Littoral-pelagial water exchange due to convective mechanisms

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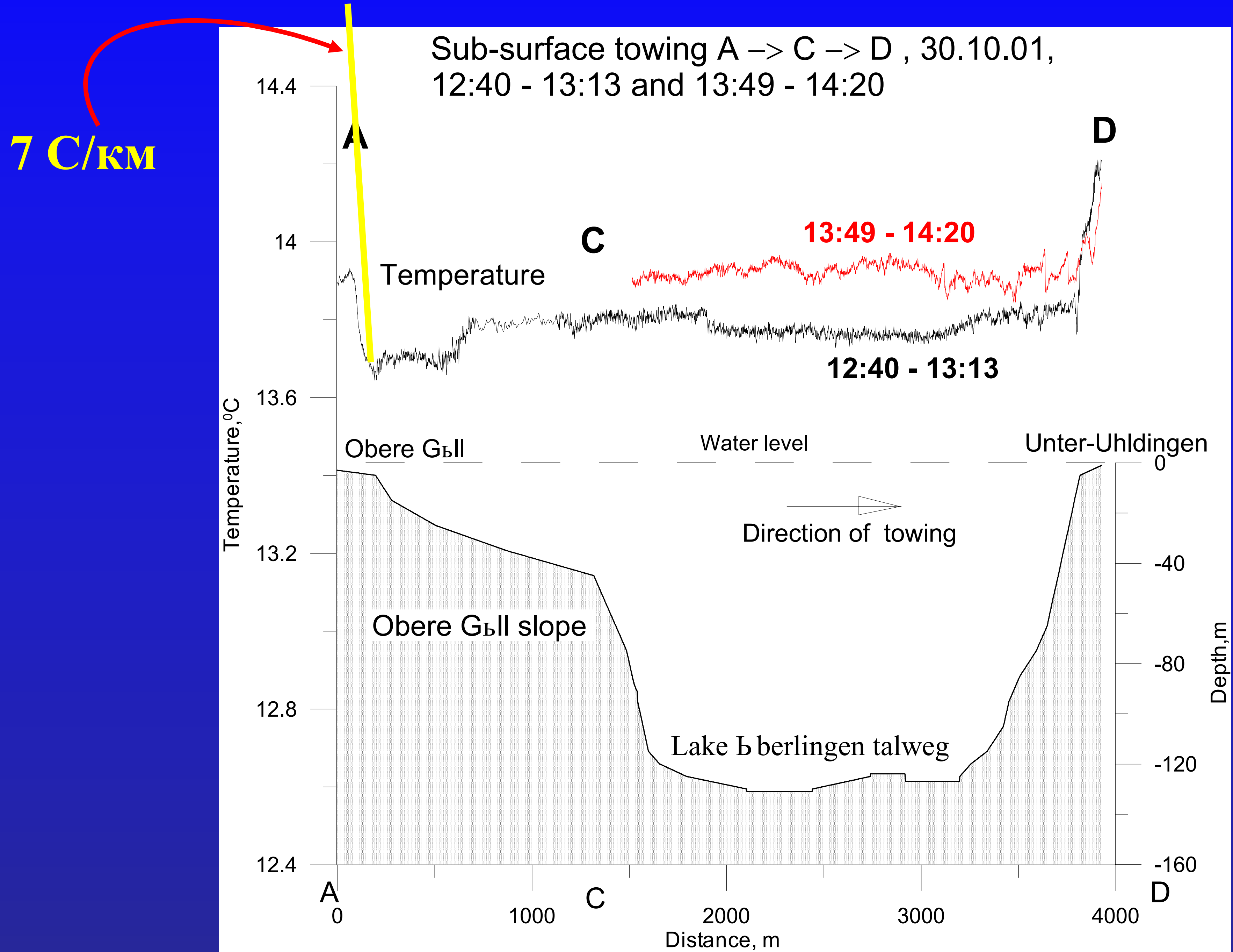
Kaliningrad

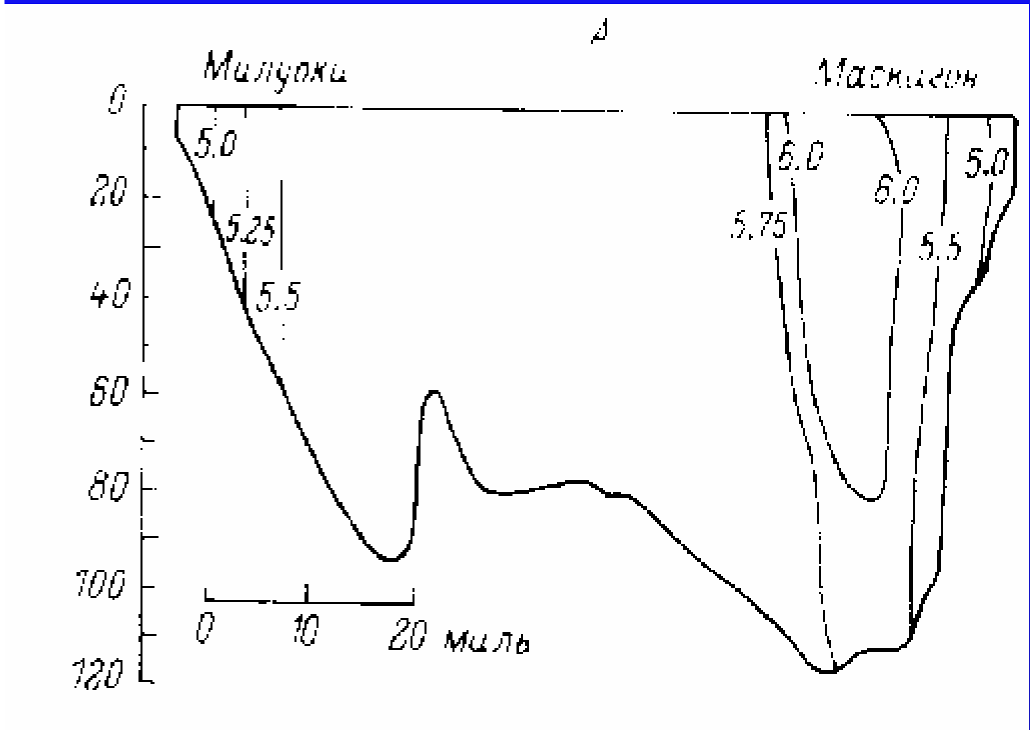
Differential coastal cooling: Examples

Day/night variations



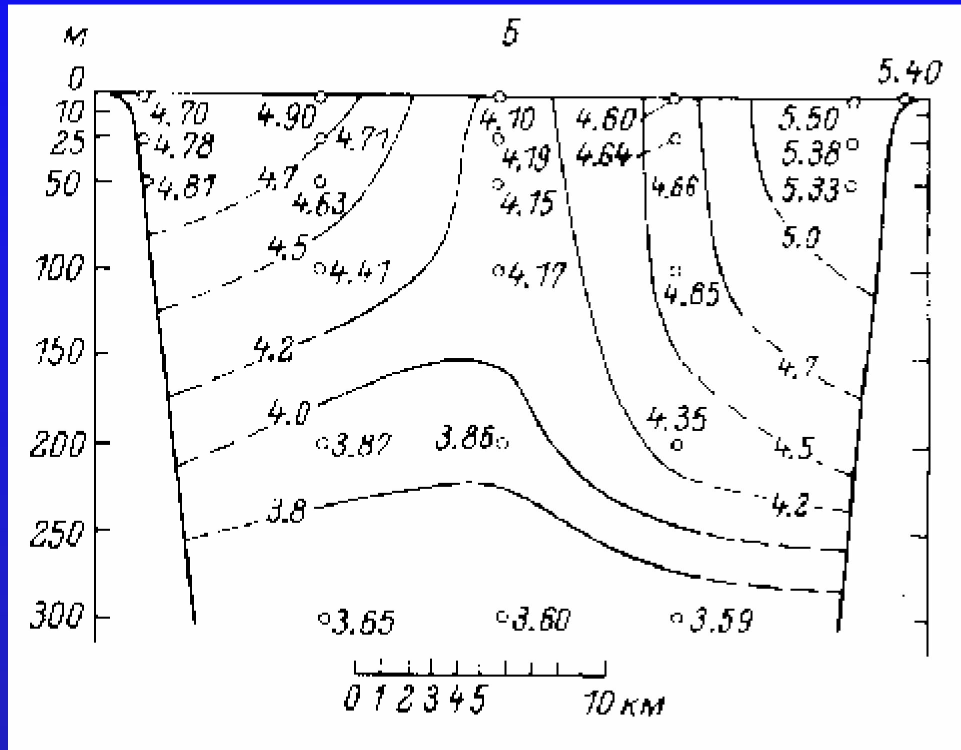
Seasonal scale:

Autumnal cooling



Lake Michigan, 19 December 1941

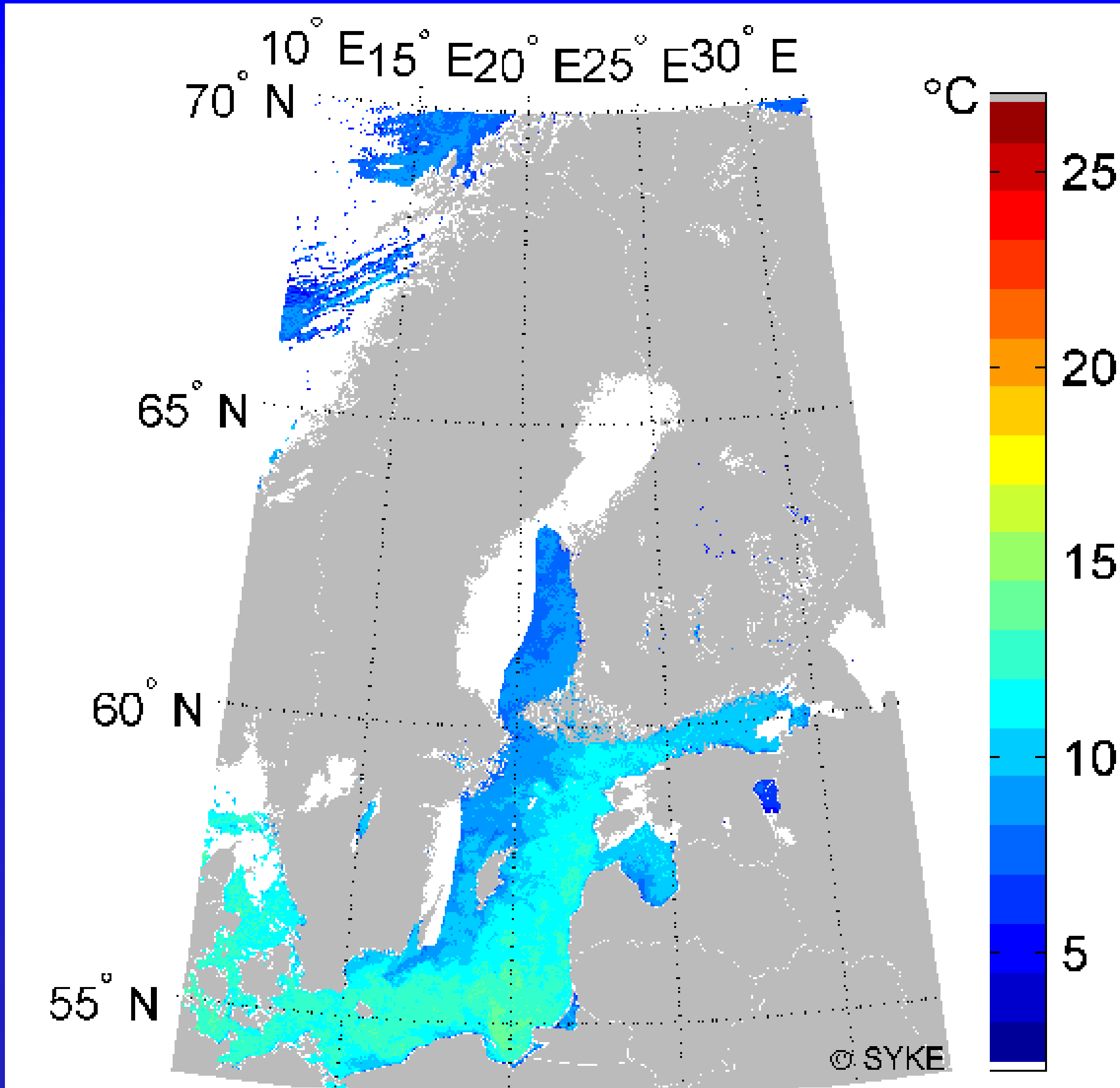
Spring heating



Lake Baikal, 11 May 1937

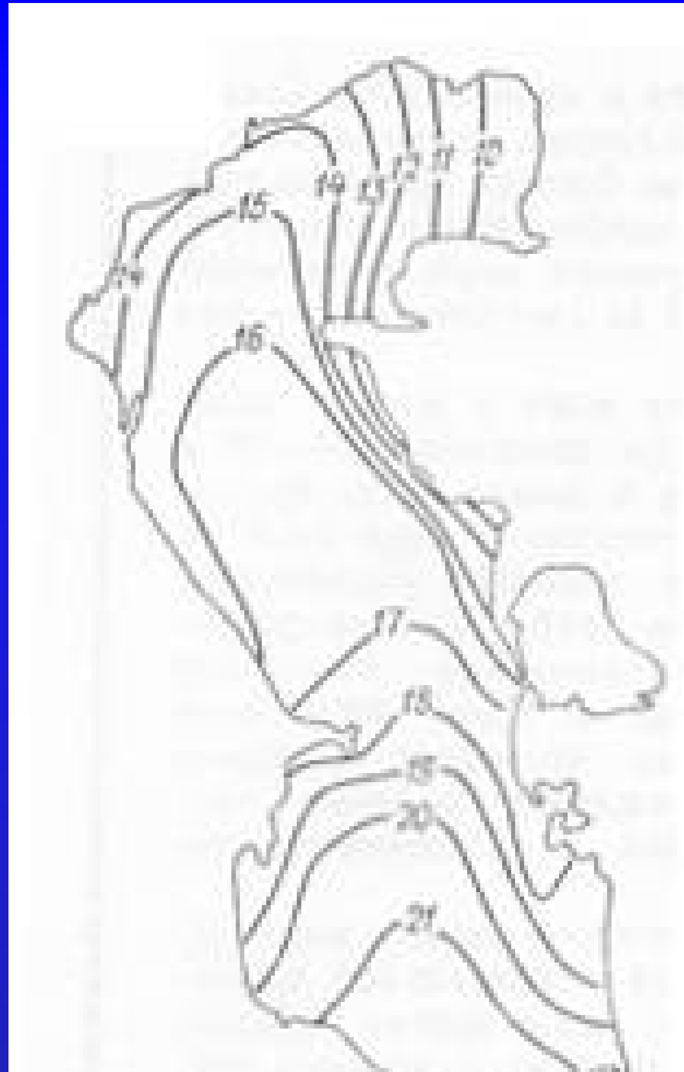
Tikhomirov, 1982

Averaged data:



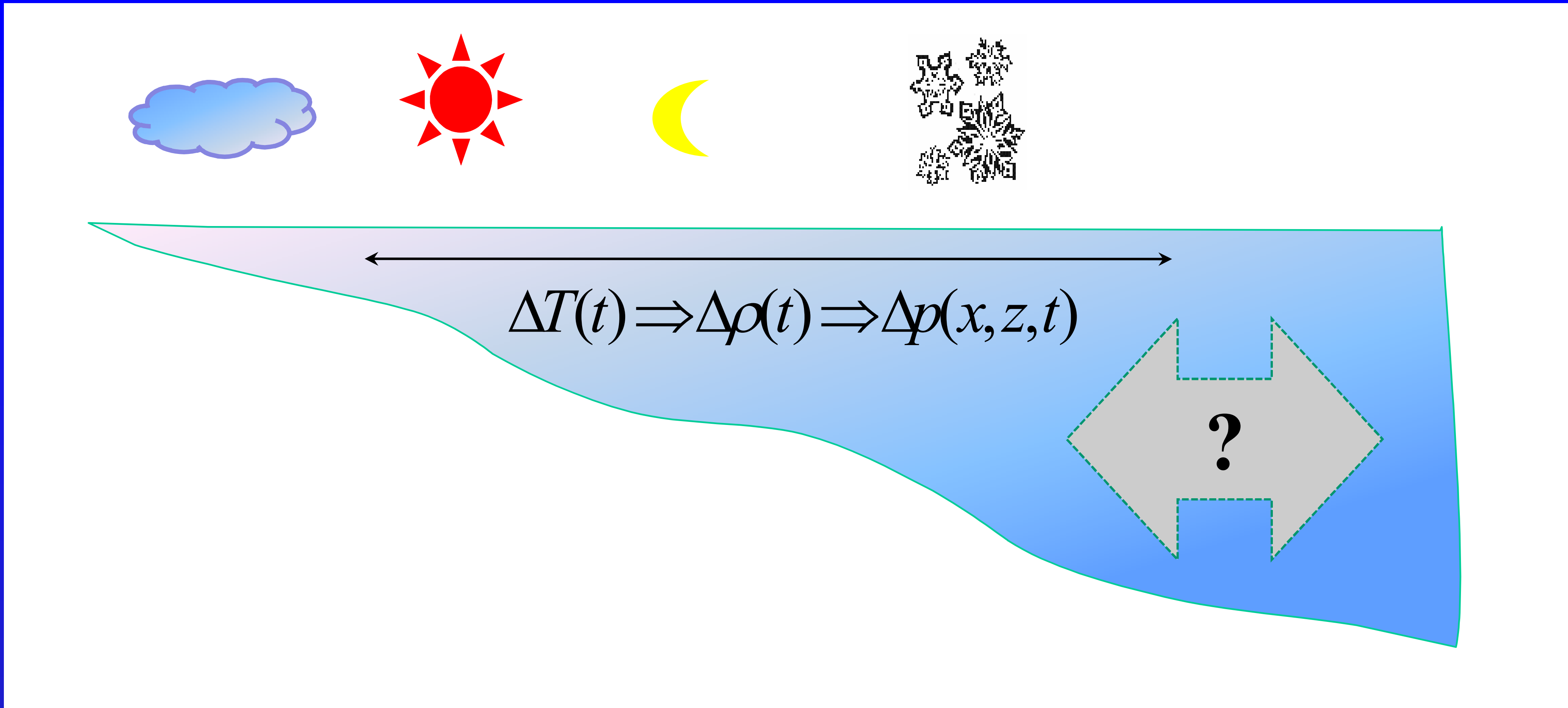
Averaged T over 1 week

SST of the Baltic for the week 43 (26-30 October) 2005 NOAA/AVHRR (http://wwwi4.ymparisto.fi)



Averaged T over 1 month

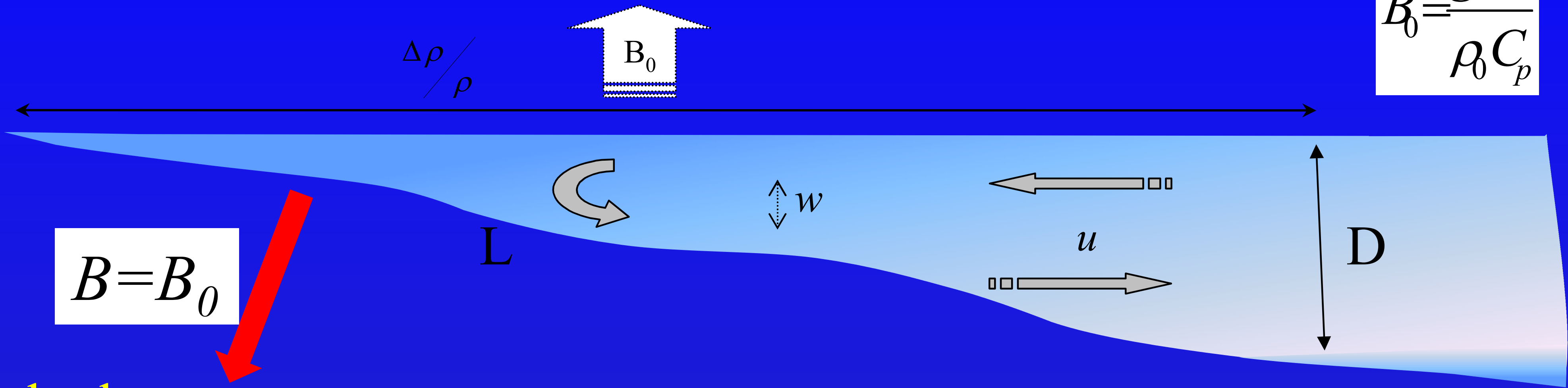
Mean annual SST in October in the Caspian Sea (Atlas of the Shelf Seas of the USSR)



What a motions are behind these temperature gradients?

