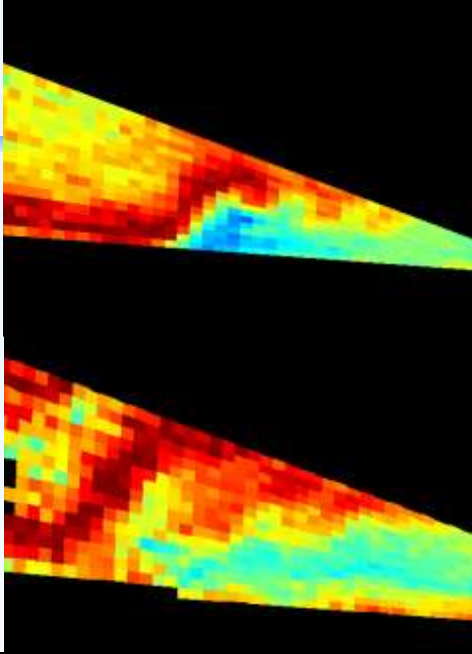

Laboratory studies on colliding gravity currents

Qiang ZHONG
Environmental Fluid Dynamics Group
University of Notre Dame
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Outlines

1 **Introduction**

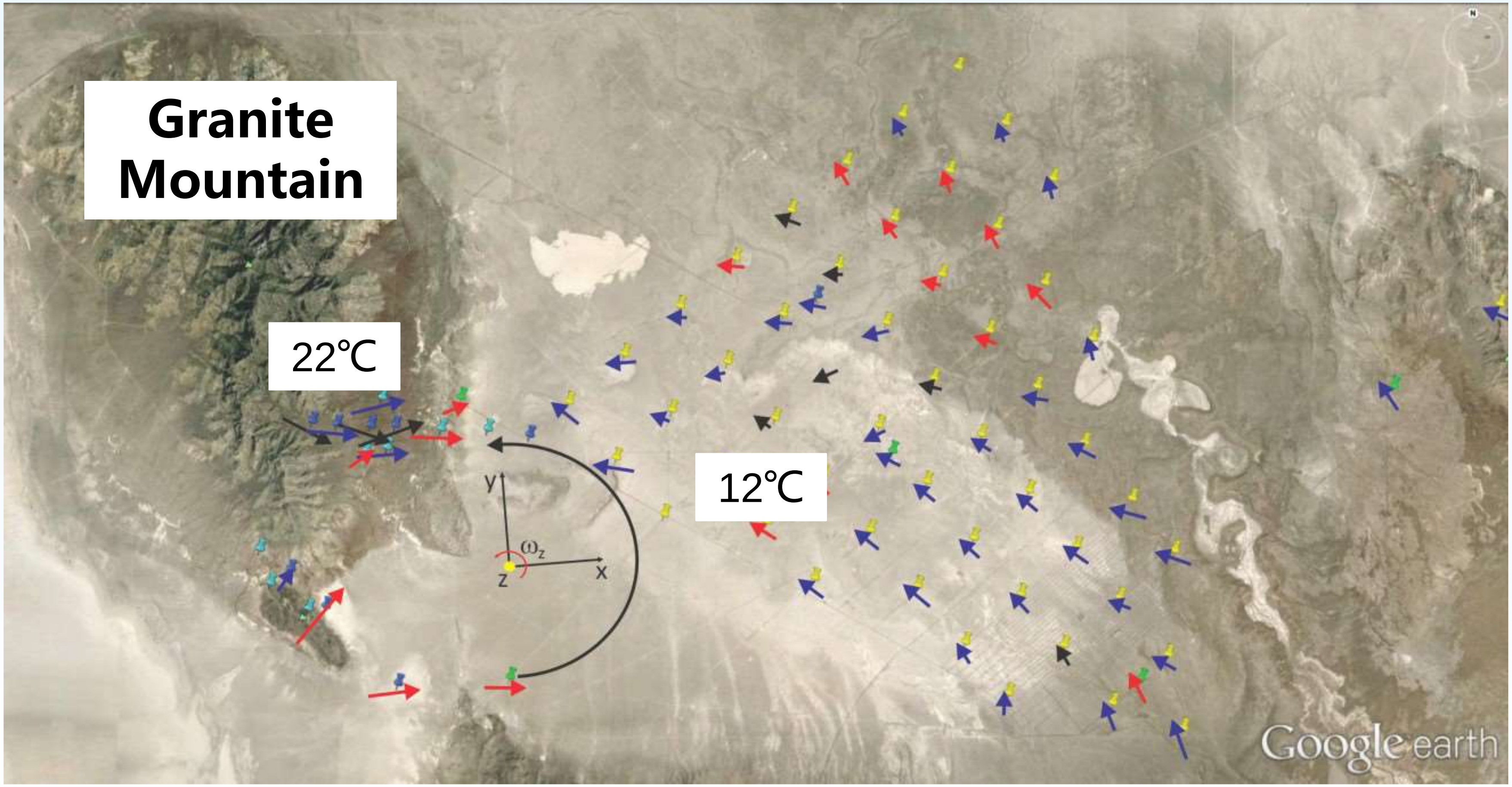
2 **Experiments**

3 **Currently Result**

4 **Conclusion**

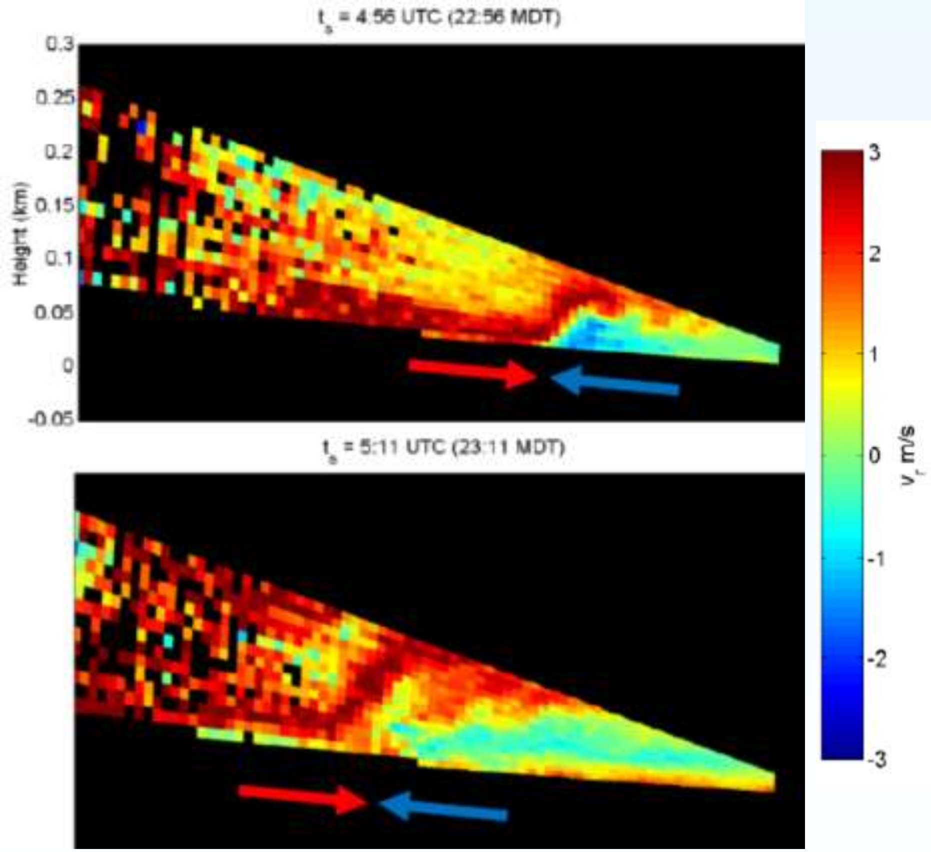
1. Introduction

1 Introduction

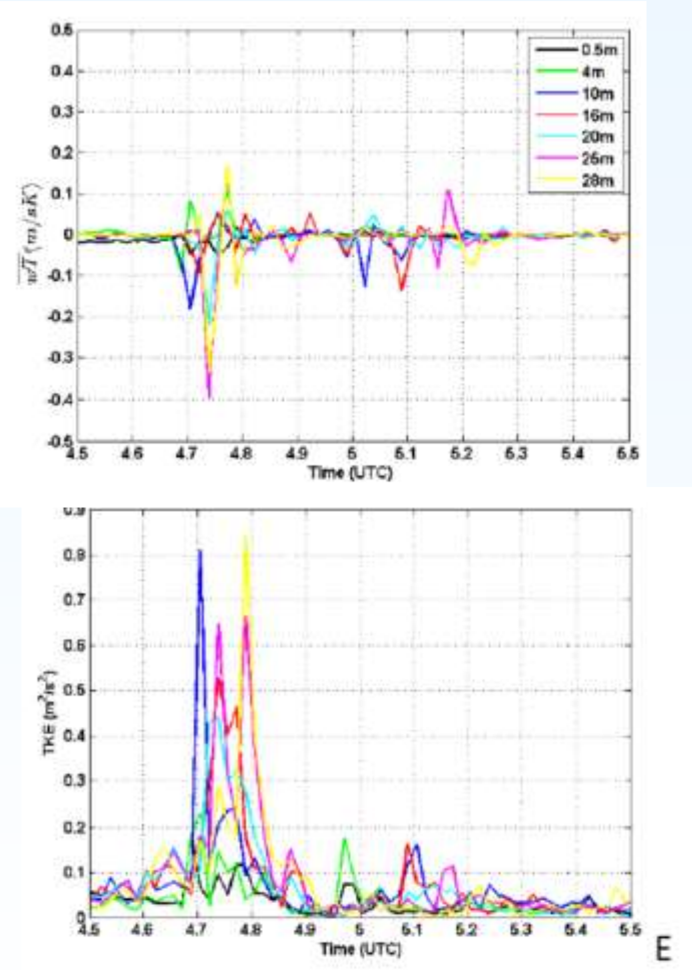


Temperature and velocity data before collision occurred (4:15 UTC 22:15 MDT)

