P.P. Shirshov Institute of Oceanology, RAS

Hydrological Cycle Laboratory

Continental discharges and river plumes in the ocean

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Megagrant 14.B25.31.0026 of the Ministry of Education and Science of the Russian Federation

Motivation: Why we need to study continental discharges?

1. <u>Importance of continental discharges</u>:

- Continental discharge is a significant component of the global hydrological cycle (about 10% of the input part of the ocean water budget on the global average).
- Buoyant fluvial inflow usually causes surface density stratification over large shelf areas. <u>River plumes</u> formed as a result of interaction between fluvial discharge and sea waters play a significant role in physical, chemical, and biological processes, especially in the inland seas and certain shelf areas.

2. <u>Complexity of river discharge estimation</u>:

- Direct measurements of discharge are expensive and laborious.
- Regular measurements of discharge at gauge stations are performed only for a relatively small number of rivers.
- Indirect methods of river discharge estimation require ancillary ground-based information (e.g., gauge measurements, bathymetry, etc.) and are prone to uncertainties .
- There is a lack of discharge data for most of rivers in a global scale.

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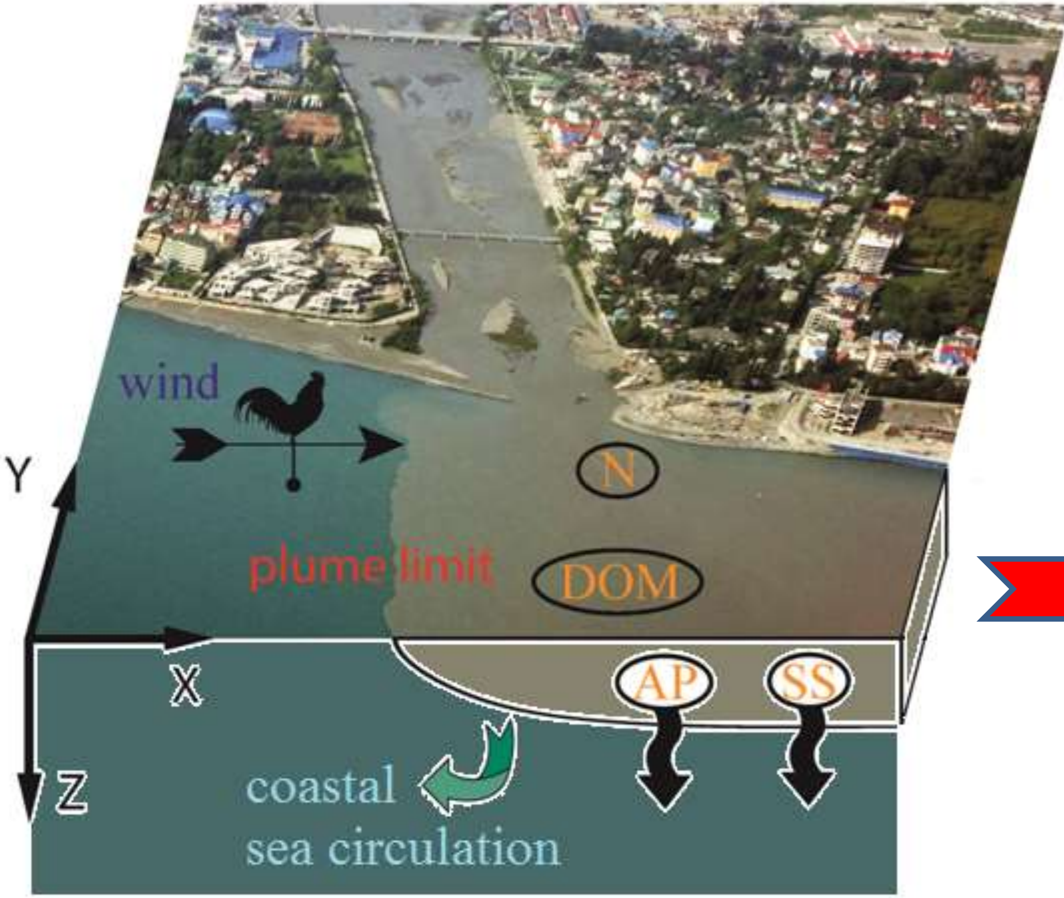
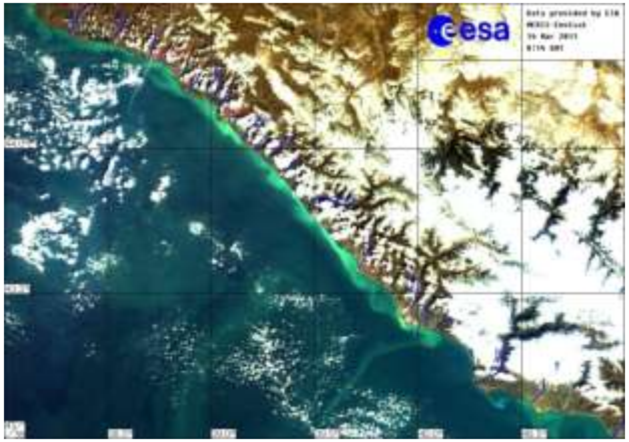
River Discharge = River Plume + Dissipation



Schematic of a plume interaction with ambient environment



River plumes can be recognized and identified using satellite imagery

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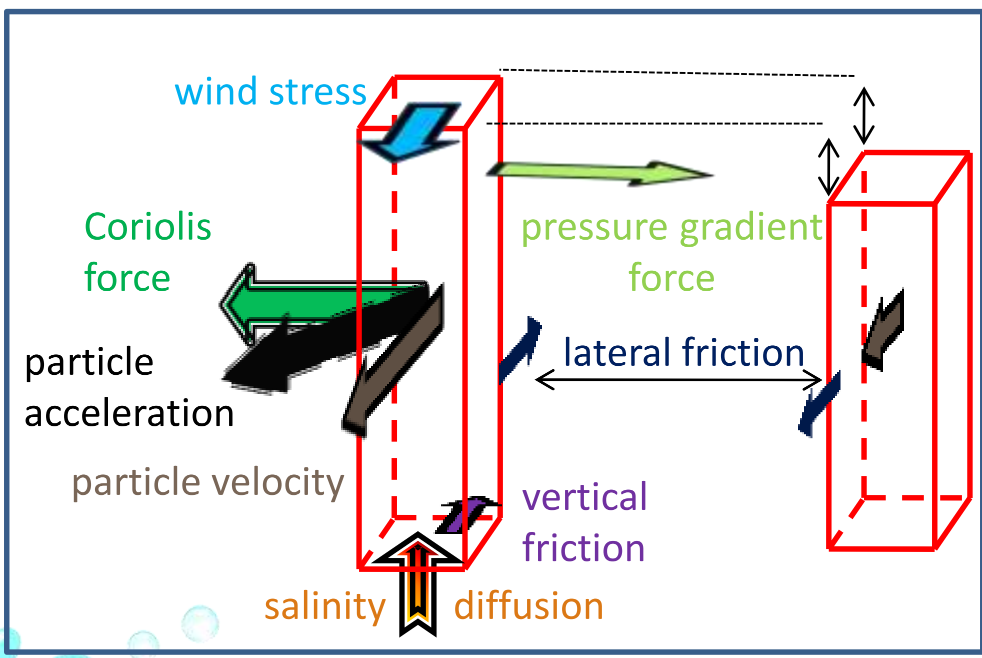
STRiPE – Lagrangian model of a river plume

