Ann. Naturhist. Mus. Wien, Serie A	113	209–224	Wien, Mai 2011

High-resolution water mass measurements around cold-water corals: a comparative test study between repeated Conductivity-Temperature-Depth (CTD) casts and continuous data acquisition of bottom waters from the West Florida Slope, Gulf of Mexico

By Sascha Flögel[1] and Wolf-Christian Dullo[1]

(With 7 figures)

Manuscript submitted on June 30th 2010,
the revised manuscript on November 14th 2010

"Maybe all of this nonsense is only partly true" –
Bruce Purser, 1991 REDSED conference, Cairo

Abstract

Cold-water corals and their associated mounds and reefs attracted a growing number of marine geologists to study these biogenic structures in detail, since these mounds may represent modern analogs to the well-known mound structures from Paleozoic and Early Mesozoic times. A key to better understand the distribution and frame building potential of cold-water corals is to correctly monitor their physical and chemical boundary conditions with new techniques.

We performed a comparative test study applying conventional Conductivity-Temperature-Depth (CTD) casts and a newly and self designed mini lander system, which was deployed on the West Florida slope at 531 m water depth for continuous bottom water measurements. Our lander data demonstrate that the mechanical movement of gear disturbs the internal structure of the bottom water mass which requires a certain time to reestablish. This questions the reliability of repeated CTD casts at the same site (yoyo-CTD) with respect to the detailed bottom water mass characteristics bathing the cold-water coral communities. Although, repeated CTD casts may provide information about the amplitude in temperature and salinity variability our data clearly exhibit that temperature and salinity maxima and minima respectively do not coincide with tidal dynamics but depend on bottom water dynamics which are current direction and intensity.

Keywords: Temperature Profiles, Cold-water corals, Florida Shelf

---

[1] IFM-GEOMAR, Leibniz-Institut für Meereswissenschaften an der Christian-Albrechts-Universität zu Kiel, Wischhofstr. 1-3, 24148 Kiel, Germany

Zusammenfassung

Kaltwasserkorallen und ihre assoziierten Mounds und Riffe haben in den letzten Jahrzehnten eine große Zahl von Meeresgeologen angezogen, welche diese biogenen Strukturen im Detail untersucht haben. Ein Grund dafür ist sicherlich eine mögliche Verwandtschaft bezüglich der Genese dieser Korallenmounds mit Beispielen aus dem Paläozoikum und dem frühen Mesozoikum. Ein Schlüssel um das Vorkommen, die Verteilung, sowie die Gerüstbildung der Kaltwasserkorallen besser zu verstehen ist eine detaillierte Aufnahme der umgebenden physikalischen und chemischen Umweltparameter mit verbesserten Techniken.

Dazu haben wir eine Vergleichsstudie am Hang vor West Florida in 531 m Wassertiefe durchgeführt. Wir haben dabei konventionelle CTD-Messungen am Bodenwasser mit den Ergebnissen eines neuentwickelten Landersystems verglichen. Unsere Landerdaten zeigen, dass bereits das Absetzen des Landers eine Störung der internen Bodenwasssserstruktur verursacht welche für mehrere Stunden besteht. Diese Ergebnisse stellen das gängige Prinzip von wiederholten einzelnen CTD-Messungen mit kurzen Zeitabständen (JoJo-CTD), um die die Kaltwasserkorallen umgebenden Bodenwassermassen zu untersuchen, generell in Frage. Obwohl wiederholte CTD-Messungen Informationen zur Amplitude z. B. der Temperatur und des Salzgehaltes liefern, zeigen unsere Daten darüber hinaus das Maxima in der Temperatur und im Salzgehalt nicht mit der Tidendynamik zusammen hängen, sondern vielmehr mit der Bodenwasserdynamik welche ein Produkt aus Strömungsstärke und –richtung ist.

Schlüsselwörter: Temperaturprofile, Kaltwasserkorallen, Florida Schelf

Introduction

Oceanography and marine geology became established through the initiative of Sir Charles Wyville Thomson, when he acted as “chief scientist” on the first marine expedition of *HMS Challenger* from December 21st 1872 to May 24th 1876 (Thomson 1878). John Murray published the major scientific results in 1895. This cruise gave rise to many different successive expeditions, such as the *Plankton* Expedition (1889) under chief scientist Victor Hensen from Kiel and the Austrian Hungarian *Pola*-Expedition (1890–1898) under chief scientist Franz Steindachner from Vienna, who was affiliated with the Naturhistorische Museum and director of the department of Ichtyology (Steindachner 1891). These early marine expeditions favored the development of “aktuogeology” (Johannes Walther 1888) and this discipline is an integral part of our research ever since.

The re-discovery of cold-water non-zooxanthellate coral reefs along the NW European continental margin (Dons 1944; Le Danois 1948; Henriet et al. 1998) has stimulated marine geological and oceanographic research on these systems to better understand the processes behind their formation and distribution. Modern cold-water coral reefs and mounds are widespread along the European continental margin (Freiwald et al. 2004; Roberts et al. 2006). They build large carbonate structures along the shelves of the Porcupine Seabight and Rockall Bank, and form dense reef ecosystems on morphological highs off Norway, the Faroe Islands, and in Scottish waters (Freiwald et al. 1999; Roberts et al. 2005). The major framebuilder of these modern carbonate mounds, *Lophelia pertusa* (Linnaeus 1758) was already observed during the Challenger Expedition by Thomson (1878) in the Atlantic. This species occurs also in the Mediterranean where it is forming larger patches (Taviani et al. 2005) and from there it was also reported by Steindachner (1891) on the occasion of the *Pola*-Expedition.

