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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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Response to Reviewer #2

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 caused us to 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

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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

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now be better set into the context of the recent study.

Specific response

» General comments This paper shows two examples of meromictic lakes in Germany where double diffusive processes strongly influence the mixing processes and stratification in the monimolimnia. Double diffusion is forced by seasonal mixing in the mixolimnion. Th epaper is well structured and easy to read. However, the title of the paper does not really reflect its contents. The title suggests a review of the importance of double diffusion intemperate meromictic lakes, whereas the paper is rather a case study of two relevant examples. «

Title changed (see “General aspects”).

» Abstract The abstract contains a few rather long sentences that might be simplified or split up. «

Abstract changed (see “General aspects”).

» Introduction The paper should be better embedded in other published studies by the same authors on the same lakes. Also it is not very clear which research questions are addressed by this paper. «

Done (see “General aspects”).

» Furthermore, some of the following publications should be mentioned which previously described double diffusive steps in temperate lakes: Osborn et al. (1973) (maybe not a very clear case), Sanchez and Roget (2007), España et al (2009). «

We included the recent studies of Sánchez and Roget (2007) and España et al. (2009) which in fact fit to the scope of our paper.

» Methods Add information about average profiling speed and response time of sensors. This is relevant for judging whether the observed gradients may be influenced by the sensor response. Also add information about the spatial scale that was used to

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calculate N2 and Rrho. «

Done (see “General aspects” and Reply to Reviewer #1).

» Conclusions Page 7492: lines 12ff: I am not convinced that the forcing is necessarily stronger in temperate than in tropical climates. In tropical lakes, temperature variations may be smaller, but the thermal expansion coefficient is much higher. The resulting density effects of temperature variations may be comparable. «

The sentence “Such conditions . . .” (p7492, line 12) was probably misleading or incomplete. Of course we agree that the density effects of temperature variations and not necessarily the temperatures themselves make up the driving forces. In our case, not only the (geothermal) upward heat flux from the sediment is accountable for the existence of DD effects but also heat input through radiation and heat conduction during summer. That is, due to the location in a temperate climate and also their shallow chemocline depths, the (and monimolimnia) are potentially more exposed to seasonal temperature variations than lakes in more more balanced climates or with deeper chemoclines. Relevant phrases in the conclusions have been changed accordingly.

» Page 7492, lines 17ff: I would even think that the stratification is supported by the double diffusive processes, as heat (the destabilizing component) is removed from the monimolimnion faster than salts (the stabilizing component). «

This is not an easy question to answer. We would agree to the referee’s statement considering the stratification across the chemocline. However, although heat may escape faster than salt, the water column inside the monimolimnion locally becomes more and more subject to DD-mixing as destabilizing T-gradients form or become stronger. Therefore, during the period of heat loss, the overall monimolimnion stability decreases. We would like to refrain from a general statement. Definitely the flux of heat is increased, but also the flux of salt is increased. Assuming a conservative salt (not subject to any chemical reactions), both components may experience a similar relative enhancement of the flux.

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» Figures Figure 3: indicate that the dotted lines depict temperature «

Done.

» Figure 4: why don't you use the same scale for conductivity here as in figure 3, which would allow seeing the steps? «

Scale for conductivity changed consistent to Fig. 3.

» Figure 6: there are 3 lines per site, what does that mean? «

Several graphs at each of the three sampling sites show profiles measured consecutively within a time frame of about 20 min. This shall document the level of reproducibility of the CTD-measurements if measured consecutively, and, by measurements at different sites, the horizontal homogeneity. We modified Figure 6 to clarify this. The Figure 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.

» Figure 7: Is most of the variability in N2 and Rrho true or can a significant part becaused by noise in the measurements or misalignment of temperature and conductivity? In the latter case it would be preferable to increase the lengths scale used for calculating the gradients from which N2 is calculated. In any case this would be preferable for the calculation of HKelly. «

We extended the discussion about variability and identification of structures in the manuscript (see "General aspects").

» It somehow does not make much sense to calculate this value for vertical scales that are much smaller than the resulting HKelly. «

H_Kelley is an item which potentially occurs (one calculates it from a profile, where DD is suspected). It was calculated in that sense and makes the existence of DD plausible.

» Technical

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Page 7484, line 7: seasonally (or remove “changing") Page 7484, line 19: redistribution of what? Page 7484, line 25: extent Page 7484, line 25: give area in m2, rather than ha. Page 7484, line 28: particulate «

Corrected or wording changed.

» Page 7487, line 2: “summer" is a bit confusing here, because during most of summer, the lakes are thermally stratified. Convective mixing may begin in late summer, but happens mostly in autumn. «

Surface layer mixing in Lake Waldsee is considerably stronger during summer (due to nocturnal surface cooling) than in the cold season. This is owing to the shallow depth of the chemocline. A hypolimnion is not existent during the thermally stratified period. We have explained this more intelligibly in the text now.

» Page 7488, line 7: Boehrer and Schulze is sufficient as a reference. Remove Karakas et al. «

Done.

» Page 7491, lines 3ff: unclear sentence. «

Phrase changed.

» References Osborn (1973), Journal of Physical Oceanography 3, 302-307 España et al. (2009). Mine Water and the Envorinment 28: 15-29 Sanchez and Roget (2007), Journal of Geophysical Research C: Oceans 112, C02012 «

We added references of España and Sanchez.

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