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# Comparing dune migration measured from remote sensing with sand flux prediction based on weather data and model, a test case in Qatar

Sylvain Michel[a,b,*], Jean-Philippe Avouac[a], François Ayoub[a], Ryan C. Ewing[c], Nathalie Vriend[d], Essam Heggy[e,f]

[a] California Institute of Technology, Department of Geology and Planetary Sciences, 1200 E California Blvd, Pasadena, CA, 91125, USA
[b] University of Cambridge, Department of Earth Sciences, Bullard Laboratories, Madingley Road, Cambridge, Cambridgeshire, CB3 0EZ, UK
[c] Texas A&M University, Department of Geology and Geophysics, 3115 TAMU, College Station, TX, 77843, USA
[d] University of Cambridge, Department of Applied Mathematics and Theoretical Physics, Cambridge, Cambridgeshire, CB3 0WA, UK
[e] University of Southern California, Viterbi School of Engineering, 3650 McClintock Ave, Los Angeles, CA, 90089, USA
[f] Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr, Pasadena, CA, 91109, USA

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ABSTRACT

This study explores validating and calibrating the wind regime predicted by Global Circulation Models (GCM) on Earth and other planets using optical remote sensing of dune dynamics. We use Spot-5 images to track the migration of 64 Barchan dunes in Qatar using the COSI-Corr technique. We estimate the volume of the dunes using a scaling law calibrated from one particular dune, which was surveyed in the field. Using volume and migration rate, we determine the sand flux from a single dune, $Q_{Dunes}$, and scale this estimate to the whole dune field. We compare the measured sand flux with those derived from wind velocity measurements at a local meteorological station as well as with those predicted from ERA-Interim (a Global Circulation Model). The comparison revealed that the wind velocity predicted by ERA-Interim is inappropriate to calculate the sand flux. This is due to the 6-h sampling rate and to systematic bias revealed by a comparison with the local wind data. We describe a simple procedure to correct for these effects. With the proposed correction, similar sand flux are predicted using the local and ERA-Interim data, independently of the value of the value of the shear velocity threshold, $u_{*t}$. The predicted sand flux is about 65% of $Q_{Dunes}$. The agreement is best assuming the value $u_{*t} = 0.244$ m/s, which is only slightly larger than the value of $u_{*t} = 0.2612$ m/s estimated based in the sand granulometry measured from field samples. The influence of the dune topography on the wind velocity field could explain the underestimation. In any case, the study demonstrates the possibility of validating GCM model and calibrating aeolian sand transport laws using remote sensing measurements of dune dynamics and highlights the caveats associated to such an approach.



## 1. Introduction

Dune fields are among the most prominent geomorphological features of arid environments on Earth. Their morphological, granulometric and compositional characteristics as well as their dynamics provide crucial insight into the geological and climatic conditions that led to their formation. Dune fields are also common geomorphological features of a number of extraterrestrial bodies such as Mars, Venus and Titan (Anderson et al., 1999; Ayoub et al., 2014; Bourke et al., 2008; Ewing et al., 2015a; Greeley and Iversen, 1985; Lorenz, 2006; McDonald et al., 2016; Tsoar et al., 1979). Their morphodynamics hold clues regarding climate and landscape evolution on these planetary bodies. One approach to investigate dune dynamics consists of comparing the observed geometry and dynamics of aeolian bedforms with sand flux predicted from General Circulation Models (GCM) (Ayoub et al., 2014; Bridges et al., 2012; Newman et al., 2017). While common, in practice, a number of factors hinder the accuracy of this approach. For example, Ayoub et al. (2014) measured seasonal variations of bedforms migration rates at Nili Patera, Mars, and could reproduce these variations based on a Mars GCM by adjusting the wind speed threshold for sand motion. The physical significance of the threshold obtained from that study is, however, unclear as it combines the threshold needed to initiate sand motion and

* Corresponding author at: California Institute of Technology, Department of Geology and Planetary Sciences, 1200 E California Blvd, Pasadena, CA, 91125, USA.
*E-mail addresses:* sylvain_michel@live.fr (S. Michel), avouac@gps.caltech.edu (J.-P. Avouac), fayoub@gps.caltech.edu (F. Ayoub), rce@tamu.edu (R.C. Ewing), nv253@cam.ac.uk (N. Vriend), heggy@usc.edu (E. Heggy).

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the much lower threshold needed to sustain saltation (Kok, 2010; Sullivan and Kok, 2017; Yizhaq et al., 2014). Moreover, the threshold that was determined for a wind regime does not account for near surface turbulence, which is critical in driving sand motion (Martin et al., 2013). Indeed, some GCMs are not able to resolve localized interference, either due to the fact that it does not account for topographic features that would influence the wind's direction and strength (Jackson et al., 2015), or either due to low time resolution that does not account for high frequency changes of wind strength and direction (Barchyn et al., 2014; Martin et al., 2013). Although resolved at higher spatial resolutions than GCMs, regional wind models may not be accurate enough either to determine local sand fluxes over a dune and through a dune field (Jackson et al., 2015). This raises the question as to whether climate models can represent winds accurately enough to predict sand fluxes.