On the western side of the Atlantic cold-water corals are concentrated on the northeast U.S. continental shelf and associated continental slope. They extend along the Atlantic coast from the Gulf of Maine to Cape Hatteras, with additional occurrences of seamounts off New England. Although *Lophelia pertusa* has been infrequently reported from waters off the northeastern U.S., no major reef-like formations are known to exist. Such formations are common south of Cape Hatteras. Cold-water scleractinian coral reefs probably reach their greatest abundance and development in the Atlantic, south of Cape Hatteras. *Lophelia pertusa* is the major structural component of reefs on the continental slope and Blake Plateau from North Carolina to Florida. The third region with well-known occurrences of cold-water corals is the Gulf of Mexico which is home to major *Lophelia pertusa* reefs, though their structure appears to differ from that observed in the southeastern U.S., growing primarily on carbonate and clay substrates rather than mounds of dead coral. The Gulf of Mexico is characterized by a number of cold-water coral occurrences of which some do form reef-like structures (Reed et al. 2006) probably comparable to sites on the European continental margin. The investigated southwest Florida lithoherm site occurs on the upper southwestern Florida slope (Reed 2004). In addition, in the northern GoM, off Mississippi and Alabama, *Lophelia* thickets grow on the upper flanks and peaks of "Viosca Knoll", a deep-water salt dome (Schroeder 2002; Davies et al. 2010), and also in an area known as "Green Canyon" off Louisiana (Reed & Ross 2005). In 1955, Moore & Bullis (1960) collected large quantities of *L. pertusa*) in 420 to 512 m of water depth from the northeastern continental slope. More recently, reports of living *L. pertusa* in the GoM are available (Cairns 1979; 2000; Cairns & Viada 1987; McDonald et al. 1989; Schroeder 2002; Schroeder et al. 2005). Each of the areas, from Pourtalès Terrace in the Florida Straits (Brooke & Schroeder 2007), to sites in the northwestern Gulf of Mexico, represent unique habitat types (Lumsden et al. 2007).

Marine geological research concentrating on cold-water coral assemblages funded by different European initiatives in the 1990s (Freiwald et al. 2004; Mienert et al. 2004) fueled an increase in research activities along the European continental margin as well as along the North and South American continental margins.

Cold-water corals record short-term to decadal changes in the ambient hydrography such as temperature, salinity, oxygen availability, and current regime. Our results (Dullo et al. 2008) showed that it is indispensable to measure present day oceanographic properties in high-resolution and continuously on various time scales of days to months (Duineveld et al. 2004, 2007; Davies et al. 2009) to understand the high variability of (hydro-) geochemical parameters recorded in the calcareous coral skeletons (Rüggeberg et al. 2007;

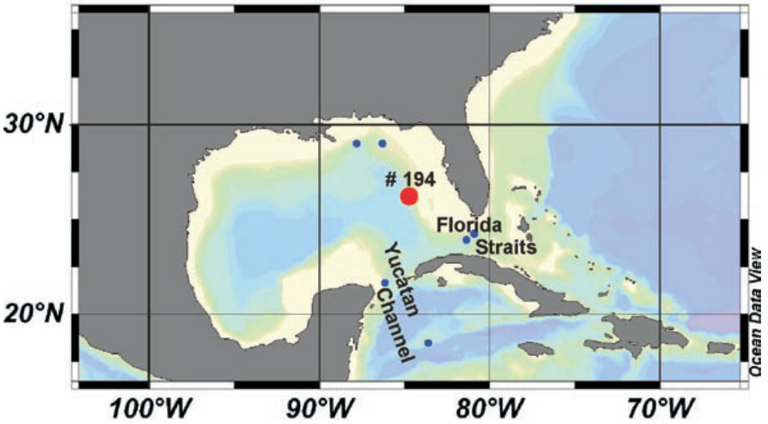

Fig. 1. Site # 194 is located in the eastern portion of Gulf of Mexico (GoM) on the western Florida slope. Inflow into the GoM is through the Yucatan Straits outflow through the Florida Straits. Water masses leaving the Florida Straits are considered the Gulf Stream. Smaller blue dots indicate additional study sites during cruise M78/1.

Raddatz et al. 2010). Until now we have used single Conductivity-Temperature-Depth (CTD) measurements to get a general idea about the properties of the water masses bathing cold-water coral habitats.

To better understand the hydrographic regime around the observed cold-water coral communities, their distribution, and their frame building potential we performed a comparative hydrographic test study. We applied conventional CTD casts and a newly designed mini lander system, which was deployed on the West Florida slope at 26°12.18' North and 84°43.84' West at 531 m water depth for continuous bottom water measurements (Fig. 1).

The focus of our hydrographic studies on the West Florida slope in the eastern GoM was to test the newly designed mini lander system and to compare the data with conventional, repeated CTD measurements.

Hydrography and setting

Hydrography

The GoM (Fig. 1) represents the northern part of the West Atlantic warm water pool, which is an important heat source for the thermohaline circulation (THC) and its heat transport to the North Atlantic. It acts as a key element within the global conveyor system of ocean currents. The Loop Current (LC) is the most prominent surface circulation feature in the GoM (Sturges & Evans 1983; Schott et al. 1988; Zavala-Hidalgo et al.

2006). The LC is fed by warm tropical waters from the Caribbean Sea, which flow through the Yucatan Channel into the Gulf before moving through the Florida Straits into the North Atlantic (JOHNS et al. 2002; EZER et al. 2003; OEY et al. 2003; OEY 2004).

The LC creates a vigorous north-south flow in the eastern GoM and migrates laterally over the west Florida shelf and slope. It produces temperature variations at shallow to intermediate depths (50–500 m), both seasonally and over longer time scales (LEIPPER et al. 1972).

The northward extension of the LC varies between two endmember modes. During summer, the warm surface-water flow through the Yucatan Channel is enhanced and occasionally reaches the Mississippi river delta (WISEMAN & DINNEL 1988; SHEINBAUM et al. 2002), heating up the western and northern Gulf (BRUNNER 1984). During winter, in its so-called port-to-port configuration, the LC describes a direct flow from the Yucatan Channel to the Florida Straits, thus leaving the northern Gulf unaffected by warm tropical surface water from the Caribbean (LEIPPER et al. 1972; STURGES et al. 1983). Throughflow fluctuations in the Yucatan Channel largely correlate with the expansion of the LC (EZER et al. 2003). The outflow through the Florida Straits equals the Atlantic inflow into the Caribbean, which proceeds through nine passages between Cuba and South America.

The surface waters of the GoM have been studied in great detail, but there is comparatively little information on circulation below 1000 m, although the presence of Antarctic Intermediate Water (AAIW) below 800 m water depth is known. Direct current measurements were rare (PEQUEGNAT 1972; HAMILTON 1990) until this century (INOUE et al. 2002; HAMILTON & LUGO-FERNANDEZ 2001). For the southern GoM, strong current events have also been observed below 1000 m, suggesting that the LC and eddies influence the hydrodynamics of the deepest portions of the GoM (HAMILTON 1990).

