Surface Freshwater Plumes Contributing to the Formation of the Barrier Layer and Salinity Fronts

Alexander Soloviev[a,b], Silvia Matt[c], Atsushi Fujimura[b]

[a]*Nova Southeastern University Oceanographic Center, Dania Beach, FL, USA*

[b]*Rosenstiel School of Marine & Atmospheric Science, Miami, FL, USA*

[c]*Naval Research Laboratory, Stennis Space Center, MS, USA*

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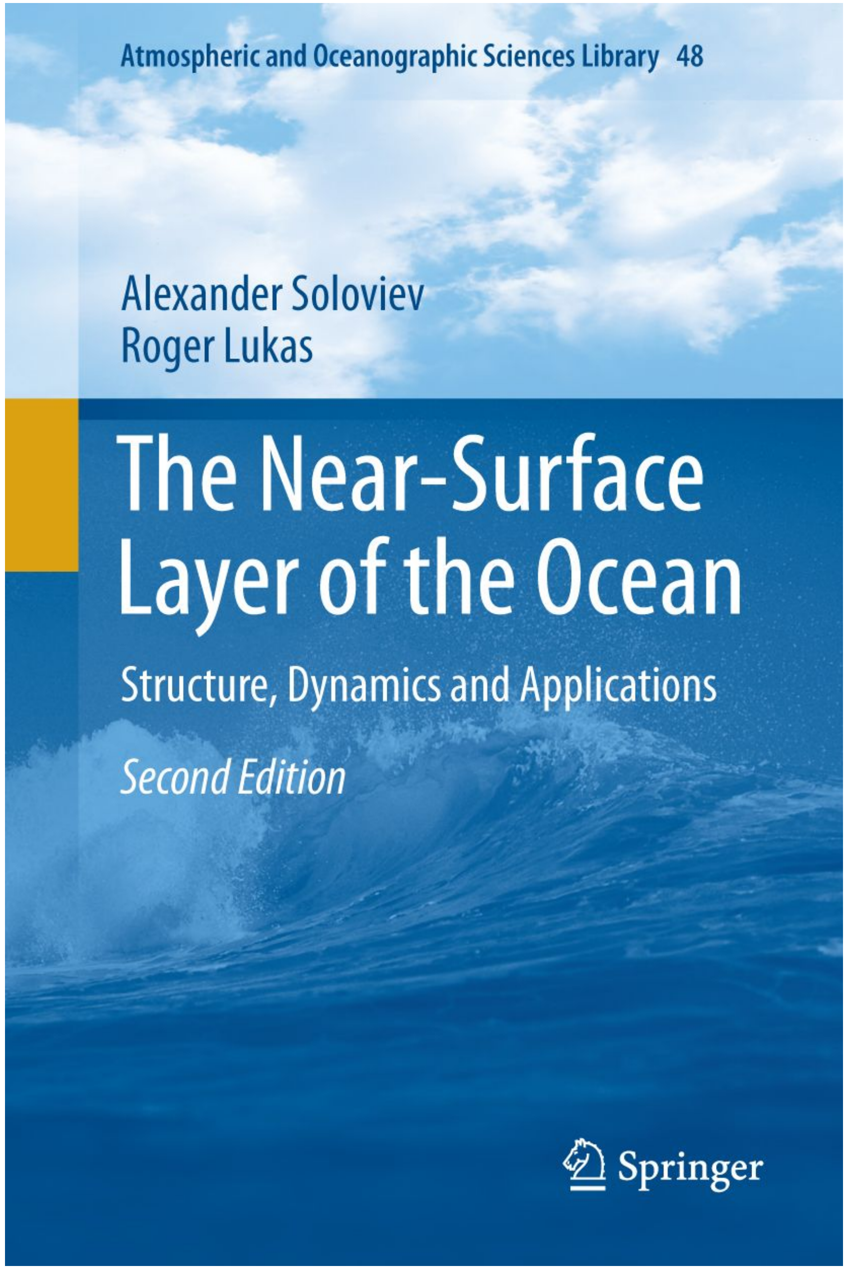
Introduction

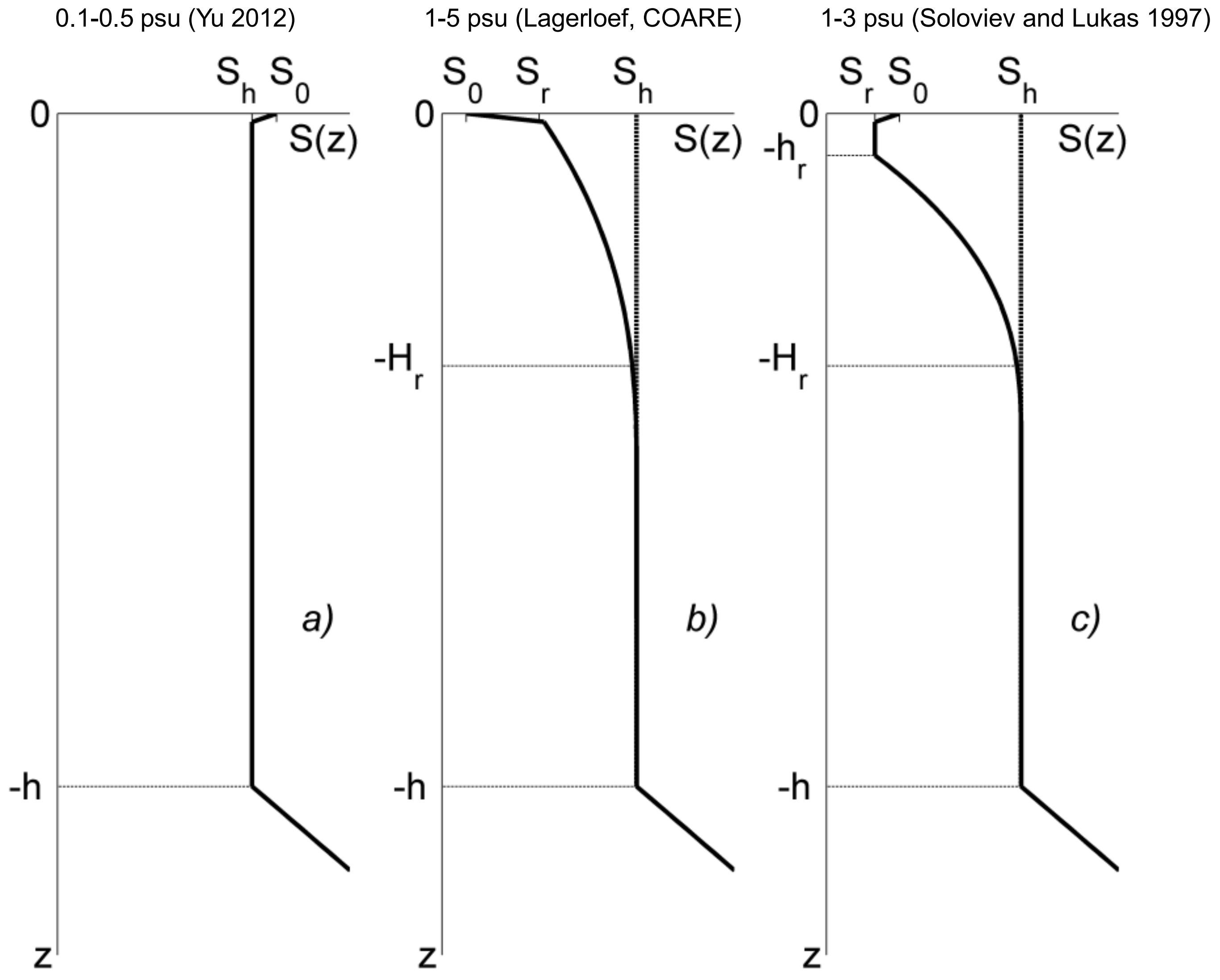
Dynamics of freshwater lenses:

- can be linked to the formation of larger scale features (e.g., barrier layer, fronts)
- thus influencing the large scale processes
- and contributing to the salinity field in the Aquarius and SMOS satellite footprints

