[課程博士・論文博士共通]

博士学位論文内容要旨
Abstract

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論文題目 Title	Dynamics of large-scale internal waves in Shiozu Bay, Lake Biwa		

Internal waves in Lake Biwa are ubiquitous features generated during summer time, when the surface temperature is much higher than the internal temperature. This layer with a high temperature gradient makes the metalimnion (or thermocline); which acts as a waveguide for the internal waves. These internal waves are generated by periodic or sudden wind forcing (breezes or typhoons, for instance) and may redistribute the stored energy in the lake to mixing at various scales, influencing the distribution of pollutant or nutrients (Saggio and Imberger, 1998). So far the consensus is the downward cascade of energy from large scale to turbulence: low frequency to high frequency internal waves then breaking. However a recent study suggests that the energy redistribution is more complex than previously thought and can occur directly from low frequency to turbulence. Because of this result and the impact on mixing and ultimately on nutrient distribution, the linkage between large-scale internal waves and turbulence intensity needs more study.

This thesis first deals with observation data in Lake Biwa, Shiga Prefecture, more precisely at the mouth of Shiozu Bay. The first objective was reached through a microstructure profiler (TurboMAP) operation carried out over the span of 48 hours inside the bay, and by using ADCPs (Acoustic Doppler Current Profiler), which measured the flow speed and direction at the mouth of the bay for 7 days. The current data where then analyzed in the frequency space and a modal analysis was performed on the TurboMAP data; upon analysis the results showed the presence of a two Kelvin waves, one with a period of 45 hours being a vertical mode 1 and horizontal mode 1, and the other wave being a vertical mode 1 and horizontal mode 2 with a period of approximately 23 hours. In addition, current associated to the internal V1H1 Kelvin wave shows the wave entering the bay, but does not exhibit clues of being reflected back.

After confirming the presence of low-frequency internal waves within the bay, the first part of my research highlighted the presence of enhanced turbulence and mixing offshore below the metalimnion (ε: 10^{-7} W kg $^{-1}$), which was previously thought to be turbulence free (10^{-10} W kg $^{-1}$). Furthermore the enhanced mixing event was linked to the low frequency waves induced current being in phase, inducing velocity shear but not strong enough to bring down the Richardson number below the shear instability threshold of one fourth. Contraction and separation of isotherm within the hypolimnion may be a link to the cause. Moreover such currents synchronization provoked sediment resuspension up to 10 meters above the bottom in enhancing bottom stress. In this section, my research shows evidence of direct energy redistribution from low frequency internal wave field to turbulence.

The second objective of this thesis is the study of low-frequency internal wave dynamic within Shiozu Bay. For this purpose the numerical simulator SUNTANS was used. SUNTANS (Stanford Unstructured Non- hydrostatic Terrain Following Adaptive Navier-stockes Simulator) is developed by Fringer *et al* 2006. The main features of this numerical simulator are the triangle-shaped cells (unstructured) and the non-hydrostatic component of the pressure

field that is already implemented.

To generate the initial conditions a nesting method was applied. To start, a simulation was run with a coarse resolution grid from winter time to summer time. Based on five meteorological stations scattered around Lake Biwa, boundary conditions (wind forcing and heat fluxes) were implemented to generate the temperature and wind field until a specific typhoon period. Then in using data from the coarse resolution to a finer grid, for a simulation starting at the end of July 2001, simulated data were compared against observed data to assess the consistency of simulated data. The simulation reproduced the observed low-frequency internal wave field with similar frequencies.

Based on the analysis of potential energy and dissipated energy time series, this research shows that a part of the internal Kelvin wave that enters Shiozu Bay does not either completely dissipate or break. Moreover isotherm elevation associated to the internal Kelvin wave frequency highlights the cyclonic rotation pattern, which is characteristic of the Kelvin wave, within the bay. This result shows that the part of the Kelvin wave entering the bay goes in and out.

Moreover the dynamic of the internal wave field within the bay displays an interesting dynamic at the narrowing of the bay. Because of the contraction below the metalimnion the flow was virtually controlled, locally speeding up the flow and generating isotherms deepening. These two processes generated turbulence by shear and convection, according to the Mellor-Yamada 2.5 turbulence model ε reached 10^{-6} W kg^{-1}. Additionally the occurrence of these enhanced turbulent events appears to depend on the amount of energy detained by the low frequency internal wave field and to occur downstream the contraction of the hypolimnetic flow.

Thanks to the combination of numerical simulation and observed data, this research exhibits the processes involved in the enhanced shear inside Shiozu Bay, as well as in the enhanced turbulence event, and the need of the strong diel wind. Intense turbulent events occurred at the bay contraction when the flow appeared to be virtually controlled by the topography. Such control of the fluid would deepen the isotherms and accelerate the flow downstream the contraction.

The findings of this research emphasize the direct role of the low frequency internal wave field in energy redistribution, and explain features that were observed during the campaign (isotherms behavior within the hypolimnion), and give a scenario. Moreover, this thesis shows that the interaction of the low frequency internal wave field with bay constriction below the metalimnion, when the waves are energized by the strong diel wind, may play a role in vertical fluxes from bottom to interface.