Utilization of Global Bathymetric Data to Characterize Large-Scale Bedforms in Atlantic Submarine Basins

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BACKGROUND

Bathymetric data are integral to oceanographic research across a wide scope of scientific disciplines because these data provide unique marine geophysical information describing details of the seafloor. GMRT Synthesis provides the public with a repository of marine science research tools, including 100 m resolution bathymetric surfaces. Knowledge of deep sea bedform morphology and stability can be used to understand deep water current flow and circulation patterns which can be analyzed in respect to climate change.

Submarine sediment waves are defined as dome or crescent shaped bedforms with a wave ridge line perpendicular to the main flow direction of the continental shelf (Yincan, 2006). Utilizing bathymetric data provided through Global Multi-Resolution Topography GMRT Synthesis, a comparative study can be generated among three Atlantic Ocean submarine basins (Argentine, Atlantic, and Labrador) where such bedforms exist. The purpose of this study is to compare the orientation, symmetry, and peakedness of deep-water bedforms to better understand wave bedform genesis. A previous study conducted by Dawson and Sautter (2018) on sandwaves at Lucifer Shoals, Ireland detected a correlation in the symmetry of waves and current velocity.

The Argentine Basin (depth: 5.5 to 5.6 km), located in the southwestern South Atlantic Ocean, has the highest sediment input of the three study areas because of its location close to the source of Antarctic Bottom Water (Flood and Manely, 1993). In Project MUDWAVES, large sediment drifts, created by this vigorous bottom water flow were observed to have heights of at least 150 m and wavelengths of up to 10 km (1993). High resolution multibeam data are scarce for this basin, limiting the scope of observation. The Atlantic Basin (depth: 4.7-5.0 km) site is located approximately 87 km east of Cape Hatteras, NC where both the North Atlantic Deep Water (NADW) and Gulf Stream flow. The Labrador Basin (depth: 3.2–3.6 km) in Newfoundland. The NADW flows through this basin as it turns southward. Each site is located approximately 500-600 km off the continental shelf break.

