Large scale oscillation patterns and rising water temperatures at Lake Neusiedl

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INTRODUCTION

Lake Neusiedl (Neusiedler See, Fertő tó) (Fig.1) is a very shallow polymictic steppe lake (area 320 km², mean depth 1.2 m) at the border of Austria/Hungary. The low ratio of water depth to water volume accounts for dynamic, air temperature-dependent developments of water temperature with the potential of unusually warm waters that are a pillar of the touristic attractiveness of the lake.

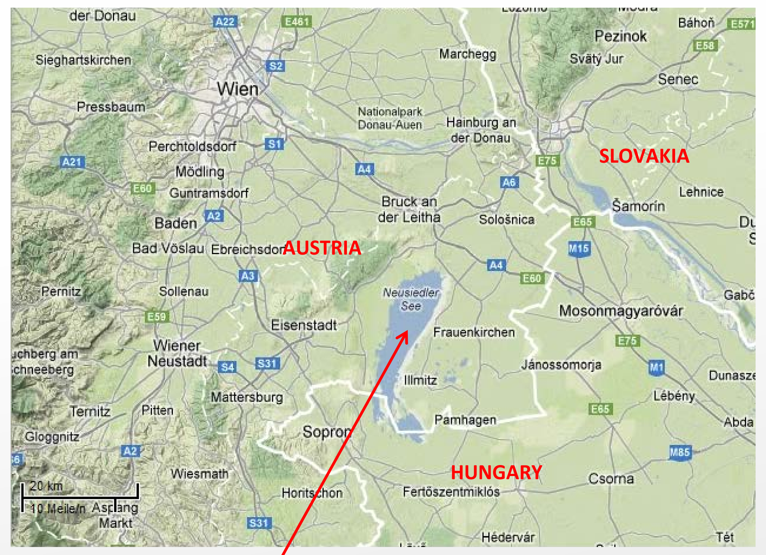

Fig. 1: Lake Neusiedl at the border of Austria/Hungary (Google ©2012)

CONCLUSIONS

- **The increase of water temperatures at Lake Neusiedl during the last four decades was more pronounced and steeper than that of air temperatures for all seasons.**
- **Decadal increases of water temperature were +0.60, 0.85, 0.55 and 0.26° C, resp., for spring, summer, autumn and winter. Neumann test showed significant increases; probable steps could be identified by cumulative sum statistics.**
- **Water temperature was closely related to air temperature.**
- **The oscillation indices with the most distinct relationships to the water temperature of Lake Neusiedl were the Atlantic Multidecadal Oscillation, the East Atlantic pattern and the Mediterranean Oscillation**

MATERIAL & METHODS

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 water temperature at 5 monitoring stations of Lake Neusiedl (eHYD and Hydrograph. Jahrbuch)[1] and the nearby air temperature monitoring station Eisenstadt - Sopron (HISTALP database and ZAMG)[2] were used to investigate the period 1971-2010 for the four seasons (spring = MAM, summer = JJA, autumn = SON, winter = DJF,). Additionally the influences of 8 teleconnection patterns[3], 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 / Cairo, and for Gibraltar / Israel, resp., the North Atlantic Oscillation (NAO) and the Scandinavia Pattern (SCA) were assessed.

