

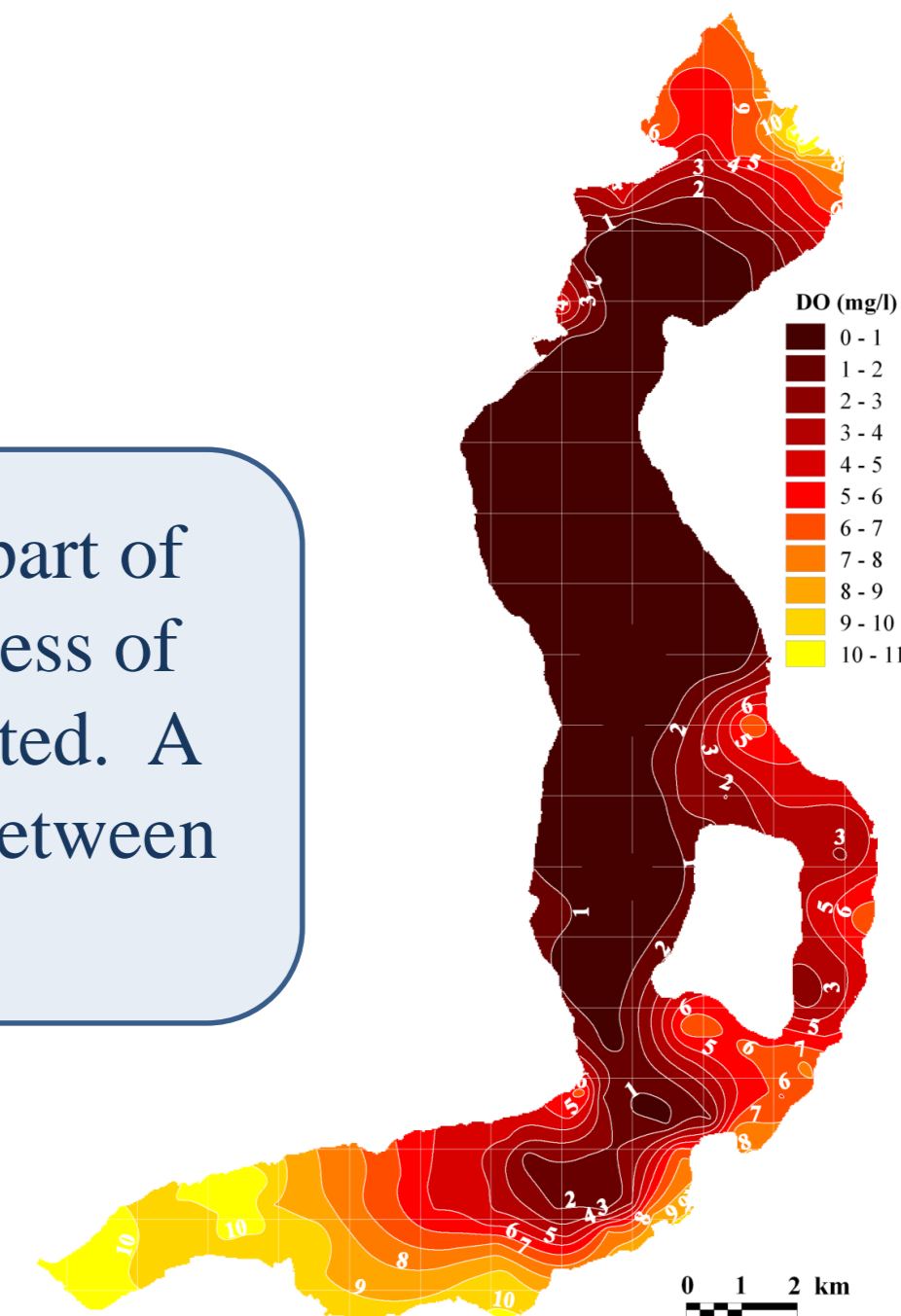
# MONITORING AND MODELING THE INTERNAL WAVES IN LAKE ISEO

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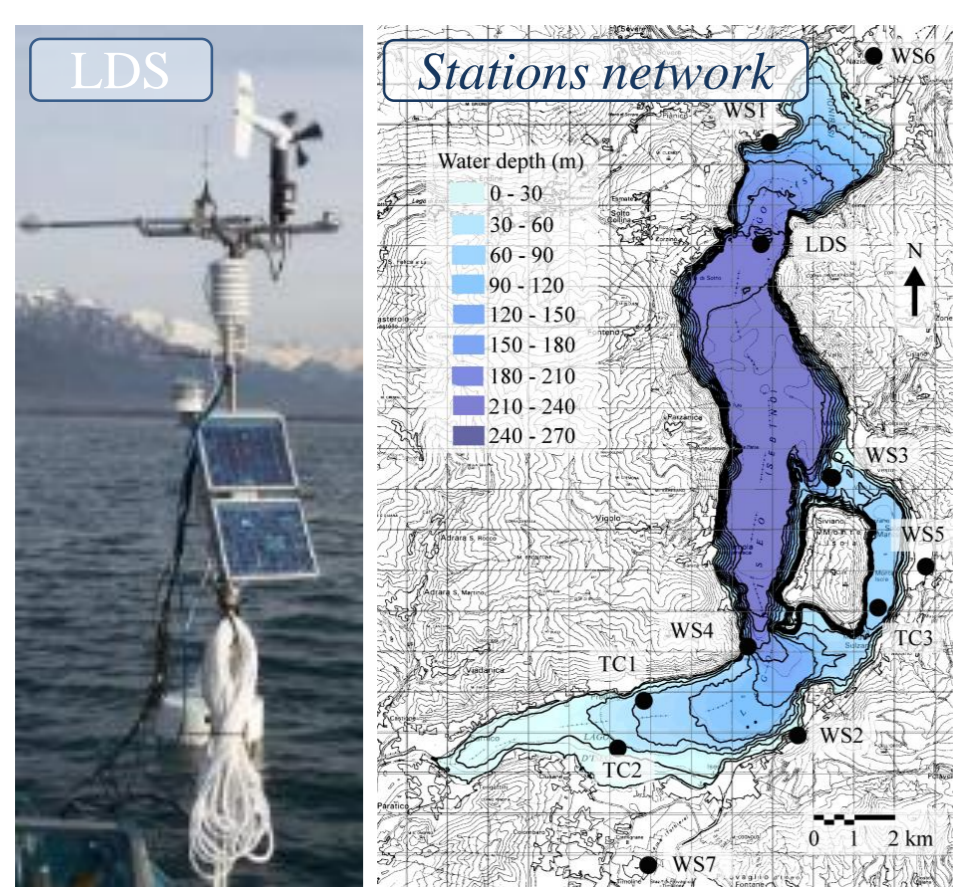
## 1. STUDIED CASE

Lake Iseo is a deep (max depth = 250m) and large (surface area = 60 km<sup>2</sup>) pre-alpine lake located in the northern part of Italy. Historically classified as warm monomictic, starting from the end of the '80 its deep-waters underwent a process of deoxygenation (Garibaldi et al. 1999) so that the possibility of evolution of this lake toward meromixis was postulated. A good understanding of heat distribution in this fragile ecosystem is a prerequisite for investigating the interactions between physical and ecological components and for forecasting its evolution.



