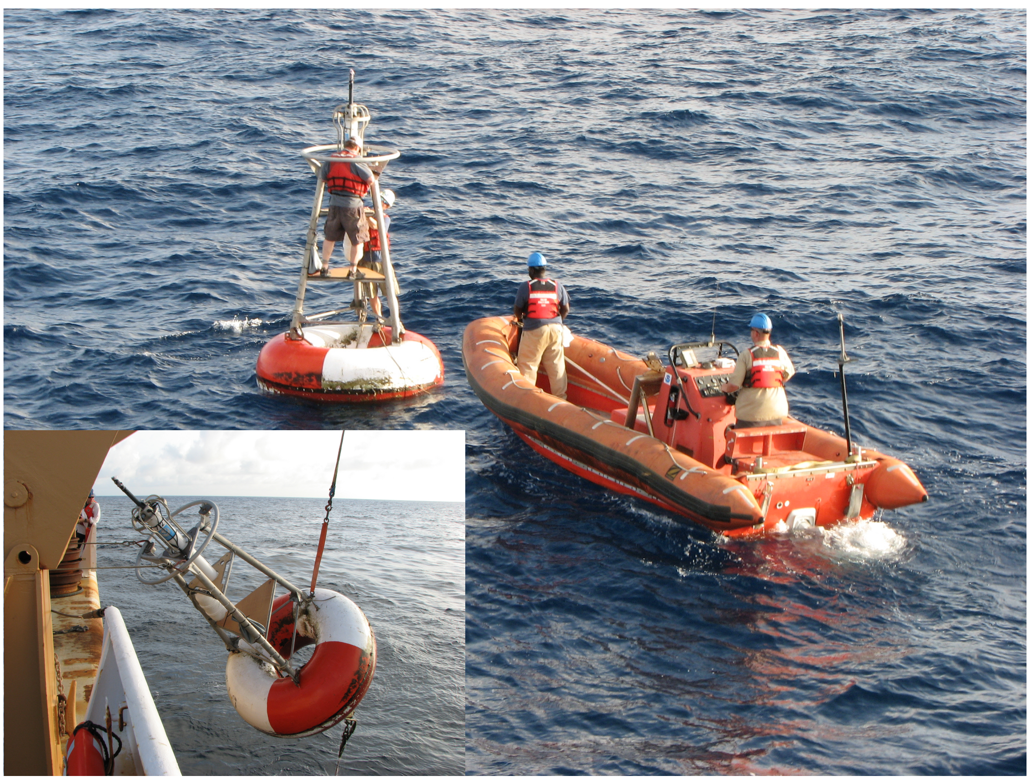
Cruise Report
PIRATA Northeast Extension 2010 & AEROSE VI

NOAA Ship *Ronald H. Brown*
RB-10-03

April 26 — May 22, 2010

Takoradi, Ghana to Charleston, SC, USA



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Note: All figures and results reported here are subject to revision after quality control and final calibration.

OVERVIEW: the 2010 PIRATA Northeast Extension Cruise RB-10-03 was designed to: (1) collect a suite of oceanographic and meteorological observations in the northeast Tropical Atlantic; (2) recover and redeploy the four moorings that belong to the Northeast Extension of the PIRATA array; and (3) to perform a tube and sensor swap (or, if necessary a full recovery and redeployment) for the PIRATA mooring at 0ºN, 23ºW. The cruise track focuses upon collecting oceanographic and meteorological observations along 23ºW, a longitude cutting through the climatologically significant Tropical North Atlantic (TNA) region, including the southeast corner of the subtropical North Atlantic (a region of subduction for the subtropical cell circulation); the Guinea Dome and oxygen minimum shadow zone where the subtropical and tropical gyres meet, and the Tropical Atlantic current system. All scientific goals of RB-10-03 were achieved.

We thank the crew and officers of the Ronald H. Brown for their tireless work and input before and during the cruise. The deck crew recovered five moorings, deployed four, and conducted several small boat operations. Their efficiency and familiarity with mooring deployment operations was evident. We thank the Chief Survey Technician, Jonathan Shannahof, for his continuous assistance. We also thank all the crew who kept ship operations running smoothly, including the winch operators, Electronic Technician, galley crew, and all the other crewmen of the Brown.

Introduction

PIRATA Northeast Extension (PNE)

The Pilot Research Moored Array in the Tropical Atlantic (PIRATA) is a three-party project involving Brazil, France and the United States that seeks to monitor the upper ocean and near surface atmosphere of the Tropical Atlantic via the deployment and maintenance of an array of moored buoys and automatic meteorological stations. The array consists of a backbone of ten moorings that run along the equator and extend southward along 10ºW to 10ºS, and northward along 38ºW to 15ºN. Given the widely varying dynamics of various sub-regions of the Tropical Atlantic the PIRATA array was extended into the Northwest, Southeast and Southwest.

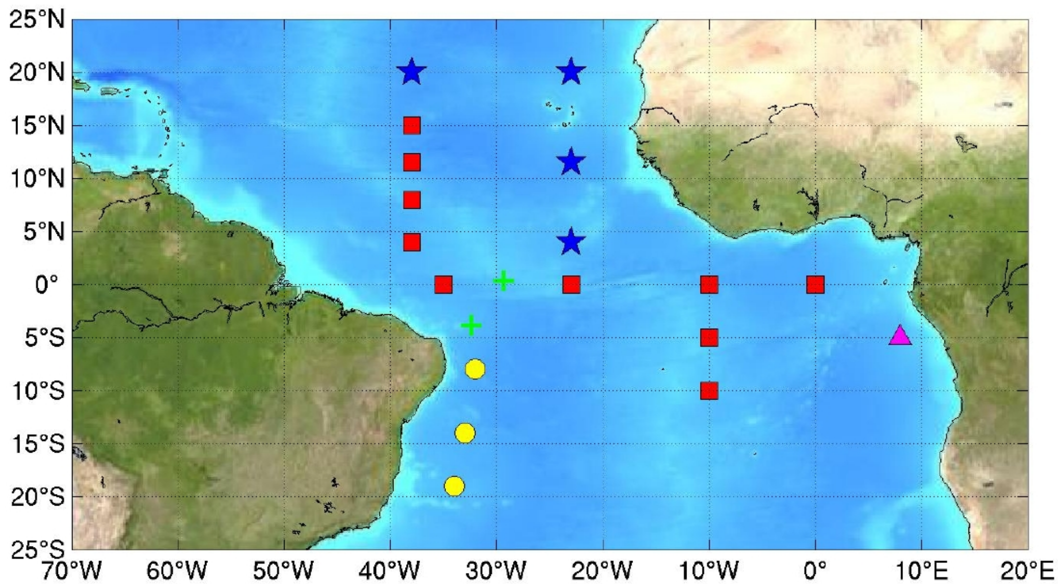

Fig. 1: The Tropical Atlantic, showing the PIRATA backbone (red squares), automatic meteorological stations (green +), southwest extension (yellow circles), southeast extension pilot site (magenta triangle), and the Northeast Extension (blue stars).

The Northeast Extension is important for the collection of data in a region of strong climate variations from intraseasonal to decadal scales, with impacts upon rainfall rates and storms for the surrounding regions of Africa and the Americas. Moored observations in these regions will improve our knowledge of atmosphere-ocean heat exchanges and dynamics impacting the West African Monsoon, marine Intertropical Convergence Zone, upper ocean dynamics affecting heat content and SST variability in the TNA, possible connections between SST patterns and North Atlantic climate regimes of variability, and the development of atmospheric easterly waves into tropical cyclones. A better understanding of the processes driving SST anomalies in the TNA region will lead to better predictions of rainfall and other climate signals across a broad geographical domain at timescales from seasonal to decadal.

On April 21, 2010, it was discovered that the French PIRATA backbone mooring at 0°N, 0°W went adrift the day before. Due to the relatively close proximity of the mooring site to the planned cruise track, it was decided to chase the mooring and recover it. This was important because the sensors contain the high-resolution data that are not transmitted in real-time.

Order of operations:

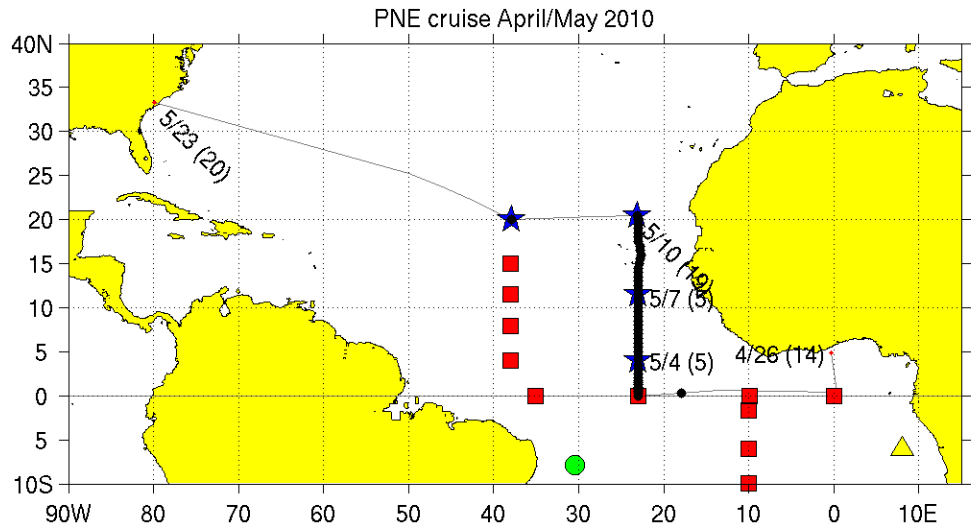

Fig. 2: cruise track of the R/V *Ronald H. Brown* during RB-10-03. Track (black line) with CTD stations (dots), PNE recovery and deployment sites (blue stars) and the PIRATA backbone moorings (red squares), the Southeast extension (yellow triangle) and one of the Southwest extension moorings (green circle) superimposed. The drifting mooring from 0º, 0º was recovered. A tube and sensor swap was performed at the 0º, 23ºW mooring.