Geographical and geological setting

The Gulf of Mexico is a semi-closed basin of approximately 1.5 million km^2 with the continental shelves surrounding a deep abyss with maximum depths of approximately 3,400 m in the eastern portion and 3,700 m in the western portion.

The deep shelf and slope regions of the northern GoM have been extensively mapped and surveyed during exploration for oil and gas deposits, which led to the discovery and subsequent research on chemosynthetic communities associated with hydrocarbon seepage. The substrate in the deep GoM is principally comprised of fine particulates; however, large amounts of authigenic carbonate deposits are precipitated from biogeochemical activity associated with hydrocarbon fluid seepage (SAGER et al. 1999). Authigenic carbonates provide hard substrate for a wide variety of benthic fauna, including the framebuilding scleractinian, *Lophelia pertusa*.

West Florida shelf and slope

The west Florida shelf is a gently sloping (1–2°) broad carbonate platform that extends 750 km from the Desoto Canyon in the north to the western Straits of Florida. Seaward of the shelf, at the 500 m isobath on the southwest Florida slope is a 20 km long zone of high-relief (10–15 m) Pleistocene coral mounds. High-resolution seismic reflection profiles have indicated that the slope hosts several lithoherms composed of rugged black phosphorite-coated limestone boulders (10-15 m in height), some of which are capped with live thickets of *Lophelia* (Newton et al. 1987; Reed et al. 2004; Reed et al. 2006b). The Florida slope then grades into the Florida Escarpment, which extends from depths of 2,500–3,280 m into the eastern GoM. The face of the escarpment has steep vertical limestone cliffs of Cretaceous age, with intervening sediment-covered planes that provide habitats for dense chemosynthetic communities (Paull & Neumann 1987; Paull et al. 1990, 1991). The West Florida Shelf lithoherms are defined as high-relief, lithified carbonate mounds, rather than unconsolidated sediment mounds and also may be covered with thickets of live coral. Furthermore, Hübscher et al. (2010) described structures pretending to be coral mounds, however video groundtruthing proved these structures to be submarine slope failures consisting of asymmetric well cemented limestone which are covered by living *Lophelia pertusa* patches.

Material and Methods

The CTD profiler used for investigation of the water column during METEOR cruise M78/1 (February-April 2009) is a SEABIRD “SBE 9 plus” underwater unit and a SEABIRD “SBE 11plus V2” deck unit. Additionally, it is equipped with two sensors to measure dissolved oxygen, a chlorophyll-a sensor and a SEABIRD bottle release unit including a rosette water sampler. For the analysis and interpretation of the measurements, the downcast raw data were processed with “SBE Data Processing” software. For the visualization of the data we used “OCEAN DATA VIEW (mp-Version 4.1.3)”. The CTD system provided by IFM-GEOMAR operated very reliable. We performed a so-called yoyo-CTD (538 m depth) at 26°12.18’ North and 84°43.88’ West. The CTD casts were performed during the time when the lander was at the sea-floor. During a yoyo-CTD the research vessel remains at one specific position over 13 hours where we performed consecutive (down-up-down-…) CTD casts, thus covering one complete tidal cycle.

At the same locality we deployed the newly designed mini-lander system to measure the physical characteristics of bottom water dynamics (Fig. 2).

The system is equipped with a Conductivity-Temperature-Depth (CTD) profiler (RBR XR-420CTm) and a high precision pressure sensor with an accuracy of 0.015 % of the total water depth. The system also carried an ADCP (Acoustic Doppler Current Profiler) to measure ocean currents above the system. To release the system from the sea-floor we used a releaser from K.U.M. Umwelt- und Meerestechnik GmbH, Kiel. In comparison

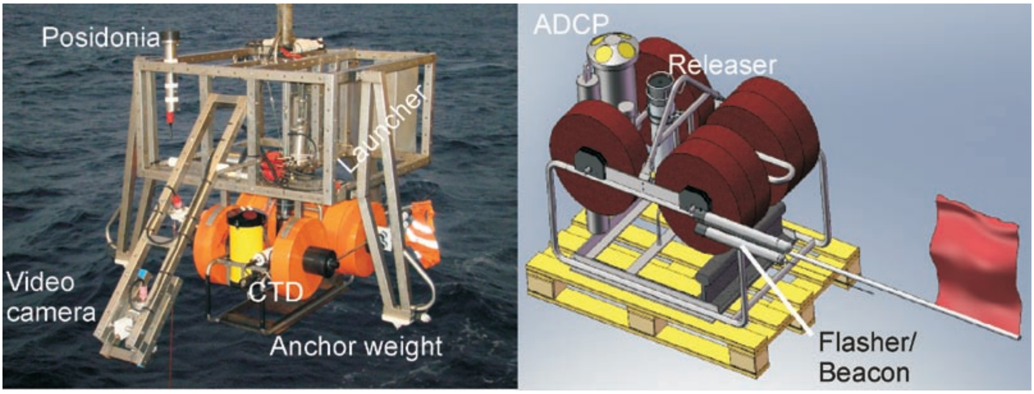

Fig. 2. The left panel shows the mini-lander system ready for deployment during cruise M78-1. Here, it is still attached to the video guided launching system which is equipped with a Posidonia system for exact positioning on the sea floor. The right panel shows a technical drawing indicating the ADCP and releaser which releases the anchor weight. For easy recovery even in rougher sea conditions the system is equipped with a flasher and a radio beacon.

to previous lander deployments (MIENIS et al. 2009) the deployed system (Fig. 2) has the advantage of being a compact design with easy handling and logistics, as well as sensors which are closer to the sediment-water interface.

Results

Our results of thirteen CTD casts at site M78/1-194 are summarized in Figure 3. In the uppermost 100 m of the water column we observed the highest salinities and temperatures. Values show no variability throughout this interval plotting around 20.65°C and 36.47 PSU respectively. We address this surface water mass as Florida Shelf Surface Water (FSSW). At this locality we found no indication of fluvial discharge in the FSSW from western Florida which is a common feature on the West Florida Shelf (HU et al. 2004). Further below between 110-120 m is a layer with waters characterized by a small but distinct step of reduced salinities of about 36.39 PSU. This feature was described by HE & WEISBERG (2003) to be a result of shelf break processes. Between 120 and 530 m we found a water mass with decreasing temperature and salinity. This water mass straddling the shelf break at the bottom is composed of relatively cool and fresh water, possibly upwelled from deeper depths also we couldn’t see it in the lander data. These waters have been described by HE & WEISBERG (2003) to be a mixture between Antarctic Intermediate Water (AAIW) and 18°C water (SCHMITZ & RICHARDSON 1991) which is characteristic of mid-depth waters found within the LC.

