EOS
EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 92 NUMBER 29
19 JULY 2011
PAGES 241–248

Dust: Small-Scale Processes With Global Consequences

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Desert dust, both modern and ancient, is a critical component of the Earth system. Atmospheric dust has important effects on climate by changing the atmospheric radiation budget, while deposited dust influences biogeochemical cycles in the oceans and on land. Dust deposited on snow and ice decreases its albedo, allowing more light to be trapped at the surface, thus increasing the rate of melt and influencing energy budgets and river discharge. In the human realm, dust contributes to the transport of allergens and pathogens and when inhaled can cause or aggravate respiratory diseases. Dust storms also represent a significant hazard to road and air travel.

Because it affects so many Earth processes, dust is studied from a variety of perspectives and at multiple scales, with various disciplines examining emissions for different purposes using disparate strategies. Thus, the range of objectives in studying dust, as well as experimental approaches and results, has not yet been systematically integrated. Key research questions surrounding the production and sources of dust could benefit from improved collaboration among different research communities. These questions involve the origins of dust, factors that influence dust production and emission, and methods through which dust can be monitored.

Where Does Dust Come From?

A common generalization is that dust emission occurs mainly on dry lakes. Though many dry and drying lakes, whether natural (e.g., Australia's Lake Eyre, Chad's Bodélé Depression) or manmade (e.g., California's Owens Dry Lake, central Asia's Aral Sea), are significant sources of dust, research has shown that not all dry lakes are dust sources or, at least, not all the time [*Reynolds et al.*, 2007]. One consequence of this generalization is the notion that nonlake sources are not significant. Yet a growing body of literature reveals that vegetated landscapes and dune fields can emit dust [*Bullard et al.*, 2008; *Rivera Rivera et al.*, 2009] (Figure 1). Recent advances using satellite data over northern Africa have also shown that dust sources may be more diverse than previously believed [*Schepanski et al.*, 2007], and in the Mojave Desert of the southwestern United States, alluvial fans and plains may be larger overall contributors to total dust emission than dry lakes [*Reheis and Kihl*, 1995].

Once the diversity of dust-producing landforms is recognized, it becomes critical to quantify the relative importance and temporal behavior of these different sources. Meeting this challenge will require concerted and collaborative efforts from field scientists, remote sensing specialists, and modelers.

