Vertical mixing intensity
Lake Constance data documentation

Updated 01 March 2018

Authors: Ursula Gaedke, Alice Boit

Lake name: Lake Constance

Contact person: Professor Dr. Ursula Gaedke (gaedke@uni-potsdam.de), Institute of Biochemistry and Biology, University of Potsdam, Maulbeerallee 2, 14469 Potsdam

If not available, try Dr. Dietmar Straile (Dietmar.straile@uni-konstanz.de), Limnological Institute, University of Constance (Konstanz)

Sampling site

Lake Constance (LC) is a temperate, large (476 km^2), deep (mean depth =101 m, max. depth 252 m), and warm-monomictic lake north of the European Alps of glacial origin. It has weak pelagic-benthic coupling, and little allochthonous input into the pelagic zone (Bäuerle and Gaedke 1998). Mixing from top to bottom occurs only during late winter. Hence, the reduction of mixing after winter mixing is crucial for the onset of the phytoplankton spring bloom as it improves the underwater light climate for phytoplankton (e.g. Gaedke et al. 1998 a, b, Stüber 1997, Tirok & Gaedke 2006, 2007). The focal measuring site is in the north-western fjord-like arm of the lake (mean depth ca. 100 m, max. depth 146 m), which may experience intensive internal seiching (Gaedke and Schimmele 1990, 1991). The hydrodynamics have been studied intensively during the study period considered here (1979-1998) (e.g. Bäuerle et al. 1998 and lit. cited therein, Ollinger & Bäuerle 1998) but also thereafter (cf. publications by Frank Peeters, Univ. of Constance, and scientists of the Institut für Seenforschung Langenargen).

Computation of vertical mixing intensity

Plankton growth is strongly influenced by the stability of the water column which is thus of major interest to understand plankton dynamics. As water turbulence is difficult to directly measure vertical mixing intensity in Lake Constance is estimated using an elaborated, carefully calibrated and validated 1 D k-epsilon hydrodynamic model (Bäuerle et al. 1998, Ollinger and Bäuerle 1998). The input to this numerical model are meteorological data (solar radiation, cloud cover, wind speed and direction, air temperature, humidity) measured e.g. at a nearby weather station in Constance. The model describes the turbulent transport of momentum, heat, and mass in the water columns. These are induced by the direct influence of the wind at the lake's surface, by shortwave and longwave radiation, and by the fluxes of latent and sensible heat.
The model assumes that the transport processes associated with turbulence may be described by turbulent exchange coefficients which are determined by means of two differential equations, one for turbulent kinetic energy and the other for the dissipation of turbulent kinetic energy. The model results based on a very high vertical (e.g. 72 layers) and temporal resolution were subsequently aggregated into 2 different measures of vertical mixing intensity (see below) to link vertical mixing

with ecological processes such as phytoplankton growth which were observed on much coarser scales (e.g. Gaedke et al. 1998 a ,b, Stüber 1997, Tirok & Gaedke 2006, 2007).

Vertical mixing intensity datasets

We provide two datasets, dataset 1 (n = 5762) and dataset 2 (n = 5547) with daily values comprising the vertical mixing intensity between 1979-1995. Vertical mixing parameters are only available for the years 1979-1995 because the meteorological data for 1996-1997 was not available at the time when the models were run (Stüber 1998). Be aware of a few gaps in the time-series when e.g. the thermistor chains used to record e.g. water temperature failed to operate properly. The mixing parameters represent aggregated results of the hydrodynamic model described above to analyze the impact of water column stability on phytoplankton growth based on the (realistic) assumption that plankton dynamics do not feedback on the mixing intensity (accounting for this feedback had hardly any impact, Bäuerle et al. 1998).