Since we focused on the comparison of different tools measuring bottom water dynamics, the results of the yoyo-CTD are displayed in high-resolution for the interval between

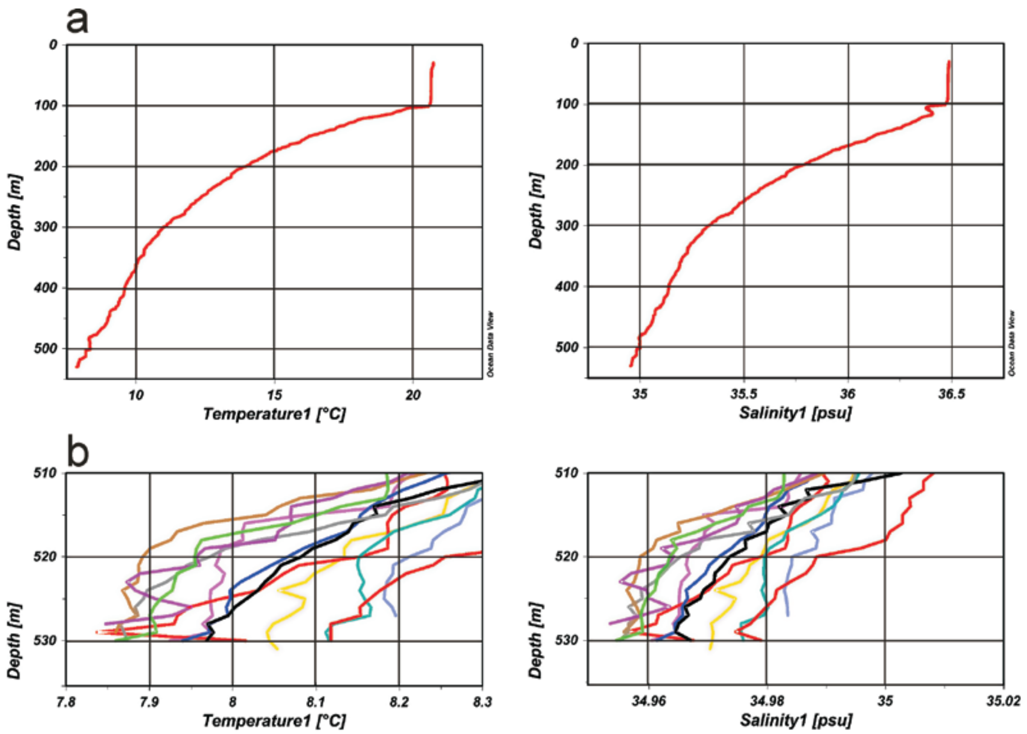

Fig. 3. **A**: Temperature and salinity data at site #194, 26°12.18' North and 84°43.84' West, 531 m water depth; **B**: Shown are the temperature and salinity records from repeated CTD casts (yoyo-CTD) at site 194 for the depth interval between 510 and 530 m.

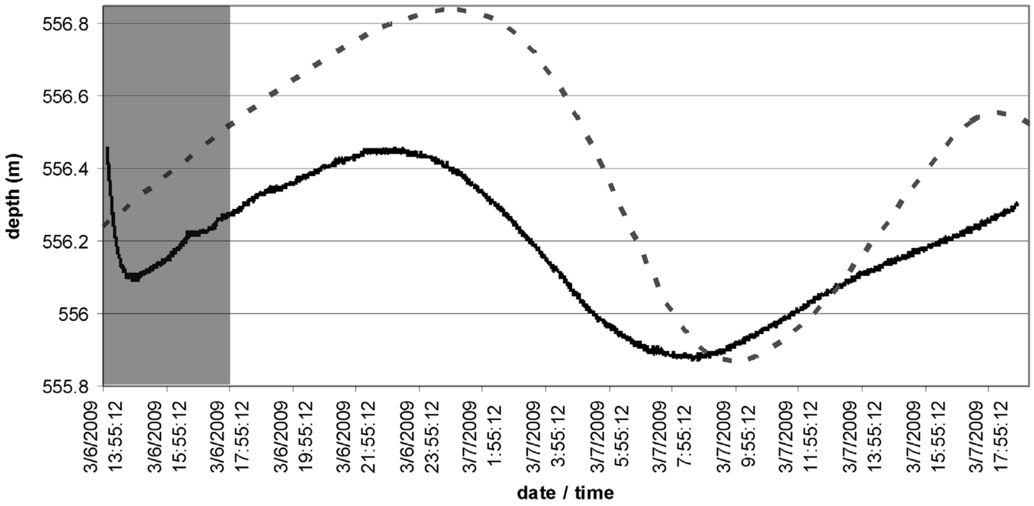

Fig. 4. High-resolution continuous depth data from lander deployment at site 194. Tidal effects as recorded on Captiva Island, West Florida are shown as a dashed line.

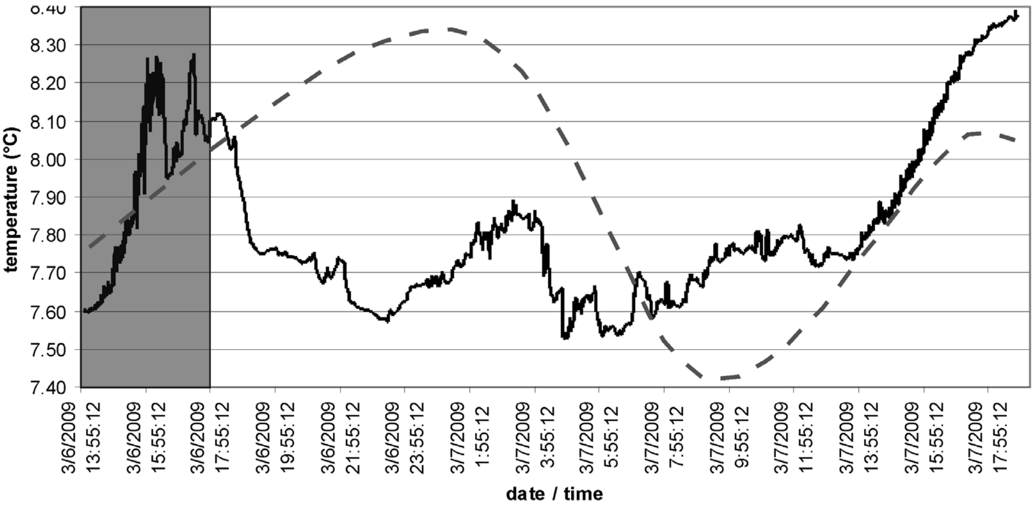

Fig. 5. 28-hour high-resolution temperature (°C) record from site 194. The transparent rectangle indicates the time window needed for the sensors to adjust.

