RESPONSE OF SHALLOW LAKES ECOSYSTEMS TO CLIMATE VARIATIONS: HIND- and FORECAST

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- Oxygen depletion in water bodies
- Brief discussion

Visual manifestations of the oxygen depletion


Image credit: PJ Hahn

Massive rock lobster "walk-out" on a beach in South Africa near Elands Bay, caused by water column anoxia.

Oxygen depletion

- Definition: oxygen depletion is a phenomenon that occurs in aquatic environments as dissolved oxygen becomes reduced in concentration to a value detrimental for aquatic organisms, living in the system. Leads to the formation of a so-called „dead zone“.

- Main reasons of appearance :

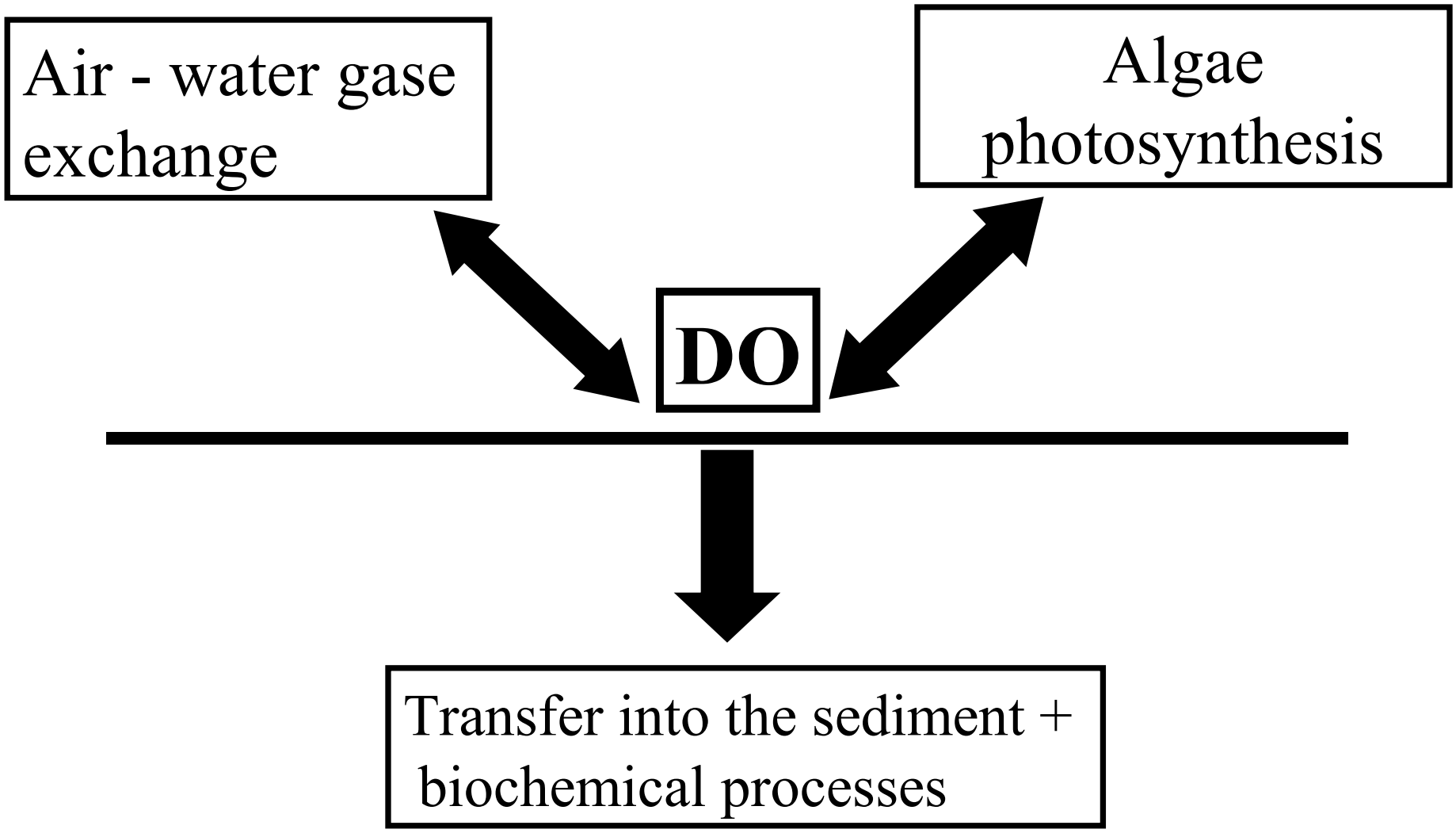
  (i) high level of algae primary production (organic matter) in a water body

  (ii) stable density stratification of the water column preventing aeration of the water column

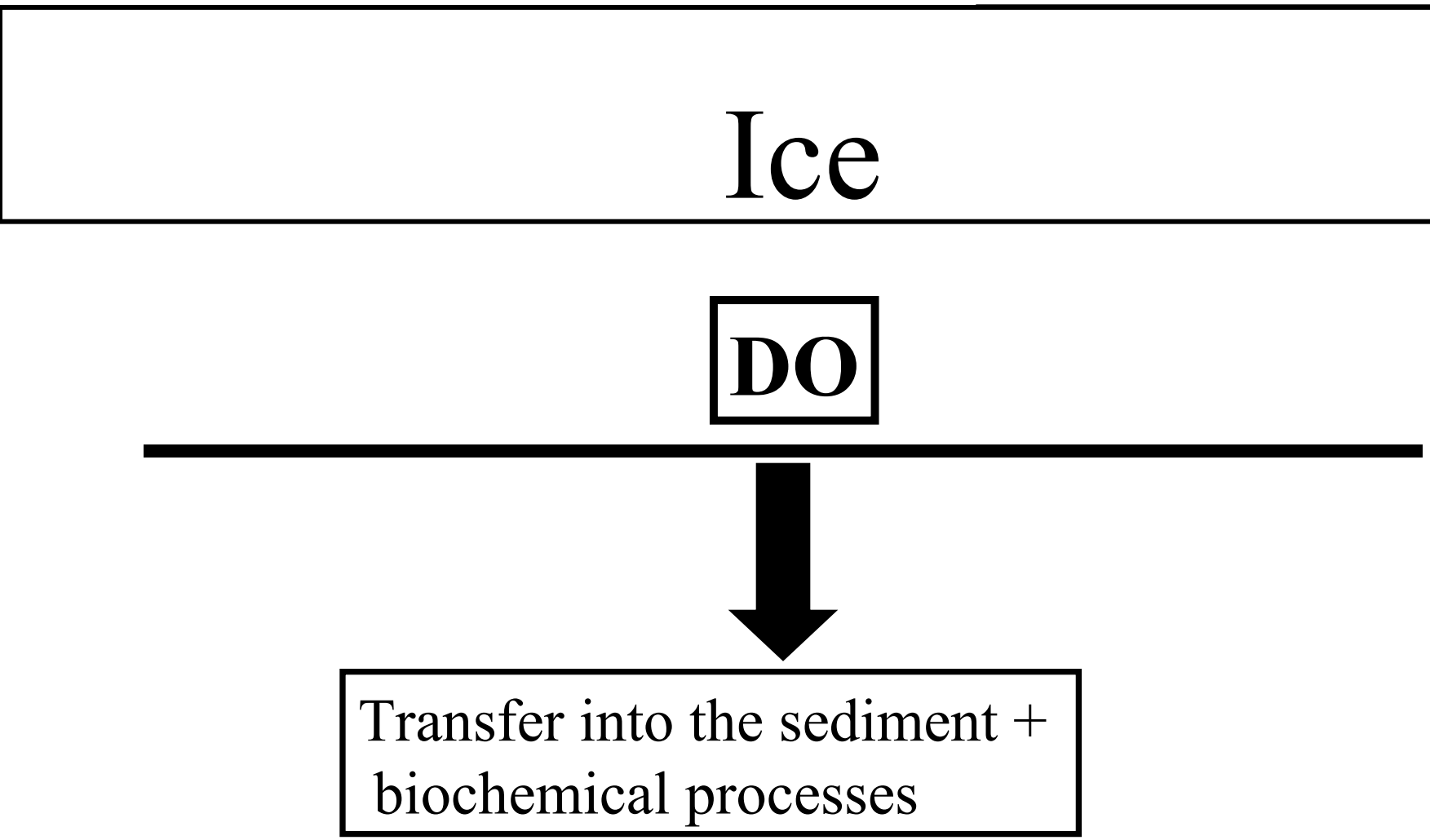
  (iii) prevailing of oxygen consumption over the penetration of dissolved oxygen into the problem zone