Dissolved oxygen measured in the 10m above the lake bottom on July 2011

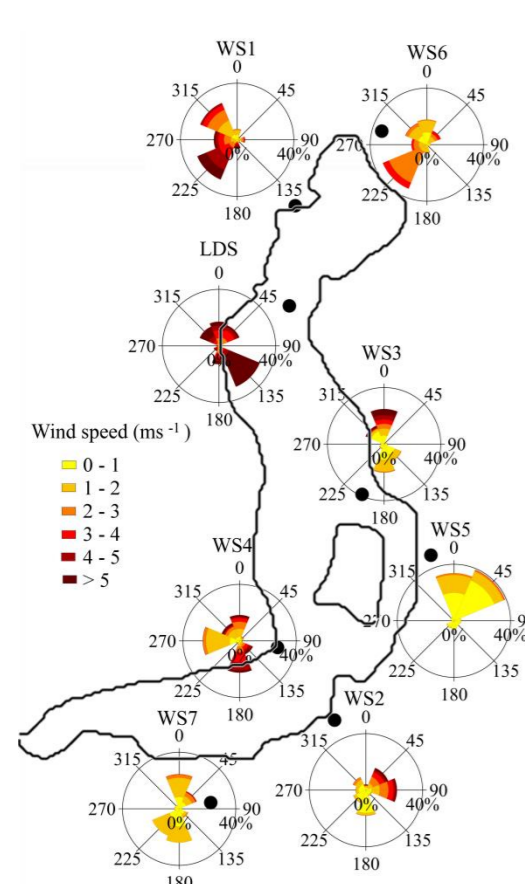
## 2. MONITORING AND DATA ANALYSIS



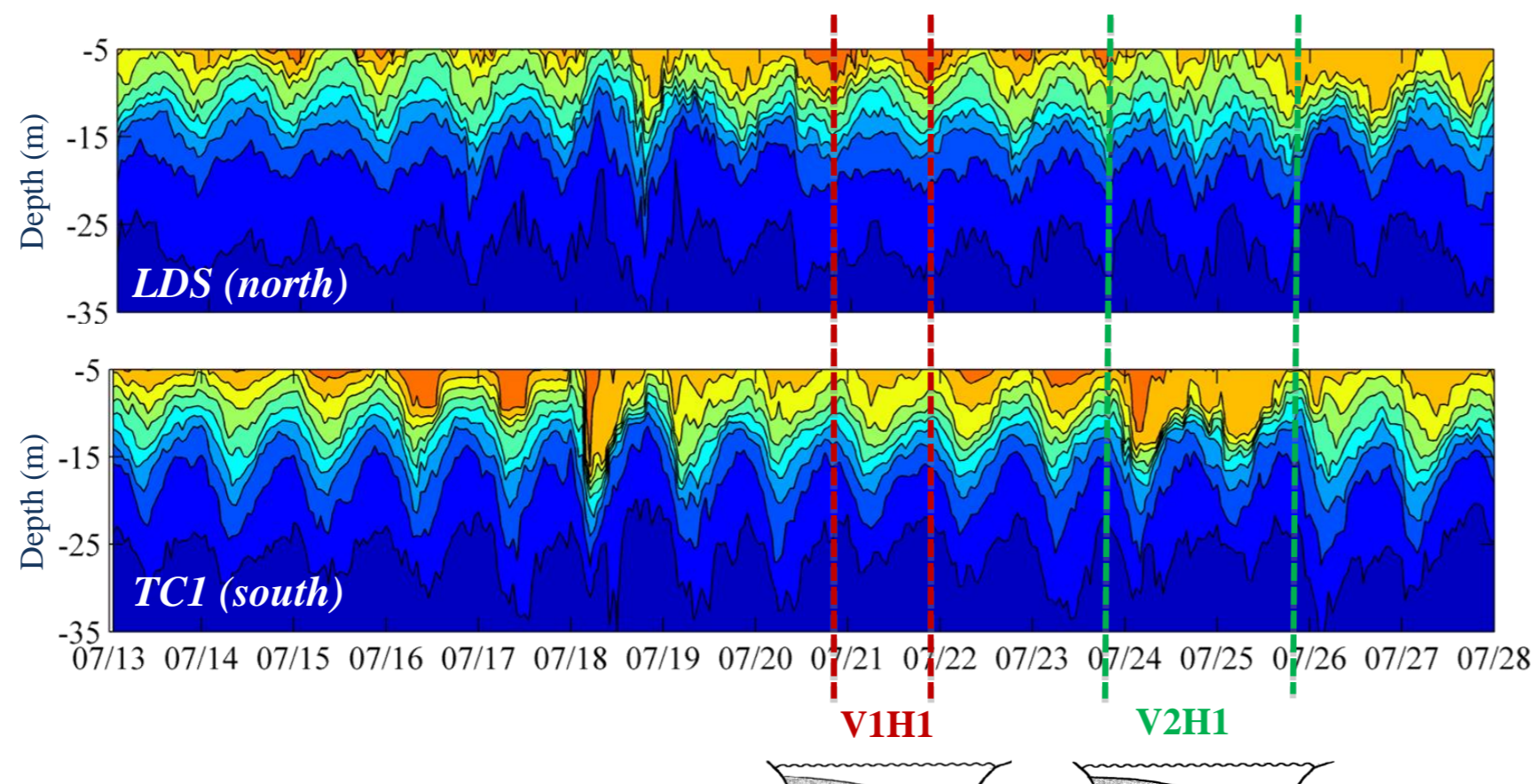
From 2009 we set up a stations network that monitors the main mechanical and thermal forcings, as well as the thermal structure of the lake (Pilotti et al. 2013). A full meteorological station (LDS) was installed in the northern part of the lake, also measuring the lake temperature in 21 depths. During a 20-days long field experiment in July 2010, the temperature of the first 50m of the lake was monitored in 4 points (TC) of the lake at 10s intervals, and wind speed and direction was measured in 8 points (WS) of the lake area.

