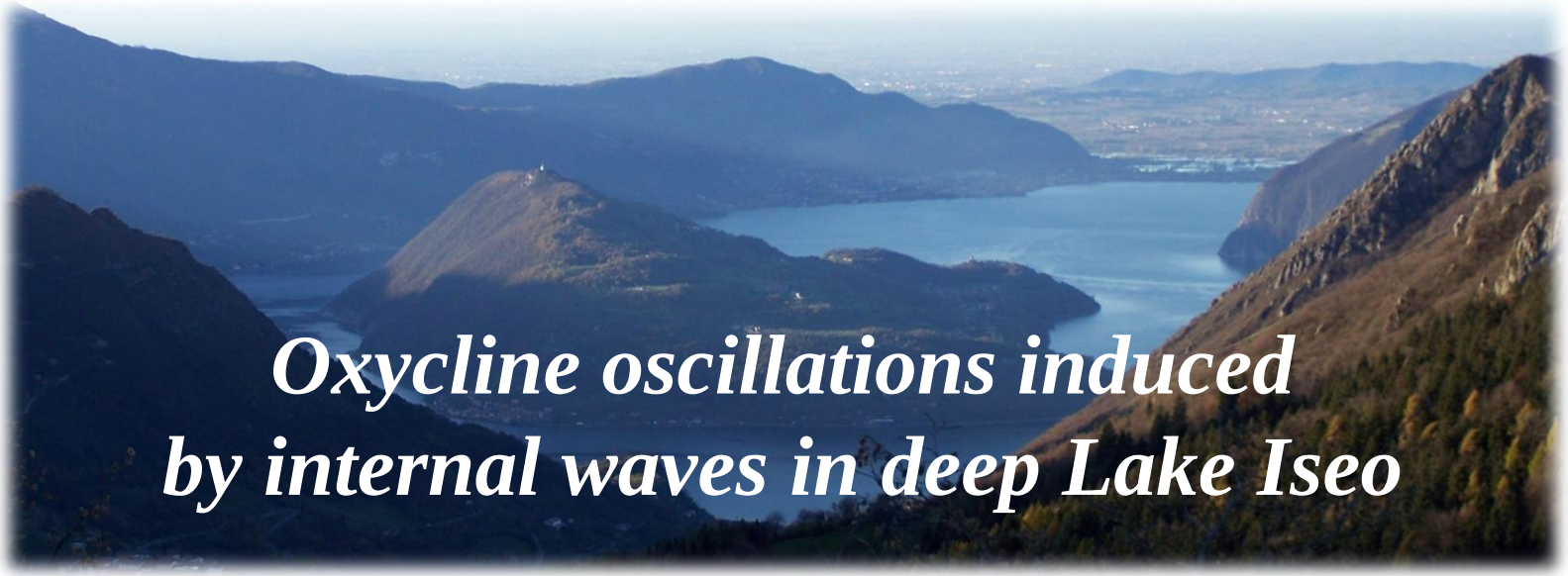


Oxycline oscillations induced by internal waves in deep Lake Iseo

Giulia Valerio[1], Marco Pilotti[1], Michael Hupfer[2], Maximilian Lau[2]

1. DICATAM, Università degli Studi di Brescia, via Branze 43, 25123 Brescia, Italy
2. Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, 12587 Berlin, Germany

e-mail: giulia.valerio@unibs.it
Website: www.ing.unibs.it/hydraulics

1 – Motivations - eutrophy and oxygen deficit due to anthropogenic stressors

1967

Prof. m	Temp. °C		mg O_2/l		pH		Cond. µS 18 °C		µg $P(PO_4'')$/l	
	V	XI	V	XI	V	XI	V	XI	V	XI
0	13,1	10.6	11,9	10,1	8,46	8,15	260	238	1	0
5	11,1	10,6	12,2	10,2	8,40	—	258	—	0	—
10	9,4	10,6	12,0	10,3	8,30	—	263	—	0	—
20	8,3	10,5	10,9	10,4	8,11	8,21	268	239	0	1
30	7,5	8,7	10,6	8,3	8,01	8,00	268	258	0	1
60	6,0	6,0	10,0	9,3	7,93	8,02	268	271	3	6
100	5,85	5,8	9,7	9,1	7,91	8,08	269	269	6	4
150	5,75	5,7	9,5	9,0	7,92	8,08	271	272	1	8
200	5,75	5,75	9,1	8,5	7,82	8,04	272	273	3	12
245-7	5,75	5,75	8,2	7,8	7,88	7,98	278	279	30	15

Source: Bonomi and Geerletti (1967)

2016

Depth (m)	Temp °C		mg O_2/l		Cond. 20° (µS/cm)		µg SRP/l		µg TP/l	
	IV	X	IV	X	IV	X	IV	X	IV	X
0	12.0	17.4	11.0	10.1	248	254	5	5	10	10
25	7.8	9.9	11.1	6.0	226	240	6	3	10	10
50	7.2	6.7	7.3	4.5	230	244	17	17	19	17
150	6.5	6.6	0.1	0.1	248	248	98	99	104	101
200	6.5	6.6	0.1	0.1	250	250	105	101	106	102
250	6.5	6.6	0.1	0.1	252	253	112	125	112	122

Data measured by Dr. Michael Hupfer (IGB)

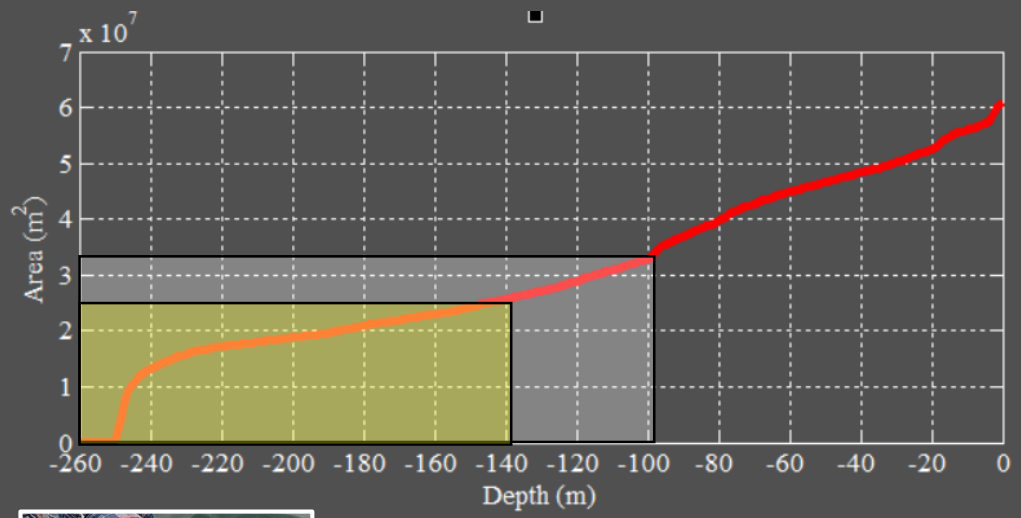
$V = 8.10^9 m^3$;
$A = 61\ km^2$
Max depth = 254m

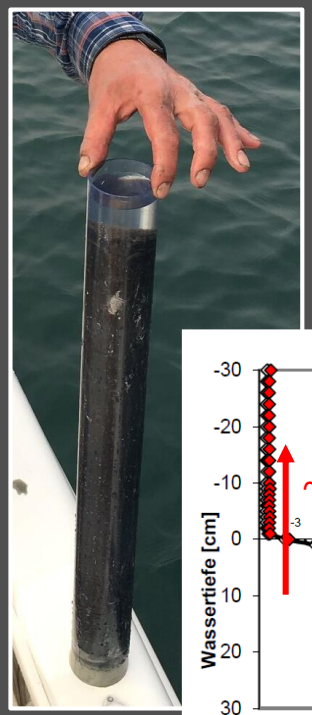
Drained watershed:
$A = 1807\ km^2$

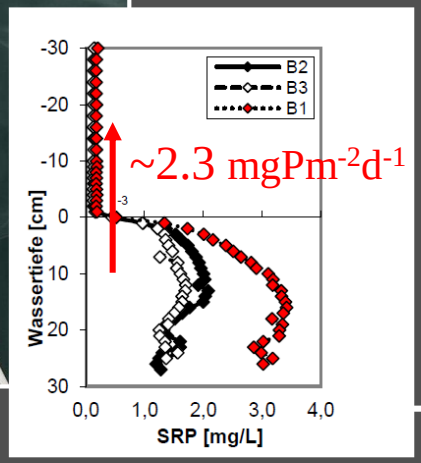
Dissolved oxygen measured in the 10m of water above the sediments

