OBSERVATIONS AND MODELING OF INTERNAL WAVES IN THE SHELF ZONE OF THE JAPAN/EAST SEA

V.V.Navrotsky, V.Yu. Liapidevskii, E.P.Pavlova

POI FEB RAS

LIH SB RAS

navrotskyv@poi.dvo.ru

liapid@hydro.nsc.ru

pavlova@poi.dvo.ru

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- General: energy and structure considerations
- Observations of internal waves in the coastal ocean
- Modeling of internal wave generation and propagation in the shelf zone
- Consequences:
  - a) diffusion amplification
  - b) fine structure formation
  - c) nonlinear fluxes to higher modes, thermocline splitting, and layering of vertical structure – positive feedback

Internal waves on a sloping bottom

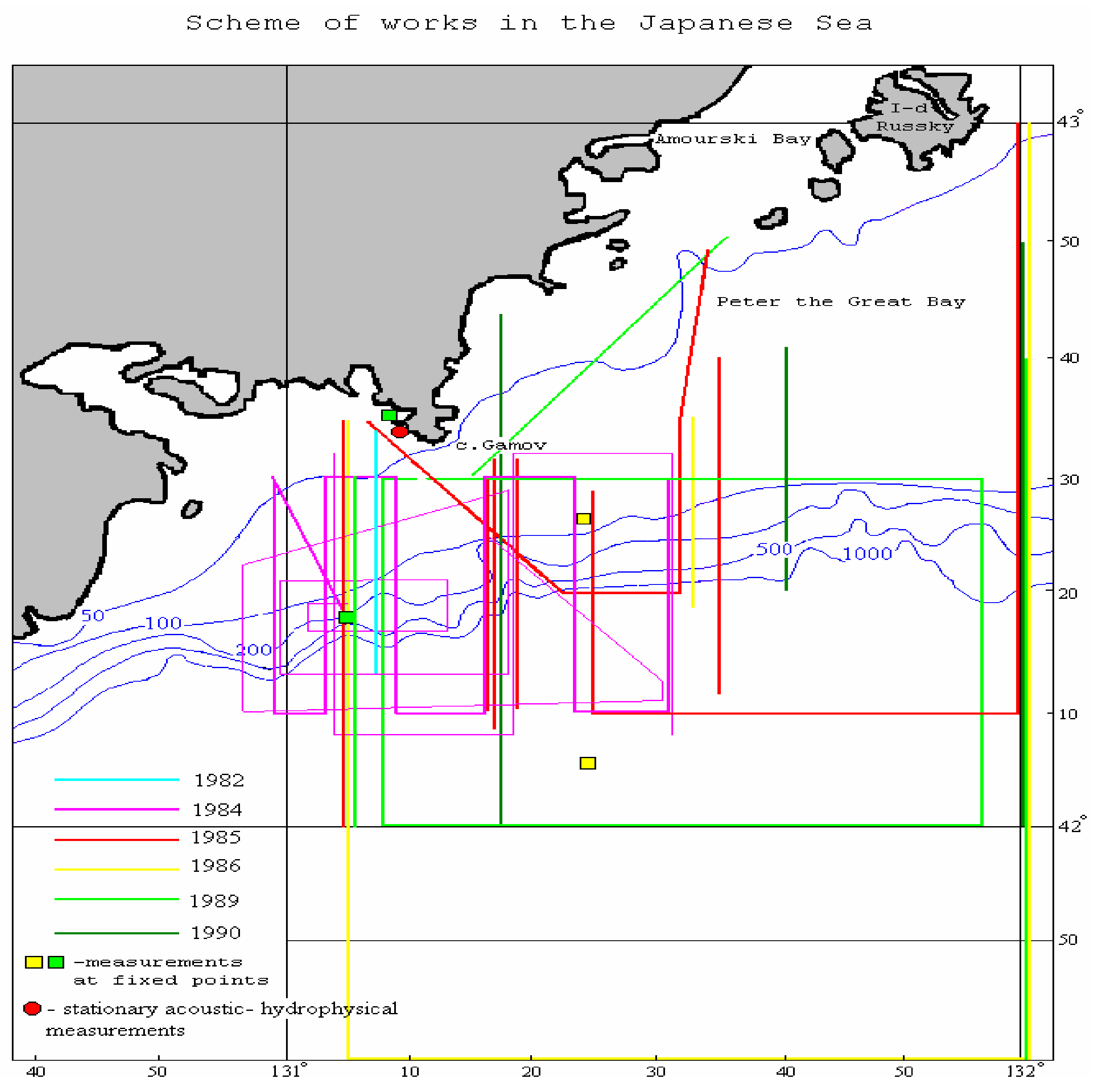
Experiments in the Japanese/East sea

Observations of internal waves in the coastal ocean

- Temporal fluctuations – examples Jap. Sea, Australian shelf (Holloway)
- Spatial fluctuations – transects with linear sensors

General view of the geophysical measurement site

Region of observations



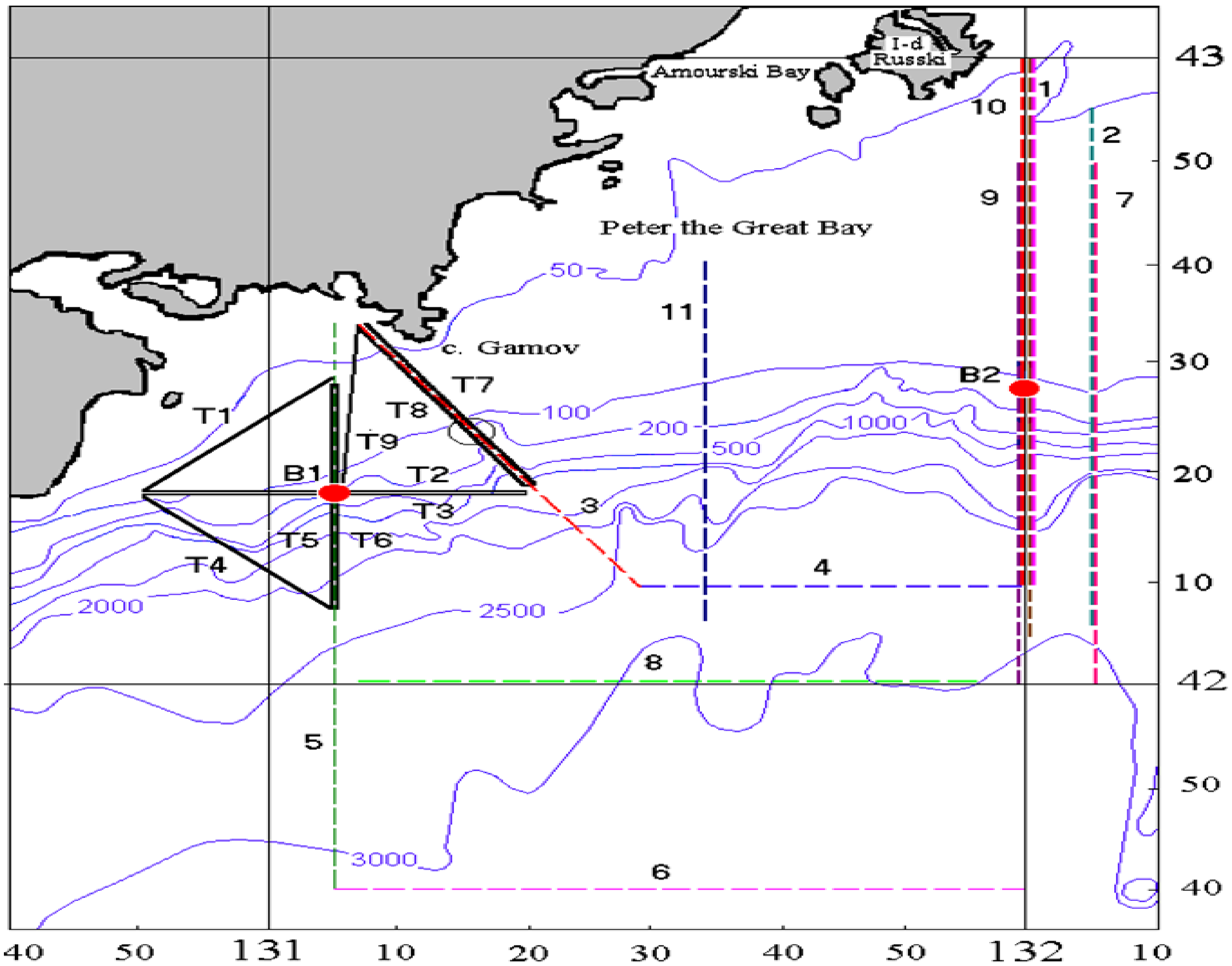
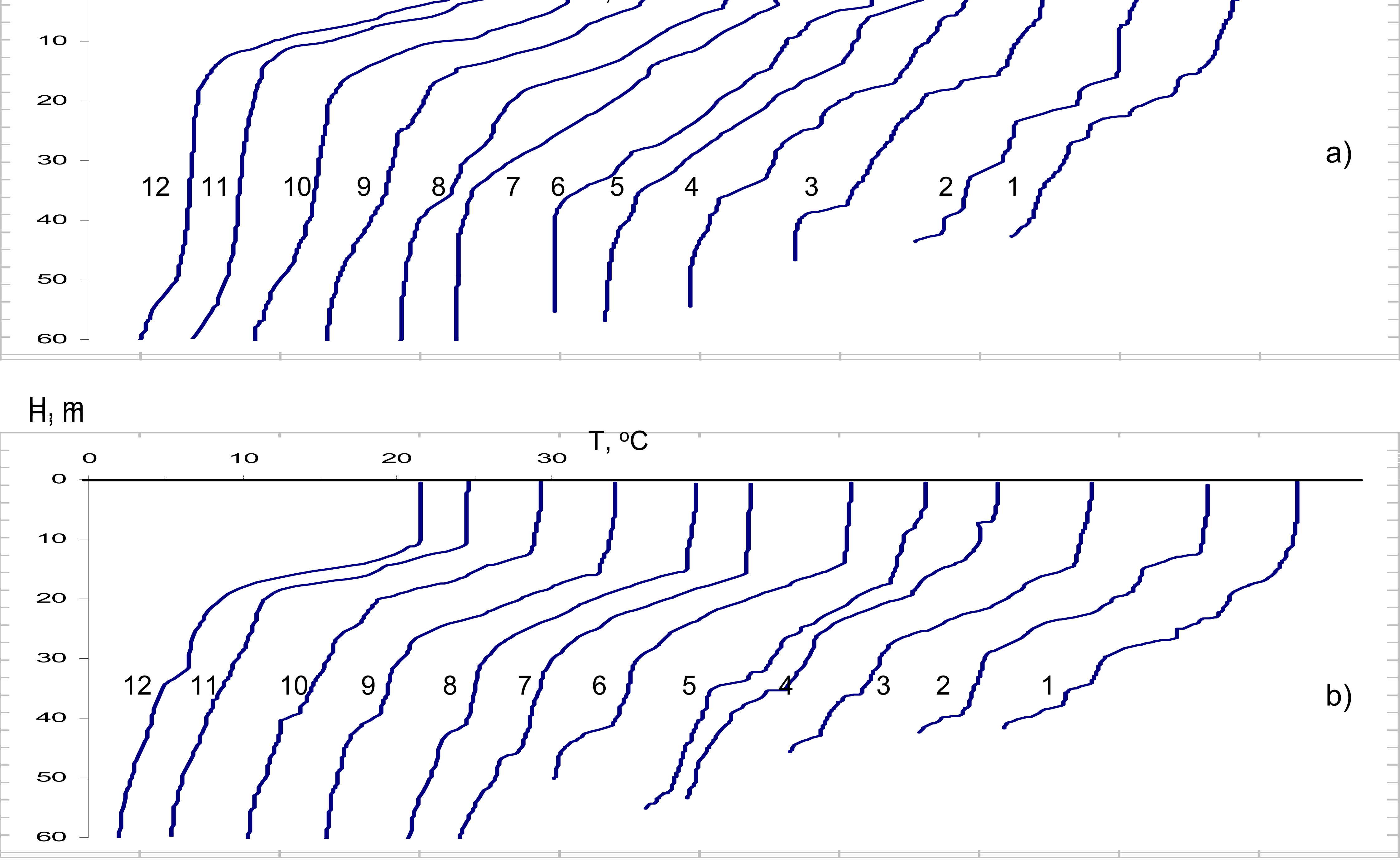


Fig. 1. The study region. Dotted lines for runs with CTD-probing, solid lines for runs with towed sensors. Black circles show locations of the stations where observations during 1-3 days were made.



Temperature profiles along transects across the shelf boundary: 12.08.2006

Fig. 2. Internal wave records in fixed points: a) Point B1 (start at 19:30, 05.09.1984);
b) Point B2 (start at 13:24, 28.09.1986).

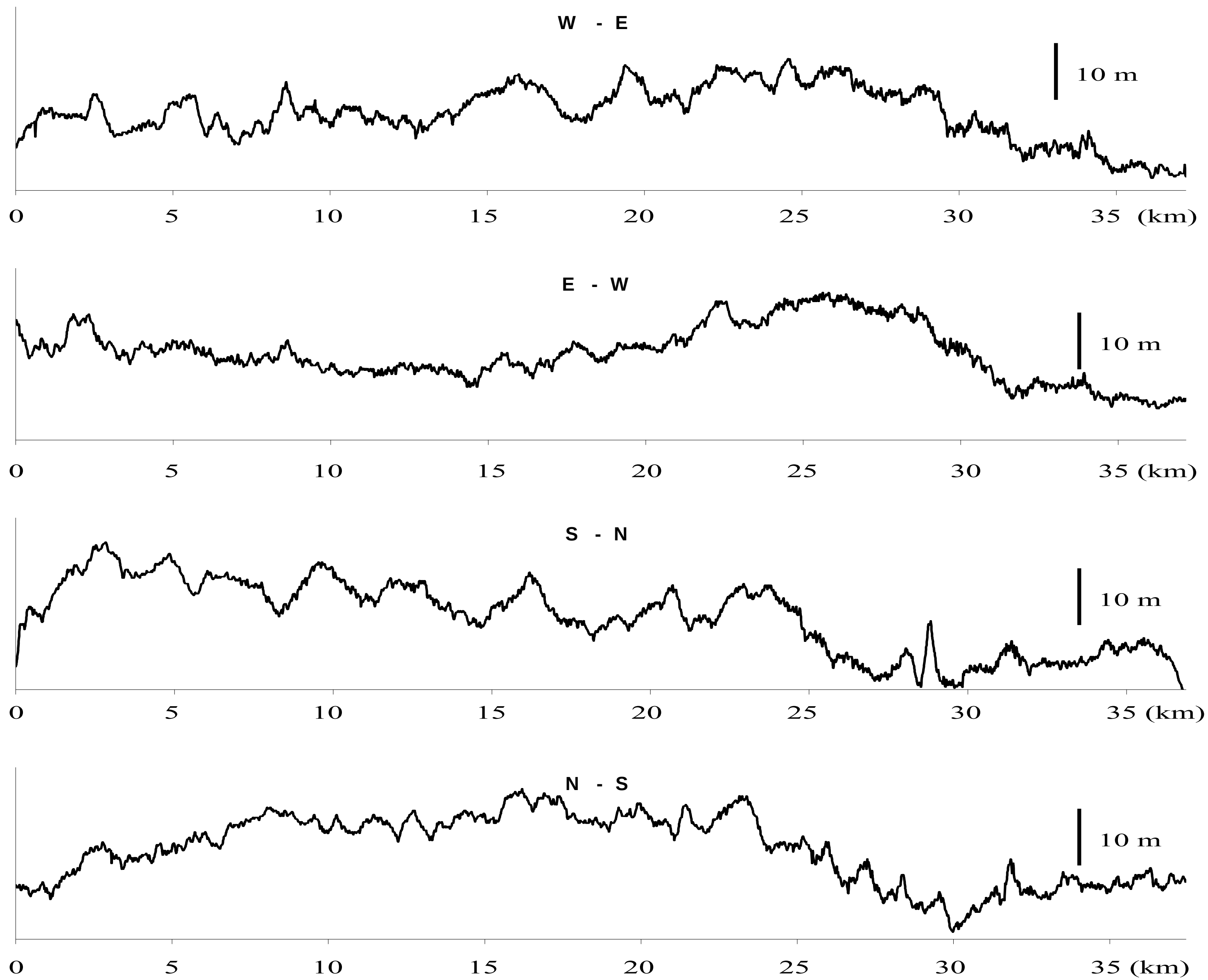


Fig. 3. Vertical movements in the thermocline, obtained with the help of the towed line sensor on crossing runs (see Fig. 1).

