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Trends in ice formation at Lake Neusiedl since 1931 and large-scale oscillation patterns

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Ice formation at Lake Neusiedl (Neusiedler See, Fertő tó), a shallow steppe lake (area 320 km^2, mean depth 1.2 m) at the border of Austria/Hungary, is of ecological and economic importance. Ice sailing and skating help to keep a touristic off-season alive. Reed harvest to maintain the ecological function of the reed belt (178 km^2) is facilitated when lake surface is frozen.
Changes in ice formation were analysed in the frame of the EULAKES-project (European Lakes under Environmental Stressors, www.eulakes.eu), financed by the Central Europe Programme of the EU. Data records of ice-on, ice duration and ice-off at Lake Neusiedl starting with the year 1931, and air temperature (nearby monitoring station Eisenstadt - Sopron (HISTALP database and ZAMG)) were used to investigate nearly 80 winters. Additionally, influences of 8 teleconnection patterns, i.e. the Atlantic Multidecadal Oscillation (AMO), the East Atlantic pattern (EAP), the East Atlantic/West Russia pattern (EA/WR), the Eastern Mediterranean Pattern (EMP), the Mediterranean Oscillation (MO) for Algiers and Cairo, and for Israel and Gibraltar, resp., the North Atlantic Oscillation (NAO) and the Scandinavia pattern (SCA) were assessed.
Ice cover of Lake Neusiedl showed a high variability between the years (mean duration 71$\pm$27 days). Significant trends for later ice-on (p=0.02), shorter ice duration (p=0.07) and earlier ice-off (p=0.02) for the period 1931-2011 were found by regression analysis and trend analysis tests. On an average, freezing of Lake Neusiedl started 2 days later per decade and ice melting began 2 days earlier per decade.
Close relationships between mean air temperature and ice formation could be found: ice-on showed a dependency on summer (R=+0.28) and autumn air temperatures (R=+0.51), ice duration and ice off was related to autumn (R=-0.36 and -0.24), winter (R=-0.73 and -0.61) and concurrent spring air temperatures (R=-0.44).
Increases of air temperature by 1˚C caused an 8.4 days later timing of ice-on, a decrease of ice duration by 11.0 days and a 5.8 days earlier ice-off. The sensitivity of ice duration and ice-off to rising air temperatures was increasing at Lake Neusiedl. This effect of warming could not be verified for the timing of ice-on.
Ice-on at Lake Neusiedl showed a significant relation to EAP (yearly index; R=0.33). Ice duration and ice-off were influenced significantly by the winter indices of MO for Algiers and Cairo (R=-0.48 and -0.45), NAO (R=-0.42 and -0.37), and EAP (R=-0.31 and -0.48).