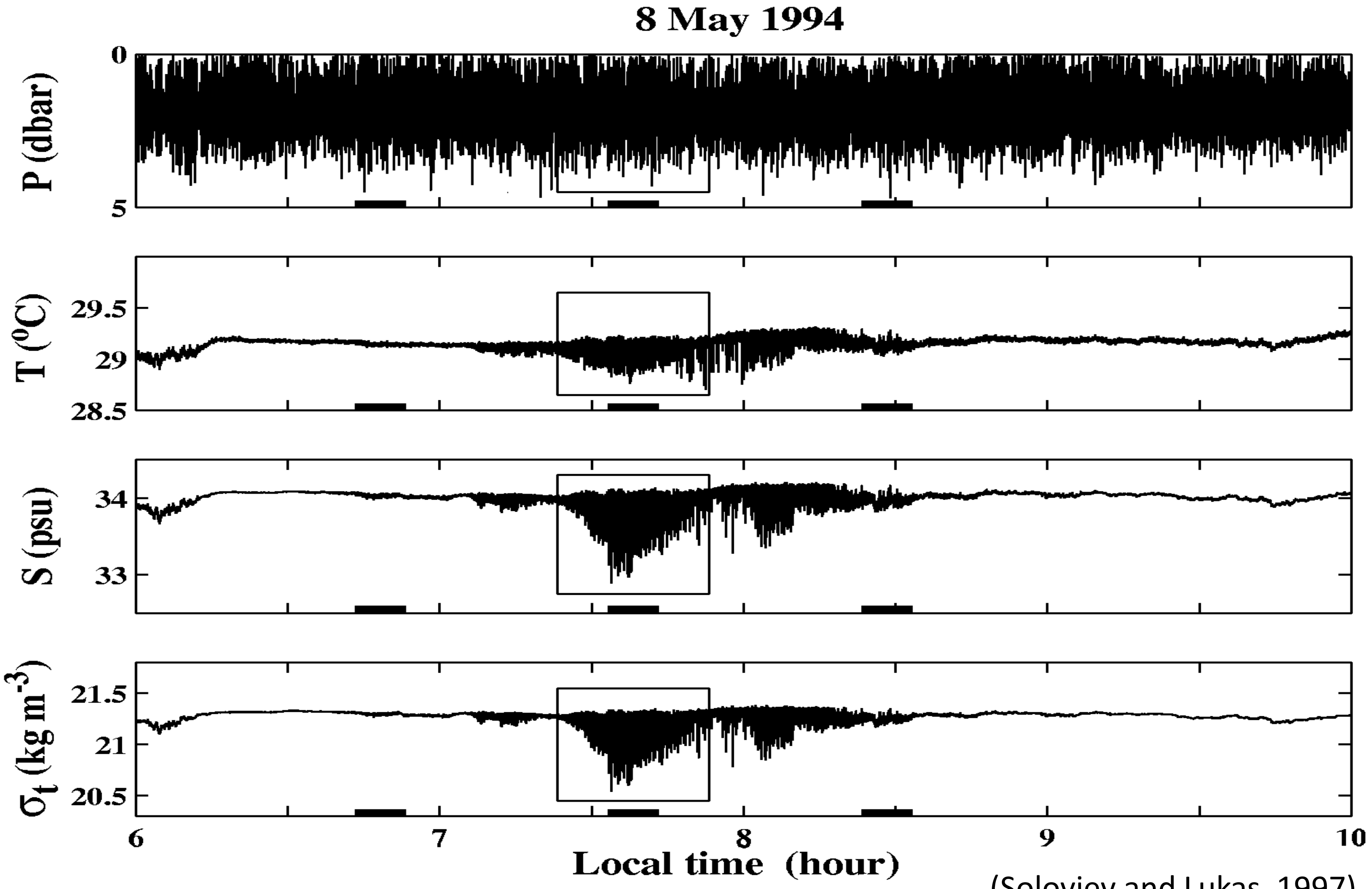
Substantial work on studying freshwater lenses was initiated by Roger Lukas and colleagues during TOGA COARE (Soloviev and Lukas 2014)

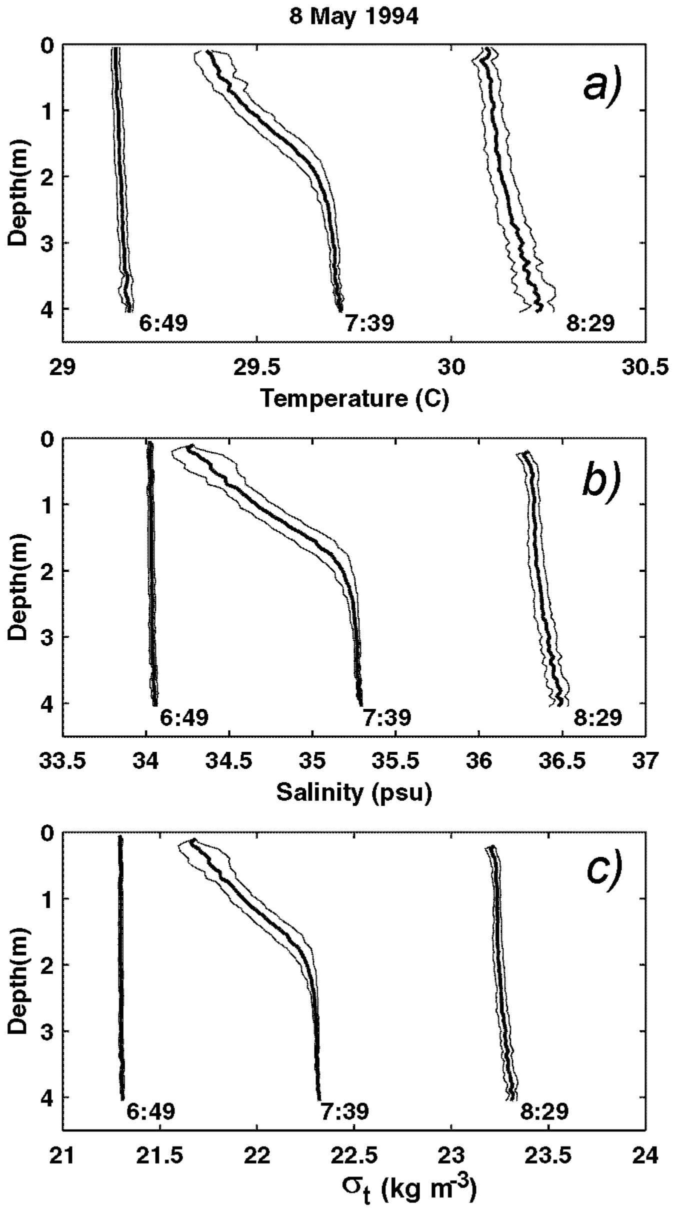


Vertical structure of salinity (no diurnal warming)



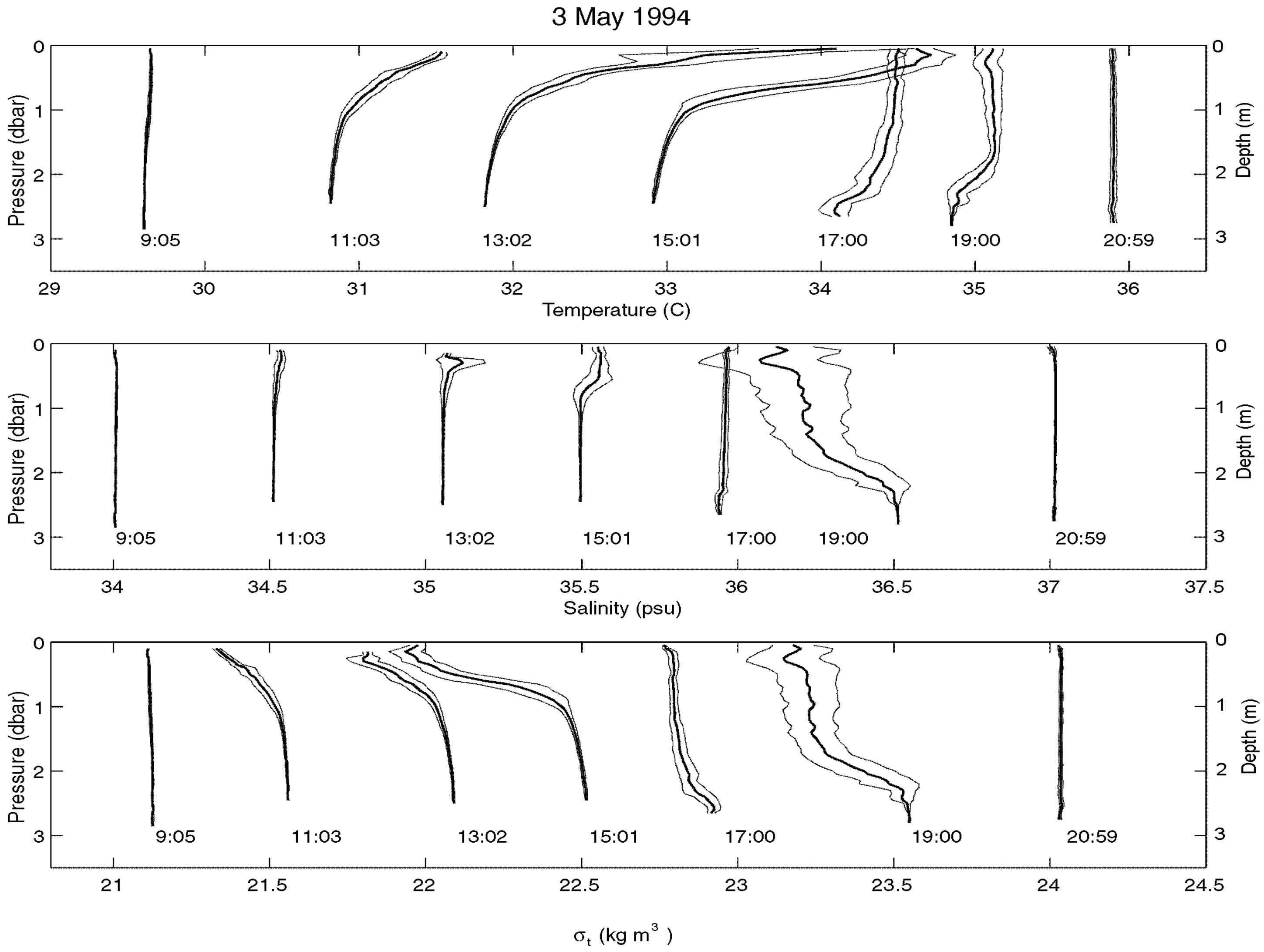
Freshwater plume observed during TOGA COARE (no substantial diurnal warming)