b) Thermocline splitting, fine structure formation

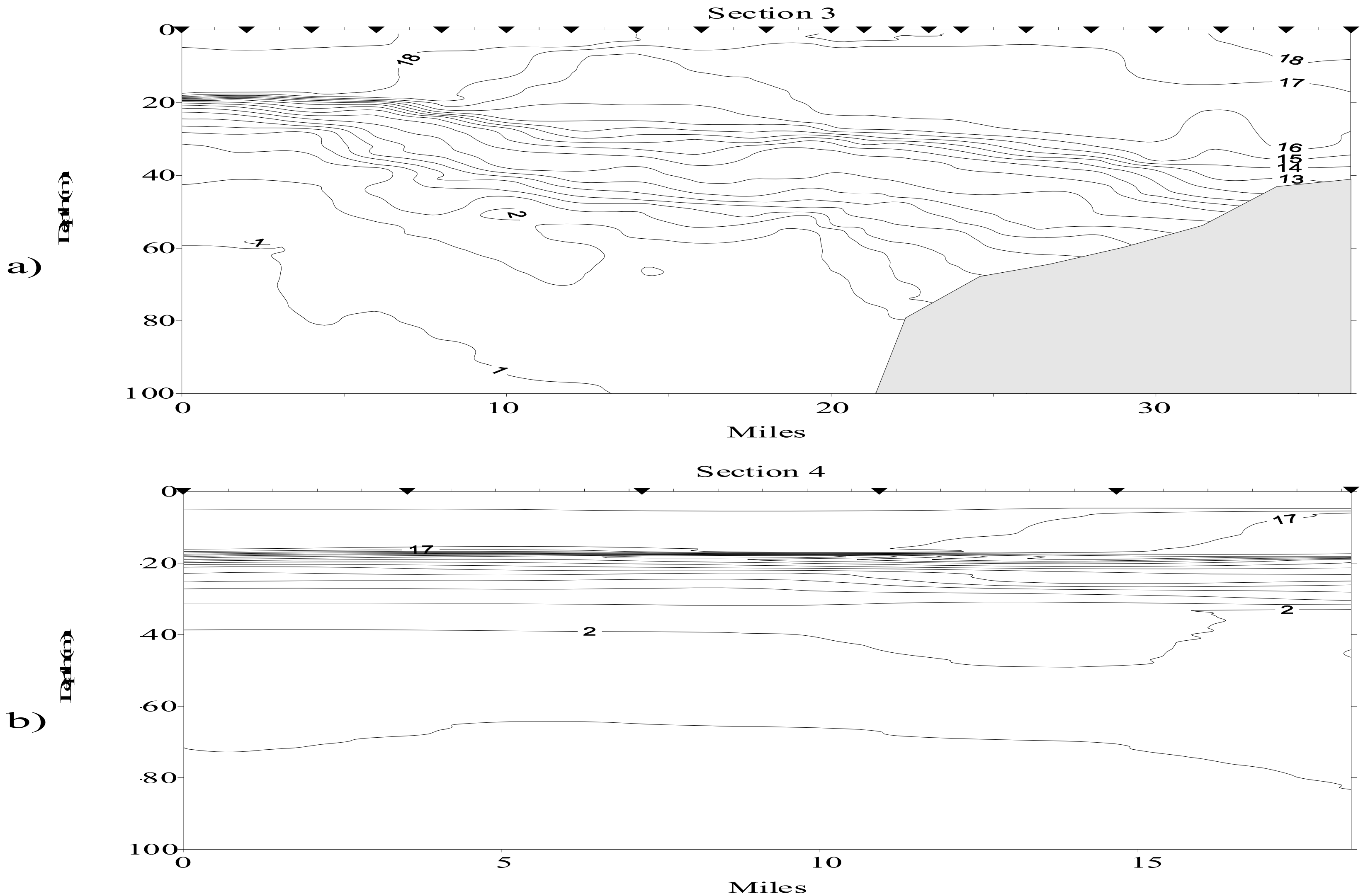


Fig. 5. Sections of temperature:
a) across isobaths, 22. 07.1985, along run 3;
b) along isobaths, 23.07.1985, along 42^{o} 10′ N.

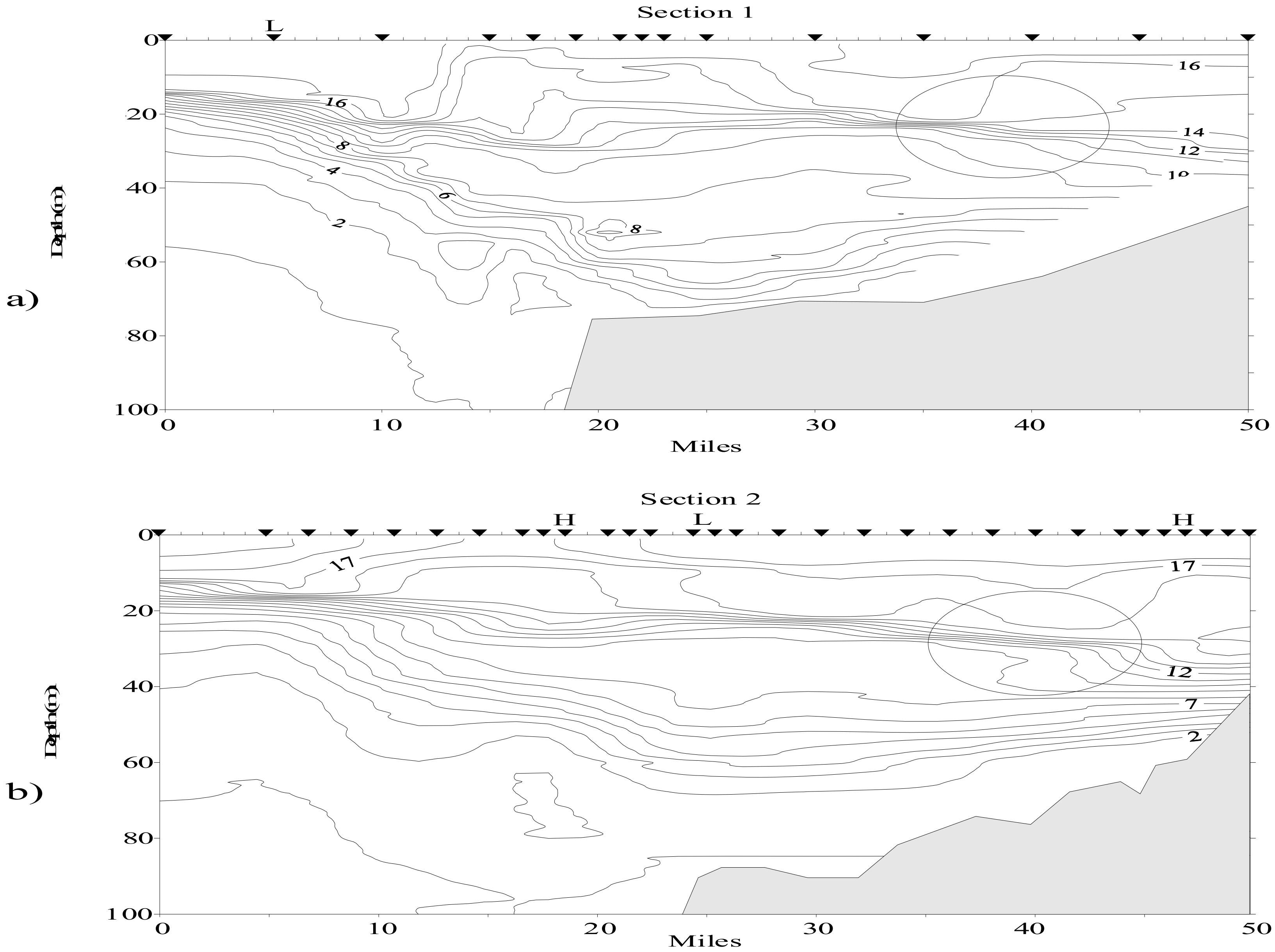


Fig. 4. Section of temperature distribution along transects across the slope and shelf boundary: a) 13-14. 07.1985; b) 15-16.07.1985. Triangles mark position of the stations with CTD-probing.

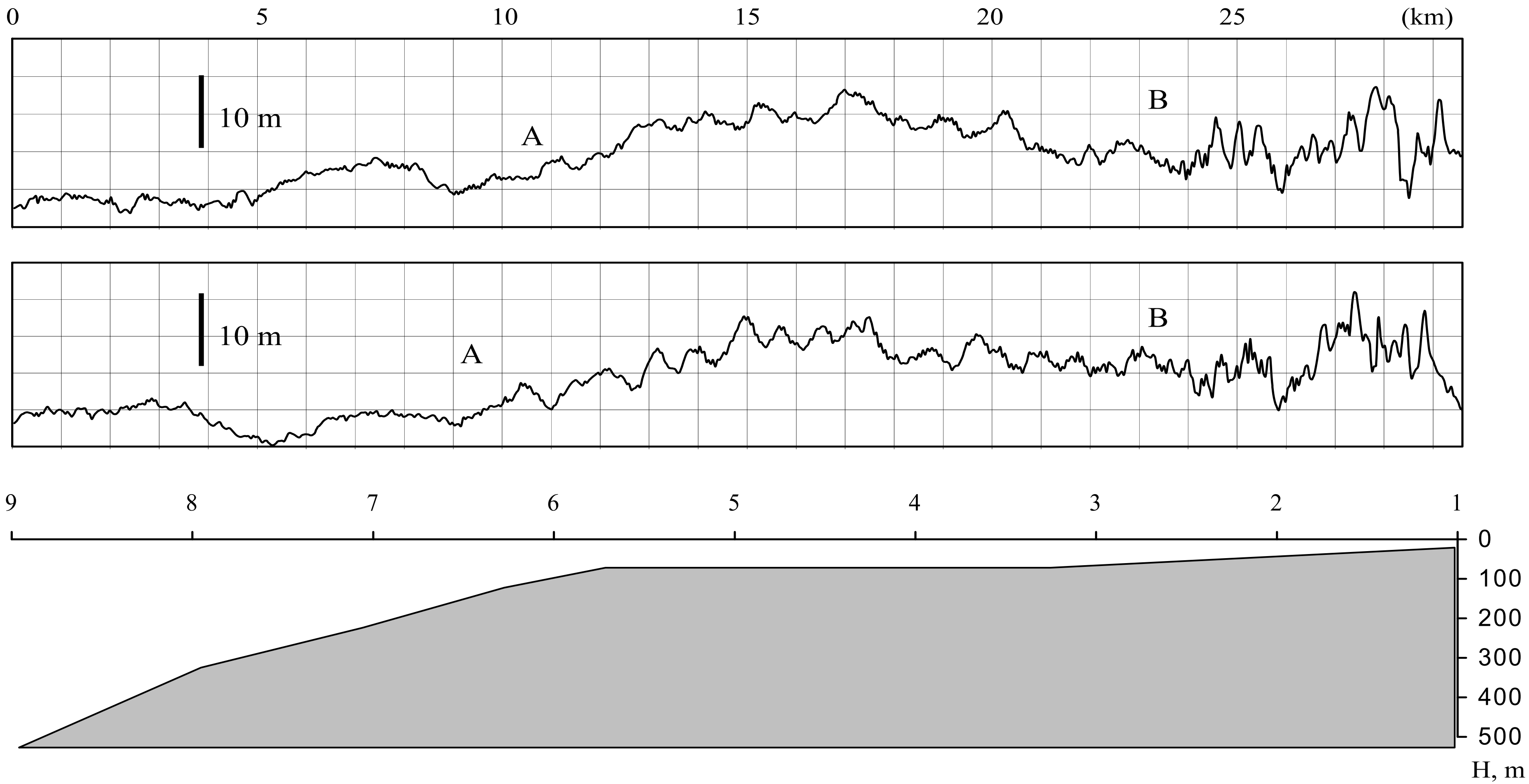


Fig. 4. Offshore and onshore runs across shelf and shelf break, 23.09.1984. Numbers 1-9 mark positions of the stations with CTD-probing.

