Climate change affecting hypolimnetic water temperatures in deep alpine lakes

Martin T. Dokulil, Katrin Teubner and Albert Jagsch

Introduction

The possibility of climate change has attracted considerable attention over the past decade (BURROUGHS 2001). As the evidence for changes in weather conditions have been substantiated, environmental impacts on aquatic systems have frequently been associated with climatic indices such as the North Atlantic Oscillation (HURRELL et al. 2003). This index is strongly related to the air and surface water temperatures of lakes in Central Europe (LIVINGSTONE & DOKULIL 2002). Variables are highly synchronised between lakes within the same lake district (DOKULIL & TEUBNER 2002).

Oligotrophic deep alpine lakes are excellent ecosystems to amplify climatic signals. In the past, trends in lake surface temperatures and ice cover have mainly been used as indicators for climatic change. Here we analyse the long-term development and trend of hypolimnetic water temperatures (HWT) of deep alpine lakes in Austria.

Key words: climate change, North Atlantic Oscillation, hypolimnetic water temperatures, deep alpine lakes

Methods

The monthly data sets used here for the alpine lakes in lake district 'Salzkammergut', located east of the city of Salzburg in Austria, mainly originate from the authors but were augmented with measurements from various authors dating back as far as 1848 (MÜLLNER 1895, RUTTNER 1937, MORTON 1950). All data shown are annual averages for the deep layers (Figs. 1–3). More detailed characteristics of the lakes investigated may be found in DOKULIL & TEUBNER (2002).

Results

Fragmentary data dating back to 1848 from the oligotrophic, highly flushed fjord-type lake Hallstättersee indicated no significant changes in deep water temperatures until 1941 when temperatures began to show a rising trend (Fig. 1). Calculated from the slopes of the regression lines (Fig. 1), hypolimnetic temperatures increased between 0.3 and 0.4 °C for the periods 1941 to 2003 and 1971 to 2003 respec-

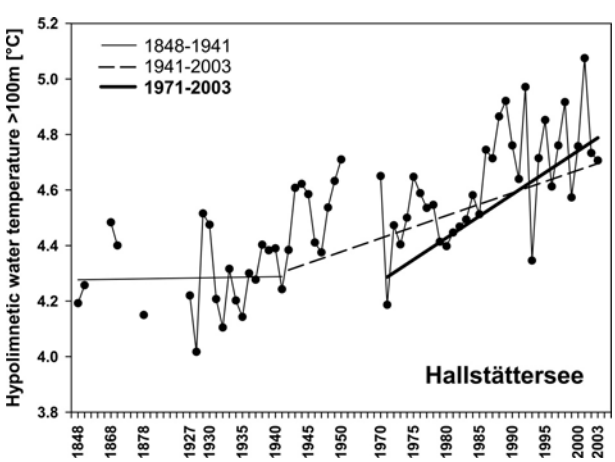

Fig. 1. Long-term development of annual average hypolimnetic water temperature > 100 m in the deep oligotrophic alpine lake Hallstättersee from 1848 to 2003. The trend lines for the different periods are indicated. For further discussion refer to the text.

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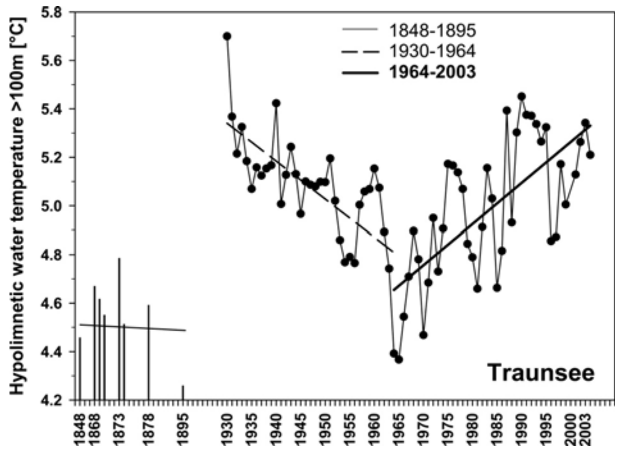

Fig. 2. Development of annual mean water temperatures at depths > 100 m in Traunsee between 1848 and 2003.