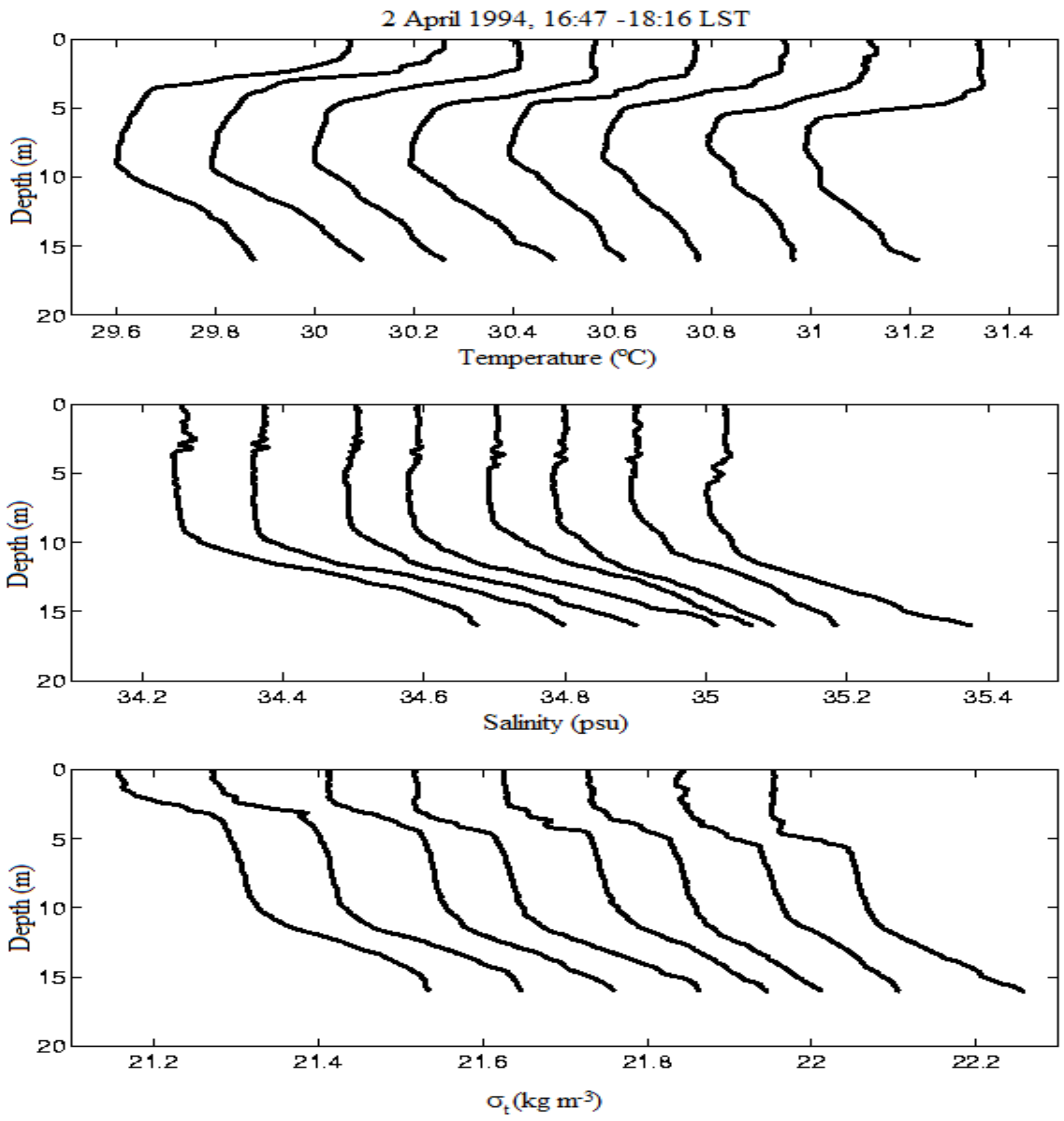
(Soloviev and Lukas, 1997)

Combined effect of diurnal warming and rain



(Soloviev and Lukas, 1997)

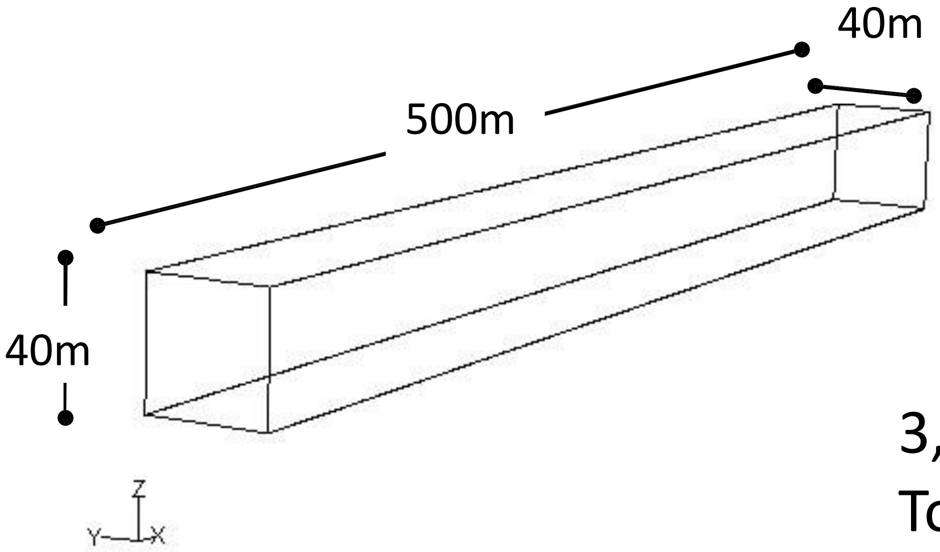
Rain-formed plume, Nighttime Cooling and Diurnal Warming



(Soloviev and Lukas, 1997)

Each successive profile is shifted by 0.2^{o}C for temperature, 0.1 psu for salinity and 0.1 kgm^{-3} for density

