The North Atlantic Oscillation

Does it Affect the Timing of Break-up of Northern Hemisphere Lakes?

The North Atlantic Oscillation is a large-scale climate phenomenon that affects the climate of much of the northern hemisphere in winter and spring. EAWAG found that it also affects the timing of ice break-up on northern hemisphere lakes. The area of influence of the North Atlantic Oscillation has shifted over the past 130 years, with an increase in its influence in Siberia and a decrease in North America.

Climate over the North Atlantic is generally dominated by the simultaneous existence of an area of low surface air pressure centered on Iceland (the Iceland Low) and an area of high surface air pressure extending approximately from the Azores to the Iberian peninsula (the Azores High) (Fig. 1). The resulting large-scale north-south gradient in surface air pressure between these two pressure centers is of course not constant, but varies according to their strength. This variation in the meridional pressure gradient over the North Atlantic is known as the North Atlantic Oscillation (NAO). The NAO is directly responsible for a great deal of the interannual variability in climate experienced by the land areas bordering the North Atlantic, but is also associated with the climate variability occurring over a large part of the rest of the Northern Hemisphere, especially at high latitudes [1]. The mean air temperature of the northern hemisphere, for instance, is linked to the NAO, and almost a third of the interannual variance in the mean air temperature can be explained statistically by the NAO. The influence of the NAO on the northern hemisphere climate is especially strong in winter and spring.

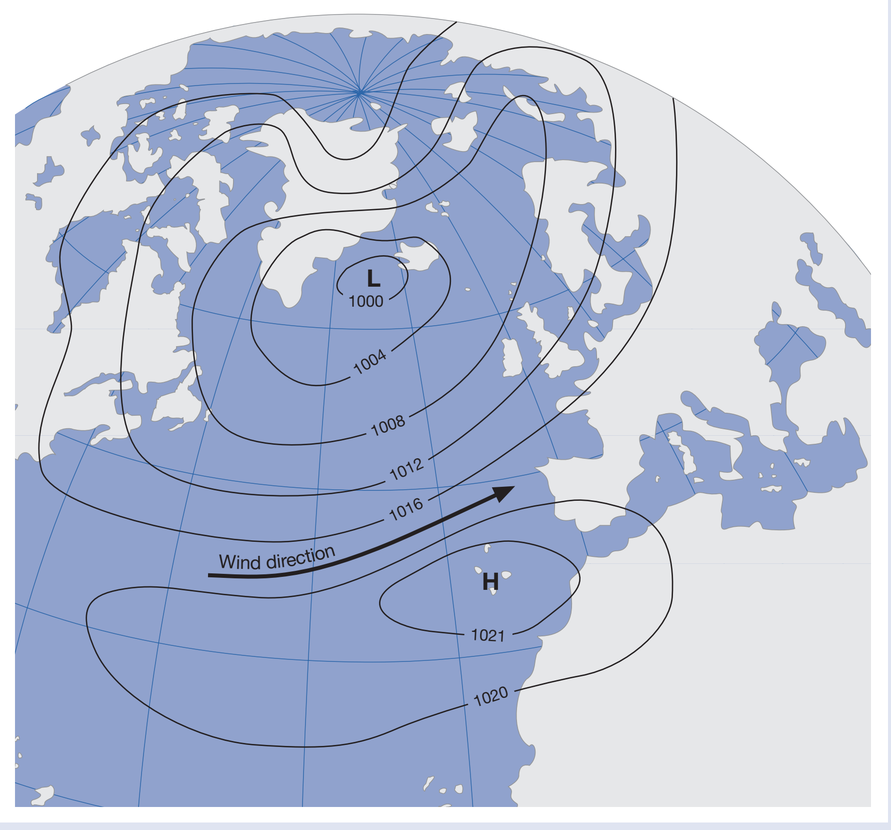

Fig. 1: The mean sea-level air pressure distribution over the North Atlantic in January (1941–1970), showing the Iceland Low, the Azores High and the prevailing direction of the winds blowing across Europe from the North Atlantic. Adapted from [2].

The Meteorological Significance of the NAO

The NAO is commonly represented in terms of an index (Fig. 2) based on the difference of the sea-level air pressure measured at a meteorological station close to the center of the Azores High and that measured at a station in Iceland [1]. A high pressure difference results in a positive index and a low pressure difference in a negative index.