Dataset 1:

Filename: "Dataset_1_Lake_Constance_Vertical_Mixing"

This dataset provides the vertical mixing intensity as three parameters p_{12}, p_{13}, and p_{23} ranging between zero and one for the years 1979-1995. These values represent the fraction of a simulated tracer which is exchanged between three water layers: 1. the uppermost layer between 0-8m depth, 2. the middle layer between 8-20m, and 3. the deepest layer between 20-100m depth (Fig. 1). For instance, p_{13} describes the fraction of the tracer transported from 0-8 m depth to 20-100 m depth. During the simulation of the water column, simulated tracer units are inserted in the uppermost water layer at the beginning of each simulation day. The model then calculates how the tracer is vertically distributed depending on the hydrodynamic conditions and the daily meteorological input data influencing the simulated turbulence during the subsequent 24 h.

The tracer stands for any passively distributed particle in the water column. Given that the active movement of phytoplankton can be disregarded compared to the turbulence of the water in deep Lake Constance, the tracer may also represent phytoplankton. That is, the vertical mixing rates are a good estimate of the fraction of algae which are distributed from the upper to the middle and deepest layer on a particular day. Supporting this hypothesis, the value of p_{13} is highly predictive of the onset of the spring bloom in Lake Constance. As long as p_{13} is continuously high, the algae remain a large amount of time in the dark depth of the lake and are therefore light-limited so that their biomass is low. When p_{13} is low, however, the algae mostly remain in the euphotic zone so that an algal bloom develops even as early as February. In contrast, the value of p_{12} has no strong influence on the onset of the spring bloom. Despite high values of p_{12}, a spring bloom may develop (Gaedke *et al.* 1998a, Gaedke *et al.* 1998b). Similar results hold for ciliates as well (Gaedke & Wickham 2004, Tirok & Gaedke 2006).

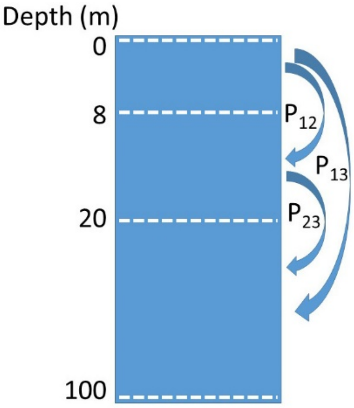

Fig. 1. Scheme of the water column with its three distinct water layers underlying Dataset 1 (Ollinger and Bäuerle 1998). Adapted from Stüber (1998).

Column headers

A. Date

B. P12 [fraction]

C. P13 [fraction]

D. P23 [fraction}

E. Day of the year [dimensionless]

Dataset 2:

Filename: "Dataset_2_Lake_Constance_Vertical_Mixing"

This dataset provides the vertical mixing intensity from another perspective to complement Dataset 1. Dataset 1 does not give an insight into what happens within any of the three discreet water layers. Especially during summer when stratification is stable, changes in turbulence are constraint to the upper layer, so that p_{12} and p_{13} are close to zero. The information how deep turbulences reach within the water column is provided by Dataset 2. To determine this depth in meters, the hydrodynamic model (Ollinger and Bäuerle 1998, outlined above) calculates two additional daily parameters T50 and T90 based on the same meteorological input data from 1979-1995. The simulation is set up as follows: Tracer units are added to the uppermost layer (Fig.2) at the beginning of each simulation day. Initially, 50% of the tracer are located within the upper 1.2m of depth, 90% are found within the layer between 0-4m depth, and 95% between 0-5m (Fig. 2a). Then, the model simulates the turbulences according to the set of differential equations outlined above (Ollinger and Bäuerle 1998). Finally, the parameter values of T50 and T90 are the depths at which 50% and 90% of the tracer are found at the end of the day, respectively. This is a practical measure of the depths which passively transported particles reach within a day due to turbulence. The relative seasonal changes of T50 and T90 are of particular importance to characterize stratification and its influence on ecological processes, e.g. the onset of the phytoplankton spring bloom.