Numerical domain for simulation of freshwater plume

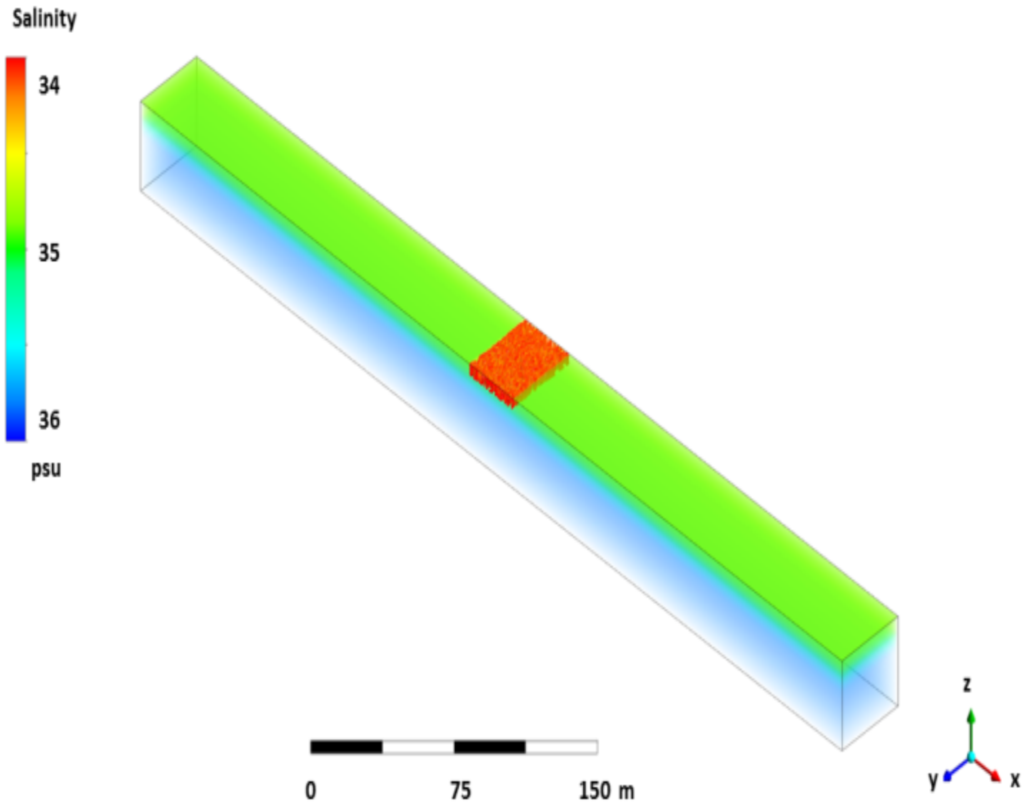


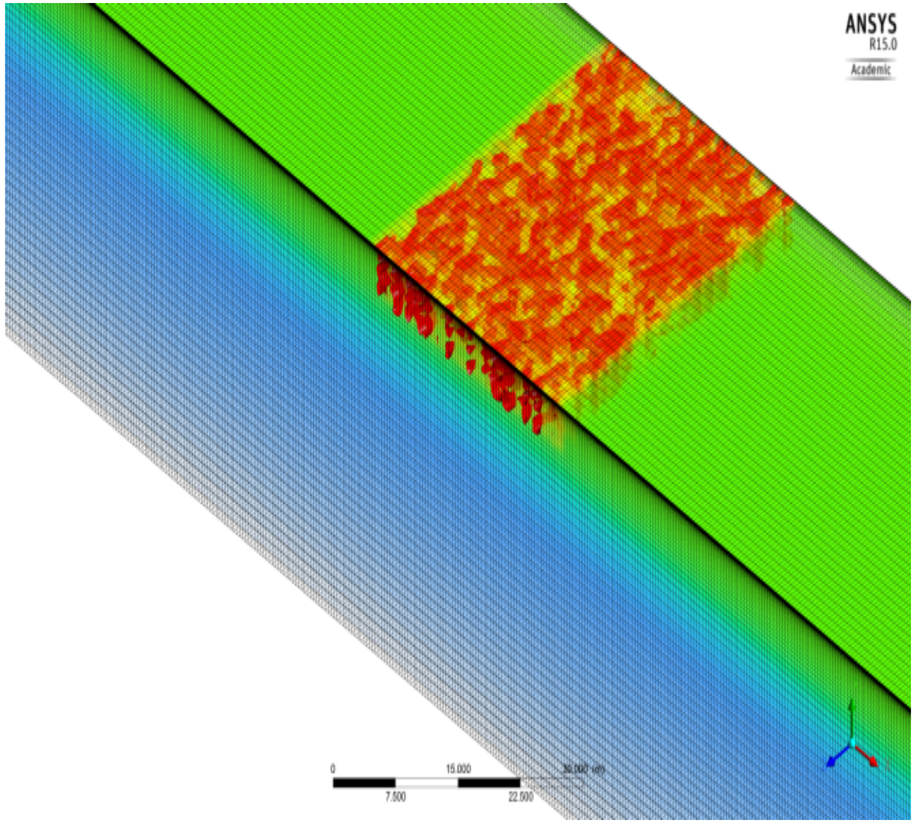
3,120,000 cells
Top cell Δz = 1 cm
Longitudinal spacing Δx = 50 cm
Lateral spacing Δy = 1 m

Matt et al. (2014)

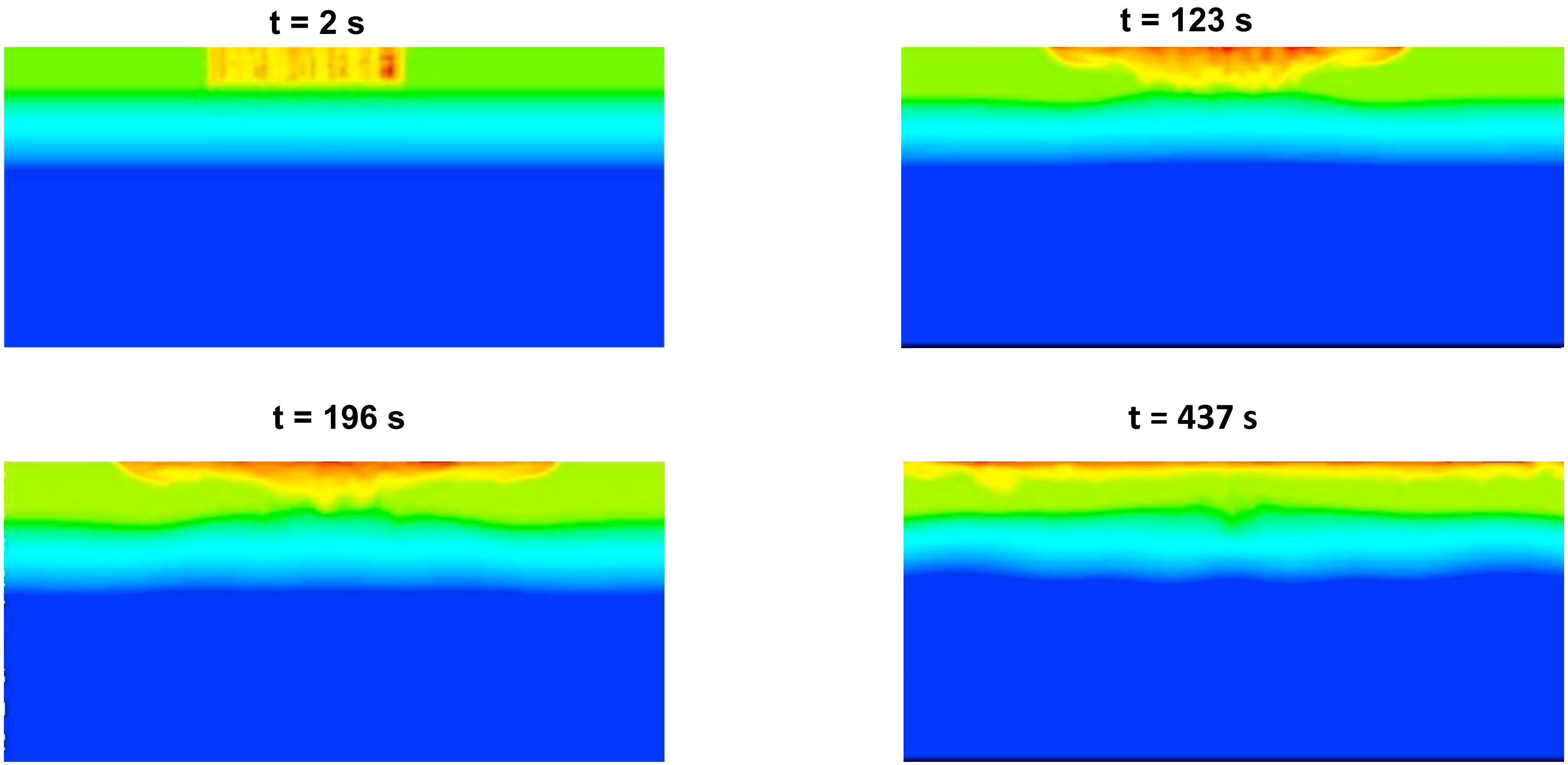
Interaction of Freshwater Lens with Environmental Stratification

