Practice of UV lidar application to the total suspended sediments evaluation in the near-surface waters

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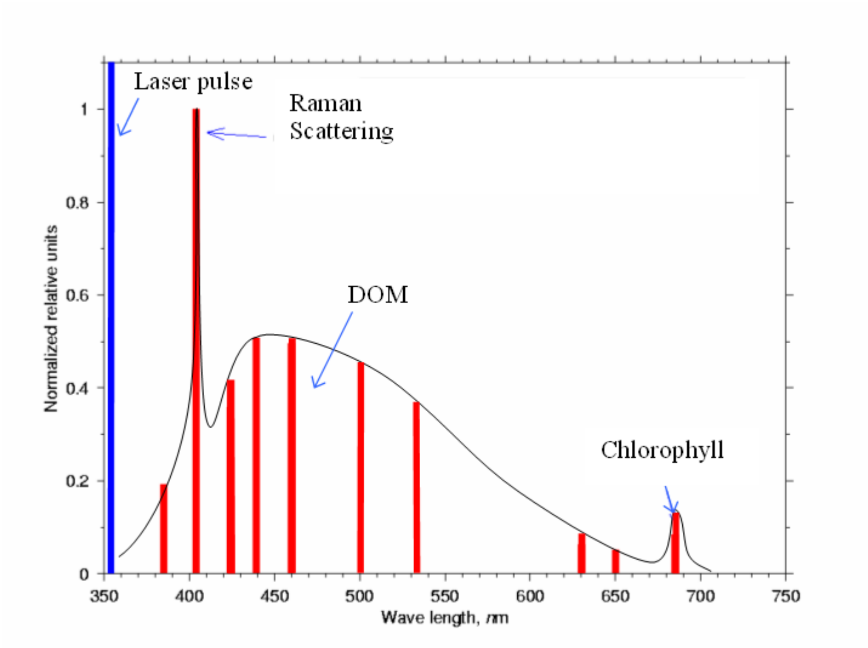
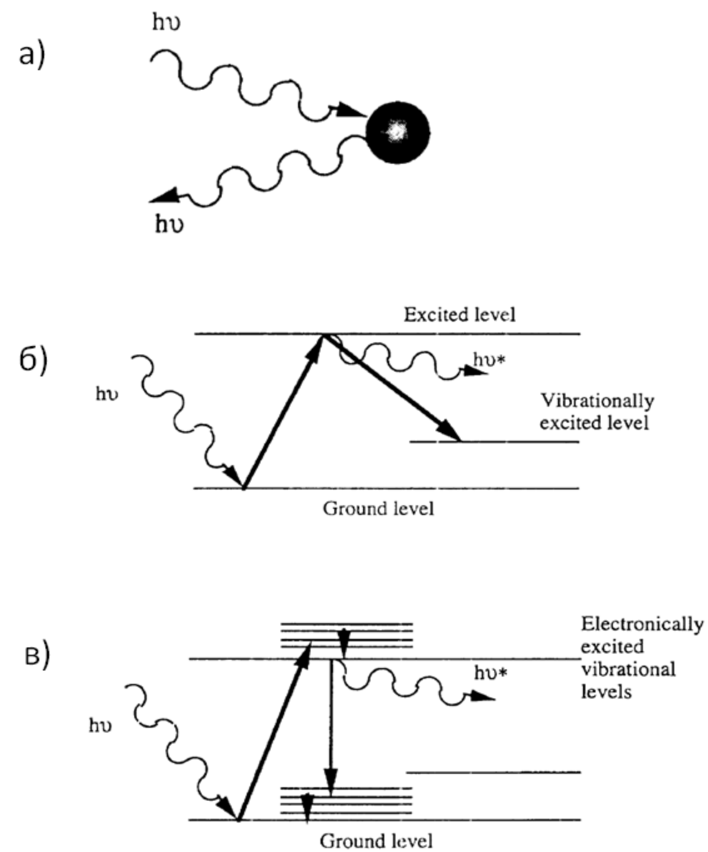
Basis of the method



Typical laser-induced fluorescence spectrum of natural waters



Hoge et al., 1988; Measures, 1992; Fang, 1994; Babichenko et al., 2003

Basis of the method

Laser pulse of energy $\mathbf{N_0}$ is sounding the sea surface in the direction, closely to vertical line. To the depth **z** it is coming energy equals to

$$N = N_0 \cdot \exp(- K_{d355}\, z),$$

where K_{d354} - vertical attenuation coefficient.

