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SHIPBOARD MEASUREMENTS OF SAHARAN DUST NEAR PUERTO RICO DURING SUMMER 2002

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Abstract

As a part of a larger effort to study the impact of Saharan dust transport on the air quality and native aerosol distributions in the Caribbean and eastern tropical Atlantic in-situ measurements of atmospheric aerosols were obtained at various locations in the Caribbean and Atlantic Ocean during two shipboard missions in June and August 2002. These measurements included total suspended aerosol mass, total suspended aerosol number density (TSP), and size distributions before, during, and after Saharan dust events. The shipboard measurements were complemented by simultaneous measurements of total suspended mass at 2.5 and 10.0 microns, size-resolved mass analysis using a quartz crystal microbalance, and aerosol optical depth at two locations on the island of Puerto Rico (El Faro and Isla Magueyes. Filter samples were also obtained from Dominica, Isla Magueyes, and aboard the ship for size-resolved chemical analysis of the aerosols.

We will present preliminary data of size and mass distributions obtained during June 2002 using the quartz crystal microbalance (QCM) cascade impactors and the laser particle counter.

1. Introduction

Saharan dust storm events are responsible for injecting huge amounts of mineral dusts into the atmosphere – by some estimates as much as two billion metric tons annually [Griffin, 2002]. Improvements in satellite technology and retrieval methods has enabled the observation of Saharan dust transport into Europe, western Asia, the eastern seaboard of the US, the Caribbean, and to South America [Prospero, et al., 1970]. The quantity of dust has the potential to induce regional health impacts - such as asthma outbreaks, particularly in sensitive subpopulations like the elderly, infants, and adolescents, and ecosystem responses – such as red tides or degradation of coral reefs due to infestation of foreign fungal or microbial populations. Saharan dust transport is also responsible for critical heavy metal and mineral deposition to the tropical Atlantic and may have impacts on regional atmospheric chemistry – via dust-induced smog and heterogeneous reactions [Goudie, et al., 2001]. Saharan or mineral dust has recently been implicated as a significant force factor in regional climate changes, specifically in influencing local precipitation patterns [Rosenfeld, et al., 2001].

The effects of Saharan dust in the Caribbean have been monitored for several years, particularly in terms of total mass deposition and potential relationships to respiratory ailments in the region [Griffin, et al., 2001]. Regional hazes associated with Saharan dust storms have also been reported more frequently over the last decade, reducing visibility and causing poor air quality. Thus, a complete understanding of the impacts of Saharan dust in the Caribbean and eastern Atlantic seaboard requires that a complete set of direct measurements be obtained. This complete set of measurements must include basic number densities, size distributions, mass distributions, chemical composition, optical properties, and basic microphysical properties. Our measurement strategy is aimed at obtaining a significant amount of information on the nature of the Saharan dust aerosols during extreme events in which the dust is transported and deposited in the Caribbean Sea.

2. NOAA Center in Atmospheric Sciences at Howard University

In October 2001 Howard University was one of four minority-serving institutions awarded in the Department of Commerce Educational Partnership Program. This initiative was aimed at providing funds for establishing partnerships between academic institutions that would expand education, research, and training opportunities in NOAA-related sciences with particular emphasis on traditionally underrepresented groups. Howard University teamed with Jackson State University, the University of Puerto Rico at Mayagüez, and the University of Texas at El Paso for a cooperative center in atmospheric sciences – the NOAA Center in Atmospheric Sciences (NCAS). Other significant collaborators include the National Centers for Environmental Prediction (NCEP), the State University of New York at Albany, and the Illinois State Water Survey (ISWS).

The goal of the ***NCAS*** program is to increase the number of highly qualified, well-trained graduates in the fields of atmospheric sciences for employment opportunities with NOAA, NWS, and other federal agencies through the establishment of a unique consortium comprised of two HBCUs and two Minority Serving Institutions (MSIs), the formation of an atmospheric sciences center at HU, and the implementation of a comprehensive academic and research training program. This ensures that the strategic objective of NOAA to fund a program in atmospheric sciences that will train and develop underrepresented students will be more than adequately met. The NCAS will help enhance capacity-building efforts through the implementation of a comprehensive academic and research-training program, which capitalizes on the strength of the university partners. All partners will contribute to training workshops and professional conferences, shared courses and seminars, outreach activities, student recruitment and mentoring, and conduct and presentation of timely, necessary NOAA-related research. Howard University has also developed a novel 3-2 BS/MS program that offers students the opportunity to obtain a BS in physics and a MS in atmospheric sciences while satisfying all of the NWS curriculum requirements.