Models of internal wave generation and propagation in the shelf zone

- Equations and calculations
    - Generation near the shelf break
- Propagation and transformation - ACD

Equations

$$\left(U+W_1\right)_\tau+\left(\tfrac{1}{2}U^2+gZ+W_2\right)_\xi+\frac{P_\xi}{\rho}-\frac{1}{\rho^2}\overline{\rho' k p'_\theta}=\frac{1}{\rho}\left[\mu\left(U_\eta+W_3\right)\right]_\eta-\nu W_4 \tag{1}$$

$$\rho C\left(T_\tau+UT_\xi\right)=\left[\lambda\left(1+\overline{z'^2_\eta}+k^2\,\overline{z'^2_\theta}\right)T_\eta\right]_\eta \tag{2}$$

$$S_\tau+\left[U\left(1-S\right)\right]_\xi=0 \tag{3}$$

$$P_\eta=-\rho g \tag{4}$$

$$\rho\left(1+Z_\zeta\right)=\rho_0\left(1-S\right) \tag{5}$$

$$\begin{aligned}&\rho\left(U-c\right)^2k^2z'_{\theta\theta}+\rho g z'_\eta+p'_\eta=0,\\ &p'=\rho\left(U-c\right)^2z'_\eta-\rho g z',\end{aligned} \tag{6}$$

$$\rho C(U-c)(kt'_\theta - T_\xi z'_\eta)' = -2(\lambda T_\eta)_\eta z'_\eta - \lambda T_\eta (z'_{\eta\eta} + k^2 z'_{\theta\theta}) \tag{7}$$

$$\left[\int \rho k^{-1} W_1 d\eta\right]_\tau + \left[\int \rho k^{-1}(U-c)\left(c\overline{z'^2_\eta} + Uk^2\overline{z'^2_\theta}\right)d\eta\right]_\xi - \int \rho^{-1}\overline{\rho' p'_\theta}\, d\eta =$$
$$- \int \mu k^{-1} W_4 d\eta + \delta\left\{\mu k^{-1}\left[\tfrac{1}{2}(U-c)\left(\overline{z'^2_\eta} + k^2\overline{z'^2_\theta}\right)_\eta + U_\eta\left(3\overline{z'^2_\eta} + k^2\overline{z'^2_\theta}\right)\right]\right\} \tag{8}$$

ξ, ζ, τ – horizontal Euler coordinate, vertical Lagrange coordinate and time,

T, *U* и *S* – mean temperature of a layer, Lagrange mean horizontal velocity and mean deformation coefficient of a layer, 1-S – horizontal compression of fluid element relative to the standard state, “layer” means the aggregate of fluid particles having the same Lagrange coordinate,

ρ_0 – standard density,

$$W_1 = (U - c)\left(\overline{z'^2_\eta} + k^2\,\overline{z'^2_\theta}\right)$$

,

$$W_2 = UW_1 + \tfrac{1}{2}(U - c)^2\left(\overline{z'^2_\eta} - k^2\,\overline{z'^2_\theta}\right)$$

,

$$\mu W_3 = \mu\left[U_\eta\left(6\overline{z'^2_\eta} + 2k^2\,\overline{z'^2_\theta}\right) + (U - c)\left(2\overline{z'^2_\eta} + k^2\,\overline{z'^2_\theta}\right)_\eta\right]$$

,

$$-\nu W_4 = -\nu\left[2U_\eta\left(k^2\,\overline{z'^2_\theta} + \overline{z'^2_\eta}\right)_\eta + (U - c)\left(k^4\,\overline{z'^2_{\theta\theta}} + 2k^2\,\overline{z'^2_{\theta\eta}} + \overline{z'^2_{\eta\eta}}\right)\right]$$

$\eta=\zeta+Z$, $\theta_\xi = \mathrm{k}$

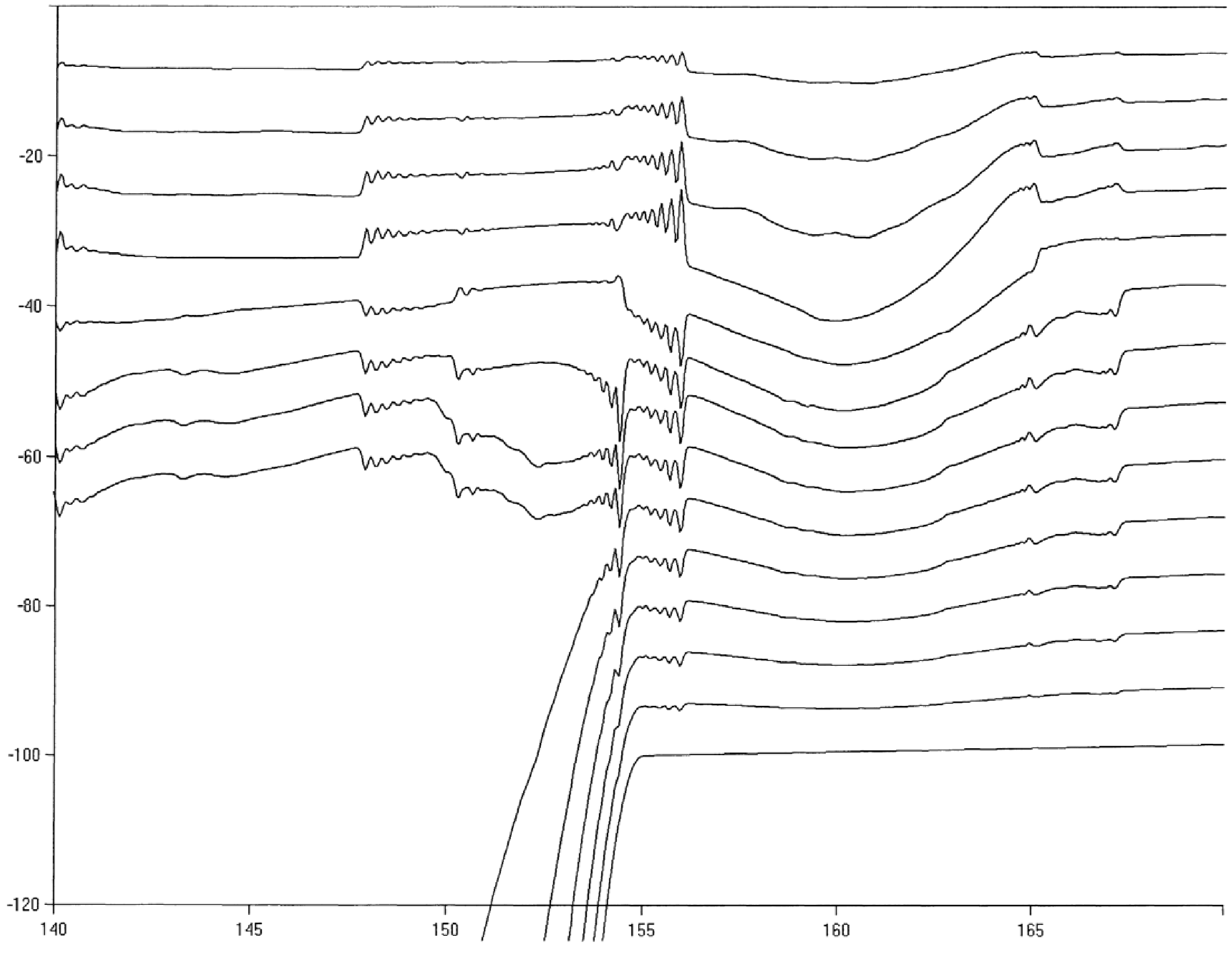
,

,

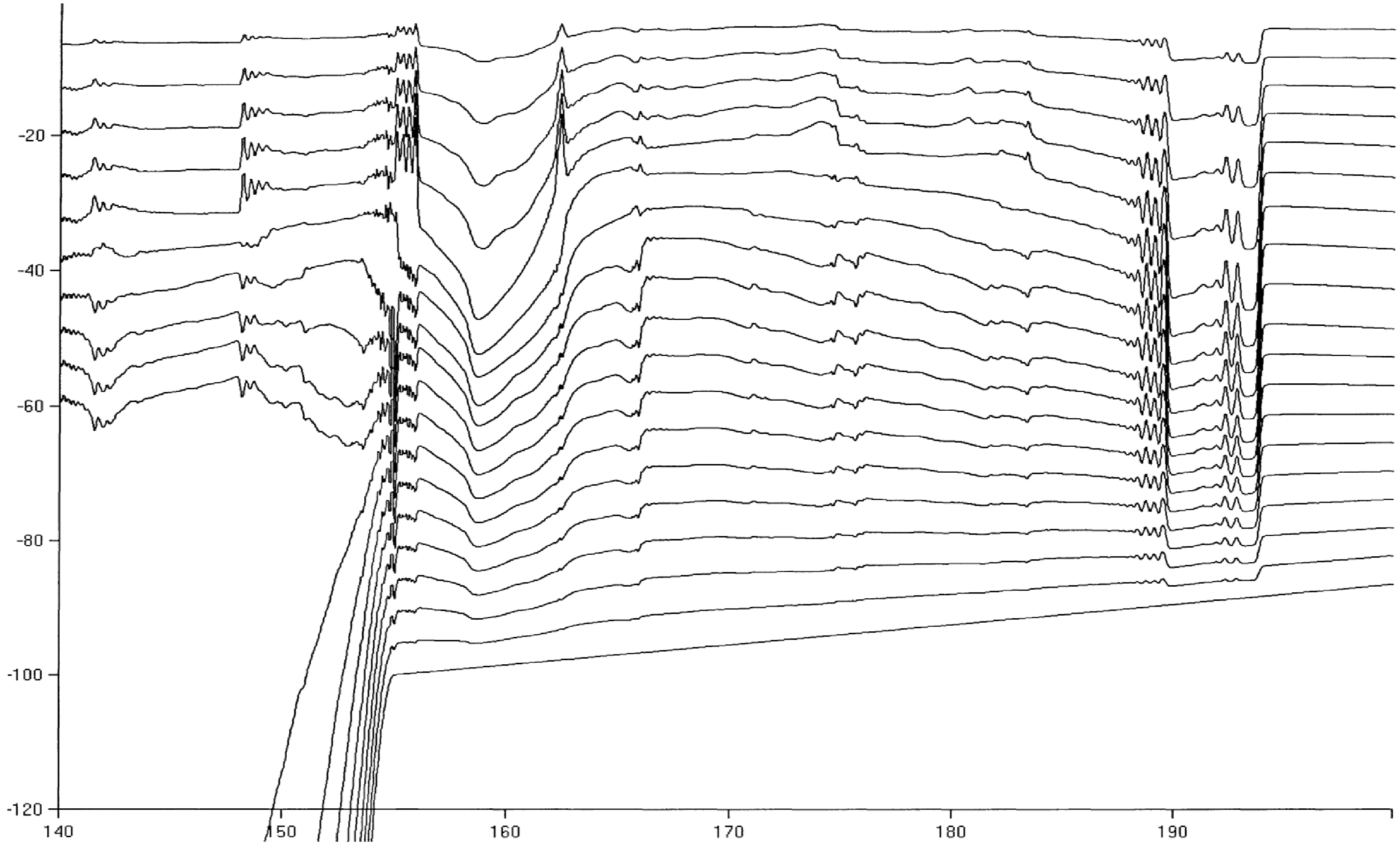
,

$$c = -\theta_\tau / k$$

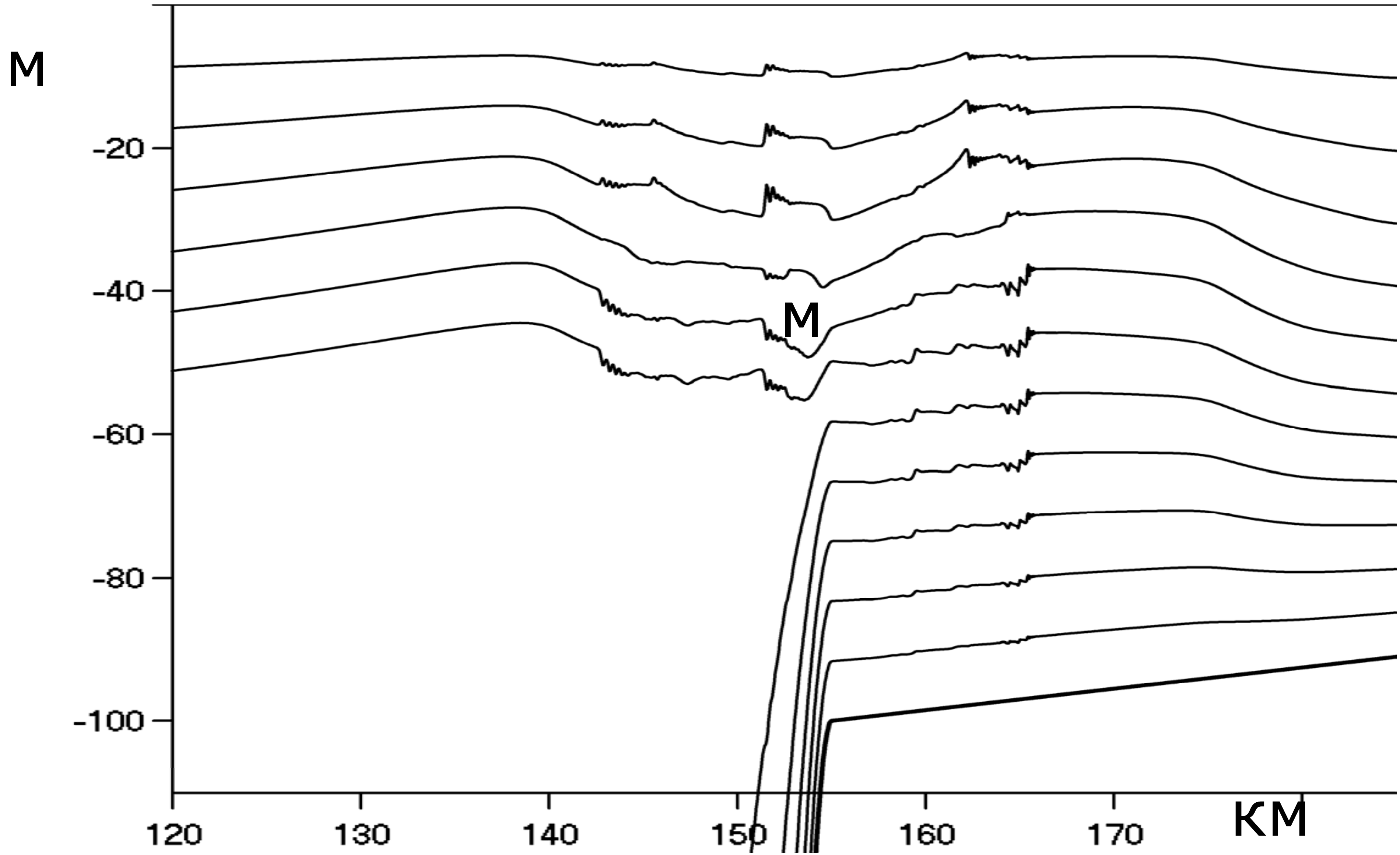
Near the ShB, v = 0.4 m/s, horiz visc = 1 sqm/s. Second mode formation



