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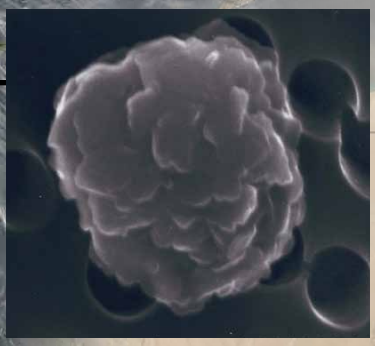
A Dusty Planet

BY ROBERT A. DUCE



(background image) MODIS image of a large Sahara dust storm on March 4, 2004. *Image courtesy of Jeff Schmaltz, MODIS Rapid Response Team, NASA-GSFC.* (inset) A one micrometer kaolinite Sahara dust particle collected at 300 m elevation near St. Croix on July 22, 2011. *Image courtesy of James Anderson, Arizona State University*

We live on a dusty planet—and the mineral matter that we commonly call "dust" is critical in many components of our Earth system, including several marine biogeochemical cycles and climate. The long-range atmospheric transport of dust has been known for centuries. The first mention of dust storms was in the ancient Chinese literature, referring to "dust rain," "dust fog," or "yellow fog," which usually occurred in the spring. The earliest known record of "dust rain" appears in 1150 BCE in the historical book *Zhu Shu Ji Nan* or *Chronicles Reported on Bamboo Slips*. Recent interest in dust in the marine environment focuses on associated iron content, which serves as a critical nutrient for marine primary productivity and nitrogen fixation in many ocean regions (see Grand et al., 2014, in this issue).

Charles Darwin noted the frequency of dust storms over the tropical Atlantic, writing: "Finally, I may remark that the circumstance of such quantities of dust being periodically blown, year after year, over so immense an area in the Atlantic Ocean, is interesting, as showing by how apparently inefficient a cause a widely extended deposit may be in process of formation…" (Darwin, 1846). Of course, his "widely extended deposit" was the terrigenous marine sediments in that region. Studies in the mid-1980s by David Rea of the University of Michigan showed that the record provided by aeolian dust accumulating in pelagic sediments was related to the long-term history of atmospheric circulation. Rea's analyses of the size, composition, and mass accumulation rate of sediment particles in the North Pacific gave independent information on both past atmospheric circulation and also the availability of material in the particles' source region. These studies, in turn,

provided information on past climate in the source regions. Investigations by Margaret Leinen and colleagues from the University of Rhode Island in 1985 showed that the mineralogy of contemporary aerosol particles collected over the western North Pacific was essentially identical to the mineralogy of oceanic sediment samples collected in the same general region, confirming that aeolian sources are responsible for a very significant fraction of the mineral material found in the sediment.

Even though the Chinese and Japanese have known about the transport of Asian desert dust for centuries, actual measurements of atmospheric dust over the ocean did not begin until the early 1960s at Barbados, when D.W. Parkin and Tony Delany were searching for airborne cosmic dust. Joseph Prospero at the University of Miami took over the Barbados site in 1966 and has been sampling atmospheric dust there ever since—making it the longest continuous record of atmospheric dust anywhere in the world. Prospero is clearly the pioneer in studies of atmospheric dust, eventually operating stations on different time scales on islands and continental margins throughout the world ocean. He first noted the seasonal cycle of dust transport from Africa across the tropical Atlantic, and he and Enrico Bonatti were the first to make actual measurements of atmospheric dust over the Pacific from a ship in 1969. The first long-term atmospheric measurements in the Pacific were made during the Sea-Air Exchange (SEAREX) program on Enewetak Atoll in the Marshall Islands in 1979; they led to the implementation of the SEAREX dust network on island stations in both the North and South Pacific. At Enewetak, the initial discovery of strong seasonal distribution of dust was an example of scientific serendipity. Sampling had been scheduled for January and February as well as August and September 1979. However, Typhoon Alice struck Enewetak in December 1978, destroying much of the sampling facility and necessitating a delay of sampling until April and May 1979. This period turned out to be the high Asian dust season, and that dust was then captured by the SEAREX team at Enewetak, 8,000 km from it source. Subsequently, similar measurements of atmospheric dust were recorded at a number of island stations in the North Atlantic as part of the Aerosol Oceanic Chemistry Experiment (AEROCE) in the late 1980s and 1990s. More extensive sampling from ships has also taken place in recent years. Of particular note are the measurements over the past decade of atmospheric dust and other substances by Alex Baker from the University of East Anglia on the AMT (Atlantic Meridional Transect) cruises in the North and South Atlantic, similar studies in the Indian Ocean by Monmohan Sarin and colleagues from the Physical Research Laboratory in India, measurements over many areas of the Pacific Ocean by Mitsuo Uematsu and students from the University of Tokyo, and measurements of atmospheric mineral aerosol and aerosol iron solubility on a series of Climate Variability and Predictability (CLIVAR) and GEOTRACES cruises by William Landing and his group at Florida State University.

