Sound speed spatial and temporal variability in Campos and Santos Basins and its influence on traveltime

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Determination of the Sound Velocity in the water column from seismic survey data.
Motivation and Objectives

- Realistic data of the water column’s sound speed and its temporal variability may improve the seismic imaging of Santos and Campos Basins ultradeep oil fields, located under water columns deeper than 2000m.
- Ocean reanalysis models combine hydrodynamic modeling and data assimilation and provide spatial and time coverage necessary for variability studies.

Therefore, this work’s objectives were:

1. **Investigating sound speed variability on Santos and Campos basin using three global ocean reanalysis data**
   - Providing insights on seismic planning, acquisition and processing, specially considering 4D Datasets

2. **Evaluating model data with in situ termohaline profiles**
   - Are the models providing accurate sound speed profiles? Is there a reanalysis model better suited for acoustic applications?

3. **Characterizing the acoustic environment on the ultradeep oil fields through zero offset travelt ime estimation**
   - Similar metrics as used in zero offset travelt ime static water column correction

Representation of an oil reservoir on ultradeep waters
Source: PETROBRAS (2020)
Sound speed in the Oceans

Sound speed in the oceans is empirically related to **temperature, pressure and salinity**
Therefore, varies due to **water masses** composition, trends, seasonal cycles and mesoscale features (eg. **eddies**)

- **Brazil Current (BC)** associated with TW and SACW
- The **South Equatorial Current (SSEC-s)** reaches the western boundary at latitude dependent depths:
  - 22ºS at the SACW depth
  - 28ºS at the AAIW depth

Semi-permanent mesoscale eddies: Vitória Eddy (VE), Cabo de São Tomé Eddy (CSTE) and Cabo Frio Eddy (CSE).

Sound speed in the oceans

- Mesoscale eddies are coherent, rotational structures on spatial scales of 50-300km and temporal scales of weeks to months
- Eddies with cyclonic (anticyclonic) rotation on the Southern hemisphere cause upward (downward) baroclinic deflection of the isopycnals
- Advect water with thermohaline properties of their origin location
- On the studied site might be originated from:
  - The Brazil Current
  - Eddy corridor between the Agulhas Current Retroflection and the western boundary

Eddy corridor evidenced by eddies’ centroid position. Red track indicates an Agulha’s Ring that reached Cabo Frio at July/2006.
Source: Guerra, Paiva e Chassignet (2018)

Sound speed vertical slices through eddies.
Source: Liu et al. (2021)
Methods

- Reanalysis models:

  Observations

  ![Satellite](image) + ![Assimilation](image) + ![Numerical model](image)

<table>
<thead>
<tr>
<th>ORAS5-ECMWF</th>
<th>GLORYS12V1</th>
<th>HYCOM Gofs 3.0</th>
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<tr>
<td>Variables</td>
<td>Temperature and salinity</td>
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<td>Horizontal resolution</td>
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<td>Time interval</td>
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Evaluation with in situ data
- 95th percentile of the error between models’ and ARGO’s sound speed profiles (page 7)

Effects of physical features
- Depth averaging on water masses layers for EOF analysis (pages 8-10)

Sound speed variability
- EOF analysis (pages 8-10)
- Hovmöller diagrams (page 11)

Sound propagation
- One-way zero offset traveltime computation for the sound speed profiles on the Hovmöller diagrams (page 11)
Results: models’ evaluation

- 95\textsuperscript{th} percentile of the bias between ARGO sound speed profiles and the models’ sound speed profiles

Higher error near the continental slope and proximities of Cabo São Tomé Eddy
GLORYS displayed less errors
Results: EOF analysis

• The first mode for all analysis displayed loadings of the same signal across the domain, indicating physical forcing actuate on a larger area on the South Atlantic.

• A north-south dipole with an axis at 25° S-26° S was frequently found as the second mode of variability.

• Previous ocean circulation studies corroborates zonal east-west flow between 28ºS-30ºS from the upper layers to the intermediate water depth, connected to the southern limb of the South Equatorial Current and the Brazil Current recirculation cell and may explain the dipole pattern.

EOF 1 and EOF 2 (expressed as correlation with 0.1 contour interval), explained variance and corresponding PC time series.
Results: EOF analysis

- The SACW and AAIW layer for each model had similar PC time series and presented positive linear trends for the ORAS and GLORYS models.

- Contrarily, HYCOM’s PCs presented a small negative trend due to the shorter time series.

EOF 1 and EOF 2 (expressed as correlation with 0.1 contour interval), explained variance and corresponding PC time series.
Results: EOF analysis

- The Principal Components (PCs) series for the TW layer across all models displayed high frequency variability, which was attenuated in the layers bellow the surface.

- The PC2 for the TW layer also displays interannual variability with periods of 4 to 10 years, possibly related to South Atlantic’s sea surface temperature (SST) variability modes.

EOF 1 and EOF 2 (expressed as correlation with 0.1 contour interval), explained variance and corresponding PC time series.
Results: Hovmöller diagrams and traveltime series

- The contours from all three models agree at long term patterns
- ORAS results displayed less variability due to the eddy-permitting resolution (1/4°)
- Corroborates linear trends on the SACW and AAIW layers
- The sound speed variability at central and intermediate water depths had a major impact on the time series of traveltime
- Short time anomalies (few months) reaching depths of up to ~1000m indicate eddies occurrences and caused peaks in the traveltime series
Conclusions

OBJECTIVES

1. Investigating sound speed variability on Santos and Campos basin using three global ocean reanalysis data

2. Evaluating model data with in situ termohaline profiles

3. Characterizing the acoustic environment on the ultradeep oil fields through zero offset traveltime estimation

(2) The evaluation indicated that GLORYS often had smaller prediction errors, although retaining some higher error values near the continental slope

(1) The SACW and AAIW layers for the ORAS and GLORYS models with longer time series presented a positive trend and may be related to long term trends of warming of the subtropical gyre or decadal oscillations of the South Atlantic

(1) Periods of positive and negative anomalies at central and intermediate depths are consistent between models and may be explained by the advection of eddies from the CB and westward propagating eddies

(3) Variability in the SACW and AAIW layers cause most of the impact on time series of traveltime. Peak events appear to be related to mesoscale eddy activity
Thanks for your attention!

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