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Measuring Trans-Atlantic Aerosol Transport From Africa

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An estimated three billion metric tons of mineral aerosols are injected into the troposphere annually from the Saharan desert [*Prospero et al.,* 1996]. Additionally, smoke from biomass burning sites in the savanna grasslands in sub-Saharan Africa contribute significant quantities of smaller-sized aerosols [e.g., *Hobbs,* 2000]. These windswept aerosols from the African continent are responsible for a variety of climate, health, and environmental impacts on both global and regional scales that span the Western Hemisphere. Unfortunately, in situ measurements of aerosol evolution and transport across the Atlantic are difficult to obtain, and satellite remote sensing of aerosols can be challenging.

The trans-Atlantic Aerosol and Ocean Science Expeditions (AEROSE) are a series of intensive field experiments conducted aboard the U.S. National Oceanic and Atmospheric Administration (NOAA) ship *Ronald H. Brown* during the Northern Hemisphere spring (March 2006) and summer (June-July 2007) and proposed follow-on cruises in alternating seasons through 2010. The ongoing AEROSE mission focuses on providing a set of critical measurements that characterize the impacts and microphysical evolution of aerosols from the African continent as they transit the Atlantic Ocean.

The three central scientific questions addressed by AEROSE are as follows: (1) What is the extent of physical and chemical evolution in the mineral dust and smoke aerosol during trans-Atlantic transport? (2) How do Saharan and sub-Saharan aerosols affect the regional atmosphere and ocean during trans-Atlantic transport? (3) How can these unique aerosol measurements be used to resolve or improve remote sensing algorithms and models of the above processes?

While there have been a variety of aerosol campaigns that have encountered mineral dust or smoke, few have focused on Saharan dust as well as sub-Saharan smoke, and none has sought to characterize the evolution of these aerosols during long-range transport as a function of season. Thus, a comprehensive suite of aerosol measurements and size-segregated sampling were performed during each AEROSE cruise to characterize the evolution of the mineral dust mass distribution with respect to number density and chemical composition.

Project Overview

AEROSE-I was a 27-day cruise conducted during March 2004. A combination of climatological and near-real-time satellite observations, along with meteorological forecasts, helped steer the vessel into one of the largest (with respect to spatial extent) dust storms ever observed during that time of the year (Figure 1a). The AEROSE science team

