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Laboratory modeling of buoyant jet in rotating fluid

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OUTLINE:

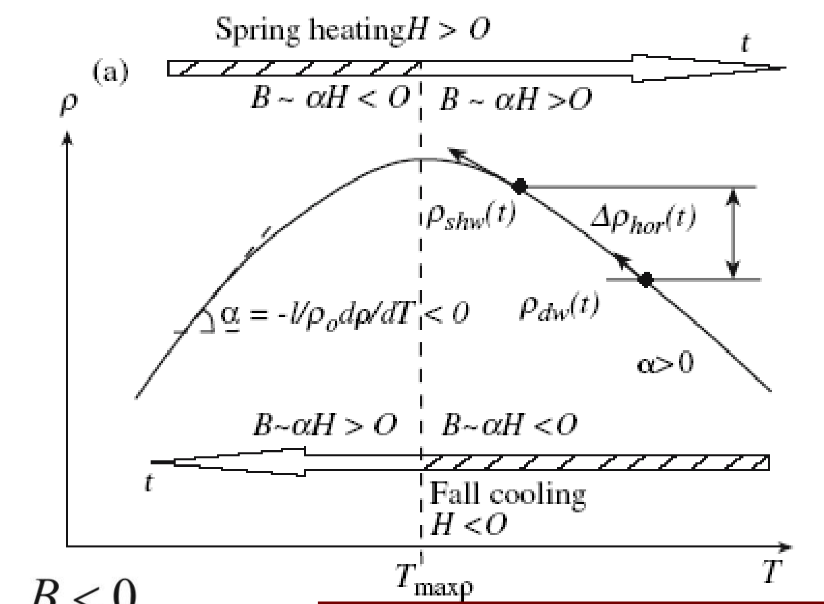