A layer of water with depth **dz** scatters back radiation of energy that equals to

$$dN_{355} = N_0 \cdot \exp(- K_{d355}\, z) \cdot \beta_{355}\, dz$$

where $\boldsymbol{\beta_{355}}$ – backward scattering coefficient by elementary volume of water at λ=355 nm.

Scattered back (BS) by elementary layer and reached to the surface energy equals to

$$dN_{BS} = N_0 \cdot \exp(-2\, K_{d355}\, z) \cdot \beta_{355}\, dz$$

Full energy scattered by semi-infinite sea medium in the direction back to the laser beam follows: (after integration by z):

$$N_{BS} = N_0 \cdot \beta_{355} \cdot 1/(2K_{d355})$$

Portion of energy having hit into the photo detector considered by introduction of multiplier **G**

$$\mathbf{N_{BS} = N_0 \cdot \beta_{355} \cdot G \cdot 1/(2\, K_{d355})}$$

Here G – «geometrical» factor, it is dependent on the altitude of the lidar above the sea surface, the slope angle of laser axle to the horizon and to the border “water-air” plane and etc.

Basis of the method

The energy of the pulse of Raman scattering that reached the receiver (i.e. N_{RS}) equals:

$$\mathbf{N_{RS} = N_0 \cdot \gamma_{RS} \cdot G \cdot 1/(K_{d405} + K_{d355})}$$

where γ_{RS} is a constant, which is defined by Raman scattering of water medium.

The concentration of TSM estimation can be made on a basis of lidar measurements by the following way. As follows from the formulas shown above for N_{BS} and N_{RS}, quotient after their division one on another equals to β_{354}/γ_{RS} (taking into account that $2\alpha_{355} \cong (\alpha_{355} + \alpha_{405})$). From that here is the following equation:

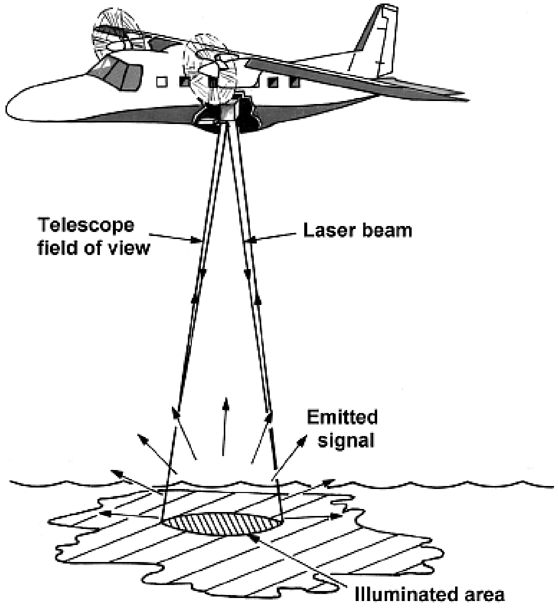
$$\mathbf{\beta_{355} = k\, N_{BS}/N_{RS}}$$

where k – a calibrating coefficient.

