Chapter 6 Synthesis

6.1 Current transport in the Mozambique Channel and implications for climate reconstructions

The Mozambique Channel is a key area with regard to the global ocean circulation as a tropical gateway for polewards-directed surface waters that feed directly into the Agulhas Current (Biastoch et al., 1999; Harlander et al., 2009) contributing more than 30% to its volume transport (van der Werf et al., 2010). It therefore significantly influences the Agulhas Current where warm Indian Ocean surface waters and cold Atlantic deep waters are exchanged (de Ruijter et al., 1999). To compensate the polewards flow of surface waters, there is a deep undercurrent of North Atlantic Deep Water flowing equatorwards into the Mozambique Channel. Thus for Indian-Atlantic exchange, the Mozambique Channel is an important conduit for present and past variability. In the Mozambique Channel, volume transport can be quantified in contrast to other major (open) ocean currents where transport can only be approximated such as the Agulhas Current (Bryden et al., 2005), the Gulf Stream (Johns et al., 1995) or the Kuroshio Current (Johns et al., 2001). Since 2003, the transport of different water masses through the Mozambique Channel has been intensively monitored by numerous instruments on moorings across its narrowest transect. Rotational current velocities at the western margin of the channel often reach maxima of 1.5 m/s in surface waters and at the bottom of the channel 0.1 m/s, as a deep counter-current. On the eastern margin of the channel rotational current velocities are slower with maxima of 0.9 m/s in surface waters and 0.02 m/s in deep waters. The surface current velocities are fast enough to re-suspend and transport bottom sediments with large grain sizes exceeding 315 µm (Rubin and Hunter, 1982), which was the upper size limit for the foraminifera used in this study. Thus, sediment samples taken on the western Mozambique Channel margin at depths above 1000 m are influenced by strong polewards-directed currents. Additionally, it has been observed that migrating eddies pass through the Mozambique Channel at a relatively constant periodicity of about seventy days (Schouten et al., 2003). Such a periodicity provides a unique signature for eddy-induced changes in the water column. Hypothetically, all parameters affected by eddy-induced changes should also show this 70-day periodicity and thereby reveal how eddy migration through the channel affects (in-) organic temperature proxies.
In order to successfully reconstruct past temperature changes in the Mozambique Channel, accurate temperature calibrations need to be established for each proxy for this little-known part of the Indian Ocean. Ideally, such a temperature calibration should be free of any biasing factors such as current transport and seasonality, which are dominating the variability in water mass characteristics in the Mozambique Channel. The strong surface currents in form of fast-rotating meso-scale eddies, can have an effect on proxy temperatures to varying degrees. Although larger foraminifera (> 250 µm) usually quickly sink through the water column (Takahashi and Bé, 1984) they can be transported by currents over hundreds of kilometers before reaching the deep sea floor (Gyldenfeldt et al., 2000). In the Mozambique Channel, rotational current velocities are so fast that even the larger foraminifera seem to be affected by (rotational) transport. However, despite the strong currents and the current transport, the proxy signal of surface-dwelling foraminifera (G. ruber and G. trilobus) in the sediment mirrors the annual mean satellite SST, which suggests that the influence of current transport on the proxy signature is not transferred to the sediment (Fallet et al., 2010). In contrast, the Mozambique Channel currents seem to strongly affect subsurface-dwelling foraminifera by inducing subsurface temperature changes. Subsurface (N. dutertrei) and deep-dwelling foraminifera (G. scitula) seem to be able to record the quick subsurface temperature changes. Flux-weighted annual mean temperatures are reflecting annual subsurface temperatures at 50 m – 70 m (N. dutertrei) and 200 m (G. scitula) depth habitat, which indicates that the subsurface and deep-dwelling foraminifera in the Mozambique Channel record temperatures of their specific depth habitat in the deep sediment. As such, the δ¹⁸O and Mg/Ca of (sub)surface foraminifera in the Mozambique Channel are valuable proxies for the reconstruction of past temperature variability at different water depths.

