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Climate Sensibility of a Large Lake

A Scenario Study Using a 3D Hydrodynamic Model and a Statistical Weather Generator

1) Introduction:

The vertical mixing behaviour of large deep lakes as e.g. Lake Constance is reflecting the long-term meteorological conditions and therefore is likely to be sensible to climate change. In this study the effects of increasing mean temperature and changed meteorological variability on the lake's mixing behaviour are analysed separately. Using artificial time series, the simulations are **not producing predictions, but "What if?" – scenarios for process understanding**.

2) Lake Constance:

Lake Constance is situated at the northern boundary of the Alps between Austria, Germany and Switzerland. It is a large lake with a maximum depth of 253m and a total volume of 50 km³.

Lake Constance is a monomictic lake, it does however not mix completely every year, but only once in 2-3 years, which leads to the typical saw-tooth pattern in the deep water temperature. (see Figure 4)

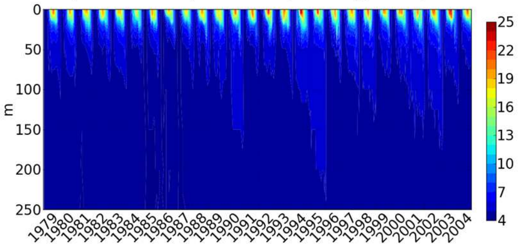

Figure 1: *Measured temperatures in Lake Constance*

3) 3D hydrodynamic model ELCOM :

ELCOM (Estuary, Lake and Coastal Ocean Model) [1], [2] was built by Centre of Water Research, University of Western Australia. It solves the RANS equation on an Eulerian grid and calculates 3D velocity fields and 3D distribution of temperature, salinity and tracers.

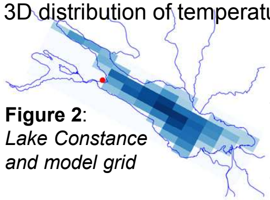

Figure 2: *Lake Constance and model grid*

Grid cell size is 2km * 5km horizontally and vertically 2.5m in the epi- and metalimnion, gradually increasing to 10m in the deep hypolimnion.

4) Boundary Conditions:

As boundary conditions the model requires in- and outflow data, which throughout this study are measured values from the tributaries, and meteorological data: air temperature T, relative humidity Φ, incident long wave radiation LW, shortwave radiation SW, and wind.

a) Measured meteorological data

Meteorological data is measured hourly by the DWD (German Weather Service) in Constance (station location indicated by red point in Figure 2)

b) Generated meteorological data

The **vector-autoregressive statistical weather generator VG** gives the opportunity either to produce time series with the statistical properties of the measured data, or to change the mean or the variability of selected variables, maintaining the dependency structure between the meteorological variables.

It is fitted on time series measured in Constance in the years 1980 – 2001.

To separate effects of increased mean temperature from effects of increased variability of temperature, this study is using the fully-crossed design:

Unchanged A	Increased Mean B
Increased Variability C	Increased Mean & Increased Variability D

Mean (Ø) and standard deviation (σ) of the simulated meteorological variables:

	T		Φ		SW		LW		Wind	
	[°C]		[-]		[W/m²]		[W/m²]		[m/s]	
	Ø	σ	Ø	σ	Ø	σ	Ø	σ	Ø	σ
A	9.7	7.2	0.77	0.13	129	94	310	41	6.0	2.3
B	16.3	7.0	0.53	0.09	135	102	318	45	6.5	3.5
C	9.1	9.6	0.77	0.19	126	103	309	46	6.3	3.4
D	16.2	9.4	0.56	0.19	134	104	318	45	6.7	3.6

5) Simulation results:

The ELCOM simulation with measured meteorological input data reproduces qualitatively the saw-tooth pattern of measured deep water temperature. The total range of temperature is 1 °C in measured data and 0.7°C in simulated data.

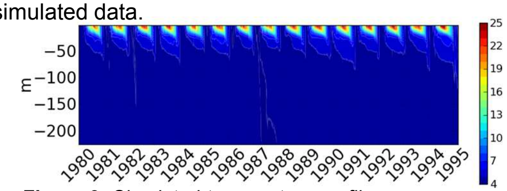

Figure 3: *Simulated temperature profile*

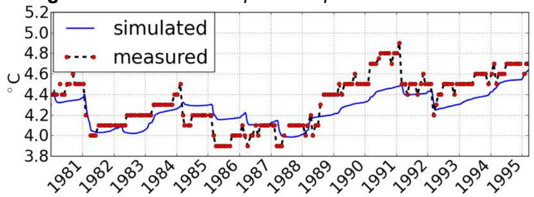

Figure 4: *Water temperature in 230m depth*

The lake is integrating over time:

Complete mixing events in cold winters can be identified as significant drops in deep water temperature, whereas in warm years the temperature slightly increases. The higher the hypolimnetic temperature is, the more likely it is that mixing will occur. Whether the lake mixes completely, thus not only depends on the actual weather conditions, but also on the thermal conditions in the lake and hence on the conditions in the preceding winters.

First simulations with generated meteorological data with increased mean temperature show, after a transition period of several years, the development of a new monomictic state at higher temperature level.

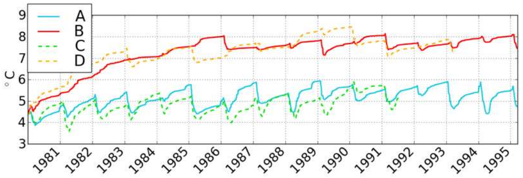

Figure 5: *Water temperatures in 230m depth: ELCOM simulations with generated meteorological input data*

6) Conclusions:

The lake's response to climate change not only depends on the temperature increase itself but also on the variability of the meteorological conditions. Due to the slow reaction of the large lake, variability on longer timescales, especially, **inter-annual variability**, is more important.

Next steps in this study will be:

•Systematic analysis of different values for increase of mean and average of air temperature

•Analysis of effects of adding a trend to mean air temperature (transition state)

7) References:

[1] Hodges and Dallimore (2010): Estuary, Lake and Coastal Ocean Model: ELCOM. v2.2 Science Manual. Centre for Water Research, University of Western Australia, 2006.

[2] Appt, J.; Imberger, J.; Kobus, H.: Basin-scale motion in stratified Upper Lake Constance. In: Limnol. Oceanogr. 49 (2004), Nr. 4, S. 919-933.

8) Acknowledgements:

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