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A morphometric comparison of the Namib and southwest Kalahari dunefields using ASTER GDEM data

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ABSTRACT

The increased availability of digital elevation models and satellite image data enable testing of morphometric relationships between sand dune variables (dune height, spacing and equivalent sand thickness), which were originally established using limited field survey data. These long-established geomorphological hypotheses can now be tested against very much larger samples than were possible when available data were limited to what could be collected by field surveys alone. This project uses ASTER global digital elevation model (GDEM) data to compare morphometric relationships between sand dune variables in the southwest Kalahari dunefield to those of the Namib sand sea, to test whether the relationships found in an active sand sea (Namib) also hold for the fixed dune system of the nearby southwest Kalahari. The data show significant morphometric differences between the simple linear dunes of the Namib sand sea and the southwest Kalahari; the latter do not show the expected positive relationship between dune height and spacing. The southwest Kalahari dunes show a similar range of dune spacings, but they are less tall, on average, than the Namib sand sea dunes. There is a clear spatial pattern to these morphometric data; the tallest and most closely spaced dunes are towards the southeast of the Kalahari dunefield; and this is where the highest values of equivalent sand thickness result. We consider the possible reasons for the observed differences and highlight the need for more studies comparing sand seas and dunefields from different environmental settings.

1. Introduction

Morphometric analysis is a long established technique in aeolian geomorphology (Wilson, 1972 Bullard et al., 1995; Fitzsimmons, 2007) and has provided numerous insights into dune forming processes and controls (Mabbutt and Wooding, 1983; Thomas, 1988; Wasson et al., 1988). The aim of much of this research is to derive empirical relationships between measurements of dune form (typically dune height and dune spacing), and to see how these relationships respond to changes in controlling variables, such as wind variability and sediment supply. A major limitation for much of this early work was the need for detailed field survey to obtain the necessary measurements; the amount of data yielded from field campaigns often being insufficient for robust statistical modelling. Nevertheless, relationships among variables were suggested, and in many cases these relationships were subsequently used to estimate unmeasured parameters. For example, relationships between dune spacing and dune height derived from field data were used to estimate dune heights from dune spacings derived from aerial photography and other sources (Wasson and Hyde, 1983a). Despite such efforts, the small sample sizes used necessitated care in interpreting the resulting data in terms of dune forming processes.

The availability of digital elevation models (DEMs) from remote sensing missions such as Shuttle Radar Topography Mission (SRTM) (Rabus et al., 2003) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) (Slater, 2011) have the potential to provide a robust sampling of dune morphometric data (Hugenholtz et al., 2012). SRTM data have been used to map aspects of dune morphometry in small areas of dunefields such as the Namib, Taklimakan and Australian dunefields (Blumberg, 2006; Bubenzer and Bolten, 2008; Potts et al., 2008), however, data quality is hampered by poor radar returns from sand surfaces, resulting in missing data over sand seas (Bubenzer and Bolten, 2008). In contrast, ASTER uses photogrammetry to estimate spot heights from parallax between the nadir and backward-looking

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NIR images, and permits much better retrievals of heights over sand than interferometric methods (Slater, 2011) and a global DEM (ASTER GDEM), produced from these data, was released in June 2009, with a 30 m horizontal resolution and an estimated absolute vertical uncertainty of c. 6 m (Telfer et al., 2015). ASTER DEMs provide considerable opportunities for two- and three-dimensional studies of aeolian sand dunes, although there are some limitations, particularly associated with spatial resolution and vertical accuracy in some areas (Hugenholtz and Barchyn, 2010). However, ASTER GDEM data are becoming the most widely used source of DEM data for studies of dunefields and sand seas (Telfer et al., 2015) and these data were selected for use in this study.

Bullard et al. (2011) demonstrated that dune morphometric relationships derived from ASTER GDEM data of the Namib sand sea, on the Atlantic coast of southern Africa (Fig. 1), are broadly comparable with relationships derived by previous methods and across a range of different dune types. The Namib sand sea comprises a complex range of active aeolian bedforms, including various types of linear dune, star dunes, barchan fields and transverse ridges (Livingstone et al., 2010). The ASTER GDEM data confirmed patterns of dune height, spacing and equivalent sand thickness mapped previously in the Namib sand sea, but the ability to extend the analysis across the entire dunefield (34,000 km^2) also added new detail to these patterns.

We seek to apply the morphometric analyses of Bullard et al. (2011) to the southwest Kalahari dunefield which has very different dune characteristics compared to the Namib sand sea. Extending about 100,000 km^2 (McKee, 1979), the southwest Kalahari covers a substantially larger area than the Namib but contains a much narrower range of dune types. Lancaster (1987) describes the southwest Kalahari dunes as predominantly simple linear dunes, covering between a third and a half of the total sand sea area. These are mostly located in the northern part of the sand sea; towards the south more complex bifurcating or compound linear forms are more common (Thomas, 1988) and localised patches of parabolic dunes also occur (Breed and Grow, 1979; Eriksson et al., 1989). For the same dune type, the southwest Kalahari dunes typically have lower heights and narrower spacings compared with those in the Namib, although there is some overlap in the range of morphometries; for example simple linear dunes in the southwest Kalahari are typically 6–20 m in height, with wavelengths varying from 110 to 1050 m (Thomas, 1988; Bullard et al., 1995) whereas simple linear dunes in the Namib have heights averaging 22 m (range 7–66 m) and wavelengths averaging 972 m (475–2674 m) (Bullard et al., 2011). The lower height of the dunes in the southwest Kalahari is likely to have an impact on our ability to measure them using ASTER GDEM data. Bubenzer and Bolten (2008) suggested that ASTER DEM data could only detect dunes taller than 20–30 m in the Namib and Hugenholtz and Barchyn (2010) were unable to detect dunes less than 15 m tall in the Badain Jaran, China.