The R/V *Ronald H. Brown* (RHB) departed from Takoradi, Ghana on April 26 at 14:30 UTC, and proceeded to steam southward to capture the mooring that broke loose on April 20. The mooring recovery was started on 27 April at 16:30 UTC and completed successfully at about 19:00 UTC (more detail is provided below).

We then continued westward towards the mooring at 0º, 23ºW. Along the way three Argo floats were deployed (at about 0.6ºN, 13.5ºW; 0.4ºN, 16.5ºW and 0.2ºN, 19.5ºW) and a CTD/LADCP test station, which was scheduled for May 1 at 9:00 UTC, was performed successfully (at about 0.3ºN, 17.8ºW). Throughout this time the ship was averaging about 12 kn. This was done to avoid arriving at the next mooring after nightfall.

The RHB arrived at the 0º, 23ºW mooring on May 2 at 11:30 UTC. Only a tube swap was scheduled for this site, since the French PIRATA team is scheduled to return after the tube is very likely to have stopped transmitting data. This work was completed after about 1 hour and we started the 23ºW section with the first CTD/LADCP station shortly after that (more detail is provided below).

Along the way to the next mooring site we performed CTD/LADCP stations 2-13 at regular spacing and deployed an Argo float was deployed at station 2. From station 9 (at 2ºN) on XBTs were dropped every 10 nm between the stations.

The recovery of the mooring at 4ºN was be started on May 4 at 10:00 UTC. and completed successfully around 13:30 UTC. The redeployment started at about 14:00 UTC and completed at about 19:30 with the dropping of the anchor. Within an hour we confirmed that the anchor had settled and that the data from all sensors are coming in.

Thanks to traveling at about 12 kn between CTD/LADCP stations 14-28 the recovery of the mooring at 11.5ºN could be started on May 7 at 10:00 UTC without having to wait for daylight at the mooring site. After the redeployment was completed it was discovered that the air temperature and relative humidity sensors failed. This was fixed by replacing the sensors before departing to the next CTD/LADCP station at 20:00 UTC.

CTD/LADCP stations (numbers 29-46) were done on the way to the next mooring site (20.5ºN, 23ºW). During our approach to the mooring site at 20.5ºN it was decided to save time by postponing the CTD/LADCP station at 20ºN and increasing the ship speed to about 13 kn. That way the RHB arrived at the mooring site on May 10 at 19:00 UTC (before nightfall) and we could recover the mooring, which was successful. During the night we did the CTD/LADCP station at the mooring site before the RHB steamed back to 20ºN to do the skipped CTD/LADCP station. These two stations completed the CTD/LADCP section along 23W. The RHB then returned to 20.5N to redeploy the mooring in the morning on May 11. Again, the deployment was successful (completed at about 13:00 UTC).

An Argo float was deployed as the RHB started to steam westward to 20°N, 38°W, the site of the final PNE mooring. Along the way two more Argo floats were deployed (at about 20.3ºN, 28.1ºW and 20.1ºN, 34.5ºW). The RHB made good time along the way. This was partly due to an increasing of the speed (following seas and a westward current helped) to ensure an arrival at the mooring site in the morning. The recovery could be started on May 14 at 10:00 UTC and the mooring work was completed at about 16:00 UTC. The final CTD cast was performed before the RHB went on its way to Charleston. Along the way for Argo floats were deployed (at 20.0°N, 37.9°W; 22.4°N, 43.0°W; 23.7°N, 46.1°W and 25.2°N, 50.0°W).

Oceanographic work performed and data collected on this cruise:

1. ATLAS moorings of the Pilot Array in the Tropical Atlantic (PIRATA) were recovered and redeployed at four existing sites. These moorings compose the

PIRATA Northeast Extension (PNE), a US contribution to PIRATA. A tube and sensor swap was performed on the French PIRATA backbone mooring at 0°, 23°W. The French PIRATA backbone mooring at 0°, 0° went adrift on April 20 and was captured. The moorings are relaying real-time data including air temperature, relative humidity, wind speed and direction, rain rate, incoming shortwave and longwave radiation, barometric pressure, sea surface temperature, subsurface currents at ~10m depth, and subsurface temperature, salinity and currents at multiple points through the upper 500m of the water column.

2. CTD data were collected at 48 stations, including 46 stations on a meridional section from 0ºN to 20.5°N along 23ºW. Most stations have an LADCP profile as well. Whenever possible, stations were conducted to a pressure of 1500 dbar, or the bottom (if shallower). The only exceptions of this are the last two stations which were terminated at 1300 m wire out (more information is provided below). On all stations water samples were taken at various depths to calibrate salinity and oxygen sensors.

3. 72 expendable bathythermographs (XBTs) were launched along the 23°W section to measure temperature profiles of the upper ocean.

4. 11 ARGO floats were deployed to measure temperature and salinity profiles in the upper 2000 dbar and currents at 1000 dbar as part of the 3000 float global array.

5. Shipboard current measurements were collected using a 75 kHz Ocean Surveyor hull-mounted Acoustic Doppler Current Profiler (SADCP). Heading data for the SADCP was provided by the MAHRS system, with data from the ship's gyro for comparison.

On this cruise, XBT temperature profiles and CTD temperature/salinity profiles were transmitted in near-real time via the Global Telecommunication System (GTS) for model calibration and validation. The RHB is the first ship to have CTD data transmitted in near-real time for weather and climate prediction. This was first done during the 2006 PNE/AMMA cruise.

ATLAS moorings

Six mooring sites were visited during this cruise (as listed in Table 1).

Table 1: list of ATLAS mooring stations.

counter	day	month	year	hour	minute	lat	lat (min)	lon	Lon (min)	task
1	27	4	2010	16	30	0	26.15	0	23.86	REC
2	2	5	2010	11	30	0	-0.93	-22	-59.25	SWAP
3	4	5	2010	10	0	4	4.77	-22	-59.50	REC
						4	3.06	-22	-58.90	DEP
4	7	5	2010	10	0	11	29.80	-23	-0.70	REC
						11	27.44	-23	-0.65	DEP
5	10	5	2010	19	0	20	26.54	-23	-8.65	REC
	11	5	2010	4	0	20	26.87	-23	-8.15	DEP
6	14	5	2010	10	0	20	2.26	-37	-53.02	REC
						20	1.30	-37	-51.86	DEP

0°, 0° (PM828A)

This site, which is maintained by France, was not originally part of the cruise itinerary but was later added to the schedule because it was discovered on 21 April that it went adrift. The diversion from the original track line was estimated to cost roughly 24 hours, with another 2 hours or so for the actual recovery, if the RHB arrives at the varying mooring location during daytime. This seemed possible because, a weather day was part of the schedule, and because, if need be, it is possible to cancel CTD stations to make up time. The RHB caught up with the mooring at 16:30 UTC on 27 April 2010. The recovery was completed in about 2.5 hours. All sensors on the mooring were recovered, which means the high-resolution data will be available for research. In addition to that a bag with a plaque from a German frigate was found on the mooring (the frigate had nothing to do with the breaking free of the mooring).

0°N, 23°W (PM822A / PM822B)

This site, which is maintained by France, was scheduled for a tube swap. The reason was that, by the time the French can replace the mooring the tube will have been operating for about 18 months, which means the risk for a tube failure is high. Since this site was on the way, it was added to the original cruise plan for a tube and sensor swap. The RHB arrived at the mooring site at 11:30 UTC on May 2. The tube swap and sensor replacement was completed in 2 hours. All sensor on the tower were recovered and replaced. A full recovery was not necessary, because the subsurface sensors of this mooring were in good shape.

4°N, 23°W (PM831A / PM897A)
This is the first of the four PIRATA Northeast extension moorings. The RHB arrived at the mooring site at about 4:00 UTC on May 4, at which time a CTD cast was performed. The recovery was started at 10:00 UTC on the same day and completed at about 3 hours later. The only sensors missing at this site were the temperature and current sensors at the depth of 13.3 m. The redeployment was started at about 14:00 UTC and completed with the drop of the anchor in about 4.5 hours. The RHB stayed near the mooring for about 1 hour for the anchor to settle and to check if we received data from all sensors, which was the case.

11.5°N, 23°W (PM832A / PM898A)
The RHB arrived at the mooring site at about 8:00 UTC on May 7, at which time a CTD cast was performed. The recovery was started at 10:00 UTC on the same day and completed about 3 hours later. The only sensors missing at this site were the temperature and conductivity sensors at the depth of 5 m. The redeployment was started at about 14:00 UTC and completed with the drop of the anchor in about 4.5 hours. While the RHB stayed near the mooring for the anchor to settle and to check if we received data from all sensors, it was discovered that the relative humidity and air temperature sensor were not working. The small boat was used to go out and replace the sensors. Then, we received good data from all sensors and continued on our way at 20:00 UTC.

20.5°N, 23°W (PM833A / PM900A)
The RHB arrived at the mooring site at about 19:00 UTC on May 10. The recovery was started immediately and completed about 3 hours later. The only sensors missing at this site were the temperature and conductivity sensors at the depth of 10 m. The redeployment was started on May 11 at about 4:00 UTC and completed with the drop of the anchor in about 4 hours. The RHB stayed near the mooring for about 1 hour for the anchor to settle and to check if we received data from all sensors, which was the case.

20°N, 38°W (PM835A / PM902A)
The RHB arrived at the mooring site at about 6:30 UTC on May 14. The recovery was started at about 8:00 UTC, after the CTD cast at the site was completed. The release responded to commands with an error code and did not release the mooring from its anchor. The recovery of the mooring was started. Once all subsurface sensors, with the exception of the temperature sensor at 180 m, were recovered, several attempts were made to get the release to work. Since this did not work a pressure-activated rope-cutter was sent down at about 11:00 UTC. This rope-cutter is designed to cut the mooring line at about 3800 m. It takes it about 1 hour to get to that depth. They usually work well, but it failed this time. Therefore, the secured wire had to be cut with hydraulic shears at deck level. This task was performed about 4 hours after the start of the mooring recovery. The redeployment was completed with the drop of the anchor in about 3 hours. The RHB stayed near the mooring for about 1 hour for the anchor to settle and to check if we received data from all sensors, which was the case.

Table 2: list of lost sensors on ATLAS moorings.