July 2012

1 – Motivations - progressive deoxygenation favoured by climate change

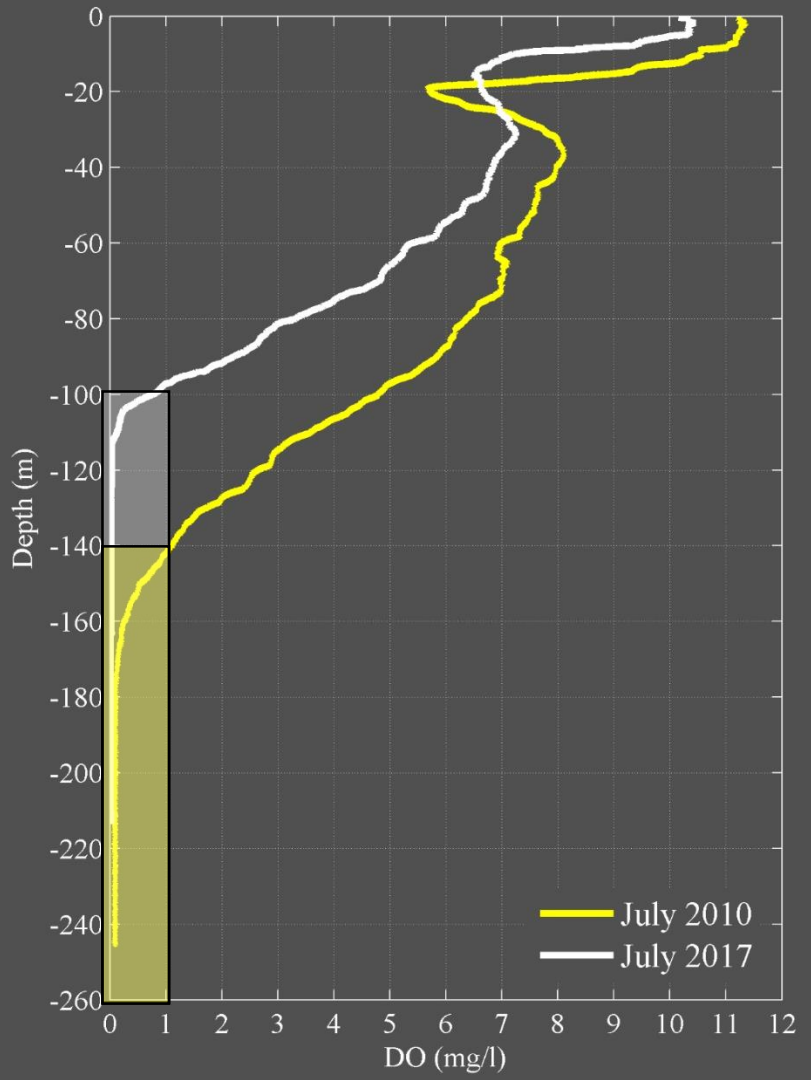




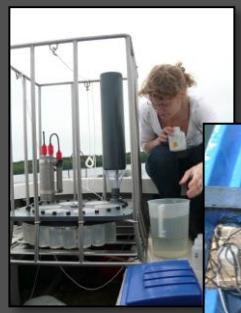


Additional **1.4 km²/year** area of sediments are in contact with water with DO < 1mg/l (+ 35% / 7 years)

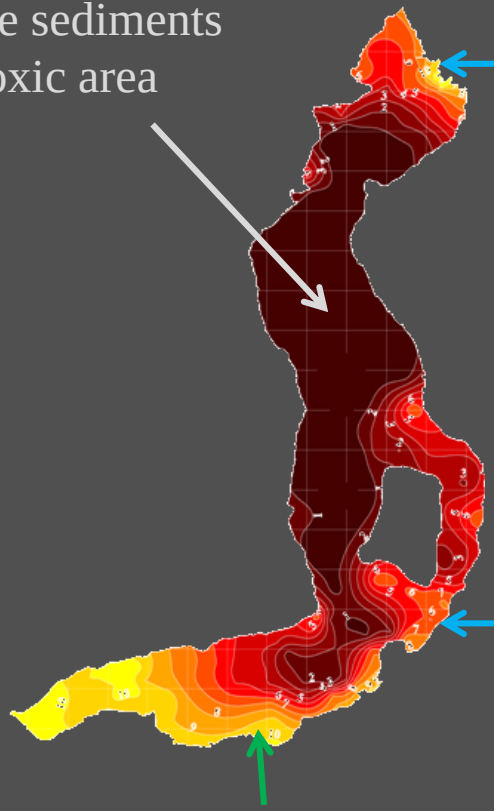
Additional SRP from monimolimnion **~ 1 tonn/year**



General objective: quantitative assessment of local pressures on the overall P load to clarify how effective will external nutrient load reductions be on the trophic evolution of Lake Iseo.



P from the sediments in the anoxic area



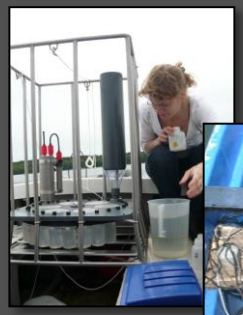
P from the main tributaries

Hydrodynamic and ecological modeling

P from the CSOWs

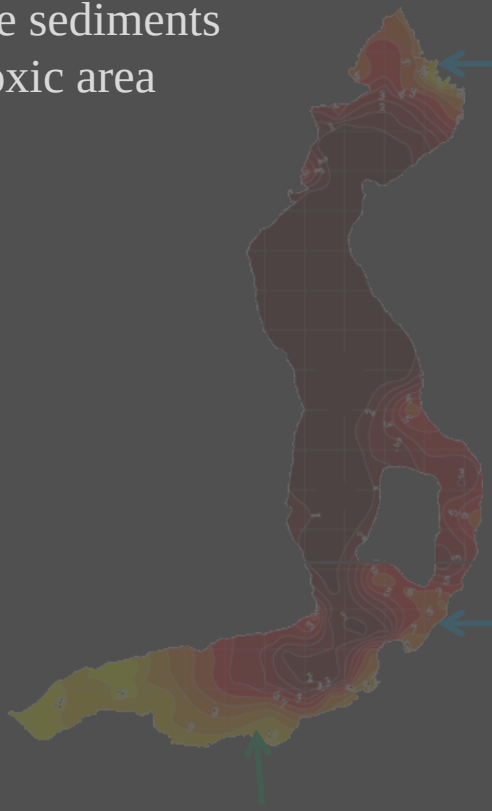
Role of the macrophytes in the shallower areas

Specific sub-objective: what are the effects of the internal waves on the release of the P from the sediments in the monimolimnion?