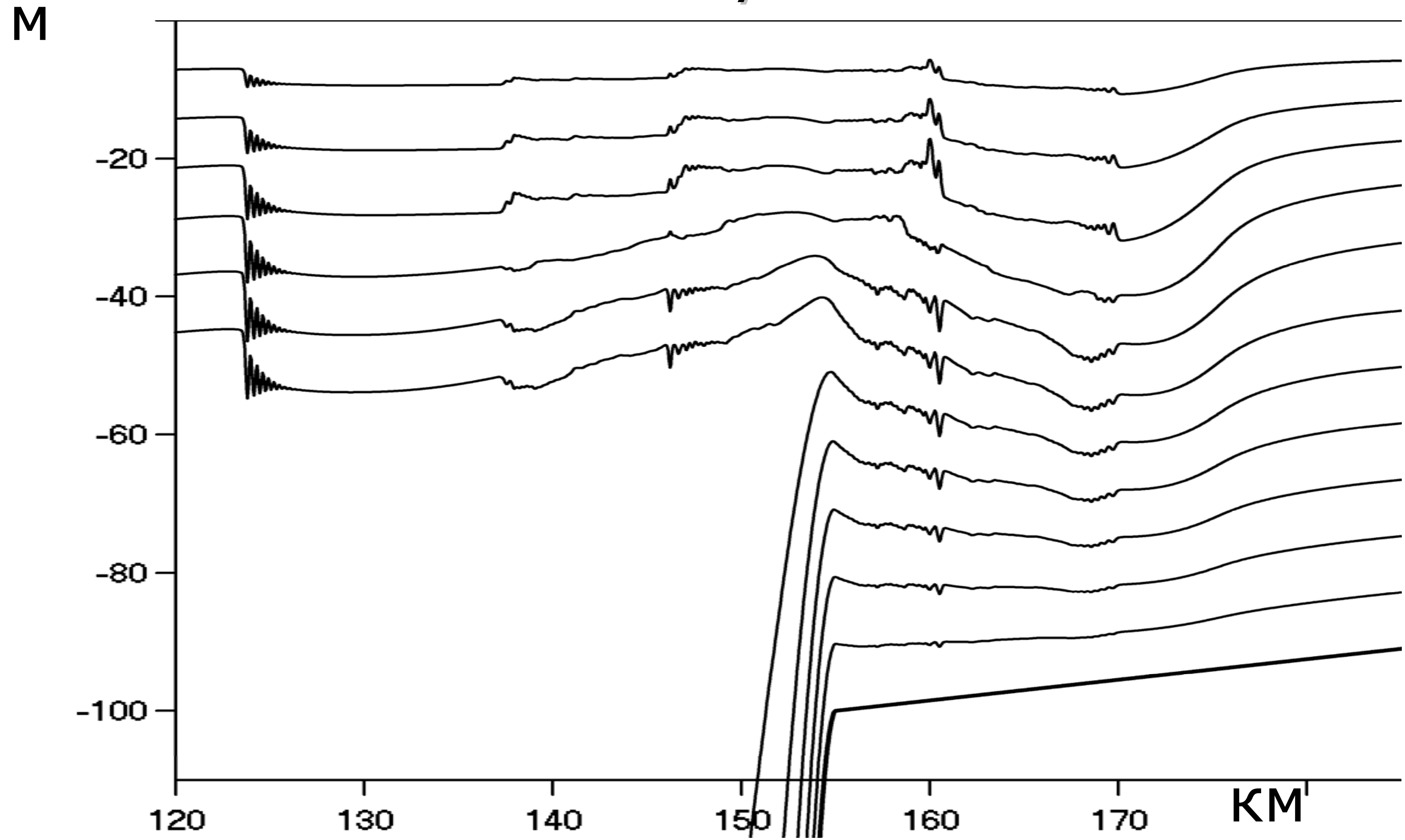
v = 0.5 m/s, vert visc = 0.002 sqm/s. Jumps formation



Maximum of internal tide 21 h after the start of 12-h surface tide from initial 0-velocity state

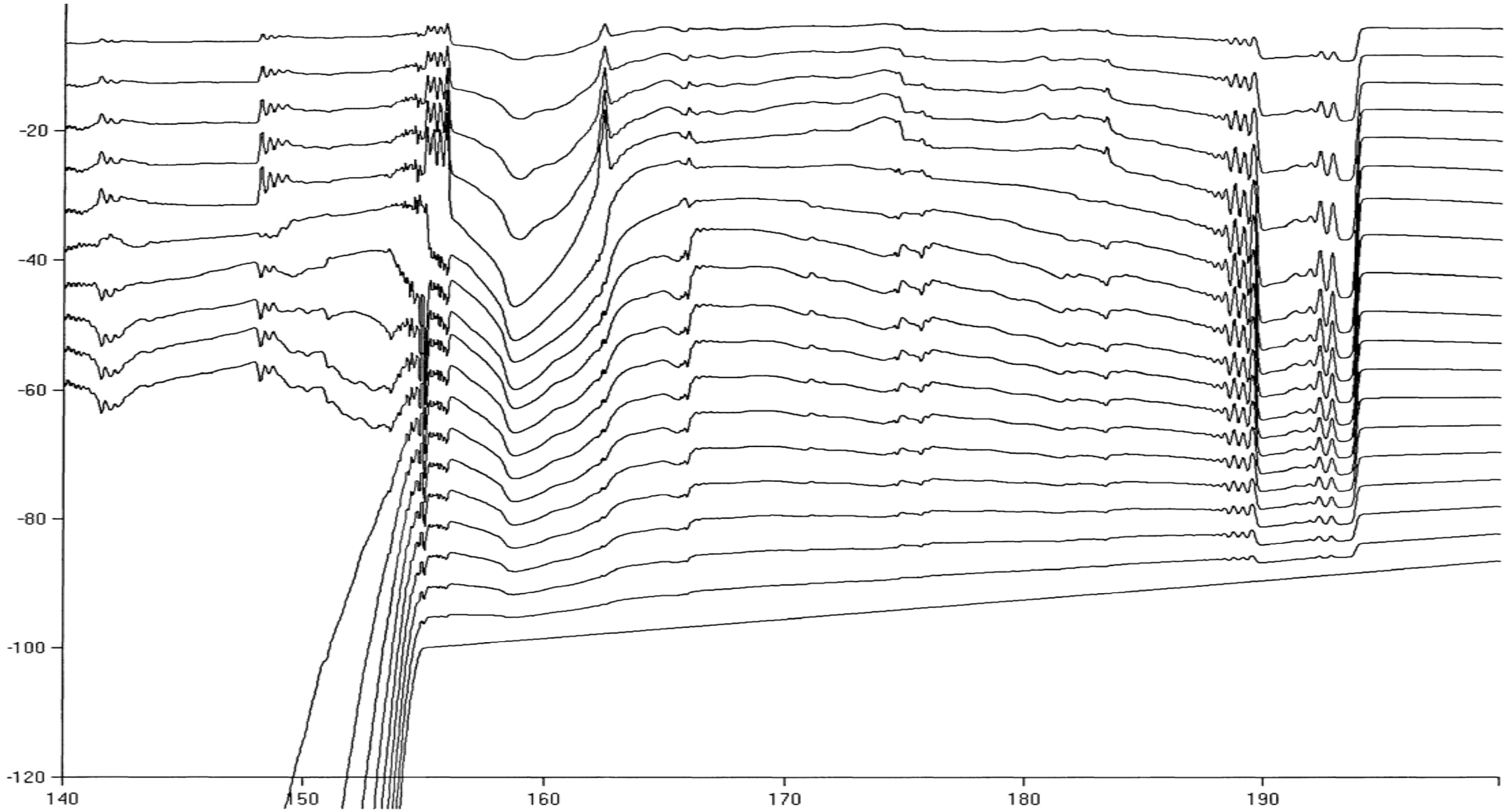


Minimum of internal tide 27 h after the start of 12-h surface tide from initial 0-velocity state



More detailed results

- 15-2, 24-3,4 – FXT
- Sel 0 (ACD) - generation
- Sel 48 (ACD) - propagation and transformation


-20
-40
-60
-80
-100
-120
140
150
160
170
180
190

- Generation near the shelf break – ACDSee – Sel-0

- Propagation and transformation - ACDSee – Sel-
- 15-2 & 24-3,4 – two steps (Nmax) – ACD?

Consequencies:
a) diffusion amplification

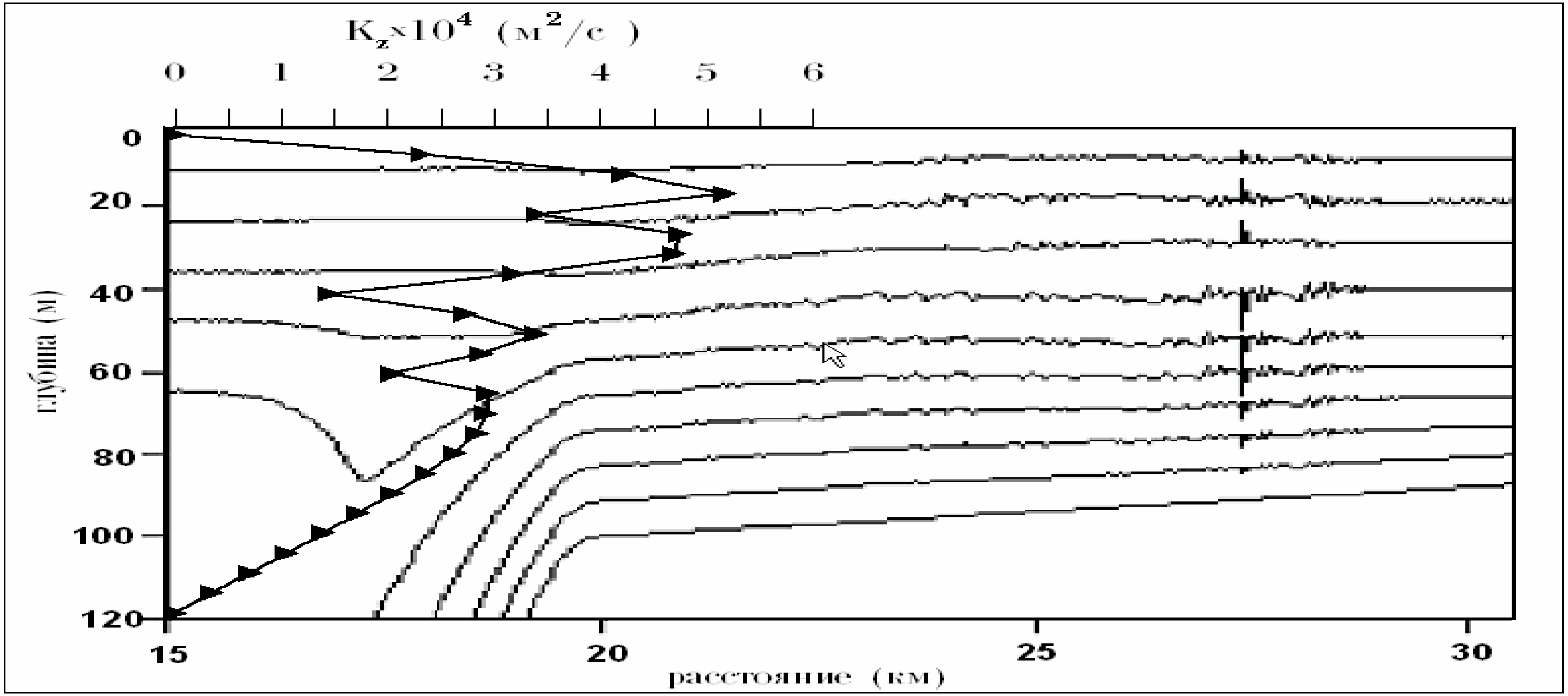


Рис. 4. Вертикальный суммарый коэффициент турбулентного обмена K_z, рассчитанный у кромки шельфа для осредненного профиля частоты Вяйсяля. Профиль K_z представлен на фоне модельного разреза изопикн, полученного Навроцким и др. (2003).

