Progress and prospects on Ocean Acidification research of the Tropical South Atlantic

Kikuchi, R. K. P
with contribution of BrOA/SOLAS WS2-6 participants
• **OA research is an emerging problem yet to be plainly explored in the national context**;

• *This is an exciting new field for which the pathways that we can follow is not yet settled*;

• *Individual initiatives might be successful but this is an eminently collaborative field of science (funding and high technology):*

• *Brazilian Ocean Acidification Network has a fundamental role in pushing this field forward*;
Global Climate Changes

- Warming
- Sea level rise

coastal erosion

coral bleaching

tribunadonorte.com.br
**Early facts: Trop. Atl. CO\textsubscript{2} System studies**

- Inventory of CO\textsubscript{2} system in the Atlantic (Guber 1998);
- Early 2000’s: the role of Amazon on the sequestration of CO\textsubscript{2} (Ternon et al. 2000 and Subramanian et al. 2008) and the identification of an **undersaturated zone in** the eastern South Atlantic (Chung et al. 2004)
  - Ito et al. (2005): seasonality of sink(winter)-source behavior of the Southwestern Atlantic Ocean (not TrAtl)
- Report of **10% reduction on coral growth** during the 90’s and early 2000’s (Oliveira, 2008)
Large river plumes: Amazonas river

Amazon River enhances diazotrophy and carbon sequestration in the tropical North Atlantic Ocean

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1Department of Earth and Environmental Sciences, University of Georgia, Athens, GA 30602 (A.S., K.B., S.A., R.S., D.G.C.); 2School of Oceanography, Oregon State University, Corvallis, OR 97331 (C.M., A.B.K., J.P.M.); and 3Department of Biotechnology, University of Connecticut, Storrs, CT 06269 (S.C.)

The fresh water discharged by large rivers such as the Amazon is transported hundreds to thousands of kilometers away from the coast by surface plumes. The nutrients delivered by these river plumes contribute to enhanced primary production in the ocean, and the sinking flux of this new production results in carbon sequestration. Here, we report that the Amazon River plume supports Ni fixation far from the mouth and provides important pathways for sequestration of atmospheric CO2 in the western tropical North Atlantic. We calculate that the sinking of C fixed by diazotrophs in the plume sequesters 3 Tmol of C annually, in addition to the sequestration of 0.6 Tmol of C yr-1 of the new production supported by NO3 delivered by the river. These processes revise our current understanding that the tropical North Atlantic is a source of C to the atmosphere. Miloslavich et al. (2007) Inverse estimates of the oceanic sources and sinks of natural CO2 and CO2 exchange with the atmosphere. Global Biogeochem. Cycles 21, 101029 (2007) The enhancement of Ni fixation and consequent C sequestration by tropical rivers appears to be a global phenomenon that is likely to be influenced by anthropogenic activity and climate change.

Fig. 3. Changes along the river plume as it moves offshore. (Top) Changes in surface nutrient concentrations as a function of salinity for each of the station types; the values and statistics are presented in Table 1. Error bars denote standard error; the thick horizontal line on the x axis indicates the mean salinity ± S.E. for each group of stations. (Middle) Changes in biological response and mass flux from floating sediment traps at 20 m presented as in A. A schematic of changes along the plume; the arrows showing the mean mass flux for the mesohaline, and oceanic stations. The brown particles represent coastal phytoplankton species; the dark green represents DDA; the red represents Trichodesmium; and the blue represents particles typical of oligotrophic oceanic phytoplankton. Phytoplankton, chlorophyll, Trichodesmium, and Richelia concentrations are shown in Table 1. Water below the euphotic zone is depicted in solid dark blue, and the 1% light depths are given in Table 1.
Early facts: proxies and effects on organisms

• Since about 2005 we are investigating the potential of (endemic) coral skeletons as natural archives of proxies;
Early facts:

- by 2010 on, some papers by Lefèbre and co-workers detail CO₂ fluxes on the Equatorial region;
- Early statements (speculative) of the possible impacts of OA on rhodoliths beds East shelf of Brazil (Amado-Filho et al. 2012);
Milestones:

• 2009 - National Institute of Science and Technology for the Global Changes (INCT MCG/Rede Clima):
  • Coastal Zone Working Group: Initial attempts to build a small scale system to test the effect of $p\text{CO}_2$ increase in calcifying corals began in 2011; Blue Carbon
• mid 2012 - National Institute of Science and Technology for Tropical Marine Environment (inctAmbTropic)
  • basin scale $\text{CO}_2$ system studies; continuing of efforts to test warming + $p\text{CO}_2$ on corals/CCA/sediments
• Dec 2012 - Brazilian OA network created