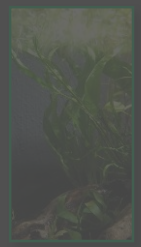
P from the sediments in the anoxic area

Hydrodynamic and ecological modeling



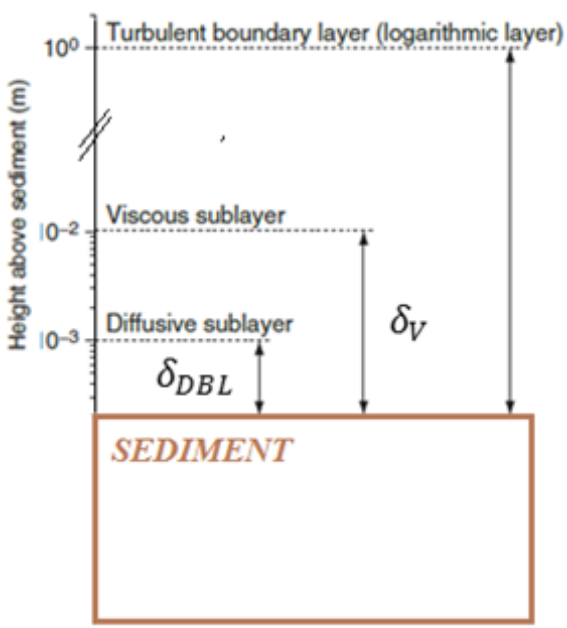
P from the main tributaries

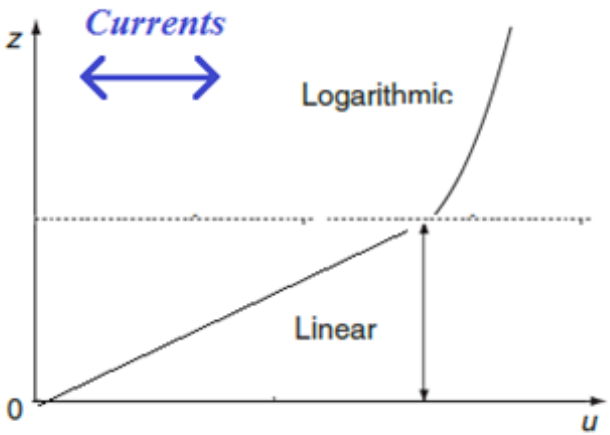
P from the CSOWs



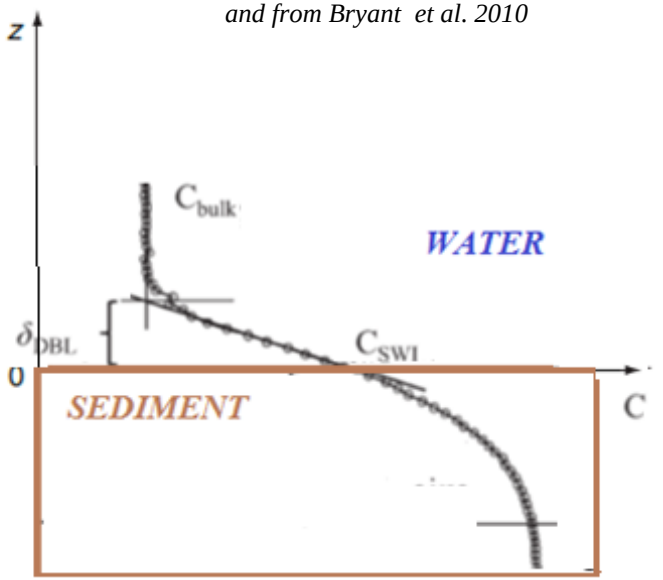
Role of the macrophytes in the shallower areas

- Temporal variations of the shear stress at the top of the bbl in the monimolimion





Modified from Lorke and Peeters, 2001 and from Bryant et al. 2010



$$\delta_V \cong 8.6\upsilon/U^* = O(1cm)$$

$$\delta_{DBL} \cong Sc^{0.5}\,\delta_V = O(1mm)$$

$$Sc = \upsilon/D$$

$$\boldsymbol{F = D\,\frac{(C_{bulk} - C_{SWI})}{\delta_{DBL}} = k(C_{SWI} - C_{bulk})}$$

F=F(t)

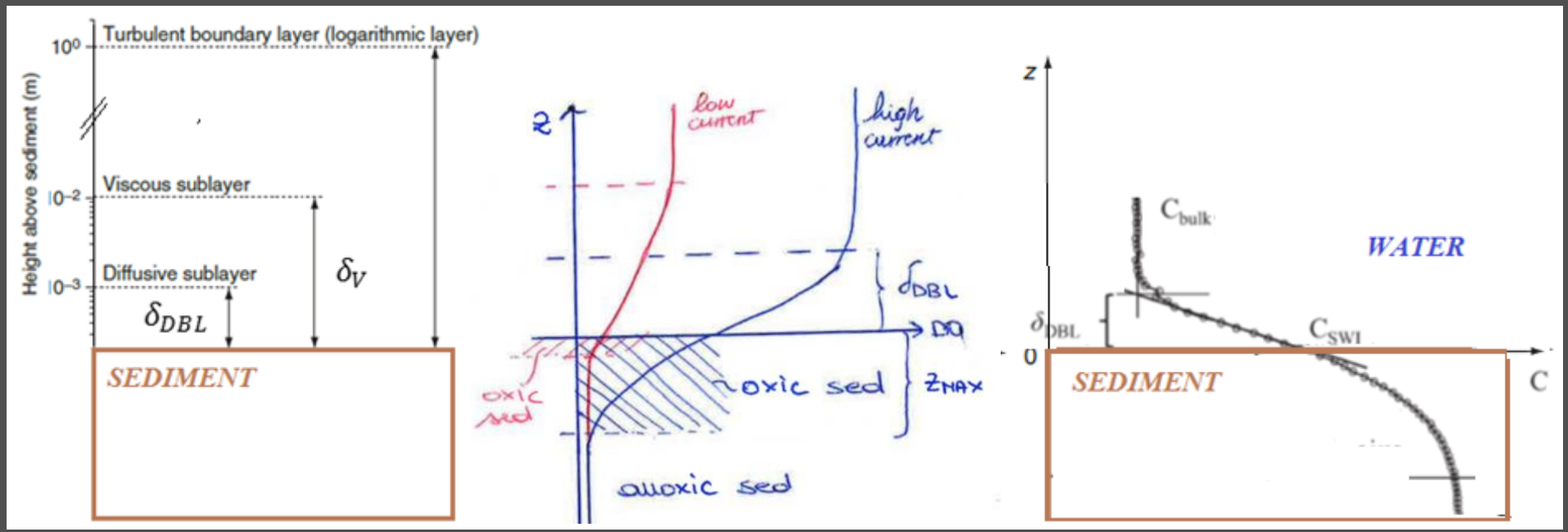
$$\begin{cases} k = \dfrac{(\varepsilon\upsilon)^{0.25}}{2\pi} Sc^{-0.5} = \dfrac{1}{2\pi}\left(\dfrac{D^2}{\upsilon}\varepsilon\right)^{0.25} \\ \varepsilon = \varepsilon(\delta_V) \end{cases}$$

** General*

$$\begin{cases} \varepsilon(z) = \dfrac{U^*}{kz} \\ k = \dfrac{U^*}{9} Sc^{-0.5} = \dfrac{U^*}{9}\left(\dfrac{\upsilon}{D}\right)^{-0.5} \end{cases}$$

*** Constant shear stress (Lorke and Peeters 2006)*

- Temporal variations of the redox conditions across the oxycline



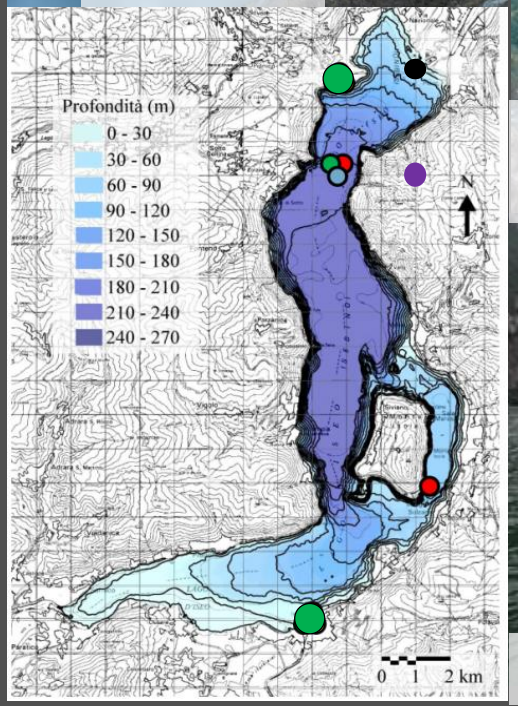
See e.g. Bryant et al. 2010 L&O
Hupfer et al. 2007 Aquat Microb Ecol

Fluctuating redox conditions could imply:

- Oxic conditions: higher mineralisation of organic bound P and temporary fixation at FeOOH
- Anoxic conditions: strong release of P due to reductive dissolution of Fe(III)

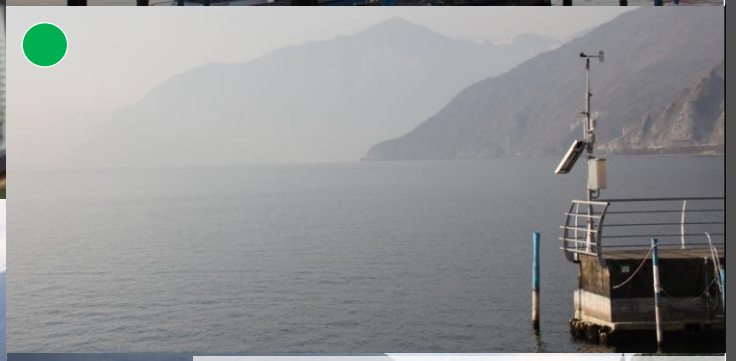
3 – Internal waves in Lake Iseo – measurements