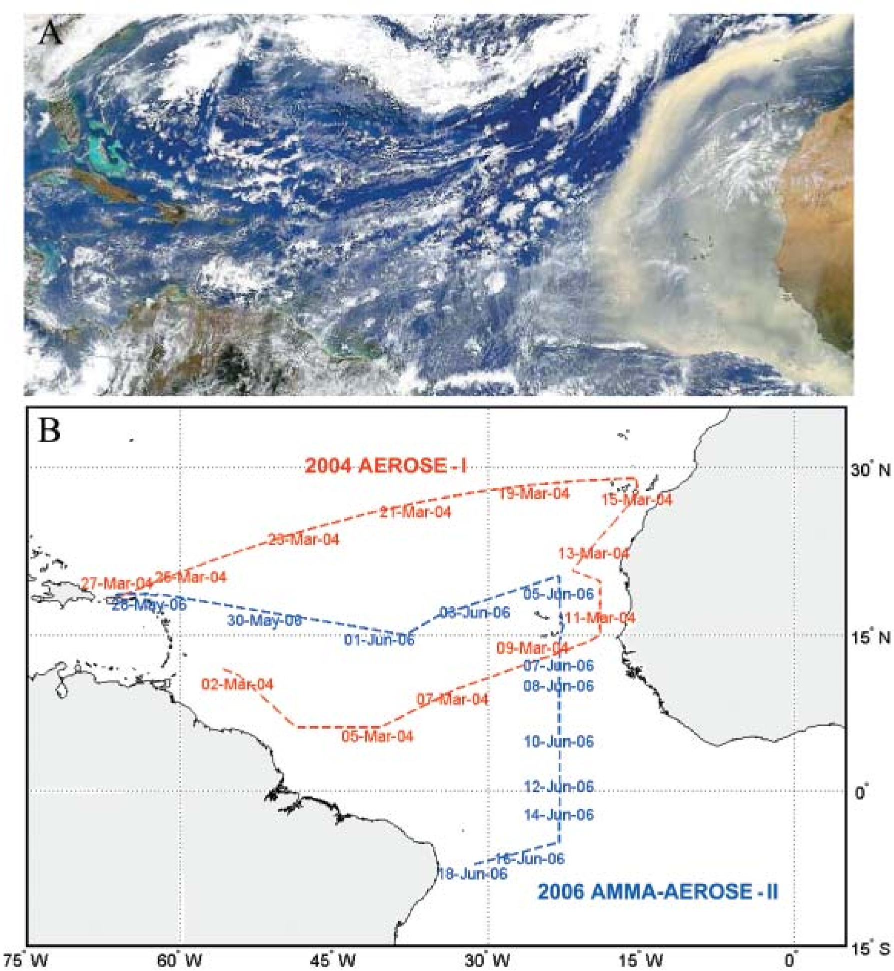

Fig. 1. (a) Moderate Resolution Imaging Spectrometer (MODIS) true color average image (5–6 March 2004) of the Saharan dust plume crossing the North Atlantic Ocean during AEROSE. (b) Cruise tracks of the Ronald H. Brown for the 2004 AEROSE-I and Leg 1 of the 2006 AMMA-AEROSE-II.

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obtained intensive surface-based and column measurements to secure a unique open-ocean data set before, during, and after a major dust event. The data complement also provided for validation of advanced satellite instruments under challenging environmental conditions [*Nalli et al.*, 2006].

AEROSE-II was a 55-day 'piggyback' mission beginning on 27 May 2006 and conducted in concert with the African Monsoon Multidisciplinary Analysis (AMMA) and the Pilot Research Array in the Tropical Atlantic (PIRATA) project. The PIRATA project is a collaborative effort between the United States, France, and Brazil to maintain an array of moored buoys to collect meteorological and oceanographic measurements for weather and climate prediction. Maintaining this array, and extending it from the existing network, requires annual cruises in the AEROSE study region. The next cruise to service these, and deploy additional, buoys currently is planned for May 2007. The AEROSE team will piggyback on future PIRATA cruises to extend the observational research record.

The cruise tracks for AEROSE-I and -II have complementary spatial transects during distinctly different meteorological regimes, as shown in Figure 1b. It is clear that while AEROSE-I provided the opportunity to conduct longitudinal surveys within dust and nondust conditions, AEROSE-II afforded the opportunity to probe cross sections of both dust and smoke, as well as their trans-Atlantic transport. The ship measurements also are complemented by simultaneous downstream aerosol measurements in Puerto Rico.

AEROSE-I Highlights

During AEROSE-I, nearly continuous in situ sampling of surface ozone, carbon monoxide, aerosols, radiation, infrared spectra, and meteorological measurements were obtained from the ship. Complementing these were high-resolution atmospheric column measurements of temperature, humidity, and winds obtained from three-hourly radiosonde launches performed throughout the cruise [*Nalli et al.*, 2005].

On 6 March 2004, the ship encountered the unusually massive plume of Saharan dust mentioned above midway across the Atlantic Ocean (Figures 1a and 1b). The leading edge of this dust, which extended in an arc from Spain to the Gulf of Guinea, had peak mass densities of 200 micrograms per cubic meter for aerosols with diameters less than 2.5 microns ($PM_{2.5}$) more than 1300 kilometers northwest of the Gulf of Guinea. The evolution of the surface mass and number distributions, as well as the size-resolved surface chemistry, within this plume subsequently was characterized. For the 6 March dust event, optical depths as large as 1.0 and surface radiative forcing of approximately 100 watts per square meter were observed as far as 1000 kilometers from the West African coastline.

The cross-sectional analyses of the sonde data depicting lower tropospheric water vapor mixing ratio and winds are shown in Figure 2. These analyses show the intrusion and evolution of the Saharan air layer (SAL) [cf. *Nalli et al.*, 2005]. The dramatic drying of the entire lower troposphere is observed down to a height of 500 meters at distances of over 1100 kilometers from the dust source region.