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Working Packages of the INCT-AmbTropic
(www.inctambtropic.org) Coordinator: José M. L. Dominguez

WP1: Coastal Zone
- WG1.1: Responses of the Coastline
- WG1.2: Fluvial Plumes
- WG1.3: Reefs and Coralline Ecosystems
- WG1.4: Mangroves
- WG1.5: Markers for Environmental Impact

WP2: Continental Shelf
- WG2.1: Geodiversity, Biodiversity of Substrates
- **WG2.2: Trophic Diversity and Structure of Pelagic Environment**
- WG2.3: Genomics, Proteomics & Biodiversity
- WG2.4: Bioprospection of Natural Products from Marine Organisms

WP3: Ocean
- **WG3.1: Ocean-Atmosphere Interaction, Climatic Variab. and Predictability in N-NE Brazil and Trop. Atl.**
- **WG3.2: Biogeochemical Cycles, CO₂ Fluxes and Acidification of the Trop. Atl.**
- **WG3.3: Living Resources in the TA and Oceanic Islands**
**Mission:**
Create a network of scientists working on Ocean Acidification in Brazil, concomitant to establishing **LONG TERM OBSERVATIONS** of CO$_2$ - related parameters in marine ecosystems.

**Objectives:**
Identify and integrate the Brazilian researchers through a cooperative **inertdisciplinary network**

**Milestone:**
**Brazilian OA network**

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Where is the infrastructure?

13 Institutions
23 Laboratories
2 mesocosm facilities
42 Researchers

BrOA's main research topics:

✓ Marine biogeochemistry (coastal and open ocean areas)
✓ Response of marine organisms to OA effects (bio-assays)
✓ Paleooceanography proxies to past ocean acidification events and \( \rightarrow \) carbonate system
✓ Biogeochemistry modeling
✓ Physical and biogeochemical processes controlling sea \( \leftrightarrow \) air \( CO_2 \) fluxes

Certified by CNPq
International Colaborations... individual.

FURG – Univ. Perpignan/France
USP – Univ. Oxford/UK & Univ. Arizona/USA
UERJ – GEOMAR/Germany
UNIFESP – Univ. Cádiz/Spain
UFF – Univ. Bourdeaux/France
UFPE – IRD/France
UFBA – ZMT/Germany
OA activities during the last two years on the Tropical Atlantic (2013 and 2014)

From estuaries/coastal to the ocean basin...

...from laboratories to the field.
PIRATA
pCO2/O2 continuous measurements

6°S 10°W (2006-2013)

8°N 38°W (2008-2013)

St. Peter/St. Paul F. de Noronha Rócas Atoll

PIRATA
pCO2/O2 continuous measurements

Araujo and Lefèbvre

8°N 38°W (2008-2013)
Advances in flux estimation

Coastal seas and estuarine regions ...

**CO$_2$ flux (mmol C m$^{-2}$ day$^{-1}$)**

- Red circles (+) source of CO$_2$ for the atmosphere.
- Blue circles (-) atmospheric CO$_2$ sinks.

Araujo et al. (2013)

Noriega & Araujo (2013)
Distribution of CO2 parameters in Western Tropical Atlantic Ocean

New relationship was determined for CT using the SSS and time factor (year);
<table>
<thead>
<tr>
<th>pH</th>
<th>AT</th>
<th>DIC</th>
<th>Ωar</th>
<th>pCO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.3 ± 0.16&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2309 ± 28.6</td>
<td>1789 ± 138</td>
<td>5.68 ± 0.91&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>204 ± 111&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>8.56 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2219 ± 105&lt;sup&gt;***&lt;/sup&gt;</td>
<td>1496 ± 246&lt;sup&gt;***&lt;/sup&gt;</td>
<td>7.6 ± 1.52&lt;sup&gt;a&lt;/sup&gt;</td>
<td>92.3 ± 86.1&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>8.29 ± 0.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2317 ± 31.9</td>
<td>1804 ± 104</td>
<td>5.62 ± 0.85&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>197 ± 59.6&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>8.33 ± 0.15&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>2309 ± 89.5</td>
<td>1761 ± 135</td>
<td>5.99 ± 1.38&lt;sup&gt;b&lt;/sup&gt;</td>
<td>178 ± 84.4&lt;sup&gt;b,c&lt;/sup&gt;</td>
</tr>
<tr>
<td>8.3 ± 0.07&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2317 ± 33.2</td>
<td>1796 ± 69.6</td>
<td>5.69 ± 0.56&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>187 ± 40.2&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>8.3 ± 0.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2329 ± 44.5</td>
<td>1811 ± 90.3</td>
<td>5.68 ± 0.91&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>189 ± 53.6&lt;sup&gt;a,b,c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Ocean
pH= 8.13 – 8.21
AT= 2380
DIC= 2059
Ωar=3.63
pCO2 = 422
Bimonthly water sampling (pH/DIC/TA) in different cross-shelf transects along the North-Northeastern Brazilian coast, from the Amazon River (equator) to the São Francisco River (10°S).

