The effect of the exceptionally mild European winter of 2006-2007 on temperature and oxygen profiles in lakes in Switzerland: A foretaste of the future?

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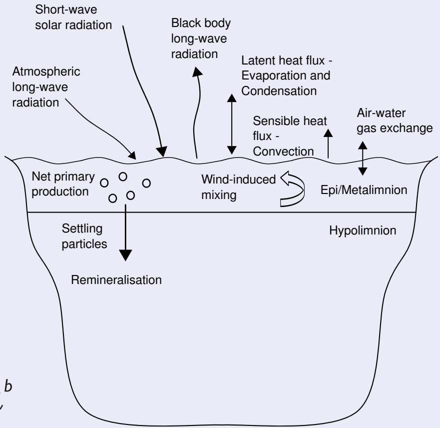
Mixing regime and heat balance (surface processes) of lakes in this study

Stratified in summer

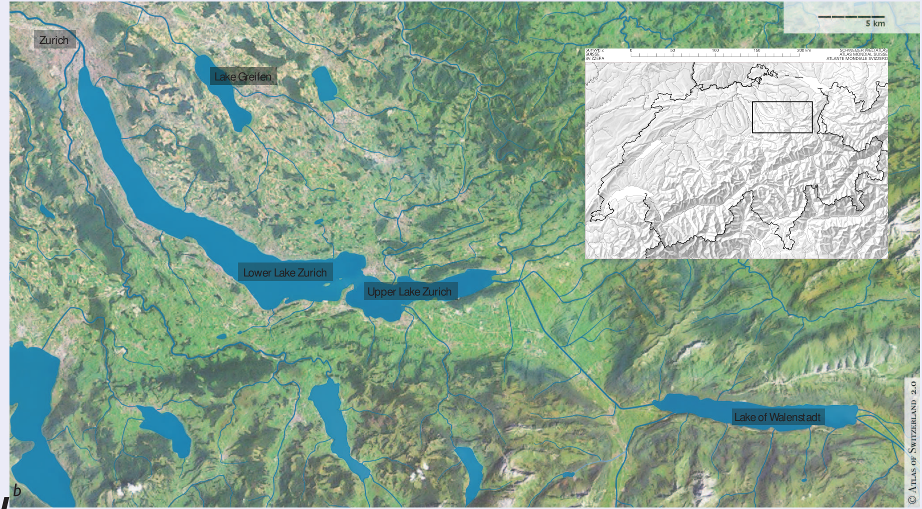
Unstratified in winter



Why should we care about lakes in general, and O_2 in particular - different approaches

- Raw drinking water obtained from lakes (for ≈1 Mio people from Lower Lake Zurich)
- O_2; important indicator of water quality
- O_2; most important lake variable aside from water itself (Wetzel 2001)
- Numerical experiments (e.g. Hondzo and Stefan 1993)
- Observations of gradual changes (e.g. Livingstone 2003)
- Effects of extreme events (e.g. Jankowski et al., 2006, Straile et al., 2010)

Study lakes



5 km
Zurich
Lake Greifen
Lower Lake Zurich
Upper Lake Zurich
Lake of Walenstadt
SCHWEIZ
SUISSE
SVIZZERA
SCHWEIZER WELTATLAS
ATLAS MONDIAL SUISSE
ATLANTE MONDIALE SVIZZERO
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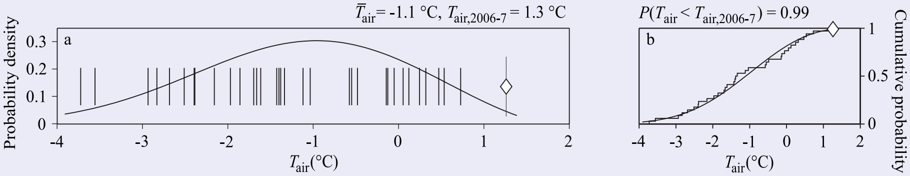
Data and statistical analysis