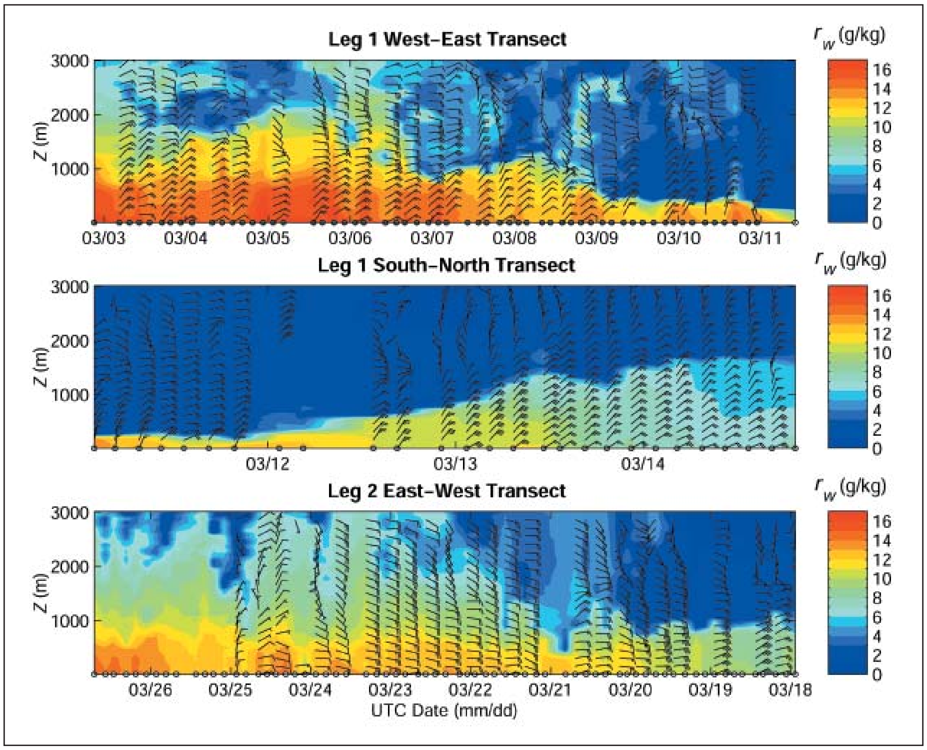

Fig. 2. AEROSE-I contour analyses of atmospheric water vapor mixing ratio, in grams per kilogram, and horizontal component wind vectors (in SI units), as a function of UTC time and geopotential height, Z, based on the three-hourly radiosonde observations [cf. Nalli et al., *2005]. The circles show the locations of sonde launches.*

In addition to atmospheric profiling, oceanographic profiles of temperature were obtained to characterize water masses. Water mass structure is depicted in the finer-grid expendable bathythermograph (XBT) series (Figure 3a), where shoaling and cooling of the mixed layer, accompanied by sharpening of the thermocline from west to east, is apparent.

AEROSE-II: Highlights

Leg 1 of AEROSE-II spanned 26 May to 18 June 2006 (see Figure 1b), which enabled measurements in three of the desired dust aerosol regimes: the unperturbed summertime tropical eastern Atlantic Ocean, the 'background' dust regime, which persists throughout the summer, and a mixed dust-urban plume air mass. The measurement suite was augmented with a micropulse lidar (MPL) to resolve vertical aerosol distributions, and ozonesonde launches were conducted in addition to the surface observations in order to explore the impacts of dust on vertical ozone distributions.

The presence of an elevated dust layer aloft from 31 May to 8 June was confirmed through analysis of satellite imagery, the MPL signature, and Microtops optical depth measurements, which increased from background levels of less than 0.1 to near 0.4 in the vicinity of the Cape Verde Islands. During Leg 2, a larger summertime dust outbreak was encountered on 6–9 July, as well as biomass burning and mixed air masses containing both dust and biomass effluents. A total of 20 ozonesondes were launched during the various dust and biomass burning regimes to characterize the impacts on both daytime and nighttime ozone chemistry. These measurements reveal structures linking transport and in situ chemistry along 23°W from 18°N to ~6°S, the results of which are being prepared for separate publication.

