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Interactive comment on "Surface seiches in Flathead Lake" *by* G. Kirillin et al.

G. Kirillin et al.

kirillin@igb-berlin.de

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In this paper, the two-dimensional seiches characteristics in Flathead Lake have been explored and their potential influence on shoreline erosion, floods, sediment transport and species invasion have been discussed. Based on the outputs from a twodimensional numerical model (the Princeton Ocean Model), a spectra method (maximum spectrum estimation) was used to determine the seiche frequencies. Subsequently, the harmonic analysis was adopted to extract the spatial distributions of water level and velocity. Generally, the paper is well organized and the contents are suitable for the publication in HESS. While the proposed methodology and the subject matter are of importance for both scientific and engineering implications, I still have some concerns on this paper, which are listed below.

We thank the Reviewer for the careful analysis of our study and the detailed comments. The Reviewer raised several questions and suggestions, which we address below. The replies follow the original comments by Reviewer and include description of changes in the original manuscript.

1. Section 2.2: calibration and verification of the numerical model. The authors only provided limited information about the numerical model, which is the basis for the subsequent analysis. Particularly, it is important to demonstrate that the numerical model is well calibrated and verificated against the observed data (e.g., water level, velocity) and the calibrated parameters (e.g., Manning's coefficient) are reasonable. The cited reference (Schimmelpfennig et al., 2012) only presented details on the model configuration applied to Lake Tegel in Berlin. Meanwhile, how sensitive of the numerical model for different wind field conditions? As far as my understanding,the lake hydrodynamics should be closely related to wind conditions, especially in a lake with complex geometry. Is the chose numerical simulation representing the typical wind condition? Is there any seasonal variation of the wind condition?

Reply: We added details of the model configuration to the manuscript: "Horizontal eddy viscosity was modeled by the Smagorinsky diffusivity [22] with a non-dimensional coefficient C =0.2. We adopted the simple bottom stress parameterization based on the law-of-the-wall and the thickness of the logarithmic layer dependent on the lake depth from Schimmelpfennig et al. (2012)."

Further adjustment of the bottom and lateral friction based on field data could improve the model performance with regard to the rates of the seiche dissipation. The latter is however out of scope of the present study, which is confined to the spatial structure of the free oscillations. This is also the reason why wind conditions did not enter model directly. In reality, wind variability over the lake and the resonance between surface oscillations of the lake and wind oscillations may potentially enforce some seiche modes *and damp other ones, as demonstrated in the last paragraph of Section "Results". Comparison of the modeling results and observations presented in this paragraph and in Fig. 9 also serves as verification of the model outcomes supporting the reliability of the moodeled modal structure and lateral distribution of seiche oscillations.*

As the model configured to produce only free oscillations, it is not sensitive directly to variations in wind conditions. The initial surface slope (or other initial impulse emulating energy input from wind, pressure oscillations, an earthquacke etc.) is the factor affecting the amplitudes and the duration of the oscillations, which do not enter the subsequent spectral analysis.

We performed model runs with different initial slope directions. All runs produced very similar spectral and spatial patterns of free oscillations. Therefore, results from a single model configuration only are presented. The surface slope directed along the main axis of the lake is rather typpical situation for elongated Flathead Lake. Seasonal patterns may appear in wind speeds and direction over the area. The potential consequences of this variability for the seiche oscillations would consist in seasonally varying typical seiche amplitudes, seasonal intensification of certain seiche modes, and seiche interaction with seasonally varying drift currents. Investigation of these processes would be most effective in the general context of seasonally variable transport within the lake including, along with seiches, the temporally and spatially variable wind drift and seasonal course of inflows/outlfows.

2. P13548, L23: Did the simulation with the south-north initial slope coincide with the prevailing wind direction as well?

Reply: Yes, the prevailing wind direction coincides with the main axis of the lake, though the wind pattern of this mountain region is more complex, as described in Section 2.1.2. As we also mentioned in the manuscript, model runs with different initial slope directions were performed leading to essentially the same spectral and spatial pattern of free oscillations.

3. Section 3: Results According to the analysis presented in this section, it seems that the seiches characteristics are only determined by the geometry of the lake. However, wind is one of the main forcing that affects the lake hydrodynamics. Is there any connection between wind and seiches characteristics in Flathead Lake?

Modal and spatial structure of seiches, which are free oscillations of the lake, is fully determined by the shape and topography of the basin. TO underprint the main idea and to outline the ways of extension of our results on variable wind conditions, we have extended the Section “Combining observations and model efforts in seiche studies” of the discussion by the following:

“As discussed above, the method applied in the present study provides an effective way to gain an information on the precise seiche temporal characteristics and, more important, on the two-dimensional lateral distribution of the seiche amplitudes and currents. The latter are difficult to reveal from direct field observations constrained to irregular point measurements at the lake surface, are however crucial for understanding the seiche contribution to the transport of suspended matter and lake-wide mixing. Moreover, knowledge on relative distribution of seiche intensity along the lake shores is of key importance for the shoreline management. With regard to estimation of seiche effects on the littoral zone, our model effectively complements the observation data on the near-shore water level variability, as well as provides guidelines for design of the water level monitoring. Our results do not include information on the absolute magnitudes of water level oscillations and currents. The latter can vary in a wide range, depending on wind forcing, wind-seiche resonance, or being produced by other disturbances, such as earthquakes (which are particularly relevant to the Flathead Lake area; Qamar et al., 1982). Variations in wind speed and direction are the major forcing for seiches, posing a number of relevant questions, among them the effects of seasonal variability in wind speeds and direction over the lake on the seiche-produced lateral mixing patterns. The potential consequences of this variability for the seiche oscillations would consist in

seasonally varying typical seiche amplitudes, seasonal intensification of certain seiche modes, and seiche interaction with seasonally varying drift currents. Investigation of these seiche-driven processes would be most efficient in the general context of seasonally variable transport within the lake including, along with seiches, the temporally and spatially variable wind drift and the seasonal variability of inflows and outlfows. To override the inevitable deficiencies of numerical modeling approaches (such as reproduction of the bottom friction, non-linear wave transport and turbulence in stratified interior), the model simulations should be combined in these complex investigations with spatially-resolved measurements at seasonal time scales."

See also our Reply to Remark 1.

4. P13550, L9-15: Since a spectral analysis was adopted at every grid point of the model domain, there exists a spatial variation of the determined significant frequencies. How did the authors determine the selected 16 frequencies? Did you have an average over the model domain?

Reply:

As described in Section 2.3 (p. 13548, Lines 5-10), our method consists in adopting the maximum value of the spectral density found in the model domain for every resolved frequency band, instead of the average value. The difference is essential, as averaging would filter out local modes having high spectral densities confined to small areas in favor of the basin-scale modes present over the eintire lake.

5. P13550, L1-18: Does the good correspondence between numerically computed periods (63.0, 32.4, 21.6, and 14.2 min) and those estimated from the Merian formula (66, 33, 22 and 16.5 min) indicate that the topography of Flathead Lake can be well represented by a simple rectangular basin of length 44 km and of uniform depth 50 m? With regard to the 117 and 48.5 min longitudinal modes, it is possible to adjust the length scale and to explain them with the

Merian formula? In other words, how does different 'lake-wide modes' response to realistic geometry?

Reply:

This is a central point of our analysis demonstrating, on the one hand, the robustness of the Merian formula for estimation of the approximate frequencies of the gravest seiche modes in elongated basins, like Flathead Lake, and, on the other hand, potential pitfalls of the channel-shape oversimplification. Adjustment of the length scale L entering the Merian formula to the observed periods is the generally wrong approach fraught with misinterpretation of the results. We addressed this issue in the following text added to the Discussion part of the manuscript:

"Our method allowed to identification of several specific features of the basin-scale oscillations in Flathead Lake, indistinguishable by the simple channel-like approximation (Eq. 1), the most crucial being the existence of the Helmholz mode strongly affecting the dynamics of the small Polson Bay connected to the main lake basin by a narrow straight. Another remarkable feature of the lake-wide modes revealed by the method is the deviation of their periods from those following from Eq. (1). The deviation is stronger for higher modes of seiches with shorter wavelengths, which are apparently stronger affected by the irregular lake morphometry: The 4th longitudinal mode has the period of 21.6 min (Table 1), which is remarkably longer than the period of the 4th channel mode of 16.5 min (Eq. 1). Hence, the simple comparison of the oscillation periods with Eq. (1) would result in a wrong association of the 4th mode with the period of 16.02 min: the potential source of confusion when applying the channel approximation to seiche analysis."

Minor comments:

P13542, L9: "primitive equation model"=="numerical model"?

Reply: we prefer to retain 'primitive equation model' as an established term for the *basic model equations set distinguishing it from other numerical models such as, e.g. the eigenvalue problem for harmonic equations used often in the seiche modeling.*

P13546, L3: "characterize" replaced with "characterized".

Reply: fixed

P13548, L20: I suggest to provide more details about the calculation of the rotary coefficient R.

We have extended the description of the rotary coefficient and added some relevant citations:

"For analysis of spatial structure of vector velocity fields, the distribution of the rotary coefficients, R, over the lake surface for each seiche mode was estimated. The rotary spectra were defined as $R = (S^{+} - S^{-})(S^{+} + S^{-})$, where S^{+} and S^{-} are the counterclockwise and clockwise rotary spectra of velocity vectors respectively. The rotary spectra were calculated by taking Fourier transform of the complex velocity vector $u + iv$, where u and v are the orthogonal cartesian components of the 2-dimensional velocity, resulting in a two-sided spectral power density estimation, with positive (right-side) range of frequencies corresponding to the the anticlockwise rotation and negative (left-side) range of frequencies corresponding to the the clockwise rotation (Gonella, 1972; Hayashi, 1979). As such, the rotary coefficient ranges from -1 for purely clockwise rotation to +1 for counterclockwise rotation, and is zero for unidirectional motion (see Thomson and Emery, 2001, for details)".

References

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