



IFM-GEOMAR

Leibniz-Institut für Meereswissenschaften
an der Universität Kiel



IFM-GEOMAR Report 2002-2004

From the Seafloor to the Atmosphere

- Marine Sciences at IFM-GEOMAR Kiel -



June 2005



Preface

For the first time, the Leibniz Institute of

Marine Sciences (IFM-GEOMAR) presents a joint report of its research activities and developments in the years 2002-2004. In January 2004 the institute was founded through a merger of the former Institute for Marine Research (IfM) and the GEOMAR Research Center for Marine Geosciences. This report addresses friends and partners in science, politics and private enterprises. It gives an insight into the scientific achievements of IFM-GEOMAR and its predecessor institutes during the last three years.

3. Scientific Highlights

3.1 Tropical Atlantic Variability

The Tropical Atlantic has turned out in recent years to be a key region for improved understanding of climate variability and predictability, not only for the adjacent regions of Africa and South America but for the European sector as well. And yet, present-day coupled climate models show disturbing biases for the tropical Atlantic, with anomalously warm sea surface temperatures (SSTs) instead of a minimum in the region of the eastern tropical „cold tongue“. Several modes of Tropical Atlantic variability (TAV) have been identified; these include the Meridional Gradient Mode, the Atlantic Niño and the Benguela Niño and they are all strongly coupled to the seasonal cycle. Furthermore, the Pacific El Niño itself influences also the tropical Atlantic. As an example, Figure 1 shows the summer correlation between the first Empirical Orthogonal Function (EOF) of tropical rainfall with the surface winds (vectors) and SSTs (colours), indicating a strong role of the eastern tropical Atlantic in affecting precipitation of the region. In turn, droughts and related dust events and disease outbreaks in western Africa are all related to tropical Atlantic SST, making its prediction extremely important.

The gradient mode, in former times also called „dipole mode“, occurs at interannual to decadal time scales and is most pronounced in boreal spring. Its SST pattern is associated with meridional wind anomalies blowing toward the warm hemisphere where it turns against the prevailing Trades, thus enhancing the effect, causing a positive feedback loop. Warm SST anomalies that occur primarily in the cold tongue region are referred to as Atlantic Niño. In some years, the warm anomalies propagate southward along the southwest African coast to beyond 20°S where they are known as Benguela Niños. The reduction in upwelling and thus nutrient supply associated with the Atlantic and Benguela Niños has large impacts on the ecosystem of the region, also including strong reduction of CO₂ outgassing into the atmosphere.

Physical Mechanisms of Tropical Atlantic Variability

The ocean can play a role in TAV through a number of mechanisms. While the intraseasonal to interannual variability in the eastern tropics and along the eastern boundary can to a large extent be explained by tropical and boundary wave processes that offer some degree of predictability, the longer-term processes in the interior are more complex. One of the yet poorly understood mechanisms is that of the shallow Subtropical Cells (STCs; Fig. 2). The STCs connect the subduction zones of the eastern subtropics (in both hemispheres) through equatorward thermocline currents with the Equatorial Undercurrent (EUC) and eastern upwelling regimes. Eastward off-equatorial undercurrents (NEUC, SEUC in Fig. 2) may also play a role in supplying the eastern upwelling domes.

Anomalies of the STC circulations, for example through varying wind stress and thus a change in equatorial upwelling, can result in equatorial SST anomalies that in turn affect the atmos-

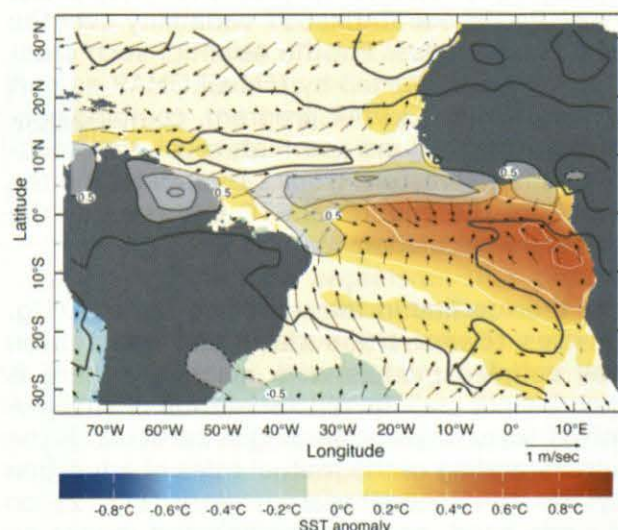


Figure 1: Typical boreal summer variability in the tropical Atlantic region presented in terms of the first EOF (explains 23% of the variance) of the June-August rainfall (contours in mm/day). The June-August SST anomaly (colours, in °C & white contours, every 0.2°) and surface wind anomaly (vector, in m/sec) are determined through regression on the time series of the rainfall EOF.