TYPE	DEPTH	SITE	Mooring ID #
Temp/Currents	13.3m	4°N-23°W	PM831A
Temp/Conductivity	5m	11.5°N-23°W	PM832A
Temp/Conductivity	10m	20.5°N-23°W	PM833A
Temp	180m	20°N-38°W	PM835A

CTD/LADCP stations

We conducted 48 CTD/LADCP stations, including a test station at 0.3ºN, 17.8ºW (Fig. 2 and Table 3). For all deep stations 12 Niskin bottles were used to collect water samples. Oxygen and salinity were sampled from 12 of these bottles for sensor calibration.

During stations 3 and 4, the downward looking LADCP did not start up, so only CTD data were collected. It was discovered later, that a disconnection of the LADCP from the power supply solves this problem.

Station 4 had a problem with the primary sensors. This started at about 600 dbar with a large anomaly of the salinity and oxygen. The typical cause for such anomalies is a blockage of the flow of water through the sensors. The secondary sensors worked well. Since only oxygen sensor existed, which was attached to the primary pump, no good oxygen values are available for this station. The chief survey technician flushed the primary sensors thoroughly after the cast and reported significant initial resistance. This solved the problem, i.e., the sensors were performing well for all following casts.

One station, #19 at about 7ºN, 23ºW, was conducted above a bathymetric feature associated with the Sierra Leone Rise where the bottom depth was 1480m; this station was conducted to 1466 dbar, 20m above the bottom according to the altimeter on the CTD package.

Between CTD/LADCP stations 42 and 43 the LADCP data files were not renamed. Therefore, they were overwritten (this is a weakness of “bbtalk”, the program does not issue a warning if a file is overwritten). On 10 May, during CTD/LADCP station 45, a broken strand was discovered at 1348 m on the CTD wire. Therefore, the last two CTD/LADCP stations (numbers 46 and 47) were terminated at 1300 m of wire out.

No communication problems between the CTD acquisition computer and the package were experienced, except for stations 13 and 46. On station 13, the computer reported that a bottle had been fired prior to the cast. This happened twice, so the cast was restarted twice. On station 46, the bottle firing from the computer did not work and the modulo error count reached 5. The problem, most likely, was that the seasave software was not closed before starting the cast. The bottles were fired from the deck unit. Before the next and last station the computer was rebooted, just in case. No problems occurred during that cast.

To summarize the casts with problems:

- no LADCP data are available for stations 3, 4, 20 and 42.

- for station 4 the data from the primary sensors of are bad.

CTD processing was performed using Seabird software and Matlab routines developed by Carlos Fonseca and others, with modifications by Claudia Schmid during the cruise.

LADCP processing was performed with the routines developed by Visbeck, with modifications by Claudia Schmid during the cruise.

Recommendation for the future:

- Find out if there is a way to change the settings of bbtalk to get a warning if a data file is overwritten.
- CTD and LADCP processing software is poorly documented. It is recommended to add precise definitions of each input argument to functions (especially those that are called directly by the user). The same needs to be done for input files. The documentation needs to be written in a way that the purpose of input arguments are explained in detail. Examples should be provided whenever possible.
- Improve the documentation of the advanced data processing software

CTD/LADCP stations are listed in Table 3, and preliminary sections are shown at the end of this preliminary cruise report.

Table 3: list of CTD/LADCP stations.

station	**day**	**month**	**year**	**hour**	**minute**	**latitude**	**longitude**	**comment**
0	1	5	2010	10	2	0º20.27'N	17º51.38'W	
1	2	5	2010	13	10	0º1.03'S	23º0.36'W	
2	2	5	2010	16	0	0º14.94'N	22º59.98'W	
3	2	5	2010	18	46	0º30.02'N	22º59.98'W	no LADCP data
4	2	5	2010	21	34	0º44.98'N	23º0.02'W	no LADCP data, primary data bad
5	3	5	2010	0	21	1º0.10'N	23º0.01'W	
6	3	5	2010	3	4	1º15.15'N	22º59.95'W	
7	3	5	2010	5	45	1º30.03'N	23º0.03'W	
8	3	5	2010	8	24	1º45.01'N	23º0.04'W	
9	3	5	2010	10	59	1º59.96'N	23º0.03'W	
10	3	5	2010	15	4	2º30.00'N	23º0.02'W	
11	3	5	2010	18	57	2º59.95'N	23º0.01'W	
12	3	5	2010	22	58	3º30.04'N	23º0.03'W	
13	4	5	2010	4	21	4º5.04'N	23º0.71'W	
14	4	5	2010	22	30	4º30.00'N	23º0.00'W	
15	5	5	2010	2	31	5º0.05'N	22º59.95'W	
16	5	5	2010	6	28	5º30.00'N	22º59.96'W	
17	5	5	2010	10	26	5º59.67'N	23º0.03'W	
18	5	5	2010	14	25	6º29.21'N	22º59.99'W	
19	5	5	2010	18	30	6º59.94'N	23º0.00'W	
20	5	5	2010	22	23	7º28.85'N	22º59.98'W	no LADCP data

station	day	month	year	hour	minute	latitude	longitude	comment
21	6	5	2010	2	44	8º0.05'N	23º0.01'W	
22	6	5	2010	6	39	8º30.00'N	23º0.02'W	
23	6	5	2010	10	38	8º59.57'N	22º59.99'W	
24	6	5	2010	15	11	9º29.94'N	22º59.99'W	
25	6	5	2010	19	16	9º59.86'N	22º59.99'W	
26	6	5	2010	23	27	10º29.57'N	23º0.03'W	
27	7	5	2010	3	40	11º0.00'N	23º0.01'W	
28	7	5	2010	7	46	11º28.99'N	22º59.00'W	
29	7	5	2010	23	9	11º59.66'N	23º0.01'W	
30	8	5	2010	3	19	12º29.98'N	23º0.00'W	
31	8	5	2010	7	21	13º0.01'N	23º0.02'W	
32	8	5	2010	11	35	13º30.01'N	23º0.07'W	
33	8	5	2010	15	36	13º59.83'N	22º59.99'W	
34	8	5	2010	19	37	14º29.94'N	23º0.03'W	
35	8	5	2010	23	37	14º59.43'N	22º52.17'W	
36	9	5	2010	3	56	15º30.03'N	22º44.02'W	
37	9	5	2010	8	8	16º0.01'N	22º36.00'W	
38	9	5	2010	11	48	16º30.01'N	22º43.98'W	
39	9	5	2010	15	58	16º59.81'N	22º48.96'W	
40	9	5	2010	19	51	17º29.43'N	22º59.78'W	
41	10	5	2010	0	1	17º59.83'N	23º0.03'W	
42	10	5	2010	4	1	18º30.04'N	22º59.98'W	no LADCP data
43	10	5	2010	7	50	18º59.97'N	23º0.04'W	
44	10	5	2010	11	46	19º29.96'N	23º0.04'W	
45	10	5	2010	21	50	20º26.57'N	23º8.63'W	
46	11	5	2010	1	40	20º0.05'N	22º59.99'W	to 1300 m wire out
47	14	5	2010	6	36	20º1.01'N	37º51.48'W	to 1300 m wire out

The Temperature-Salinity structure from the CTD stations is shown in Fig. 3. The warm-water portion of the curves shows the differences of the surface water salinity with the fresh water in the ITCZ region (predominantly in 4ºN to 16ºN), the slightly higher salinity near the equator (two of the blue curves), and significantly higher salinity in the subduction region of the southern subtropical gyre (north of 16ºN, black curves). Below the surface layer, the nearly linear T-S relationship is the signature of Central Water, while Antarctic Intermediate Water is indicated by the salinity minimum between 5 to 7°C, with a density (σ_0) of about 27.3. Farther down, the increase of salinity is associated with the presence of North Atlantic Deaap Water (below the maximum depth of the CTD casts).

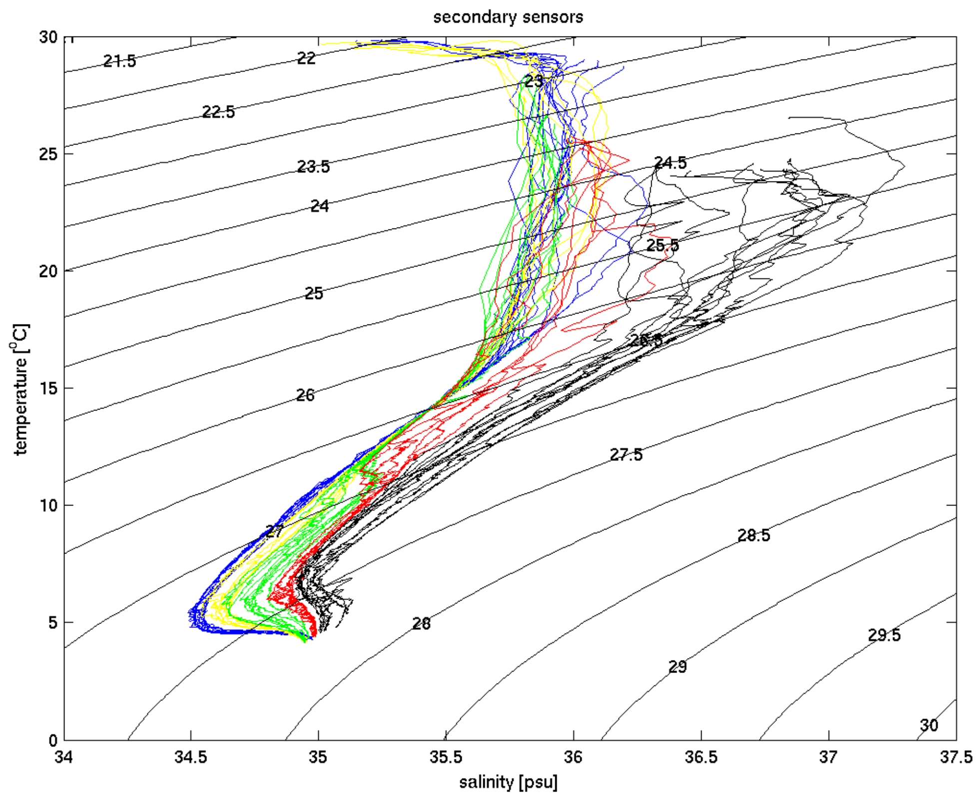

Fig. 3: salinity vs. temperature. Colors indicate latitude band: 16—20.5ºN (black), 12—16ºN (red), 8—12ºN (green), 4—8ºN (yellow) and 0—4ºN (blue). Contours are values of constant density σ_0.