Transport equation for a particle

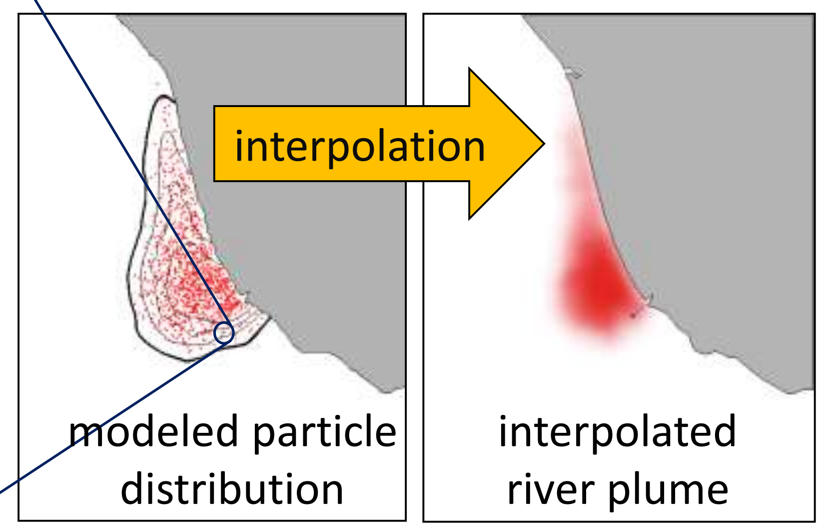
Coriolis force | wind stress | vertical friction | lateral friction | pressure gradient force

$$a_x^{i+1} = f v^i + \frac{\tau_x^i}{\rho^i h^i} - \frac{\mu_v^i}{h^i}\frac{u^i - u_{sea}^i}{h^i} + \frac{\mu_h}{h^i}\left(\frac{u_{x+\Delta x\,y}^i + u_{x-\Delta x\,y}^i - 2u^i}{\Delta x} + \frac{u_{x\,y+\Delta y}^i + u_{x\,y-\Delta y}^i - 2u^i}{\Delta y}\right) - g\varkappa \frac{h_{x+\Delta x\,y}^i - h_{x-\Delta x\,y}^i}{\Delta x}$$

$$a_y^{i+1} = -f u^i + \frac{\tau_y^i}{\rho^i h^i} - \frac{\mu_v^i}{h^i}\frac{v^i - v_{sea}^i}{h^i} + \frac{\mu_h}{h^i}\left(\frac{v_{x+\Delta x\,y}^i + v_{x-\Delta x\,y}^i - 2v^i}{\Delta x} + \frac{v_{x\,y+\Delta y}^i + v_{x\,y-\Delta y}^i - 2v^i}{\Delta y}\right) - g\varkappa \frac{h_{x\,y+\Delta y}^i - h_{x\,y-\Delta y}^i}{\Delta y}$$



Schematic of the forces applied to an individual particle of the plume



STRiPE – Lagrangian model of a river plume

$$a_x^{i+1} = -f u_y^i + \frac{\tau_x^i}{\rho^i h^i} + \frac{\mu_h}{h^i}\frac{u_x^i - v_{sea,x}}{\Delta z} + \mu_v \frac{\Delta u_x^i}{\Delta x} - g\varkappa \frac{\Delta h^i}{\Delta x};$$

$$a_y^{i+1} = f u_x^i + \frac{\tau_y^i}{\rho^i h^i} + \frac{\mu_h}{h^i}\frac{u_y^i - v_{sea,y}}{\Delta z} + \mu_v \frac{\Delta u_y^i}{\Delta y} - g\varkappa \frac{\Delta h^i}{\Delta y}$$

$$x^{i+1} = x^i + v_x^i \Delta t + \sqrt{2D_h \Delta t}\,\eta_x\,;\; y^{i+1} = y^i + v_y^i \Delta t + \sqrt{2D_h \Delta t}\,\eta_y$$

$$D_h = \zeta_h \sqrt{\left(\frac{\Delta u_x}{\Delta x}\right)^2 + \frac{1}{2}\left(\frac{\Delta u_y}{\Delta x} + \frac{\Delta u_x}{\Delta y}\right) + \left(\frac{\Delta u_y}{\Delta y}\right)^2}\,\left[\frac{m}{s}\right]$$

