Listening fish to recover Ocean's physical properties

I. Feasibility and first results

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Received September 10, 2019; accepted October 29, 2019

ABSTRACT

~~*Context.*~~ To investigate the feasibility to use acoustic observations as a proxy for a physical description of the whole water column, CTD data is analysed and compared to acoustical ones providing by echosounders.
~~*Aims.*~~ It is shown that acoustic observations trace the marine life activity. We suppose a part of living organisms follow a certain isopycne. Due to high biological activity in our study area we cannot use directly acoustic response as a density tracer. We seek a metric that can be used to relate acoustical observations to CTD measurements.
~~*Methods.*~~ We propose to use the MLD calculated from CTD data set, and compare it to the 38 kHz acoustical layer. We also construct a Thorpe length scale to look if identified turbulent mixing can be seen in acoustic observations.
~~*Results.*~~ The MLD is found to mostly follow the 38 kHz upper limit. Blurred acoustical response seems to have higher L_T value compared to a stratified one.

Key words. Acoustic – Mixed Layer Depth – Thorpe length scale

1. Introduction

The Mad-Ridge cruise has been set up off Madagascar during the end of 2016, near a sea-mount located between the south coast of Madagascar and 29°S. This region is classified as an ecologically or biologically significant marine area *(EBSA)*, mainly because of the large amount of different species that have been identified. During the survey an echosounder and a Scanfish[1] mounted by CTD[2] sensors were recording at the same time and provided acoustical and physical measurements.

Bertrand *et al.* have related acoustic observations of the vertical distribution of marine organisms to the upper limit of the OMZ[3] near the Peruvian coast. They show that it is possible to perform high-resolution monitoring of the upper limit of the OMZ with multi-frequency echosounders, allowing to probe physical processes that structure the upper ocean and the marine ecosystems. Their method relies on the hypothesis that biological activities follow the physics (e.g., density and temperature gradient, turbulence~~..~~). The main interest to implement this approach to the Mad Ridge data is to recover physical knowledge of the water column from acoustic observations, which are easier to record and ensure ~~more fine~~ scale resolution within horizontal and vertical plane.

Here, we perform a feasibility assessment of such method. We propose to look if the bottom of the mixed layer can be a limit of an acoustical layer, and if a change in acoustical response can be a result of a turbulent process by using both echosounder and CTD data.

In the next section we will discuss about our different metrics and their specific criterion. A synthetic part of our work will be show in the Results section, followed by our conclusions and our perspectives for the future.

2. Method

Thanks to the multi-frequency echosounder, we get 4 different intensity values (Sv[4]) for each point, obtained with the following frequencies: 38/70/120 & 200 kHz. The first thing we did is to set a detection limit. To keep a good signal to noise ratio, it is generally considered to keep data over -80 dB. A fish of 8 cm long has a retroflected intensity of about -50 dB. We have decided to take those values as our detection thresholds. The vertical and horizontal resolution are fixed by the aperture angle and the ping. Echo-sounders that were used during the survey had an angle of $\theta = 7°$ and the ping was $\tau = 0.3\ ms$. After the echo-integration, we end up with a vertical resolution of 0.5 m and 10 s horizontally.

A first approach to visualize the acoustical response of the water column, for different frequencies at the same time, is to construct a RGB image. To construct an RGB image we redefine our Sv values on a linear scale, which has 255 intervals, and where the minimal value (-80 dB) will be set at 0 and the maximal one (-50 dB) at 1. In order to get 3 colors (*red, green, blue*) we need to stack 3 frequencies together. We use the 38, 70 and 120 kHz (120 and 200 kHz frequencies show a strict similar

[1] Towed vehicle device
[2] Conductivity Temperature Depth
[3] Oxygen minimum zone
[4] Scattering Volume : strength that an insonified volume remitted.

response). Sv is mean filtered with a window of 11 by 3 pixels on horizontal and vertical axis respectively.

CTD measurements have been recorded by a scanfish device at 700 m away, in the ship's wake. The scanfish oscillates and provides physical measurements into the water column. To relate physical observation to acoustical ones, CTD data are corrected from the vessel speed and time synchronised with echosounder data.

