International Research Experiences for Students: Coastal Oceanography in East Africa

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February 19, 2008

This is the project summary and description that formed part of the revised proposal submitted to the National Science Foundation on February 19, 2008.

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Project Summary

The proposed project offers students the combination of discovering the virtually unknown dynamics of the Zanzibar Channel, an about 40km-wide and 100km-long area of ocean bounded by the Tanzanian mainland and the island of Zanzibar, and experiencing research at the Institute of Marine Sciences (IMS) in Zanzibar, Tanzania. This international research experience will therefore allow students to produce new research results while experiencing Tanzania, a country that is strikingly different to the US. The project is supported by the Intergovernmental Oceanographic Commission (IOC), the World Bank, and several leading US oceanographic institutions and universities.

The opportunities offered by the proposed project will be open to three undergraduate and graduate students in the US each year from 2009 to 2011. The overall research goal will be to develop a model of the dynamics of the Zanzibar Channel that produces an annual cycle that resembles as closely as possible the real annual cycle and thus forms a base for further model development aimed at addressing natural resource management issues. A different group of three students each summer will spend two months at IMS in Zanzibar, working on two different types of projects, one focusing on the model development and the other on making oceanographic measurements in the Zanzibar Channel to provide observational data for the model. The students will be mentored by senior local scientists, Dr. Javier Zavala-Garay at Rutgers University, who will be with the students in Zanzibar for 1.5 months each year, and a global network of experts that has already been created for the proposed project.

Oceanographic institutions in the East African region, including IMS, recently made coastal modeling one of their top priorities, citing its cost-effectiveness in understanding processes that affect their coasts. The prioritization of modeling is encouraged and fully supported by the IOC and the World Bank as both have a mandate to promote capacity development in the marine sciences in the developing world. Both are actively supporting the proposed project, representing partnerships that the National Science Board strongly recommends.

Intellectual Merit The proposed project is the logical extension of the PI's previous NSF-supported student research project and collaboration on IOC regional training activities. It benefits from the PI's 12 years of experience of sending students to Africa. Because relatively little physical oceanographic research on the dynamics of the Zanzibar Channel has been conducted, the proposed research will provide a first understanding of the dynamics of the Zanzibar Channel. Beyond local relevance, coastal oceanographers are interested in new cases that might reveal new coastal processes or could be used for comparison with other coastal regions. To maximize the model's benefit it will also be important to investigate its usefulness to other fields such as coral reef research. Because the proposed project addresses one of IMS' top priorities, IMS will provide new oceanographic instrumentation and use of a research boat. Additional instruments and a computer cluster will be provided at no cost by the Scripps Institution of Oceanography and the Georgia Institute of Technology, respectively.

Broader Impacts The combination of the relatively unknown dynamics of the Zanzibar Channel and the support of a dedicated and diverse Advisory Committee will provide the students with an exciting research and learning experience. A diverse group of students will be selected because it can better master the challenges of the research and the different culture, thus making the experience more rewarding. Because students can be selected nationwide, many new partnerships within the US will originate which will also become connected through the students to the networks already existing in East Africa. Results of the research and the experiences made by sending students to Zanzibar will be documented in publications, at conferences, and via a website.

Project Description

Revision Notes

The PI thanks the reviewers of the original proposal for their positive comments and constructive criticism. In response to their reviews the PI revised the proposal. Major changes are:
⋆ There will be no official partnership with the IGERT Program at the Scripps Institution of Oceanography and therefore also no separate environmental context projects (section 4.4).
⋆ The duration of the student projects will be reduced from three to two months (section 6.3).
⋆ The number of students will be reduced from four to three because of the budget limit.
⋆ Professor Chris Reason of the University of Cape Town, South Africa, will not spend two weeks each year at the Institute of Marine Sciences (IMS) in Zanzibar to supervise the students but will remain involved and visit IMS for only a few days in the first year (sections 3.4 and 5.3).
⋆ Dr. Javier Zavala-Garay at the Institute of Marine and Coastal Sciences of the Rutgers University will be with the students each year for 1.5 months during their two months at IMS to supervise their projects and also train local IMS scientists (section 5.3 and attached letter).
⋆ The student projects will be made an integral part of the students' US academic programs (section 5.1). In particular, the Oregon State University and the University of California at San Diego are officially committed to this effort (attached letters of Dr. Harte and Dr. Teranes, respectively).
⋆ The students will go on the field cruises (section 4.3).
⋆ The students will interact with local undergraduate students (section 5.3).

1 Goals and Outline **(revised)**

The proposed project offers undergraduate and graduate students in the US international research experiences in coastal oceanography at the Institute of Marine Sciences (IMS) in Zanzibar, University of Dar es Salaam, Tanzania. Each summer, from 2009 to 2011, a group of three students will spend two months at IMS to carry out projects focused on understanding the dynamics of the Zanzibar Channel and its implications. They will be supervised by senior local IMS scientists and Dr. Javier Zavala-Garay, a physical oceanographer at the Institute of Marine and Coastal Sciences, Rutgers University, who will spend 1.5 months with them in Zanzibar.

The students will conduct two types of research projects: 1) Modeling projects, which will further develop the model of the dynamics of the Zanzibar Channel begun by the PI's previous student, Gabriela Mayorga-Adame, using the Regional Ocean Modeling System (ROMS); and 2) Data projects, which will make measurements in the Zanzibar Channel, especially those needed for the model development. Besides these two research focuses the students will develop an understanding of the wider environmental context of their research, which is the scientific, social, and economic aspects of issues, such as pollution, beach erosion, and the health of coral reefs, that the modeling effort is eventually expected to address in the future. The research has the overall goal of developing a model for the first time that produces an annual cycle that resembles the real annual cycle of the Zanzibar Channel as closely as possible.

As a result of their participation in this international research experience, the PI anticipates that: 1) Students will gain firsthand appreciation of the opportunities and challenges associated with international research. 2) Students, through interactions with peers and mentors, will develop collaborative learning skills. 3) Students' modeling and field activities will support achievement of their near-term academic goals.

The proposed project is the natural extension of the education and outreach component of the PI's previous NSF-supported work summarized in section 2. Its success, like that of any

project, relies on sustained commitment of all partners involved. Section 3 therefore presents the partners and their motivations and expected benefits. Section 4 and 5 detail the proposed research and education plans, respectively. Organizational aspects not covered in the previous sections, including a program evaluation plan, are covered in section 6.