Inall et al. 2000

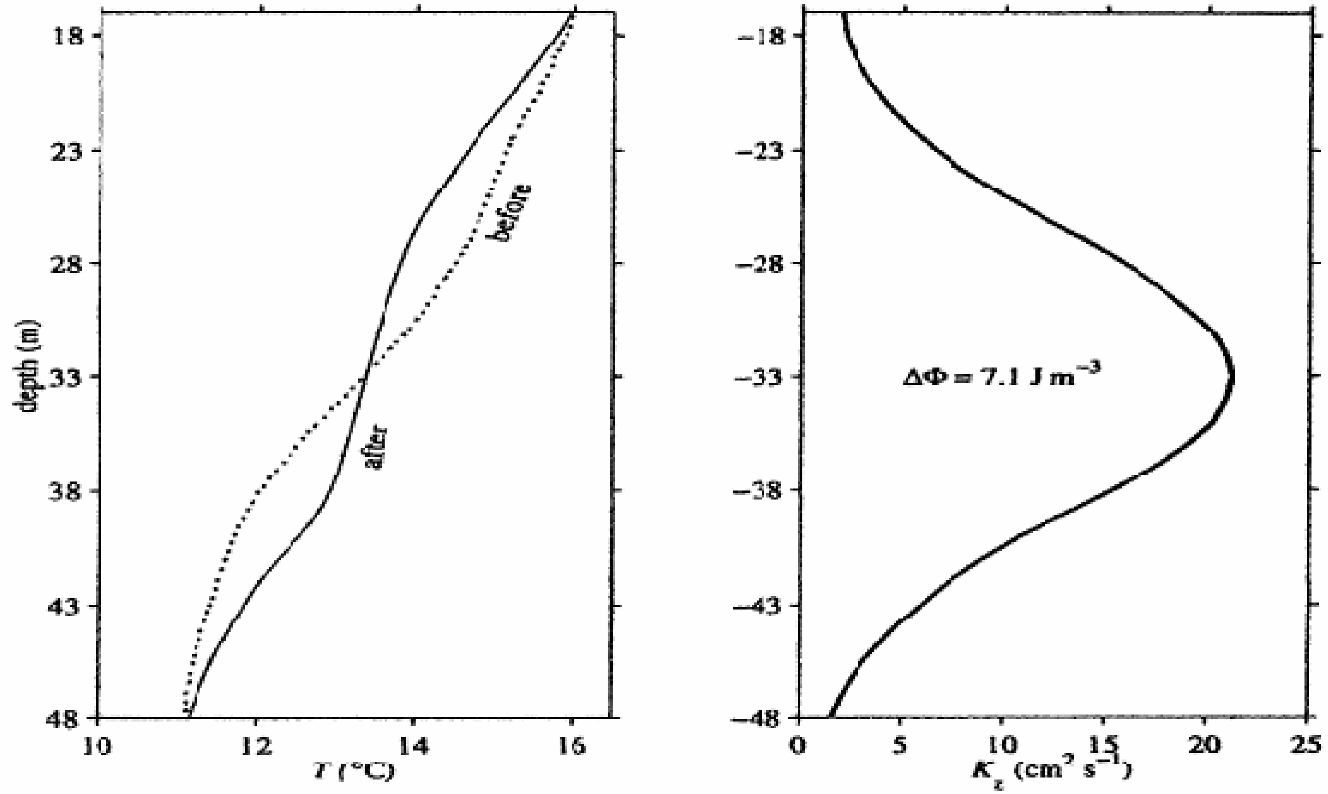
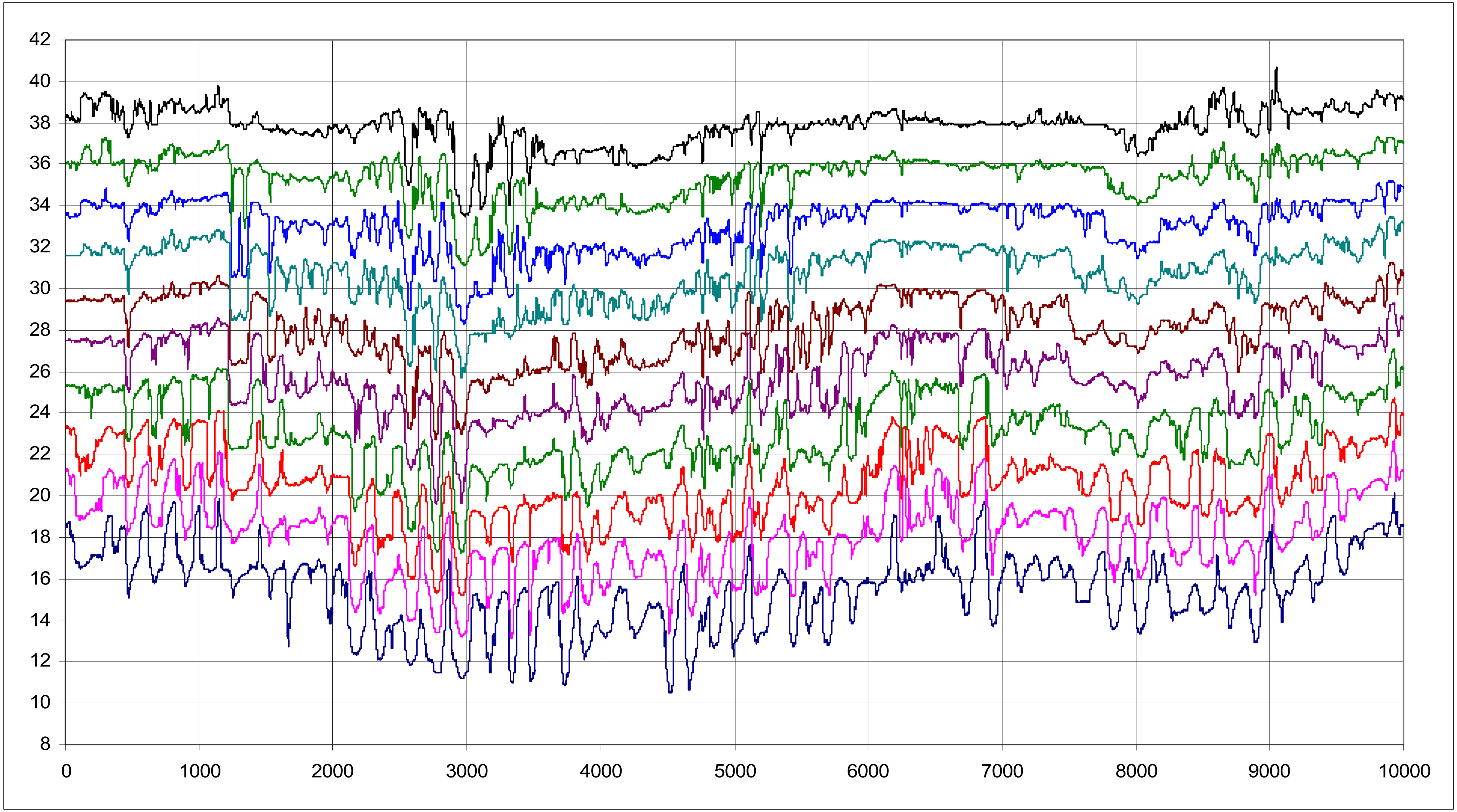
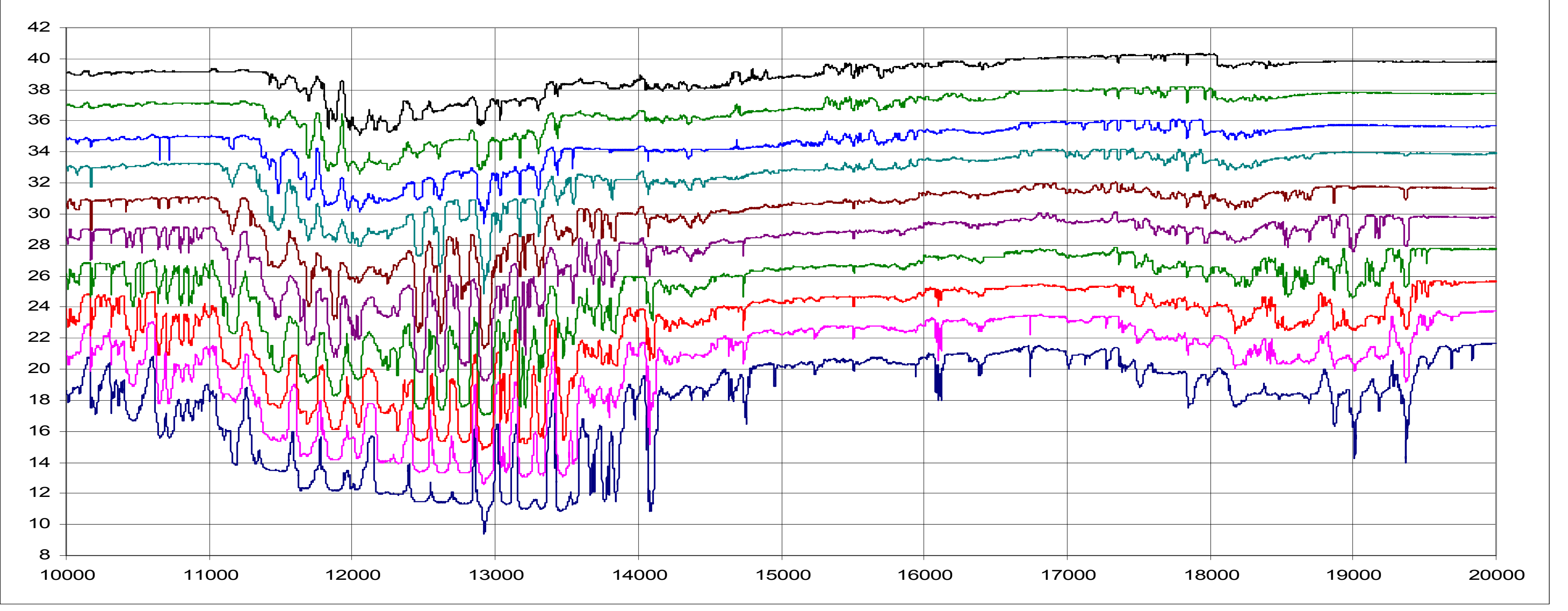


Figure 12. Mean temperature profiles before and after passage of packet of NIWs. K_z as a function of z calculated from the diffusion equation (see text for details).

Temperature fluctuations at 10 levels in the near-bottom thermocline




42
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22
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10
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11000
12000
13000
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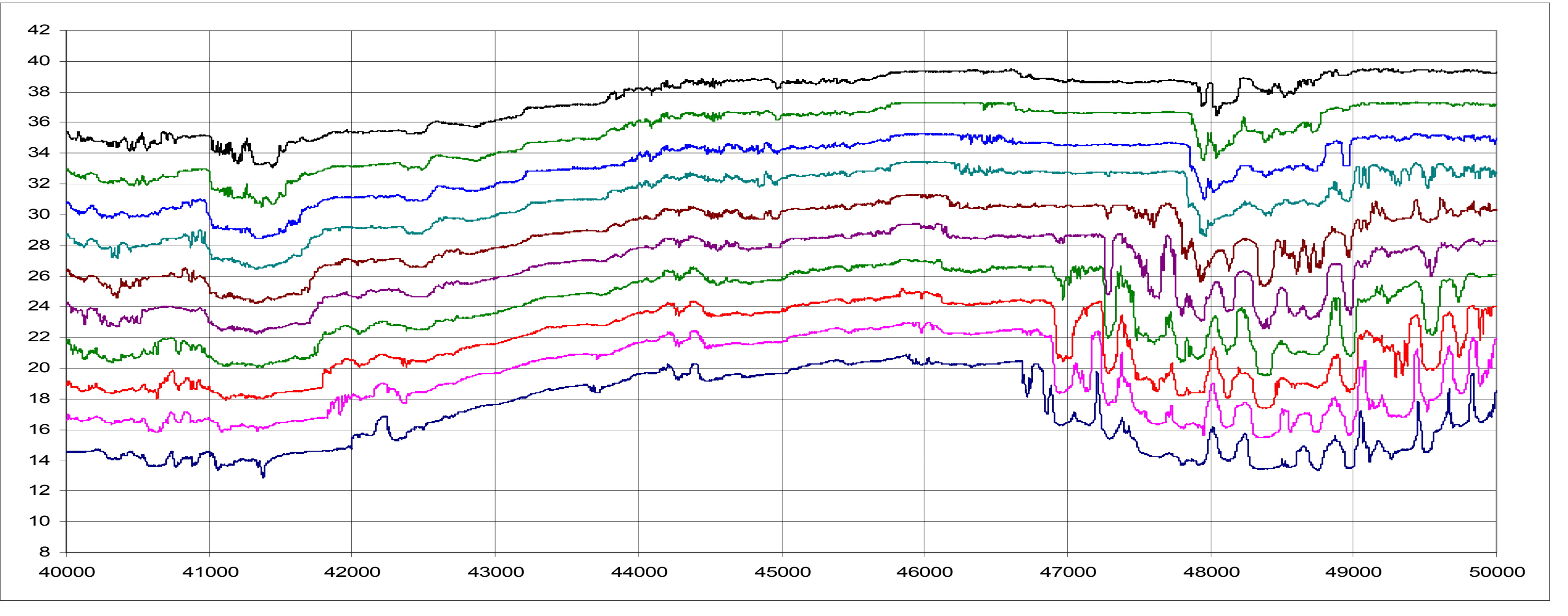
16000
17000
18000
19000
20000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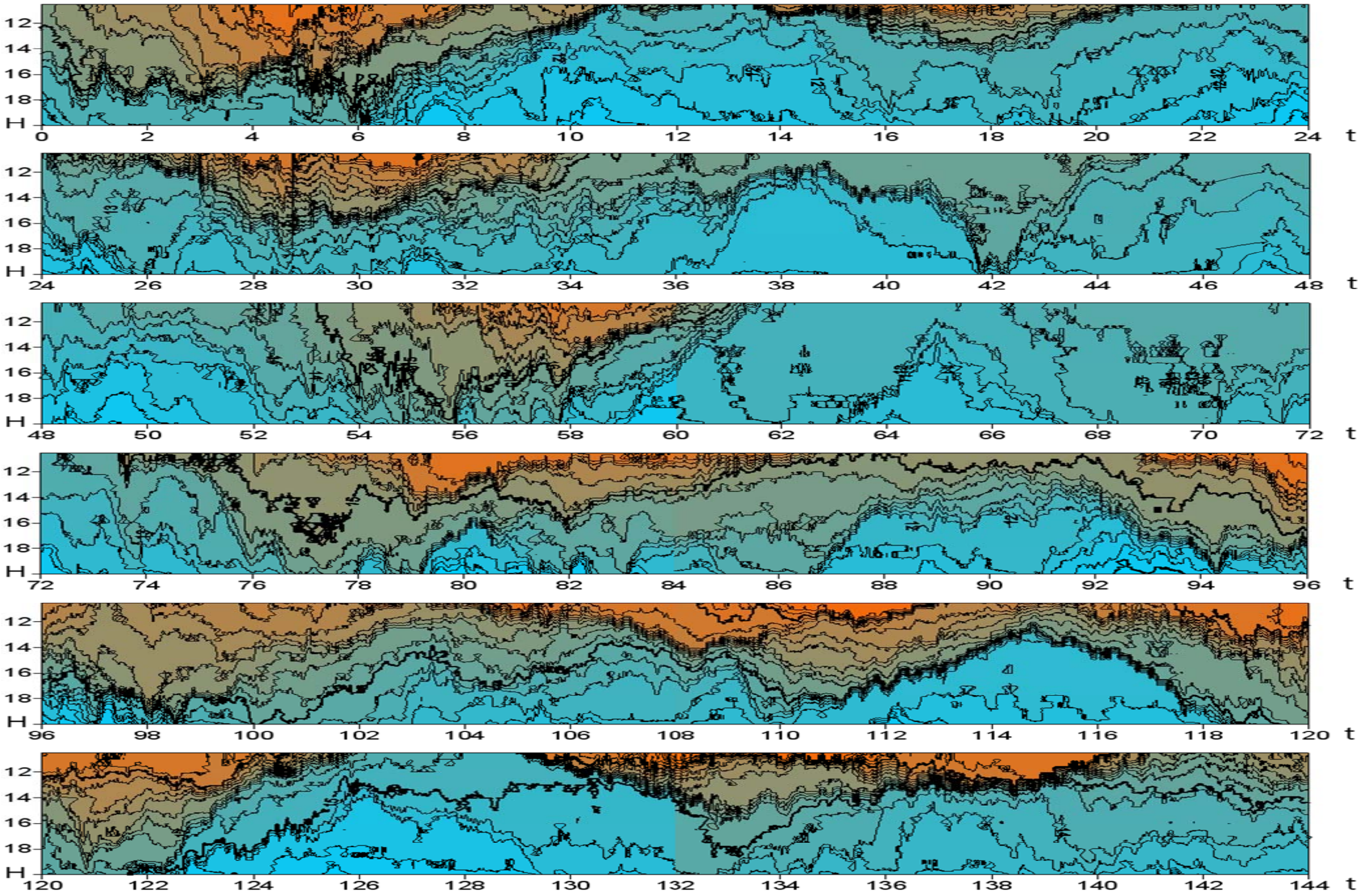
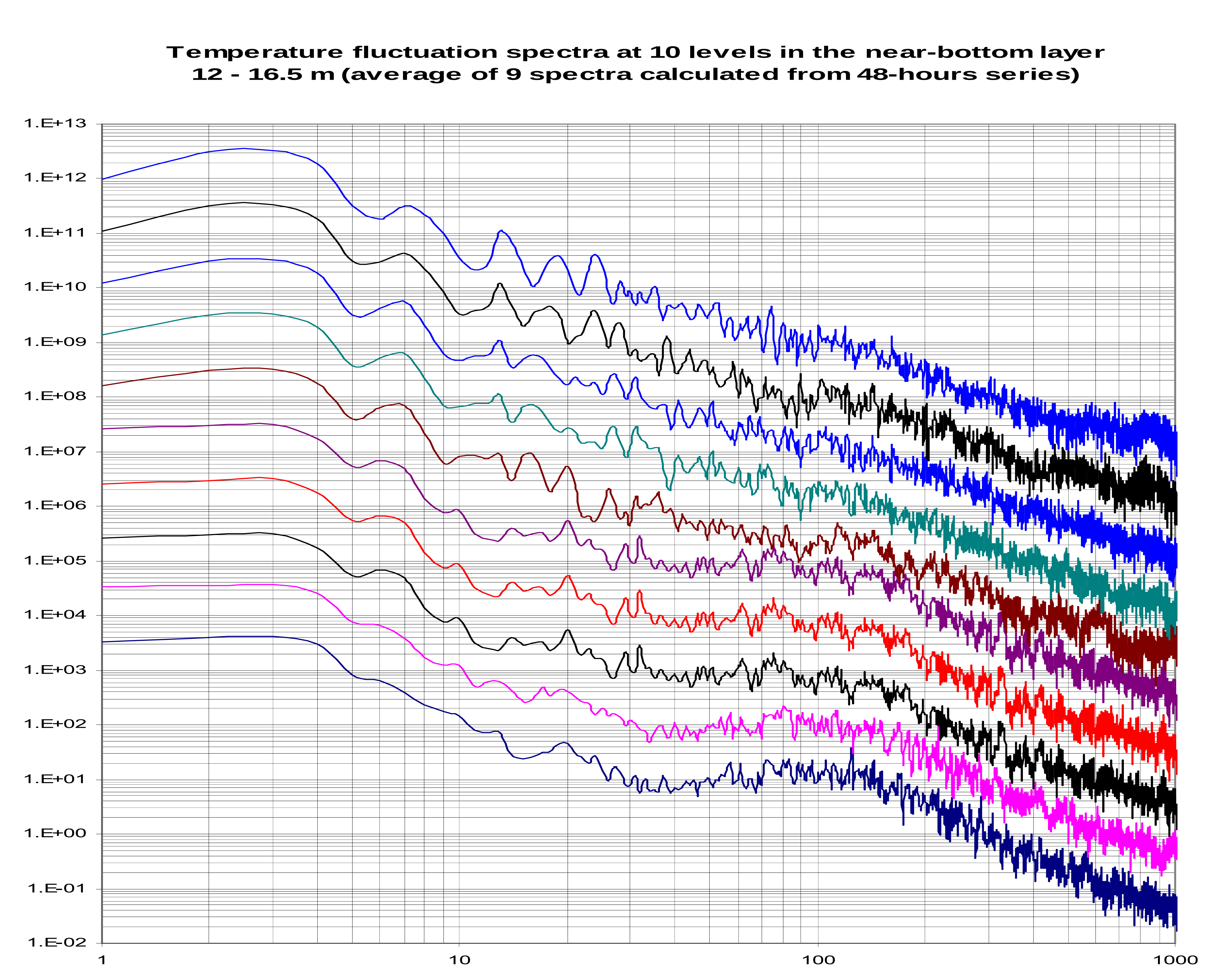
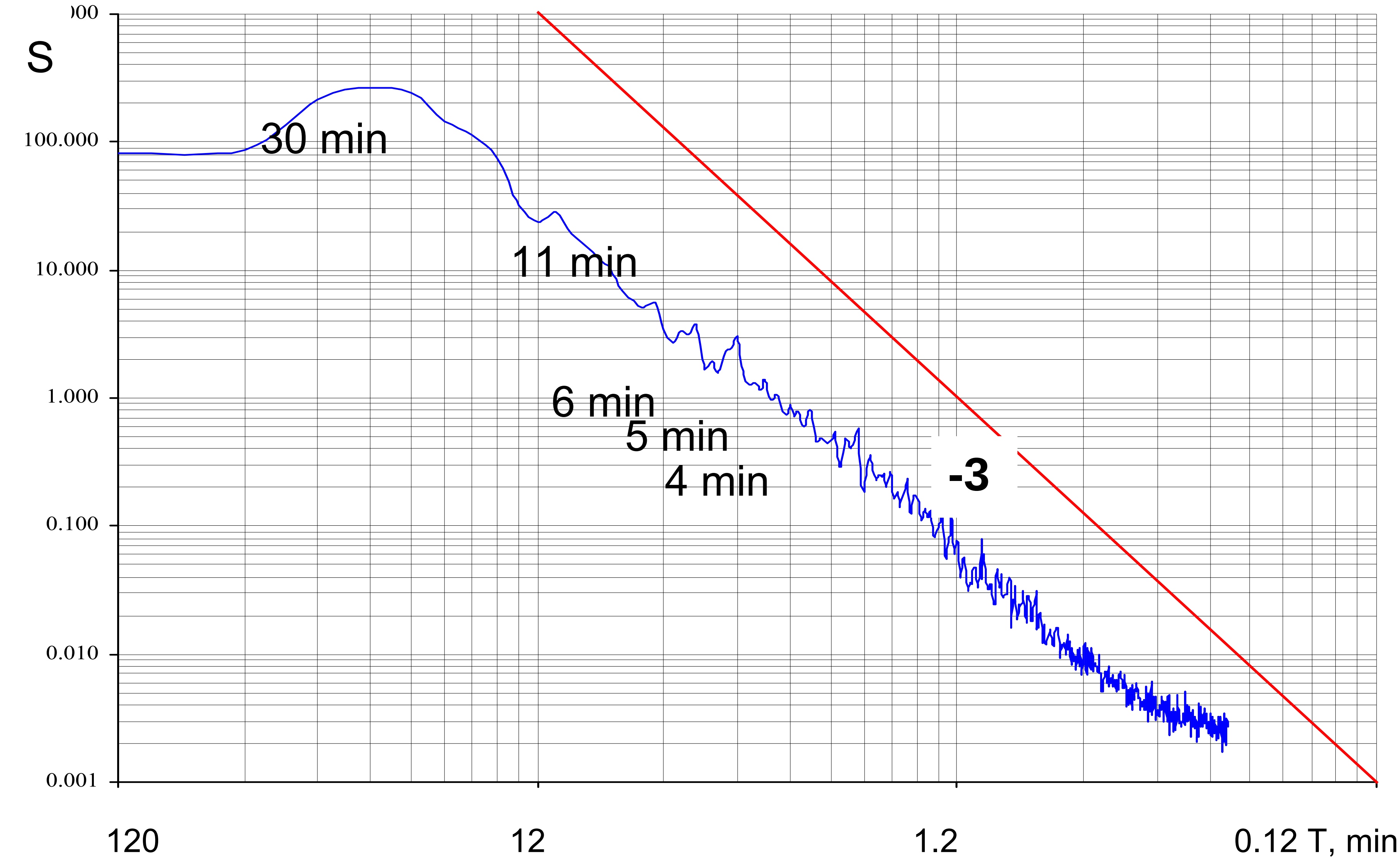
47000
48000
49000
50000