In contrast to the heavy foraminifera and their associated temperature proxies, the organic temperature proxies (\(U^{14} \text{C}\) and TEX₈₆) are likely to be more influenced by current transport due to their lighter weight and less compact structure. This suggests that organic matter and foraminifera in Mozambique Channel sediments might originate from different source areas thereby biasing reconstructions based on temperature proxies from these particles. Some studies have shown that organic matter can sink through the water column as marine snow which increases their sinking rates and probably weakens the effect of current transport (Lee et al., 2008; Wakeham et al., 2009). For the organic proxies in the Mozambique Channel, flux-weighted annual mean proxy temperatures yield values that are very similar to annual mean satellite SSTs even though they do not show a pronounced seasonal cycle. This can
indicate that the source of the organics is at least close to, if not in, the Mozambique Channel. The strong rotational currents close to the African shelf (Bidigare et al., 2003) can sweep organics off the shelf areas and transport them mid-channel before they reach the deep ocean floor. These results imply that both, organic and inorganic proxies, have to be used with caution when reconstructing past temperatures. Yet, I argue that a multi-proxy approach would significantly minimize biases that might occur due to eddy-induced transport.

6.2 Effects of water mass properties on inorganic temperature proxies

Offsets in $\delta^{18}$O and Mg/Ca between different planktonic foraminifera have been explained in terms of differential depth habitats (Shackleton and Vincent, 1978; Tedesco et al., 2007), pH and carbonate ion concentration (Spero et al., 1997) and salinity changes (Ferguson et al., 2008). In the surface-mixed-layer waters of the central Mozambique Channel the seasonal temperature range is between 25 °C and 30.2 °C, the salinity range between 34.8 and 35.2 g/kg and the total alkalinity range between 2285 and 2300 mEq/L. This implies that in the central Mozambique Channel, the pH, carbonate ion concentration and salinity variations are small and can thus be considered constant with respect to foraminiferal $\delta^{18}$O and Mg/Ca on an intra-annual time-scale. However, high-resolution satellite observations show that, especially in summer, SST varies strongly between open-ocean and coastal waters (also see chapter 5). Additionally, previous studies in the Mozambique Channel (Zinke et al., 2008), in situ measured data and satellite observations (chapter 5) have indicated a strong salinity variation of at least 1 g/kg between central (34.8 g/kg) and coastal waters (35.8 g/kg) at the end of the dry season. In contrast, at the end of the rain season, coastal waters are much less saline than open ocean waters. Such a salinity variation can affect foraminiferal $\delta^{18}$O and Mg/Ca and shift proxy-based temperature reconstructions towards warmer or cooler values. Similarly, coastal waters also exhibit larger temperature variability with minima and maxima by about 1 °C lower or higher than open ocean waters.

Another uncertainty with regard to foraminiferal proxies is caused by measuring $\delta^{18}$O and Mg/Ca on foraminifera with large differences in shell size (Elderfield et al., 2002). As planktonic foraminifera were abundant in the Mozambique Channel sediment traps, the analyzed size fraction could be constrained to 250 – 315 µm to minimize size-effects. As the foraminiferal isotope signal depends on the isotope signal of the ambient seawater, which
changes with depth, it was also necessary to constrain depth habitats for each analyzed species. This is done with plankton nets towed through the water at specific depths which yields data about the vertical structure of plankton abundance in the water column. Since no such data were available within this PhD project, available data were used on foraminiferal depth habitats in the Arabian Sea, the SE Atlantic and the Somalia Basin (Conan and Brummer, 2000; Loncaric et al., 2006; Peeters and Brummer, 2002). These previously established depth habitats were combined with the δ¹⁸O of the ambient seawater measured in the Mozambique Channel. Additionally, the potential δ¹⁸O and Mg/Ca offset from equilibrium calcification of the foraminiferal species must be known. For the two surface-dwelling species *G. ruber* and *G. trilobus*, a mean offset of 0.17 ‰ for δ¹⁸O was measured similar to previous observations on plankton tow samples from the Indian Ocean (Duplessy et al., 1981). For Mg/Ca this offset was 1.2 mmol/mol, about three to four times higher than in previous studies (Anand et al., 2003; Huang et al., 2008). Combined, the hydrography of the Mozambique Channel provided a strong basis for δ¹⁸O and Mg/Ca temperature calibrations from an ensemble of planktonic foraminifera in the SW Indian Ocean.