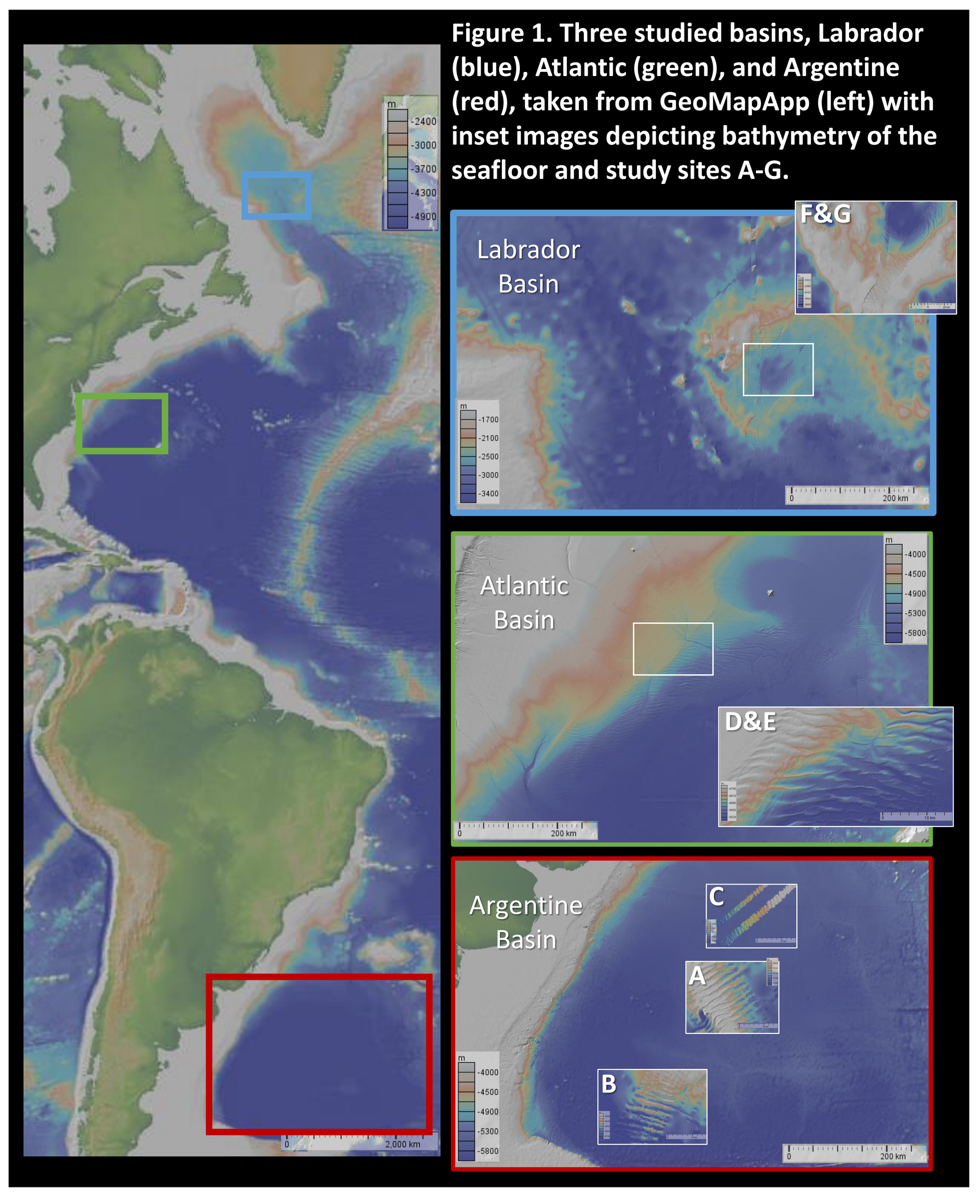


Figure 1. Three studied basins, Labrador (blue), Atlantic (green), and Argentine (red), taken from GeoMapApp (left) with inset images depicting bathymetry of the seafloor and study sites A-G.

ABSTRACT

Through bathymetric analysis, marine geophysical information can be utilized in oceanographic research throughout multiple scientific disciplines. The Global Multi-Resolution Topography (GMRT) Synthesis provides access to high resolution multibeam data acquired throughout the global ocean, with a focus on data from the US Academic Research Fleet. GMRT Synthesis 100 m resolution products allow for the generation and analysis of detailed ocean floor geomorphology visualizations. Knowledge of deep sea bedform morphology and stability can be used to understand deep water current flow and circulation patterns. Large-scale undulating bedforms were observed in three focus areas for which high-resolution multibeam data exist, including the Labrador Basin, the Atlantic Basin and the Argentine Basin. Study sites are located on the abyssal plain, 500 to 600 km off the continental shelf break. The observed bedforms vary in size and have average heights ranging from 120 m in the Argentine Basin to 40 m in the Labrador Basin, with wavelengths as great as 10 km. A unified understanding of the morphological classification, formation/development mechanisms, and dynamic migration of these bedforms does not exist at this time, nor have comparisons been made across these different environments.

This study explores the morphology of deep-water bedforms to better understand mechanisms of their formation. GeoMapApp was utilized to analyze and generate cross-sectional profiles of sediment wave geometry and orientation to infer bottom current direction. Symmetry and peakedness were calculated and compared to extant circulation maps to determine the regional dominant current. The Argentine Basin was observed to have strongly opposing currents , The Atlantic Basin was found to have bidirectional currents with large linear wavelengths up to 8.5km, while arced 1.91km wavelength waves with consistent heights and symmetry were detected in the Labrador Basin. Climate research would benefit from observations of temporal change in these bedforms.

Figure 2. 3D rendering of 100m resolution surfaces depicting the bathymetry of The Argentine, Atlantic, and Labrador Basins (VE 10x).