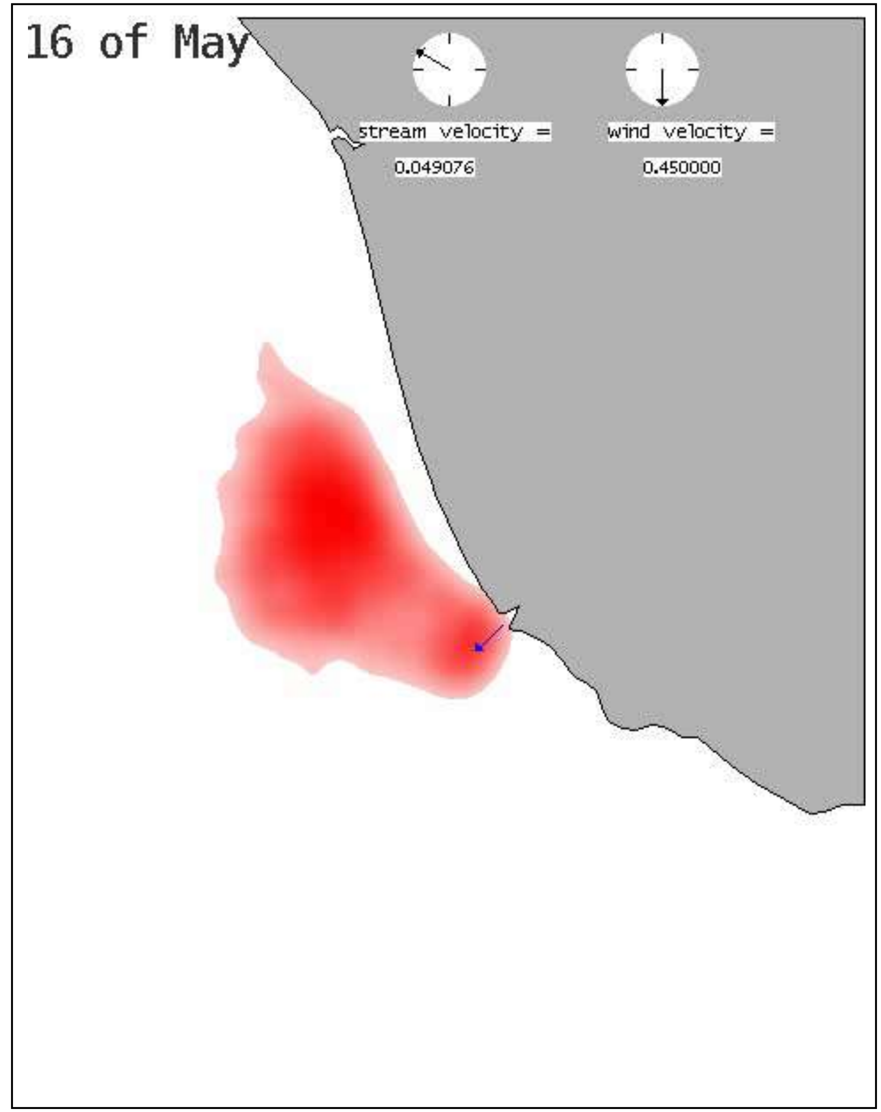
$$D_v = \zeta_v (1 - \min(1, Ri)^2)^3 \left[\frac{m}{s}\right]$$

Time step: 10 minutes

Input data: local wind, coastal currents, river discharge volume

Vertical dissipation: $\sim Ri^{-2/3}$

Horizontal mixing: Smagorinsky formula + random walk scheme



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STRiPE – Lagrangian model of a river plume

1. A. Osadchiev and P. Zavialov
Lagrangian model of a surface-advected river plume
Continental Shelf Research, 58: 96-106, 2013.

2. K. Korotenko, A. Osadchiev, P. Zavialov, R.-C. Kao, C.-F. Ding
Effects of bottom topography on dynamics of river discharges in tidal regions: case study of twin plumes in Taiwan Strait
Ocean Science, 10: 865-879, 2014

3. A. Osadchiev, P. Zavialov, A. Polukhin, A. Izhitskiy, V. Pelevin, P. Makkaveev, and Z. Toktamysova
Structure of the buoyant plume formed by Ob and Yenisei river discharge in the southern part of the Kara Sea
submitted to *Journal of Physical Oceanography*

4. A. Osadchiev, K. Korotenko, P. Zavialov, W.-S. Chiang, C.-C. Liu
Transport and bottom accumulation of fine river sediments under typhoon conditions and associated submarine landslides
submitted to *Natural Hazards and Earth System Sciences*

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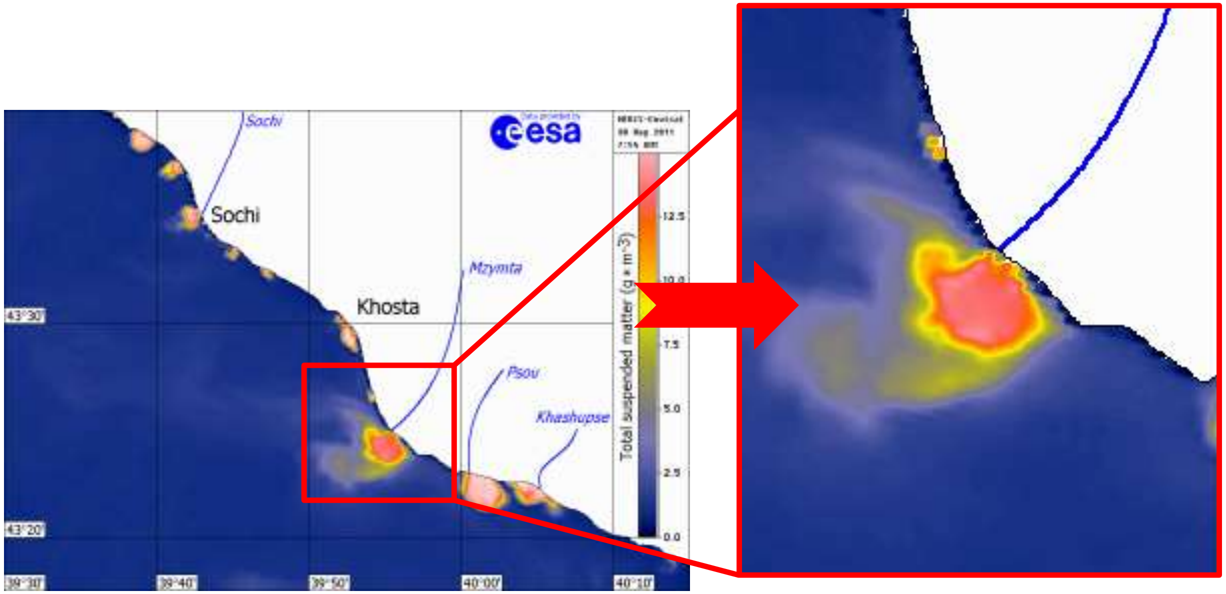
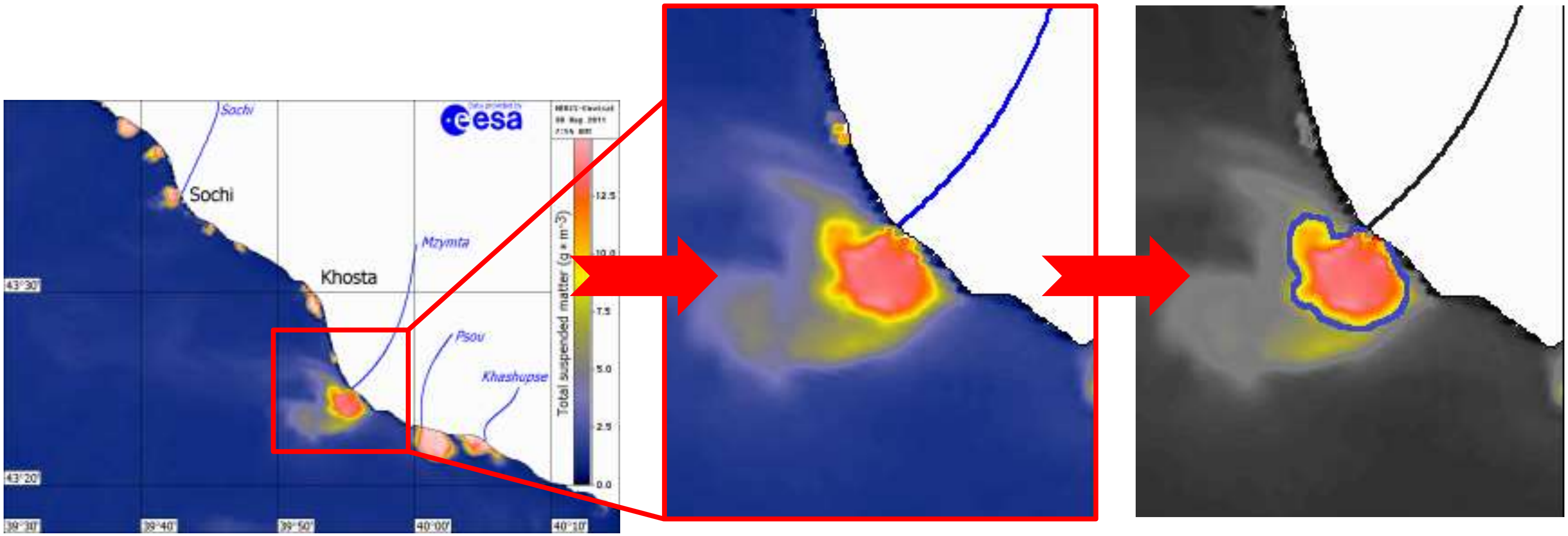
Quantifying freshwater discharge from satellite observations and Lagrangian modelling of river plumes



