Analysis of sound propagation in the Southwest Coast of Portugal Eddies [OS13A-17]

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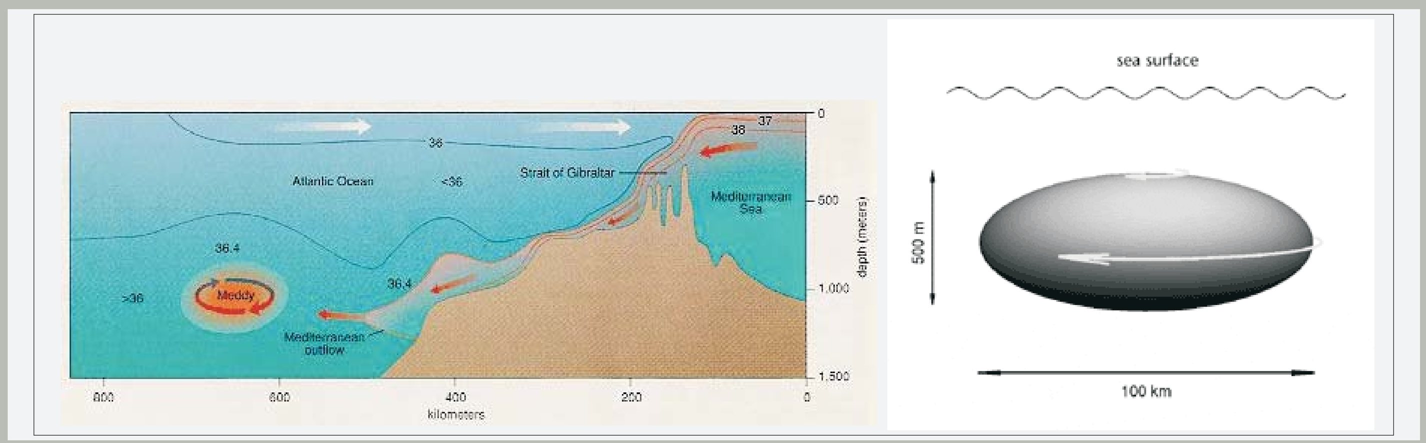
Introduction

The sound is a powerful tool to acquire information about fundamental physical parameters of the ocean environment. However, the ocean is a very dynamical complex natural system where the sound speed is an increasing function of salinity, pressure and temperature such that the ocean behaves an acoustic wave guide, where the sound speed and the water bodies play the same role as the refraction index and lens in optics (Jensen, 1994). Here we analyse the acoustic propagation in presence of the eddy related to the Mediterranean outflow in the North Atlantic (Darras, 1991).