0.1. Why and how do the horizontal gradients appear?

$$B_0 = \frac{g\alpha F}{\rho_0 C_p}$$

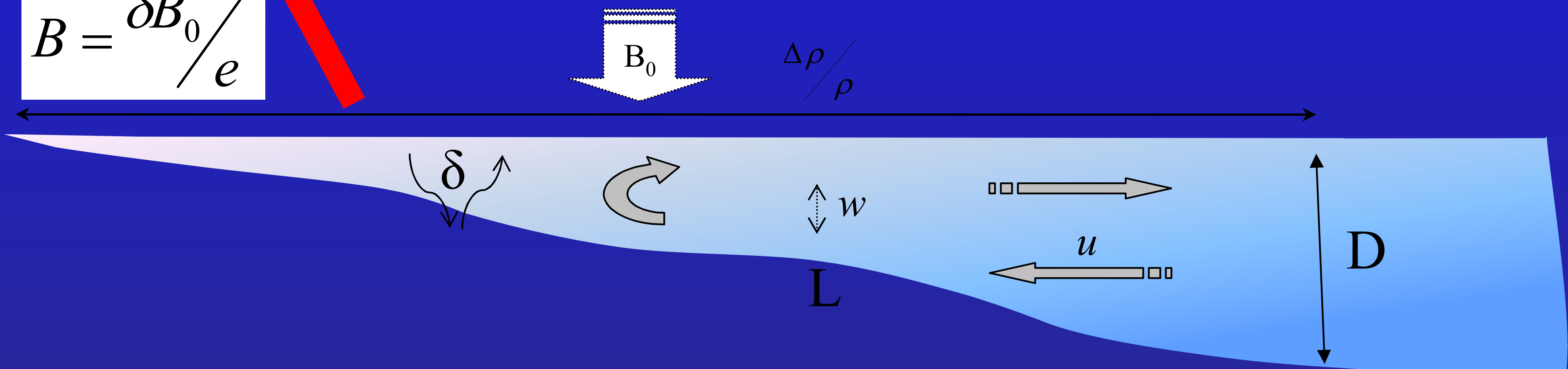


$$B = B_0$$

In both cases,
the *destabilizing* buoyancy flux
is of importance

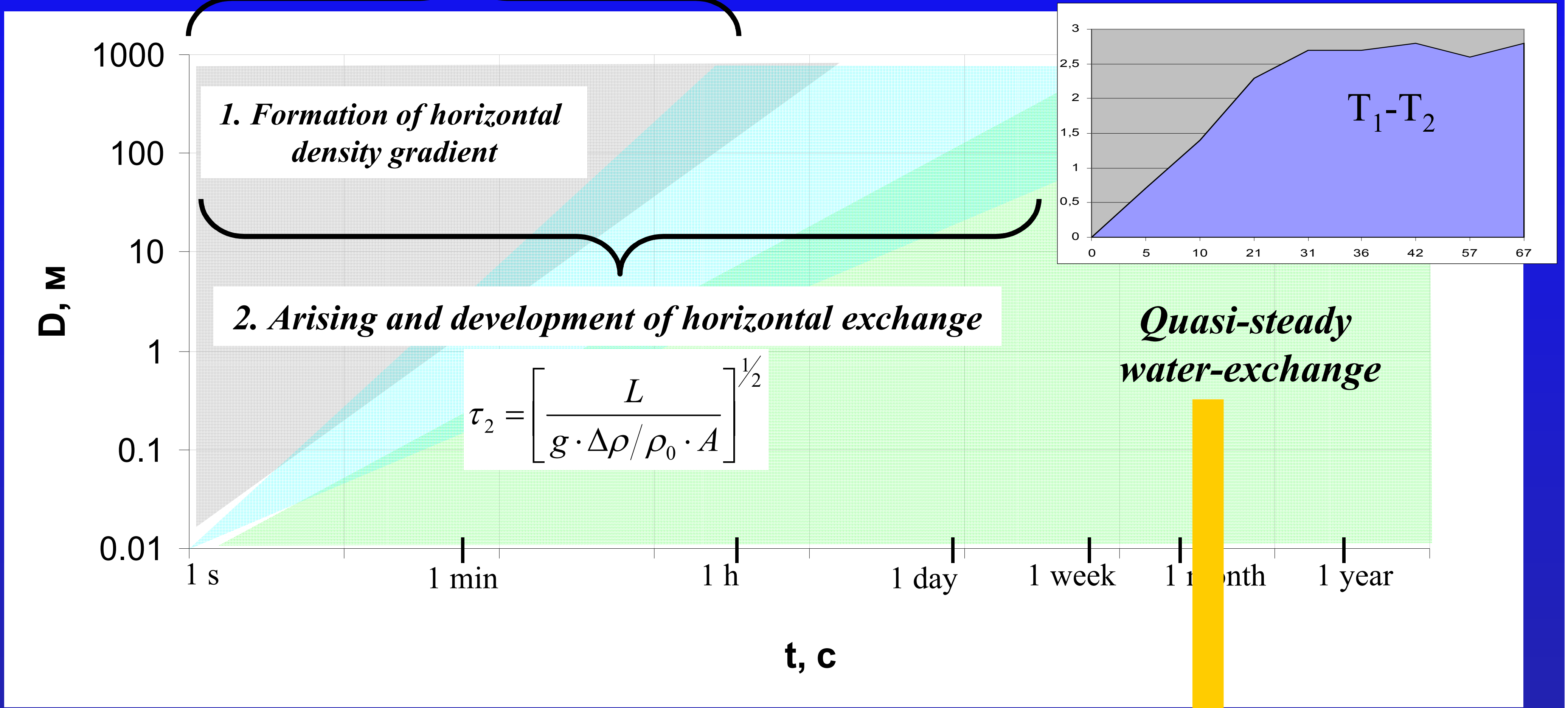
$$\tau_1 \sim \left(D^2/B\right)^{1/3}$$

$$B = \delta B_0 / e$$



0.2. Development of the horizontal exchange with time

$\tau_1 \sim \left(D^2/B\right)^{1/3}$ → **For L~10-60 m and B~10^{-6}-10^{-8} $m^2 s^{-3}$ it has an order of tens of minutes only**



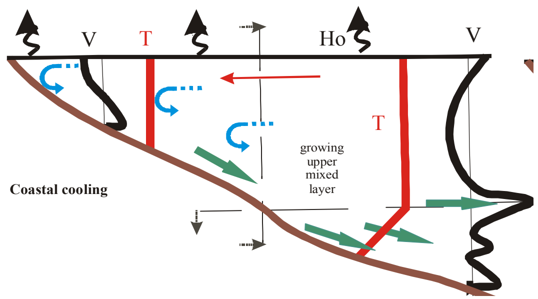
$$\tau_2 = \left[\frac{L}{g \cdot \Delta\rho/\rho_0 \cdot A}\right]^{1/2}$$

Flushing time

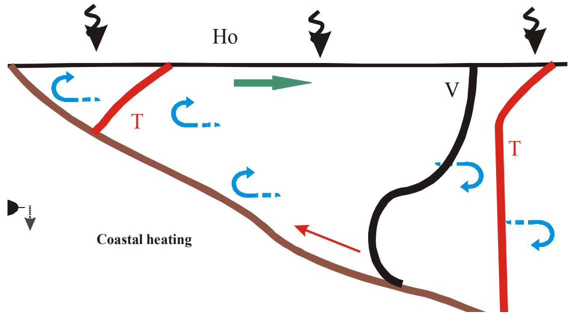
$$\tau_3 = \left[\frac{L}{g \cdot \Delta\rho/\rho_0 \cdot A}\right]^{1/2}$$

The dynamics of water exchange

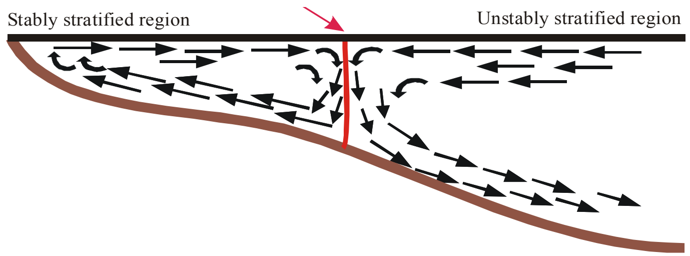
1 Cascading



2 Upwelling



3 Change of the structure



1. Cascading

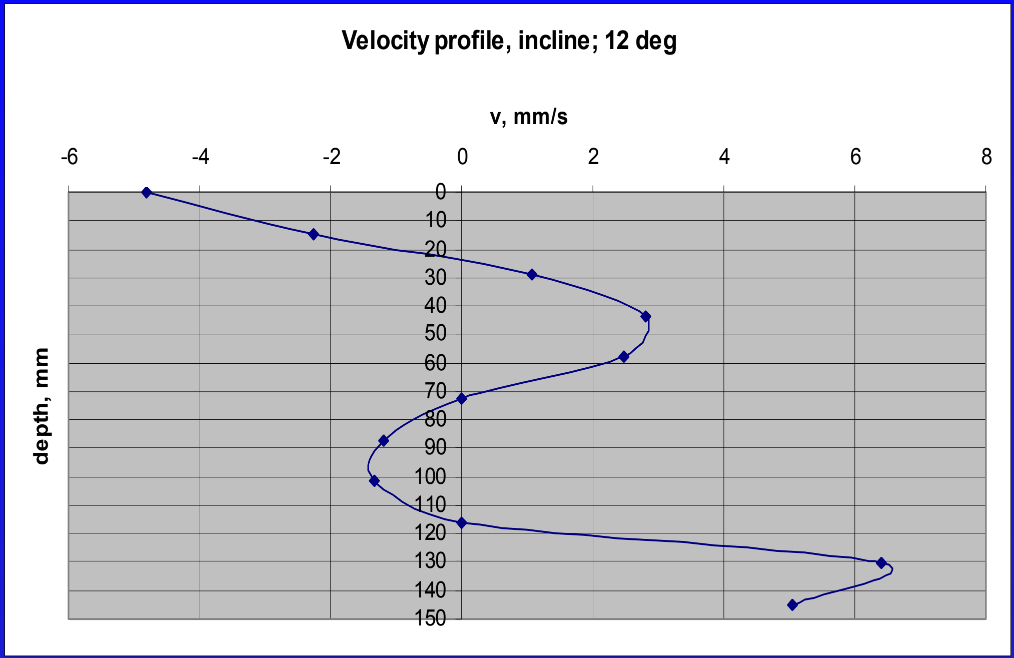
Characteristic features of the flow:

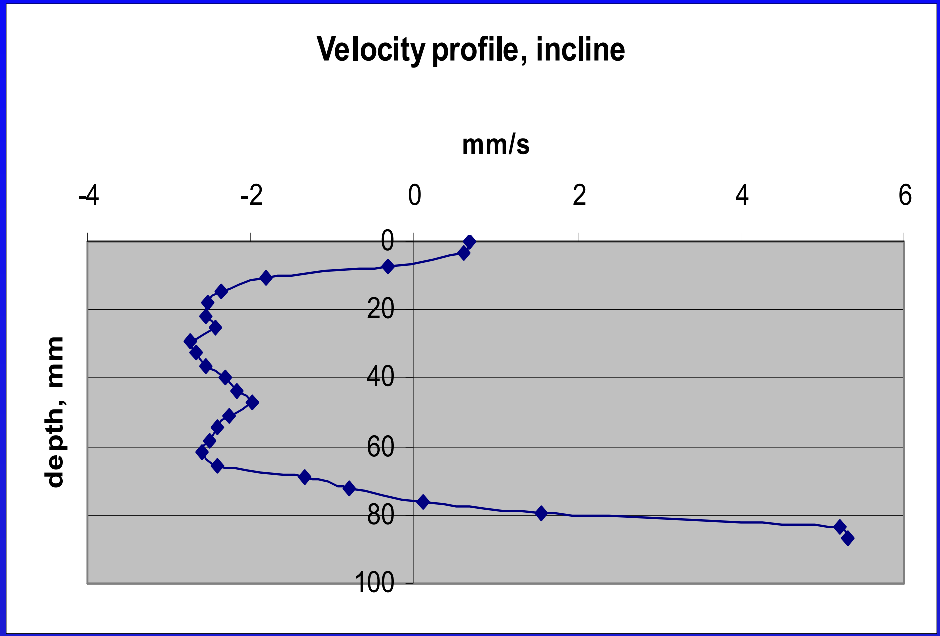
- no final steady state

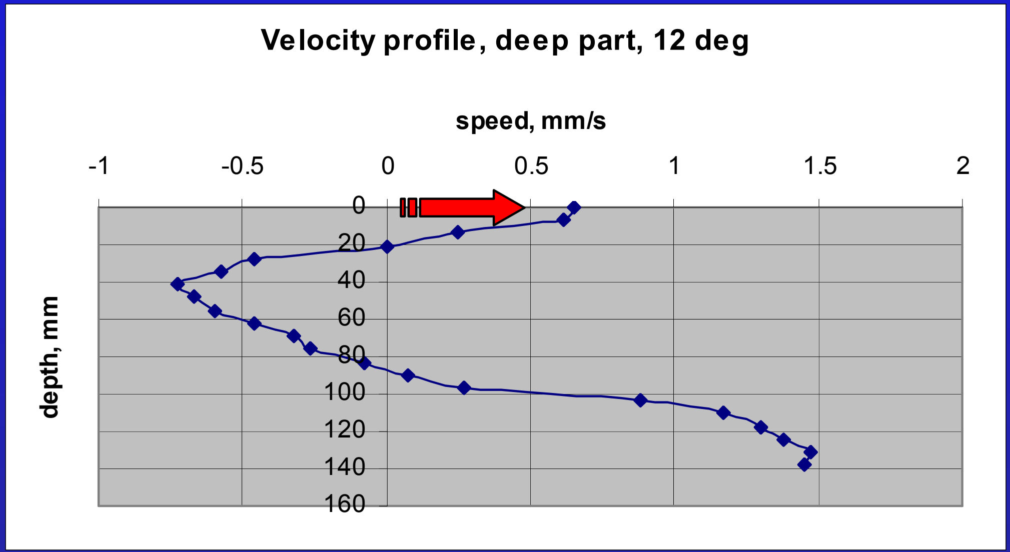
-the flow is the combination of vertical convection and horizontal advection

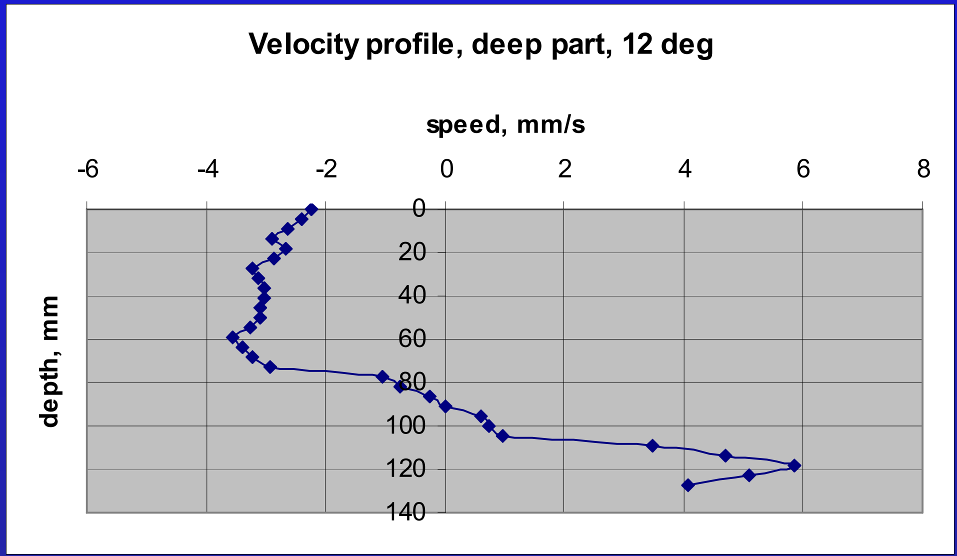
- horizontal velocity maxima are inside the layer

