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a. REPORT	b. ABSTRACT	c. THIS PAGE			Jasper Kok
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RPPR Final Report
as of 30-Aug-2021

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Agreement Number: W911NF-15-1-0417

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Final Report for Period Beginning 01-Aug-2015 and Ending 31-Dec-2019
Title: Area 9 Material Sciences: Fundamental Advances in Predicting Aeolian Transport: Moving Beyond the Fluid Threshold and Precipitation Control Paradigms
Begin Performance Period: 01-Aug-2015
End Performance Period: 31-Dec-2019
Report Term: 0-Other
Submitted By: Jasper Kok
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STEM Degrees: 3
STEM Participants: 3

Major Goals: The overarching objectives of the proposal are:
- Task 1: Develop a probabilistic model for sand transport occurrence over dry sand.
- Task 2: Test hypothesis that soil moisture from precipitation rarely inhibits aeolian transport.
- Task 3: Utilize the probabilistic model of transport occurrence (Task 1) and the simplified description of soil moisture effects (Task 2) to derive improved relations
for sand and dust fluxes, especially for intermittent transport conditions.

Accomplishments: See the uploaded pdf

Training Opportunities: Three PhD students have been trained in the course of this project. The first student, Mr. Francis Turney, has left my group in Fall 2018 because he did not meet expectations and has since received a Master's degree. The second student, Ms. Yue Huang, worked on this project for a few months in the beginning of the grant to process data that was used in subsequent publications. The third student, Danny Leung, started in Fall 2018 and has worked on implementing the effects of turbulence on dust fluxes in a global atmospheric model. His work is progressing well and he is now funded by a grant from the Engineering Research and Development Center.

In addition, the grant contributed to developing the careers of two (now former) postdoctoral scholars. The first, Francesco Comola, took a position in the
reinsurance industry because of a two-body situation. He wrote the culminating article on this grant that developed an improved parameterization of sand fluxes and dust emission that accounts for turbulence-driven intermittency in those fluxes (Comola et al., 2019). In addition, the career of a postdoctoral scholar, Dr. Raleigh Martin, was further developed under his grant. Dr. Martin took a AAAS Science & Technology fellowship at NSF after concluding his work in my group and is now an NSF Program Manager.

Results Dissemination: The results of this work have been disseminated in a number of publications (see Products), as well as conference presentations at meetings of the Geological Society of America meeting, the American Geophysical Union Fall Meeting, the European Geosciences Union General Assembly meeting, the ARO-organized dust workshop in Chicago in 2017, and in a keynote talk at the International Conference for Aeolian Research. In addition, the results of this work have been presented at seminars at the University of California - Santa Barbara, the California Institute of Technology, the University of Arkansas, and the University of Washington.

Results have also been reported in 6 published papers and one paper in review. All these papers had a first author supported by this grant (mostly postdocs from PI Kok's group).

Honors and Awards: The PI received the 2019 Henry Houghton Early Career award from the American Meteorological Society for “novel approaches to studying the physics of dust emissions into the atmosphere and the interactions of dust aerosols with Earth’s climate and beyond.”

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: Graduate Student (research assistant)
Participant: Yue Huang
Person Months Worked: 2.00 **Funding Support:**
Project Contribution:
National Academy Member: Y

Participant Type: Graduate Student (research assistant)
Participant: Francis Turney
Person Months Worked: 2.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Graduate Student (research assistant)
Participant: Danny Min Leung
Person Months Worked: 4.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Postdoctoral (scholar, fellow or other postdoctoral position)
Participant: Francesco Comola
Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Postdoctoral (scholar, fellow or other postdoctoral position)
Participant: Raleigh Martin
Person Months Worked: 9.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: PD/PI
Participant: Jasper Frank Kok
Person Months Worked: 7.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Co PD/PI
Participant: Gregory Okin
Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
National Academy Member: N

International Collaboration:

USA

ARTICLES:

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
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Date Submitted: 8/28/17 12:00AM Date Published: 8/30/16 7:22AM
Publication Location: Washington, DC, USA
Article Title: Wind-invariant saltation heights imply linear scaling of aeolian saltation flux with shear stress
Authors: Raleigh Martin, Jasper Kok
Keywords: aeolian transport, wind erosion, multiphase flows, planetary geomorphology, dust aerosols
Abstract: Wind-driven sand transport generates atmospheric dust, forms dunes, and sculpts landscapes. However, it remains unclear how the flux of particles in aeolian saltation—the wind-driven transport of sand in hopping trajectories—scales with wind speed, largely because models do not agree on how particle speeds and trajectories change with wind shear velocity.Wepresent comprehensive measurements, fromthree newfield sites and three published studies, showing that characteristic saltation layer heights remain approximately constant with shear velocity, in agreement with recent wind tunnel studies. These results support the assumption of constant particle speeds in recent models predicting linear scaling of saltation flux with shear stress. In contrast, our results refute widely used older models that assume that particle speed increases with shear velocity, thereby predicting nonlinear 3/2 stress-flux scaling. This conclusion is further supported by direct field measurements of saltation flux
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Volume: 123 Issue: First Page #: 1546
Date Submitted: 9/19/18 12:00AM Date Published: 7/17/18 7:00AM
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Article Title: Distinct Thresholds for the Initiation and Cessation of Aeolian Saltation From Field Measurements
Authors: Raleigh Martin, Jasper Kok
Keywords: Aeolian transport; sediment transport thresholds; dust emission
Abstract: Wind-blown sand and dust models depend sensitively on the threshold wind stress. However, laboratory and numerical experiments suggest the coexistence of distinct fluid and impact thresholds for the initiation and cessation of aeolian saltation, respectively. Because aeolian transport models typically use only a single threshold, existence of separate higher fluid and lower impact thresholds complicates the prediction of wind-driven transport. Here we extend the statistical Time Frequency Equivalence Method to derive the first field-based estimates of distinct fluid and impact thresholds from high-frequency wind and saltation measurements at three field sites. Our measurements show that when saltation is mostly inactive, its instantaneous occurrence is governed primarily by wind exceedance of the fluid threshold. As saltation activity increases, so too does the relative importance of the impact threshold, until it dominates under near-continuous transport conditions. Although both thre
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Article Title: The intermittency of wind-driven sand transport and dust emission
Authors: Francesco Comola, Jasper Kok, Marcelo Chamecki, and Raleigh Martin
Keywords: Saltation, dust emission, turbulence
Abstract: Wind-blown sand is the main driver of dune development and dust emission from soils and is thus of fundamental importance for geomorphology, ecology, climate, and air quality. Even though sand transport is driven by nonstationary turbulent winds, and is thus inherently intermittent, current parameterizations in atmospheric models assume stationary wind and continuous transport.We draw on extensive field measurements to show that neglecting saltation intermittency causes biases in the timing and intensity of predicted fluxes.We present a simple parameterization that accounts for saltation intermittency and produces substantially improved agreement against measurements.We investigate the implications of accounting for transport intermittency in atmospheric models by analyzing 35 years of hourly wind speed data from climate simulations.We show that accounting for intermittency leads to significantly different predictions of sand mass fluxes throughout the year, with potential implications
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

Partners

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I certify that the information in the report is complete and accurate:
Signature:
Signature Date:

Most of the goals of the proposal were achieved, with some additional important findings. Below follows a summary:

- Co-PI Okin has investigated the effect of precipitation on dust uplift potential (DUP) in the Sahel, where the majority of DUP occurs during the wet seasons because the erosive winds are produced by the same convective cells that produce precipitation. He also has expanded some of this analysis worldwide (Fig. 1). The global study has used MERRA reanalysis wind data with TRMM satellite precipitation data, whereas the regional study used ERA meteorological data. The results indicate that the median suppression of dust uplift potential (DUP) during the wet season is about 9% (that is 100% - 91%) for agricultural areas of Niger where dust emission can occur due to vegetation disturbance. No effect of precipitation is seen in the dry season. These results have been submitted and the manuscript is under revision after review (Okin, *Geophysical Research Letters,* in review). This work addressed Task 2 in the proposal.

- We used extensive field measurements and theory to establish that sand does not actually bounce any higher when it's blown by stronger winds (Martin and Kok, *Science Advances*, 2017). This counterintuitive result supports recent theories and confirms that the sand flux scales 'only' linearly with wind stress, which we further confirmed with measurements at three different field sites (Fig. 2). These results dispute longstanding non-linear sand flux laws that are in widespread use in climate and weather models and allows for the simplification of current dust emission models. This work addressed Task 3 in the proposal.