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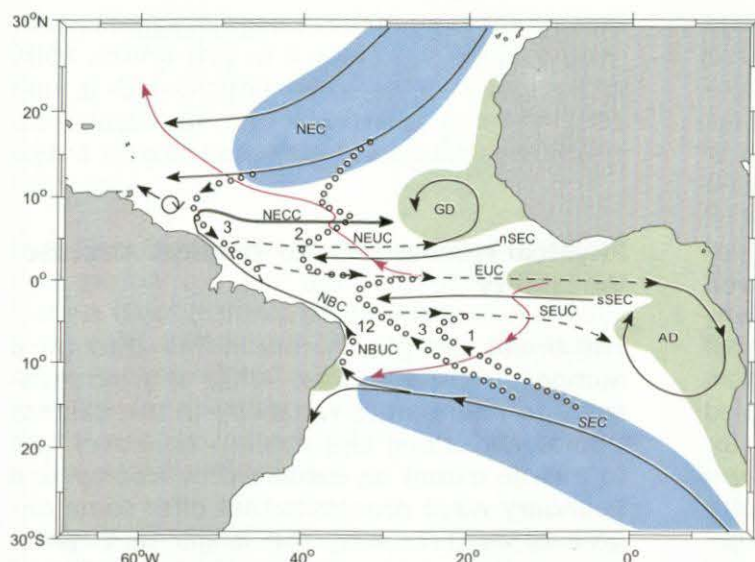


Figure 2: Schematic representation of the tropical Atlantic circulation with subduction (blue) and upwelling (green) zones. Current branches participating in the Shallow Subtropical Cell (STC) are NEC = North Equatorial Current; nSEC, sSEC = South Equatorial Current north and south of the equator; NECC = North Equatorial Countercurrent; EUC = Equatorial Undercurrent; NEUC, SEUC = North and South Equatorial Undercurrent; NBC, NBUC = North Brazil Current and Undercurrent; GD, AD = Guinea and Angola domes. Interior equatorward thermocline pathways dotted, transport estimates for the STC branches given in Sverdrups ($Sv = 10^6 m^3 s^{-1}$); surface poleward pathways for the central basin (from drifter tracks marked by thin, magenta lines).

phere and climate (Fig. 1). This mechanism has just recently been proven to be a major factor in the Pacific equatorial SST variability over the past two decades. For the Atlantic, such studies have been started by IFM-GEOMAR as part of the German CLIVAR program, combining sustained observations and high-resolution modelling in the western tropics to understand the supply of the equatorial STC branches by the boundary circulation.

The thermocline in the upwelling regions (Fig. 2) rises toward the surface and one reason why coupled models work so poorly there is their lack of realistic representation of shallow-mixed-layer physics. Missing in particular is the understanding of the mutual roles of advection by the zonal equatorial currents (Fig. 2) on the one hand, and of upwelling and mixing on the other. Problems with the simulation of low-level stratus clouds in the atmosphere models increase these errors further. It is also suggested that Tropical Instability Waves (TIWs) at periods of a few weeks, generated by instabilities of the large zonal currents, play a role in the longer-term variability of the water

mass distributions and SST. To answer these questions, experiments in the Atlantic cold tongue regime are planned as part of an international "Tropical Atlantic Climate Experiment" (TACE) with IFM-GEOMAR participation. These would combine moored stations, seasonal ship surveys and targeted mixing studies in the upper-thermocline and near-surface layer. The analysis of the observations would be combined with ocean-only and coupled modelling.

Why are the tropical ocean mechanisms of the Atlantic not only regionally important, but also affecting the North Atlantic and European climate? As known from observations and model studies, the North Atlantic Oscillation (NAO), which is the major atmospheric pattern of the Atlantic domain, strongly affects ocean circulation and stratification at mid- and higher latitudes. However, there is very little direct feed-back from the higher-latitude North Atlantic to the atmosphere. Instead, model simulations suggest that the variability of Labrador Sea convection and thermohaline overturning caused by NAO-related atmospheric forcing in the north is propagated toward the tropics along the western boundary and then affects tropical circulation and SST some time later. Tropical SST in turn forces the atmosphere which finally couples back to European latitudes, making the tropical Atlantic an important link in our climate system. However, these model suggestions still need confirmation by sustained observations; and plans are being proposed within CLIVAR to implement a network of stations.