XBTs also were launched at intervals of about 60 kilometers west of 38°W during Leg 1 (Figures 3b and 3c). These data reveal perturbations in the east-west temperature distribution caused by ocean eddies, and show the north-to-south shoaling of the thermocline and increase in upper ocean heat content. Continuous near-surface sampling was conducted using the ship's flow-through system while depth profiles of physical, chemical, and biological parameters were obtained at 104 oceanographic stations using a conductivity-temperature-depth/rosette system.

Ongoing Work

AEROSE is organized and led by Howard University (Washington, D.C.) under a grant from the NOAA Center for Atmospheric Sciences (NCAS) in collaboration with the NOAA National Environmental Satellite, Data, and Information Service (NESDIS) Center for

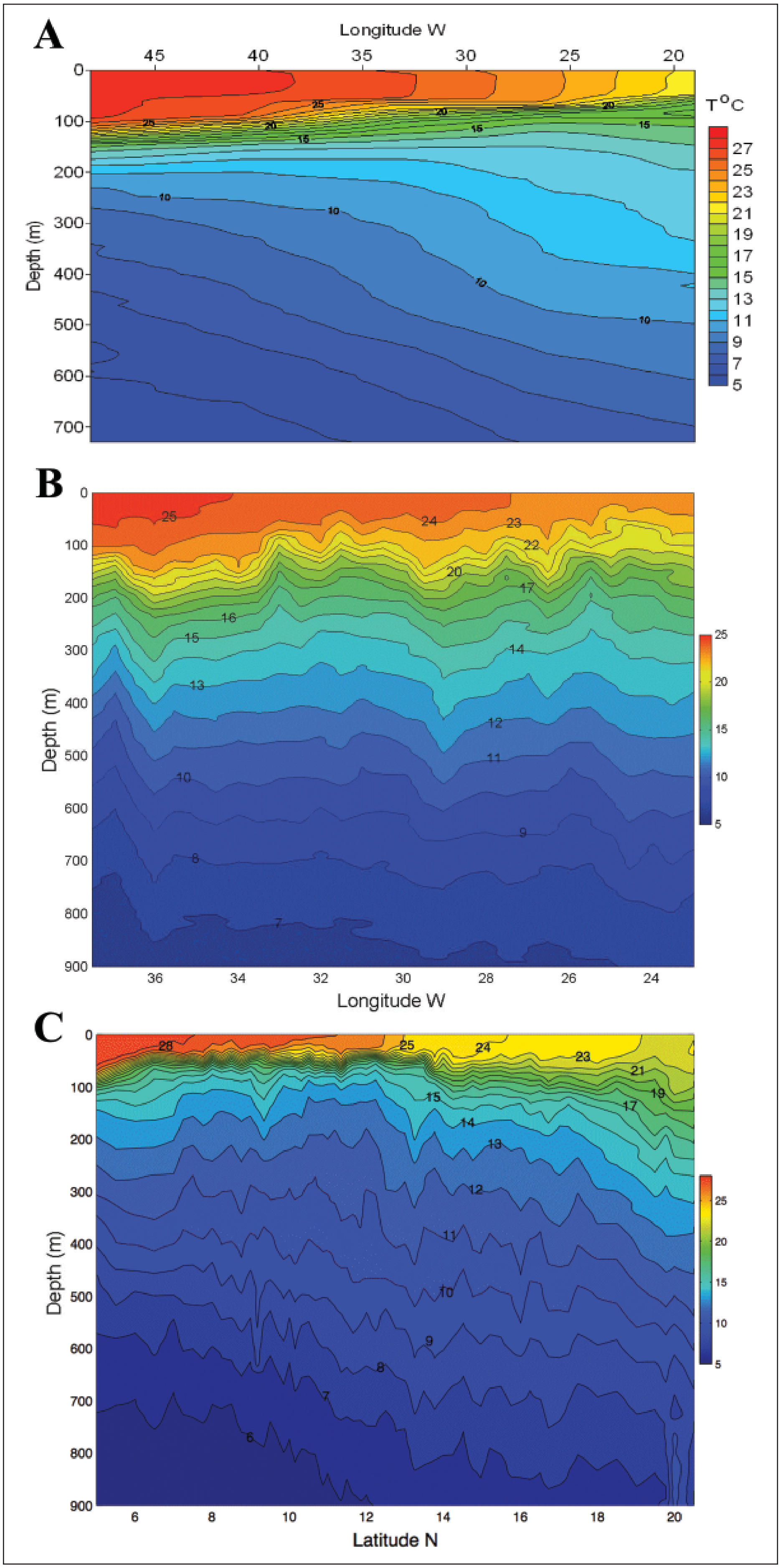

Fig. 3. XBT ocean temperature cross section along (a) the AEROSE-I eastward transect, (b) the AMMA-AEROSE-II eastward transect, and (c) the AMMA-AEROSE-II southward transect during Leg 1.