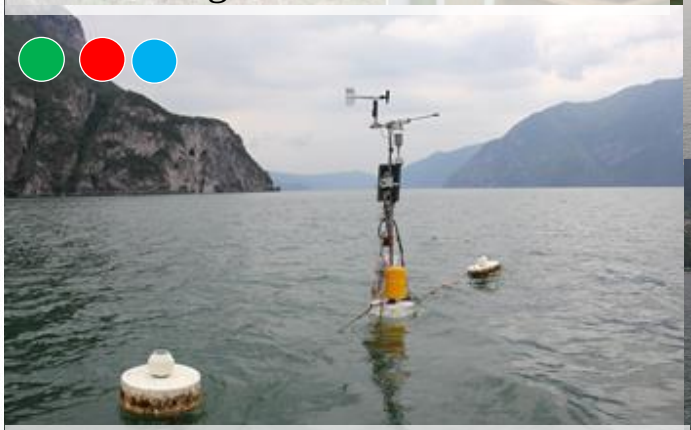
Webcam



Temp. conductivity and incoming P-$PO4^{3-}$ in Oglio river

Wind, SW rad, air temp., Rel. hum





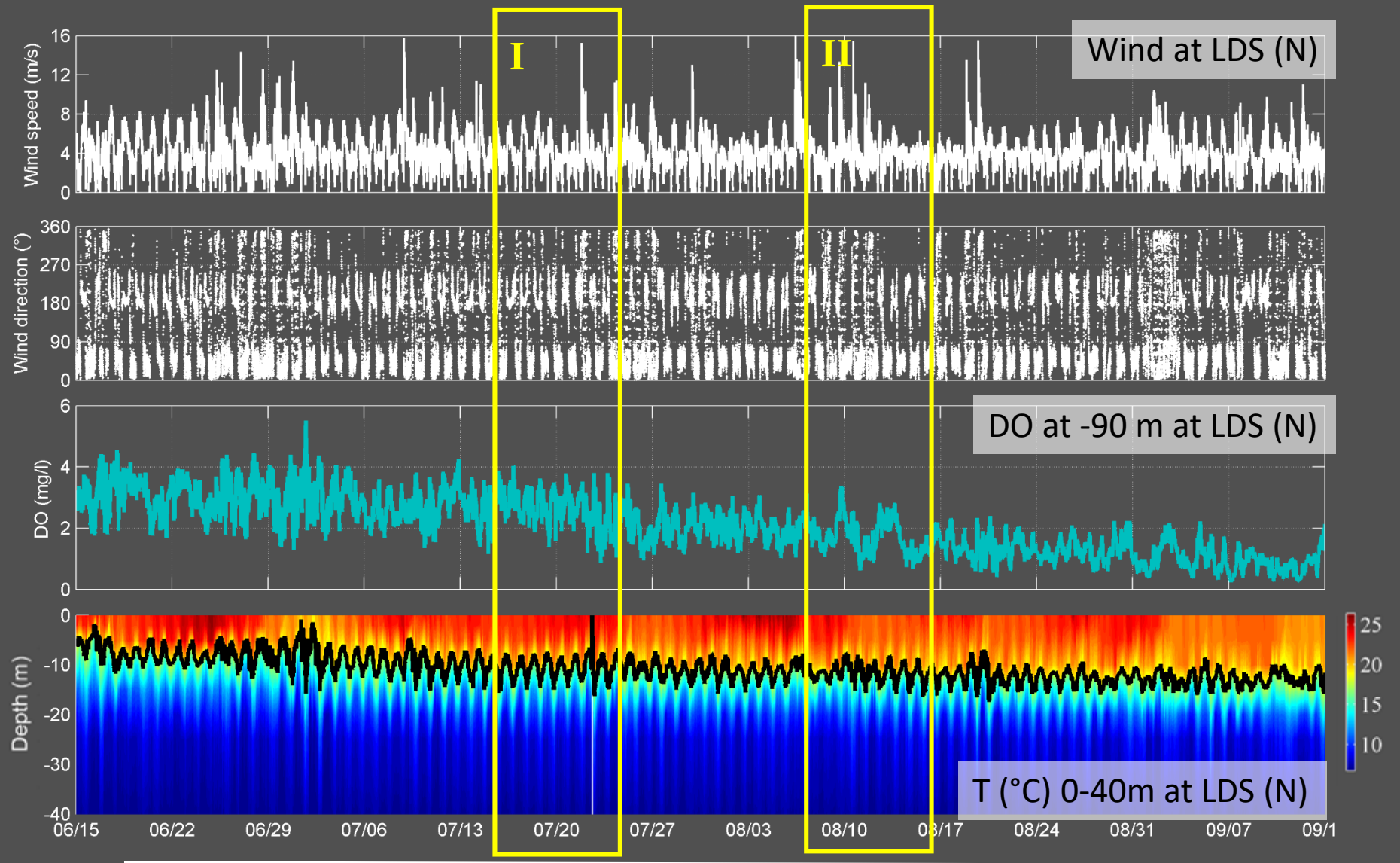
Oxygen -90m; Net rad

Water temperature 0-150m

Real-time data available at:
http://hydraulics.unibs.it/hydraulics/il-monitoraggio-del-lago-diseo/real-time-data-from-lake-monitoring-system/

see Pilotti et al. 2014 WRR

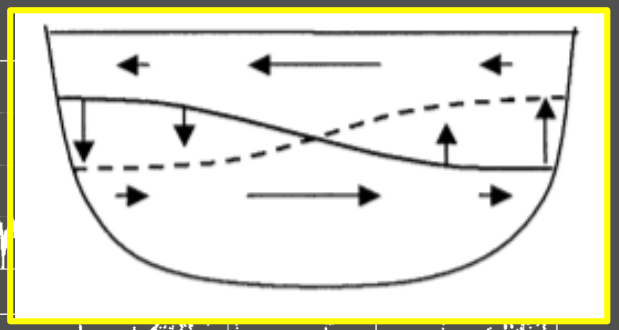
Dominant V1H1 mode in resonance with the wind and occasional V2H1 by long-lasting wind



see Valerio et al. 2012 L&O

- Dominant V1H1 mode in resonance with the daily wind

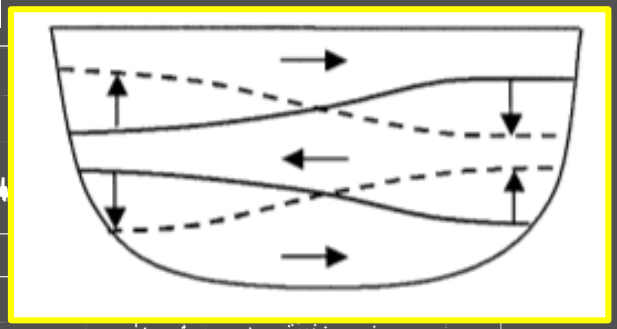
T = 25 hours



(I)

- Occasional excitation of V2H1 by long-lasting wind

T = 73 hours

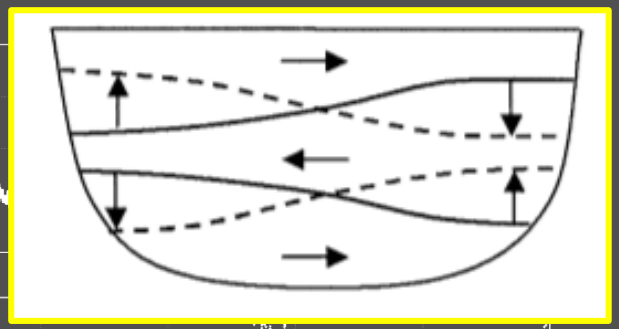


(II)

2 – Internal waves in Lake Iseo – measurements

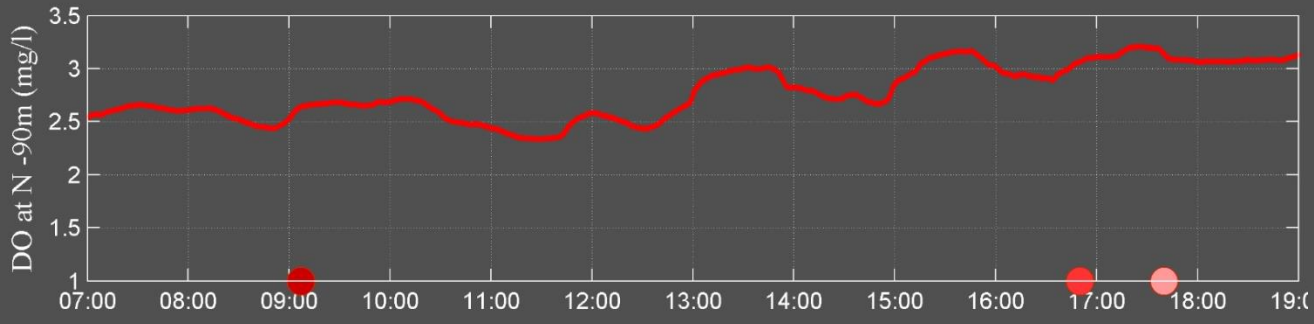
(II)