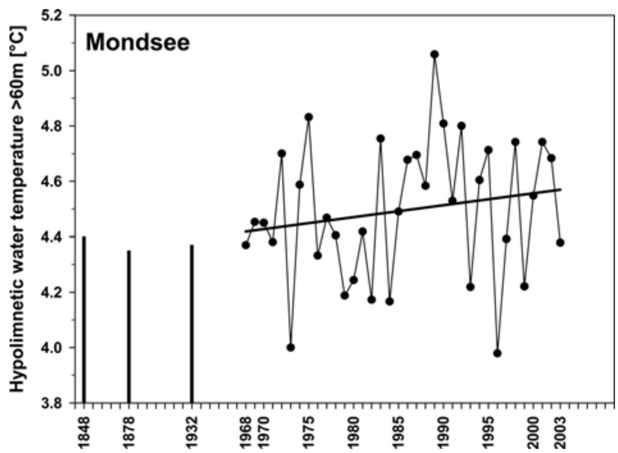

Fig. 3. Deep water temperatures > 60 m in Mondsee for 1848, 1878, 1932 and 1968–2003 (yearly means).

tively. These findings result in a consistent increase of approximately 0.1 °C per decade.

A greater increase of 0.64 °C for 1964–2003 was observed in Traunsee, resulting in a calculated temperature rise of 0.16 °C per decade (Fig. 2). As in Hallstättersee, data prior to 1900 do not show any trend. The peculiar high deep water temperatures in 1930 and the decreasing trend between 1930 and 1964 has been ascribed to the input of industrial tailings into the lake which began in 1928 and rendered the lake partially meromictic during this time (SCHMIDT & DOKULIL 2002). In the early 1960s the input practice changed, leading to a return to holomixis.

The few measurements from Mondsee before 1900 and from 1932 suggest that no significant changes in deep water temperatures occurred during this time. Based on the monthly monitoring data from 1968 to 2003, hypolimnetic temperatures increased by about 0.2 °C during this time, or just under 0.1 °C per decade (Fig. 3). This temperature rise in the hypolimnion of lakes is consistently repeated in several other lakes of the region and in Europe in general (data not shown here).

The observed increase in hypolimnetic water temperature (HWT) in these lakes can be attributed to the influence of the North Atlantic Oscillation (NAO) affecting weather situations

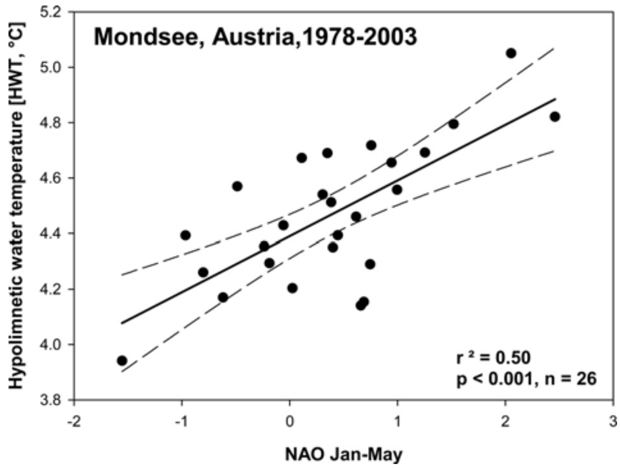

Fig. 4. Correlation of annual average hypolimnetic water temperature (HWT) to the mean North Atlantic Oscillation Index (NAO) for January to May. The regression line, 95% confidence limits and statistical values are given.

across Europe. As an example, HWTs from Mondsee spanning 1978–2003 were regressed against the average NAO index for January to May (Fig. 4). The correlation is highly significant ($r^2 = 0.50$, $P < 0.001$, $n = 26$).

Discussion

Warming trends in deep waters have already been observed in the Mediterranean Sea in the second half of last century (BETHOUX et al. 1990). Recently, similar observations and conclusions were reported from the Pacific (FUKASAWA et al. 2004) leading to shifts in deep sea communities (RUHL & SMITH 2004). Measurements of hypolimnetic temperatures affected by climate change have been reported from freshwater lakes in Switzerland and Italy by LIVINGSTONE (1993) and AMBROSETTI & BARBANTI (1999). Similar observations on the effect of warming on lakes were made outside Europe by VERBURG et al. (2003) and others.

European lakes are driven by the weather and climate changes induced by the atmospheric circulation variability across the North Atlantic. The most prominent and recurrent pattern of this circulation is the North Atlantic Oscillation (NAO), which strongly affects freshwater systems in Europe as we have shown here. More observations and correlations to climatic indices from a large number of lakes in Europe will be published elsewhere.

Conclusion

Long-term data sets from the hypolimnion of deep alpine lakes in Austria show consistent trends of warming which can be linked to the NAO-Index as a measure of climate change.

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