### 6.3 Effects of water mass properties on organic temperature proxies

A number of processes can affect the accuracy of past SST reconstruction for the organic proxies, which are broadly grouped into ecological (light, nutrients, salinity), physiological (seasonal blooms) and genetic (different morphotypes) and diagenetic effects (Herbert, 2001 and references therein). For the oligotrophic Mozambique Channel, effects of nutrient (and light) variations are probably very small as intra-annual chlorophyll *a* variation in surface waters (where the majority of the organics is expected to form) ranges between 0.075 mg/m³ in summer and 0.25 mg/m³ in winter (Fallet et al., 2010). Similarly, the salinity gradient in the Mozambique Channel is probably too small to significantly affect the temperature signature in the alkenones (Blanz et al., 2005; Sonzogni et al., 1997) and the GDGTs (Wuchter et al., 2004). Additionally, seasonality in alkenone and GDGT fluxes has not been observed which is probably caused by eddy transport that averages the temperature signal over a large area (Conte et al., 1992). The genetic influence on the alkenone temperature is likely also negligible as a number of plankton studies in the (sub-) tropical oceans found that the majority of the coccolithophorid assemblage is made up of *Gephyrocapsa oceanica* (Volkman et al., 1995). Diagenetic influences such as degradation of alkenones in the water column and the
sediment seem to play a moderate role (at least in the Mediterranean) in affecting the $U_{37}^{K}$ signature by shifting it to warmer values (Rontani et al., 2009). As the accuracy of organic and inorganic temperature proxies are (mostly) affected by different factors, our multiple proxy approach provides a good setting to assess how foraminiferal $\delta^{18}O$ and Mg/Ca as well as organic $U_{37}^{K}$ and TEX$_{86}$ record temperature in sediments of the tropical SW Indian Ocean.

6.4 Effects of diagenetic changes on temperature proxies

In addition to the primary constraints with regard to proxy-based temperature calibrations, there are a number of secondary effects that can alter temperature proxies after burial in the sediment. Such secondary effects for foraminifera are dissolution, re-crystallization and for the organics, microbial degradation and in situ production. For both, foraminifera and organics, the input of old, re-suspended material can alter the initial proxy signature. Dissolution and re-crystallization might significantly alter the chemical structure of foraminiferal shells thereby decreasing or increasing proxy-based temperatures. Yet, for the Mozambique Channel, dissolution artifacts down to 2700 m water depths were not observed in scanning electron microscope (SEM) images or shell weights. SEM close-ups of foraminiferal wall structures did not reveal any dissolution of the foraminiferal shell where $\delta^{18}O$ and Mg/Ca values could be most significantly altered. To double-check for dissolution, shell weight was determined for cleaned specimens from sediment traps and coretop samples in the 250 – 315 µm size range thereby testing the hypothesis that alteration in coretop specimens would alter shell weights. Yet, both data sets show statistically identical shell weights, which strongly suggests that neither dissolution nor precipitation affected coretop specimens. Thereby, my data suggest that the foraminifera in the well-oxygenated, deep Mozambique Channel are not affected by diagenetic alteration.

However, in these oxygenated waters organic compounds can be substantially altered. Degradation at the sediment – water interface may decrease organic matter by up to 50 % (Thunell et al., 2000). It has been estimated that often only about 1 – 2 % of the total organic matter produced in the surface oceans finally reaches the sediment at the deep ocean floor (Thunell et al., 2000). Indeed, the organic carbon content in coretops from the Mozambique Channel was measured to be only 1 – 3 wt % whereas organic carbon content in particle fluxes from sediment traps ranged between 5 – 9 wt%. In addition to degradation at the sediment – water interface, organic matter can be consumed while sinking through the water
Synthesis

column. Thus, organic matter degradation can influence the signature of the organic proxies, both while settling and after sedimentation.