The Temperature-Oxygen structure from the CTD stations is shown in Fig. 4. The oxygen concentration decreases from the high values (saturation) near the surface to very low values at mid-depth and then increases again to values as large as (and sometimes larger than) the values at the surface, at a pressure of 1500 dbar. The structure of the low-oxygen zone is quite complex. At some latitudes the oxygen drops to a minimum at about 17ºC, rises again to a maximum at about 13ºC and decreases to another minimum at about 10ºC (red and green curves, 8-16ºN). At other latitudes, the layer has a minimum at 3 depths and a maximum at two depths (blue curves, 0-4ºN). Only one minimum exists near the northern end of the section (black curves, 16-20.5ºN).

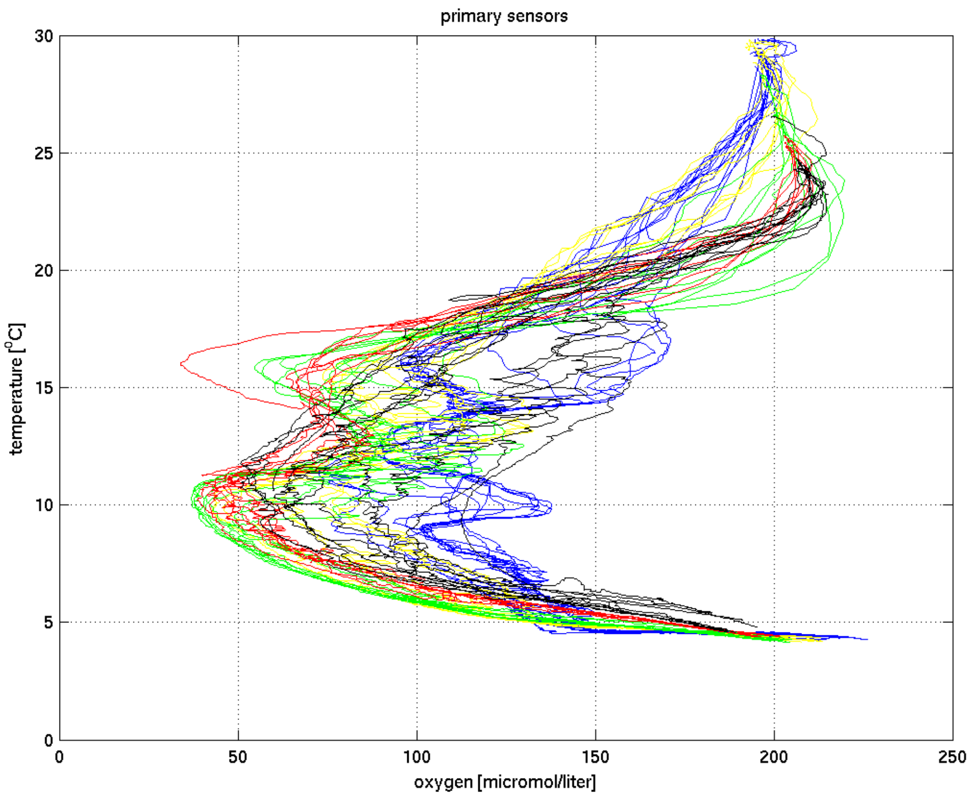

Fig. 4: oxygen vs. temperature. Colors indicate latitude band: 16—20.5ºN (black), 12—16ºN (red), 8—12ºN (green), 4—8ºN (yellow) and 0—4ºN (blue).

Argo Floats

Eleven Argo floats were deployed during the cruise, as shown in Table 4. The floats were Argo WHOI-SOLO, designed to sink to a parking depth of 1000 dbar, stay there for 10 days following currents at that depth, then take a profile from 1000 to 2000 dbar to the surface while profiling temperature and conductivity. The data are transmitted to satellites disseminated in real-time.

Table 4: list of deployed floats. SN = Serial number, TID = transmission ID (PTT for Argos floats, SRNB for Iridium floats - blue), WMOID = unique ID assigned by World Meteorological Organization.

counter	day	month	year	hour	minute	latitude	longitude	SN - TID - WMOID
1	30	4	2010	12	58	0º38.253'N	13º29.664'W	849 - 80386 - 1901458

counter	day	month	year	hour	minute	latitude	longitude	SN - TID - WMOID
2	1	5	2010	3	10	0º25.869'N	16º30.605'W	953 - 28670 - 1901467
3	1	5	2010	18	56	0º13.493'N	19º30.343'W	930 - 91953 - 1901462
4	2	5	2010	17	18	0º15.080'N	22º59.995'W	954 - 32230 - 1901468
5	11	5	2010	2	58	20º0.420'N	23º0.050'W	818 - 28320 - 1901457
6	12	5	2010	12	21	20º18.75'N	28º8.400'W	924 - 84847 - 1901459
7	13	5	2010	15	55	20º7.099'N	34º31.903'W	938 - 37220 - 1901466
8	14	5	2010	17	48	20º1.590'N	37º53.138'W	925 - 84848 - 1901460
9	15	5	2010	21	17	22º23.731'N	43º0.117'W	974 - 21640 - 1901464
10	16	5	2010	13	31	23º42.732'N	46º3.519'W	972 - 95482 - 1901463
11	17	5	2010	10	20	25º13.664'N	50º1.826'W	928 - 84851 - 1901461

Expendable Bathythermograph (XBT) casts

A total of 72 XBTs were dropped during the cruise (Table 5). The deep blue XBTs we used can measure temperature to depths of up to 900m. The first 11 drops were recorded with the MK21 software (which cuts of the profile at 760 m). It was then decided to switch to the more sophisticated AMVERSEAS.

Table 5: list of XBT casts.

counter	day	month	year	hour	minute	latitude	longitude	comment
1	3	5	2010	13	16	2º10.488'N	23º0.004'W	
2	3	5	2010	14	7	2º20.164'N	23º0.004'W	
3	3	5	2010	17	17	2º41.187'N	23º0.004'W	
4	3	5	2010	18	5	2º50.045'N	23º0.005'W	
5	3	5	2010	21	16	3º10.674'N	23º0.003'W	2 bad drops
6	3	5	2010	22	2	3º19.547'N	23º0.005'W	
7	4	5	2010	1	18	3º39.382'N	23º0.857'W	
8	4	5	2010	2	27	3º50.257'N	23º1.845'W	
9	4	5	2010	20	39	4º10.320'N	23º0.907'W	
10	4	5	2010	21	31	4º20.147'N	23º1.047'W	
11	5	5	2010	0	39	4º39.848'N	23º0.003'W	last MK21
12	5	5	2010	5	32	5º20.09'N	22º59.99'W	first AMVERSEAS
13	5	5	2010	8	39	5º40.33'N	22º59.99'W	
14	5	5	2010	9	31	5º50.23'N	22º59.99'W	
15	5	5	2010	12	39	6º10.07'N	22º59.99'W	
16	5	5	2010	13	35	6º20.09'N	22º59.99'W	
17	5	5	2010	16	37	6º39.52'N	22º59.99'W	
18	5	5	2010	17	35	6º49.91'N	22º59.99'W	
19	5	5	2010	20	43	7º10.31'N	22º59.99'W	
20	5	5	2010	21	31	7º19.32'N	22º59.99'W	
21	6	5	2010	0	39	7º39.31'N	22º59.99'W	
22	6	5	2010	1	43	7º51.24'N	22º59.99'W	
23	6	5	2010	4	50	8º10.24'N	22º59.99'W	

counter	day	month	year	hour	minute	latitude	longitude	comment
24	6	5	2010	5	41	8º19.76'N	22º59.99'W	
25	6	5	2010	8	44	8º39.41'N	22º59.99'W	
26	6	5	2010	9	30	8º47.60'N	22º59.99'W	
27	6	5	2010	12	55	9º9.08'N	22º59.99'W	
28	6	5	2010	13	54	9º19.47'N	22º59.99'W	
29	6	5	2010	17	17	9º39.15'N	22º59.99'W	
30	6	5	2010	18	19	9º49.94'N	22º59.99'W	
31	6	5	2010	21	34	10º9.99'N	22º59.99'W	
32	6	5	2010	22	34	10º20.46'N	22º59.99'W	
33	7	5	2010	1	46	10º39.96'N	22º59.99'W	
34	7	5	2010	2	39	10º49.48'N	22º59.99'W	
35	7	5	2010	5	55	11º10.54'N	22º59.63'W	
36	7	5	2010	6	47	11º19.54'N	22º59.32'W	
37	7	5	2010	21	16	11º40.49'N	22º59.36'W	
38	7	5	2010	22	19	11º50.56'N	22º59.69'W	
39	8	5	2010	1	27	12º9.90'N	22º59.99'W	
40	8	5	2010	2	26	12º20.55'N	22º59.99'W	
41	8	5	2010	5	27	12º39.42'N	22º59.99'W	
42	8	5	2010	6	23	12º49.62'N	22º59.99'W	
43	8	5	2010	9	36	13º10.32'N	22º59.99'W	1 bad drop
44	8	5	2010	10	30	13º19.73'N	22º59.99'W	
45	8	5	2010	14	4	13º43.32'N	22º59.99'W	
46	8	5	2010	14	46	13º50.92'N	22º59.99'W	
47	8	5	2010	17	50	14º10.43'N	22º59.99'W	
48	8	5	2010	18	41	14º19.79'N	22º59.99'W	
49	8	5	2010	21	55	14º40.53'N	22º57.18'W	
50	8	5	2010	22	47	14º50.26'N	22º54.59'W	
51	9	5	2010	2	8	15º12.20'N	22º48.74'W	
52	9	5	2010	3	3	15º20.34'N	22º46.57'W	
53	9	5	2010	6	6	15º39.90'N	22º41.35'W	
54	9	5	2010	7	5	15º50.14'N	22º38.62'W	
55	9	5	2010	9	42	16º9.76'N	22º34.91'W	
56	9	5	2010	10	41	16º19.64'N	22º38.00'W	
57	9	5	2010	13	57	16º38.40'N	22º45.39'W	
58	9	5	2010	15	1	16º49.76'N	22º47.28'W	
59	9	5	2010	18	1	17º9.99'N	22º52.65'W	
60	9	5	2010	18	54	17º19.57'N	22º56.16'W	
61	9	5	2010	22	15	17º40.35'N	22º59.99'W	
62	9	5	2010	23	8	17º50.16'N	22º59.99'W	
63	10	5	2010	2	16	18º10.18'N	22º59.99'W	
64	10	5	2010	3	9	18º20.36'N	22º59.99'W	
65	10	5	2010	6	3	18º39.52'N	22º59.99'W	
66	10	5	2010	6	57	18º49.89'N	22º59.99'W	
67	10	5	2010	9	42	19º6.75'N	22º59.99'W	
68	10	5	2010	10	56	19º20.78'N	22º59.99'W	

counter	day	month	year	hour	minute	latitude	longitude	comment
69	10	5	2010	14	44	19º40.18'N	23º0.54'W	
70	10	5	2010	15	32	19º50.24'N	23º2.47'W	
71	10	5	2010	17	14	20º11.26'N	23º5.55'W	
72	10	5	2010	18	9	20º22.22'N	23º7.86'W	

Preliminary property sections

Preliminary sections along 23°W from the equator to 20.5°N, are derived from CTD or XBT stations.

