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# Influence of floe-floe interactions on wave damping in marginal ice zones

*Aleksey Marchenko, The University Centre in Svalbard, Norway*

*Evgeny Karulin, Krylov State Research Center, Russia*

*Peter Chistyakov, Lomonosov Moscow State University, Russia*

*Vladimir Markov, Steklov Mathematical Institute, Moscow, Russia*

## Physical mechanisms of wave damping in ice infested regions: in-situ experiments and modeling

EGU2020 OS4.2: Surface Waves and Waves-Coupled Effects in Lower Atmosphere and Upper Ocean

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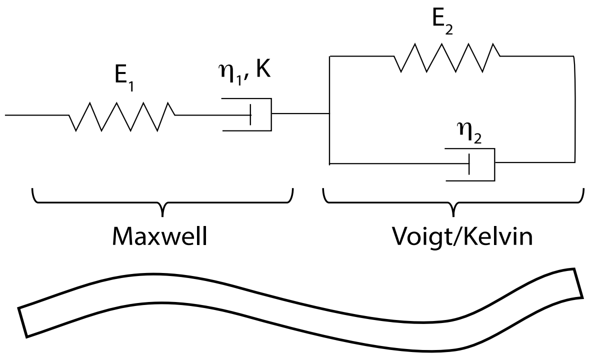
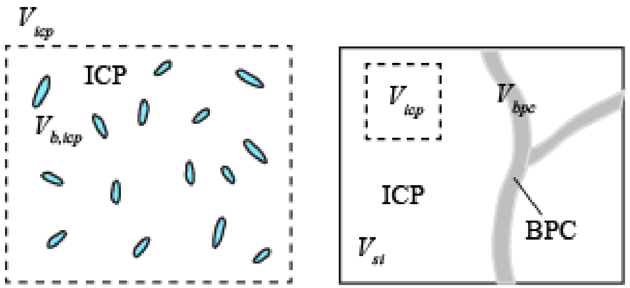
# Physical mechanisms of wave damping in ice infested waters (wave scattering is not considered)


Sinha, 1978;
Wadhams et al, 1986;
Weber, 1987;
Cole, 1995;
Shen and Squire, 1998;
Golden et al., 2007;
Marchenko and Lishman, 2016;
Renshaw et al, 2018;
Marchenko et al, 2019;
Rabault et al., 2019;
……………


## Energy damping inside the ice

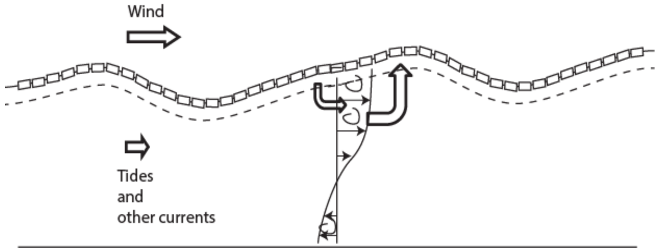



Viscous and anelastic properties of ice in bending deformations

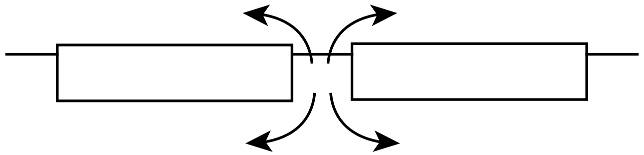



Migration of liquid brine in channels

## Energy damping in the water




Energy dissipation in wave induced oscillating boundary layer below drift ice



Energy dissipation caused by floe-floe interactions

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Field observations of floe-floe interactions in compacted ice (jets formation)

and broken ice in MIZ (no visible floe-floe collisions)

Laboratory observations (HSVA ) of floe-floe interactions in solid ice (floods near cracks)

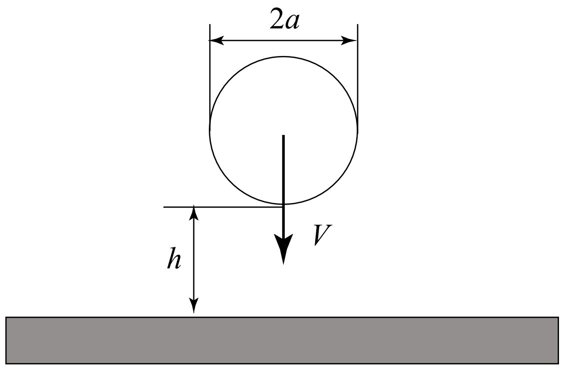
and broken confined ice (rotational motion production of and slush)

