Inverting acoustic travel time into temperature

During the EU-project CANIGO two-way acoustic travel time measurements across the Strait of Gibraltar were carried out in order to examine their suitability for long-term monitoring of the water mass exchange through the Strait. Two sections were covered by the acoustic rays, one was perpendicular while the other was diagonally to the main axis of the strait.

The topography of the Strait of Gibraltar is shown to the left, together with the position of the acoustical instruments T1, T2, T3 and the ray path between them (line). Some p217 CTD stations (○-□) are shown as dots. Depth contours are in 100m steps.

The mean flow through the strait is rather simple. Atlantic Surface Water is flowing into the Mediterranean Sea, beneath the Mediterranean Water flowing into the Atlantic Ocean. However, it is superposed by various processes like seasonal variations, wind and pressure driven currents, strong fronts and internal bores propagating from west to east.

The travel time of the ±2 rays can be associated with a sound speed model state.

In the Strait of Gibraltar, most of the variations in temperature, salinity and sound speed occurs in the upper 270m (see left). A modelled sound speed section is build out of two mean profiles $\tau_z$ and $\tau_s(z)$ representing conditions in the northern and southern part of the section to which a fraction of their standard deviation profile is added over 270m (Figure to the left and equation below). The two standard deviation profiles are nearly identical with the first EOFs.

$$ c(z) = \begin{cases} \hat{c}(z) + f_z\hat{c} \hat{z} & \text{for } z \leq 270m \\ \hat{c}(z) & \text{for } z > 270m \end{cases} $$

However the much smaller variation underneath 270m also affect the travel time of the ±2 rays. Therefore the long periodic effect of the lower layer was eliminated from the measured travel time by using the T1T2-travel-time of the S1S-ray which almost completely samples only the lower layer. For further inversions only the thus adjusted data of the ±2 rays were used and the sound speed was assumed constant underneath 270m.

The travel time of the ±2 rays was calculated by a raytrace program for all model states resulting in two functions:

$$ t_{+2} = g_+g_s f_+f_s $$

$$ t_{-2} = g_-g_s f_-f_s $$

These two matrices were used to relate the measured travel time to the model states. A measured ±2 travel time represents a contour line in the upper matrix of left figure and defines the possible $f_z$ values of the model section to reproduce the measured ±2 travel time. Analogously a measured ±2 travel time defines a contour line in the lower matrix of left figure. In the $f_z$ space, the intersection of these two lines gives the unique $f_z$ values for which the model section reproduces the measured ±2 travel times. Therefore every measured pair of ±2 travel times can be associated with a sound speed model state.

To relate the sound speed to temperature and salinity the CTD casts of the p217 cruise were used. To obtain an unique relation the pressure effect was removed from the sound speed (potential sound speed). Plotting T and S against potential sound speed gives an empirical relation function which inserts potential sound speed to temperature and salinity (Figure to the left).

The sound speed in water depends mostly on temperature, $c = c(T)$. This formula can be inverted to calculate the temperature from the sound speed. Knowing the travel time and the ray path length allows to calculate the mean sound speed along the ray path. Previous work showed that in the case of our experiment the path of the ±2 ray depends much on the temperature variations (see above). Therefore a direct 2-D lookup method was used to invert the travel time sums of different rays.

Comparison and Results

At the central station of 14 repeated CTD casts over 12 hours are available. This data was not used in the prior calculations of the model profiles, therefore it is independent of the model section. Different temperature and salinity depths are compared in Figure above. The most evident signal is the vertical shifting of the isohalines and isotherms with the most significant modulation with the S2 tide is visible. All other were diagonal to the main axis of the strait.

Abrupt changes in the interface depth which are produced by the passing of a strong internal bore can clearly be seen during the first few days. Long term variations of no tidal origin are emphasised by the low pass filtered curve.

Using the inversion results from both sections, allows to calculate the slope across and along the strait. However, here the errors are quit large (light blue trace). A running mean over two days decrease the statistical error, therefore long term variations could be studied.

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Acoustic Thermometry in The Strait of Gibraltar

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