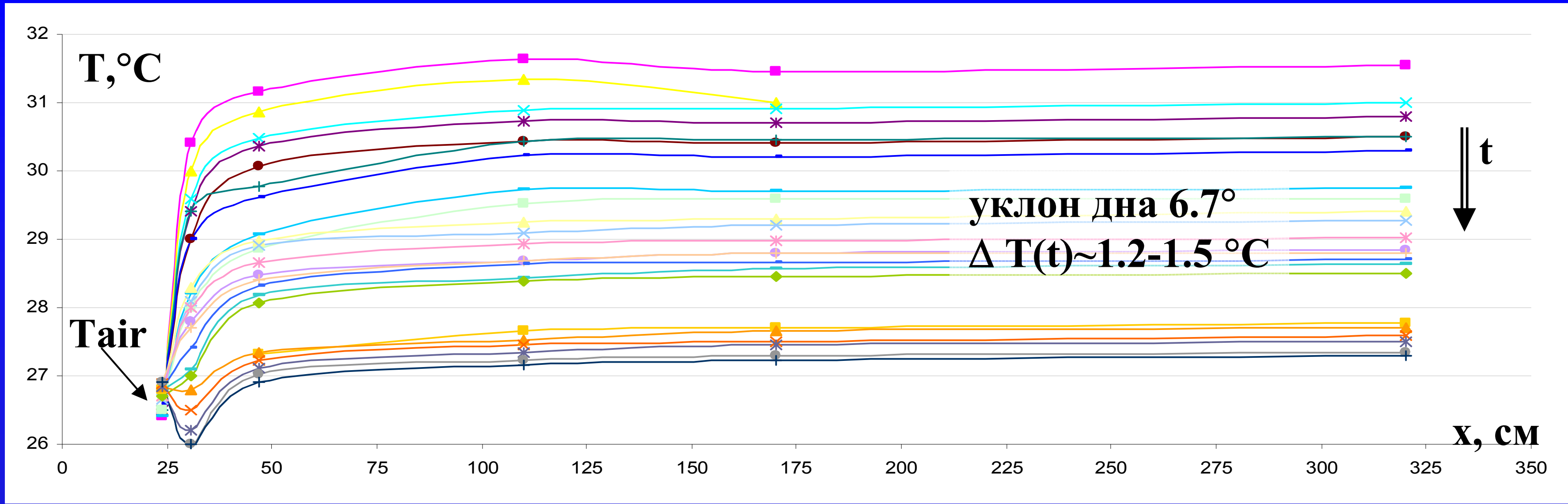
Velocity profiles

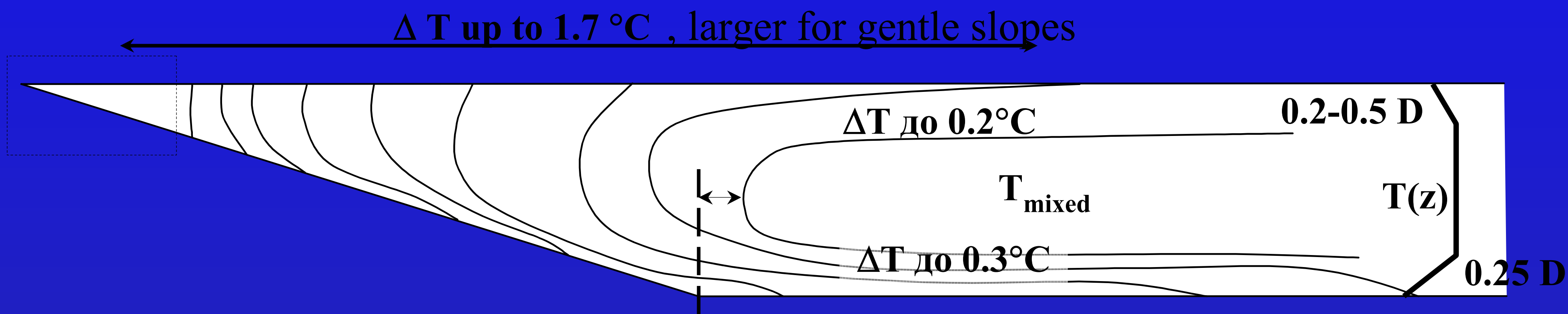


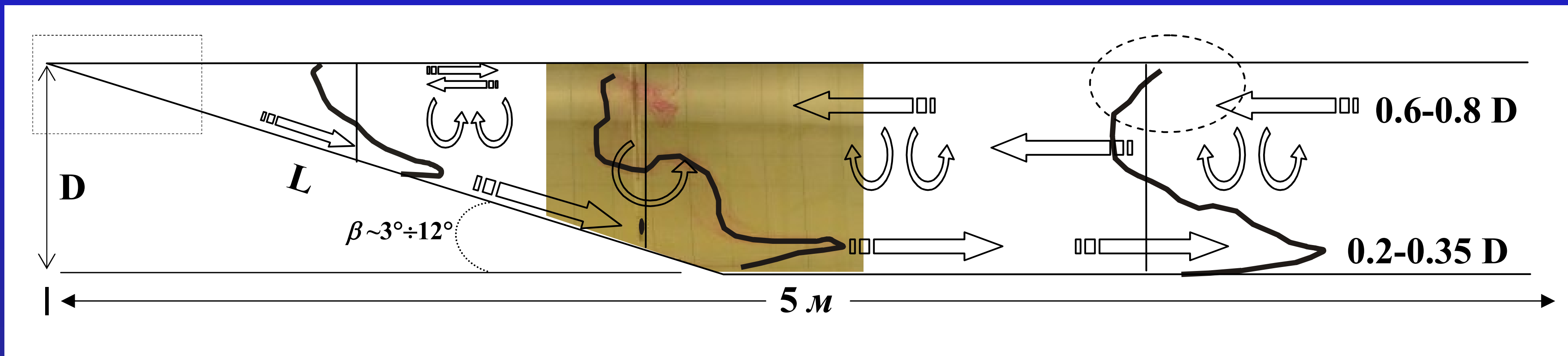






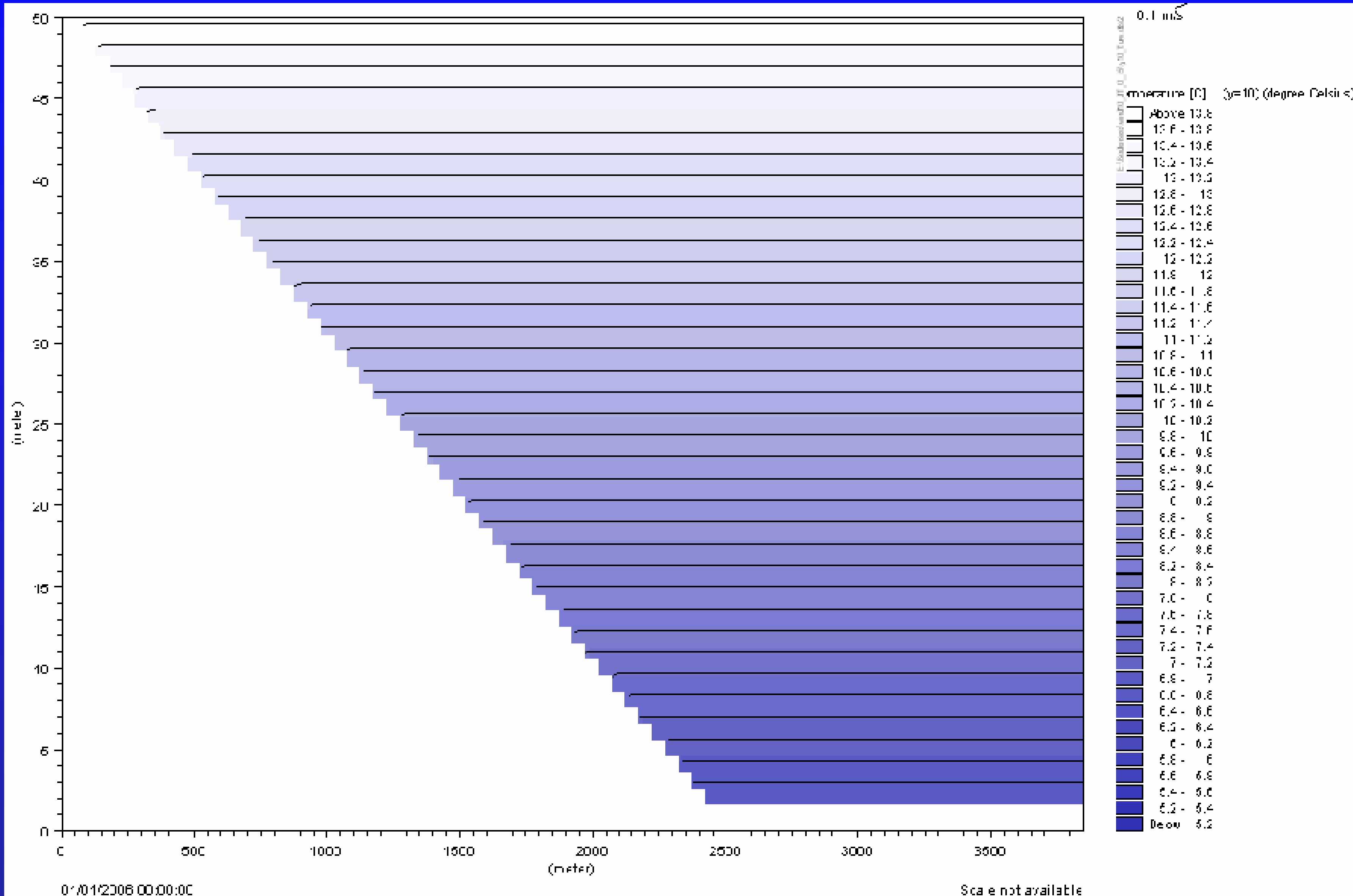

T,°C
32
31
30
29
28
27
26
Tair
t
уклон дна 6.7°
Δ T(t)~1.2-1.5 °C
x, см
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350


Δ T up to 1.7 °C , larger for gentle slopes
ΔT до 0.2°C
0.2-0.5 D
T mixed
T(z)
ΔT до 0.3°C
0.25 D


D
L
β~3°÷12°
0.6-0.8 D
0.2-0.35 D
5 м

Cooling from the surface
3D-nonhydrostatic model MIKE3-FlowModel

50 m

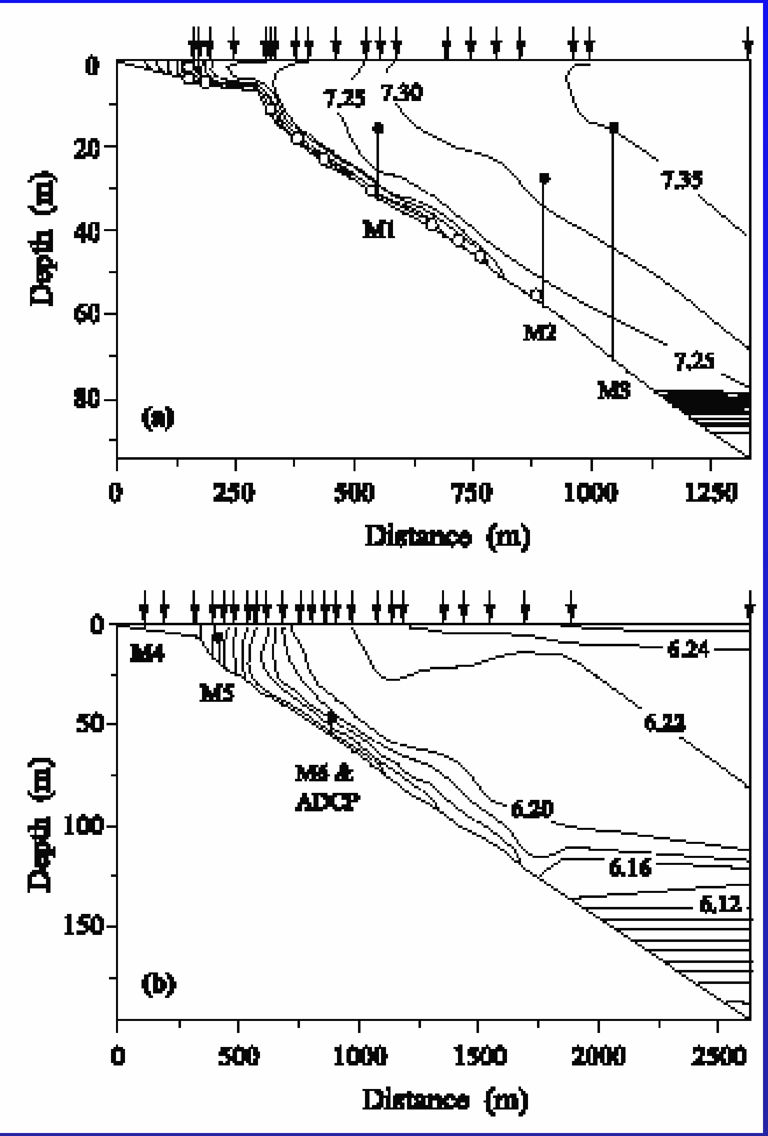


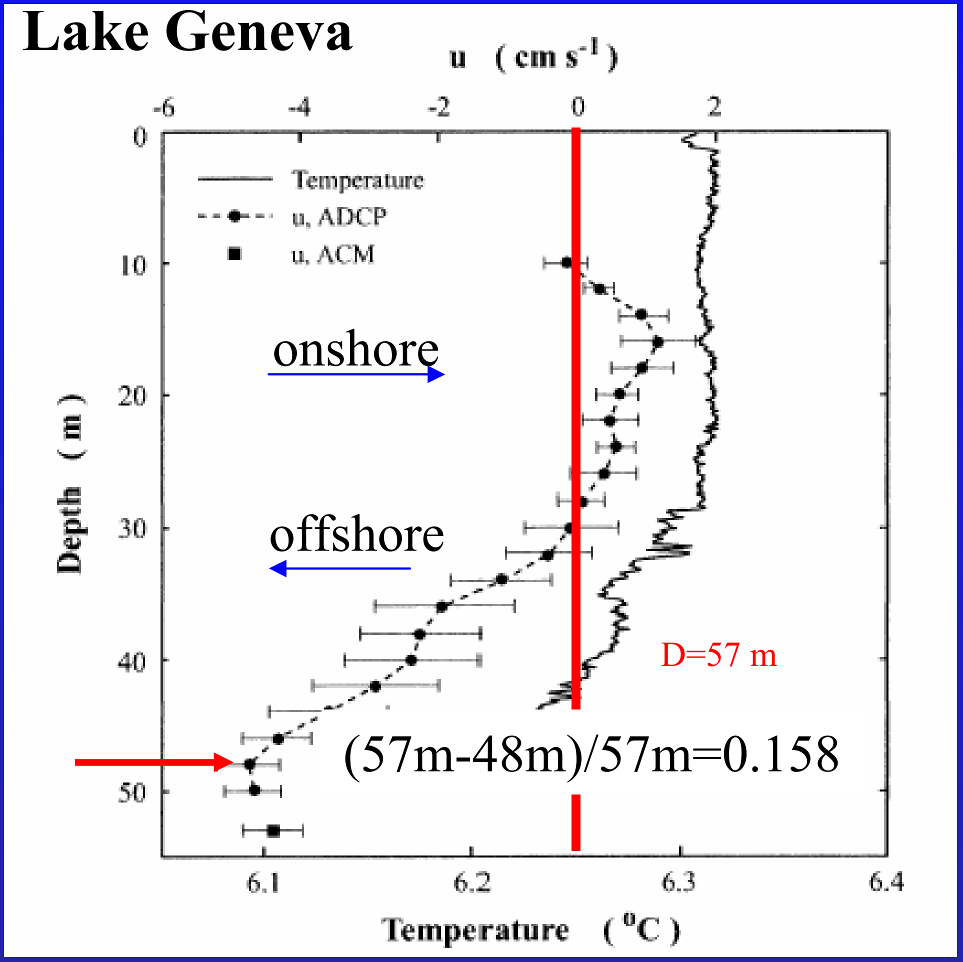
5 km

2 km x 5 km x 50 m

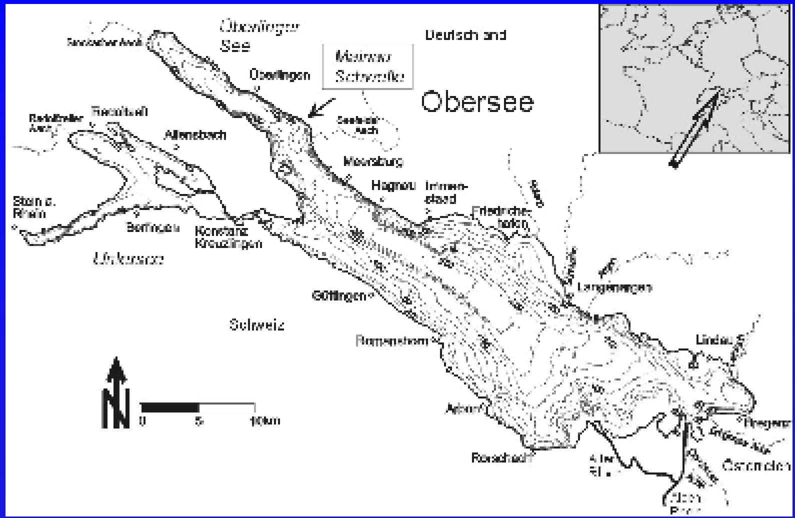
Field measurements: Lake Geneva

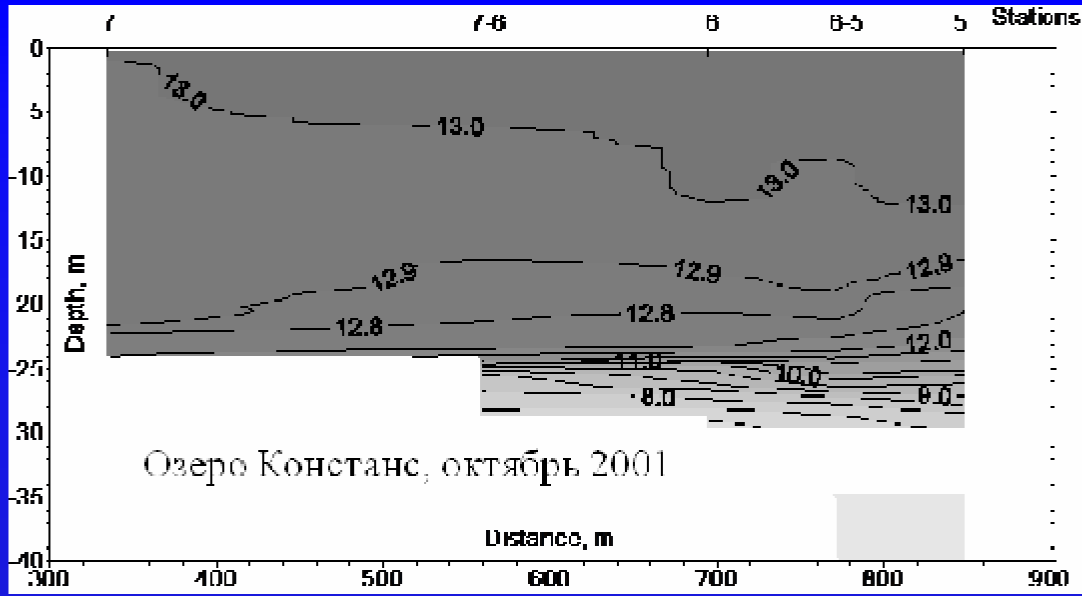
Winter cascading of cold water in Lake Geneva
I.Fer, U.Lemmin, S. A. Thorpe
JOURNAL OF GEOPHYSICAL RESEARCH,
VOL. 107, NO. C6, 10.1029/2001JC000828, 2002





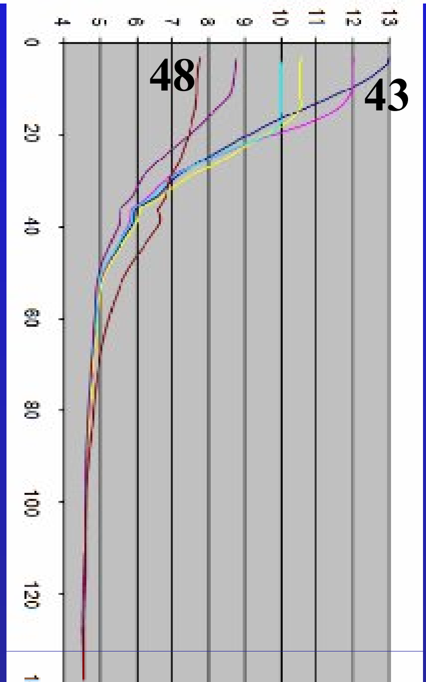
Lake Consance



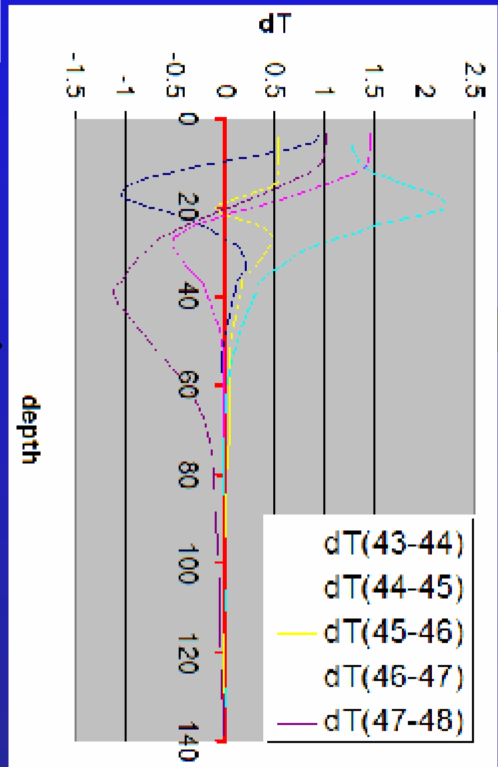


Central part of the lake

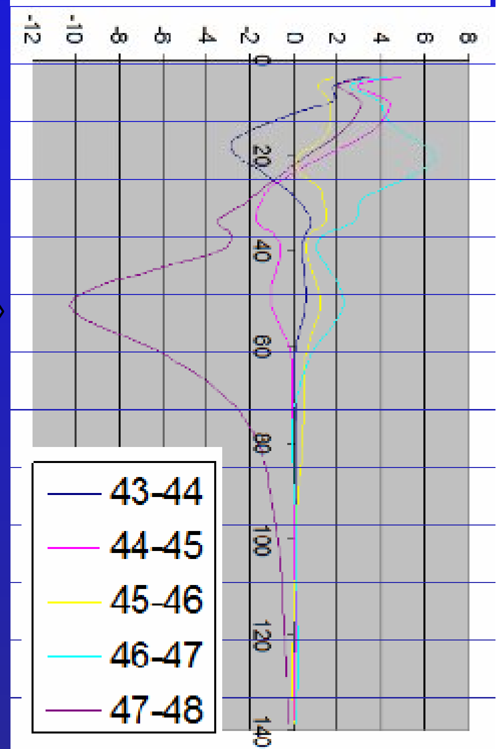
Temperature profiles versus depth,
averaged over 1 week,
from November,20 till December,1, 1988