1 Introduction

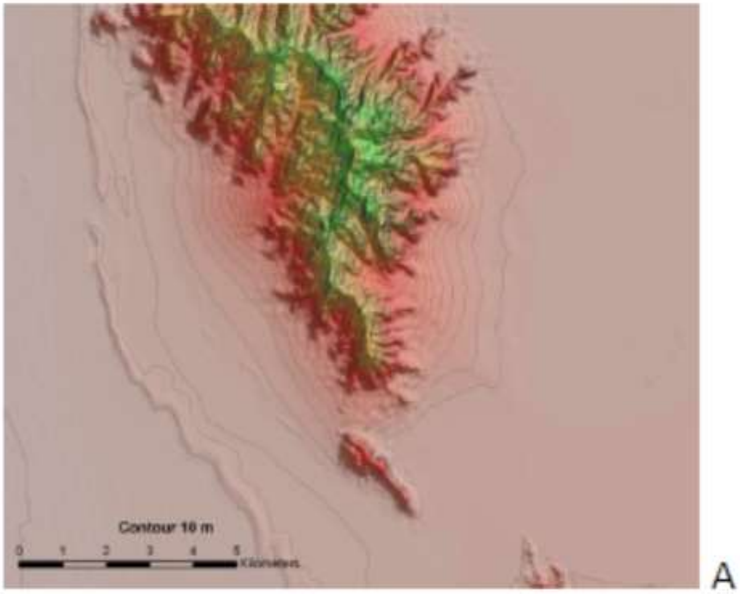


Time series of UU LiDAR data located at the slope. Here shows the initial collision between the downslope (red) and valley flow (blue).

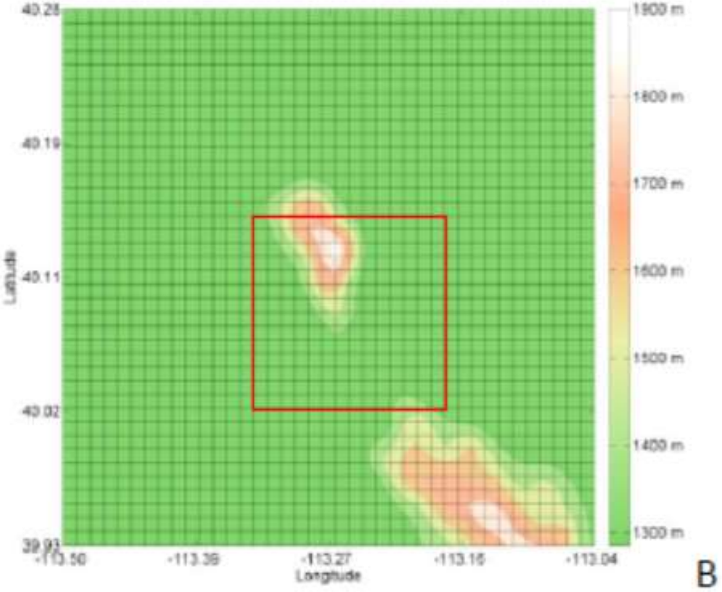


The collision events great impact the TKE production and temperature flux.

1 Introduction



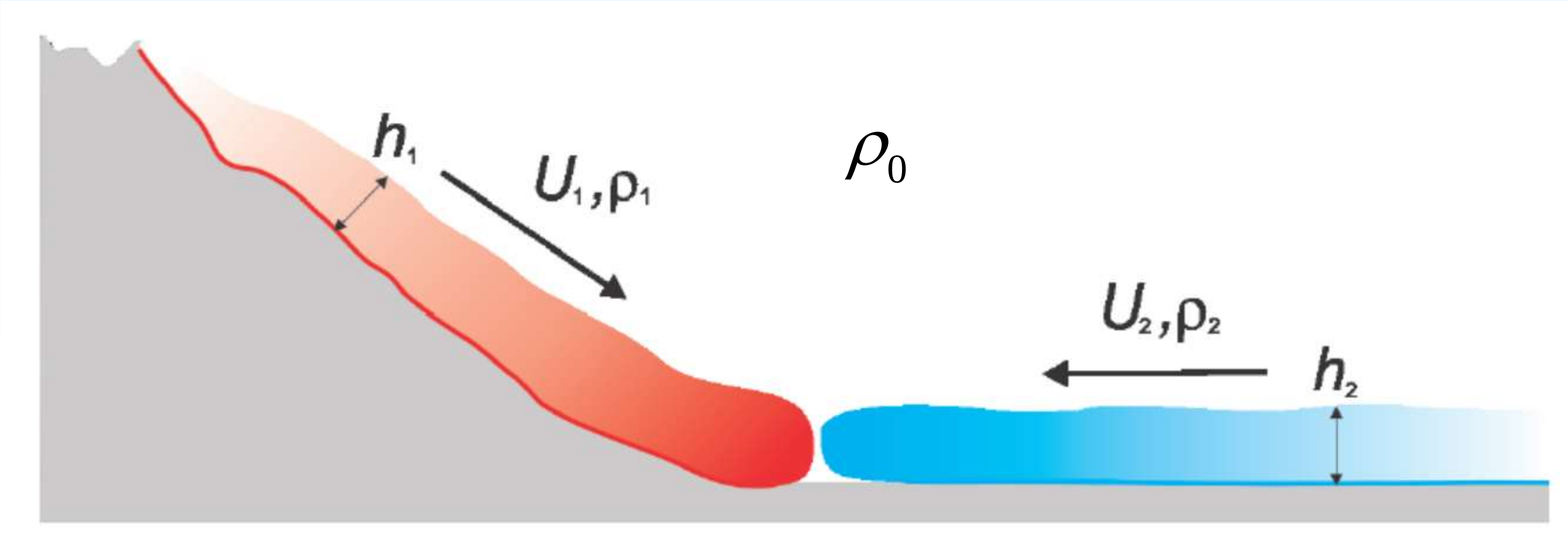
10m contours map of Granite Mountain



1-km grid used for mesoscale models

1 Introduction

Important: (1) the length and time scale of collision events (2) buoyancy and momentum flux



$$\Sigma_{b'w'} = \int_{-\infty}^{T} b'(t)\,w'(t)\,dt \qquad b'(t) = b(t) - \bar{b}(t) \quad w'(t) = w(t) - \bar{w}(t)$$

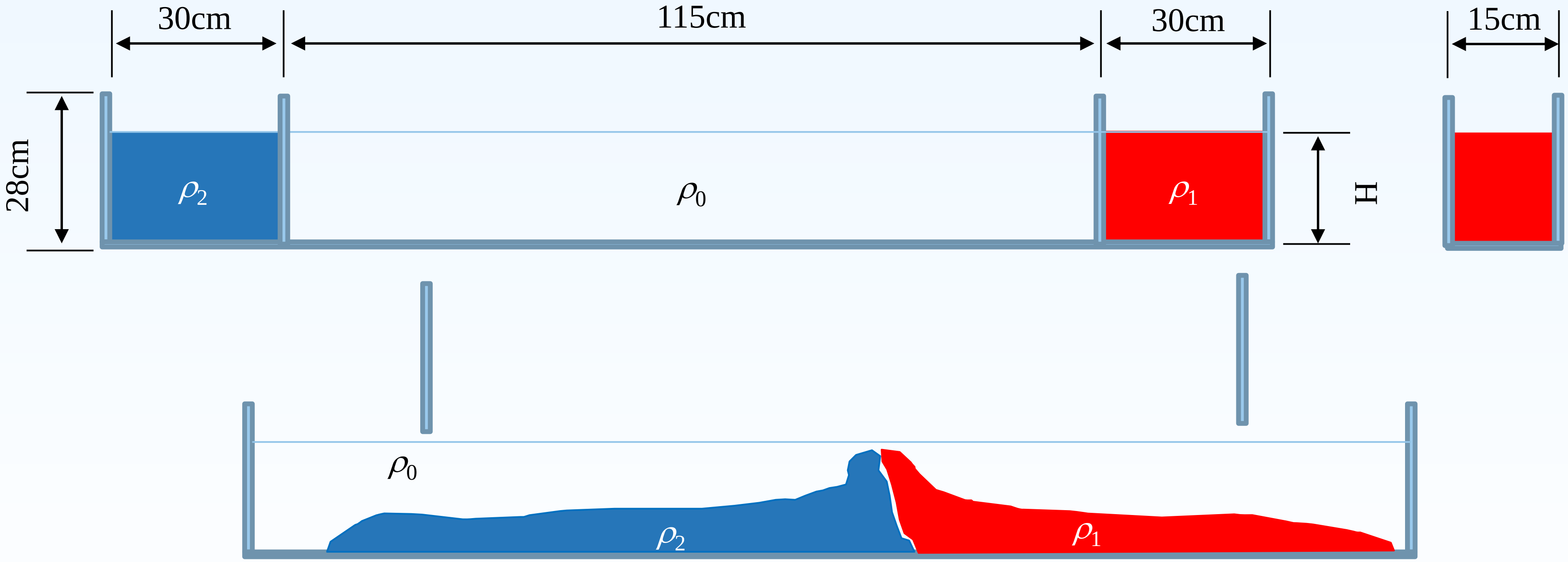
$$\Sigma_{b'w'} = f\left(\rho_0, \rho_1, \rho_2, U_1, U_2, h_1, h_2, \theta, \nu\right)$$