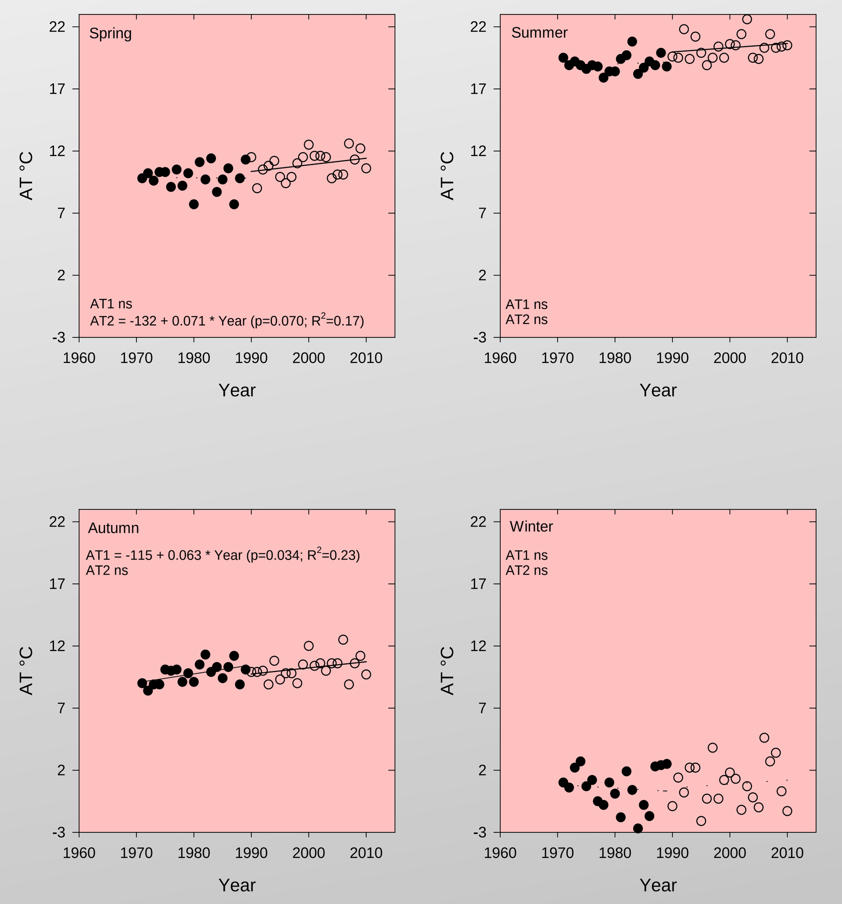

Fig. 2: Seasonal means of air temperature (AT) in ° C in the Lake Neusiedl region from 1971-1990 (AT1) and 1991-2010 (AT2) (data from HISTALP and ZAMG[2])

