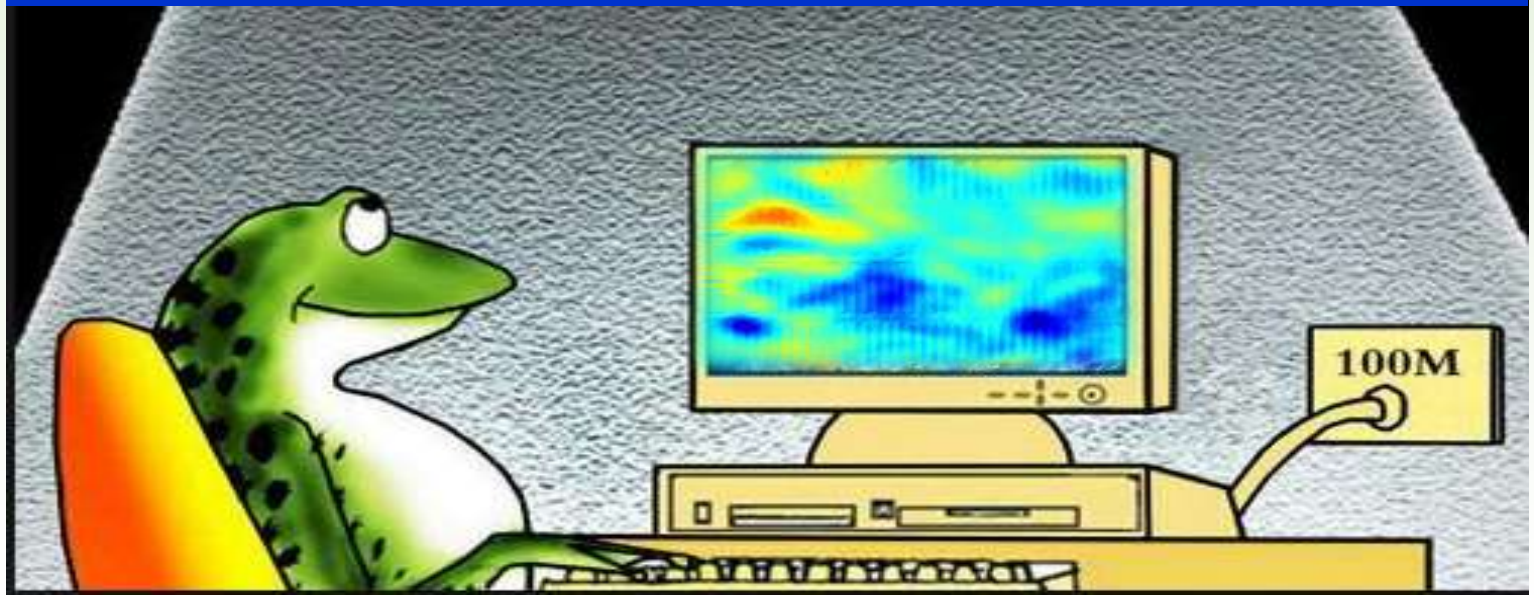
Velocity and heat flux over a square urban area

Yifan Fan[a] Julian Hunt[b,c] Yuguo Li[a]

[a]The University of Hong Kong, HKSAR;
[b]University of Cambridge, UK;
[c]University College London, UK.

Urban area

Observe the flow under the ‘urban area’



Principle-velocity

Our objective can be achieved by recording consecutive thermal images.

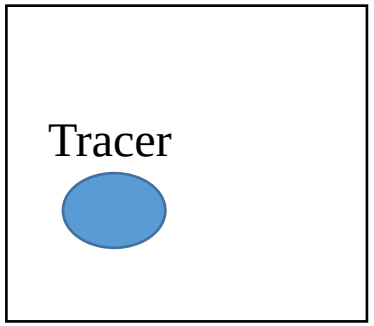
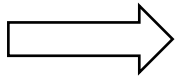


Image 1

Δt



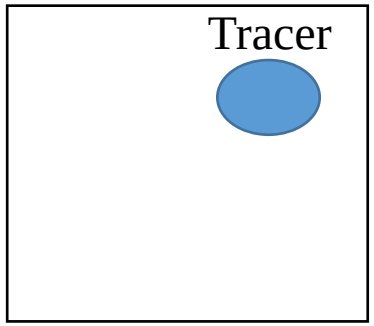
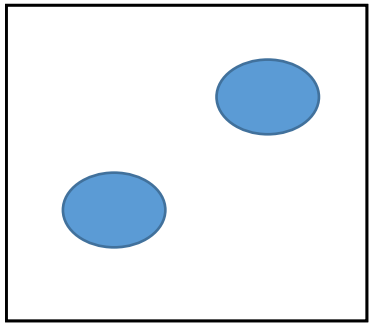
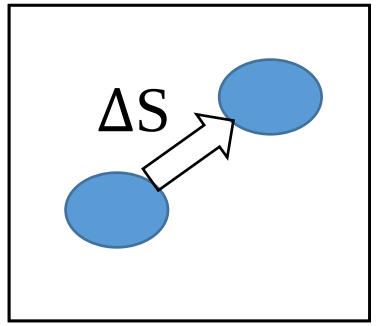


Image 2



Combined image 1 and image 2



Combined image 1 and image 2

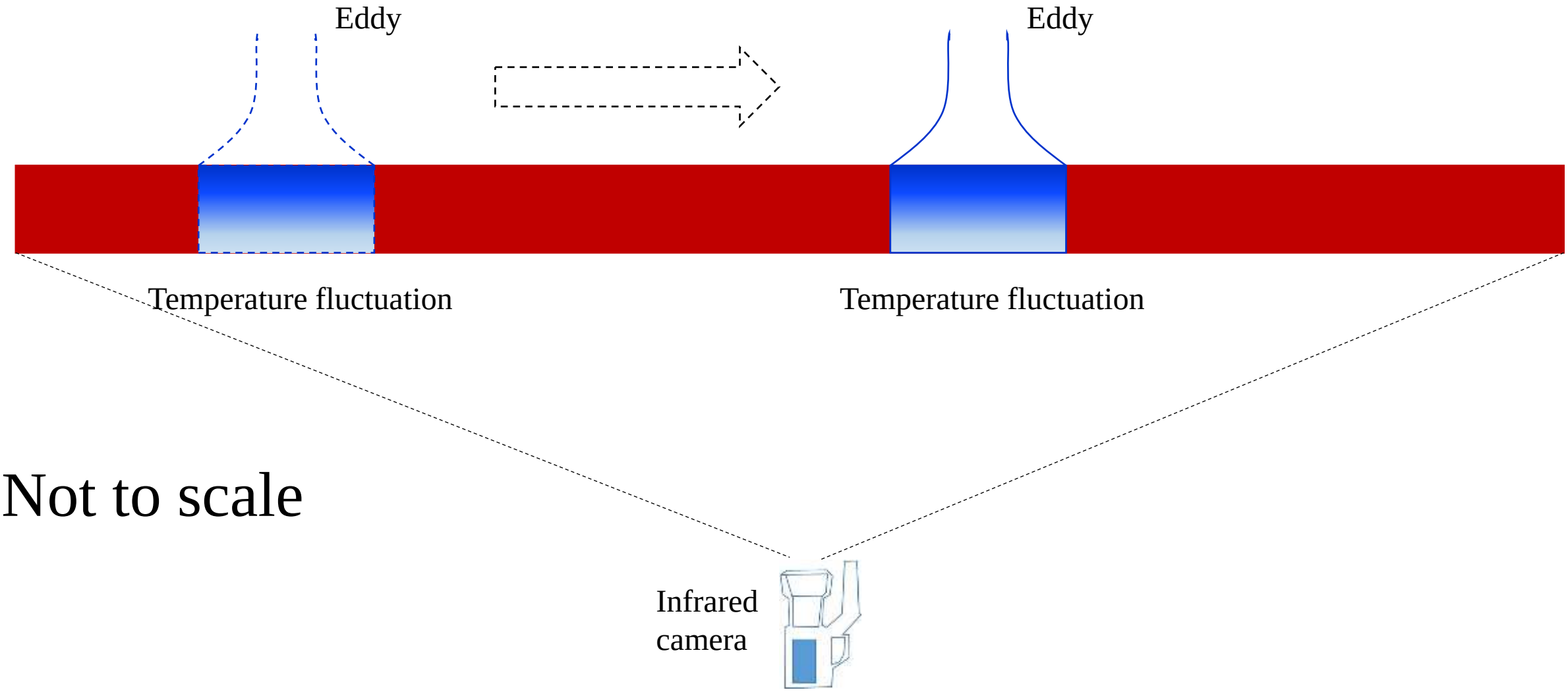
Velocity $u = \Delta S / \Delta t$

Principle – Obtaining time difference and displacement

Δt Time difference between two consecutive images.
Known and be controlled.

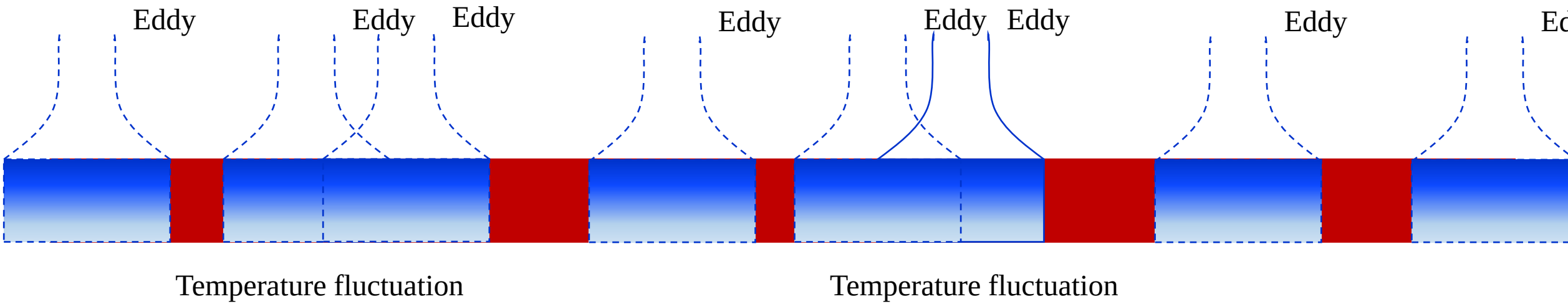
ΔS To obtain displacement.
We need to have a Tracer.

Principle – Tracer



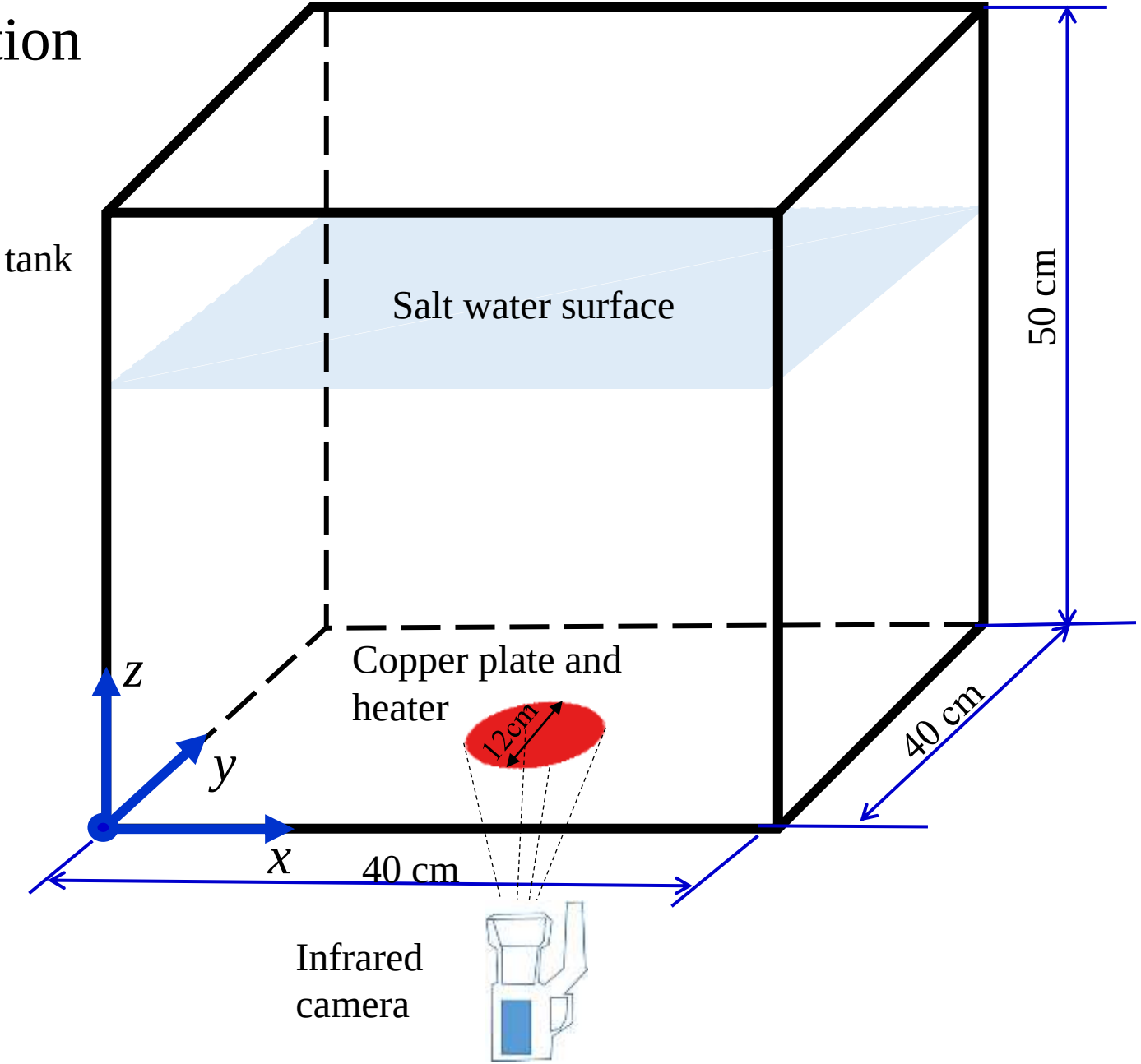
Not to scale

Principle – Too much eddies, How do we know which are the ones we are tracing?

