Tropical Atlantic Climate Experiment (TACE) –

Variability of the Equatorial Atlantic Cold Tongue

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Climate fluctuations in the tropical Atlantic sector are dominated by two distinct patterns of coupled ocean/atmosphere variability, collectively referred to as Tropical Atlantic Variability (TAV). They are tightly phase-locked to the pronounced Atlantic seasonal cycle and vary on interannual to decadal timescales. During boreal spring, when the equatorial Atlantic is uniformly warm, conditions are favorable for the development of an interhemispheric gradient of sea surface temperature (SST) anomalies, often referred to as the meridional mode. The so-called zonal mode is frequently viewed as the Atlantic counterpart of the Pacific El Nino Southern Oscillation (ENSO) and is most pronounced during boreal summer, coinciding with the seasonal development of the eastern equatorial cold tongue. The interannual variability of SST in the cold tongue during boreal summer is closely linked to rainfall variability in the countries surrounding the Gulf of Guinea and in the northeast region ("Nordeste") of Brazil (Kushnir et al., 2006). Coupled ocean–atmosphere general circulation models (GCMs) suffer serious biases in the tropical Atlantic and fail to reproduce the eastern equatorial cold tongue in boreal summer (Richter and Xie, 2008). Cold tongue SST is controlled by different oceanic and atmospheric processes, including surface heat fluxes, vertical mixing, as well as mean and eddy advection. A multinational observational program is currently in place as part of the Tropical Atlantic Climate Experiment (TACE), including shipboard and moored instrumentation as well as autonomous floats, drifters and gliders (Fig. 1). This program aims at quantitatively linking the year-to-year variability of the central and eastern equatorial upper ocean heat budget and SST to the different oceanic and atmospheric processes at work. The overarching goal of TACE is to advance the understanding of coupled ocean/atmosphere processes and to improve climate prediction for the tropical Atlantic region.

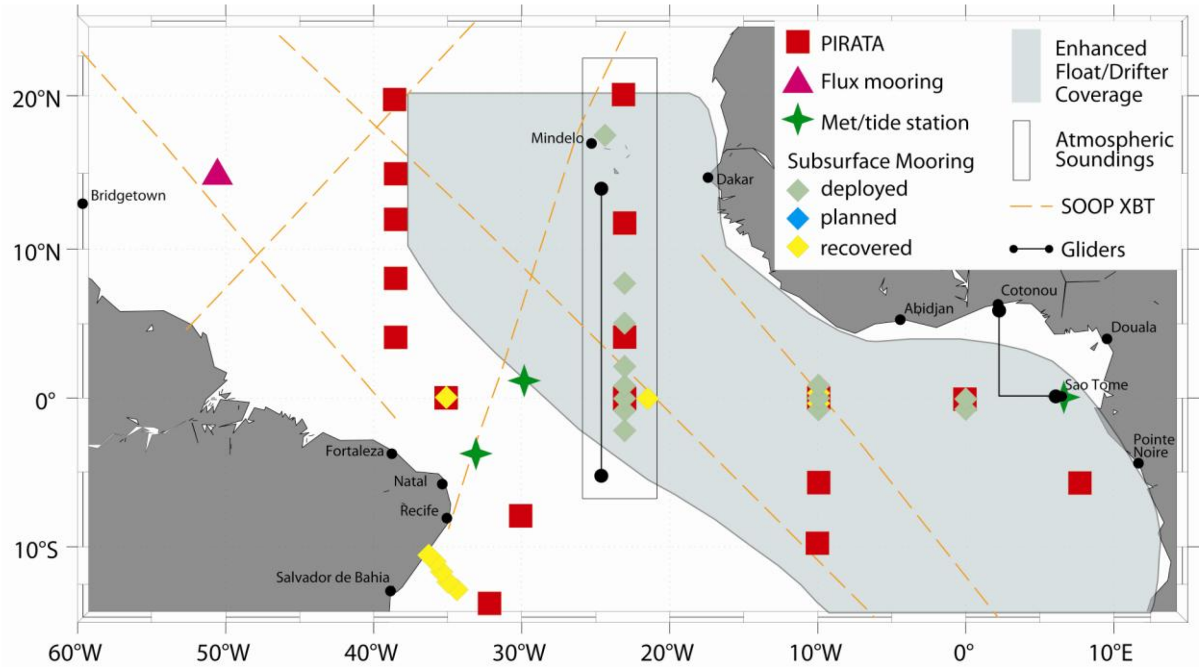

Fig. 1: The TACE observing system including the PIRATA array (http://tace.ifm-geomar.de/).