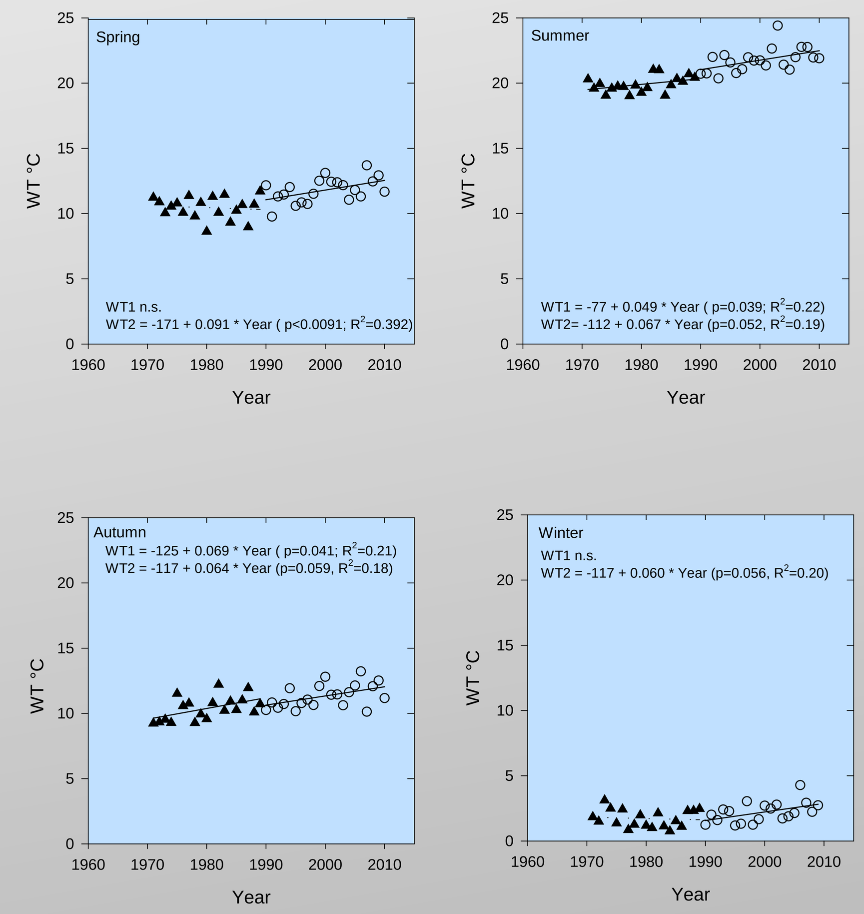

Fig. 3: Seasonal means of water temperature (WT) in ° C at Lake Neusiedl from 1971-1990 (WT1) and 1991-2010 (WT2) (mean of five stations, data from eHYD and HJ [1])

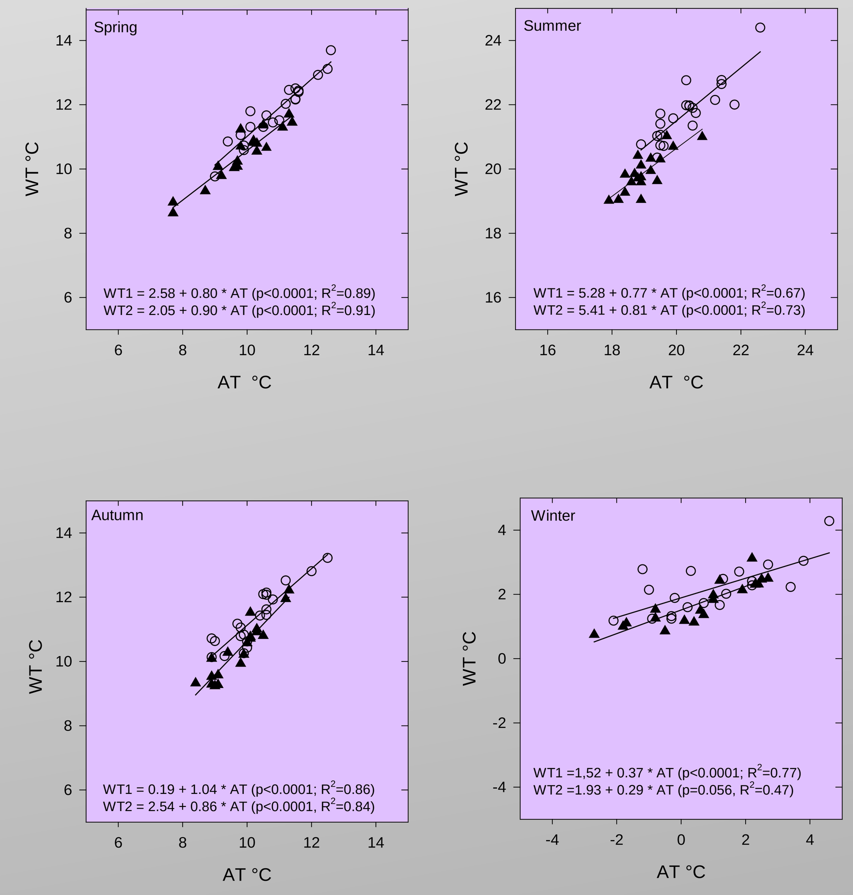

Fig. 4: Relations between seasonal means of water (WT) and air temperature (AT) in ° C at Lake Neusiedl from 1971-1990 (WT1, AT1) and 1991-2010 (WT2, AT2)

Table 1: Correlation coefficients for indices (annual; djf=winter) of large scale oscillations[3] of air pressure differences (abbreviations see Material & Methods) and water temperature for the four seasons at Lake Neusiedl for the period 1971 to 2011 (red = significant at p<0.05)