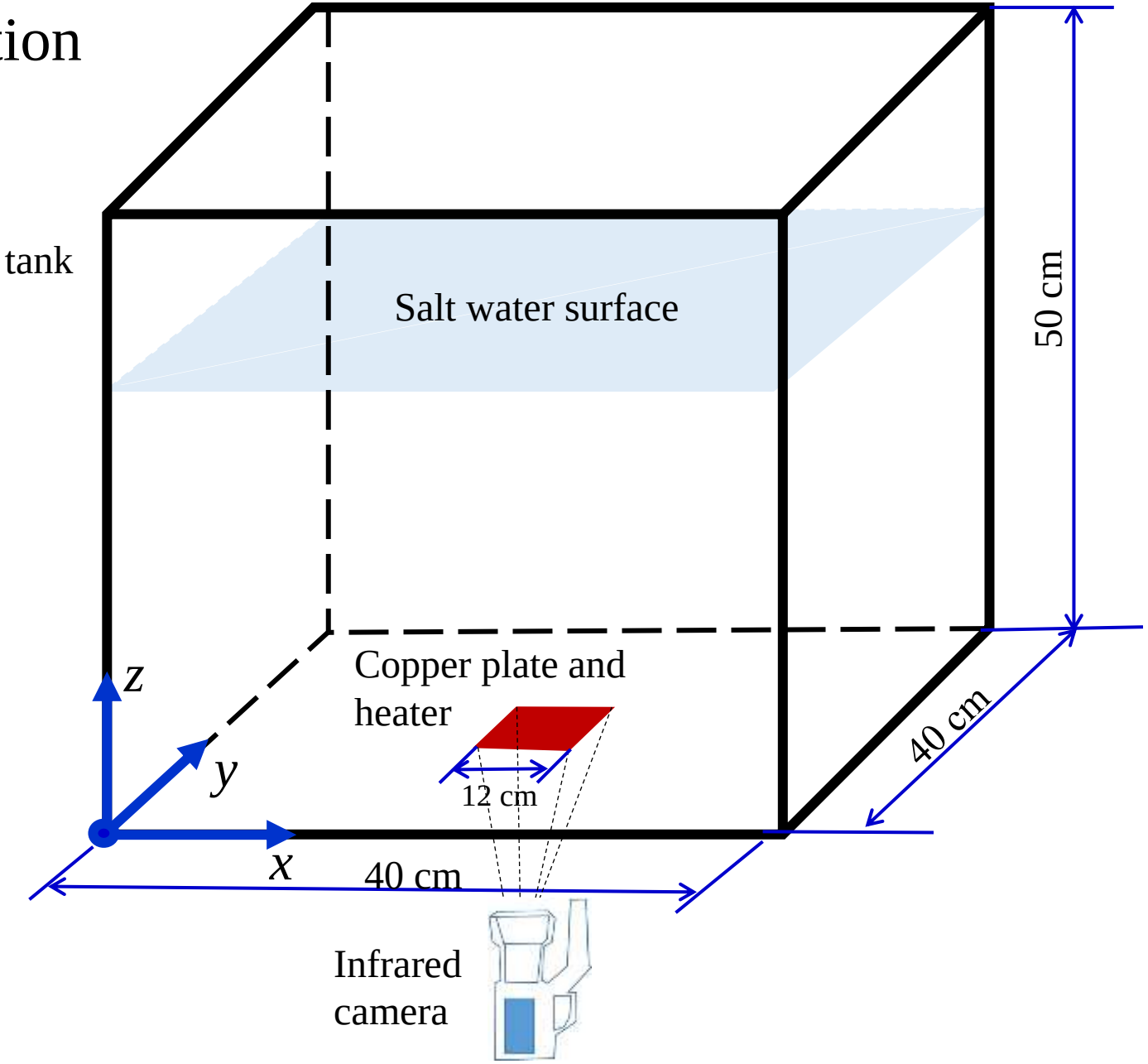


Statisticcal model: Cross correlation

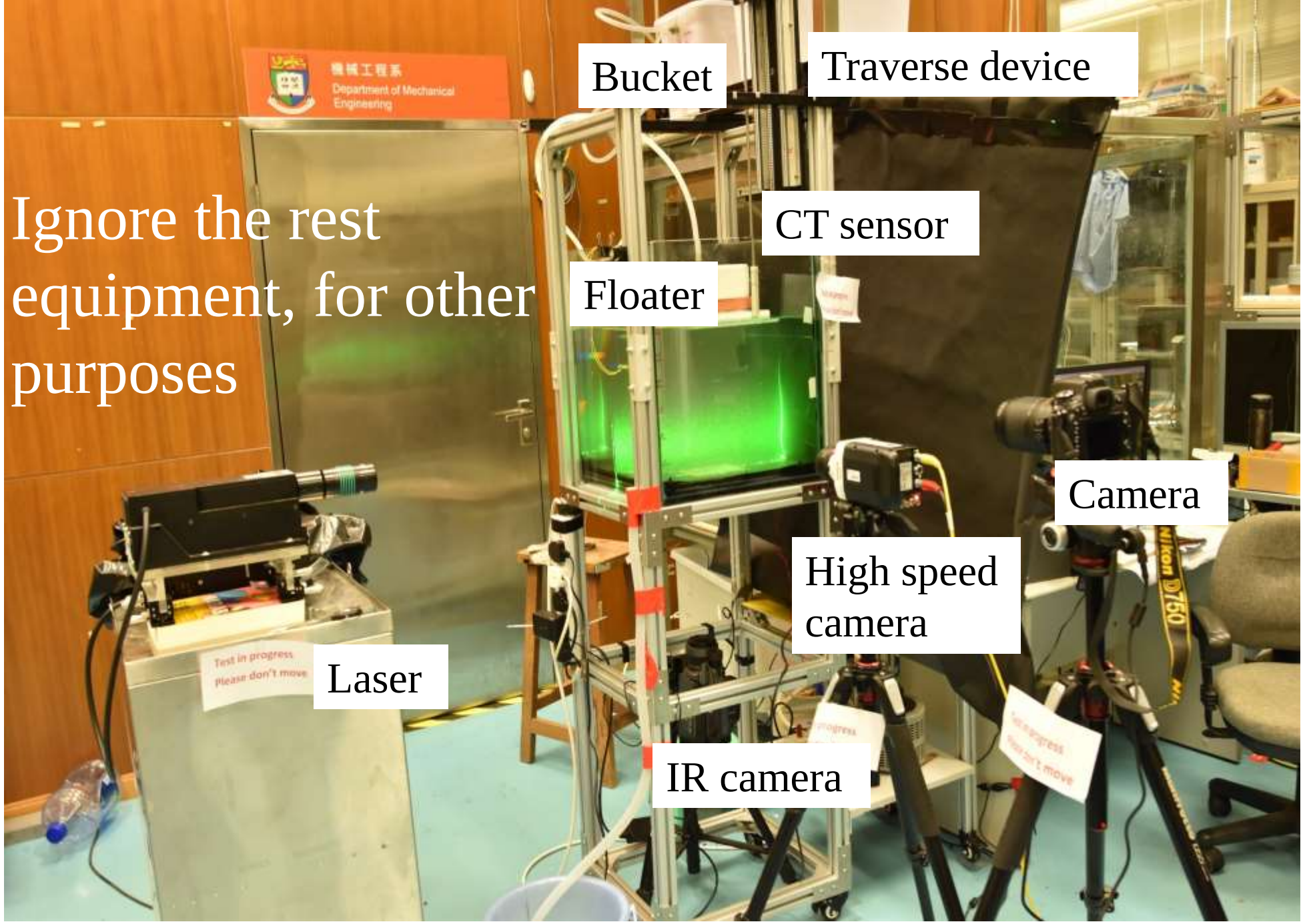
Setup- illustration



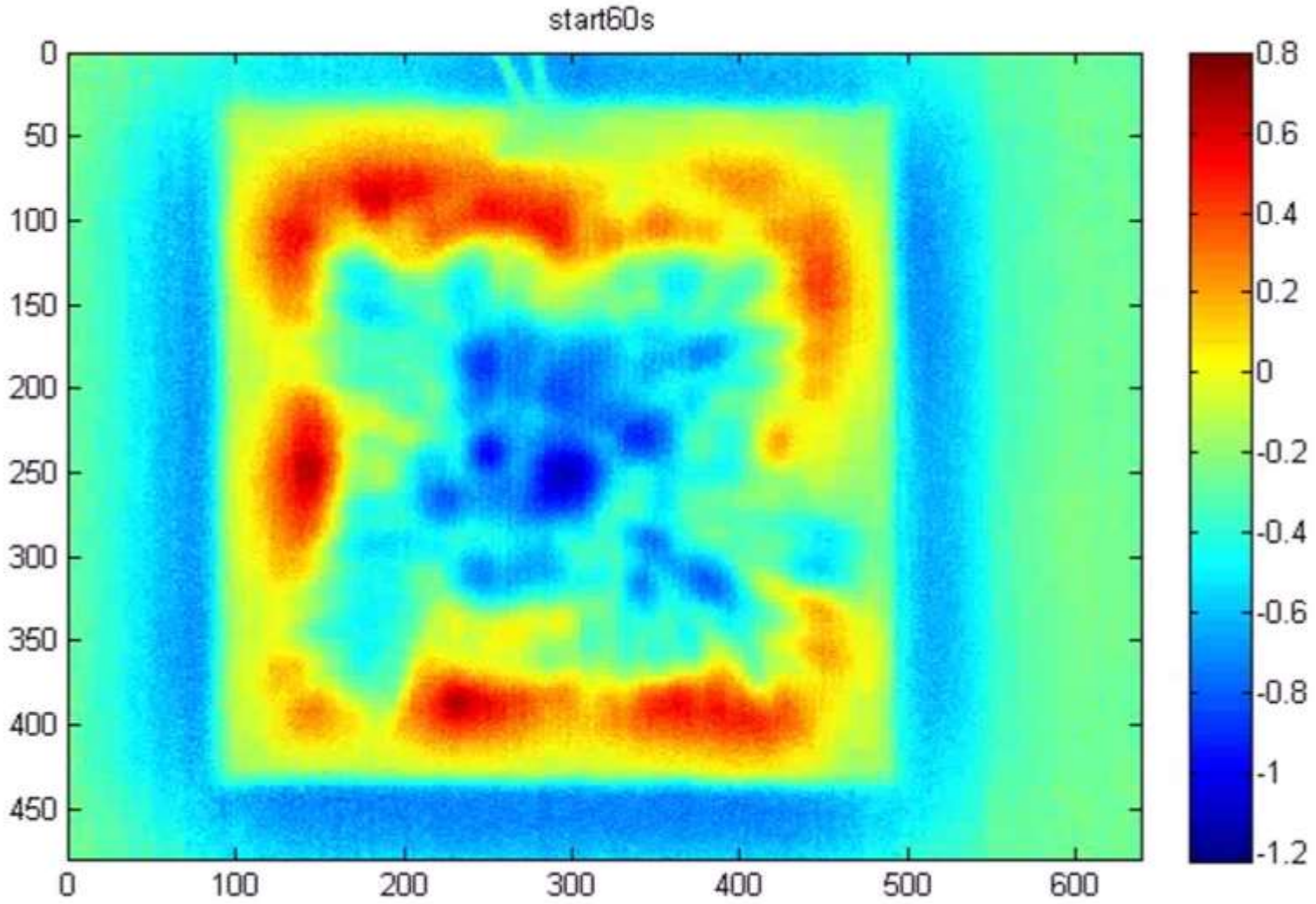
Setup- illustration



Setup

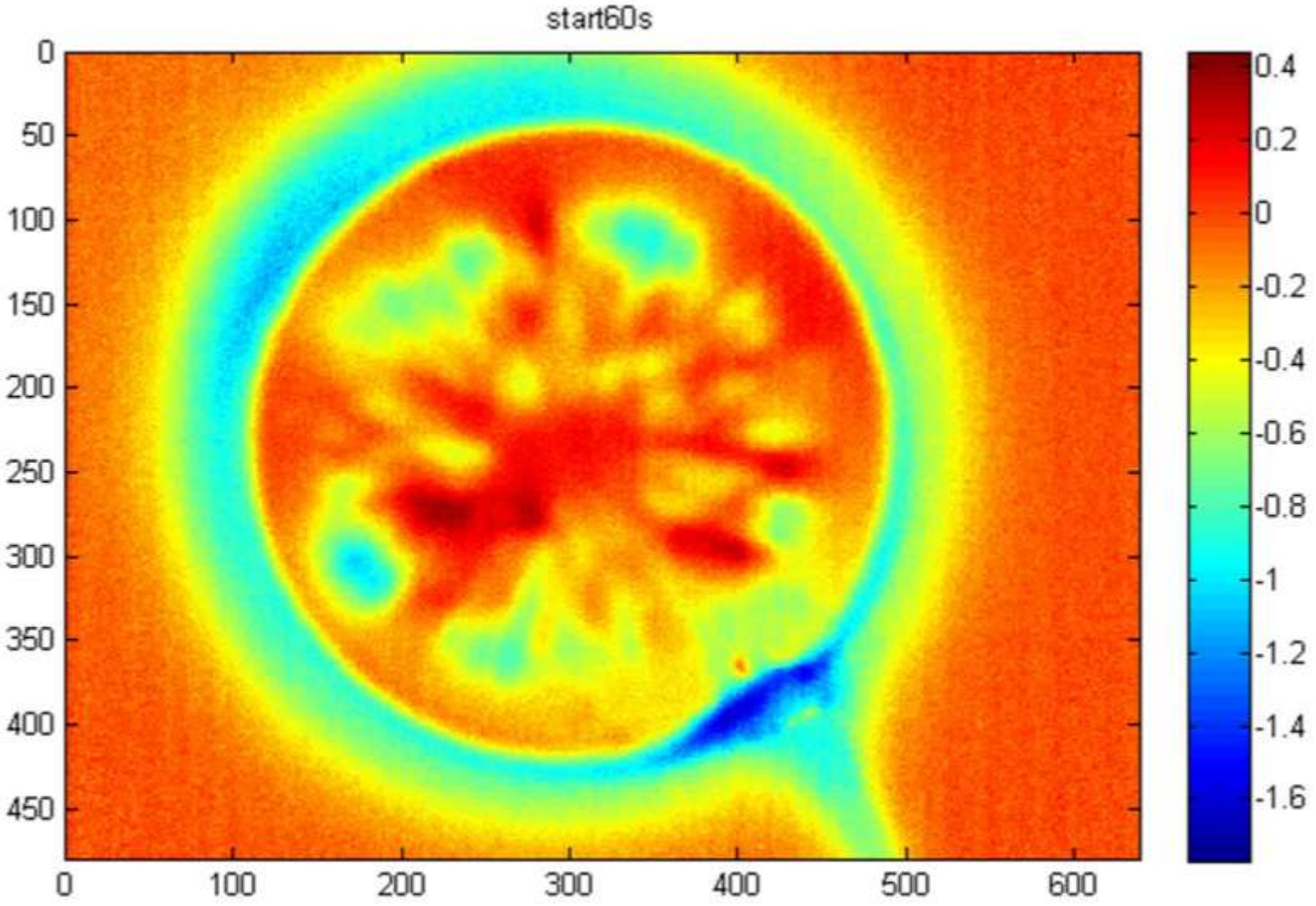

Department of Mechanical Engineering
Ignore the rest equipment, for other purposes
Bucket
Traverse device
CT sensor
Floater
Camera
High speed camera
Laser
IR camera

Results – visualization eddies moving (square heater)



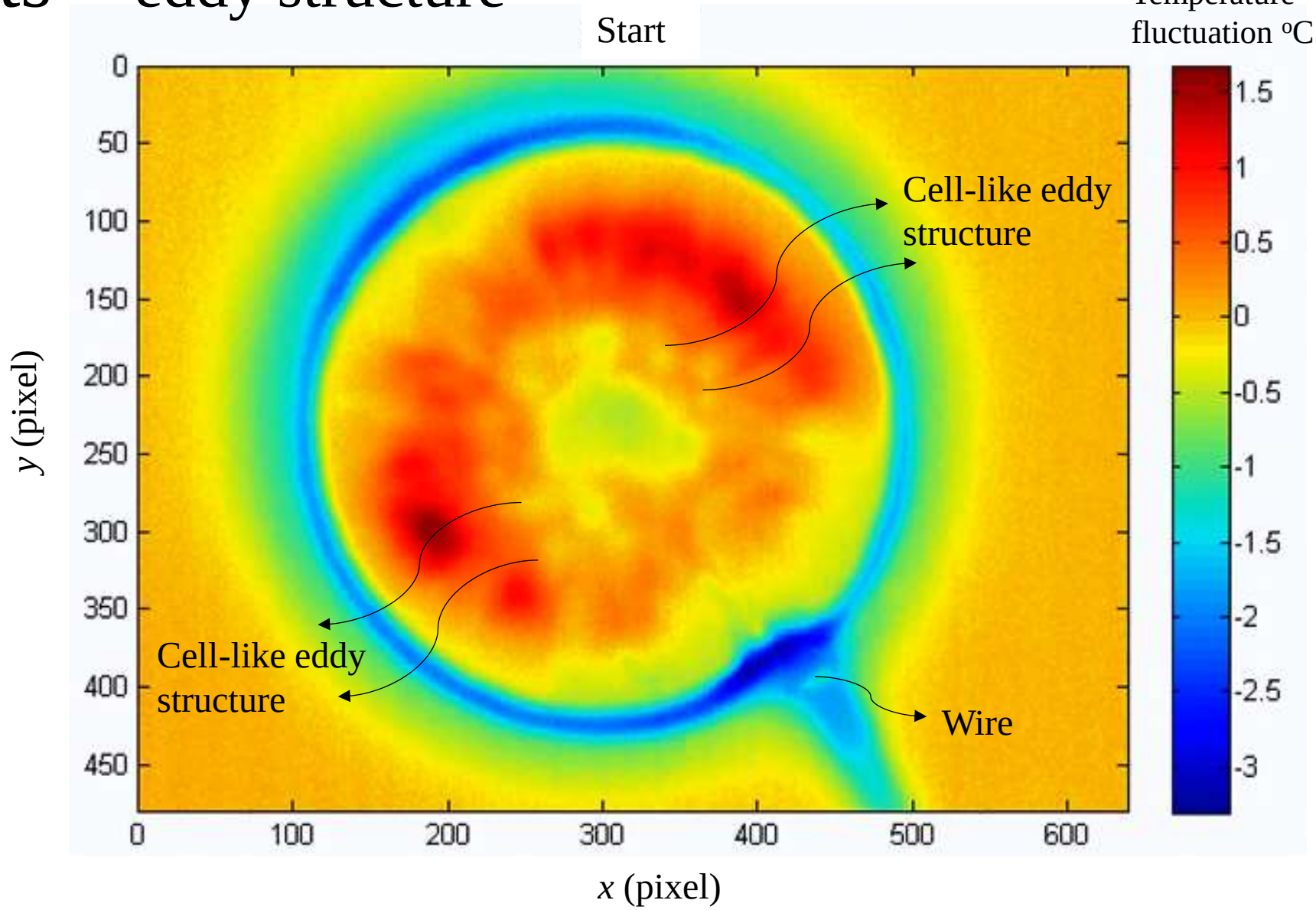
Flow towards the center

Results – visualization eddies moving (circular heater)