The primary research goal of the NCAS centers on the general theme of developing more accurate regional climate models, particularly their aerosol parameterization schemes. Each of the projects seeks to maximize the interaction among faculty and students main partner institutions. The projects are:

1) The development of an instrument test-bed, validation, and training facility for aerosol and surface-based aerosol and radiometric measurements
2) The development of improved radiative parameterizations for the Weather Research and Forecast (WRF) Model that includes the coupling of cloud microphysics and surface fluxes with atmospheric radiative transfer.
3) A study of the climate and environmental impacts of the long-range transport of Saharan and mineral dust aerosols on the eastern US and Caribbean regions.

This paper will discuss recent research results stemming from efforts within the last major project area.

3. Project Overview and Measurement Strategy

In response to the potential impacts of Saharan dust on regional air quality, public health, and marine ecosystems the NCAS seeks to quantify these impacts and determine their significance in the western Atlantic and southeastern US. The research plan will involve the integrated use of satellite data, regional climate modeling, and in-situ measurements.

The measurement program will consist of the implementation of a continuous aerosol-monitoring network in the Caribbean, centered in Puerto Rico, and field intensives aboard research vessels in the Caribbean Sea and Atlantic Ocean. The focus of the measurement program is the characterization of the chemical and microphysical evolution of Saharan Dust as it is transported across the Atlantic and through the Caribbean, and to the eastern US coastline.

In order to achieve the goals of the measurement program we will perform a series of field measurements aboard the NOAA Research Vessel (RV) Chapman in the Caribbean assist in the implementation of a long-term aerosol measurement monitoring network in Puerto Rico, and perform chemical and microphysical analysis of collected samples of aerosols.

The specific objectives of the measurement program are:

1. To obtain comprehensive in-situ measurements of Saharan dust aerosols in the Caribbean and more specifically in Puerto Rico,
2. To quantify the microphysical (with focus on morphology, aerodynamic, and optical properties) and chemical evolution of the Saharan dust during transport through the Caribbean and across the island of Puerto Rico,
3. To determine the changes in total suspended mass of aerosols, PM2.5, PM10, and respirable aerosol in the Caribbean as a result of Saharan dust events, and
4. To quantify mass deposition of Saharan dust aerosol in Puerto Rico and to the local Caribbean waters.

An understanding of the microphysical and chemical evolution of the mineral dust will enable several advancements that can benefit chemistry and climate modelers, chemical oceanographers, marine biologists, and medical researchers. The most relevant and immediate contributions will enable:

- More accurate modeling of cross-Atlantic transport of the Saharan dust
- More accurate initialization of chemical modeling of Saharan dust impacts on the atmospheric chemistry of the Caribbean
- Improved understanding of mineral deposition from Saharan dust to land surfaces and into the Caribbean Sea
- Improved understanding of regional cloud processing of aerosols and their affects on local cloud properties
- Improved retrievals of ocean properties from satellite measurements
- More accurate initialization of dust optical properties for regional climate modeling

The island of Puerto Rico was chosen for a variety of reasons. The wind patterns across the island are basically zonal, from east to west, which facilitates modeling and interpretation of in-situ measurements. The majority of industrial development and pollution is concentrated in the northeast portion of the island. This means that the first continental air mass that the Saharan dust encounters for northern trajectories in most cases is a polluted continental air mass. This can be contrasted with clean continental air masses that the dust will encounter if the trajectories bring the dust into the southern portion of the island. The Cordillera Central Mountains, which extend along the central portion of the island nearly permit for complete separation of the two types of case studies. Ideally, this topography allows for the study of aerosol evolution in different climatic regions and interacting with unique air parcels over the same spatial region and similar flow patterns. Finally, we can take advantage of extensive research contacts and collaborations within Puerto Rico, including scientists at the campuses of the University of Puerto Rico at Mayagüez and Rio Piedras (Recinto de Ciencias Medicas), Universidad del Turabo, Universidad Metropolitana, and access to the EPA monitoring networks (12 EPA stations). This network of collaborators includes existing aerosol monitoring research stations in several parts of the island including Isla Magueyes (Lajas), El Faro (Fajardo), San Juan (San Juan), Turabo (Caguas), Mayagüez, and planned sites in El Yunque (Luquillo) and other locations presently under consideration (Mayagüez, Aguadilla). The capabilities of these stations are provided in **Table 1**.