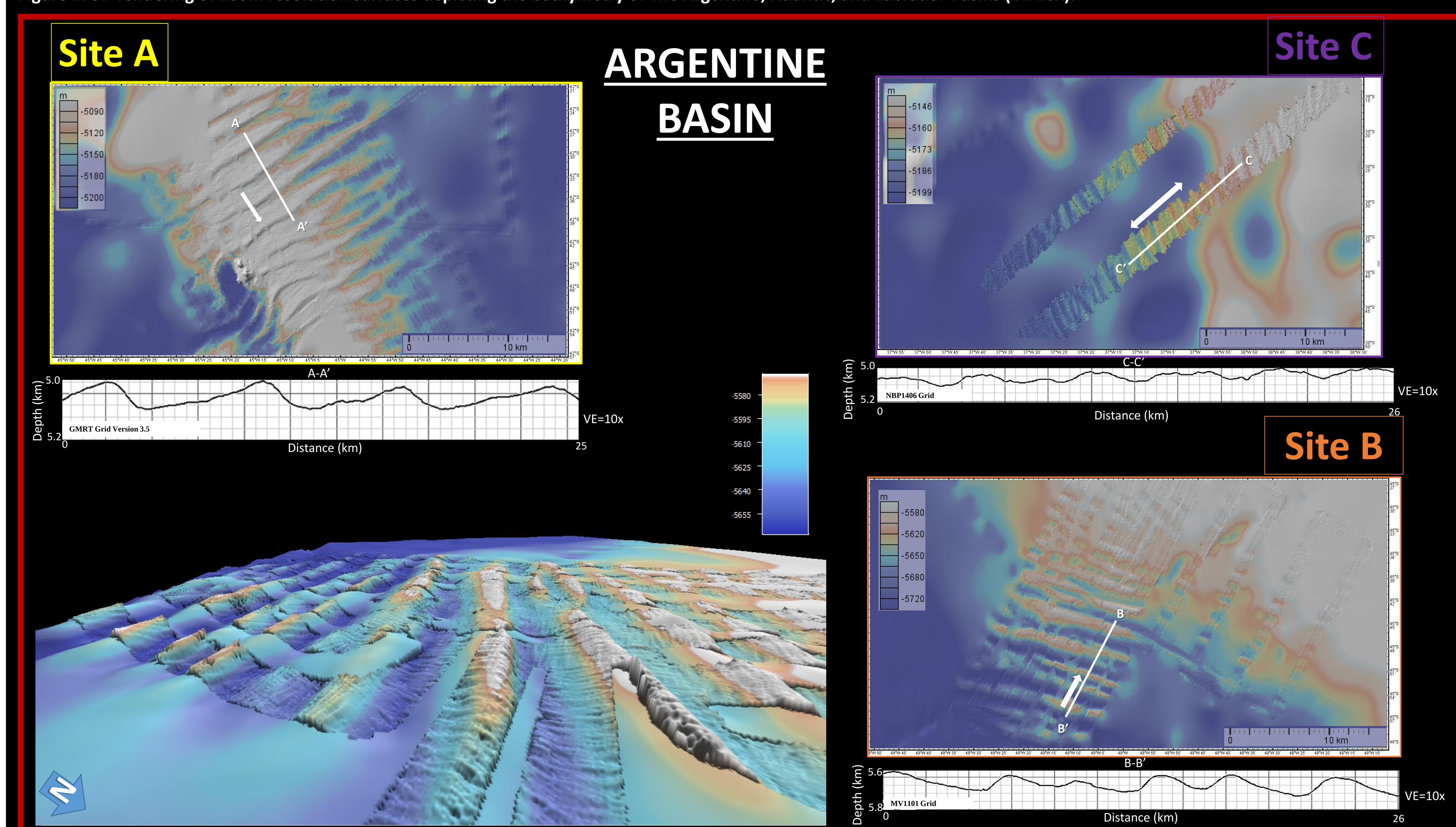
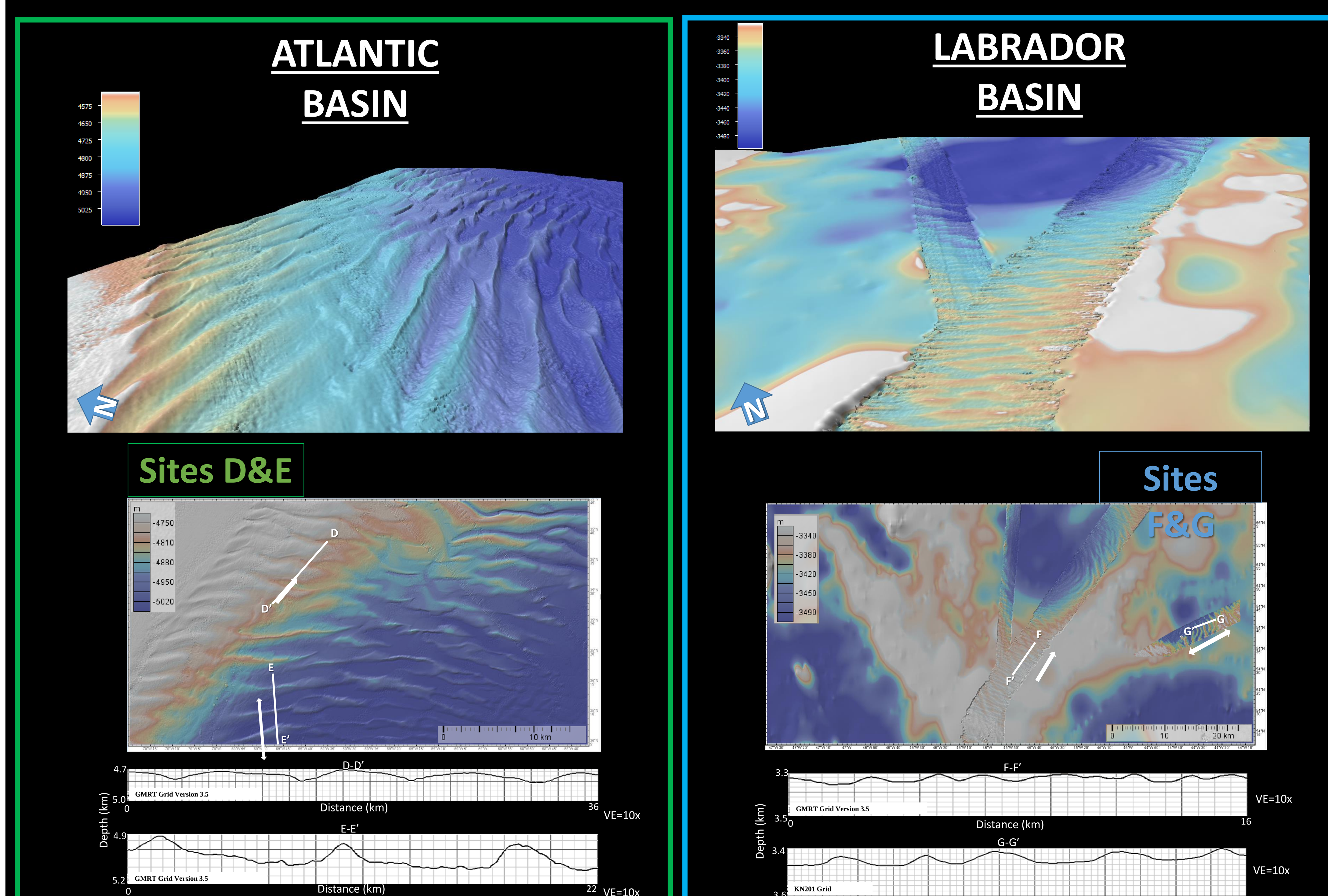