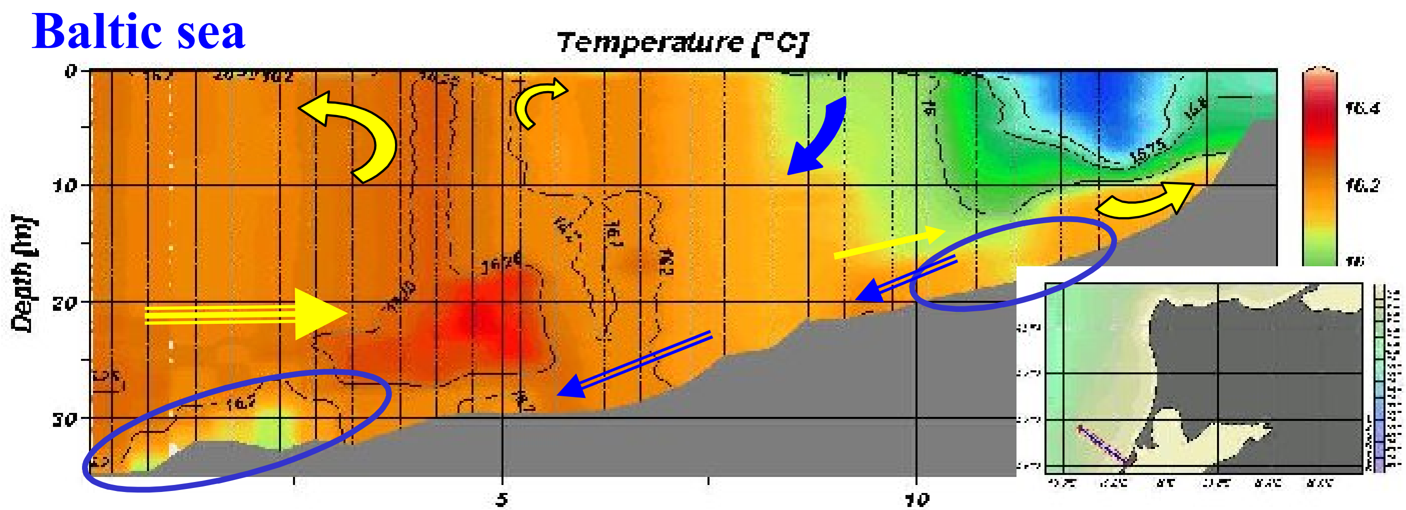
Autumn 1988, station Boje Mitte

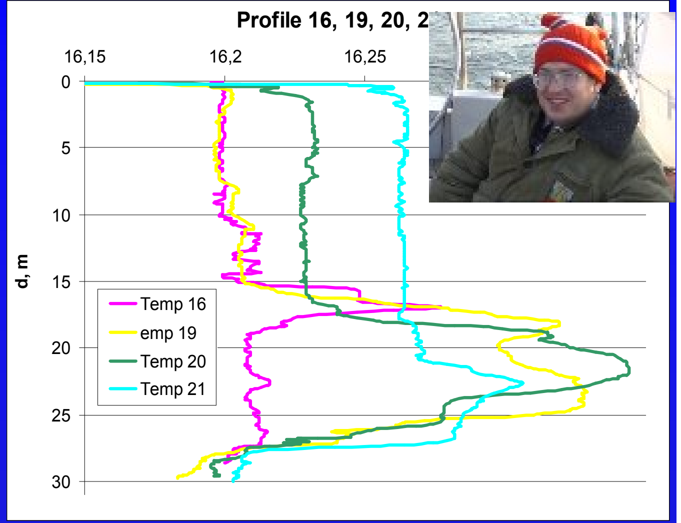


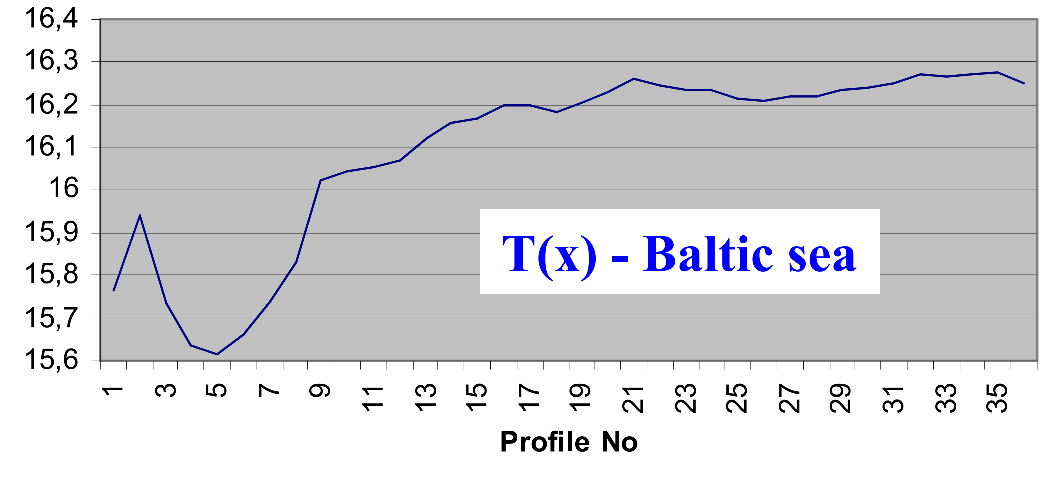
Heat loss from dh
1/2(dT1+dT2)*dh

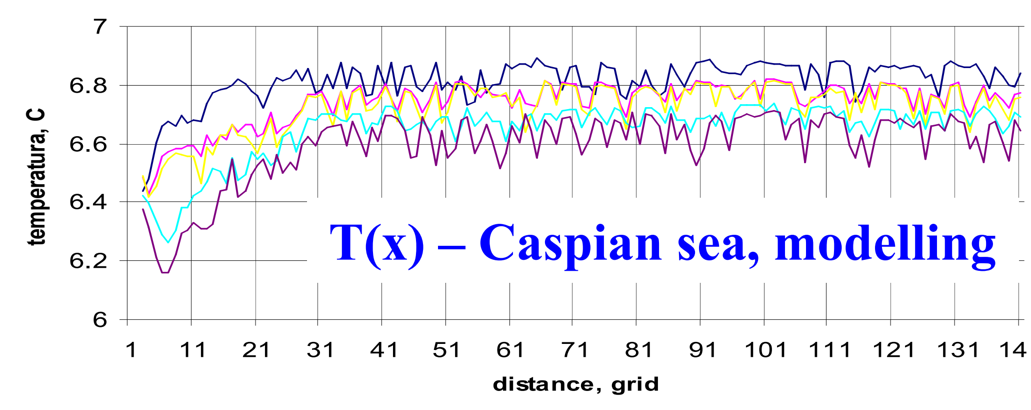


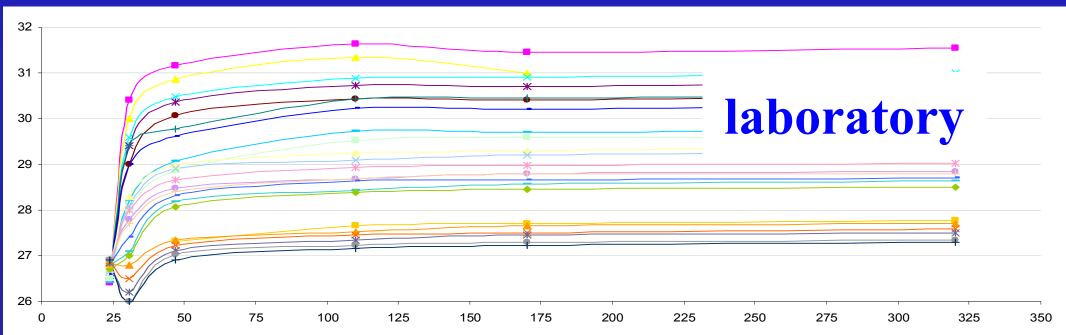
The Baltic Sea, October, 2006

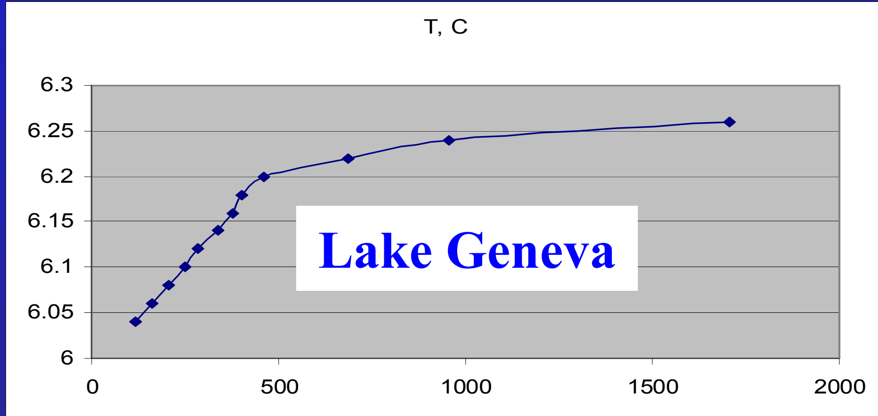




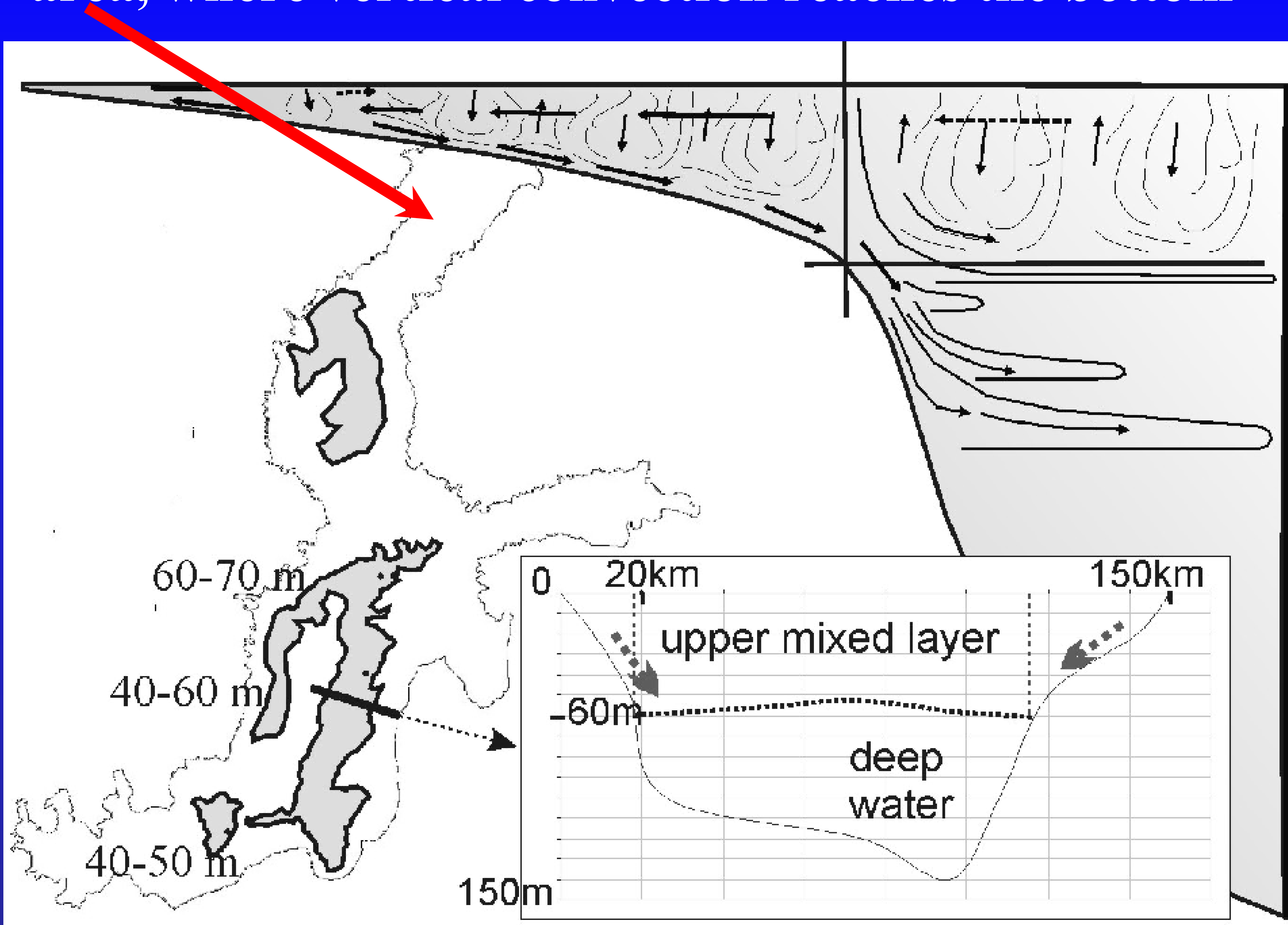




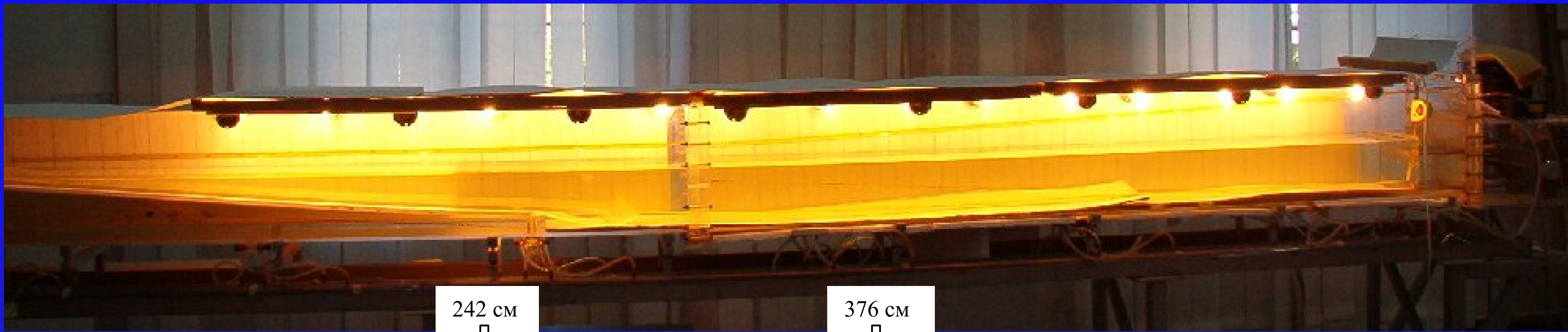


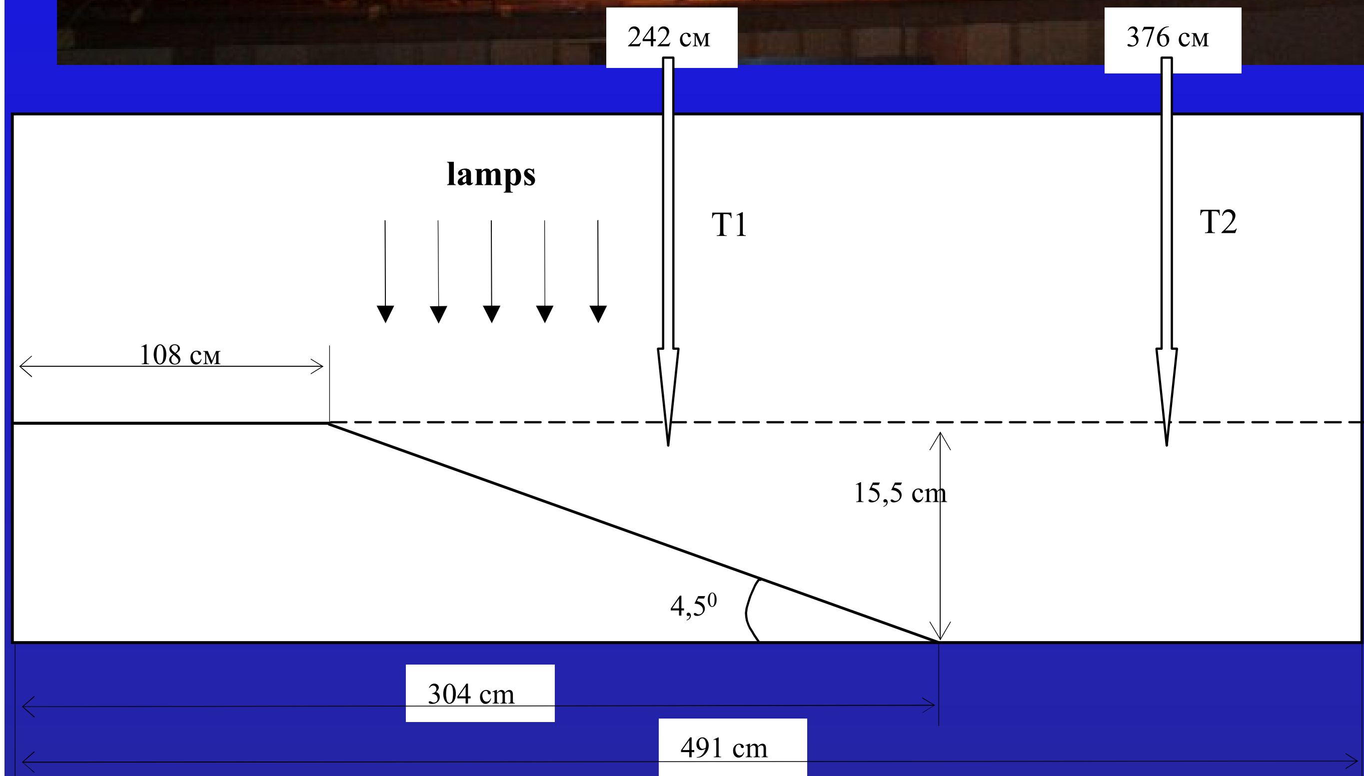


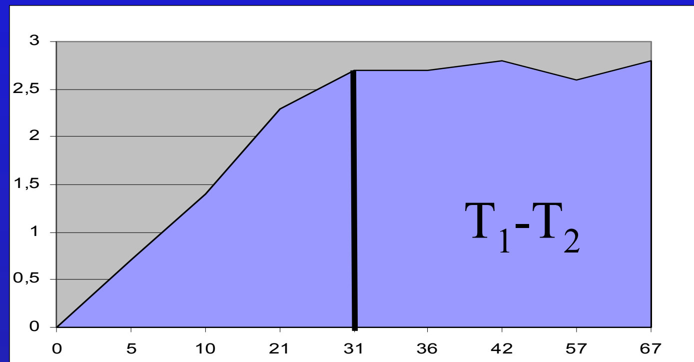
The Baltic Sea:
area, where vertical convection reaches the bottom