2. Experiments

2.1 Facilities

2.1.1 Channel

Lock Exchange Rectangular Channel

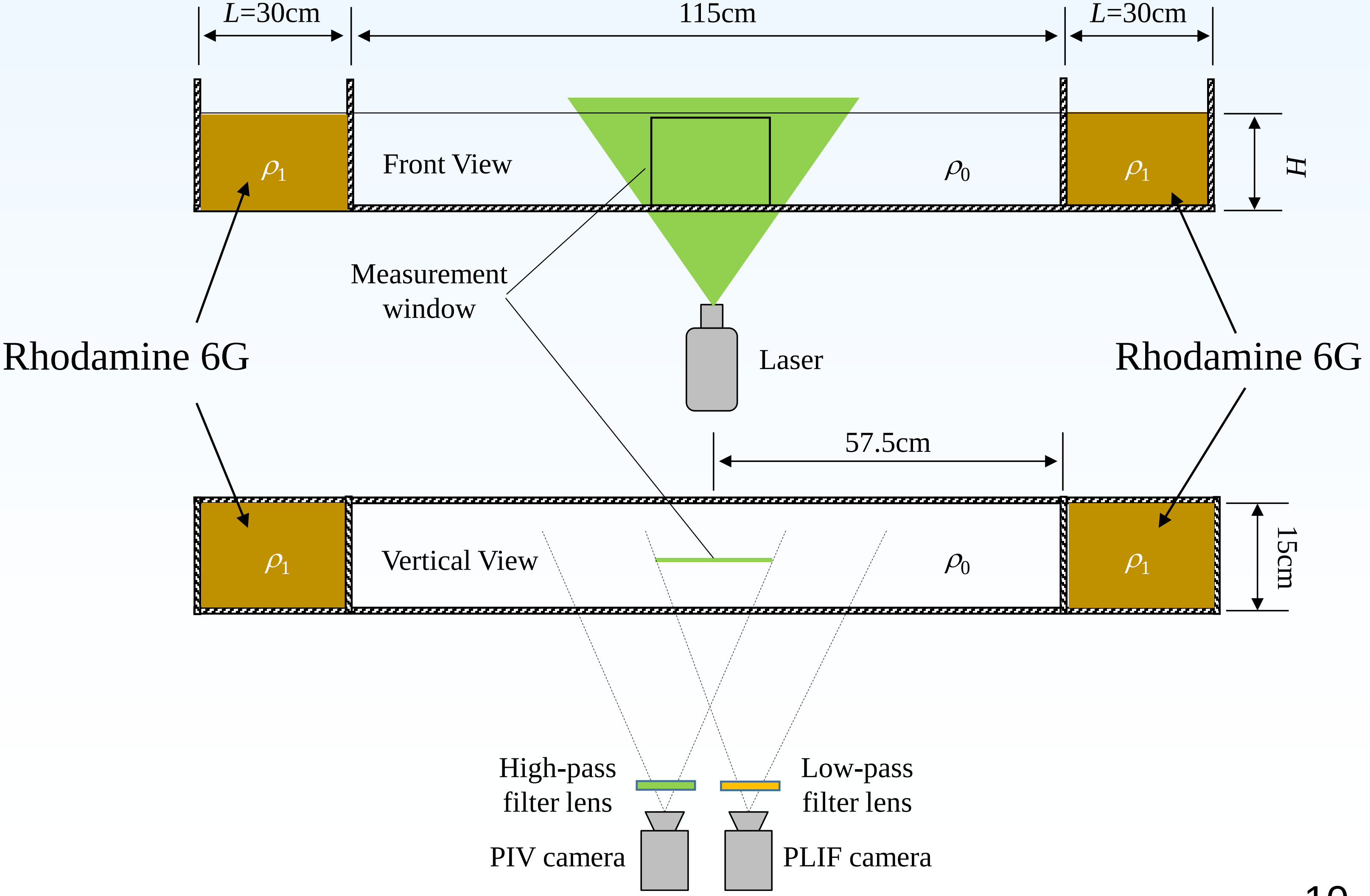


$$f\left(\rho_0,\rho_1,\rho_2,U_1,U_2,h_1,h_2,\theta,\nu\right)\Rightarrow f\left(\rho_0,\rho_1,\rho_2,h_{curr},\nu\right)\Rightarrow f\left(\rho_0,\rho_1,h_{curr},\nu\right)$$

$$\mathrm{Re}=\frac{u_f h_{curr}}{\nu}=\frac{C\sqrt{g' h_{curr}}\cdot h_{curr}}{\nu}=\frac{C\sqrt{g\frac{\rho_1-\rho_0}{\rho_0}h_{curr}}\cdot h_{curr}}{\nu}$$

2.1 Facilities

2.1.2 Particle Image Velocimetry (PIV) and Planar Laser-Induced Fluorescence (PLIF)



2.2 Experimental Parameters

Case	H m	ρ_0 kg/m^3	ρ_1 kg/m^3	u_f m/s	Re $u_f h_{\mathrm{curr}}/\nu$
1	0.10	990.4	1009.9	0.056	2807
2	0.05	991.0	1010.8	0.040	989
3	0.10	980.7	1027.8	0.087	4339
4	0.05	980.9	1028.0	0.061	1534
5	0.10	987.4	1016.8	0.068	3416
6	0.05	994.4	1004.3	0.028	698

Basic parameters

H	whole water depth	ρ_1	density of light fluid
$h_{\mathrm{curr}}=H/2$	depth of gravity currents	$g' = g\dfrac{\rho_1 - \rho_0}{\rho_0}$	reduced gravity
ρ_0	density of dense fluid	$u_f = 0.57\sqrt{g' h_{curr}}$	front velocity