Our measurement strategy is an implementation of coordinated continuous land-based measurements, ocean-based intensive observation periods, and analysis of remote sensing data. The land and shipboard instruments are identical and consist of optical characterization (laser particle counter), gravimetric and size-fractionation characterization (QCM cascade impactors), and filter sampling for post-analysis of chemical composition (high-volume samplers). Our primary instruments and their measurement capabilities are more fully described in **Table 2**. The measurements are designed to correspond to specific data requirements of the science questions. This relationship is detailed in the traceability matrix presented in **Table 3**. The ultimate aim of the measurement strategy is to provide detailed chemical and microphysical information on the aerosols independently as a function of both mass- and size distributions.

4. 2002 Summer Intensives

The paper will focus on aerosol morphology, total suspended mass, aerodynamic optical diameter, and mass/size distribution for sizes ranging from 25 µm to 0.05 µm. We will conduct a series of filter measurements to obtain size-resolved chemical analysis of dust. We conducted two measurement intensives in Puerto Rico during summer 2002. The first intensive was designed to be a proof of concept experiment to test the instrument sensitivity, configurations, and sampling strategy. The second intensive was planned to measure pre dust event, dust event, and post dust event aerosol properties in the marine boundary layer in the tropical Atlantic and Caribbean Sea. The dates were planned based on a combination of NAAPS model predictions and satellite observations (TOMS and SeaWiFS). The NAAPS is the Navy Aerosol Analysis and Prediction System. This is a global multi-component aerosol analysis and modeling capability developed by the NRL to enable global forecasts of aerosol distributions.

On June 20th the 6-stage Quartz crystal Microbalance (QCM) cascade impactor was set up to collect measurements in Isla Magueyes, a coastal site located on the southeastern portion of Puerto Rico. The aerosol-sampling platform was located about 40 m above sea level. The QCM semi-continuously collected size resolved total suspended particle and mass - resolved fractionated samples for sizes ranging between 5 – 0.15 µm. On June 23rd the 10-stage QCM was set up in El Faro in Fajardo, a coastal site located in the northeastern tip of Puerto Rico. The aerosol-sampling platform was located about 45 m above sea level. At this platform the QCM collected the same type of measurements as in Isla Magueyes, however, the size range varied from 0.5- 0.05 µm. A High Volume Cascade Impactor (HVCI) and a Laser Particle Counter (LPC) was also set up in this site. The HVCI measured size-resolved filter samples and the LPC measured in situ size distribution in the range of 25 – 0.3 µm. In this particular El Faro site we took measurements over a period of 2 days. In addition to the land sites, on June 25th we collected ocean-based measurements aboard the RV Chapman – a former NOAA platform donated to the University of Puerto Rico-Mayagüez. The RV Chapman traveled 30 km South (17° 36.000´ N, 067° 00.000´ W) into the Caribbean Sea. The instruments used in the research vessel were the same instruments used for the land-based measurements in El Faro. Samples were collected for a period of 9 hours beginning at approximately 4:45 am. The QCM measured semi-continuous and the HVCI and LPC measured continuously. A complementary set of QCM measurements were collected at Isla Magueyes during the same period. After sunrise, the haze layer observed above the ocean during the June 25 measurement period was clearly distinguishable from clear sky conditions encountered during the August measurements.

During August 5 – 9, we conducted land-based and ocean-based measurements as well. The aerosol-sampling platform for the land-site was located at Isla Magueyes. In this site we setup the 6-stage QCM, which collected continuously for the entire trip. The research vessel traveled across the Atlantic and the Caribbean Sea as indicated in **Figure 1**. The instruments and measurements collected at each station were the same as for the June trip. The 10-stage QCM was set to sample between the 10 – 1.0 μm size cuts.

