Spatial structure, temporal variability and dynamical features of small river plumes observed by aerial drones

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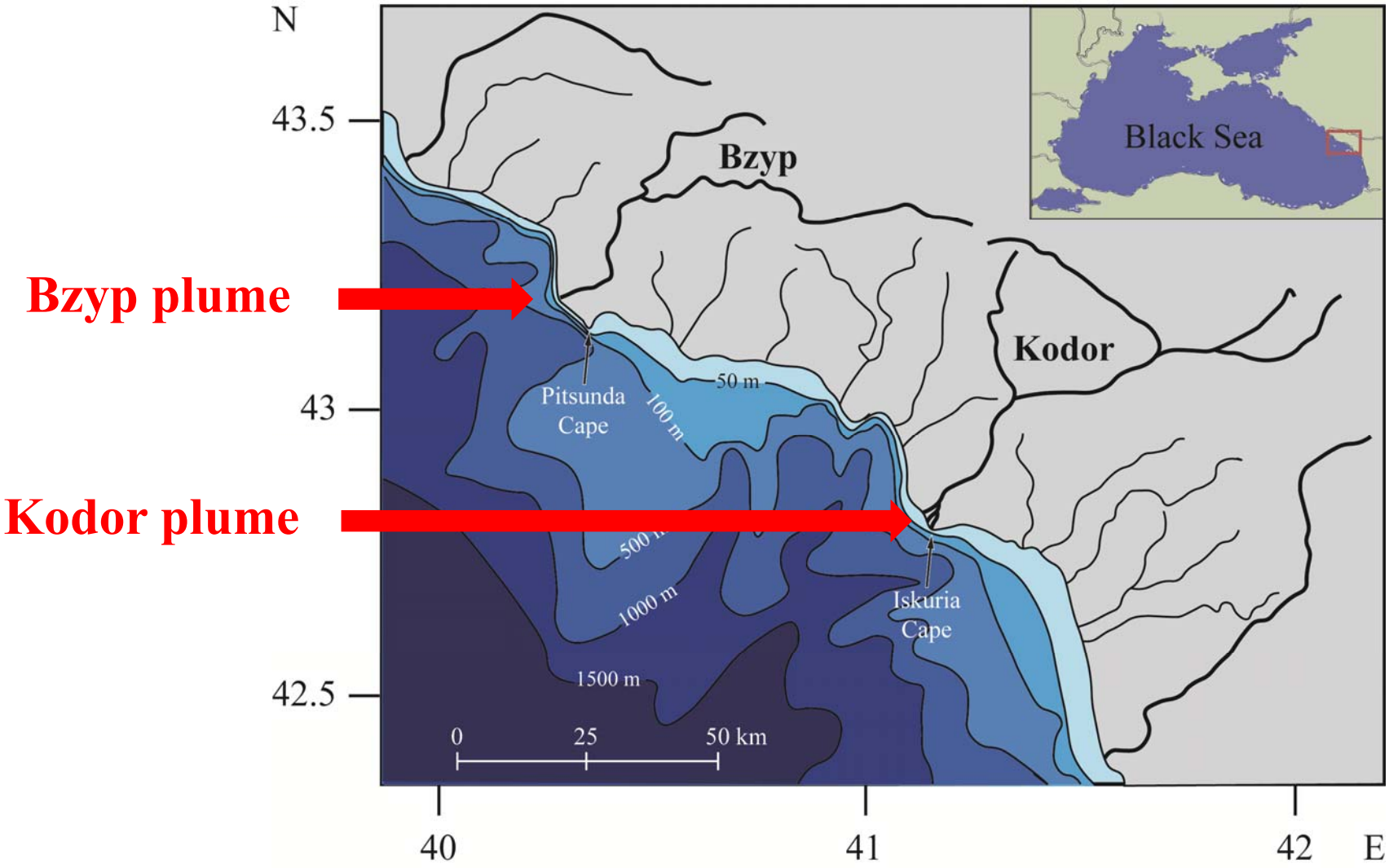
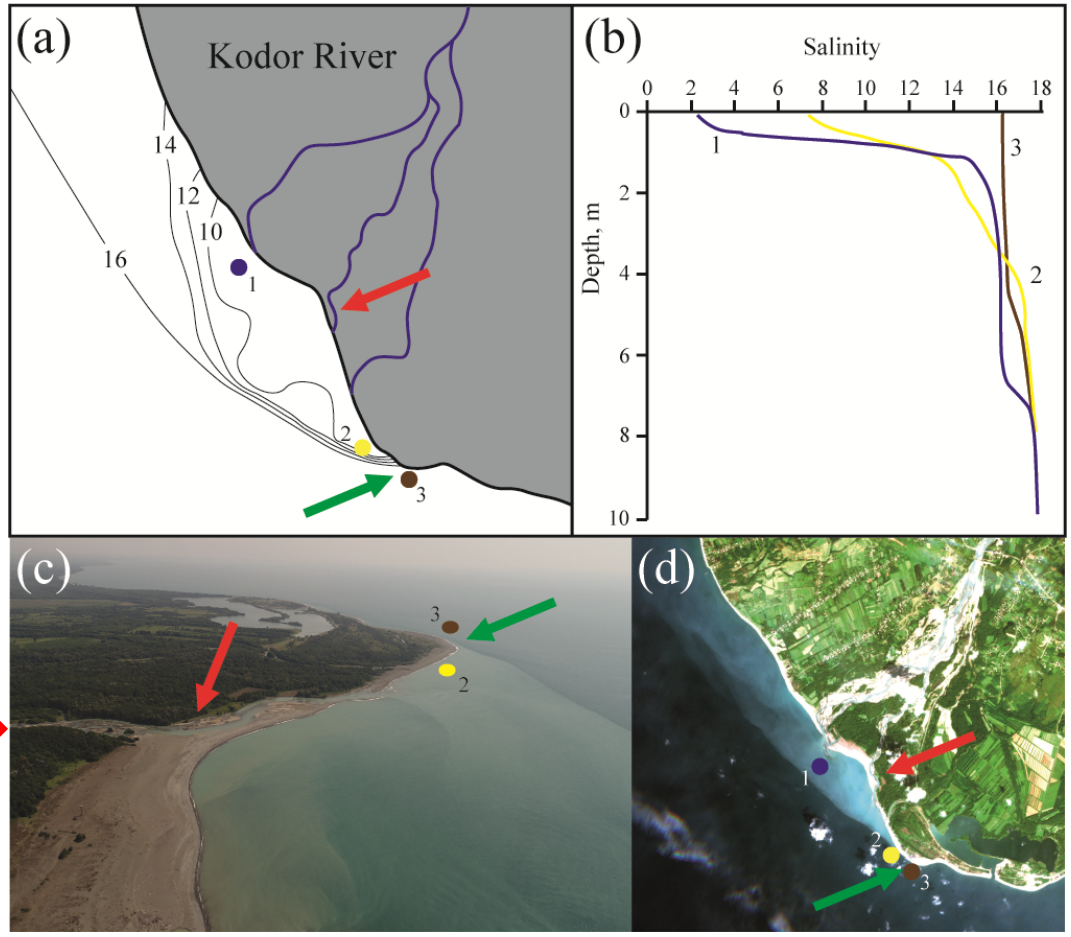
Study area


Bzyp plume
Kodor plume
N
43.5
43
42.5
40
41
42
E
Bzyp
Kodor
Black Sea
Pitsunda Cape
Iskuria Cape
50 m
100 m
1000 m
1500 m
0
25
50 km

