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# Deep water coastal upwelling events during wintertime in a large lake (Lake Geneva)

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Convective winter cooling is an important process in the annual cycle of a lake ecosystem, because it brings oxygen to the deeper layers. However, in deep lakes, convective processes are often not strong enough to extend the mixing down to the deepest layers. This may become even more problematic in the future considering climate change and potentially milder winters.

In large deep lakes, two other processes originating in the coastal zone can significantly contribute to winter deep water renewal: cold-water density currents on the lateral slopes caused by differential cooling between the shallow literal zone and the deep off-shore region, and upwelling of deep water masses over the lateral slopes which results from wind forcing and may be influenced by the Coriolis force.

Previous field experiments in Lake Geneva, the largest freshwater lake in Western Europe (max. depth 310 m), have shown that cold-water density currents are a common phenomenon during wintertime, frequently reaching the thermocline at O(100m) depth..

As part of a project investigating winter mixing dynamics in Lake Geneva, we examine wind-driven, Coriolis-influenced upwelling in order to better understand its role in the deep-water exchange during the weakly stratified period (December-March).

The study is based on field observations taken on the northern shore of the lake, 20 km west of Lausanne in the winters of 2017-19. Near-bottom water temperatures are inferred from a fiber-optic based Distributed Temperature Sensing (DTS) system, laid down on the lateral slope starting at the shore, with a spatial and temporal resolution of O(1m) and O(0.1°C), respectively. Temperature and current velocities in the water column are recorded by several ADCP and thermistor chain moorings. The data set is completed by regular CTD campaigns following wind events favoring upwelling.
These field measurements were combined with a validated 3D hydrodynamic model (MITgcm) in order to analyze and quantify the exchange between the littoral zones and deeper parts of the lake.

It was observed that following medium to strong northeast-bound wind events (i.e. winds parallel to the main axis of the central lake) lasting for at least one day, near-shore temperatures at all instruments suddenly dropped to the same temperatures as those in the deep open waters and remained low for several days. This indicates that, triggered by persistent wind-stress and under the influence of the Coriolis force, hypolimnetic water reached the surface in the near shore zone, where it is subject to heat and gas exchange with the atmosphere, before returning to the deep layers. Numerical modeling of these events showed comparable results and allowed to trace the origin of this cold water to the deep layers.

Our field observations and the numerical results suggest that in addition to the previously observed cold-water density currents, wind-driven upwelling is a common phenomenon in Lake Geneva during the weakly stratified winter period and potentially a significant mechanism for deep-water renewal.