2 Results from Previous NSF Support

NSF OCE-0550658: PI Theiss J., Equatorial Macro Turbulence: Extending Mid-Latitude Macro Turbulence Studies to the Equatorial Region. March 1, 2006 - February 28, 2009.

http://www.theissresearch.org/zanzibar/

The education and outreach component of this NSF award provided the PI with support for one physical oceanography student to obtain a three-month research experience in East Africa. The Intergovernmental Oceanographic Commission (IOC) at UNESCO, which has close working relations with East African oceanographic institutions, recommended and helped the PI to develop a student research project in collaboration with the Institute of Marine Sciences (IMS) in Zanzibar. The goal of this student research project was to configure an application of the Regional Ocean Modeling System (ROMS) for the Zanzibar Channel. To help guide this effort the PI formed an advisory committee of experts. Following a nationwide call for applications, Gabriela Mayorga-Adame was selected. She spent the first two weeks of April 2007 with the PI in La Jolla, CA. He prepared her for her time in Zanzibar, drawing on his 12-year experience working with African academics (section 3.3). The PI and Mrs. Mayorga-Adame met with coastal oceanographers at the Scripps Institution of Oceanography and UCLA, and Mrs. Mayorga-Adame started to prepare a computer, which she subsequently took to Zanzibar and intentionally left there. During her three months at IMS, which immediately followed her visit of the PI, she set up ROMS for the Zanzibar Channel and conducted various numerical studies. They are described in section 4.2 below. Due to the immense interest in coastal modeling at IMS, five local research staff were assigned to participate in her project. Mrs. Mayorga-Adame remains involved in the proposed project as a member of the Advisory Committee (section 6.1). The unique research and cultural experiences she made in Zanzibar will be of great benefit to the proposed project.

3 Motivation and Benefits **(one subsection revised)**

3.1 Students

In an increasing competitive and globalized academic community students strive to excel in their research while also seeking opportunities to develop complementary skills. An opportunity for this is given by the proposed project. Students will conduct research and at the same time experience working on an international assignment which allows, for example, developing skills in becoming immersed and accepted in a different culture, working within a network of people that has a large range in geography, expertise, and level of seniority, and solving applied problems. By making these experiences students can thus differentiate themselves from others and become more competitive. This is particularly crucial since many students will nowadays pursue a career in science and engineering in the private sector, as pointed out by a study of the National Academy of Sciences (Committee on Science, Engineering, and Public Policy (COSEPUP), 1995). This study furthermore states that "employers complain that new PhDs are often too specialized for the range of tasks that they will confront and that they have a difficult time in adapting to the demands of the

nonacademic world." This world is globalized and therefore this demand is for a workforce that can operate in a diverse and interconnected world. The proposed project will give the students the opportunity to develop skills to meet this contemporary demand.

Although the study of the National Academy of Sciences recommends that students become more versatile it also emphasizes that this should not be achieved at the expense of the existing strength of their training for careers in academic research. Following this recommendation the proposed project offers opportunities for academic research because relatively little is known about the dynamics of the Zanzibar Channel, thus student research projects have the potential of producing new and publishable results.

3.2 Institute of Marine Sciences in Zanzibar

A strong commitment of the host institution, the Institute of Marine Sciences (IMS) in Zanzibar, to the proposed project will help ensure its success. The director of IMS, Dr. Alfonse Dubi, (support letter is appended) closely worked with the PI for about a year to develop the previous student research project described in section 2. He gave the PI his full attention, although the project was rather minor compared to the multi-million dollar projects of the European Union and the World Bank in which Dr. Dubi, who was also a Vice-Chairperson of the Intergovernmental Oceanographic Commission (IOC) at UNESCO, is involved. Dr. Dubi also invested in the student research project by purchasing a fast computer, required software, and assigning five members of his staff to it. The reason for this extraordinary commitment is that modeling of marine and coastal physical, ecological, and biological processes has recently been made a top priority at many oceanographic institutions in the East African region. This is particularly so at IMS where Dr. Dubi strives to make IMS a regional leader in coastal modeling. This priority emerged during a series of workshops in the East African region co-organized by IOC that started in 2005 (www.theissresearch.org/ioc/). These workshops raised awareness that in other developing countries coastal modeling created potential for growth of the institutes there because coastal modeling turned out to be an effective tool for delivering science-based solutions to decision-makers of coastal zone resource management and to conduct quality research in general.

Dr. Dubi's extraordinary commitment is sustained. He recently introduced three new post-graduate courses on marine and coastal oceanography and purchased oceanographic instruments for collecting data for the model of the Zanzibar Channel.

3.3 PI

The proposed project represents for the PI an ideal combination of his various interests. While studying physics, he became also interested in development co-operation and therefore after graduating, he worked as an intern at UNESCO headquarters for five months in 1995. Inspired by UNESCO's objective to integrate the scientists in the developing world better into the global scientific community, the PI devised a project that sends German physics undergraduate students to Nairobi, Kenya. His rationale was that as students they would primarily learn from Africans, which is paramount because many development co-operations fail because the partner in the industrialized world lacks a true understanding of Africa (e.g. Harden, 1990). This rationale is also reflected in the proposed project.

The PI developed his UNESCO internship project into an organization called the Berlin-Nairobi Exchange (www.berlinnairobi.org). Together with a few dedicated volunteers he has sent in total 23 German physics undergraduates each for one academic year to two universities in Nairobi, Kenya. This activity allowed the creation of a long-term co-operation in solar cells research, which in

particular led to a two-week solar cells research summer school with five lecturers from Germany and Kenya and 30 students from eight East African countries. The PI has been raising financial support for all these activities from the German Academic Exchange Service (DAAD), the German Science Foundation (DFG), the Volkswagen Foundation, and UNESCO.

While preparing the proposal for his current NSF award (OCE-0550658) the PI was encouraged by Dr. Gisele Muller-Parker of NSF in 2005 to develop an education and outreach component that is similar to the Berlin-Nairobi Exchange but for U.S.-based students in physical oceanography. This lead to the PI's NSF-supported project described in section 2, which forms the base for the proposed project.

3.4 Regional and Global Scientific Community (revised)

Building capacity and collaborative networks has been a long standing goal of international organizations working in the region. More recently, the capacity development program of the IOC brought together leaders of coastal and marine management and a clear consensus was reached on regional priorities, including improved institutional capacity in the use of tools for coastal management (www.theissresearch.org/ioc/). The proposed project contributes to these goals.

While being able to communicate about the proposed project with East African oceanographic institutions through IOC, the PI has established his own mailing list with currently 45 subscribers mainly from the region in order to engage them in the proposed project. The PI will post updates on the work at IMS, especially on the tropical Western Indian Ocean ROMS model (section 4.2), which includes parts of the East African coast and is thus of interest to the region.