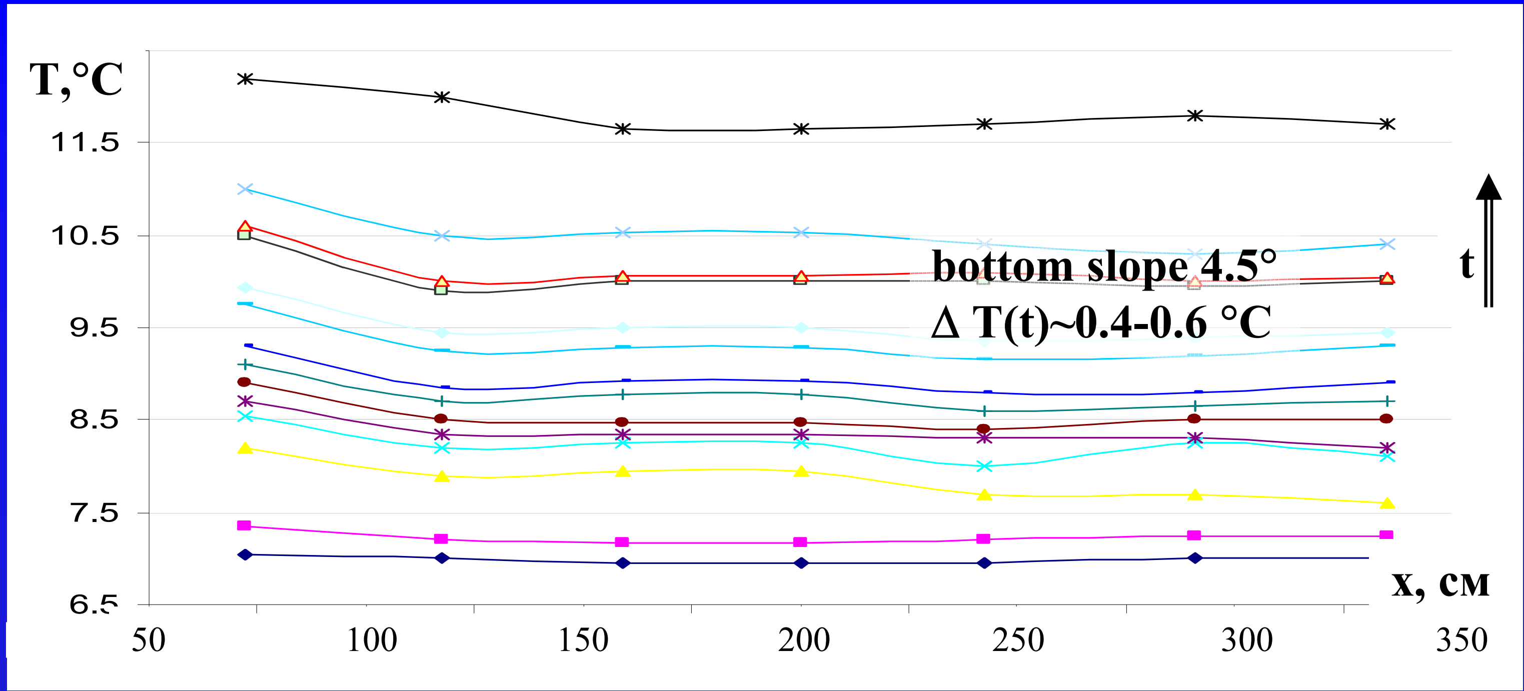


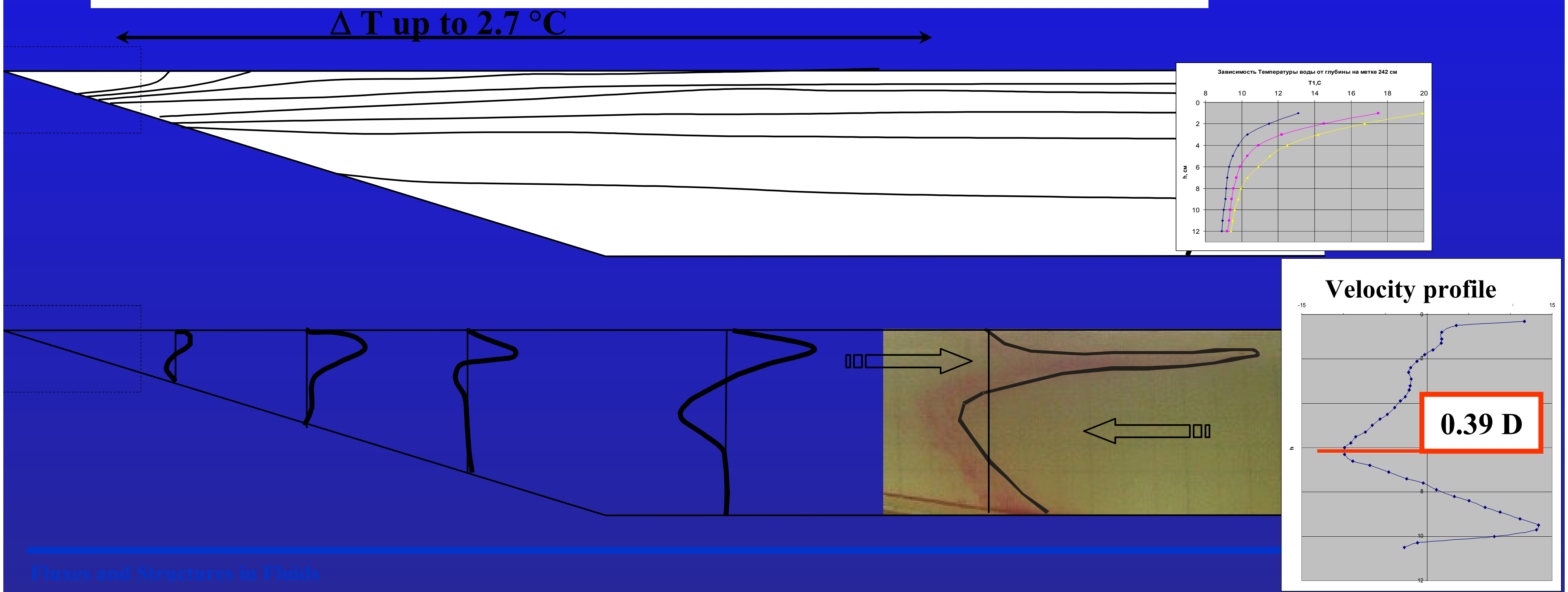
2. Upwelling



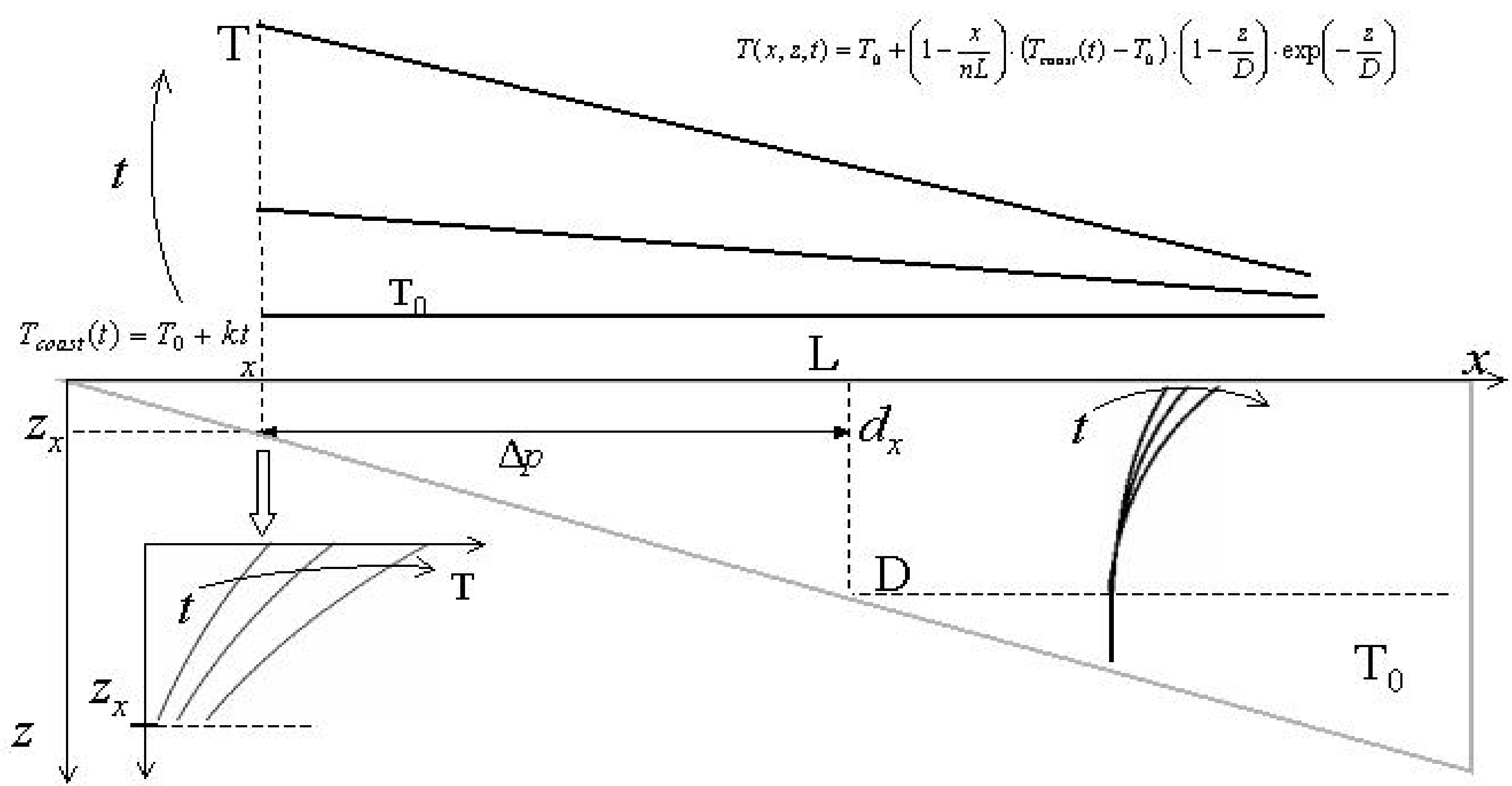

242 см
376 см
lamps
T1
T2
108 см
15,5 cm
4,5⁰
304 cm
491 cm


3
2,5
2
1,5
1
0,5
0
0
5
10
21
31
36
42
57
67
T1-T2


T,°C
11.5
10.5
9.5
8.5
7.5
6.5
50
100
150
200
250
300
350
x, см
t
bottom slope 4.5°
Δ T(t)~0.4-0.6 °C


Δ T up to 2.7 °C
Зависимость Температуры воды от глубины на метке 242 см
T1,C
Velocity profile
0.39 D

What is the reason for this flow?

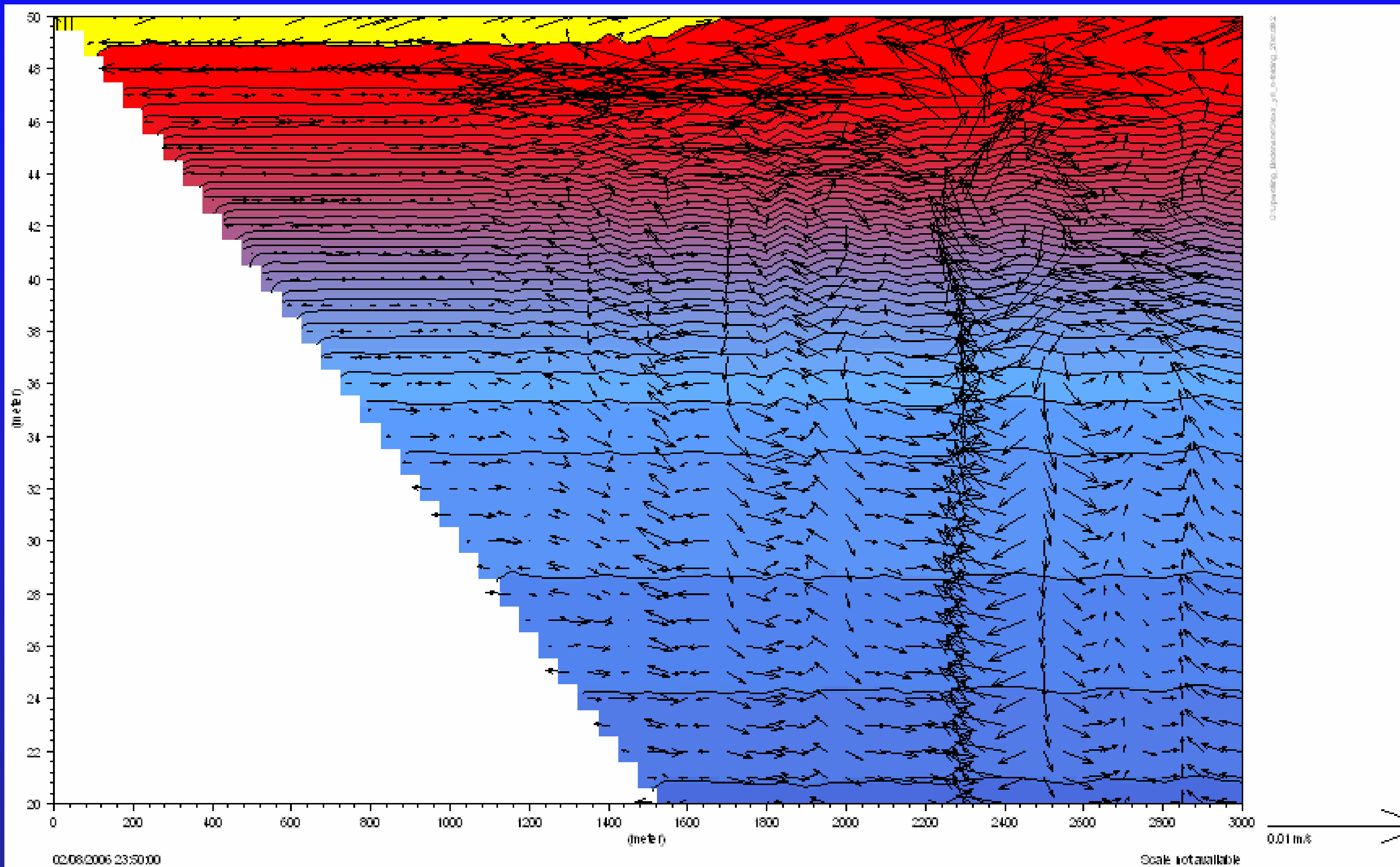


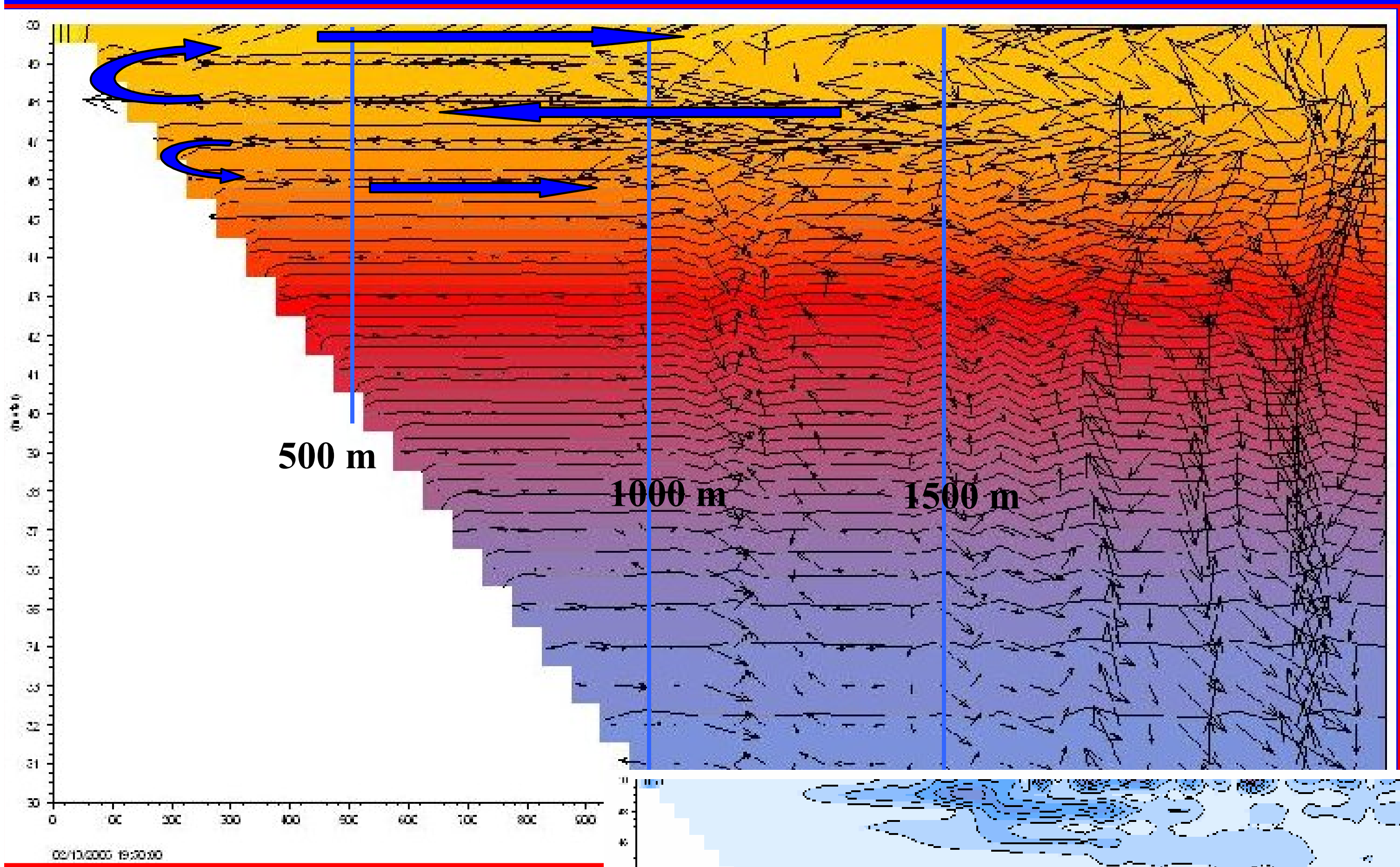
$$\Delta p = \alpha_* g \int_0^d \left[T(x_d, z, t) - T(x_{глуб}, z, t)\right] dz = \alpha_* g \frac{(T_{coast} - T_0)}{\beta} d\,(D - d) \exp(-\frac{d}{D}).$$

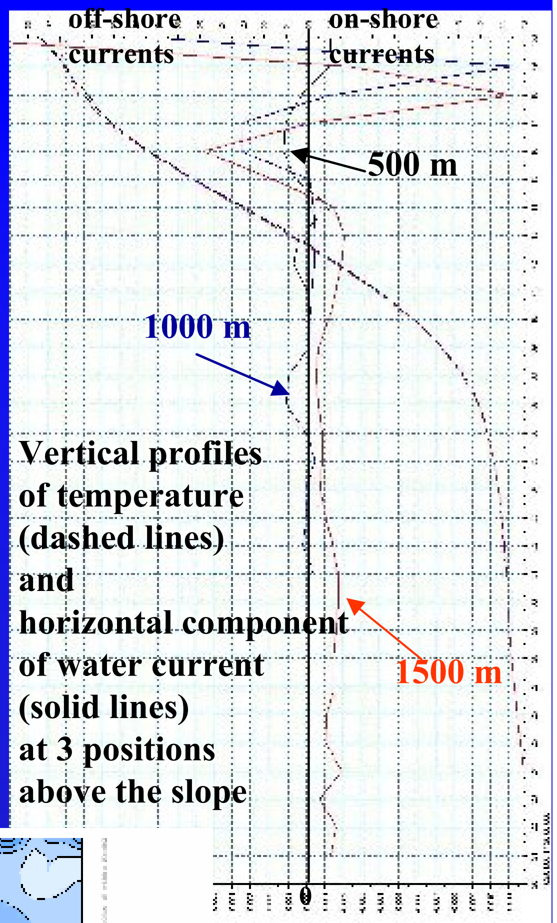
This function has a maximum $(\Delta p)' = 0$ at $d = 0.38D$

Numerical modelling, MIKE3-FlowModel

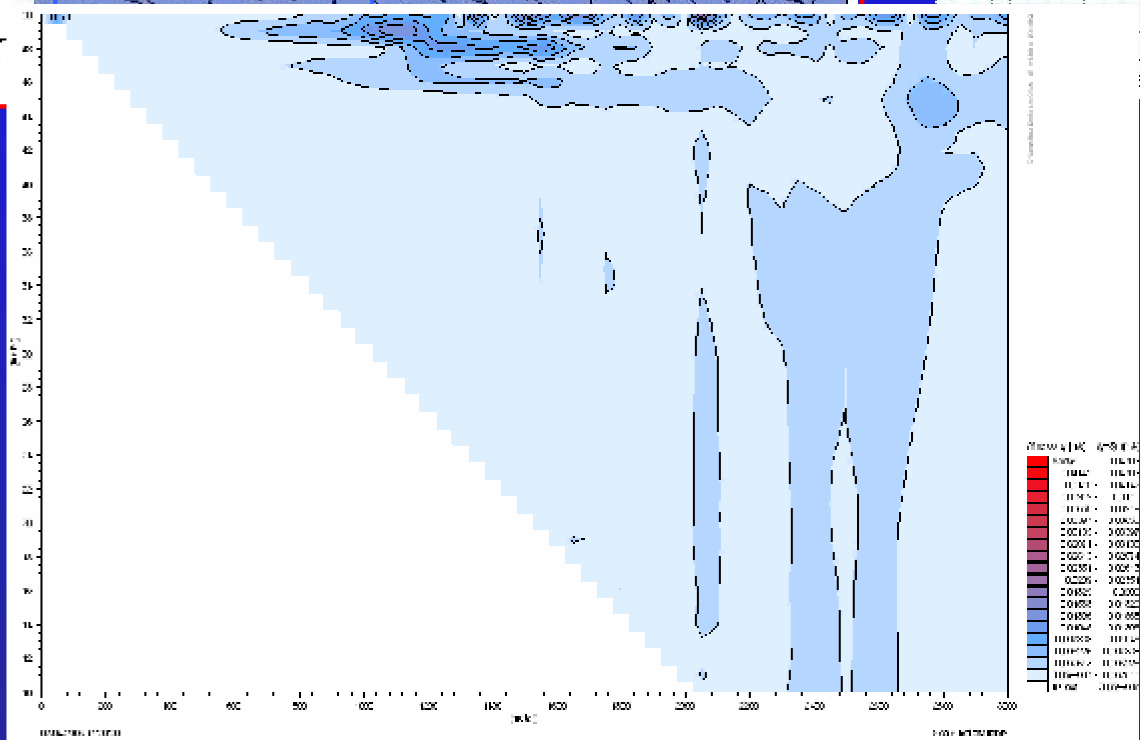
3D, non-hydrostatic, linear initial Tstratification, A=0.01, 1 m vertical layer, grid 100 x 30 cells, 50 x 50 m, time step 3 s, day-night variations, solar heating at mid-latitudes, T_{air}=30 C, $T_{in,\ water\ surface}$= 22 C, 10 days, no wind