Figure 3. ***Sites A-G*** **Bathymetric depictions of each site within the studied basins. Profiles taken from north to south. Profiles were taken of both extant surveys merged into GeoMapApp and surveys which are being processed through the GMRT Synthesis workflow as indicated on profile. Gaps of low resolution imaging represent predicted bathymetry. Arrows on 2D bathymetric images indicate current direction, but not magnitude.**



METHODS

- Multibeam data were collected aboard multiple vessels spanning from 1984 to 2015.
- Interdisciplinary Earth Data Alliance (IEDA) processed and merged surveys into GMRT Synthesis and GeoMapApp for public use and research (Fig. 1).
- 100 m resolution 3D surfaces were generated using QPS Fledermaus and draped on the predicted bathymetry (Fig. 2).
- Seven sites (A-G) within the Argentine, Atlantic, and Labrador basins, were chosen based on the presence of large sediment bedforms and variability of wave morphology (Fig. 3).
- Measurements were made from north to south profiles to determine crest to crest wavelengths. Individual sediment waves were measured for their base length (on both the north and south sides), and height (Fig. 4).
- Symmetry was determined by dividing the south base length by the north base length and evaluated by relating current dominance with respect to 1, where 1 indicates symmetry and bi-directional currents.
    - Values less than 1 indicate a **northward current**
    - Values greater than 1 indicate **a southward current**.
- Peakedness was calculated by dividing wave height by total base length.
- Results were compared to known circulation patterns (Fig. 5).