The model formulation

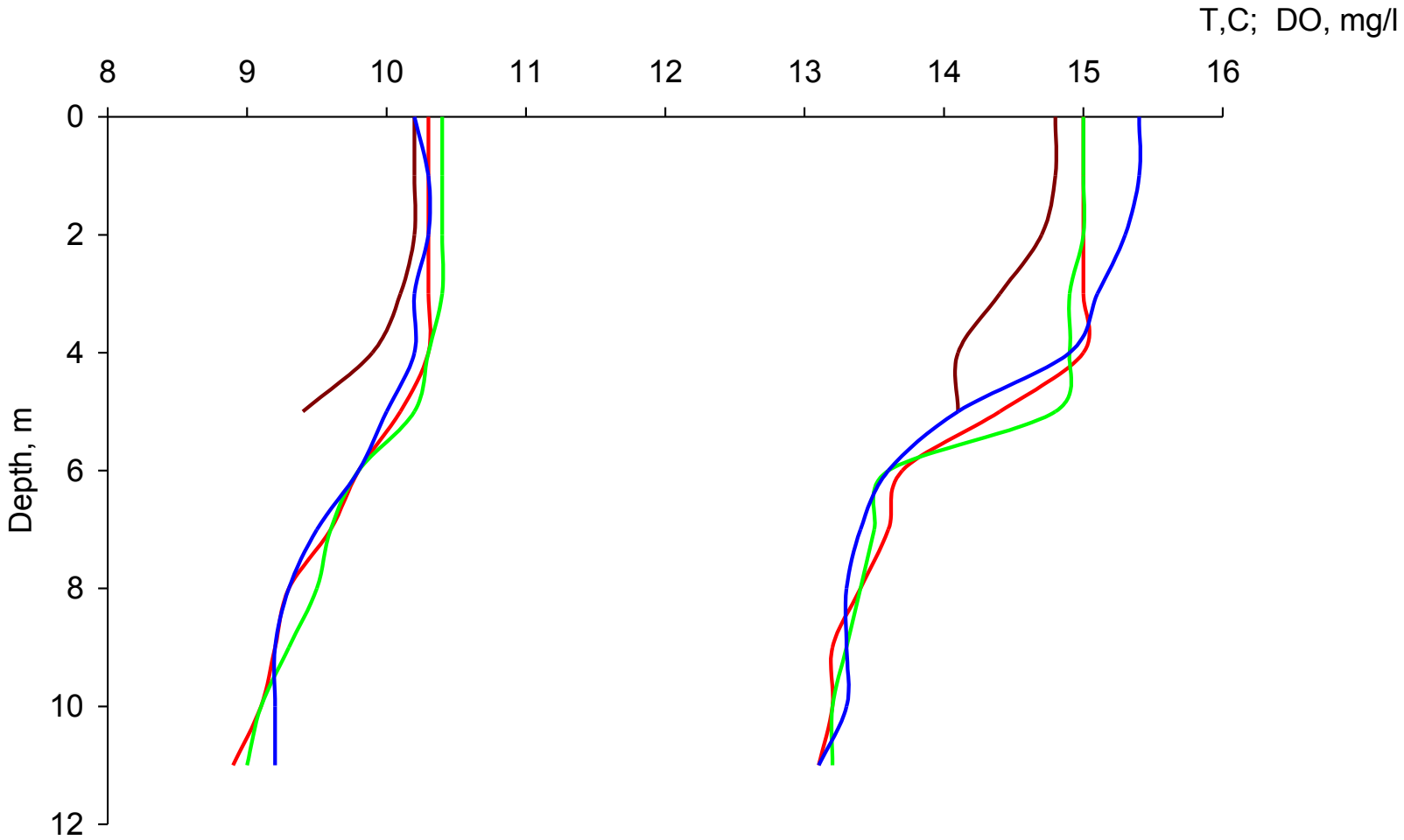
DO budget in a Lake (open water case)



DO budget in a Lake (ice-covered case)



Vertical temperature and DO profiles measured simultaneously (Lake Vendyurskoe, Russia, June 2010)



Model formulation

$$\frac{\partial C(z,t)}{\partial t} = -\frac{\partial Q}{\partial z} - \gamma\left[T(z,t)\right]\cdot C(z,t)$$

$$C(z,t) = \begin{cases} C_S - (C_S - C_D)\cdot f\left(\dfrac{z-h}{D-h}\right) & at\ h \le z \le D\ and\ C_D > 0 \\ C_S - \left[1 - f\left(\dfrac{z-h}{H-h}\right)\right] & at\ h \le z \le H \le D\ and\ C_D = 0 \end{cases}$$

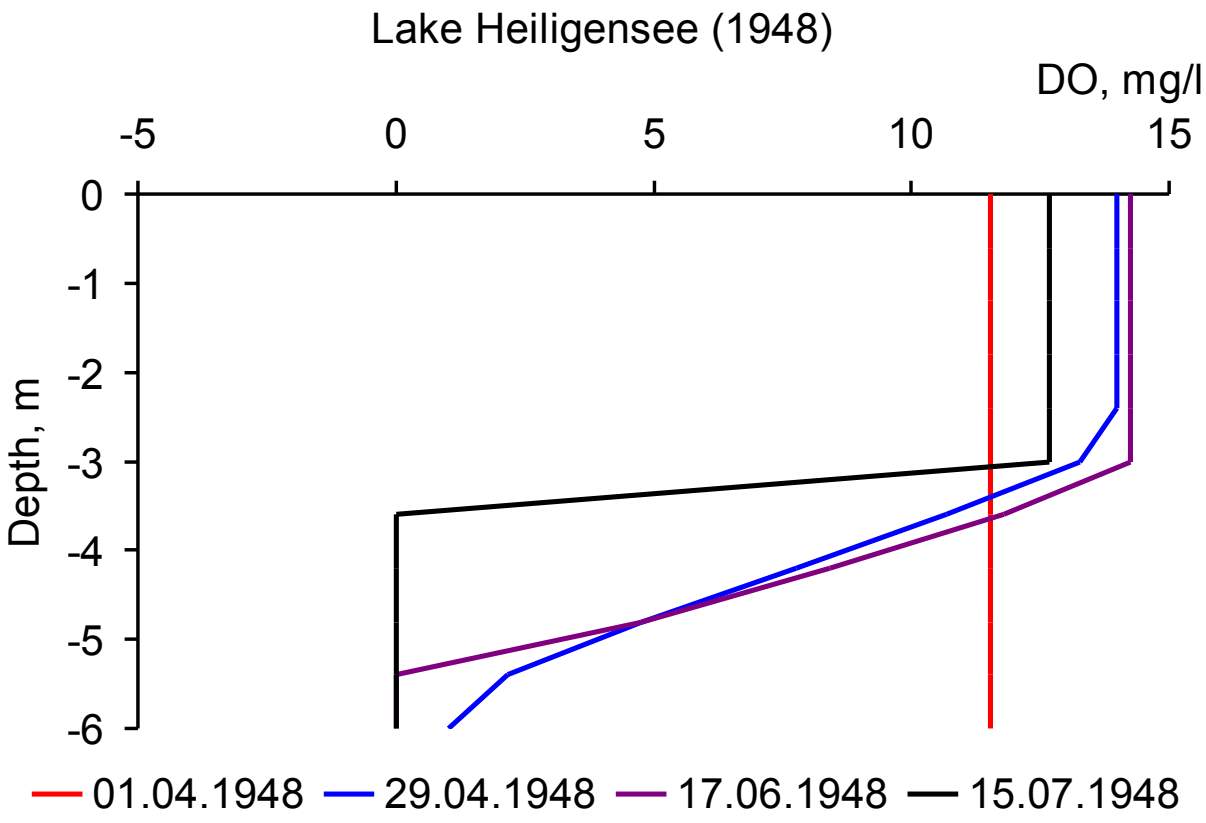
$$\gamma(z,t) = \gamma_{\min} + (\gamma_{\max} - \gamma_{\min})\cdot f\left(\frac{z-h}{D-h}\right) \qquad at\ \ h \le z \le D$$

$\gamma_S = const$ – rate of DO consumption in upper sediments

Representation of the DO profiles in a water column by function f

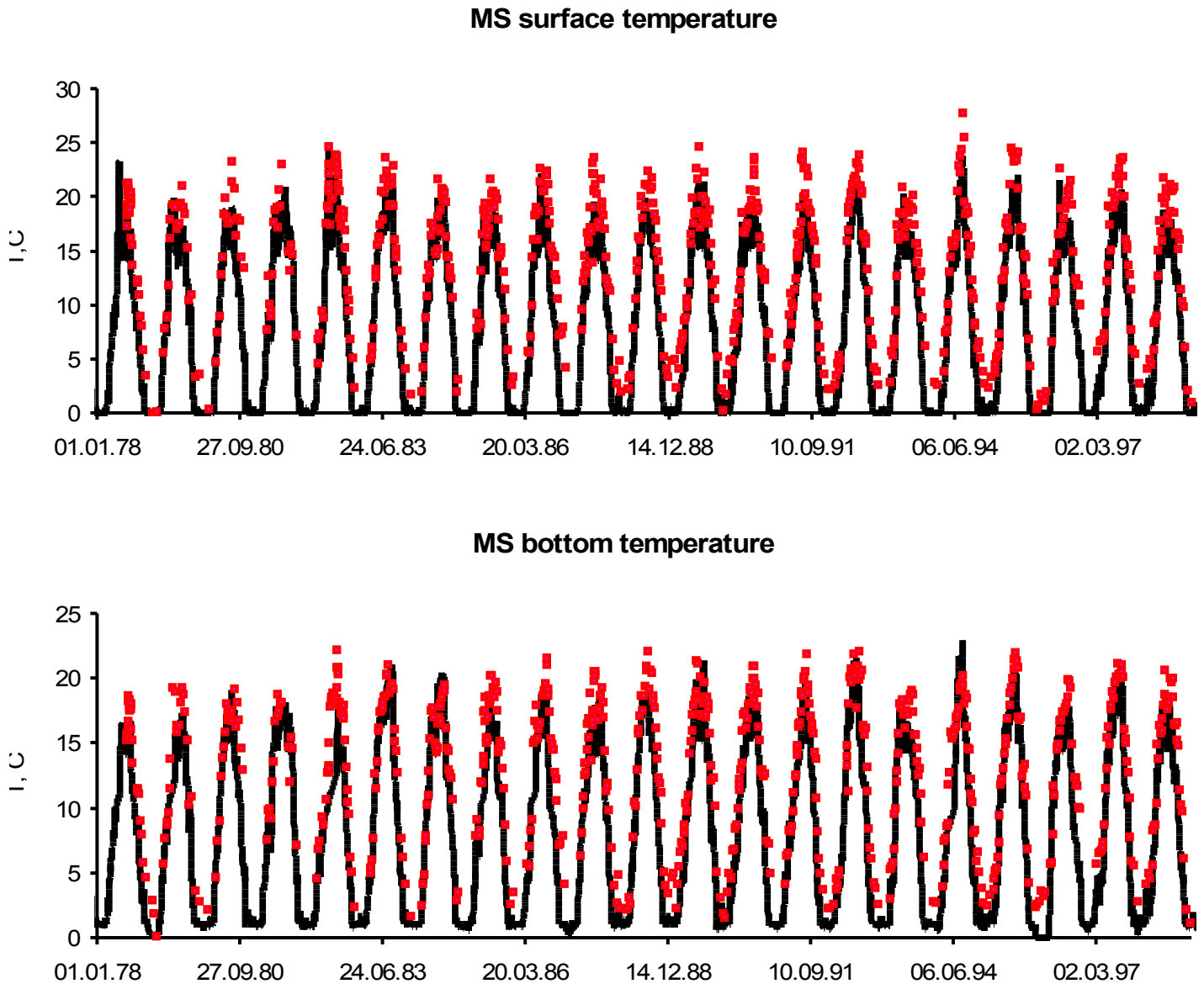
$$f(\xi) = \xi + (1 - A)\cdot\xi^{3} + (A - 1)\cdot\xi^{4}$$

