Inverse Estimate of Ocean Mixing from Observations

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1. Mixing in the ocean

The ocean, as we observe it (using ARGO, WOCE, etc.), is the result of an interplay between advection and water-mass transformation. Here water-mass transformation refers to a change in a water-mass’s Absolute Salinity ($S_a$) and Conservative Temperature ($Θ$). Water-mass transformation is caused by boundary (mainly air-sea) fluxes of $S_a$ and $Θ$ and mixing. Therefore, mixing has an important role in modifying the state of the ocean. Global observations of $S_a$ and $Θ$ are currently more accurate and readily available than that of velocity.

Here I present a technique that utilizes gridded climatologies based on observations of $S_a$ and $Θ$ distribution to estimate mixing and water-mass transformation, without using velocities.

2. The World Ocean in ($S_a$, $Θ$) coordinates

We study changes in the ocean’s ($S_a$, $Θ$) distribution, by representing the ocean in ($S_a$, $Θ$) coordinates. All changes in the ocean’s volume distribution in ($S_a$, $Θ$) coordinates (Figs. 1 and 2), requires a water-mass transformation. For a water-mass transformation salt and heat fluxes are required. Note: advection may lead to a change in the position of a volume with a particular ($S_a$, $Θ$), but it does not change the ($S_a$, $Θ$) values itself and therefore its effect does not show up in ($S_a$, $Θ$) coordinates.

3. Diathermaline streamfunction

For a steady state ocean, the volume transport in ($S_a$, $Θ$) coordinates is non-divergent (trends can be corrected for). We can therefore represent the resulting 2-Dimensional non-divergent flow as the Diathermaline Streamfunction in ($S_a$, $Θ$) coordinates. The Diathermaline Streamfunction is directly forced by salt and heat fluxes due to air-sea fluxes and mixing (Fig. 4). The mixing term however, contains unknown diffusion coefficients. The ($S_a$, $Θ$) gradients upon which these diffusivities operate can be obtained from the climatologies. We use of structure functions to represent the spatial variability of the mixing strengths. A solution is obtained using a matrix inversion (least squares).

4. The results

The obtained water-mass transformations (Fig. 5) and resulting Diathermaline Streamfunction (Fig. 6) are realistic and comparable to previous studies⁵. The small-scale turbulent mixing ($D$) and horizontal mesoscale mixing ($K_h$ in the mixed layer) are comparable to other modeled and observed studies (Table 1). However, the mesoscale isopycnal mixing ($K_i$ in the interior layer) is a first of a kind estimate which is up to 2 orders of magnitude smaller than that used in models.

5. Can Isopycnal mixing be so small?

Errors are due to averaging processes, irregular and limited spatial and temporal resolution and imperfect mixing structure functions. Effects of solar penetration depth, geothermal heating or Brine rejection are not included, and the choices of column and row weighting influence the results. In our opinion it is unlikely that improvements can increase $K_i$ by a factor 100. $K_i$ is well constrained in ($S_a$, $Θ$) Coordinates, and such an increase will lead to unrealistic water-mass transformation (Fig. 5 and 6).

Therefore we conclude that the interior small scale diffusion is much smaller than currently thought and applied in models. Future work should focus on improve the mixing estimates⁶ and on understanding the impact of a small isopycnal mixing, for ocean models.

⁵Not discussed in poster. Discuss with presenter.

Fig. 1: Distribution of ocean basin in ($S_a$, $Θ$) coordinates.

Fig. 2: Log of the ocean volume distribution in ($S_a$, $Θ$) coordinates.

Fig. 3: Thermocline forcing leading to displacement of fluid parcels in ($S_a$, $Θ$) coordinates.

Fig. 4: Some of the mathematical details of the Thermohaline Inverse Method (THI).

Fig. 5: Water-Mass Transformations due to heat fluxes (top) and salt fluxes (bottom) for surface forcing and mixing. These processes drive the circulation in ($S_a$, $Θ$) Coordinates. The arrows indicate direction of flow.

Fig. 6: The Diathermaline Streamfunction representing ocean circulation in ($S_a$, $Θ$) coordinates.

Table 1; Diffusivities.

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<thead>
<tr>
<th></th>
<th>$D$</th>
<th>$K_h$</th>
<th>$K_i$</th>
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<tbody>
<tr>
<td></td>
<td>$(6.18 ± 0.04) \times 10^{-4}$ m$^2$ s$^{-1}$</td>
<td>$(20,900 ± 200)$ m$^2$ s$^{-1}$</td>
<td>$(200 ± 20)$ m$^2$ s$^{-1}$</td>
</tr>
<tr>
<td>mean($K_h$)</td>
<td>$1800$ m$^2$ s$^{-1}$</td>
<td>mean($K_i$)</td>
<td>$8$ m$^2$ s$^{-1}$ (surprise)</td>
</tr>
<tr>
<td>mean($D$)</td>
<td>$5.2 \times 10^{-4}$ m$^2$ s$^{-1}$</td>
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