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Spatial variability of dune form on Moreton Island, Australia, and its correspondence with wind regime derived from observing stations and reanalyses

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ABSTRACT

Wind regime (speed and direction) are typically highly variable in space and in time. Studies often use a selected meteorological station as representative of a specific dune field. However, wind regime may differ widely even between sites located just a few kilometers apart. In this study we explore wind variability and its relationship to dune morphology on Moreton Island, a dune barrier island located in south-east Queensland, Australia. Using wind data from meteorological stations around Moreton Island and from global and regional reanalyses, we analyzed the correspondence between wind power and wind direction, using the variables of resultant drift potential (RDP) and resultant drift direction (RDD). RDP values were higher in the ocean-facing stations than on the adjacent mainland, and the correspondence of wind regime between the different stations was dependent on both distance from station and on wind magnitude. Ocean facing stations were best correlated with the PRECIS regional reanalysis. Wind regime was found to vary between the ocean and bay sides of Moreton Island, especially in the winter months. Three different slip face orientations (towards the north-west, north and north-east) on Moreton Island were successfully explained based on wind regime and topographic details using data from a LiDAR-derived digital elevation model. We conclude that regional reanalysis models are able to fill in spatial and temporal gaps in wind regime data, necessary for understanding dune form and dune activity.

1. Introduction

Wind regime is one of the major factors affecting dune form (Wasson and Hyde, 1983; Tsoar, 2001; Blumberg, 2006), and wind power is recognized as one of the most important controls on dune activity (Fryberger and Dean, 1979; Tsoar, 2005; Levin, 2011; Yizhaq et al., 2013). However, quantifying the actual wind power within a dune field is not trivial for several reasons: the often sparse coverage of meteorological stations measuring wind direction and wind speed, the natural variability of wind speed, the length and frequency of wind measurements, and the effects of surface roughness on wind speed (Levin et al., 2008; Ellis et al., 2012). In places where no stations are available, dune form effectively records the long term wind regime (wind direction), as has been demonstrated for dunes on Mars (Edgett and Blumberg, 1994) and for dunes on Earth using climate models (Blumberg and Greeley, 1996). Many studies use just one meteorological station as representative of a specific dune field (e.g., as in Fryberger and Dean, 1979; Levin, 2011). This may be the common practice due to the scarcity of meteorological stations especially in remote areas. However, wind regime may widely differ even between sites located just a few kilometers apart due to topographic controls, beach orientation, and sea-breeze, especially around islands (Jennings, 1957; Short and Hesp, 1982). Hesp et al. (2007) have shown for two adjacent coastal dune fields in southern Brazil that transgressive dunes may be migrating in almost opposite directions, due to spatial variability in wind regime. Therefore, the question arises as to what degree does the wind regime recorded at a specific meteorological station reflect the actual wind regime on a dune field located, for example, 5 km, 10 km or 50 km away from that station?

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The goal of this paper is to examine the spatial variability in wind regime within a coastal dune field setting, using measured wind data, modeled wind data derived from gridded reanalysis datasets and dune form and orientation.

More specifically, we aim to address the following questions:

1. To what degree does wind regime (wind speed and wind direction) correspond between adjacent meteorological stations surrounding a dune field?
2. To what degree does the wind regime correspond between meteorological stations and modeled wind regime from gridded datasets?
3. To what degree does wind regime correspond with actual dune morphology in an adjacent coastal dune field?

2. Methods

2.1. Study area

Moreton Island is a wedge-shaped sand island located about 40 km from Brisbane (Queensland, Australia). It is located at the eastern part of Moreton bay on the southeast coast of Queensland, Australia (Fig. 1). The island is 37 kilometers long, about 10 kilometers wide, 13 kilometers at its widest point, and covers a total area of 186 km^2. The highest point on the island is Mount Tempest, presumably the highest permanent coastal sandhill in the world, which rises over 280 m above sea level. Moreton Island has a humid subtropical climate with a hot and humid summer and a moderately warm winter. The mean minimum and mean maximum temperature range from 13.2 to 18.9 °C in July to 22 and 26.9 °C in January. The average monthly precipitation ranges from 178 mm in March to 65 mm in September, with mean annual rainfall of 1495 mm. The dominant wind direction is from the southeast (Stock, 1990).