South Africa, which borders the East African region, has a natural interest in collaborating with its neighbors. Dr. Elizabeth Lyons of NSF explained the PI in 2005 that she sees great benefit for the scientific community in the way South African scientists are reaching out to their colleagues in the rest of Sub-Saharan Africa. This is also reflected in Prof. Chris Reason of the University of Cape Town, South Africa (see "Biographical Sketch" and attached letter), who fosters many relations to East African colleagues and is also involved in the proposed project (sections 4.2 and 5.3).

Globally, members of the developer and user community of the Regional Ocean Modeling System (ROMS) have welcomed ROMS' introduction to the East African region as it will add new users and produce a new application. Coastal oceanographers in general are always interested in new cases of coastal dynamics that might provide new general insight in coastal processes. In this regard, the proposed project will add a case to the "library of cases" (Neil Banas, personal communication).

As the PI and many of his colleagues experienced, scientific discoveries made by scientists in the developing world are often reported in so-called "gray literature", i.e. technical reports, theses, or local journals. Thus, their work is not widely known, which is of disadvantage to both, the scientists in the developing world and the global scientific community. All gray literature relevant to the proposed project, as for instance Harvey (1977) and Mohammed et al. (1993), will be reviewed in the proposed project's future publications and also be made more accessible through existing international initiatives such as www.oceandocs.net and through the proposed project's website to the extent the authors and publishers will permit.

4 Research (three subsections revised)

4.1 Overview (revised)

The Zanzibar Channel, the focus of all student research projects, is located between the Tanzanian mainland and the island of Zanzibar (Fig. 1 and 2). It lies within 38.8°E-39.6°E and 5.5°S-6.8°S. The dominant winds are those of the western Indian Ocean Monsoon, alternating between the Southwest

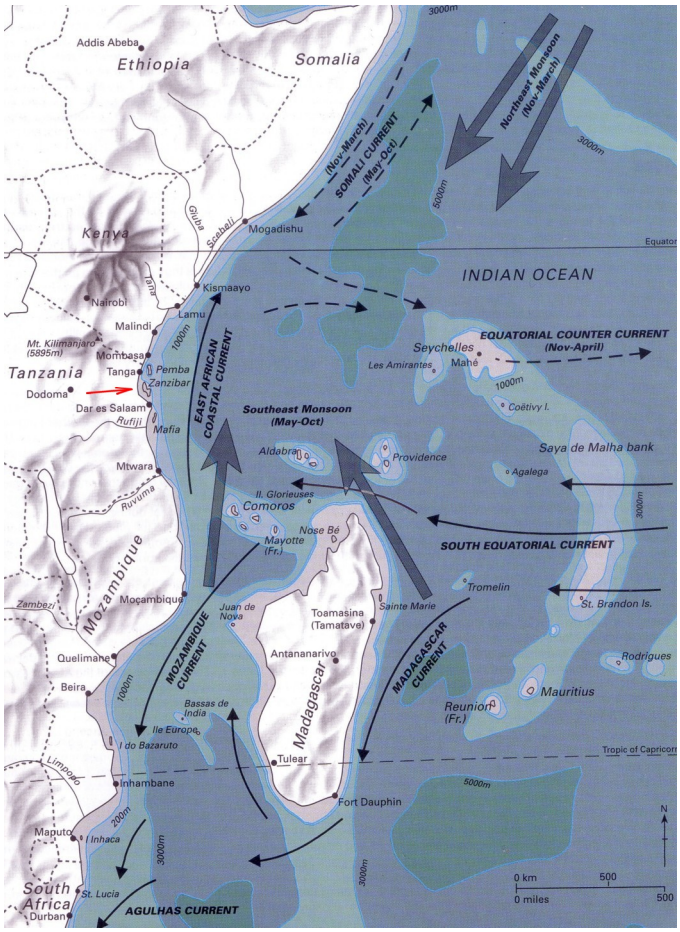

Figure 1: Large-scale features affecting the Zanzibar Channel. The location of the Zanzibar Channel is indicated by the red arrow and lies within 38.8°E-39.6°E and 5.5°S-6.8°S. In particular, schematically shown are the two phases of the monsoon and the East African Coastal Current (EACC), which directly affect the Zanzibar Channel. The figure is taken from Richmond (1997).

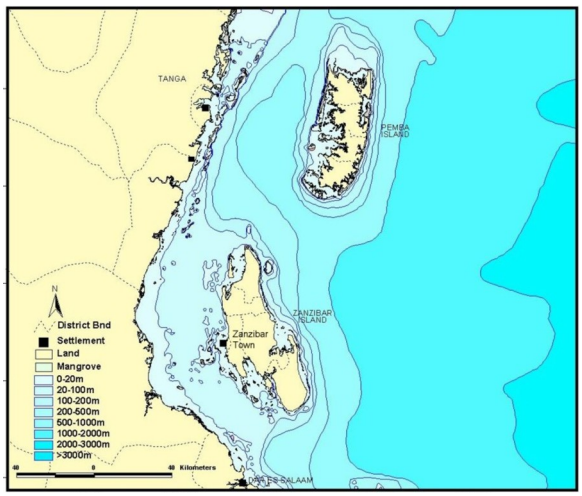

Figure 2: Bathymetry of the Zanzibar Channel and of its immediate surrounding. The Zanzibar Channel lies within 38.8°E-39.6°E and 5.5°S-6.8°S.

Monsoon (southeasterly in the Zanzibar Channel) from May to October and the Northeast Monsoon from November to March (Hellerman and Rosenstein, 1983; Ngusaru and Mohammed, 2002). In contrast to the East Coast of North America, the East Coast of Africa has a narrower shelf. Small-scale processes in the Zanzibar Channel are therefore not isolated from large-scale processes beyond the shelf but instead influenced or even dominated by them (Shetye and Gouveia, 1998). One such large-scale process affecting the Zanzibar Channel is the northward flowing East African Coastal Current (EACC) (Swallow, 1991), which partly flows through the Zanzibar Channel with a speed varying from 0.25m/s to 2m/s (Newell, 1957). The EACC is the northern branch of the westward flowing South Equatorial Current. During the Southwest Monsoon the EACC is fast and merges into the northward flowing Somali Current while during the Northeast Monsoon the EACC is slow and merges with the southward flowing Somali Current into the Equatorial Counter Current. The EACC is primarily the western boundary current of the clockwise tropical gyre in the South Indian Ocean, which is driven by wind forcing over the open ocean.

