

Title	Paleoceanography of the Brazilian Equatorial Margin (PBEM)		
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### Abstract

Tropical regions are a major source of heat to mid- and high-latitudes. The Atlantic Ocean-Atmosphere system is unique as it is the only system that currently transports heat across the equator. Therefore, to accomplish accurate global climate reconstructions in large-scale climate models it is essential to understand the sensitivity of Atlantic climates in the geologic past and to implement this into numerical models. This, however, has been hampered for most of the Cenozoic due to the lack of sufficient low-latitude sediment records. Here we propose to investigate Cenozoic paleoceanographic changes driven by long and short term forcing from the Eocene greenhouse to Quaternary icehouse conditions, through the reconstruction of atmospheric, oceanographic and biological processes. The Brazilian Equatorial Margin (BEM) is a passive and stable continental margin that developed following the Mid-Cretaceous opening of the central Atlantic Ocean. A peculiar aspect of this margin is that it remained tectonically "passive" and approximately at the same equatorial latitude since its formation and, consequently, it has maintained continually an oligotrophic inter-tropical environment. This project will take advantage of these unique attributes for obtaining high-quality sedimentological, paleoclimatic, and paleoceanographic data for the Cenozoic. We propose drilling transects across the BEM from the uppermost part of the continental slope to the abyssal plain near Fortaleza (Ceará and Potiguar Basins). The expected stratigraphic continuity along these transects will allow a detailed study of the relation between pCO<sub>2</sub>, climate changes and existing eustatic constraints throughout the Cenozoic by providing the fundamental parameters for calculating climate sensitivity. This stratigraphic record will define the low-latitude climatic response to the major Cenozoic climatic events, such as the EECO, MECO, EOT, OMT, MCO and iNHG (see text for details). Sediments are expected to yield calcareous and organic microfossils, which will allow us to study the response of tropical ecosystems to these climatic events and provide independent basis for climate and carbon cycle reconstructions. By undertaking a depth transect of sites selected from a wealth of seismic reflection data, progress on all of the scientific objectives will be achieved even if some unresolvable geologic risks are found in the cored sections. In particular, these sites were chosen to establish a landmark for high-resolution Eocene-Mio/Pliocene tropical climate reconstructions, which will provide the following outcomes: 1) quantify the relationship between tropical climate (temperature), atmospheric pCO<sub>2</sub> and eustasy; 2) evolution of the Atlantic Meridional Overturning Circulation driven by longer (tectonic) and shorter term (Milankovitch) forcings.

## Scientific Objectives

1. Investigate the intrinsic relationship between climate, atmospheric pCO<sub>2</sub>, and existing eustatic constraints from Eocene to the Mio/Pliocene  
Hypothesis 1.1 Does the relationship between local and regional climate on the Brazilian continental shelf, glacio-eustasy and global atmospheric CO<sub>2</sub>, and local and regional climate vary as a function of background climate state?  
Hypothesis 1.2 – How the CCD in the Central Atlantic was affected by the major pCO<sub>2</sub> and climatic variations during the Cenozoic?
2. The relationship between AMOC and SAMS is a response to the major climatic events of the Cenozoic  
Hypothesis 2.1 - Is the onset of the SAMS related to significant changes in the Central Atlantic water circulation, such as the intensification of the NBC in Northeast Brazil? Which is the intrinsic relation between NBC, ITCZ, NBC retroflection, AMOC and SAMS?  
Hypothesis 2.2 – Do intense SAMS phases lead to fresher surface waters in the South Atlantic, which are carried across the equator by the NBC? Can episodes of enhanced cross-equatorial heat transport be linked to stronger AMOC and intensified NADW formation in the North Atlantic (for example between 2 and 1.5 Ma)?  
Hypothesis 2.3 – Does circulation in the Atlantic Ocean change in response to tectonic and paleogeographic modifications? (i.e. retroflection of the NBC in response to a weakening of the AMOC or to possible phases of upwelling due to continuation of El Niño into the Equatorial Atlantic when Panama was opened).