5. Results

In the following discussion we present preliminary analysis of selected raw data sets from the June and August measurement intensives. These data sets include both QCM and LPC measurements aboard the RV Chapman and Isla Magueyes. Based on model predictions and physical observations aboard the ship, we believe that we encountered a dust event during the proof of concept phase (June 25) but did not encounter a significantly perturbed air mass during the August cruise.

Figure 2 shows QCM shipboard data for several of the smaller aerosol size fractions during the measurement period. Presuming that we were indeed experiencing a dust event, we note that there were few variations in the fine aerosol mass fraction but the larger size fractions (cut-off sizes greater than 0.5 μm). We did not sample mass fractions greater than 1.0 μm during the June shipboard measurements for logistical reasons. We sampled mass fractions at 1.0, 0.5, 0.2, 0.1, and 0.05 μm aboard the RV Chapman. The 1.0 μm stage saturated during the first hour of sampling. However, if the trend in increasing variability and mass with increasing size bears out it is fully consistent with our expectations of a Saharan dust event. Further evidence to support this was observed in the high volume filter samples showing visible, yellowish deposits and similar deposits on the upper stage QCM crystals themselves. The filter and QCM samples are currently undergoing chemical analysis for elemental composition.

Figure 3 shows the raw data for the laser particle counter measurements at the CaTS on June 25 and on August 9. During both of these occasions, the ship was not in motion and the prevailing winds were easterly. These results show an order of magnitude increase in the total number density of aerosols. On closer inspection we also observe that the increase is largely due to aerosols in the 1 to 10 μm size range rather than the fine aerosols. This is consistent with the observed size distributions for transported Saharan dust aerosol in the literature. The August 9 data show several spikes in the 0.3-0.5 micron data. These are largely due to repositioning of the ship after it drifted from station periodically during the measurement period.

Figures 4 and 5 show the NRL atmospheric aerosol prediction system (NAAPS) results for the two dates that we sampled aerosols at the CaTS of Figure 1. These plots indicate that during the June measurements at this location there was a significant amount of dust in the region but that during the August measurements far less dust was predicted to have been present. This is consistent with our laser particle counter observations in **Figure 3**, but we are performing more detailed trajectory analyses to determine the source region of the air parcels sampled.

6. Acknowledgements

This research was performed under the sponsorship of the Department of Commerce and NOAA under award number NA17AE1623. We also would like to acknowledge our collaborators at the University of Puerto Rico at Mayagüez, Department of Marine Sciences, Drs. Roy Armstrong and Yasmin Detres. Finally, we thank the Caratlan cruise research team for granting our request for research space aboard the RV Chapman.

Table 1. Current and Proposed Land-Based Aerosol Measurements in Puerto Rico

Cruise Sampling	Isla Magueyes	El Faro	Dominica	San Juan
Size Distributions and number densities (LPC)	TSP AOD (AERONET)	PM2.5 PM10	PM2.5/10	PM2.5 PM10
Size-resolved TSP (QCM)		Chemical analysis	Gravimetric analysis	
Size-resolved filter sampling			Fungal and Microbial Analysis	
	Proposed NCAS implementations to Current Measurements			
Chemical Analysis	Size distributions (LPC)	Size distributions (LPC)		
Fungal & Microbial analysis	Size-resolved TSP (QCM)	Size-resolved TSP (QCM)	Size-resolved TSP (QCM)	
Rainwater sampling and analysis	Size-resolved filter sampling	Size-resolved filter sampling		Size-resolved filter sampling
	Chemical analysis		Chemical analysis	Chemical analysis
		Fungal & Microbial Analysis		Fungal & Microbial analysis