13 – 28 July 2010 FIELD EXPERIMENT DATA SET

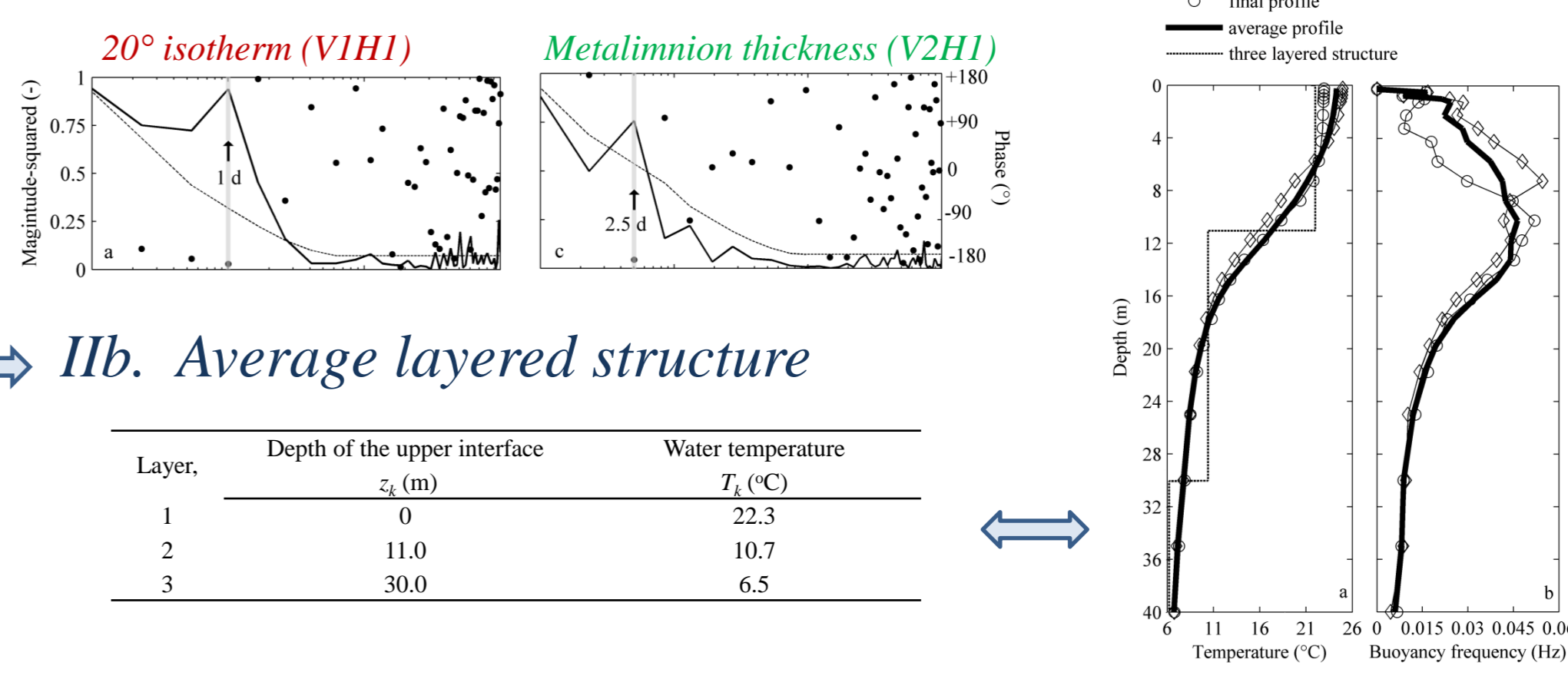
### I. Wind field



### II. Thermal regime



### IIa. Energy spectra: LDS vs TC1



### IIb. Average layered structure

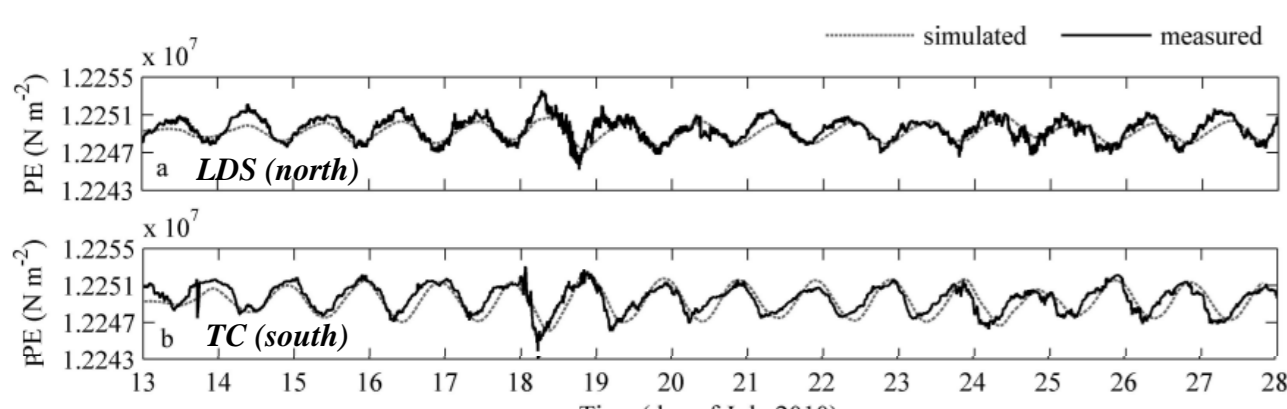