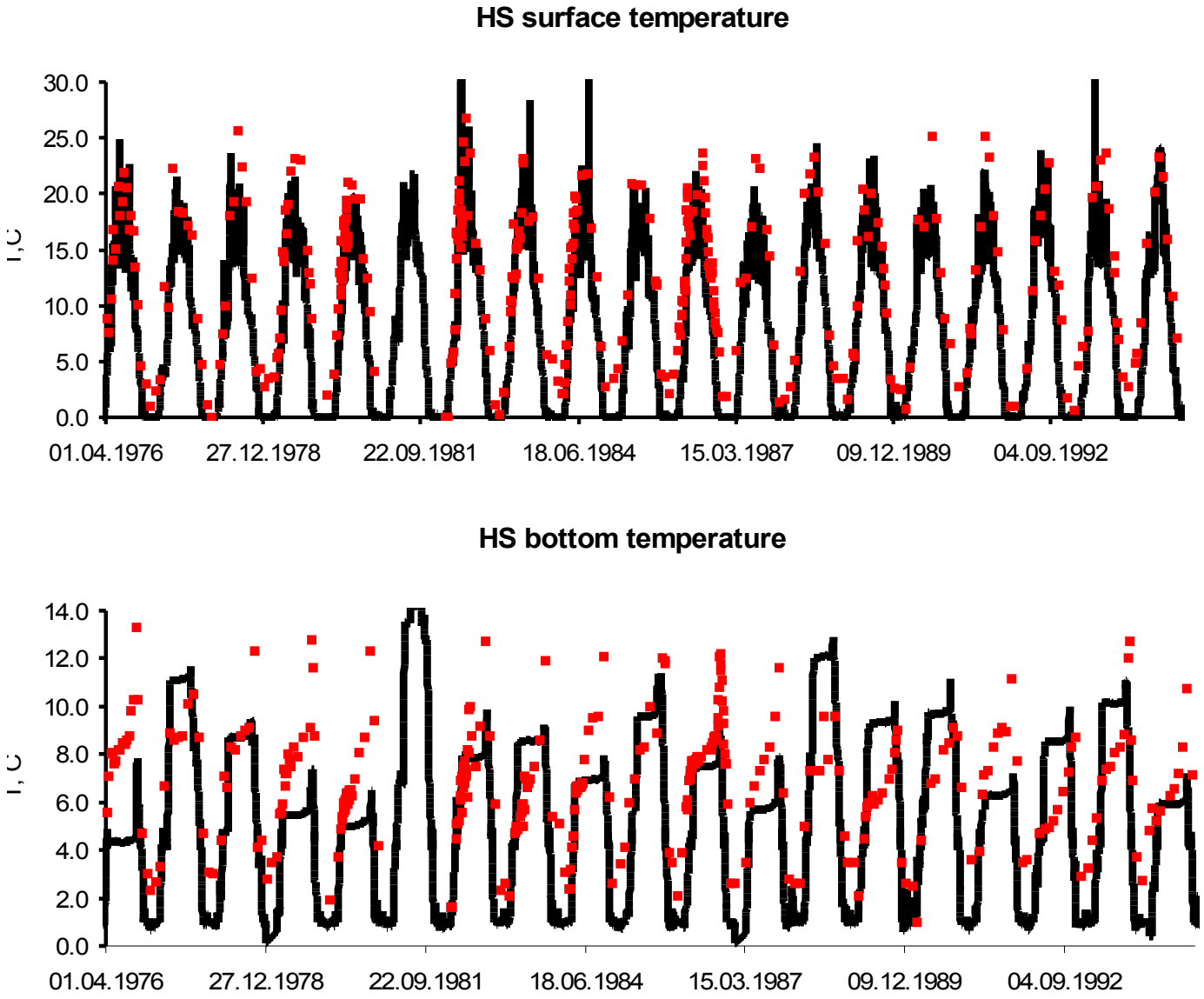
$$A = \frac{Q_D \cdot (D - h)}{\chi_{eff} \cdot (C_S - C_D)}$$