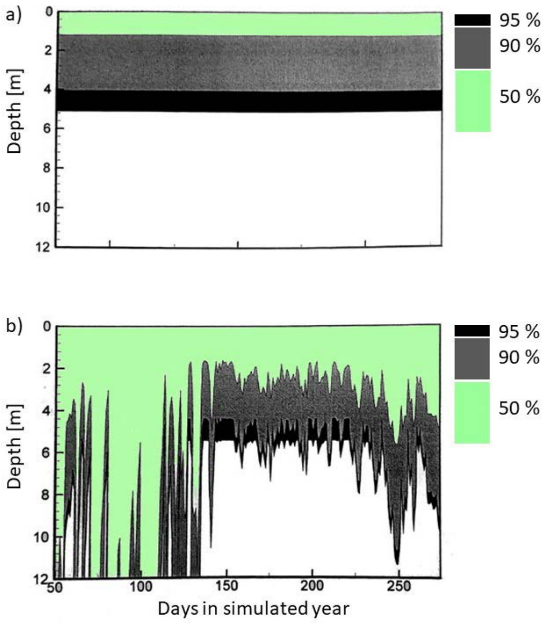

Fig. 2. Vertical depth profile of the hydrodynamic model used to generate Dataset 2. a) Initial tracer distribution at the beginning of each simulation day. The green area indicates the depth interval which contains 50% of the tracer and T50 is its maximal depth. The green and the gray areas combined indicate the depth interval which contains 90% of the tracer. T90 is the lower end of this depth interval, i.e. the depth above which 90% of the tracer are found. The black area adds another 5% to the accumulated amount of the tracer. The white area is devoid of the tracer except for the last 5%. b) Example of a simulated tracer distribution at the end of each simulation day (the distribution is reset to the state shown in a) every simulated morning). Color code as in a). Adapted from Stüber (1998).

Column headers

F. Date

G. T50 [m]

H. T90 [m]

I. Day [dimensionless]

References

General references on Lake Constance

Bäuerle E, Gaedke U (1998) Lake Constance: characterization of an ecosystem in transition. Stuttgart, Germany: Schweizerbartsche Verlagsbuchhandlung.

Specific references for this data package

Bäuerle, E, D. Ollinger und J. Ilmberger (1998) Some meteorological, hydrological and hydrodynamical aspects of Upper Lake Constance, *Arch. Hydrobiol. Spec. Issues: Adv. Limnol.* 53: 31–83

Gaedke U, Ollinger D, Bäuerle E, Straile D (1998a) The impact of the interannual variability in hydrodynamic conditions on the plankton development in Lake Constance in spring and summer. *Arch*. *Hydrobiol. Spec. Issues Advanc. Limnol.* 53: 565-585

Gaedke U, Ollinger D, Kirner P, Bäuerle E (1998b) *The influence of weather conditions on the seasonal plankton development in a large and deep lake (L. Constance). III. The impact of water column stability on spring algal development*. In: George G and Jones G (eds.), NATO ASI Series, Plenum Press, New York, USA

Gaedke, U. & M. Schimmele (1990). The potential impact of internal seiches on observed population dynamics of planktonic organisms in Lake Constance. *In Verh. int. Ver. Limnol.* 24: 80-84.

Gaedke U, Schimmele M (1991) Internal seiches in Lake Constance - influence on plankton abundance at a fixed sampling site. *Journal of Plankton Research*, 13, 743-754.

Gaedke, U. & S. Wickham (2004) Ciliate dynamics in response to changing biotic and abiotic conditions in a large, deep lake (L. Constance). *Aquatic Microbial Ecology (AME)* 34:247-261.

Ollinger D, Bäuerle E (1998) *The influence of weather conditions on the seasonal plankton development in a large and deep lake (L. Constance). II Water column stability derived from one-dimensional hydrodynamical models*. In: George G and Jones G (eds.) NATO ASI Series, Plenum Press, New York, USA

Stüber, K (1998) *Der Einfluss unterschiedlicher Nährstoff- und Wetterbedingungen auf die saisonale Planktonentwicklung im Bodensee*. Diploma thesis, University of Constance, 186 p., available on request from gaedke@uni-potsdam.de

Tirok, K. & U. Gaedke (2007) The effect of irradiance, vertical mixing and temperature on spring phytoplankton dynamics under climate change – long-term observations and models. *Oecologia* 150: 625-642

Tirok, K. & U. Gaedke (2006). Spring weather determines the relative importance of ciliates, rotifers and crustaceans for the initiation of the clear-water phase in a large, deep lake. *J. Plankton Res*., 28: 361-373.