Estimates of the total quantity of mineral dust emitted to the atmosphere from terrestrial sources have ranged from early values of ~ 60 Tg yr^{-1} to current estimates that range as high as 6,000 Tg yr^{-1} (Natalie Mahowald, Cornell University, *pers. comm.*, August 30, 2013). A recent comparison of 15 AeroCom models by Nicolas Huneeus from France and colleagues calculated a median emission value of ~ 1,100 Tg yr^{-1}, with values ranging from ~ 500 to ~ 4,300 Tg yr^{-1}, indicating the great uncertainty in dust emissions. Current estimates of the total deposition of mineral dust to the ocean are roughly 400–500 Tg yr^{-1}. The distribution of this deposition is, of course, closely related to the wind patterns carrying the dust downwind of the major arid

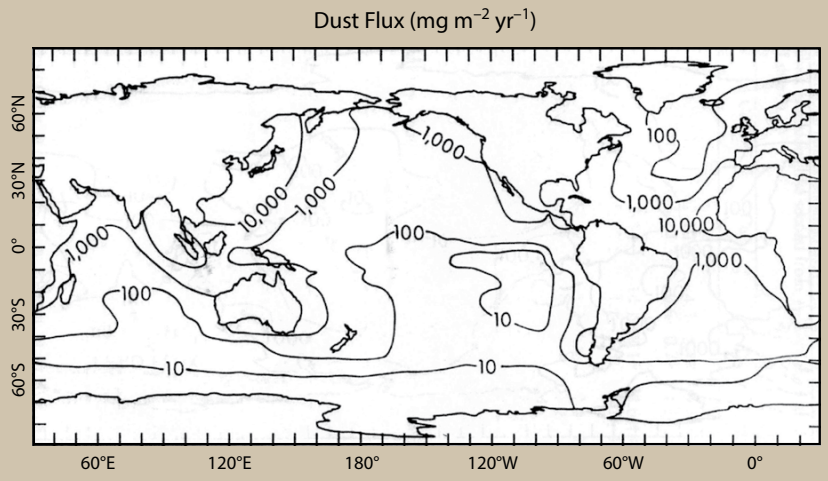


Figure 1. Atmospheric dust deposition to the ocean, in mg m^{-2} yr^{-1}. *From Duce et al. (1991), reproduced with permission of John Wiley & Sons, Inc.*

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and desert regions of the world, as clearly shown in an early map of dust deposition (Figure 1) and a more recent and accurate estimate (Figure 2). Natalie Mahowald and colleagues from Cornell University have led the way in modeling the transport and impact of mineral dust on both long and short time scales.

Typically, mineral dust contains ~ 3.5% iron. In 1984, Bob Moore at Dalhousie University was among the first to investigate the solubility in seawater of the iron present in mineral dust and to suggest that sufficient iron could dissolve to be an important source of iron in surface seawater. And in 1986, the present author showed by simple modeling studies that in the North Pacific Gyre and the Sargasso Sea regions, atmospheric deposition could be the major source of iron in surface waters. At about this same time, a series of papers by John Martin and colleagues from Moss Landing Marine Laboratory suggested that in many areas of the ocean, phytoplankton growth is limited by the availability of iron, leading to his famous Iron Hypothesis. Following the lead of Pat Patterson at Cal Tech, contamination-free sampling and analytical techniques for the measurement of iron in seawater were then being developed by Martin and by Ken Bruland at the University of California, Santa Cruz, among others, enabling dissolved iron to be measured reliably in seawater. All of this led to an explosive growth of interest in the marine biogeochemistry of iron and its role in primary productivity, and also in atmospheric dust, its transport, deposition to the ocean, and solubilization in seawater.