1. The initial satellite image.

Quantifying freshwater discharge from satellite observations and Lagrangian modelling of river plumes



1. The initial satellite image.
2. Identification of border and spatial structure of the plume.

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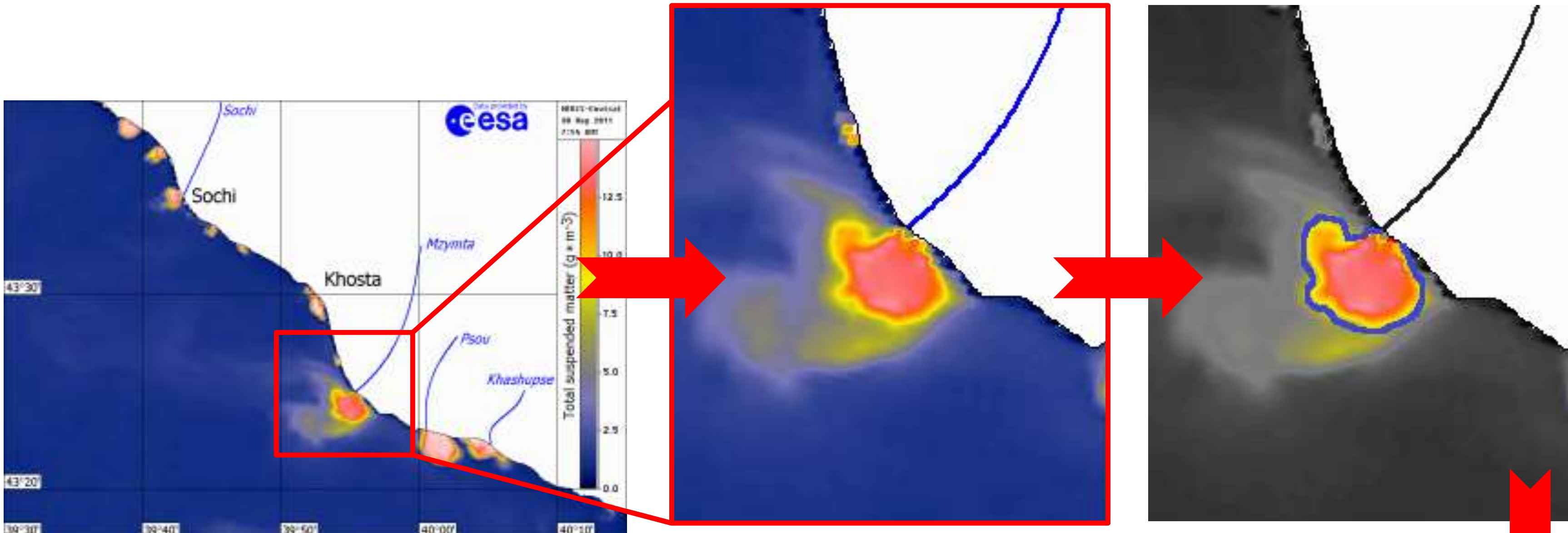
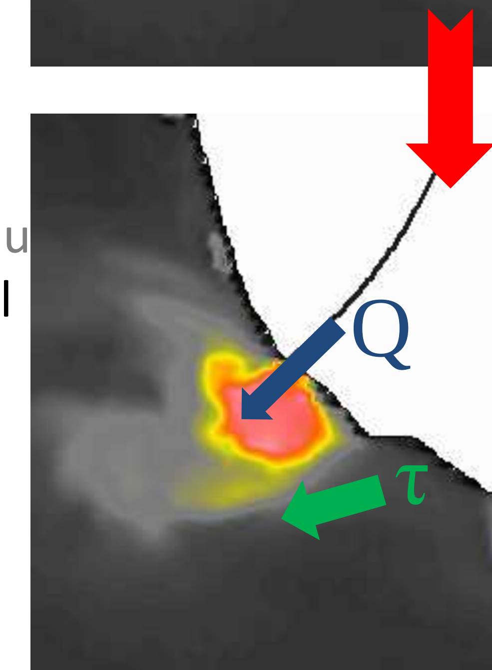
Quantifying freshwater discharge from satellite observations and Lagrangian modelling of river plumes



1. The initial satellite image.
2. Identification of border and spatial structure of the plu
3. Prescribing river discharge and external forcing model configuration