1. Introduction to the process

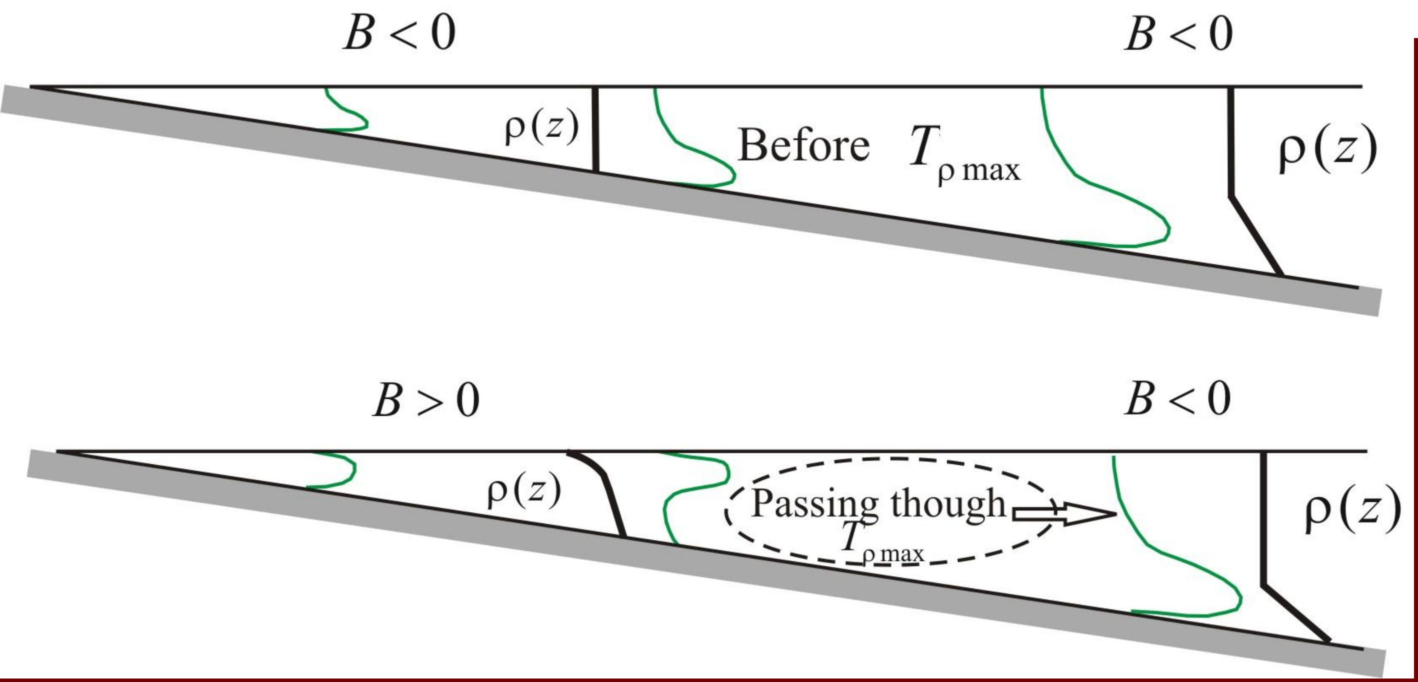
2. Laboratory experiments

3. Scaling analysis

4. Conclusions

1. Introduction to the process

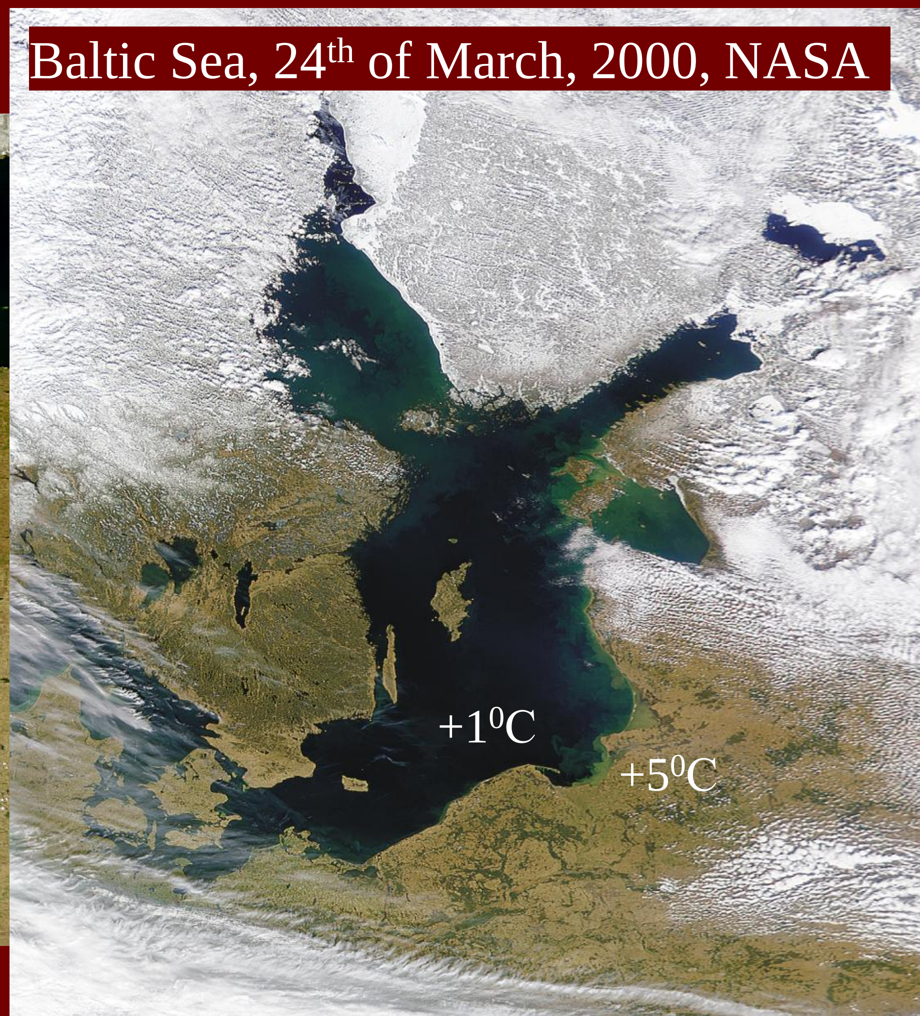


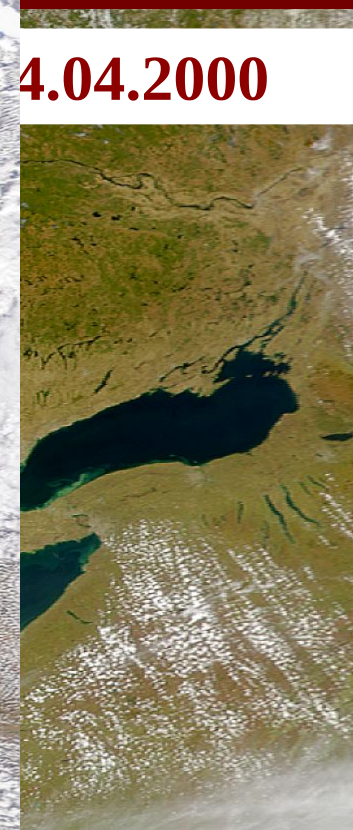