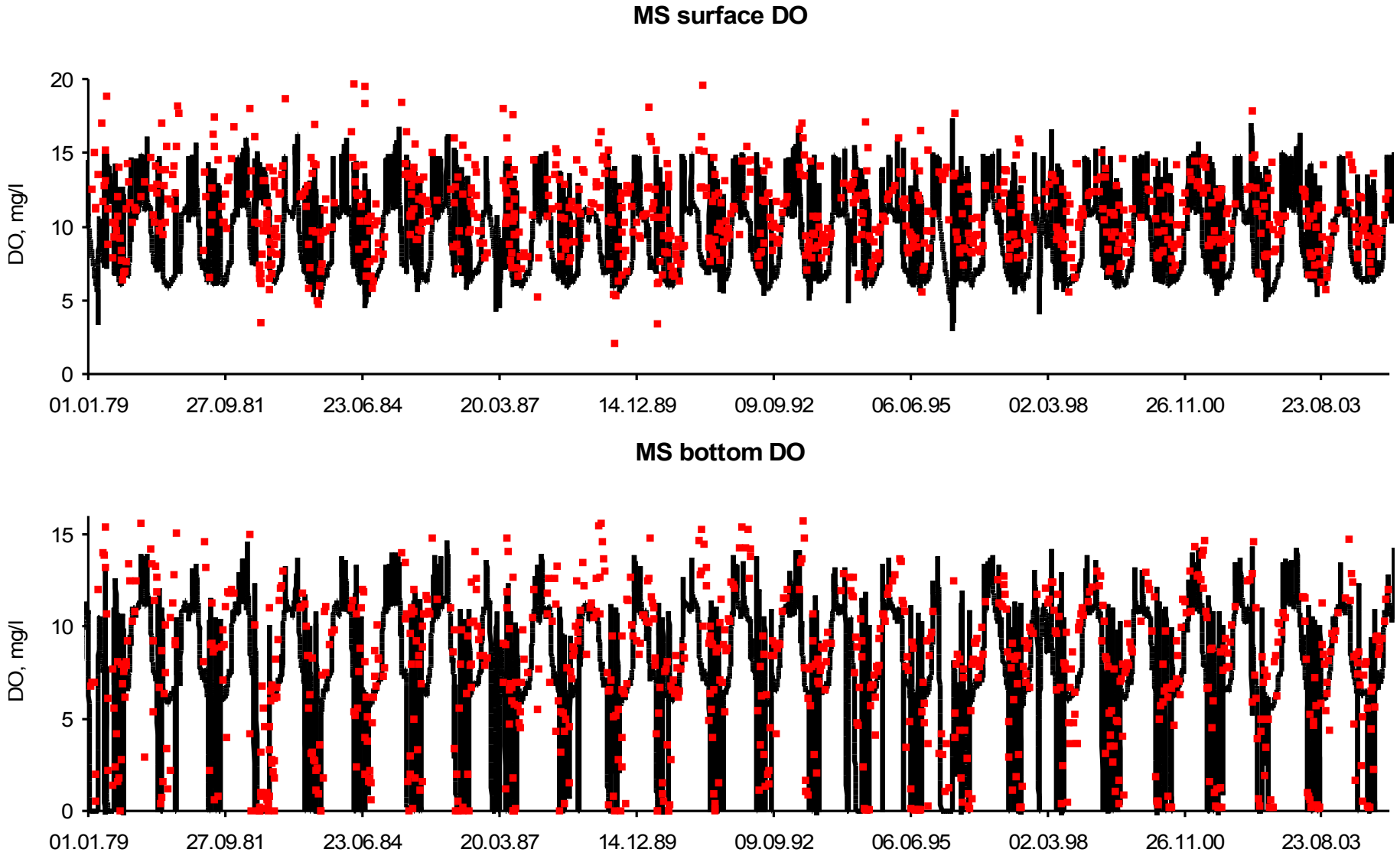


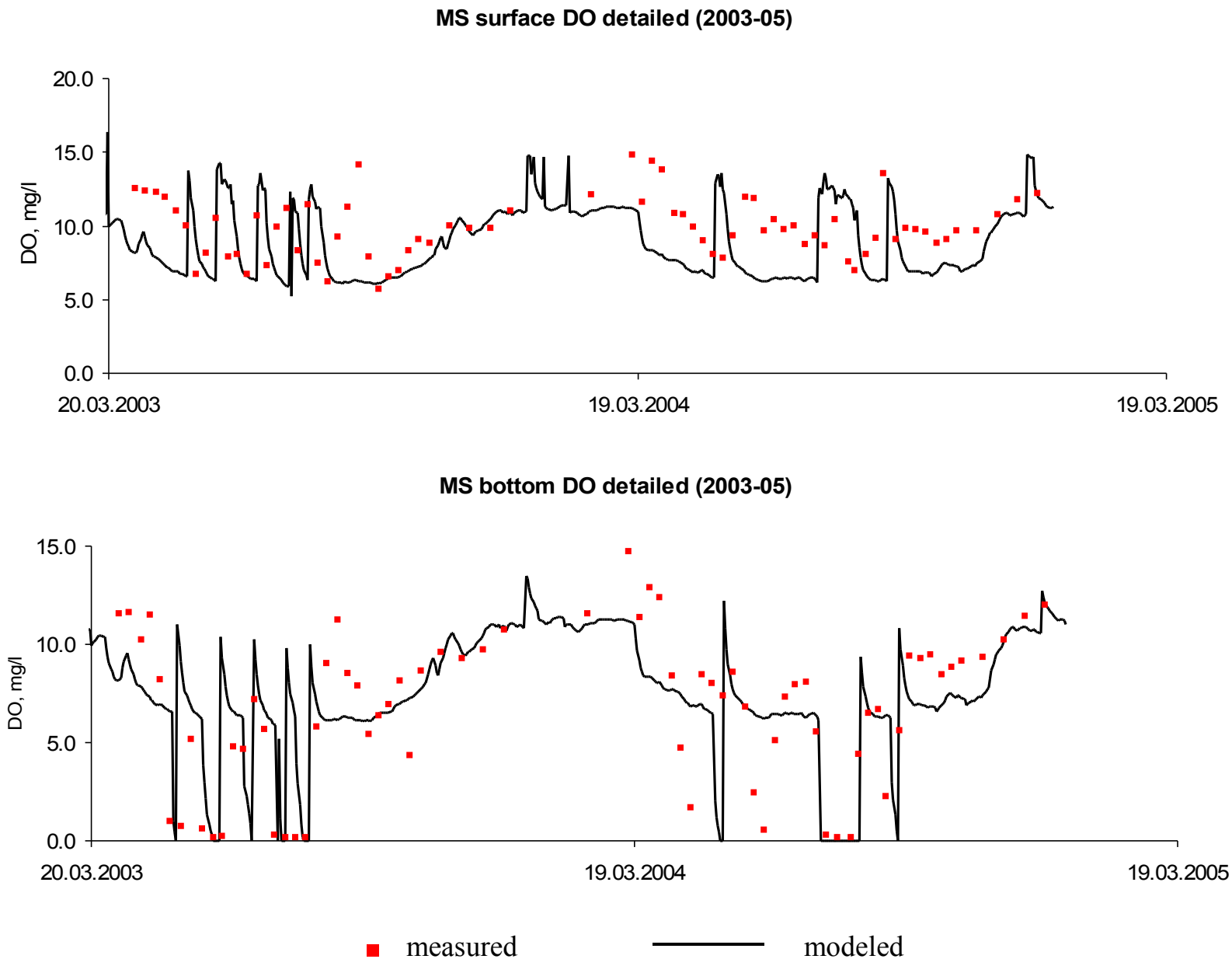
Model verification

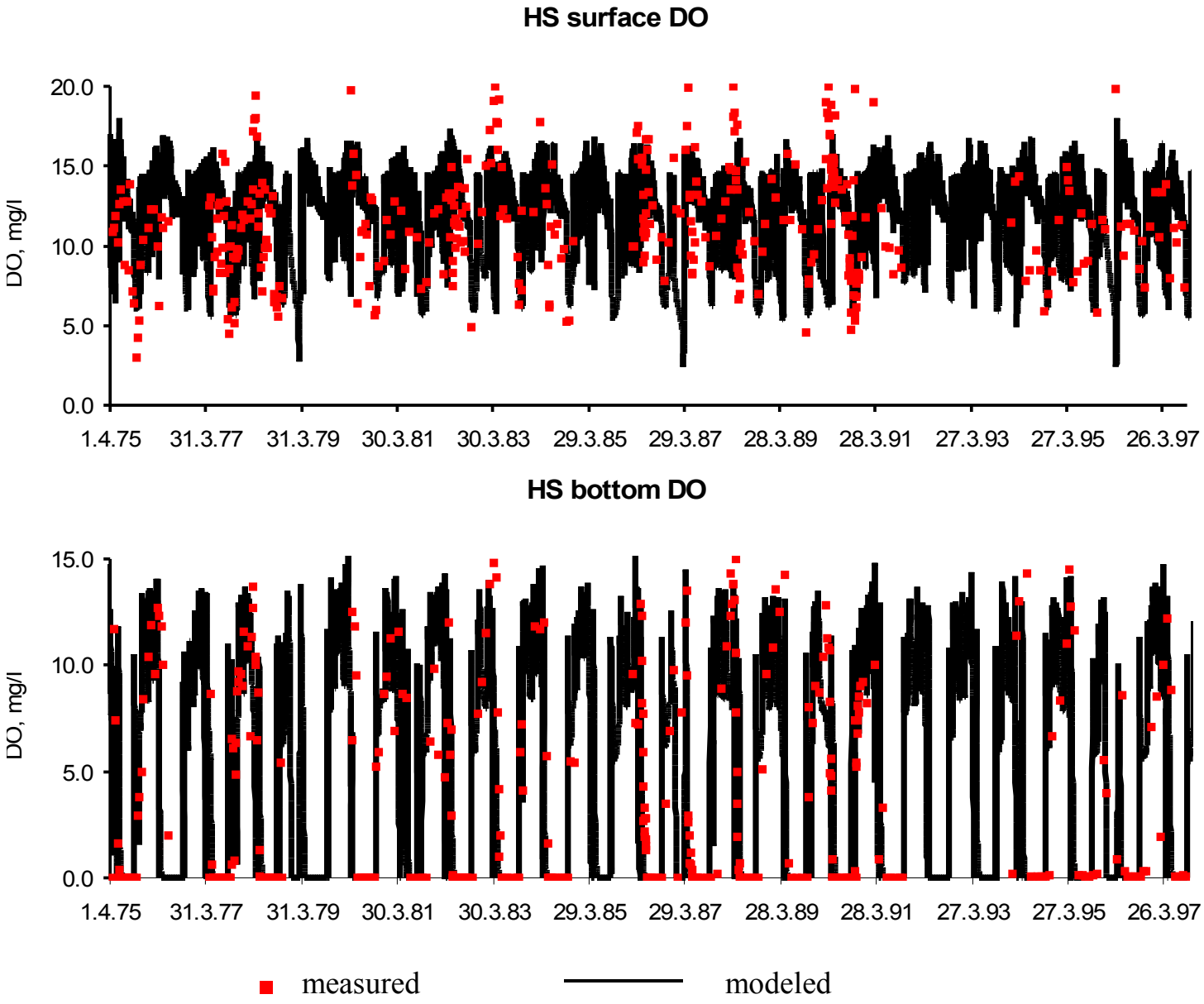
(MS – Mueggelsee; HS – Hielegensee; meteorological forcing from NCEP reanalysis)

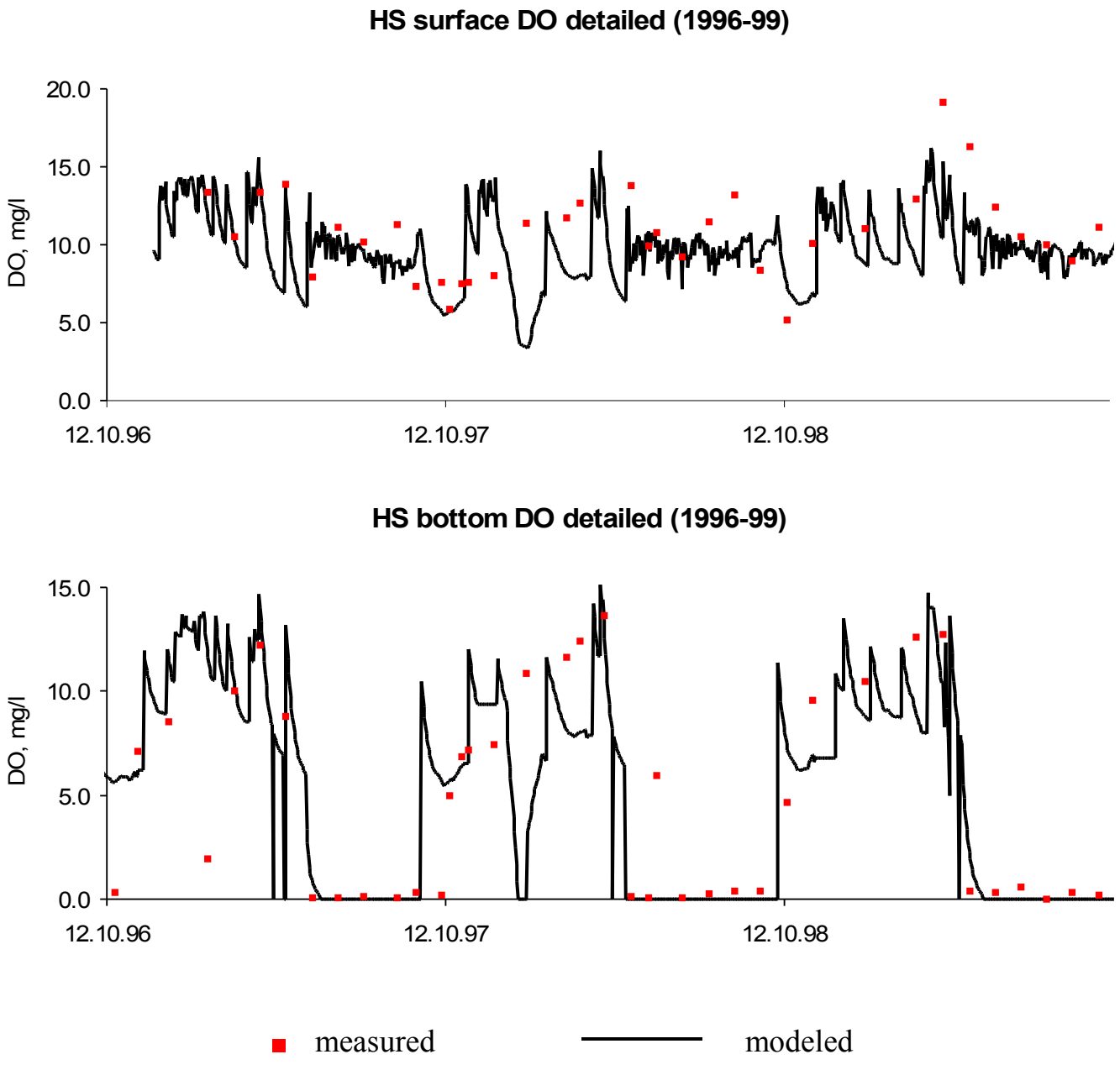

MS surface temperature
t, C
30
25
20
15
10
5
0
01.01.78
27.09.80
24.06.83
20.03.86
14.12.88
10.09.91
06.06.94
02.03.97
MS bottom temperature
t, C
25
20
15
10
5
0
01.01.78
27.09.80
24.06.83
20.03.86
14.12.88
10.09.91
06.06.94
02.03.97
measured
modeled