- We determined whether different particle sizes in a soil have different threshold wind speeds above which they become mobile (Martin and Kok, *Journal of Geophysical Research – Earth Surface*, 2019). The prevailing wisdom is that they do, such that sand transport and dust emission are governed by "size-selective susceptibility", with larger particles requiring greater wind speed to become mobilized, and this is implemented in most dust emission models. We showed that sand tranpost and dust emission are in fact governed by a single initiation threshold for the entire soil ("equal susceptibility"; see Fig. 3). This important insight is easy to implement in dust emission modules and thus can improve dust simulations in large-scale models. This work addressed the objectives of Task 3 in the grant.

- In order to understand and parameterize the effects of turbulence on sand transport and dust emission (see next bullets), we developed innovative methods to measure the sand flux in the field down to very short timescales of <1 sec (Martin et al., *Aeolian Research*, 2018). We achieved this by calibrating high-frequency optical particle sensors ("wenglors") to well-calibrated low-frequency sand traps. The result is an extensive data set with simultaneous high-frequency sand flux and turbulence (at 6 vertical levels) measurements. This work addressed the objectives of Tasks 1 and 3 in the grant.

- We used this extensive data set to develop predictability of sand and dust fluxes at short time scales. First, we determined that even though the instantaneous occurrence of transport depends on how the instantaneous wind speed compares to the threshold wind speeds for initiating and ceasing saltation, sand fluxes averaged over longer time periods are best described in climate models using only the threshold wind speed for ceasing transport (Martin and Kok, *Journal of Geophysical Research – Earth Surface*, 2018). This differs from the current treatment in climate models, which uses only the threshold wind speed to initiate transport, which is larger. We also determined that this cessation threshold is relatively insensitive to the effects of soil cohesion (Comola et al., *Geophysical Research Letters*, 2019a). These findings can be implemented directly into large-scale models, including the large-scale models used by the Army and other branches of the military. This work addressed Task 1 in the grant.
- We used the extensive data set of high-frequency sand fluxes at three different field sites obtained in Martin et al. (Martin et al., *Aeolian Research*, 2018) to obtain a parameterization of the sand flux that accounts for the effects of turbulence-generated intermittency (Comola et al., *Geophysical Research Letters*, 2019b). This was the main objective of the grant. This parameterization indeed shows substantial skill in predicting intermittent sand transport (Fig. 4b), whereas current parameterizations in weather and climate models have little or no skill in predicting these fluxes (Fig. 4a). This parameterization uses only physical variables that are already available in weather and climate models, and is thus relatively easy to implement into such models. Graduate student Danny Leung is currently testing this promising parameterization in an atmospheric model (the Community Earth System Model), partially supported by a grant from the U.S. Army Engineer Research and Development Center. This work completed the objectives of Tasks 1 and 3 in the grant.
- The improvements in the parameterization of dust fluxes are currently being implemented and evaluated into a leading global model, the Community Earth System Model. This work is funded by the Engineering Research Development Center. The final result will hopefully be implementation of the validated parameterization into models used by the Army Research Office.

Overall, we consider this grant very successful. The main objectives of the grant were met, and the work resulted in six publications in premier journals out of our research groups, with one more publication in review.