Our first approach is to look if acoustical layers can trace the bottom of the mixed layer. The mixed layer is the upper part of the ocean, where a physical parameter (e.g., temperature, density) is well mixed through turbulent processes. The~~se~~ turbulence ~~are~~ due to winds, heat fluxes, evaporation, and salinity fluxes. The bottom of the mixed layer can change in depth depending on the seasons and latitude. This limit, called also Mixed Layer Depth (*MLD*), is the boundary between the mixed layer and the Thermocline. MLD is defined from the 10 m depth temperature (T_{10m}) and a threshold criterion $\Delta T = 0.2°C$ (de Boyer Montégut *et al.*, 2004) and correspond ~~at~~:

$$MLD_T = \text{Depth where } (T = T_{10m} \pm 0.2°C) \tag{1}$$

An equivalent definition using the density instead the temperature is also given by de Boyer Montégut. Here we set a density threshold criterion at $\Delta\rho = 0.3\ kg.m^{-3}$.

$$MLD_\rho = \text{Depth where } (\rho = \rho_{10m} + 0.3\ kg.m^{-3}) \tag{2}$$

We have set the MLD as the average between MLD_T and MLD_ρ, both determined from CTD data.

Our second investigation tends to verify if turbulent processes can be identified with a blurred acoustical response. To characterize turbulent processes in the water column from our CTD data, we look at the Thorpe length scale, that measure vertical displacement. The measure of this vertical displacement can be used to distinguish the presence of vertical mixing. We assume that if the vertical mixing is strong then the living organisms will be spread over a thick region, which would led to a blurred and mixed acoustic response. On the contrary, if vertical mixing is low then, living organisms might concentrate at one given isopycne. The Thorpe method is based on the re-organization of density (or temperature) profiles. The density is sorted in ascending order from the surface to the bottom of the water column. A comparison is made between the density profile and the ordered one. This comparison gives us the displacement that we need to apply on fluid parcels at each depth, if we want to get a stable profile (Thorpe, 1977).

To avoid a false detection of overturns we follow the Gargett and Garner method. Based on Ferron *et al.*(1998), they proceed by creating an intermediate profile from the measured one by tracking only significant differences in the density profile. A significant difference is defined relative to a threshold noise level below which a density difference is considered as due to random noise. When density data differ from each other more than the threshold value, the intermediate profile is set as the original one. On the contrary, differences less than the threshold value are rejected and we keep the preceding value in the intermediate profile. The intermediate profile remains at a constant density until we reach a change greater than the threshold value. As recommended by Gargett & Garner (2008), the threshold is determined as the RMS of density anomalies over 10 m segments

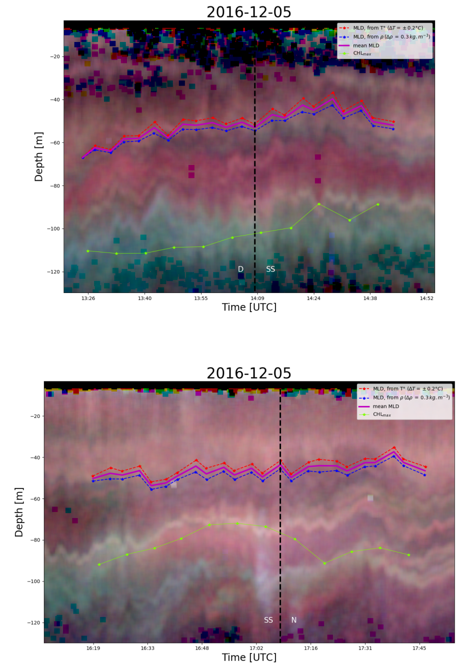

Fig. 1. Mixed layer depth & the max of Fluo on acoustic RGB image. White letters at the bottom of the plot indicate the time of day (*D : day, SS : sunset, N : night, SR : sunrise*).

into "well-mixed" layers within a radial. The purpose of this step is to reduce the random noise that can create false overturns.

Gargett & Garner (2008) propose to built two intermediate profiles instead of just one. One goes from the top to the bottom (down profile), and the second one from the bottom to the top (up profile). A final intermediate profile is then created as the average of the two individual (downward and upward) profiles.

Before to compute the Thorpe length scale an overturn validation must be applied. Gargett & Garner (2008) proposed to define an overturn ratio, $R_0 = \min(\frac{L^+}{L}, \frac{L^-}{L})$, where L is the total vertical extent of an overturn and L^+ (L^-) is the cumulative extent occupied by positive (negative) Thorpe displacements. A perfect overturn can be define as an overturn with equal positive and negative parts ($L^+ = L^-$), this leads to $R_0 = 0.5$. The R_0 ratio is used as a criterion to validate overturns. Gargett & Garner (2008) suggest a threshold R_0 value of 0.2, below which the overturn is discarded. We choose a criterion of 0.25, based on Park *et al.* (2014).