The two types of research projects that the three students, primarily advised by Dr. Javier Zavala-Garay, will carry out are described in detail in the follwing two subsections.

4.2 Modeling Projects

The modeling projects will further develop a model of the dynamics of the Zanzibar Channel using the Regional Ocean Modeling System (ROMS), which is a free-surface, terrain-following, primitive equations ocean model (Shchepetkin and McWilliams, 2005). The aim is to have the model of the Zanzibar Channel produce an annual cycle and to understand in detail the relative importance of the various processes causing this cycle. With regard to the eventual application of the model in understanding pollution and coral larvae dispersion, ROMS' numerical particle tracking capability will be used.

The modeling projects will continue the work began by the PI's NSF-supported previous student project carried out by Gabriela Mayorga-Adame at the Institute of Marine Sciences (IMS) in Zanzibar (section 2). Because so little is yet known about the dynamics of the Zanzibar Channel, Mrs. Mayorga-Adame began to study semi-idealized cases. She considered two cases with constant wind forcing, using a typical speed and direction during the peak of each of the two monsoon phases as measured by the meteorological station at Zanzibar airport. As an initial condition she assumed constant temperature and salinity throughout the channel and the northern and southern channel entrances were considered open boundaries. The model output shows that in both cases the surface flow has largely the same direction as the wind. Its speed is small near Zanzibar Town in the center of the eastern part of the channel where the flow is also being deflected westward. The bottom flow follows mainly the bottom topography. A difference between the two cases is that upwelling occurs at the western shore of Zanzibar only during the Southwest Monsoon (southeasterly winds). A third study was on tidal dynamics. The global tide model TPX07 reveals that the M_2 tidal component generates the largest velocities in the channel and was therefore selected as the forcing on both channel entrances. The resulting dynamics produced by the model features water masses entering the channel at both entrances and piling up approximately in front of Zanzibar Town during flood and exiting at both entrances during ebb. For this case, fortunately, direct observations had been made in the past (Shaghude et al., 2002), confirming that the model qualitatively reproduces this unique feature and the flow speeds are comparable (see also Harvey, 1977; Mohammed et al., 1993).

Two different lines of model studies are proposed to build on Mrs. Mayorga-Adame's work.

Tropical Western Indian Ocean Model The first involves the consideration of the large-scale dynamics that affects the Zanzibar Channel, most notably the EACC described in the previous

subsection. The students will therefore study the large-scale dynamics given by the output of the ROMS model of the tropical western Indian Ocean. This model was recently developed by Prof. Chris Reason, who will guide this study (section 5.3 and appended support letter), and his postdoc Dr. Juliet Hermes (Hermes and Reason, 2008). To obtain an understanding of the accuracy of the model output the students could compare it with data available for the open ocean, for instance, through HydroBase, from ALACE floats (Chapman et al., 2003), and ARGO floats. Since the focus is the effect of the large-scale dynamics on the Zanzibar Channel, it might become beneficial to re-configure the model appropriately and re-run it. This would also be a good learning experience for the students as they could familiarize themselves under the supervision of Prof. Reason how such ROMS models are set up. The re-run can be done at no cost to the proposed project on the computer cluster of Dr. Emanuele Di Lorenzo (support letter is appended). Ultimately, these proposed activities should provide initial and boundary conditions for the model of the Zanzibar Channel, which is described next.

Zanzibar Channel Model The other line of study is to generalize Mrs. Mayorga-Adame's model setup with the aim of producing an annual cycle. The wind forcing will therefore be chosen to be again constant in space but annually varying in time. The annual signal will be extracted from a ten-year wind data record from three meteorological stations along the coast of the Zanzibar Channel. Similarly, nearby data points from NCEP or ERA40 heat and freshwater fluxes will be used to determine a surface forcing that is constant in space and annually varying in time. It is worth noting that precipitation varies significantly annually ranging from 47mm (July) to 401mm (April) (WMO website) with the two rainfall seasons being March-May and September-November due to the movement of the ITCZ. Since no major river empties into the Zanzibar Channel, fresh water input through rivers appears unlikely to be a dominant forcing. Because no published data appears to exist local knowledge will be sought. Mrs. Mayorga-Adame's initial condition of a constant vertical temperature and salinity profile could be replaced by exponentially decreasing one, by one from the above-mentioned tropical Western Indian Ocean model, and eventually by the one measured by the data projects described in the next subsection. Boundary conditions at both channel entrances will be provided by the tropical Western Indian Ocean model, whereby the effect of the EACC will be particularly important. This is because the observed average speeds of the portion of the EACC flowing through the Zanzibar Channel range from 0.25m/s to 2m/s (Newell, 1957) and thus the lower end of the range is comparable with the range of speeds generated by Mrs. Mayorga-Adame's model that did not include the EACC.

A series of studies will be carried out to determine the relative importance of the various processes. Of particular interest will be to determining whether the EACC alone causes a total mass flux through the channel or whether local wind forcing or other processes are contributing significantly as well.

One of the applications of the model is to understand dispersion of pollution and coral larvae. The latter is also of particular interest to the World Bank's Coral Reef Targeted Research and Capacity Building (CRTR) Program (www.gefcoral.org), which is one of the proposed project's partners (support letter is appended). It is therefore proposed to track numerical particles as the model is being refined.

Dr. Alfonse Dubi, Director of IMS, would like to make a comparison with the model ADCIRC (www.adcirc.org). At least one student will therefore be selected to help in this effort.

4.3 Data Projects (revised)

The data projects will measure velocity, salinity, temperature, and pressure in the Zanzibar Channel, which is virtually unexplored in this regard. This represents a unique opportunity for the students since they can learn about standard measurements and at the same time produce new results worth publication. Such a combination is hard to find along the U.S. coast where standard measurements most likely have been taken already.

The Scripps Institution of Oceanography (SIO) is kindly providing an ADCP and a CTD to the proposed project at no cost (see attached letters of Dr. Clinton Winant and Dr. Ralf Goericke). The ADCP measures continuously bathymetry and vertical profiles of velocity during the planned cruises and the CTD measures at certain locations vertical profiles of salinity, temperature, and pressure. IMS has recently ordered two different ADVs and a CTP recorder. All three instruments are designed to be moored. The two ADVs measure velocity, temperature and pressure and the CTP recorder salinity, temperature, and pressure. These instruments are listed in more detail in section "Facilities, Equipment and Other Resources" of this proposal. IMS will also provide their research boat. This boat, however, is not fit to venture near the entrances and certain other parts of the Zanzibar Channel and therefore IMS and the proposed project will jointly rent a more suitable boat for cruises in these regions.