Non-standard measurements technology needed to achieve the proposed scientific objectives

## Proposed Sites (Total proposed sites: 20; pri: 5; alt: 15; N/S: 0)

Site Name	Position (Lat, Lon)	Water Depth (m)	Penetration (m)			Brief Site-specific Objectives
			Sed	Bsm	Total	
PBEM-01B (Alternate)	-0.8407644444 -37.7896324444	4373	1164	0	1164	Moderate-resolution Eocene-Mio/Pliocene Central Atlantic deep-water paleoceanographic history from a constant equatorial setting. Measure deep-water circulation and carbonate compensation depth (CCD) changes will be reconstructed with a suite of geochemical proxies. Correlation to shallower sites will test if changes in the CCD in the equatorial Atlantic are related to sea level or climate changes. Test if the onset of the SAMS can be related to uplift of the Andes causing restricted air-circulation across South America and can change the NBC, NADW, AMOC, AADW.
PBEM-02C (Alternate)	0.113072 -38.15928	4401	638	0	638	Moderate-resolution Eocene-Mio/Pliocene Central Atlantic deep-water paleoceanographic history from a constant equatorial setting. Measure deep-water circulation and carbonate compensation depth (CCD) changes will be reconstructed with a suite of geochemical proxies. Correlation to shallower sites will test if changes in the CCD in the equatorial Atlantic are related to sea-level or climate changes. Test if the onset of the SAMS can be related to uplift of the Andes causing restricted air-circulation across South America and can change the NBC, NADW, AMOC, AADW.
PBEM-03B (Alternate)	-3.2061111111 -37.5886111111	259	955	0	955	High/Moderate-resolution Eocene- Mio/Pliocene Central Atlantic shallow-water paleoceanographic history from a long-term persistent oligotrophic equatorial setting. Sea-level changes SST, pCO <sub>2</sub> , and productivity will be reconstructed using respective proxies. Test if sea-level changes that are linked to pCO <sub>2</sub> and the macrofaunal response to warming conditions. We expect to drill hemipelagic clays, marls, and calcareous ooze as primary lithologies. Bioclastic foraminiferal carbonate sands, limestone conglomerate, and hardgrounds are uncertain possible secondary lithologies although these lithologies still provide critical information about sea-level changes. Test if the onset of the SAMS and the relation with the changes of the NBC, NADW, AMOC, AADW.
PBEM-04B (Alternate)	-3.4156583333 -37.5198055556	280	902	0	902	High/Moderate-resolution Eocene- Mio/Pliocene Central Atlantic shallow-water paleoceanographic history from a long-term persistent oligotrophic equatorial setting. Sea-level changes SST, pCO <sub>2</sub> , and productivity will be reconstructed using respective proxies. Test if sea-level changes that are linked to pCO <sub>2</sub> and the macrofaunal response to warming conditions. We expect to drill hemipelagic clays, marls, and calcareous ooze as primary lithologies. Bioclastic foraminiferal carbonate sands, limestone conglomerate, and hardgrounds are uncertain possible secondary lithologies although these lithologies still provide critical information about sea-level changes. Test if the onset of the SAMS and the relation with the changes of the NBC, NADW, AMOC, AADW.
PBEM-05A (Primary)	-2.444500638889 -36.963564305556	3520	438	0	438	Moderate-resolution Eocene-Mio/Pliocene Central Atlantic deep-water paleoceanographic history from a constant equatorial setting. Measure deep-water circulation and carbonate compensation depth (CCD) changes will be reconstructed with a suite of geochemical proxies. Correlation to shallower sites will test if changes in the CCD in the equatorial Atlantic are related to sea level or climate changes. Test if the onset of the SAMS can be related to uplift of the Andes causing restricted air-circulation across South America and can change the NBC, NADW, AMOC, AADW.
PBEM-06A (Primary)	0.1214523056 -37.0647670833	4493	542	0	542	Moderate-resolution Eocene-Mio/Pliocene Central Atlantic deep-water paleoceanographic history from a constant equatorial setting. Measure deep-water circulation and carbonate compensation depth (CCD) changes will be reconstructed with a suite of geochemical proxies. Correlation to shallower sites will test if changes in the CCD in the equatorial Atlantic are related to sea level or climate changes. Test if the onset of the SAMS can be related to uplift of the Andes causing restricted air-circulation across South America and can change the NBC, NADW, AMOC, AADW.
PBEM-07A (Alternate)	0.1376591111 -34.9521935000	4517	490	0	490	Moderate-resolution Eocene-Mio/Pliocene Central Atlantic deep-water paleoceanographic history from a constant equatorial setting. Measure deep-water circulation and carbonate compensation depth (CCD) changes will be reconstructed with a suite of geochemical proxies. Correlation to shallower sites will test if changes in the CCD in the equatorial Atlantic are related to sea level or climate changes. Test if the onset of the SAMS can be related to uplift of the Andes causing restricted air-circulation across South America and can change the NBC, NADW, AMOC, AADW.