	Spring	Summer	Autumn	Winter
AMO	0.43	0.68	0.48	0.24
EAP	0.49	0.61	0.49	0.22
EA/WR	-0.18	-0.04	-0.18	0.14
MOA	0.37	0.24	-0.12	0.16
MOG	0.12	0.08	0.00	-0.09
NAO	-0.02	-0.13	-0.09	-0.14
SCA	-0.17	-0.36	0.15	0.01
AMO djf	0.49	0.68	0.46	0.32
EAP djf	0.34	0.21	0.26	0.44
EA/WR djf	-0.11	0.02	0.03	0.15
EMP djf	-0.02	0.00	0.27	0.12
MOA djf	-0.02	0.14	0.35	0.50
MOG djf	-0.07	0.03	0.03	0.14
NAO djf	0.05	0.07	-0.05	0.21
SCA djf	0.03	-0.18	-0.11	0.02

RESULTS & DISCUSSION

The increase of temperature during the 40-year observation period was more pronounced for water than for air (Fig.2 and 3). The increase of water temperature was significant ($p<0.05$) for all seasons with a decadal increase of +0.60, 0.85, 0.55, 0.26° C resp. for spring, summer, autumn, winter, but not so for air temperature (significant only in spring, summer, and autumn (increase per decade +0.47, 0.56, 0.33° C, resp.). Seasonal maxima of water temperature for the period 1971-2010 all occurred after 2002, minima before 1985. The average increase of (surface) water temperature for Lake Neusiedl was found to be above that of other Austrian lakes.[4]

The Neumann-test confirmed trends in water temperature data for the period 1971-2010 for spring, summer, and autumn, but not for winter and not for air temperature data except for summer. Mann-Kendall-trend test found significant trends for all seasons for water temperature and for spring and summer air temperatures. Probable step changes (Cusum statistics) were found for water temperature in all seasons (1981), which could not be detected for inneralpine Austrian lakes[5].

A close relationship between air and water temperatures could be observed (Fig. 4). 80-90% of the variation in water temperature of spring, summer and autumn, and 60% in winter was determined by air temperature.

The oscillation indices with the most distinct relationships to the water temperature of Lake Neusiedl were AMO, EAP and MO for Algiers and Cairo (Table 1). The EAP consists of a north-south dipole of anomaly centers spanning the North Atlantic from east to west. The positive phase of the EAP is associated with above-average surface temperatures in Europe in all months[3] and was effective in rising the water temperature at Lake Neusiedl throughout the year.

MOA (annual index) effects could be verified only for spring water temperatures, MOA (winter index) showed effects for autumn and winter months. Correlations of MO with water temperature in summer were weaker perhaps because weather then is highly affected by convection which is weakly related to the synoptic scale. In contrast to Dokulil et al. (2010)[4] NAO did not regulate water temperatures at Lake Neusiedl in our study for the period 1971-2010. But Soja et al. (2013)[6] found significant relationships of NAO and MOI with air temperature of the Lake Neusiedl region for a 50-years period.

1 eHYD: http://gis.lebensministerium.at/eHYD/frames/index.php?&146=true&gui_id=eHYD; Hydrographisches Jahrbuch v. Österreich, 1971-1976, ed. :BMLFW, Wien
2 HISTALP: http://www.zamg.ac.at/histalp/content/view/35/1/index.html; ZAMG: http://www.zamg.ac.at/klima/jahrbuch/
3 AMO: http://www.esrl.noaa.gov/psd/data/timeseries/AMO/; EAP, EA/WR, NAO, SCA: http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml, EMP: http://www.limno.eu/archives/emp/ , MO: http://www.cru.uea.ac.uk/cru/data/moi/
4 Dokulil, M. et al.: The impact of climate change on lakes in Central Europe p.387-409, in: George, D.G. (ed.), The Impact of Climate Change on European Lakes, Springer, 2010
5 Arvola, L. et al. The impact of the changing climate on the thermal characteristcs of lakes.p. 85-101, in: George, D.G. (ed.), The Impact of Climate Change on European Lakes, Springer, 2010
6 Soja, G. et al.:Climate impacts on water balance of a shallow steppe lake in Eastern Austria (Lake Neusiedl). J. Hydrology 480, 115-124, 2013

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