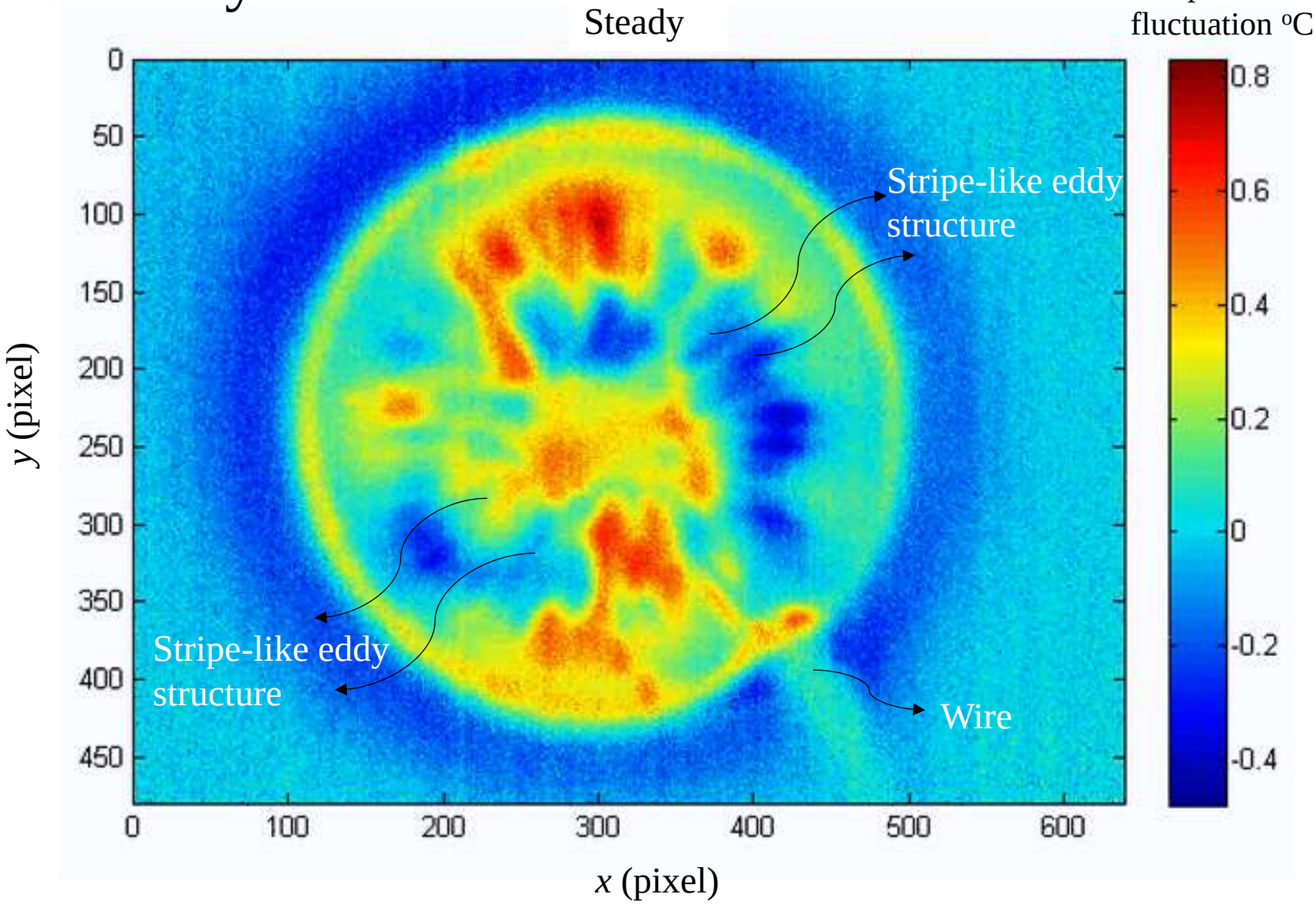


Flow towards the center

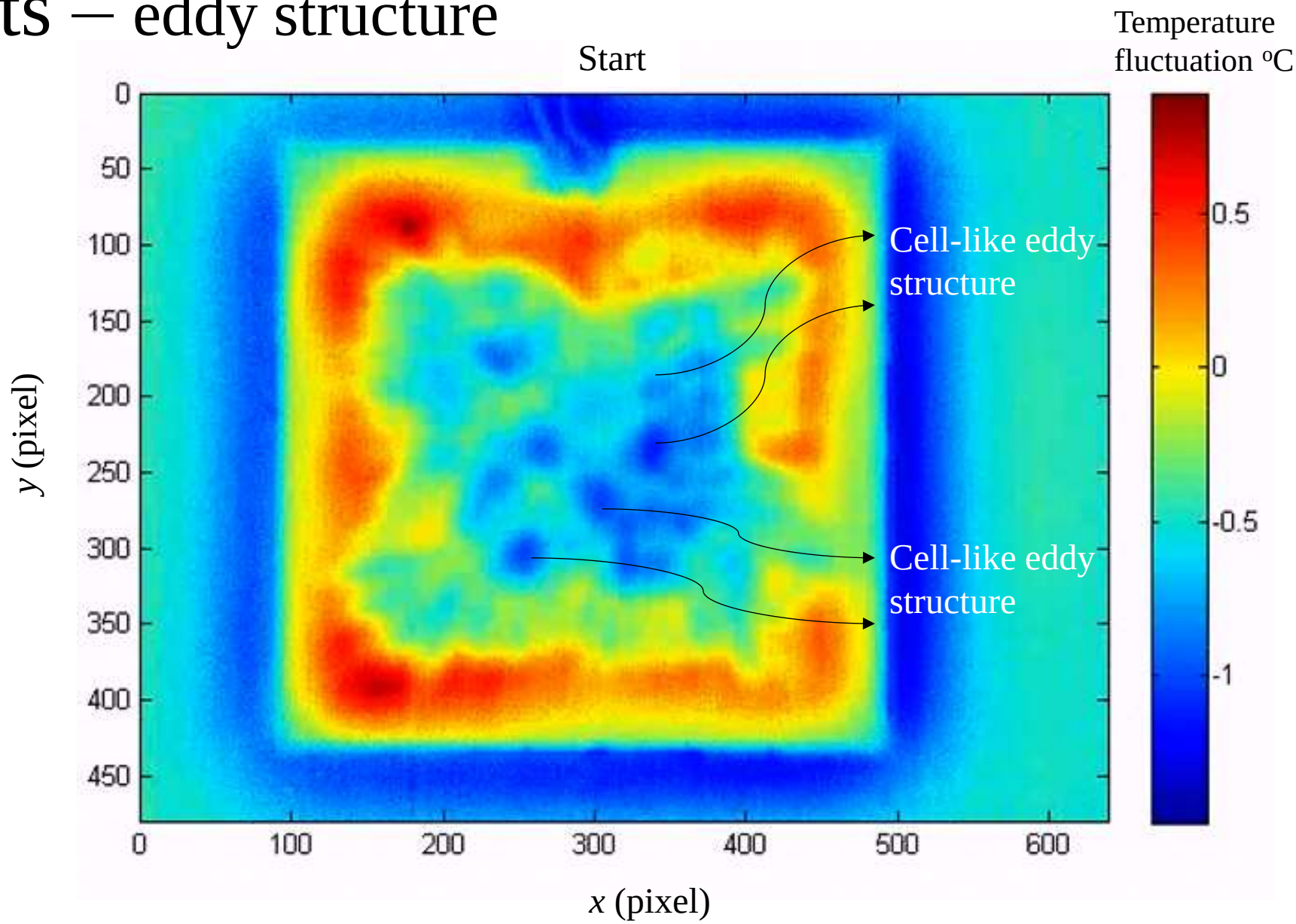
Results – eddy structure



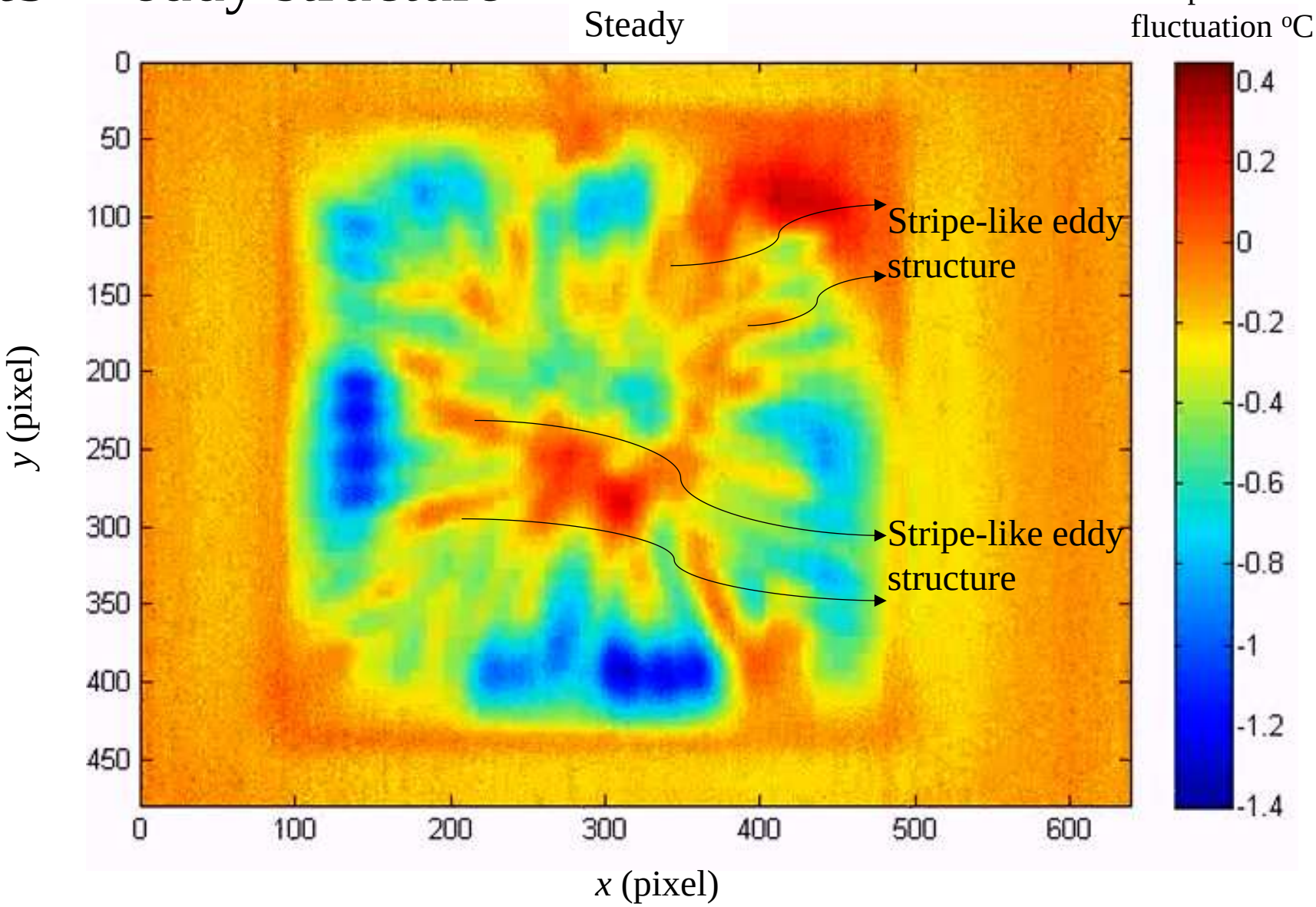
Results – eddy structure



Results – eddy structure

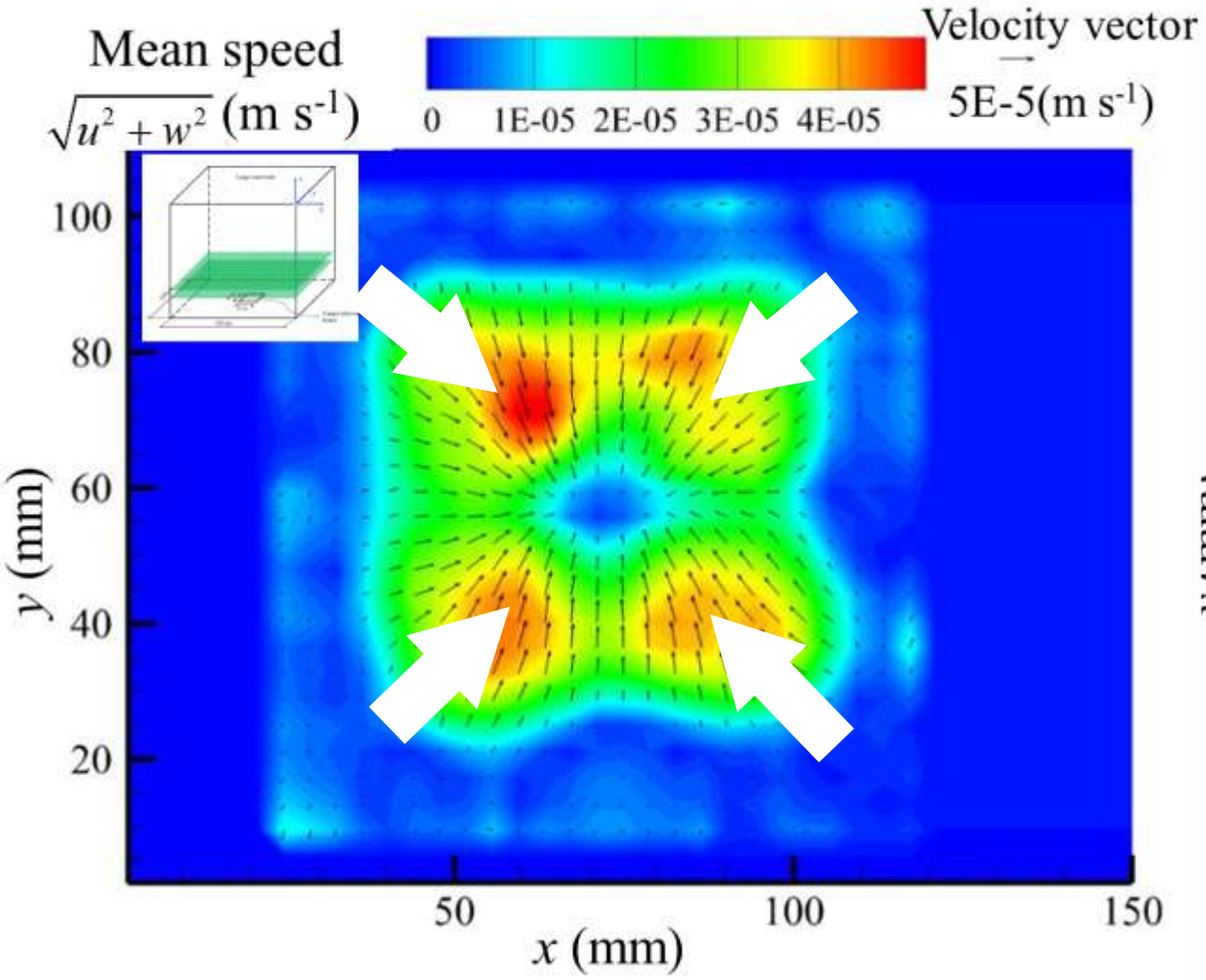


Results – eddy structure

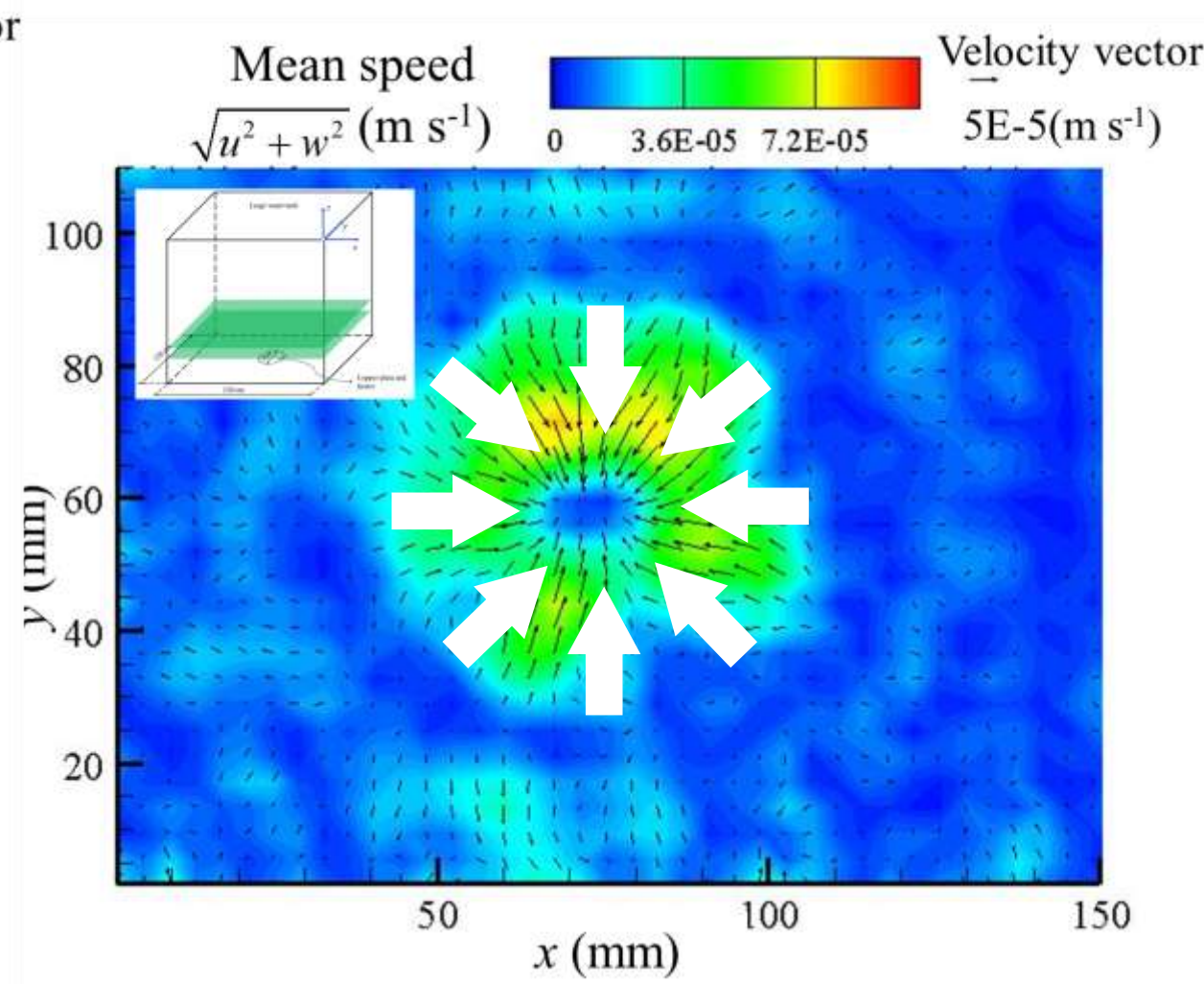


Results – calculated velocity fields

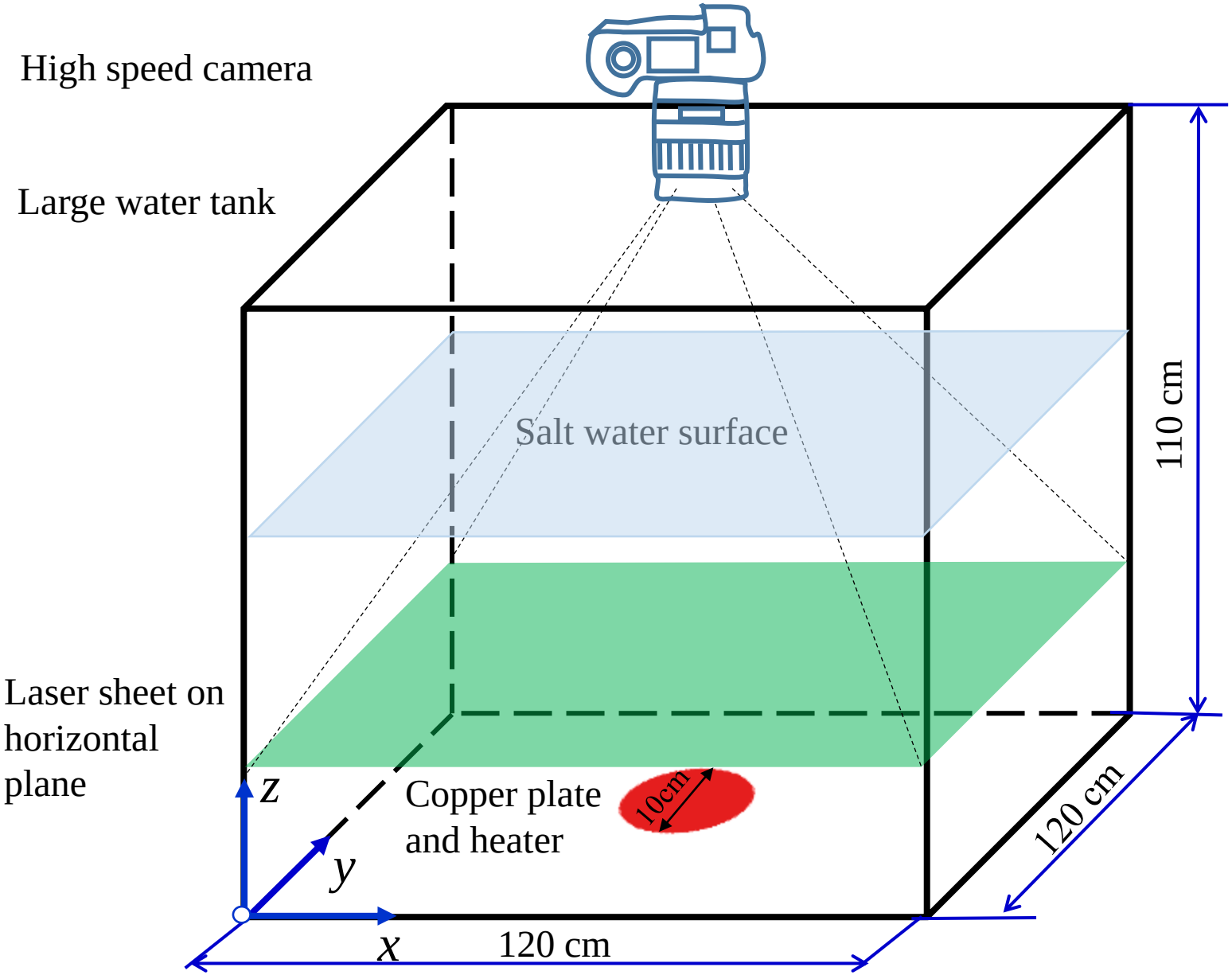
Square

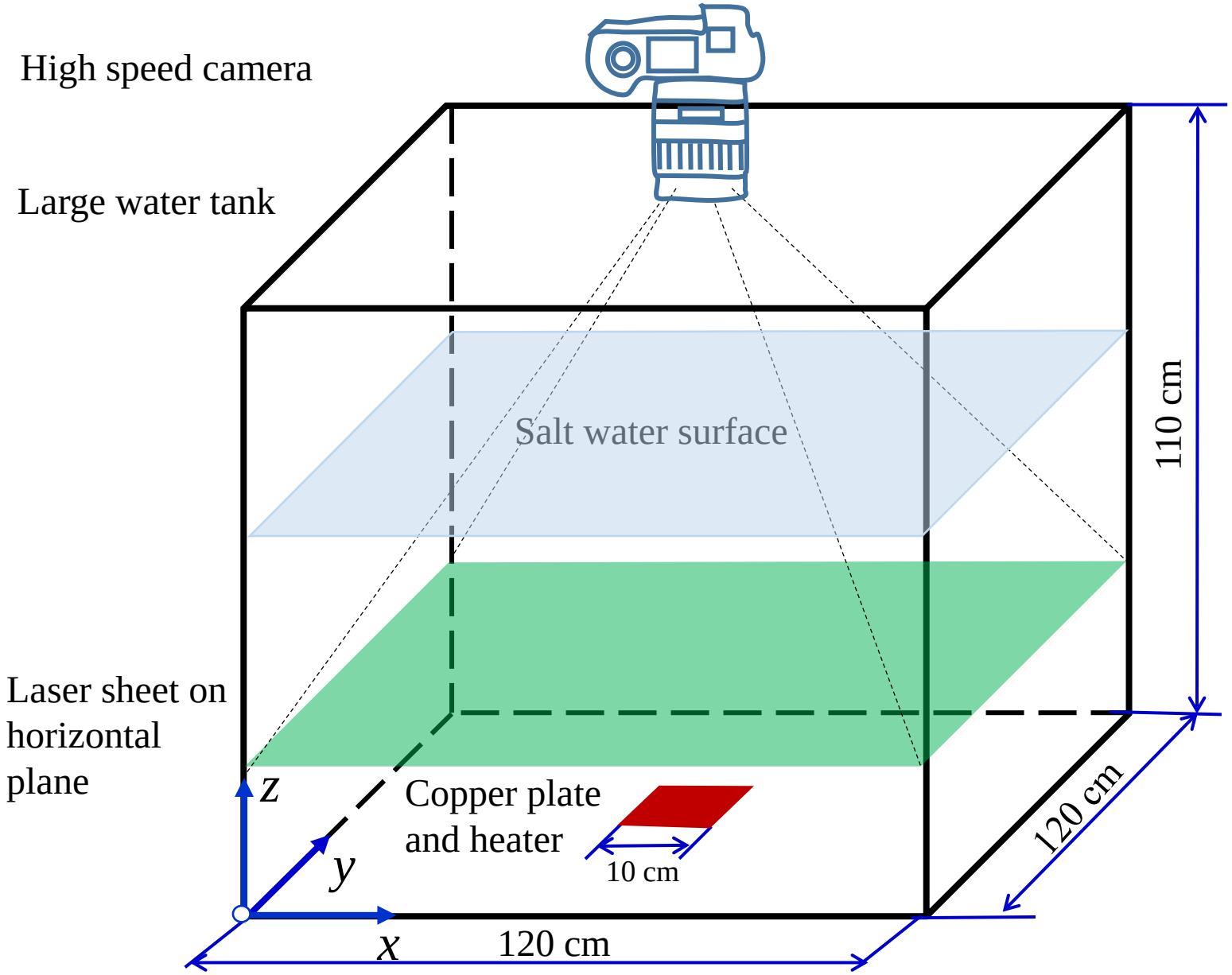


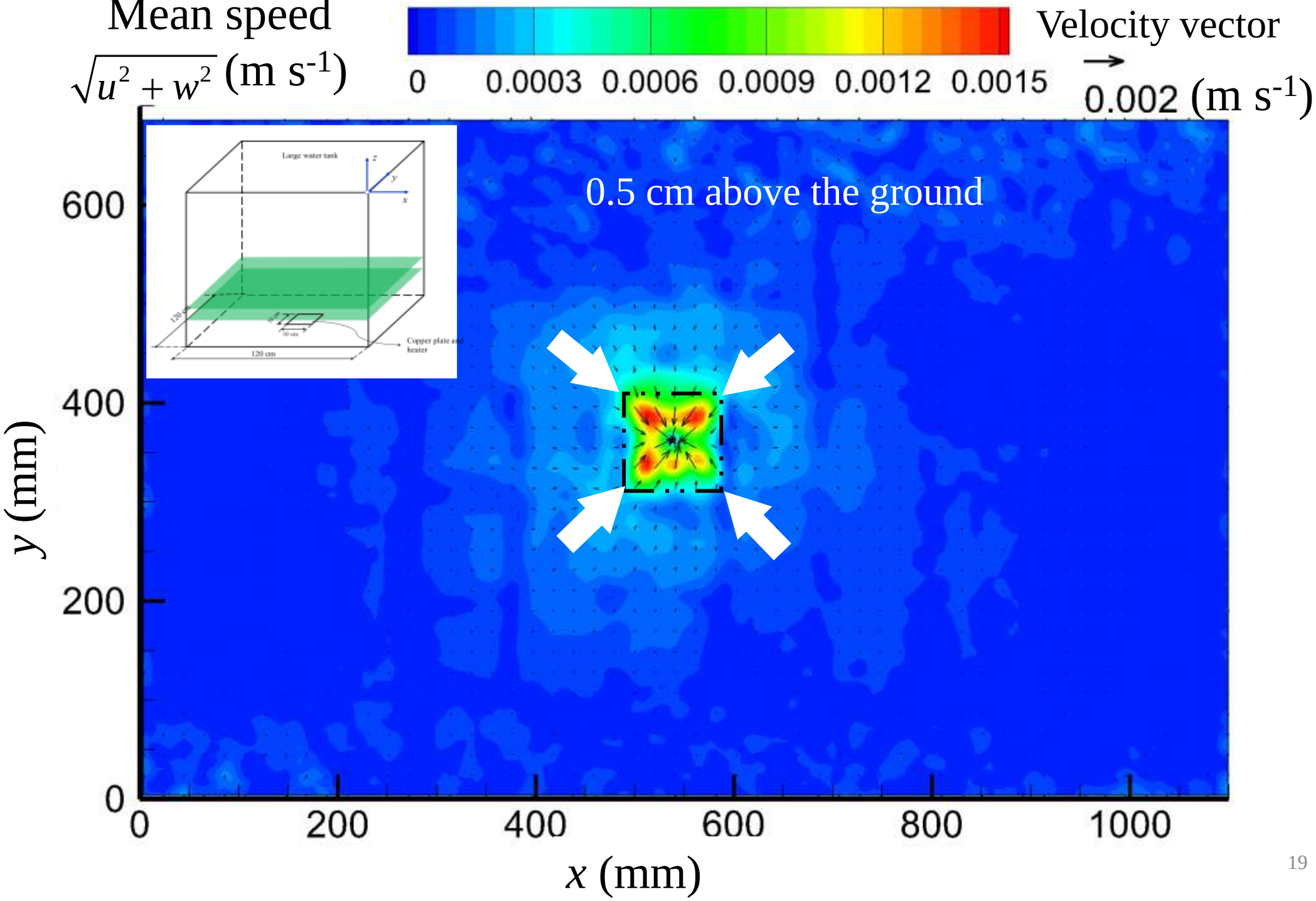
Circular

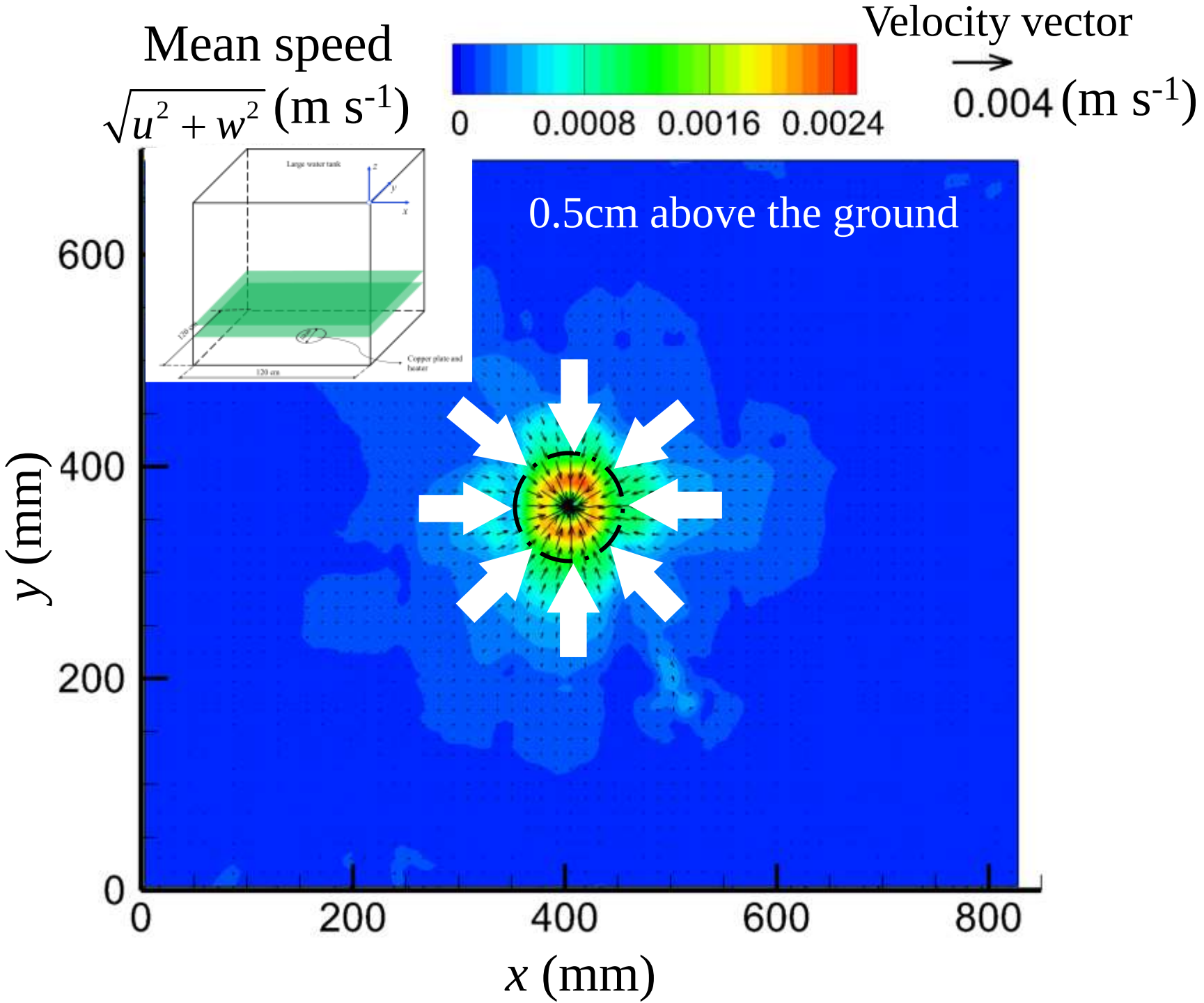