6.5 Inferences for past current regimes

An important pre-requisite for past climate reconstruction is the stability of current regimes throughout time. It has been repeatedly shown for e.g. the Agulhas Current at the southern tip of Africa that current velocities and volume transport can change through time. There, the exchange between warm Indian Ocean surface waters (the Agulhas Current) and cold Atlantic deep waters takes place. This Indian-Atlantic exchange has varied considerably in the past (Peeters et al., 2004) and may have been strongly reduced during the Last Glacial Maximum about 20,000 years ago (Bard and Rickaby, 2009), causing warming of the Indian Ocean and cooling of the South Atlantic (Levi et al., 2007). From information on the Atlantic Ocean, it can be hypothesized that the exchange between Indian and Atlantic Ocean has slowed down during past cold periods (Peeters et al., 2004) caused by significant shoaling of NADW (Lynch-Stieglitz et al., 2007). Additionally, the pathway of the Agulhas Current probably became narrower during past cold periods due to a significant broadening of the African shelf (Peeters et al., 2004). This possibly forced the exchange of water masses into a defined corridor thereby reducing the Indian-Atlantic exchange. As the Mozambique Channel is directly coupled to the Agulhas Current (de Ruijter et al., 2002; Harlander et al., 2009; van der Werf et al., 2010), one may argue that during past cold periods, there is less water-mass transport in the Mozambique Channel accompanied by a broadening of the African and Madagascan shelf. Thus, for future down-core studies that extend into glacial periods, information about (past) current systems need to be considered for climate reconstructions.

6.6 Significance of time-series analysis with sediment traps

In order to reconstruct past temperature changes, accurate calibrations are needed from modern time-series studies coupled to satellite SST or preferably in situ measured temperatures across the thermocline. To obtain such time-series data, climate research strongly relies on sediment trap studies, which are associated with a number of uncertainties, which I will discuss below.
In order to obtain temperature calibrations for each Mozambique Channel proxy, time-series analysis was applied to the different datasets. The statistical results that came forth from these analyses strongly depend on the length and resolution of the original dataset. With regard to statistical measures, the Mozambique Channel time-series are relatively short (2.5 to 4 years) and have a low-resolution (17 to 23 days). Programming time-intervals for sediment traps always has shortcomings: a high-resolution time-series is relatively short and a long time-series inevitably has a lower resolution. Shortly deployed, high resolution time-series need to be recovered and re-deployed at a higher frequency which poses difficulties (ship-time, financing, etc.) for remote study areas such as the Mozambique Channel. Therefore, the sediment traps in the Mozambique Channel were programmed at a tri-weekly time-interval in order to stretch the time-series to its maximum length before it could be serviced during the next scientific cruise. However, this comes at a trade-off of only three sampling intervals per migrating eddy, which is the statistical data minimum to determine eddy frequency in particle fluxes and temperature proxies. Subsequently, the time-interval of the sediment traps has been changed to 17 days for the time-series from 2008 onwards in order to better capture the migration of eddies through the Mozambique Channel every about 70 days. However, despite this shortcoming of our (initial) data set, the time-series parameters from the sediment trap yielded not only a clear seasonal but also the 70-day eddy periodicity which can be coupled to the eddy migration through the channel. Thus, even with the low tri-weekly resolution, the signal in particle fluxes (and specific temperature proxies) at 2250 m water depth reflected eddy migration in surface waters.

In this project, time-series data from a single site are used for temperature calibration in the Mozambique Channel, essentially a single point measurement with a collecting area of 1 m². As the Mozambique Channel is highly dynamic (but even if it were not), such a small catchment area seems to be diminutive in comparison to the area it should represent. Building on my findings and others in the Mozambique Channel (Harlander et al., 2009; Schouten et al., 2003; van der Werf et al., 2010), sediment traps are now deployed along a depth transect in the Mozambique Channel for comparison of the different foraminiferal and organic fluxes as well as associated temperature proxies. Additionally, a trap on the Madagascan side of the channel would be useful to have as current velocities differ strongly between the eastern and western part of the Mozambique Channel as explained earlier (chapter 6.1).
6.7 Research prospects

