Essay

Time and length scales of physical processes in the global oceans

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Motions in the global oceans cover a wide range of scales: Small scale isotropic turbulence is present as well as global mean circulation, spanning time scales from seconds to millennia and length scales from millimeters to the Earth's circumference. Illustrations of the scale of motions are in text books[1] usually presented in a way similar to the Figure shown below, simplifying at least two aspects: (i) The third axis, perpendicular to the page, is denoted as *importance* and therefore lacks a physical unit. (ii) Separation of scales. It is a priori not given that physical processes at different scales are independent[2] or whether gaps of *importance* actually exist. This essay aims to present a data-based method that could be conducted with data sets such as ECCO2[3] to approach this issue, at least within the range of resolved scales.

It is proposed to analyze the locally dominant length and time scales regarding correlation for each available spatial point $\mathbf{x}_i$ from a variable φ, that represents physical motions. The variable $\varphi_{ik} = \varphi(\mathbf{x}_i, t_k)$, where subscripts denote the i-th grid cell, and the k-th of n available time steps, is assumed to be normalized and standardized in time for simplicity. After removing the seasonal cycle length scales τ_i are estimated by the lag, where the discrete autocorrelation function $R_i(\tau) = \frac{1}{n}\sum_{k=1}^{n-\tau} \varphi_{i,k}\varphi_{i,k+\tau} = e^{-1}$ decreases below a chosen threshold e^{-1}, the inverse of Euler's number. Horizontal length scales L_i can be estimated from the cross-correlation Matrix $P_{ij} = \mathrm{corr}(\varphi_i, \varphi_j)$ by integrating for every i the area A_i, where the correlation is above the threshold. Then assuming A_i to be a disc of radius L_i yields

$$L_i^2 = \frac{1}{\pi}\sum_j P^*_{ij} dA_j, \quad P^*_{ij} = \Big\{ 1 \quad \text{if } P_{ij} > e^{-1} \text{ and } V_{ij} = 1, \quad 0 \text{ else.}$$

with dA_j being the area of the j-th grid cell. In practice, a criterion V_{ij} to denote vicinity (where $V_{ij} = 1$) should be chosen to make it unnecessary to evaluate P_{ij} for very large distances between $\mathbf{x}_i$ and $\mathbf{x}_j$ (where $V_{ij} = 0$), which also disables the influences of spatial re-emergences (teleconnection patterns). We then define the *importance* by the frequency at which (τ_i, L_i) occur in the global oceans.

However, the presented method to estimate τ_i and L_i only accounts for the locally dominant time and length scale regarding correlation and ignores other scales that are presumably present. The method could therefore be extended by a spectral perspective: Fourier-transforming φ to estimate the spectral energy per horizontal wavenumber and frequency would interpret *importance* as the energy the ocean has at given time and length scales.

If conducted, the study would presumably reveal interesting aspects that are hidden behind such simplified illustrations, as shown in the Figure.

References

[1] D Olbers, J Willebrand and C Eden, 2013. *Ocean Dynamics*, Springer.
[2] RB Scott, F Wang, 2005. *J. Phys. Oceanogr.*, 35, 1650-1666.
[3] Estimating the circulation and climate of the ocean, phase II. `ecco2.jpl.nasa.gov`

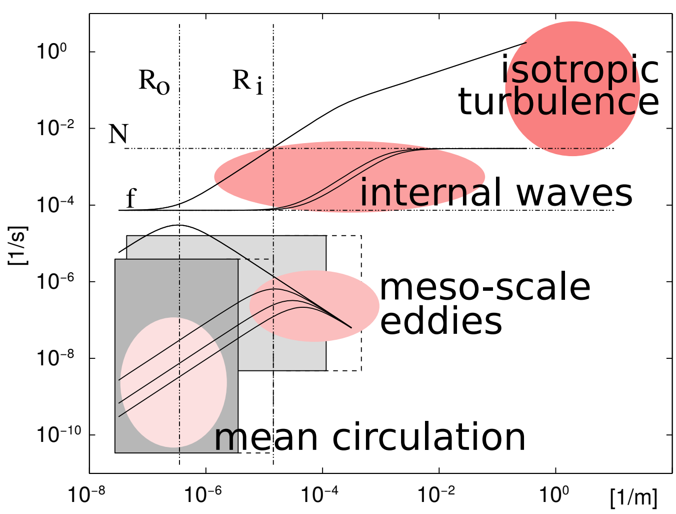

Figure: Time and length scales of important physical processes in the oceans, from Olbers et al. 2013. Grey boxes roughly span the scales that can be represented by current global ocean circulation simulations. Black lines result from theory.