Supported by another studies-shape effects

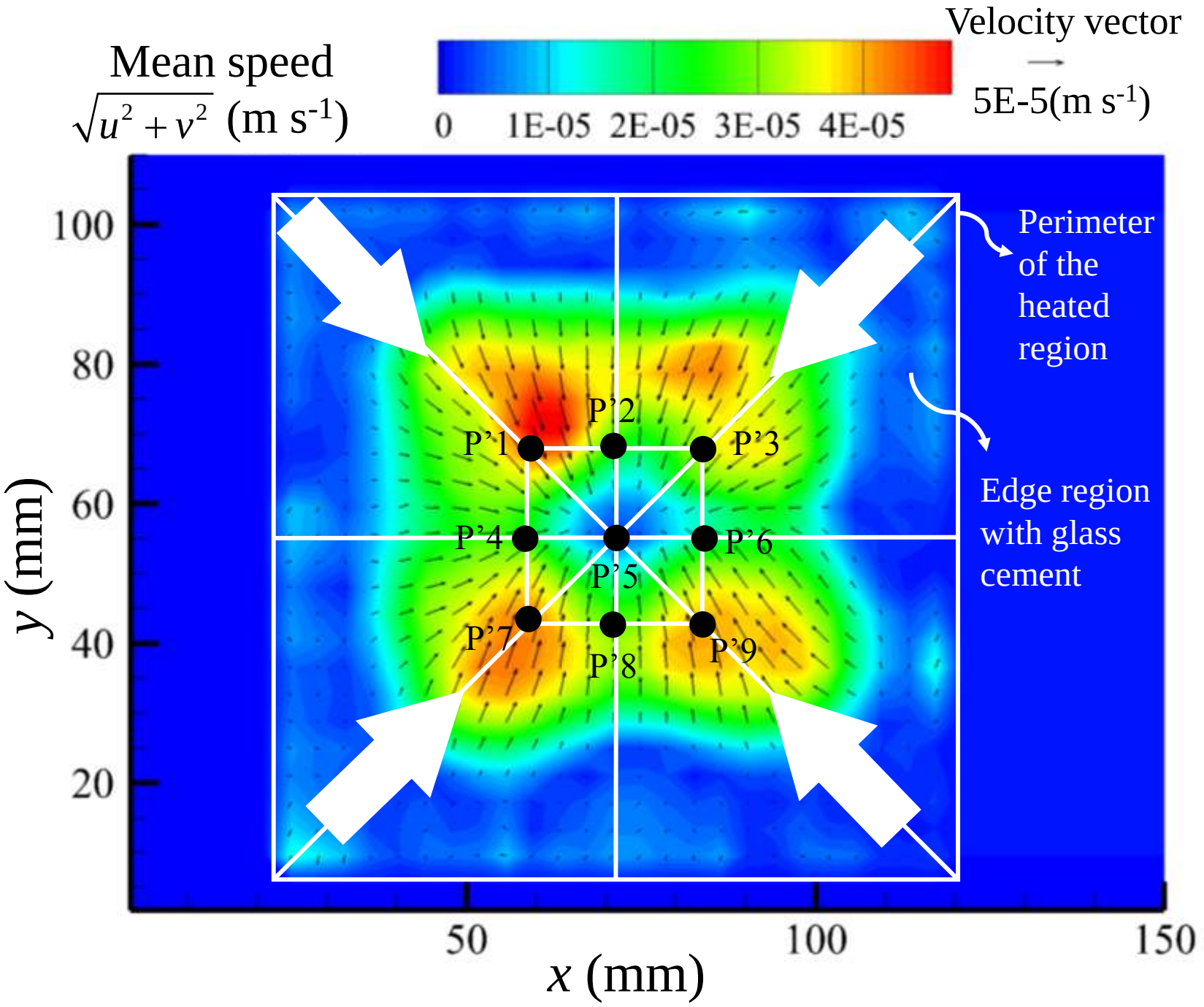

High speed camera
Large water tank
Salt water surface
110 cm
Laser sheet on horizontal plane
z
Copper plate and heater
10cm
y
120 cm
x
120 cm


High speed camera
Large water tank
Salt water surface
110 cm
Laser sheet on horizontal plane
z
y
x
Copper plate and heater
10 cm
120 cm
120 cm


Mean speed
$\sqrt{u^2 + w^2}$ (m s^{-1})
0
0.0003
0.0006
0.0009
0.0012
0.0015
Velocity vector
0.002 (m s^{-1})
0.5 cm above the ground
Large water tank