Table 2. NCAS Primary Instrument Descriptions and Measurement Capabilities

	Climet	High-Volume Sampler	QCM
Description	• Laser Particle counter • 6 size cuts (0.3, 0.5, 1.0, 5.0, 10, 25) • Accuracy size resolution 0.3 µm	• Cyclone cascade impactor • 12 stages • Filter sampling for chemical and physical analysis	• Quartz crystal microbalance cascade impactor • Six-stage and ten-stage units • Mass and aerodynamic size fractional samples • Continuous sampling
Capabilities	• Continuous/variable average • Number densities • Size distribution • Integrated and differential measurements	• Large size-fractionated filter samples • Presently uncalibrated • Suitable for bulk sampling and analysis	• Mass fractionated sampling • Total suspended particulate mass • Size-fractionated samples • Post analysis with SEM, EDX • Calibrated and traceable measurements
Measurement/ Sampling Schedule	• Continuous – to semi-continuous • No samples collected	• El Faro, Isla Magueyes, Dominica, and other based upon weather	• El Faro and Isla Magueyes • Sampling on stations

	during rain • Simultaneous RH and Temperature measurements	patterns • Unique samples at each station • Isolate samples for analysis at HU	• Continuous open sea measurements

Table 3. Traceability Matrix

Impact Areas	Science Questions	Data / Measurements
Atmospheric Sciences • **Regional Climate** • **Regional Air Quality** • **Remote Sensing**	**What are the regional meteorological affects of Saharan dust? (clouds, surface radiation budgets)** **What is the impact of Saharan dust on regional air quality?** **How does Saharan dust contribute to the ambient aerosol loading and deposition in the region?** **How do surface measurements compare to space-based measurements of Saharan dust?**	**Surface AOD, in-situ size-resolved mass and number densities, size-resolved filter sampling, chemical analysis of dust aerosols as a function of size and transport time**
Oceanography • **Remote Sensing** • **Atmospheric Deposition and Chemistry**	**How does Saharan dust affect space-based sensing of ocean properties?** **How does Saharan dust affect the chemistry and composition of surface waters through deposition of minerals, heavy metals, and organics?**	**Surface AOD, in-situ aerosol size distribution, mass densities, and number densities, aerosol mass fluxes**
Marine Biology • **Transport of fungi** • **Transport of microorganisms**	**Does Saharan dust efficiently transport bacteria and fungal spores foreign to Caribbean waters and land surfaces?** **What microorganisms are present on Saharan dusts?**	**Size-resolved filter sampling for fungal and microbial analysis**
Medical Sciences • **Public Health** • **Impacts on Sensitive Populations**	**How does Saharan dust contribute to public health in Puerto Rico?** **Are there statistically significant correlations between Saharan dust factors and public health indicators in sensitive populations?**	**PM_{10}, $PM_{2.5}$, Respirable aerosols**

