Analysis of Remotely Sensed Ocean Data by the Optimal Spectral Decomposition (OSD) Method

Peter C. Chu
Naval Postgraduate School
Monterey, CA 93943
pcchu@nps.edu; http://faculty.nps.edu/pchuch
Collaborators

• Charles Sun (NOAA/NODC)
• Carlos Lozano (NOAA/NCEP)
• Leonid M. Ivanov (California State Univ)
• Chenwu Fan (NPS)
• Tateana Margolina (NPS)
• Oleg Melnichenko (Univ of Hawaii)
References


- These papers can be downloaded from:
  - http://faculty.nps.edu/pcchu
How can we effectively use remotely observed data to represent and to model/predict the ocean state?
Outline

• (1) Theory and Methodology

• (2) Application
  – ARGO Data: Baroclinic Rossby Waves in Tropical Atlantic
  – CODAR Data: Monterey Bay Surface Circulation
Part-1
Theory and Methodology
Spectral Representation - a Possible Alternative Method

Theoretical Base: Fourier Series Expansion

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

\[ \triangle \Psi_k = -\lambda_k \Psi_k, \quad \Psi_k|_\Gamma = 0, \quad k = 1, \ldots, \infty \]

\[ \triangle \Phi_m = -\mu_m \Phi_m, \quad \frac{\partial \Phi_m}{\partial n}|_\Gamma = 0, \quad m = 1, \ldots, \infty. \]

Eremeev et al. (1992 JGR)
Basis Functions (Open Boundaries)

(Chu et al., 2003 a,b JTECH)

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

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

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

\[ \left[ \frac{\partial \Psi_k}{\partial n} + \kappa(\tau) \Psi_k \right]|_{\Gamma_1'} = 0, \quad \Phi_m|_{\Gamma_1'} = 0, \]
Boundary Conditions

\[
\frac{\partial^2 \Phi}{\partial n \partial z} = 0 \\
\Psi = 0 \\
\frac{\partial \Phi}{\partial z} = 0 \\
\frac{\partial \Psi}{\partial n} + \kappa \Psi = 0 \\
\frac{\partial \Phi}{\partial n} = 0 \\
\frac{\partial \Psi}{\partial n} = 0
\]
Benefit of Using OSD

• Ocean Topographic Configuration ➔
  
  Basis Functions (Pre-Determined)
Optimal Mode Truncation

\[
J(a_1, \ldots, a_K, b_1, \ldots, b_M, \kappa, P) = \frac{1}{2} \left( \| u_p^{\text{obs}} - u_{KM} \|_P^2 + \| v_p^{\text{obs}} - v_{KM} \|_P^2 \right) \rightarrow \min,
\]
Vapnik (1983) Cost Function

$J_{emp} = J(a_1, \ldots, a_K, b_1, \ldots, b_M, \kappa, P)$.

$\text{Prob} \left\{ \sup_{K,M,S} |\langle J(K, M, S) \rangle - J_{emp}(K, M, S) | \geq \mu \right\} \leq g(P, \mu)$

$\lim_{P \to \infty} g(P, \mu) = 0$
Optimal Truncation

- Gulf of Mexico, Monterey Bay, Louisiana-Texas Shelf, Tropical Atlantic

- $K_{opt} = 40$, $M_{opt} = 30$
Determination of Spectral Coefficients
(Ill-Posed Algebraic Equation)

\[ A \hat{a} = QY, \]
Part 2 Applications
2.1. Argo Drifters
• [http://www.argo.net/index_flash.html](http://www.argo.net/index_flash.html)

• 3000 Argo drifters → Sampling the Global Ocean
Opportunities

• (1) 4D (T, S) fields

• (2) Deep ocean currents

• (3) Physical phenomena $\rightarrow$ Rossby wave propagation in mid-depth, ...
Challenges

• Argo (T, S) profile and drift data
  → Noisy and inhomogeneously distributed
ARGO Observations (Oct-Nov 2004)

(a) Subsurface tracks

(b) Float positions where (T,S) were measured
Circulations at 1000 m estimated from the original ARGO float tracks (bin method)
April 2004 – April 2005

It is difficult to use such noisy data into ocean numerical models.
Boundary Configuration ➔
Basis Functions for OSD

Azores Islands

Γ_1, Γ_2, Γ_3

Γ^/
Basis Functions for Streamfunction
Mode-1 and Mode-2
Circulations at 1000 m (March 04 to May 05)
Bin Method

Circulation patterns are depicted on the map, showing vector arrows indicating the direction of flow at different latitudes and longitudes. The map is color-coded with a scale of 5 cm/s, and the bin method and OSD are indicated for comparison.
Baroclinic Rossby Waves in Tropical North Atlantic
Annual Component
Semi-annual Component
# Characteristics of Annual Rossby Waves

<table>
<thead>
<tr>
<th>Latitude</th>
<th>March, 04 – May, 05 float data</th>
<th>March, 04 – May, 06 float data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$c_p$ (cm/s)</td>
<td>$L_1$ (km)</td>
</tr>
<tr>
<td>$5^0N$</td>
<td>12</td>
<td>1200</td>
</tr>
<tr>
<td>$8^0N$</td>
<td>16</td>
<td>2500</td>
</tr>
<tr>
<td>$11^0N$</td>
<td>14</td>
<td>2200</td>
</tr>
<tr>
<td>$13^0N$</td>
<td>11</td>
<td>2100</td>
</tr>
</tbody>
</table>

Western Basin | Eastern Basin | Western Basin | Eastern Basin
CODAR
Monterey Bay
Place for comments: left - radar derived currents for 17:00 UT December 1, 1999
right – reconstructed velocity field.
Conclusions

• OSD is a useful tool for processing real-time velocity data with short duration and limited-area sampling.

• The scheme can handle highly noisy data.

• The scheme is model independent.

• The scheme can be used for velocity data assimilation.

• Phase space consideration