500 and 530 m in Figures 3a and b. These time lapse measurements portray a slight variation which on the first look might be related to tidal dynamics. Due to current dynamics and related navigational issues the repeated casts never reached the accuracy needed for the hydrographical study of cold-water coral ecosystems. Even CTD casts performed from a fully DGPS (Differential Global Positioning System) controlled surface vessel still would have to cope with dynamic current regimes in the water masses the CTD is penetrating. Thus, it is virtually impossible to run the CTD repeatedly in the exact same position. This problem is getting larger with increasing water depths. Figure 3b displays the missing accuracy of these measurements.

Being aware of these problems, we applied our self-designed mini-lander which was deployed video-controlled on the envisaged spot and stayed there for 28 hours. Figure 4 shows the depth variation recorded by a high-resolution pressure sensor. The shaded rectangle indicates the time delay of recorded data due to adjustment of the sensors. Reliable measurements can be expected two to three hours after the lander settled on the sea floor. Furthermore, simply the action of deployment disturbs the structure, current regime, and stratification of the bottom water mass. The impact of repeated CTD casts on stratification is even higher which makes the interpretation gained by this technique even more difficult. Nevertheless, conventional CTD-casts are still highly needed to explore large scale water properties throughout the whole water column, like e.g. tidal cycles. But they only provide snap shots in time.

The data of the pressure sensor nicely displays 1 ½ tidal cycles with high accuracy (Fig. 4). The tidal amplitude is about 65 cm and has an asymmetric shape with high-tide

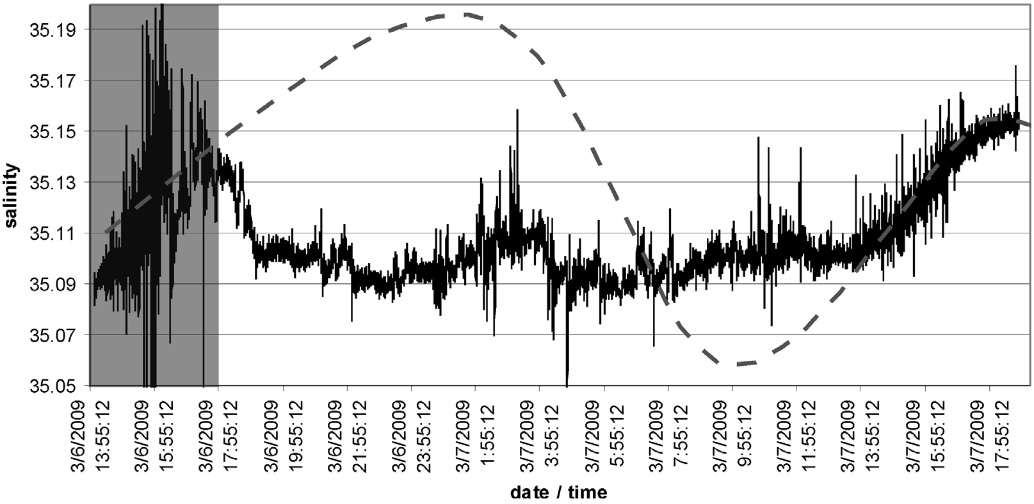

Fig. 6. 28-hour high resolution salinity (PSU) record from site 194. The transparent rectangle indicates the time window needed for the sensor to adjust.

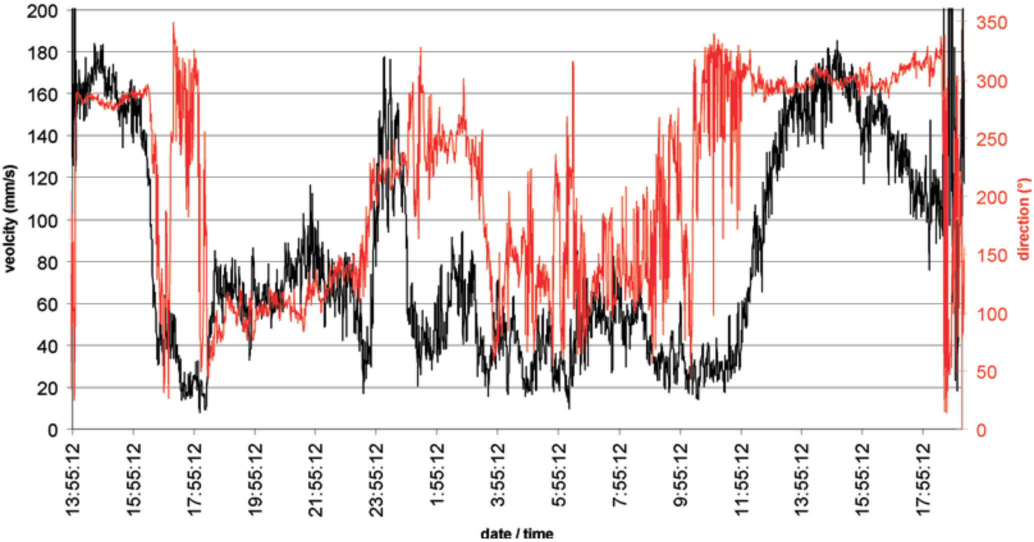

Fig. 7. 28-hour high resolution bottom water ADCP record from site 194. The left y-axis shows the current velocities in mm/second while the y-axis on the right shows current directions between 0° and 360°.

coming in slower than low-tide. For comparison we plotted the nearest coastal oceanographic station from Captiva Island, West Florida (dashed red line). The coastal data show a similar course with respect to the timing of high- and low tide. However, the coastal amplitude reaches approximately 90 cm. Our first high-resolution data demonstrate that cold-water corals thrive under tidal dynamics as well as their shallow water counterparts. The importance and control of this physical parameter has not been studied so far since there is virtually no data available due to the lack of such instrumentation.