1. Introduction to the process

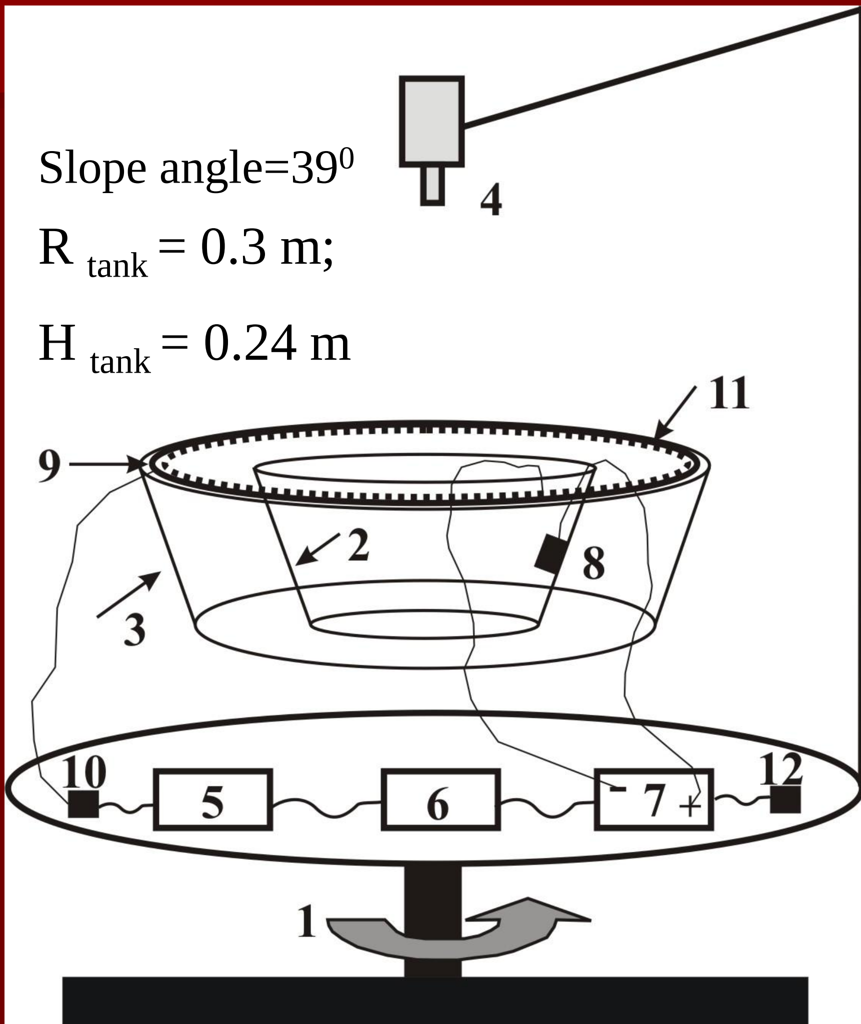
Q: **how the Coriolis force and bottom topography influence on the propagation of the surface warm buoyant jet in fresh waters?**