Reliably measuring atmospheric dust and its deposition to the open ocean is a complex endeavor. While the sampling of dust from ships and from a few island stations over relatively short time periods has been very useful in defining the gross features of the atmospheric input of dust and iron to the ocean, the current global coverage and spatial and temporal resolution of this information has generally not been sufficient to be used with great success in biogeochemical modeling efforts. More long-term measurements at remote oceanic sites are necessary to constrain the outputs of global dust models. Responding to the recent call for more long-term island sampling sites for dust will be expensive and very labor intensive. One innovative approach to this issue is the work of Chris Measures and colleagues at the University of Hawaii, who use surface-ocean dissolved aluminum concentrations as an indicator of dust deposition. Because aluminum has no other significant source in open ocean regions, dissolved aluminum can be used as an integrator of dust deposition and solubilization over an extended period of time. Grand et al. (2014, in this issue) present the results of such measurements from a series of CLIVAR cruises, and their paper shows the very clear impact of atmospheric dust on the dissolved aluminum content downwind from Earth's major arid regions, which they relate to dissolved iron. The patterns of dissolved aluminum they found are consistent with the patterns of dust deposition shown in Figures 1 and 2.

The ancient Chinese would undoubtedly be delighted to see how far we have progressed in understanding our dusty planet since their reports of "dust rain" and "yellow fog" in *Zhu Shu Ji Nan* well over 3,000 years ago, but they would also wisely say that we still have a long way to go.

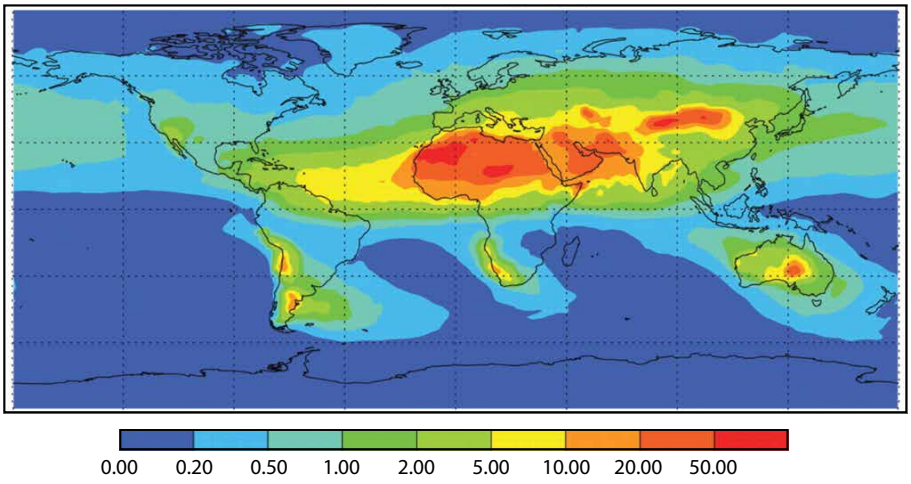

Figure 2. Atmospheric dust deposition to Earth's surface, in g m^{-2} yr^{-1}. *From Jickells et al. (2005), reprinted with permission from AAAS*

REFERENCES

Darwin, C. 1846. An account of the fine dust which often falls on vessels in the Atlantic Ocean. *Quarterly Journal of the Geological Society* 2:26–30, http://dx.doi.org/10.1144/GSL.JGS.1846.002.01-02.09.

Duce, R.A., P.S. Liss, J.T. Merrill, E.L. Atlas, P. Buat-Menard, B.B. Hicks, J.M. Miller, J.M. Prospero, R. Arimoto, T.M. Church, and others. 1991. The atmospheric input of trace species to the world ocean. *Global Biogeochemical Cycles* 5:193–259, http://dx.doi.org/10.1029/91GB01778.

Grand, M.M., C.S. Buck, W.M. Landing, C.I. Measures, M. Hatta, W.T. Hiscock, M. Brown, and J.A. Resing. 2014. Quantifying the impact of atmospheric deposition on the biogeochemistry of Fe and Al in the upper ocean: A decade of collaboration with the US CLIVAR-CO_2 Repeat Hydrography Program. *Oceanography* 27(1):62–65, http://dx.doi.org/10.5670/oceanog.2014.08.

Jickells, T.S., Z.S. An, K.K. Andersen, A.R. Baker, G. Bergametti, N. Brooks, J.J. Cao, P.W. Boyd, R.A. Duce, K.A. Hunter, and others. 2005. Global iron connections between desert dust, ocean biogeochemistry, and climate. *Science* 308:67–71, http://dx.doi.org/10.1126/science.1105959.