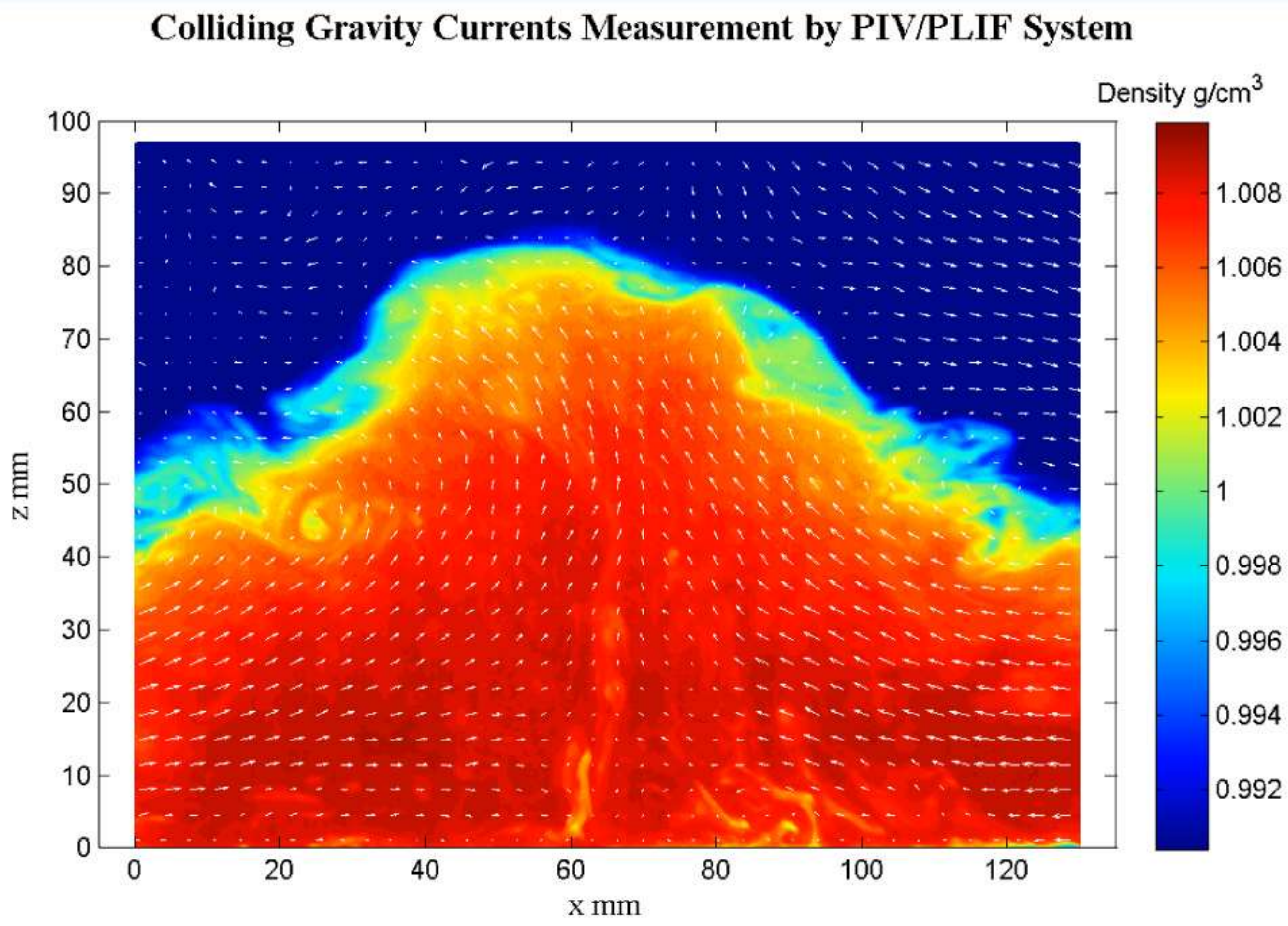
3. Current Result

Scale

Average Process

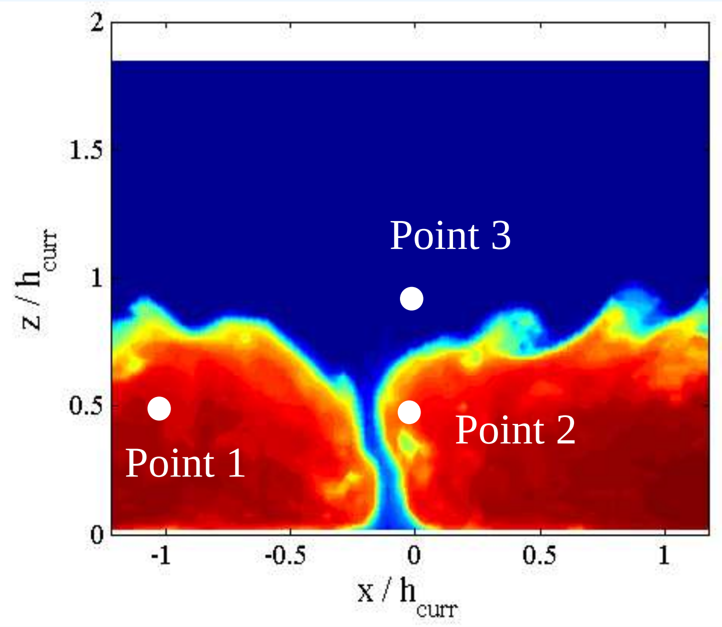
Turbulence Fluctuation

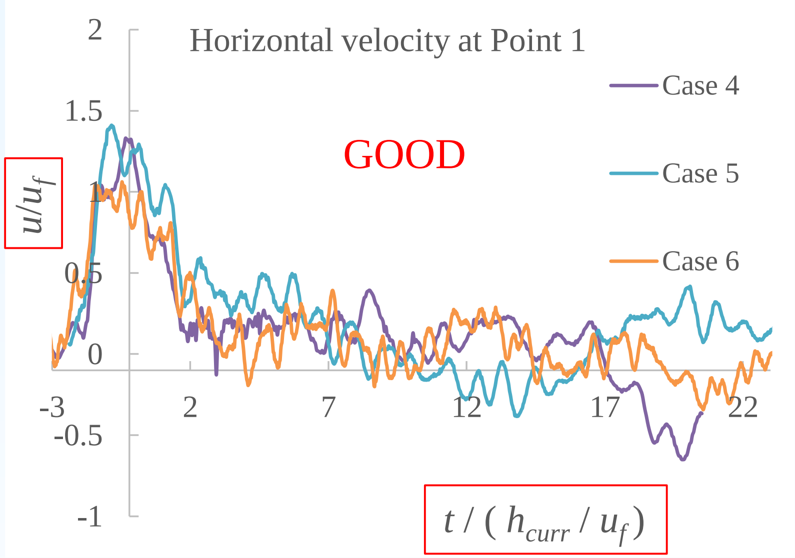
3.1 Time, length and velocity scale

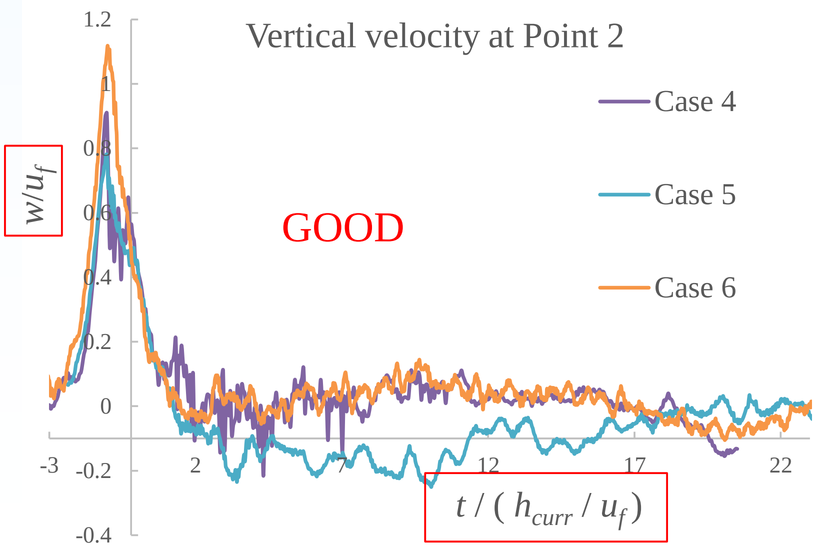


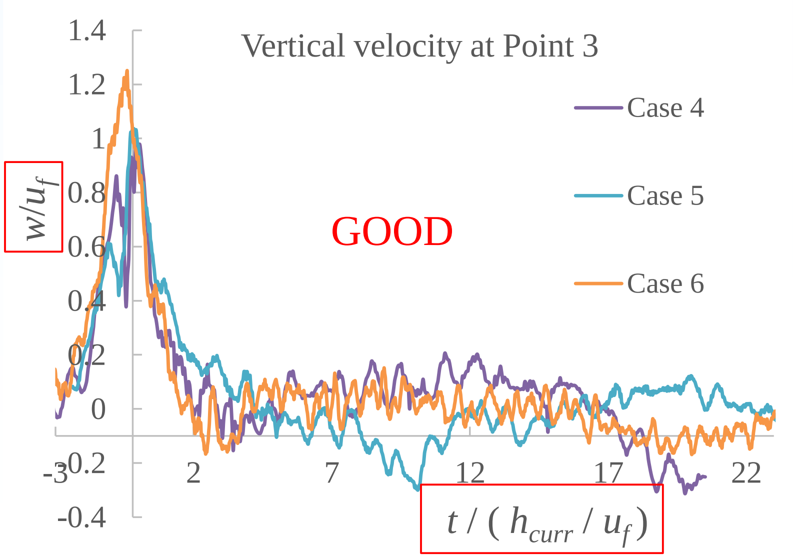
The density of heads is smaller than that of current bodies. During collision, mixing both happens between two heads and between current and ambient. Strong vertical motion is triggered by collision. The dense fluid itself is stratified after collision.