Model domain for simulation of freshwater plume

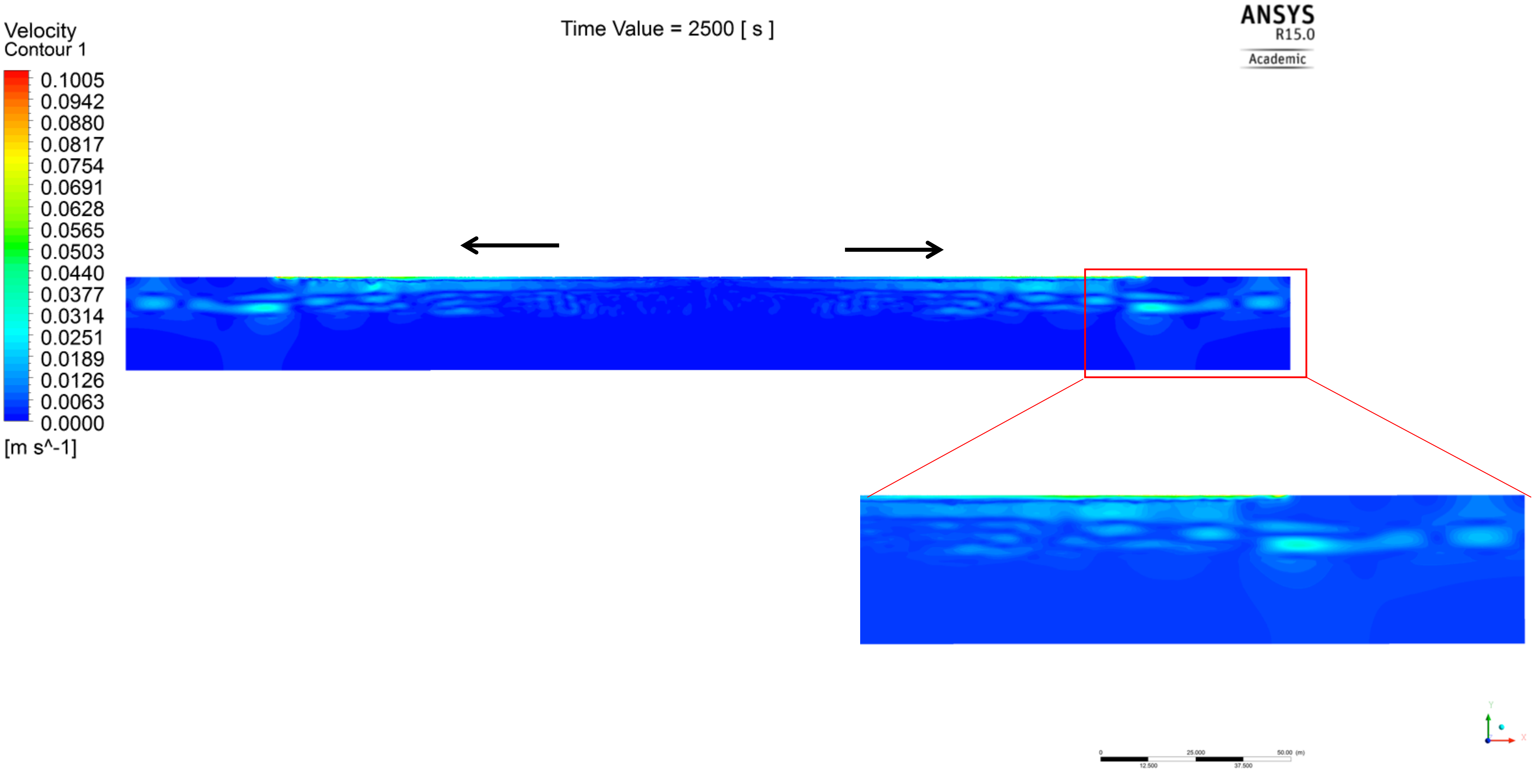




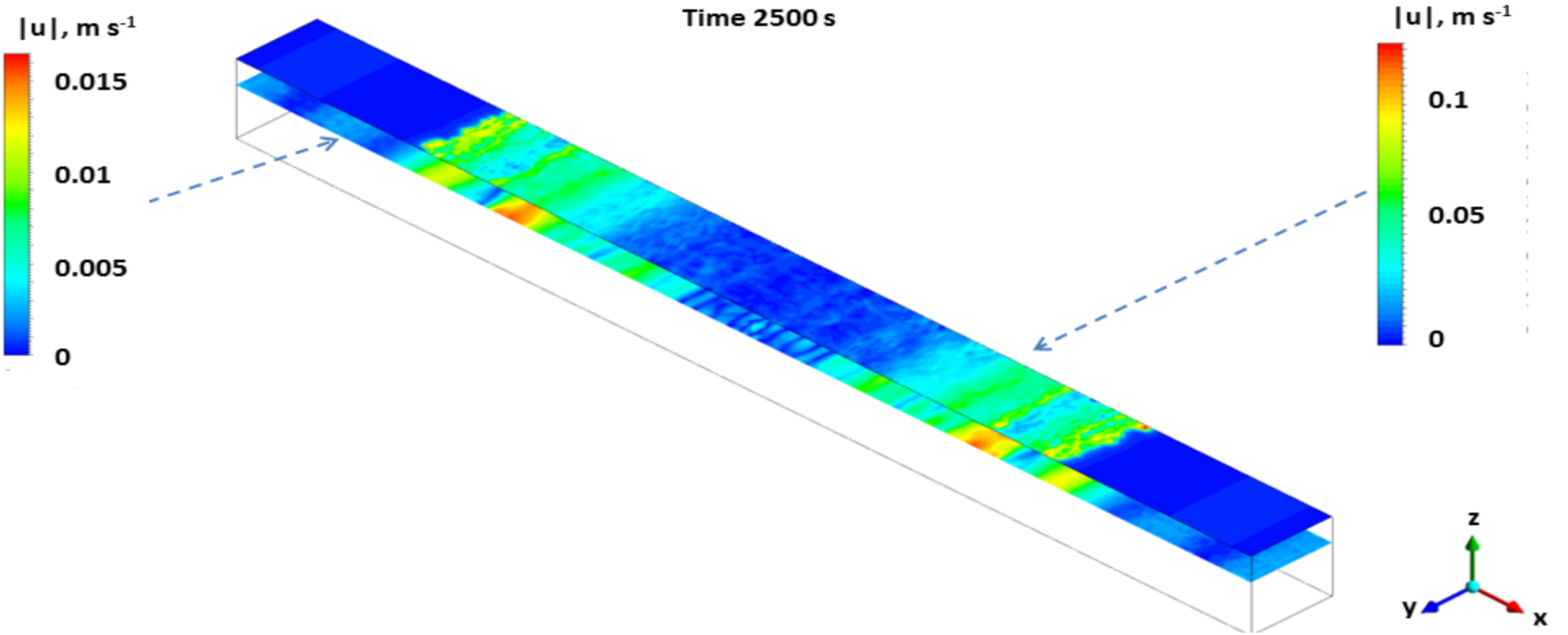
Freshwater lens spreading in the stratified environment

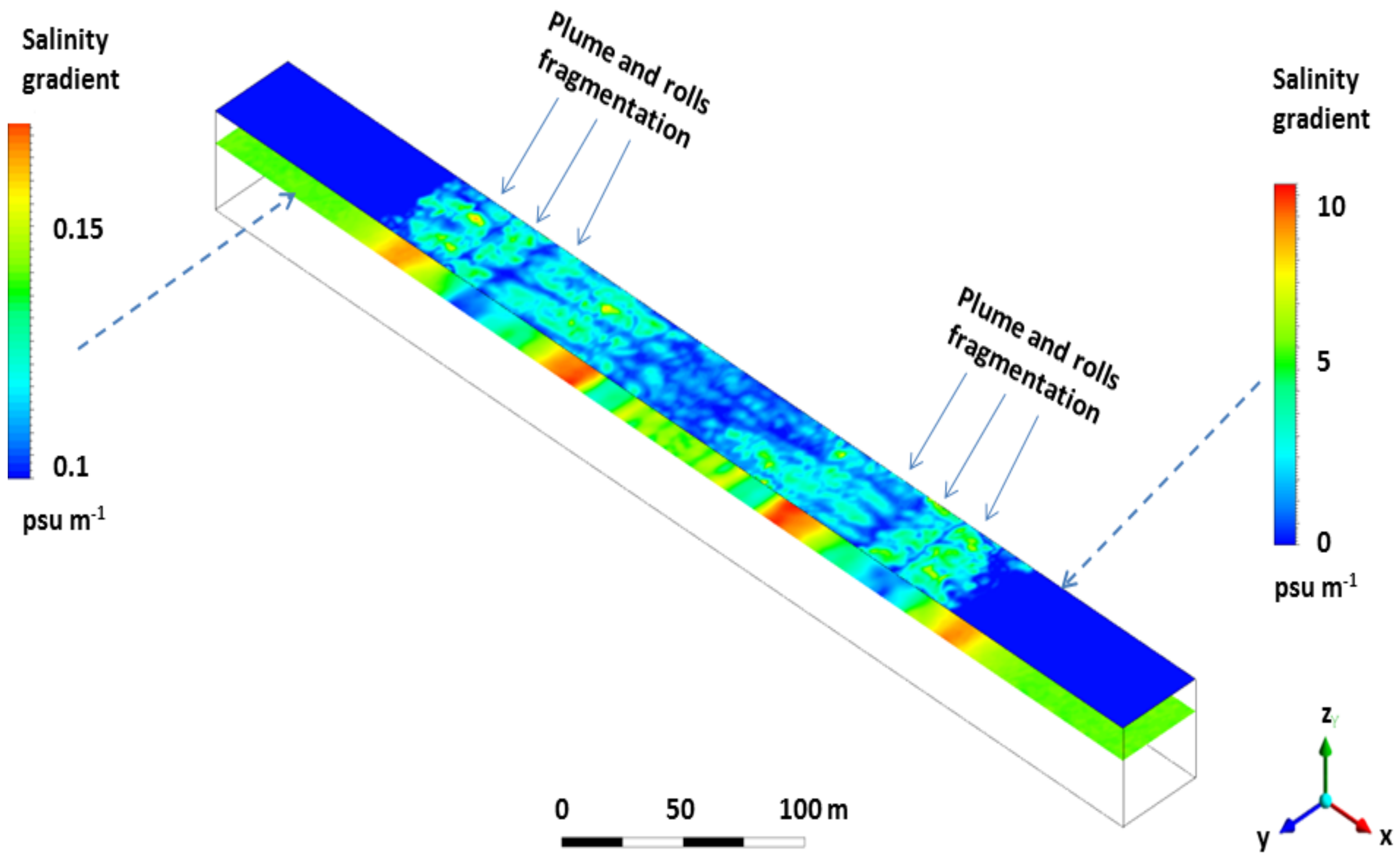


Internal waves generated by spreading lens



Velocity field at the surface and 13 m depth in the freshwater lens propagating above the barrier layer





Salinity gradient
0.15
0.1
psu m-1
Plume and rolls fragmentation
Plume and rolls fragmentation
Salinity gradient
10
5
0
psu m-1
0
50
100 m
z
y
x

Plume fragmentation due to resonant interactions with environmental stratification (e.g., barrier layer)

Following Simpson (1987) and Soloviev and Lukas (2006), to generate internal waves the Froude number *Fr* should satisfy:

$$Fr = \frac{\sqrt{g'h}}{NH} < {}^{1}/_{\pi} \quad , \quad \frac{h}{H} < 0.2$$

where $$g' = g\,\frac{\Delta\rho}{\rho_0}$$ is the reduced gravity

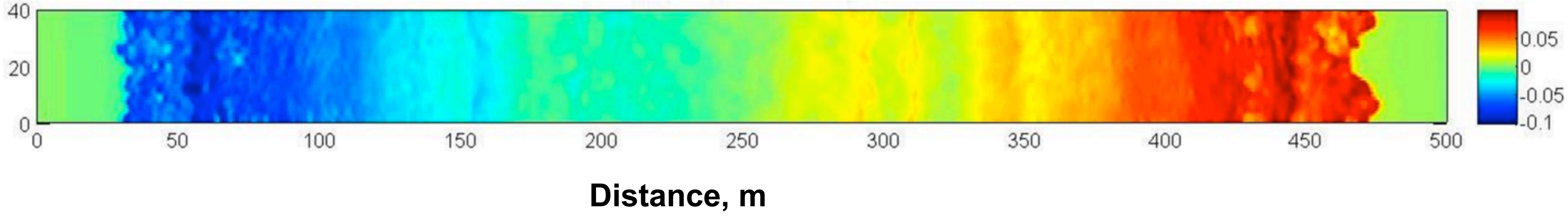
$$N^2 = -\frac{g}{\rho_0}\frac{\partial\rho}{\partial z}$$ is the Brunt-Väisällä frequency