## Proposed Sites (Continued; total proposed sites: 20; pri: 5; alt: 15; N/S: 0)

Site Name	Position (Lat, Lon)	Water Depth (m)	Penetration (m)			Brief Site-specific Objectives
			Sed	Bsm	Total	
PBEM-08B (Alternate)	-2.235563 -37.316151	3414	420	0	420	Moderate-resolution Eocene-Mio/Pliocene Central Atlantic deep-water paleoceanographic history from a constant equatorial setting. Measure deep-water circulation and carbonate compensation depth (CCD) changes will be reconstructed with a suite of geochemical proxies. Correlation to shallower sites will test if changes in the CCD in the equatorial Atlantic are related to sea level or climate changes. Test if the onset of the SAMS can be related to uplift of the Andes causing restricted air-circulation across South America and can change the NBC, NADW, AMOC, AADW.
PBEM-09C (Primary)	-2.94746 -38.6048343	1581	688	0	688	High/Moderate-resolution Eocene-Miocene Central Atlantic intermediate-water paleoceanographic history from constant equatorial slope setting. Water circulation, OMZ fluctuations, pCO <sub>2</sub> , CCD changes, and detrital input will be determined with a suite of proxies and compared to the reconstructions from shallower and deeper sites to obtain a complete view on a depth transect across the BEM. Test how was the condition before the onset of the SAMS, NBC, and changes in the NADW, AMOC, AADW since the early Eocene.
PBEM-10C (Alternate)	-2.906111194444 -38.62867002777	1436	802	0	802	High/Moderate-resolution Eocene-Miocene Central Atlantic intermediate-water paleoceanographic history from constant equatorial slope setting. Water circulation, OMZ fluctuations, pCO <sub>2</sub> , CCD changes, and detrital input will be determined with a suite of proxies and compared to the reconstructions from shallower and deeper sites to obtain a complete view on a depth transect across the BEM. Test how was the condition before the onset of the SAMS, NBC, and changes in the NADW, AMOC, AADW since the early Eocene.
PBEM-12A (Alternate)	-3.2294361111 -37.5611777778	253	899	0	899	High/Moderate-resolution Eocene- Mio/Pliocene Central Atlantic shallow-water paleoceanographic history from a long-term persistent oligotrophic equatorial setting. Sea-level changes SST, pCO <sub>2</sub> , and productivity will be reconstructed using respective proxies. Test if sea-level changes that are linked to pCO <sub>2</sub> and the macrofaunal response to warming conditions. We expect to drill hemipelagic clays, marls, and calcareous ooze as primary lithologies. Bioclastic foraminiferal carbonate sands, limestone conglomerate, and hardgrounds are uncertain possible secondary lithologies although these lithologies still provide critical information about sea-level changes. Test if the onset of the SAMS and the relation with the changes of the NBC, NADW, AMOC, AADW.
PBEM-13A (Alternate)	-3.3823250000 -37.5475030000	282	962	0	962	High/Moderate-resolution Eocene- Mio/Pliocene Central Atlantic shallow-water paleoceanographic history from a long-term persistent oligotrophic equatorial setting. Sea-level changes SST, pCO <sub>2</sub> , and productivity will be reconstructed using respective proxies. Test if sea-level changes that are linked to pCO <sub>2</sub> and the macrofaunal response to warming conditions. We expect to drill hemipelagic clays, marls, and calcareous ooze as primary lithologies. Bioclastic foraminiferal carbonate sands, limestone conglomerate, and hardgrounds are uncertain possible secondary lithologies although these lithologies still provide critical information about sea-level changes. Test if the onset of the SAMS and the relation with the changes of the NBC, NADW, AMOC, AADW.
PBEM-14A (Primary)	-4.072515222 -37.02851975	1815	190	0	190	High/Moderate-resolution Mio/Pliocene-Recent Central Atlantic intermediate water paleoceanographic history along a long-term persistent equatorial setting. Water circulation, CCD changes, and detrital input will be determined with a suite of proxies and compared to reference sea-level and pCO <sub>2</sub> , stable isotope and dust deposition record. Test the intermediate depth response to major climatic changes at equatorial latitudes, such as the onset of the SAMS, NBC, and changes in the NADW, AMOC, AADW.
PBEM-15A (Alternate)	-4.206811833 -36.7313375	2346	207	0	207	High/Moderate-resolution Mio/Pliocene-Recent Central Atlantic intermediate water paleoceanographic history along a long-term persistent equatorial setting. Water circulation, CCD changes, and detrital input will be determined with a suite of proxies and compared to reference sea-level and pCO <sub>2</sub> , stable isotope and dust deposition record. Test the intermediate depth response to major climatic changes at equatorial latitudes, such as the onset of the SAMS, NBC, and changes in the NADW, AMOC, AADW.