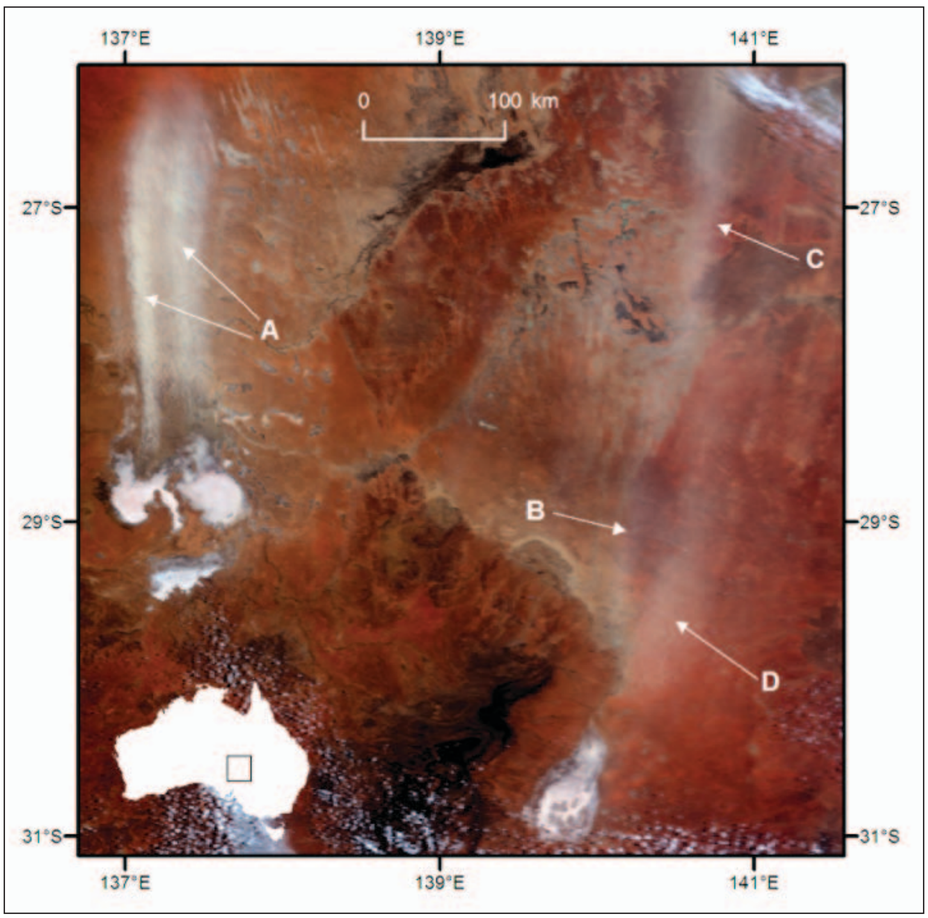

Fig. 1. True-color image from the Moderate Resolution Imaging Spectroradiometer (MODIS) on 2 February 2005 showing dust from a diversity of sources within an approximately 520- × 520-kilometer portion of a northwestern region of the state of South Australia, Australia. These include a combination of dry lake and alluvial terminus sources in Lake Eyre (arrows labeled A), dominantly dry lake sources in Lake Callabonna (arrow B), alluvial sources in the Cooper Creek Floodplain (arrow C), and sand dunes east of Lake Callabonna (arrow D).

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How Do Vegetation Properties Influence Dust Production?

Although vegetation typically reduces eolian activity, vegetation cover and dust emission are not related in a simple way, making it difficult to determine thresholds at which vegetation inhibits dust emissions or even whether such thresholds exist. Recent studies show that unvegetated gaps control dust production on vegetated landscapes [*Okin et al.*, 2006], meaning that dust emissions from areas with large gaps can be considerable even in the presence of extensive vegetation cover (Figure 2).

Distinguishing between perennial and annual vegetation is also important in understanding dust emission potential and timing. Perennial desert plants typically persist through dry periods, whereas rapid and dense growth of annual plants may follow precipitation, depending on its timing and amount. Thus, drylands with sparse perennial vegetation can emit dust but with reduced propensity when significant annual plant cover is supported by prior precipitation [*Urban et al.*, 2009]. The representation of responses of different plant functional types to intra-annual and interannual climate variation is critical for accurately simulating dust emissions over vegetated areas.

Fig. 2. Photograph of dust being emitted from a loamy mesquite shrubland during a dust storm in southern New Mexico in summer 2010. Photo by Matthew Baddock.

How Do Soil Processes Influence Dust Production?

The ability of a soil to emit dust is not a simple function of its surface particle size distribution, nor does the size distribution of dust mirror the size distribution of the source soil. Soil particle sizes are typically calculated from fully disaggregated suspensions in liquid, but dust emission is more a function of dry aggregate size distributions. Dust is largely produced by the collisions between saltators—bouncing particles transported as bed load, themselves often weakly consolidated aggregates of soil—or between saltators and the surface, though in some special cases, emissions are possible without saltation [see *Kjelgaard et al.*, 2004]. Additionally, mineral grains may have clay or oxide coatings that are accreted as soils form, abraded during transport, and released as dust, thus allowing deposits that nominally contain no fine particulates to be a source of aerosols [e.g., *Bullard and White*, 2005].

The remote sensing of soil surfaces in a way that can contribute meaningfully to the study of dust is in its infancy, and though there are increasingly better geospatial databases of soil properties, these do not reflect aggregate formation, soil stability, or particle coatings. Better understanding of how soil reflectance or existing soil databases can be used in dust emission models that represent soil processes will ultimately lead to better predictions of dust emission and atmospheric loading.

What Role Does Human Activity Play in Dust Emission?

Dust plumes are commonly observed originating from areas of localized human disturbance such as roads, agricultural fields, military installations, construction sites, and off-road vehicle areas. Grazing is a widespread, dust-producing disturbance, and grazed areas consistently produce more dust than areas never grazed. Grazing removes vegetation, breaks protective soil crusts, and promotes large-scale shrub encroachment on grassland, which itself can lead to order-of-magnitude increases in emissions by changing the unvegetated gap size distribution in a landscape. A clear understanding of the myriad ways in which human disturbance promotes dust emission and the magnitude of the effects of different land use types on dust production are both critical for predicting how changes in land usage (and thus changes in land use policies) will influence dust emission, loading, and deposition in the future.

What Information Does Remote Sensing Provide About Dust Sources?

Satellite remote sensing has revolutionized the study of dust, particularly at the regional and global scales important for climate analysis. As a result, there is a very good picture of the major dust-producing areas of global importance. Dust plumes observed from satellites are vivid indications of concentrated dust emission and large sources of atmospheric dust.