Temperature fluctuations in fixed points (garlands of sensors)

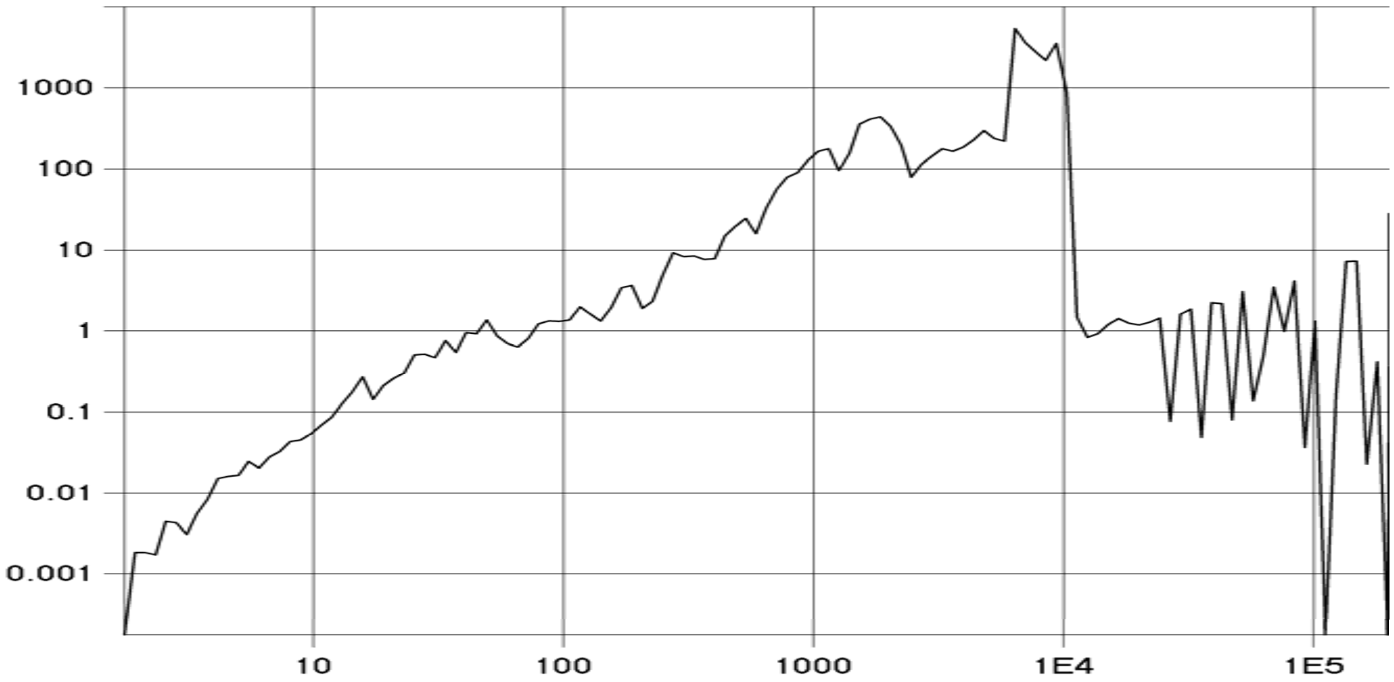



Temperature fluctuation spectra at 10 levels in the near-bottom layer
12 - 16.5 m (average of 9 spectra calculated from 48-hours series)
1.E+13
1.E+12
1.E+11
1.E+10
1.E+09
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1
10
100
1000

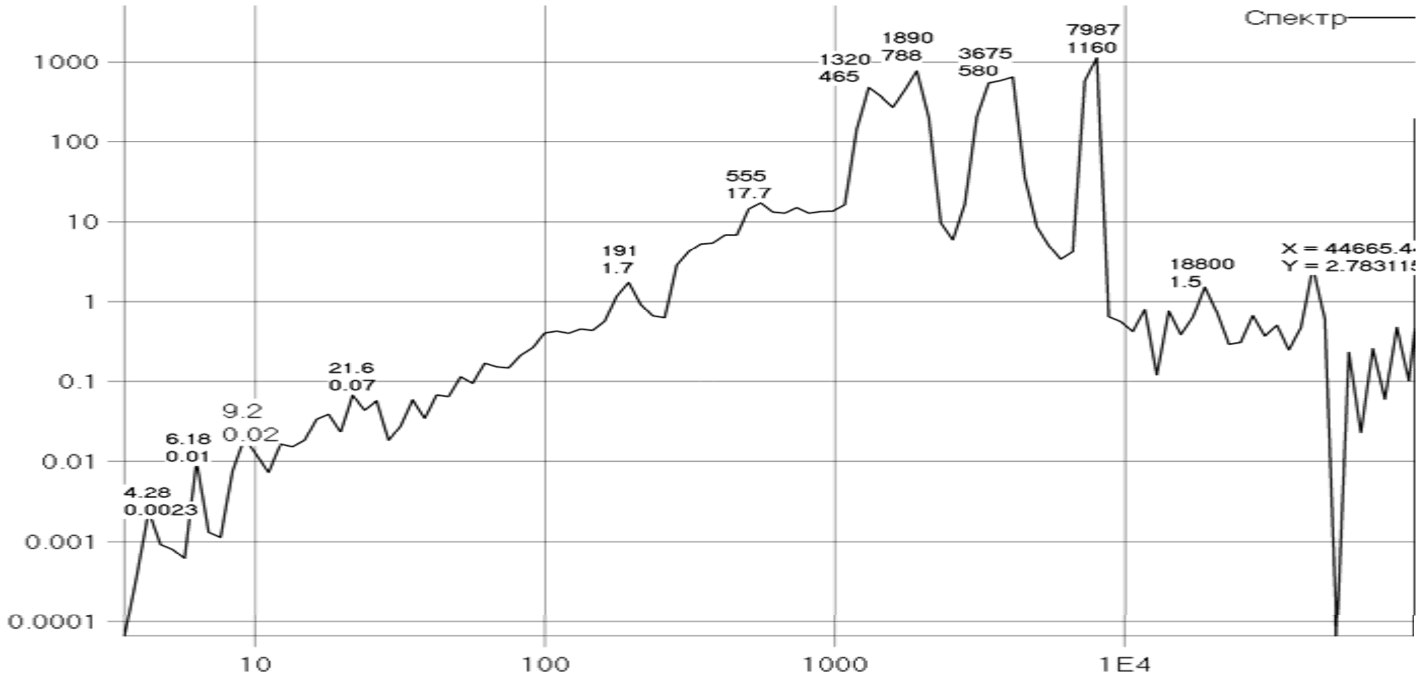


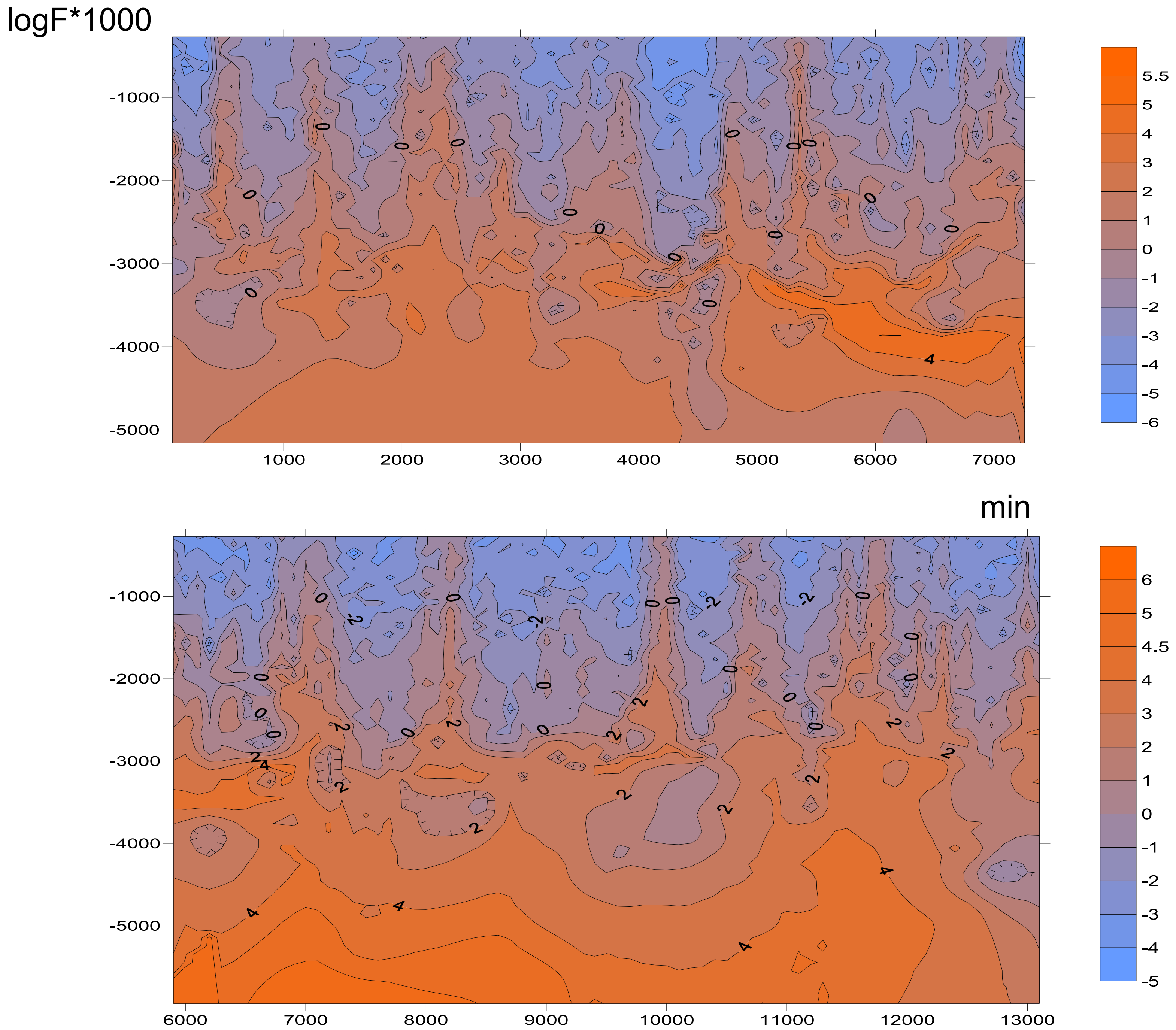
Averaged spectrum of temperature fluctuations in the near-bottom layer

Spectrum of temperature fluctuations at 12 m (August 2006)