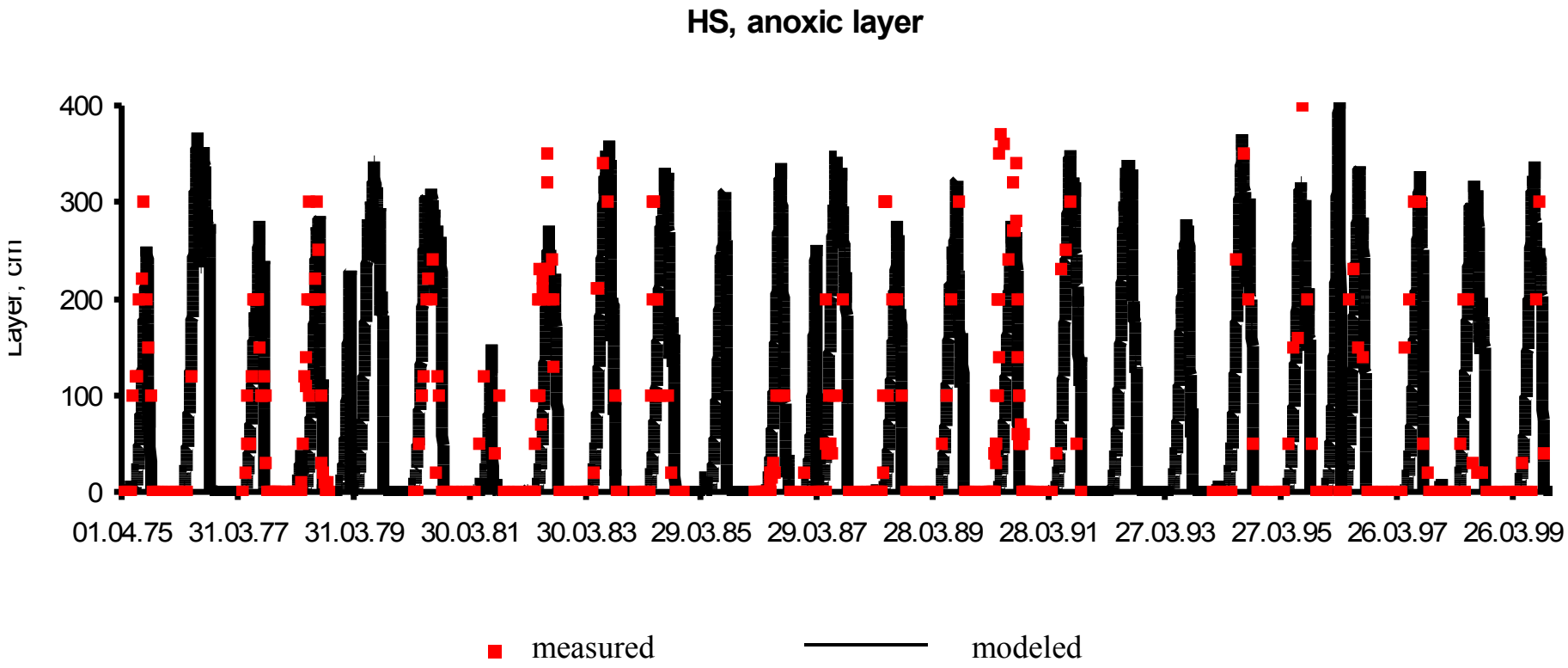

HS surface temperature
30.0
25.0
20.0
15.0
10.0
5.0
0.0
t, C
01.04.1976
27.12.1978
22.09.1981
18.06.1984
15.03.1987
09.12.1989
04.09.1992
HS bottom temperature
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
t, C
01.04.1976
27.12.1978
22.09.1981
18.06.1984
15.03.1987
09.12.1989
04.09.1992
measured
modeled


MS surface DO
DO, mg/l
20
15
10
5
0
01.01.79
27.09.81
23.06.84
20.03.87
14.12.89
09.09.92
06.06.95
02.03.98
26.11.00
23.08.03
MS bottom DO
DO, mg/l
15
10
5
0
01.01.79
27.09.81
23.06.84
20.03.87
14.12.89
09.09.92
06.06.95
02.03.98
26.11.00
23.08.03
measured
modeled


MS surface DO detailed (2003-05)
20.0
15.0
10.0
5.0
0.0
DO, mg/l
20.03.2003
19.03.2004
19.03.2005
MS bottom DO detailed (2003-05)
15.0
10.0
5.0
0.0
DO, mg/l
20.03.2003
19.03.2004
19.03.2005
measured
modeled

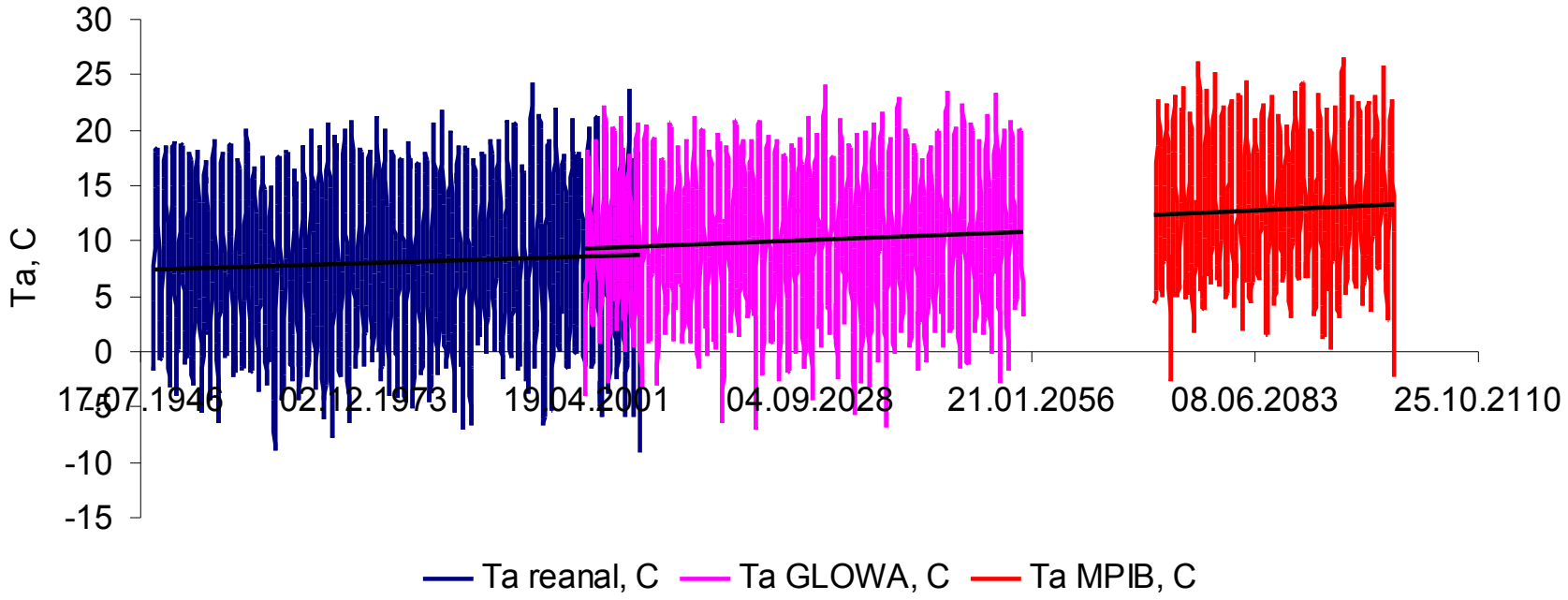

HS surface DO
DO, mg/l
20.0
15.0
10.0
5.0
0.0
1.4.75
31.3.77
31.3.79
30.3.81
30.3.83
29.3.85
29.3.87
28.3.89
28.3.91
27.3.93
27.3.95
26.3.97
HS bottom DO
DO, mg/l
15.0
10.0
5.0
0.0
1.4.75
31.3.77
31.3.79
30.3.81
30.3.83
29.3.85
29.3.87
28.3.89
28.3.91
27.3.93
27.3.95
26.3.97
measured
modeled


HS surface DO detailed (1996-99)
DO, mg/l
20.0
15.0
10.0
5.0
0.0
12.10.96
12.10.97
12.10.98
HS bottom DO detailed (1996-99)
DO, mg/l
15.0
10.0
5.0
0.0
12.10.96
12.10.97
12.10.98
measured
modeled