Meddy Features

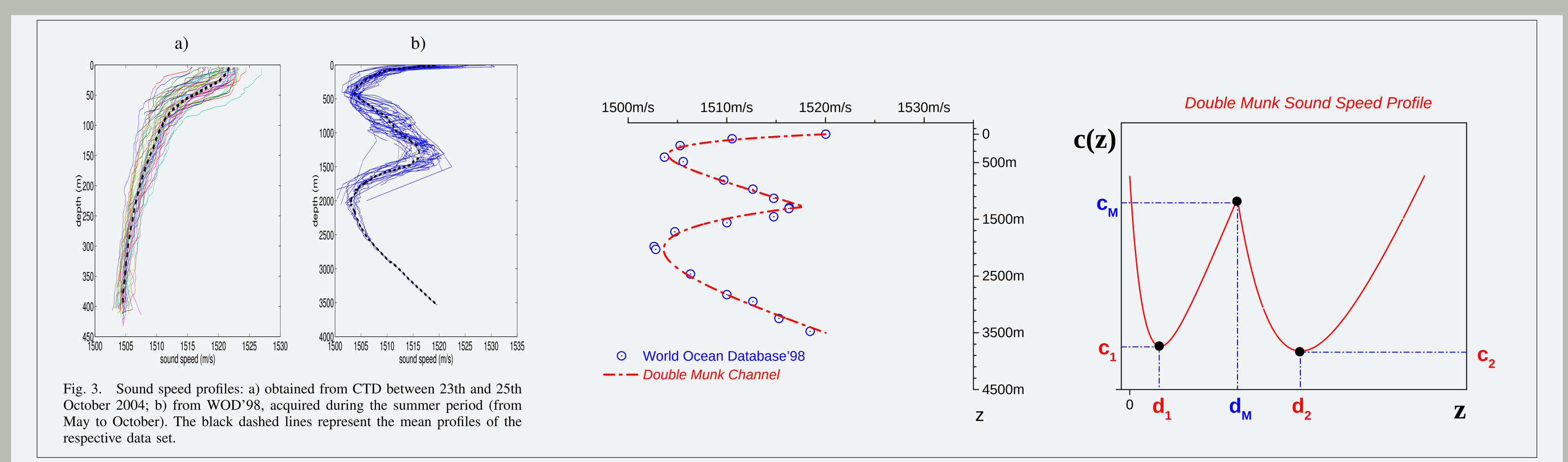
Eddies form when warm, salty Mediterranean water flows out of the Strait of Gibraltar beneath cooler incoming water and descends along the continental slope. At a depth of around 1000 metres, the salty and warm tongue of Mediterranean water reaches neutral buoyancy with the surrounding ocean water and separates from the continental slope. Pieces of this water pinch off and drift southwestward in the Atlantic Ocean as clockwise-rotating (=anticyclonic) lenses of salty, warm water that are called Meddies.



Meddy origin and dimensions.

Typical Meddies are around 500 to 800 metres thick and 100 kilometers in diameter. They contain about 0.08 percent more salt than the surrounding ocean water, which corresponds to around 2 billion tons of salt per Meddy. The number of Meddies are living quite long because rotate rapidly ($v_{rot} \approx 30cm/s \approx 25km/day$) and translate slowly ($v_{trans} \approx 2cm/s \approx 1.5km/day$) through the calm waters of the Canary Basin: they are quite stable. The number of Meddies in the Canary Basin is unknown but may be around 25 at a time (Richardson (1993) and van Geffen).

The Double Munk Sound Speed Profile Model



Comparing the Ocean'98 database result (Felisberto, 2007) with the Double Munk Model.

Related to canonical Munk profile (Jensen, 1994),

$$\tilde{c}(z; c_{\min}; \varepsilon; d; L) \equiv c_{\min}\left[1+\varepsilon\left(2\frac{(z-d)}{L}-1+\exp\left(-2\frac{(z-d)}{L}\right)\right)\right]. \quad (1)$$

We define the Double Munk Sound Speed Profile as,

$$c(z) \equiv \tilde{c}(z; c_1; \varepsilon_1; d_1; L_1)\Theta\left[d_M - z\right] + \tilde{c}(z; c_2; \varepsilon_2; d_2; L_2)\Theta\left[z - d_M\right]. \quad (2)$$

Where Θ is Heaviside step function and the best fit parameters are given by:

$$c_1 = 1504.05183\text{ m/s},\ \varepsilon_1 = 0.00217,\ d_1 = 363\text{m},\ L_1 = 350.12058\text{m},$$
$$c_2 = 1503.60584\text{ m/s},\ \varepsilon_2 = 0.00650,\ d_2 = 2030\text{m},\ L_2 = 1127.80315\text{m}.$$

and $d_M = 1278.299020$m, $c_M = 1517.870207$m/s.