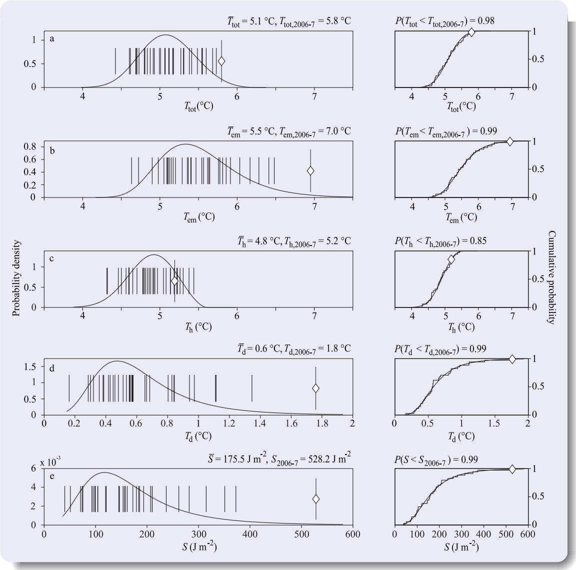
- Observations: Approximately monthly time-series of T and O_2; Lower Lake Zurich (since 1944), Greifensee (since 1956), Upper Lake Zurich and Lake of Walenstadt (1972-2000).
- Standardisation of observations; linear interpolation with depth, cubic spline interpolation in time. Calculated monthly/winter arithmetic mean (e.g. Livingstone 2003, Jankowski et al., 2006).
- Temperature data: Daily minimum and maximum, Zurich meteorological station. Calculated daily (Bilbao et al., 1991) and winter arithmetic mean.
- Fitted general extreme value distribution to each time-series of winter means.
- Performed Kolmogorov-Smirnov goodness-of-fit test.
- Applied boot-strapping technique to ensure "no bias due to interpolation" (Efron 1979).

Mean winter (DJF) air temperature - Zurich



- Warm winter (December, January, February; DJF)
- Cyclonic storm Kyrill, 17 to 19 January 2007 (Fink et al., 2009)

Mean temperatures and stability - Lower Lake Zurich



T - Entire lake

T - Epi/Metalimnion

T - Hypolimnion

T - Difference

Schmidt stability

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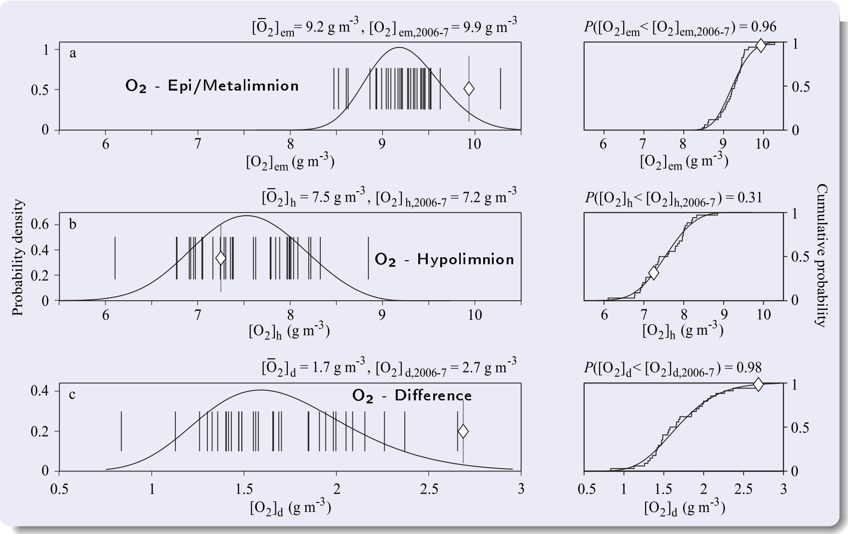
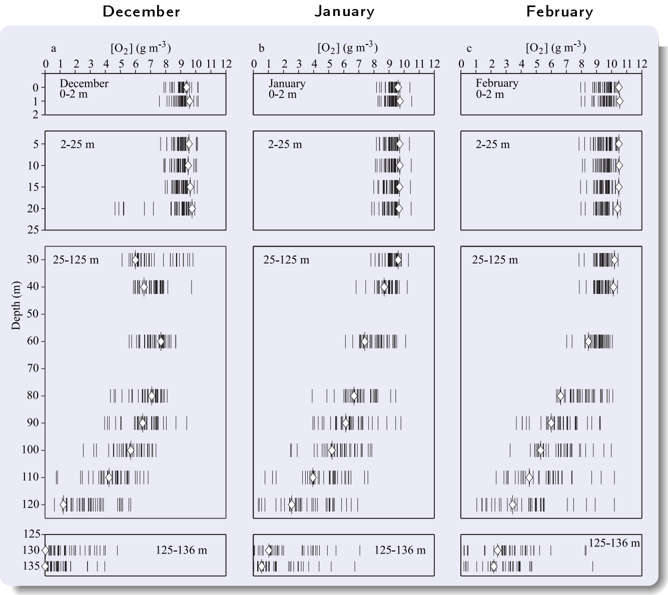
O_2 concentrations - Lower Lake Zurich

