Innovative observations of ocean/atmosphere interactions in the tropical/subtropical Atlantic Ocean

People on the Indian sub-continent are not the only ones to rely on monsoon-induced changes. West Africa has highly variable seasonal rainfalls as well. Whether certain regions in West Africa will be exposed to major rainfall or near-drought conditions is largely determined by water temperatures in the central and eastern equatorial Atlantic. A comprehensive oceanic and atmospheric measurement and modeling program at IFM-GEOMAR is aimed at improving the seasonal predictability of precipitation patterns in countries adjacent to the Gulf of Guinea and the northeastern regions of Brazil. This in turn might lead to early preventive measures in the fight against climate-related diseases, such as dengue fever, malaria, cholera, and meningitis, and might lead to an improved adaptation of agricultural usage to regional climate conditions.

It has been known for quite some time that the variability of sea surface temperature in the equatorial Atlantic – or more specifically, in the equatorial cold water tongue – plays a special role for precipitation fluctuations across West Africa. It is yet unclear, however, what effect ocean dynamics in comparison to atmospheric driving forces may have for the variability of sea surface temperatures in this region. Due to the time-delayed effects of processes in the ocean's interior on the sea surface, a predictability time scale for sea surface temperatures and thus precipitation in the range of weeks to several months would result.

The equatorial cold water tongue is located along the equator east of 20°W (Fig. 1) and is particularly well developed in boreal summer. The sea surface temperatures are then between 20 and 25°C, thus significantly cooler than the surrounding waters. The cause for this "chilling" effect is the upwelling of colder water from depths of about 100 m. The upwelled waters in turn are supplied by the so-called Equatorial Undercurrent, an eastward subsurface

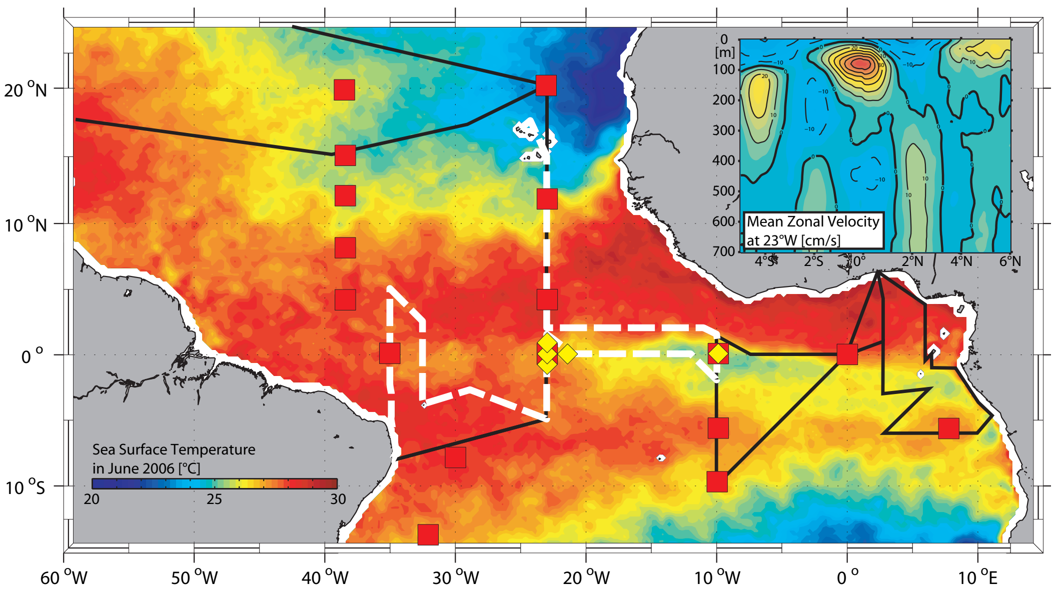

Fig. 1: Sea surface temperature in June 2006, revealing the equatorial cold water tongue (area between 20°W and 0° along the equator). During a R/V "Meteor" cruise in June 2006 (dashed white line), a number of moorings (yellow diamonds) were deployed, intended to measure transport fluctuations of the Equatorial Undercurrent over several years for the first time. This eastward current, concentrated along the equator at about 100 m depth, with current velocities of about 80 cm/s (yellow and red, small insert, top right) supplies water to the upwelling areas within the cold water tongue. Fluctuations in strength and temperature of this current therefore have a direct effect on the sea surface temperature of the cold water tongue. In addition, the map shows cruise tracks of the French R/V "L'Atalante" in the Gulf of Guinea, and of the U.S R/V "Ronald H. Brown" in the central tropical Atlantic (black lines), as well as the PIRATA surface buoy network (red squares). Ocean observations are part of CLIVAR's Tropical Atlantic Climate Experiment, see http://tace.ifm-geomar.de.

flow on the equator that transports water from the oceanic regions off Brazil to the eastern Atlantic (Fig. 1, top right). On average, the transport of the Equatorial Undercurrent amounts to 20 million cubic meters of water per second, about 100 times the volume transport of the Amazon River.