Baltic Sea, 24[th] of March, 2000, NASA





2. Laboratory experiments: experimental set-up



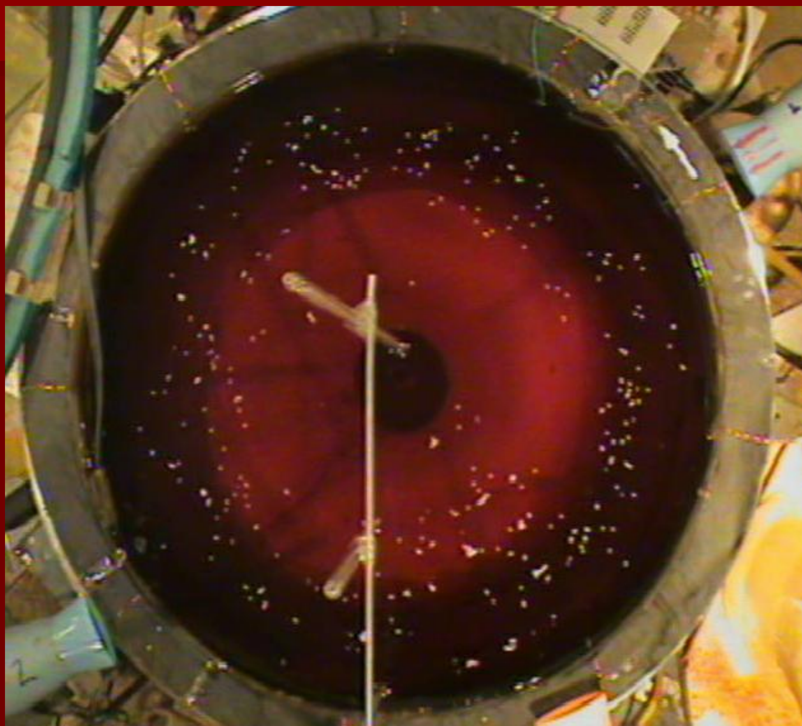
1 – rotating table; 2 – slope; 3 – tank wall; 4 – video camera; 5 – autotransformator; 6 – ampermeter; 7 – voltage supply; 8 – copper plate (anode); 9 – heating resistance isolated cable; 10, 12 – outlets; 11 – nichrome wire (cathode).

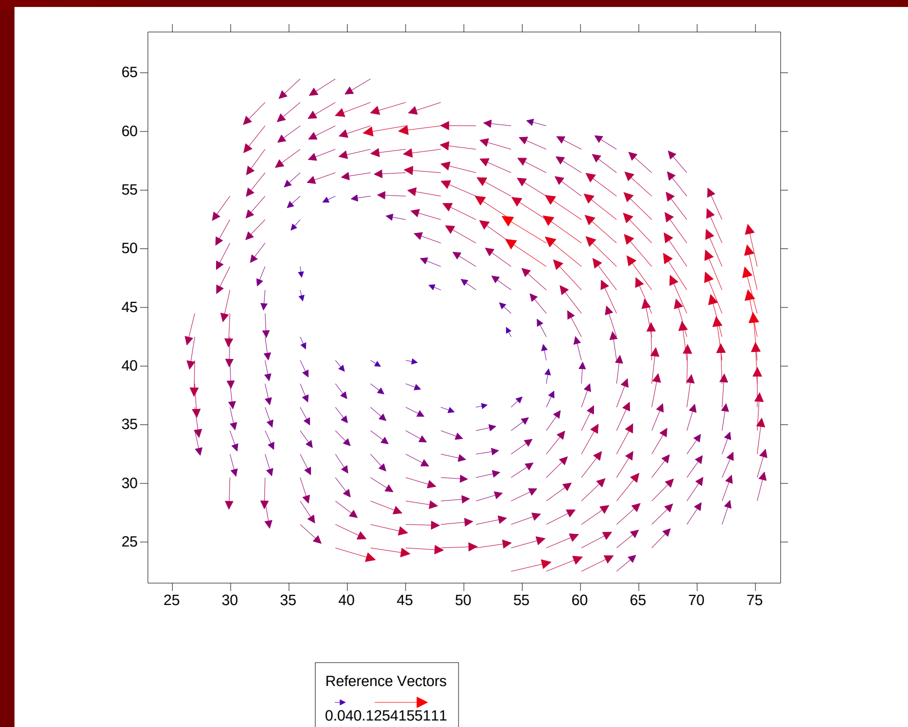
Experiments were performed: (i) with rotation for rotation periods of 5, 10, 15 s, and Coriolis parameter, f = 2Ω - 0.8, 1.25, 2.5 s^{-1}, respectively; and (ii) without rotation using various specific power supply q, Wt/m (25.7; 13.1; 6.37 Wt/m) in a tank with slopping and horizontal bottom