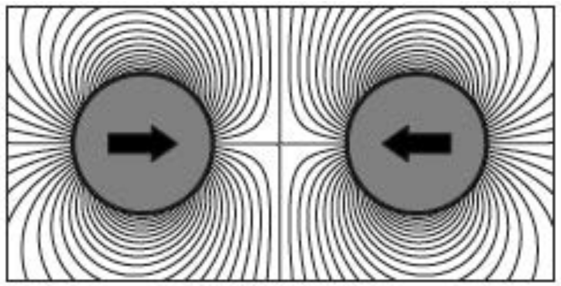
# Approaching of a sphere to a plane in ideal incompressible fluid (Lamb, 1945. Hydrodynamics)

- Kinetic energy of the fluid

$$2T_f = \frac{2}{3}\pi\rho a^3\left(1+\frac{3}{8}\frac{a^3}{h^3}\right)V^2, V = \frac{dh}{dt},$$

$$T_f \to \infty \; by \; h \to 0, T_{sp} + T_f = cons$$



- Momentum balance of the sphere

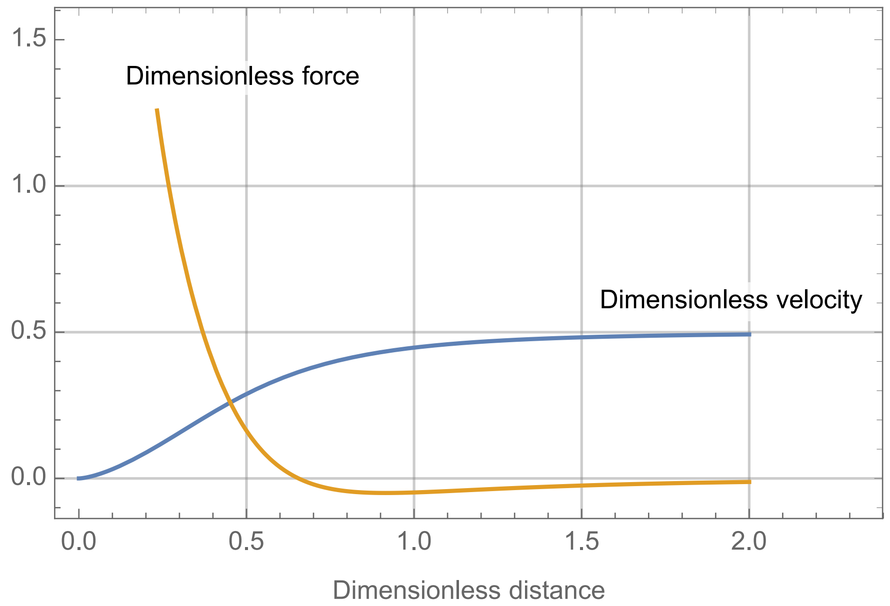
$$\left(M + \frac{2\pi\rho_w a^6}{8h^3}\right)\frac{d^2h}{dt^2} = \frac{3\pi\rho_w a^6}{8h^4}\left(\frac{dh}{dt}\right)^2,$$

$$M = M_{sph} + M_{add}, M_{add} = \frac{2}{3}\pi\rho_w a^3$$

$\left(m + \frac{1}{4\eta}\right)u'u = \frac{3}{16\eta^2}u^2$ - momentum balance in dimensionless variables

$$u(\eta) = \eta', u' = \frac{du}{d\eta}$$

$u = C\frac{(\sqrt{m\eta})^{3/2}}{\sqrt{1+4m\eta^2}}, C = \frac{V_0}{am^{3/4}}\frac{\sqrt{1+4m\eta_0^2}}{(\sqrt{m\eta_0})^{3/2}}$ – solution



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# Field experiment on collisional interaction of ice block (0.5x0.5x0.5 m) with ice wall

t=0

t=0.88 s

t=1.2 s

t=2 s

The ice block is mounted by a chain on Λ – shape rig


https://www.bksv.com/media/doc/bp2262.pdf

Sampling interval is 0.2 ms. The accelerometer is screwed to the the surface of the ice block.

