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Wind-driven interbasin exchange and hypolimnetic upwelling during wintertime in a large, deep lake (Lake Geneva)

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Distinct sub-basins and large embayments are a ubiquitous feature of many lakes. Horizontal gradients in water quality between basins can result from a number of processes. For example, different seasonal mixing regimes between basins with different maximum depths can produce biochemical gradients between their hypolimnia. Consequently, interbasin exchange can be an important process with significant ecological consequences.

Combining field observations, 3D hydrodynamic modeling, and model-based Lagrangian particle tracking, we investigated wind-driven interbasin exchange between the shallow *Petit Lac* (max. depth 75 m) and deep *Grand Lac* (max. depth 309 m) basins of Lake Geneva, Western Europe's largest lake, during early winter. In addition to CTD casts conducted in the *Petit Lac*, several ADCP and thermistor chain moorings were deployed at the confluence between the two basins during the winter 2018/2019.

Following a strong northeast-bound, along-axis wind event lasting from 7 to 10 December 2018, a two-layer flow pattern established at the confluence: epilimnetic water from the *Petit Lac* was pushed by the wind into the *Grand Lac* and was compensated for by a bottom inflow of deep hypolimnetic waters from the *Grand Lac* into the *Petit Lac*. Consequently, temperatures in the lower part of the water column gradually decreased at all moorings, with the lowest temperatures corresponding to values found at 180 m depth, as indicated by full-depth temperature profiles taken in November and December 2018.

For approximately 3.5 days, deep *Grand Lac* water was continuously transported into the *Petit Lac*, with observed inflowing current velocities near the bottom exceeding 27 cm s^{-1}. Approximately 1.5 d after the wind subsided, the current patterns at the confluence reversed and the previously upwelled *Grand Lac* water was drained again from the *Petit Lac* in a bottom-hugging current with measured velocities reaching 19 cm s^{-1}.

The current and temperature patterns at the confluence were well represented by a 3D hydrodynamic model (MITgcm). Model-based particle tracking confirmed the deep origin of the upwelled *Grand Lac* waters. Furthermore, it revealed that the interbasin upwelling event effectively formed a current loop, during which, over the course of more than one week,

hypolimnetic water from below 150 m depth first upwelled into the *Petit Lac*, intruding approximately 10 km into the shallow basin, and subsequently descended back into the *Grand Lac* hypolimnion. Moreover, low model-based gradient Richardson numbers and temperature inversions observed in the CTD profiles indicate turbulent mixing between the deep, upwelled *Grand Lac* waters and the "fresher," i.e., better quality *Petit Lac* waters.

Our field observations and modeling results show that enhanced wind-driven interbasin exchange and deep hypolimnetic upwelling between the shallow *Petit Lac* and deep *Grand Lac* basins of Lake Geneva frequently occur during early winter. Furthermore, our results suggest that these hypolimnetic interbasin upwelling events may present a potentially important mechanism for hypolimnetic-epilimnetic exchange and deep-water renewal in Lake Geneva and possibly in other deep multi-basin lakes under similar wind conditions; especially, when considering the expected weakening of the classical deep convective cooling during wintertime due to climate change effects.