# Preface to Volume II

This second volume to the treatise *Physics of Lakes* is dedicated to a single topic, namely *Lakes as Oscillators*. There are several reasons why this topic plays such a prominent role.

First, oscillations in lakes belong to those subjects, which were already studied by the pioneers in the seventeenth century. As Mortimer writes: “Readily observed, rhythmic fluctuations in lake level have long exercised a fascination and have stimulated mathematical modeling, but often with a longtime gap between observation and theoretical resolution [20]. The first detailed set of observations ([9], on Léman, 1730, introducing the local name ‘seiche’) and recognition of their occurrences in many lakes [26] were, it is interesting to note, preceded by systematic observations and conjectures by a Jesuit missionary [3] in 1671, describing the large but irregular ‘tides’ at the head of Green Bay (a gulf which opens onto Lake Michigan) and attributing to a combination of lunar tidal influence and to the main influence of the lake. Three centuries elapsed before those conjectures were confirmed by spectral analysis and numerical modelling [12, 13, 19]”, from [20].

Mortimer continues: “With early observations and conjectures as a prelude, physical limnology was launched as a distinct branch of geophysical fluid mechanics (L’ océanographie des lacs) by Forel’s lifetime study of Léman seiches and temperature regime [10]. But again, in one respect priority must go to Lake Michigan, i.e. to a US Army surveyor’s 1872 interpretation [8] of the conspicuous 2.2 h seiche at Milwaukee as a standing wave, thereby antedating Forel’s similar interpretation [11] by 3 years and providing yet another example of an original idea occurring to two persons at about the same time. Mathematical modelling of this seiche (as the first transverse mode [23]) confirmed the 1872 interpretation. In fact, hydrodynamic modelling may be said to have ‘cut its teeth’ on seiches . . .”, from [20].

Second, since the availability of electronic computation and the development of electronically based measuring techniques, which permitted relatively long term recording of detailed time series of density (via temperature and electrical conductivity) and velocity, the internal motion of the water in lakes became ‘observable’ via the construction of isotherm-depth or isopycnal time series at fixed mooring positions. Fast Fourier and more recently wavelet transforms and cross correlation analyses of such time series between synoptically recorded quantities became key working techniques to interpret whole-basin or localized internal processes. These findings could be compared with predictions of theoretically deduced models. These measuring techniques did not only disclose the lake interior to our 'eyes', they made the internal whole-basin dynamics interpretable as the baroclinic variants of the surface or barotropic seiches observed already in the eighteenth and nineteenth century.

Parallel with the development of the electronic measuring techniques, software was developed by which such internal motions could be computed with much better adjustment of the lake geometry than was possible heretofore. This development took place in the 1970s and 1980s and allowed theoretical numerical interpretation of field observations; however, storage limitations often prevented optimal coincidence which had to await more sophisticated hardware. In this phase of development *numerical* modeling of lake hydrodynamics may reasonably be said to have 'cut its teeth' on *internal* seiches.

Third, it is a simple fact that, starting in the 1960s and 1970s of the last century, the dynamic response of lakes under barotropic and baroclinic conditions became the principal focus of research activities of a number of lake research centers all over the world: Among these mention might be made of the Center of Great Lakes Studies (CGLS), University of Wisconsin-Milwaukee, the NOAA Great Lakes Environmental Research Laboratory (GLERL), Ann Arbor Michigan, the Canadian Centre for Inland Waters (CCIW), Burlington, Ontario, the Centre for Water Research (CWR) at the University of Western Australia, Perth. In 1972 the International Field Year of the Great Lakes Studies was in operation. In the same year the Institut für Meereskunde at the University of Kiel conducted with the support of the Government of Baden-Würtemberg, a synoptic field campaign in Lake Constance (including Lake Überlingen) and deployed a number of moored thermistor chains and current meters [15, 17]. This was the first serious European lake campaign of physical limnology, in which experimental techniques known in physical oceanography were 'copied' for research of lake physics. In 1976 in Switzerland, the 5 year National Programme of the Swiss Science Foundation on Fundamental Problems of the Water Cycle in Switzerland (Grundlegende Probleme des Schweizerischen Wasserhaushaltes), 1977–81, was created with field studies similar to those above in Lake Zurich in 1978 [17, 18], Lake of Lugano in 1979 [1, 25] and 1984 [24], with scientists of the Laboratorio di Fisica Terrestre, ICTS, Lugano-Trevano, in Lake Geneva during the same 1977-81 period by the Laboratoire d' Hydraulique (LHYDREP) at Ecole Polytechnique Fédérale, Lausanne [21, 22], and again in Lake Constance in 1993 by the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) [14] at the Swiss Federal Institute of Technology and the Swiss Federal Institute for Water Resources and Water Pollution (EAWAG), in part with the support of the Limnological Institute at the University of Constance, and the Landesamt für Umweltschutz, Baden-Würtemberg, Germany. Many similar measuring campaigns, generally somewhat smaller in scope than the large synoptic programmes above, followed in the years to come by scientists of these and other institutions. A 1 month whole-basin synoptic programme in Lake Constance was again conducted in 2001 by the Limnological Institute at the University of Constance and the CWR, at the University of Western Australia and further support from the Institute of Mechanics at Darmstadt University of Technology and the Atlantic Branch of the Shirshov Institute of Oceanology, Russian Academy of Sciences at Kaliningrad. The measurements, taken with moored and towed instruments recording temperature, current and atmospheric wind, temperature and humidity are collected in internal reports [4, 5, 7]. In these field measurements free and whole basin-scale analyses of the internal wave motion were made using the linear and non-linear surface and internal waves, and wave induced circulation dynamics were numerically implemented with software apt to describe these processes in detail.

