О возможном механизме проявления на поверхности моря подводного сброса сточных вод

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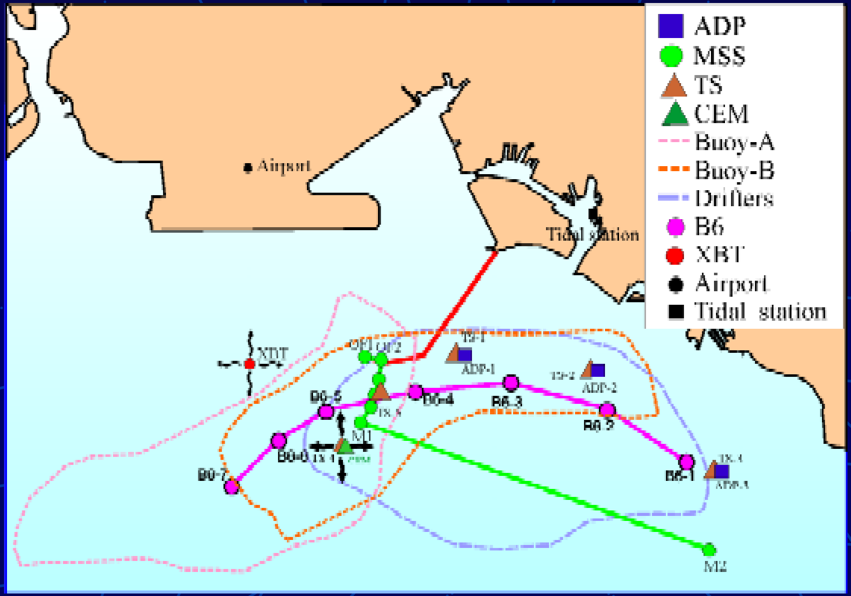
I

Motivation for the laboratory modelling of excitation of internal waves by turbulent buoyant plumes discharged from a submerged wastewater outfall

International oceanographic experiments for the monitoring of anthropogenic influences on coastal water areas (Mamala Bay, Hawaii, September 2002-2004)

КОСМИЧЕСКИЕ И ПОДСПУТНИКОВЫЕ СРЕДСТВА УЧАСТВОВАВШИЕ В ЭКСПЕРИМЕНТЕ

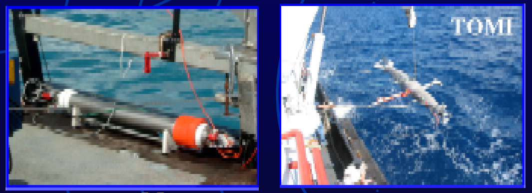
Корабли участвовавшие в экспериментах



Платформа NOAA

Установка АС-9

Compact EM

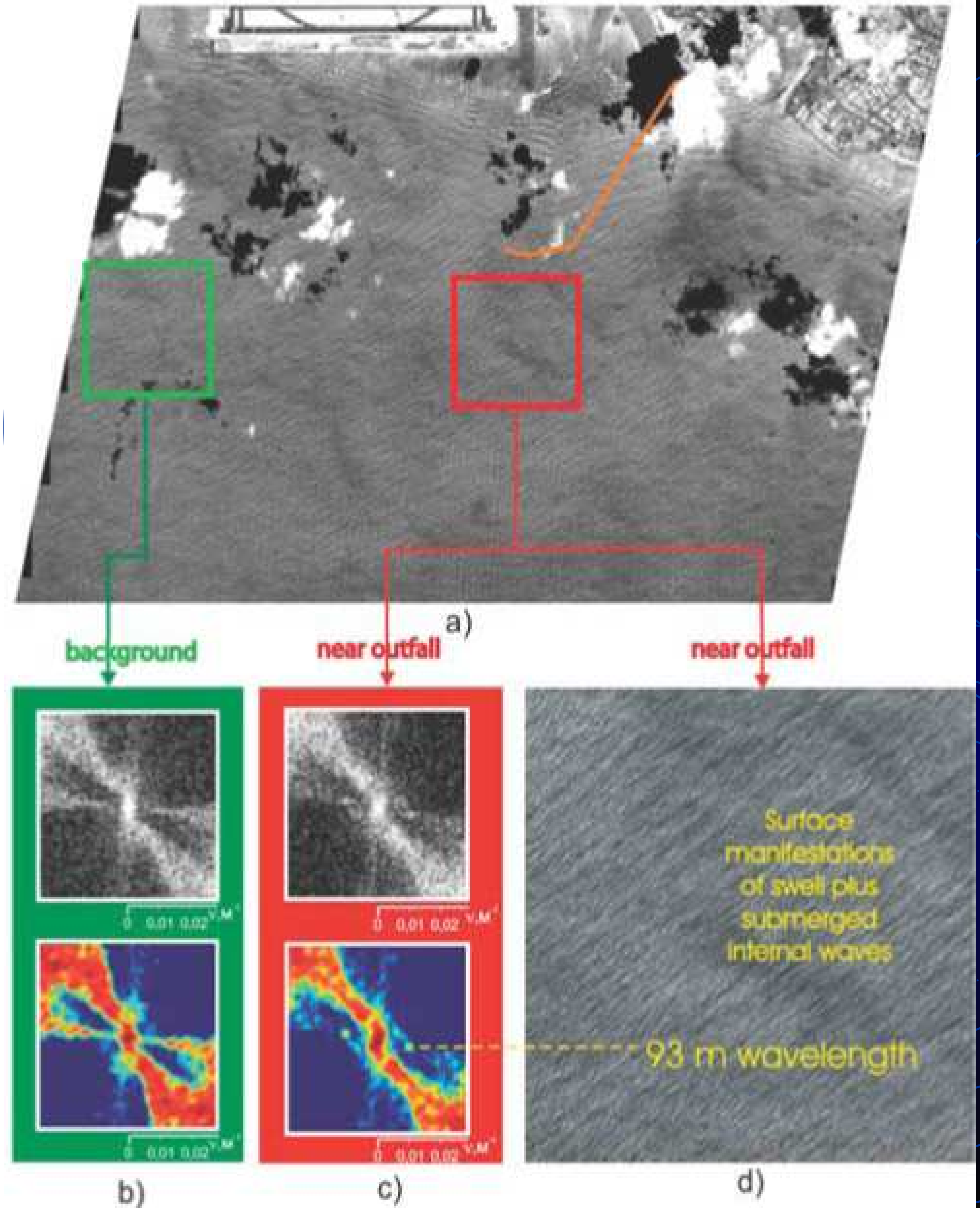


Микроструктурные зонды

Установка волнового буя

«Современные проблемы дистанционного зондирования Земли из космоса»
Москва, ИКИ РАН, 14-17 ноября 2005 г.

The purpose of the experiments was to study surface manifestations of the Sand Island Honolulu wastewater outfall

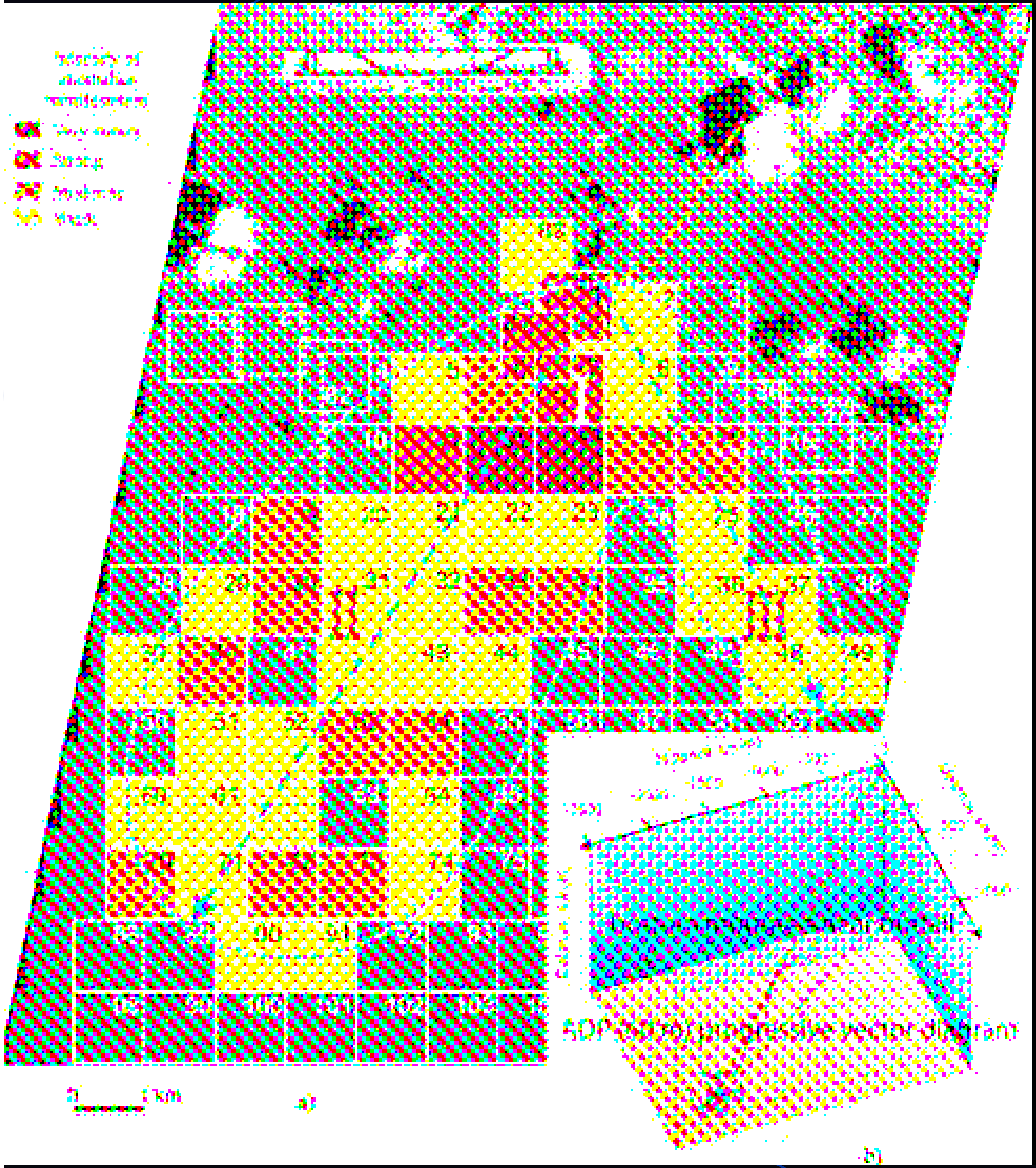


Fragment of Mamala Bay (Honolulu, Hawaii) water area Ikonos image 2002/9/2 with marked location of the outfall pipe (a) ,

2D spectra of optical images

(b) background area, and (c) outfall area with narrow-band spectral maxima .

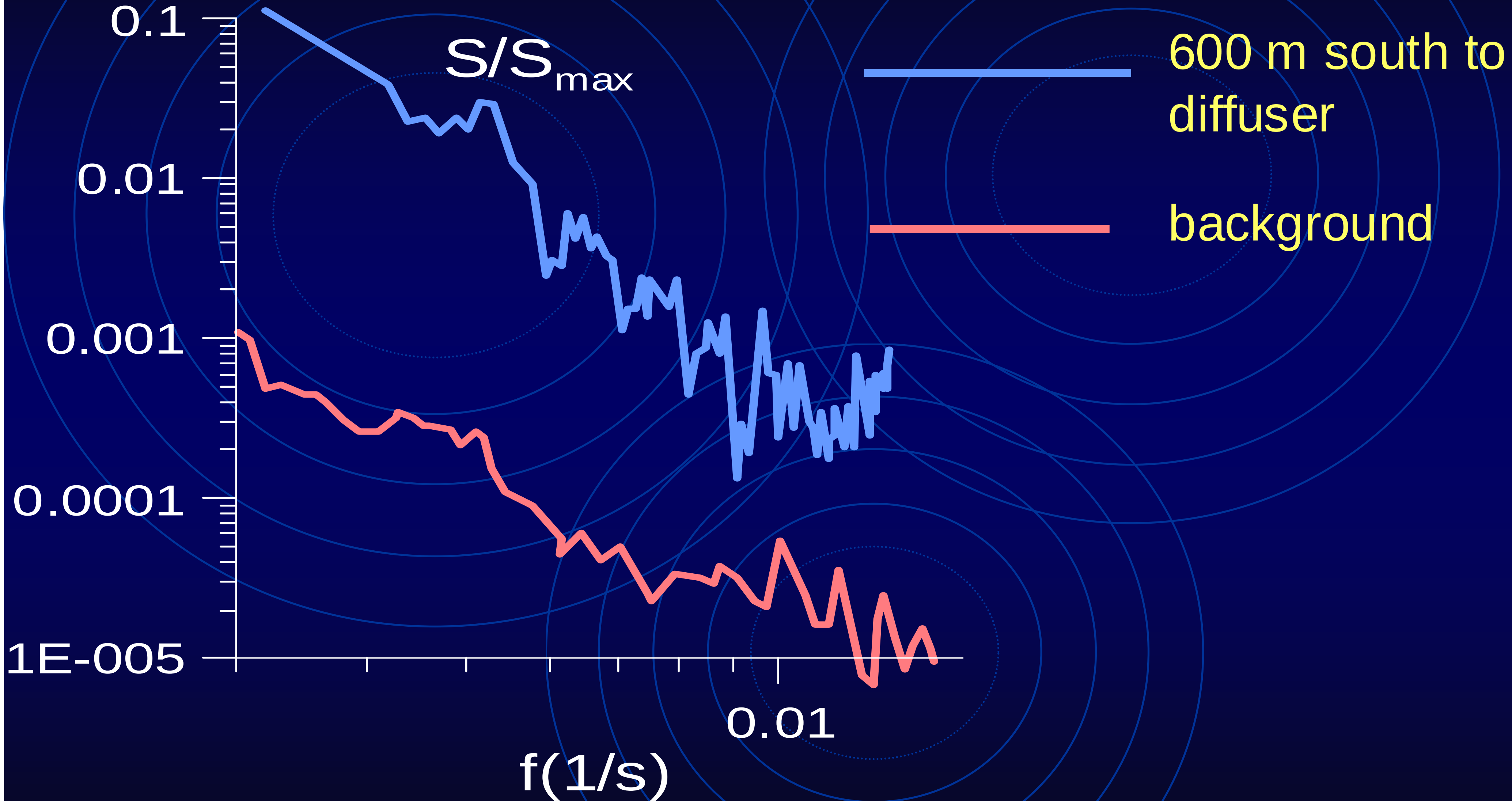
(fig.1 from ***Keeler R., Bondur V., Gibson C. Optical satellite imagery detection of internal wave effects from a submerged turbulent outfall in the stratified ocean GRL, Vol. 32, 2005, 12 p.)***



Spatial distribution of anomalous spectral brightness on the space image of Mamala Bay (Honolulu, Hawaii) water area

(fig.2 from ***Keeler R., Bondur V., Gibson C. Optical satellite imagery detection of internal wave effects from a submerged turbulent outfall in the stratified ocean GRL, Vol. 32, 2005, 12 p.)***

Frequency spectra of oscillations of the pycnocline near the Sand Island Honolulu wastewater outfall (Mamala Bay, Hawaii)



«Современные проблемы дистанционного зондирования Земли из космоса»
Москва, ИКИ РАН, 14-17 ноября 2005 г.