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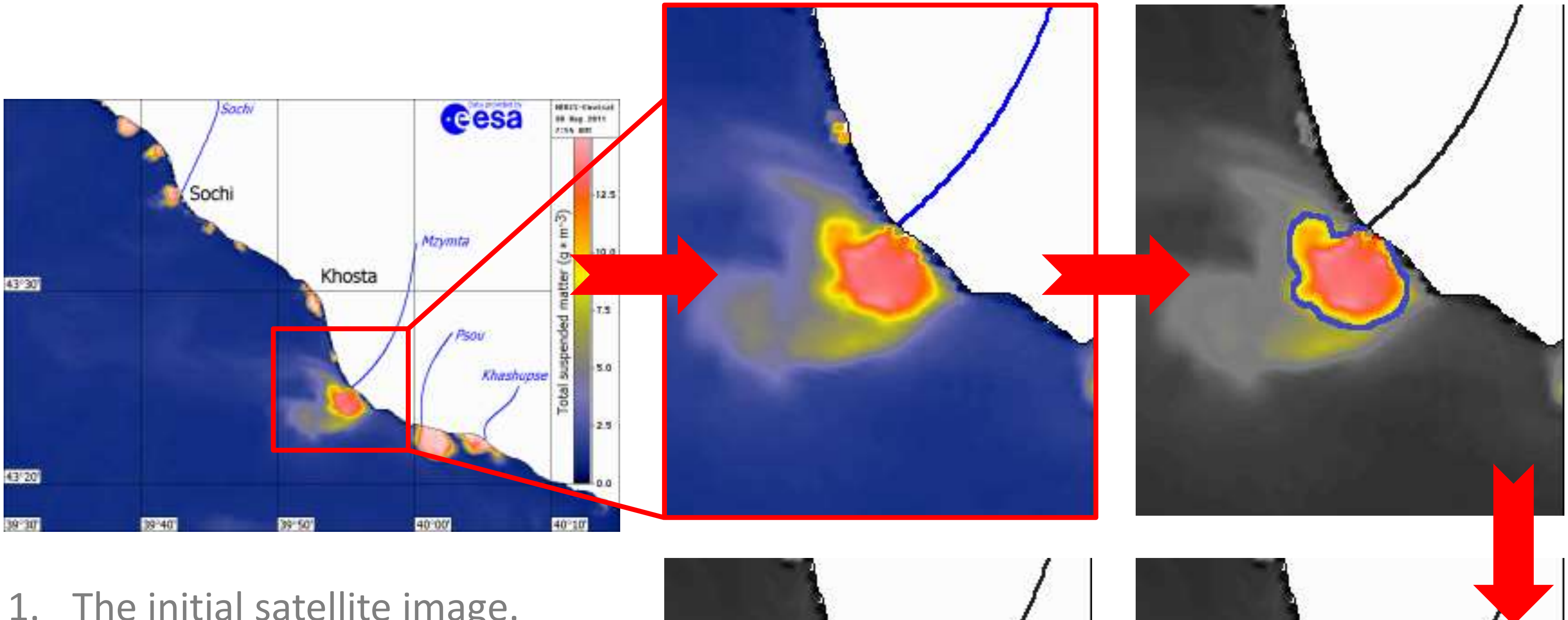

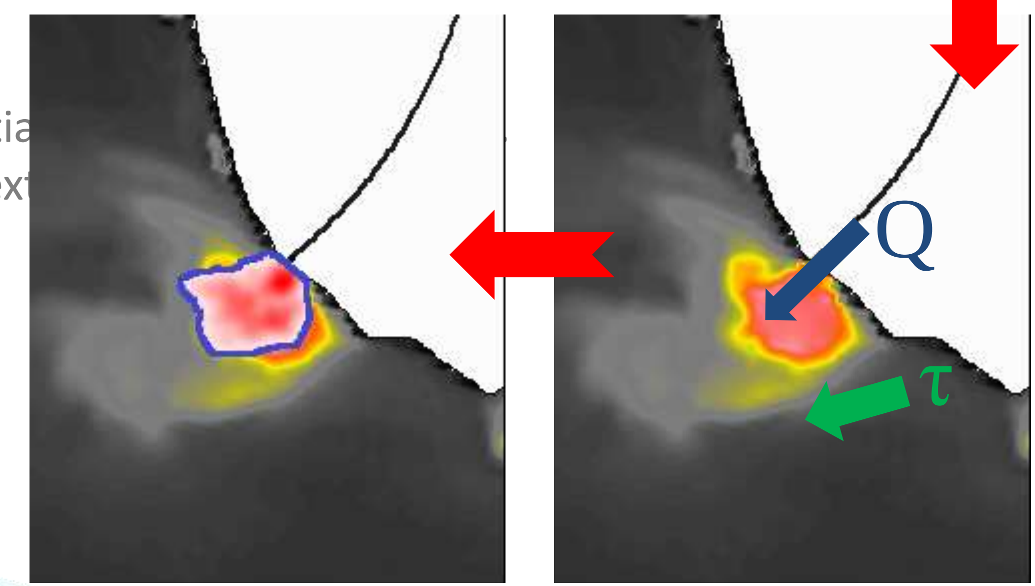

1. The initial satellite image.
2. Identification of border and spatia
3. Prescribing river discharge and ext configuration
4. Modeling river plume under prescribed conditions