## Proposed Sites (Continued; total proposed sites: 20; pri: 5; alt: 15; N/S: 0)

Site Name	Position (Lat, Lon)	Water Depth (m)	Penetration (m)			Brief Site-specific Objectives
			Sed	Bsm	Total	
PBEM-16A (Alternate)	0.116813 -37.629127	4462	541	0	541	Moderate-resolution Eocene-Mio/Pliocene Central Atlantic deep-water paleoceanographic history from a constant equatorial setting. Measure deep-water circulation and carbonate compensation depth (CCD) changes will be reconstructed with a suite of geochemical proxies. Correlation to shallower sites will test if changes in the CCD in the equatorial Atlantic are related to sea-level or climate changes. Test if the onset of the SAMS can be related to uplift of the Andes causing restricted air-circulation across South America and can change the NBC, NADW, AMOC, AADW.
PBEM-17A (Alternate)	0.129727 -35.989207	4509	566	0	566	Moderate-resolution Eocene-Mio/Pliocene Central Atlantic deep-water paleoceanographic history from a constant equatorial setting. Measure deep-water circulation and carbonate compensation depth (CCD) changes will be reconstructed with a suite of geochemical proxies. Correlation to shallower sites will test if changes in the CCD in the equatorial Atlantic are related to sea-level or climate changes. Test if the onset of the SAMS can be related to uplift of the Andes causing restricted air-circulation across South America and can change the NBC, NADW, AMOC, AADW.
PBEM-18A (Alternate)	-2.10152 -37.527998	3296	453	0	453	Moderate-resolution Eocene-Mio/Pliocene Central Atlantic deep-water paleoceanographic history from a constant equatorial setting. Measure deep-water circulation and carbonate compensation depth (CCD) changes will be reconstructed with a suite of geochemical proxies. Correlation to shallower sites will test if changes in the CCD in the equatorial Atlantic are related to sea-level or climate changes. Test if the onset of the SAMS can be related to uplift of the Andes causing restricted air-circulation across South America and can change the NBC, NADW, AMOC, AADW.
PBEM-19A (Alternate)	-2.93105 -38.58682	1547	753	0	753	High/Moderate-resolution Eocene-Miocene Central Atlantic intermediate-water paleoceanographic history from constant equatorial slope setting. Water circulation, OMZ fluctuations, pCO <sub>2</sub> , CCD changes, and detrital input will be determined with a suite of proxies and compared to the reconstructions from shallower and deeper sites to obtain a complete view on a depth transect across the BEM. Test how was the condition before the onset of the SAMS, NBC, and changes in the NADW, AMOC, AADW since the early Eocene.
PBEM-24A (Alternate)	-3.78652 -37.35026	1705	238	0	238	High/Moderate-resolution Mio/Pliocene-Recent Central Atlantic intermediate water paleoceanographic history along a long-term persistent equatorial setting. Water circulation, CCD changes, and detrital input will be determined with a suite of proxies and compared to reference sea-level and pCO <sub>2</sub> , stable isotope and dust deposition record. Test the intermediate depth response to major climatic changes at equatorial latitudes, such as the onset of the SAMS, NBC, and changes in the NADW, AMOC, AADW.
PBEM-25A (Primary)	-3.915589 -37.4458	713	320	0	320	High/Moderate-resolution Mio/Pliocene-Recent Central Atlantic intermediate water paleoceanographic history along a long-term persistent equatorial setting. Water circulation, CCD changes, and detrital input will be determined with a suite of proxies and compared to reference sea-level and pCO <sub>2</sub> , stable isotope and dust deposition record. Test the intermediate depth response to major climatic changes at equatorial latitudes, such as the onset of the SAMS, NBC, and changes in the NADW, AMOC, AADW.