However, field studies have shown that considerable dust emission can also occur from diffuse or relatively small sources that do not produce plumes visible from space. Dust plumes that are readily sensed remotely may originate from the strongest dust sources in a region, but generally the source areas for these plumes occupy a small fraction of the landscape. In contrast, diffuse sources (including dust devils [see *Koch and Renno*, 2005]) might produce dust at rates considerably lower than plume-producing areas but with spatial extents several orders of magnitude higher. Even when these diffuse sources produce a coalesced dust plume dense enough to be detected in satellite imagery, the source areas may be impossible to identify in remote sensing imagery. This condition leads to underestimation of the contributions of diffuse dust sources to regional and global emissions.

Furthermore, the relative timing of satellite overpass and dust emissions, the presence of undetectable dust beneath clouds, and the underestimatation of near-surface dust by some sensors all tend to bias remote sensing estimates of dust emission. Though identifying massive, plume-producing dust sources is important, it is also necessary to acknowledge less obvious dust sources so that a more comprehensive picture of the distribution, amount, and timing of dust emissions can be produced.

Global-scale research has provided breakthrough advances in understanding dust emissions and their role in the Earth system. However, one outcome of regional-scale and global-scale analyses at relatively coarse resolution—facilitated by satellite data and necessitated by current model resolution and computational constraints—is that complex processes have been simplified. The need to simplify multifaceted environments into manageable modeling problems inevitably produces generalizations about the location, intensity, and dynamics of different dust sources. It is critical not to take these generalizations as complete descriptions of dust emission processes. As the spatial resolution of models increases, research should focus on strategies for incorporating smaller-scale and short-term temporal variability of dust emissions. Some strategies are being explored for both past and contemporary dust emissions, but there is clearly also a need to expand these strategies to include anthropogenic influences.

A Comprehensive Approach

Finally, understanding the production and role of dust in the Earth system would greatly benefit from active dialogue among the different observation-oriented and model-oriented communities, as well as investigators who work on multiple scales, to ensure that dust emission processes can be included with high fidelity, while maintaining the computational simplicity required for ever more complex global and regional models. At present, both disciplinary boundaries and interest in dust at different, and difficult to reconcile, scales impede progress in the study of dust. In this sense, dust emission is not so different from a variety of other phenomena in which small-scale processes have global consequences, such as cloud formation, anthropogenic carbon dioxide emission, and land use change. Funding and workshop opportunities that directly address these difficulties, both generally and specifically with regard to dust, are required so that scientists can strive for better accuracy in the next generation of predictions about the future of the Earth system.

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NEWS

Continuity of Ocean Color Data Record at Risk, According to U.S. National Research Council

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Report

Satellite remote sensing of ocean color is important for a number of research and operational uses, including detecting the impacts of climate change on primary productivity; assisting with fisheries and ecosystem-based management; understanding the optical environment of coastal waters for the operation of ships, submarines, and divers; and monitoring oil spills. However, according to a U.S. National Research Council (NRC) report released on 7 July, U.S. access to the continuous ocean color data record collected by satellites currently is "at risk."

The report, *Assessing Requirements for Sustained Ocean Color Research and Operations*, calls for several measures to limit or eliminate a potential interruption in the ocean color record, which "would severely hamper the work of climate scientists, fisheries and coastal resource managers, and an expanding array of other users, from the military to oil spill responders."

The risk of a data gap is due to several factors, including the 2010 demise of the Sea-viewing Wide Field-of-view Sensor (SeaWiFS); the aging of other instruments (including the Moderate Resolution Imaging Spectroradiometer (MODIS, on board NASA's Terra satellite); and the need for the United States to ensure use of data from sensors operated by others, including the European Space Agency and the Japan Aerospace Exploration Agency. In addition, although NASA's Pre-Aerosol, Clouds, and Ecosystem (PACE) mission is expected to advance ocean color research capabilities, this first of three planned missions is not scheduled to launch before 2019.

The Visible Infrared Imager Radiometer Suite (VIIRS) is scheduled to be launched on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project later this year, and the report recommends steps to ensure that VIIRS can adequately fill ocean color data needs until PACE is launched. The recommended steps include monthly spacecraft maneuvers to look at the surface of the Moon (i.e., lunar looks) to monitor sensor stability and rate of degradation; periodic data reprocessing; postlaunch vicarious calibration; and a system to archive, make freely available, and distribute data products to the national and international user community.

Unless these measures are taken, "there is an excellent chance that [VIIRS] just won't be a science quality or climate quality data set," NRC committee chair James Yoder told *Eos*. Yoder, vice president for academic programs at the Woods Hole Oceanographic Institution, Woods Hole, Mass., said, "The shorthand is: Save VIIRS."

Yoder added that two U.S. federal agencies involved with VIIRS—NASA and the National Oceanic and Atmospheric

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