During R/V "Meteor" cruise 68/2 in summer 2006, a series of instruments moored to the ocean floor were deployed in the central equatorial Atlantic. Their task is to measure the fluctuations of ocean currents within the supply path of the cold water tongue over a period of several years (Fig. 1, Cruise track and mooring positions near equator). These measurements are part of the collaborative project NORDATLANTIK, funded by the German Federal Ministry of Education and Research, investigating the oceanic circulation, its transition from warm to cold water phases and its effect on climate. Concurrent to the R/V "Meteor" expedition, there were research cruises aboard the French R/V "L'Atalante" in the Gulf of Guinea, and aboard the U.S. R/V "Ronald H. Brown" in the central tropical Atlantic (Fig. 1). During these expeditions, oceanic turbulence measurements covering the entire region of the cold tongue were carried out for the first time. Turbulence in the ocean is a process that occurs on rather small scales, from meters down to millimeters. It mixes the relatively warm water at the sea surface with colder water below and thus cools the upper ocean. The required energy is supplied by the wind at the sea surface, by the oceanic current system, and from internal waves. Since September 2005, as part of a DFG Emmy Noether Junior Research Group, turbulence measurements have been carried out during six international research cruises within the cold water tongue to study the variability of cooling by turbulence. First results indicate that cooling of the sea surface temperature by turbulence is much larger than expected and amounts to 2-3 degrees per month during summer. Turbulence thus represents one of the most significant processes for the generation of the cold water tongue.

State-of-the art climate models show a particularly large SST bias toward higher temperatures in the tropical Atlantic that strongly reduces the reliability of climate predictions by these models. Aside from oceanic processes not well represented in these models, errors in the radiative forcing might contribute significantly to the model SST bias. Our planet receives and absorbs most of the available solar energy in the tropical and subtropical ocean. Today, our understanding of this radiative forcing is severely hampered due to the diverse effects of clouds. In 2003, the Meridional Ocean Radiation Experiment (MORE) was initiated by IFM-GEOMAR and the P. Shirshov Institute for Oceanology. The research goal is to conduct long-term collocated observations of energy fluxes above the ocean and of the corresponding state of the atmosphere.

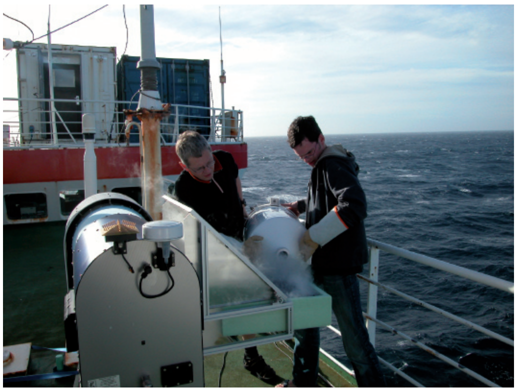

Fig. 2: Filling the HATPRO microwave radiometer with liquid nitrogen for calibration.

In April/May and October/November 2007 the German R/V "Polarstern" carried out the 6th and 7th MORE cruise (Atlantic transects ANT-XXIII-10 and ANT-XIV-1). For the first time, a multichannel microwave radiometer (Fig. 2) was used in the open ocean for continuous observations (temporal resolution of 1 sec) of atmospheric temperature and humidity profiles, as well as cloud liquid water path and precipitable water path.

Additional information on clouds and cloud-free atmospheric conditions from full sky imager and radiosondes, among others, will be utilized to quantify cloud-radiation correlations, and to validate corresponding parameterizations used in coupled ocean/atmosphere climate models. The collected data are used to provide validations of satellite-based retrievals of surface radiation budgets by means of the SEVIRI radiometer onboard the Meteosat Second Generation satellites. First comparisons show a generally good agreement indicating that our present understanding of cloud remote sensing from space is sufficient for a satellite based analysis of cloud-radiative interactions over the Atlantic ocean. As of 2008, MORE will be joined by the WGL-PAKT Initiative OCEANET with participation from the Leibniz Institute for Tropospheric Research, the Alfred-Wegener-Institute for Polar and Marine Research and the GKSS Research Center.

The oceanic and atmospheric measurements in the tropical/subtropical Atlantic provide valuable "ground truth" for the quality assessment of various climate model simulations. An improved model representation of various observed processes, plus the direct assimilation of observations in model runs, are intended to improve prognostics for sea surface temperature, a significant foundation for the successfully projection of climate in the Atlantic sector, and particularly of the monsoon precipitation over West Africa.

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Highlighted Publications 2007

Jakobsson, M., Backman, J., Rudels, B., Nycander, J., **Frank, M.**, Mayer, L., Jokat, W., Sangiorgi, F., O'Regan, M., Brinkhuis, H., King, J. and Moran, K., 2007: The Early Miocene onset of a ventilated circulation regime in the Arctic Ocean. *Nature*, **447**, 986-990.

Markert, S., Arndt, C., Felbeck, H., Becher, D., Sievert, S.M., **Hügler, M.**, Albrecht, D., Robidart, J., Bench, S., Feldman, R.A., Hecker, M. and Schweder, T., 2007: Physiological Proteomics of the Uncultured Endosymbiont of *Riftia pachyptila*. *Science*, **315** (5809), 247, doi:10.1126/science.1132913.

Riebesell, U., Schulz, K.G., Bellerby, R.G.J., **Botros, M.**, **Fritsche, P.**, **Meyerhöfer, M.**, Neill, C., Nondal, G., **Oschlies, A.**, **Wohlers, J.** and **Zöllner, E.**, 2007: Enhanced biological carbon consumption in a high CO_2 ocean. *Nature*, **450** (7169), 545-548.

Weldeab, S., Lea, D.W., Schneider, R.R. and Andersen, N., 2007: 155,000 years of West African monsoon and ocean thermal evolution. *Science*, **316**, 1303-1307.

The complete list of publications can be found in Appendix 5.