In addition to being at the suggested limit or threshold for detection of dune heights, the southwest Kalahari dunes are also less active than the Namib sand dunes because the majority have a partial vegetation cover. The Namib sand sea is a coastal desert with a hyperarid climate and consequently there is very little vegetation on the dunes and they have bare, active surfaces (Livingstone, 2013). Aridity decreases with increasing distance inland such that, although the western margin of the southwest Kalahari dunefield is only 200 km away from the eastern margin of the Namib sand sea in places (Fig. 1), climate conditions are very different. The southwest Kalahari dunes experience an arid climate receiving primary summer rainfall of less than 200 mm annual rainfall but which is sufficient to sustain a vegetation cover on the linear dunes (Goudie, 2002). The impact of vegetation on linear dune morphology has been widely discussed (Ash and Wasson, 1983; Wiggs et al., 1996). Furthermore, the presence of vegetation on dunes may make it more difficult to determine dune height from the ASTER GDEM if there is no clearly-defined crest and also due to its potential for affecting the apparent level of the surface of the dune from photogrammetry. The impact of vegetation on DEM accuracy may be spatially varied in the southwest Kalahari because there is not a uniform cover of vegetation on the dunes; typically the plinths are more densely vegetated than the dune crests. The vegetation of the southwest Kalahari is classified as Kalahari xeric savannah, known locally as thornveld, comprising grasses interspersed with trees dominated by Acacias (Camel Thorn *Vachellia erioloba*, Grey Camel Thorn *Vachellia haematoxylon* and Blackthorn *Senegalia mellifera*) (van Rooyena and van Rooyena, 1998). Grove

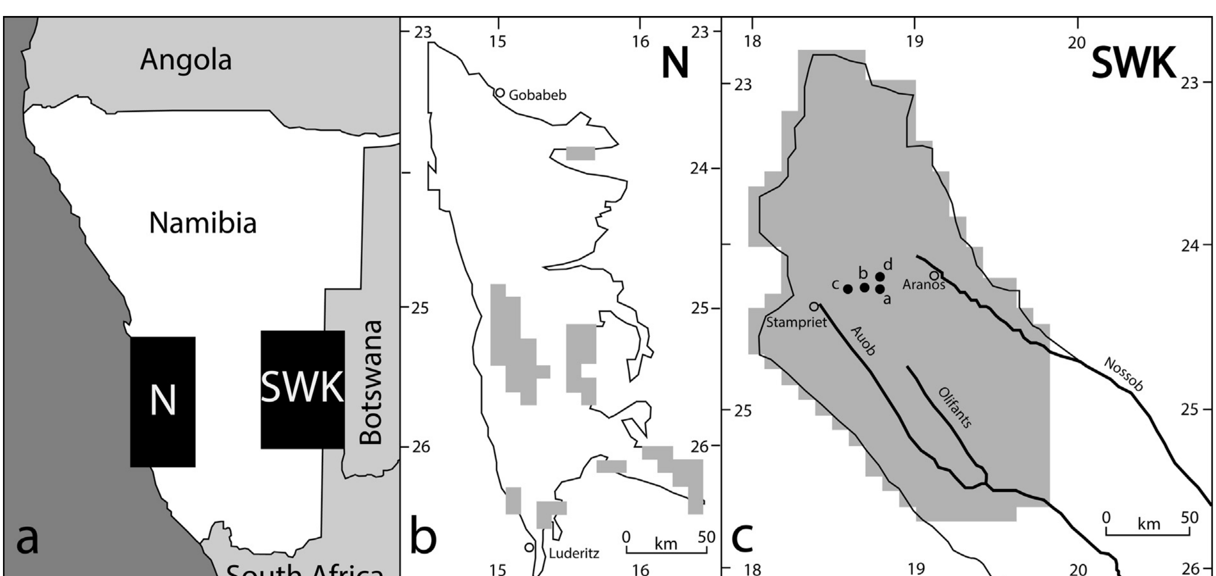

Fig. 1. Location map, showing places mentioned in the text. (a) Location of Namib sand sea (N) and southwest Kalahari dunefield (SWK). (b) Sampled 10 km grid squares in the Namib sand sea (simple linear dunes) shown in grey, solid line shows outline of the sand sea. (c) Sampled 10 km grid squares in the southwest Kalahari shown in grey, solid line shows outline of the dunefield. Filled dots show location of 2012 field survey transects a–d, shown in Fig. 2.