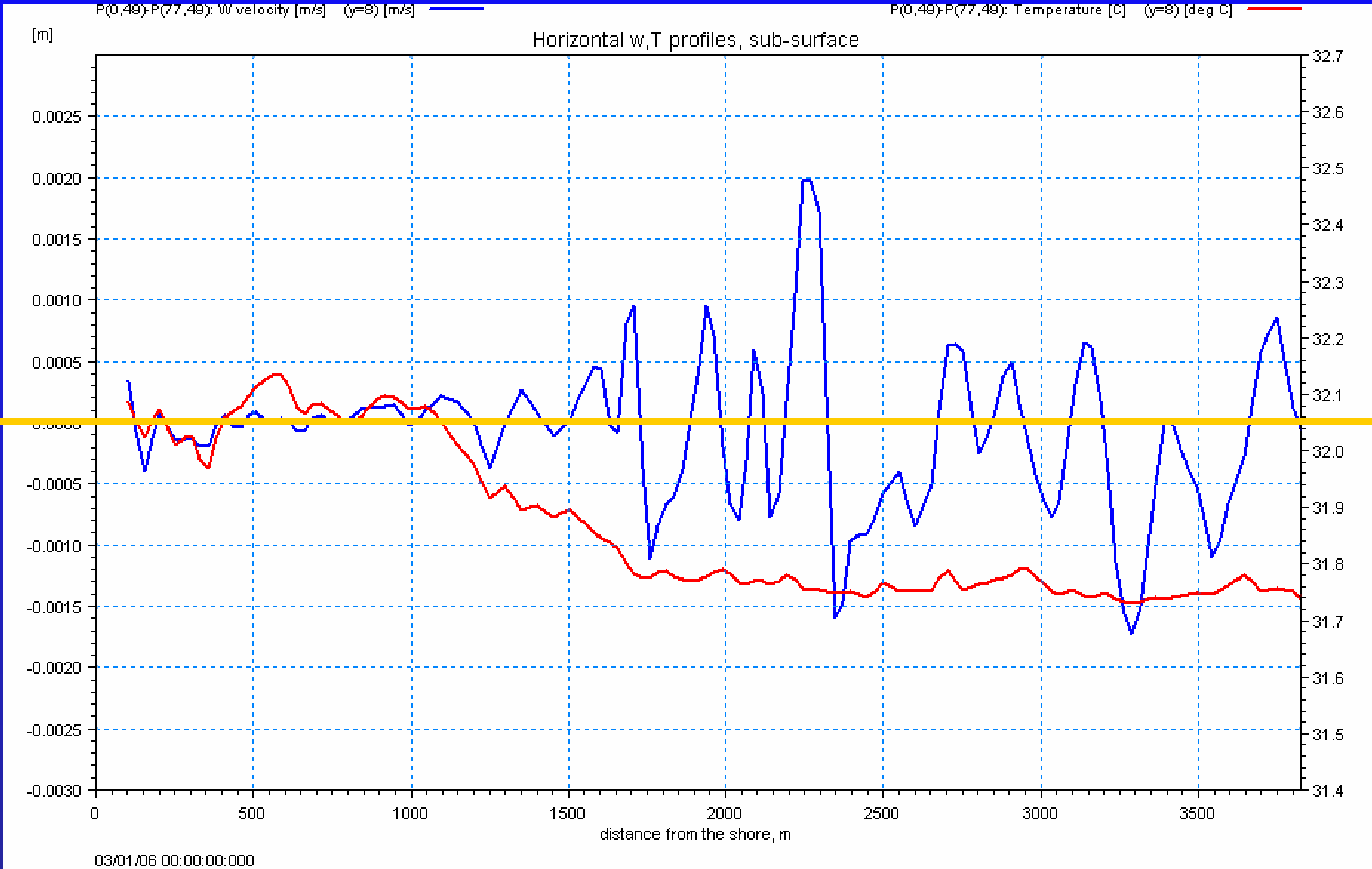




Velocity modulo

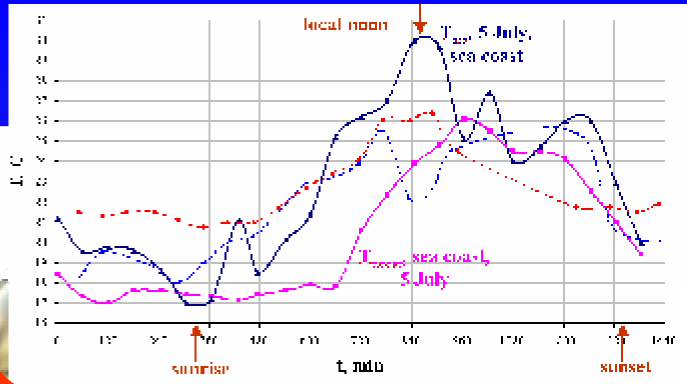


Horizontal water temperature and vertical velocity profiles in sub-surface layer

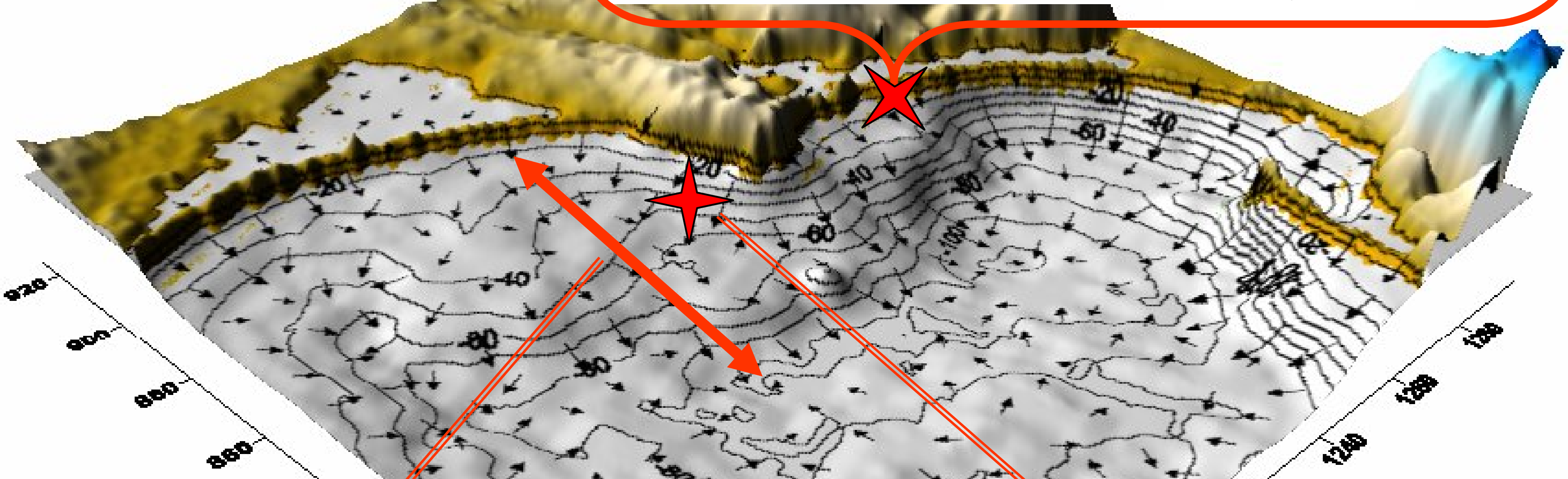


Field data: the Baltic Sea

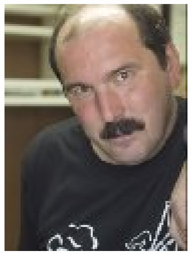
4 July 2006



Student practice
3-5 July, 2006

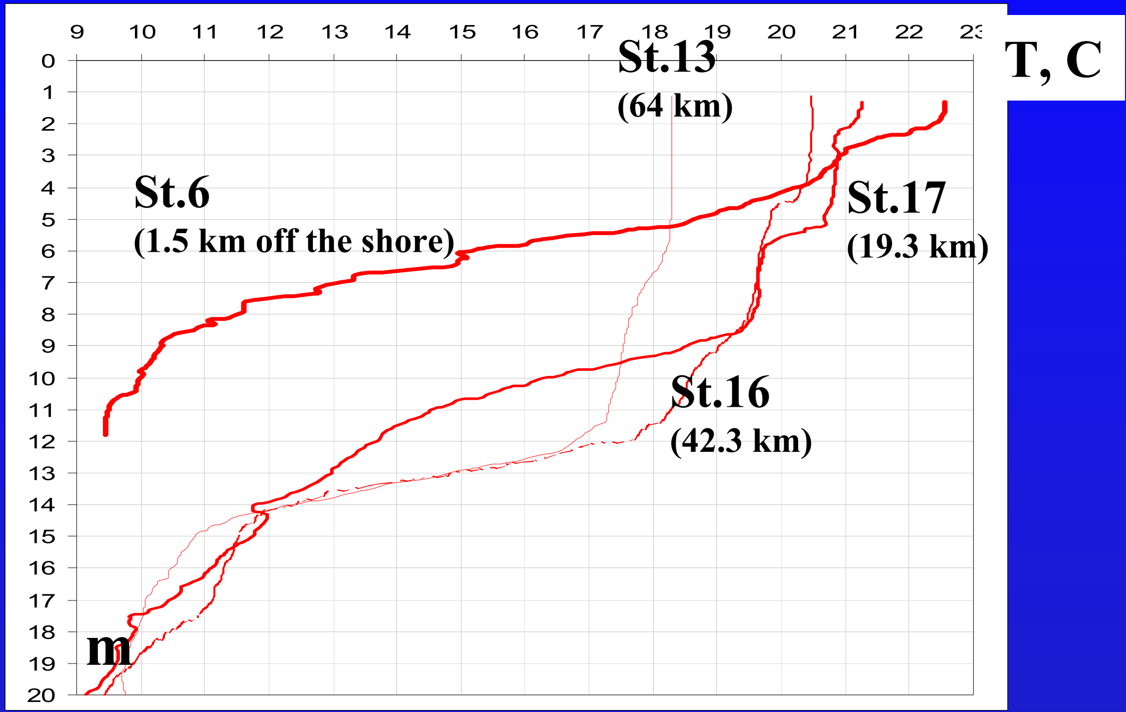


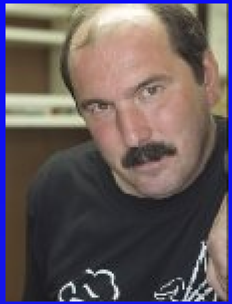
78 cruise
«Prof.Stockman”
1-5 July



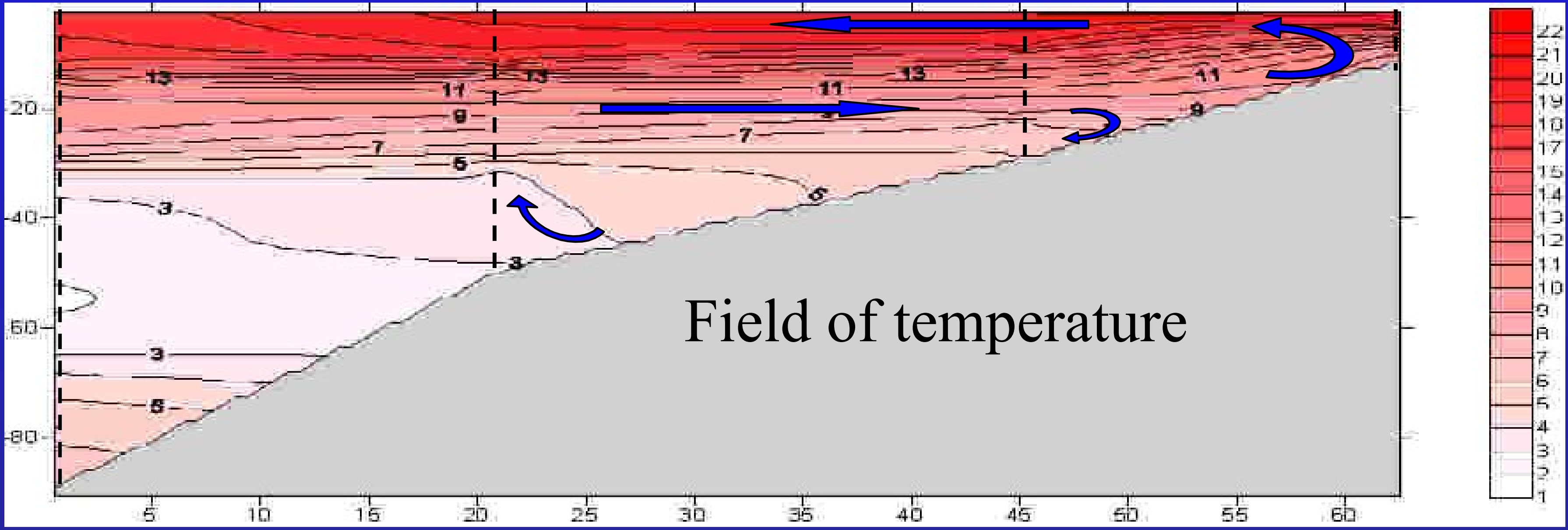
yacht
«Aquarius:
4 July

Coastal heating: ΔT(horiz)=4.27º/62 km

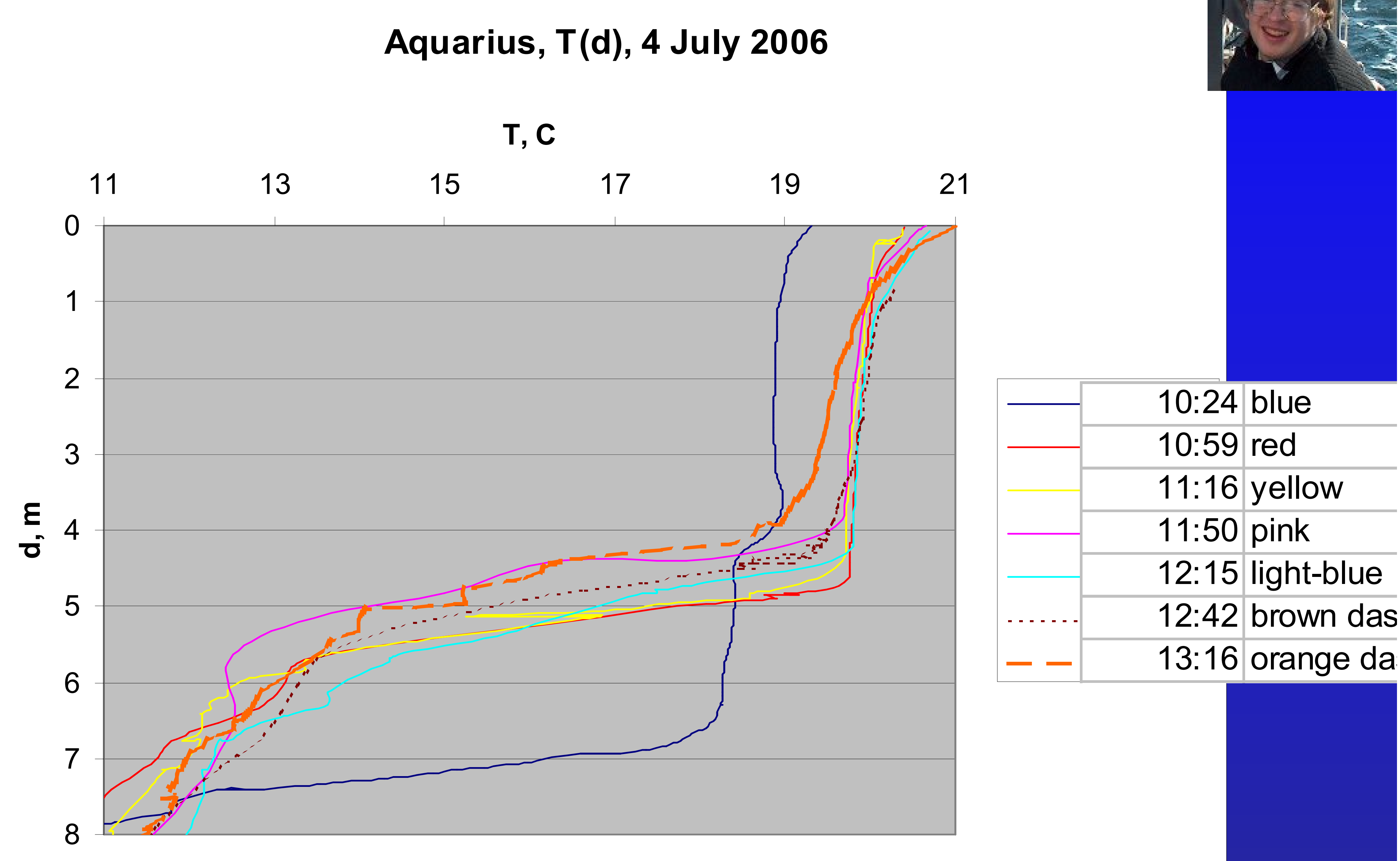




S.Shchuka

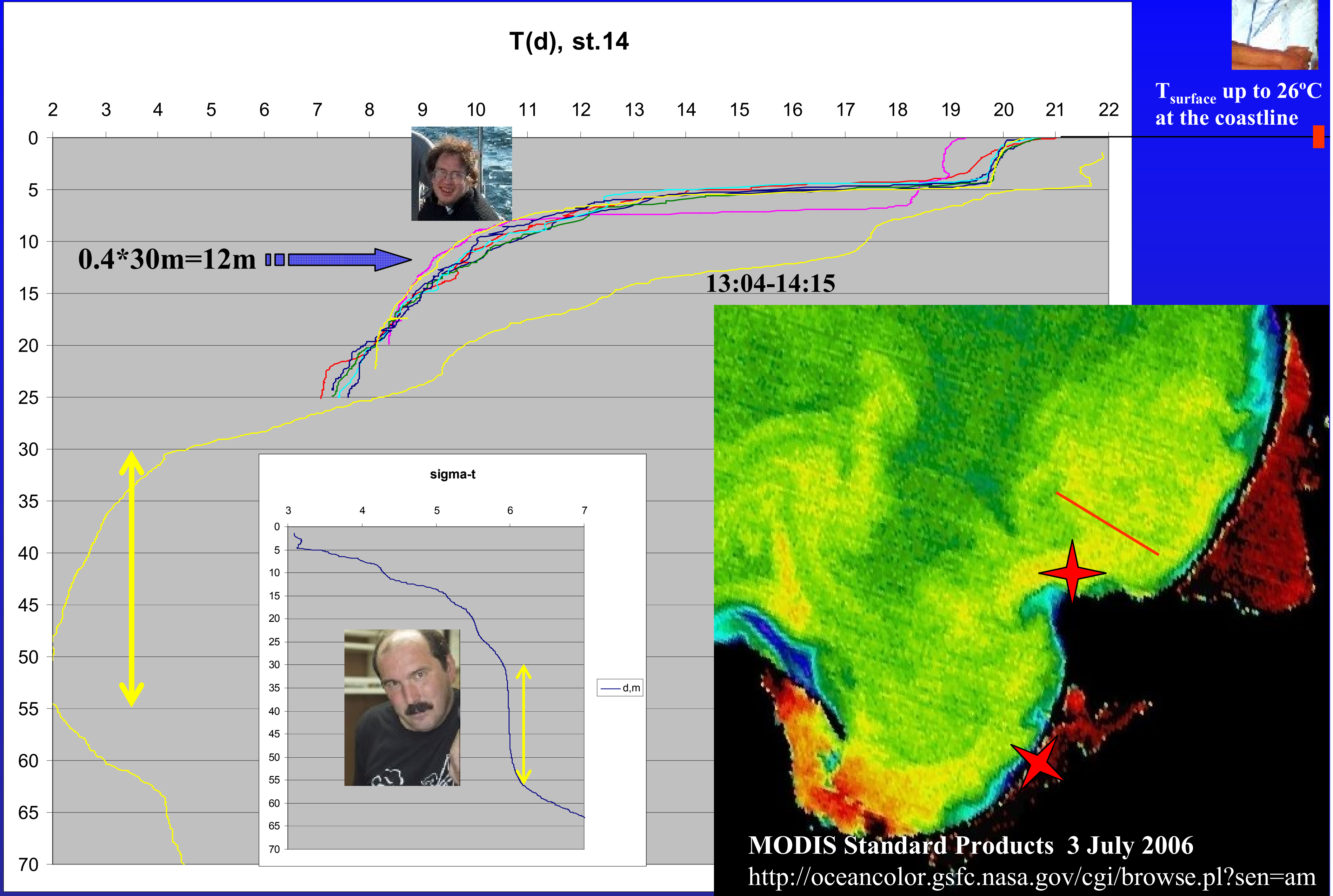


Yacht «Aquarius»



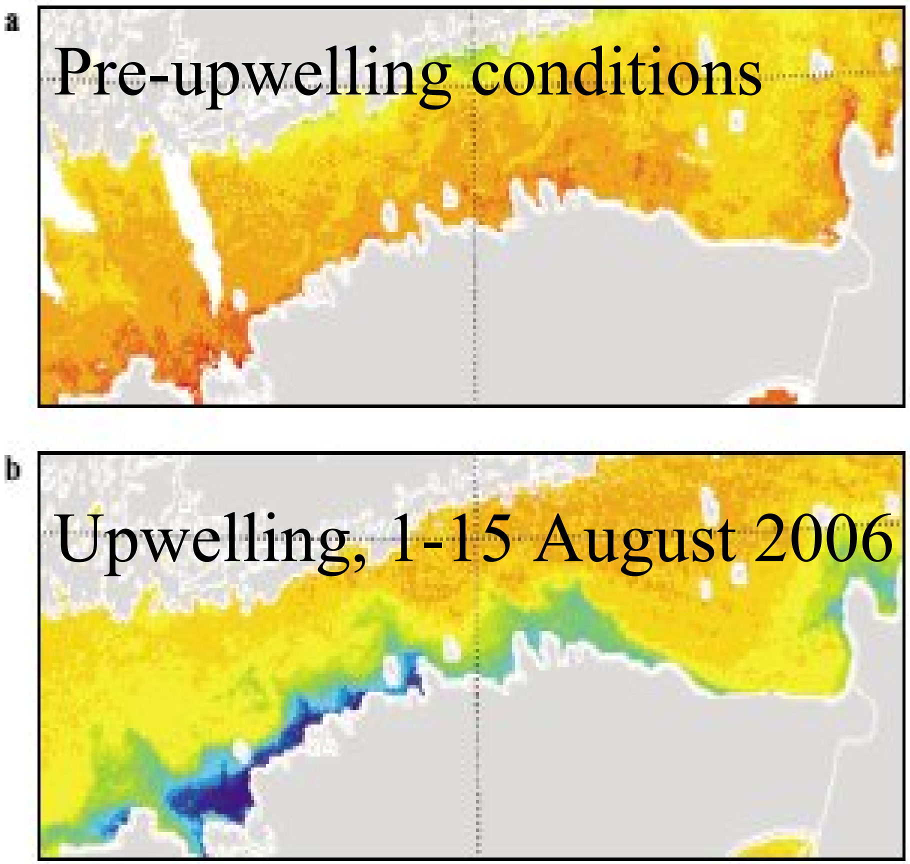
«Aquarius» + «Prof.Stockman» + measurements at spit