Figure 1: Measurement Platform Sites

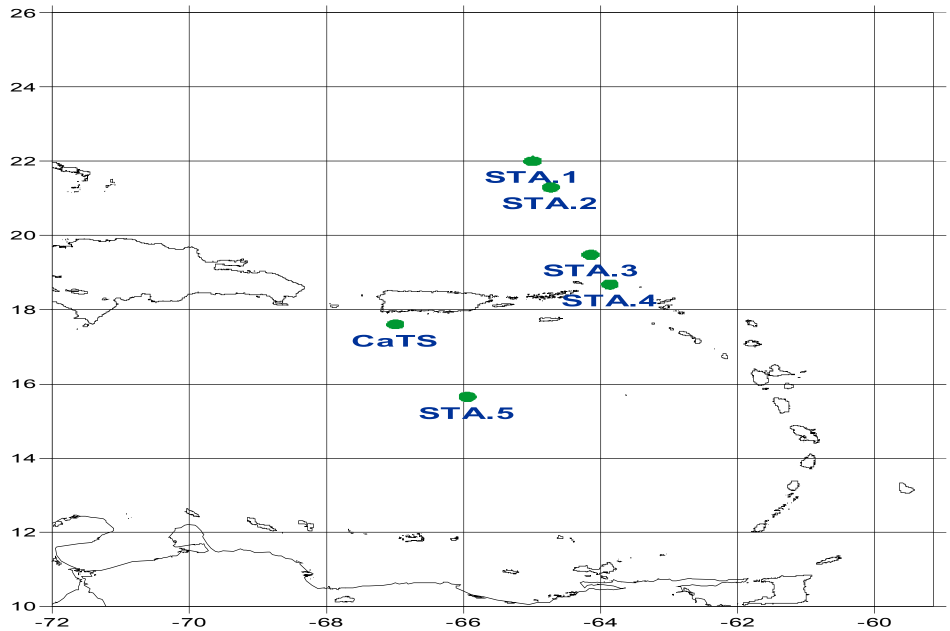


Figure 2. **June 25 Research