Dr. Yohanna Shaghude ("Biographical Sketch" is included), a senior IMS scientist, has already conducted cruises in the Zanzibar Channel and therefore will act as chief scientist of the proposed cruises. The first year will be particularly challenging because the ADCP and CTD will be brought to Zanzibar and used there for the first time. Since the same cruises will be carried out each year it is particularly important that the use of the ADCP and CTD is perfected and documented as much as possible in the first year. To this end, Robert Thombley (see attached "Biographical Sketch" and letter), a technician at SIO, will therefore visit IMS for two weeks in the first year.

The students, Mr. Thombley, and Dr. Zavala-Garay can all go on the field cruises but must sign a waiver stating that they do so at their own risk. This was suggested to the PI by Dr. Wayne Patterson at NSF. Mr. Thombley and Dr. Zavala-Garay already agreed to this arrangement and the PI will only consider student applicants if they also agree to this arrangement. In the event that a student does not want to go on field cruises although the student agreed originally, the student can still gain valuable experience by being involved in the cruise planning, instrument preparation, and data analysis, or by being re-assigned to a modeling project.

Three measurement campaigns are proposed:

Central Transects Cross-channel ADCP transects and various CTD casts directly from Zanzibar Town are proposed. They will provide the needed data for the model and also have two practical advantages. One is that the starting point of the transect would be just outside IMS thus avoiding a transit. Another is that most of the central part of the channel is quiet. Therefore, IMS's own research boat, at no cost to the proposed project, can be used and measurements are also easier to conduct. Cruises will carried out during the day whenever possible. A more suitable boat will be rented to make measurements where IMS's own boat cannot go.

If time and resources allow, the transect and CTD casts can be repeated more times to obtain a better average and measurements along different cross-channel transects can be made to obtain information about the horizontal variability.

Northern and Southern Transects Dr. Shaghude has already conducted bathymetry measurements and collected sediment samples in the central channel (Shaghude and Wannäs, 1998). He is currently planning on doing the same in the northern and southern channel in the next few

years while the students are there. He submitted a proposal on this to the Western Indian Ocean Marine Science Association (WIOMSA, www.wiomsa.org) in November 2007. This will be a good opportunity to also make measurements with the ADCP and CTD. A more suitable boat for these measurements will be rented jointly.

Moorings IMS has made no plans yet where, when, and for how long, it will moore the above-mentioned two ADVs and the CTP recorder. It would be an additional experience for the students if they were moored or retrieved while the students are there so that they can participate in their preparation and deployment.

The measurement campaign in the central channel will produce a vertical profile and if time and resources allow also a horizontal section of velocity, salinity, temperature, and pressure with the tidal signal averaged out as well as is possible. This will provide an initial condition for the model. A first rough validation of the model output would be to compare its total mass transport through the channel with these observations. If these quantities are in good agreement more elaborate validations can be made. The measurements in the northern and southern part would provide bathymetry data at a higher resolution than the current one as well as vertical and horizontal sections of velocity, salinity, temperature, and pressure. The moored instruments would provide a time series of velocity, salinity, temperature, and pressure with which the annual variability produced by the model could be validated.

The proposed project will last for three years, which provides the opportunity to repeat the above measurements each year in the same month and thus an average could be obtained. An alternative would be to make these measurements in a different month each year or in at least one year. This would depend whether students would be available if it is not the summer months.

4.4 Environmental Context Projects (revised)

The development of a model of the Zanzibar Channel and the required collection of data is driven by the need to better understand some of the urgent issues affecting the Zanzibar Channel. One is pollution, especially from the rapidly growing city of Dar es Salaam, the capital of Tanzania (on the mainland at the bottom of Fig. 2). The model would help to understand better its dispersion in the channel. Another one is beach erosion, which is particularly serious just north of Dar es Salaam and is affecting the tourist industry there. The model study and data collection will contribute to data and training tools of the Tanzanian component of IOC's capacity building program, and other regional initiatives such as the Kenyan-Tanzanian shoreline change project. A third is the general health of the fragile marine ecosystem in which coral reefs play a vital role. This third issue is also of global importance as there are only few areas in the World Ocean covered by coral reefs, which are the richest repositories of marine biodiversity, and this area is shrinking due to economic development and global climate change (www.gefcoral.org). World Bank's Coral Reef Targeted Research and Capacity Building (CRTR) Program, a partner of the proposed project (see attached letter), is a global network addressing this issue. The Institute of Marine Sciences (IMS) in Zanzibar is a Center of Excellence in this network. The model aims at eventually helping the CRTR program to understand how coral larvae are being dispersed.

There will be no separate environmental context projects as described in the original proposal. However, the students will nevertheless learn about the environmental context to better understand the long-term goal that is the motivation for their focused work on the modeling and data projects. This understanding will be developed by speaking to relevant experts not only at IMS but also at other organizations nearby. The PI is already in contact with such experts at the Tanzania

Meteorology Agency in Zanzibar, the Faculty of Aquatic Sciences and Technology (FAST) of the University of Dar es Salaam, and the Tanzania Fisheries Research Institute in Dar es Salaam. Contacts to the Marine Parks and Reserves Unit and the Tanzania Coastal Management Partnership (TCMP) still need to be made. Furthermore, if relevant workshops or symposia are held by the Intergovernmental Oceanographic Commission (IOC) or the Western Indian Ocean Marine Science Association (WIOMSA) (see attached letter of IOC) in Zanzibar or nearby the students will be encouraged to participate. These activities will not only give the students a general understanding of the environmental problems that the region is facing but also help them to refine the objectives of their modeling and data projects.

5 Education (all subsections revised)

5.1 Continuous Preparation (revised)

It is key to select the students early to allow for a long preparation time and to fully integrate them into the network of people associated with the project. Besides the obvious advantage of giving the students sufficient time and assistance to prepare since they will already be very occupied with their current studies and research, it will also instill in them the feeling of being an integral part of a bigger effort. The advantage of this is that they will become more dedicated. This is one of the essential lessons the PI learned over the past 12 years of sending German undergraduate physics students to study in Nairobi, Kenya through the Berlin-Nairobi Exchange (section 3.3).

The PI will spend a substantial amount of time regularly communicating with the students about everything ranging from practical to cultural and scientific matters and facilitating the communication between the students and others who can help prepare them, including Advisory Committee members (section 6.1), former student participants of the Berlin-Nairobi Exchange, and those who are involved in other NSF IRES projects with Africa.

