Hydrol. Earth Syst. Sci. Discuss., 6, C3497–C3503, 2010
www.hydrol-earth-syst-sci-discuss.net/6/C3497/2010/

Hydrology and Earth System Sciences Discussions

Interactive comment on "Double diffusion in meromictic lakes of the temperate climate zone" *by* C. von Rohden et al.

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Received and published: 18 March 2010

Response to Reviewer #1

Journal: HESS Title: Double diffusion in meromictic lakes of the temperate climate zone Author(s): C. von Rohden et al. MS No.: hess-2009-260

We thank the anonymous referee for the thorough review of our manuscript. The helpful comments made us rearrange and complete the manuscript in parts to tighten and clarify our ideas.

In the first section of the response, we address the more general comments given by both referees concerning similar aspects. This section is identical in the responses to

both referees. Afterwards we reply step by step to further individual comments.

General aspects

We agree that the original title was too general. We changed it to "Evidence for double diffusion in temperate meromictic lakes".

Following the referees suggestions we modified the abstract towards a clearer and more concise synopsis of the manuscript, and included some quantitative information.

Changes in the introductory section were done to make more clear what the questions of interest are. We rearranged parts of the manuscript to improve the general structure: After the introduction, the second section ("Site description and methods") now combines the general description of the studied lakes with the methods used (CTD-profiles). We think that the site description in terms of their general stratification and seasonal mixing pattern based on the measured CTD-profiles, together with a description of the data acquisition and technical quality, is a good base for the discussion of the double diffusive effects in the monimolimnia, which is the main aim of the paper. The effects are discussed in the following section ("Evidence for double diffusive steps") separately for the two study sites. Technical information about CTD-profiling and sensor construction and characteristics is now given in more detail. We believe that the response time of the temperature and conductivity sensors is not a restricting factor with respect to the identification of the DD-structures (DD = double diffusion) and with respect to the overall significance of our conclusions. We state that basic DD-mixing characteristics within the monimolimnion can be well resolved with our measurements at vertical scales larger than $\sim$10 – 18 cm. We therefore smoothed the vertical gradients needed for calculation of and according to these vertical scales. This of course does not exclude the existence of smaller structures associated with DD, which should be the scope of further research based on methods with higher spatio-temporal resolution.

Citation of own previous work at one of the presented lakes (Lake Waldsee) should now be better set into the context of the recent study.

Specific response

» General Comments The authors present observations and analysis of double diffusive processes in two small mining lakes from the perspective of the annual cycle. They present bathymetry and CTD data. From this they derive calculated parameters associated with likely double diffusive response. The paper concludes that the seasonal cycle, through it's influence on surface layer T, can modulate vertical mixing through turning diffusiveconvective effects on and off.

Specific Comments The question of transport and diffusion in such systems is important and falls within the scope of HESS. The data are new as far as I'm aware although treatment for other purposes of some of the data has appeared elsewhere (Boehrer et al 2009; von Rhoden et al. 2009). It would have been good to have the present work placed in the context of these published studies. «

Done (see "General aspects").

» In terms of a title I think "lakes of the temperate climate zone" is a little general as they are presenting data from small mining void lakes and so a little idiosyncratic. «

Title changed (see "General aspects").

» In fact one of them is about the smallest water body I've seen referred to as a lake. In reality they have a very coarse sampling of conditions over a year and a couple of very intriguing and promising snapshots. The paper needs to pose some questions or aims. As it is, the reader has to guess what they are specifically going to look at. «

Done (see "General aspects").

» The first half of the abstract is introductory material and inappropriate for a short synopsis of a paper aimed at experts. The remainder of the abstract could do with some quantitative information. «

Abstract changed (see "General aspects").

» The methods are straightforward enough although the authors steer clear of determining density from conductivity (Pieters et al., 2009) and instead choose a completely empirical method. How uniform is the distribution of their salts? «

Applying our empirical approach to estimate density based on temperature and conductivity (relative accuracy of density measurements better than 10ˆ(-5)) yields 3 – 4 times larger vertical density gradients in the chemoclines of both lakes compared to the formula of Chen and Millero (1986) (besides higher overall absolute densities). This involves respective differences for calculated Nˆ2 and R_rho. Therefore we think that our approach yields more reliable results, although some (unknown) systematic uncertainties may remain. We claim that the formula of Chen and Millero (1986) is not applicable to the studied lakes.

» Do they know what they likely diffusivity of their "salty water" is as this is implicit in understanding double diffusion. «

The occurrence of double diffusion implies diffusivities at the molecular level. The temporal and spatial scales of the monimolimnion temperature profiles – apart from the rather localized DD layering – suggest that heat conduction is the relevant heat transport process. Estimation of effective diffusivities by balancing methods for heat or solutes (e.g., by conservative tracers) is difficult owing to interferences with signals by inflowing groundwater or the radiation-absorption regime and is part of our ongoing research.