3.1 Time, length and velocity scale





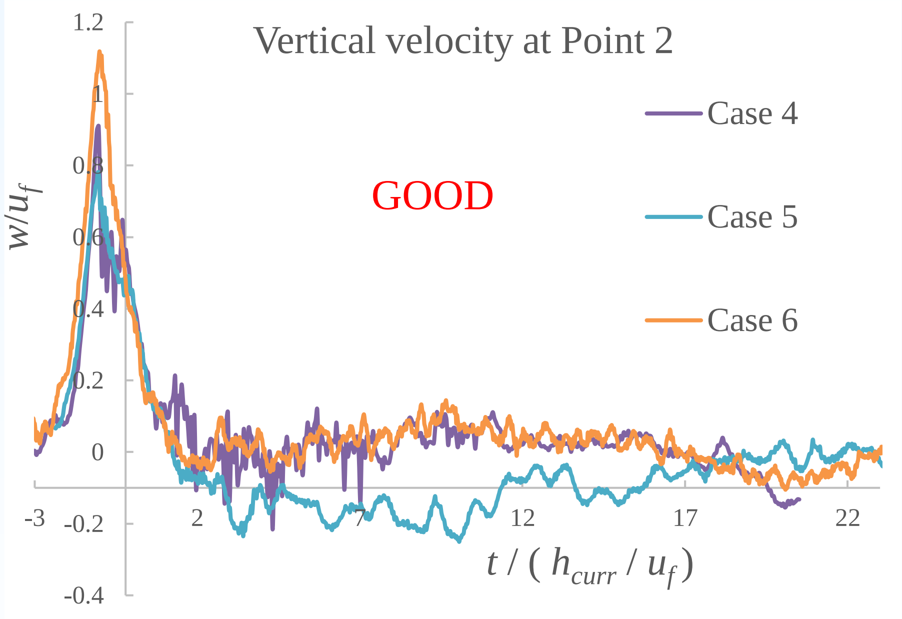


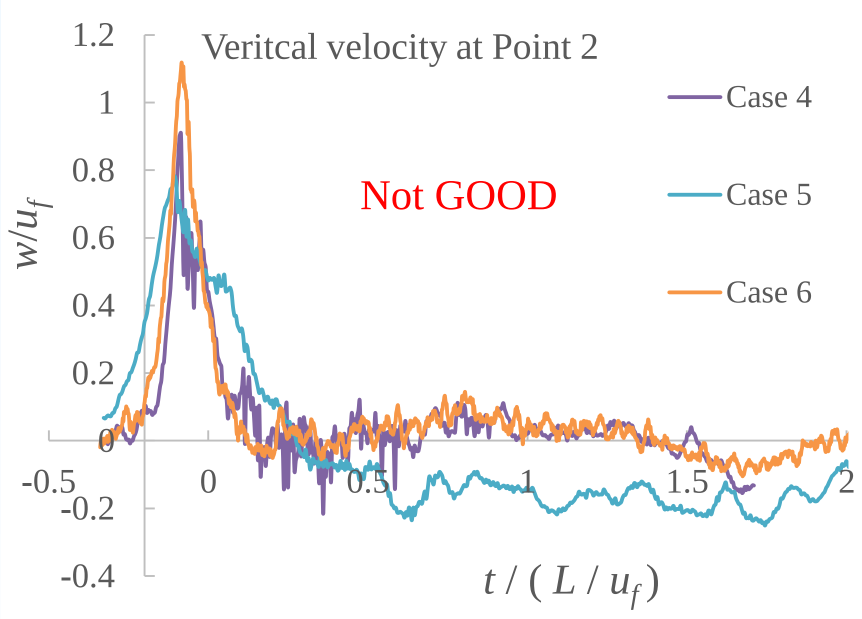


3.1 Time, length and velocity scale

$$t_* = h_{curr} / u_f$$

$$t_* = L / u_f$$



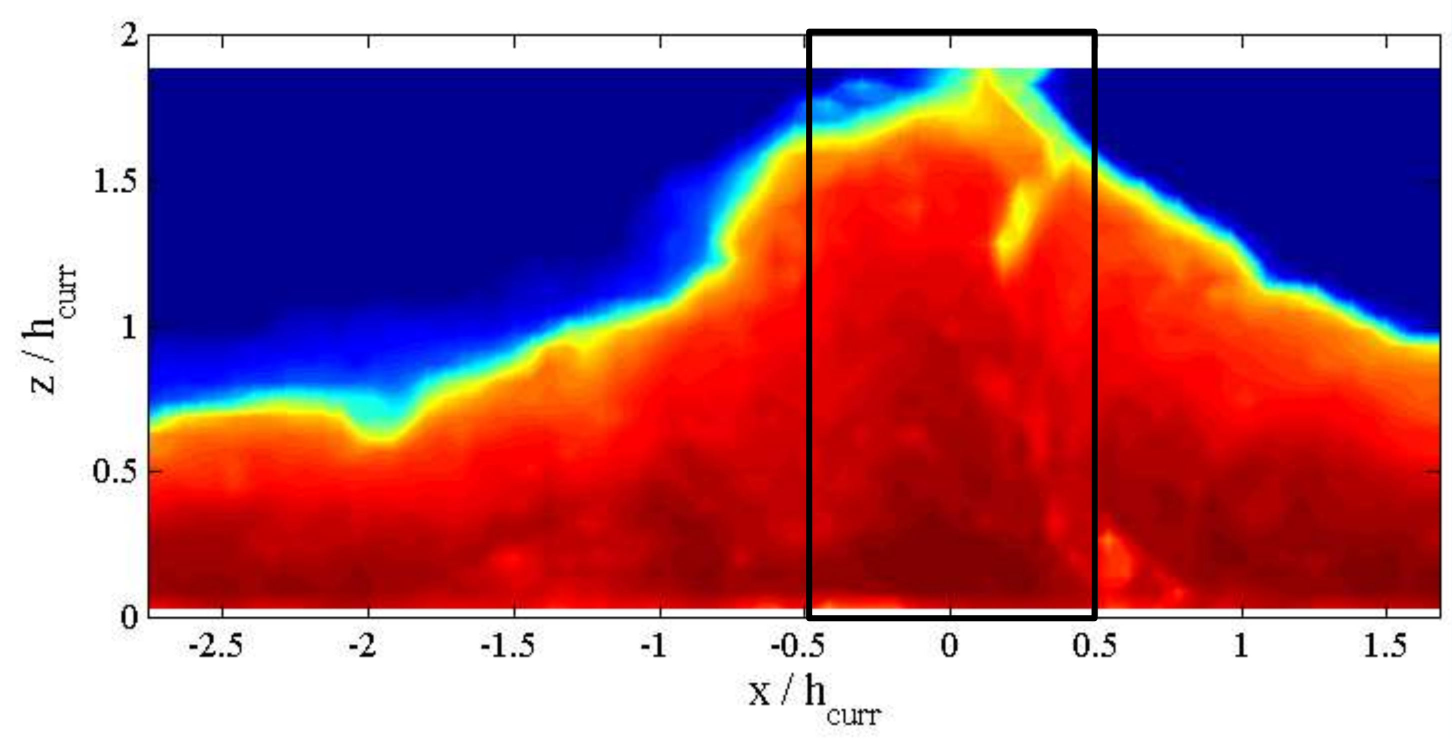


Velocity Scale	u_f
Length Scale	h_{curr}
Time Scale	$t_* = h_{curr} / u_f$

3.2 Average Process

3.2.1 Vertical motion of dense fluid front

dense fluid height in the collision area



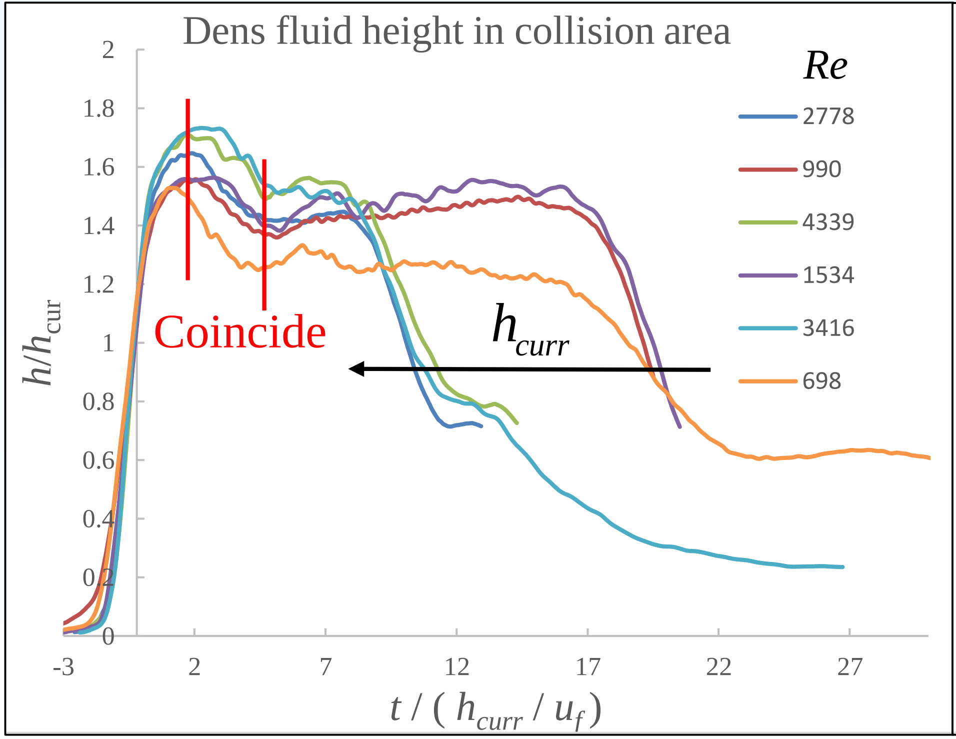
Define the dense fluid height in the collision area in the black box as:

$$h(t) = \frac{1}{2h_{curr}} \int_{-h_{curr}/2}^{h_{curr}/2} \int_{0}^{2h_{curr}} \frac{\bar{\rho}(x,z,t) - \rho_0}{\rho_1 - \rho_0} \, dz dx$$