$$\text{Symmetry} = \frac{\text{South Base Length}}{\text{North Base Length}} \qquad \text{Peakedness} = \frac{\text{Height}}{\text{Total Base Length}}$$

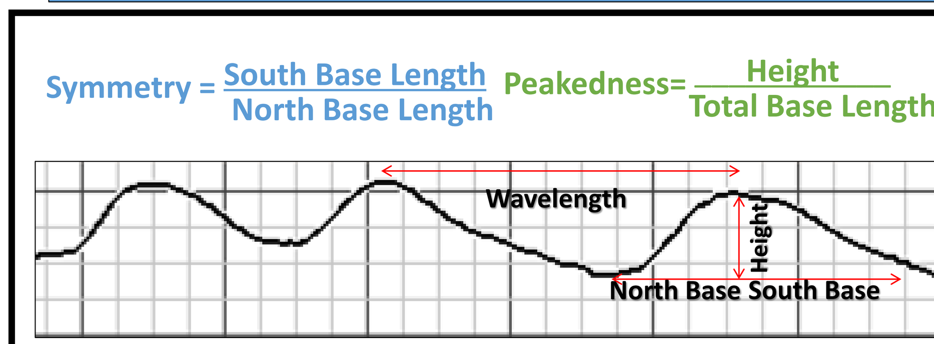


Figure 4. Measurements used to calculate Symmetry and Peakedness as derived from Dawson and Sautter (2018).

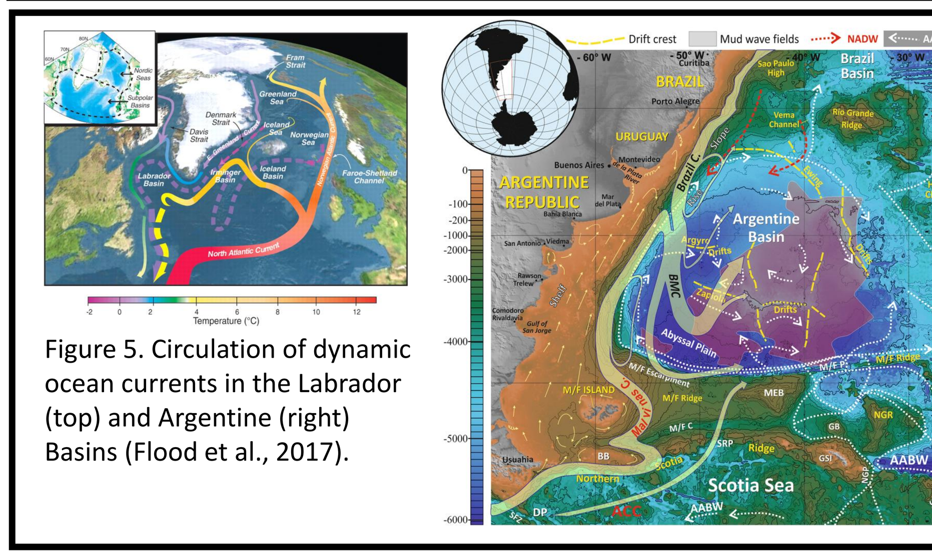


Figure 5. Circulation of dynamic ocean currents in the Labrador (top) and Argentine (right) Basins (Flood et al., 2017).

Table 1. Average wavelength, height, and base lengths of bedforms, measured along north-to-south profiles.

Site	Wavelength (km)	Height (km)	North Base (km)	South Base (km)	Symmetry	Peakedness
Argentine						
A-A’	6.33	0.12	3.75	1.92	0.51	0.02
B-B’	4.11	0.11	1.46	2.49	1.70	0.03
C-C’	4.41	0.06	2.01	2.19	1.08	0.01
Atlantic						
D-D’	8.50	0.12	3.86	5.13	1.33	0.01
E-E’	7.60	0.14	1.25	1.42	1.13	0.05
Labrador						
F-F’	1.91	0.03	0.69	0.88	1.27	0.02
G-G’	2.69	0.04	0.79	0.89	1.14	0.02

Figure 6a. (below) Profiles of waves from sites B, D, and F at the same scale compared to the height of the Washington Monument (169m) and the length of the Lincoln Monument Reflecting Pool (618m) indicated by the teal line.