In situ measurements, aerial and satellite observations

in situ salinity

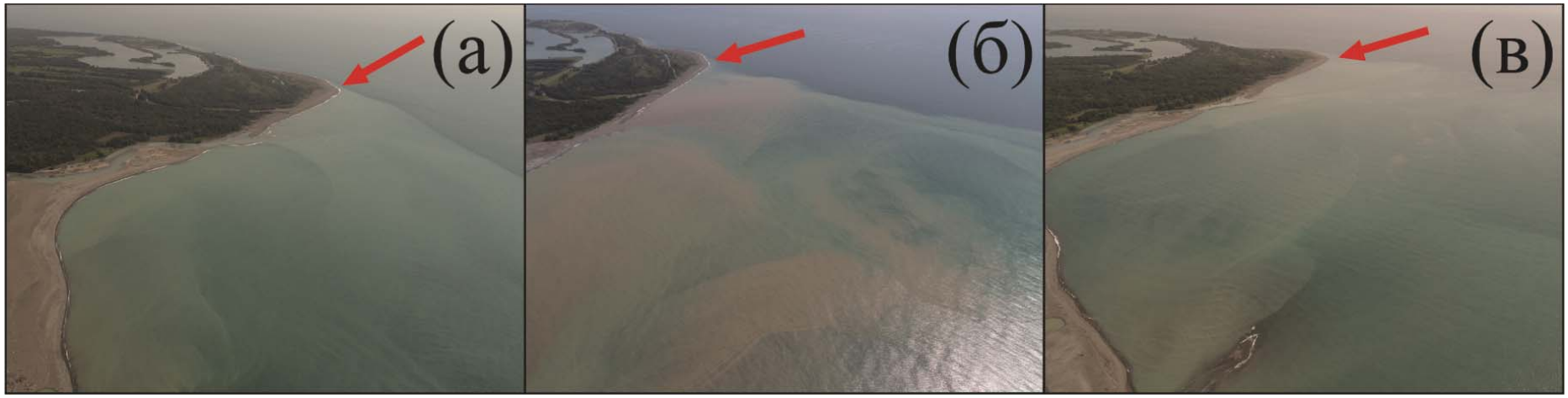
Quadcopters provide opportunity to perform continuous and high-resolution observations of small river plumes



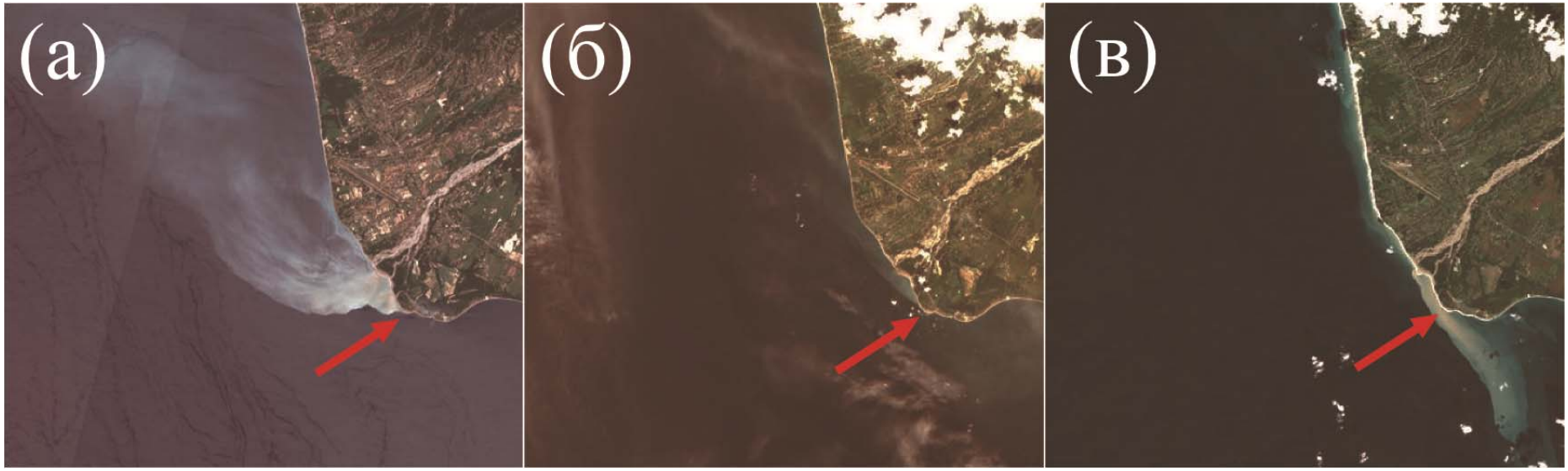
quadcopter **satellite**

Inhomogeneous structure of a small plume

Inhomogeneous structure of a small plume



Inhomogeneous structure is evident at aerial imagery

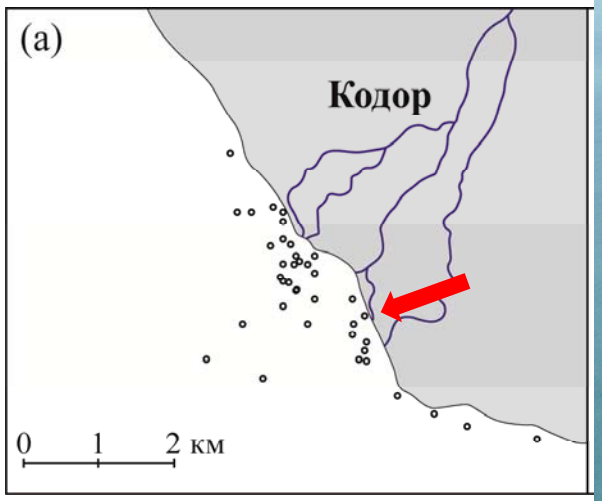


Inhomogeneous structure is blurred at satellite imagery

Inhomogeneous structure of a small plume

Reasons of inhomogeneity:

1. **Multiple deltaic branches**



Kodor River has several deltaic branches

Inhomogeneous structure of a small plume

Reasons of inhomogeneity:

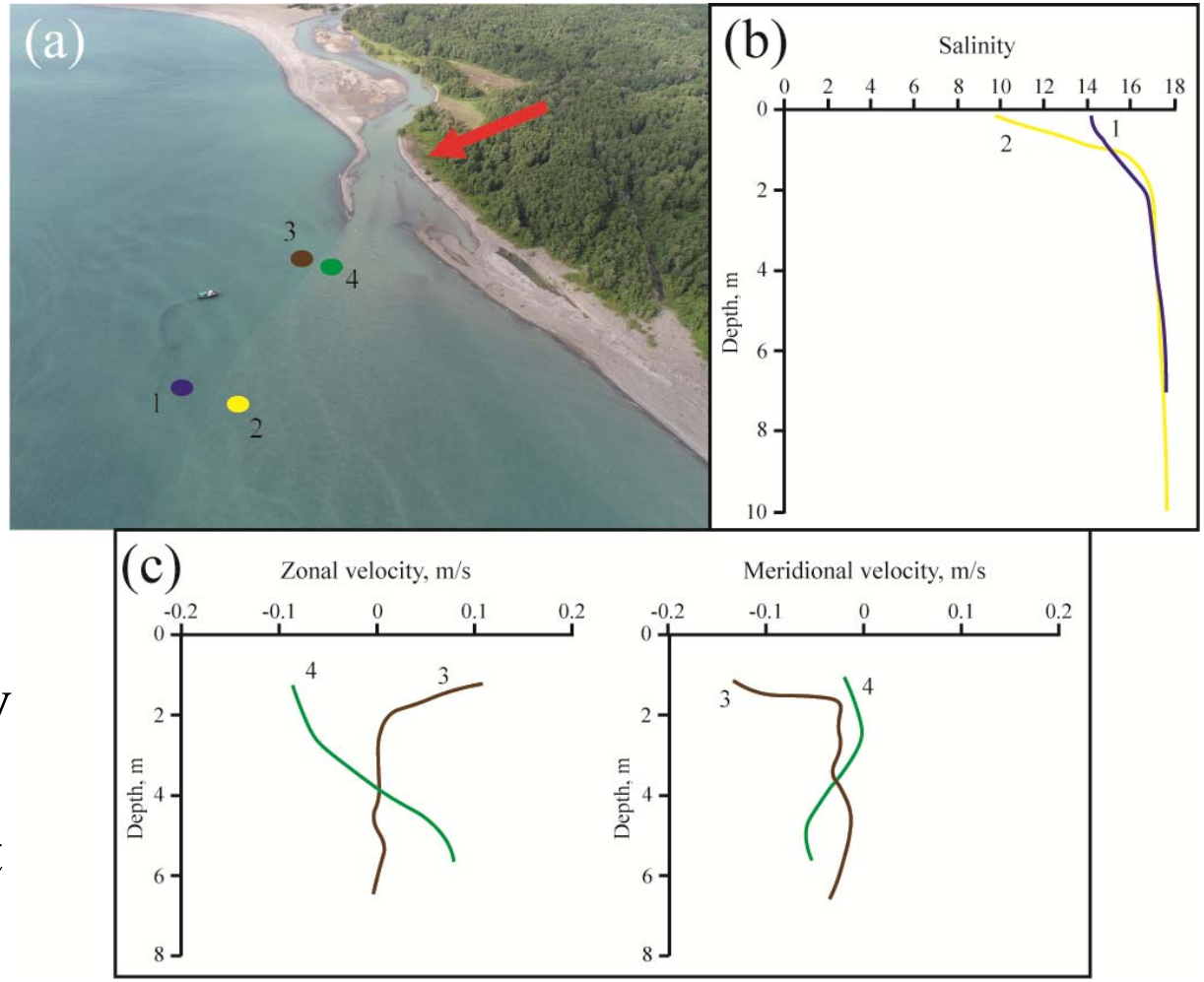
1. **Multiple deltaic branches**

Frontal zone between river plumes formed by different deltaic branches

Inhomogeneous structure of a small plume

Reasons of inhomogeneity:

1. **Multiple deltaic branches**



large difference in salinity and velocity of river plumes formed by different deltaic branches

Inhomogeneous structure of a small plume

Reasons of inhomogeneity:

1. Multiple deltaic branches
2. **Emerging (“new”) and residual (“old”) plumes**

Inhomogeneous structure of a small plume

Reasons of inhomogeneity:

1. Multiple deltaic branches
2. **Emerging (“new”) and residual (“old”) plumes**

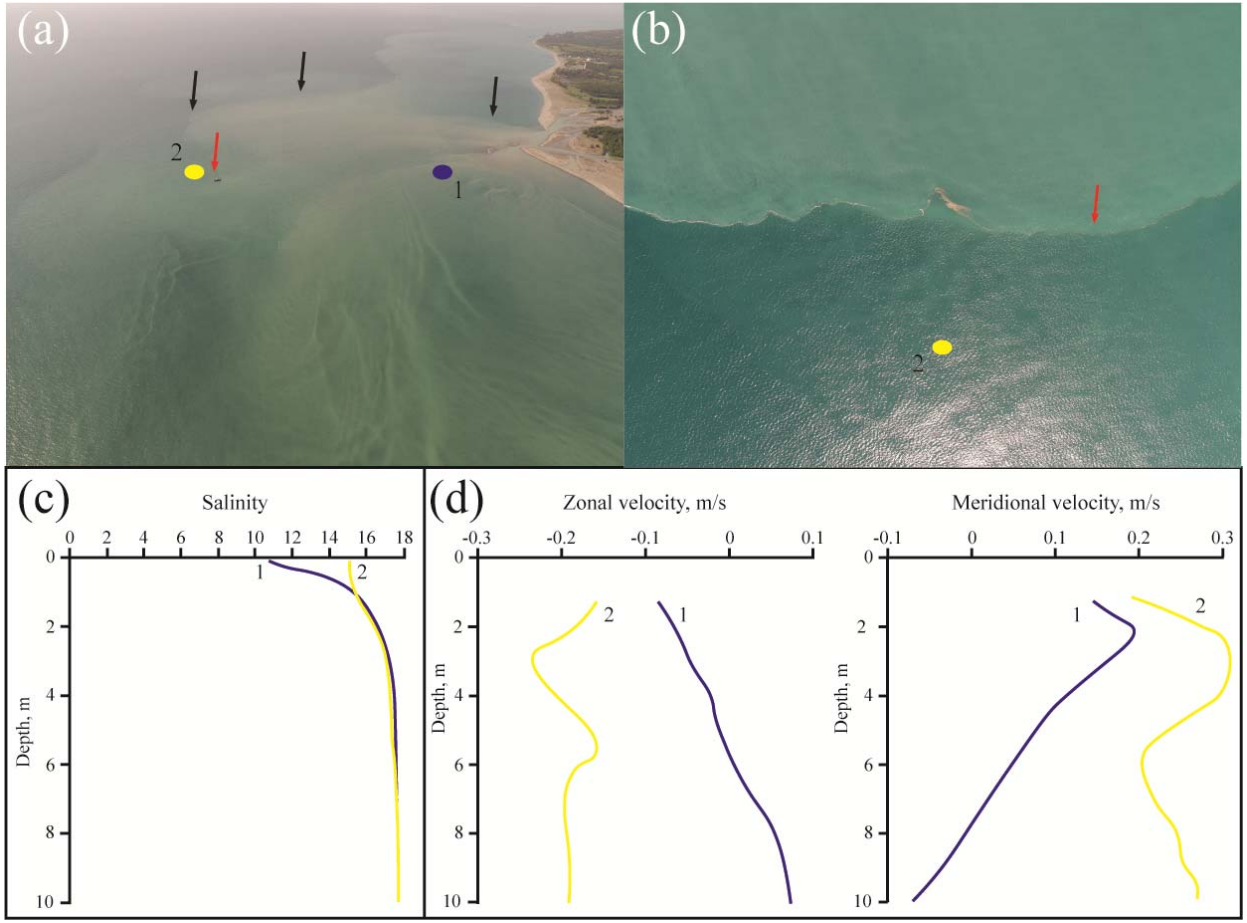
frontal zone between the emergent plume and the residual plume

Inhomogeneous structure of a small plume

Reasons of inhomogeneity:

1. Multiple deltaic branches
2. **Emerging (“new”) and residual (“old”) plumes**

large difference in salinity and velocity of emergent plume and residual plume



Inhomogeneous structure of a small plume

Reasons of inhomogeneity:

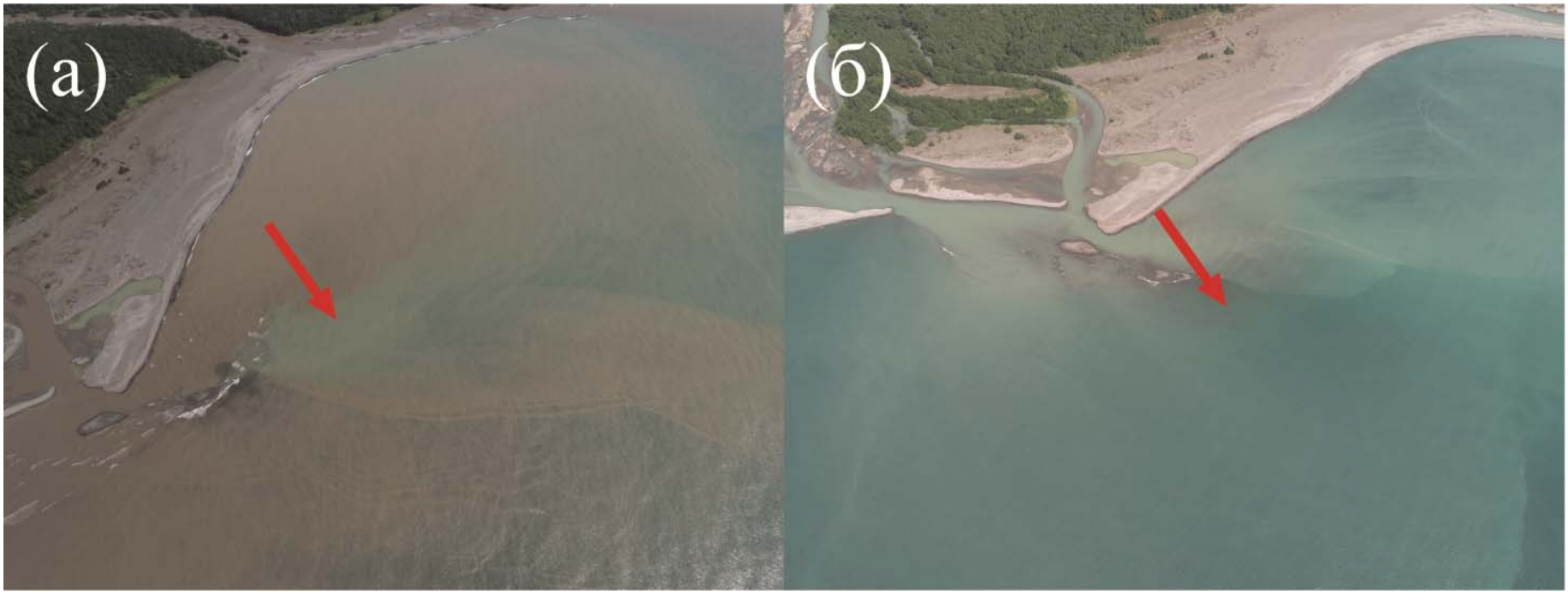
1. Multiple deltaic branches
2. Emerging (“new”) and residual (“old”) plumes
3. **Influence of bathymetry features – not expected dynamical effect**