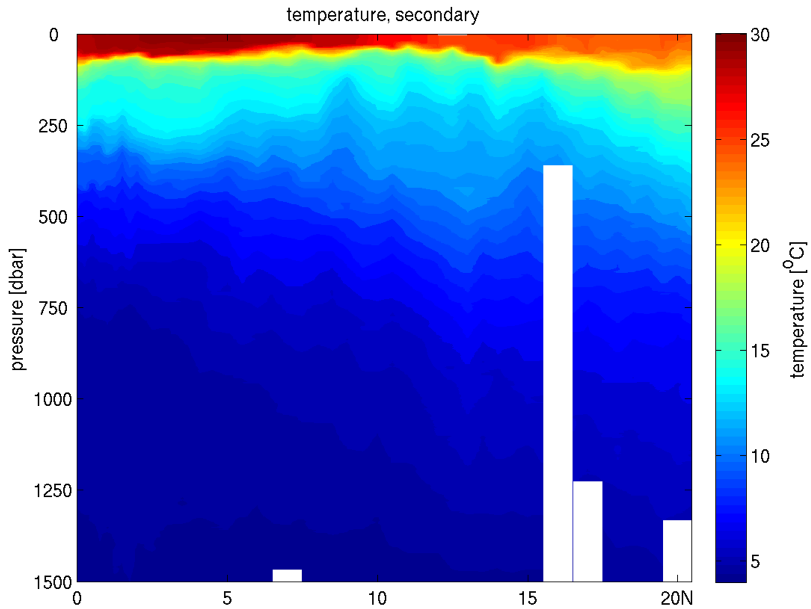

Fig. 5: CTD temperature along 23ºW.

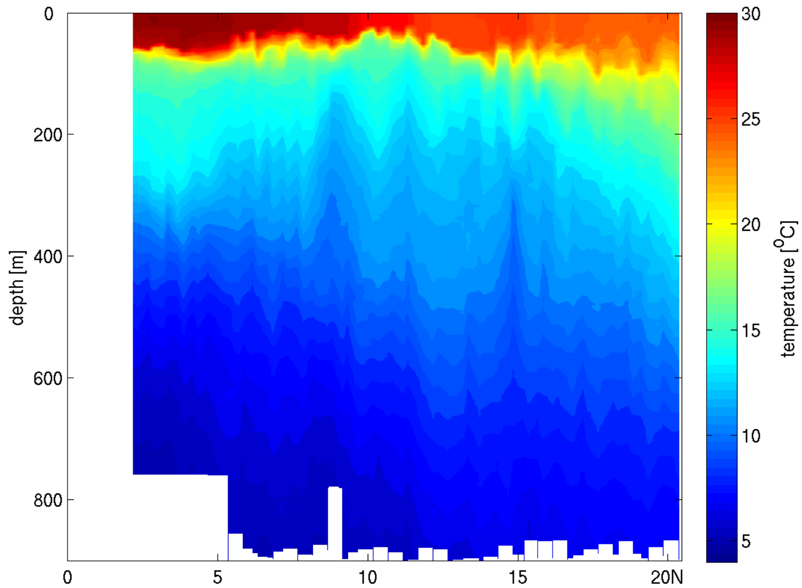

Fig. 6: XBT temperature along 23ºW

Surface features in the temperature sections include the warm, thick subtropical gyre and warmer, shallow tropical surface water layer (Figs. 5 and 6). Below the mixed layer the temperature drops rapidly within the thermocline to less than 10ºC. The horizontal slopes of the isotherms can be associated with specific currents. E.g.: the rapidly shoaling isotherms from 14ºN to 11ºN around the depth of about 400 dbar may be associated with the cyclonic Guinea Dome (Siedler *et al.*, 1992).

The salinity and oxygen fields shown below have undergone preliminary comparisons with estimates from the water samples. Median differences between estimates of salinity and oxygen concentration from the water samples versus the corresponding measurements of all individual CTD profiles do not exceed 0.006 psu and 9 micromol/l, respectively.

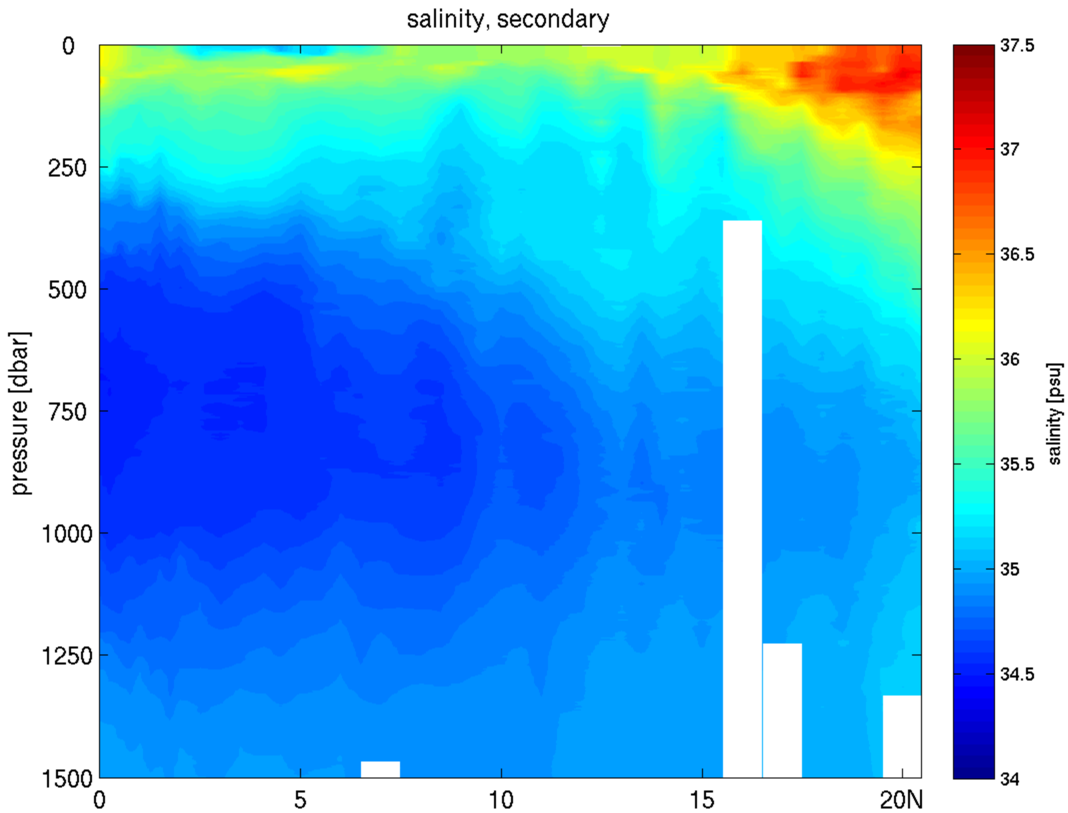

Fig. 7: CTD salinity (psu) along 23ºW.

The salinity section shows the increased salinity of the subtropical waters to the north, in the region where increased evaporation-minus-precipitation drives subduction and the production of Subtropical Mode Water which is characterized by high salinity (Fig. 7). Relatively fresh water is seen in the mixed layer that is influenced by the precipitation associated with the Intertropical Convergence Zone. At 500—1000 dbar, the northward-spreading fresh Antarctic Intermediate Water dominates the salinity section.

The oxygen section along 23ºW clearly shows the large are of low-oxygen water, with its lowest values at 400—500 dbar (Fig. 8). This water is in the stagnant shadow zone of the North Atlantic, that is not participating in the circulation associated with the ventilated thermocline of the subtopical gyre (e.g., Luyten and Stommel, 1986). The abrupt increase in oxygen values north of 14ºN marks the Cape Verde Frontal Zone, which also marks the boundary between North and South Atlantic Central Water (Stramma *et al.*, 2005).

