Reconstruction of surface water temperature based on air temperature: a comparison among different lakes

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Water temperature; lake; air temperature; heat budget; climate change.

EXTENDED ABSTRACT

Introduction
The temperature of surface water is a crucial factor for lakes hydrodynamics and ecology, and its accurate estimation usually requires a significant amount of information that is not always available or reliable. In this work, we present the results of a simple lumped model that has been developed to estimate water temperature in the well-mixed surface layer (epilimnion) as a function of air temperature only.

Methods
The model air2water (described in detail in Piccolroaz et al., 2013), which is based on the simplification of the complete heat budget of the well-mixed surface layer, is set up in terms of an ordinary differential equation comprising a few parameters (whose number varies from 4 to 8 depending on the different formulations). Being related to physically based assessable quantities, the range of variation of the parameters is limited, so they can be easily calibrated using two long-term series of air and water temperatures. Moreover, the model is able to provide a qualitative estimation of the depth of the epilimnion during the annual stratification cycle. Given the simplicity of the model, a Monte Carlo calibration can be performed using a large number of randomly chosen sets of parameters ($10^8$ realizations in the examined cases).

Results and discussion
Four lakes characterized by different morphological features and mixing regimes have been examined: Lake Superior and Lake Erie (USA-Canada), Lake Garda (Italy) and Lake Mara (Canada). For all of them, a satisfactory reproduction of both seasonal and inter-annual fluctuations of water temperature has been achieved (e.g., in terms of the Nash-Sutcliffe efficiency index) over decadal periods. Figure 1 shows an example of the validation of the model applied to Lake Superior, where we note that the difference between cold and warm seasons is correctly reproduced (e.g., between years 2009 and 2010).

In particular, the model is able to properly account for the thermal inertia of the water mass and thus to follow the hysteresis between air temperature and water temperature. In Figure 2 the annual average cycles of Lake Superior (left panel) and Lake Erie (right panel) are compared. The qualitative difference between the first lake, deep (average depth 147 m), and the second one, shallow (average depth 19 m), is clearly and well reproduced even in the simplest version (4 parameters) of the model, with only some minor deviations that are
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characteristic of buoy measurements (they are not present in the satellite-reconstructed temperatures).

The analysis of the results, and of the values of the model’s parameters, allows for the characterization of the behaviour of each lake subjected to varying atmospheric conditions. In this way, the differences among the different lakes can be highlighted, appreciating for instance the different response of the lakes to variations of the air temperature. In this way, some suggestions can be drawn about the expected modifications to surface water temperature due to future changes in climate.

![Figure 1](image1.png)

Figure 1. Validation of the model results (water temperature $T_w$, model with 4 parameters) against the observed surface water temperature ($T_w$ obs., satellite data) in Lake Superior; air temperature $T_a$ obs. is also indicated (modified from Piccolroaz et al., 2013).

![Figure 2](image2.png)

Figure 2. Average annual cycle of the temporal variation of air and water temperature: the model results (4 parameters) are compared with measurements collected at buoys. Note the wider hysteresis cycle in the deeper Lake Superior (left) with respect to the shallower Lake Erie (right).

REFERENCES