The preparation time will especially allow to ensure that the students' projects are designed such that they become an integral part of the students' US academic programs and that the students are fully supported by their advisors. In the original proposal the PI refrained from setting this concrete goal since he deemed in unrealistic. However, his recent advertisement campaign (section 6.3) revealed that most interested students are keen and able to achieve exactly this. Furthermore, two institutions in particular, the Oregon State University and the University of California at San Diego (UCSD), are officially offering to work with their students and the PI to ensure such an integration (see attached letters of Dr. Harte and Dr. Teranes, respectively).

The PI will hire a student to assist him with the project management. If one of the participating students is at UCSD or any other institution in the San Diego area, where the PI is based, the PI would hire this student as his assistant. This participating student would then have the additional benefit of learning more about the organizational aspects of this proposed project.

5.2 Preparation Meeting (revised)

The continuous preparation described in the previous subsection will be complemented by a 4-day meeting in La Jolla, CA, where the PI is based. This is in contrast to the suggestion in the original proposal to hold the meeting in a different location each year, because many people involved in the proposed project are based at the Scripps Institution of Oceanography (SIO) in La Jolla, CA. These meetings will bring together the participating students, Dr. Javier Zavala-Garay, a physical oceanographer at the Institute of Marine and Coastal Sciences, Rutgers University, who will be with the students at the Institute of Marine Sciences (IMS) in Zanzibar and supervise their projects, Robert Thombley, a technician at SIO, who will be at IMS in Zanzibar in the first year to help set up

and use the oceanographic instruments that will be taken to Zanzibar for the first time (section 4.3), and Dr. Sharon Franks, an educational program specialist at SIO, who will advise and assess the students and be in general responsible for the evaluation of the proposed project (section 6.4). In the first year, Mrs. Mayorga-Adame, who carried out the PI's first student project at IMS in Zanzibar in the summer of 2007 (section 2), will also participate. Besides these committed participants, others might join the meeting. For example, several SIO students and faculty members have offered the PI to give presentations. Dr. Brian Arbic, a physical oceanographer at the University of Texas, has offered to participate at no cost to the proposed project to speak about his three years as a US Peace Corp volunteer in West Africa (see attached letter).

The meeting will consist of presentations and discussions addressing all practical, cultural, and scientific issues and of sessions in which the committed participants discuss their individual expectations and objectives and then, as a group, formulate a concrete common agenda for the time at IMS in Zanzibar. The purpose of the meeting is therefore to draw together the results from all the discussions that will have taken place prior to the meeting, as described in the previous subsection. By actively contributing to the development of an overall agenda for the time in Zanzibar the students will have formulated goals for themselves and thus be far more motivated to pursue these goals than if they would just be assign a pre-defined project. The process of collectively developing an agenda will also promote team building among all committed participants.

5.3 Zanzibar (revised)

At the Institute of Marine Sciences (IMS) in Zanzibar, comprehensive mentoring of the students will be crucial to their success and the success of the entire proposed project. It will primarily be provided by local senior scientists and Dr. Javier Zavala-Garay, a physical oceanographer at the Institute of Marine and Coastal Sciences, Rutgers University, who will spend 1.5 months during the students' 2-month stay in Zanzibar (attached "Biographical Sketch" and letter). Further mentoring will be provided up on demand by members of the Advisory Committee, which the PI will co-ordinate. In particular, support will be provided by the members Prof. Chris Reason at the University of Cape Town in South Africa, who has developed a ROMS model of the Western Indian ocean (section 4.2) and Robert Thombley at the Scripps Institution of Oceanography, who will set up the oceanographic instruments. Both will be visiting the IMS in the first year.

Local IMS senior scientists will be dedicated to providing the best support to the students because coastal modeling is one of their top priorities as described in section 3.2. The extraordinary commitment IMS is willing to make is represented in the fact that Dr. Alfonse Dubi, the Director of IMS, personally supervised the PI's previous student in the summer of 2007 (section 2). Dr. Yohanna Shaghude, a senior scientist at IMS, (see attached "Biographical Sketch") is also already involved and helped the PI devise the data projects presented in section 4.3.

Dr. Zavala Garay will spend each year 1.5 months with the students at IMS, receiving his usual salary for 1 month and volunteering for 0.5 months. He is using the Regional Ocean Modeling System (ROMS), which will be used in the proposed project (section 4.2), in his own research. Besides his on ROMS applications he is already intimately familiar with the ROMS application of the Zanzibar Channel developed by the PI's previous student (section 2) because he advised her remotely while she was at IMS in Zanzibar. He also trained a visiting scientist from Mexico on ROMS and is offering the same training to IMS scientists, which would contribute to capacity development at IMS. Dr. Zavala-Garay has also extensive experience in oceanographic campaigns, mainly in the acquisition of hydrographic data using a CTD. He has participated in several oceanographic cruises in the Gulf of California with research institutes from Mexico, the "Joint Air-Sea Monsoon Interaction Experiment (42 days in east Indian Ocean and Bay of Bengal, 1999), and the

North American Monsoon Experiment (Gulf of California, summer 2004). Dr. Zavala-Garay's past research and educational work will make him an ideal advisor to the participating students.

Prof. Chris Reason (see attached "Biographical Sketch" and letter), will help guide the model projects presented in section 4.2, especially because his and Dr. Juliet Hermes' ROMS model of the tropical Western Indian Ocean (Hermes and Reason, 2008) will be studied and possibly re-configured and re-run by the students. Prof. Reason will therefore visit IMS in the first year. Because two IMS scientists are currently taking the Master's course on Applied Marine Science in Prof. Reason's department, Prof. Reason suggested that their theses could be contributions to the proposed project and his visit to Zanzibar will help bring these various efforts together. Prof. Reason has a unique perspective on Africa, having supervised many African students including two Tanzanian Master students (Kijazi, 2003; Ngwali, 2007), who now work at the Tanzania Meteorological Agency, and he is also the co-Chair of CLIVAR Africa.

Robert Thombley (see attached "Biographical Sketch" and letter), a technician at the Scripps Institution of Oceanography (SIO), who will visit IMS in the first year to supervise the use of the instruments on loan from SIO, will also teach the students about the instruments.

Besides these close advisors, the students will be actively encouraged during the preparation phase to approach also other experts that can give advice. Beyond IMS, the PI has already established contacts to other local institutions (section 4.4).