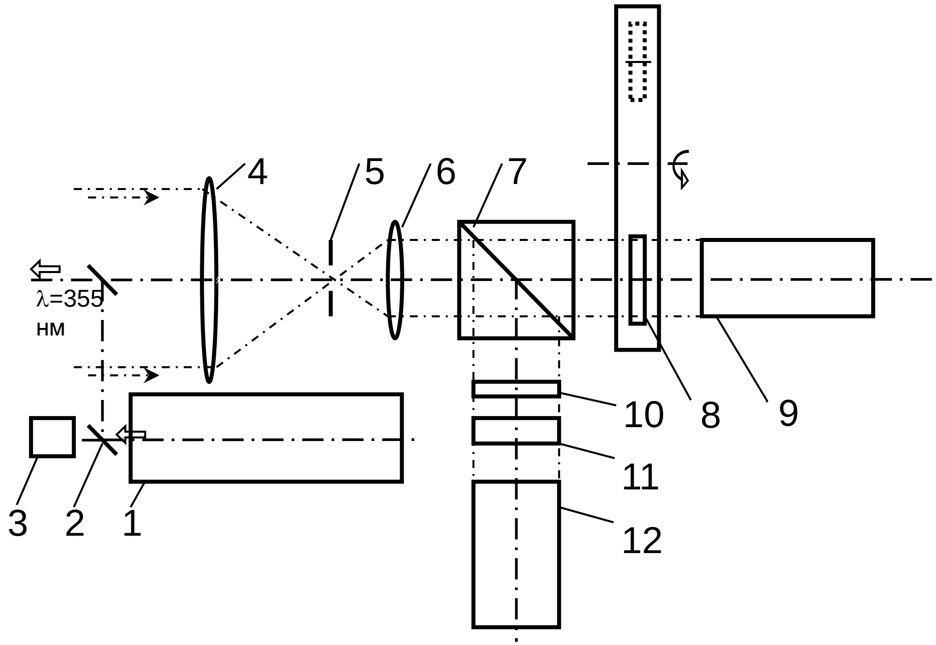
Suspended matter concentration we suppose is proportionate to β_{354}, i.e. backward scattering coefficient of the medium at this wavelength, with the deduction of backward scattering being created by the "absolutely pure" sea water.

Limitations of the method:

- Foam on the sea surface - OK
- Bubbles in the water - OK
- Fog and aerosol in the air on the way of laser beam - NO WAY
- Difficulties for airplane applications - Strongly limited

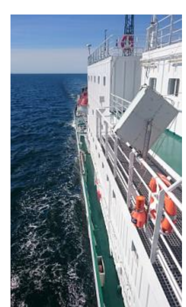


LiDARs UFL series



Principal optical scheme
of the compact fluorescent LiDAR UFL-7

1- laser; 2- coaxial system; 3- energy pulse detector; 4- objective; 5- diaphragm; 6- collimating optics; 7- beam splitter; 8,10- dichroic filters; 9,12- photomultipliers; 11- attenuator



UFL-9 LiDAR specification:

- **Excitation laser wavelengths – 355 and 532 nm**
- **Pulse repetition rate – 2 Hz**
- **Pulse energy – 2+2 mJ**
- **Pulse duration – 6 ns**
- **Telescope clear aperture - 140 mm**
- **Working distance range – 1.5÷25 m**
- **Receiver central wavelength, transect mode - 355, 404, 440, 685 nm**
- **Additional spectral channels - 385, 424, 460, 499, 532, 620, 651 nm**
- **Dimensions, weight – 800 × 550 × 250 mm; 35 kg**
- **Power supply – 220 AC / 12 DC**
- **PC-controlled, GPS geo tagged**
- **Water-proof housing, working at any weather or sunlight conditions**

Основные параметры флуоресцентного лидара УФЛ-9

- Длина волны лазера – 355, 532 нм;
- Частота зондирования – 2 Гц;
- Энергия зондирующего импульса (355 нм) – 1,5 мДж;
- Длительность зондирующего импульса – 6 нс;
- Входная апертура приемника – 140 мм;
- Диапазон дальностей работы – 2–30 м;
- Количество оптических каналов приемной системы – 4;
- Постоянные спектральные каналы – 355, 404, 440 нм;
- Сменные спектральные каналы приемника в турели –385, 424, 460, 497, 550, 620, 651, 685 нм;
- Вес прибора, габариты – 35 кг, 700x500x230 мм;

ДИАПАЗОНЫ ИЗМЕРЯЕМЫХ ВЕЛИЧИН

концентрация хлорофилла «а», мг/м^3	0,01÷400;
концентрация общего органического углерода, мг/м^3	0,1÷100;
окрашенное органическое вещество ($a_{ООВ,440}$), м$^{-1}$	0,003÷10;
содержание взвеси, мг/л	0,1÷500;
толщина слоя зондирования, м	0,1–10.