Disposal of wastewaters of coastal cities to the ocean is a usual world practice.

Summary of characteristics of major Pacific outfalls

(*Koh C. Y., Brooks H. N. Annu. Rev. Fluid. Mech, 1975, V. 7. 187-211.*)

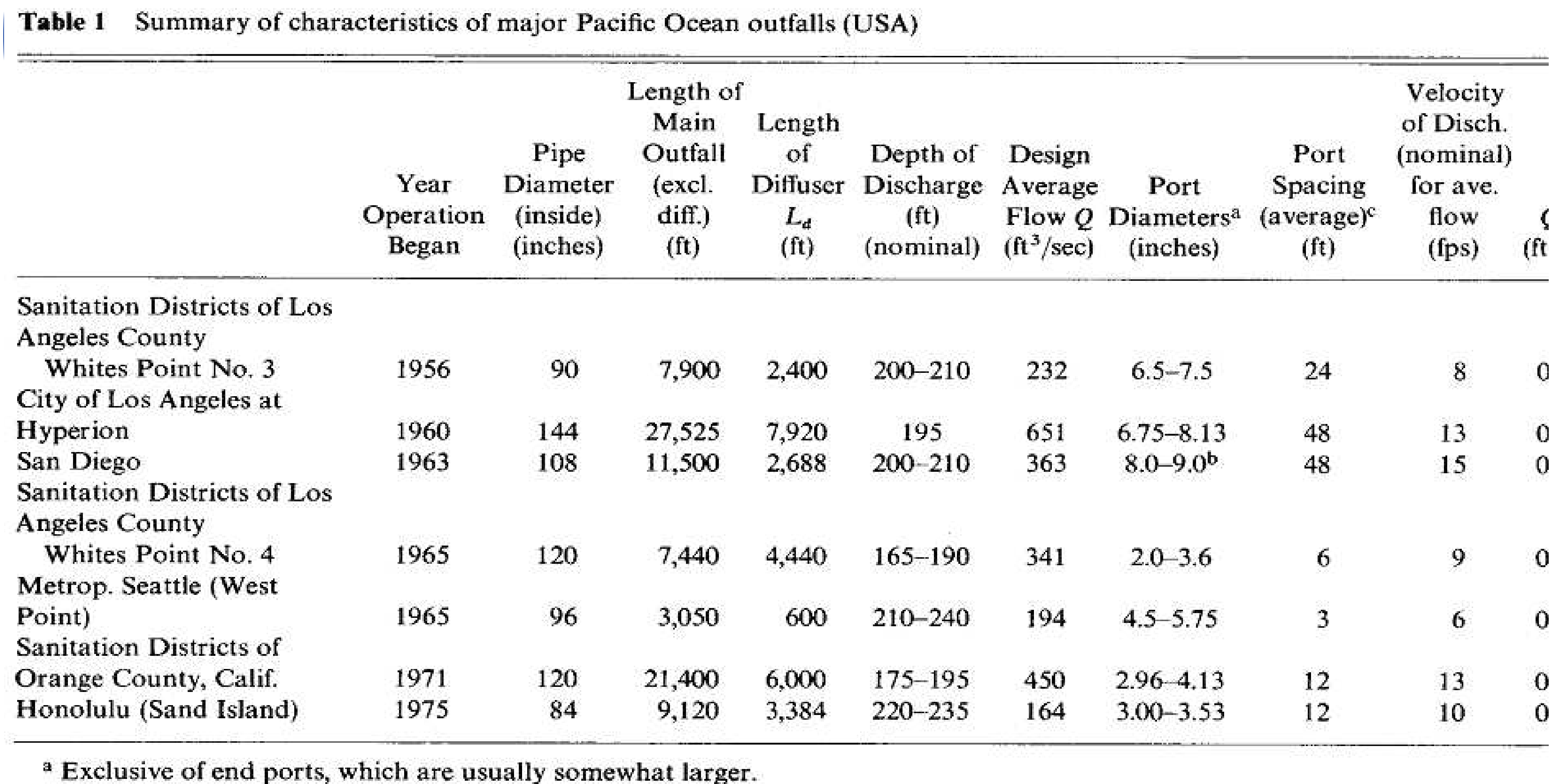


Table 1 Summary of characteristics of major Pacific Ocean outfalls (USA)

	Year Operation Began	Pipe Diameter (inside) (inches)	Length of Main Outfall (excl. diff.) (ft)	Length of Diffuser L_d (ft)	Depth of Discharge (ft) (nominal)	Design Average Flow Q (ft^3/sec)	Port Diameters[a] (inches)	Port Spacing (average)[c] (ft)	Velocity of Disch. (nominal) for ave. flow (fps)	((ft
Sanitation Districts of Los Angeles County Whites Point No. 3	1956	90	7,900	2,400	200–210	232	6.5–7.5	24	8	0
City of Los Angeles at Hyperion	1960	144	27,525	7,920	195	651	6.75–8.13	48	13	0
San Diego	1963	108	11,500	2,688	200–210	363	8.0–9.0[b]	48	15	0
Sanitation Districts of Los Angeles County Whites Point No. 4	1965	120	7,440	4,440	165–190	341	2.0–3.6	6	9	0
Metrop. Seattle (West Point)	1965	96	3,050	600	210–240	194	4.5–5.75	3	6	0
Sanitation Districts of Orange County, Calif.	1971	120	21,400	6,000	175–195	450	2.96–4.13	12	13	0
Honolulu (Sand Island)	1975	84	9,120	3,384	220–235	164	3.00–3.53	12	10	0

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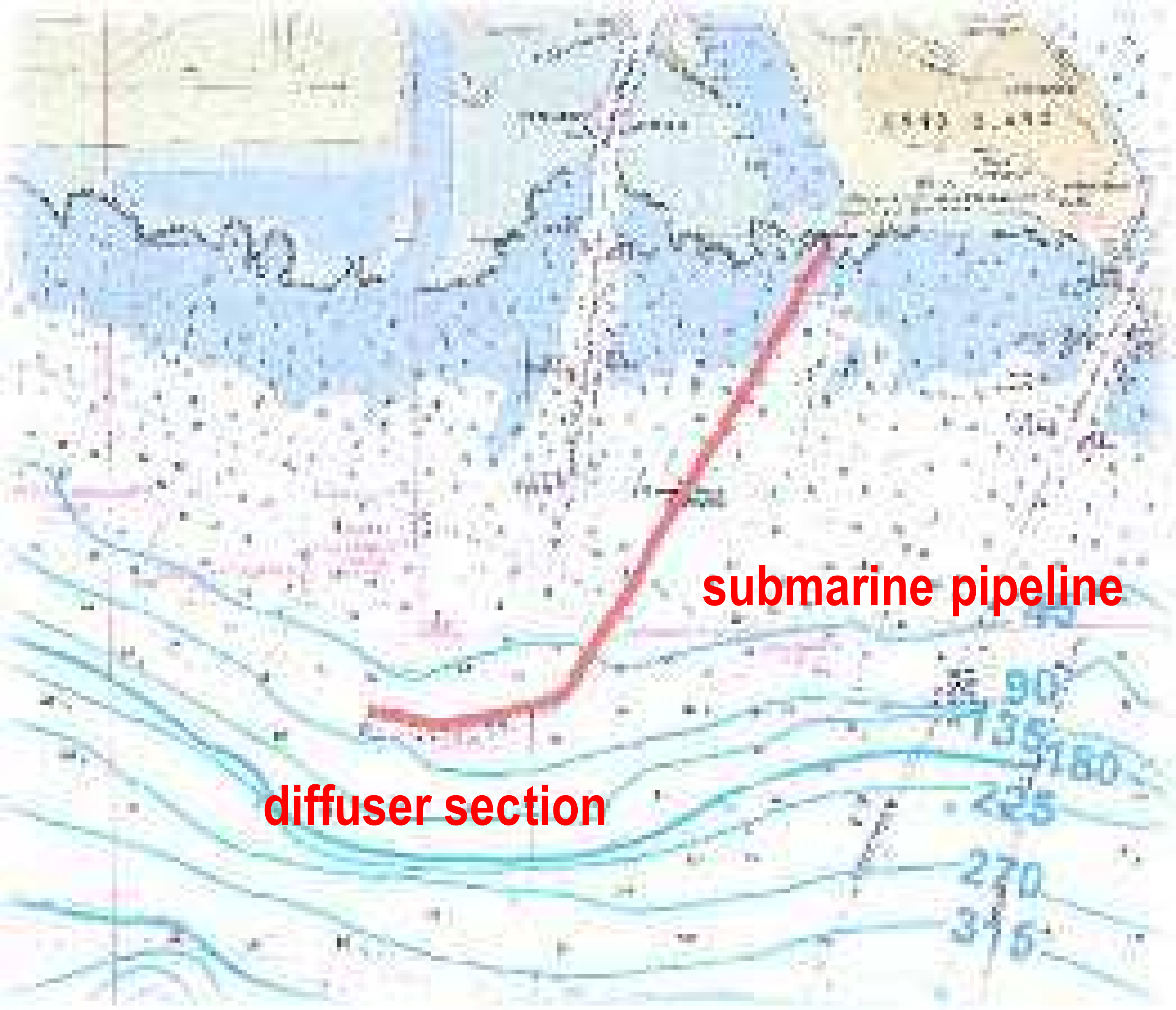
[a] Exclusive of end ports, which are usually somewhat larger.

A typical outfall geometry

(The Sand Island Honolulu wastewater outfall)



A laboratory model of waste water discharge from the diffuser

Fresh water is discharged to ambient salty ocean water at rates 1-5 m/s

A buoyant plume

The main aim of the present work is investigation of possibility of internal wave excitation by buoyant turbulent plumes and estimation of efficiency of such mechanism basing on laboratory scale modelling.

The dimensionless parameters of the flow in the buoyant plumes

The global Richardson number of the buoyant plumes

$$Ri = \frac{g\Delta\rho_0 b_0}{\rho_0 U_0^2}$$

The parameter of stratification

$$Str = \frac{N_0^2 b_0 \rho_0}{g\Delta\rho_0}$$

Dimensionless thickness of the pycnocline

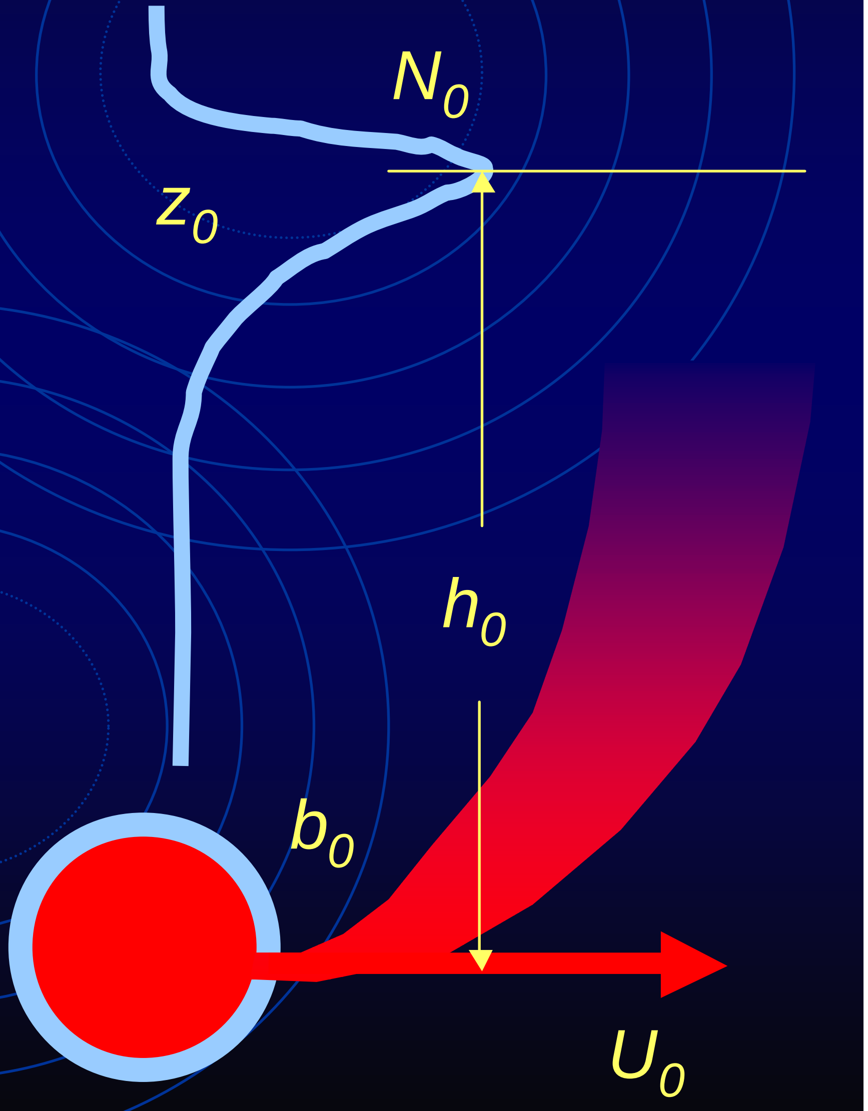
$$\tilde{z}_0 = z_0 / b_0$$

Dimensionless depth of the diffuser

$$\tilde{h} = h / b_0$$

The geometrical scale *k*=27,

The Reynolds number *Re*=3000



The parameters of the flow and stratification providing the scale modelling in the field conditions and in the laboratory experiment