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# Theory: approaching of a cylinder to a plane in ideal incompressible fluid

- Mass balance of the water

$$r\frac{dh}{dt} + h\frac{\partial(rv_r)}{\partial r} = 0$$

- Momentum balance of the water layer

$$\frac{\partial v_r}{\partial t} + v_r\frac{\partial v_r}{\partial r} = -\frac{1}{\rho}\frac{\partial p}{\partial r}$$

- Momentum balance of the cylinder

$$M\frac{d^2h}{dt^2} = F, V = \frac{dh}{dt}, F = 2\pi\int_0^{r_0} prdr$$

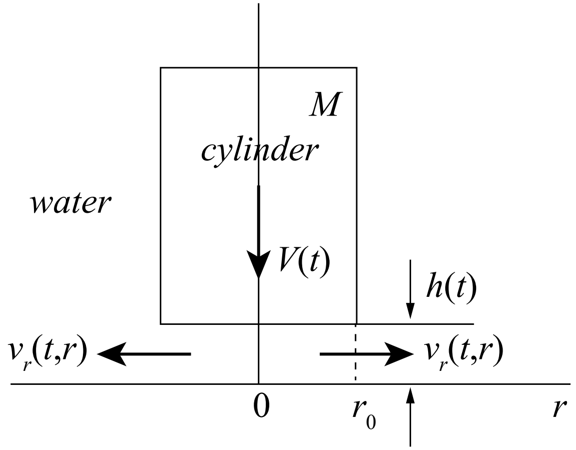
- Final equation to solve

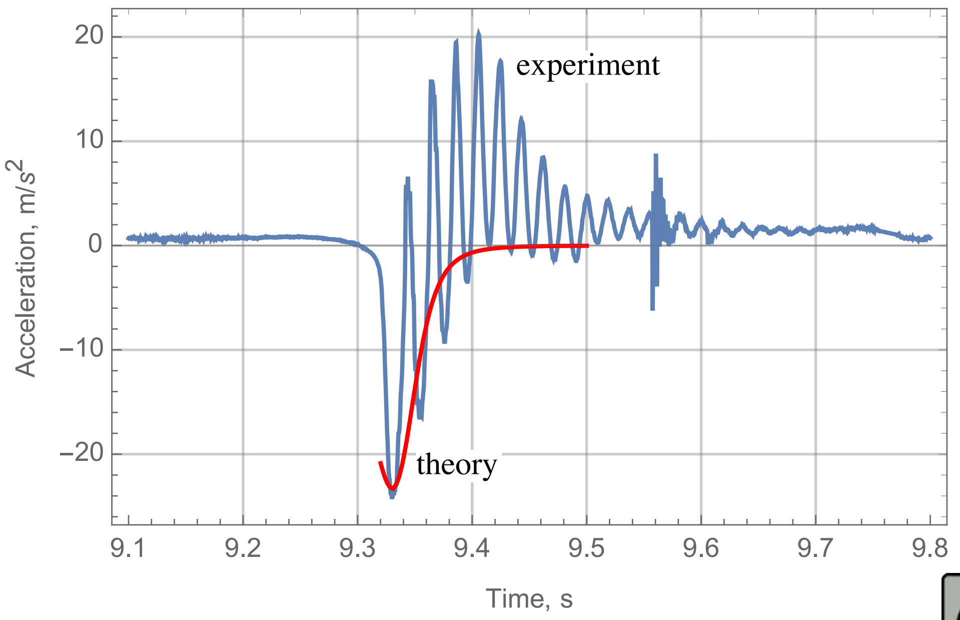
$$\frac{dh}{dt} = V_0\left(\frac{r_0 + 8mh_0}{h_0}\right)^{3/2}\left(\frac{h}{r_0 + 8mh}\right)^{3/2},$$