$T_{surface}$ up to 26ºC at the coastline



Estonia, August 2006

220 Ü. Suursaar, R. Aps



222 Ü. Suursaar, R. Aps

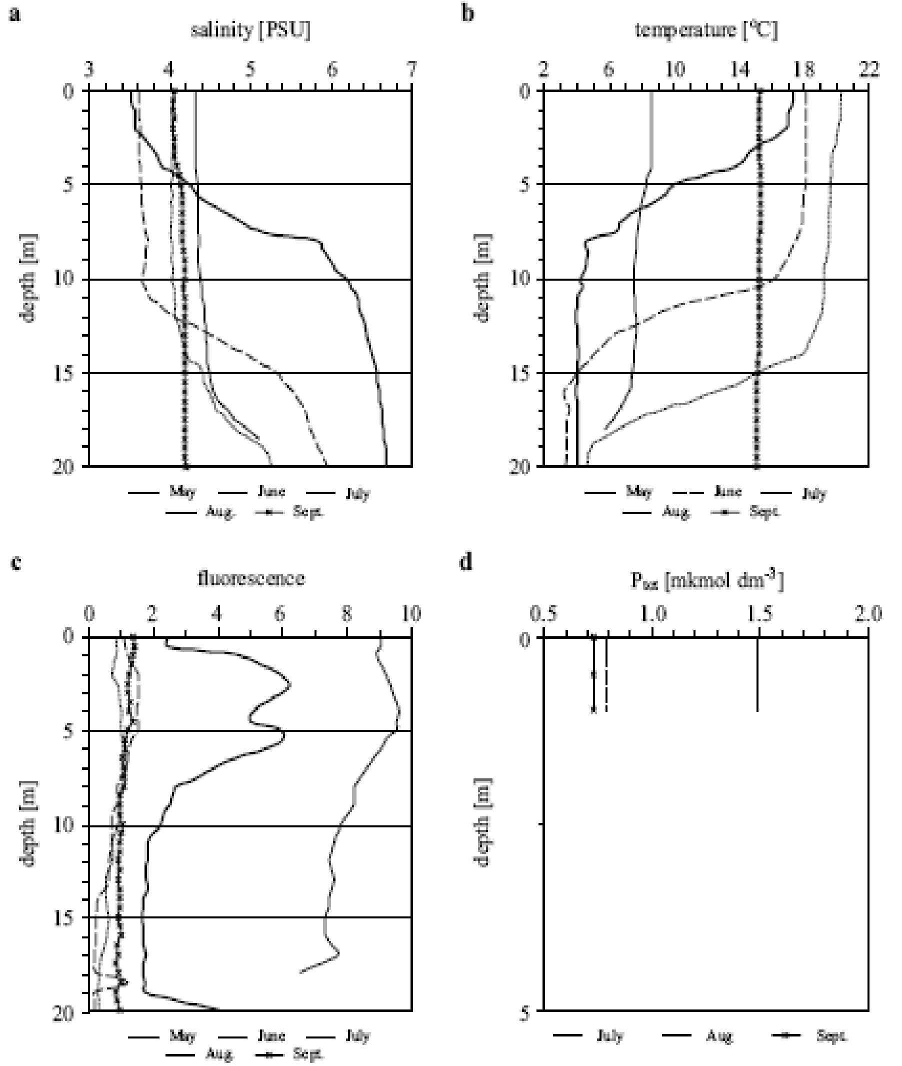
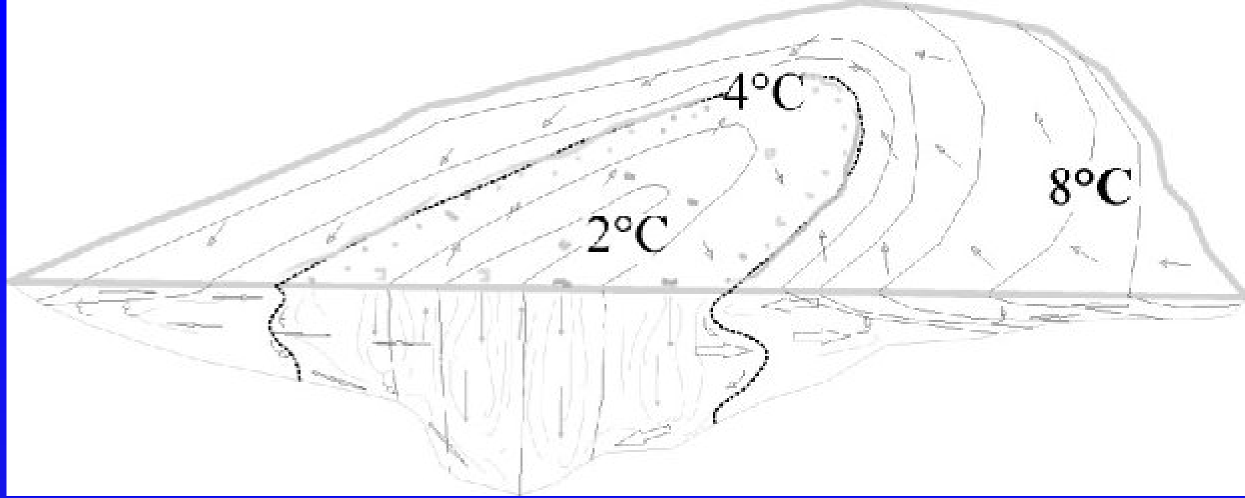
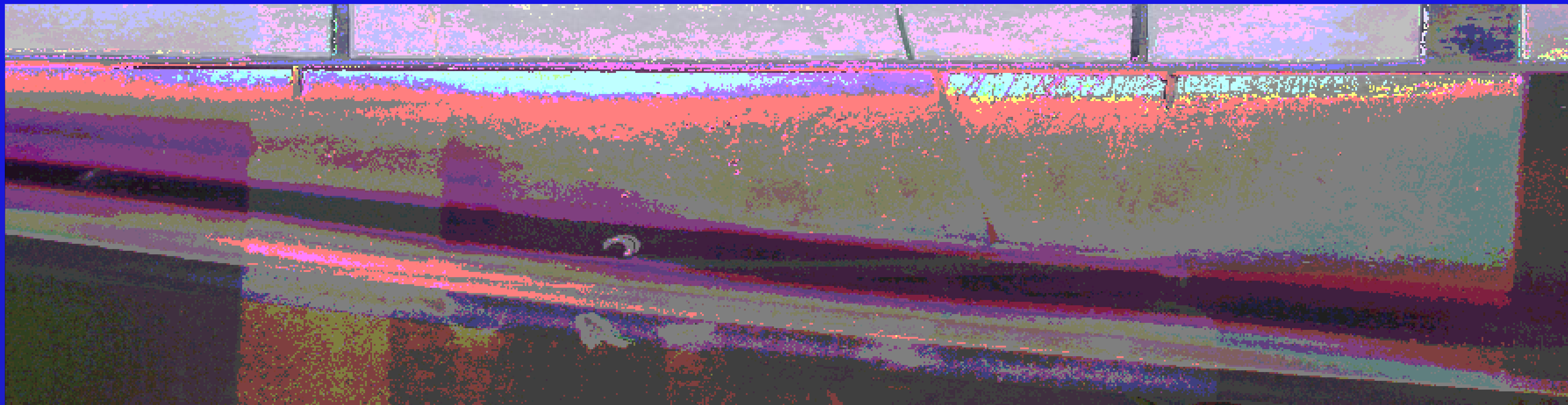
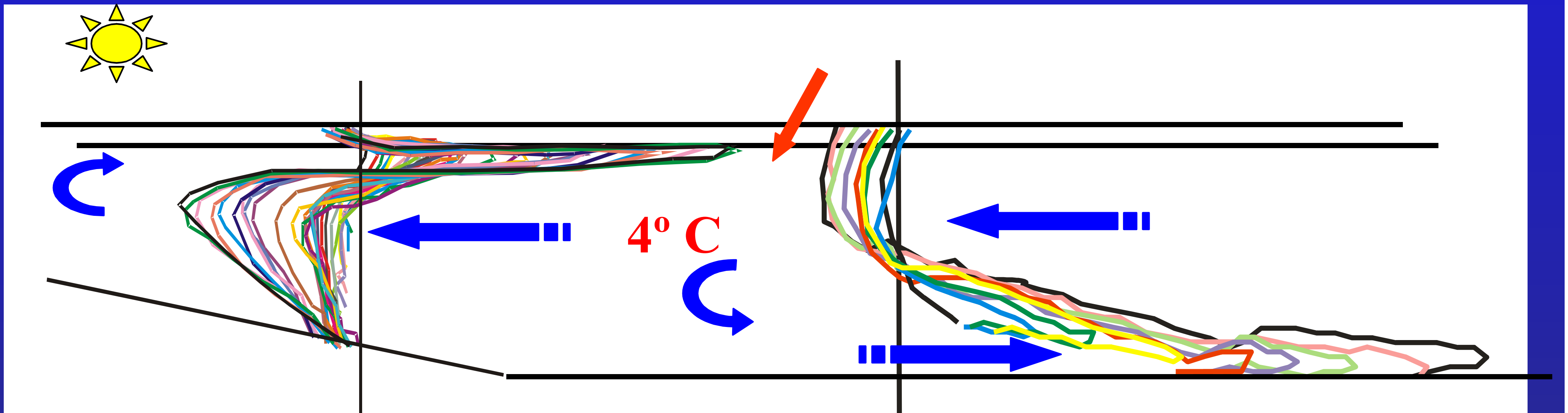


Fig. 6. Vertical profiles of salinity (a), temperature (b) and fluorescence (c), and the averages of three parallel samples of P_{tot} taken from the upper 1 m layer during the three surveys (d) near Kunda. Only the August profiles represent upwelling conditions

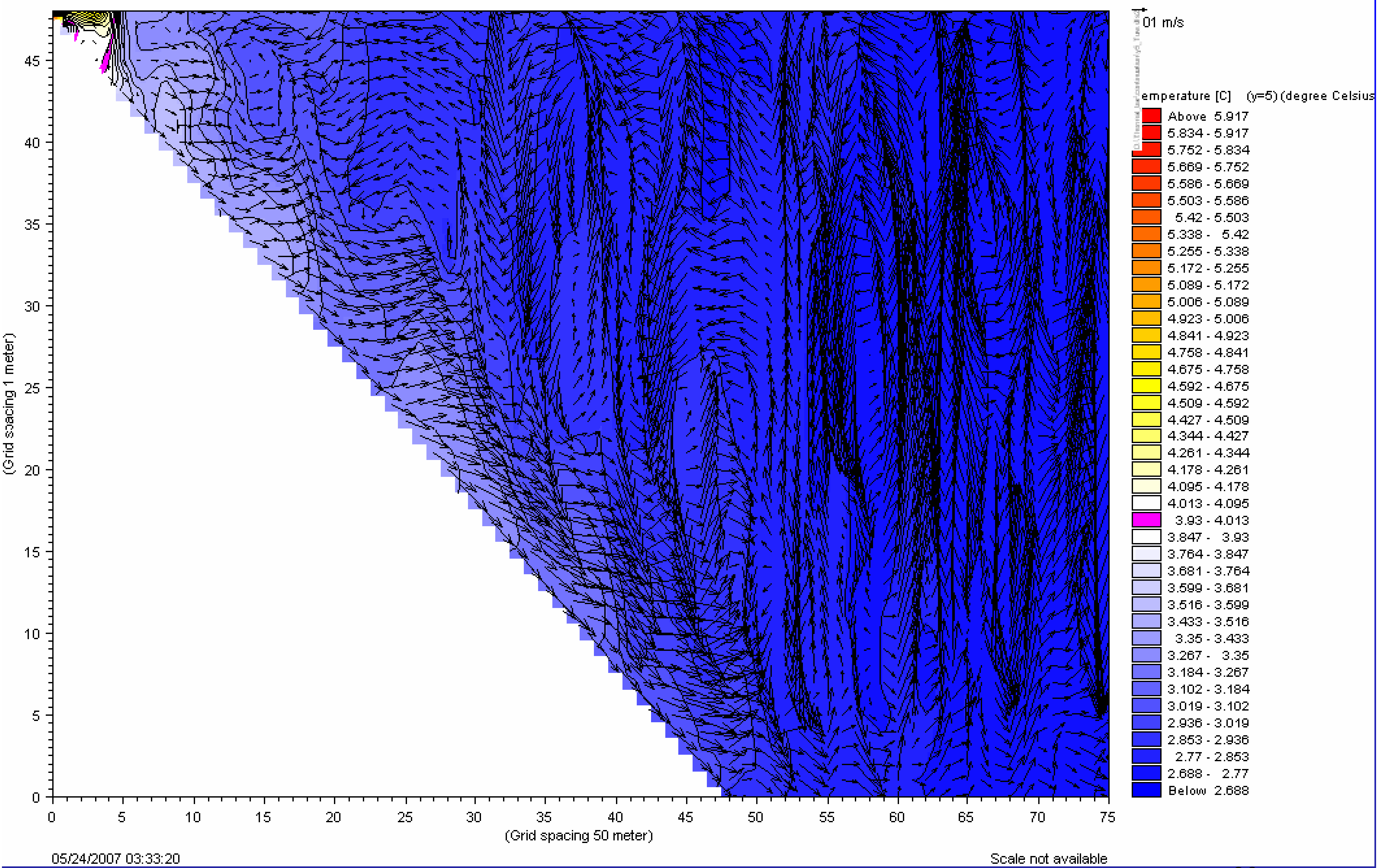
3. Change of the structure: Thermal bar



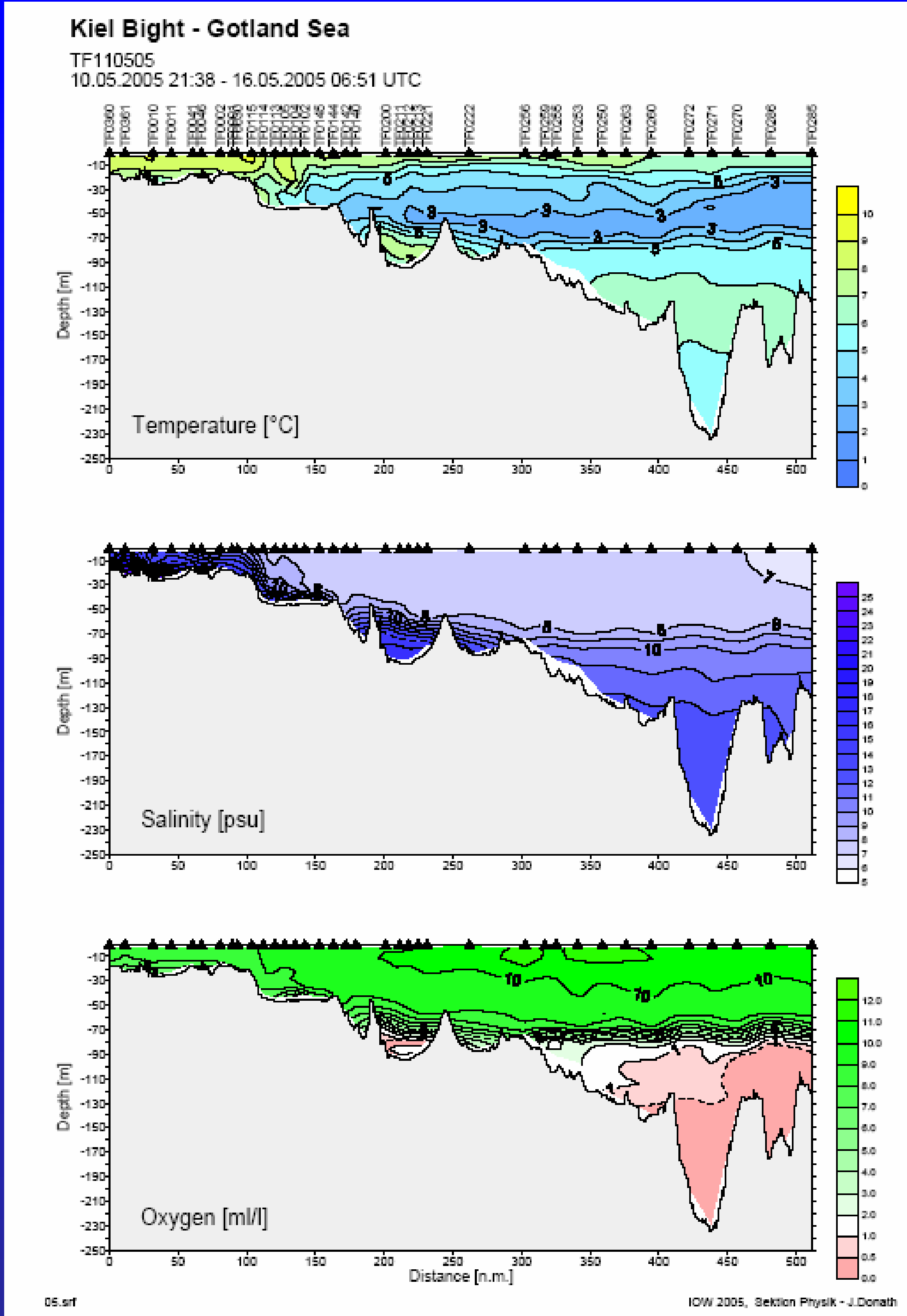


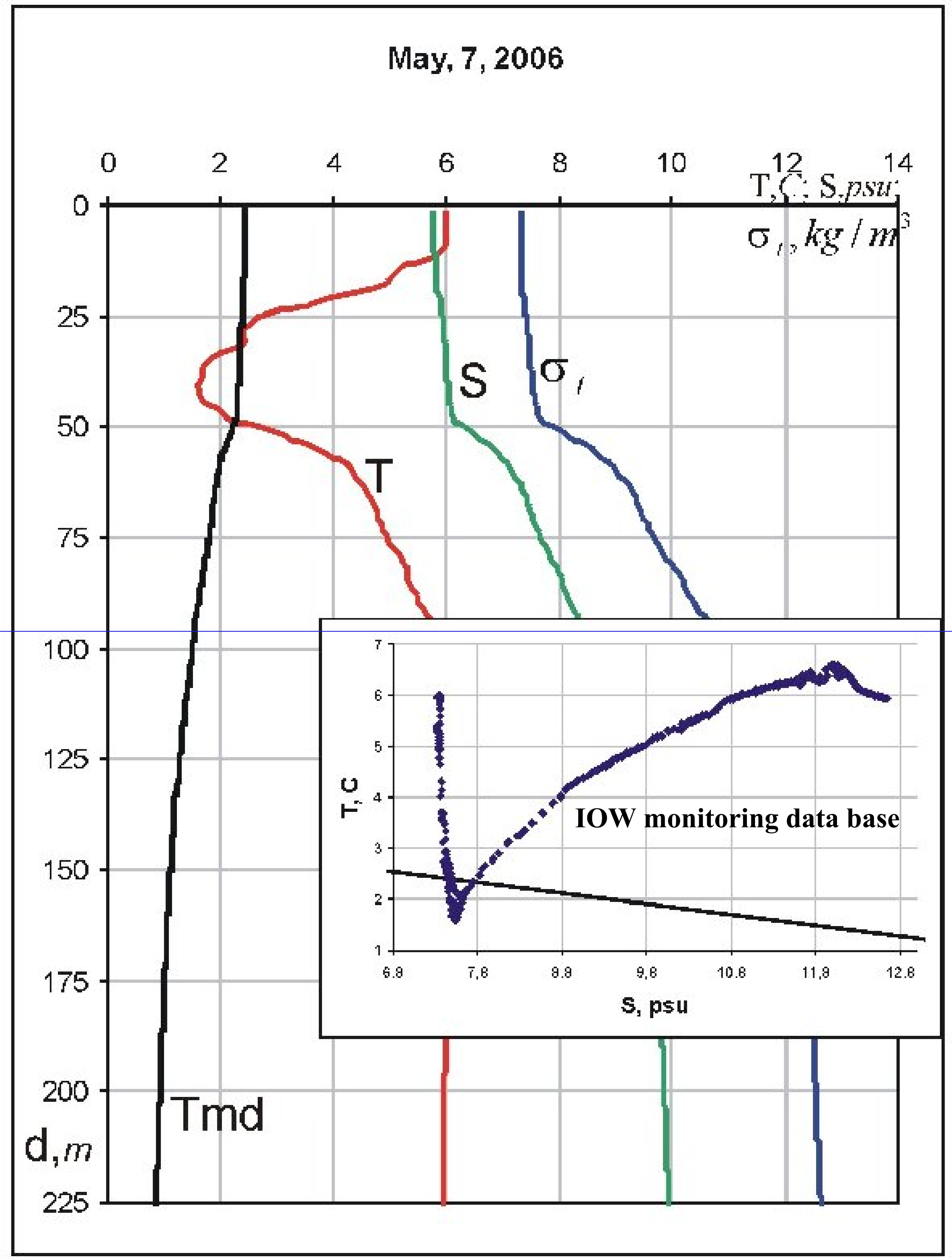


Numerical modelling, MIKE3-FlowModel



Monitoring IOW, May 2005 г.

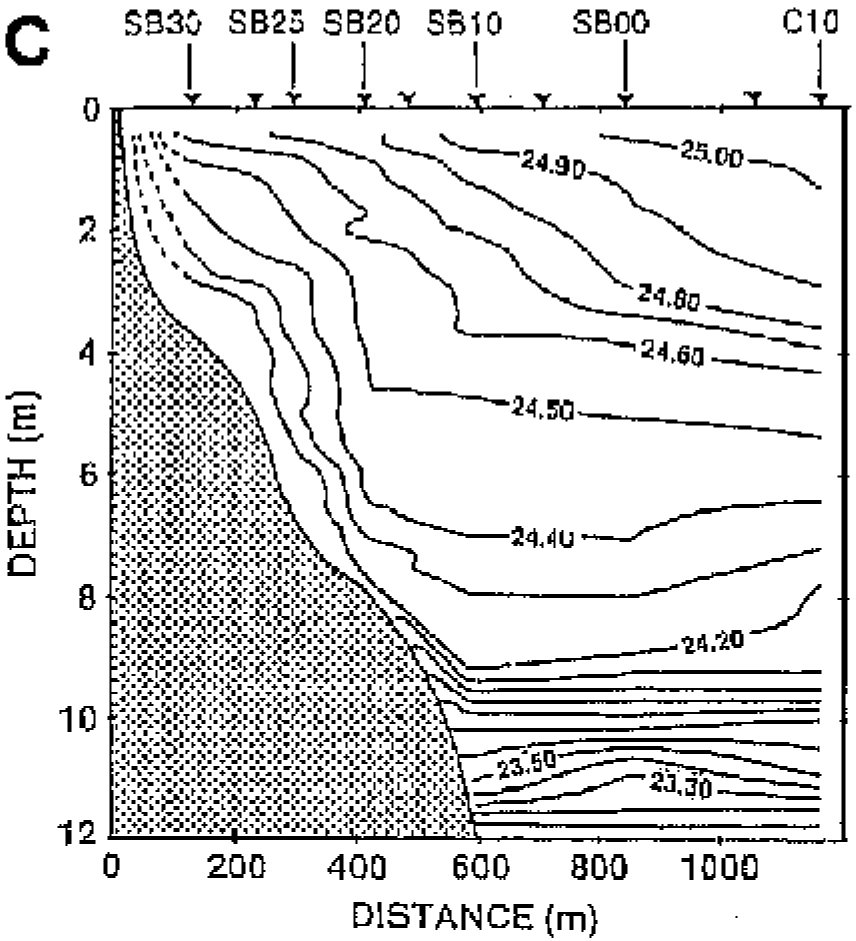


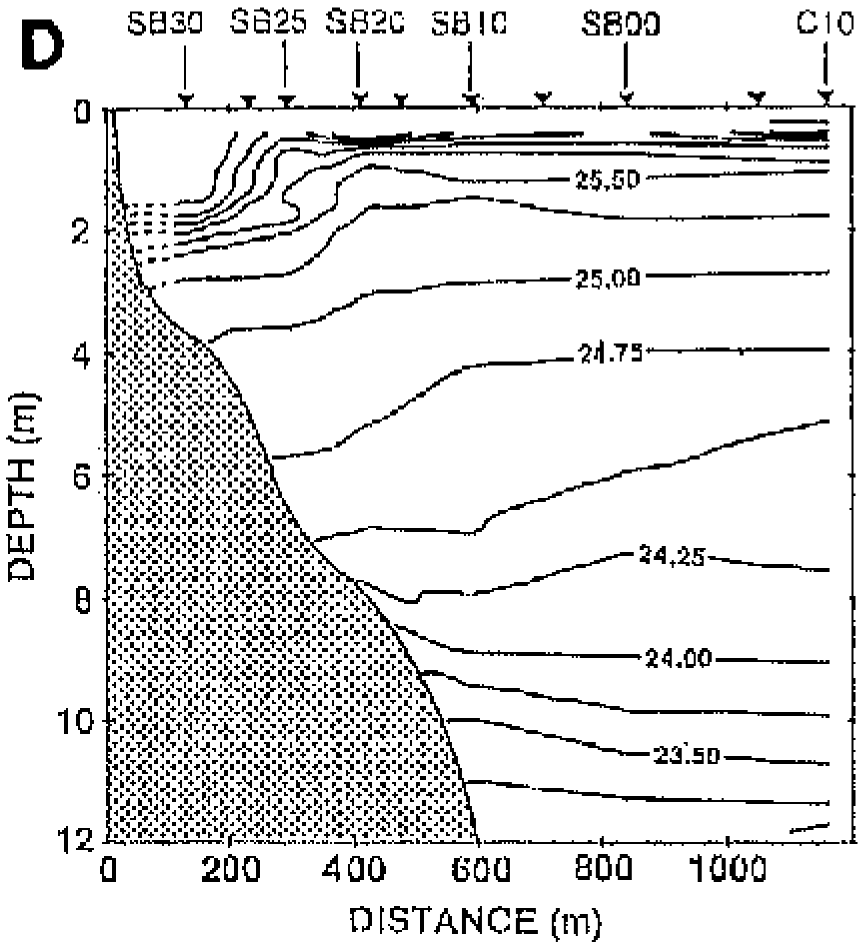

May, 7, 2006
0
2
4
6
8
10
12
14
T,C; S,psu;
σ, kg / m3
0
25
50
75
100
125
150
175
200
225
d,m
T
S
Tmd
IOW monitoring data base
T, C
S, psu
1
2
3
4
5
6
7
6.8
7.8
8.8
9.8
10.8
11.8
12.8