Moreton Island developed from a rocky formation, now at the northernmost tip of the island (known as Cape Moreton). The formation of the island sand dunes started at least 500,000 years ago, when the sea level was lower than at present (Stock, 1990). The main source of sand is granites and Mesozoic metasediments from the eastern New South Wales highlands (Pye, 1983), transported northward along the coast during the Quaternary. There are several generations of parabolic and transgressive dune fields that correspond to episodic sedimentation of the island that occurred throughout the late Quaternary (Stock, 1990; Pye, 1983). At present, the majority of the island's paleo-dunes are fixed by vegetation, except for some active dune fields along the eastern coast, two transgressive dune fields in the south of the island (locally known as Little Sand Hills and Big Sand Hills) and the active dune field near Tangalooma Resort on the western side of the island (locally known as The Desert) (Fig. 1).

2.2. Wind data

In this study we assembled wind data from all available stations in the area of Moreton Island. Wind data (at least twice daily) were provided by the Australian Bureau of Meteorology (BOM) for the Cape Moreton station and 12 other stations in southeast Queensland and northern New South Wales, focusing on the Moreton Bay area (Table 1; Fig. 1). These stations include five "ocean stations" (i.e. located along the Pacific Ocean coast), three "bay stations" (located within Moreton Bay), and five "mainland stations" (located within 10 km of the coast west of Moreton Bay); these

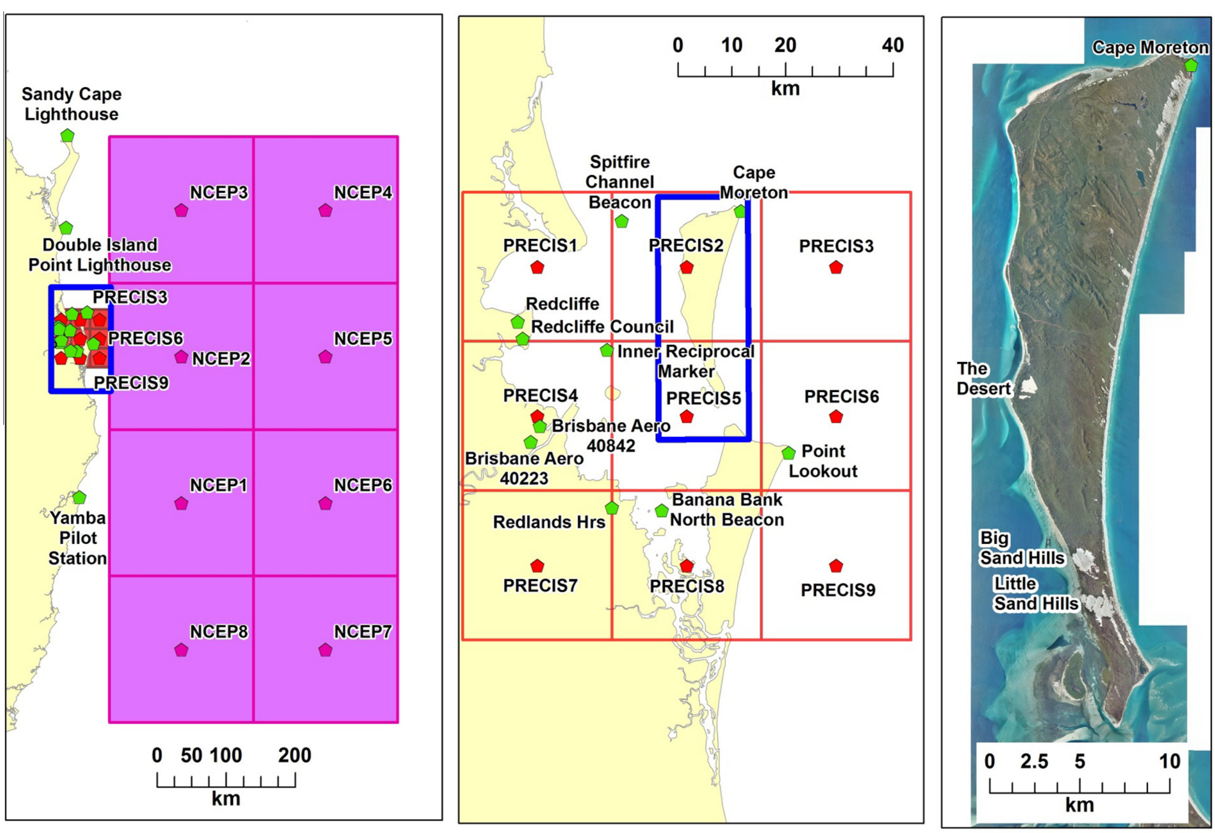

Fig. 1. Location map, showing Moreton Island and the location of the meteorological stations and the grid cells of the reanalysis products. Australian Bureau of Meteorology stations are shown as green pentagons. PRECIS 25 × 25 km grid cells are shown in red, and NCEP/NCAR grid cells are shown in magenta. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)