$$h = h_0, \frac{dh}{dt} = V_0, t = 0$$

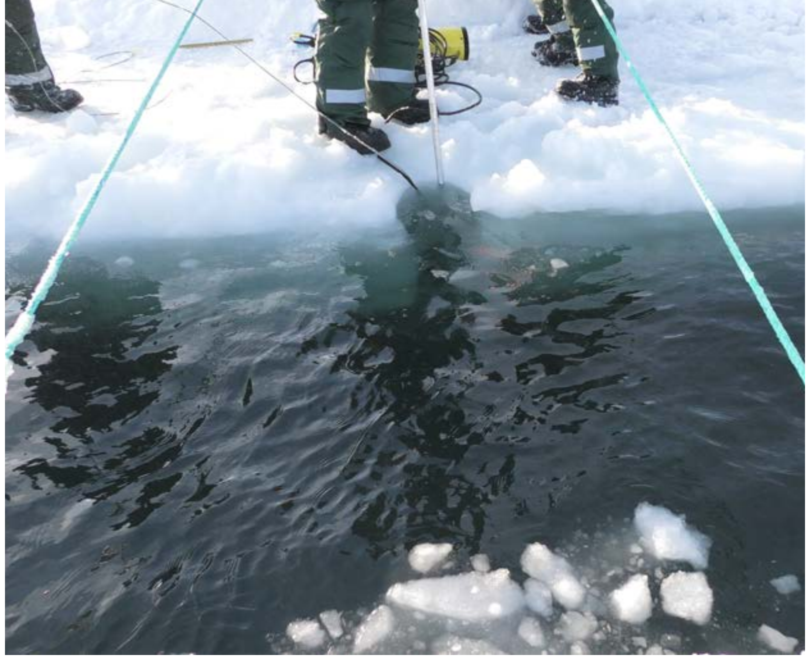
$$M = M_{cyl} + M_{add}, m = \frac{M}{\pi\rho_w r_0^3}$$