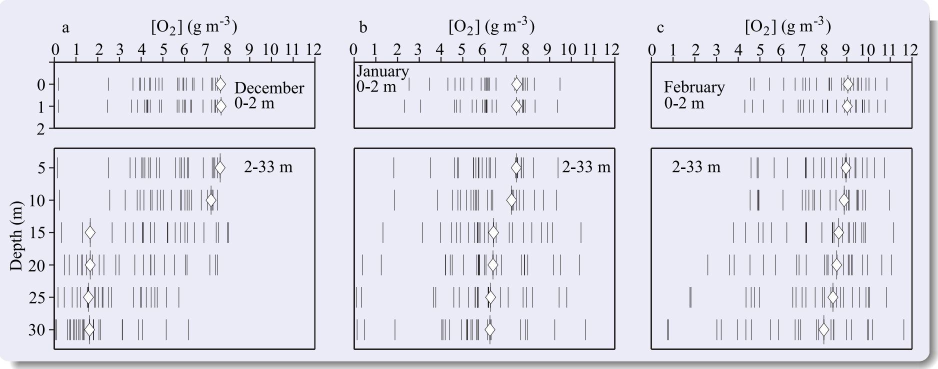


Profiles of monthly O_2 concentrations - Lower Lake Zurich



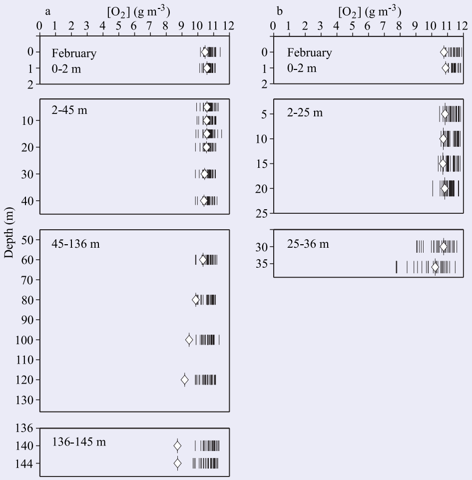
Profiles of monthly O_2 concentrations - Greifensee

December | January | February



Profiles of O_2 concentrations in February 2007 - Lake of Walenstadt and Upper Lake Zurich

February
Lake of Walenstadt



February
Upper Lake Zurich

Summary and Conclusions

- Mean winter air temperature in 2006-2007 exceeded long-term mean.
- Water temperatures, and stability of water column were affected in Upper Lake Zurich and Greifensee.
- Effect on mean winter O_2 was less clear.
- Monthly O_2 profiles partly indicate effect.
- Cyclonic storm in January affected O_2 profiles paticularly in shallow and much less in deep lakes.
- Note: Effect of consecutive mild winters will differ from effect of only one mild winter!
- Increasing winter air temperatures will likely affect mixing in deep but not in shallow lakes even if a severe storm occurs.

Thank you for your attention!

Characteristics of the lakes

	LLZ	GS	LW	ULZ
Altitude a.s.l. (m)	406	435	419	406
Surface Area (km^2)	65	8	24	20
Volume (km^3)	3.3	.15	2.24	0.47
Mean depth (m)	51	18	103	23
Maximum depth (m)	136	33	145	48
z_h (m)	20	17	20	30
Mean retention time (yr)	1.2	1.5	1.4	1.4
Trophic status (m)	Mesotrophic	Hypertrophic	Oligotrophic	Mesotrophic

LLZ: Lower Lake Zurich GS: Greifensee
LW: Lake of Walenstadt ULZ: Upper Lake Zurich

Does anthropogenic eutrophication and following oligotrophication effect results from this study?

Rather no:

- Temperature (physical lake variable) is not affected
- Neither is stability of the water column (e.g. via chemical stratification)
- O_2 might be, but (in Lake Constance);
  - Phytoplankton growth in winter depends on mixing dynamics (i.e. light)
  - Zooplankton development in winter/spring depends on temperatures (rather than on nutrient availability, refs. in Straile et al., 2010)

Stability of the water column (Schmidt 1928, Idso 1973)

$$S = \frac{g}{A_0} \int_0^{z_m} (z_v - z) * (\rho_h - \rho(z)) * A(z) dz \quad (1)$$

g	gravitational acceleration
A_0	Lake surface area
z_m	Maximum depth of lake
z_v	Depth of center of gravity
ρ_h	Hypothetical density following mixing
ρ(z)	Density at depth z
A(z)	Surface area of Isobath at depth z

Density ρ(z) was derived from temperature and conductivity profiles (Bührer and Ambühl 1975)