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Climate Change and its Potential Consequences to the Thermodynamics of an Alpine Lake

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The characteristics of mixing processes as well as duration, frequency, and stability of an alpine lake's stratification are strongly coupled to the local climate conditions. These physical processes then again define the way in which life – from bacteria to human being – develops in this environment. Hence, probably economic and cultural lake uses are affected by climate change. Studies discovered reactions of lake physics due to global warming in central Europe in measured time series.
The question is: What changes in alpine lake's thermodynamic processes do we have to expect in the next decades? This question is directed at first to general lake properties like water temperature, metalimnion depth, and heat balance and their behavior in space and time. Secondly, there is a need for information about mixing processes in these monomictic lakes. Mixing is important for the distribution of e.g. nutrients and oxygen. Thus, it is necessary to know how mixing intensity changes under likely future climate conditions.
For this purpose three representative lakes were selected: Lake Constance (international), Lago di Viverone (Italy), and Woerthersee (Austria). For each lake a 1dv hydrodynamic model was built up, calibrated with an evolutionary algorithm, and finally validated. The model's source code is in an experimental state and it was provided by Deltares (Netherlands). During calibration the calculated mean monthly temperatures in different depths were compared to measurements. Then, based upon measured meteorological data "what if"-scenarios of air temperature, wind speed, cloud cover and relative humidity were developed by changing the mean value or by removing the old trend and adding a new one. When driving the model with this broad range of meteorology the result is a sensitivity study. This allows the determination of the lake's sensitivity e.g. regarding mixing intensity on changing climate, in a way that is independent from rough regional climate projections.
Here, mixing intensity is defined as a ratio of a concentration of a numeric tracer in deep water to the concentration in the upper water levels at the end of the mixing period. This tracer is injected in the surface layer in autumn (end of stagnation). The results show, that mixing intensity declines rapidly at Lake Constance if the air temperature rises. At the other lakes this effect is smaller. The mean surface water temperature is linearly coupled to the mean air temperature when the regression coefficient is nearly one. The water temperature in the hypolimnion reacts slightly on this change. The position of the thermocline only changes significantly if mean wind speed rises. No wind results in a thermocline position, similar to the case, when there is measured wind. No wind also reduces evapotranspiration at Lake Constance by 15%, at Woerthersee by 7%, and at the Lago di Viverone by 14%.
This study is part of the EU-project SILMAS (Sustainable Instruments for Lake Management in the Alpine Space). The results are assembled to a guideline for stakeholders, lake managers, and politicians.