## 3. MODELING THE INTERNAL WAVES

### → Forced oscillations

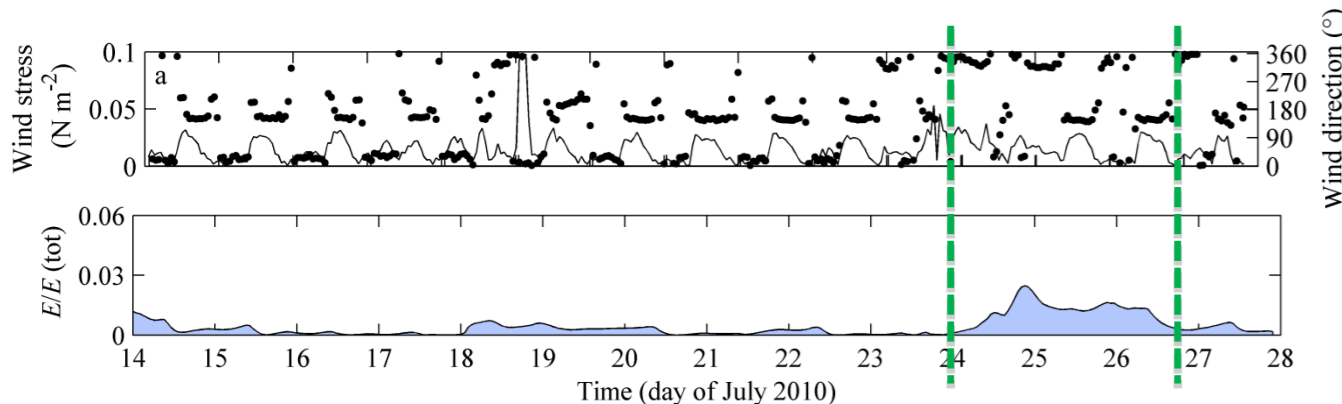
$$\xi(\vec{x}, i, t) = \sum \xi^{(i)}(\vec{x}, i) a^{(i)}(t)$$

$$\frac{\partial \xi^{(i)}}{\partial t} = i\omega^{(i)} \xi^{(i)}(t) + s^{(i)}(t)$$