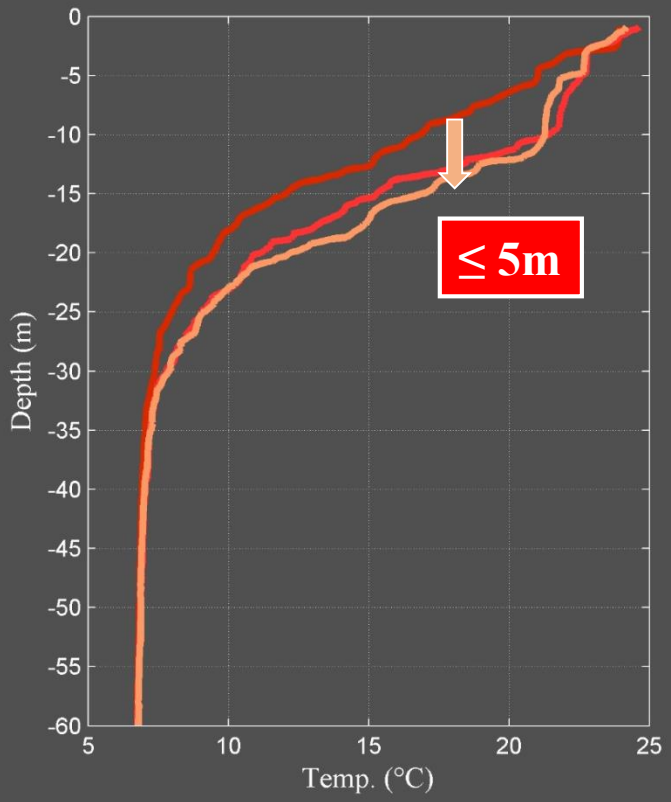
T = 73 hours

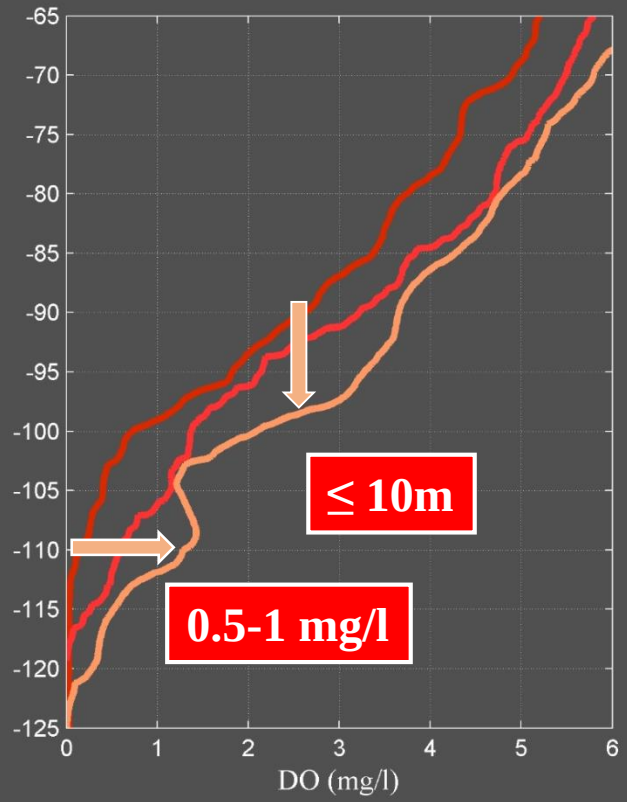


3 – Internal waves in Lake Iseo – measurements

(I)



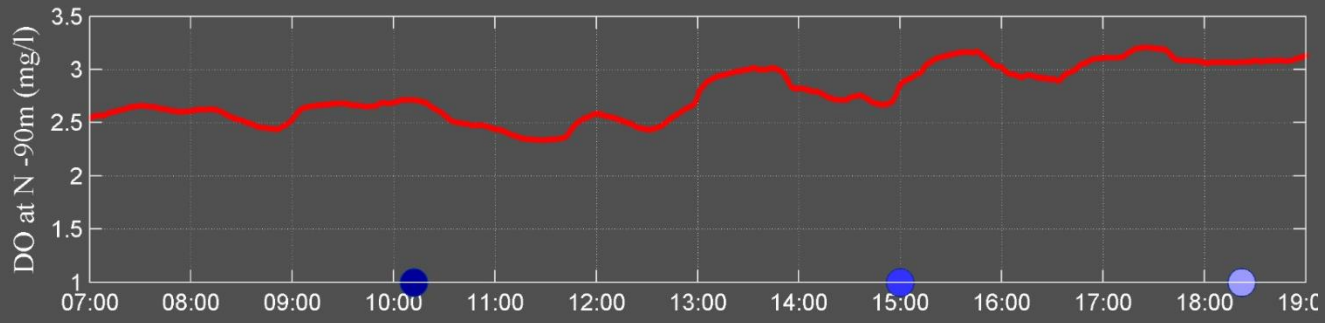


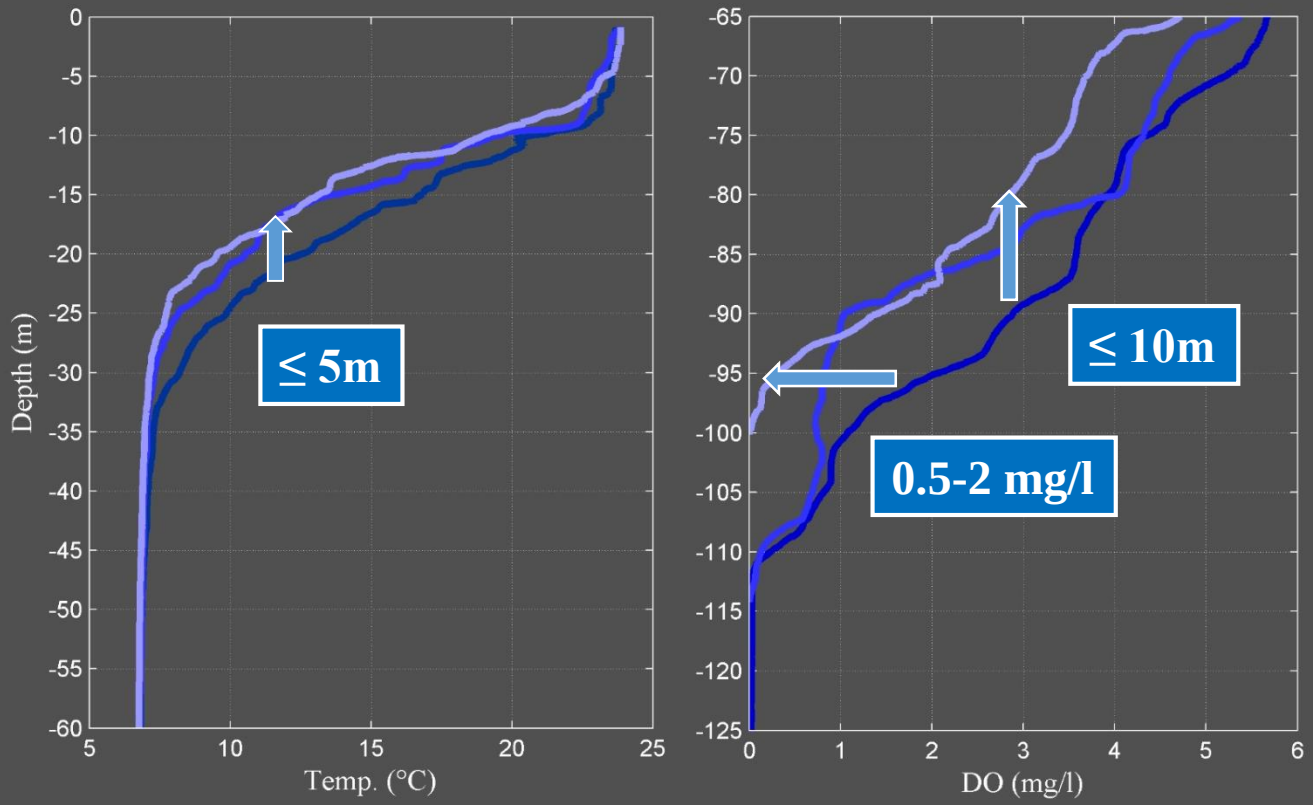


21 July 2017

2 – Internal waves in Lake Iseo – measurements

(I)