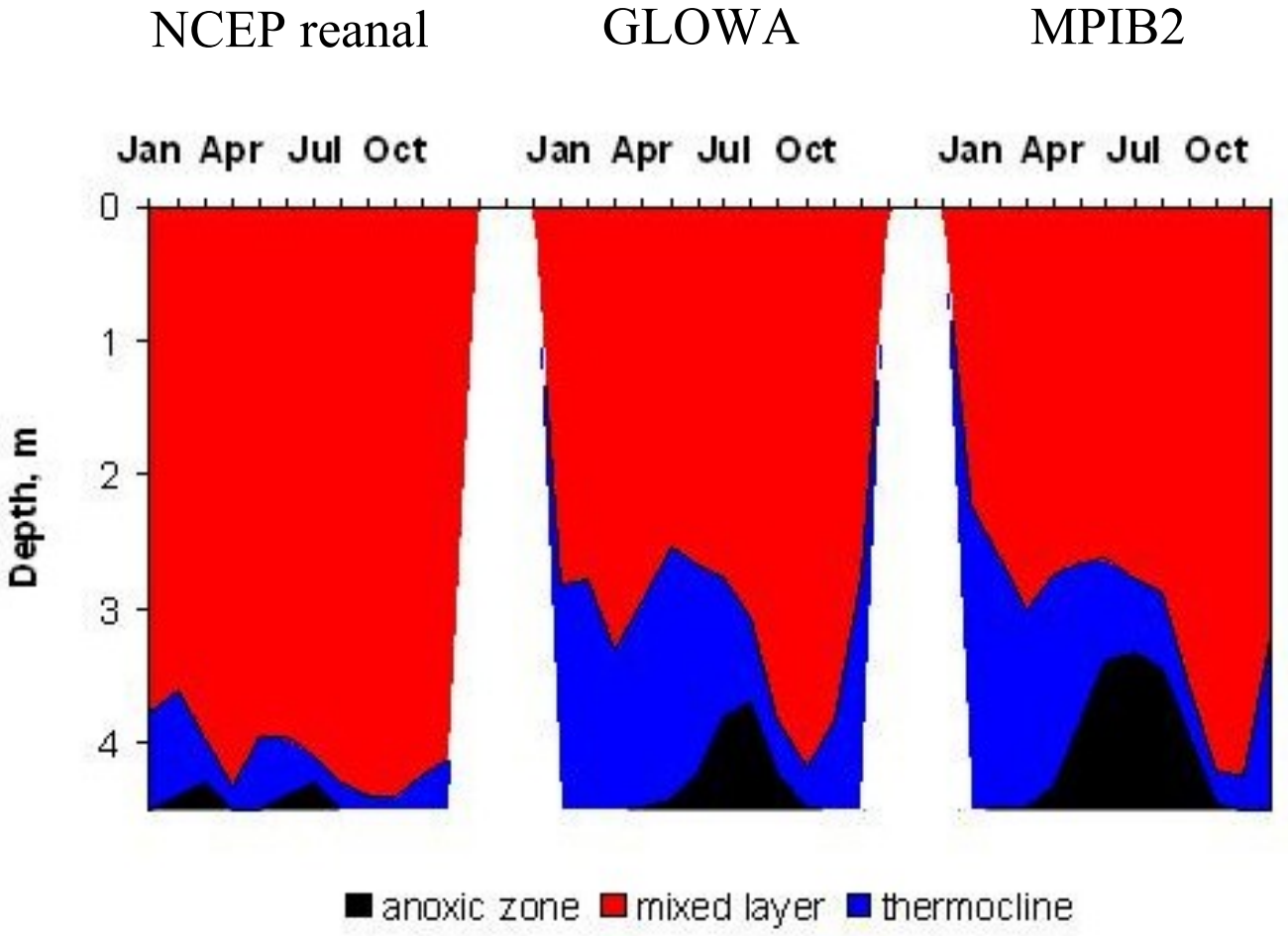

HS, anoxic layer
Layer, cm
400
300
200
100
0
01.04.75
31.03.77
31.03.79
30.03.81
30.03.83
29.03.85
29.03.87
28.03.89
28.03.91
27.03.93
27.03.95
26.03.97
26.03.99
measured
modeled

And, finally, forecasting…

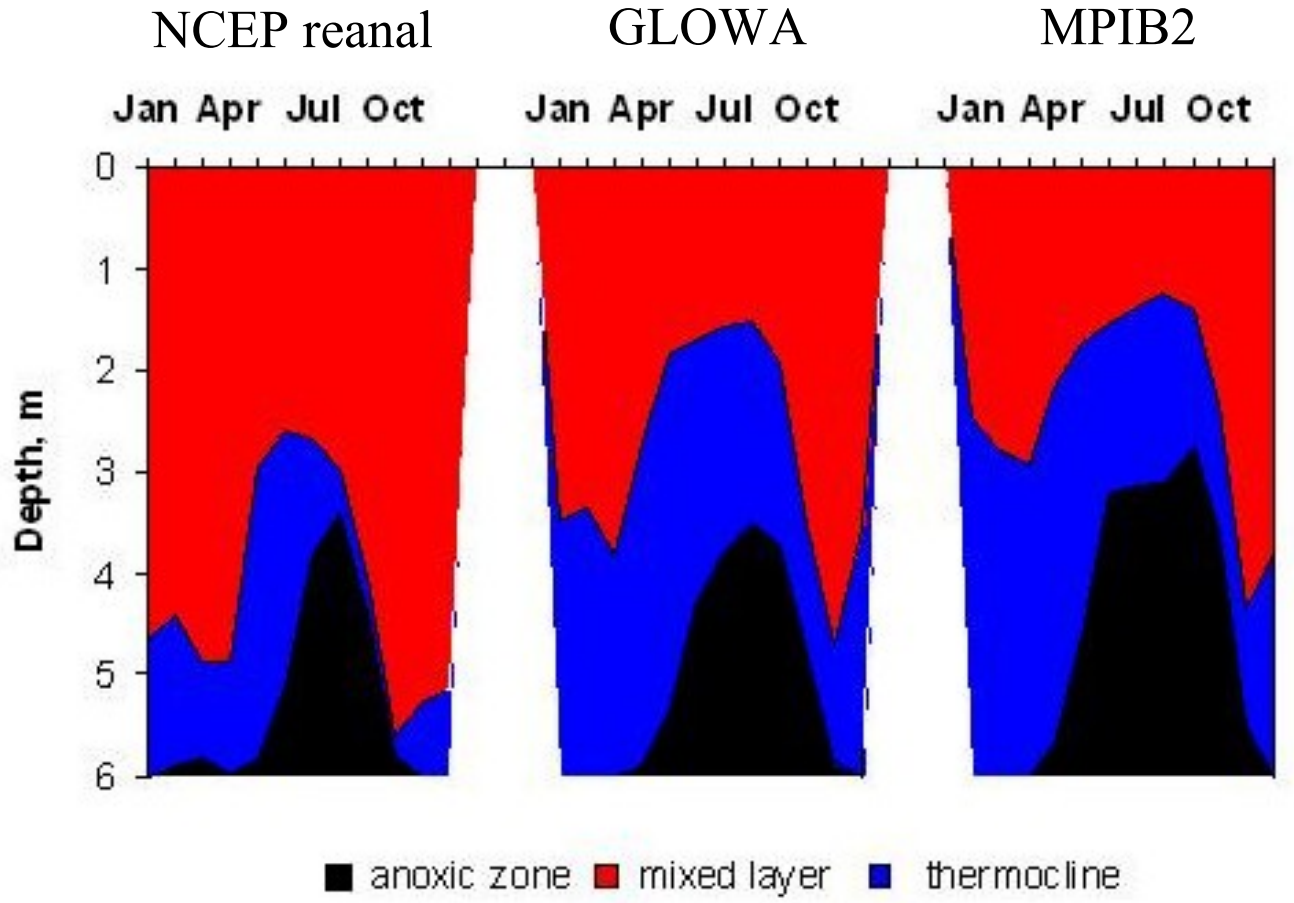
The course of air temperature according to different scenarios



The anoxic layer development in the near-bottom layer according to the different scenarios (MS)



The anoxic layer development in the near-bottom layer according to the different scenarios (HS)



Expected forecast:

- Under such conditions, the oxygen depletion is a trigger that provokes =>
- A large amount of reduced substances (H_2S, CH_4, etc.) delivered to the water column from sediments
- As the worst result, the catastrophic decrease of biodiversity in water bodies is expected.
- Then, eventually, we may face gradual degradation of the Earth ecosystem damaging the whole human civilization ☹