The 28 hour temperature record ranges between 7.54 and 8.35 °C and displays high frequency variability (Fig. 5). It is obvious that the temperature curve does not parallel the tidal signal (Fig. 4) although the increase encompassing the last 10 hours may imply a tidal control. A similar pattern as for the measured temperature values is seen in the salinity plot (Fig. 6). A longer deployment would be needed to investigate the role of tidal cycles on the bottom water temperatures at this locality. Salinities vary from 35.09 PSU to a maximum of 35.15 PSU but do not indicate an interrelation to the tidal cycle.

The missing relation between temperature/salinity and tidally controlled pressure (water depth) argues for a horizontal component impacting on the observed intermediate water masses and their cold-water corals. Our ADCP current measurements (Fig. 7) show a general pattern of dominating stronger westerly and weak easterly currents. We analyzed the data for the depth interval from the lander up to 18.25 m above the lander. During the 28 hour deployment four phases can be distinguished. The first time window between 18:00 and 23:00 on March 6 is characterized by weak easterly currents of ~70 mm/s. This is followed by increased bottom currents from the West between 23: 00 and 03: 00 on March 7. The third time window however (03:56 – 10:16, March 7 2009) is characterized by oscillating current directions and highly reduced current intensities. Below 40 mm/s no distinct current direction could be observed. Elevated current velocities however are associated again with a westerly direction (12:00 – 18:00, March 7).

The bottom currents correlate positively with increasing temperatures and salinities originating from the interplay between the wind regime and the Loop Current system. Easterly currents are indicated by reduced current velocities, lower temperatures, and reduced salinities.

Conclusions

Our lander data demonstrate that the mechanical movement of gear disturbs the internal structure of the bottom water mass which requires a certain time to reestablish. This questions the reliability of repeated CTD casts at the “same” site (yoyo-CTD) with respect to detailed and precise bottom water mass characteristics bathing the cold-water coral communities. Furthermore, the lander data highlight the dynamical environmental control of the bottom water mass around cold-water coral communities which have not been known to occur in such settings. Although, repeated CTD casts may provide information about the amplitude in temperature and salinity variability our lander data clearly exhibit that temperature and salinity maxima and minima respectively do not coincide with tidal dynamics but depend on bottom water dynamics which are current direction and intensity. Therefore, the interpretation of yoyo-CTD data with respect to bottom waters and tidal resolution is questionable although previous studies have shown that repeated CTD casts yield valuable information regarding tidal movements if one considers the complete water column. We want to note that more long-time deployments would be needed to explore cyclic or non-cyclic behaviour at this special or any other site being investigated.

The obtained data proved that our newly designed mini-lander system is capable to record water mass dynamics on high resolution. This calls for further development of similar or comparable lander systems which measure these hydrographical data in an integrated approach and over largely extended time periods. A cluster of such lander systems under the control of a master lander may record and even fully quantify water mass dynamics in a 4D-mode which has high-resolution in time and space. As a vision we intend to build a cluster of up to four mini-landers (satellite landers) of the presented type which are hydroacoustically linked to a master lander. This provides the technical base for event controlled enhanced data acquisition – e.g. in case of an optically detected productivity event the system would increase its sampling rate automatically. Ultimately, the major purpose of these local but high resolution measurements is the implementation into numerical models of ocean and biogeochemical circulation and cycling. This kind of empirical observation is a prerequisite to better define boundary conditions of regional and even global models, following Trümpy's statement "that a bad fossil is more valuable than a good working hypothesis" (TRÜMPY 1971).

Acknowledgements

We thank the captain, crew, technicians, namely Asmus PETERSEN and Bernhard BANNERT, and ship-board scientific party of cruise M78/1. This study is a contribution to EU-HERMES (GOCE-CT-2005-511234-1). Financial support was provided by the Leibniz-Award (Du 129/33), which is gratefully acknowledged. We further thank our colleagues Olaf PFANNKUCHE, Peter LINKE, Joachim SCHÖNFELD, Thomas KUMBIER for their valuable discussions in designing and constructing the mini-lander. We are indebted to the A. P. Laudenbacher Foundation in La Punt Chamues-ch for providing an excellent atmosphere for a working and research retreat.

We although want to thank three non-anonymous reviewers (Furu MIENIS, Markus REUTER and Thomas BRACHERT) for their linguistic and scientific suggestions which strongly improved the content of this manuscript.

References

Brooke, S. & Schroeder W.W. (2007): State of deep coral ecosystems in the Gulf of Mexico region: Texas to the Florida Straits. – In: Lumsden, S.E., Hourigan, T.F., Bruckner, A.W. & Dorr, G. (eds): The State of Deep Coral Ecosystems of the United States – pp. 271–306, Silver Spring, MD (NOAA Technical Memorandum CRCP-3).

Brunner, C.A. (1984): Evidence for increased volume transport of the Florida Current in the Pliocene and Pleistocene. – Marine Geology, **54**: 223–235.

Cairns, S.D. (1979): The deepwater scleractinia of the Caribbean Sea and adjacent waters. – Studia Fauna Curacao, **50**: 1–341.

— (2000): A revision of the shallow water azooxanthellate Scleractinia of the Western Atlantic. – Studies Natural History of the Caribbean Region, **75**: 1–231.

— & Viada, S.T. (1987): Range extensions of ahermatypic scleractinia in the Gulf of Mexico. – Northeast Gulf Science, **9**: 31–134.

Davies, A.J., Duineveld, G.C.A., Lavaleye, M.S.S. Bergman, M.J.N. & vam Haren, H. (2009): Downwelling and deep-water bottom currents as food supply mechanisms to the cold-water coral *Lophelia pertusa* (Scleractinia) at the Mingulay Reef complex. – Limnology and Oceanography, **54:** 620–629.

—, Duineveld, G.C.A., van Weering, T.C.E., Mienis, F., Quattrini, A.M., Seim, H.E., Bane, J.M. & Ross, S.W. (2010): Short-term environmental variability in cold-water coral habitat at Viosca Knoll, Gulf of Mexico. – Deep-Sea Research, **57**: 199–212.