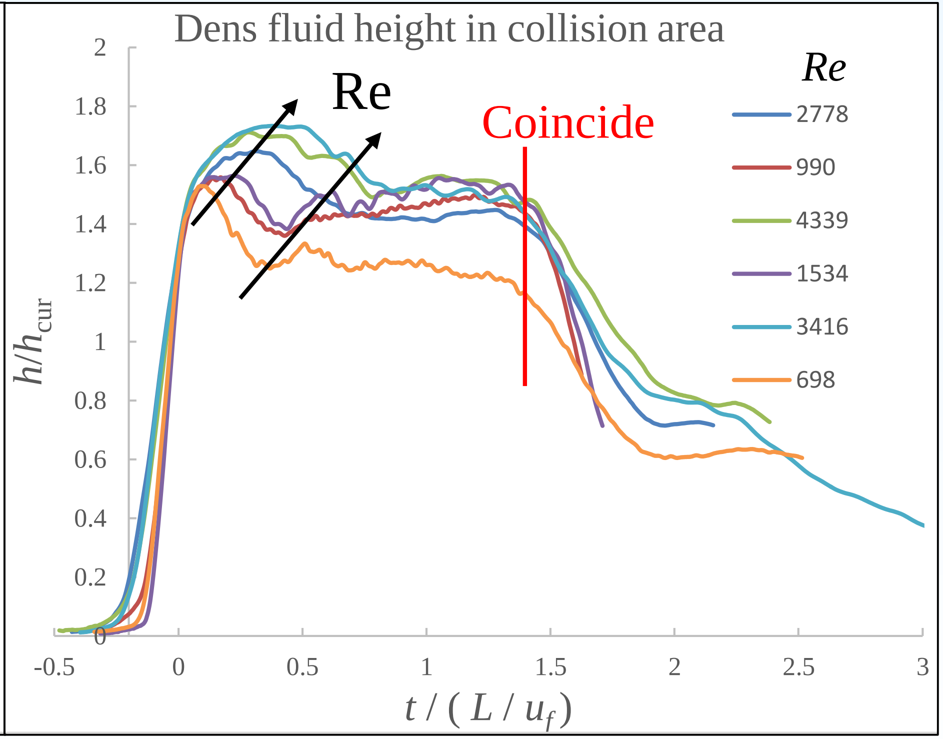
3.2 Average Process

3.2.1 Vertical motion of dense fluid front

$$t_{*1} = h_{curr} / u_f$$



$$t_{*2} = L / u_f$$



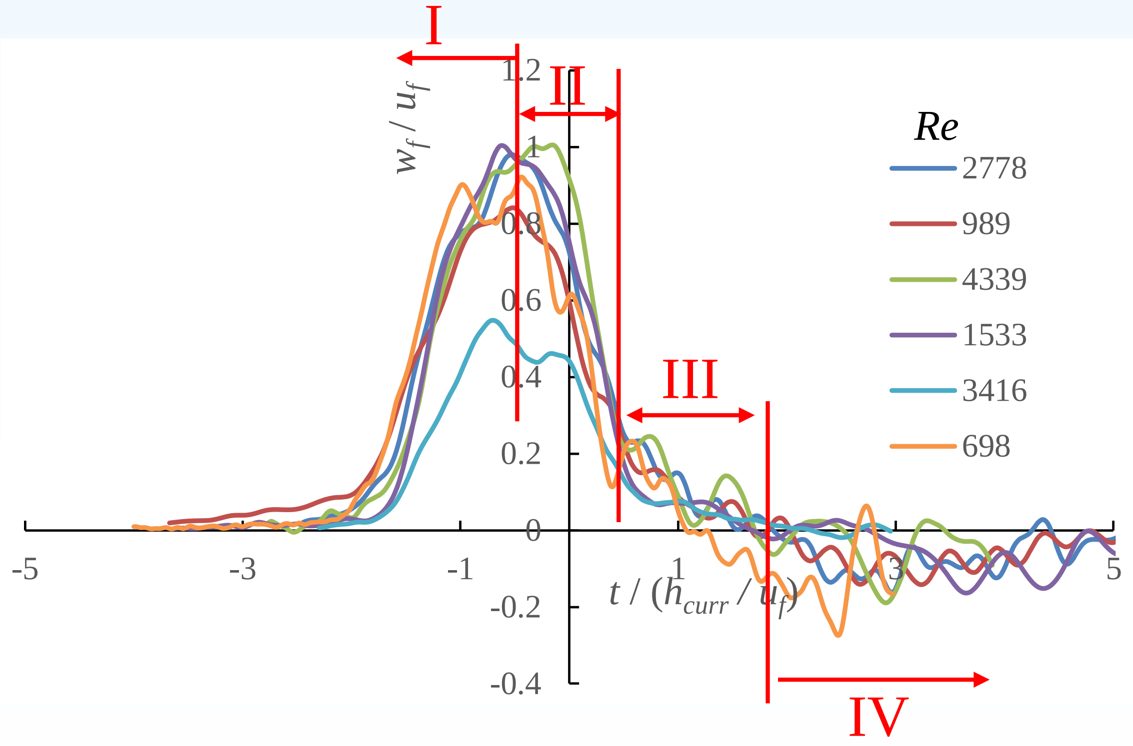
There are two time scale for $h(t)$. t_{*1} can scale the collision section but can not scale the entire durations, and t_{*2} is just the opposite. This indicates that the currents approaching, deceleration and colliding phase are dominated by the local parameters h_{curr} and u_f, but the entire duration has relationship with the total amount of dense fluid (L is the length of the dense water tank).

3.2 Average Process

3.2.1 Vertical motion of dense fluid front

Vertical front velocity

$$w_f\left(t\right)=dh\left(t\right)/dt$$



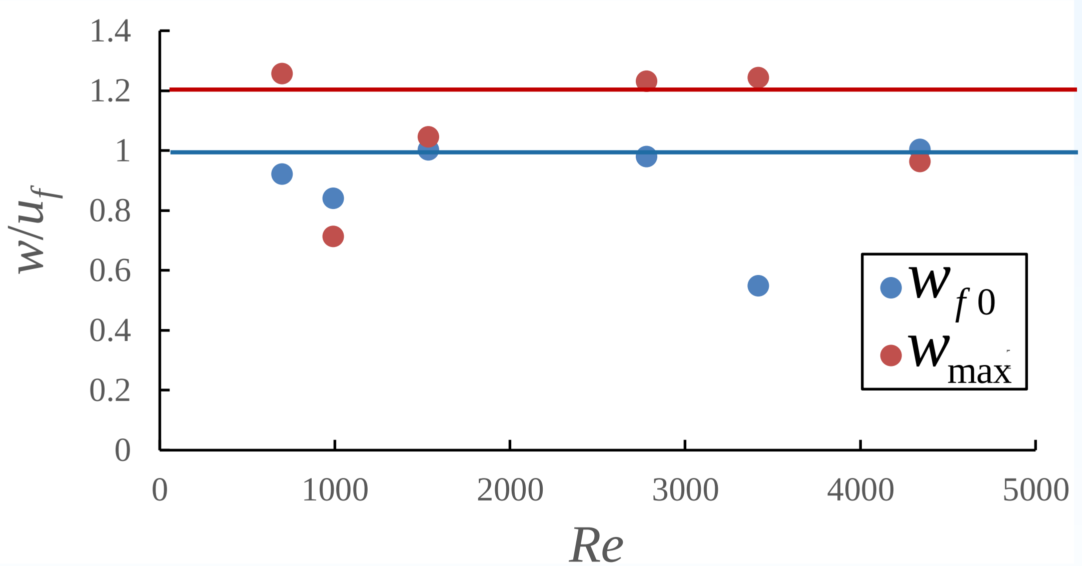
The vertical front velocity process shows 4 period obviously. w_f achieves maximum at the end of period I. The negative buoyancy force slows the upward motion in period II. At the end of period II water surface comes into play and the acceleration changes. The dense fluid reaches the highest position at the end of period III and then starts to return to the bed, thus w_f changes to negative.

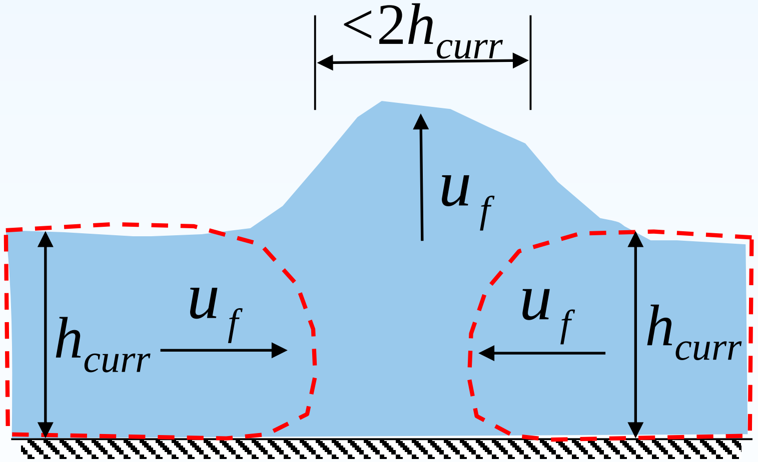
The maximum vertical front velocity can be considered as the initial velocity w_{f0} of period II.

3.2 Average Process

3.2.1 Vertical motion of dense fluid front

Initial vertical front velocity



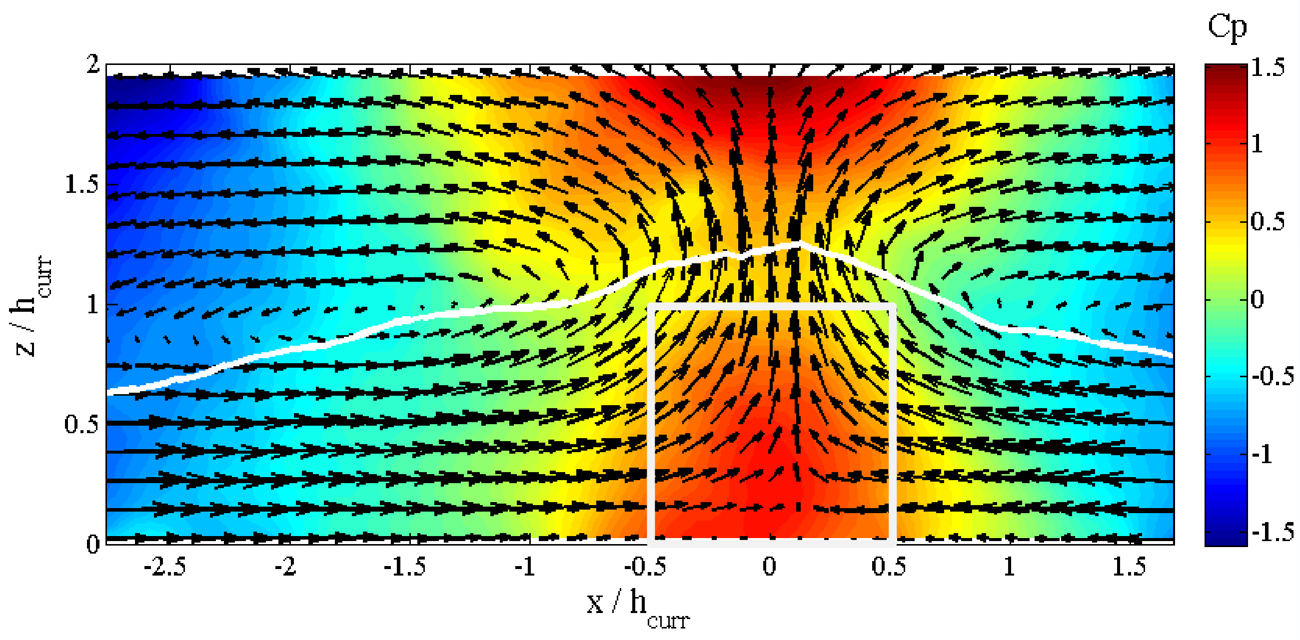


w_{f0} (blue points) is the maximum vertical front velocity, and $w_{\max}$ (red points) is the maximum vertical velocity inside the dense fluid from PIV data. It can be seen that w_{f0}/u_f is about 1 and $w_{\max}$ is about 1.2. This is similar as the velocity structure in gravity currents, where the velocity inside is about 1.5 times front velocity. Although the vertical front velocity equals to the horizontal front velocity of typical gravity current, the front size after collision is smaller than $2h_{curr}$. Thus, in general there are some kinetic energy lost during collision.