Shipboard and Moored Current Observations

During the TACE period (starting in 2005), enhanced shipboard observations were carried out in the tropical Atlantic resulting in a large number of meridional and zonal velocity sections. This dataset allows the compilation of mean velocity sections describing the supply pathways of the equatorial and coastal upwelling regions [Brandt et al., 2006; Kolodziejczyk et al., 2009]. Due to large flow variations that are mostly due to the presence of strong intraseasonal fluctuations, shipboard velocity sections can hardly be used to study interannual to decadal variability of the circulation. To study these longer-term changes, subsurface mooring arrays are installed at different longitudes in the equatorial region. Along 23°W, a current meter mooring array was deployed in June/July 2006 as part of the German BMBF North Atlantic, project which will be maintained until 2011. The time series at the equator already started in 2002 with the deployment of a French mooring. It is planned to continue the moored observations at the equator beyond 2011 in the framework of the PIRATA program (http://www.pmel.noaa.gov/pirata/). Along 10°W and 0°, a French/U.S. current meter mooring array was installed in 2007 which will be maintained until 2011. This array particularly focuses on the termination of the Equatorial Undercurrent in the eastern equatorial Atlantic.

Hydrographic Observations

The availability of hydrographic observations increased strongly due to enhanced shipboard observations, increased number of ARGO floats, and the use of gliders. In the Gulf of Guinea, several research cruises were carried out in the framework of the French EGEE project ("Etude de la circulation océanique et des échanges océan-atmosphère dans le Golfe de Guinée") as part of the AMMA project (http://amma-international.org/). To assess seasonal and interannual variability, six EGEE cruises are conducted, with two cruises per year during 2005-2007. Cruises were scheduled to coincide with the monsoon onset and development of equatorial upwelling in early boreal summer (end of May to July), and during the mature phase of the monsoon (September-October) when the cold tongue is still well developed. Strong year-to-year variability in the hydrographic structure during early boreal summer represents a preconditioning for the development of a cold/warm event [Marin et al., 2009]. The PIRATA (''Prediction and Research Moored Array in the Atlantic'') network of surface buoys represents the backbone of the tropical Atlantic observing system. PIRATA aims at providing high-resolution time series of surface heat and moisture fluxes, SST and SSS, and subsurface temperature and salinity in the upper 500m. The inclusion of PIRATA data into the MERCATOR assimilation system resulted in a general improvement of the equatorial circulation [Bourlès et al., 2008]. Cruises to service the PIRATA moorings are also used to further complete hydrographic datasets at the mooring sites and throughout the tropical Atlantic region.

Gliders, Floats, Drifters, XBT

As part of different German research projects, a repeated glider section along 23°W was established. Typical distances between individual CTD profiles along a glider transect are 4 km, allowing the study of small-scale hydrographic variability. Additionally, in 2011 a coordinated glider swarm experiment using about 8 gliders in the cold tongue region is scheduled during the onset and height of equatorial upwelling.

The sparsity of subsurface observations in the eastern equatorial and tropical South Atlantic during recent years was strongly reduced due to an increased number of ARGO float deployments. Since mid-2005, about 200 ARGO profiles per month were obtained in the box between 10°N/S and east of 25°W. Additionally, the high-density XBT line from Cape Town to North America delivers a large number of temperature profiles in the central equatorial Atlantic, currently scheduled four times a year since December 2000. Along these lines as well as during regular research cruises, surface drifters, partly including SST, SSS and SSP sensors, are deployed in the tropical Atlantic. However, due to the equatorial divergence, surface drifters tend to stay in the equatorial region for a short period only. There are still gaps in the distribution of floats drifters and moorings particularly in the eastern tropical South Atlantic.

Vertical Flux Observations

Surface heat fluxes were intensively measured during a research cruise (EGEE-3) in boreal spring/summer 2006. These fluxes as well as fluxes from different model outputs differ considerably. Mixed layer heat budget calculations will require improved surface heat fluxes. Microstructure measurements were carried in the frame of a German initiative during EGEE and other research cruises. These observations are aimed at quantifying the downward diapycnal heat flux out of the mixed layer into the deep ocean. Diapycnal heat fluxes of up to 90 W m^{-2} out of the mixed layer were inferred for a region between 3°S and 1°N and are associated with elevated turbulence due to shear instability below the mixed layer that tend to be very shallow (10-20m depth). Furthermore, helium isotope concentrations were measured from water samples in the upper ocean during several cruises that allow a determination of upwelling velocities. An asymmetric distribution about the equator was found, with higher vertical velocities occurring south of the equator.

Satellite Observations

To understand TAV, different remote sensing products are of prime importance. Among them are sea surface height, sea surface temperature, surface winds, and rainfall (see e.g. http://www.aoml.noaa.gov/phod/regsatprod/atl3/index.php and http://realtime.sea.uct.ac.za/). The availability of sea surface salinity with the upcoming SMOS (Soil Moisture & Ocean Salinity) mission is expected to improve mixed layer heat and freshwater budget calculations.

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