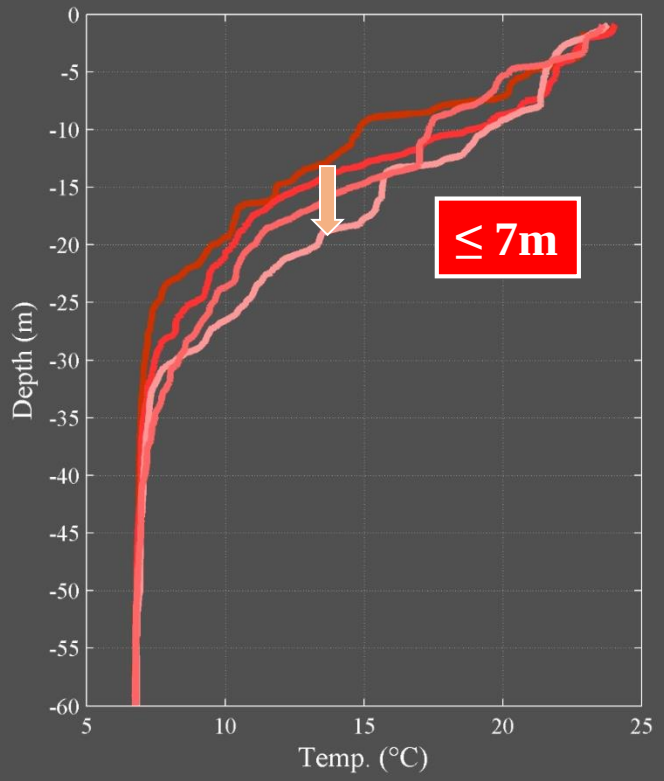


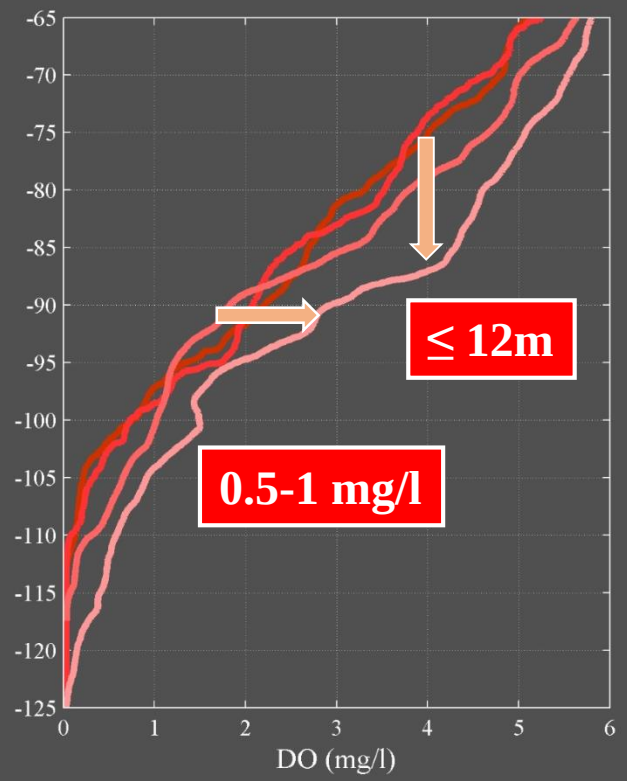


21 July 2017

3 – Internal waves in Lake Iseo – measurements

(I)

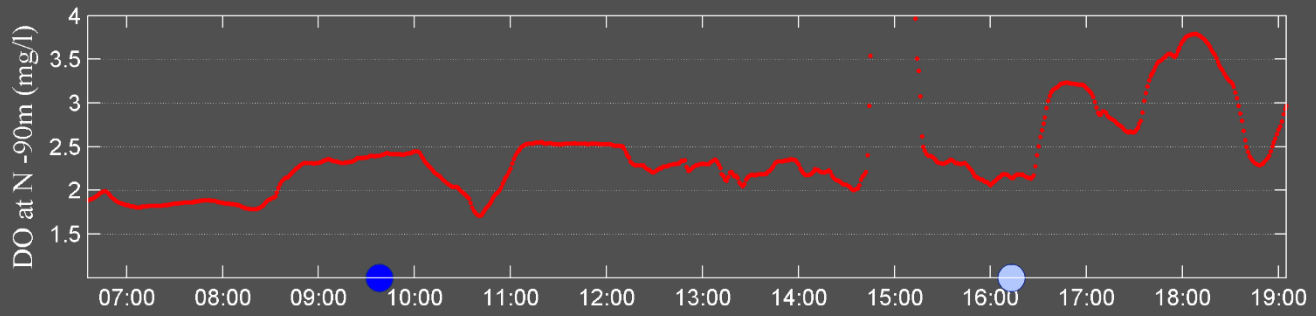


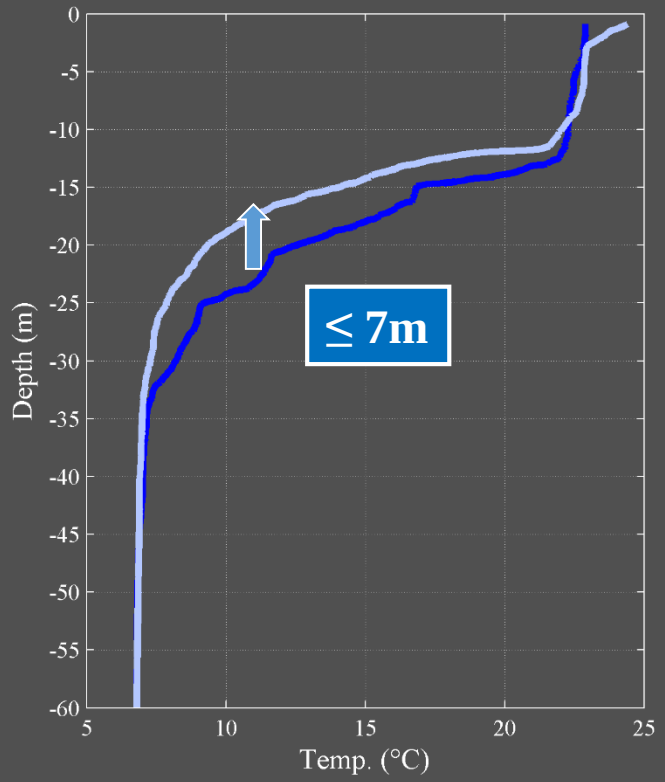


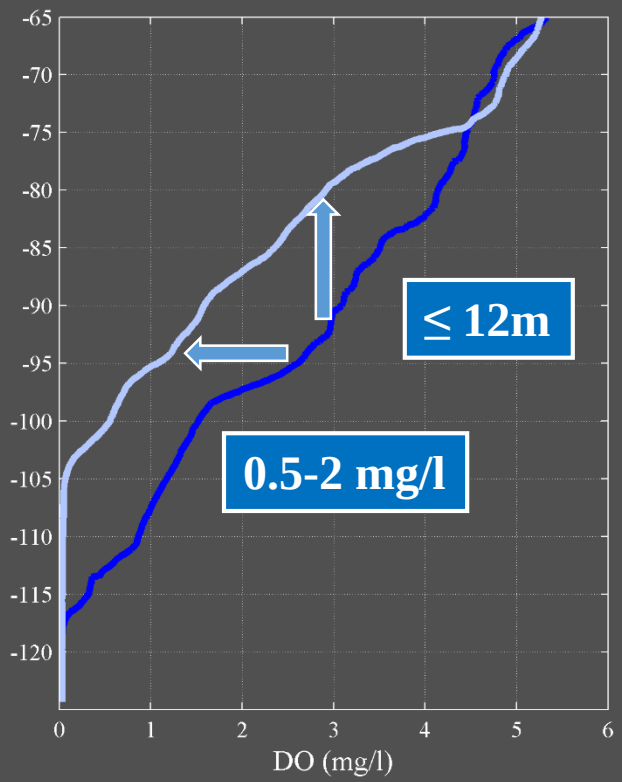
22 July 2017

3 – Internal waves in Lake Iseo – measurements

(I)