large and stable low turbid and high saline area within the plume behind the shoal

Inhomogeneous structure of a small plume

Reasons of inhomogeneity:

1. Multiple deltaic branches
2. Emerging (“new”) and residual (“old”) plumes
3. **Influence of bathymetry features – not expected dynamical effect**



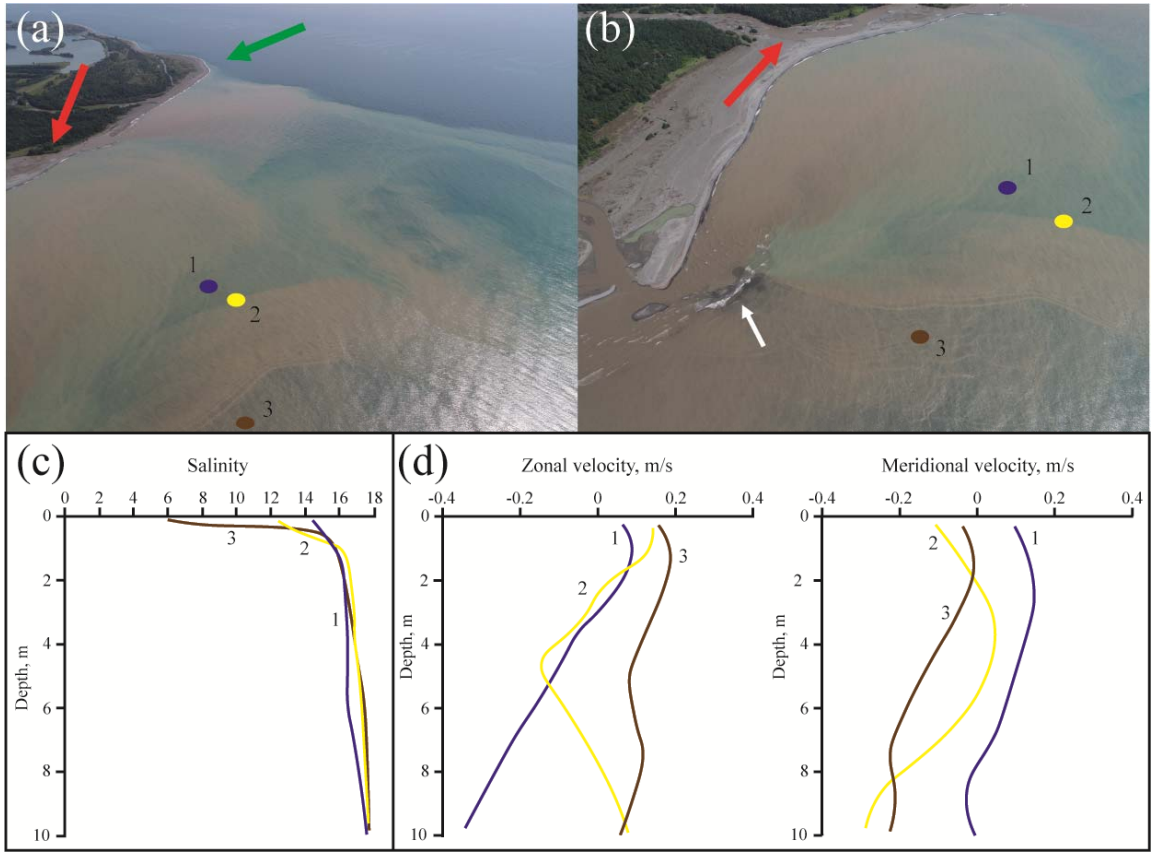
Frontal zone between river plume and low turbid area behind the shoal

Inhomogeneous structure of a small plume

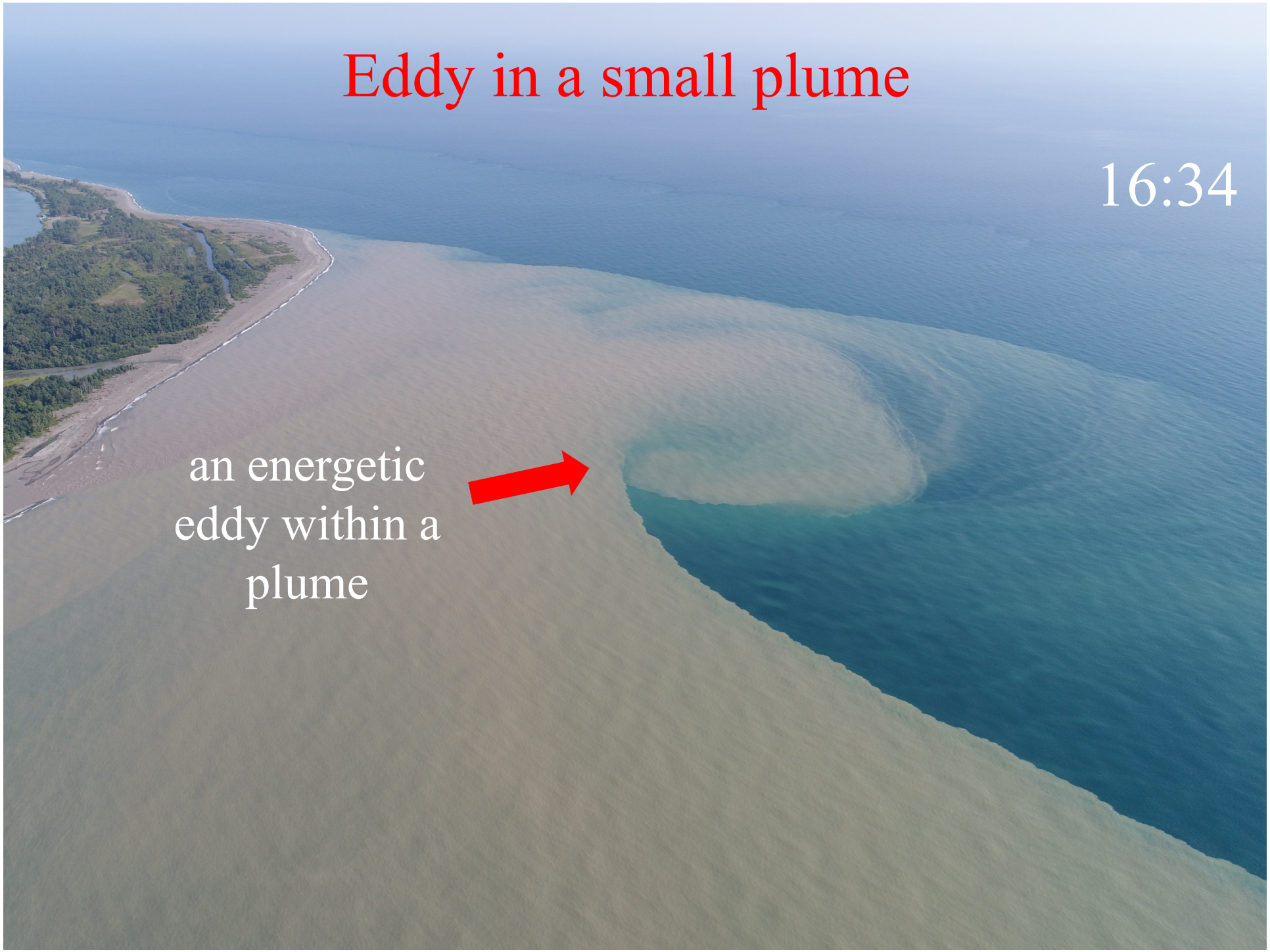
Reasons of inhomogeneity:

1. Multiple deltaic branches
2. Emerging (“new”) and residual (“old”) plumes
3. **Influence of bathymetry features – not expected dynamical effect**

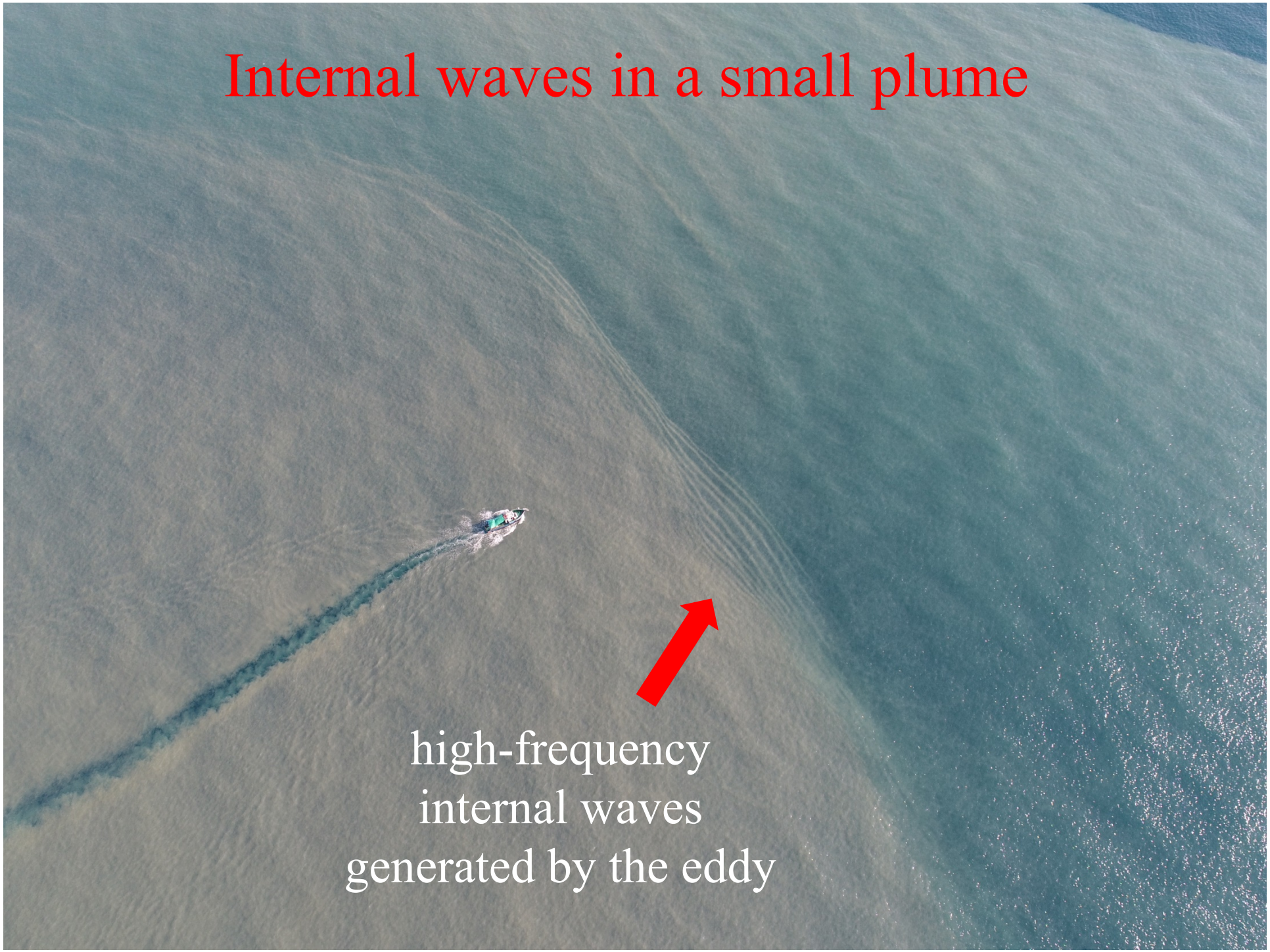
large difference in salinity and velocity of turbid plume and low turbid area behind the shoal