2. Laboratory experiments

MOVIE 1

2. Laboratory experiments



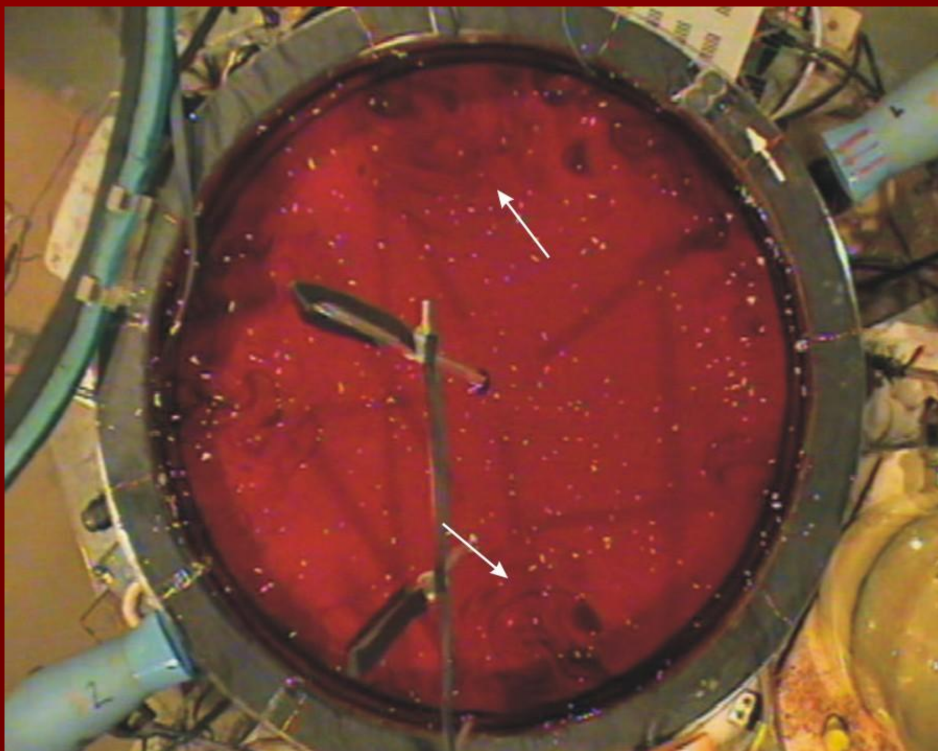


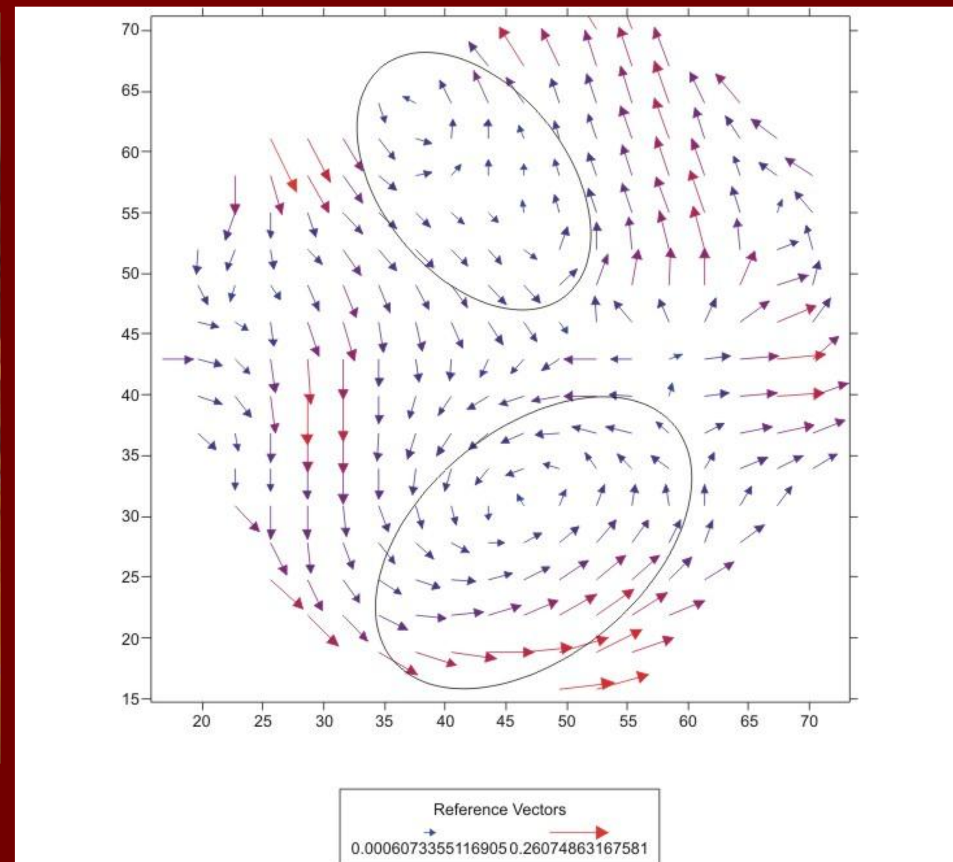
Case with rotation, slopping bottom, view from above: a) warm buoyant jet colored in dark blue propagating from the wall to the deep central part of the tank; b) velocity field, calculated from paper pellets displacement using Tank Field Calculator program. Time from the start of the run - 35 min; specific power supply q = 25.7 Wt/m.