In this Volume 2 of *Physics of Lakes* the external and internal dynamics of many lakes worldwide are studied with the focus on oscillations and comparison of measured data with the 'reproduced' model results. We start with the description of the theory and its simplifications under various conditions. Attention is devoted to the role played by the rotation of the Earth as it modifies gravity modes of barotropic and baroclinic motions and how it contributes to the independent formation of topographic Rossby waves, a subject which is treated by itself in three chapters. We study the influence of the density stratification when it is implemented by more than just a two-layer model. Such higher order baroclinicity was seldom analyzed in the past but has been the subject of more intense studies in recent years. The theoretical findings are verified either with results obtained by laboratory experiments or more frequently by the data collected in field campaigns. We close this book with an analysis of internal waves in lakes by a systematic derivation of channel models, which generalize the classical Chrystal model, and remove the somewhat biased approach in using 'Kelvin-wave dynamics' when incorporating the rotation of the Earth.

We assume the reader to be familiar with the subjects of Volume 1. Moreover, the statistical methods to handle data from time series of synoptically recorded temperature, salinity and velocity time series are equally assumed known, and will be used and demonstrated, but not separately explained.

Zürich, Switzerland *Kolumban Hutter*
Darmstadt, Germany *Yongqi Wang*
Kaliningrad, Russia *Irina Chubarenko*
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## References

1. Anonymous 82: *Hydrologische Messungen mit verankerten Instrumenten im Nordbecken des Luganersees während der Monate Juli/August 1979.* Gemeinsamer Bericht der Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie an der ETH Zürich und des Laboratorio di Physica Terrestre, Lugano-Trevano (unpublished) (1981)
2. Anonymous 83: *Misure Idriologiche Lago di Lugano.* Gemeinsamer Bericht des Laboratorio di Physica Terrestre, Lugano-Trevano und der Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie an der ETH Zürich (unpublished) (1983)
3. André, Father Louis; quoted and translated in Relation of 1671-72, and in Relation of 1676-77; In: Thwaites, R. G.: *The Jesuit Relations and other Documents*, **60**, Burrow, Cleveland, Ohio, 1671, 1676