h is the depth of the gravity current

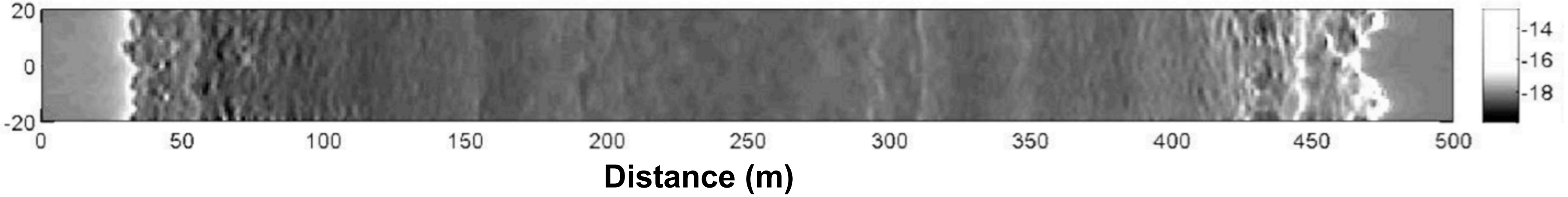
H is the total water depth

Combined Hydrodynamics and Radar Imaging Simulation
(top view: t=1850 s)

Surface velocity



Radar mage (X- band)



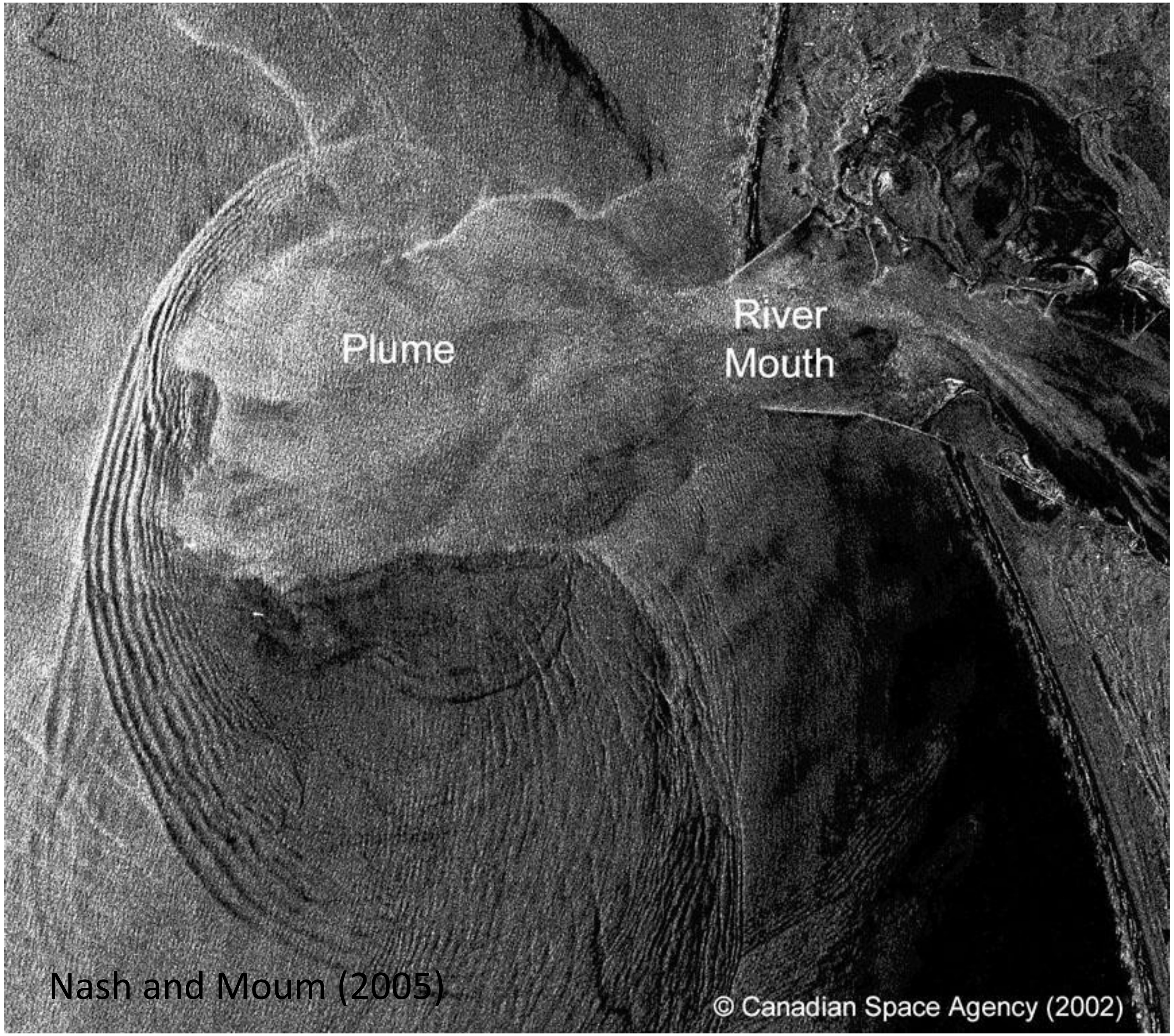
Polarization: HH
Incidence angle: 35 degs

4.0 m/s wind

radar look

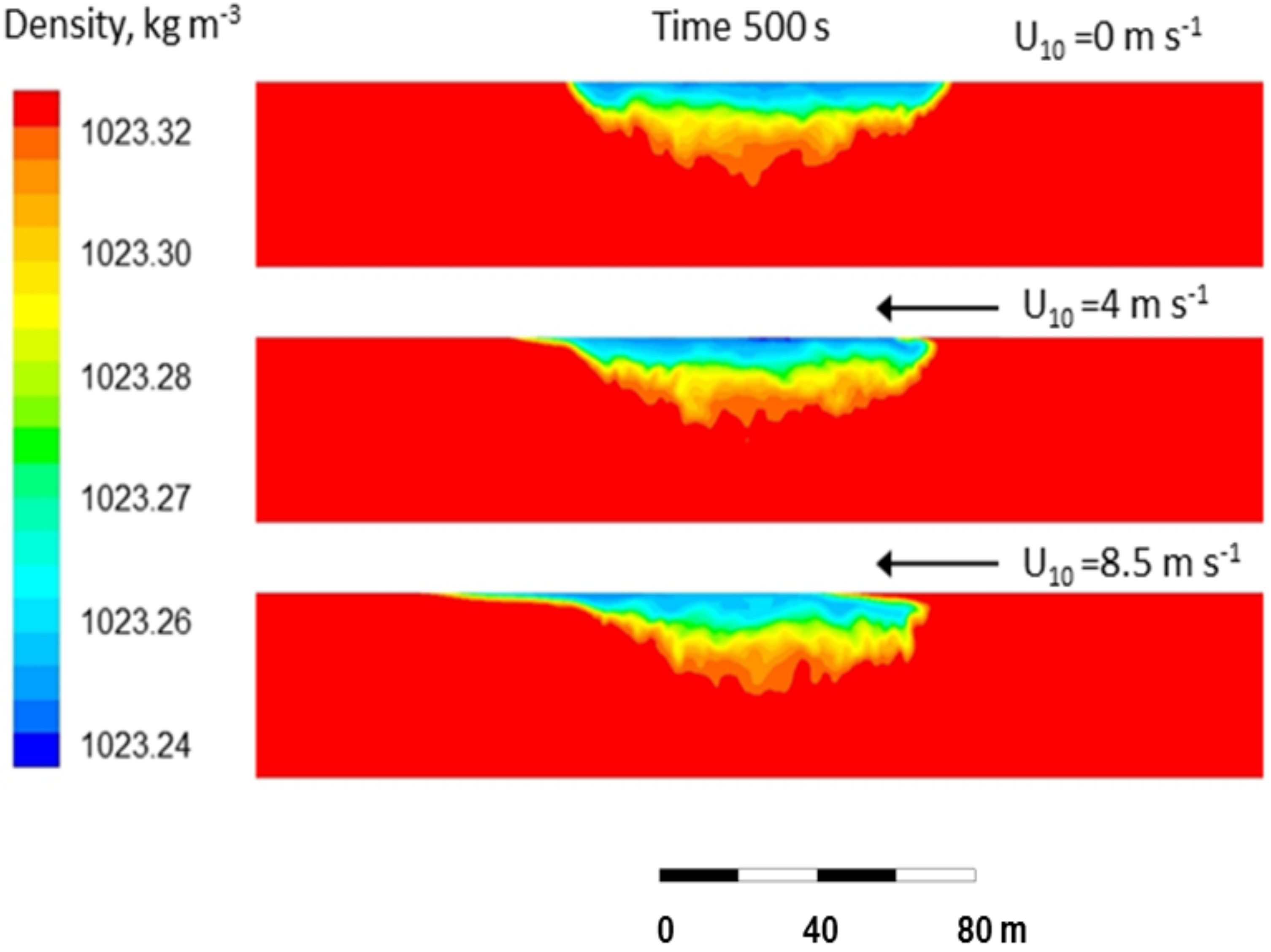
Radar imaging algorithm (M4S 3.2.0) of Prof. R. Romeiser (UM RSMAS)

