

# The Mixing of Cold Water Upwelled in the Upper Ocean Turbulent Boundary Layer by an Artificial System

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Artificial upwelling driven by surface waves can provide significant societal benefits ranging from maricultural farming to modification of extreme local climates. One of the first upwelling devices using the energy of surface waves (wave-inertia pump) was developed and tested on the Black Sea by Vershinsky et al. (1987). (This design is believed to be the most efficient artificial upwelling system even now.) The cold water upwelled by a wave-inertia pump is of a higher density and therefore sinks back down in the form of a convective jet, which resembles the convective jet in the atmospheric turbulent boundary layer. The plunging jet triggers Kelvin-Helmholtz instability in the shear layer at the bottom of the mixed layer and in the thermocline, thereby increasing vertical mixing in the thermocline and entrainment of cold water to the mixed layer. The process has been simulated using ANSYS Fluent computational fluid dynamics software. The large eddy simulation indicates that there is an increase of the mixing efficiency due to developing coherent structures in the form of Kelvin-Helmholtz billows. We have considered the potential application of the artificial upwelling system for reduction of hurricane intensity in coastal areas, before the hurricane landing, and mitigation of the arid climate in the Levant. The ocean heat content (OHC) is the "fuel" for hurricanes. The surface layer mixing with the upwelled cold water produced by wave-inertia pumps reduces the OHC accessible to hurricanes. At the same time, the results of the numerical simulation indicate that some additional heat is accumulated below the thermocline. Long term observations have shown a correlation between the heat content accumulated during summer off the coastline of Haifa and precipitation in Jerusalem in winter. By increasing upper ocean mixing, an artificial upwelling system on the Israel coast of the Mediterranean Sea is expected to increase precipitation in the Levant during wintertime and reduce air-temperature in summer. Computer simulation can help us better understand the feasibility of these geoengineering approaches and their environmental consequences.

Reference: Vershinsky, N.V., Pshenichnyy, B.P., and Soloviev, A.V., 1987: Artificial upwelling using the energy of surface waves. *Oceanology* 27(3), 400-402.

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