Predicting Potential Aeolian Sand Supply to a High and Steep Foredune

1. Introduction

Background
Foredune growth results predominantly from sand that is blown landward from the beach and backshore. Predictions of multi-annual potential aeolian sand supply that are based on wind data from a regional meteorological station, however, often grossly overpredict measured deposition volumes on the dune.

Problem
High and steep foredunes modify the regional wind field but this is not considered in predictions of aeolian sand supply.

Aims
• To relate local (i.e., on the beach) to regional wind data using field measurements at a high and steep foredune and to quantify the effect of using local versus regional wind in predicting multi-year potential aeolian sand supply.

2. Modelling potential sand supply
We use Hsu (1971) to predict the onshore potential transport rate \( q_{\text{on}} \) [g cm\(^{-3}\) year\(^{-1}\)]. In default form, it reads:

\[
q_{\text{on}} = 0.14 \left( \frac{U}{U_0} \right)^{0.6} ( \cos \theta + \alpha )
\]

(1)

Here, it is a granule dependent aeolian sand transport coefficient [g cm\(^{-3}\) s\(^{-1}\)], \( U \) is the wind speed [m/s], \( U_0 \) is the regional wind speed [m/s], \( \theta \) is the wind direction (°), and \( \alpha \) is an empirical exponent (0.6). The regional wind speed and \( \theta \) are measured at an instrument height of 10 m above the surface. With \( U_0 = 0.025 \text{ cm} \) and \( \alpha = 3.56 \), this results in the commonly quoted \( q_{\text{on}} = 1.16 \times 10^3 \text{ g cm}^{-3} \text{ s}^{-1} \text{ cm} \). With local wind data and \( \alpha = 3.56 \), this reduces substantially, to 24.0 m\(^3\) m\(^{-1}\) year\(^{-1}\).

3. Regional versus local wind

Methodology
Wind speed and direction measurements in October 2017 using (1) 4 Ultrasonic Anemometers in a cross-shore array from the beach-dune interface to the water line and (2) a mast of 5 cup-anemometers at Egmond beach (Netherlands, Figure 1). The latter data resulted in \( \theta = 0.1 \text{ mm} \) and \( \alpha = 3.56 \). Regional data are available from the [Netherlands meteorological station], 15 km to the south of Egmond.

Wind speed
(Figure 2a) Local wind speed is lower than regional wind speed, with the largest speed reduction (to about 70% of the regional value) for shore-normal wind.

Wind direction
(Figure 2b) The wind at the beach-dune interface is steered shorewards. The steering is maximum (about 15°) for shore-oblique winds, and minimum for onshore and almost offshore winds.

4. Predictions

Input
Ten years of regional wind data (2007-2016), converted to local data using correction functions of Figure 2, with \( D = 0.025 \text{ cm} \) to predict potential annual supply \( Q_{\text{on}} \) [m\(^3\) m\(^{-1}\) year\(^{-1}\)]. Measured deposition on the foredune is about 15 m\(^3\) m\(^{-1}\) year\(^{-1}\) (Donker et al., 2018).

Output
(Table 1) The default scenario with regional wind data and \( \alpha = 4 \) results in \( Q_{\text{on}} = 86.4 \text{ m}^3 \text{ m}^{-1} \text{ year}^{-1} \). With local wind data and \( \alpha = 3.56 \), this reduces substantially, to 2.40 m\(^3\) m\(^{-1}\) year\(^{-1}\). Other scenarios illustrate that the reduction in wind speed affects \( Q_{\text{on}} \) more (0.9 to 2.8 m\(^3\) m\(^{-1}\) year\(^{-1}\)) than the shoreline steering at the beach-dune interface (60.9 to 52.5 m\(^3\) m\(^{-1}\) year\(^{-1}\)).

5. Conclusions and outlook
• The ratio of local to regional wind speed as well as the directional steering at the beach-dune interface depend on the regional wind approach angle. The largest reduction in speed (to 70%) is observed for onshore winds, and the largest steering (about 15°) for shore-oblique winds.
• The use of local wind data diminishes the overprediction of aeolian sand supply from the beach substantially (here, from a factor of 5.8 to 1.6).
• Future work will focus on (1) deriving regional to local conversion functions for arbitrary shoreline shapes using Computational Fluid Dynamics and (2) exploring to what extent the remaining overprediction is due to supply-limiting factors, such as surface moisture.

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References
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