Parameter	Field conditions	Lab conditions
Diameter of the output hole , b_0	8 cm	0.3 cm
Distance from the collector to the canter of the pycnocline , z_p	30 m	110 cm
Width of the pycnocline , h	5.5.m	20 cm
Distance between the holes in the diffuser , l	7 m	30 cm
Maximum of buoyancy frequency , N_0^2	$5{\cdot}10^{-2}$ s^{-1}	0.45 s^{-1}
Initial difference of the discharged and ambient fluid , $(\rho_1 - \rho_0)$	0.0235 g/cm^3	0.07 g/cm^3
Discharge rate , U	3 m/s	1 m/s

N_0^2

II

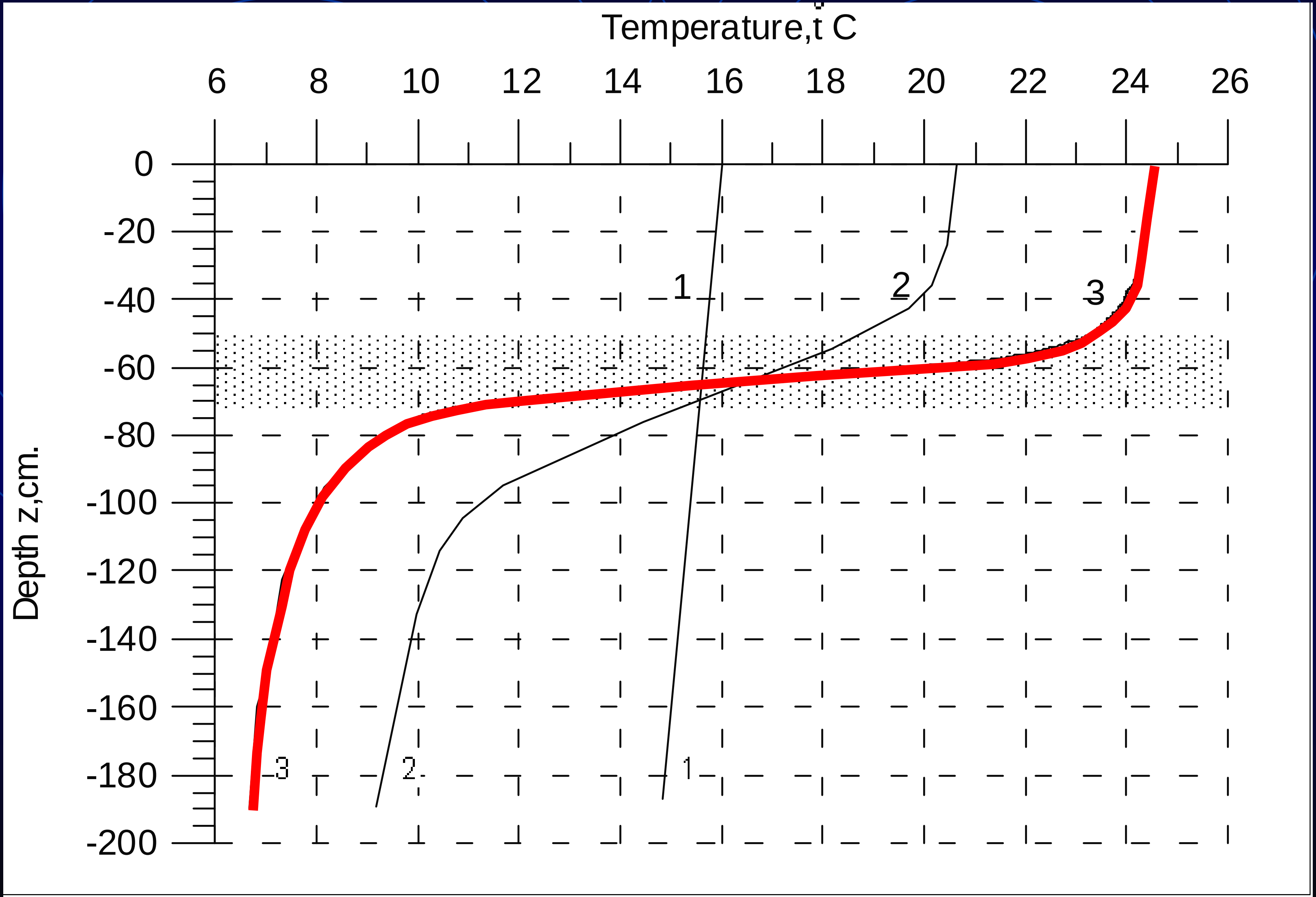
Experimental setup and scale modeling

The large thermostratified tank of IAP RAS

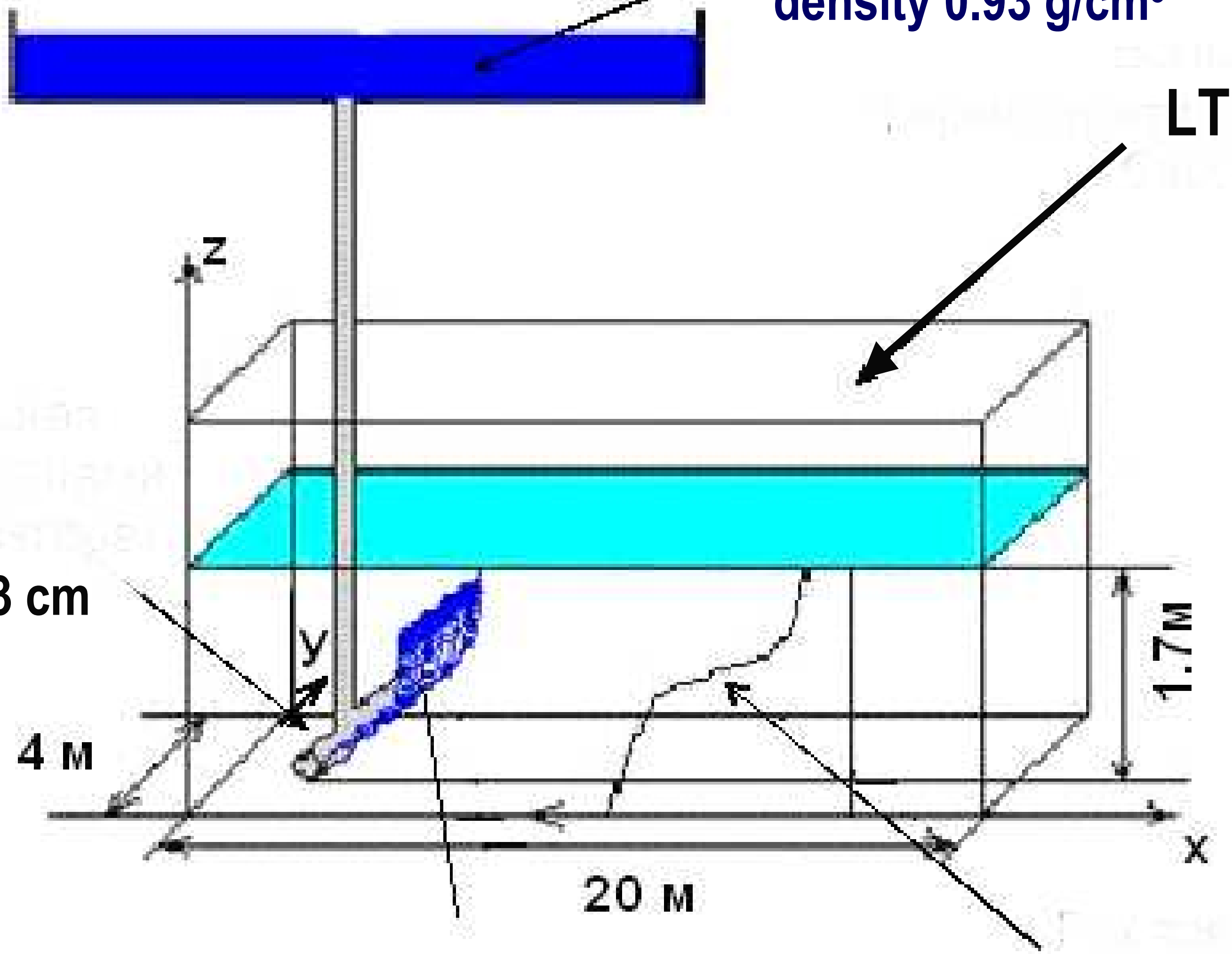
Overall sizes: length 20m, width 4m , depth 2m.

Artificial thermocline-like temperature stratification.

Temperature profiles in LTST: 1 – initial profile; 2 – after 8 hours of operation of the cooling machines; 3 – after 20 hours of operation of the cooling machines.



Sketch of laboratory experiment in LTST



Alcohol solution with density 0.93 g/cm^3

LTST

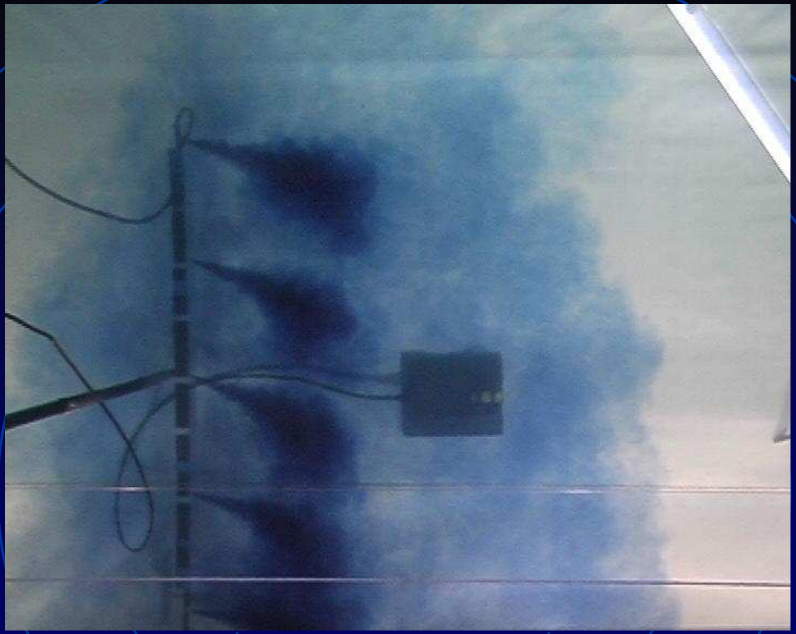
Model of diffuser

Length = 1.3м

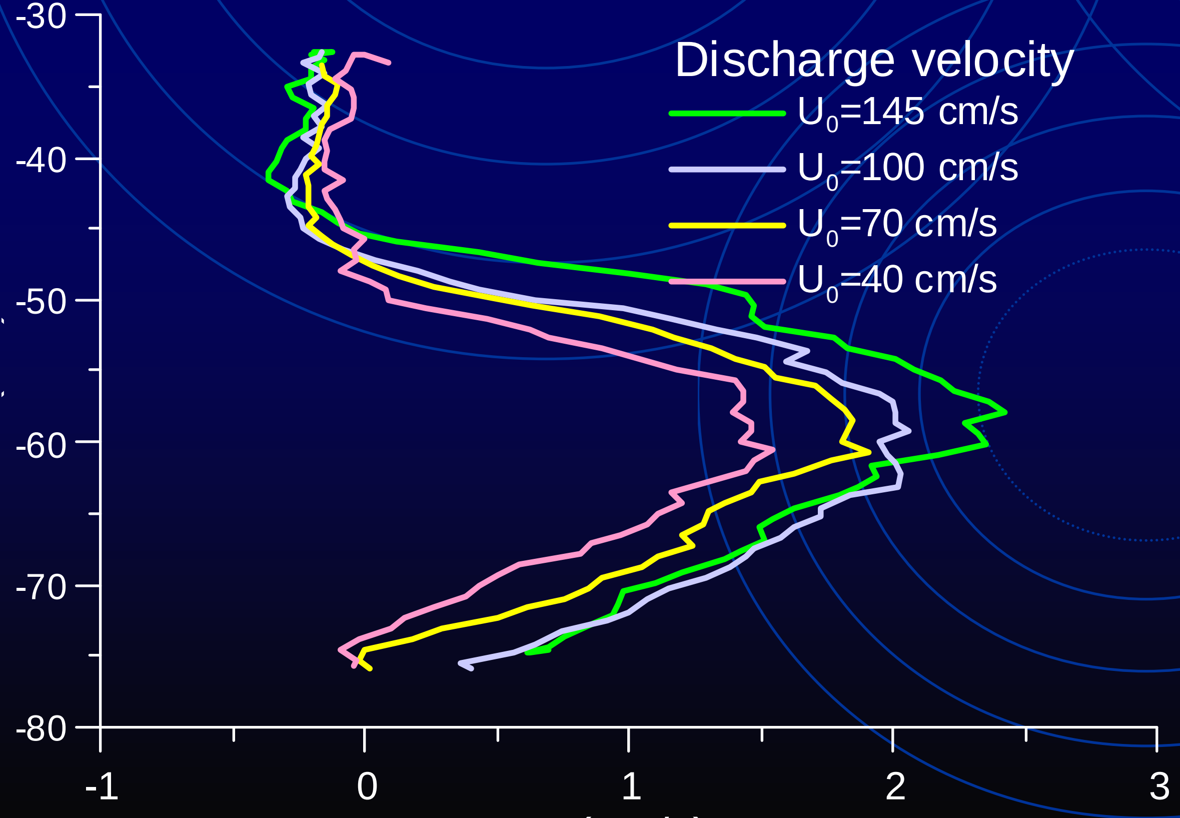
Hole diameter 0.3 cm

Buoyant plumes

T(z)