Helmholtz Wave Equation

For a given frequency f, the harmonic pressure fields $\Phi(\mathbf{r})exp(-i\omega t)$ ($\omega = 2\pi f$) propagating with speed $c(z)$ are solution of the Helmholtz's wave equation:

$$\left(\nabla^2 + \frac{\omega^2}{c(z)^2}\right)\Phi(\mathbf{r}) = 0 \quad (3)$$

Besides, adopting the circular cylindrical coordinate system (where the depth increases in the positive z direction) and assuming the ocean as system with azimuthal symmetry, then in the Sommerfeld–Weyl picture the regular solutions of eq.(3) can be written as:

$$\Phi(\mathbf{r}) \equiv \int_0^\infty dk\ A(k)kJ_0(kr)\Psi(z,k). \quad (4)$$

Where k is the radial wave number, J_0 is the zero–th order Bessel function. In addition, *"the vertical wave function"* Ψ satisfies the following wave equation:

$$\frac{d^2\Psi}{dz^2} + \left(\frac{\omega^2}{c(z)^2} - k^2\right)\Psi = 0. \quad (5)$$

Wave Propagation: Normal Modes and Ray Tracing Pictures

Applying Cauchy's residue theorem, the Sommerfeld–Weyl integral (4) can be rewritten as:

$$\Phi(\mathbf{r}) \equiv \int_0^\infty dk\ A(k)kJ_0(kr)\Psi(z,k).$$
$$= \underbrace{2\pi i\sum_n \text{Residue Series}}_{\text{Normal Modes: Discrete Spectrum}} + \underbrace{\frac{1}{2}\int_{\Gamma\in C} dk\ A(k)\ k\ H_0^{(1)}(kr)\Psi(z,k)}_{\text{Continuum Spectrum}}$$

While the Asymptotic *Ray Tracing* expansion theory satisfies the following equations:

$$\Phi(\mathbf{r}) = e^{i\omega\tau(\mathbf{r})}\sum_{j=0}^{\infty}\frac{A_j(\mathbf{r})}{(i\omega)^j} \quad (6)$$

$$|\nabla\tau|^2 = c^{-2}(\mathbf{r}) + O(\omega^2)\ \text{(Eikonal)}$$
$$2\nabla\tau\cdot\nabla A_0 + (\nabla^2\tau)A_0 = 0 + O(\omega)\ \text{(Amplitud)}$$

Rays are the wave front orthogonal curves family, $\omega\,\tau(\mathbf{r}) \equiv$ constant, such that:

$$\frac{d\,\mathbf{r}}{d\,s} = c\nabla\tau. \quad (7)$$

Finally, we calculated (in dB) the Transmission Loss (TL) function, namely:

$$TL(\mathbf{r}) = -20\log\left|\frac{\Phi(\mathbf{r})}{\Phi_0}\right| \quad (8)$$