22 July 2017

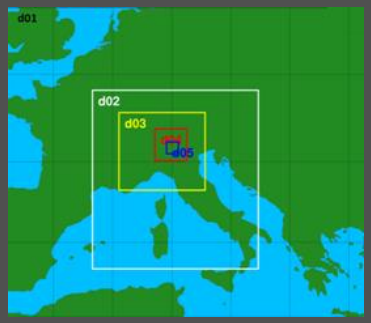
4 – Internal waves in Lake Iseo - model

6-hourly NCEP Climate Forecast System v2 data at ~0.5 degree

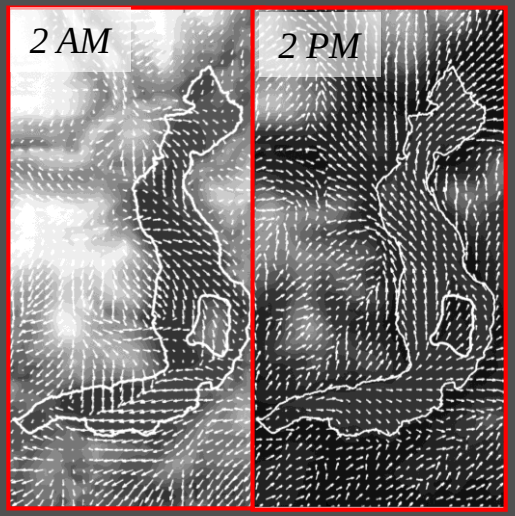
Corine Land Cover

Surface lake temperature at LDS

WRF model vers. 3.7



- 5 two-way nested grids ds = 30 km – 250m
- 35 eta levels 8m- 21km
- model spin-up: 3 days



spatially varying wind

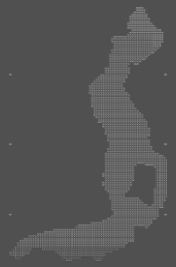
Wind data at the different stations

Inflow/outflow temp, cond, discharge

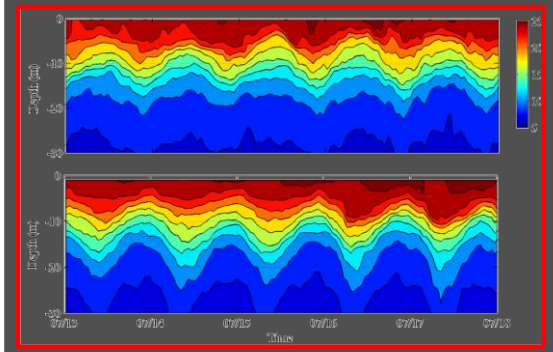
Air temp, rel. hum, radiative fluxes

h.r. Temp and DO vertical profiles

AEM3D – Z-grid model



- Hyrostatic
- Cartesian grid 80x80m
- dz = 1m (0-100),
- dz <=15 m (100-250)
- dt = 1min

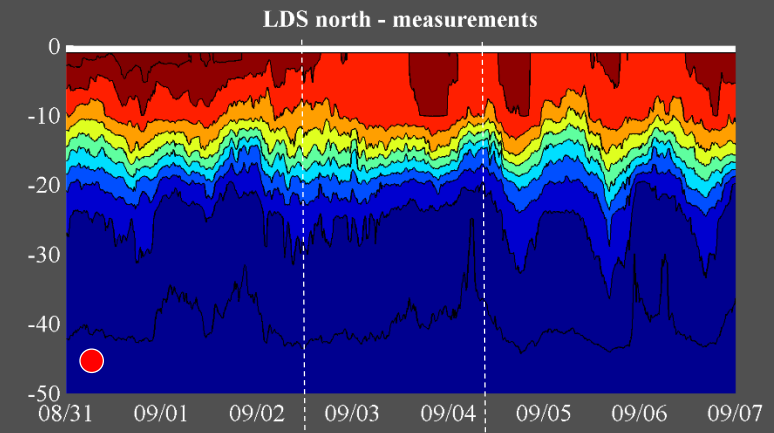


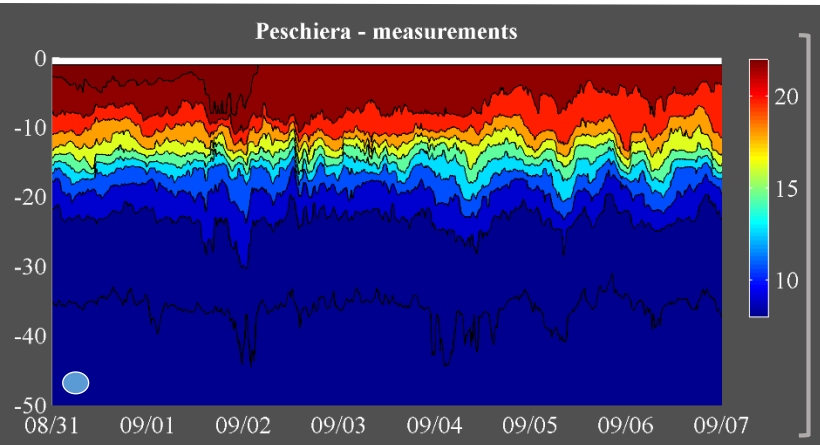
water temperature and DO (space, time)

Water temp (0-150m) and DO data -90m

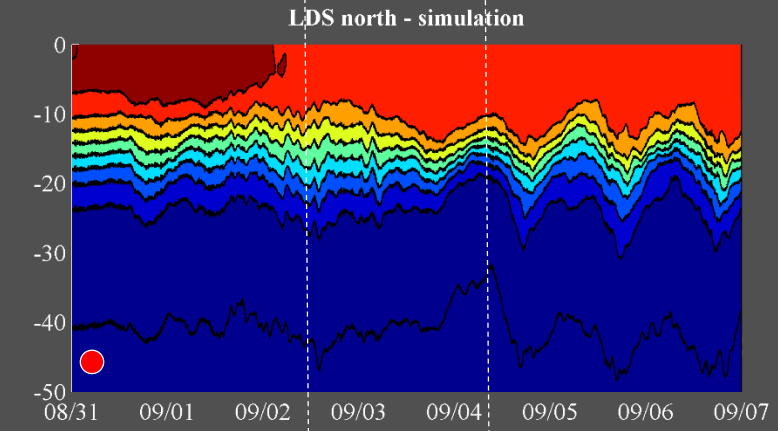
see Valerio et al. 2017 WRR

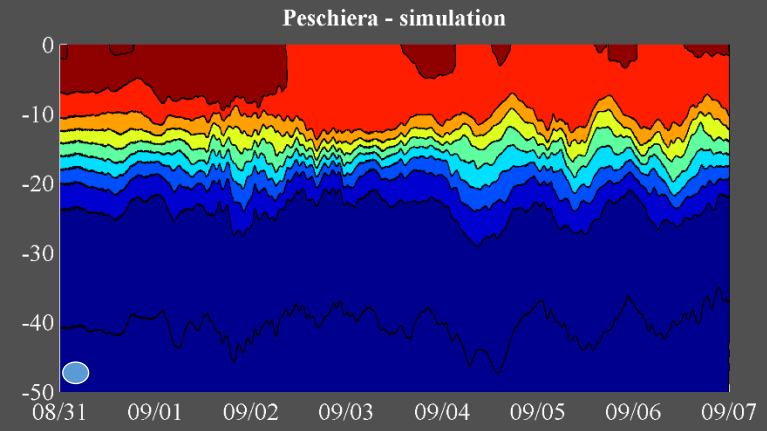
2 – Internal waves in Lake Iseo – example of the model results (Sept. 2017)