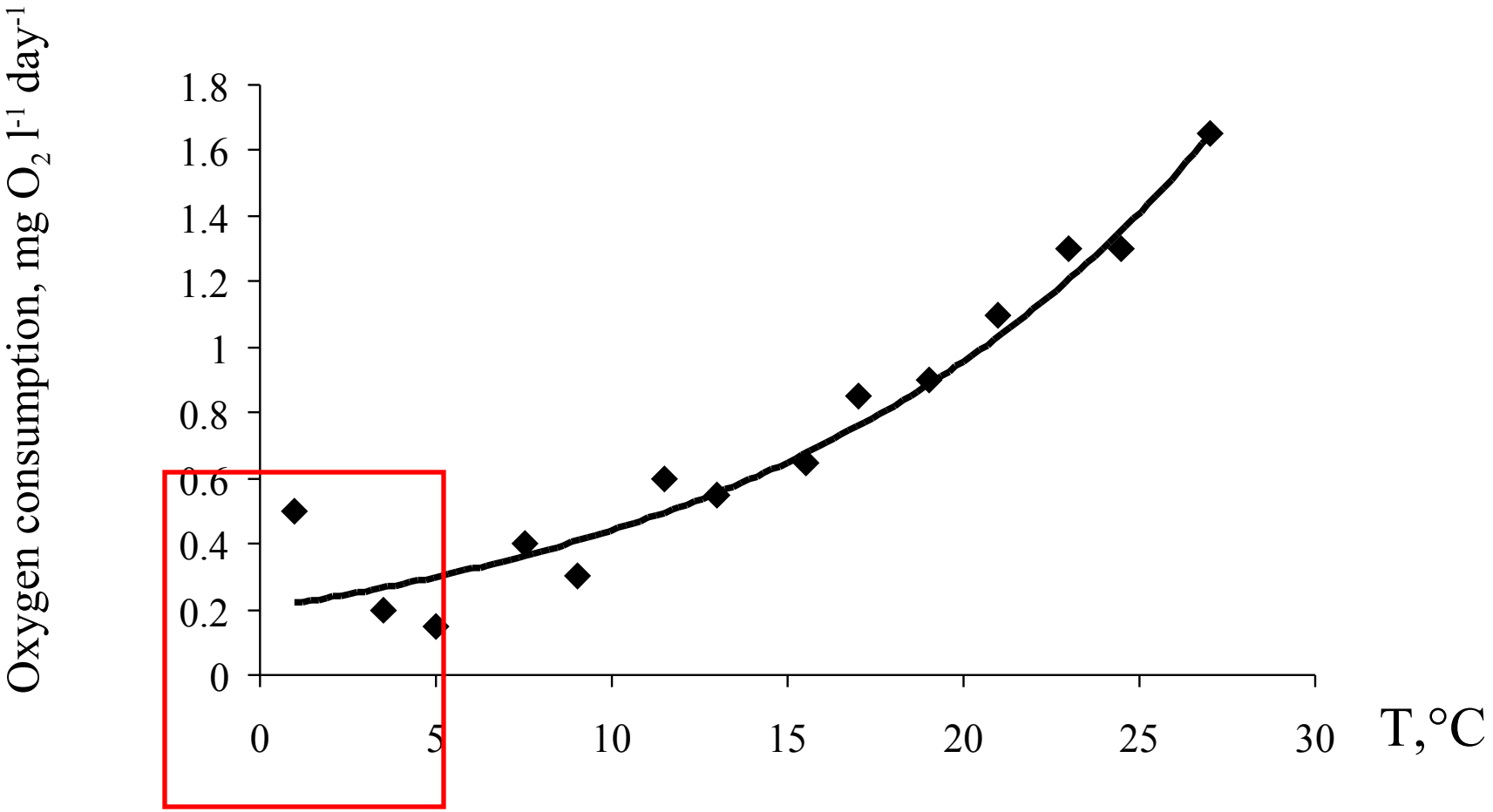
“Apotheosis (Triumph) of the War” by Vasiliy Vereschagin
(famous Russian painter)

The feedback of such forecast might be unpredictable.

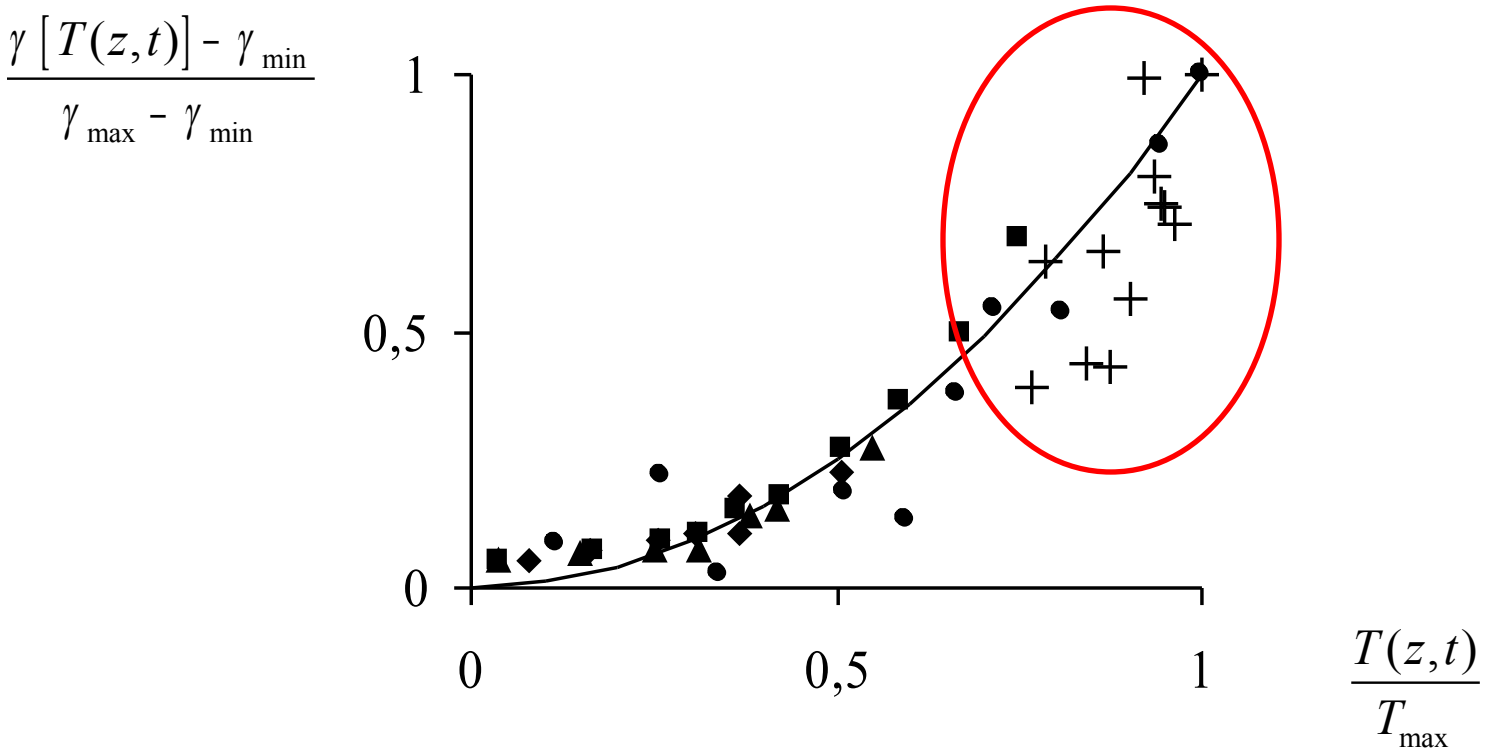
Thus, we are responsible for scenarios formulated.

Thanks for your attention!

Oxygen consumption (0 – 30 °C range)

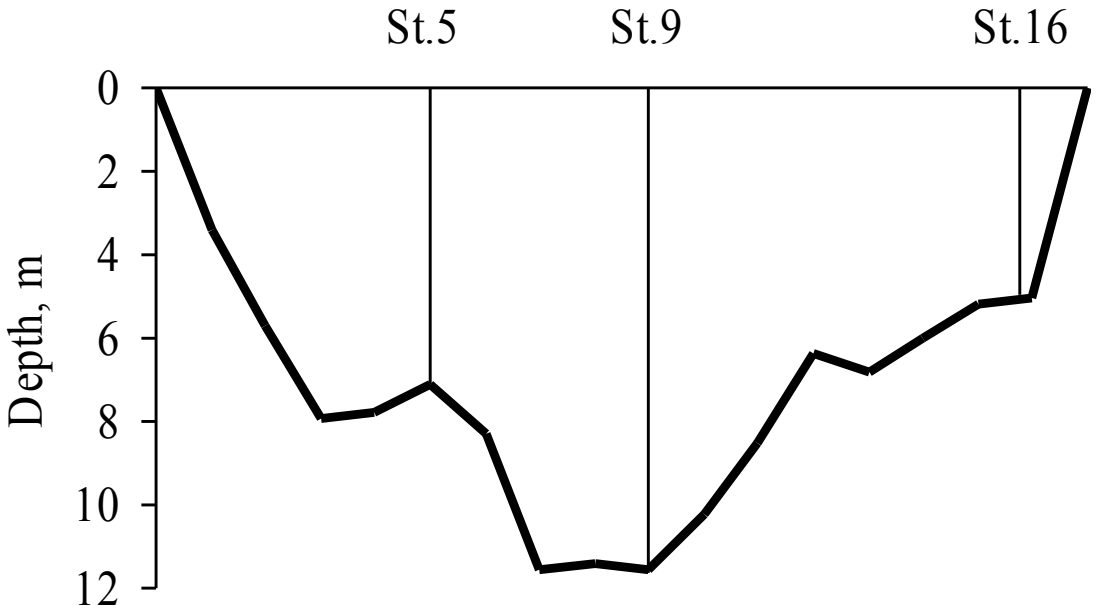


DO consumption within the 0-4°C range



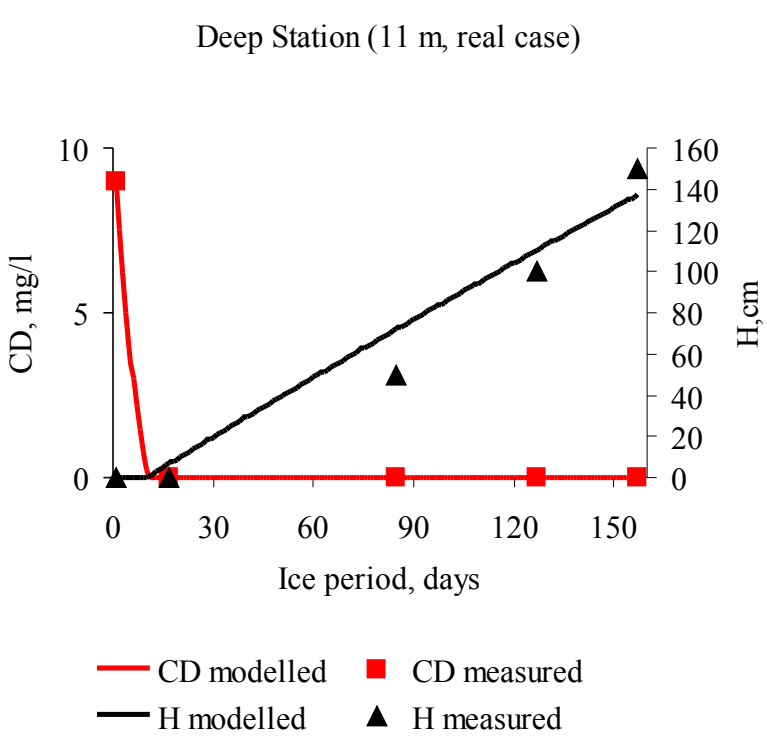
Lakes: ●- Chainoe, ■ - Krasnoe, ▲ - Vendyurskoe (Russia), + - Alequosh (Northern America)