For the quantification of volume transport to the Agulhas Current the Mozambique Channel forms a unique ocean setting, exceptional for paleoceanographic research. The Mozambique Channel is important for past climate change since it is at the source of the Agulhas Current contributing more than 30% to its volume transport (van der Werf et al., 2010). It therefore significantly influences the Indian-Atlantic exchange (de Ruijter et al., 1999). Future work in the Mozambique Channel could aim at exploiting the extensive knowledge of the modern oceanography in the Mozambique Channel in form of detailed time-series provided by the LOCO project. From time-series δ¹⁸O and Mg/Ca in foraminiferal shells, temperature calibrations have been generated that provide the basis for future downcore studies and the reconstruction of past ocean temperatures. It would therefore be timely to continue these studies downcore to obtain long-term time-series of changes in oceanographic conditions in the Mozambique Channel.

Below, I will shortly outline a research idea for the reconstruction of past changes in deep-water circulation in the Mozambique Channel.

6.7.1 Rationale

The Mozambique Channel is a key area with regard to the global ocean circulation because its polewards-directed surface waters feed directly into the Agulhas Current (Biastoch et al., 1999; Harlander et al., 2009) where warm Indian Ocean surface waters and cold Atlantic deep waters are exchanged (de Ruijter et al., 1999). To compensate the polewards flow of surface waters, there is a deep undercurrent with North Atlantic Deep Water (NADW) flowing equatorwards through the Mozambique Channel (Figure 6-1). The passing of different water masses through the Channel has been intensively monitored by a set of numerous instruments deployed across the narrowest transect of the channel that record time-series of current velocities (Harlander et al., 2009), temperatures and salinities (van der Werf et al., 2010). Additionally, there are detailed in situ measured nutrient and δ¹⁸O profiles available for the Mozambique Channel essential for past temperature and nutrient reconstruction (Figure 6-2). Based on this information two cores were taken in the deep Mozambique Channel, one at 2700 m water depth, right in the pathway of modern NADW (PE304-74) and one at 2000 m
Synthesis

(D289-25) which currently is just in the pathway of polewards flowing Red Sea Modified Water (RSMW).

**Figure 6-1:** a) Pathways of the greater Agulhas Current with fast-rotating, surface Mozambique Channel eddies feeding the Agulhas Current (red) and the deep counter current entering the Indian Ocean from the South Atlantic and the Circum-Polar Current (blue). Core locations are indicated in yellow with a blue margin for reconstructing deep water flow. b) Cross-section of the Mozambique Channel transect with core positions (blue crosses) and depth of moored current meters (CM), Acoustic Doppler Current Profilers (ADCP), conductivity-temperature-depth sensors (CTD) and sediment trap. With this set-up, modern current velocities can be calibrated against sortable silt in core-top samples and used as proxy for past current speed down-core.

At the water depth of 2700 m from which core PE304-74 was taken, NADW flows currently equatorwards with temperatures around 2 °C, salinities of 34.8 and $\delta^{18}O_w$ values around 0.3 ‰. At the water depth of 2000 m from which core D289-25 was taken, Red Sea Modified Water (RSMW) flows currently polewards where ambient water temperatures are around 4 °C, salinities around 34.8 and $\delta^{18}O_w$ values around 0.4 ‰. There is a distinct possibility that NADW shoaled significantly during the Last Glacial Maximum (Lynch-Stieglitz et al., 2007). In such a case, Circumpolar Deep Water (CPDW), with lower temperatures (< 2 °C) and nutrient contents (Donohue and Toole, 2003), possibly entered the deepest parts of the Mozambique Channel. Thus, the two selected cores would be ideally positioned to record the subsurface and deep water pumping through the Channel with emphasis on recording the depth of past NADW and CPDW. Within the GATEWAYS and GLOW programs, scientists
already work on records from shallower cores to capture the intermediate water mass changes (Figure 6-2).