A front view of the buoyant plumes trapped by the thermocline

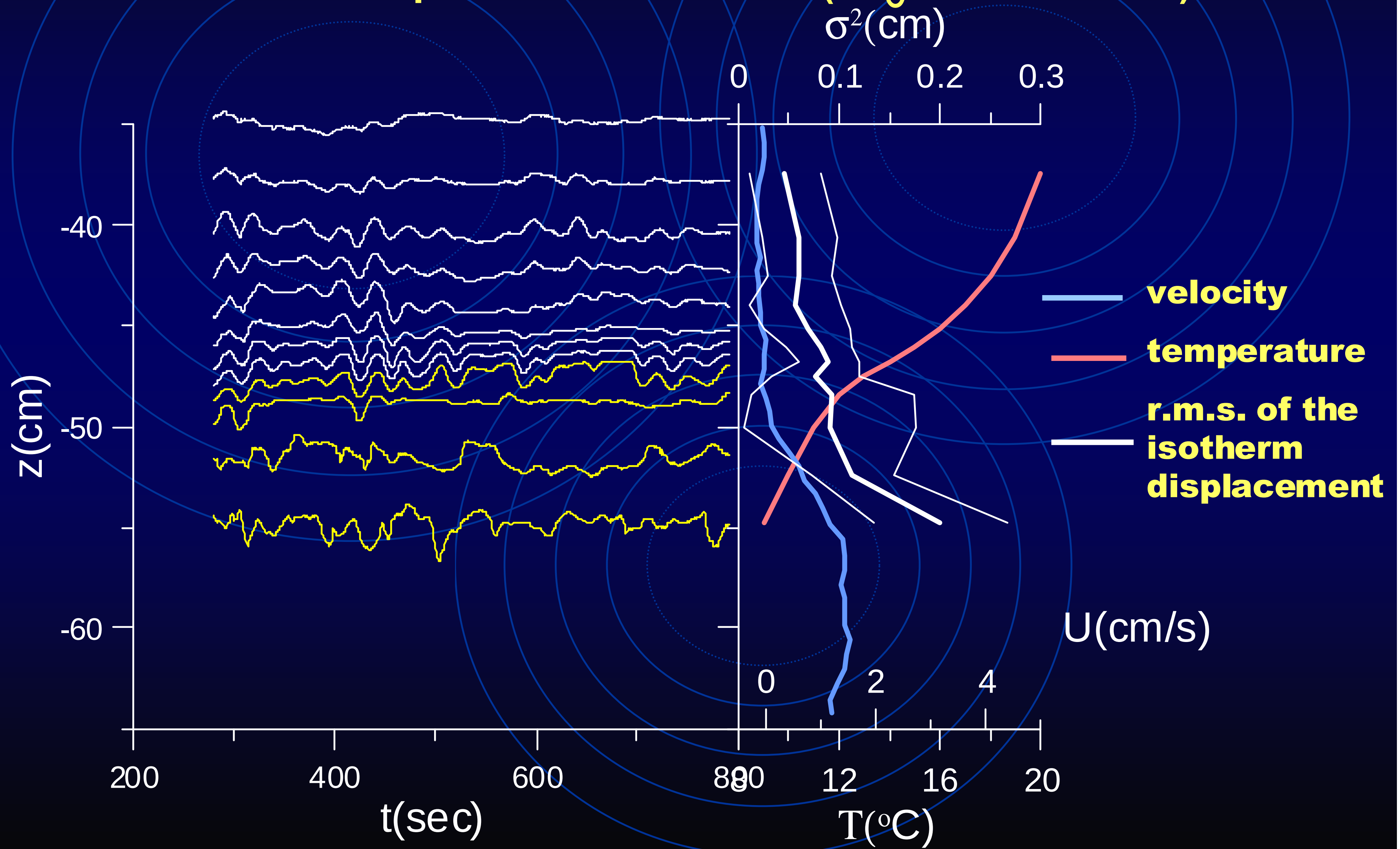


The jets velocity profiles measured at the distance 2 m from the model diffuser in our experiment for various discharge rates

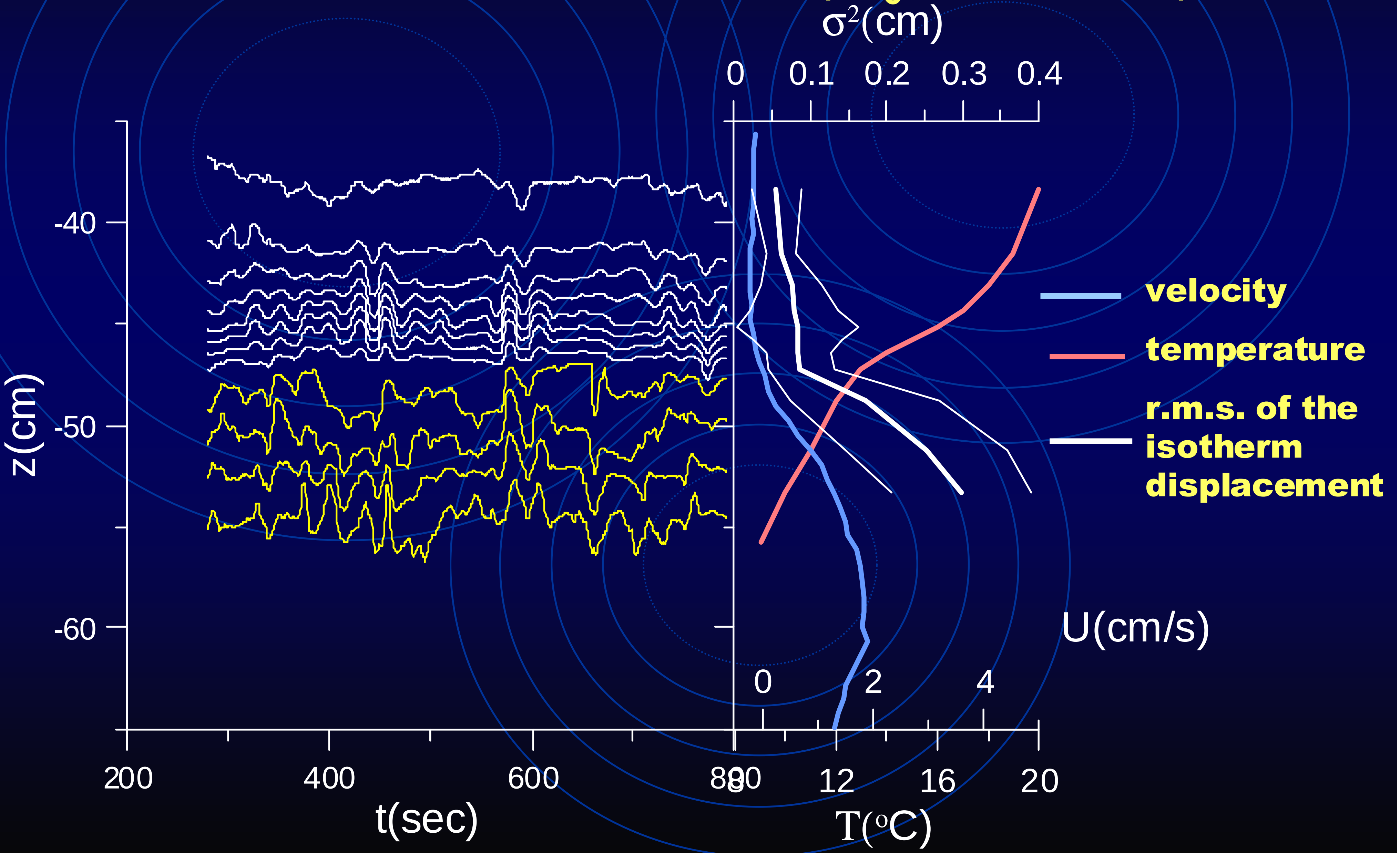
III

Experimental results

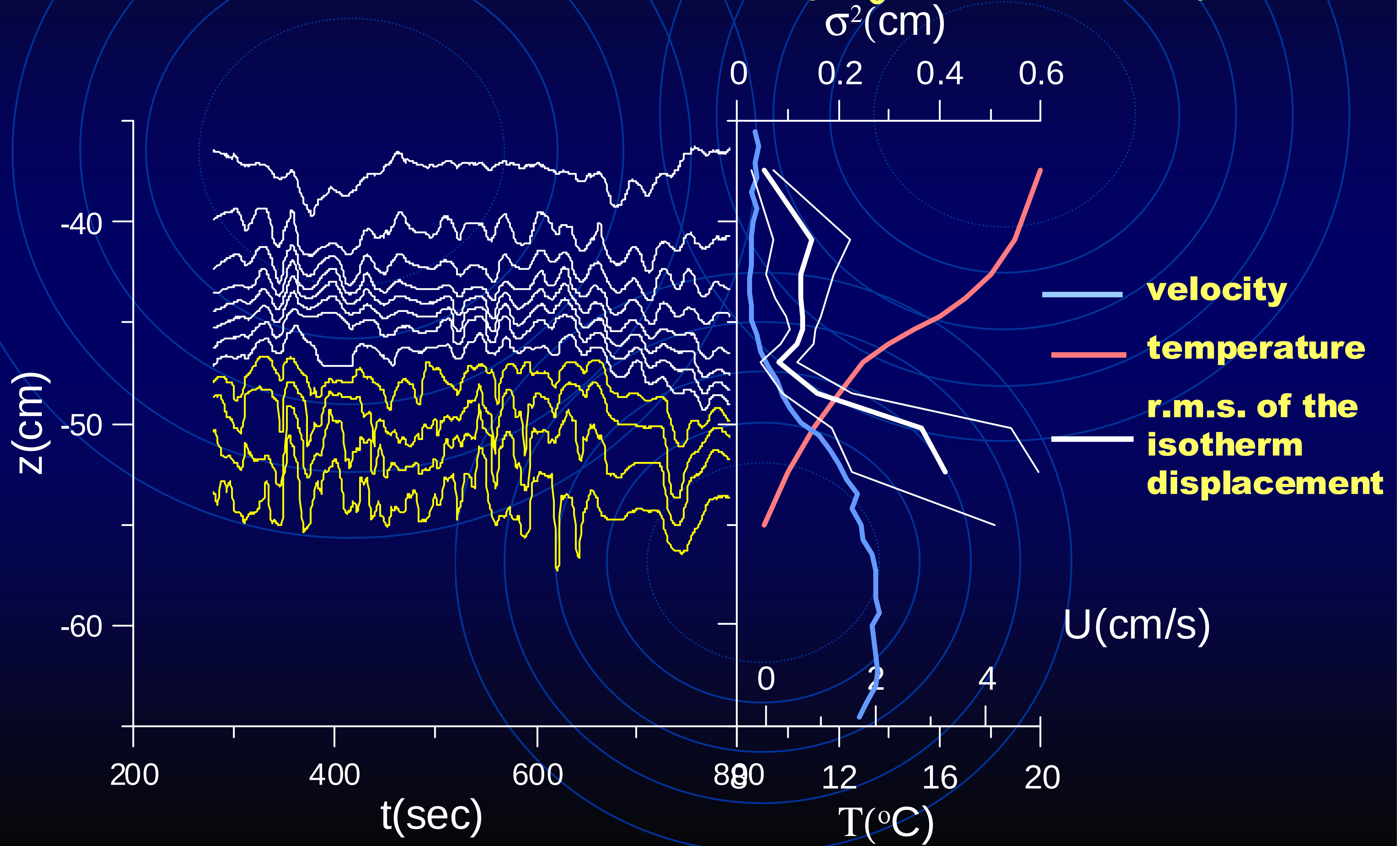
The examples of time cross-sections of the temperature field (U_0=40 cm/s)



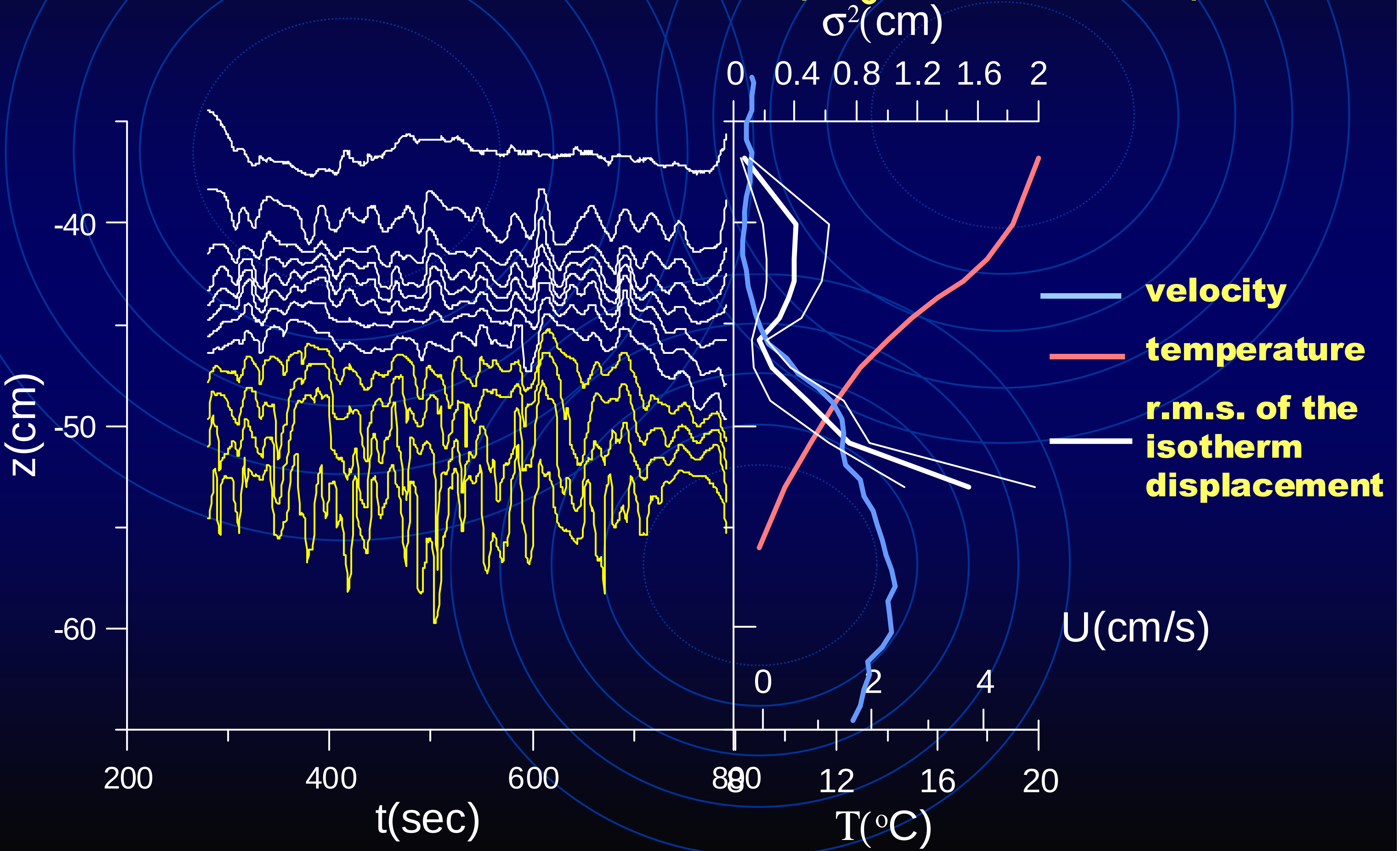
The examples of time cross-sections of the temperature field (U_0=70 cm/s)