Случайные и полные погрешности измерений концентраций хлорофилла «а» [мкг/л], ООВ [мг/л] и взвеси [мг/л] лидарами УФЛ-8 и УФЛ-9:

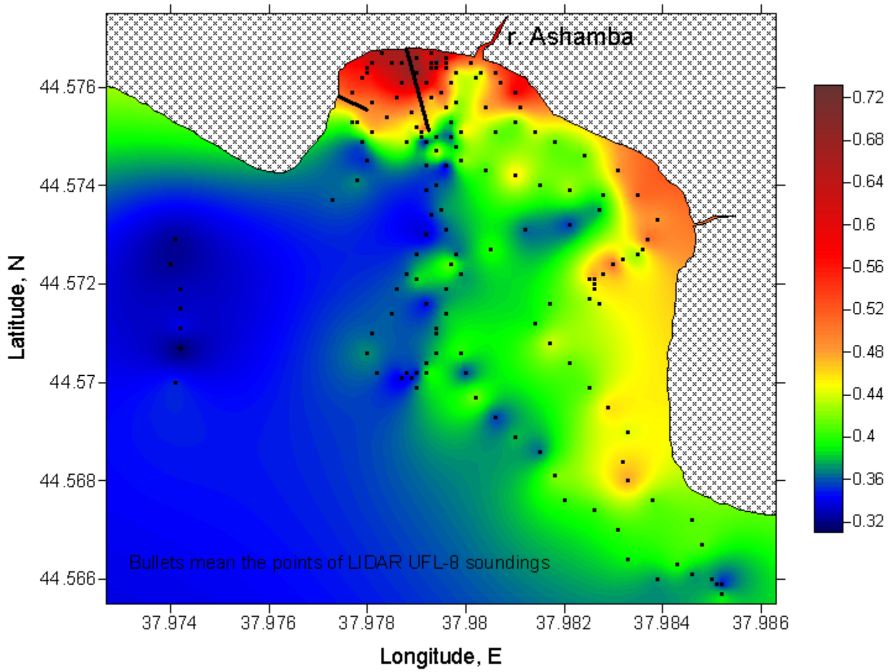
Длина серии, шт.	Хлорофилл «а»		ООВ		Взвесь	
	$\Delta x_{сл}$,%	Δx,%	$\Delta x_{сл}$,%	Δx,%	$\Delta x_{сл}$,%	Δx,%
3 (режим разреза)	12	16	2.5	10	3	10
10 (режим станции)	6	11	2.5	10	3	10
20	5	11	2	10	2	10
100	3	10	1	10	1	10

Mapping water quality parameters, using any kind of research vessel – from the ocean cruise ship to inflatable boats

