Measuring Trans-Atlantic Aerosol Transport From Africa

An estimated three billion metric tons of mineral aerosols are injected into the troposphere annually from the Sahara desert [Prospero et al., 1996]. Additionally, smoke from biomass burning sites in the savanna grasslands in sub-Saharan Africa contribute significant quantities of small-sized aerosols [e.g., Holben, 2000]. These wind-swept 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 Sahara 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 analysis of the above processes?

While there have been a variety of aerosol campaigns that have encountered mineral dust or smoke, few have focused on Sahara dust as well as sub-Saharan smoke, and none has sought to characterize the evolution of these aerosols during longrange

Project Overview

AEROSE 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 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 collected are provided for validation of advanced satellite instruments and the near-real-time operational conditions [Neff et al., 2001].

AEROSE was a 55-day “piggyback” mission beginning on 27 May 2006 and continues in concert with the African Monsoon Multiphase Analysis (AMMA) and the Firé Research Array in the Tropical Atlantic (FIRATA) project. The FIRATA 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 FIRATA cruises to extend observational research record.

The challenge to characterize the trans-Atlantic Aerosol and Fire-1 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 combine complementary 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 II Highlights

During AEROSE II, nearly continuous in situ sampling of surface ocean, 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 [Neff 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 290 micrometers 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

Rapid Export of Organic Matter to the Mississippi Canyon

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

This study presents data that indicate (readily open to chemical, physical, or biological change) sedimentary organic matter produced by diatoms 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 ROMars are important conduits for transporting fixed carbon from highly productive plumes seaward on the shelf to deeper benthic communities.

The Louisiana Shelf as a ROMar

The Mississippi–Atchafalaya River delivers 66% 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 is biologically fixed on the Louisiana shelf, and decoupled, buried, or transported to deeper regions in the Gulf of Mexico. Vertical fluxes of organic carbon (OC) in the Mississippi River are estimated to transport 1.6×10$^6$ tons fixed carbon (C) per square meter per day that have been observed during spring [Buckley et al., 1994], but are lower during other seasons (0.25–0.95 grams C per square meter per day) and away from the immediate plume (0.18–0.63 grams C per square meter per day).

Much of the in situ plume productivity as supported carbon flux is composed of detrital organic carbon. In the Gulf of Mexico, the shelf is the 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.sds-margins.org/S2S2015.html) is to develop a quantitative understanding of margin sediment dispersal systems, including DC 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 Zones (LOICZ), the European Union’s European Land-Ocean Interaction Studies (ELOISE), Shelf-Edge Exchange Processes (SEEP I and II), Coastal Ocean Processes (CoOP), Ocean Margin Program (OMP), and ROMar (http://www.nosbar.edu/~romar/).

Many ROMar systems export a relatively small volume of river-borne particulate material within the shelf break due to (1) their location on wide, passive continental margins whose salinity structure is confined to the inner shelf and (2) alongshore-dominated coastal currents. However, other ROMar systems are characterized by high export to the lower continental margin (e.g., Sepik, Ganges-Brahmaputra, Eel) due to a narrow (active continental margin) shelf and/or landward incision of the associated subma-
Rapid OC Export From the Delta to the Mississippi Canyon

In this study, four box-cores from the Mississippi Canyon (Figure 1a) were investigated. Surface sediments from station ICC-Can (Integrated Carbon Cycle-Canyon) were collected in July 2003, while Hurricane Ivan stations (HI-8, HI-9, and HI-10) were sampled in October 2004, one month following Hurricane Ivan. These samples are part of a series of funded studies that have been ongoing in this region for the past five to six years. This work is also relevant to research currently underway that examines post-Katrina effects. Water depths for these stations ranged from 320 to 665 meters. Sediments at all stations were fine terrigenous muds (<1% calcium carbonate at ICC-Can). The ICC-Can station had an extensive benthic macrofaunal assemblage of tube-dwelling polychaetes, something not commonly observed on the delta front, due presumably to the high sedimentation rates and mobile seafloor (Figure 1b).