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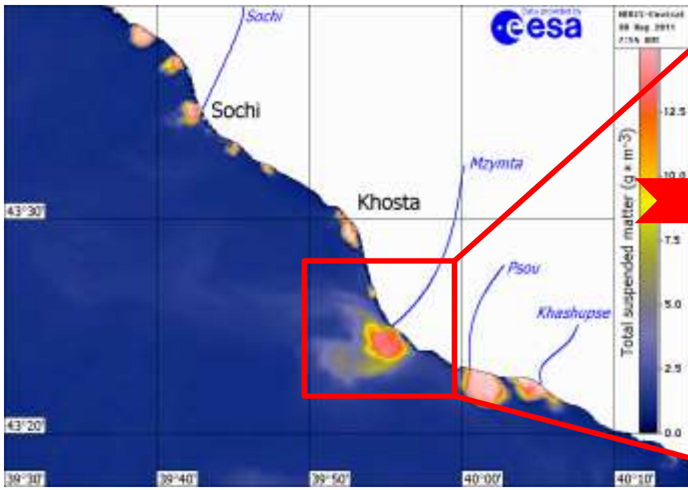
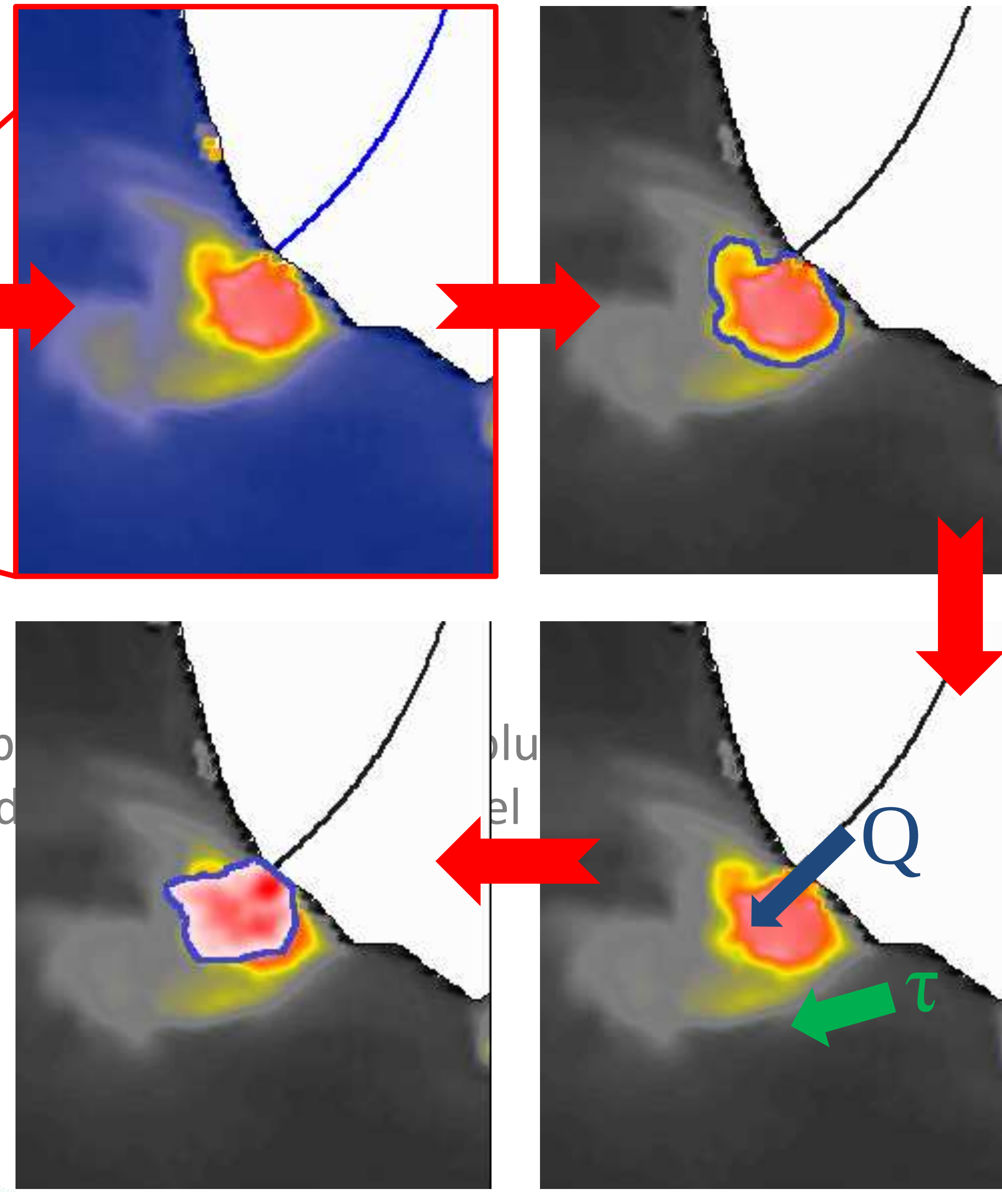
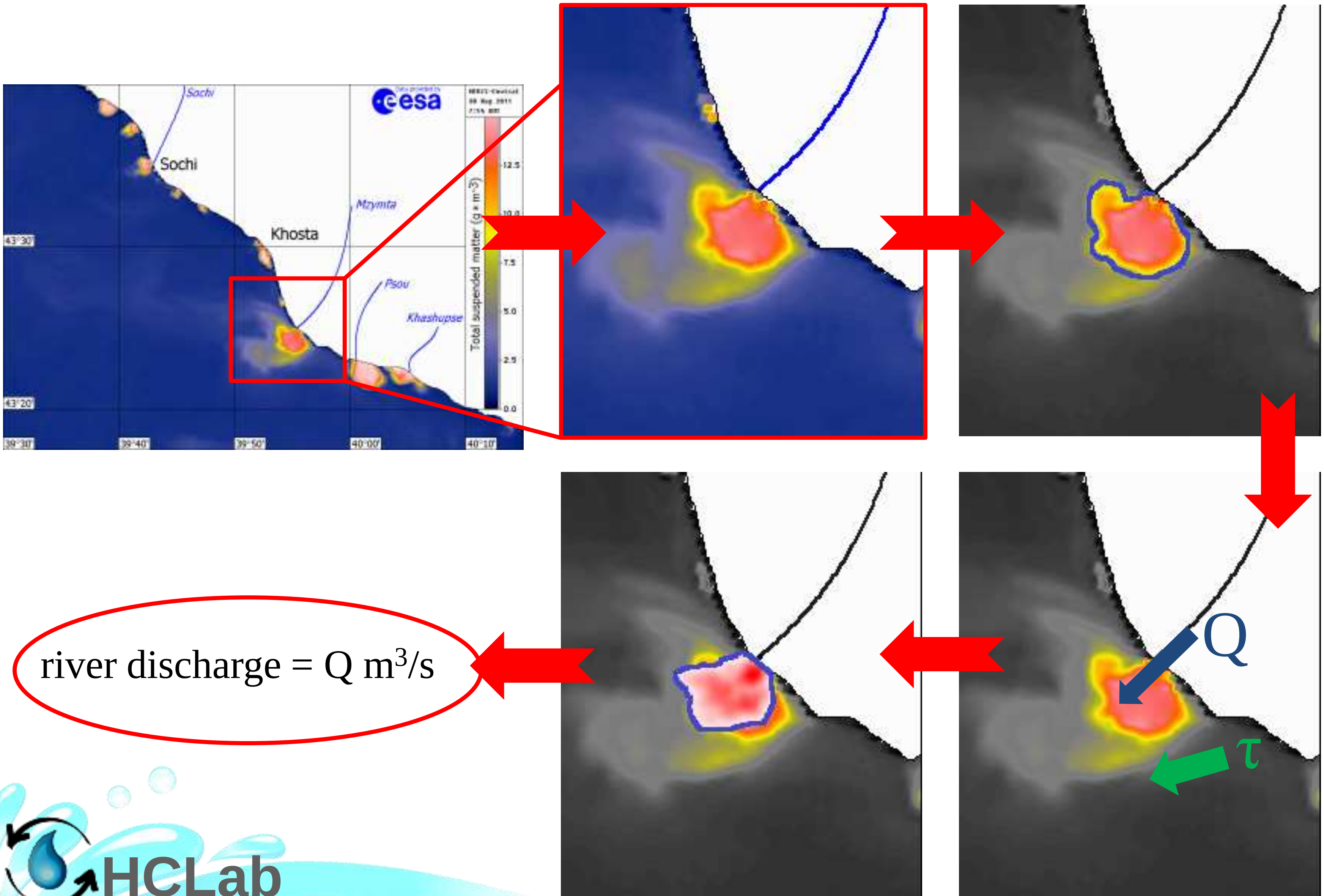
Quantifying freshwater discharge from satellite observations and Lagrangian modelling of river plumes