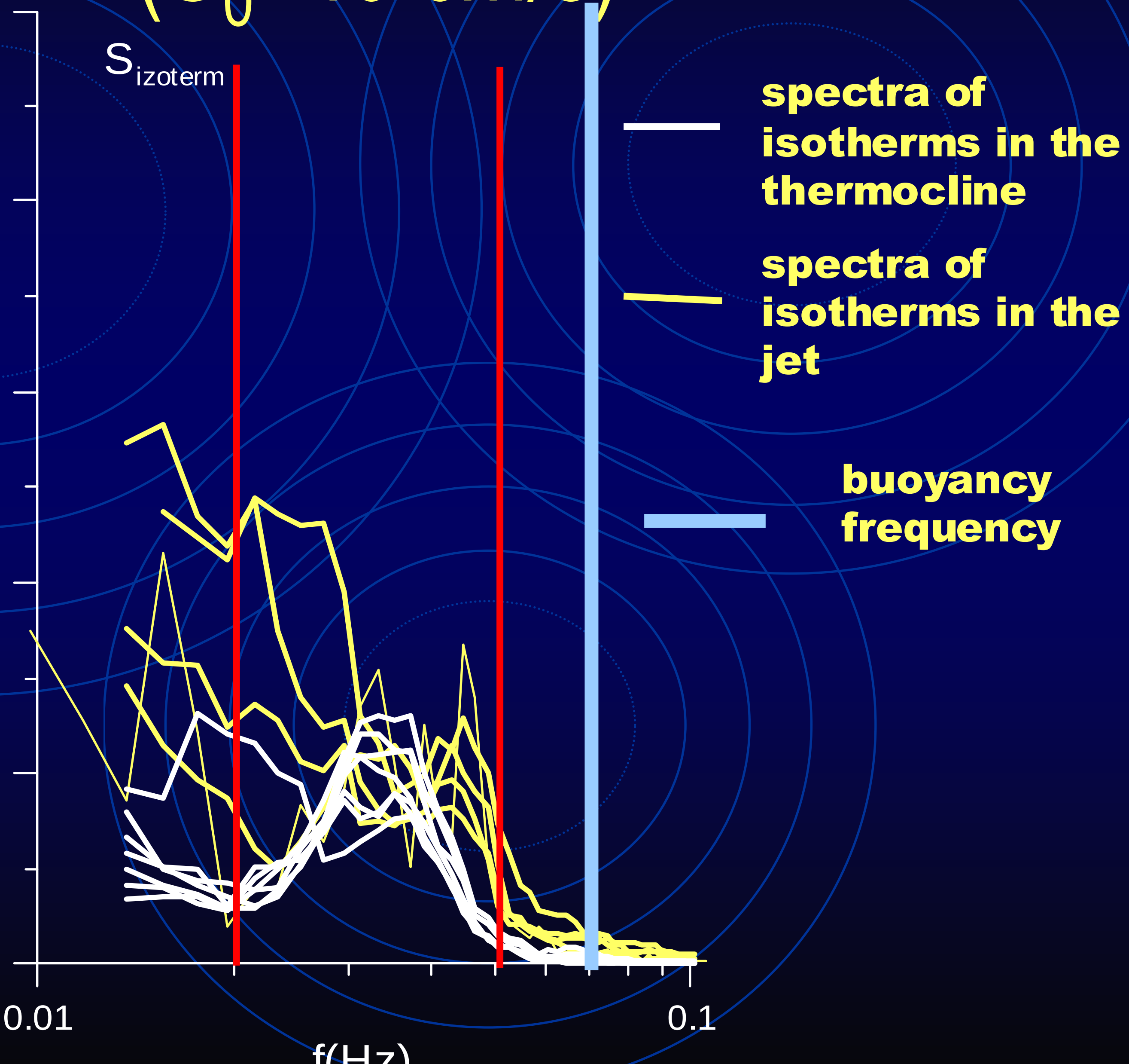
The examples of time cross-sections of the temperature field (U_0=100 cm/s)



The examples of time cross-sections of the temperature field (U_0=145 cm/s)



Spectra of displacements of isotherms (U_0=40 cm/s)