Since April 2013 - ...
u-CO$_2$ equipment on board NHo. Cruzeiro do Sul (Oceanic islands 2012)

New u-CO$_2$ equipment DOCEAN/UFPE (operacional since jan./2014)
Souza et al. and Kikuchi et al.

Fluxes of carbon and nutrients in the Cachoeira River estuary, Ilheus, Bahia – FAPESB/CNPq (2013 – 2016)

Effects of \( pCO_2 \) on metabolism and carbonate dissolution by epi and endolithic communities – UESC (2014 – 2016)


Effects of interaction of acidification and temperature rise on the calcification of corals and crustose coraline algae CNPq (2013-2015)
Community/organismal level

Sarmento et al. 2015a and b (this symposium): increase of meio-fauna invertebrates followed the decrease of pH

Horta 2015 (this symposium): similar organisms may respond differently to a combination of factors (pH and Nutrients); reduction of pH leads to a decrease in photosynthetic efficiency in CCA
Paleoceanography and Paleoclimatology Laboratory

Research area:
Evaluation of proxies for marine carbonate system

Researchers:
Dr. Adriana Rodrigues Perretti
Prof. Dr. Cristiano Mazur Chiessi

Present project:
Evaluation of marine carbonate dissolution proxies on a low carbonate ion saturation environment

Partnerships established
- Recent records (coral):
  Ruy Kikuchi (UFBA - BR)
  Julia Cole (University of Arizona – USA)
- Element/Ca proxies (multiproxy study):
  Ros Rickaby (University of Oxford – UK)

Instalation of mass spectrometer MAT 253 with Kiel IV:
Will allow the analysis of stable isotopes ($\delta^{18}$O and $\delta^{13}$C), on small carbonate samples (foraminifera and corals), used to reconstruct the environmental properties of past ocean
Coral reefs in Western South Atlantic

“Rithms in the blue”

*Siderastrea stellata*

*Mussismilia braziliensis*
$\delta^{18}O \times SST$

**Abrolhos reefs**

**Mussismilia braziliensis**

**Siderastrea stellata**

**Todos os Santos Bay reefs**

Domingues (2009)
Rocas atoll

- $\delta^{18}O \times$ Equatorial mode

Yes: the Equatorial Mode imprint is in the coral geochemistry of *Porites*
Prospects:

• Organizational:
  • identify the research groups dedicated to the theme of OA;
  • enhance synergy between these groups

• Scientific
  • identify research priorities, benefitting from experience from the more advanced groups
  • identify economic problems associated with OA
  • share infrastructure
Prospects

• Modeling
  • of future state of CO$_2$ system scenarios;
  • enhance resolution of models (meso to submesoscale)

• Select case studies of each coastal ecosystem to understand the effect of OA

• Produce time series (buoy) in strategic sites;
• Experiments: effects on selected organisms/habitats;
• Calibrate proxies (corals)
WP3.2 Mathematical modeling: Large scale (TrAtl)
CO2 Fluxes Forecast (2012-2100)

\[ K_{CO_2} = g_1(u^2_{10}, \text{Sc}) \]
\[ p_{CO_2\text{ATM}} = g_4(\text{PH}_2\text{O}, \text{XCO}_2) \]
\[ p_{CO_2\text{SEA}} = g_3(\text{SST, SSS, TA, DIC}) \]
\[ FCO_2 = K_{CO_2} \alpha (p_{CO_2\text{SEA}} - p_{CO_2\text{ATM}}) \]
Thank you!

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