Eddy in a small plume
13:52

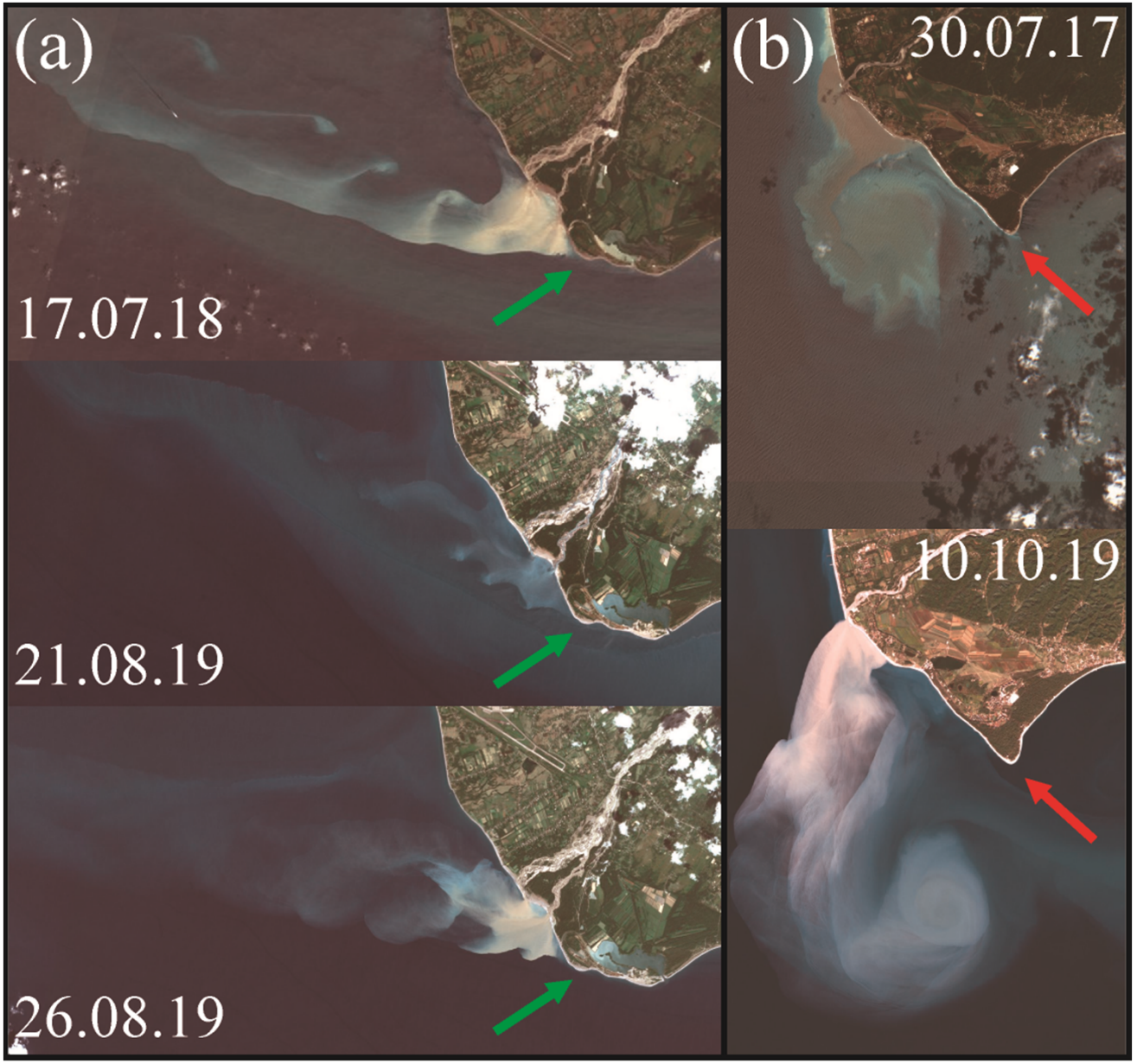

Eddy in a small plume
16:34
an energetic eddy within a plume

Internal waves in a small plume



Eddies in small plumes

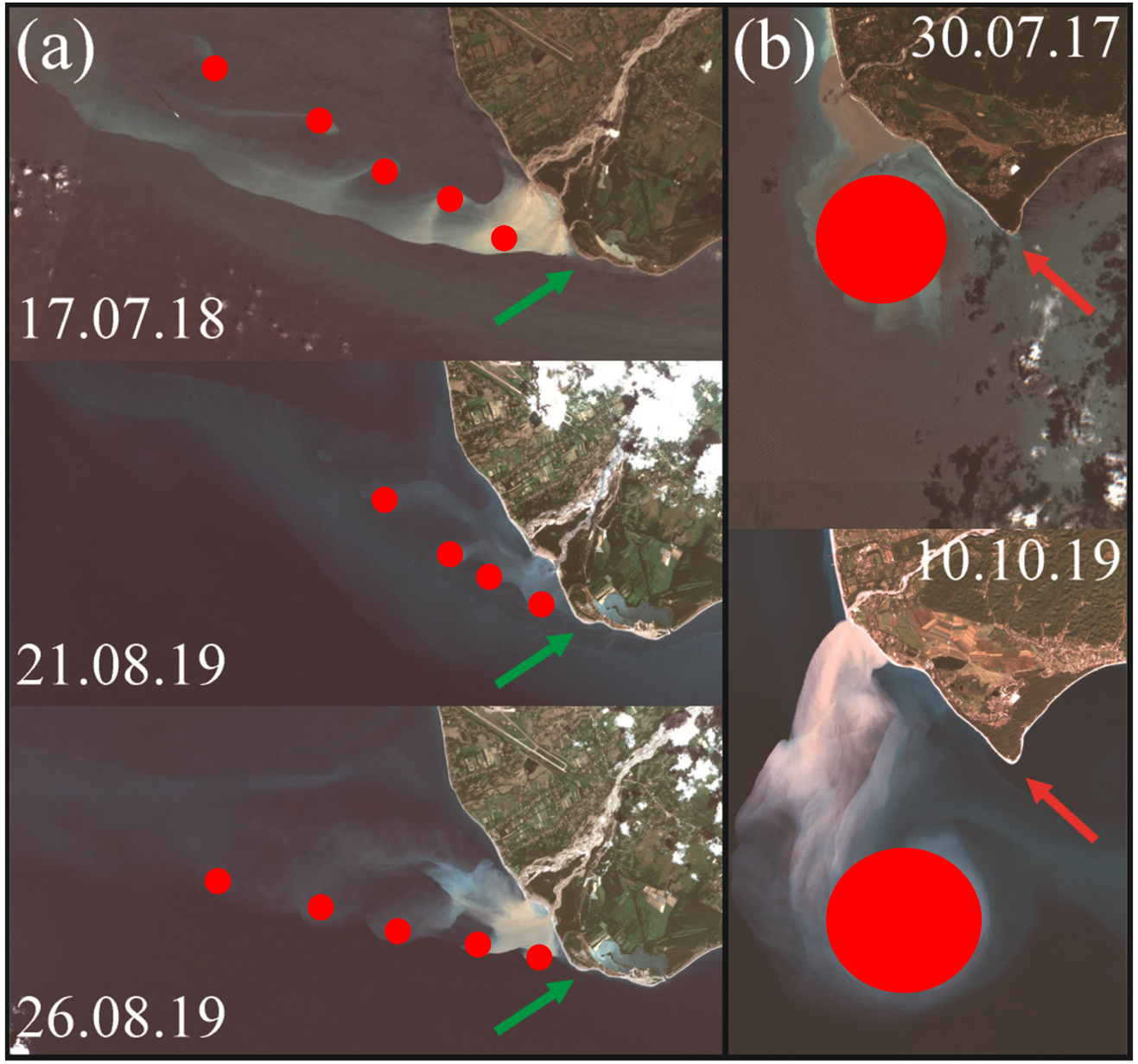
eddy chains in the Kodor plume



single eddies in the Bzyp plume

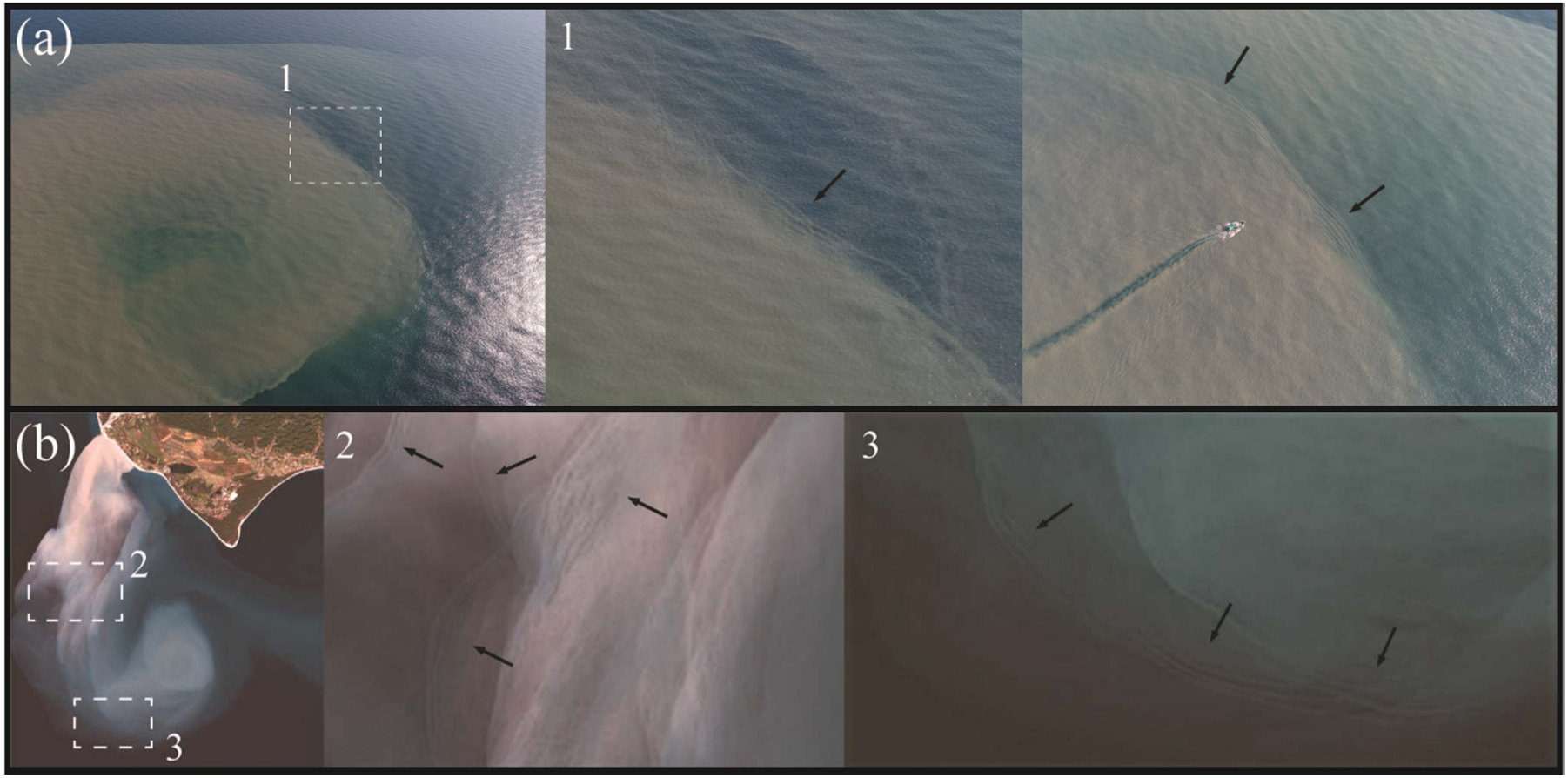