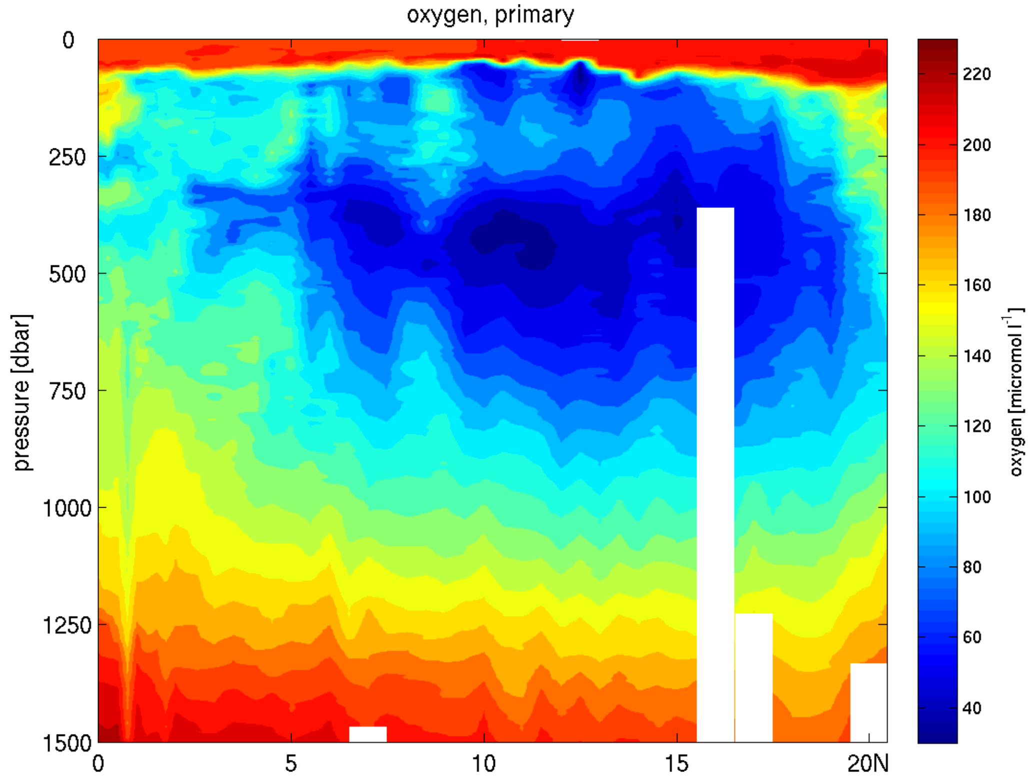

Fig. 8: CTD oxygen section along 23ºW.

The zonal velocity section from the LADCP clearly shows the strong eastward velocity associated with the Equatorial Undercurrent (EUC) at the southern end of the section (Fig. 9). Below that current, one can see the alternating currents of eastward and westward velocity (the so-called Equatorial Deep Jets). To the north of the EUC (about 2-4ºN) is a westward surface-intensified current that is the northern South Equatorial Current. This current is followed by the eastward North Equatorial Countercurrent at about 4-6ºN.

The meridional velocity is quite high near the surface in 2-5ºN, which is the region where the Tropical Instability Waves are important during part of the year (Fig. 9). Another are of high meridional velocity is just east of the Cape Verde Islands (around15.5ºN).

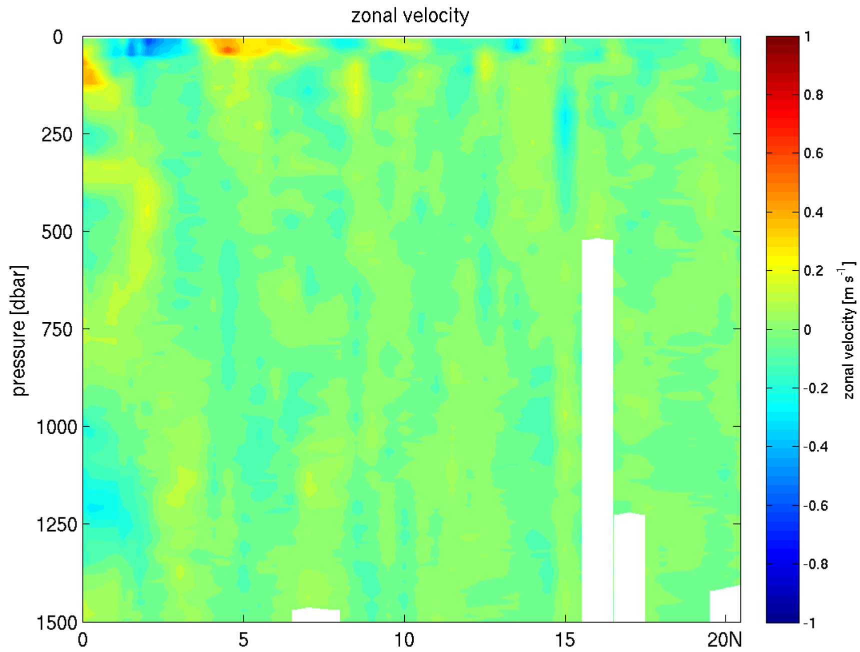

Fig. 9: LADCP zonal velocity section along 23ºW.

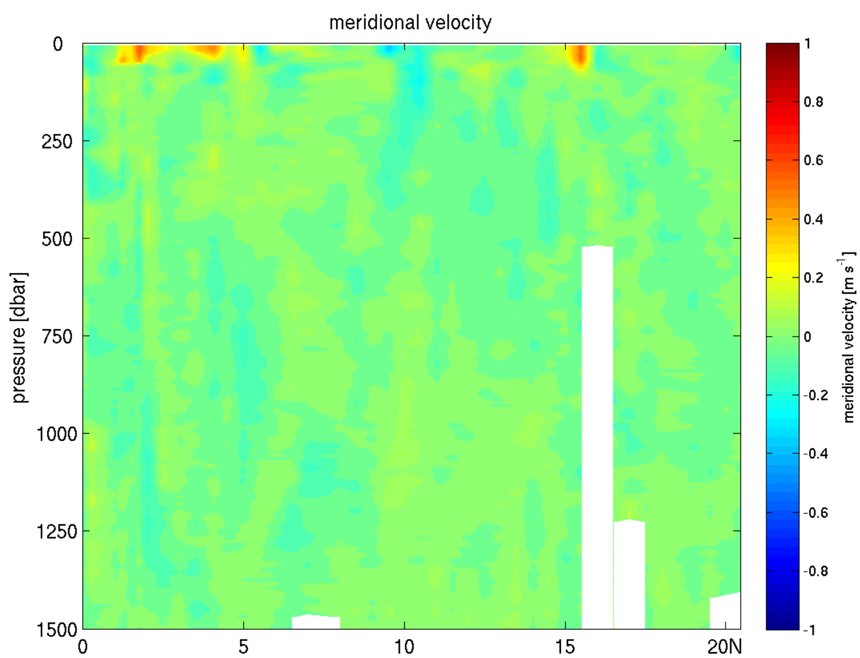

Fig. 10: LADCP meridional velocity section along 23ºW.

Atmospheric work performed and data collected on this cruise (AEROSE)

1. Overview

- A total of 75 Vaisala RS92 rawinsonde observations (RAOBs) were successfully obtained during the cruise; 19 of these were interfaced with EN-SCI ECC ozonesondes.
- Continuous measurements of select trace gases; ozone (O_3), carbon monoxide (CO), and sulfur dioxide (SO_2) were collected throughout the cruise using a suite of gas analyzers deployed on the 02 Level inside the Howard van.
- Surface-level aerosol mass and number distribution characteristics were measured throughout the cruise using a condensation particle counter, two laser particle counters, and two quartz crystal microbalance cascade impactors.
- Continuous radiometric broadband flux measurements employing shortwave and longwave radiometers mounted atop the Howard University van were obtained throughout the cruise. Additionally, spectral measurements of the direct solar radiation were collected using a handheld sunphotometer. These latter data allow calculation of the columnar aerosol optical depth (AOD) and an estimation of the aerosol size distribution in the column. Atmospheric sampling of ambient aerosols for off-line biological (both fungi and bacteria), chemical (total organics, heavy metals, cations and anions, and elemental analysis), and physical characterization were collected throughout the cruise using a battery of size-specific and bulk filter instruments.
- As with previous AEROSE campaigns, AEROSE data from the 2010 PNE/AEROSE cruise will be made available for download from web/ftp servers located at NOAA/NESDIS/STAR and NOAA/ESRL/PSD.

2. Radiosonde Observations (RAOBs) and Satellite Validation

Vaisala RS92 GPS rawinsondes were launched approximately 2–4 times per day, with no sounding losses. These sondes provide tropospheric thermodynamic soundings of pressure, temperature and humidity (PTU), along with GPS-derived soundings of geometric height (independent of pressure), and kinematic wind speed and direction. All launch times were scheduled to coincide with specific low-earth orbit (LEO) satellite overpasses, namely the EUMETSAT MetOp and EOS A-Train Aqua, which fly advanced passive infrared sounders, namely the Infrared Atmospheric Sounding Interferometer (IASI) and Atmospheric Infrared Sounder (AIRS). AIRS and IASI spectra are to be used as proxies for the future Joint Polar Satellite System (JPSS) Cross-track Infrared Microwave Sounding Suite (CrIMSS). The RAOB matchups are critical for providing independent correlative measurements for validation of CrIMSS sensor and environmental data records (SDR/EDR).

Ozonesondes interfaced with the RS92 rawinsondes were launched approximately 1 per day, again scheduled to coincide with MetOp or Aqua overpasses for validation of the CrIMSS ozone retrieval Intermediate Product (IP). The dynamics of tropospheric ozone over the tropical Atlantic is currently an area of active research, with elevated quantities hypothesized to have continental origins, including biomass burning and lightning in Africa. Thus, satellite ozone validation is all the more important in this region, especially when considering the long term commitment of NOAA and EUMETSAT to high spectral resolution passive infrared sounders over the upcoming decades.

Figure 11 shows the locations of PTU and O_3 sonde launches; note the excellent zonal (E-W) and meridional (S-N) cross-sectional transects of the tropical North Atlantic and the Gulf of Guinea. Figure 12 shows the cross-section of relative humidity (RH) during the 23°W S-N transect. As in previous AEROSE campaigns (i.e., *Nalli et al.* 2005), this cross-section reveals the Saharan air layer (SAL) as a low-level dry filament just above the marine boundary layer to the north of the Intertropical Convergence Zone (ITCZ) between ≈9–20°N. Figure 13 shows the full complement of ozonesonde tropospheric ozone profiles (along with concurrent RH). High levels of ozone are often associated with dry filaments, suggesting possible continental or stratospheric origins.