Paleo-Analysis of Tropical Atlantic Variability

Analysis of the paleo records, including Caribbean corals and Sclerosponges, is an important ingredient in shedding more light on TAV. Previously, it has been difficult to obtain long, seasonally resolved proxy records from Atlantic corals because of sampling problems that severely affected the quality of the proxy data. Scientists at IFM-GEOMAR have now obtained very good results using fast growing corals from the Caribbean. The combination of stable isotope and strontium-calcium (Sr/Ca) measurements allows the reconstruction of SST and salinity changes in the Caribbean

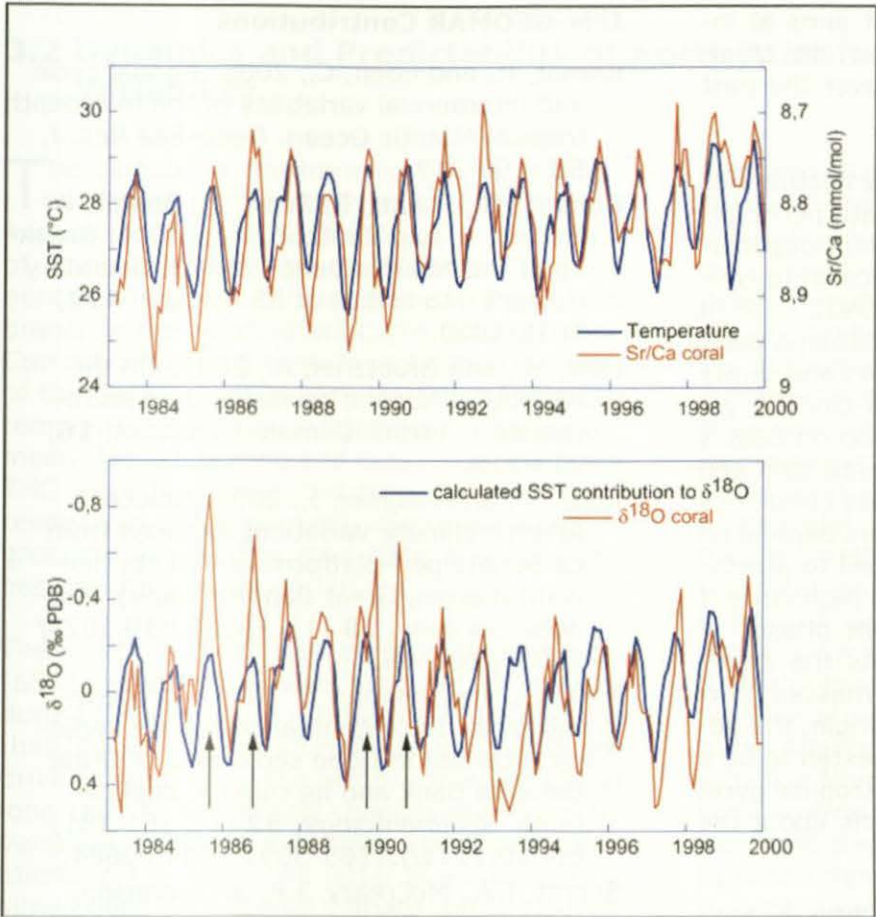


Figure 3: Monthly resolved proxy data from a *Diploria* coral (Guadeloupe). $\delta^{18}\text{O}$ and Sr/Ca ratios were measured from the same subsamples of coral aragonite. (a) the Sr/Ca ratios (top, red line) follow instrumental SST data (blue line). The slope of the Sr/Ca-SST relationship is $-0.5 \text{ mmol/mol per } ^\circ\text{C}$, confirming that Sr/Ca captures the full amplitude of the seasonal SST cycle. (b) coral $\delta^{18}\text{O}$ (red line) shows much larger interannual variations, with large negative anomalies in late boreal summer (arrows), when low-salinity water from the Orinoco enters the Caribbean. The estimated SST contribution is shown by the blue line.