Figures

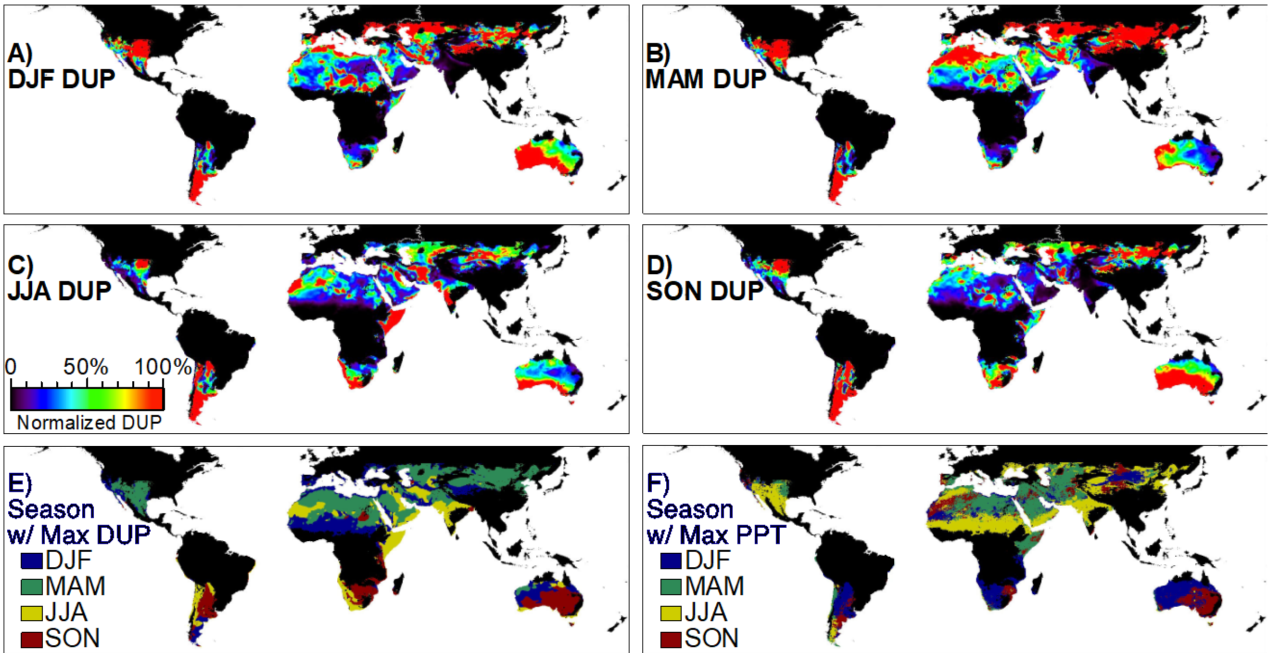

Figure 1. Dust uplift potential (DUP) calculated for (A) December – February (DJF), (B) March – May (MAM), (C) June – August (JJA), and (D) September – November (SON), normalized by the highest global value of DUP among all seasons. Panels (E) and (F) represent the seasons with the greatest DUP and precipitation, respectively.

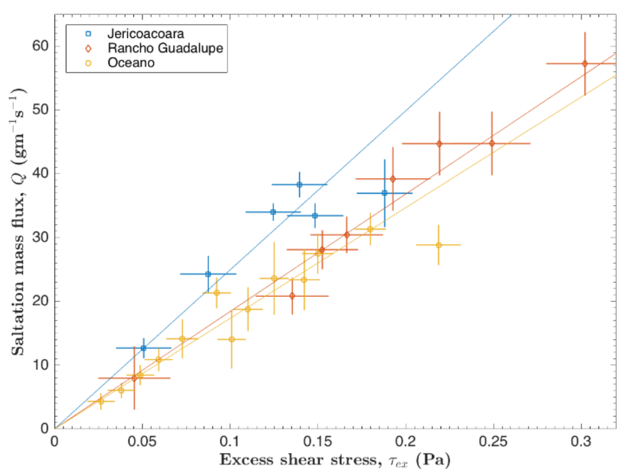

Figure 2. Saltation mass flux Q versus the wind shear stress in excess of the saltation threshold, τ_{ex}. Fluxes are grouped into τ_{ex} bins with vertical bars denoting flux uncertainties and horizontal bars denoting stress uncertainties for each bin. Solid lines indicate linear sand flux laws for each of three different field sites. From Martin and Kok (*Science Advances*, 2017).