**Figure 6-2**: In situ measured temperature, salinity, nutrient, oxygen and $\delta^{18}O_w$ profiles in relation to the position of the two sample cores in blue and the two comparison cores in red as located in the modern water masses (Circumpolar Deep Water (CPDW), North Atlantic Deep Water (NADW), Red Sea Modified Water (RSMW), Sub) Tropical Surface Water (S)TSW). Antarctic Intermediate Water (AAIW) may intermittently enter the Channel when southwards eddy migration ceases thereby replacing RSMW at depths between 1000 and 1500 m.

With this research idea, the transect of cores into the deepest parts of the Channel would be completed in order to constrain volume transports from the North Atlantic. Deep water data could then be contrasted with surface ocean records from shallower cores PE304-80 at 1329 m and core GIK16162-2 from the Mozambique Channel.

6.7.2 Age model of the Mozambique Channel cores

For this research idea, an age model needs to be established. This has been achieved in a pilot study by measuring bulk stable oxygen isotopes on the carbonates in core PE304-74 (Figure 6-3). The oxygen isotope profile of core PE304-74 shows distinct features matching those from a nearby core in the SW Indian Ocean (Bard et al., 1997), suggesting sediment rates of 5
- 7 cm/1000 years. These results show that core PE304-74 allows reconstruction of deep water circulation from the Holocene (MIS 1) through the Last Glacial Maximum (MIS 2) into the first interstadial (MIS 3) which covers a time-span during which large and rapid variations in sea surface temperatures occurred (Figure 6-3).

![Graph](image)

**Figure 6-3:** The lower panel shows bulk stable isotopes from core PE304-74, whilst the upper panel shows bulk stable oxygen isotopes from core MD85674 in the SW Indian Ocean (Bard et al., 1997). Marine isotope stages (MIS) are indicated together with the Holocene Maximum (H.Max) and the Bølling-Allerød (BA) as warm intervals and the Younger Dryas (YD) and the Last Glacial Maximum (LGM) as cold intervals.

### 6.7.3 Benthic foraminifera as recorders of temperature and nutrients

Other pilot investigations of the benthic foraminiferal assemblages revealed that the epibenthic foraminifera *Cibicidoides wuellerstorfi* is extremely well-preserved in both cores. SEM photos of shells clearly show the pristine structure of the walls (Figure 6-4). These would be ideal specimens for ion-probe and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) analysis. As *C. wuellerstorfi* is a distinctive deep water indicator that most commonly lives at lower bathyal depths (2000 to 3000 m) it has been frequently used for the reconstruction of deep water ventilation in the Atlantic, Indian and Pacific Oceans (Sarnthein et al., 1994). Calcifying benthic foraminifera that live on the deep ocean floor record specific
properties of bottom water masses (temperature and nutrients) via their shell isotope (δ^{18}O and δ^{13}C) and trace element (Mg/Ca and Cd/Ca) ratios. The δ^{18}O ratio of benthic foraminiferal calcite reflects both the changing temperature and the δ^{18}O of the ambient seawater which generally co-varies with salinity (including ice-volume), whereas the Mg/Ca ratio depends solely on temperature (Elderfield et al., 2006). Measured together in benthic foraminifera, these two proxies can be used to reconstruct temperature and past variation in δ^{18}O_w of the ambient water mass.

Figure 6-4: SEM images of the epibenthic foraminifera C. wuellerstorfi from 20 – 21 cm core depth (~ 5000 years old) showing the well-preserved wall structure which makes them highly suitable for element ratio and stable isotope analysis. From left to right: overview image and close-up of pore of the same specimen.

Past changes in nutrient distributions are recorded by the carbon isotope composition (δ^{13}C) and Cd/Ca in shells of benthic foraminifera. For instance, since primary producers in the surface ocean take up both nutrients and carbon, they discriminate against the heavy isotope of carbon (Curry and Oppo, 2005). This leads to high δ^{13}C values in surface-derived (low-nutrient) water masses such as the NADW. Higher nutrient concentrations and lower δ^{13}C reflect the longer time these waters have spent away from the surface, collecting nutrients and ^{13}C-poor carbon from the decay of organic matter transported to depth in particulate and dissolved forms. However, other effects such as surface water productivity may influence the δ^{13}C values. To overcome this problem, detailed pore water profiles are available from several multi-cores in the Mozambique Channel to correct the δ^{13}C values for the Mackensen effect (Mackensen et al., 1993). In addition, past nutrient distributions have been reconstructed from the ratio of cadmium to calcium (Cd/Ca) in tests of benthic foraminifera (Marchitto and
Broecker, 2006). The combination of $\delta^{13}$C and Cd/Ca in tests of benthic foraminifera represents a robust way to record the nutrient related changes of water mass changes through time.