Dons, C. (1944): Norges korallrev. – Det Kongelige Norske Videnskabers Selskabs Forhandlinger, **16**: 37–82.

Duineveld, G.C.A. (2007): Benthic foodweb studies. In: Rees, H.L. et al. (Eds): Structure and dynamics of the North Sea benthos. – ICES Cooperative Research Report, **288**: 153–155.

—, Lavaleye, M.S.S. & Berghuis, E.M. (2004): Particle flux and food supply to a seamount cold-water coral community Galicia Bank, NW Spain. – Marine Ecology Progess Series, **277**: 13–23.

Dullo, C., Flögel, S. & Rüggeberg, A. (2008): Cold-water coral growth in relation to the hydrography of the Celtic and Nordic European Continental Margin. – Marine Ecological Progress Series, **371**: 165–176.

Ezer, T., Oey, L.-Y., Lee, H.-C., & Sturges W (2003): The variability of currents in the Yucatan Channel: analysis of results from a numerical ocean model. – Journal of Geophysical Research, **108**: 3012.

Freiwald, A., Fosså, J.H., Grehan, A., Koslow, T. & Roberts, J.M. (2004): Cold-water coral reefs. UNEP-WCMC, Cambridge.

—, Wilson, J.B. & Henrich, R. (1999): Grounding Pleistocene icebergs shape recent deep-water coral reefs. – Sedimentary Geology, **125**: 1–8.

Hamilton, P. (1990): Deep currents in the Gulf of Mexico. – Journal of Physical Oceanography, **20**: 1087–1104.

— & Lugo-Fernández, A. (2001): Observations of high speed deep currents in the northern Gulf of Mexico. – Geophysical Research Letters, **28**/14: 2867–2870.

He, R. & Weissberg, R.H. (2003): A Loop Current intrusion case study on the West Florida Shelf. – Journal of Physical Oceanography, **33**: 465–477.

Henriet, J.P., De Mol, B., Pillen, S. & Vanneste, M (1998): Gas hydrate crystals may help build reefs. – Nature, **391**: 648–649.

Hu, C., Muller-Karger, F.E., Vargo, G.A., Neely, M.B. & Johns, E. (2004): Linkages between coastal runoff and the Florida Keys ecosystem: A study of a dark plume event. – Geophysical Research Letters, **31**: L15307, doi: 10.1029/2004GL020382.

Hübscher, C., Dullo, C., Flögel, S., & Titschack, J. (2010): Contourite drift evolution and related coral growth in the eastern Gulf of Mexico and its gateways. – International Journal of Earth Sciences, doi: 10.1007/s00531–010–0558–6.

Inoue, M., Welsh, S.E., Rouse, L., & Weeks, E. (2002). Observation of deep water manifestation of Loop Current and Loop Current rings in the eastern Gulf of Mexico. EOS, – Transactions, American Geophysical Union, **52**: 321.

Johns, W.E., Townsend, T.L., Fratantoni, D.M., & Wilson, W.D. (2002): On the Atlantic inflow to the Caribbean Sea. – Deep-Sea Research, **49**: 211–243.

LeDanois, E. (1948): Le profondeur de la mer. Paris (Payot).

Leipper, D.F., Cochrane, J.D. & Hewitt, J.F. (1972): A detached eddy and subsequent changes. – In: Capurro, L.R.A. & Reid, J.L. (eds) Contributions on the physical oceanography of the Gulf of Mexico. – Texas A&M Oceanographic Studies, **2**: 107–117. Houston, Texas (Gulf Publishing Co.).

Lumsden, S.E., Hourigan, T.F., Bruckner, A.W. & Dorr, G. (2007): The State of Deep Coral Ecosystems of the United States. NOAA Technical Memorandum CRCP-3. Silver Spring MD.

MacDonald, I.R., Boland, G.S., Baker, J.S., Brooks, J.M., Kennicut, M.C. & Bidigare, R.R. (1989): Gulf of Mexico hydrocarbon seep communities II Spatial distribution of seep organisms and hydrocarbons at Bush Hill. – Marine Biology, **101**: 125–128.

Mienert, J., Weaver, P.P., Berné, S., Dullo, C., Evans, D., Freiwald, A., Henriet, J., Joergensen, B., Lericolais, G., Lykousis, V., Parkes, J., Trincardi, F. & Westbrook, G. (2004) Dynamics and Evolution of European Margins. – Oceanography, **17**/4: 12–29.

Mienis, F., de Stigter, H.C., de Haas, H. & van Weering, T.C.E. (2009): Near-bed particle deposition and resuspension in a cold-water coral mound area at the Southwest Rockall Trough margin, NE Atlantic, Deep-Sea Research Part I. – Oceanographic Research Papers, **56**/6: 1026–1038.

Moore, D.R. & Bullis, H.R. (1960): A deep-water coral reef in the Gulf of Mexico. – Bulletin of Marine Science, **10**: 125–128.

Murray, J. (1895): Report on the scientific results of the voyage of H.M.S. Challenger during the years 1872–76 under the command of Captain Sir George S. Nares. R.N., F.R.S. and the late Captain Frank Tourle Thomson, R.N., prepared under the superintendence of the late Sir C. W. Thomson Knt., F.R.S., Regius professor of natural history in the University of Edinburgh, Director of the civilian scientific staff. A summary of scientific results published by order of her Majesty's government.

Newton, C.R., Mullins, H.T. & Gardulski, A.F. (1987): Coral mounds on the West Florida Slope: unanswered questions regarding the development of deepwater banks. – Palaios, **2**: 359–367.

Oey, L.-Y. (2004): Vorticity flux through the Yucatan Channel and Loop Current variability in the Gulf of Mexico. – Journal of Geophysical Research, **109**: C10004.

–––, Lee, H.C. & Schmitz, W.J. (2003): Effects of wind and Caribbean eddies on the frequency of Loop Current eddy shedding: a numerical model study. Journal of Geophysical Research, **108**: 3324.

Paull, C.K. & Neumann, A.C. (1987): Continental margin brine seeps: their geological consequences. – Geology, **15**: 545–548.

–––, Chanton, J., Martens, C., Fullagar, P., Neumann, A.C. & Coston, J. (1991): Seawater circulation through the flank of the Florida Platform: evidence and implications. – Marine Geology, **102**: 265–279.