Copper plate and heater
120 cm
600
400
200
0
y (mm)
0
200
400
600
800
1000
x (mm)


Mean speed
$\sqrt{u^2+w^2}$ (m s^{-1})
0
0.0008
0.0016
0.0024
Velocity vector
0.004 (m s^{-1})
0.5cm above the ground
600
400
200
0
0
200
400
600
800
y (mm)
x (mm)

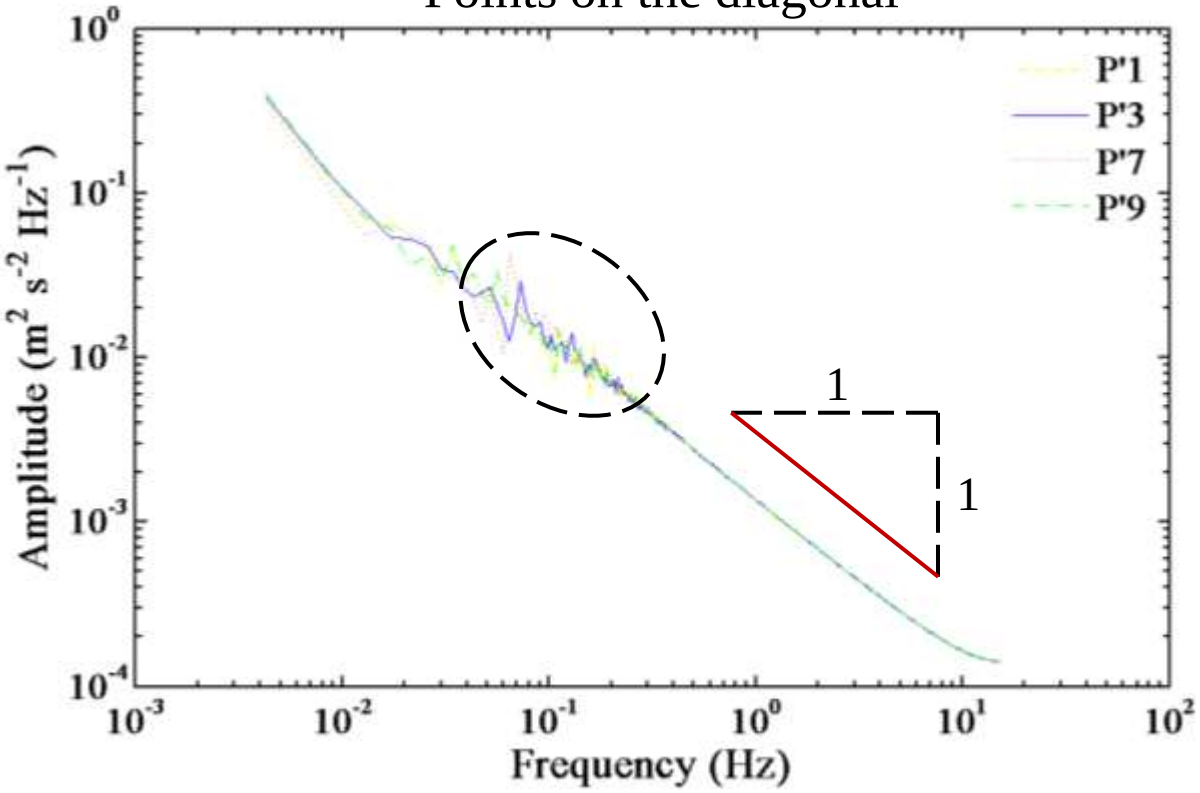
Heat transfer analysis


Mean speed
$\sqrt{u^2+v^2}$ (m s^{-1})
0
1E-05
2E-05
3E-05
4E-05
Velocity vector
5E-5(m s^{-1})
Perimeter of the heated region
Edge region with glass cement
P'1
P'2
P'3
P'4
P'5
P'6
P'7
P'8
P'9
100
80
60
40
20
y (mm)
50
100
150
x (mm)