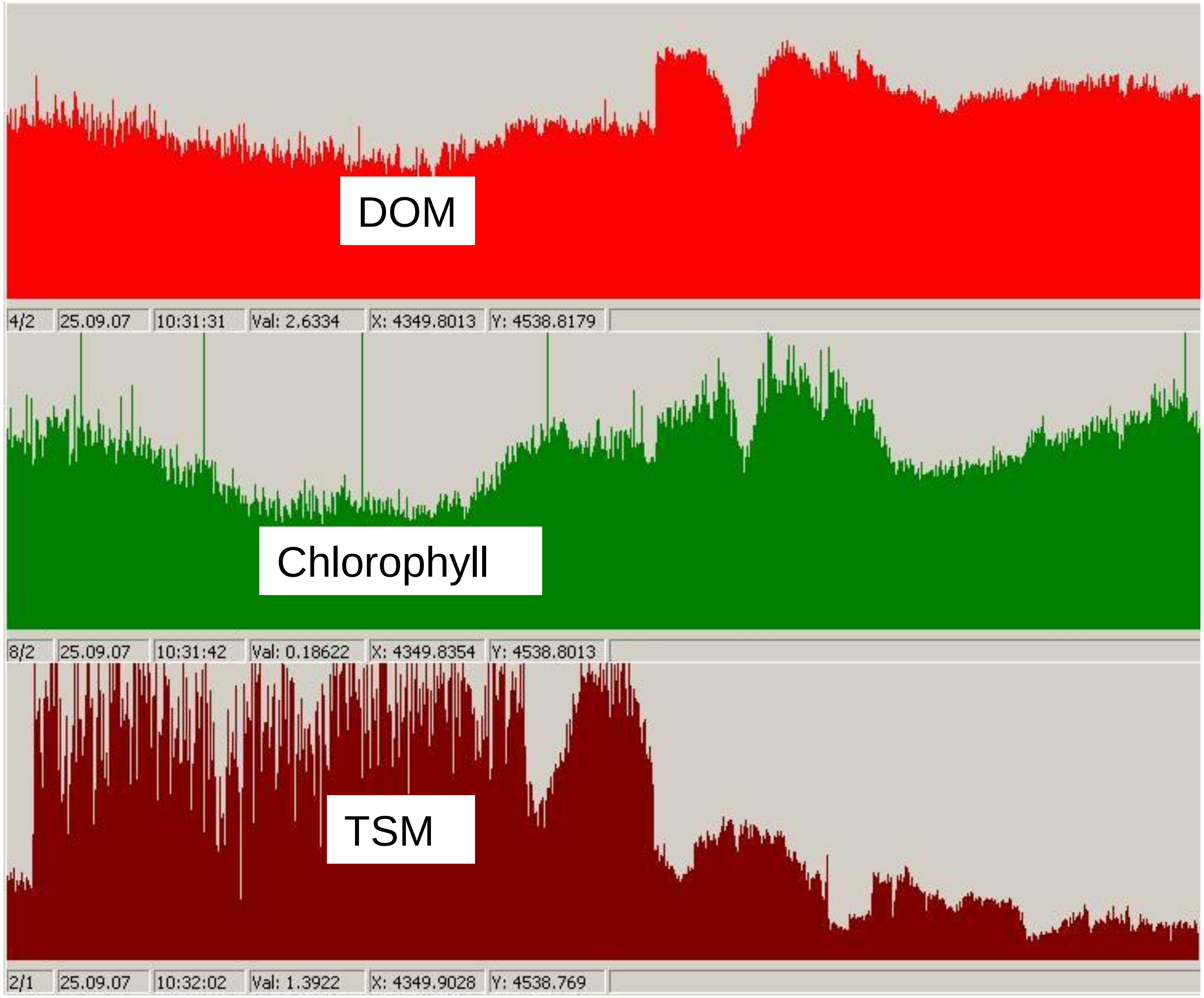
LiDAR UFL-9 obtains with 2Hz sampling rate:

- Oil slick detection and estimation of oil film thickness
- Colored dissolved organic matter (CDOM) concentration
- Chlorophyll *a* concentration
- Total suspended sediments (TSS) concentration

DOM (relative units). Ashamba river, Black Sea, May 2007.



An example of 12-hours section, made by UFL-8 onboard R/V “Akademik M.Keldysh” in 54th cruise in the Kara Sea, 2007.