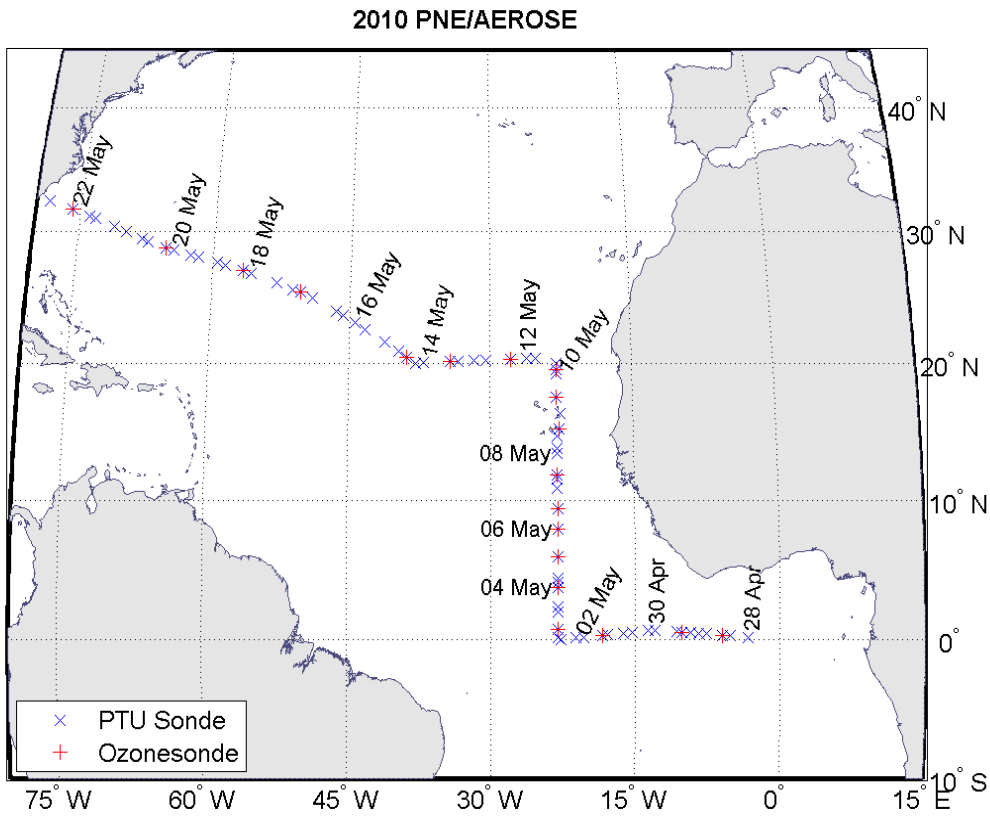

Figure 11: AEROSE RS92 rawinsonde and ECC ozonesonde launch locations and times.

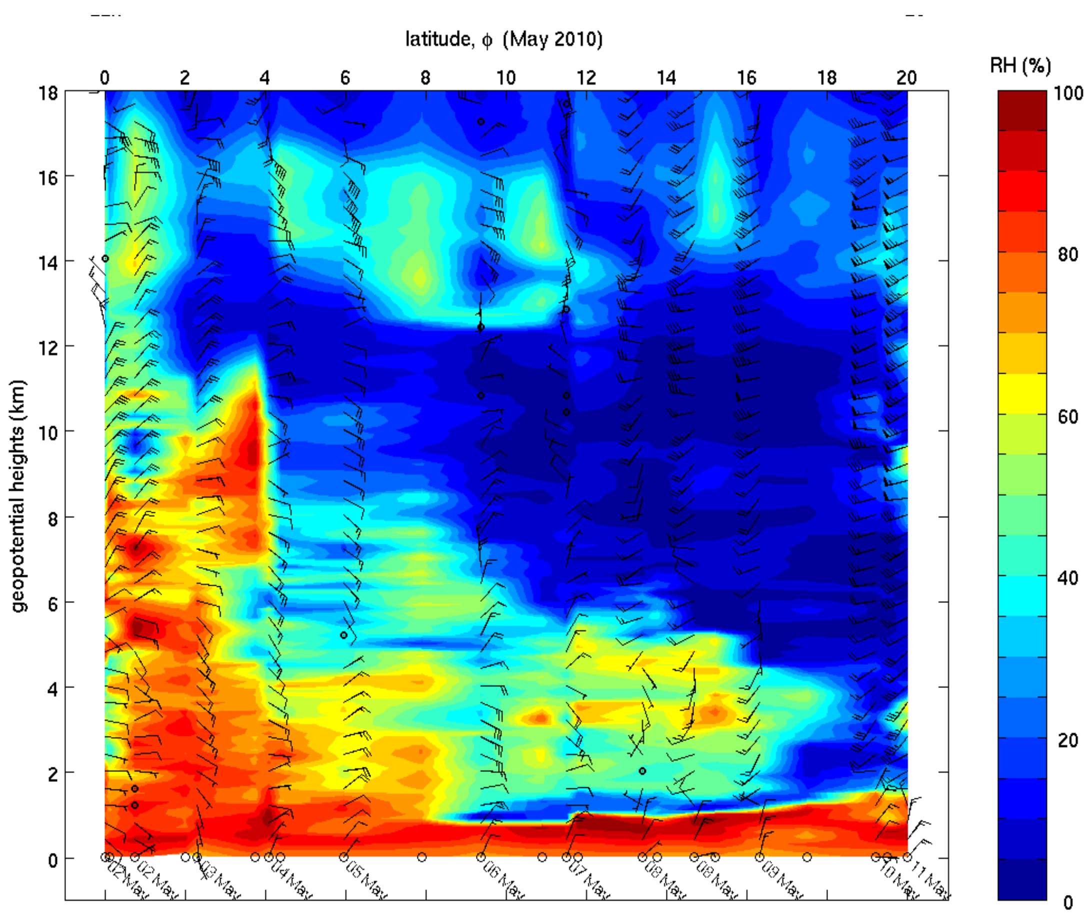

Figure 12: Cross-section of relative humidity during the 23°W S-N transect showing Saharan air layer (SAL) dry filament to the north of the ITCZ between ≈9–20°N.

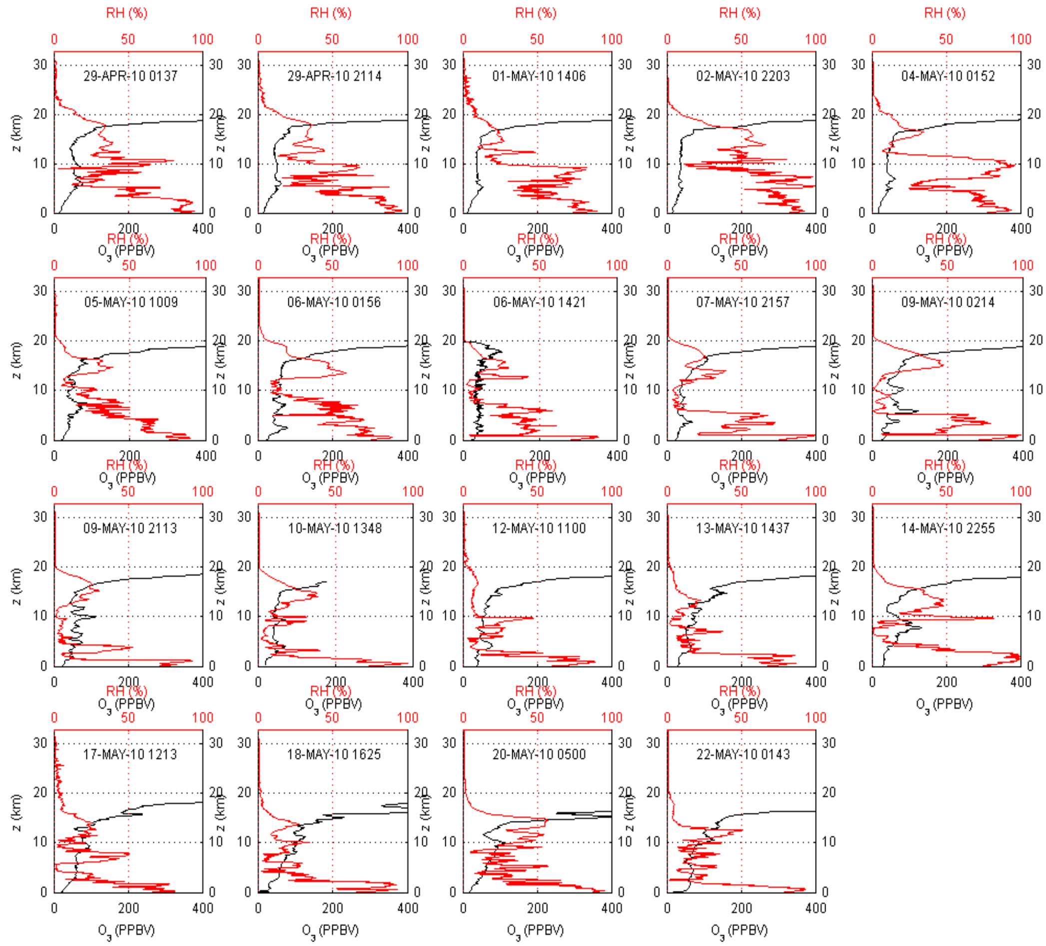

Figure 13: Ozone and relative humidity (RH) profiles obtained during ozonesonde launches. Note the presence of elevated tropospheric ozone in dry layers, suggesting continental or stratospheric origin.

The satellite validation component is a critical component of the AEROSE data set and provides unprecedented mapping of atmospheric thermodynamics under various aerosol and moisture regimes.

3. In Situ Trace Gases

Ambient measurements of trace gases (ozone, carbon monoxide, and sulfur dioxide), were conducted. These measurements are essential counterparts to studies of oxidizing efficiency of the tropical troposphere under heavy aerosol loading conditions. Previous observations for the trace gas measurements indicate that ambient concentrations of ozone tend to increase in biomass aerosol regimes with increasing aerosol loading, with the opposite occurring in dusty regimes with increased aerosol loading. We also observe that O_3 has a stronger anti-correlation with SO_2 than its correlation with CO in both dusty and biomass burning air masses. Analysis of the 2010 campaign data has been ongoing.