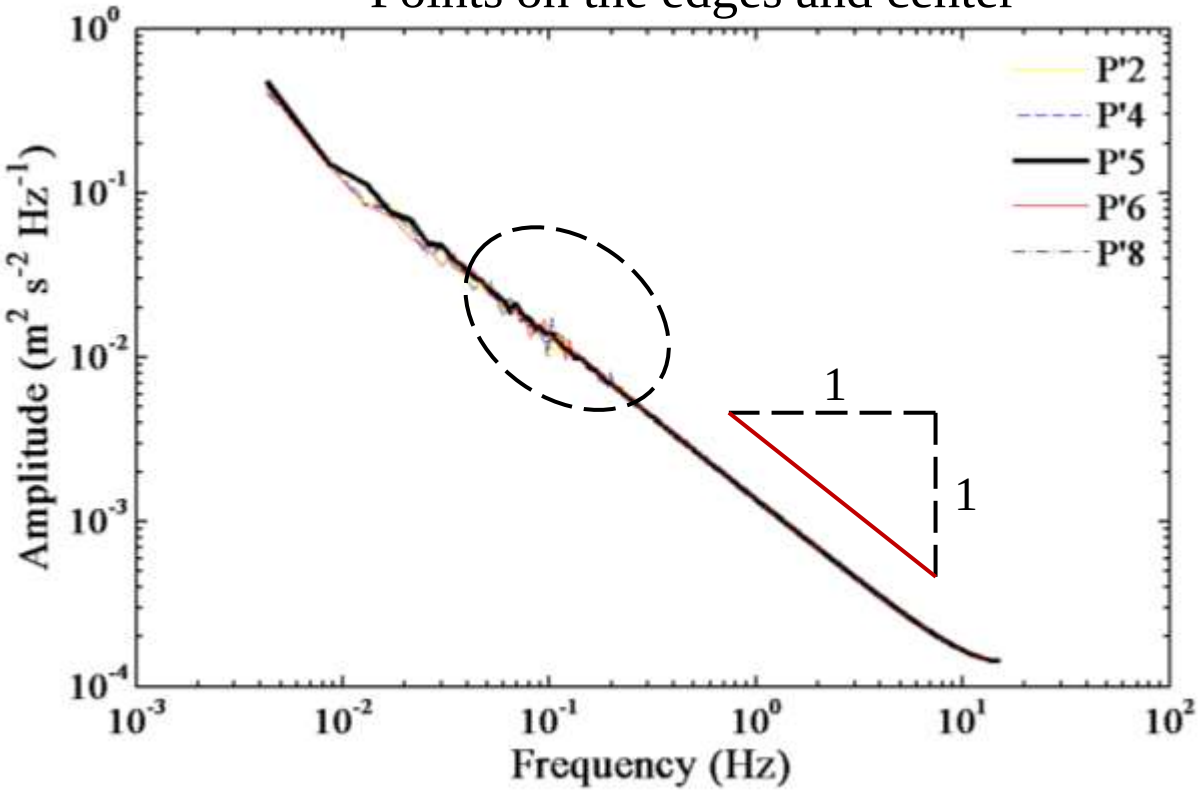
Results – energy spectrum

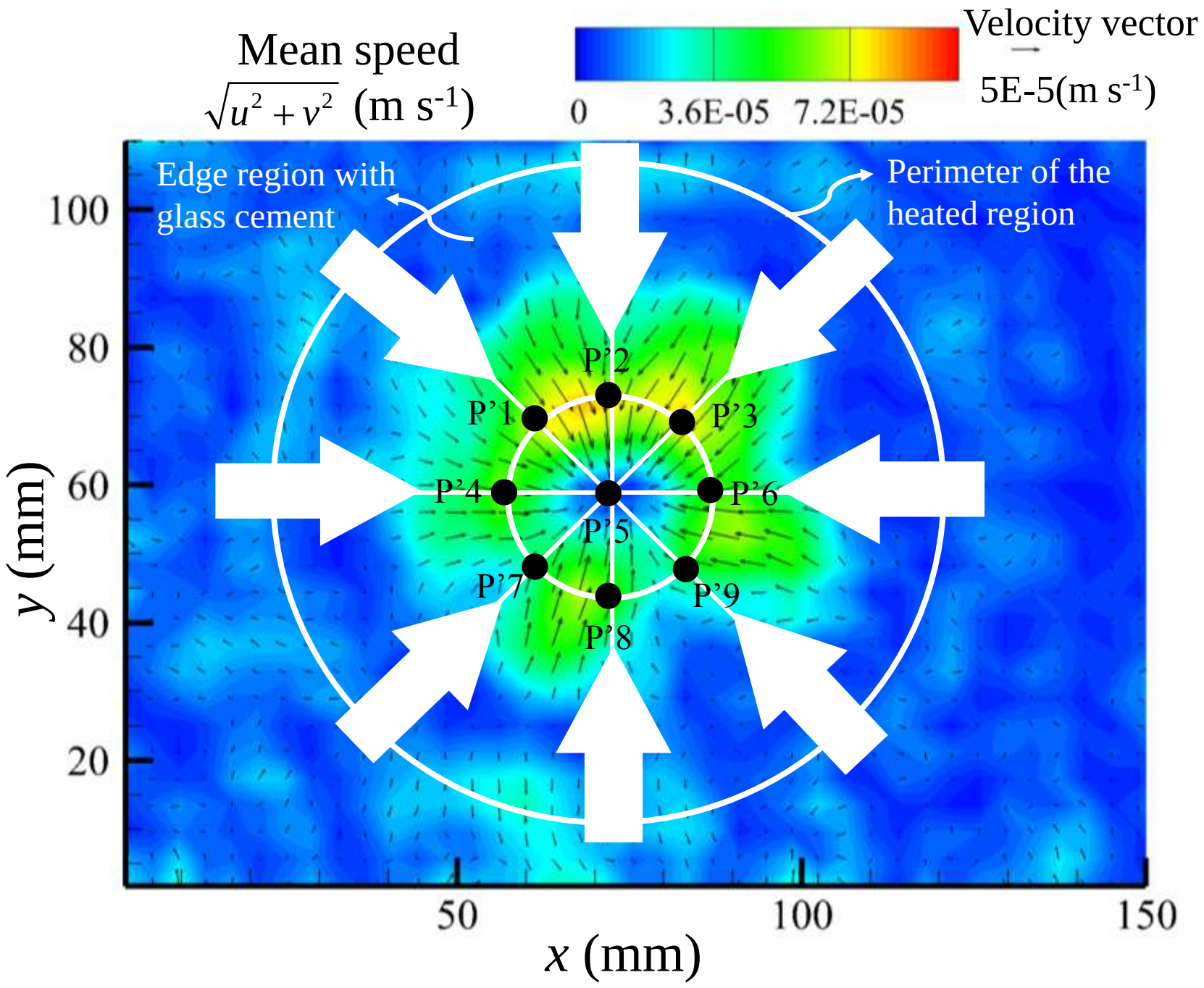
Square Steady

Points on the diagonal



Points on the edges and center

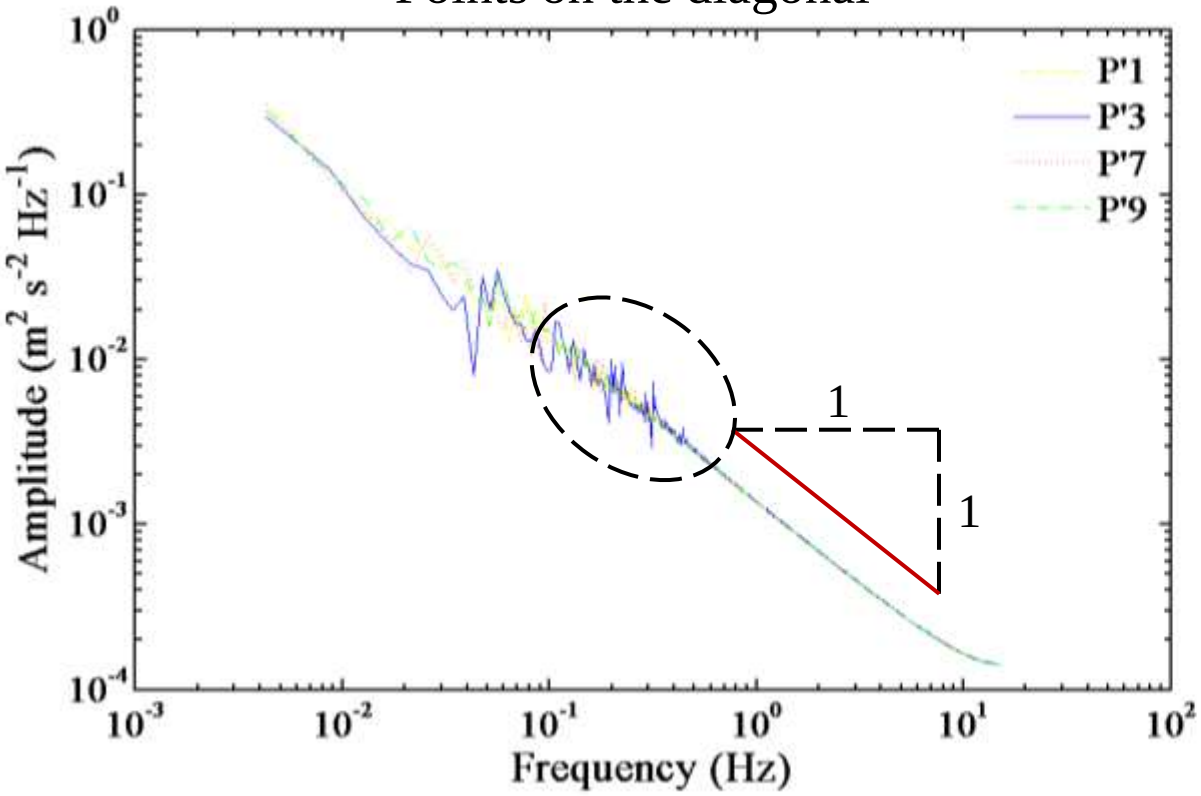



Mean speed
$\sqrt{u^2+v^2}$ (m s-1)
0
3.6E-05
7.2E-05
Velocity vector
5E-5(m s-1)
Edge region with glass cement
Perimeter of the heated region
P'1
P'2
P'3
P'4
P'5
P'6
P'7
P'8
P'9
100
80
60
40
20
y (mm)
50
100
150
x (mm)