2. Laboratory experiments

MOVIE 2

2. Laboratory experiments





Case with rotation, horizontal bottom, view from above: a) warm meandering temperature front at q=25.7 Wt/m and Coriolis parameter f = 0.8 s^{-1}; b) calculated surface velocity field with baroclinic eddies marked by ovals.

3. Scaling analysis: rotating case

? Radial velocity of the jet propagation, U,m/s ?

Main external dimensional parameters:

buoyancy flux (initiated by line source), B, m^3/s^3;

Coriolis parameter, f, s^{-1};

depth of the tank, H, m;

the time, t, s;

thermal diffusivity, k_T, m^2/s;

kinematical viscosity, ν, m^2/s.

3. Scaling analysis: rotating case

Results of laboratory experiments have shown that:

$U \sim B^{1/2}$;

$U \sim f^{-1}$;

k_T and ν are nearly constant;

U does not depend on time.

Main dimensionless parameters governing the process:

$$Ra_F = \frac{g\alpha F H^3}{\rho_0 c_p \kappa_T^2 \nu}$$ - (flux) Rayleigh number or $$Ra_B = \frac{B H^3}{\kappa_T^2 \nu}$$

$$Ek = \frac{\nu}{fH^2}$$ - Ekman number

3. Scaling analysis: rotating case

Therefore, we may parameterize the velocity of the buoyant jet as the follows:

$$\frac{U}{B^{1/3}} \sim \left(Ra^{1/2} \cdot Ek\right)$$

In the final form, the formula for the radial velocity of the jet is defined as:

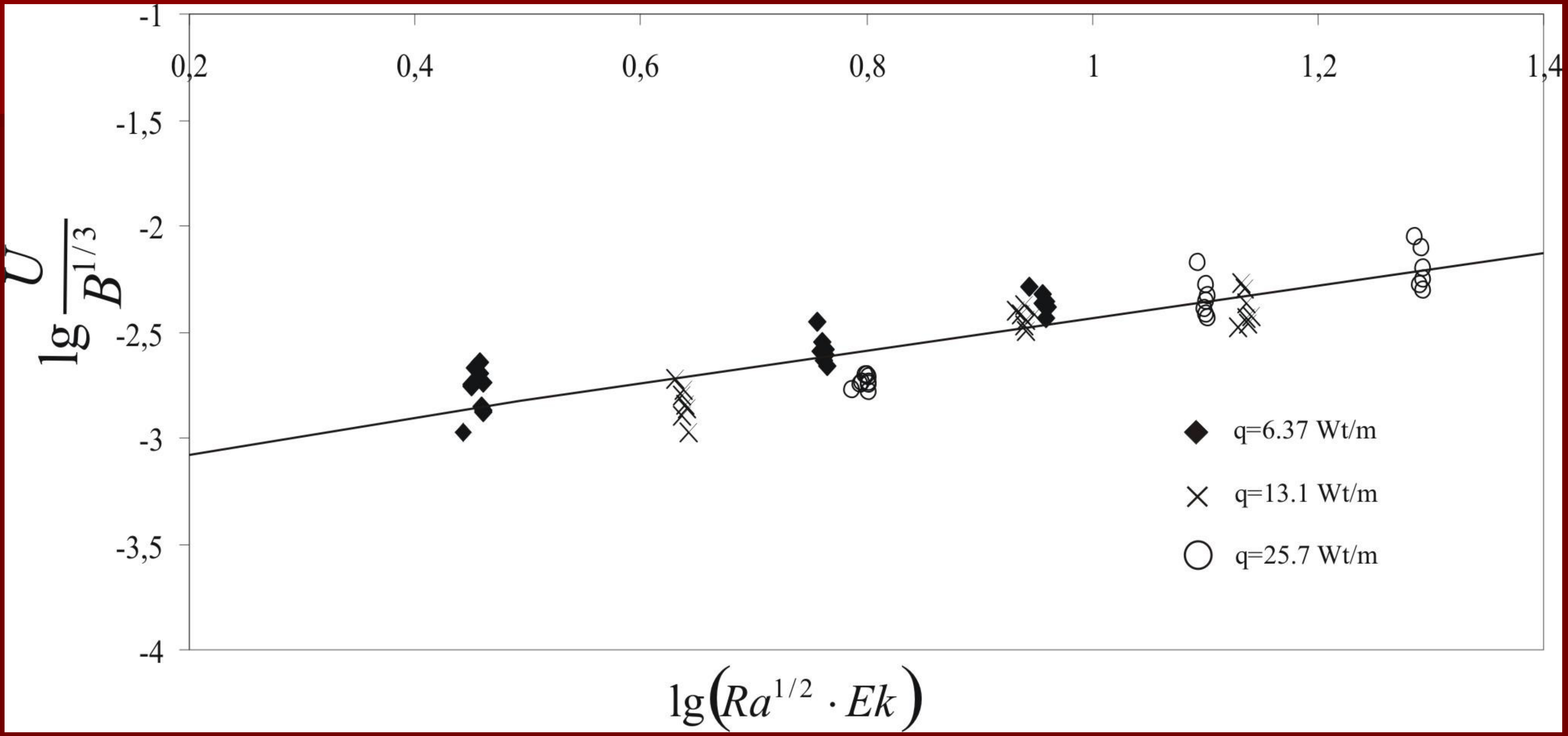
$$\frac{U}{B^{1/3}} \sim \frac{B^{1/2} \nu^{1/2}}{k_T H^{1/2} f}$$