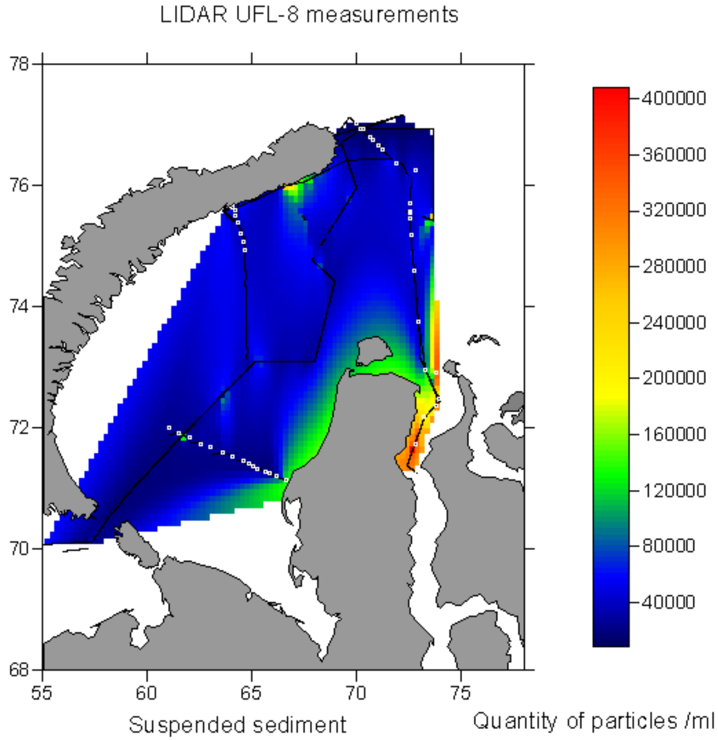


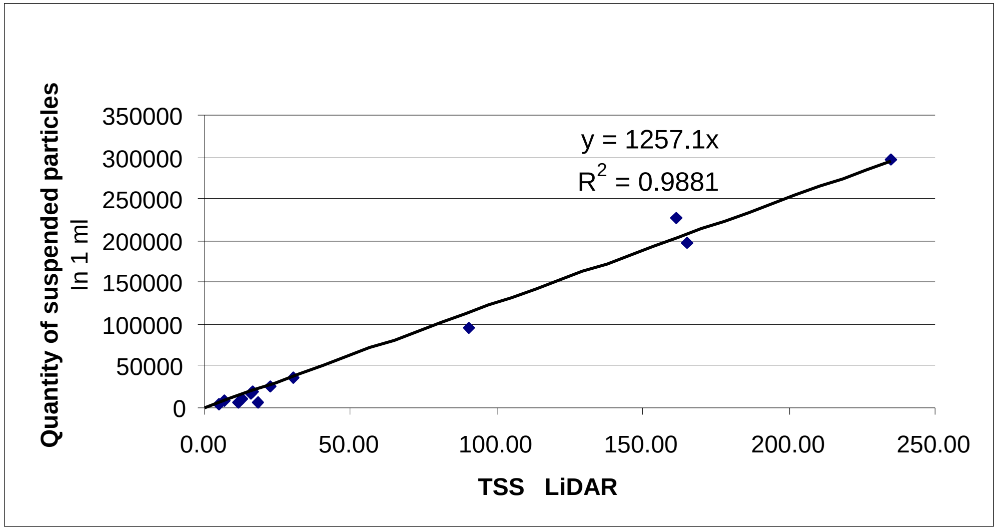
UFL-9 tank experiment, cooperation with Balaton Limnological Institute, 2012

	n	Minimum	Maximum	Average	Median	Standard Deviation
TSM ($g \cdot m^{-3}$)	32	<0.10	128.39	24.21	2.62	39.39
CDOM ($a_{CDOM}(440)$)	11	0.003	0.122	0.013	0.007	0.024
Chla ($mg \cdot m^{-3}$)	32	0.01	377.88	44.86	3.31	96.47

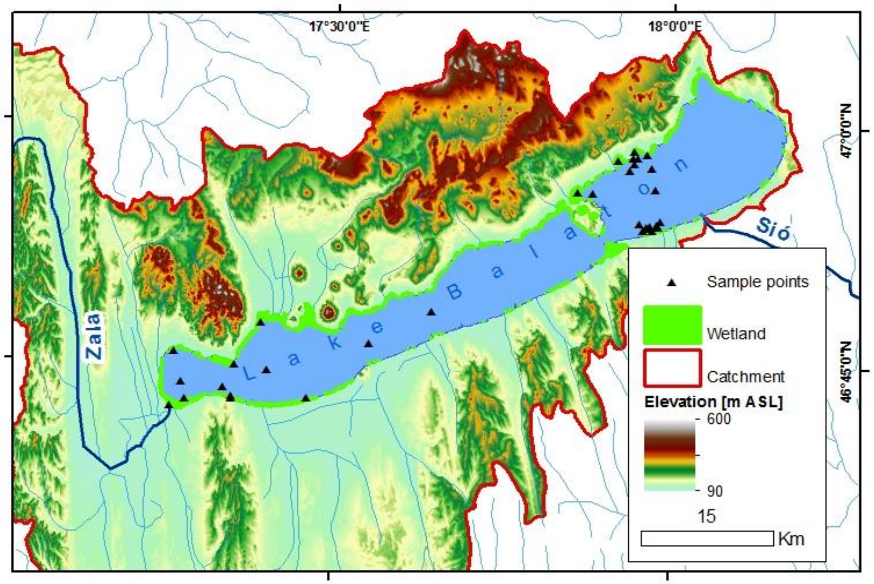
	Equation	R	p
TSM ($g \cdot m^{-3}$)	$7.24 \times UFL_{355} + 57.07$	0.96	<0.001
CDOM ($a_{CDOM}(440)$)	$451.97 \times UFL_{440} - 1.50$	0.97	<0.001
Chla ($mg \cdot m^{-3}$)	$0.003 \times UFL_{685} + 0.04$	0.92	<0.001