4. Appt, J.: *Analysis of basin-scale Internal Waves in Upper Lake Constance*. Mitteilungen des Institutes für Wasserbau, Universität Stuttgart, **123**, XXXIV + (1–177), (2003)
5. Appt, J. and Stump, S.: *Die Bodensee-Messkampagne 2001, IWS/CWR Lake Constance Measuring Program 2001*. Mitteilungen des Institutes für Wasserbau, Universität Stuttgart, **111**, 67 pp. (2002)
6. Aubert, E. J. and Richards, T. L: (Eds.) *IFYGL – The International Field Year for the Great Lakes*. U. S. Dept. Commerce, National Oceanic and Atmospheric Administration. Great Lakes Environ. Res. Lab., U.S. Dept. Commerce, Ann Arbor, MI, U.S.A. 48104, 410 pp (1981)
7. Bäuerle, E., Chubarenko, B., Chubarenko, I., Halder, J., Hutter, K. and Wang, Y.: *Experimental campaign in the Mainau Island Littoral Zone of Lake Constance*. Report on field experiments 12 October – 19 November 2001. Darmstadt University of Technology and University of Constance, 1–85 (unpublished) (2002)
8. Comstock, C.B.: Tides at Milwankee, Wisconsin [and] Irregular oscillations in surface of Lake Michigan at Milwaukee. Rpt. Secy. War to 42nd Congress, Vol. 3. *Ann. Rpt. Survey of the Northern and Northwestern Lakes*, App. A., g-14, App. B 14-15, Washington, D.C. **14**, (1872)
9. Duillier, F. de: Remarques sur l' histoire du lac de Genève in Spon. *Histoire de Genève* **2**, 463 (1730)
10. Forel, F.A.: *Lac Léman*. Monographie Limnologique, Vol. 2, Lausanne Ronge (1895) Facsimile Ed: Slatkine Reprints genève (1969)
11. Forel, F.A.: Les seiches, vagues d' oscillation fixe des lacs, $1^{er}$ discours, *Actes Soc. Helvétique Sci. Nat.*, Andermatt, 575 (1875)
12. Heaps, N.S.: Resonant tidal co-oscillations in a narrow gulf. *Arch. Met. Geophys. Bioklim.* Ser A, **24**, 361 (1975)
13. Heaps, N.S., Mortimer, C.H. and Fee, E.J.: Numerical models and observations of water motion in Green Bay, Lake Michigan. *Phil. Trans. Roy. Soc.* A, **306**, 371 (1982)
14. Heinz, G.: *Strömungen im Bodensee. Ergebnisse einer Messkampagne im Herbst 1993* Mitteilungen der Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie an der ETH Zürich, **135**, 1–237 (1995)
15. Hollan, E.: Strömungen am Bodensee. *Bericht AWBR*, **6**, 111–187 (1974)
16. Hollan, E., Rao, D.B. and Bäuerle, E.: Free surface oscillations in Lake Constance with an interpretation of the 'wonder of the rising water' at Constance in 1549. *Arch. Met. Geophys. Biokl.*, Ser A, **29**, 301–325 (1980)
17. Horn, W.: *Seeströmungen im Zürichsee. Ein Einblick in physikalisch-limnologische Prozesse und ihre messtechnische Erfassung*. Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie an der ETH Zürich,VAW, Internal Report I/4 (1978)
18. Horn, W.: *Zürichsee 1978. Physikalisch-limnologisches Messprogramm und Datensammlung*. Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie an der ETH Zürich, VAW, Internal Report I50 (1981)
19. Mortimer, C.H.: Spectra of long surface waves and tides in Lake Michigan and Green Bay, Wisconsin. *Great Lakes Res. Div. Univ. Mich.*, Publ. No. **13**, 304–325 (1965)
20. Mortimer, C.H.: Measurements and Models in Physical Limnology. In: Hutter, K.: Ed. *Hydrodynamics of Lakes* CISM Courses and Lectures No. 286 Springer Verlag Wien-New York, 287–319 (1984)
21. Prost, J.-P., Bauer, S.W., Graf, W.H. and Girod, H.: Campagne de mesures des courants dans Le Léman *Bull. Tech. Suisse Romande* **103**, 19 (1977)
22. Prost, J.-P., Perrinjaquet, C. and Beguin, Ph.: Campagne des mesures de la basse couche atmosphérique sur le Léman *Bull. Tech. Suisse Romande* **106**, 23 (1980)
23. Rao, D.B., Mortimer, C.H. and Schwab, D.: Surface normal modes of Lake Michigan: Calculations compared with spectra of observed water level fluctuations. *J. Phys. Oceanogr.* **6**, 575 (1976)
24. Stocker, T. and Salvadè, G.: *Interne Wellen im Luganersee*. Interner Bericht Nr. I/85 der Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie an der ETH Zürich (unpublished) (1986)

25. Salvadè, G., Zamboni, F. and Hutter, K.: Physikalisch limnologische Felddmessungen im Luganersee. Interner Bericht des Laboratorio di Physica Terrestre, Lugano-Trevano und der Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie an der ETH Zürich (unpublished) (1982)
26. Vaucher, J.P.E. : Mémoire sur les seiches due Lac de Genève, composé de 1803 à 1804. *Mem. Soc. Phys. Genéve*, **6**, 35 (1833)

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