3.2 Average Process

3.2.3 Pressure Distribution

Case 6, h_{curr}=25mm, Re=698, $t/(h_{curr}/u_f)$=-0.4



$$Cp = \frac{p - p_{ref}}{\frac{1}{2}\rho_1 u_f^2}$$

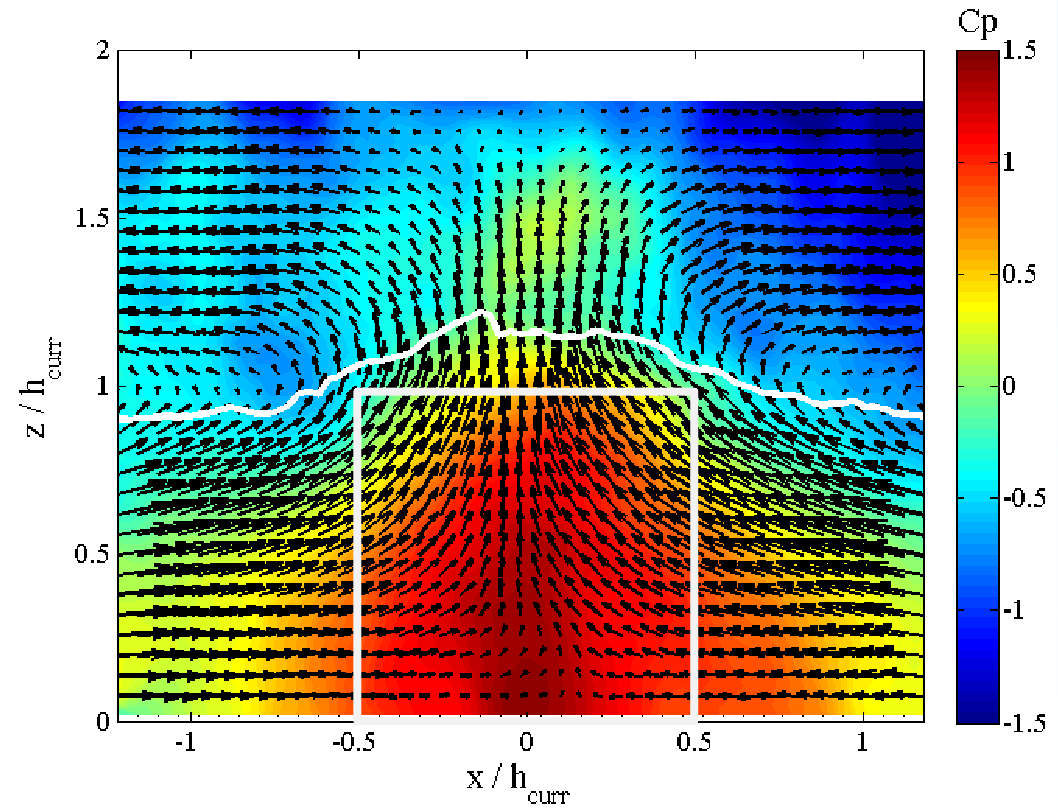
where p_{ref} is the average pressure in the filed.

There are two high pressure area during collision. The water surface inhibition causes the upper one. In the atmosphere, the water surface does not exist. Thus, the lower high pressure area is more interesting, and it is cased by the horizontal velocity decreasing. The area range changes during collision, we can find the maximum situation as the characteristic range. This figure is the maximum situation of case 6, and the width and height of high pressure area are both about h_{curr}.

3.2 Average Process

3.2.3 Pressure Distribution

Case 5, h_{curr}=50mm, Re=3416, $t/(h_{curr}/u_f)$=-0.38



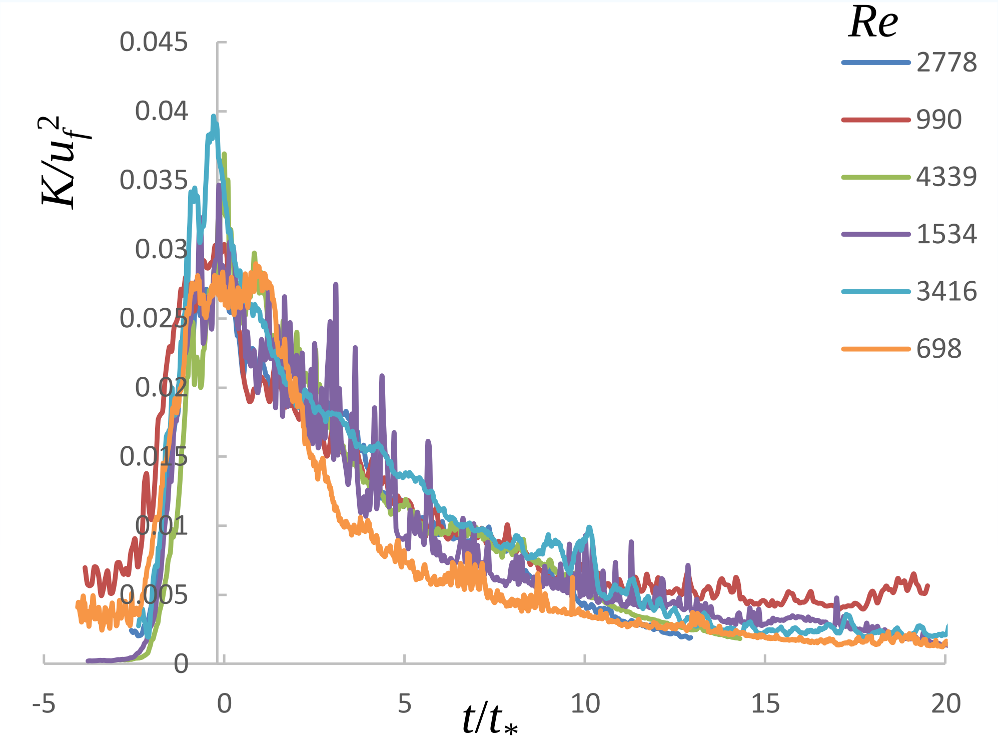
The width and height of high pressure area for different cases are both about h_{curr}. The time of occurrence is just after the heads hit each other. Direction of flow is deflected by this high pressure core between two gravity currents and convection is triggered.

3.3 Turbulence fluctuation

3.3.1 turbulent kinetic energy

$$K(i,t)=\frac{1}{4h_{curr}^2}\int_0^{2h_{curr}}\int_{-h_{curr}/2}^{h_{curr}/2}\left[u^2(x,z,t,i)+w^2(x,z,t,i)\right]dxdz$$

$$\bar{K}(t)=\frac{1}{N}\sum_{i=1}^{N}K(i,t)$$

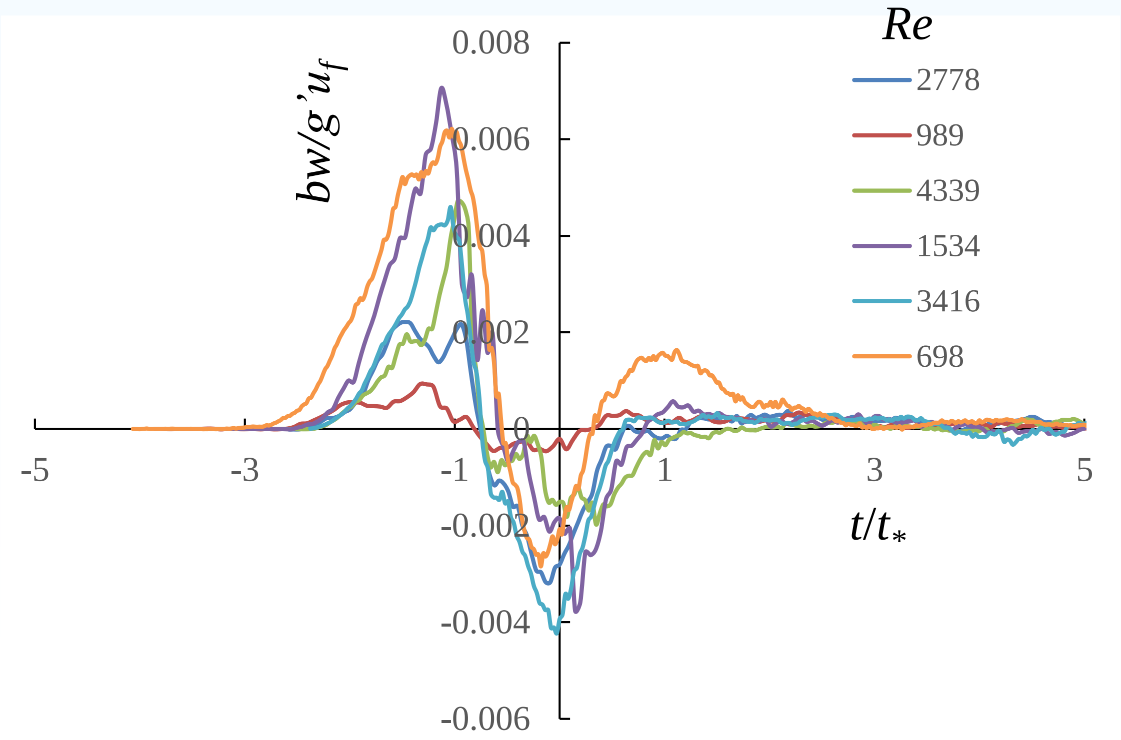


3.3 Turbulence fluctuation

3.3.2 Buoyancy flux

$$b(x,z,t,i) = g\,\frac{\bar{\rho}(x,z,t,i) - \tilde{\rho}(x,z,t,i)}{\rho_0} \qquad bw(x,z,t) = \frac{1}{N}\sum_{i=1}^{N} b(x,z,t,i)\cdot w(x,z,t,i)$$