Possible hypotheses for this research idea could be that NADW shoaled and its flow speed slowed down during past cold periods (Last Glacial Maximum and Younger Dryas) in the Channel, allowing Circum-Polar Deep water (CPDW) to enter (Figure 6-5). In other words, with evidence from the two sediment cores, taken directly in the flow paths of modern NADW and RSMW in the Channel, it could be tested whether CPDW entered the Channel during periods when the northern hemisphere was cold and overturning in the N-Atlantic was reduced.

![Figure 6-5](image)

**Figure 6-5:** a) Modern water mass transport in the Mozambique Channel with the North Atlantic Deep Water (NADW) core indicated between 1800 and 2700 m (modified after Harlander et al., 2009). b) Hypothesized water mass transport during cold periods with shoaling (blue arrows) of NADW that allows Circumpolar Deep Water (CPDW) intrusion.

Secondly, one could hypothesize that the temperature evolution of the surface and deep waters in the Mozambique Channel is decoupled. Similar to surface and deep water histories in the Arabian Sea (Jung et al., 2009), surface waters in the Channel probably have a temperature evolution controlled by northern hemisphere climate changes and deep waters have a temperature evolution controlled by southern hemisphere climate changes.

Possible aims for this research idea are the reconstruction of millennial scale temperature evolution of deep waters by producing $\delta^{18}$O and Mg/Ca proxy time-series in the two selected cores from deep parts of the Channel. Thereby, the hypothesis could be tested that deep water
evolution has a southern hemisphere climate component as deep waters enter the Mozambique Channel from the South. Additionally, this project set-up would allow for contrasting $\delta^{18}$O-derived temperature from deep water benthos (C. wuellerstorfi) with $\delta^{18}$O of surface water plankton (G. ruber) from the same core. Also surface and deep water temperature signals could be compared with the $\delta^{18}$O and Mg/Ca time-series produced on nearby shallower cores. Thereby, the hypothesis could be tested that surface water temperature evolution is out of phase with deep water evolution at the millennial-scale (Jung et al., 2010). Such a set-up would also allow for the reconstruction of nutrient related deep water mass changes by producing millennial-scale time-series of $\delta^{13}$C and Cd/Ca to test the hypothesis that Circum-Polar Deep Water entered the Channel during cold northern hemisphere periods in the same selected cores.

With the detailed time-series dataset of the modern hydrography in the channel, proxy records can be placed in their modern oceanographic context, which is quite unique for paleoceanographic studies. This would allow putting anthropogenic change into a longer-term framework of variability in oceanographic conditions.
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Curriculum Vitae

Ulrike Fallet was born on November 16, 1978 in Rostock, Germany. After finishing high-school in 1997, she went for two years to the United States to start university. It was there, at the University of Wisconsin/Milwaukee, where she first got acquainted with the subjects of geology and English literature and noticed her interest in both the human and natural sciences. After her time in the States, Ulrike continued her studies at the Friedrich-Schiller-University of Jena (Germany) in the subjects English literature, geology and sport sciences. Throughout semesters, Ulrike often worked as a student scientist for the department of geology. In the semester breaks, she has been a tour guide on Svalbard explaining the geology, biology and history of that archipelago to tourists. During her studies in Jena, she acquired funding for an internship in geology at the University of Auckland in New Zealand and used this opportunity to also travel around the country. Ulrike graduated in 2005 in the subjects English literature, geology and sport sciences. For her PhD thesis, she specialized in (marine) geology at the Royal Netherlands Institute for Sea Research (NIOZ) on the island of Texel. Currently, Ulrike and her partner live with their two children in the Netherlands, close to Amsterdam.