Deep Madagascar Basin (DMB) Experiment: A Quest to Find the Abyssal Water Pathways in the Southwest Indian Ocean

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Submitted to the National Science Foundation

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Proposal Summary

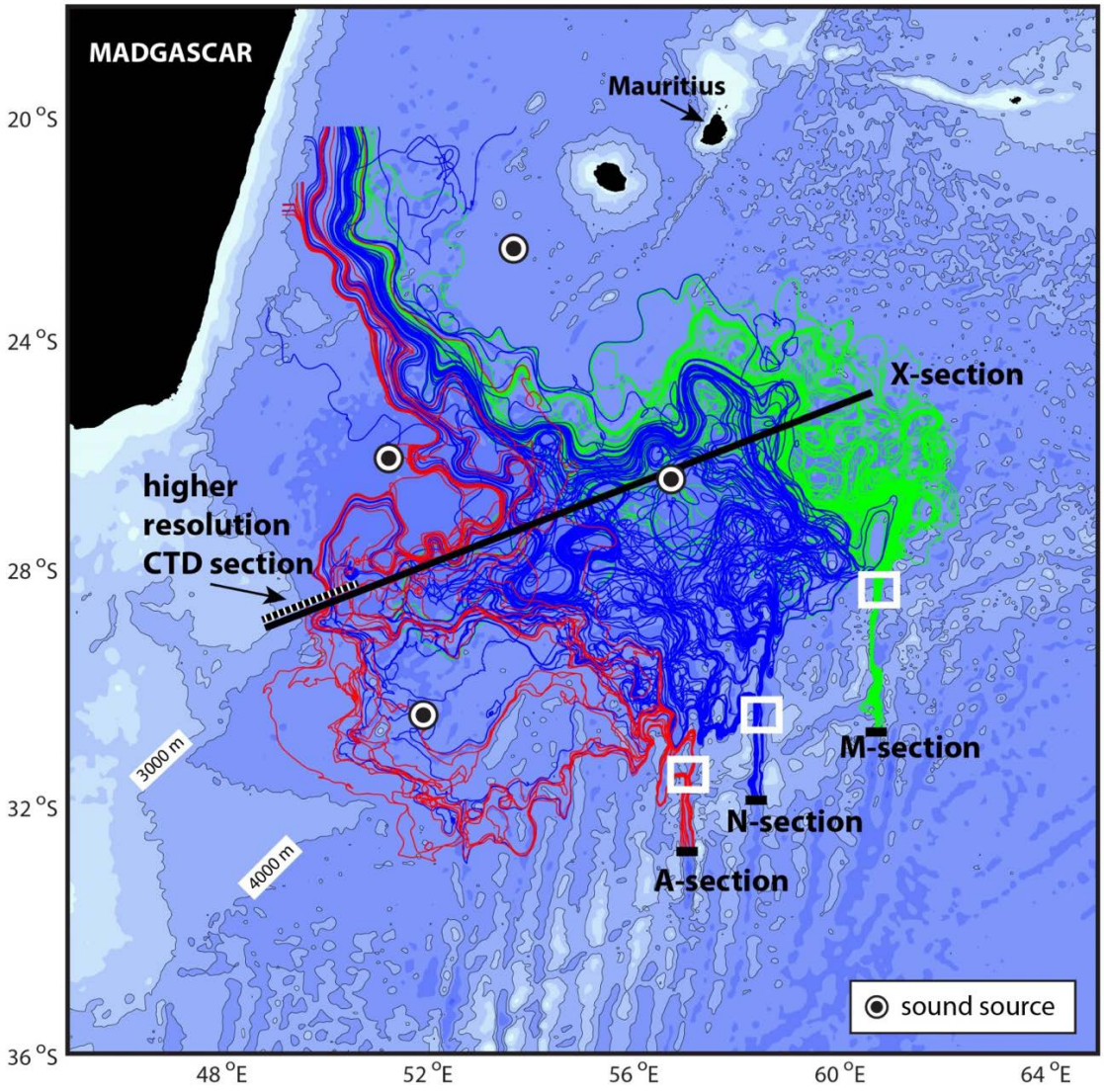
Overview: The deep and abyssal (> 4000 m) oceans both store and redistribute heat, freshwater, carbon, and other substances, and play a crucial role in regulating the Earth's climate on multidecadal to millennial timescales. Repeated hydrographic observations from the last three decades have revealed compelling evidence of changes in these deep oceanic layers. In the Southern Hemisphere, abyssal warming is widespread, except in the Crozet, Madagascar and Mascarene basins in the southwestern Indian Ocean where anomalous cooling exists. At least half of the northward inflow of southern-origin abyssal waters in the whole Indian Ocean (IO) is through these basins (in the IO, no deep or bottom water is formed in the North). Could the cooling be an alias due to sampling bias since few observations exist? In 2018, after 23 years, the US GO-SHIP program occupied for a second time the I07N line in the western IO. The section started about 270 km north of the Atlantis II fracture zone, a main gateway for the abyssal water into the Deep Madagascar Basin (DMB). A comparison between the new and previous observations revealed an unexpected and massive (10 to 40 times) increase in chlorofluorocarbons (CFCs) below 3500m. The CFC increase implies that the DMB abyssal water has been replenished between 1995 and 2018, and may indicate changes in the strength of deep Indian Ocean Meridional Overturning Circulation (IMOC). A back-of–the-envelope calculation using the CFC and SF6 (Sulfur hexafluoride) partial pressure ratio indicates that part of the DMB abyssal waters may have been in contact with the atmosphere as recently as the mid-1990s. Where did these CFC-rich abyssal waters come from, and by which pathways have they spread in the DMB?