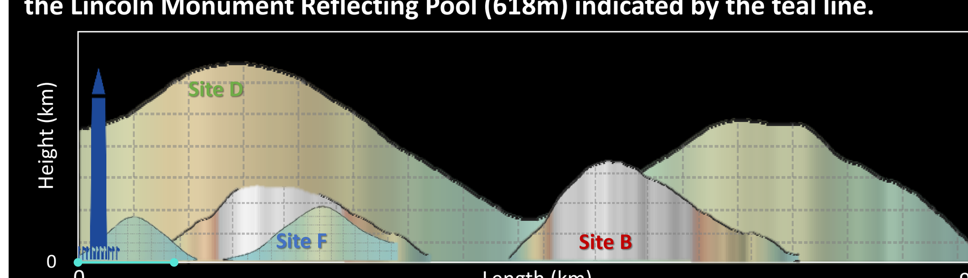
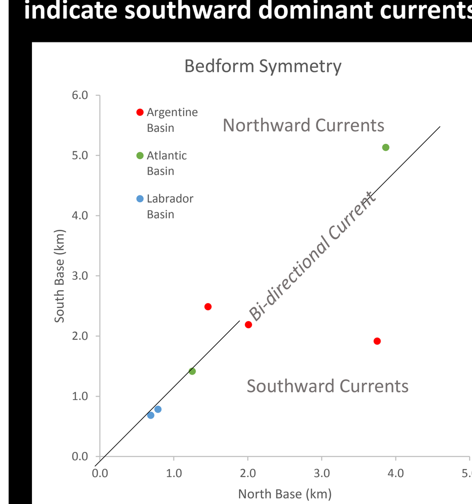


Figure 6b. (below) Bedform symmetry of the seven study sites. Above the black bidirectional current line are areas of northward dominant current, and below indicate southward dominant currents.



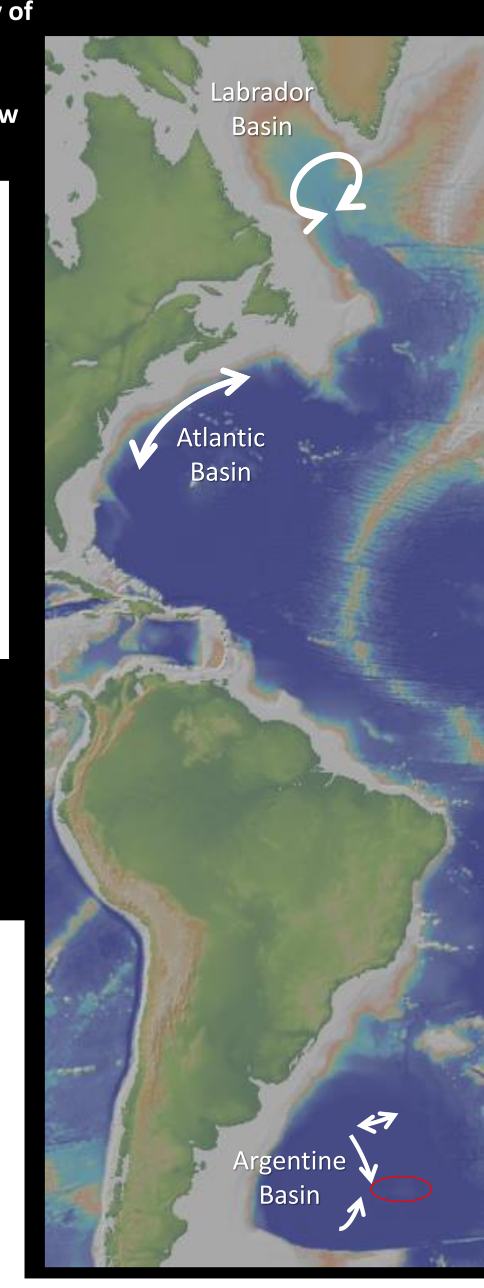


Figure 6c. (right) Predicted direction of currents utilized to compare to Fig. 5 for analysis. Currents oriented perpendicular to the wave created a circular pattern in the Labrador Basin and followed the margin in the Atlantic Basin. The Argentine Basin currents exhibit complex and conflicting dominant currents.

