Observing and predicting internal wave interactions between the Amazon plume and the equatorial currents in the tropical West Atlantic

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Projects:

SOUTHAIMS: Internal wave systems in the tropical and western south Atlantic: from satellite views to local predictability (funded by Brazilian CNPq)

AMAZOMIX: Amazon Shelf Mixing and its impact on ecosystems (international venture)
Remote Sensing survey (150 images):
• Envisat-ASAR
• TerraSAR-X
• Sentinel-1
• Sentinel-2
• Sentinel-3
• MODIS
• MERIS
Surveyed features include:

- Internal Solitary Waves (multiple modes)
- Transcritical Internal Solitary Waves
- Internal Solitary Waves over the shelf
- Fronts
- Instabilities
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In situ sampling includes:

- Long-term moorings (1 year): ADCP and CTDs;
- En route long-stations (12h): CTDs and VMPs Yoyos
- En route short-stations (4-6h): CTDs, VMPs, and Bio. Geo.
- Gliders

An in situ sampling program is planned off the Amazon River mouth (2020 - AMAZOMIX) to survey mixing and turbulence and contributions thereof for biological and biogeochemical processes. Internal waves will be measured to assess dissipation at generation sites and along their propagation paths. Satellite observations and modelling will complement the in-situ observations.
• France: A. Koch-Larrouy (IRD), A. Bertrand (IRD), V. Vantrepotte (LOG), I. Dadou (LEGOS), J.F. Ternon (MARBEC), F. Lyard (LEGOS), F. Hernandez (LEGOS), L. Carrere (CLS), J. Jouanno (LEGOS), L. Stemmann (IMEV), T. Desclaux (LEGOS/UFPE ?)

• Guyana: F. Blanchard (LEEISA)

• Brazil: M. Araujo (UFPE), A. Costa Da Silva (UFPE), M. Silva (UFPE), R. Swchamborn (UFPE), S. Neumann Leitão (UFPE), F. Lucena-Frédou (UFRPE), T. Frédou (UFRPE), M. Kampel (INPE), J. Lee (UFPA), V. Isaac (UFPA), M. Rollnic (UFPA), S. Monteiro (UFPA), J. E. Martilleni Filho (UFPA), P. Calil (FURG)

• Portugal: José da Silva, J. Magalhaes (FCUP.)

• USA: M. Buijsman (Univ. of Southern Mississippi), A. Subramaniam (Lamont), J.P. Montoya (GATECH)
Charaterization of dissipation and propagation of Internal waves on the Amazon Shelf

- Internal waves generation on the shelf and shelf break
- Some propagate others not
- This will induce strong vertical mixing

Questions:

Dissipation local vs. far away from generation sites?

Intensity of dissipation?
Could it reach the surface?

Interaction with the current and eddies?
Impact of mixing on biogeochemistry and ecosystem

Coral reefs and Planckton bloom may be influenced by this mixing. They might also be influenced by the Amazon River Plume and the currents.

Questions:

What is the distribution of
- Nutrients
- Oxygen
- Plankton
- Meso and benthic pelagic

How mixing, currents, and Amazon plume influence the ecosystem?
INTERNAL SOLITARY WAVES OR INTERNAL SOLITONS

Orbital velocities classified as currents in metocean
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude</td>
<td>50m to 150m</td>
</tr>
<tr>
<td>Horizontal velocity</td>
<td>0.5m/s to 2.0m/s</td>
</tr>
<tr>
<td>Vertical velocity</td>
<td>about 1/3 horizontal velocities (0.7 m/s)</td>
</tr>
<tr>
<td>Other submesoscale Processes</td>
<td>typical vertical velocities: 0.03 m/s</td>
</tr>
<tr>
<td>Length scale</td>
<td>few hundred m to a few km</td>
</tr>
<tr>
<td>Duration</td>
<td>15 to 45 minutes</td>
</tr>
<tr>
<td>Crest length</td>
<td>200km to 250km (in study region)</td>
</tr>
<tr>
<td>Vertical heat fluxes</td>
<td>up to 1000 times more than background</td>
</tr>
<tr>
<td>Remote Sensing</td>
<td>SAR imaging and SAR altimetry</td>
</tr>
</tbody>
</table>
• Lagrangian diagnostics (Finite Size Lyapunov Exponents): transport barriers and trajectories of passive tracers
• Predict some structures that are below the altimetric resolution (sub-mesoscale); e.g. interactions of the flow with postbloom chlorophyll and in situ production (nutrients renewals)

Quantification of Soliton Velocities
Simple Two Layer Theory

\[ u_1 = \frac{c \, \eta}{(h_1 + \eta)} \]
Along-track Satellite SAR altimetry (Sentinel-3 missions)

Vertical displacements at the sea surface owing to ISWs

\[ \frac{|\eta|}{h} \approx \frac{g'H^2}{gH} \quad \Rightarrow |\eta| = O(0.1) \text{m} \]

hydrostatic limit, (Stokes, 1847)

\( Z = \eta(x,t) \)

\( Z = -H_1 + h(x,t) \)

\( h \approx -100 \text{ m} \)

\( \approx 10 \text{ km in the South China Sea} \)
Conclusions & recommendations:

• The generation, propagation and dissipation of internal wave energy is an important factor relating to ocean climate, specially in the tropical Atlantic where some of the largest waves in the world interact with currents involved in the AMOC;

• A new method is available to estimate and predict internal wave amplitudes and propagation in the tropical Atlantic Ocean, based on new generation of satellite altimeters (SAR technique);

• Need support to conduct *in situ* experiments near in the tropical Atlantic, specially near the equator band, where singularities (rotation/Coriolis) prevent the full understanding and predictability of currents and internal waves;

• Algorithms for retrieving IW parameters (such as amplitudes and current profiles) are available, but need tuning/validation with in situ data for more widely applications;
Thank you!
Extra Slides
Internal Wave Generation Slides
“Internal tide release” may be considered as “the nonlinear evolution of the internal tide”, also denominated “nonlinear desintegration of the internal tide”, which may be viewed as, another “facet” of the nonlinear desintegration of Zabusky-Kruskal’s waves.
North Equatorial Counter Current (NECC) shows large variability on multiple time scales, with a strong annual cycle (e.g. Garzoli and Katz 1983) and evidence of interannual fluctuations; Hence, a challenge to build a predictable model of ISWs.

Schematic representation of mean currents in the tropical Atlantic with warm-water pathways in red and deep water (DW) pathways in blue. Indicated are the south equatorial current (SEC), the north Brazil current (NBC), the equatorial undercurrent (EUC), the north equatorial undercurrent (NEUC) merged with the north equatorial counter current (NECC) and the DWBC with alternating zonal flows marked at the Equator.

Dengler et al. 2004
Nonlinear parameter

\[ \alpha = \frac{A}{H_t} \]

Frequency dispersion term

\[ \delta = \left( \frac{H_t}{L} \right)^2 \]