Intellectual Merit: The proposed research will investigate the largely unknown DMB abyssal circulation, how abyssal temperature varies in the DMB interior and the effects of the tortuous seafloor topography in steering the DMB abyssal flows. The primary objective is to find out by which pathway(s) the CFC-rich abyssal water that enters through deep fracture zones in the Southwest Indian Ridge (SWIR) spreads in the basin, which is crucial for a better understanding of the IMOC and its variability. Two existing, and conflicting, hypotheses guide the proposed work. One hypothesis is that a continuous, narrow, well-defined, and permanent Deep Western Boundary Current transports this water. A second hypothesis is that a northwestward interior flow between 30ºS-23ºS also exists, and contributes to the spreading of younger abyssal waters across the DMB. To determine the pathways and the transformation of the abyssal waters in the DMB interior an array of 75 neutrally buoyant RAFOS floats and 3 deep SOLO Argo floats will be deployed, complemented by hydrographic sections (including tracer analysis) across the mid-basin and the fracture zones. The in-situ observations will be paired with a state-of-art modeling component, which will be used to investigate the underlying dynamics and time evolution of the deep flow field. The proposed research will be a US contribution to the 2nd International Indian Ocean Expedition (IIOE-2) and will provide the first direct estimate of the abyssal circulation and temperature variability in the DMB on a basin-scale. It will also give the first quasi-synoptic volume transport estimates of the three most significant fracture zones in the SWIR, which are vital to quantifying the IMOC strength.

Broader Impacts: The project will support two undergraduate students that will be selected to participate in the DMB cruise. The PIs will also host and mentor UCAR's Significant Opportunities in Atmospheric Research and Science and Woods Hole Partnership in Education students for each summer. Scripps Undergraduate Research Fellowship students will also be mentored each summer. Moreover, the cruise will be available to the IO community in general for piggy-back projects, and in particular for Mauritius' oceanographers and students, the start and end port for the cruise.

The DMB Observational Experiment

The observational program consists of: (a) 75 Lagrangian RAFOS floats, which will map out the flow and temperature fields at one pressure level; (b) a high spatial resolution CTD survey, to provide full-water column snapshot of ocean properties; (c) Three Deep SOLO Argo floats. The observational program will be implemented using a single 24-day cruise stationed out of Port Louis, Mauritius.



Map of the DMB field program, along with trajectories of all virtual floats at 4100 m deployed inside the fractures zones that reached the DWBC. Red is used for floats that were initialized at the Atlantis II, blue for Novara and Green for Melville. ETOPO-2 bathymetry is shaded every 1000-m. The A-, N-, M-sections will have five CTDs each; the X-section will consist of 24 CTD stations and RAFOS float deployment will be performed along this section. In the western end of the X- section, the CTD stations will be more closely spaced. The white boxes indicate the fracture zone exits where RAFOS floats and deep SOLO Argo floats will be deployed.

CTD Survey

In the DMB experiment, four CTD/tracer sections will be occupied: the longest ones will be the X-section transecting the DMB basin, along which the RAFOS floats will be also deployed (see map), and three short sections transecting the fracture zones (A-, N- and M-sections). For each of the 42 planned stations, CTD and bottle measurements (salinity, dissolved oxygen, nutrients and CFCs/SF6 tracers) will be collected. Bottle data will consist of 24 discrete levels (surface to bottom), and a staggered station scheme will be used in each section to improve the resolution of vertical gradients (similar to

the schemes used for the GO-SHIP sections). Geostrophic current and volume transports at each section will be estimated using the hydrographic data referenced to the shipboard ADCP (Acoustic Doppler Current Profiler) that will be collected during the cruise and processed by the WHOI ADCP group.

Scripps Institute of Oceanography's Ocean Data Facility (ODF) will collect, calibrate and process the CTD and bottle data, ensuring high-quality measurements commensurate with that achieved by US GO-SHIP program. Tracer sampling and analysis will be performed by the Tritium Laboratory, Rosenstiel School of Marine and Atmospheric Science, University of Miami, at the same high-quality level as the US GO-SHIP cruises.

The X-section across the DMB basin will consist of 24 stations with higher horizontal resolution near the Madagascar Plateau and lower resolution in the DMB interior (with an average of 50 km). The A-, N- and M-sections in the three SWIR fracture zones will consist of five stations each, with stations spacing of about 5-10 km. These unique quasi-synoptic observations will reveal the similarities and difference in the vertical structure of temperature, salinity, oxygen, current and nutrients of the fracture zone outflows. It will also allow us to estimate for the first-time the Novara and Melville abyssal outflow transport magnitude in relation to the Atlantis II. For verification purposes, three additional CTD casts will be performed at the deployment sites of each of the three deep Argo floats.