3. Results

The Mixed Layer Depth

MLD seems to follow the acoustical discontinuity, where there is a change in the frequency response (red layer) during most part of the day (*see* Figure 1). During the night part, the mixed layer base does not really fit acoustical variations. The MLD boundary tends to get closer to the 38 kHz upper limit when the acoustic response is stratified. This is clearly visible in Figure 2, where the superior limit of the 38 kHz layer is determined from S_v differences, that allows to distinguish acoustical layers. It deviates from the 38 kHz upper limit when the acoustic gets blurred. We

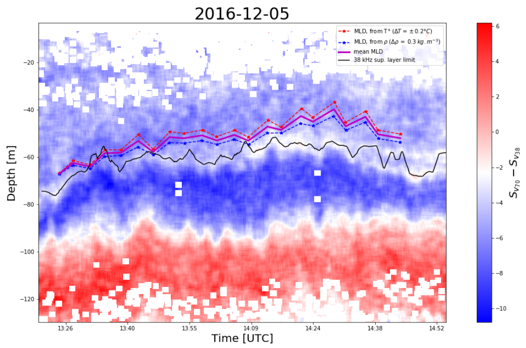

Fig. 2. Mixed layer depth & the 38 kHz upper limit, determined from $S_{v70} - S_{v38}$.

assume that the acoustical blurring is due to turbulence into the water column.

The Maximum of Chlorophyll

The maximum of Chlorophyll, that traces the presence of phytoplankton, has been also determined from scanfish data (*see* Figure 1). The CHL_{max} line seems to be encompassed between the green (70 kHz) and blue (120 kHz) layers, that is where we expect to detect the phytoplankton.

The Thorpe length scale

Here we present our results for two different radials, one visibly stratified and the other completely blurred (*see* Figure 3). Thorpe length scales (L_T) are shown only for depth below the MLD, due to the high level of displacements into the mixed layer. Both radials are during the day. The stratified one shows low L_T values (1 to 7 m) compared to the blurred radial, that contains high L_T values (5 to 10 m). For all of our radials there is no apparent change in L_T when we go through acoustical layers.

4. Conclusions

1. The use of acoustical observations, that trace biological activity, as a probe of the physics underneath seems to work in some places here. But we don't have a good method that relate clearly the physic to the acoustic.
2. The mixed layer depth seems to correspond to the higher limit of the 38 kHz acoustic layer. But we don't have enough precision to relate it directly to the acoustic. It is not a sufficient criteria to isolate an acoustic layer.
3. The maximum of Chlorophyll found into our radials is pretty much contained between the 70 & 120 kHz layer. Those frequencies are suspected to trace phytoplankton.
4. We have shown that a profile which has a non-stratified acoustic response shows large L_T values (that corresponds to high level of turbulence) compared to a stratified one, as we have assumed. But the lack of such "blurred" radials avoid any conclusion.
5. Many bias have to be considered here, the most important one is the fact L_T that we have calculated has two contributions. A vertical and also an horizontal parts, due to the scanfish trajectory. The time synchronisation has to be considered also as a non-negligible bias.

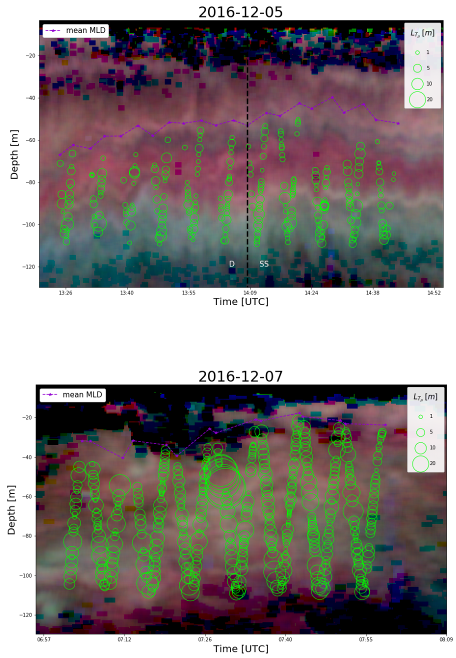

Fig. 3. Thorpe length scale displayed only below the MLD, for a perfectly stratified (*top panel*) & completely blurred radials (*bottom panel*).

5. Perspectives

For the future, to get a better identification of micro-turbulence with the acoustic we need to go higher in frequency. This can allow to recover clear acoustical structures and it may be easier to make the distinction between layers. It can be interesting to look at CTDs that have been done during the cruise, and compared the L_T determined from it to ours. Finally, it will be useful to get a mathematical criteria, lying on image processing, to make a better distinction between a "well-stratified" acoustic response to a "blurred" one.

Acknowledgements. The cleared and echo-integrated acoustic data are providing by Angelee Annasawmy (IRD/MARBEC, Sète).

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