Cruise QCM Data**

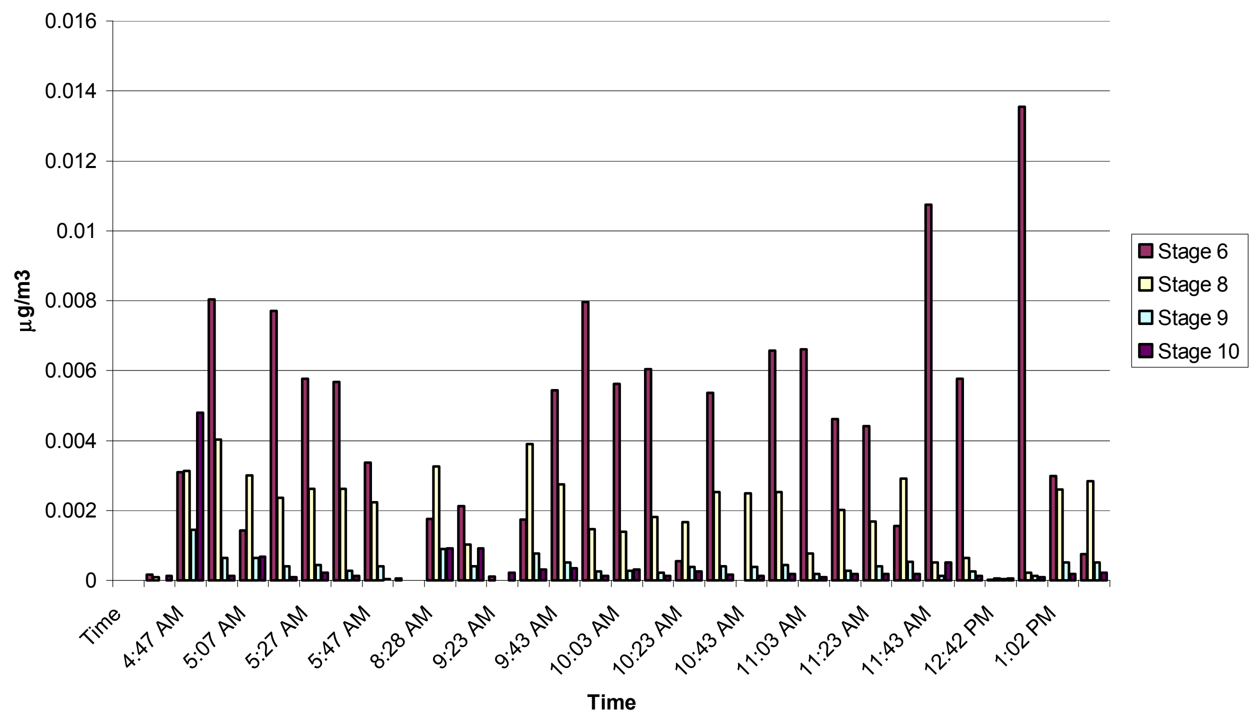
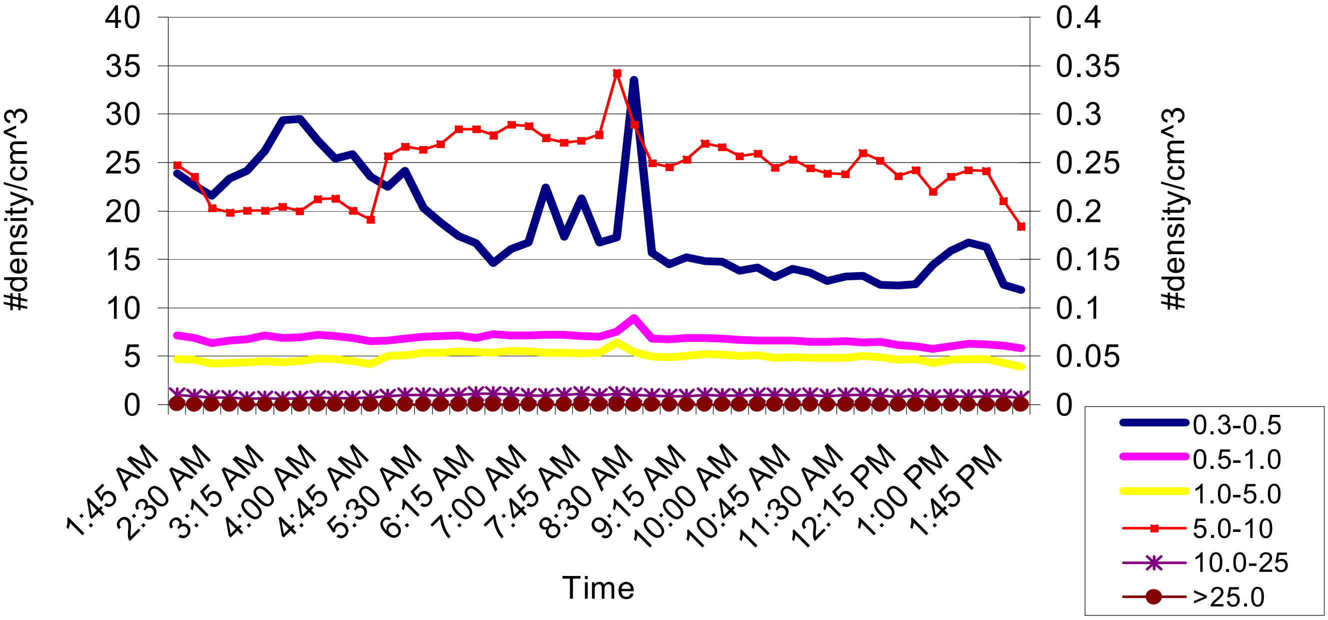


