Long Baroclinic Rossby Waves Identified in the Tropical Atlantic from ARGO Floats

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Important Element in Climate System
Meridional Overturning Circulation (MOC)

(Rahmstorf 2006)
Mid-Depth (1000 m) Circulation →
MOC Variation →
Heat Transport Variation →
Climate Change
• Q1: Are mid-depth (~1000 m) ocean circulations steady?

• Q2: If not what mechanisms cause the change?

A: Rossby wave propagation
6-12 hours at surface to transmit data to satellite

Total cycle time 10 days

Descent to depth
~10 cm/s (~6 hours)

1000 db (1000m)
Drift approx. 9 days

Salinity & Temperature profile recorded during ascent
~10 cm/s (~6 hours)

Float descends to begin profile from greater depth
2000 db (2000m)
October-November 2004 ARGO
(a) float tracks, and (b) float positions where temperature profiles were measured.
Circulations at 1000 m estimated from the original ARGO float tracks (bin method)
April 2004 – April 2005
OSD
Spectral Representation

\[ c(x, z_k, t) = A_0(z_k, t) + \sum_{m=1}^{M} A_m(z_k, t) \Psi_m(x, z_k), \]

Spatial Variability is represented by the basis functions
References


- These papers can be downloaded from:
Basis Functions of Laplace Operator
(Open Boundaries)

\[ \triangle \Psi_k = -\lambda_k \Psi_k, \]

\[ \triangle \Phi_m = -\mu_m \Phi_m, \]

\[ \Psi_k \big|_\Gamma = 0, \quad \frac{\partial \Phi_m}{\partial n} \big|_\Gamma = 0, \]

\[ \left[ \frac{\partial \Psi_k}{\partial n} + \kappa(\tau) \Psi_k \right] \big|_{\Gamma_1'} = 0, \quad \Phi_m \big|_{\Gamma_1'} = 0, \]
Basis Functions for Streamfunction
Mode-1 and Mode-2
Mid-Depth Circulations (1000 m)
(a) Apr 04-Apr 05, (b) Jun-Jul 04
(c) Oct-Nov 04, (d) Mar-Apr 05
Temperature (°C)

Apr 04 – Apr 05

T
(950 m)

Dashed Curves ➔ WOA

Jul 04

Nov 04

Apr 05
Temporal Decomposition
Annual + Semiannual

\[ \hat{\phi} \approx \bar{\phi}(\mathbf{x}_\perp) + \psi_1(\mathbf{x}_\perp, t) + \psi_2(\mathbf{x}_\perp, t), \]

\[ \psi_1(\mathbf{x}_\perp, t) = \sum_{s=1}^{2} A_{\omega_1, s} \cos(\omega_1 t + \theta_{\omega_1, s}) Z_s(\mathbf{x}_\perp) + \sum_{k=1}^{K_{\text{opt}}} B_{\omega_1, k} \cos(\omega_1 t + \phi_{\omega_1, k}) \Psi_k(\mathbf{x}_\perp), \]

\[ \psi_2(\mathbf{x}_\perp, t) = \sum_{s=1}^{2} A_{\omega_2, s} \cos(\omega_2 t + \theta_{\omega_2, s}) Z_s(\mathbf{x}_\perp) + \sum_{k=1}^{K_{\text{opt}}} B_{\omega_2, k} \cos(\omega_2 t + \phi_{\omega_2, k}) \Psi_k(\mathbf{x}_\perp), \]
Temporal Decomposition
Annual + Semiannual

\[ \hat{T}(x_\perp, z, t) \approx \overline{T}(x_\perp, z) + T_1(x_\perp, z, t) + T_2(x_\perp, z, t), \]

\[ T_1(x_\perp, z, t) = \sum_{m=1}^{M_{opt}} C_{\omega_1, m}(z) \cos[\omega_1 t + \chi_{\omega_1, m}(z)] \Xi_m(x_\perp, z), \]

\[ T_2(x_\perp, z, t) = \sum_{m=1}^{M_{opt}} C_{\omega_2, m}(z) \cos[\omega_2 t + \chi_{\omega_2, m}(z)] \Xi_m(x_\perp, z), \]
Time-longitude diagrams of meridional velocity along 11°N (cm/s)
Two wave-like signals in Annual currents

(a) May-Jun 04  (b) Jul–Aug 04  
(c) Sep–Oct 04  (d) Nov–Dec 04
Annual monthly temperature anomaly at 950m depth

(a) Jun 04  
(b) Aug 04  
(c) Oct 04  
(d) Dec 04.
Kinematic characteristics of the annual Rossby wave propagating in the eastern sub-basin

<table>
<thead>
<tr>
<th>Latitude</th>
<th>March, 04 – May, 05 float data</th>
<th>March, 04 – May, 06 float data</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$c_p$ (cm/s)</td>
<td>$L_1$ (km)</td>
</tr>
<tr>
<td>5°N</td>
<td>12</td>
<td>1200</td>
</tr>
<tr>
<td>8°N</td>
<td>16</td>
<td>2500</td>
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<tr>
<td>11°N</td>
<td>14</td>
<td>2200</td>
</tr>
<tr>
<td>13°N</td>
<td>11</td>
<td>2100</td>
</tr>
</tbody>
</table>
Zonal cross-sections of the annual component of the temperature anomaly (°C)

6°N in Jun 04 →

11°N in Oct, 04 →

16°N in Oct 04 →
Baroclinic Modes

(a)

Depth (m)

(b)

Depth (m)

$\Phi_l$

$\Phi_{l,\text{combination}}$

1 2 3
Annual Component in the Western Sub-Basin

Mean wind KE

Mean KE for mid-depth currents

Correlation between Winds and currents

Correlation between wind Stress curl and streamfunction (solid: no-lag, dashed: 3 mon lag)

Zonal: circle
Meridional: square
Annual Component in the Eastern Sub-Basin

Mean wind KE

Mean KE for mid-depth currents

Correlation between Winds and currents

Correlation between wind Stress curl and streamfunction (solid: no-lag, dashed: 3 mon lag
Semi-annual currents at 1000 m depth (2004)

(a) 5/15
(b) 5/30
(c) 6/14
(d) 6/29
(e) 7/13
Semi-annual monthly temperature anomaly at 950m depth

(a) Jun 04
(b) Aug 04
(c) Oct 04
(d) Dec 04.

(a) 6/4
(b) 7/4
(c) 8/4
(d) 9/4
Semi-annual temperature anomaly at 550m depth (2004)

(a) 5/15
(b) 6/29
Semiannual Component in the Western Sub-Basin

(a) wind KE
(b) current KE
(c) corr wind stress and currents
(d) corr between semi-annual currents and mean wind
(e) corr between semiannual currents and annual wind stress.
Semiannual Component in the Eastern Sub-Basin

(a) wind KE
(b) current KE
(c) corr wind stress and currents
(d) corr between semi-annual currents and mean wind
(e) corr between semiannual currents and annual wind stress
Conclusions

• (1) OSD has capability to process ARGO data

• (2) The annual and semi-annual unstable standing Rossby waves are detected in both the western and eastern sub-basins.

• (3) The wind-driven Ekman pumping seems to be responsible for the standing wave generation in both the sub-basins.