Eddies in small plumes

eddy chains in the Kodor plume



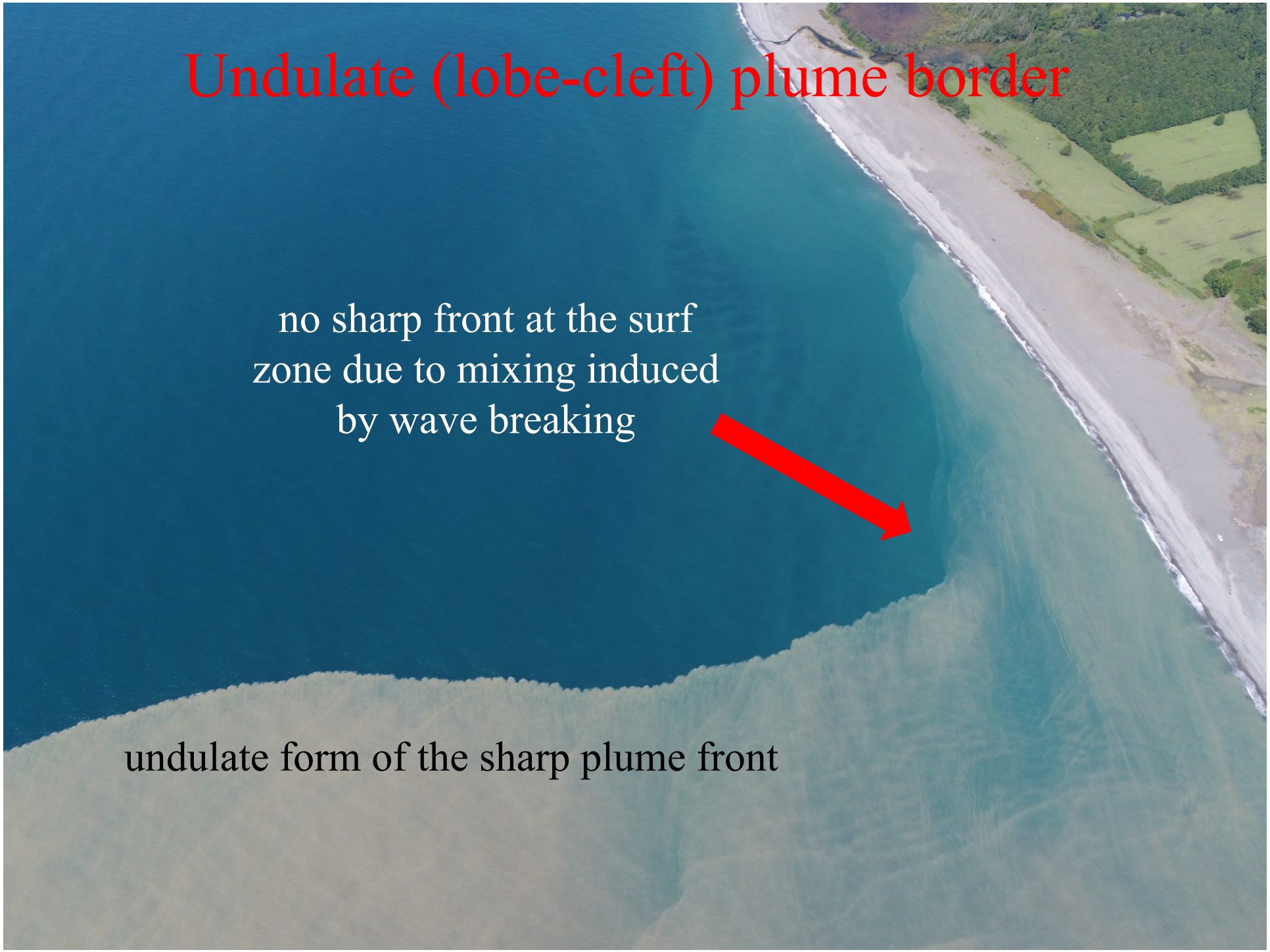
single eddies in the Bzyp plume

Eddies and internal waves in small plumes

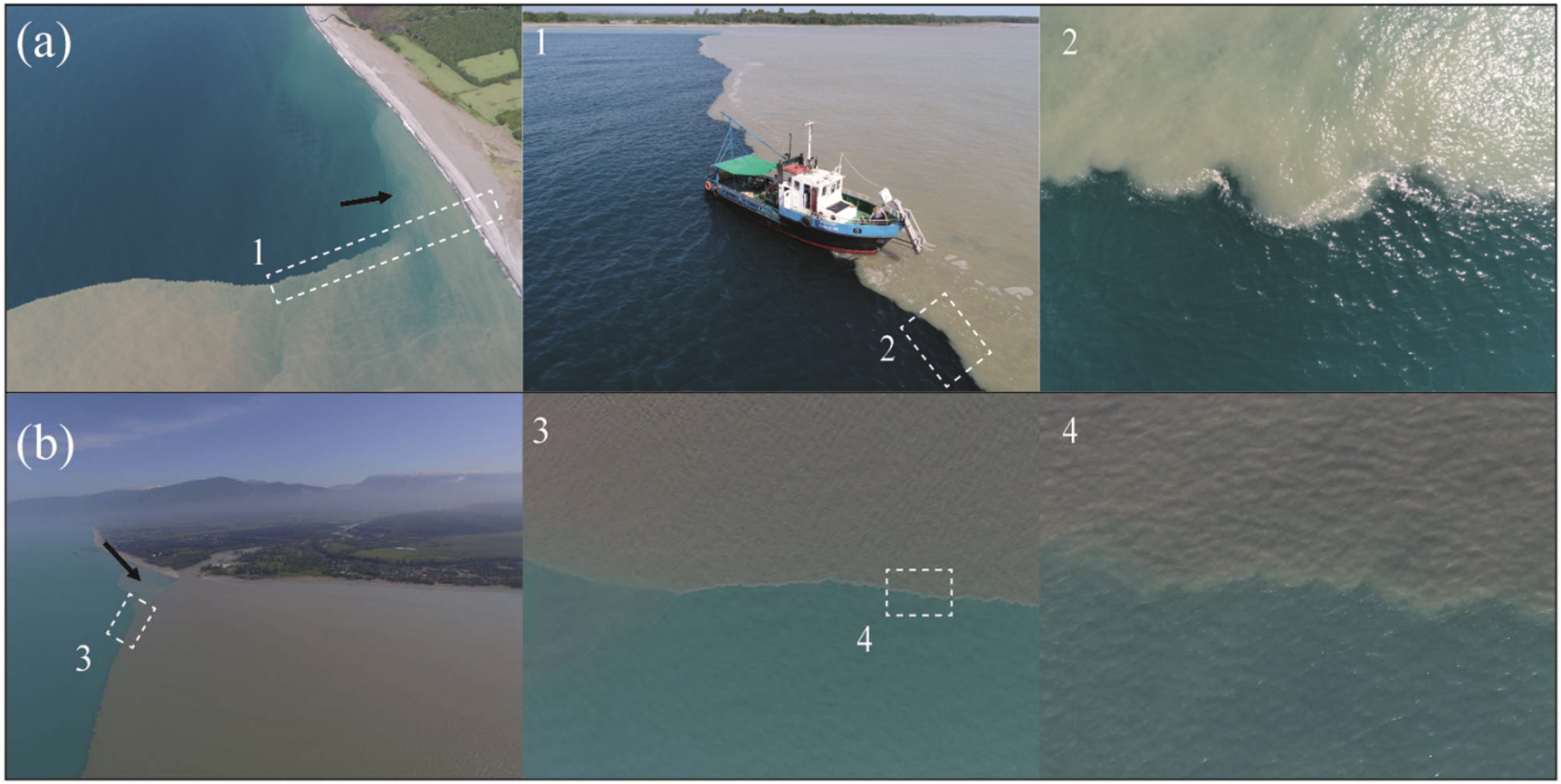


generation of high-frequency internal waves by eddies observed by aerial and satellite imagery