1. The initial satellite image.
2. Identification of border and sp … plu
3. Prescribing river discharge and … el configuration
4. Modeling river plume under prescribed conditions
5. Comparing the modeled and the observed plumes.

Quantifying freshwater discharge from satellite observations and Lagrangian modelling of river plumes

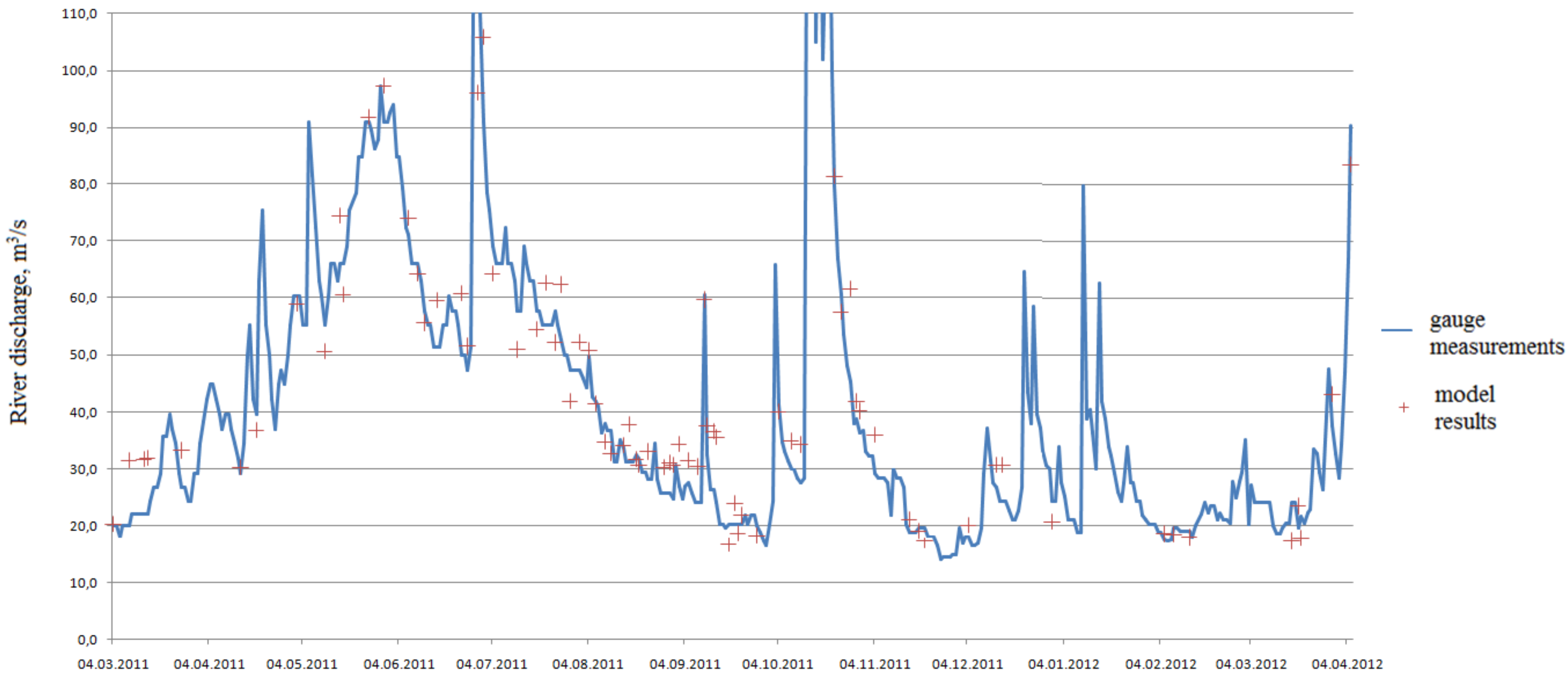


Application of the method for rivers at the Russian Black Sea coast

Mzymta River – average annual discharge 50 m^3/s

Sochi River – average annual discharge 16 m^3/s

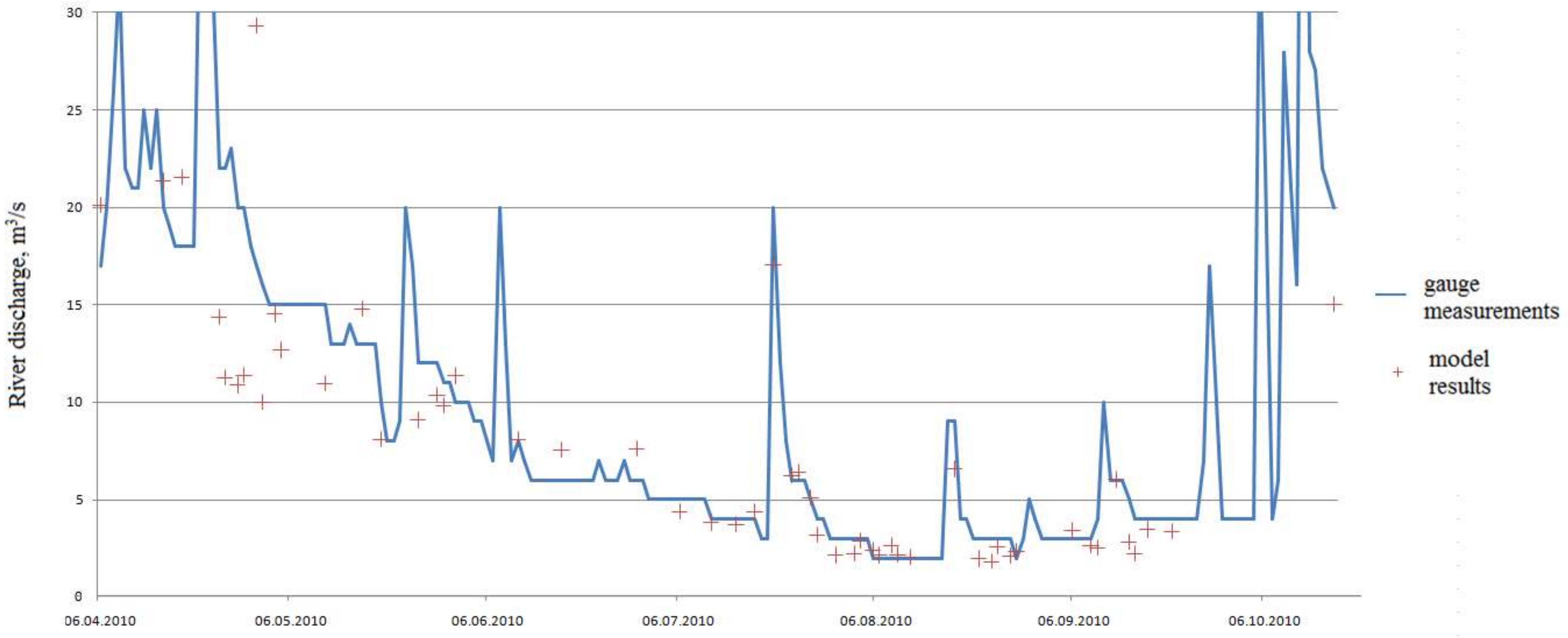
Validation for the Mzymta River (April 2011 – April 2012)