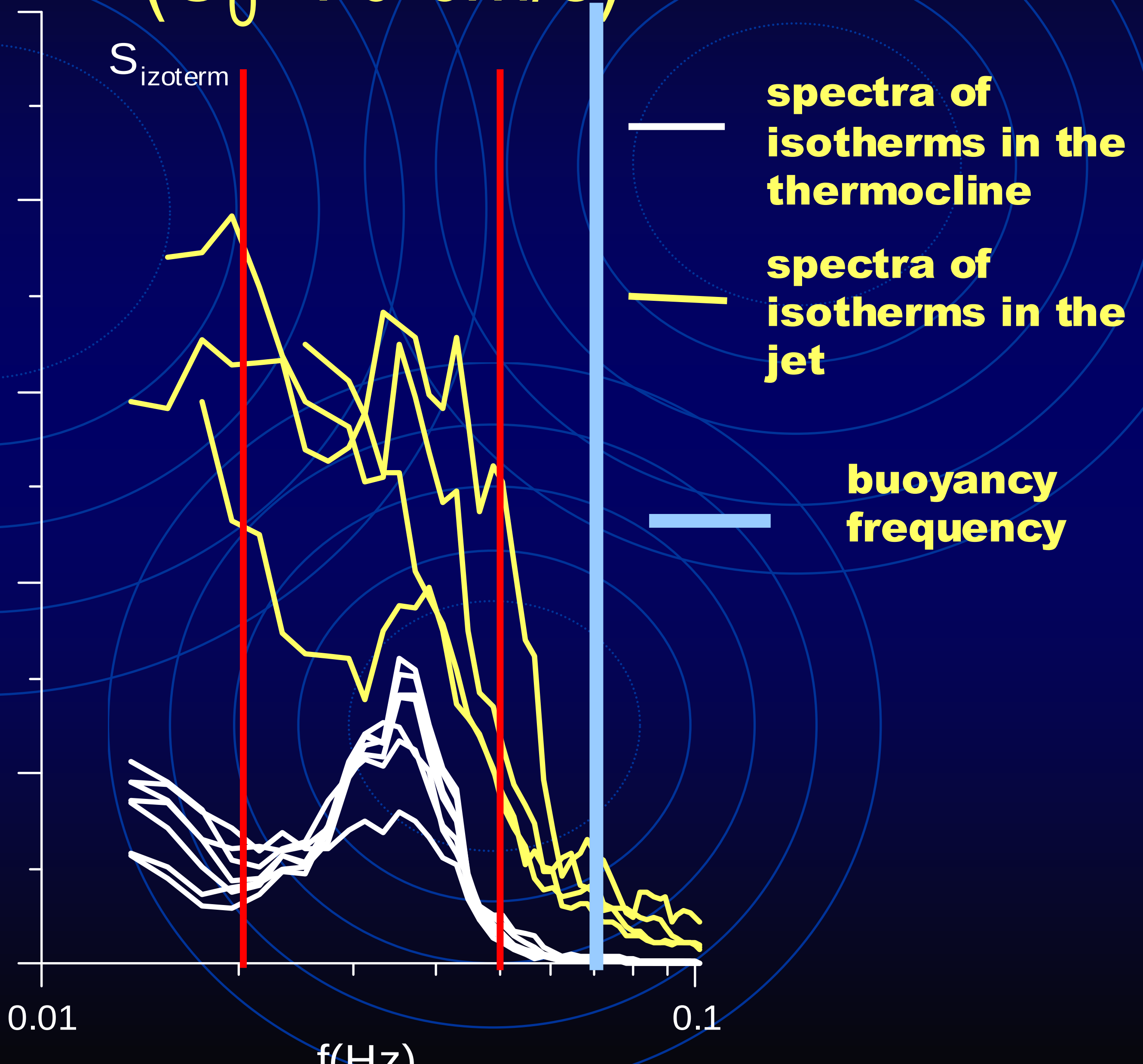


spectra of isotherms in the thermocline

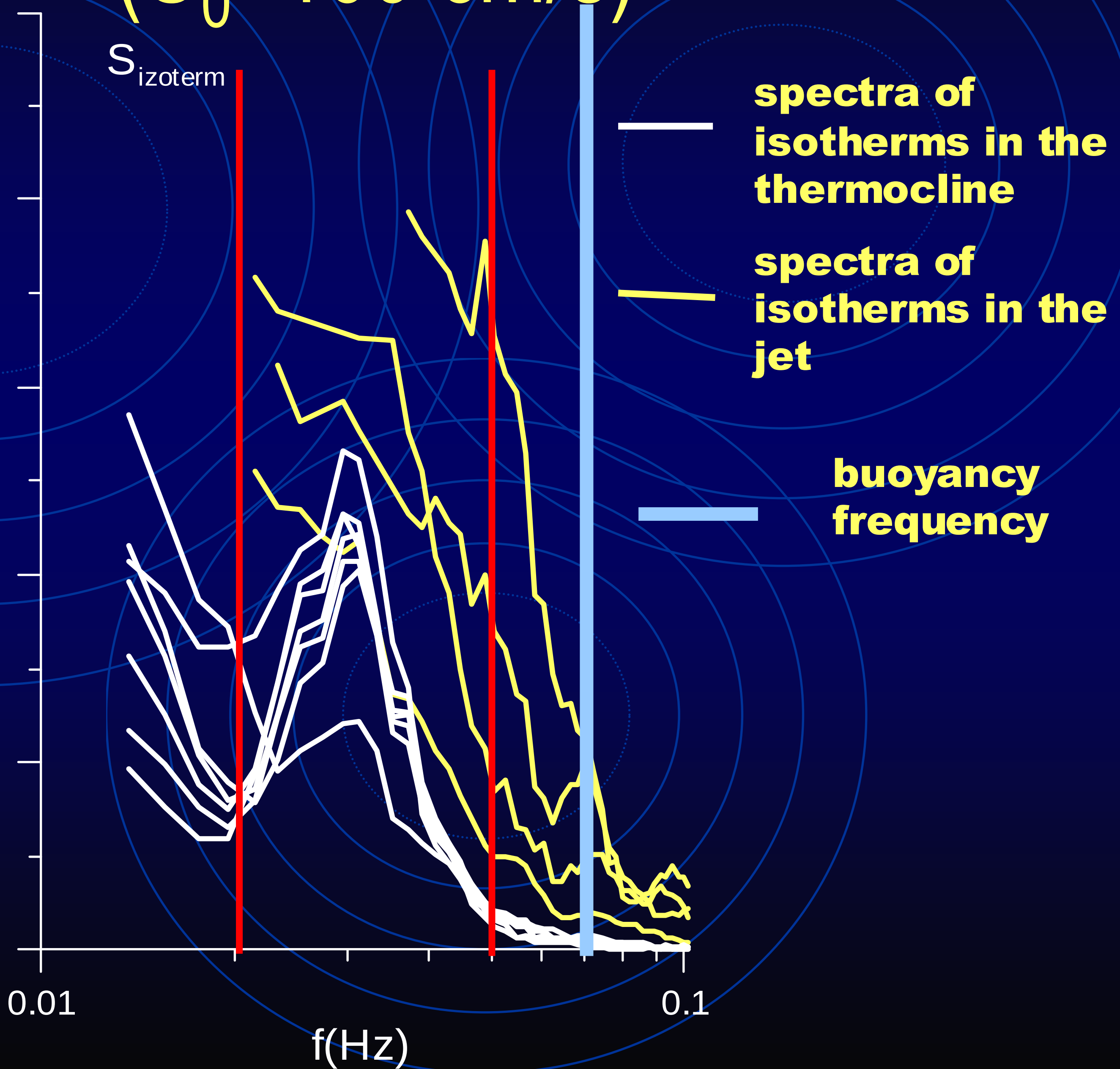
spectra of isotherms in the jet

buoyancy frequency

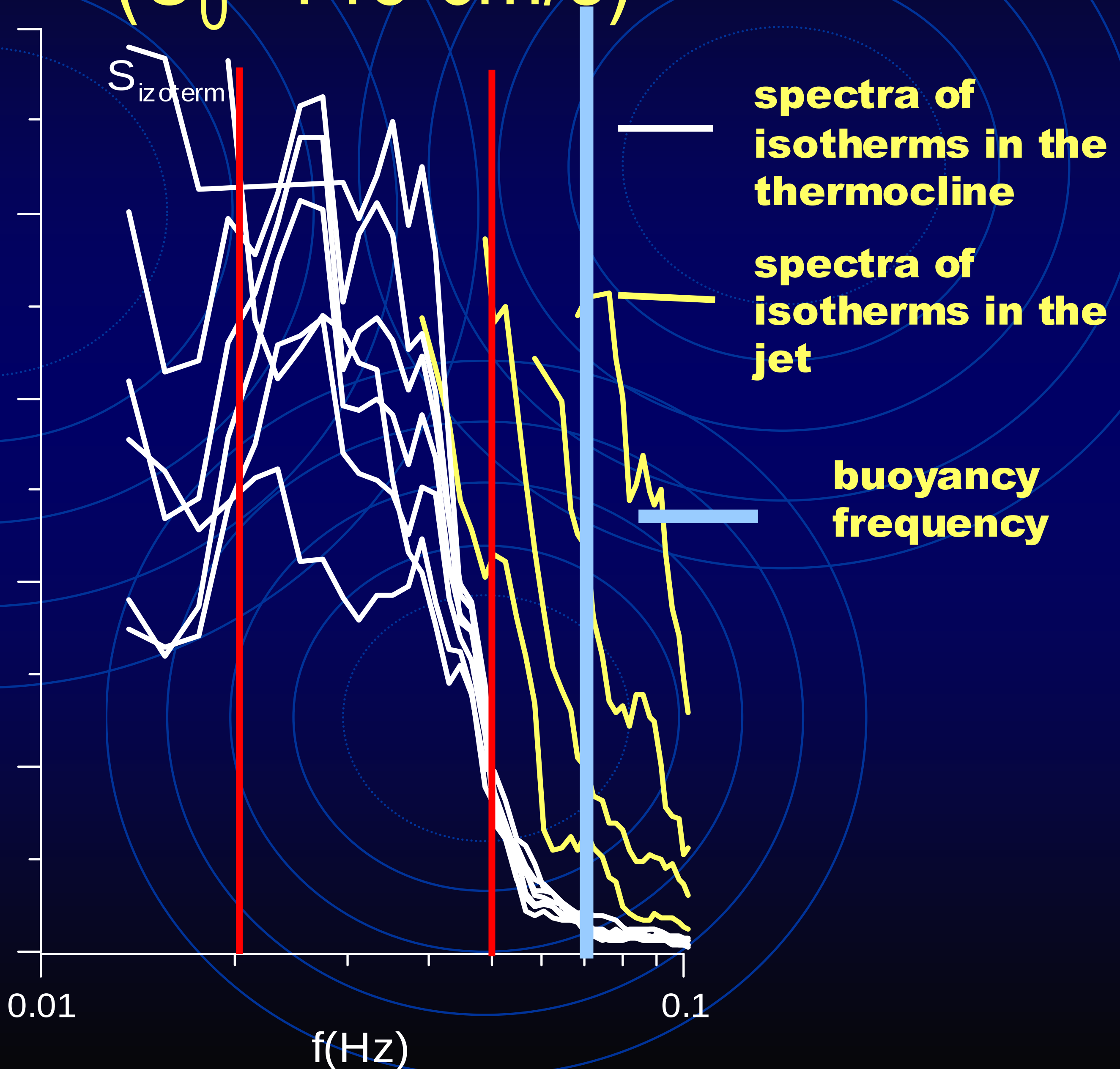
Spectra of displacements of isotherms (U_0=70 cm/s)



Spectra of displacements of isotherms (U_0=100 cm/s)



Spectra of displacements of isotherms (U_0=145 cm/s)



IV

Possible interpretation of experimental results in terms of self-sustained oscillations

Quantitative parameter of oscillations

R.m.s. displacement of the isotherms within the spectral interval of the pronounced spectral peak 0.02-0.05Hz

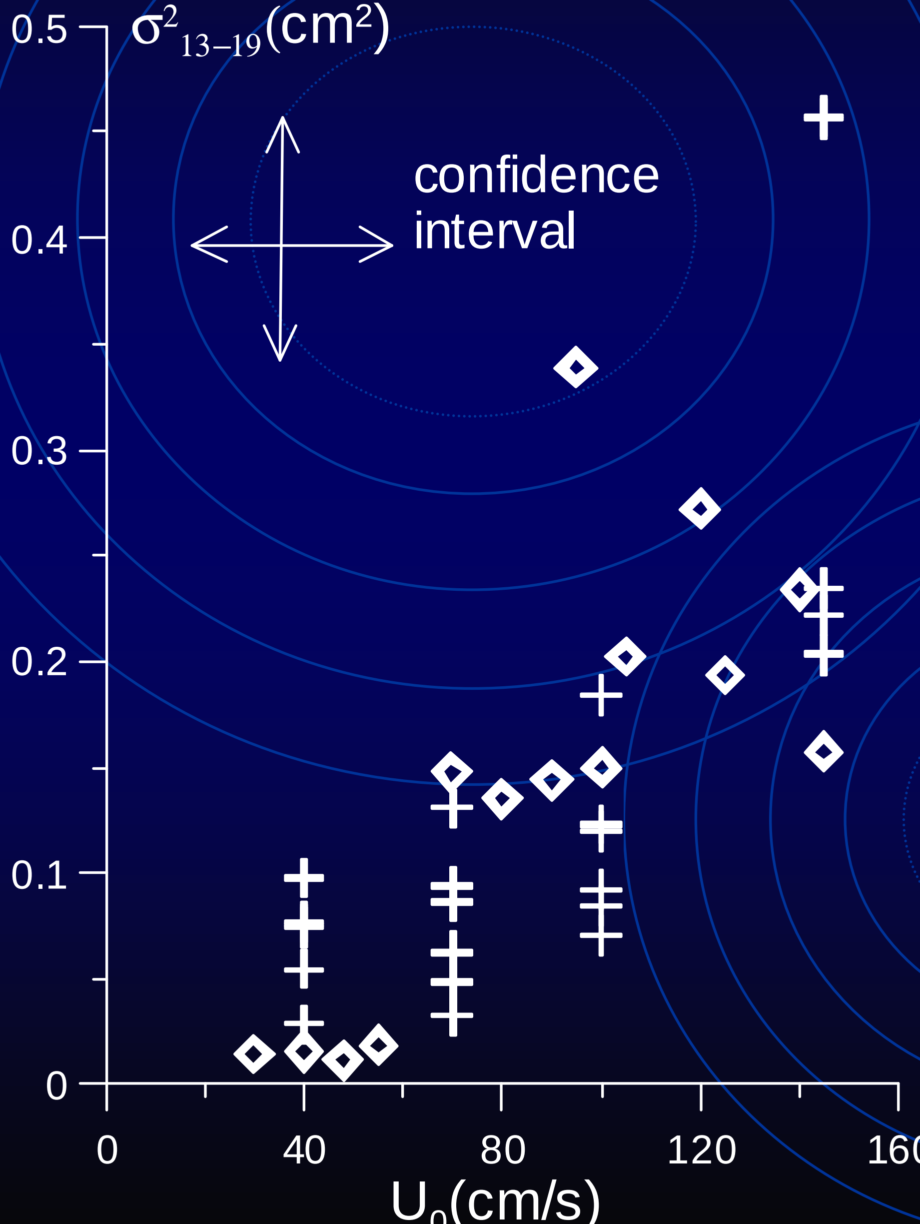
$$\left\langle \sigma_{\eta}^{2} \right\rangle = \int_{f_0}^{f\,\max} Sp(f)df$$

f_0=0.02 Hz, f_{max}=0.05 Hz

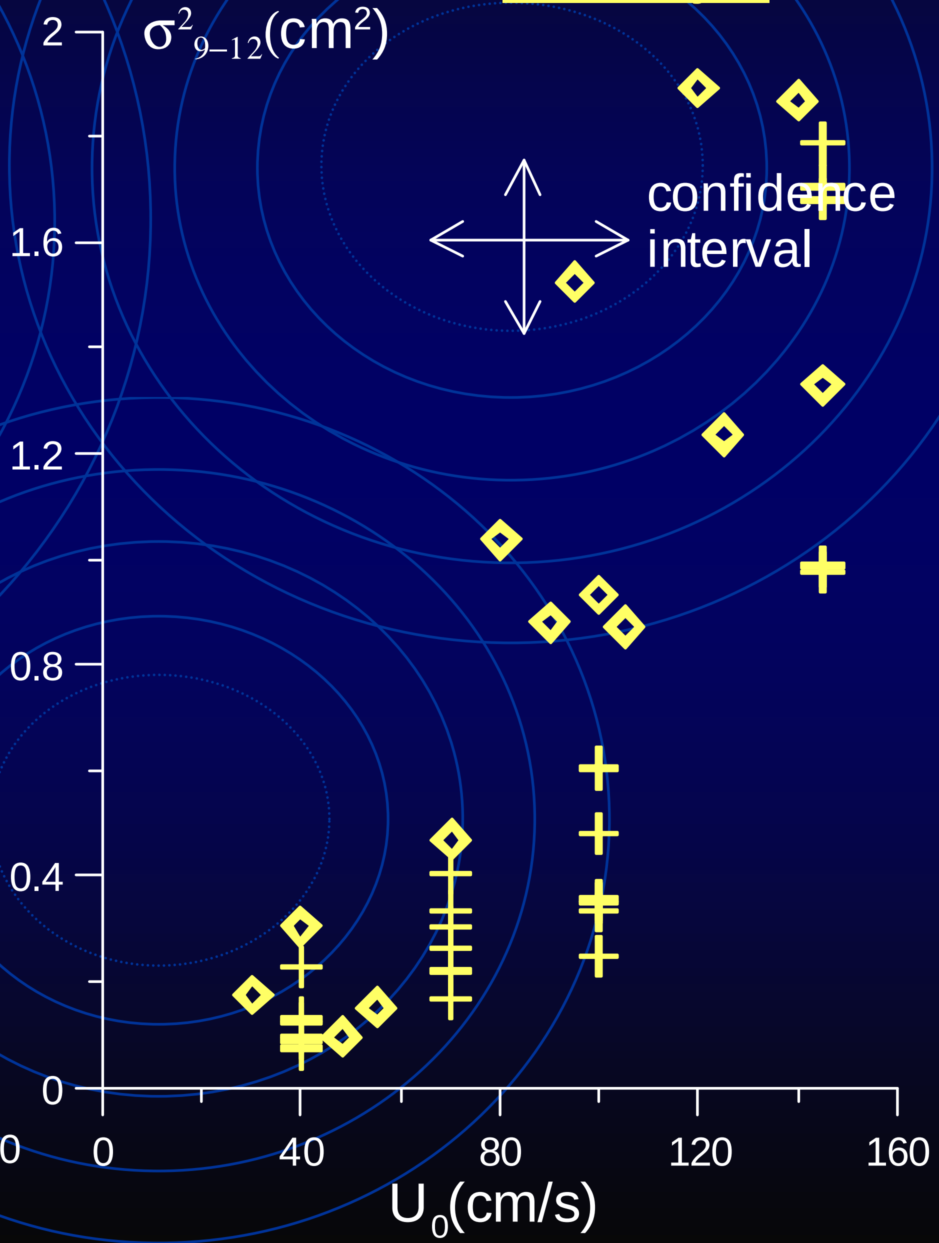
Control parameter – the discharge rate U_0