Some Meddy References

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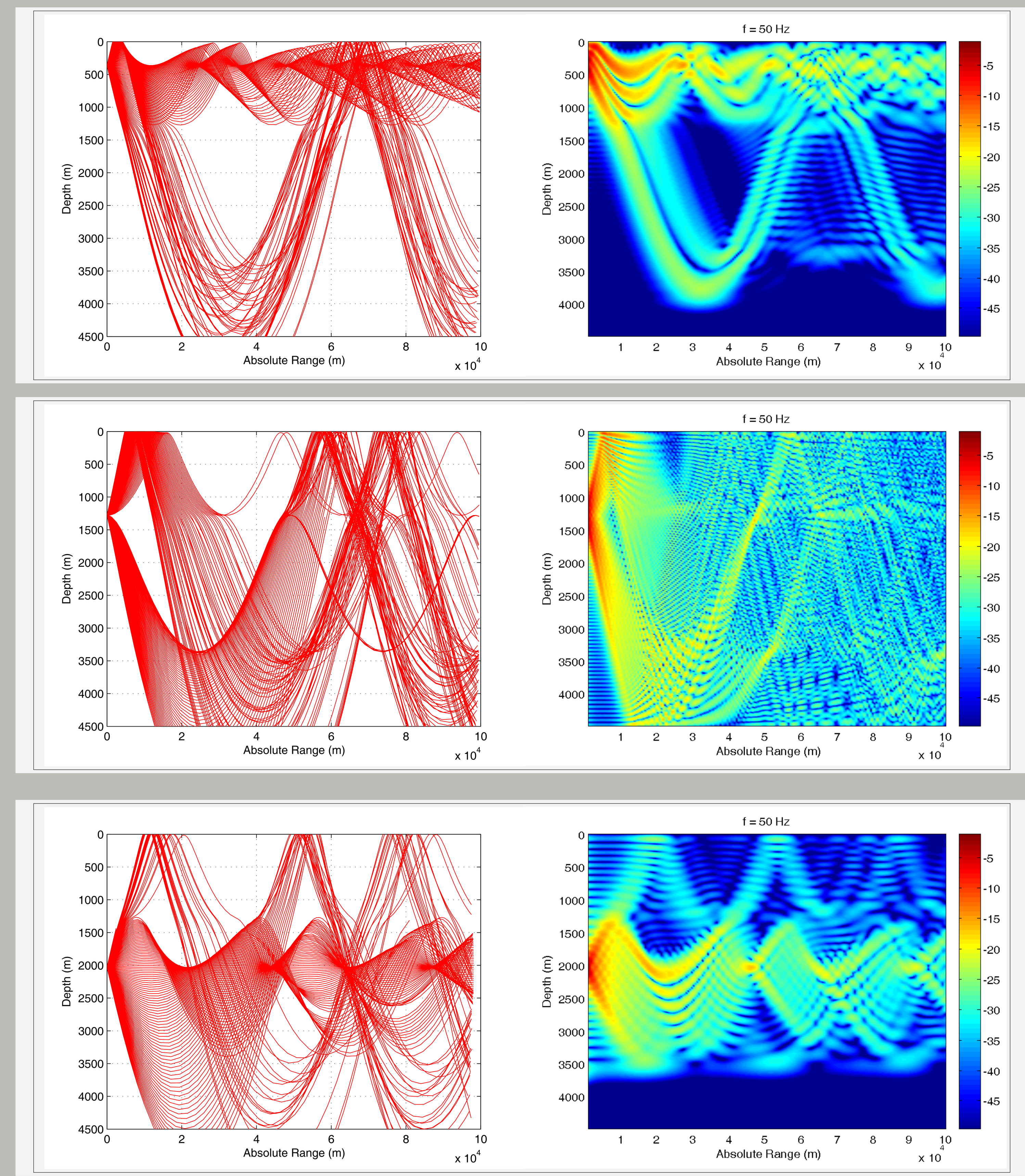
Numerical Results



The Top, Middle and Bottom panels compare the ray tracing (left side pictures) and normal mode theories (right side color map pictures) in the case of the source located at depth 360m, 1278m and 2030m respectively.

Conclusions

Based on the World Ocean database'98 for the Southwest coast of Portugal and the related phenomenological Munk double channel sound profile(2), the present numerical results, calculated by ray tracing and normal modes theories, suggest that the main feature of the sound propagation in meddy environment is basically characterized by broken of the pure Atlantic principal channel (PC) in another two deep sound channels, the upper channel (UC) and the lower channel (LC) respectively (see Top and Bottom panels in above figure). However, in the particular case where the source is located at the $z = d_M \approx 1278m$, the middle panel of the above figure shows that all channels UC, LC and PC are simultaneously acoustically excited. In order to improve these preliminary results, we are developing a more realistic model that permits introduce pertubatively some ocean acoustical anisotropies as well as meddy rotation effects. Work in this issue are in progress and planed to be published briefly.

Acknowledgements

We would like to thank the Ocean Acoustics Library team (http://oalib.hlsresearch.com/) by use of the acoustical toolbox numerical codes. This work is partially supported by EAGE PACE fund and by Ocean Acoustic Exploration (OAEx – 230855, EU Marie-Curie program FP7 IRSES) project.