The particle-reactive radionuclide beryllium-7 ($^{7}$Be; $t_{1/2}$ = 53.3 days) can be used as a tracer of recent river-derived inputs, and its presence in all surface sediments in the Mississippi Canyon (Figure 2) suggests that sediments are rapidly transported from the delta to the canyon. It is estimated that about 50% of the sediments delivered to this region are temporarily stored near the delta, with a large fraction transported along/across the shelf [Corbett et al., 2004, 2006]. Winter fronts are most likely responsible for the resuspension and transport of sediments along and off the Louisiana coast [Allison et al., 2000; Corbett et al., 2004]. The $^{7}$Be inventory at HI-9 is higher than at ICC-Can, its nearest site (Figure 2e). Since $^{7}$Be inventories integrate inputs over time (~250 days), the passage of Hurricane Ivan between sampling at ICC-Can (July 2003) and HI-9 (October 2004) may explain this difference.

Sediment deposition following the passage of hurricanes Katrina and Rita was 6–19 times the typical annual accumulation at the 50-meter isobath and deeper [Corbett et al., 2006]. The macrobenthos observed at station ICC-Can in July 2003 (see Figure 1b) was not present at station HI-9, or at the other canyon stations in October 2004 [Corbett et al., 2006], indicating slow recovery of these deeper macrobenthic communities [Corbett et al., 2006]. Gravity cores collected at ICC-Can also show evidence of mud turbidites at decimeters below the tube-dwelling community, indicating that hyperpycnal down-canyon transport is active at a lower frequency than storms and erosionally scouring epibenthic communities. While there is a 25-meter difference in elevation between station ICC-Can and HI-9, inputs of $^{7}$Be and chlorophyll to these sites are similar, which would not be the case if these sites were associated with a more sheltered versus a gravity flow region of the canyon floor.

Sources of Labile Organic Carbon in Mississippi Canyon

Algal pigments and polyunsaturated fatty acids (PUFA) were observed in surface sediments at all four canyon stations. These algal biomarkers are labile compared with other biomarkers, so they, like $^{7}$Be, reflect recent accumulation [Canuel and Martens, 1996]. The open waters of the Gulf are oligotrophic (poor in nutrients), and except for rare occasions when the Mississippi River plume extends farther southwest, vertical
inputs of algal debris through the canyon are small. Lohrenz et al. (1994) suggested that some biomarkers likely derive from sediments re-distributed from the productive shelf region where diatom productivity and fluxes to sediments are high (Dagg et al., 2004).

Furthermore, algal pigments and PUFAs decrease in concentration, whereas sterols (sterol alcohol found in plant lipids) increase in concentration between the shelf and the Mississippi Canyon (Fig. 3b). Redistribution of sediments from the delta to the canyon associated with Hurricane Ivan may have promoted decomposition of labile compounds and/or resulted in their dilution by mixing with deeper (older) sediments deposited in labile conditions but enriched in more stable compounds such as sterols. Figure and PUPA inventories at station

**Mississippi**

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ICCCCan confirm that stable phytoplankton (decomposing phytoplankton) is advected to the canyon, most likely during passage of winter storms and sporadically by hurricanes (Corbett et al., 2004, 2006). It is likely that communities of macrophytic polyplastos (a marine animal ward) in the canyon are supported by shellfish-derived rich in diatom phytoplankton.

This study concludes that labile sediments of organic matter produced by in situ diatom production in the Mississippi River plume, is rapidly (days to weeks) shunted to Mississippi Canyon. Transport probably occurs during winter storms and hurricanes, and possibly by turbulences originating in the upper reaches of the canyon. The supply rate of this labile phytoplankton is temporally consistent to support macrophytes.

**polyplastos populations that do not exist in nearshore waters off the Louisiana coast.** Thus, despite the predominant notion that canyon sediments are typically unstable and lack adequate food resources to support significant macrobenthic communities, productive ROVs can indeed serve as important conduits for transporting labile carbon from highly productive phytoplankton waters on the shelf to the deep Southern continental communities. Nevertheless, further work is needed to determine the importance of these food resources for macrobenthic communities.

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