or, using Pr number,

$$U \sim \left(\frac{B^{1/3}}{k_T f^2 H}\right)^{1/2} \mathrm{Pr}^{1/2}$$

where Pr number is constant and for the experiments Pr~7

3. Scaling analysis: rotating case



Velocity of radial propagation of the warm buoyant jet, U, is non-dimensionalized by versus Rayleigh and Ekman numbers in double logarithmic scale. Data of the described experiments in presence of the slope configuration for rotation rates f = 2.5; 1.25; 0.8 s^{-1} ; correlation coefficient R^2=0.7488.

3. Scaling analysis: non-rotating case

Results of laboratory experiments for non- rotating case have shown that:

$U \sim B^{1/2}$;

k_T and ν are nearly constant;

U does not depend on time.

Main dimensionless parameter:

$$Ra_F = \frac{g\alpha F H^3}{\rho_0 c_p \kappa_T^2 \nu}$$

- (flux) Rayleigh number or

$$Ra_B = \frac{B H^3}{\kappa_T^2 \nu}$$

3. Scaling analysis: non-rotating case

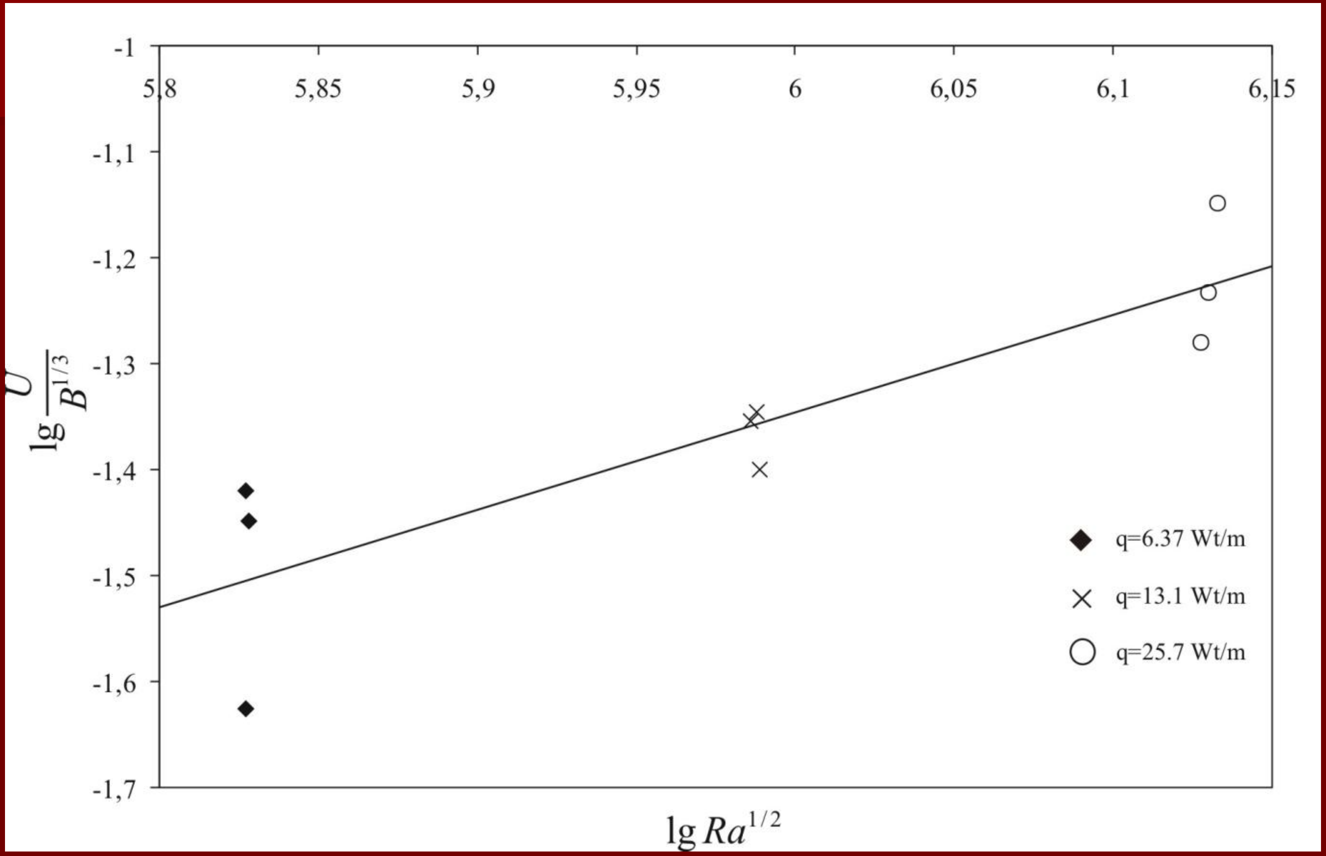
By analogy with rotating case, we should parameterize the velocity of the buoyant jet as the follows:

$$\frac{U}{B^{1/3}} \sim Ra^{1/2}$$

Thus, the formula for the velocity jet is obtained in final form:

$$U \sim \left(\frac{B^{1/3} H^3}{k_T^2 \nu} \right)^{1/2}$$

3. Scaling analysis: non-rotating case



Non-dimensional radial velocity of the warm buoyant jet is as a function Rayleigh number in the double logarithmic scale for non-rotating case. Non-dimensional radial velocity of jet propagation depends on Rayleigh number by the law of $U/B^{1/3} = 4 \cdot 10^{-8} Ra^{1/2}$ with correlation coefficient R^2=0.767

4. Conclusions

1. The rotation of the system strongly affects the characteristics of the warm buoyant jet and the velocity of its radial propagation. It has been revealed, that in rotating fluid a strong along-wall cyclonic current is formed. The radial velocity of buoyant jet propagation is about an order of magnitude less than in non-rotating fluid.
2. The bottom slope stabilizes the propagation of the temperature front of the buoyant jet, preventing for its breaking-up and formation of the baroclinic eddies. Upon the horizontal bottom radial propagation of the buoyant jet is effected and accelerated by the lateral eddy diffusivity.

4. Conclusions

3. Scaling analysis has show that Rayleigh and Ekman numbers are the key non-dimensional parameters that determines the regimes and regularities of the warm buoyant jet in the rotating case, but only Rayleigh number is important for the non-rotating case. The processing of the experimental data revealed that the non-dimensional radial velocity of jet propagation depends on Rayleigh and Ekman numbers by the law of $U/B^{1/3} = 3 \cdot 10^{-4} Ra^{1/2} \cdot Ek$ for rotating case and by the law of $U/B^{1/3} = 4 \cdot 10^{-8} Ra^{1/2}$ for non-rotating case.

Thank You for attention!!!