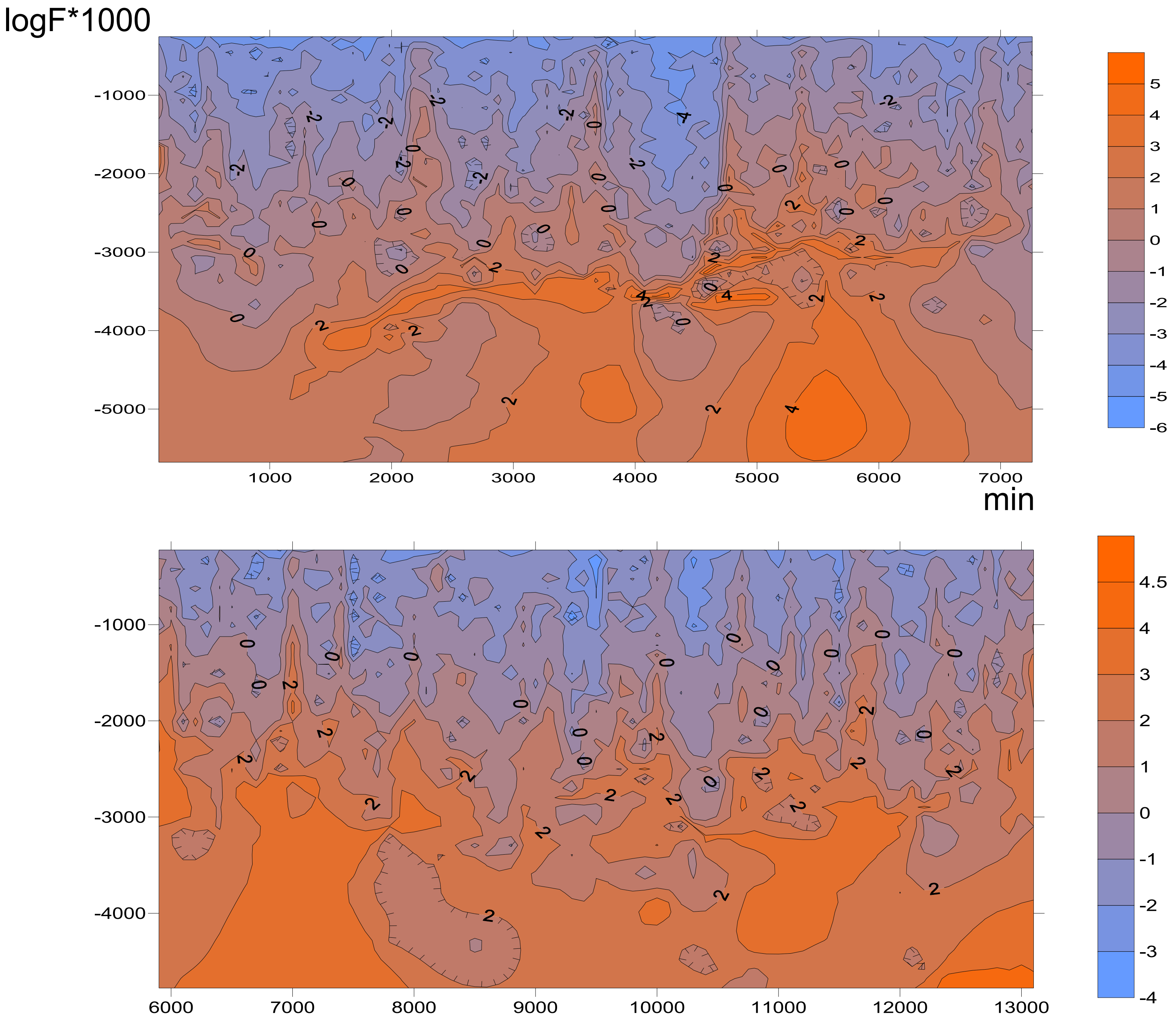


Spectrum of temperature fluctuations at 16 m (August 2006)

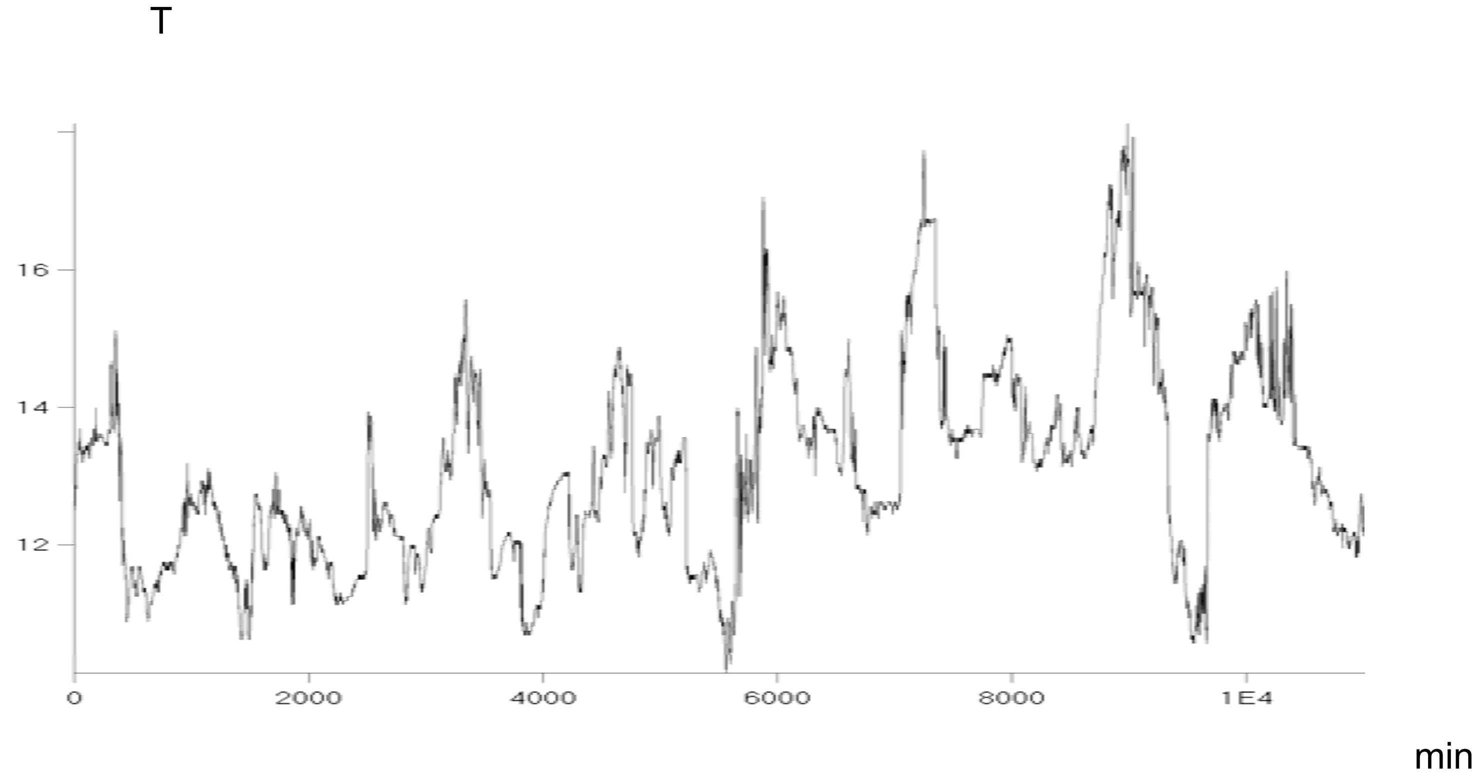




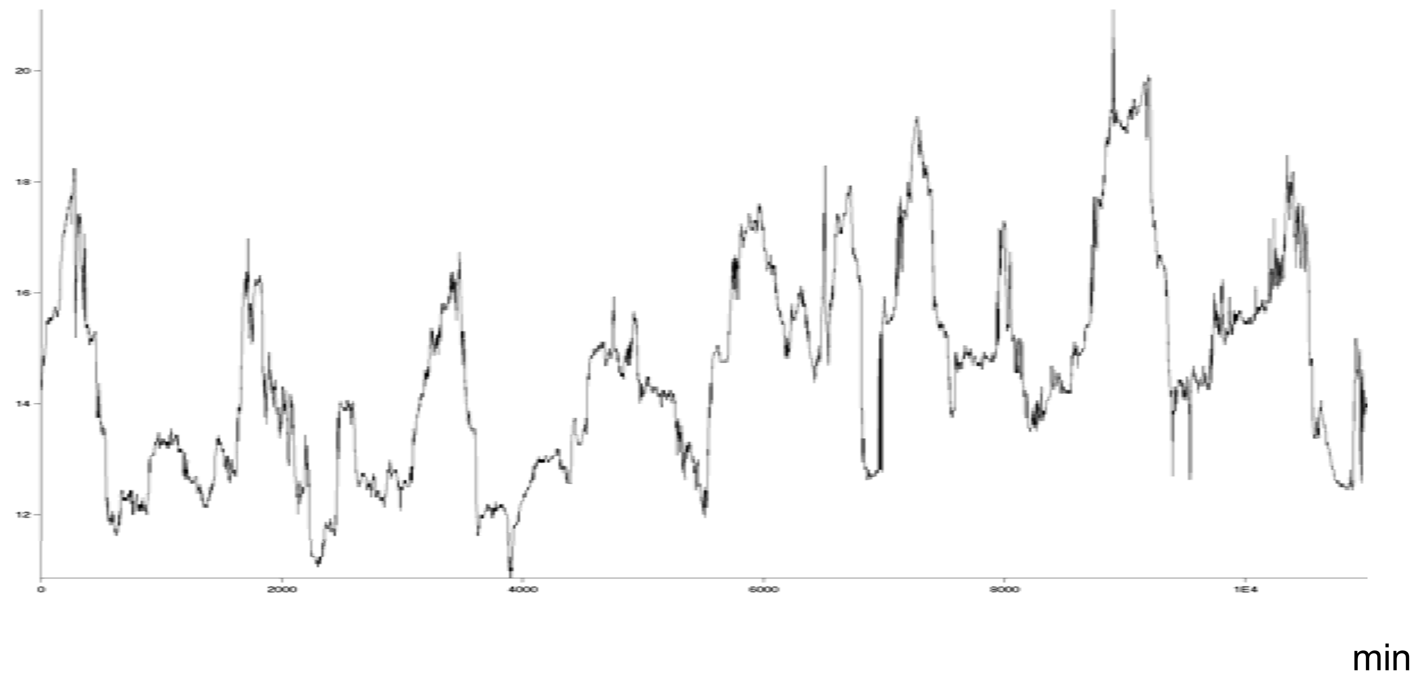
Time-frequency structure of temperature fluctuations at 12 m level in Aug-Sept 2006



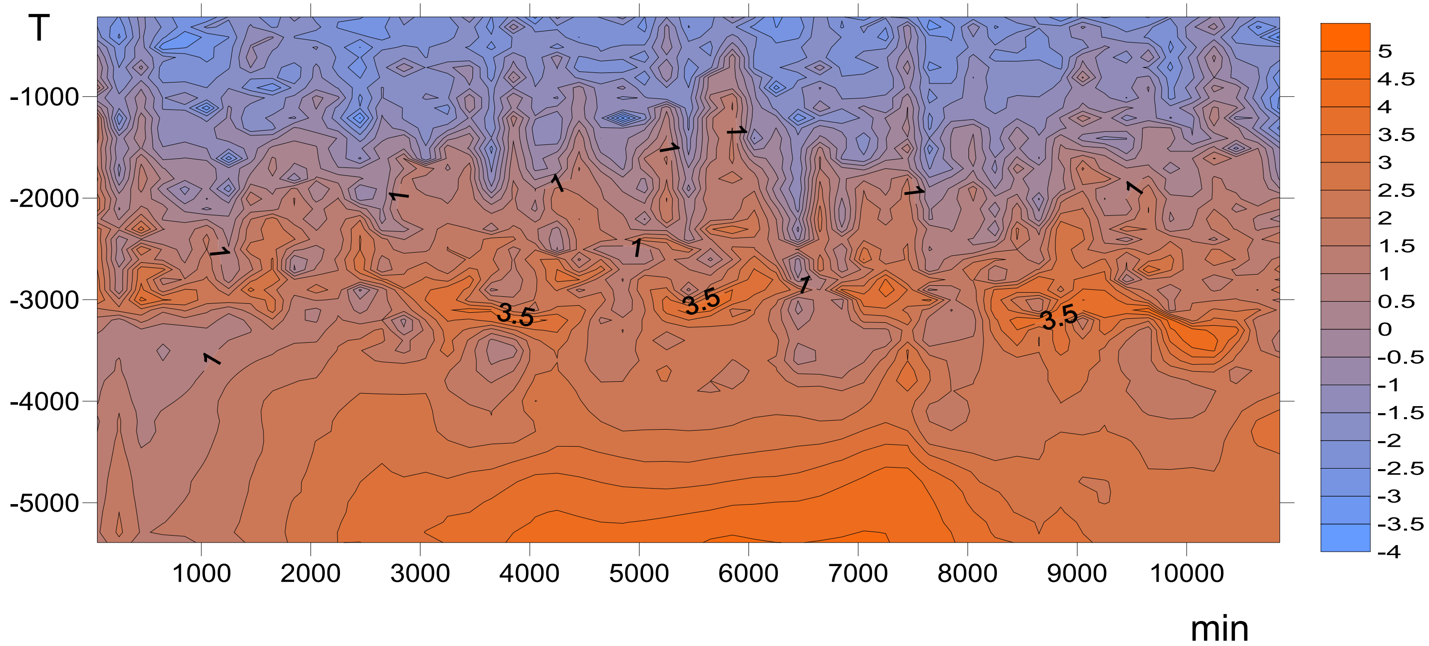
Time-frequency structure of temperature fluctuations at 16 m level in Aug-Sept 2006