Figure 3. LPC June and August Cruise Data



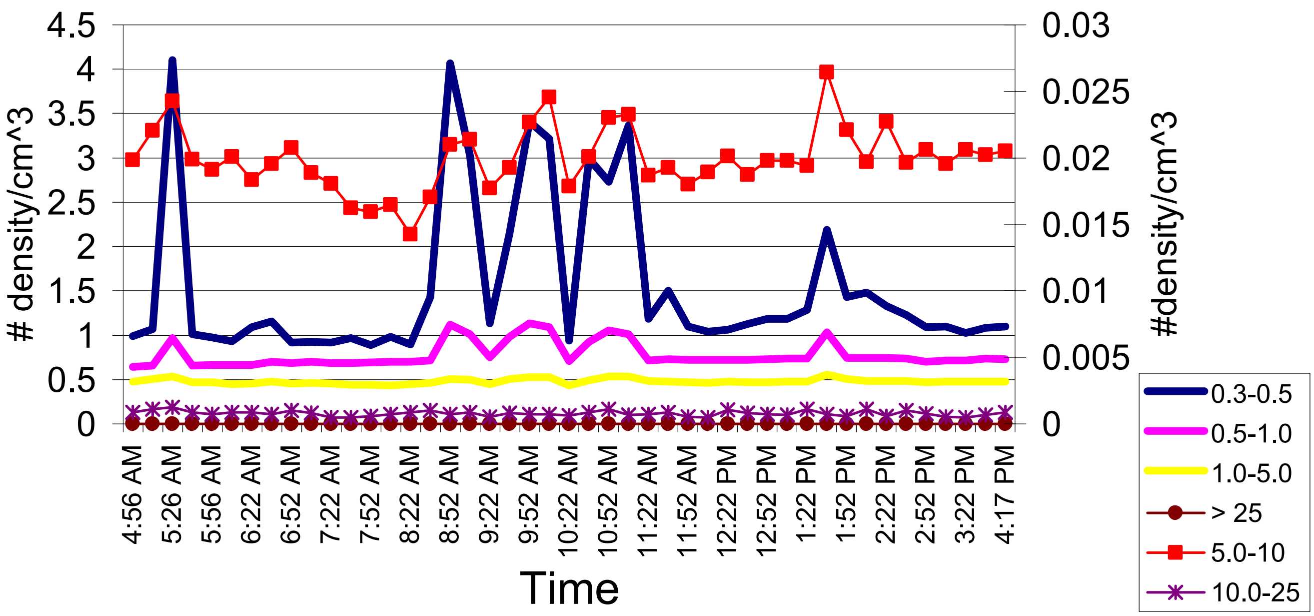


Figure 4. NAAPS Optical Depth, 850 mb winds for 06:00Z 25 June 2002

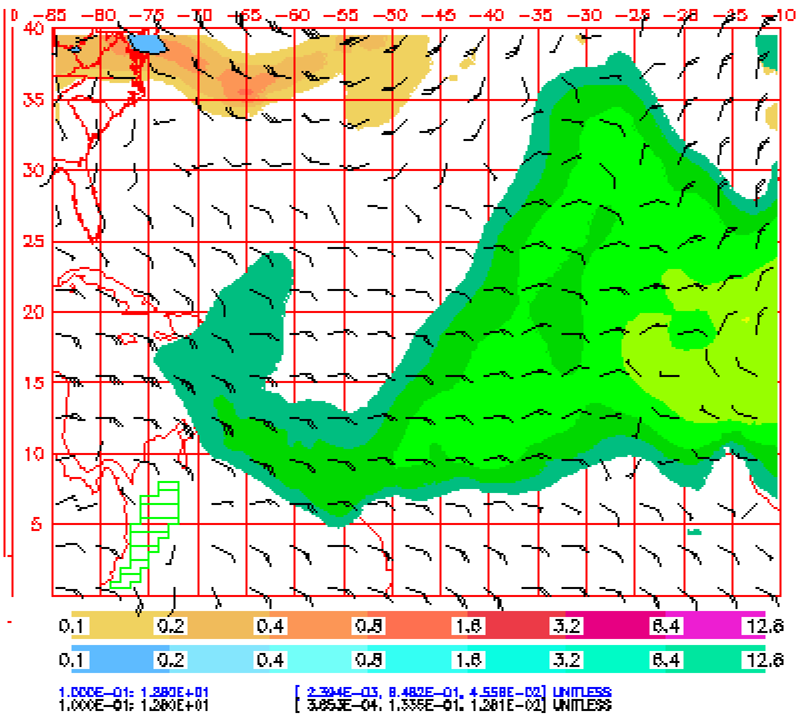
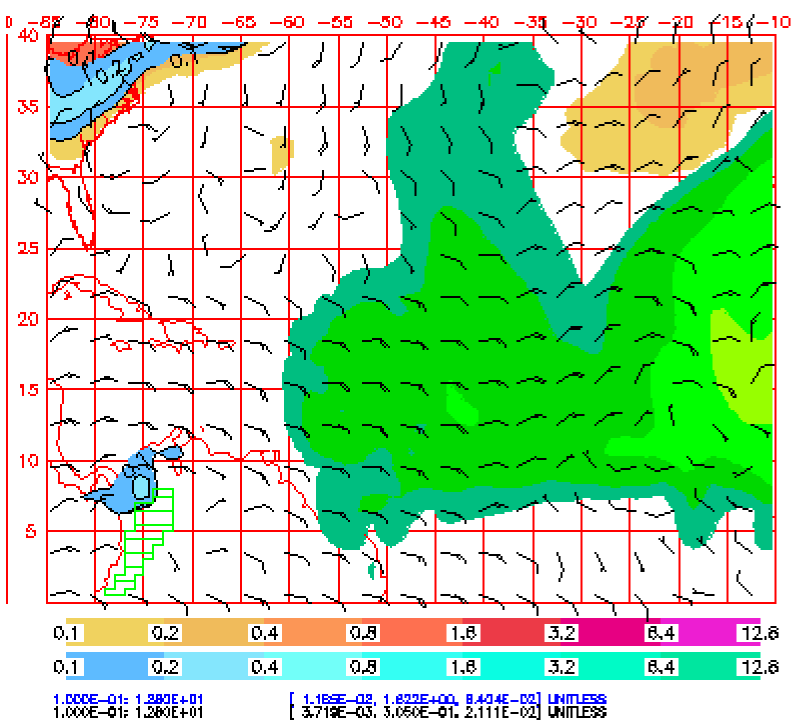


Figure 5. NAAPS Optical Depth, 850 mb winds for 06:00Z 9 August 2002



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