Dependence of the r.m.s. displacement of isotherms on the discharge rate

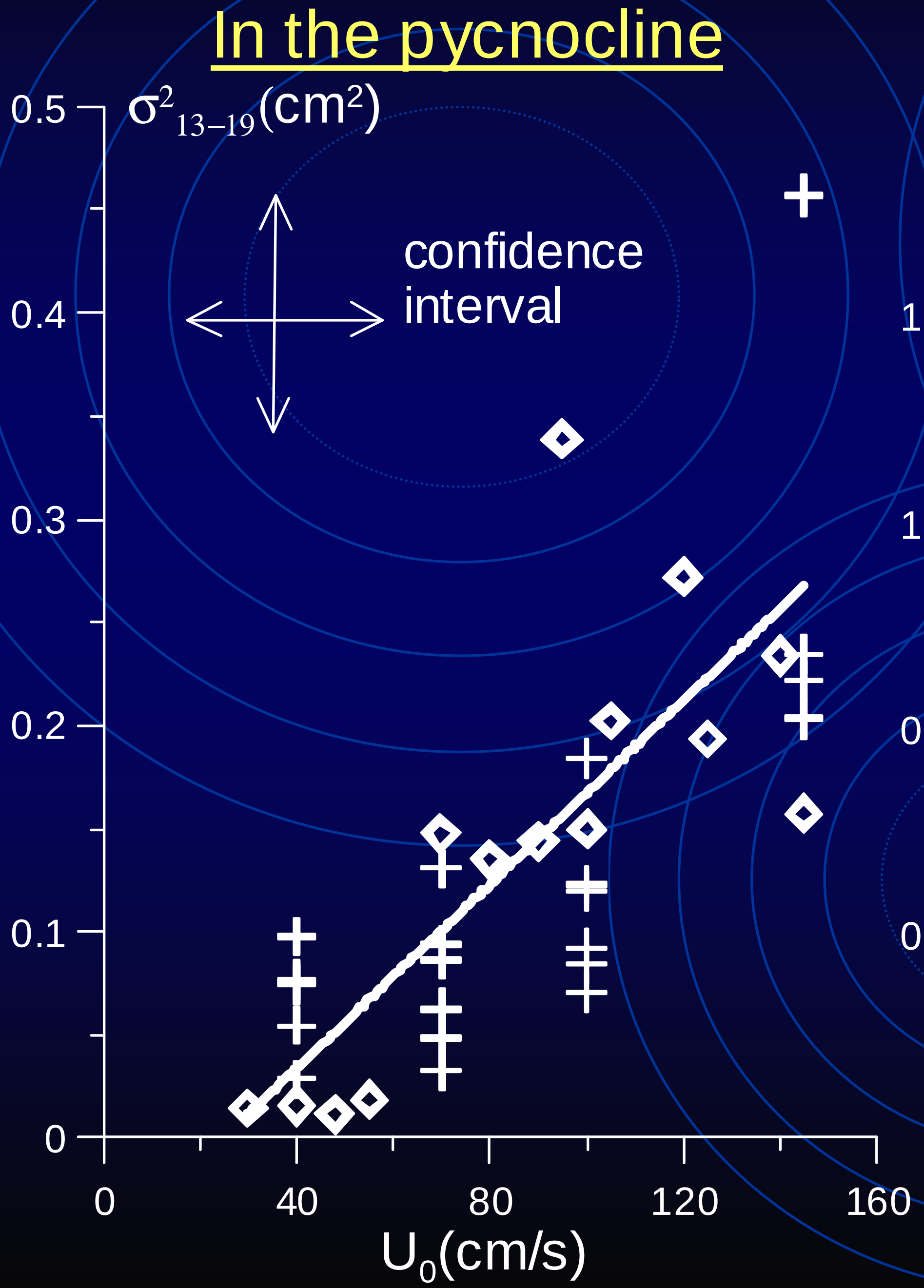
In the pycnocline

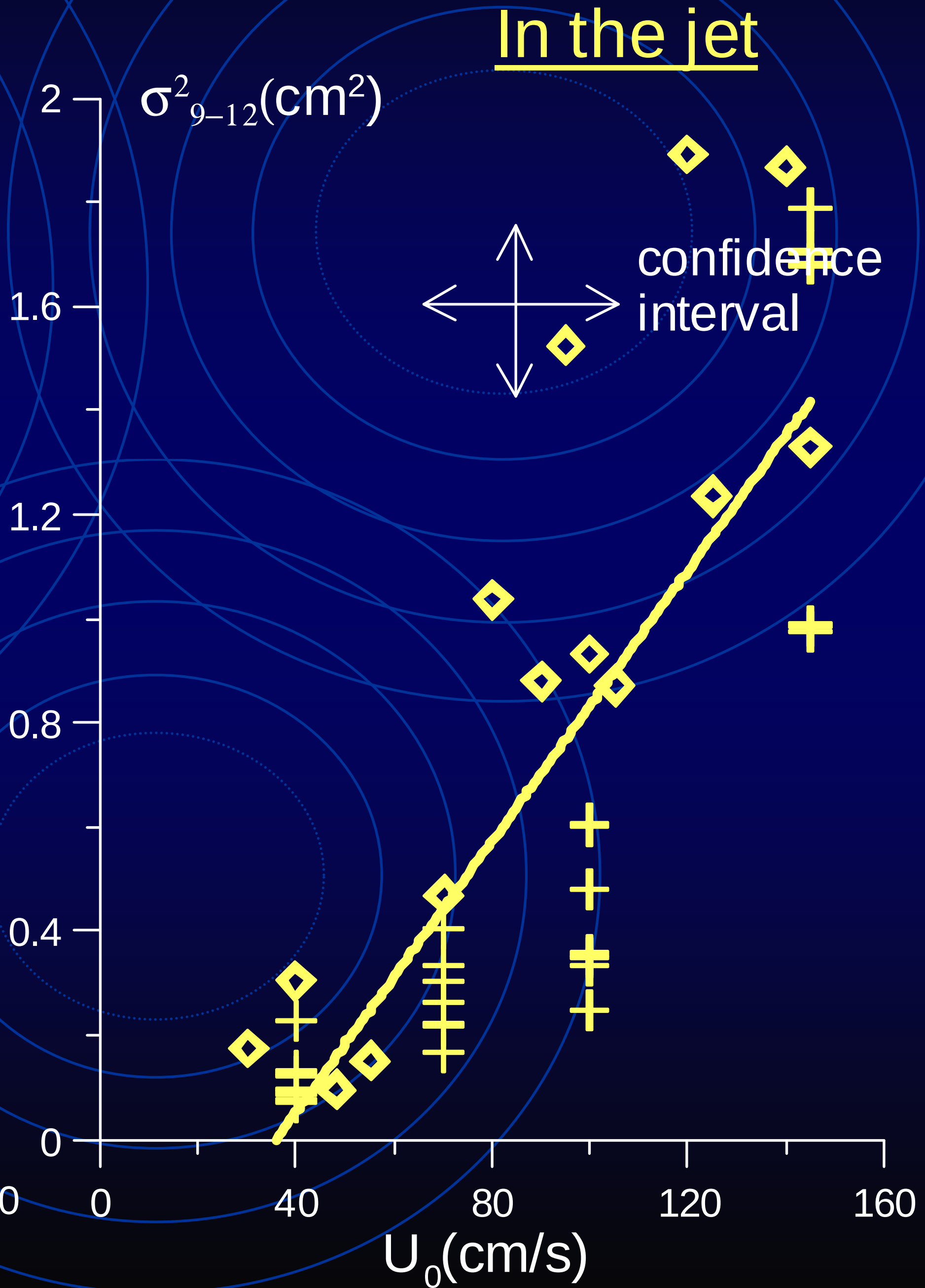


In the jet



Dependence of the r.m.s. displacement of isotherms on the discharge rate





The linear dependence of square of amplitude of oscillations on the control parameter is an indication of excitation of self-sustained oscillations in a system.

The Landau equation for the amplitude of oscillations

$$\frac{da}{dt} = a\left(\mu\left(U_0 - U_{0c}\right) - \nu|a|^2\right) \qquad \left\langle\sigma_\eta^2\right\rangle = |a|^2$$

The stationary solution to the Landau equation

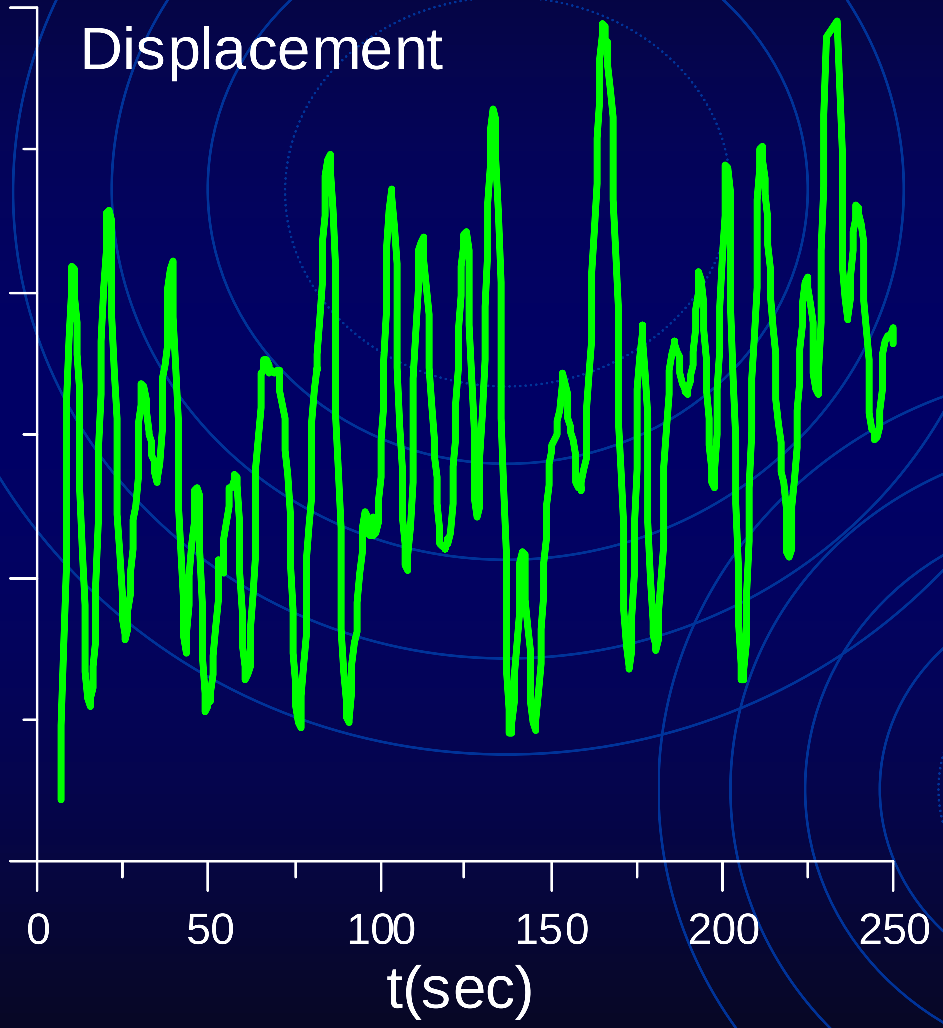
$$\left(\left(U_0 - U_{0c}\right) - \frac{\nu}{\mu}\left\langle\sigma_\eta^2\right\rangle\right)\sqrt{\left\langle\sigma_\eta^2\right\rangle} = 0$$

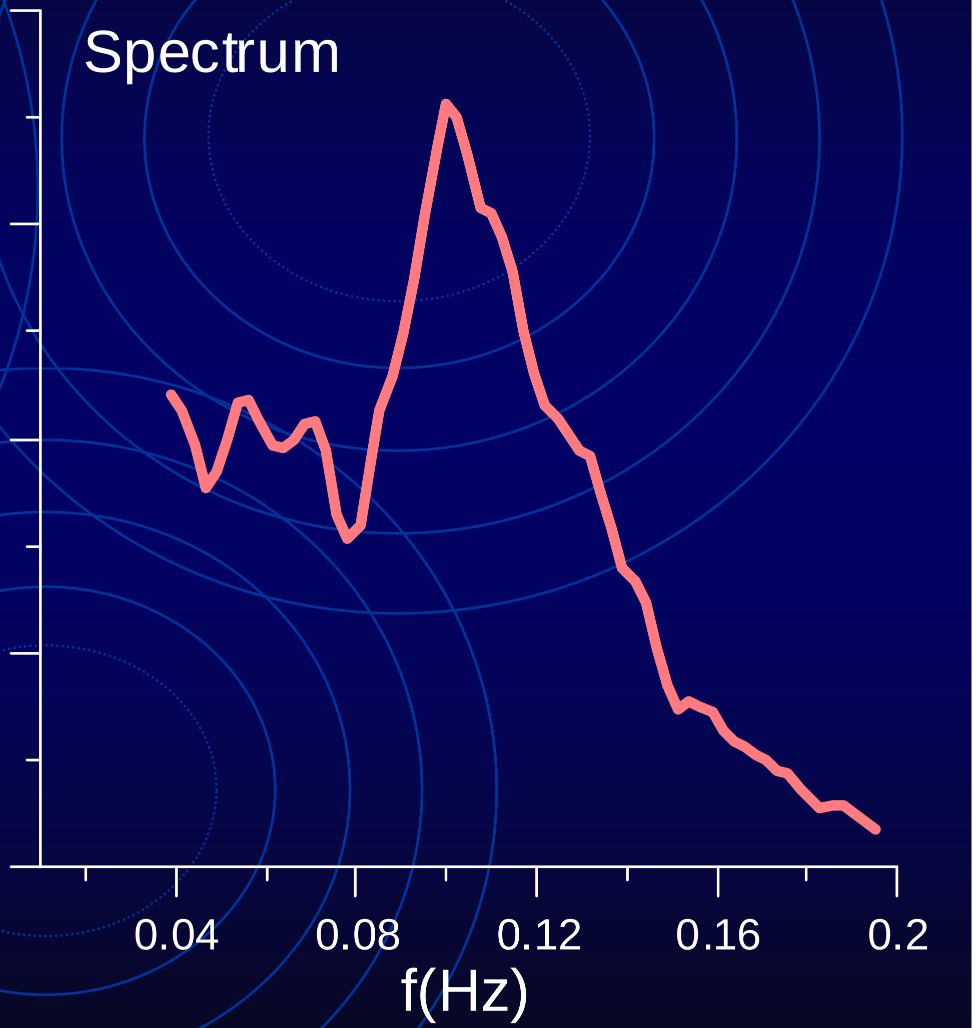
Linear dependence of r.m.s. displacement of isotherms on the control parameter

$$\left\langle\sigma_\eta^2\right\rangle = \frac{\mu}{\nu}\left(U_0 - U_{0c}\right)$$

Oscillations of the top of the buoyant jet impacting pycnocline

Time dependence of the position of the top of the buoyant plume and frequency spectrum of the oscillations



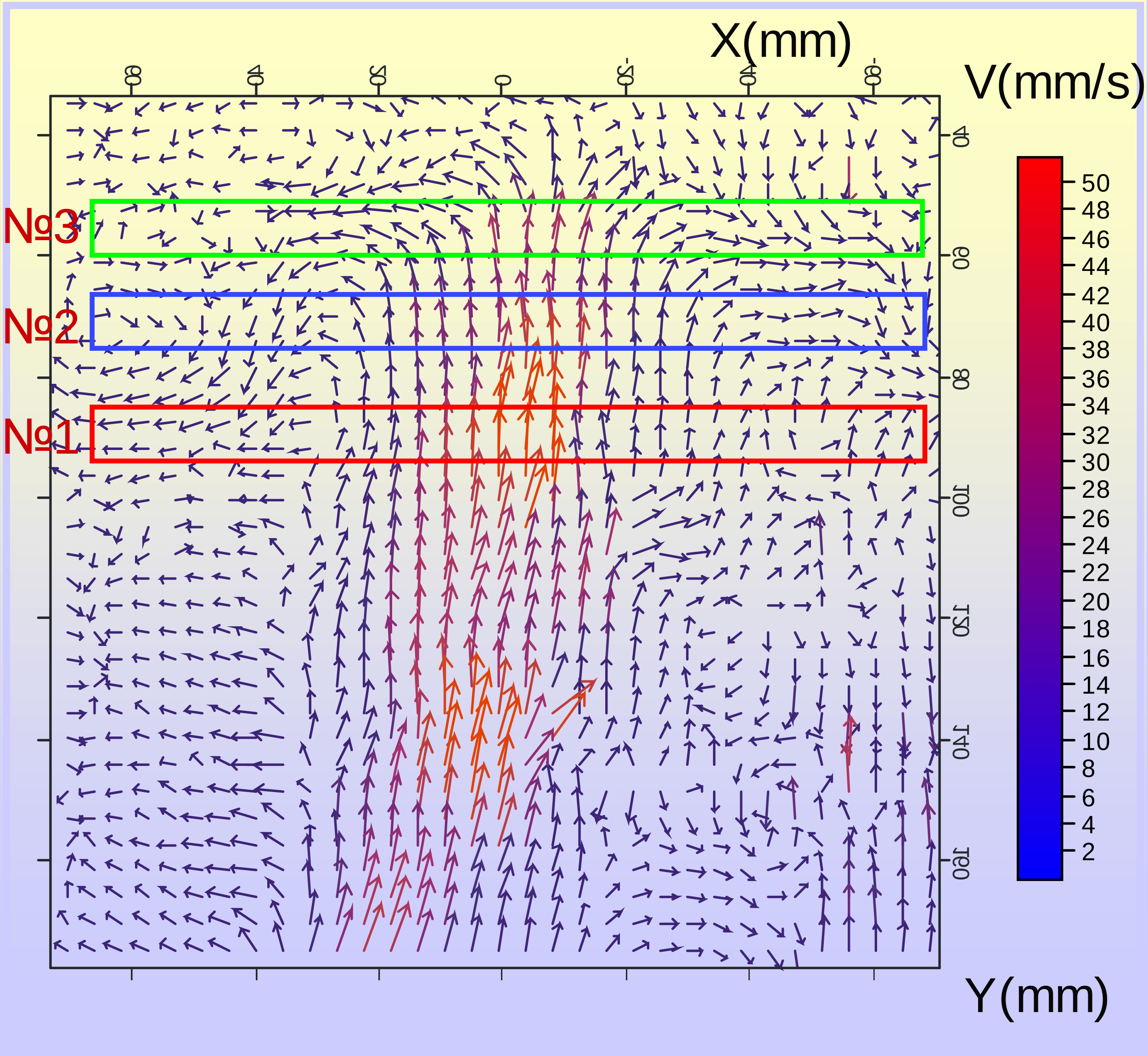


These oscillations are considered as a possible candidate for the source of the observed internal waves