High winter NAO indices indicate a steep meridional (i.e., north-south) pressure gradient over the North Atlantic. This results in strong westerly winds that transport warm, moist maritime air eastwards across Europe (Fig. 1), giving rise to mild, wet winters in Europe and much of central Asia. Low winter NAO indices indicate a relatively weak meridional pressure gradient with correspondingly weak westerlies over the North Atlantic and colder, drier winters in Europe. In eastern Canada the situation is the opposite, with high NAO indices being associated with strong northerly winds and cold winters, and low NAO indices being associated with weaker northerly winds and warmer winters. Rare winter reversals of the normal pressure distribution over the North Atlantic (i.e., high pressure over Iceland and low pressure over the Azores) cause polar air to be transported southward over Europe, resulting in extremely cold winters there [2]. This occurred, for instance, in January 1963, when both the Lake of Zurich and Lake Constance froze over – a very rare event indeed.

Analyses of historical data records

The timing of break-up of ice on lakes is highly dependent on the air temperatures prevailing during winter and spring (see also article on p. 19 of this issue). Since this is when the climatic influence of the NAO is at its greatest, it is likely that the NAO will determine to some extent the interannual variability in the timing of break-up of the lakes that lie within its extensive geographic range of influence. This hypothesis was investigated for various lakes distributed throughout the Northern Hemisphere for which long series of observations of the timing of break-up exist [3–6]. Here we will look at four representative lakes: Kallavesi (Finland), Lej da San Murezzan (or Lake of St. Moritz, Switzerland), Lake Baikal (Siberia) and Lake Mendota (Wisconsin, USA). Whether there really is an association between the NAO and the timing of break-up of these four lakes was investigated by correlating the time series of the calendar dates of their break-up with seasonal NAO indices. In general, any correlation obtained would be expected to be negative, since high NAO indices are associated with mild winters, presumably resulting in early break-up, and vice-versa. To find out additionally how the degree of influence of the NAO has varied through time, correlations were computed for a series of overlapping 50-year historical data windows, beginning with 1865–1914 and ending with 1947–1996.

The correlation coefficients obtained are illustrated in the form of two-dimensional contour plots in Fig. 3. In each plot, the correlation coefficient is shown as a function both of the season for which the NAO index was computed and of the historical data window. Significant negative correlations are shown as dark-blue areas in the plots. They indicate a high probability that the NAO influences the timing of break-up.

Lake Baikal in Siberia is frozen over during 4–5 months of the year.

Has the Area of Influence of the NAO Shifted?

The influence of the NAO on air temperature is known to be extremely strong in Finland [1], so a consistently strong NAO signal might therefore be expected to manifest itself in the timing of break-up of Kallavesi. This is indeed the case: throughout the entire record, there is a significant negative correlation between the calendar date of break-up of Kallavesi and the NAO indices from the previous winter and spring (Fig. 3). The maximum correlation obtained for

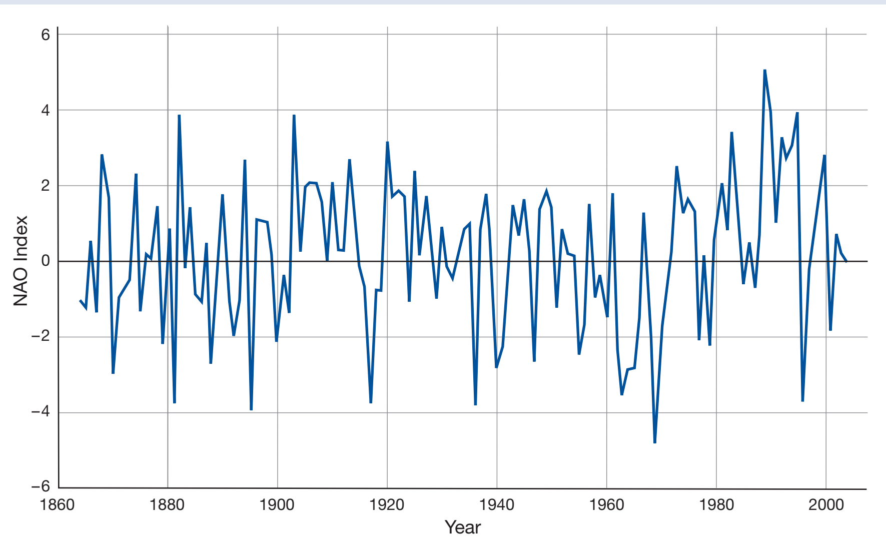

Fig. 2: The variation in the North Atlantic Oscillation (NAO) in winter (December to March) since 1864, expressed in terms of the NAO index. Adapted from [1].

Kallavesi corresponds to 43% shared variance; i.e., 43% of the variability in the break-up date can be explained statistically by the variability of the NAO index. This is a surprisingly high figure in view of the simplicity of the NAO index as a representation of the complex climatic effects operating on the lake.

