Internal wave weather heterogeneity in a deep multi-basin subalpine lake resulting from wavelet transform and numerical analysis

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The internal wave-field of a Y-shaped lake (Lake Como, North Italy) was investigated over a 3-year long period applying wavelet time–frequency analysis to temperature and wind data time series, recorded at the edge of each of the three arms. The comparison with the results from a modal model allowed to identify the presence of both first and second vertical modes of oscillations. The field data analysis underlined a heterogeneous baroclinic response with the eastern arm decoupled from the remaining part of the lake constituted by the northern and western arms (north–south west transect). This disjoined response is expected to enhance the water exchange between the northern and the western arm, with relevant consequences on the inter-basins water exchanges and on the distribution of chemical and biological species. In the north–south west transect the analysis of the low power signals in winter underlined a residual internal wave activity ascribed to the first vertical free mode of oscillation (V1H1).

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1. Introduction

Stratification in lakes and reservoirs plays a crucial role in the overall ecology of the lake water body [5,18,37]. In a fresh water ecosystem the stratification of the water column is generally due to thermal stratification [32,56] resulting from the combination of different meteorological stressors such as solar heating, radiative cooling and wind stirring. The vertical variation of water density, associated with these changes in temperatures, support internal wave motions forced by wind-generated pressure gradients [50]. Internal wave activity is ubiquitous in stratified lakes and provides one of the main driving forces for vertical and horizontal transport under the wind mixed layer (e.g. [31]). Internal waves have an important role on the lake biogeochemistry and their impact on lake ecology [36] has recently been the subject of different papers. Internal waves have been demonstrated to enhance the nutrient fluxes from the hypolimnion to the epilimnion (e.g. [30]) and the light availability at which phytoplankton cells are exposed thus influencing phytoplankton community composition and primary production (e.g. [4]). More recently Pannard et al. [37] demonstrated the role of internal waves in controlling the phytoplankton community by the contrasting gradients of light and nutrients that enhanced the metalimnetic community of cyanobacteria in a small lake. Similar results have been found by Cuypers et al. [15] in a deep alpine lake where internal waves showed a direct impact on the light availability and an indirect influence on both the vertical and horizontal distribution of the cyanobacteria community proliferating in the metalimnetic layer.

Internal wave motions can be classified according to the number of nodal points in term of both vertical (Vi) and horizontal (Hm) modes where i and m are the number of nodal points. The most observed mode [34] is the V1H1, but many observations of higher horizontal and vertical modes were documented in the literature (e.g. [25,26,35]).

The spatial and the temporal structure of internal waves in lakes is constrained by both the density gradients and by the geometric properties of the inclosing basin [45]. The baroclinic response to wind has been extensively investigated in single-basin