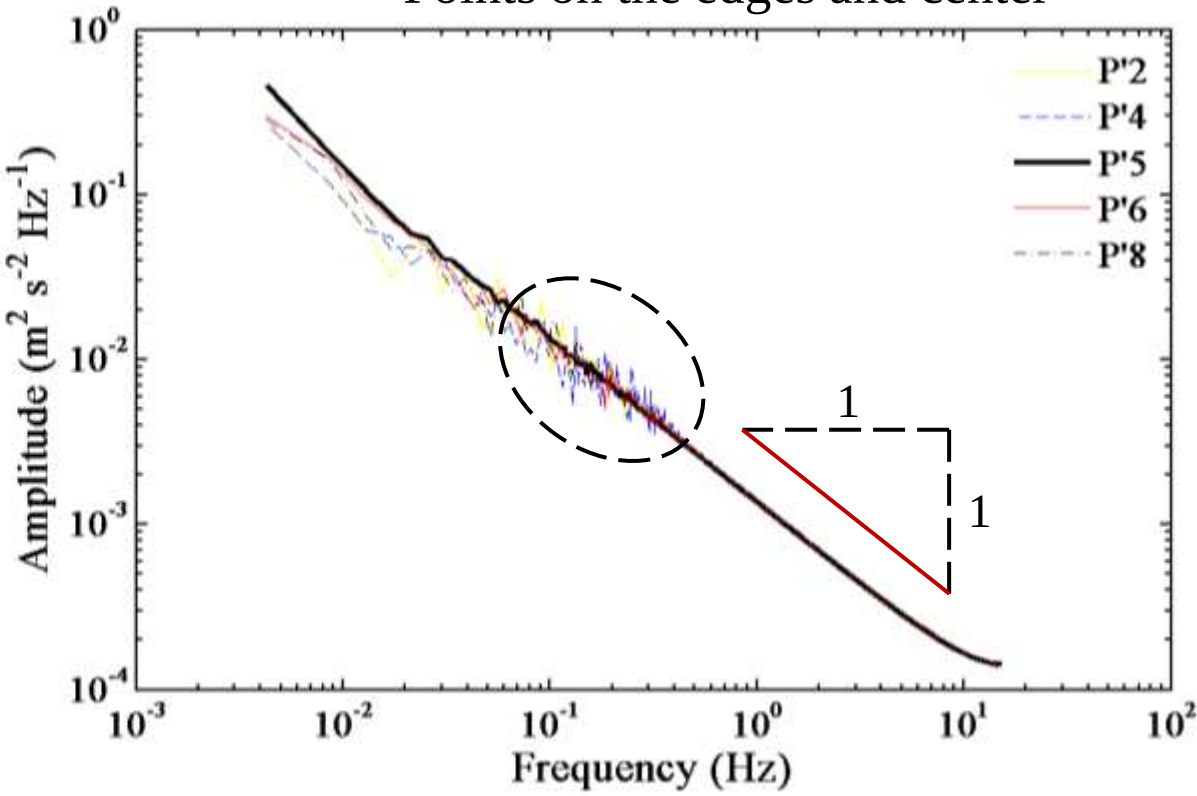
Results – energy spectrum

Circular Steady

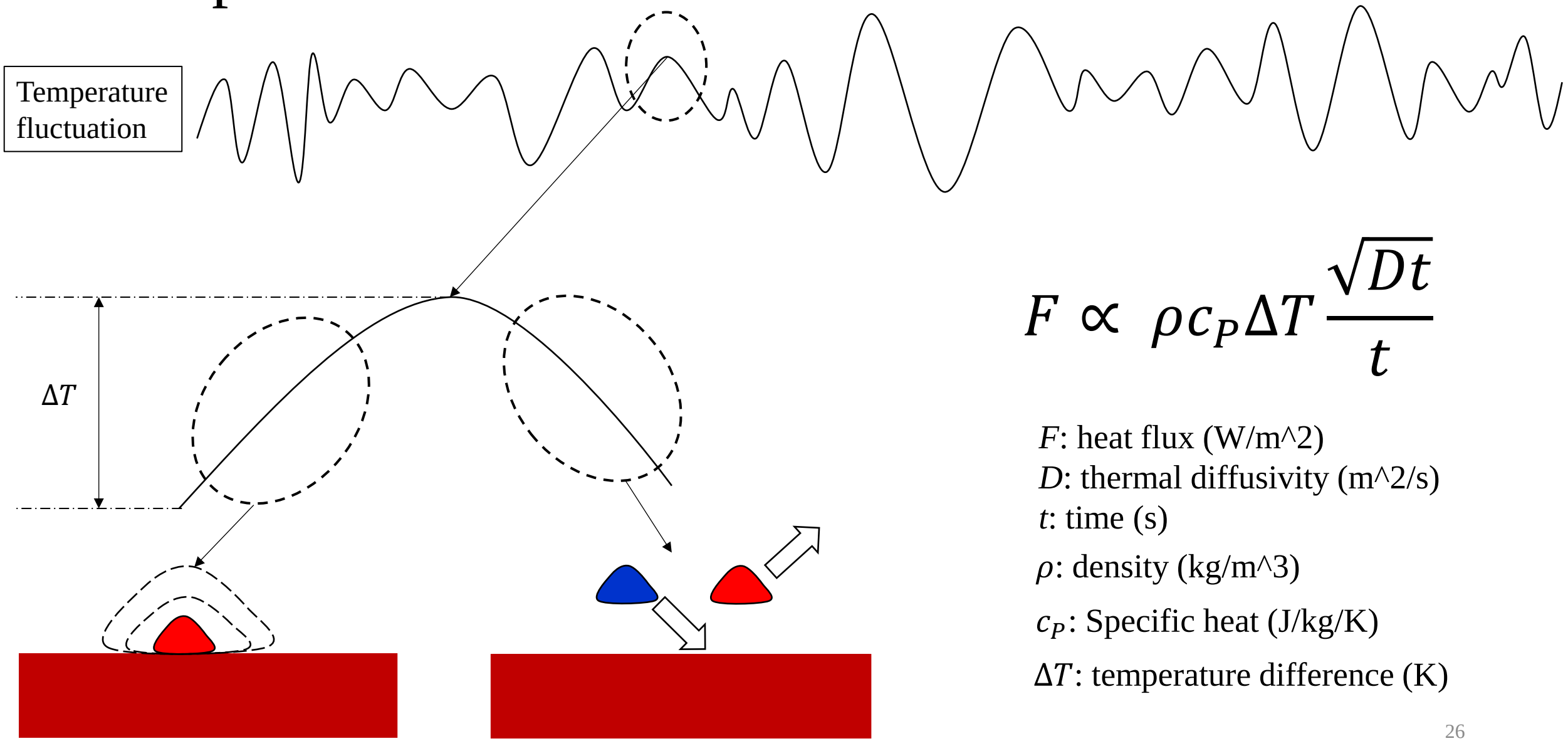
Points on the diagonal



Points on the edges and center



Principle-heat flux calculation

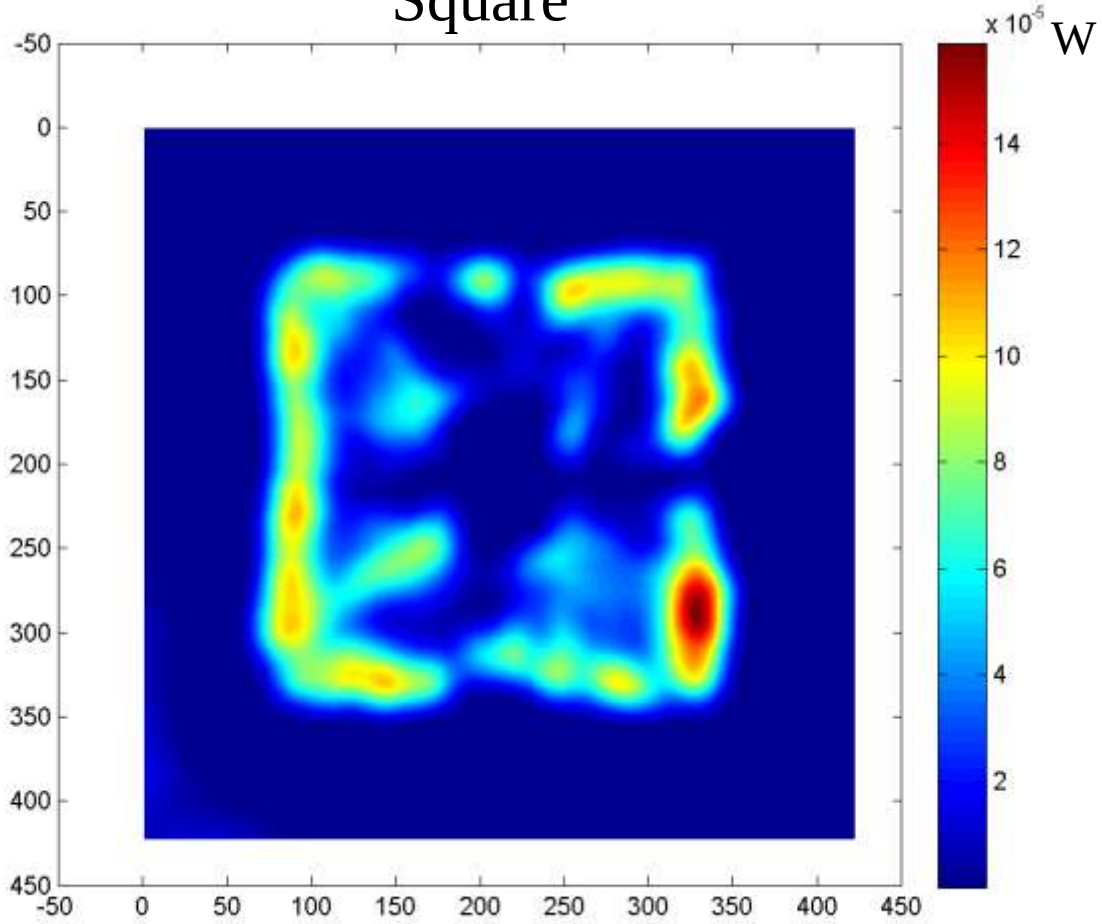


$$F \propto \rho c_P \Delta T \frac{\sqrt{Dt}}{t}$$

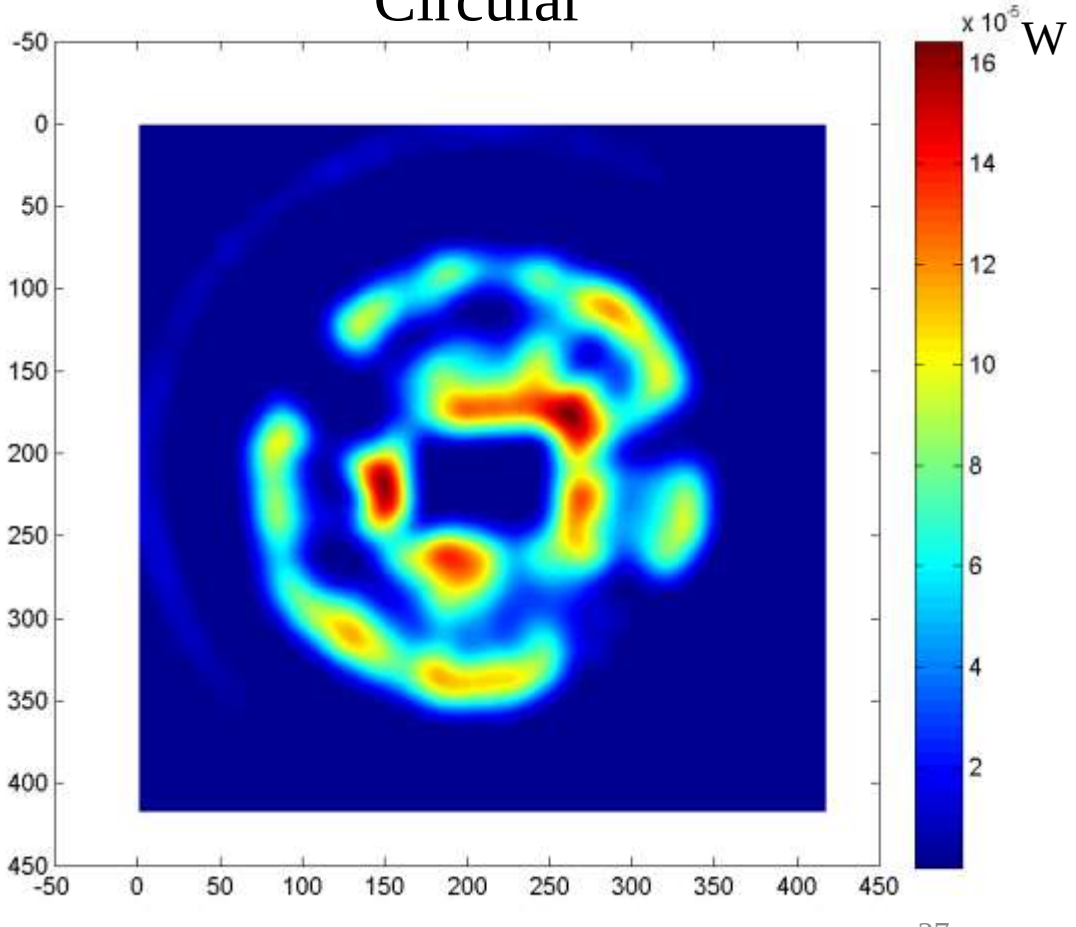
F: heat flux (W/m^2)
D: thermal diffusivity (m^2/s)
t: time (s)
ρ: density (kg/m^3)
c_P: Specific heat (J/kg/K)
ΔT: temperature difference (K)

Results – heat flux distribution

Square



Circular



Advantages

Non-intrusive

Whole field

Heat flux distribution

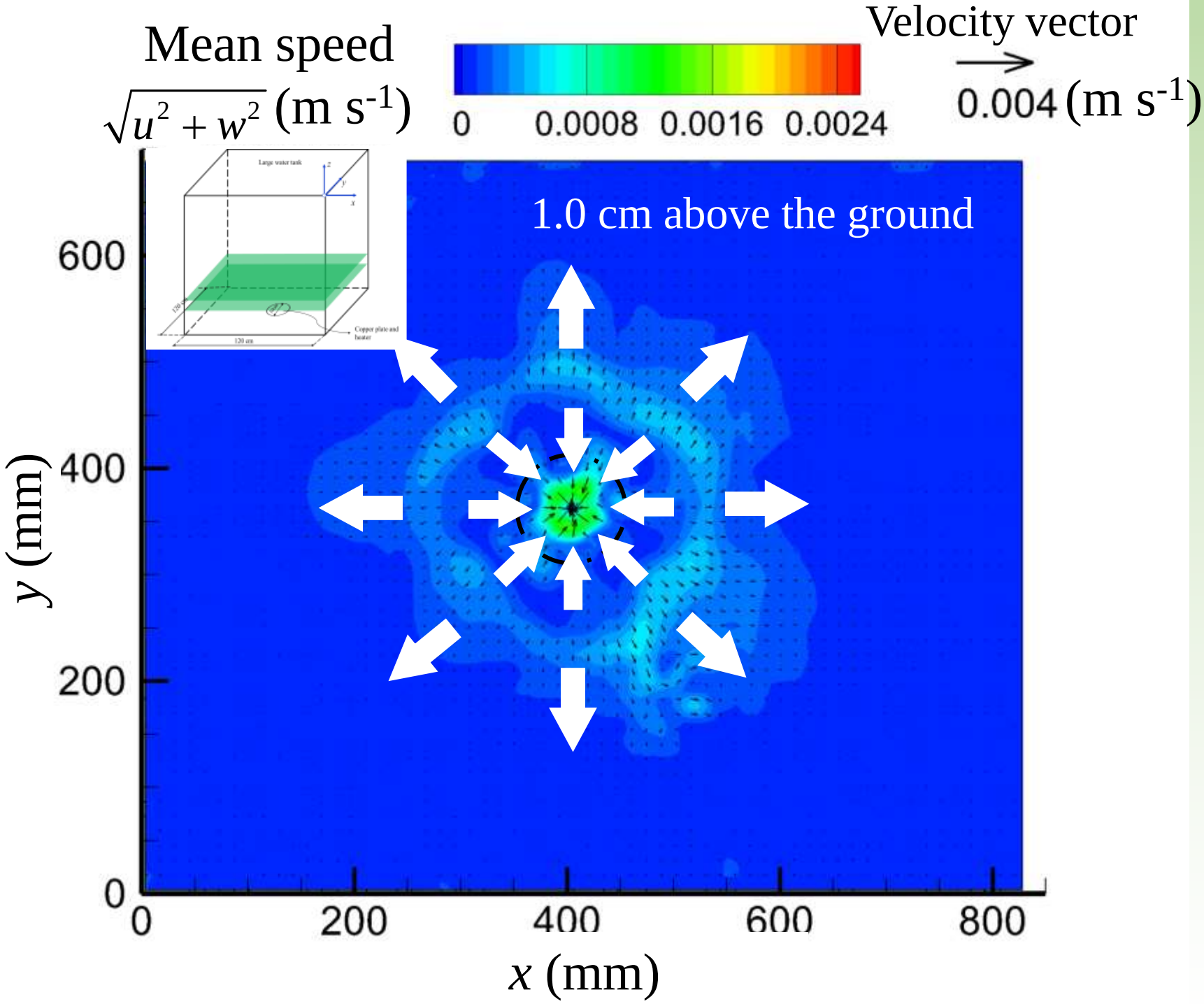
Disadvantages or improvement in the future

Time and space resolution (Only large eddy can penetrate the ‘ground’ and be visualized)

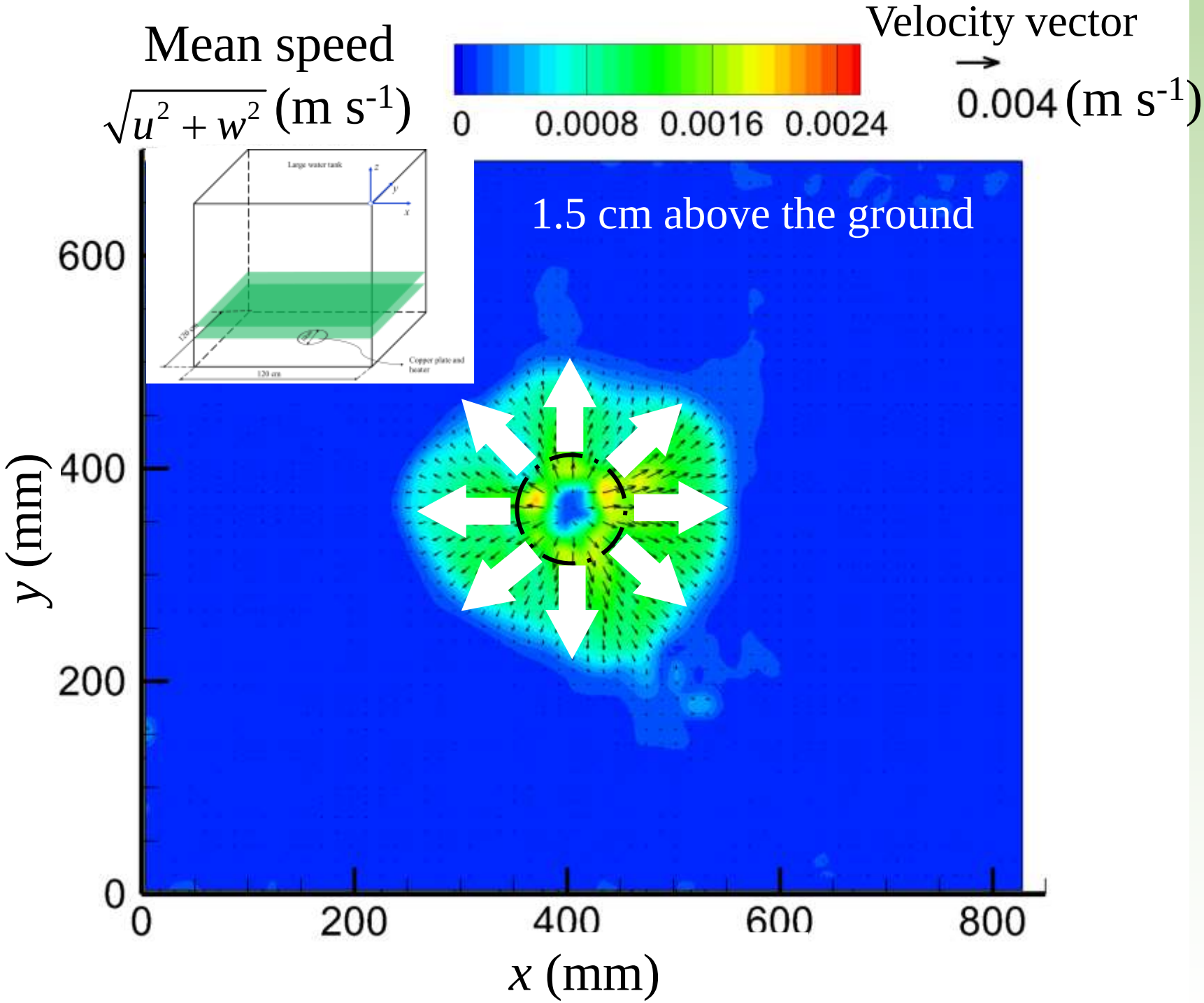
Calibration may range from situation - need further study.

Thank you

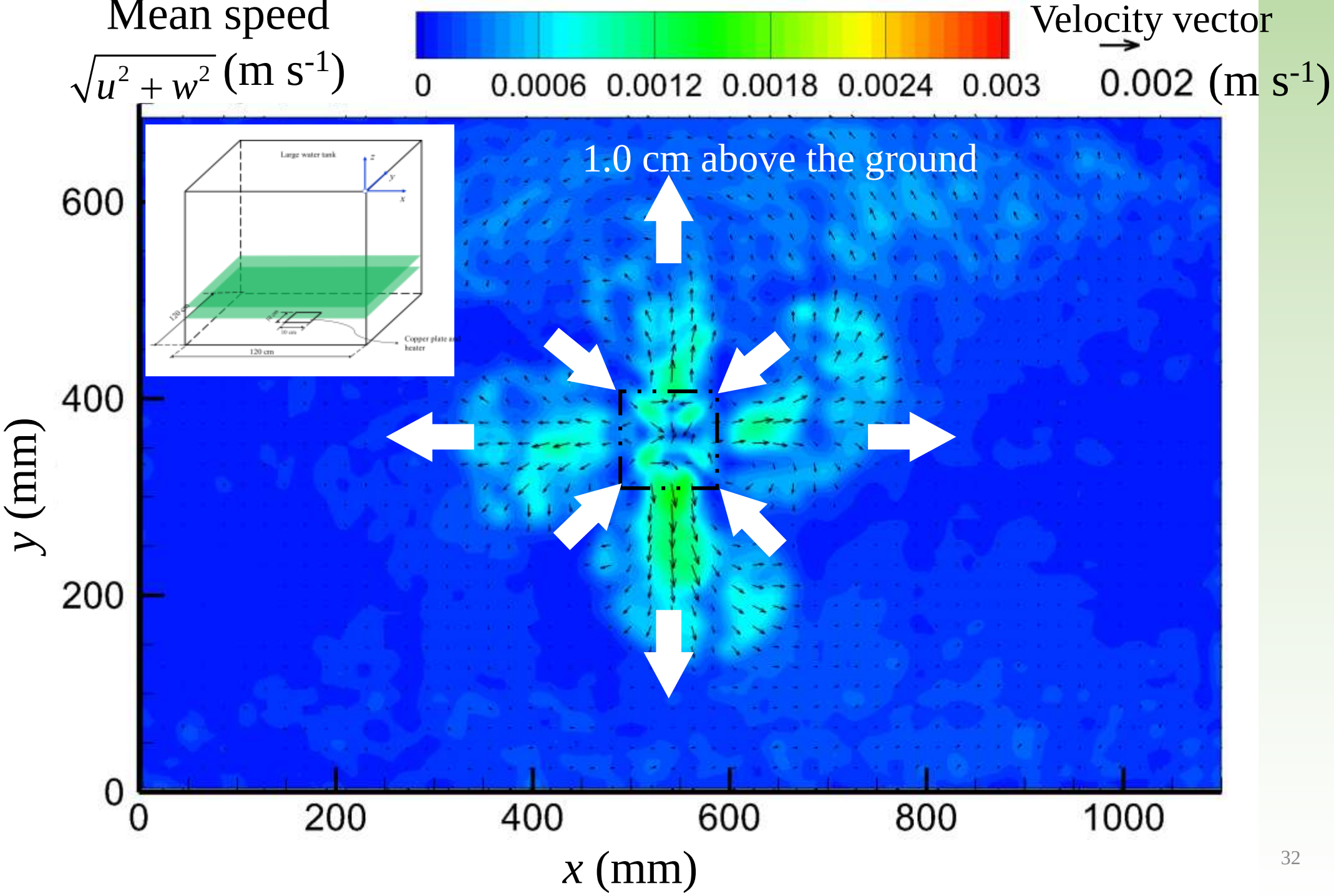
Case64 1.0cm


Mean speed
$\sqrt{u^2+w^2}$ (m s^{-1})
0
0.0008
0.0016
0.0024
Velocity vector
0.004 (m s^{-1})
1.0 cm above the ground
600
400
200
0
0
200
400
600
800
y (mm)
x (mm)