Undulate (lobe-cleft) plume border

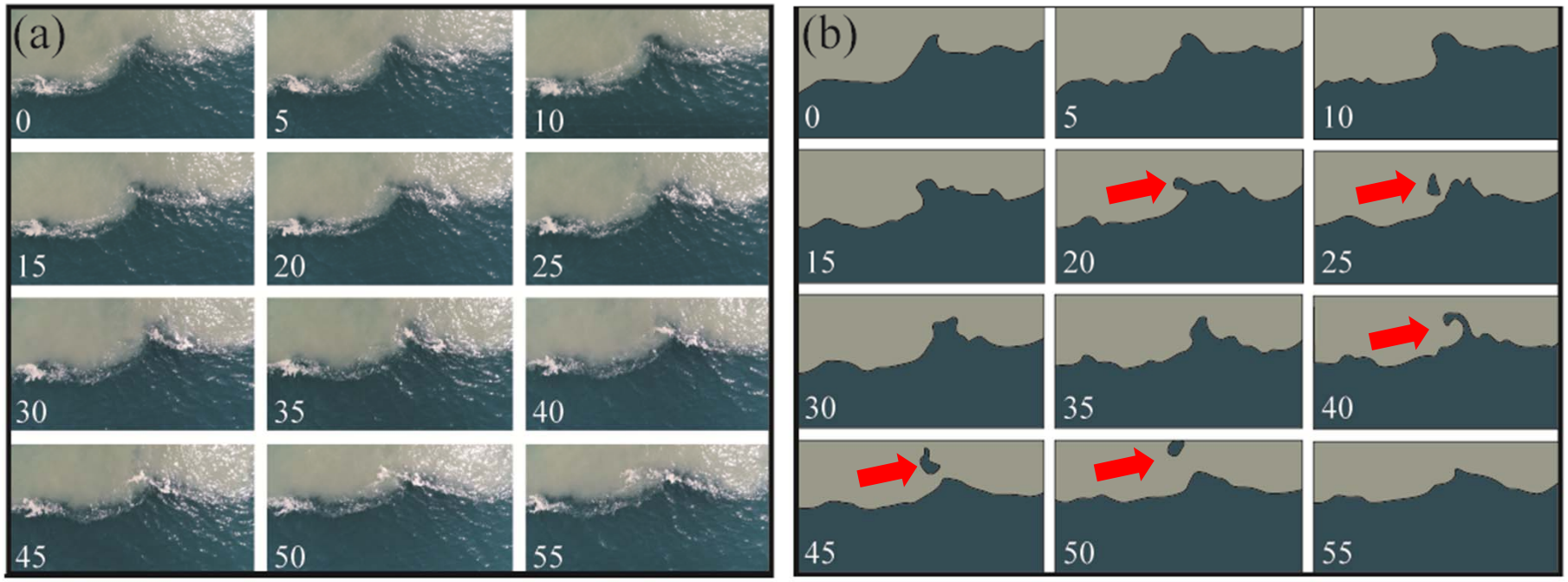

Undulate (lobe-cleft) plume border
no sharp front at the surf zone due to mixing induced by wave breaking
undulate form of the sharp plume front

Undulate (lobe-cleft) plume border



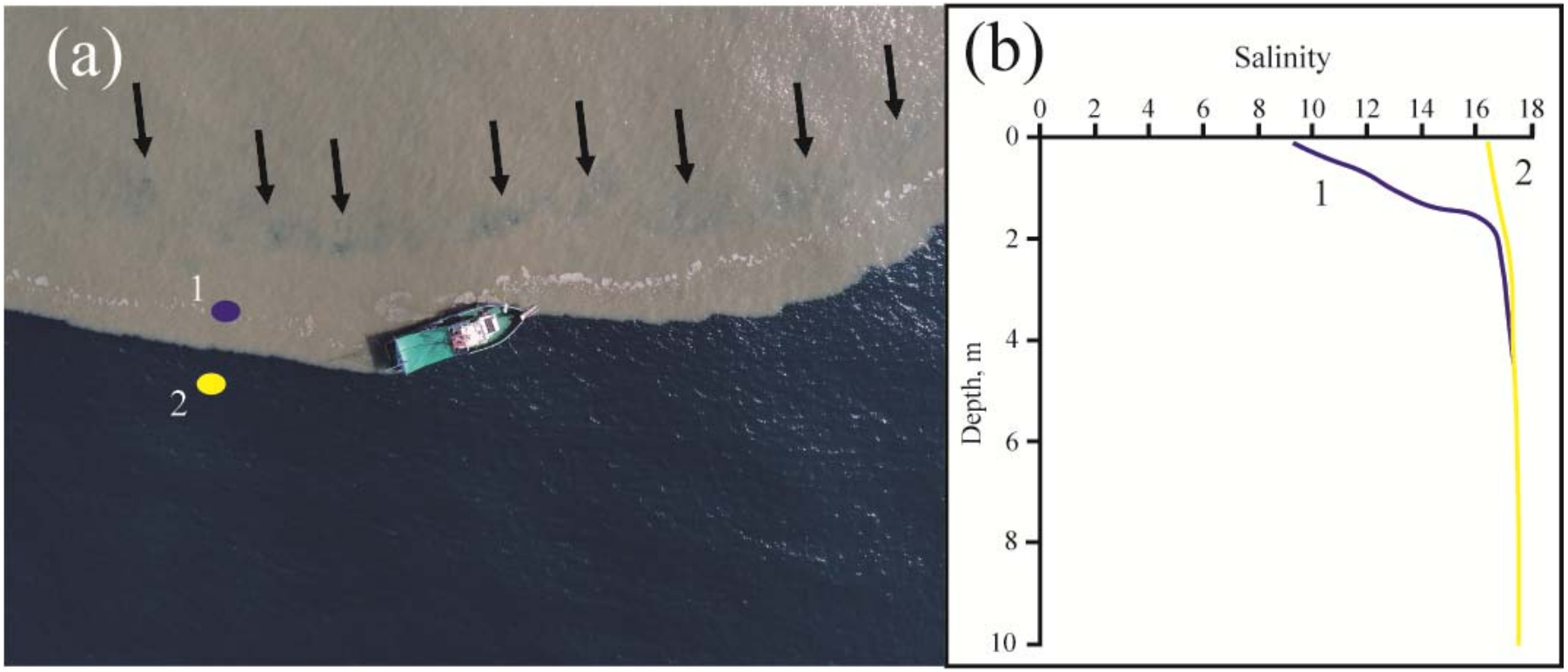
undulate form of the sharp plume front at different spatial scales

Undulate (lobe-cleft) plume border



circulation of the undulate front and transport of segments of saline sea across the plume border – important mixing mechanism!

Undulate (lobe-cleft) plume border



stripe of low turbid water within the plume formed as a result of transport of segments of saline sea across the plume

Undulate (lobe-cleft) plume border

circulation within the undulate front and transport of foam and floating litter along the front

Conclusions

1. Quadcopter aerial imagery is a new efficient tool for observations and measurements of small river plumes
2. We registered and described inhomogeneous internal structure of small river plumes with complex and energetic frontal zones within plumes.
3. We registered and described interaction of a small river plume and rotating eddy, as well as formation of high-frequency internal waves as a result of this interaction.
4. We studied undulate (lobe-cleft) outer boundaries of small river plumes, we registered and described intense horizontal mixing across these fronts induced by baroclinic instability.

Thank you for your attention!