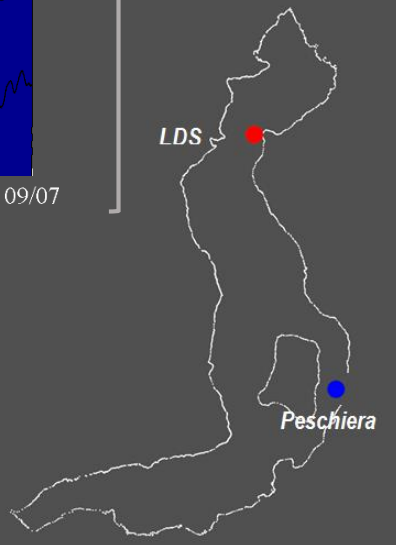
T(°C) Data



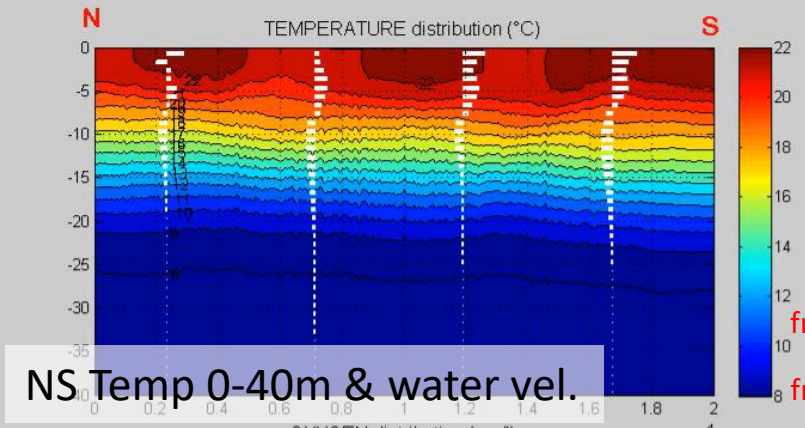


T(°C) Sim

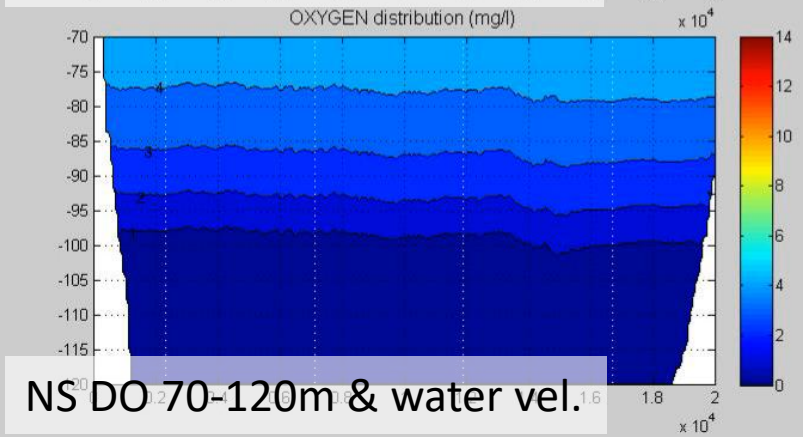
DO Sim vs Data (-90m)



4 – Effects of the internal waves on the sediment-water exchange processes

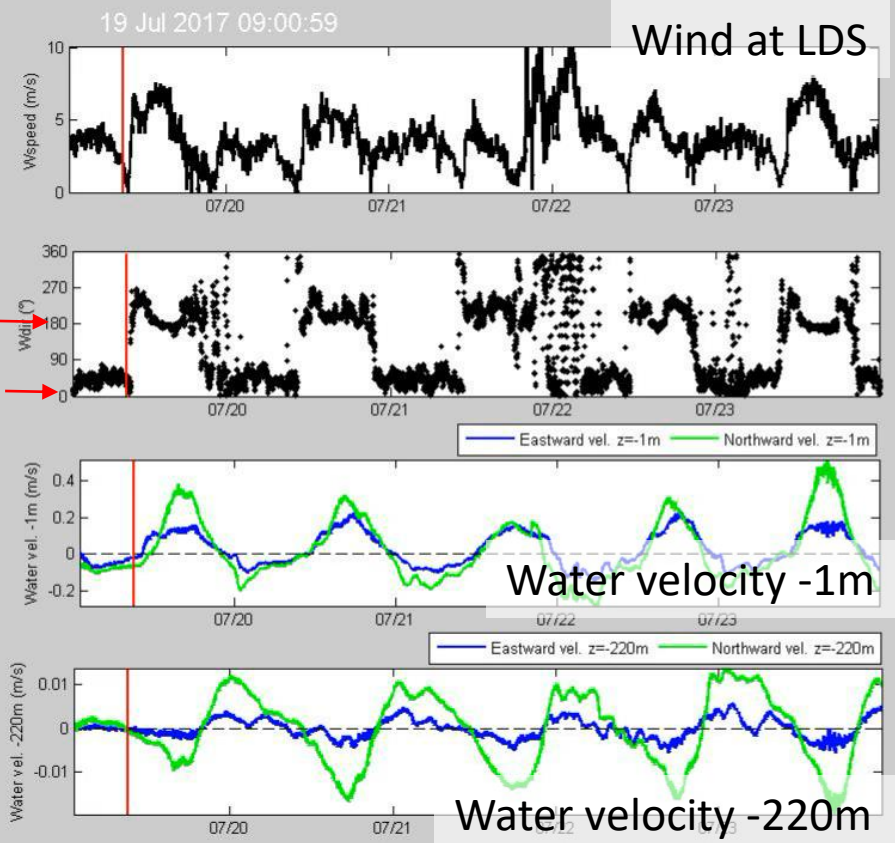


NS Temp 0-40m & water vel.



NS DO 70-120m & water vel.

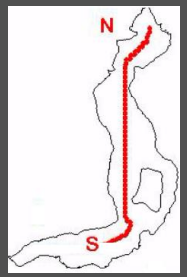
fromS → fromN →

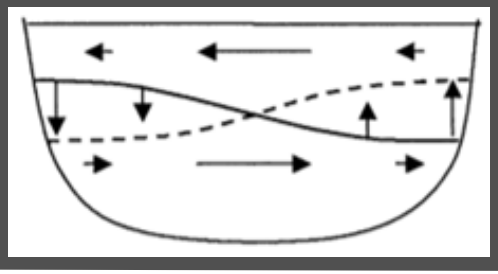


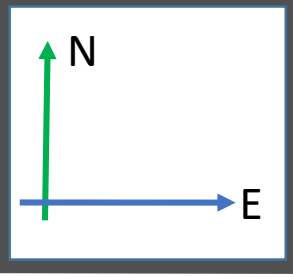
Wind at LDS

Water velocity -1m

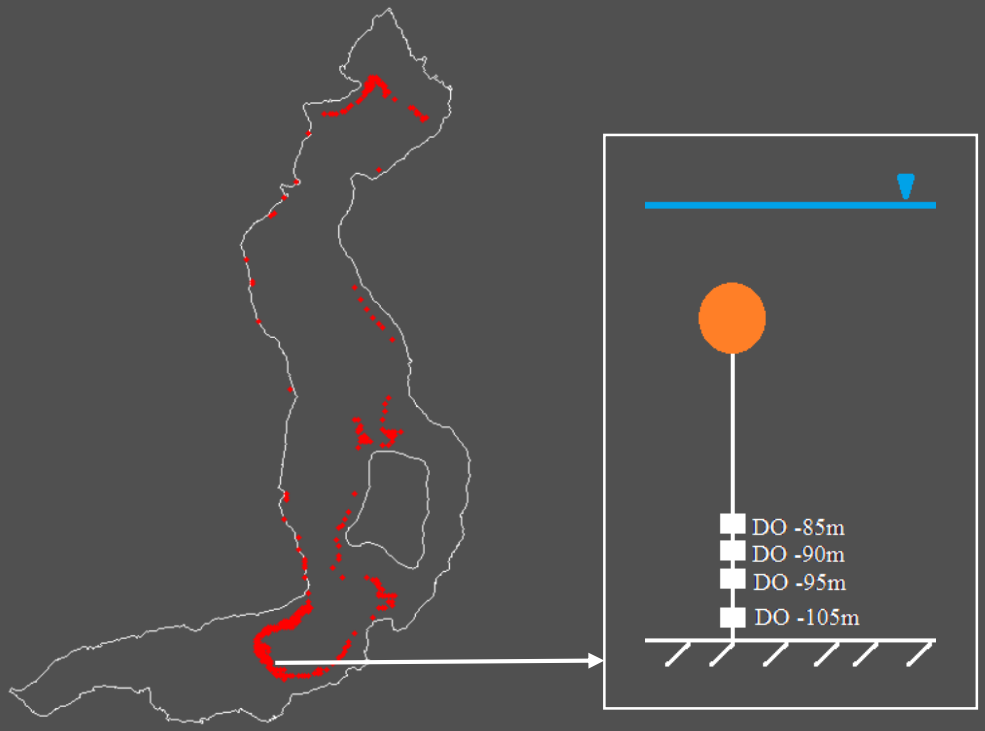
Water velocity -220m







We estimated about 2 km^2 with 1-3 days intermittent redox conditions.



- ✓ Monitoring the oxygen just above the sediments
- ✓ Planning specific lab. experiments to quantify the effects of the alternation of the redox conditions on the P fluxes
- ✓ Quantifing the effect of the V1H1 velocity field in the monimolimnion on the thickness of the diffusive boundary layer

Thanks for your attention




e-mail: giulia.valerio@unibs.it
Website: www.ing.unibs.it/hydraulics