### Dominant VIH1 response:



### V2H2 excitation after long-lasting winds:

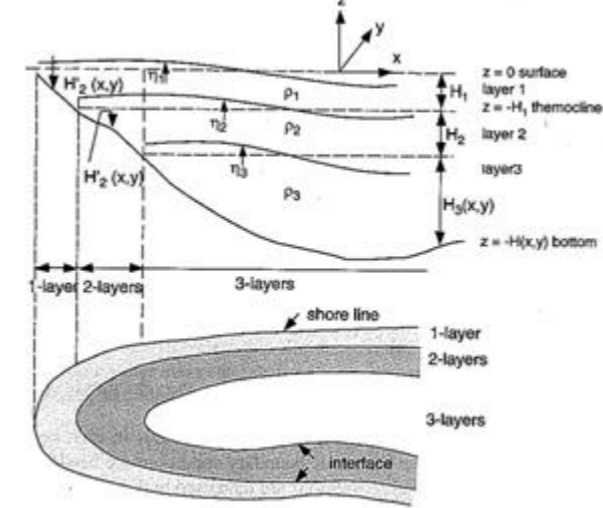


Momentum and continuity equations for a Boussinesque fluid in the rotating earth

$$\rho_0 \frac{D\vec{u}}{Dt} = -\nabla p' - \rho' g \vec{z} - 2\rho_0 \vec{\Omega} \times \vec{u} + \rho_0 D_{\nu,0}$$

$$\nabla \cdot \vec{u} + \frac{\partial w}{\partial z} = 0$$

### Layered model



$$\frac{\partial(\eta_1 - \eta_2)}{\partial t} + \nabla \cdot \vec{v}_1(\eta_1 - \eta_2 + H_1)$$

$$\frac{\partial(\eta_2 - \eta_3)}{\partial t} + \nabla \cdot \vec{v}_2(\eta_2 - \eta_3 + H_2)$$

$$\frac{\partial \eta_3}{\partial t} + \nabla \cdot \vec{v}_3(\eta_3 + H_3)$$

$$\frac{D\vec{v}_i}{Dt} + \Omega \vec{v}_i + \left( \nabla \eta_i + \frac{\rho_2 - \rho_1}{\rho_1} \nabla(\eta_2 - \eta_1) \right) = 0 \quad i=2$$

$$\left( \nabla \eta_i + \frac{\rho_2 - \rho_1}{\rho_1} \nabla(\eta_2 - \eta_1) + \frac{\rho_3 - \rho_2}{\rho_2} \nabla(\eta_3 - \eta_2) \right) = 0 \quad i=3$$