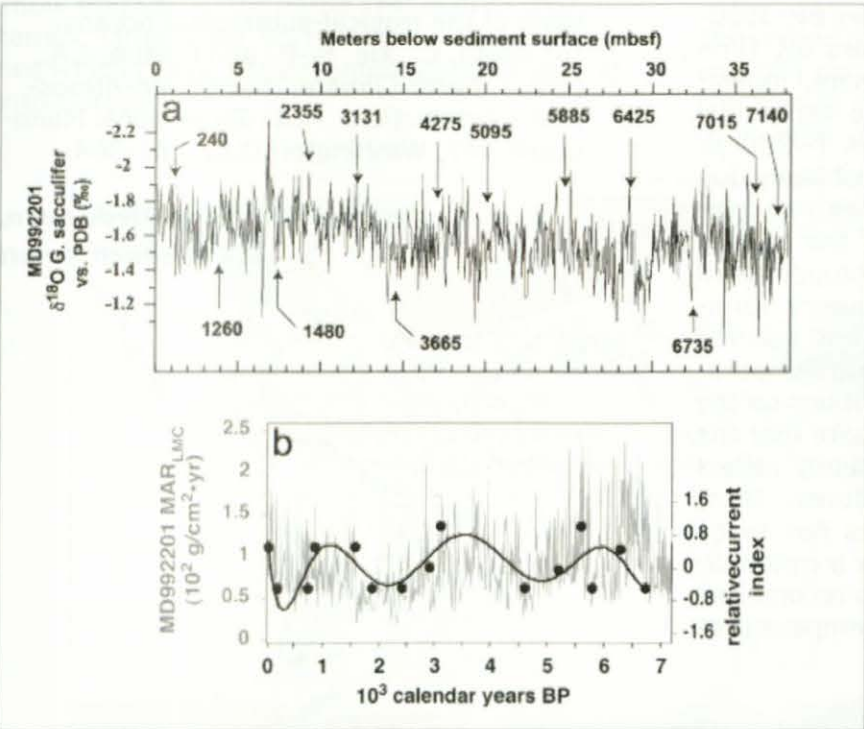


Figure 4: (a) Planktonic oxygen isotope data (*G. sacculifer*) for sediment record MD992201 and radiocarbon dates in calendar years BP marked by arrows. (b) Mass accumulation rates of aragonite and changes in relative current speed.

on timescales from seasonal to centennial (Fig. 3). Currently, century long, monthly resolved coral records from Guadeloupe and Venezuela are being developed. The Sr/Ca ratios of these records reflect SST variations in the tropical North Atlantic associated with the gradient mode of SST.

Sclerosponges are slow-growing marine organisms that provide climate information at least over the past 800 years. The advantage of the sponges is that they are not limited to shallow surface waters thereby recording the response to basin-wide changes in the Atlantic Ocean circulation.

IFM-GEOMAR is actively involved in European initiatives and projects aimed at the development of long, high-resolution multi-proxy records using Caribbean corals, sclerosponges

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and bivalve molluscs. The project aims at investigating the interaction between the tropical Atlantic Ocean and the NAO over the past millennium.

To assess tropical Atlantic climate fluctuations during the late Holocene, carbonate peri-platform sediments provide an excellent opportunity to reconstruct changes on decadal to centennial time scales. The core MD992201 from the leeward margin of the Great Bahama Bank (GBB) comprises the last 7200 years and shows sedimentation rates of up to 138 cm/100 yrs (Fig. 4). The aragonite precipitation on GBB is controlled by exchange of carbonate ions and CO₂ loss due to temperature-salinity conditions and biological activity. These factors depend on the ocean circulation and are linked to atmospheric forcing. Thus, periods with high current speeds are proposed to represent phases of strong atmospheric circulation. As the dominant proportion of surface water masses flowing over GBB is of North Atlantic origin, the deduced current strengths are suggested to be a measure of the North Atlantic subtropical gyre, and thus may provide informations about the long-term behavior of the NAO.

The strength of the currents on GBB was high during the periods 6000–5100 years BP, 3500–2700 years BP, and 1600–700 years BP. Time series analyses identified dominant, quasi-periodic oscillations on decadal to centennial timescales. Four of these signals (~200-yr, ~150-yr, ~100-yr, ~88-yr) are most likely due to solar forcing. The remaining cycles may originate from internal fluctuations of the climate system. The planktonic oxygen isotope record (Fig. 4) is indicative of high frequency variations in sea surface temperature and salinity. First planktonic foraminiferal Mg/Ca-temperature reconstructions revealed variations on the order of up to 3°C. They also indicate that the oxygen isotope record did not mainly reflect changes in sea surface temperatures. Thus, variability in sea surface salinities has to be considered. One important task for a continuation of this research is therefore to reconstruct paired records of sea surface temperatures and salinities.

IFM-GEOMAR Contributions

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