» The results appear to be sufficient to support the interpretations and conclusions. However, it would have been nice to have seen some data recorded at higher spatiotemporal frequency – perhaps a transect along the lake? «

Occasionally measured CTD-profiles at several sites across the lakes (exemplarily shown for three sites in Lake Moritzteich in Fig. 6b) most widely confirm horizontal homogeneity, also with respect to size and depth of DD-steps.

» Also simply having step structure in density doesn't necessarily mean there is double diffusion. «

We agree. However we think that we can point out the evidence for DD qualitatively by considering the temporal and spatial appearance of the structures at the scale of our observations, and to some degree quantitatively by estimation of stability ratios and the comparison of estimated and measured step sizes.

» Treatment of double diffusion in such systems has been considered elsewhere (Hamblin et al 1999). Are the smoothed interfaces seen in Fig. 6 instrumental or real? They appear thicker than the 2cm quoted resolution of the instrument yet one would expect very thin interfaces in actively driven diffusive-convective layering. «

It is obvious that the conductivity sensor in some way averages over its length of 4.5 cm. An interesting point is, however, that the interfaces in general are even smoother for temperature than for conductivity (fairly viewable in Figs. 3 and 4, not shown in original Fig. 6), although the temperature sensor should not significantly average due to its construction. The respective section has been formulated more precisely now. We also modified Figure 6. It now consists of two panels both including temperature profiles. The left panel a) illustrates the reproducibility of CTD-profiles measured consecutively at one site, the right panel b) compares single profiles from different sites.

» As I'm sure the authors are aware, double diffusive parameterization involves dividing one gradient operator by another. This is a recipe for noise. Furthermore, conductivity spiking whereby the temperature sensor is likely not collocated exactly with the conductivity sensor nor does it have the same temporal characteristics. These are all minor issues at the large scale but when it comes to looking at layers a few 10's of cm thick and their isolation using derivative operators it becomes more difficult. A few more details on their errors and accuracy would help. «

We are aware that the parameterization brings along enhanced noise based on the fluctuations of the measured signals. Our averaging intervals are therefore chosen in a way that structures greater than this can confidently be identified. The response time of both sensors is 50 ms. The tip of the temperature sensor is within 1 cm collocated with the center of the conductivity cell (now noted in the manuscript text, together with more detailed accuracy information).

» Why two lakes? Do we gain anything from them both appearing? It would be useful to understand more clearly the similarities and differences in response. The smaller lake's response on the whole will have a seasonal cycle but surely must be highly driven by local weather? Is it truly meromictic? «

We chose the two lakes to show that the processes in the monimolimnia are similar whereas size and depth of the lakes and seasonal mixing in the mixolimia are very different. Thus, it becomes more evident that DD is not a single phenomenon in a specific lake but possibly common in lakes of this type. The differences and similiarities of both lakes are now better motivated in the text. Lake Waldsee is permanently meromictic. The density difference across the chemocline is typically 0.7 g/l at a vertical distance of $\sim$ 20-30 cm. The lake is widely sheltered from wind by the surrounding forest.

» Could the authors not have demonstrated their point by picking a monimolomnion T and S then considered a seasonally cycling surface alayer above and calculated propensity for double diffusion? Given that double diffusion is potentially climatically modulated, what are the implications for vertical transport? «

This requires modeling of the system, as the local changes in (inverse) temperature gradients depend upon the heat flux out of the monimolimnion, which is not directly assessable. Further research will include modeling of the DD convection besides the detailed observations of temporal changes of the profiles. The reason for the DD is the heat flux out of the monimolimnion during the cold season. Changing the heat flux due to different (low) mixolimnion temperatures and the duration of the inverse temperature profile, changes the vertical mixing within the monimolimnion according to the intensity of the DD convection.

» Technical

Pg 7484 line 26 – “lesser extent”? «

Changed.

» Pg 7486 line 2 – do the authors mean iron or ion? «

Yes, we mean “iron”, which essentially “regulates” density gradients by its two, dissolved and particulate, occurrences within the redox cycle at the chemocline.

» Pg 7489 line 10 “exemplary shows late year” – not quite sure what this means. «

Wording changed.

» Pg 7490 line 27 – “(weak) internal waves” – weak in the sense of small amplitude or small potential energy variation? «

Refers to “weak” amplitudes, wording changed.

» References Hamblin, P.F., C.L. Stevens and G.A. Lawrence 1999 Simulation of vertical transport in a mining pit lake, ASCE J.Hyd.Eng. Vol. 125 (10), 1029-1038. «

Included.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 6, 7483, 2009.