Aeolian transport laws used to predict sand flux (Bagnold, 1941; Martin and Kok, 2017; White, 1979) are based on necessary simplifications that might hinder the accuracy of the forecast. For example, aeolian sand transport can result from saltation or reptation (Anderson et al., 1991; Andreotti, 2004; Lammel et al., 2012). A particle in saltation, or 'salton', corresponds to a high kinetic energy grain ejected from the surface that will have enough energy to eject further particles when it impacts the sand bed again, whereas a particle in reptation, or 'repton', is a low kinetic energy grain that will hop without moving any other sand grain at its impact with the surface (Anderson et al., 1991; Andreotti, 2004; Bagnold, 1941). However, transport laws only account for saltons and the relative contribution of reptons and saltons to the total sand flux involved in migration of bedforms of particular scale, ripples or dunes for example, are little considered (Butterfield, 1999). In addition, empirical transport laws are typically obtained for transport over flat surface at sand saturated conditions and do not consider bedform topography or sediment availability-limited scenarios. This makes comparison of model predictions with nature difficult and highlights the need for calibration. Potentially, a scale-dependent correction factor might need to be applied when a given transport law is used. In this study, we address the issue of sand flux prediction discrepancy obtained from GCMs and surface measurements. We selected a sand dune field site in Qatar for its simple geographic setting. We measured dune migration using the COSI-Corr technique (Leprince et al., 2007) applied to a time series of optical images and compared the observation with wind velocity measured from a local station and predicted from a GCM. We used the GCM ERA-Interim (Dee et al., 2011), as well as data from a meteorological station to assess ways of correcting the GCM predictions for near-surface wind turbulence.

## 2. Dunes migration and estimated sand flux at the study site in Qatar

Before focusing on sand flux prediction from meteorological data, we estimate sand fluxes from field measurements and remote sensing data. Those results serve as point of comparison with weather-based predictions and provide an estimation of their accuracy.

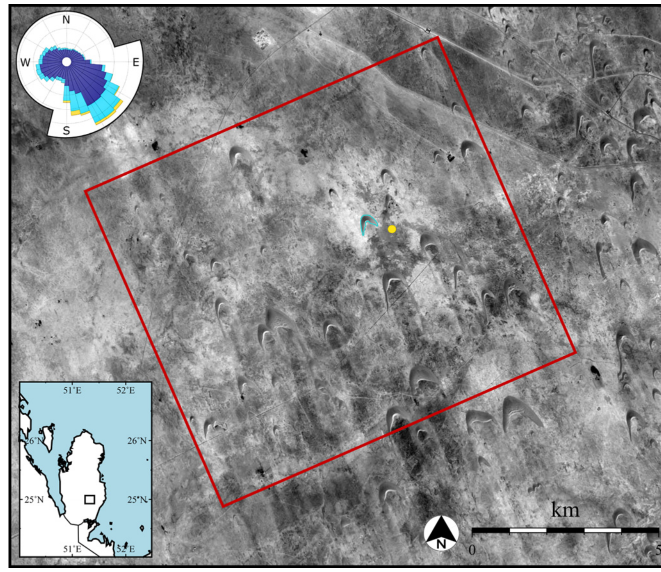


**Fig. 1.** Regional setting. The red square represents our area of study. The yellow dot is the location of the meteorological station. The dune surrounded in blue corresponds to the one we have computed a DEM for. The wind rose at the upper left corner of the figure indicates dominating winds going to the SE. Dark blue, light blue and yellow histograms of the wind rose indicate the percentage of wind under 5 m/s, between 5–10 m/s, and over 10 m/s, respectively. (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

### 2.1. Setting of study area in Qatar

The study area is a barchan dune field located in southeastern Qatar (Fig. 1). The region is dominantly affected by the Shamal, a unidirectional wind coming from the NW, which is stronger in winter and summer (Edgell, 2006). The lithographic unit of the exposed bedrock of Qatar is almost exclusively carbonates (e.g., limestone and dolomite). The topography is flat for most of Qatar, with a slight north-south anticline located on the west side of the dune field, which rises to ∼103 m above sea level. The very simple general setting of this region makes it a perfect case study for our test. The dune mineralogy indicates that the sand source does not come from Qatar, delimited as it is now, but from sediments now laying under the Persian sea that were previously exposed during a Pleistocene sea-level low stand (Embabi and Ashour, 1993; Garzanti et al., 2013). The sediment itself originates from the Zagros region (Garzanti et al., 2013). This source was cut off around 8000–12000 years ago, when the Persian Gulf was flooded due to the sea level rise at the beginning of the latest inter-glacial period (Lambeck, 1996). We focus on the upwind dunes located on the NW end of the dune field (Fig. 1). The study area is about 8.4 $10^4$ $km^2$ and contains 64 SE migrating dunes, with widths between 55 and 808 m.

### 2.2. Remote sensing analysis

The average migration velocities of the 64 dunes were estimated from the comparison of the dunes locations on two SPOT5 images (Table 1), with a ground sampling distance of 2.5 m, acquired 10 yr apart in 2003 and 2013. The two satellite images were orthorectified and accurately coregistered using the Co-registration

**Table 1**
Optical images data set.

| Satellite | Acquisition date | Time (UTC) | Spectral band | Resolution | Incidence angle |
|---|---|---|---|---|---|
| SPOT 5 | 22 Mai 2003 | 07:23:11.9 | Panchromatic | 2.5 m | 0.8° |
| SPOT 5 | 02 April 2013 | 07:11:53.4 | Panchromatic | 2.5 m | 23.3° |