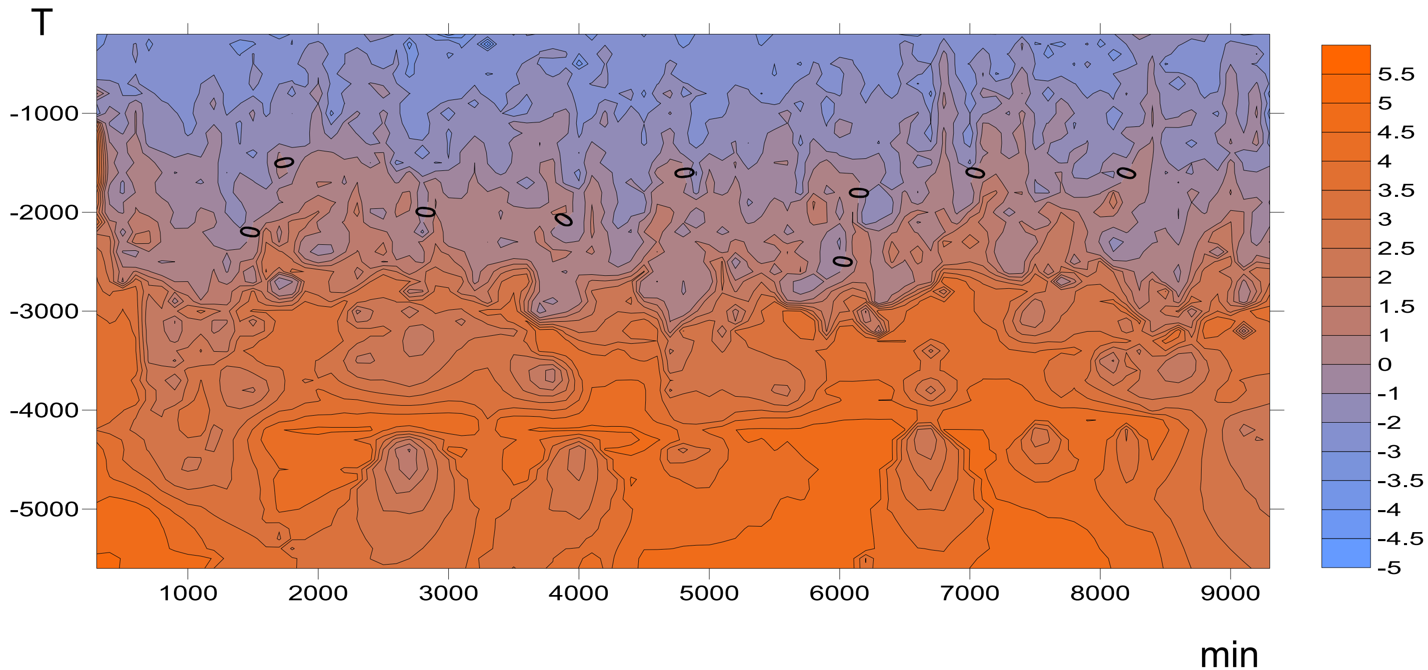
Temperature fluctuations at 12 m (August 2007)



Temperature fluctuations at 16 m (August 2007)

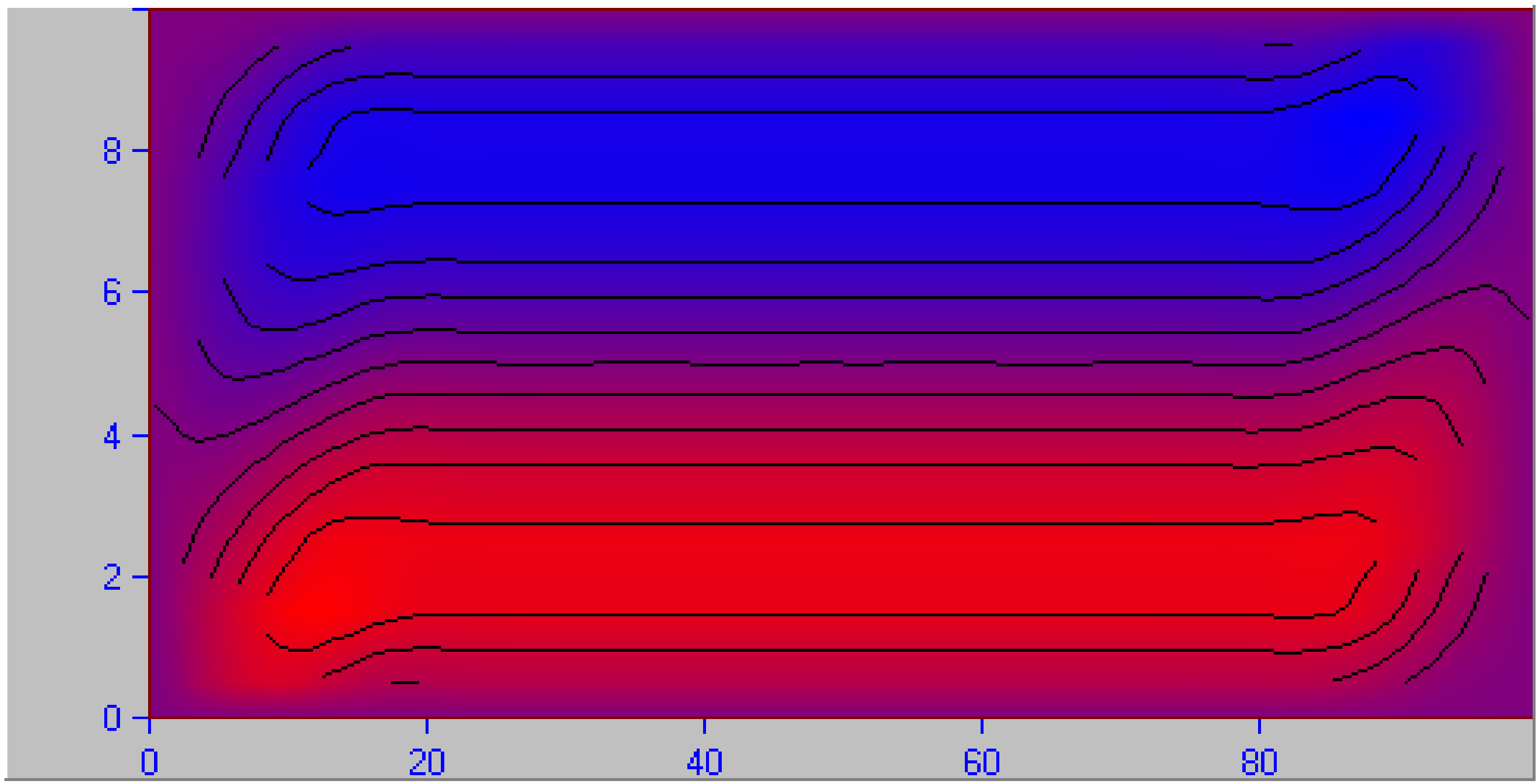


Time-frequency structure of temperature fluctuations at 12 m in Aug-Sept 2007

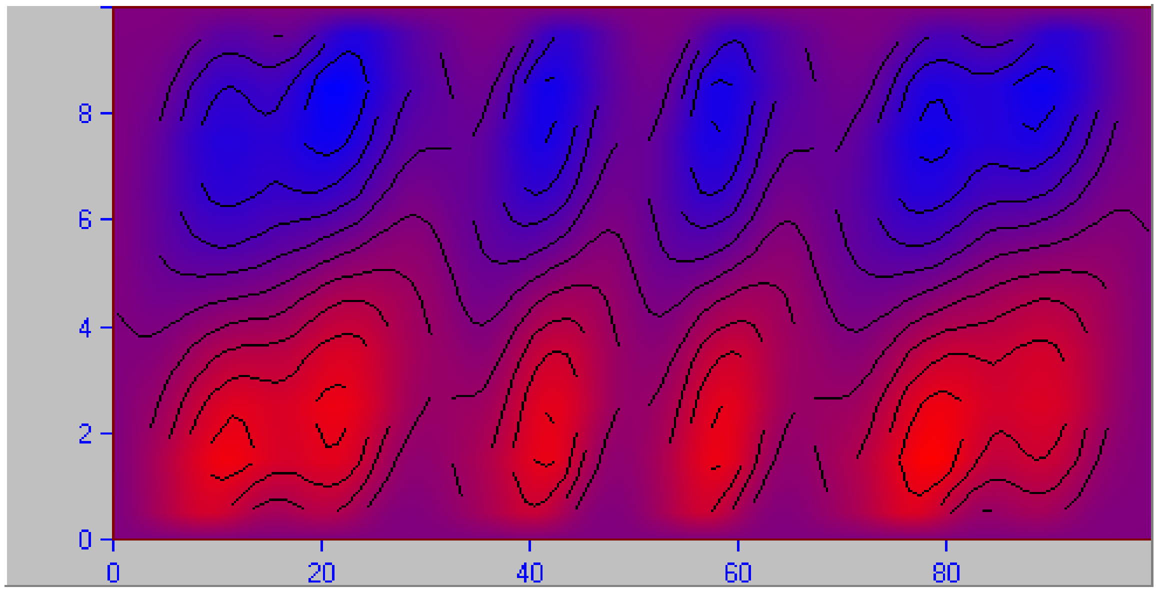


Time-frequency structure of temperature fluctuations at 16 m in Aug-Sept 2007

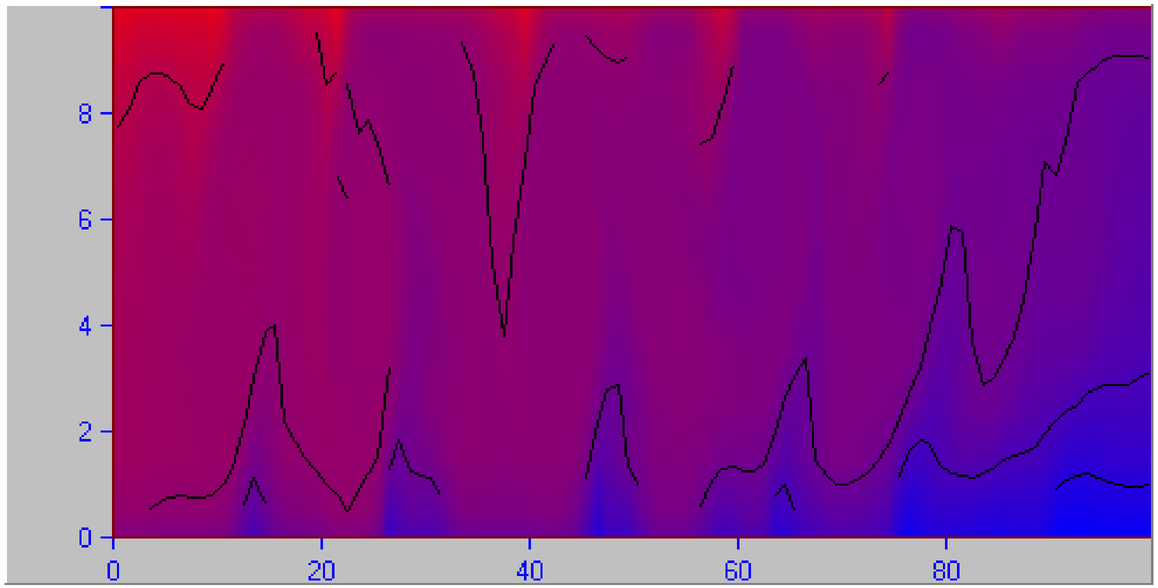
Low velocity, high viscosity



Higher velocity

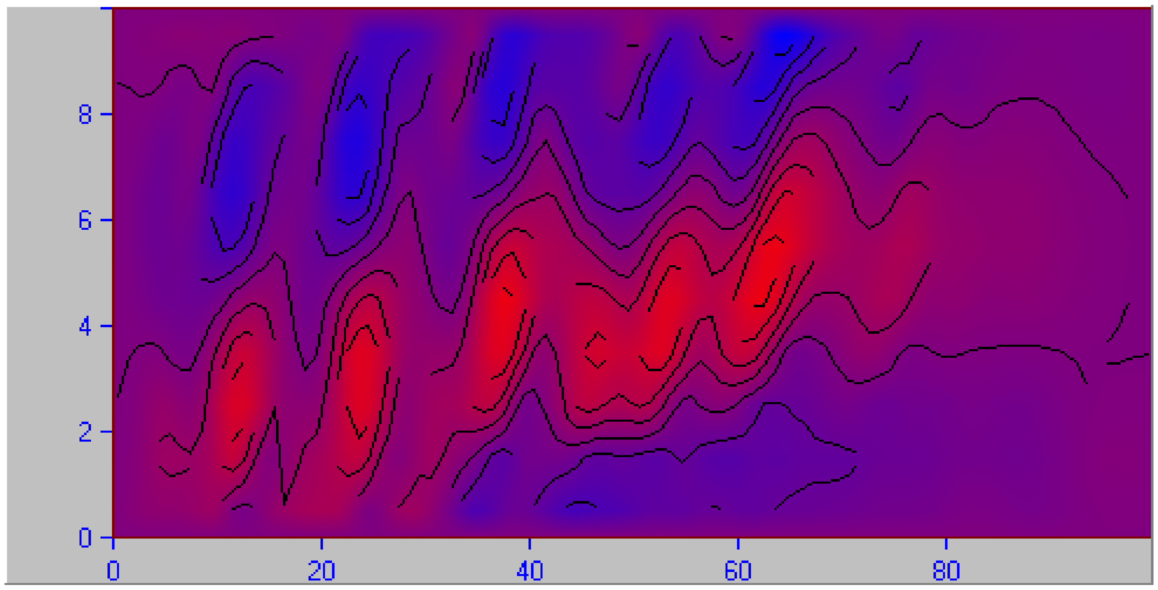


Velocity field

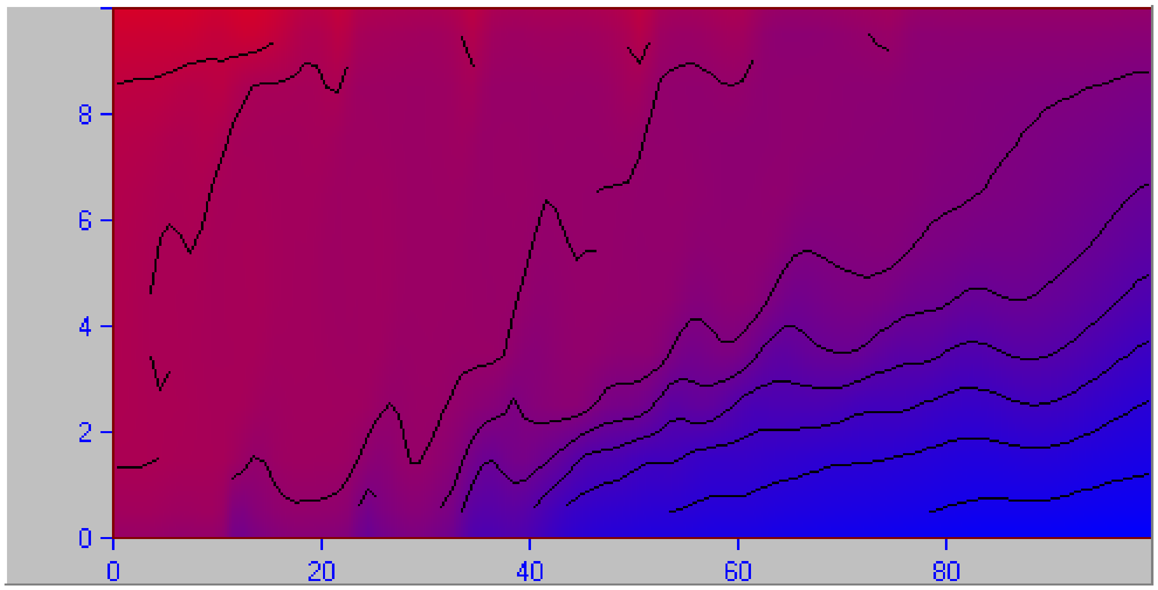


Temperature field

High velocity



Velocity field



Temperature field

CONCLUSIONS

IW lead to considerable mixing in stratified layers and changes in vertical structure of hydrophysical characteristics

IW lead to vertical and horizontal fine structure formation, and both of them – IW and FS – are very important for hydroacoustics

Internal mixing produced by IW is one of the most important factors of bioproductivity, and it is especially important as a mechanism of effective control of the harmful effects of pollution in shelf zones

IW on a sloping bottom lead to intense turbulence generation, specific structure of near-bottom currents and horizontal and vertical transport of different matter