77 points in total

Average error – 15%

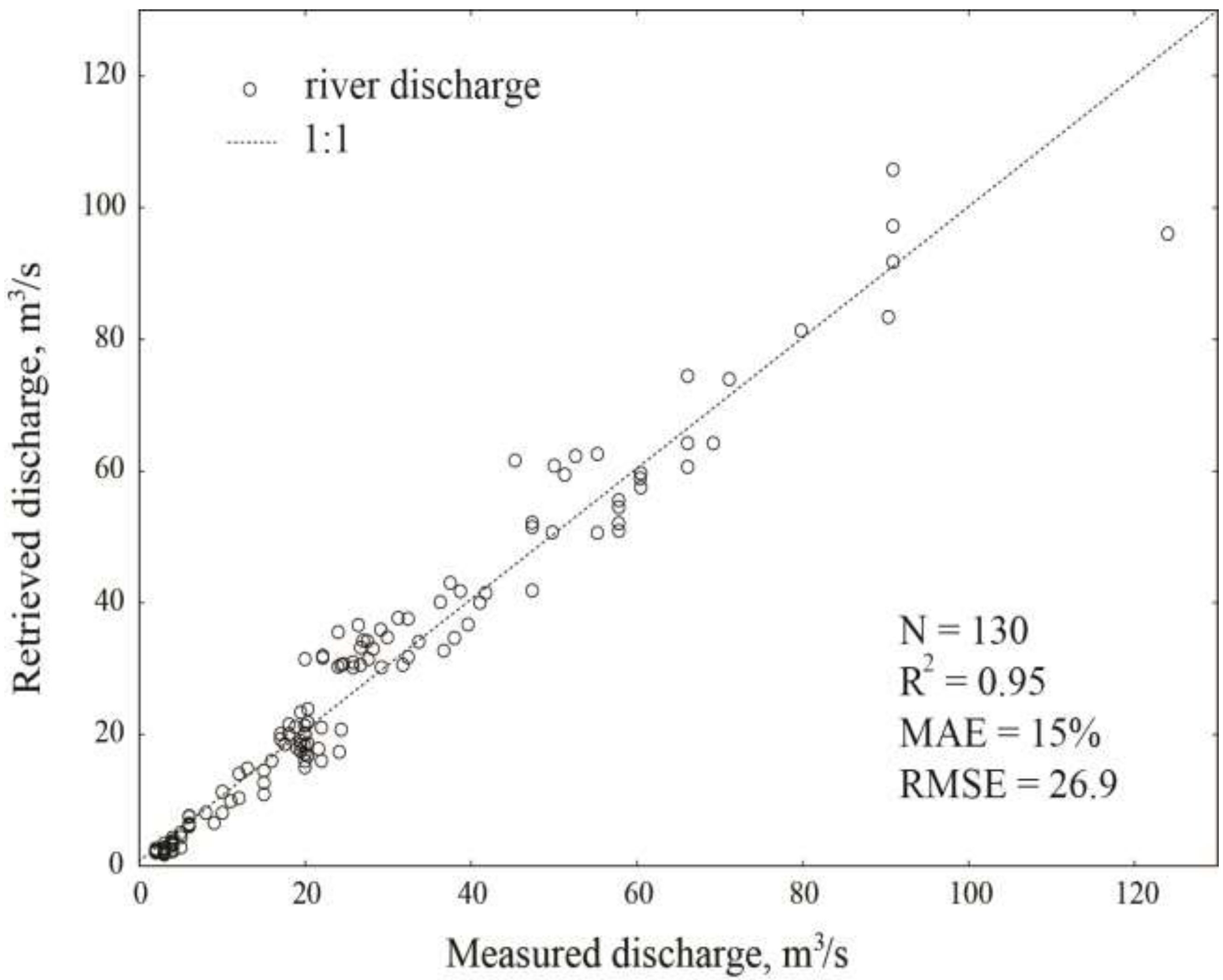
Validation for the Sochi River
(April 2010 – October 2010, 53 points)



53 points in total

Average error – 21%

Validation results



Quantifying freshwater discharge from satellite observations and Lagrangian modelling of river plumes

A. Osadchiev
A method for quantifying freshwater discharge rates from satellite observations and Lagrangian numerical modeling of river plumes
Environmental Research Letters, 10, 085009, 2015.

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Summary and conclusions

- A Lagrangian particle tracking model of a surface-advected river plume (STRiPE) is developed. The main advantage of STRiPE lies in its ability to provide realistic results at relatively low computational cost as compared to Eulerian models.
- A method of estimating river discharge using satellite imagery and numerical modeling was developed. This method is an alternative for the expensive and laborious direct measurements of the river discharge.
- The proposed method can be used to evaluate freshwater discharges from small rivers with narrow riverbeds and complex watershed systems like deltas and coastal marshes where other indirect methods encounter substantial difficulties.
- Remote sensing techniques aimed at obtaining indirect estimates of the discharge from small rivers hold promise to provide improved quantitative assessments and new insights into the land-ocean fluxes of freshwater, dissolved and suspended matter, nutrients and pollutants at the global and regional scales.

Thank you for your attention!

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