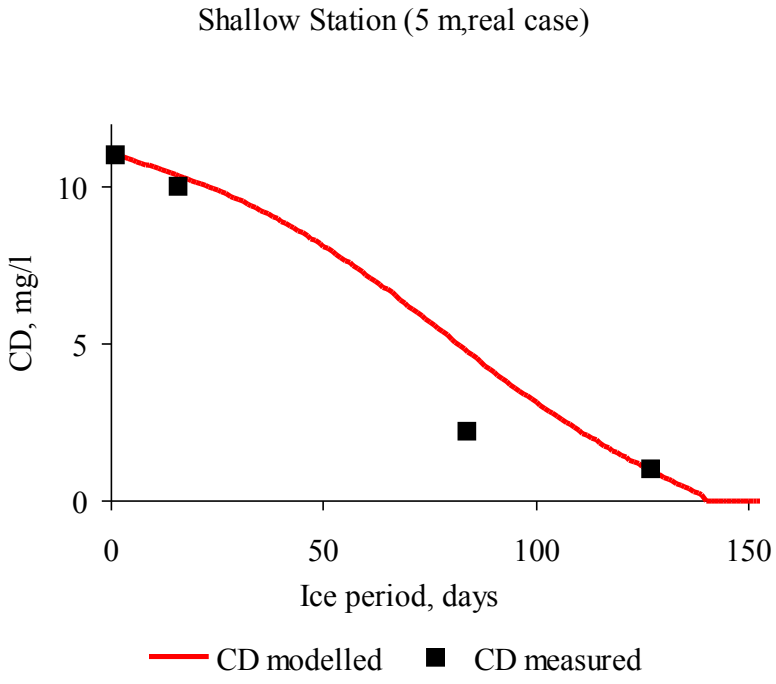
Verification of the model



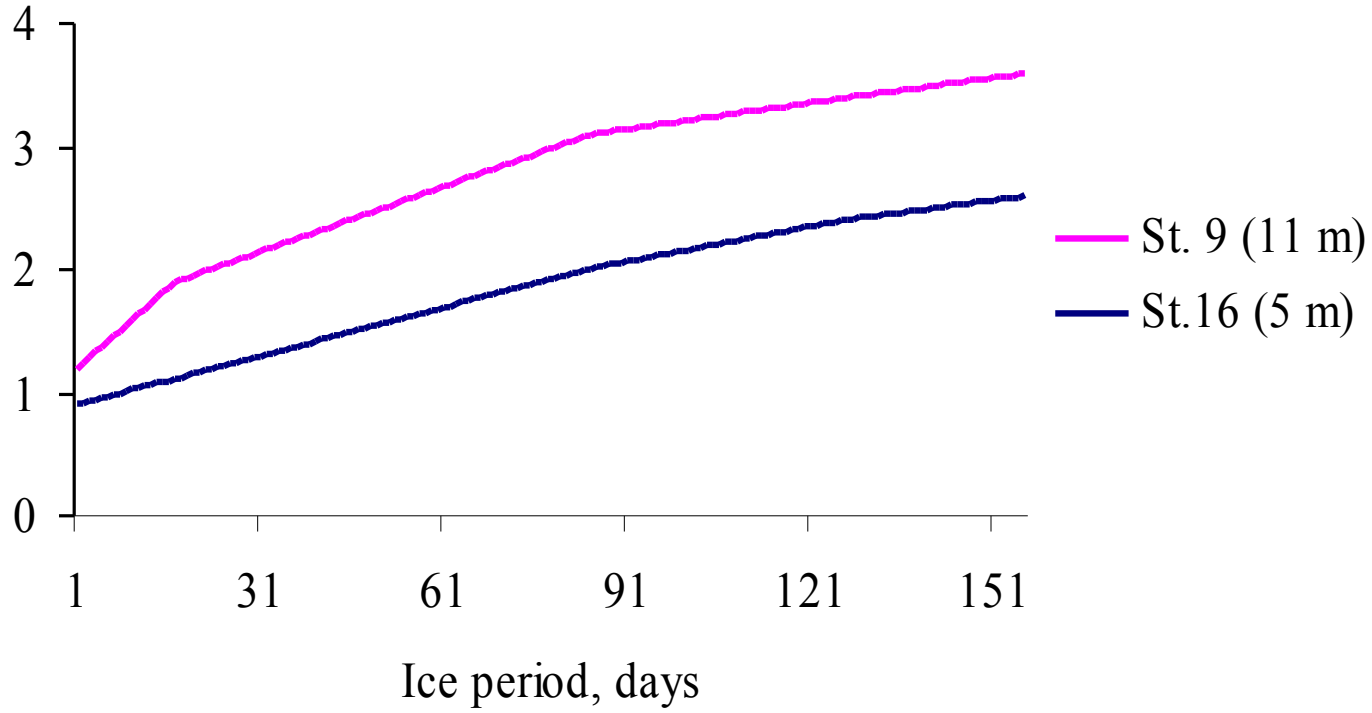
Schematic representation of the cross-section along the Lake Vendyurskoe and location of the stations chosen.

Near-bottom **DO** concentration at both stations



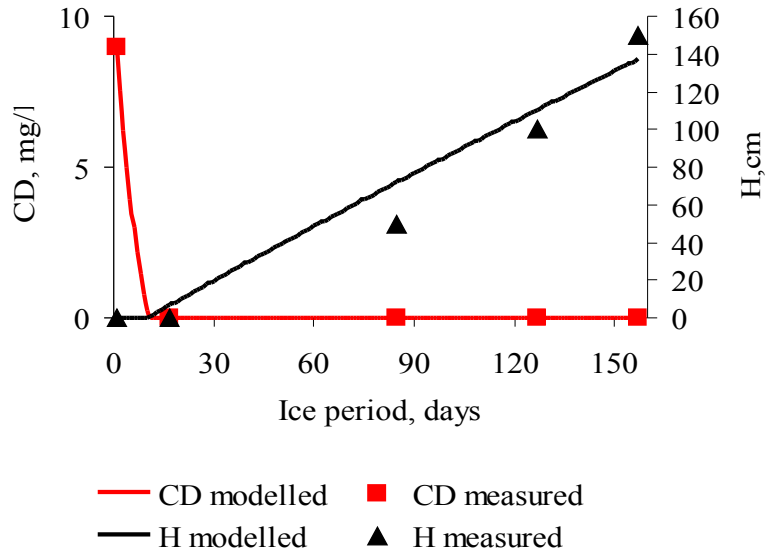


Difference in temperature courses between the chosen stations

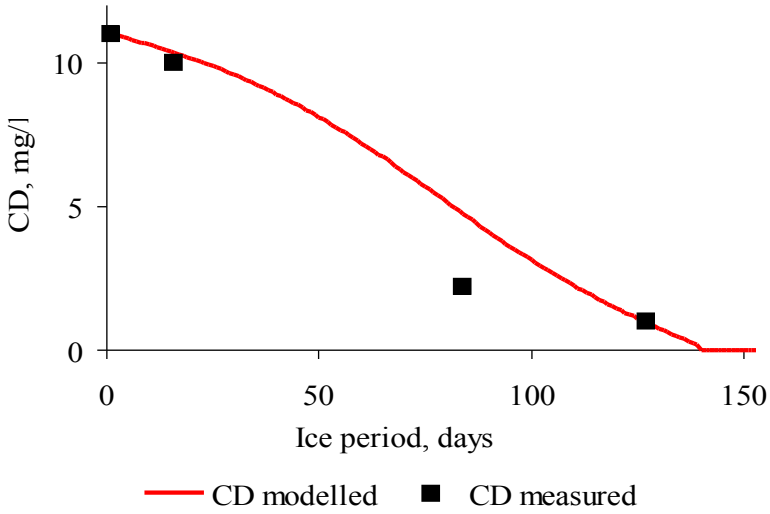


Effect of "warm/cold" winter on DO depletion

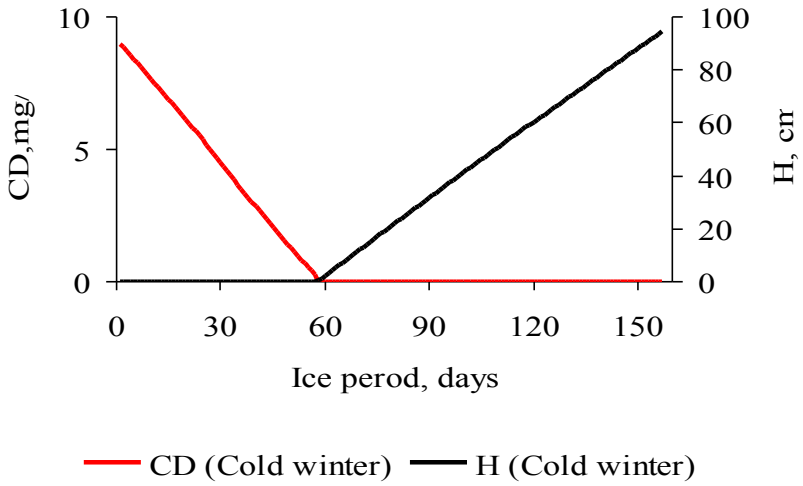
Deep Station (11 m, real case)



Shallow Station (5 m,real case)



Deep Station 9 (cold winter)



Shallow Station 16 (warm winter)