Each summer undergraduate students from the University of Dar es Salaam come to IMS in Zanzibar to carry out research internships as part of their studies. The PI cannot guarantee that they will be sufficiently qualified to play a minor role in the data projects but they will certainly be fully involved in the data projects, thus building possibly long-lasting relations to the US students.

5.4 Continued Involvement (revised)

The interdependence of the individual student research projects, not only of one year but also between different years, the team building effort, and the integration of the students' projects into the students' US academic programs will encourage the students to remain involved for the remainder of the proposed project. More generally, the proposed project offers research experiences in a different environment and context than their research experience at home. This will allow the students to envision additional career paths and thus motivate them to remain engaged in science.

6 Organization (three subsections revised)

6.1 Advisory Committee

All members of the Advisory Committee for the proposed project listed below have already substantially contributed to the PI's previous NSF-supported student project (section 2) and to developing this proposal. The PI is therefore certain that they will remain committed and thus provide diverse and invaluable advice.

L: Support letter is appended; **B**: "Biographical Sketch" is included

Clinton Winant (L), professor at the Scripps Institution of Oceanography (SIO), advises on ROMS and observations and provides an instrument (ADCP).
Gabriela Mayorga-Adame, graduate student at Oregon State University, carried out the PI's previous student research project at the Institute of Marine Sciences (IMS) in Zanzibar.
Javier Zavala-Garay, scientist at Rutgers University, advises on ROMS.

Emanuele Di Lorenzo (L), professor at the Georgia Institute of Technology, advises on ROMS and provides computer cluster.
Alfonse Dubi (L,B), director of IMS in Zanzibar, advises on all aspects of oceanography of the Zanzibar Channel.
Sharon Franks (L), co-director of the Scripps Center of Educational Outreach Connections, assists with recruiting, mentoring, evaluation, and dissemination.
Francois Colas, postdoc at UCLA, advises on ROMS.
Martin Theiss, formerly at Proctor & Gamble (biggest consumer goods company) and currently marketing director at Danone U.K. (Dannon in the U.S.) leading a team of 20 people and overseeing a budget of about $80 million, advises on recruiting as well as on team building, leadership, and assessment.
Yohanna Shaghude (B), scientist at IMS in Zanzibar, advises on observations and will be chief scientist on research cruises.
Chris Reason (L,B), professor at the University of Cape Town, advises on ROMS and will visit IMS to work with the students.
Brian Arbic (L), formally U.S. Peace Corps volunteer for three years in West Africa and currently senior oceanographer at the University of Texas, advises on living in a different culture.
Aurelien Ponte, graduate student at the SIO, advises on ROMS and observations.
Andrey Shcherbina, postdoc at APL at the University of Washington, advises on ROMS and observations.
David Hill, professor at Pennsylvania State University, advises on the ADCIRC model.
Nicolas Le Dantec, graduate student at the SIO, advises on observations.
Robert Thombley (L), technician at the SIO, advises on equipment, provides an instrument (CTD), and will visit IMS to work with the students.
The **Intergovernmental Oceanographic Commission (IOC)** (L) and the **World Bank** (L) both provide advice as institutions.

6.2 Timeframe (revised)

The proposed project will continuously be advertised. The formal application process will be from June to September, the 4-day preparation meeting will be between January and March, subject to the availability of all proposed participants, and the 2-month student projects in Zanzibar from mid-June to mid-August.

The modeling projects will produce a series of model studies of increasing complexity and at the end of the proposed project the last model in this series should produce an annual cycle that resembles the real annual cycle as closely as possible. The timeframe for the data projects is simple. Each year the measurement campaigns described in section 4.3 will be repeated.

6.3 Recruitment (revised)

To recruit the best students nationwide the PI will be advised by Dr. Sharon Franks and Martin Theiss (section 6.1), who have complementary experiences in professional recruiting. The PI will also draw from his 12 years of experience in recruiting German undergraduate physics students to study one academic year in Nairobi, Kenya (section 3.3).

Before the original proposal was declined the PI had already started advertising the proposed student projects in Zanzibar in the summer of 2008 in order to have a pool of candidates in case the original proposal would have been successful. This advertisement campaign resulted in 11 students expressing an interest and most of them are now also interested in participating in the summer of 2009. It is also encouraging that they consider the student projects perfect for their Master's

thesis, a senior project class or to count as an internship. A full integration of the students' projects in Zanzibar into the students' US academic programs now appears realistic. The PI also learned that students have only time for two rather than three months in the summers to carry out their projects in Zanzibar and therefore a duration of only two months is now proposed.

To advertise the proposed project two effective channels are the Coastal List of the University of Delaware, with over 1,700 subscribers, and the ROMS User Forum with over 1,300 members, which reaches practically everyone that uses ROMS. The PI will also ask his colleagues at various US institutions to advertise. The following US institutions have officially stated that they will advertise the proposed project: Woods Hole Oceanographic Institution (James Yoder, Dean), Oregon State University (Lori Hartline, Office of Student Programs of COAS), Hampton University (Benjamin Cuker, Professor), University of Washington (Russel McDuff, Director of the School of Oceanography), and University of Miami (Larry Peterson, Associate Dean of RSMAS). Furthermore, the additional letters of the Oregon State University (Dr. Harte) and the University of California at San Diego (Dr. Teranes) state that they will also work with their students and the PI to make the students' projects in Zanzibar an integral part of the students' US academic programs.

The PI wants to recruit a diverse group of students each year, which is motivated by his own background. He grew up in an environment where it was not understood that one attends university. He has therefore always experienced his life in academia as a privilege rather than an entitlement. Naturally he enjoys working with like-minded people, who have emerged from a variety of diverse backgrounds. Such a diversity of people is not only enjoyable but can increase their overall productivity. The more diverse people are, the greater is the variety of ways to tackle scientific questions and to adept to a new cultural environment. For the proposed project both of these benefits are of importance. One student might successfully address a specific scientific question but might be unable to cope with the very different way of life in Zanzibar. If the group of students is diverse they will experience different difficulties and thus be able to support each other and also become a true team in this way. As a result, not only the research will benefit from diversity but also the general well-being of the group of students.

To succeed in recruiting a diverse group of students, the PI will work with Dr. Benjamin Cuker of Hampton University (see attached letter), who is dedicated to fostering diversity in the marine sciences. For example, he can advertise the proposed project in his Multicultural students in Aquatic Sciences newsletter. Also, Dr. Sharon Franks (see attached letter) at SIO has contacts to many colleges and universities with students from various under-represented groups.