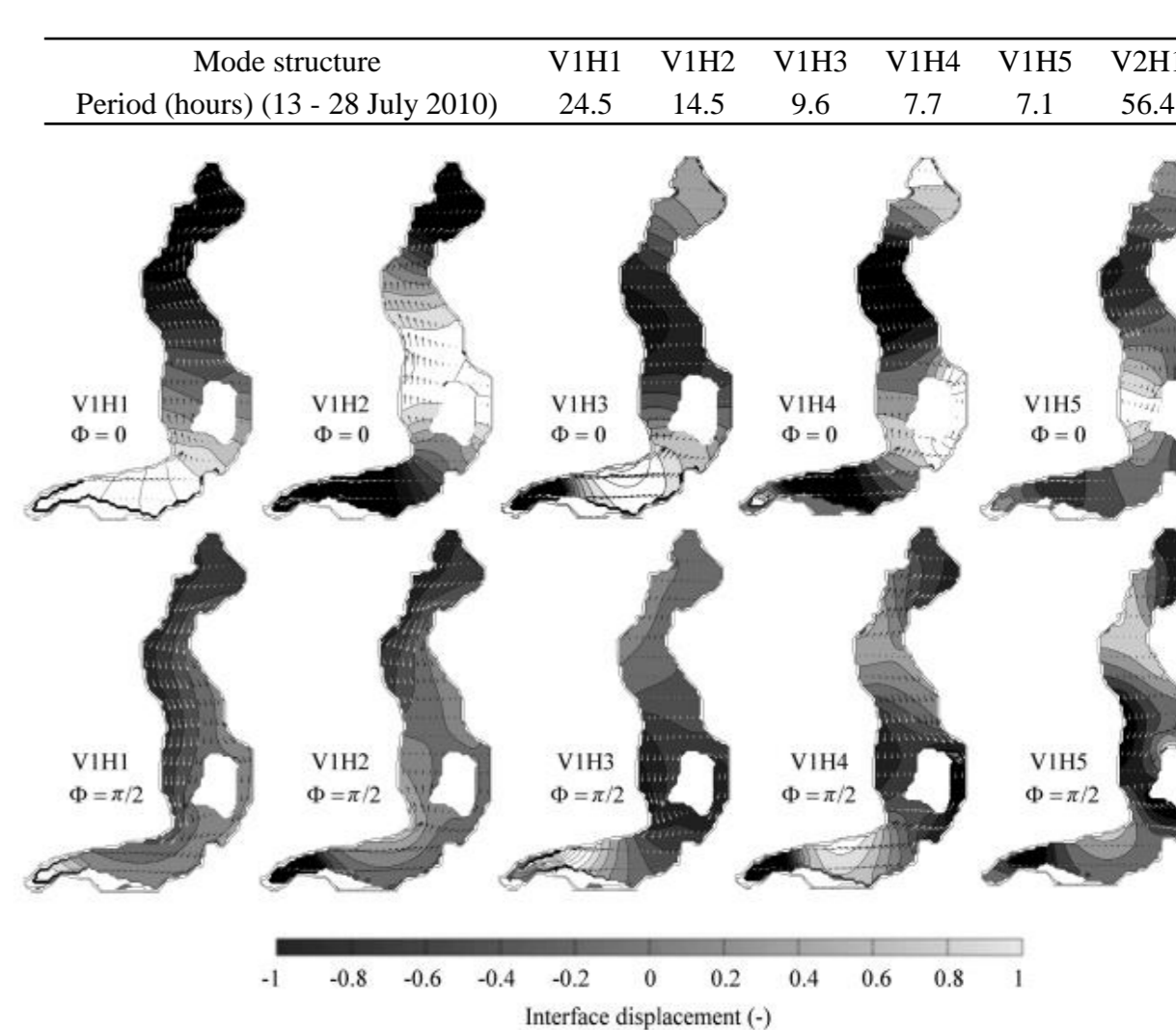
### Linear approximation

$$T_i = \frac{T_j}{3\theta_0} \frac{h_2 + h_3}{h_1 h_2} < T_i \rightarrow \frac{D\vec{v}_i}{Dt} = \frac{\partial \vec{v}_i}{\partial t}$$

### → Structure of the free modes

$$\xi(\vec{x}, i, t) = [\eta_i \quad \vec{V}_i \quad \vec{V}_i^T]^T \quad \xi(\vec{x}, i, t) = \xi(\vec{x}, i) e^{i\omega t}$$

$$i\omega \xi(\vec{x}, i) + M \xi(\vec{x}, i) = 0$$



- ✓ Iseo lake bathymetry influence the temporal and spatial structure of the internal waves;
- ✓ Internal waves response in Iseo are driven by the spatial and temporal structure of the forcing; a wind-wave resonance that occurs during most of the stratified period justifies the measured dominant VIH1 response. Occasional long-lasting winds tend to excite VIH2 modes.
- ✓ The modal layer model well reproduced the oscillatory motions during the stratified period; accordingly it could be a useful instrument for long-term analysis, that could be integrated with 1D hydrodynamic models.

## REFERENCES:

- ✓ Garibaldi, L., V., Mezzanotte, M.C., Brizzio, M., Rogora, and R., Mosello. 1999. The trophic evolution of Lake Iseo as related to its holomixis. J. Limnol. 62: 10-19.
- ✓ Pilotti, M., Valerio, G., Leoni, B. 2013. Data Set For Hydrodynamic Lake Model Calibration: A Deep Pre-Alpine Case, Water Resources Research, 49, 1-5.
- ✓ Pilotti, M., Valerio, G., Gregorini, L., Milanesi L. and Hogg C. 2013. Study of tributary inflows in Lake Iseo with a rotating physical model, J. Limnol., in press.
- ✓ Valerio, G., Pilotti, M., Marti, C.L., and Imberger J. 2012. The structure of basin scale internal waves in a stratified lake in response to lake bathymetry and wind spatial and temporal distribution: Lake Iseo, Italy. Limnology and Oceanography, 57: 772-786.