Day/night circulation

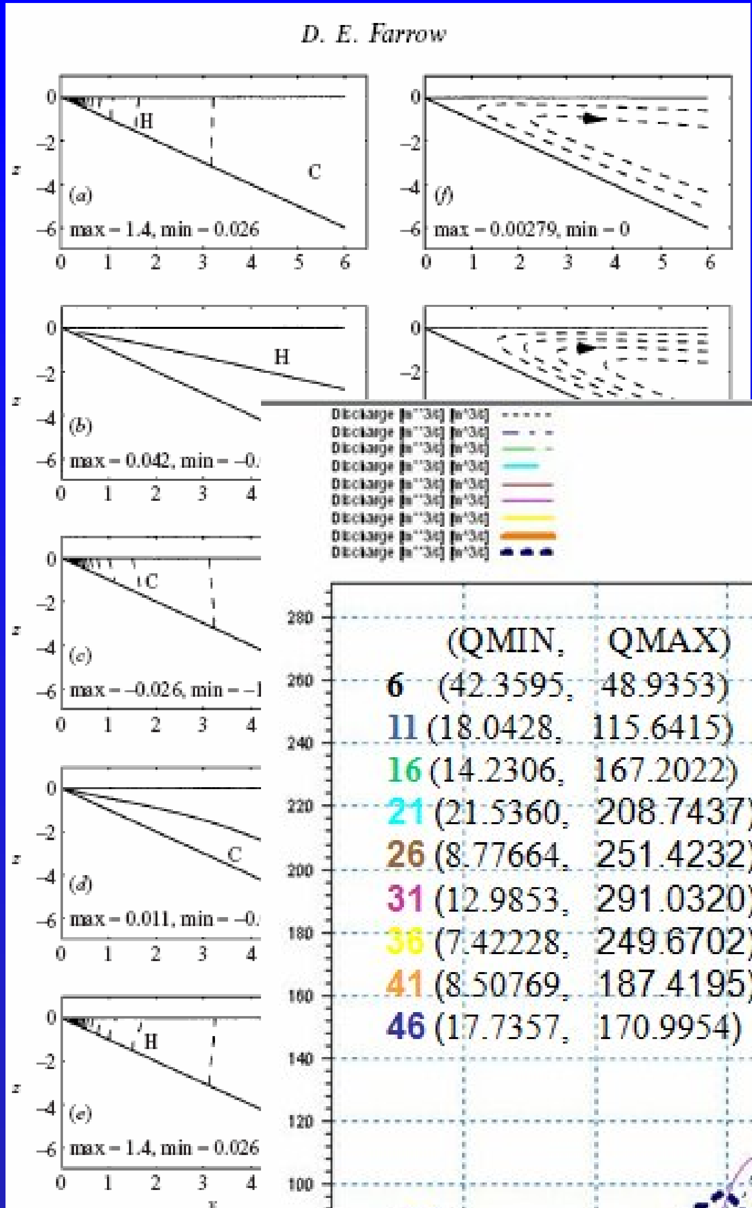
9:00 24 February

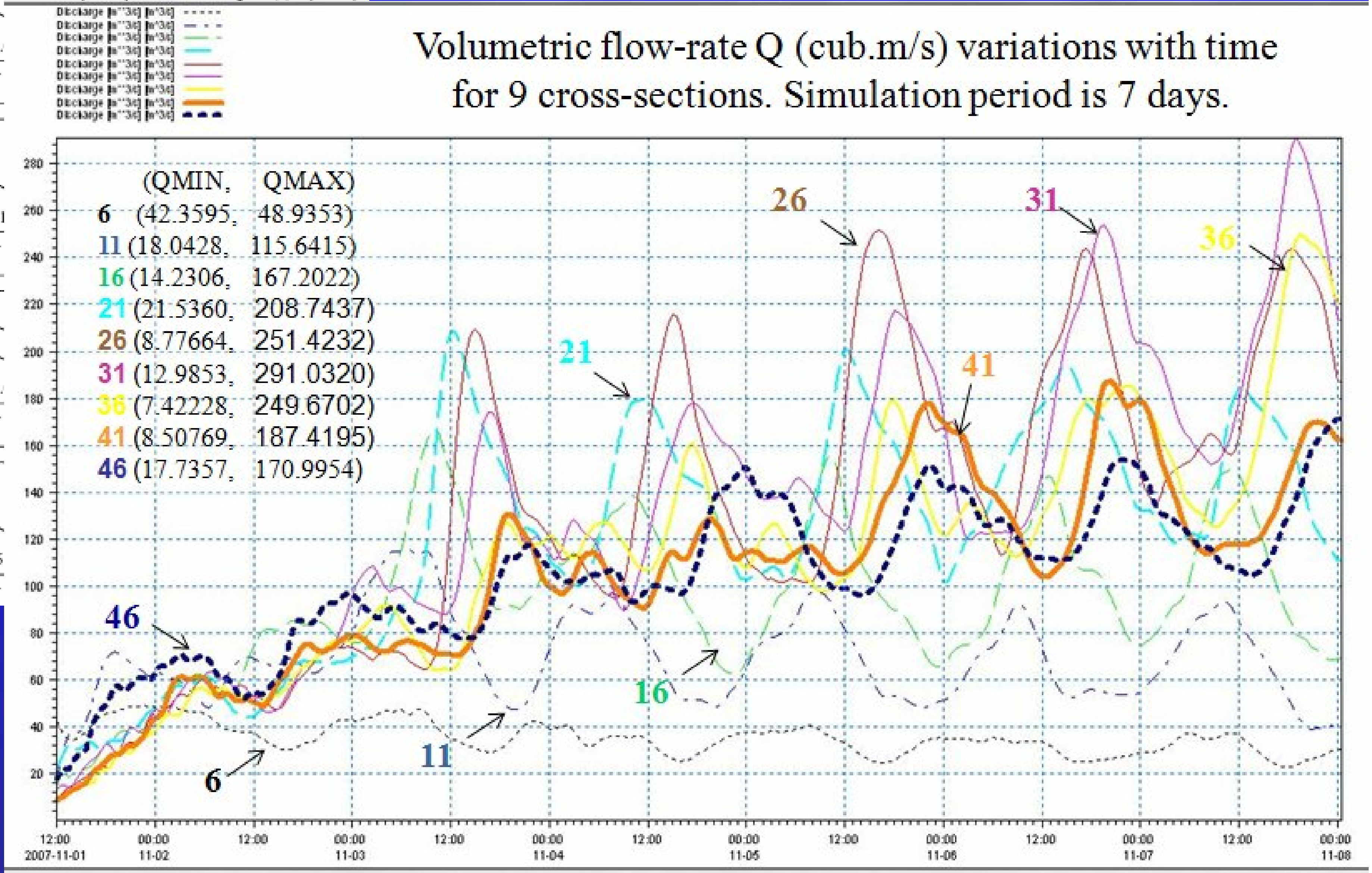
12:00 24 February



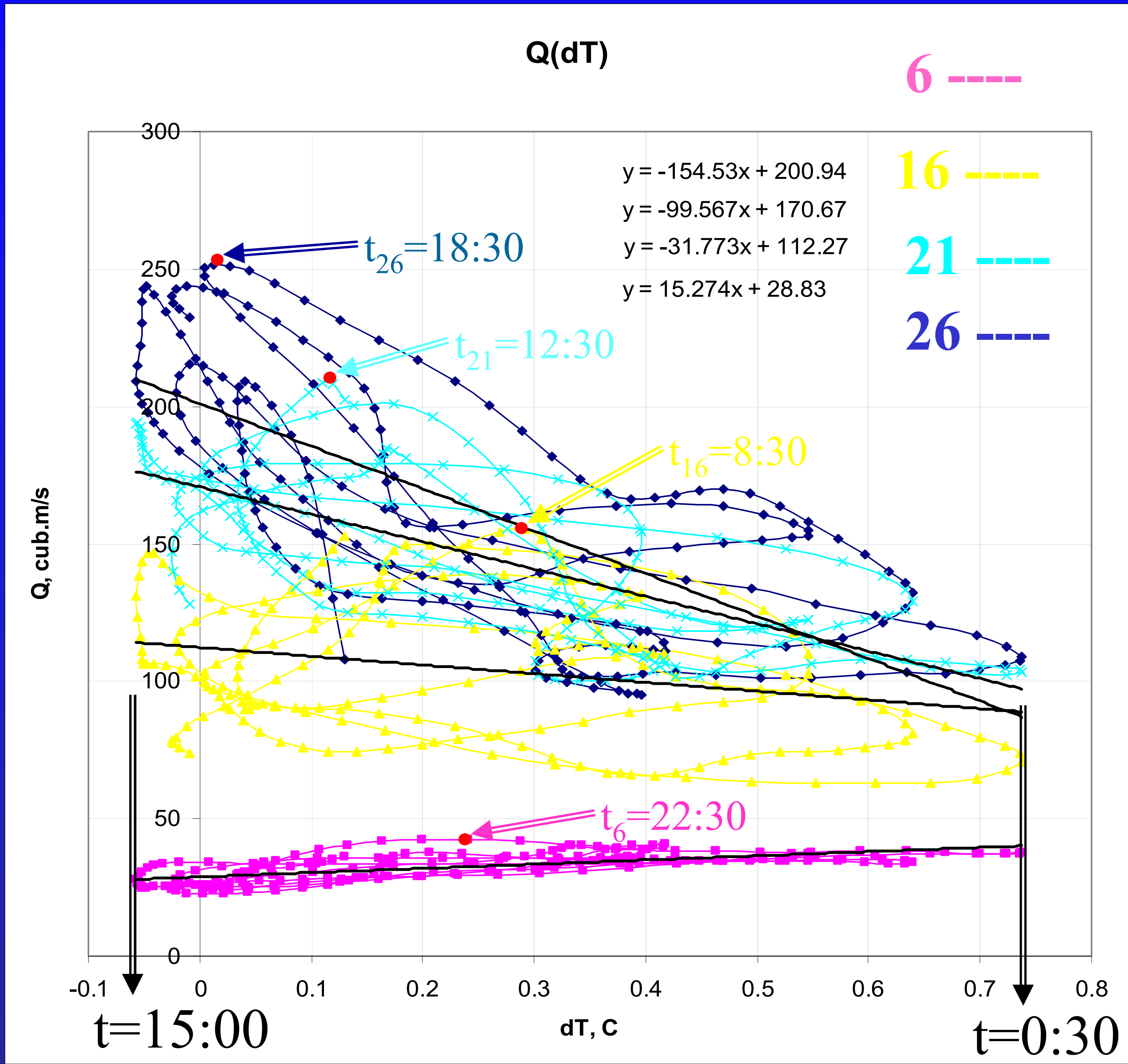


Wellington Reservoir, Australia
Monismith et al., 1985


D. E. Farrow
(a)
max = 1.4, min = 0.026
(f)
max = 0.00279, min = 0
(b)
max = 0.042, min = −0.
(c)
max = −0.026, min = −1
(d)
max = 0.011, min = −0.
(e)
max = 1.4, min = 0.026


Volumetric flow-rate Q (cub.m/s) variations with time
for 9 cross-sections. Simulation period is 7 days.
(QMIN, QMAX)
6 (42.3595, 48.9353)
11 (18.0428, 115.6415)
16 (14.2306, 167.2022)
21 (21.5360, 208.7437)
26 (8.77664, 251.4232)
31 (12.9853, 291.0320)
36 (7.42228, 249.6702)
41 (8.50769, 187.4195)
46 (17.7357, 170.9954)
12:00
2007-11-01
00:00
11-02
00:00
11-03
00:00
11-04
00:00
11-05
00:00
11-06
00:00
11-07
00:00
11-08

Phase curve Q(dT) for the process, plotted for the simulated data at 6 vertical cross-sections. Maximum Q never coincides with maximum dT, and the delay depends on the length along the slope. This shows that in fact the currents are never in phase with external forcing.



Volumetric flow-rate

For the scale of the volumetric flow-rate we have:

$$Q \sim u \cdot h = \left[\frac{\Delta\rho}{\rho} \cdot g \cdot h \right]^{1/2} \cdot h \sim h^{1.5}$$

Horsh&Stefan, 1988; Horsh, et al., 1994:

$$Q \sim Ra^{1/n}, \; where \; 2 < n < 3$$

$$Q \sim h^{1.3 \div 2}$$

Sturman et al. (1999)

$$Q = 0.24\, B^{1/3} (l \tan\theta/(1 + \tan\theta))^{4/3}.$$

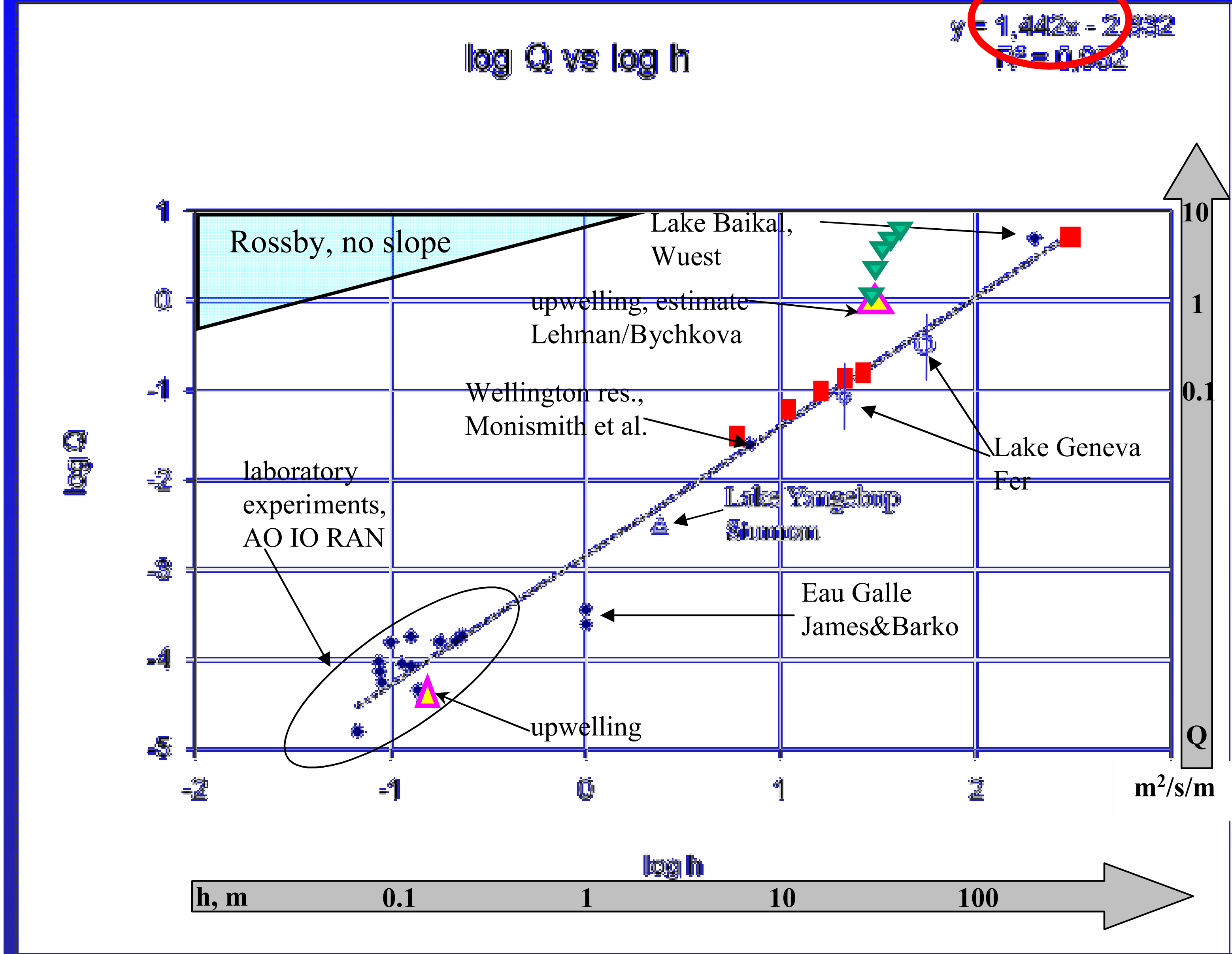
$$Q \sim h^{1.3}$$

Rossby, 1965 (no slope)

$$V \sim \kappa_T Ra_F^{1/6}$$

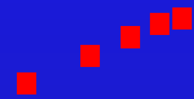
$$V \sim L^{0.66}$$

Steady-state horizontal flow-rate versus the thickness of the thermally affected layer

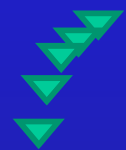


$$Q \sim \left[\frac{\Delta\rho}{\rho} \cdot g \right]^{1/2} \cdot h^{3/2}$$

The trend is calculated from the experimental data only.
Points

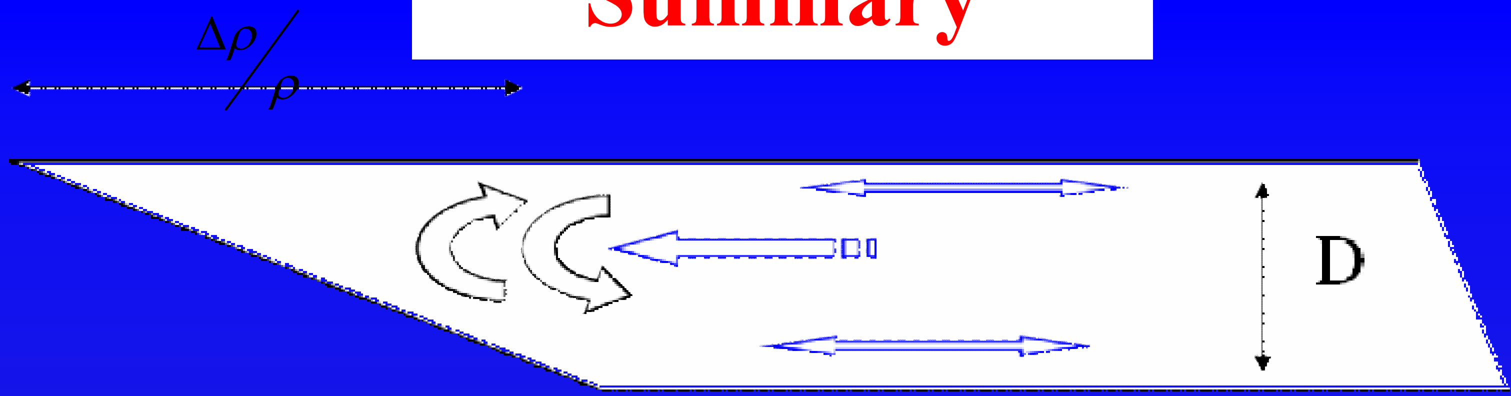


are from numerical modelling, and points



- estimates for the Blach Sea (Титов, 2004)

Summary



-the exchange embraces the entire basin in horizontal, and is generally two-layered in vertical;

-horizontal convective exchange flows are unsteady (even under constant external conditions); 3-dimensional, prone to the formation of the convective cells, rolls etc.;

- the flow is inertial; currents lag after external forcing;

- for the volumetric flow-rate and flushing time, the main governing parameter is the thickness of the thermally-affected layer; surface buoyancy flux and bottom slope are less important;

-the horizontal convective exchange is larger (i) at the end of the slope, (ii) near gentle rather than steep slope, (iii) under stronger surface heat fluxes.


Thank you
for your attention!