Interested students will be asked to express simply and informally their interest to the PI. This will give the PI a first impression of the number and quality of potential candidates. Depending on the number, all or selected candidates will be asked to submit an application consisting of a CV, an essay on the motivation to participate in the proposed project, and a reference letter of the advisor. A subcommittee of the Advisory Committee (section 6.1), chaired by the PI, will be formed to review the applications, conduct telephone interviews, discuss with the candidates' advisors their concrete involvement, and finally select the students.

6.4 Assessment (revised)

Three evaluation questions, aligned with the educational goals of the project, will guide the PI's assessment:
1) To what extent does participation in this research experience impact students' attitudes and motivation with respect to collaborative, international research?
2) What educational gains are made by the students in terms of increased content knowledge and improved interpersonal and communication skills?

3) How relevant and useful is the experience in terms of the students' progress and ultimate completion of the US academic programs in which they are enrolled?
Formative and summative evaluation conducted during and after the preparation and experiential stages of the project will yield qualitative and quantitative data about educational impact of students' international research experiences. The project team will collaboratively develop evaluation instruments including semi-structured interviews and simple surveys designed to document changes in students' awareness, understanding, and attitudes as a result of their experiences. Informal communications amongst students, the PI and the on-site mentor Dr. Javier Zavala-Garay will provide valuable supplementary information. Funds have been requested in a separate proposal to support the involvement of Dr. Sharon Franks (see attached "Biographical Sketch" and letter) to serve as an external evaluator in overseeing the development and administration of the evaluation instruments, as well as analysis, interpretation and reporting of the data collected.

6.5 Dissemination of results

All students will be asked to produce regular progress reports, which will be posted on a website and announced to a growing list of people with an interest in the PI's collaboration with IMS in Zanzibar. The Western Indian Ocean Journal of Marine Science (www.wiomsa.org → Publications) represents a suitable publication to publish work produced each year. At the very end of the proposed project the overall results will be published in a more internationally known journal like the Journal of Geophysical Research. The final report of the PI (see subsection above) will be publicly available through the project's website and send to all parties associated with the proposed project. Conferences that the PI and students will attend because of their other work will also be used as an opportunity to present research results and general experiences with running or participating in the proposed project. The collected data will be submitted to oceanographic databases. In particular, IOC has already expressed an interest to make the data available through the National Ocean Data Center for Tanzania (www.nodc-tanzania.org).

6.6 Leveraging U.S. and foreign resources

Resources provided to the proposed project at no cost are: A CTD and an ADCP from the SIO (appended support letters of Dr. Ralf Goericke and Dr. Clinton Winant); Processing time on a computer cluster at the Georgia Institute of Technology (appended support letter of Dr. Emanuele Di Lorenzo); A research boat, housing, facilities, especially computers, from the Institute of Marine Sciences in Zanzibar (appended support letter of Dr. Alfonse Dubi).

6.7 Practical matters

The PI has gained a good understanding of the practical matters, such as visas, vaccinations, and travel insurance, through his previous student project at IMS. Because IMS's guesthouse might not be able to accommodate all five students each year, IMS will assist in finding local accommodation near IMS for rent at local rates. The equipment borrowed from the SIO will be fully insured against damage and loss. The PI will use Customhouse Marine Insurance Services of the H.T. Bailey Insurance Group, which is the one also used by the Woods Hole Oceanographic Institution.

References

Chapman, P., S. Di Marco, R. Davis, and A. Coward: 2003, Flow at intermediate depths around Madagascar based on ALACE float trajectories. *Deep-Sea Res. II*, **50**, 1957–1986.

Committee on Science, Engineering, and Public Policy (COSEPUP): 1995, *Reshaping the Graduate Education of Scientists and Engineers*. National Academy Press, Washington, DC.

Harden, B.: 1990, Good intentions. *Africa: Dispatches from a fragile continent*, W.W.Norton, New York - London, chapter 5, 177–216.

Harvey, J.: 1977, Some aspects of the hydrography of the water off the coast of Tanzania: A contribution to CINCWIO. *University Science Journal - University of Dar es Salaam*, **3**, 53–92.

Hellerman, S. and M. Rosenstein: 1983, Normal wind stress over the world ocean with error estimates. *J. Phys. Ocean.*, **13**, 1093–1104.

Hermes, J. and C. Reason: 2008, Annual cycle of the South Indian Ocean (Seychelles-Chagos) thermocline ridge in a regional ocean model. *J. Geophys. Res.*, in press.

Kijazi, A.: 2003, *Teleconnections between seasonal rainfall in coastal Tanzania and ENSO*. M.Sc. thesis, University of Cape Town, South Africa.

Mohammed, S., A. Ngusaru, and O. Mwaipopo: 1993, Determination of the effects of pollution on coral reefs around Zanzibar Town. A technical report to the National Environment Managment Council), Dar es Salaam, Tanzania. Technical report, Institute of Marine Sciences, Zanzibar, University of Dar es Salaam.

Newell, B.: 1957, A preliminary survey of the hydrography of the British East Africa Coastal waters. Colonial Office Fishery Publication 9, HMSO, London.

Ngusaru, A. and S. Mohammed: 2002, Water, salt and stoichiometrically linked nutrient budgets for Chwaka Bay, Tanzania. *Western Indian Ocean J. Mar. Sci.*, **1**, 97–106.

Ngwali, M.: 2007, *Sea level and climate variability at Zanzibar*. M.Sc. thesis, University of Cape Town, South Africa.

Richmond, M.: 1997, *A guide to the seashores of Eastern Africa and the Western Indian Ocean islands*. Sida/Department of Research Cooperation, SAREC.

Shaghude, Y. and K. Wannäs: 1998, Morphology and sediment distribution of the Zanzibar Channel. *Ambio*, **27**, 729–733.

Shaghude, Y., K. Wannäs, and S. Mahongo: 2002, Biogenic assemblage and hydrodynamic settings of the tidally dominated reef platform sediments of the Zanzibar Channel. *Western Indian Ocean J. Mar. Sci.*, **1**, 107–116.

Shchepetkin, A. and J. McWilliams: 2005, The Regional Ocean Modeling System: A split-explicit, free-surface, topography following coordinates ocean model. *Ocean Modelling*, **9**, 347–404.

Shetye, S. and A. Gouveia: 1998, Coastal circulation in the North Indian Ocean. *The Sea*, A. Robinson and K. Brink, eds., John Wiley and Sons, Inc., volume 11, chapter 18, 523–556.

Swallow, J.: 1991, Structure and transport of the East African Coastal Current. *J. Geophys. Res.*, **96**, 22,245–22,257.