$m = 2.5, V_0$=-0.85 m/s, $r_0 = 25$ cm, $h_0$=2 cm



# Tow of ice floe experiment (10x5x0.7 m)



Generation of wave due to the floe collision with ice

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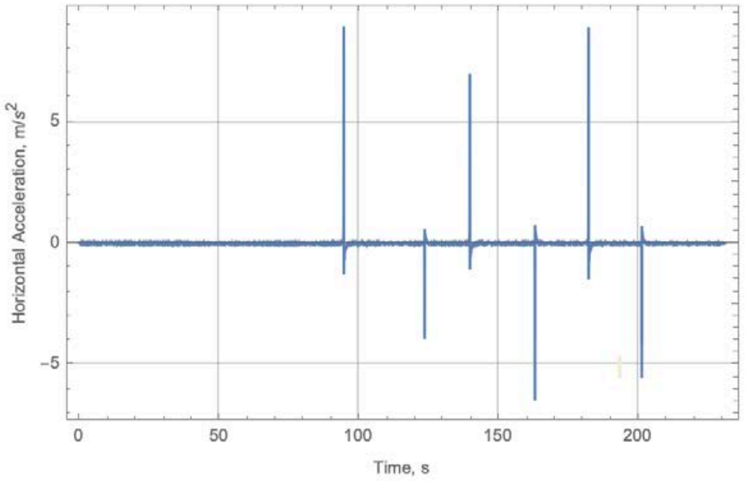
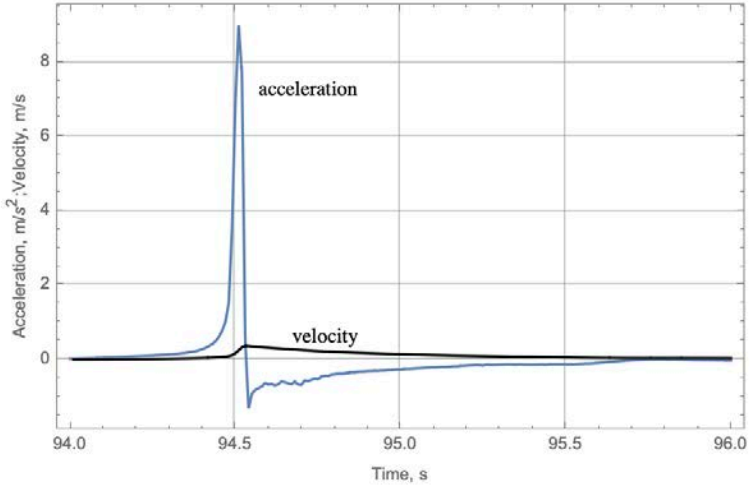
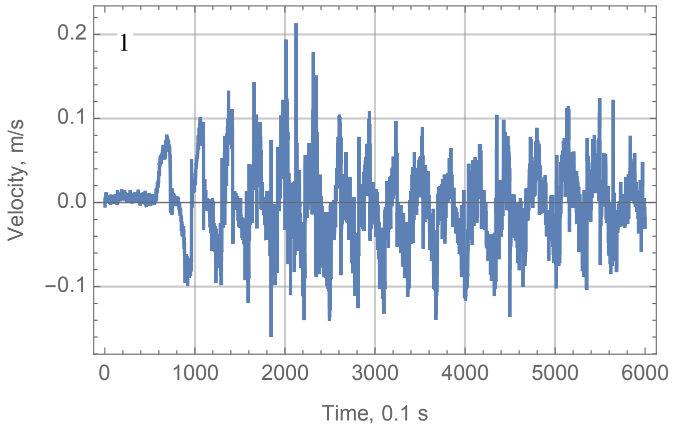
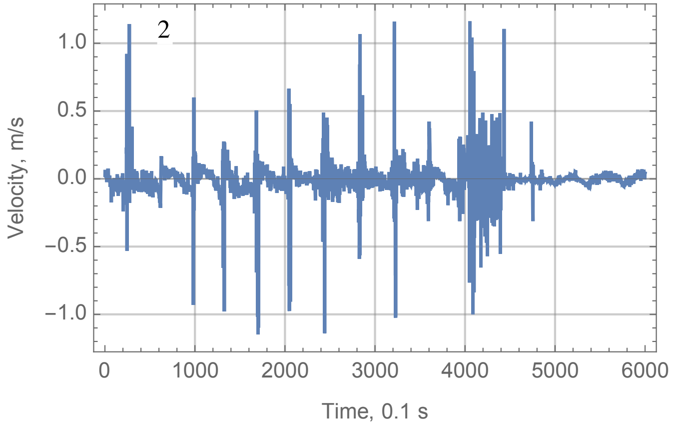
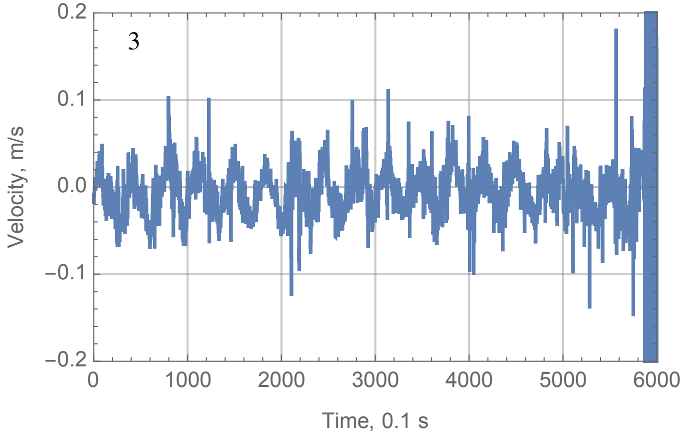
# Floe accelerations and water velocities measured along the floe displacements