Satellite Applications and Research (STAR) and the University of Puerto Rico at Mayagüez. More piggyback cruise opportunities aboard the *Ronald H. Brown* are expected over the next three years. The AEROSE science plan includes surface measurements of radiation and aerosols in Puerto Rico throughout the corresponding calendar years. The database compiled from these experiments will serve the atmospheric sciences community by providing key measurements of aerosol properties in data-sparse regions under dust conditions. These measurements will facilitate improvements in satellite retrievals and climate model predictions, and they also will aid in understanding the chemistry and transport of African aerosols across the Atlantic Ocean.

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Rapid Export of Organic Matter to the Mississippi Canyon

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Coastal margins, where rivers serve as the dominant control on productivity and delivery of dissolved and particulate materials, have been understudied. The potential importance of certain river-dominated margins (RiOMars), such as those of the Mississippi River plume, to the global carbon budget is garnering increased attention because of their disproportionate role in transporting terrigenous materials to the ocean [*Dagg et al.,* 2004; *McKee et al.,* 2004].

This study concludes that labile (readily open to chemical, physical, or biological change) sedimentary organic matter, produced by in situ diatom production in the Mississippi River plume, is rapidly transported to the Mississippi Canyon. Despite the notion that canyon sediments are typically unstable and lack adequate food resources to support significant macrobenthic communities, this study suggests that productive RiOMars are important conduits for transporting fixed carbon from highly productive plume waters on the shelf to deeper benthic communities.

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The Louisiana Shelf as a RiOMar

The Mississippi–Atchafalaya River delivers 60% of the total suspended matter and 66% of the total dissolved materials transported from the conterminous United States to the ocean. Particulate organic carbon (POC) introduced by the river or biologically fixed on the Louisiana shelf is carried along-shelf, decomposed, buried, or transported to deeper regions in the Gulf of Mexico. Vertical fluxes of organic carbon (OC) in the Mississippi plume as high as 1.80 grams carbon (C) per square meter per day have been observed during spring [*Redalje et al.,* 1994], but are lower during other seasons (0.29–0.95 grams C per square meter per day) and away from the immediate plume (0.18–0.40 grams C per square meter per day). Much of the in situ plume productivity supporting carbon flux is composed of diatoms [*Lohrenz et al.,* 1999], as reflected in surface sediments below the plume.

Finally, a unique characteristic of this passive margin, where the Mississippi River discharges into the Gulf of Mexico, is the relatively short distance to the Mississippi Canyon; this setting may allow for the rapid transport of shelf-derived primary production to the canyon floor. In fact, there is evidence that layers of increased suspended matter and resuspension events are important advection mechanisms in this setting (C.A. Burden et al., unpublished data, 2006).

Source-to-Sink

Understanding the connectivity between coastal systems and the deep sea has received considerable attention in recent years. A primary goal of the U.S. National Science Foundation (NSF) MARGINS Source-to-Sink program (http://www.nsf-margins.org/S2S/S2S.html) is to develop a quantitative understanding of margin sediment dispersal systems, including OC export from river mouth and shelf regions. Similarly, the global importance of the coastal ocean has been recognized in national and international efforts, for example the Land-Ocean Interactions in the Coastal Zone (LOICZ), the European Union's European Land-Ocean Interaction Studies (ELOISE), Shelf-Edge Exchange Processes (SEEP I and II), Coastal Ocean Processes (CoOP), Ocean Margins Program (OMP), and RiOMar (http://www.tulane.edu/~riomar/).

Many RioMARs export a relatively small volume of river-derived particulates seaward of the shelf break due to (1) their location on wide, passive continental margins where deltaic sedimentation is confined to the inner shelf and (2) along-shelf dominated coastal currents. However, other RioMARs are characterized by high export to the lower continental margin (e.g., Sepik,