/R^2$ and independent of the angle between the laser pulse and the beach surface. For $R < 15$ m, the $1/R^2$ relationship does not hold, while for $R > 60$ m reflectance drops off rapidly, most likely due to the strong distortion of the laser footprint at these range values. We also observed that reflectance is linearly related to surface moisture content for the full range from dry to saturated sand, with a standard error of about 2.6%. This represents an improvement over earlier TLS studies with smaller wavelengths, in which reflectance was insensitive to moisture content larger than some 5%. Also, the standard error is lower than typically reported for optical (video) estimates of moisture content. Finally, we found that the reflectance measurements are highly robust, with a typical repeatability in moisture content of about 0.3%. To conclude, short-wave infra-red TLS has the capability to derive values of surface moisture accurately and robustly over its full range in a spatially extensive area at spatial and temporal resolution infeasible with standard in-situ techniques.