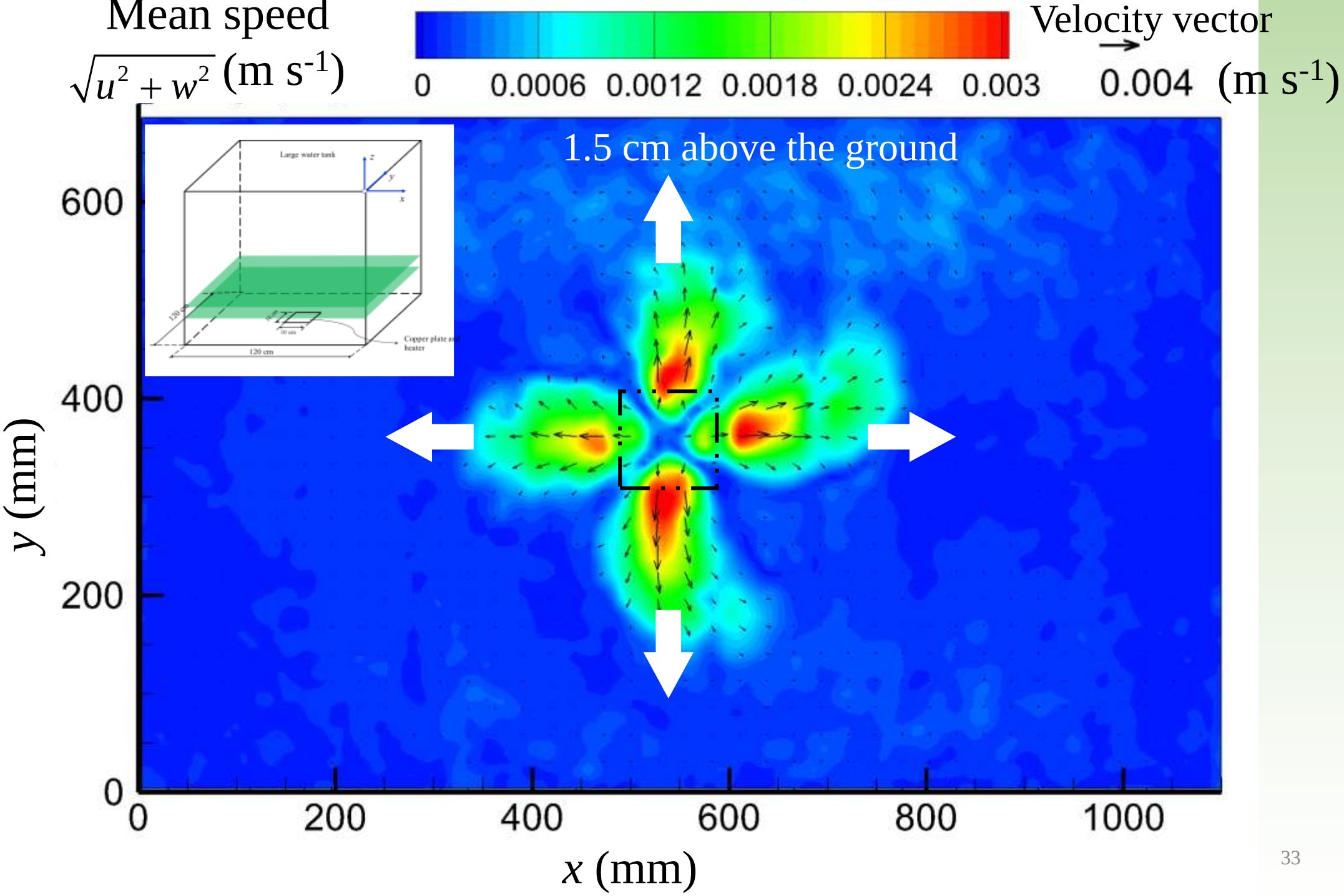
Case64 1.5cm

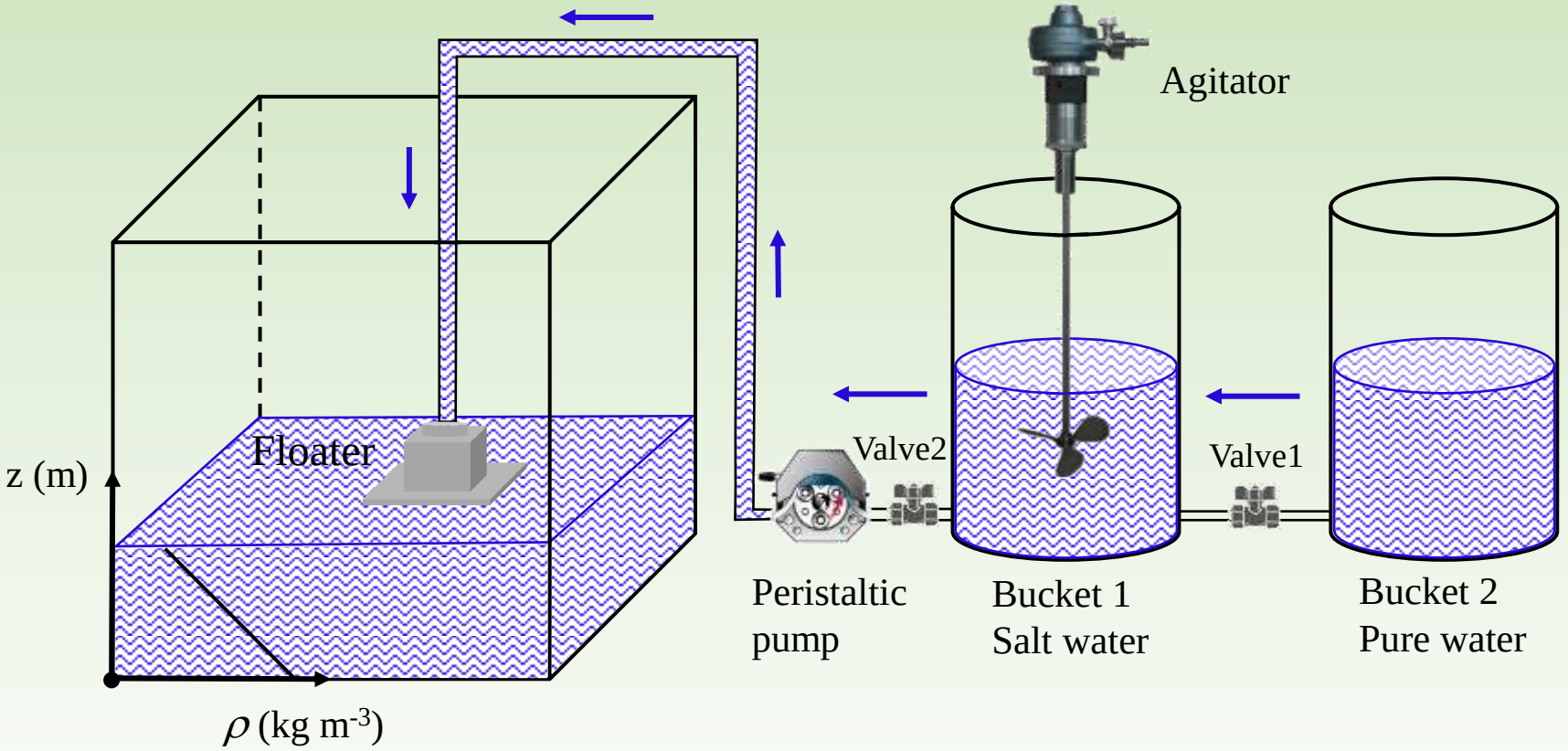

Mean speed
$\sqrt{u^2+w^2}$ (m s^{-1})
0
0.0008
0.0016
0.0024
Velocity vector
0.004 (m s^{-1})
1.5 cm above the ground
Large water tank
Copper plate and heater
120 cm
600
400
200
0
y (mm)
0
200
400
600
800
x (mm)

9 1.0cm


Mean speed
$\sqrt{u^2+w^2}$ (m s^{-1})
0
0.0006
0.0012
0.0018
0.0024
0.003
Velocity vector
0.002 (m s^{-1})
1.0 cm above the ground
Large water tank
Copper plate and heater
120 cm
600
400
200
0
y (mm)
0
200
400
600
800
1000
x (mm)

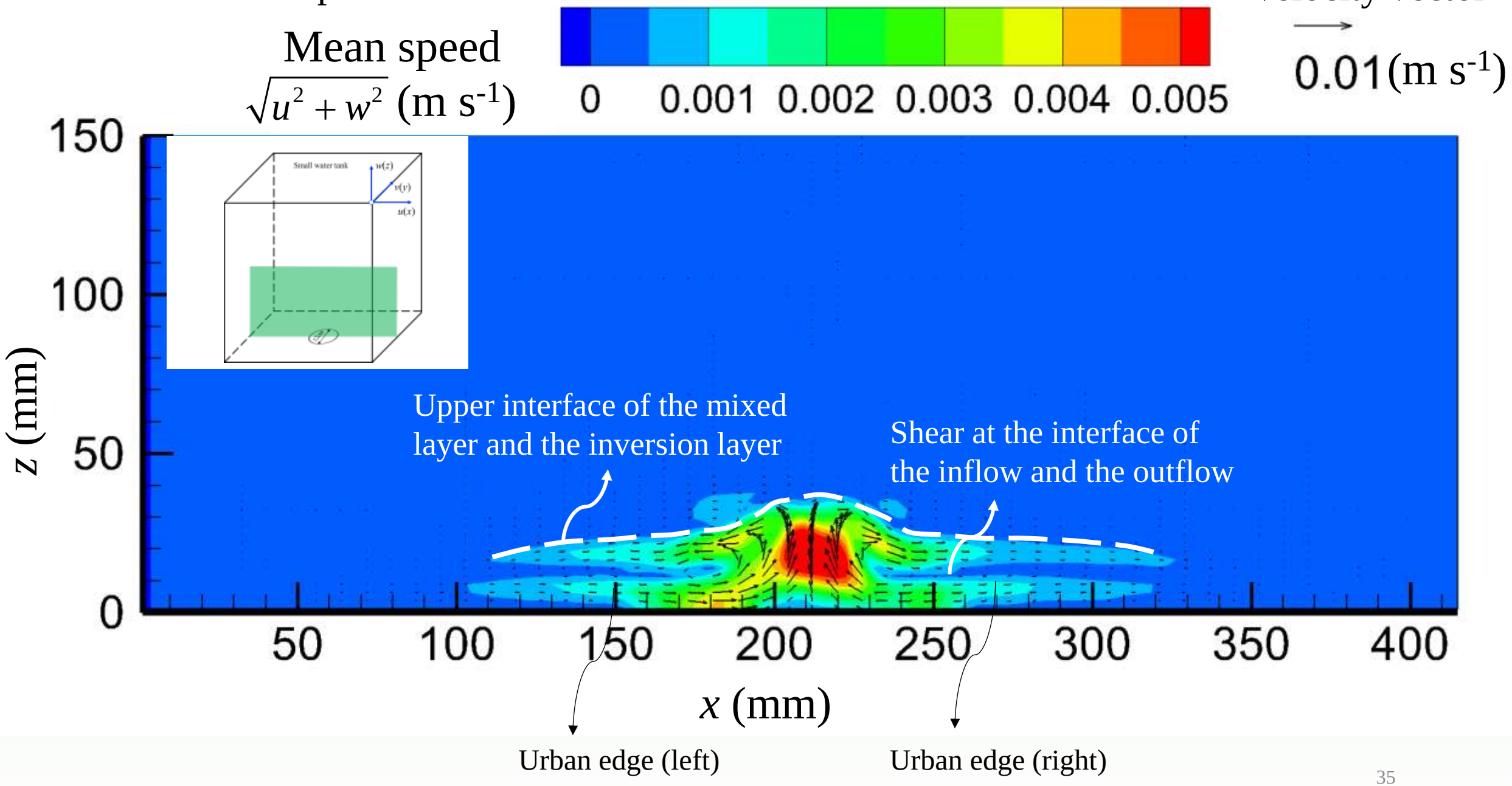
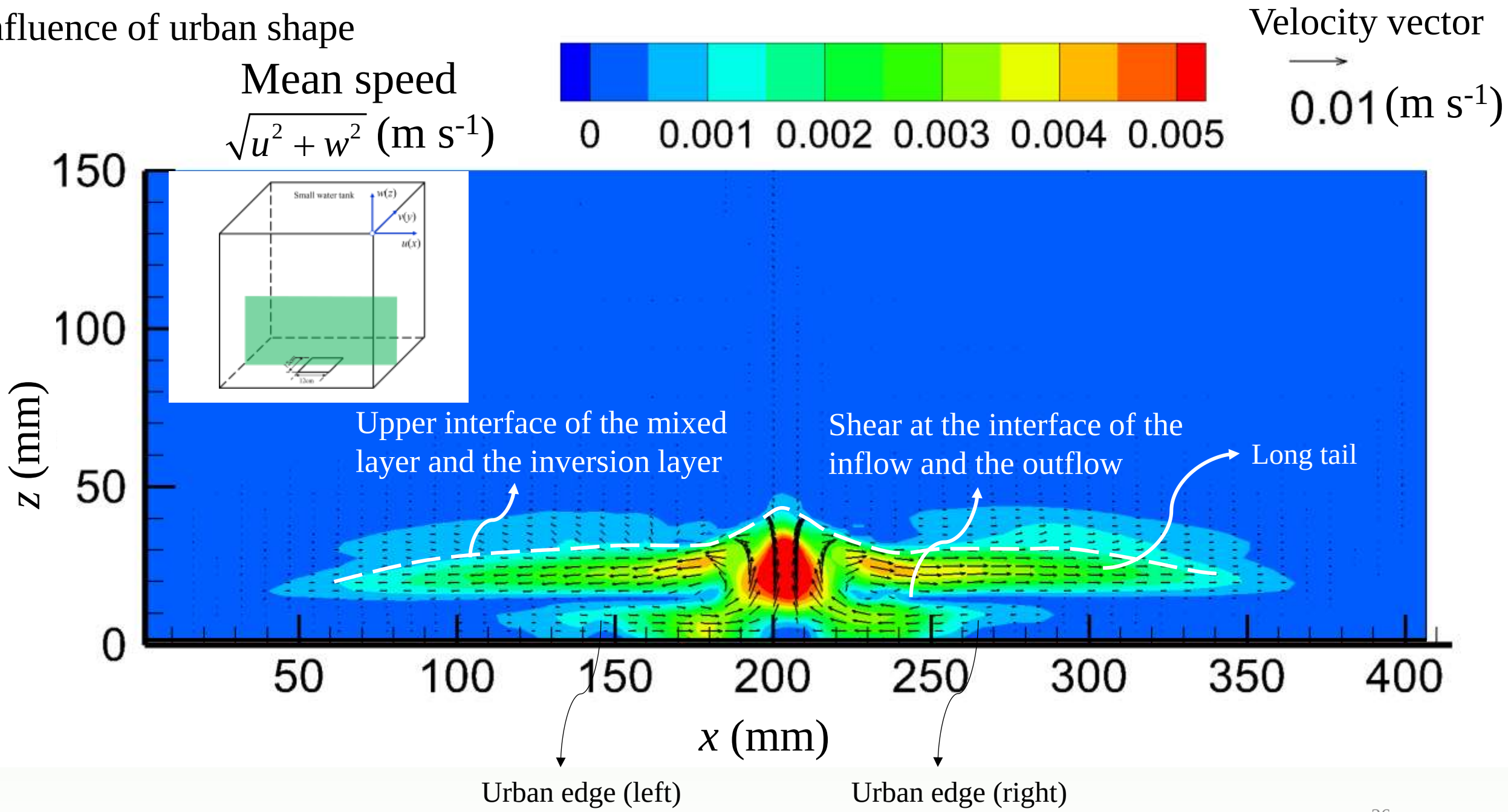
e59 1.5cm


Mean speed
$\sqrt{u^2+w^2}$ (m s^{-1})
0
0.0006
0.0012
0.0018
0.0024
0.003
Velocity vector
0.004 (m s^{-1})
1.5 cm above the ground
Large water tank
Copper plate and heater
120 cm
600
400
200
0
y (mm)
0
200
400
600
800
1000
x (mm)



Experiment water tank with linear stratified salt water

Influence of urban shape



Influence of urban shape