Self-sustained oscillations in spatially developing flows (buoyant plums) in terms of globally unstable modes of such flows

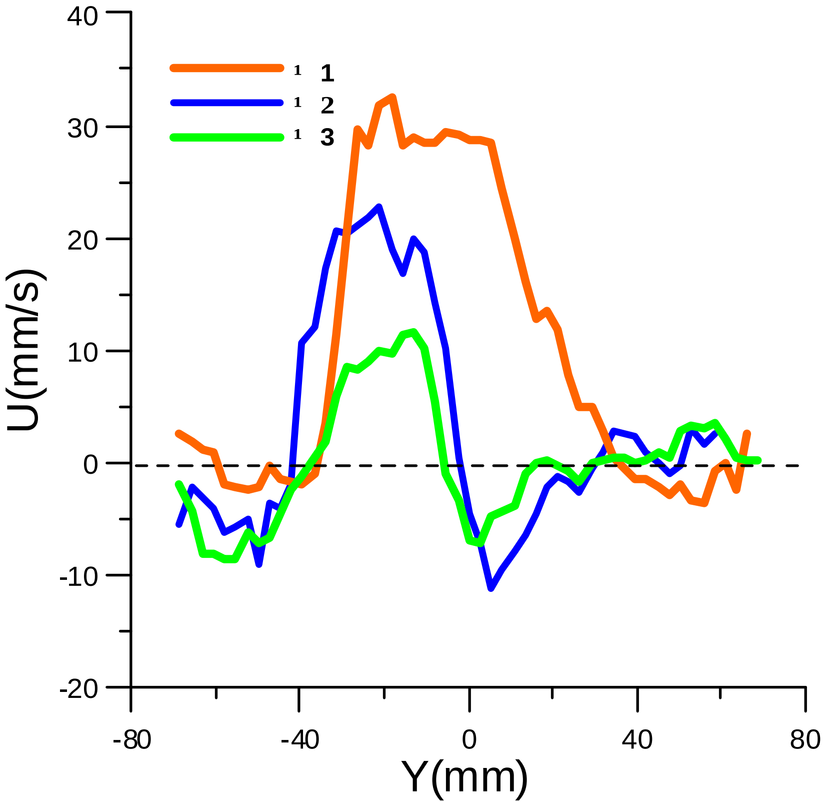
(Huerre, Monkewitz (1986-1990))

Flow velocity field in the buoyant plum measured by PIV-method



Flow velocity profiles in 3 sections

1. Below the level of neutral buoyancy
2. At the level of neutral buoyancy
3. Above the level of neutral buoyancy



Near the top of the buoyant plum the pronounced counter-flow exists

Absolute and convective instability

Type of instability (absolute or convective) is determined by the sign of imaginary part of ω in the point, where the complex group velocity is zero.

$$\frac{d\omega}{dk}(k_0) = 0$$

If $\mathrm{Im}\,\omega(k_0)>0$ absolute instability

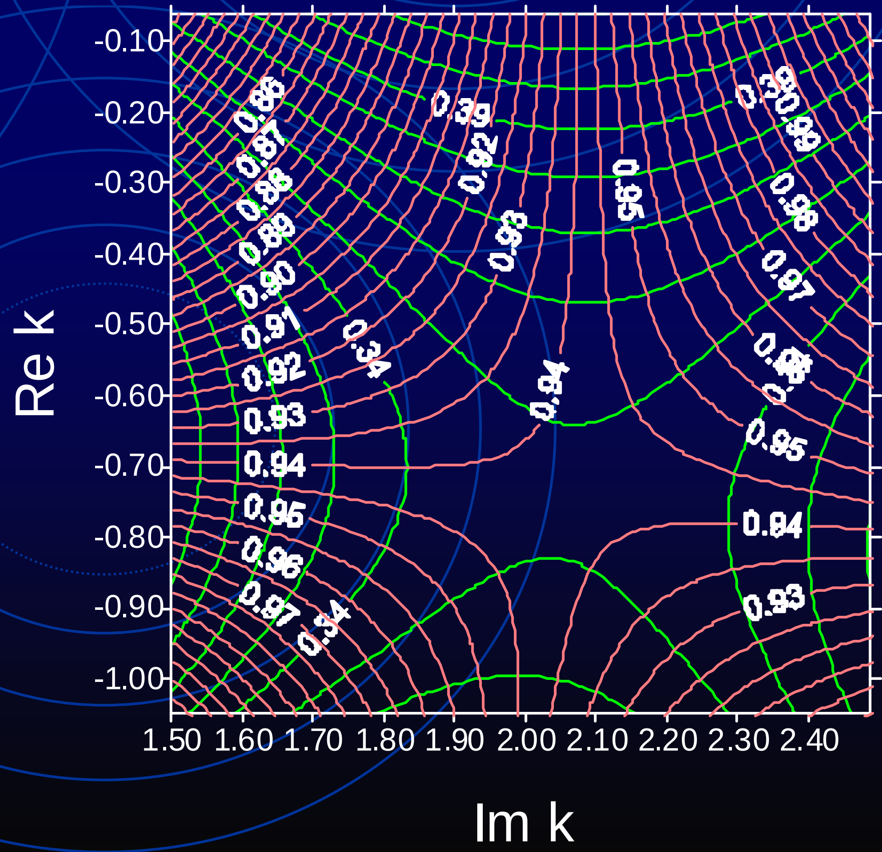
If $\mathrm{Im}\,\omega(k_0)<0$ convective instability

Dispersion relation is obtained as a solution to the boundary eigen-value problem for the analog of the Rayleigh equation for the jet flow

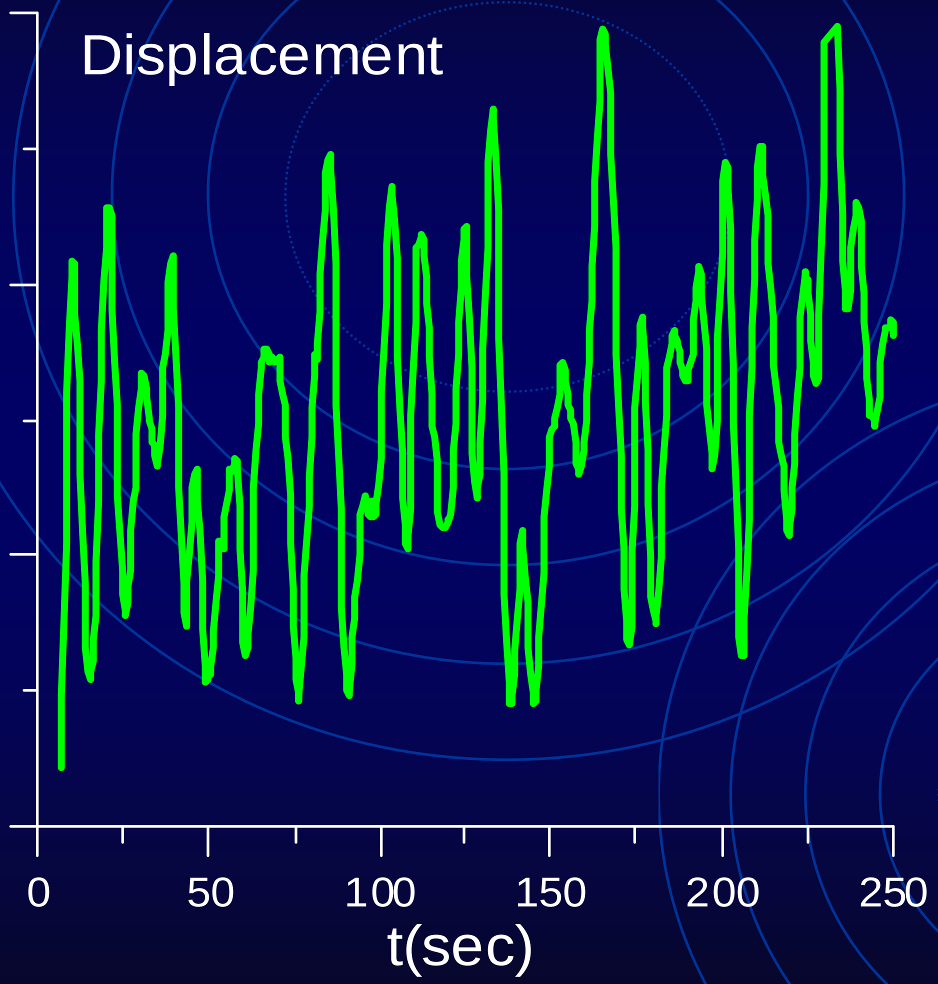
$$\frac{\partial^2 p}{\partial r^2} + \frac{1}{r}\frac{\partial p}{\partial r} - \frac{2U_0'}{U_0 - c}\frac{\partial p}{\partial r} - k^2 p = 0$$

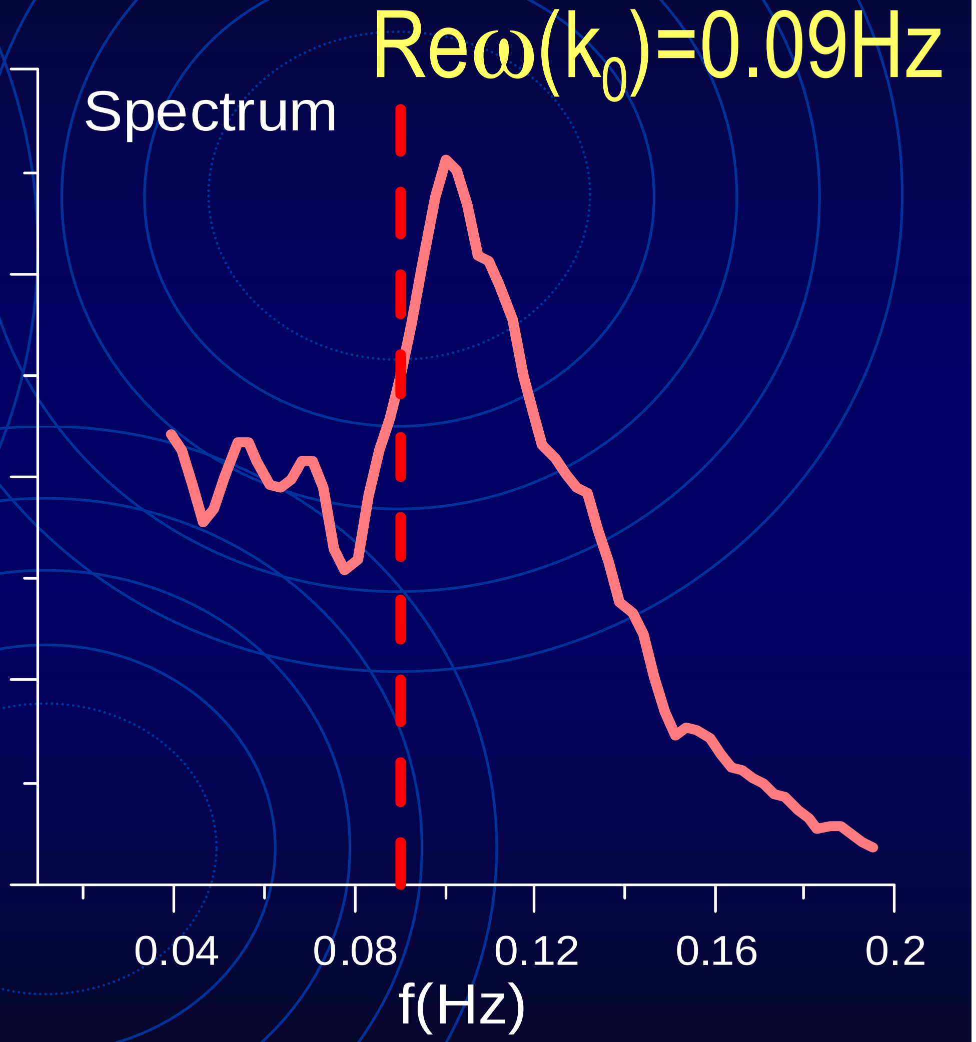
$$p(0) = 1; \quad p(\infty) = 0$$

For the jet with the counter-flow there is absolute instability



The calculated frequency of the most unstable mode is close to the peak in the spectrum of oscillations of the position of the top of the buoyant plume





It confirms our hypothesis that the observed oscillations can be interpreted as self-sustained oscillations of the globally unstable mode. These oscillations are considered as a possible candidate for the source of the observed internal waves

V. Conclusions

- Scale modelling of of internal wave excitation by buoyant turbulent plumes discharged from diffusers of submerged outfalls was carried out in the large testing tank (overall sizes 20mx4mx2m) with artificial thermocline-like stratification.
- Excitation of intensive temperature oscillations was observed at significant distance from the model of diffuser for the discharge rates, corresponding to the scale-modelling conditions .
- The measured dependency of the amplitudes of oscillations on the control parameter of the problem was typical for the presence of the self-sustained oscillations. The observed internal waves were interpreted as a result of impact of the oscillations on the thermocline.