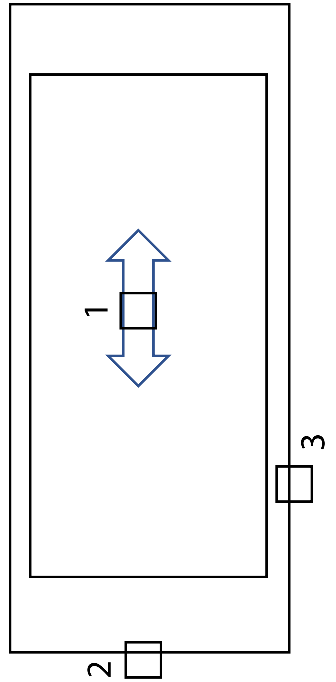


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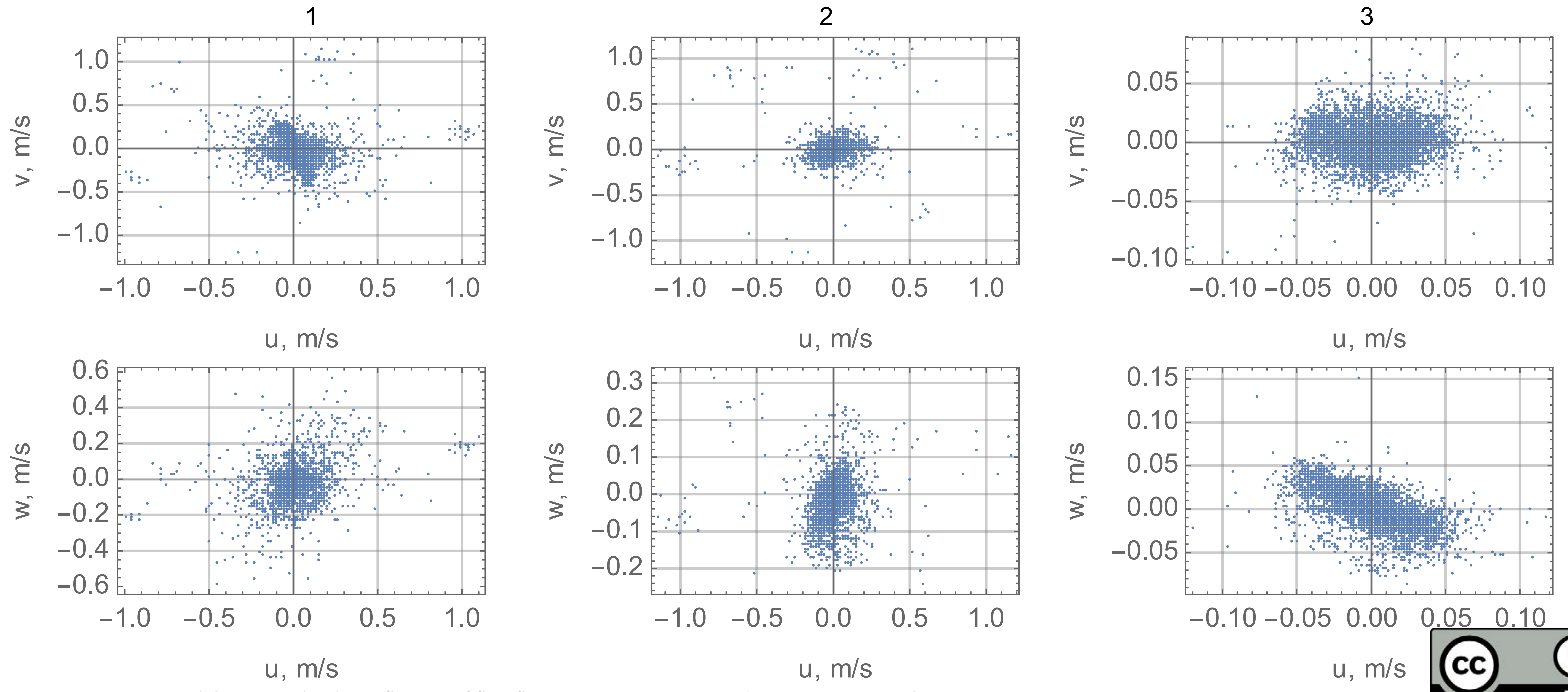
# Water velocities measured with ADV (SonTek, 5 MHz) in 3 locations below the ice



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# Conclusions

- Floe-floe collisions caused by wave propagation in ice covered water were observed in conditions of confined broken ice with high concentration in the Arctic and HSVA ice tank. Floe-floe collisions are **rare events in marginal ice zone** of the Barents Sea.
- In-situ experiments on collisional interaction of submerged ice blocks of **relatively small masses** ($\sim 100$ kg) with ice wall demonstrated that most of the block energy is transformed into the kinetic energy of water.
- Observed "rebound" effects were mostly related to the water motion and wave excitation around moving ice blocks.
- Experiment on collisional iteraction of the prepared **ice floe (5x10x0.7 m, mass is around 3.22 T)** with floating solid ice demonstrated significant energy transfer into the water. Mean water velocities in the direction of the flow towing and in the vertical direction measured below the floe and below the solid ice near the floe were similar to the floe velocities.
- Ice-ice collisions influence propagation of **elastic waves** inside the ice and in the water, propagation of **surface gravity waves** on the water surface, **jet currents and vorticity** in the water.