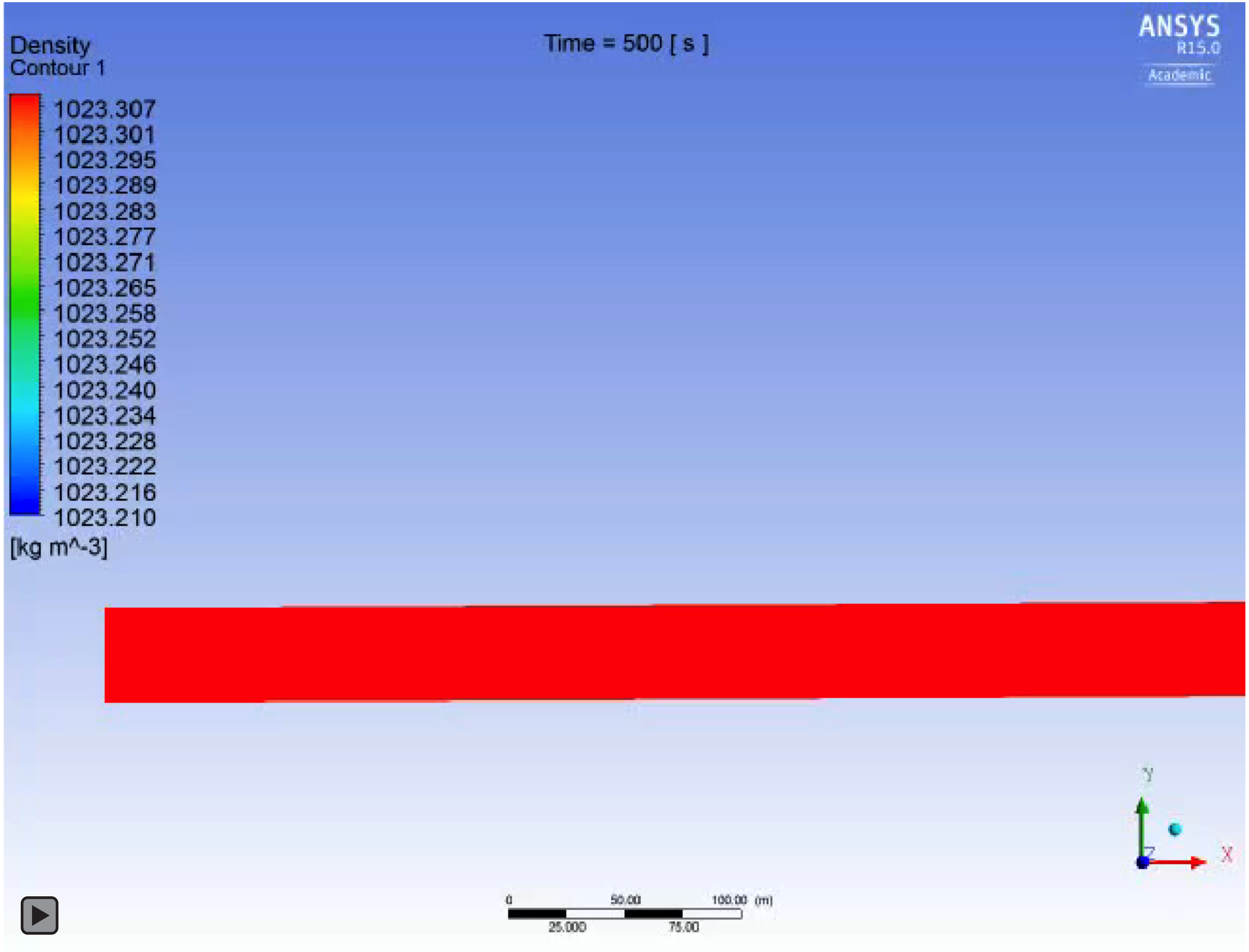
Freshwater Plumes May Have SAR Signature



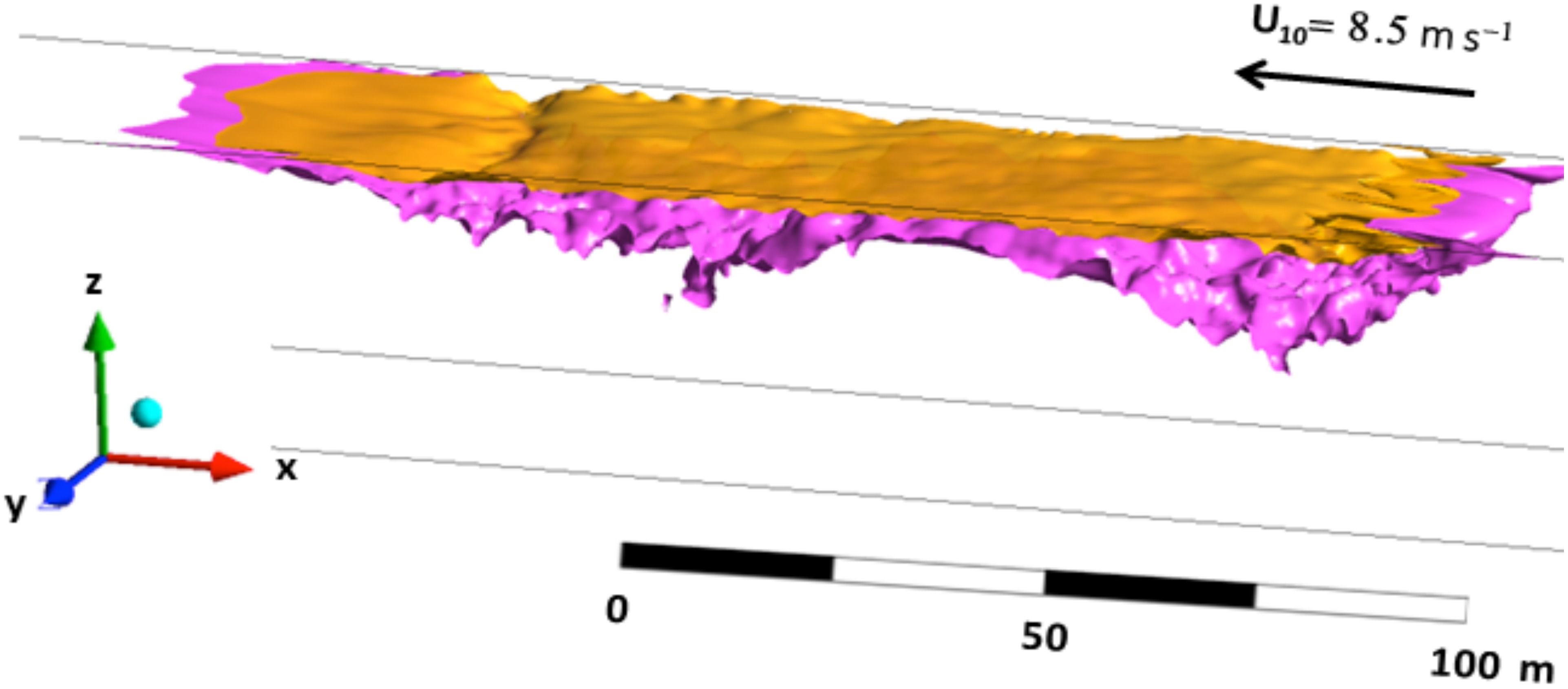
Interaction of Freshwater Lens with Wind Stress

Freshwater plume interacting with wind stress (side view)



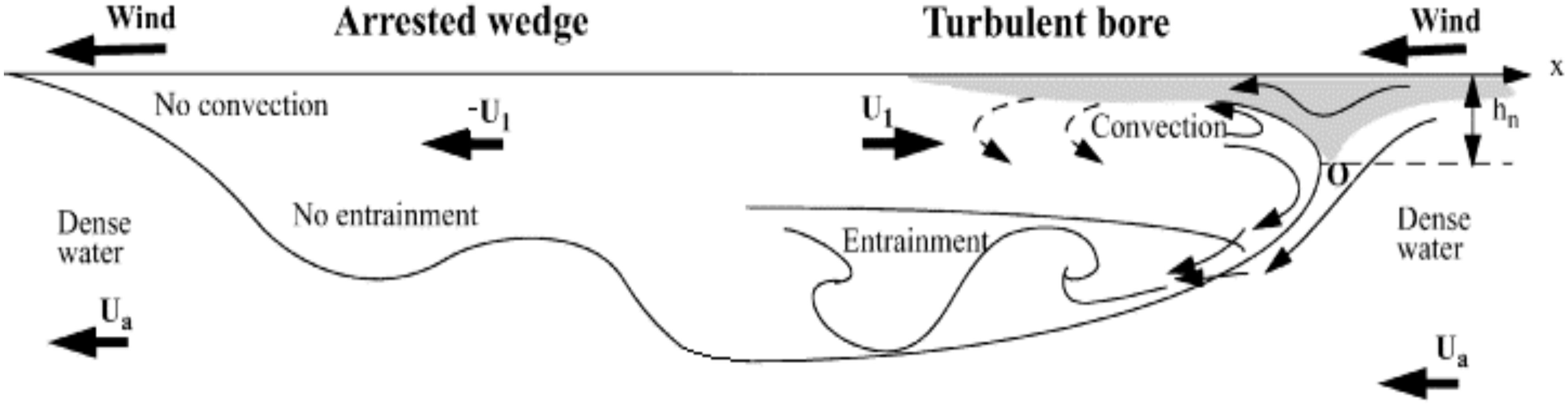

Density
Contour 1
Time = 500 [s]
ANSYS
R15.0
Academic
1023.307
1023.301
1023.295
1023.289
1023.283
1023.277
1023.271
1023.265
1023.258
1023.252
1023.246
1023.240
1023.234
1023.228
1023.222
1023.216
1023.210
[kg m^-3]
0
50.00
100.00 (m)
25.000
75.00
Y
X
Z