RESULTS

Results are illustrated in Figures 5 and 6. Data are from Table 1.

Argentine Basin

Consistently linear sediment waves found throughout the basin were the longest continuous bedforms of the three study areas.

- Site A (Central)- Bedforms show the highest average heights and wavelengths within the basin. The strong asymmetry at this site indicates a southward flowing current.
- Site B (South)- Strongly asymmetrical waves present reveal a dominant northward current direction. Peakedness in this region was the highest.
- Site C (North)- Wavelengths are similar to those in Site B, however the heights and peakedness of the bedforms were the lowest overall. Symmetrical waves in this region indicate equal flow of current.

Atlantic Basin

Bedforms were found to have the highest average wave heights and the longest wavelengths, while peakedness was detected to be highly variable. Two different types of wave were found in this region, successive dome waves and tall peaked waves with large flat valleys.

- Site D- Bedforms were the highest measured wavelengths of all studied sites. The waves were found to be fairly symmetric with a moderate northward current. Peakedness at this site was low.
- Site E- Bedform peakedness at this site was found to be significantly higher than in Site D, however waves were found to be symmetrical indicating no dominate current direction.

Labrador Basin

Overall the site showed the lowest average wavelengths and heights. Bedforms were observed to be the least linear, curving in a gyre like pattern. Peakedness was found to be low and consistent in the observed region.

- Site F- Overall the symmetry of the bedforms at this site indicated a slight northward flowing current with the shortest average wavelengths across all study sites.
- Site G- Symmetrical waves indicate no current dominance. Wavelengths of bedforms were highest in this study site.

DISCUSSION and CONCLUSIONS

Through comparison of wave symmetry with existing knowledge of ocean circulation, local currents within submarine basins can be predicted (Figs. 6a -c). Figure 6a show comparisons in wave height between study areas.

Argentine Basin

The flow of the Antarctic Bottom Water (AABW) along with sediment input shapes the abyssal plain in this area. Bedforms in this basin showed the greatest asymmetry (Fig 6b.), indicative of strong uni-directional current flow. However Sites A and B are observed to have opposite dominant currents, possibly due to a shallower zone (Fig. 6c, circled in red), which may obstruct the two different currents. Due to the time gap between data collection at Site A (1987) and Site B (2011), and the migratory behavior of the mudwaves, the observed current direction could also be evidence for overall change in the dominant current. Detected at Site C were bedforms which were very different from A and B in both morphology and in symmetry, potentially indicating a change in energy at this location.

Atlantic Basin

The Atlantic Basin’s presence of two sediment wave types within the same study area indicates significant differences in bottom current energy, or that the more peaked waveforms seen in Site E are an extension of the waved beds in Site D. Large sediment input from the North American coastline, along with high energy currents have likely created conditions that generated these large domed bedforms. The bidirectional current in this zone (Figure 6c) could be due to the presence of both the Gulf Stream and the NADW flowing through the area.

Labrador Basin

Arced sediment waves were found throughout the study area, most of which were similar in symmetry and peakedness. Bi-directional current, along with the gyre-like bathymetry are expected to be due to the NADW flowing in and out of the basin as it follows the continental margin. Figure 6a illustrates the difference in both wavelength and height of the Labrador Basin compared to the other two study areas as well as the magnitude of these waved bedforms.

The dynamic environments of submarine basins are important indicators of climate. Large deep ocean thermohaline circulation patterns such at the NADW and the AABW flow through the Atlantic Ocean, forming and migrating these waved bedforms. Observing changes in bedform geomorphology could be utilized to predict changing current patterns. Predicted bathymetry has too low resolution and does not show complete or accurate detail of the seafloor which is necessary for in-depth bedform research. Conducting high-resolution surveys which fill gaps in seafloor coverage in places such as The Argentine Basin would provide the framework necessary to study the temporal change of bedforms.

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