4. Aerosol Measurements

a) In situ

Aerosol microphysical measurements were conducted using three aerosol instruments were deployed from inside the Howard University van (located on the forward 02 Level) and sampling through a shrouded intakes located 1 meter above the van roof. The QCM sampled through a $PM_{2.5}$ impactor. The laser particle counters (LPCs) measured aerosol number density in a combined nine size fractions between the two instruments. The QCM cascade impactors measure size-segregated mass densities in either six or ten size bins. The QCMs were deployed individually and in tandem based on the type of air mass encountered. These instruments are also capable of collecting size segregated samples for single particle and morphological analysis. The condensation particle counter, (model 3010 TSI incorporated) was deployed in the Howard University sampling van on the 02 Level of to collect samples of total particle concentration in the atmosphere in support of the AEROSE team science plan. The instrument was operated in an episodic sampling scheme, alternating days of sampling to conserve the condensing alcohol in the chamber (which was brought in limited quantities) and to sample air masses of interest. The raw data was retrieved from the instrument when it was stopped to refill the chamber with alcohol or during buoy recovery, repair and deployment operations. Shoreside analysis of these data is currently ongoing.

b) Microtops Sun Photometer

Spectral measurements of the direct attenuated solar radiation obtained by the Microtops handheld sunphotometer provide information to retrieve the columnar aerosol optical depth (AOD). Additionally, the size distribution of aerosols can be inferred from the multichannel AOD retrievals, typically from the 440 nm and 870 nm channels. The negative slope (or first derivative) of AOD with wavelength in logarithmic scale is known as the Angstrom Coefficient (AC). Values of AC closer to 2.0 indicate fine mode particles (e.g., smoke particles and sulfates) exist, while values of AC near zero indicate the presence of coarse mode particles such as desert dust (*Eck et al.*, 1999). The raw Microtops data are then processed using NASA's Maritime Aerosol Network (MAN), from AERONET, method (*Smirnov et al.*, 2009).

Figure 14 shows the AOD and AC values for the entire cruise. The data shown in this figure strongly suggest encounters with regions containing different types of aerosols observed during the period of measurements performed with the Microtops instrument.

There is a clear transition in the data between 2 and 5 May. This is also the time during which the ship traversed the ITCZ on the northbound transect. The absence of sunphotometer measurements during this time is because of cloudy conditions prevented data from being collected. On the north side of the ITCZ the AC values are observed to remain below 0.5, corresponding to coarse aerosol, namely mineral dust (compare with

Figure 12). However, starting around 8 May the AC values are seen to increase as AOD value abruptly decrease, indicating passage outside of a Saharan dust plume.

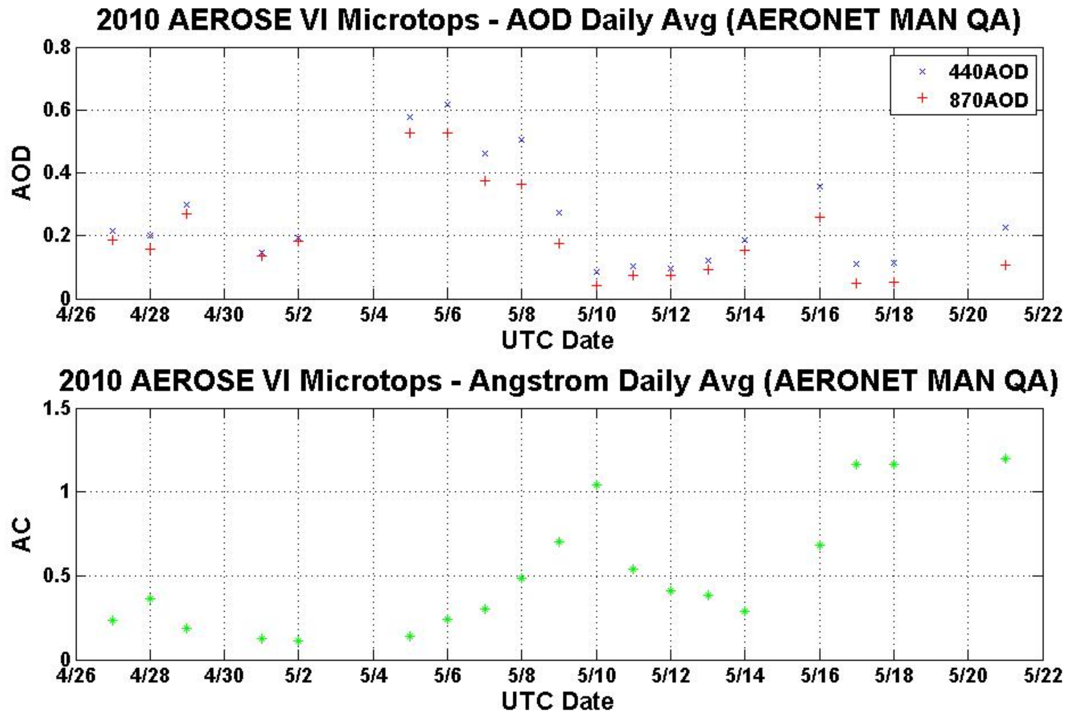

Figure 14: Calibrated daily mean AOD and Angstrom coefficients observed during PNE/AEROSE. The raw data are processed using NASA's Maritime Aerosol Network (MAN) methodology (*Smirnov et al.* 1999).

5. Broadband Radiometer Surface Fluxes

Multiple independent broadband pyranometers and pyrgeometers measured downwelling shortwave (SW) solar-spectrum (visible) and terrestrial (infrared) radiation for radiative energy balance calculations at the surface. Figure 15 shows the downwelling SW and LW as measured by the Howard University instrumentation. The diurnal cycle of SW flux is readily apparent, with the low SW flux near the beginning of the cruise the result of persistent cloudiness within the ITCZ. The gradual increase in LW flux from 2–8 May, along with an attendant suppression of daytime SW when compared to the period following this, is believed to be the impact of dust aerosols (cf. Figures 14 and 12). This vital information, including that acquired from previous AEROSE campaigns, is important for climate studies, and will be implemented into radiation models. Given concurrent measurements of downwelling LW and SW irradiance from broadband flux, as well as atmospheric profiles radiative forcing will be calculated in order to understand more the radiation budget in the atmosphere and its thermodynamics.

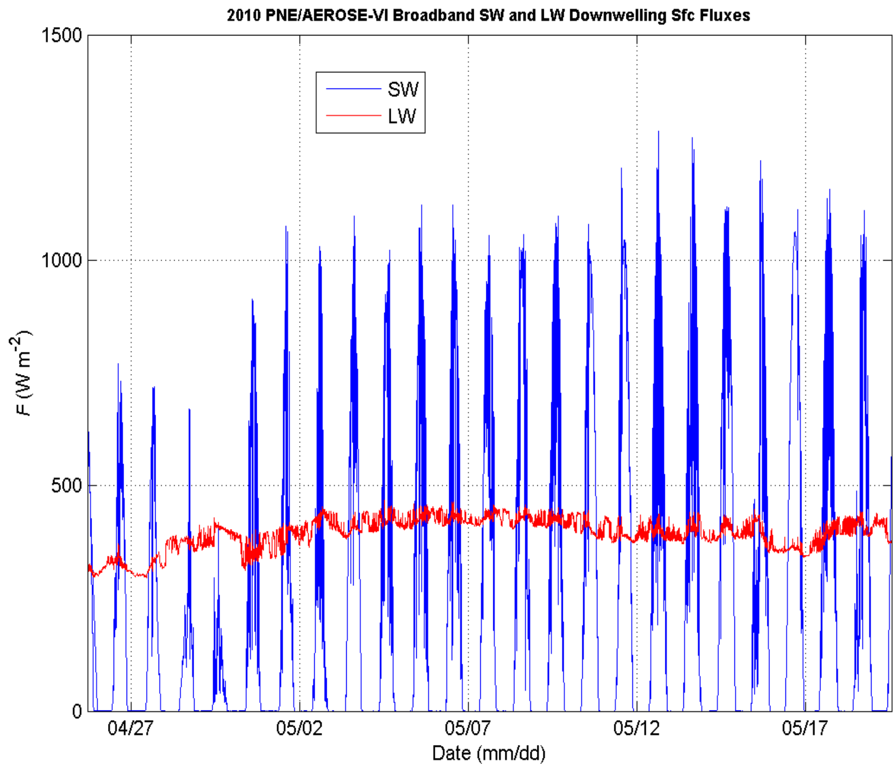

Figure 15: 2010 PNE/AEROSE-VI broadband SW and LW downwelling surface fluxes measured by the Howard University pyranometers and pyrgeometers.

6. Chemical and Aerobiological Sampling

Chemical and aerobiological sampling were conducted on the 03 Level forward of the bridge using a Partisol-Plus 2025 sequential air sampling unit equipped with a PM_{10} impactor, two three-stage air samplers (Respicon), and an S&S sampling canister (fungi). The Partisol-Plus is an automated sampling system, which was set at sampling intervals based on the observed aerosol loading and designed to obtain samples that effectively captured temporal segments of individual air masses that resolve their physico-chemical transformations. Sampling intervals ranged from 12 to 48 hours. These filters will be used for bulk chemical analysis.

The Respicon three-stage samplers operated at a constant volume flow rate of 12.9 lpm, were employed in parallel, and equipped with 0.22 µm pore quartz fiber filters. These devices collected size-segregated samples of 2.5, 1.0, and 0.5 µm. All filter samples and blanks were dated, geo-located, and stored under dry conditions at 17°C.

Aerobiological samplers were deployed specifically for airborne fungi in addition to the other air filter samplers. These samplers were not size-specific and were collected daily throughout the cruise. Sampling frequency for fungi was increased during periods of heavy aerosol loading or under unique environmental conditions.

The AEROSE team was able to sample aerosols in distinctive air mass regimes. The air mass regimes were determined by satellite imagery and products in combination with forecasts from the NAAPS, NOGAPS, and WRF models. Potential source regions were identified by calculating back trajectories using the NOAA HYSPLIT model. Post-cruise analyses of these are currently ongoing.

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Stramma, L., S. Huttl and J. Schafstall, 2005: Water masses and currents in the upper tropical northeast Atlantic off northwest Africa. *J. Geophys. Res.*, **110**, C12006, doi:10.1029/2005JC002939.