A bird's-eye view of the freshwater lens under wind stress action



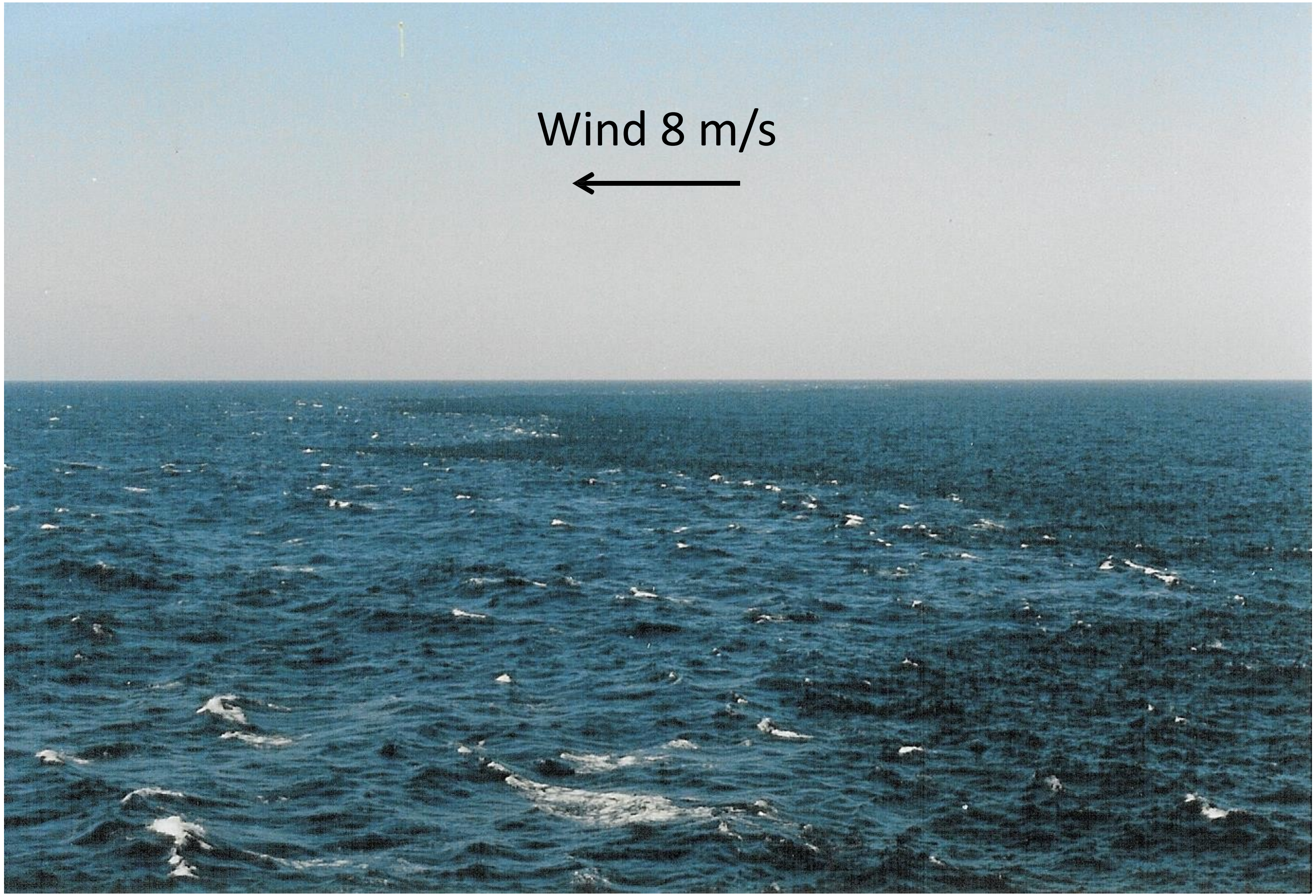
Salinity isosurfaces at 34.92 psu and 34.97 psu

Plume interaction with wind stress



Instability on the upwind edge of the plume can take place when (Soloviev et al. 2002) :

$$Re_{L\approx} \approx {}^{1}/_{60^{1/3}}\,(g'L/u_*^2)^{1/3} < 2.74$$



A frontal line observed in the western Pacific warm pool from the R/V *Kaiyo* on 13 August 1997 (Soloviev, Lukas, and Matsura 2002)

Conclusions

- Convective rains within ITCZ produce localized freshwater plumes, which have tendency to spread horizontally
- Plumes resemble gravity currents and can interact with background stratification and wind stress
- 3D processes are noticeably involved, which require high-resolution, non-hydrostatic modeling

Next Steps

Include in the numerical simulation of freshwater plumes:

- T-S stratification
- Coriolis force
- Different wind/wave regimes
- Larger domain and longer simulation time

Goal

Improve subgrid-scale mixing parameterizations in the presence of freshwater plumes

Acknowledgements

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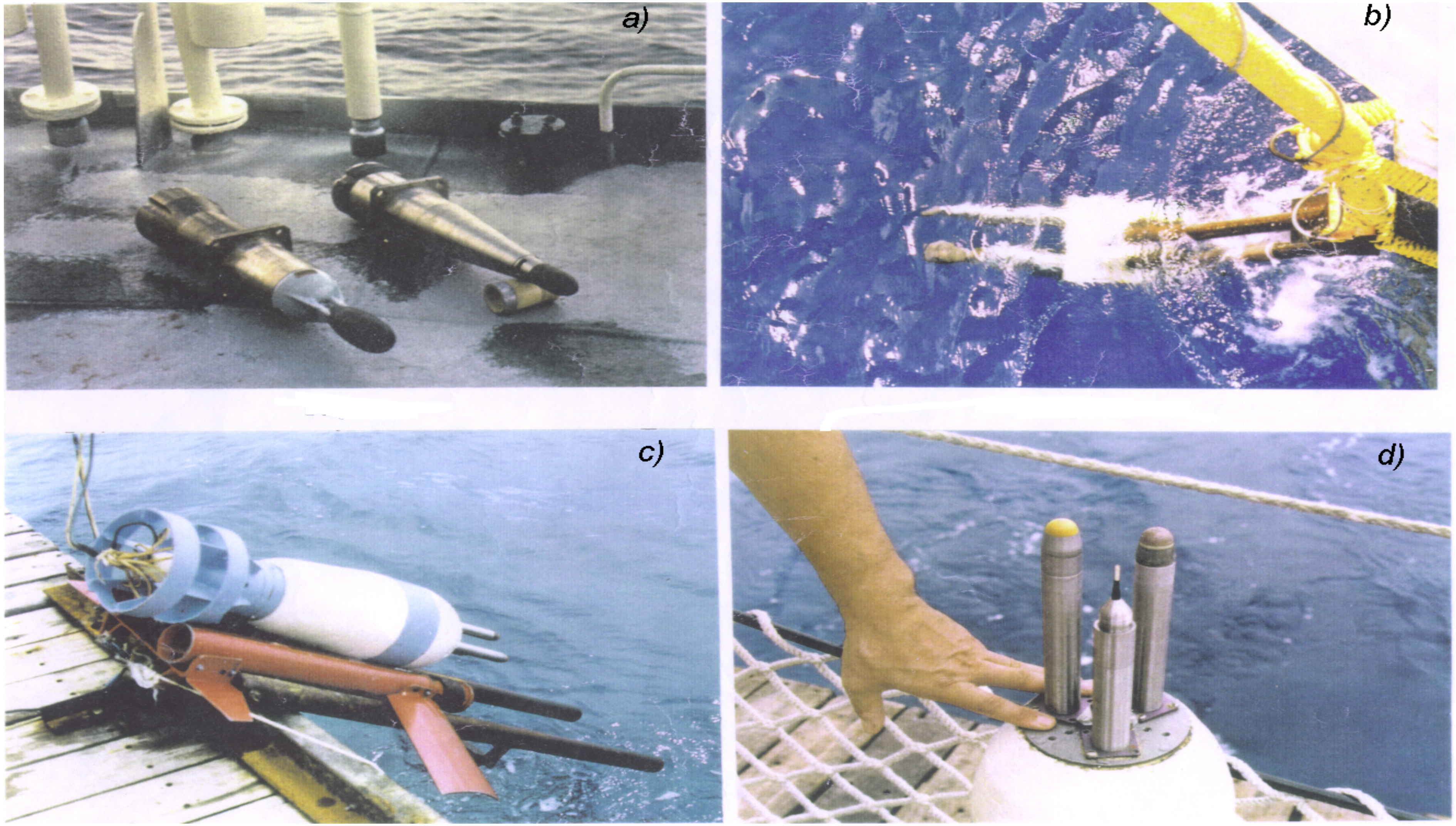
TOGA COARE Near-Surface Microstructure System



Bow sensors (a, b) and free-rising profiler (c, d)