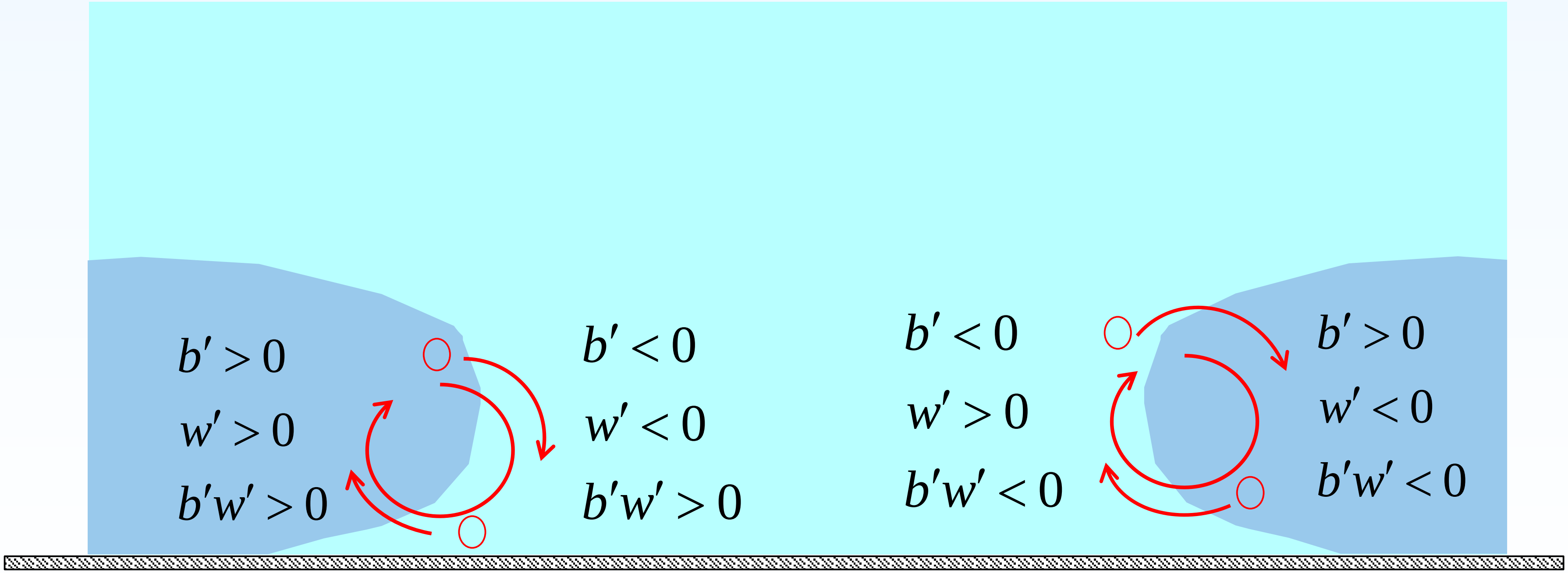
$$\overline{bw}(t) = \frac{2}{4h_{curr}^2}\int_0^{2h_{curr}}\left(\int_{-h_{curr}}^{h_{curr}} bw(x,z,t)\,dx\right)dz$$



3.3 Turbulence fluctuation

3.3.2 Buoyancy flux

$$b' = g\frac{\rho_0 - \rho}{\rho_0} - g\frac{\rho_0 - \bar{\rho}}{\rho_0} = g\frac{\bar{\rho} - \rho}{\rho_0}$$



$b' > 0$

$w' > 0$

$b'w' > 0$

$b' < 0$

$w' < 0$

$b'w' > 0$

$b' < 0$

$w' > 0$

$b'w' < 0$

$b' > 0$

$w' < 0$

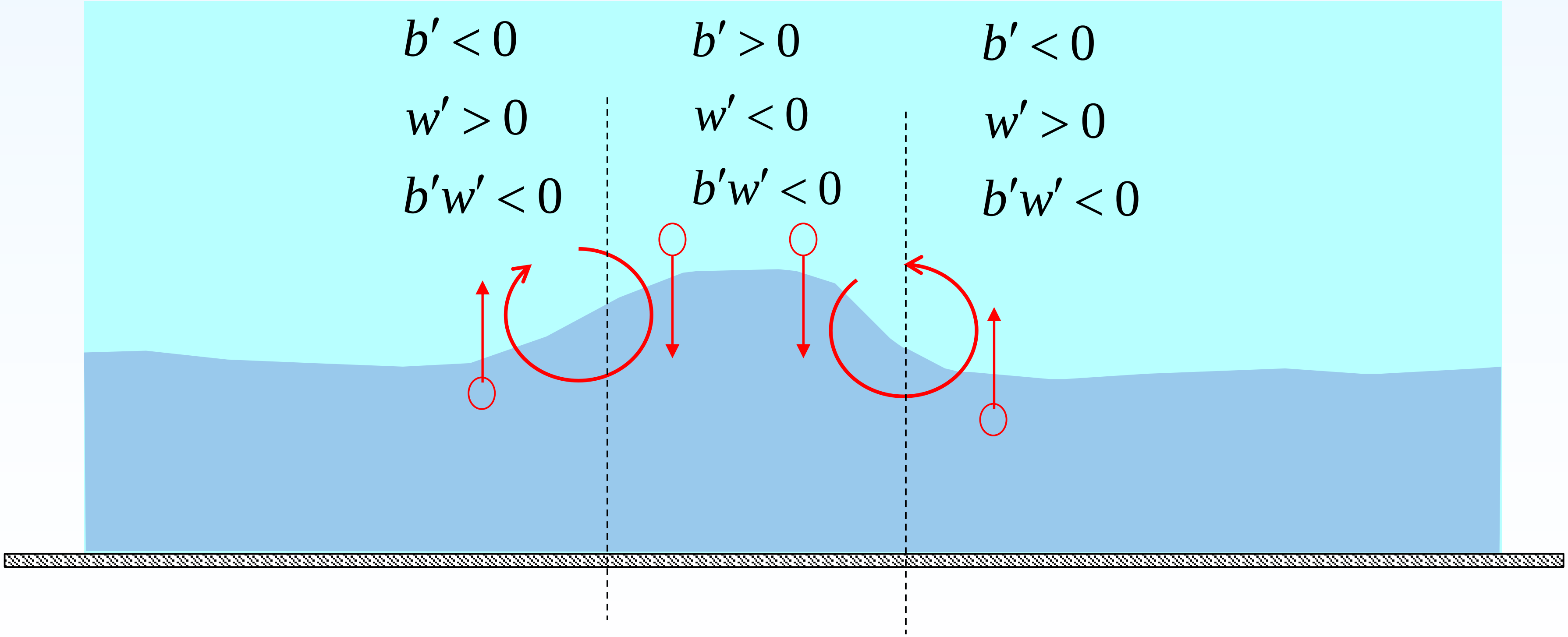
$b'w' < 0$

Before collision

3.3 Turbulence fluctuation

3.3.2 Buoyancy flux

$$b' = g\frac{\rho_0 - \rho}{\rho_0} - g\frac{\rho_0 - \bar{\rho}}{\rho_0} = g\frac{\bar{\rho} - \rho}{\rho_0}$$



$b' < 0$
$w' > 0$
$b'w' < 0$

$b' > 0$
$w' < 0$
$b'w' < 0$

$b' < 0$
$w' > 0$
$b'w' < 0$

After collision

4. Conclusion

4. Conclution

(1) Mixing both happens between two heads and between current and ambient. Strong vertical motion is triggered by collision. The dense fluid itself is also stratified after collision.

(2) The width and height of high pressure area for different cases during collision are both about h_{curr}. The time of maximum area occurrence is just after the heads heat each other. Direction of flow is deflected by this high pressure core between two gravity currents and convection is triggered.

(3) Velocity, length and time scale for collision phase are u_f, h_{curr} and h_{curr}/u_f respectively. The bores propagating phase and entire duration have relationship with the total amount of dense fluid.

(4) The value of initial vertical front velocity (just after the heads hit each other) is u_f.

(5) TKE increase very quickly when gravity currents approaching to each other and achieves maximum just after the heads hitting each other.

(6) Buoyancy flux is totally different before and after collision.

Thank you very much

for your attention!