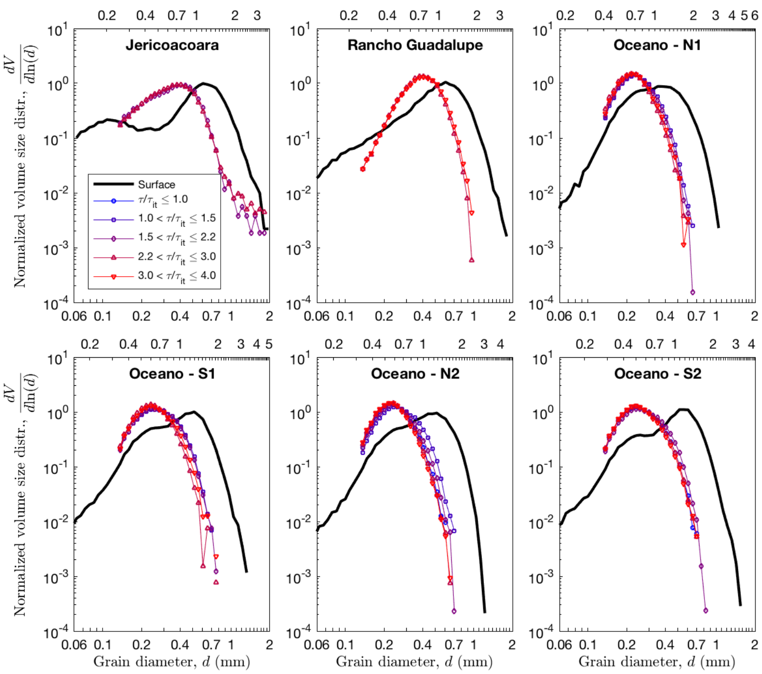

Figure 3. Site-averaged bed surface particle size distributions (PSDs), and airborne PSDs. The airborne PSDs are conditioned on specific ranges of shear stress τ, normalized by the threshold shear stress for transport at each site. Results show that a wide range of size classes move whenever saltation is active, implying equal susceptibility to saltation transport for those size classes. This contrasts with the assumption made in dust emission models that sand of a given size will be mobile only once the wind stress exceeds the threshold above which particles of that particle size can be lifted. The reason is that, once the most-readily lifted particles are in saltation, they will mobilize particles of all sizes from the surface. From Martin and Kok (*JGR*, 2019)

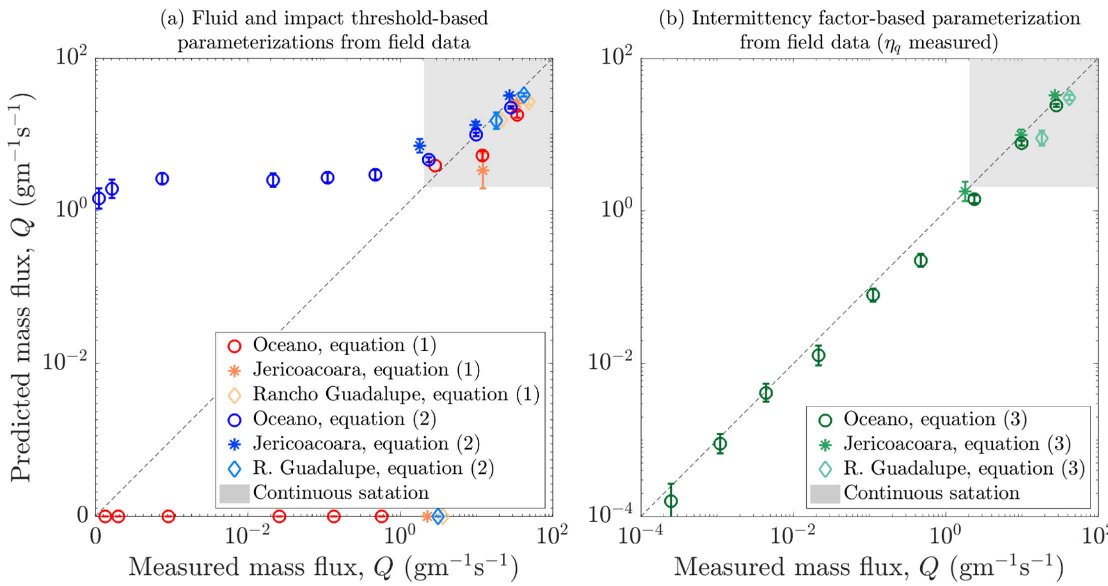

Figure 4. Predicted versus measured sand mass fluxes at three different field sites. In panel (**a**), mass fluxes are predicted with current parameterizations for continuous saltation that are in use in atmospheric models and geomorphological models. Panel (b) shows the prediction of our proposed new parameterization, which accounts for intermittency in saltation transport, showing a marked improvement in the agreement with measurements. From Comola et al. (*GRL*, 2019).

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