The Lej da San Murezzan, in the Swiss Alps, is situated in a region where air temperature is much less influenced by the NAO than it is in Finland. Thus, only slight indications of a weak association between break-up and the winter NAO during the latter part of the series are apparent (Fig. 3). Nevertheless, there is still up to 11% shared variance.

In the case of Lake Baikal, the influence of the winter NAO on break-up has increased substantially during the period covered by the data [5]. Prior to the 1918–1967 data window, the winter NAO had no detectable effect on the timing of break-up (Fig. 3); subsequently, up to 16% of the variance in break-up date can be explained in terms of the winter NAO indices.

The most surprising results are those from Lake Mendota (Fig. 3). During the last half of the 20th century, air temperatures in central North America are known to have been affected relatively little by the NAO, and the low correlations found between the break-up date of Lake Mendota and the winter NAO during the latter part of the series is in agreement with this. However, going back further in time, the magnitude of the (negative) correlation coefficient increases to the point where almost as much variance is explained as in the case of Kallavesi now. In combination with the apparent shift in the reverse direction in the case of Lake Baikal, and possibly also in Lej da San Murezzan, this suggests that the geographical area of influence of the NAO may have changed during the last 130 years. Previously, the NAO may have had a greater influence on the climate in North America than it does today, coupled with a weaker influence on the climate in Siberia.

To support these results, we are carrying out investigations into a number of other lakes in various regions of the Northern Hemisphere. Preliminary results indicate that these lakes are also influenced by the NAO. Furthermore, the Arctic Oscillation, which is strongly associated with the NAO, apparently also plays a role in determining the timing of break-up of these lakes.

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David M. Livingstone, portrait on p. 22.

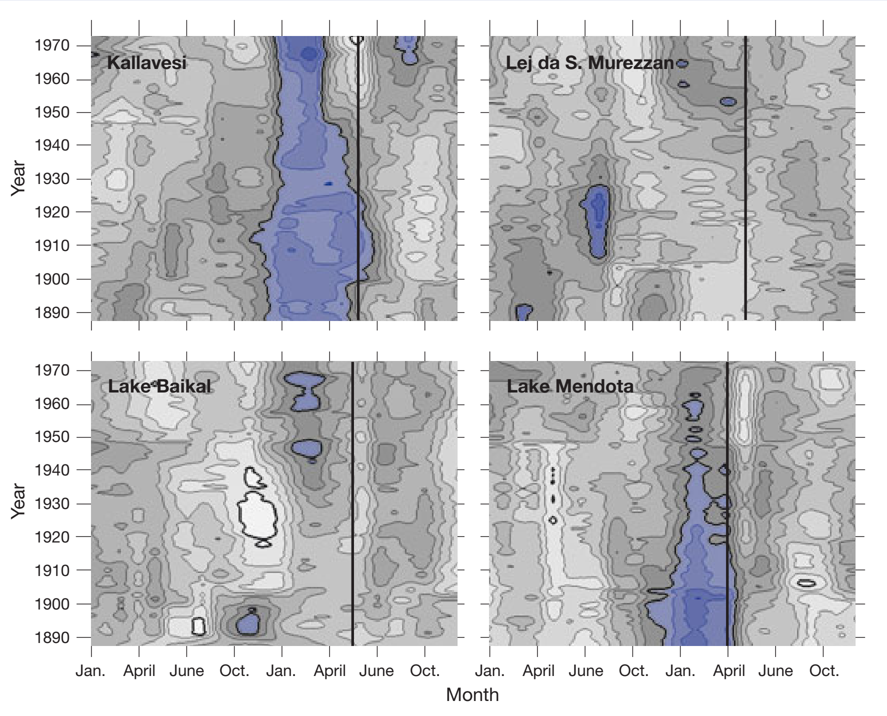

Fig. 3: Contour plot of correlation coefficients (r) between the calendar date of break-up and seasonal indices of the North Atlantic Oscillation (NAO) for 4 lakes in various parts of the northern hemisphere: Kallavesi, Finland; Lej da San Murezzan, Switzerland; Lake Baikal, Siberia; and Lake Mendota, Wisconsin, USA. The seasonal NAO indices (horizontal axis) in each case refer to a 3-month period (e.g., January to March). All correlations were calculated over a 50-year time window (vertical axis) (e.g., 1871 to 1920). To simplify the representation only the middle month of each season and the middle year of each time period are plotted. The blue areas represent significant negative correlation coefficients. The contour interval is 0.1. The thicker solid contour lines round the blue and white areas represent r = -0.3 and r = +0.3, respectively. Values of r = ±0.28 are statistically significant at the p = 0.05 level, and values of r = ±0.36 at the p = 0.01 level. The mean date of break-up for each lake is denoted by the vertical line. Adapted from [3].

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