–––, Freeman-Lynde, R., Bralower, T., Gardemal, J., Neumann, A.C., D'Argenio, B. & Marsella, E. (1990): Geology of the strata exposed on the Florida Escarpment. – Marine Geology, **91**: 177–194.

Pequegnat, W.E. (1972): A deep bottom current on the Mississippi Cone. – In: Capurro, L.R.A. & Reid, J.L. (eds): Contributions on the physical oceanography of the Gulf of Mexico. – Texas A&M Oceanographic Studies, **2**: 65–87. Houston, Texas (Gulf Publishing Co.).

Raddatz, J., Rüggeberg, A., Margreth, S. & Dullo, C. (2010): Paleoenvironmental reconstruction of Challenger Mound initation in the Porcupine Seabight, NE Atlantic. – Marine Geology, in press.

Reed, J.K. (2004): General description of deepwater coral reefs of Florida, Georgia and South Carolina: A summary of current knowledge of the distribution, habitat and associated fauna. – A Report to the South Atlantic Fishery Management Council, 71 p., NOAA, NMFS.

––– & Ross, S.W. (2005): Deep-water reefs off the Southeastern U.S.: Recent discoveries and research. – The Journal of Marine education, **21**/4: 33–37.

–––, Wright, A. & Pomponi, S. (2004): Medicines from the deep sea: exploration of the northeastern Gulf of Mexico. Proceedings of the American Academy of Underwater Sciences 23th annual scientific diving symposium. – pp. 58–70. Long Beach, California.

–––, Weaver, D. & Pomponi, S.A. (2006): Habitat and fauna of deep-water Lophelia pertusa coral reefs off the Southeastern USA: Blake Plateau, Straits of Florida, and Gulf of Mexico. – Bulletin of Marine Science, **78**: 343–375.

Roberts, J.M., Brown, C.J., Long, D. & Bates, C.R. (2005): Acoustic mapping using a multibeam echosounder reveals coldwater coral reefs and surrounding habitats. – Coral Reefs, **24**: 654–669.

–––, Wheeler, A.J. & Freiwald, A. (2006): Reefs of the deep: the biology and geology of cold-water coral ecosystems. – Science, **312**: 543–547.

Rüggeberg, A., Dullo, C., Dorschel, B. & Hebbeln, D. (2007): Environmental changes and growth history of Propeller Mound, Porcupine Seabight: evidence from benthic foraminiferal assemblages. – International Journal of Earth Sciences, **96**: 57–72.

–––, Flögel, S., Dullo, C., Hissmann, K. & Freiwald, A. (2010): Water mass characteristics and sill dynamics in a subpolar cold-water coral reef setting at Stjernsund, northern Norway. – Marine Geology, doi: 10.1016/j.margeo.2010.05.009.

Sager, W.W., Lee, C.S., Macdonald, I.R. & Schroeder, W.W. (1999): High-frequency near-bottom acoustic reflection signatures of hydrocarbon seeps on the Northern Gulf of Mexico continental slope. – Geo-Marine Letters, **18**: 267–276.

SCHMITZ, W.J. & RICHARDSON, P.L. (1991): On the sources of the Florida Current. – Deep-Sea Research, **38**: 379–409.

SCHOTT, F.A., LEE, T.N. & ZANTOPP, R. (1988): Variability of Structure and Transport of the Florida Current in the Period Range of Days to Seasonal. – Journal of Physical Oceanography, **18**/9: 1209–1230.

SCHROEDER, W.W. (2002): Observations of Lophelia pertusa and the surficial geology at a deepwater site in the northeastern Gulf of Mexico. – Hydrobiologica, **471**: 29–33.

——, BROOKE, S.D., OLSON, J.B., PHANEUF, B., MCDONOUGH, J.J. & ETNOYER, P. (2005): Occurrence of deep-water Lophelia pertusa and Madrepora oculata in the Gulf of Mexico. – In: FREIWALD, A. & ROBERTS, J.M. (eds): Cold-water corals and ecosystems. – pp. 297–307, Berlin-Heidelberg (Springer-Verlag)

SHEINBAUM. J., CANDELA, J., BADAN, A. & OCHOA, J. (2002): Flow structure and transport in the Yucatan Channel. – Geophysical Research Letters, doi: 10.1029/2001GL013990.

STEINDACHNER, F. (1891): Veröffentlichungen der Commision für Erforschung des östlichen Mittelmeeres. Vorläufiger Bericht über die zoologischen Arbeiten im Sommer 1891. – Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften., mathematisch-naturwissenschaftliche Classe**,** Abt. 1, **100**: 435–447.

STURGES, W. (1975): Mixing of renewal water flowing into the Caribbean Sea. – Journal of Marine Research, **33**: 117–130.

—— & EVANS, J.C. (1983): On the variability of the Loop Current in the Gulf of Mexico. – Journal of Marine Research, **41**: 639–653.

TAVIANI, M., REMIA, A., CORSELLI, C., FREIWALD, A., MALINVERNO, E., MASTROTOTARO, F., SAVINI, A. & TURSI, A. (2005): First geo-marine survey of living cold-water *Lophelia* reefs in the Ionian Sea (Mediterranean basin). – Facies, **50**/3–4: 409–417.

THOMSON, C.W. (1878): The Voyage of the “Challenger” The Atlantic – A preliminary account of the general results of the exploring voyage of H.M.S. “Challenger” during the year 1873 and the early part of the year 1876. By Sir C. Wyville THOMSON, Director of the civilian scientific staff of the “Challenger” expedition, in two volumes. Vol. I.

TRÜMPY, R. (1971): Stratigraphy in mountain belts. – Quarterly Journal of the Geological Society London, **126**: 293–318.

WALTHER, J. (1888): Die Korallenriffe der Sinai-Halbinsel – Geologische und biologische Beobachtungen. – Abhandlungen der mathematisch-physikalischen Classe der Königlichen Saechsischen Gesellschaft der Wissenschaften, **14**: 439– 505.

WISEMAN, W.J. & DINNEL, S.P. (1988): Shelf Current near the Mouth of the Mississippi River. – Journal of Physical Oceanography, **18**/9: 1287–1291.

ZAVALA-HIDALGO, J., MOREY, S.L., O’BRIAN, J.J. & ZAMUDIO, L. (2006): On the Loop Current eddy shedding variability. – Atmósfera, **19**: 41–48.