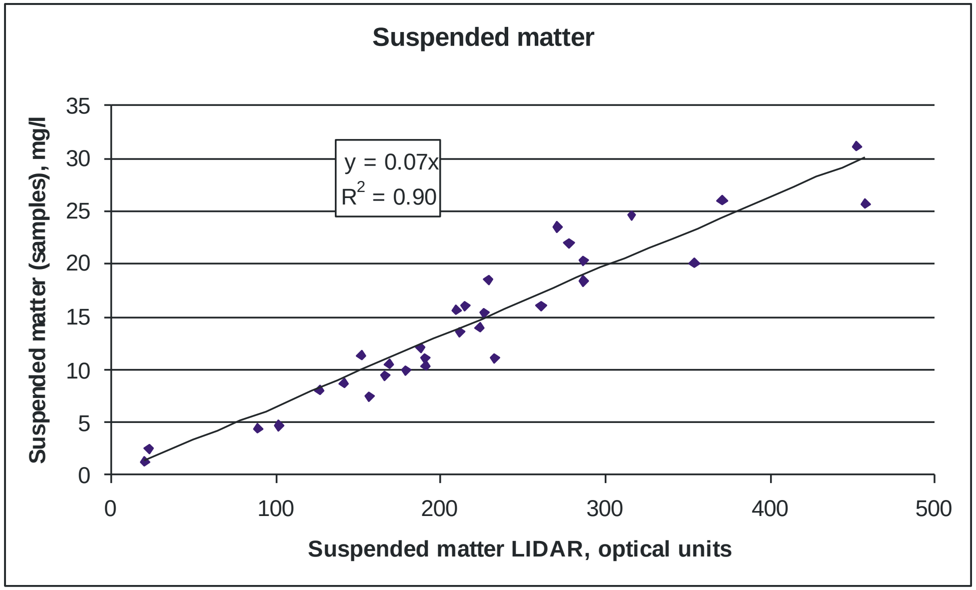
UFL-8 calibration, the Kara Sea, 2007



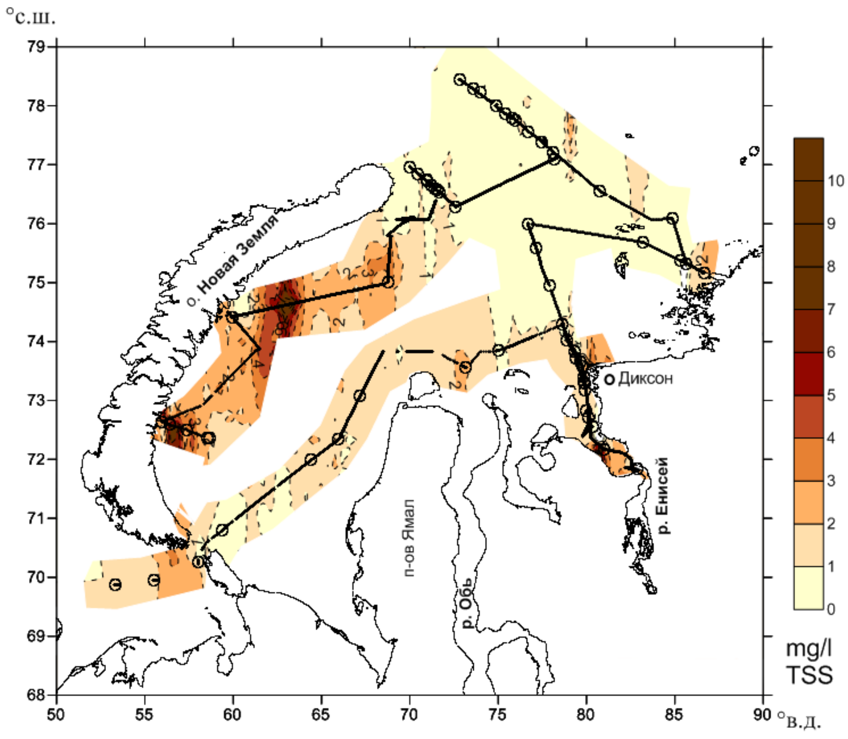


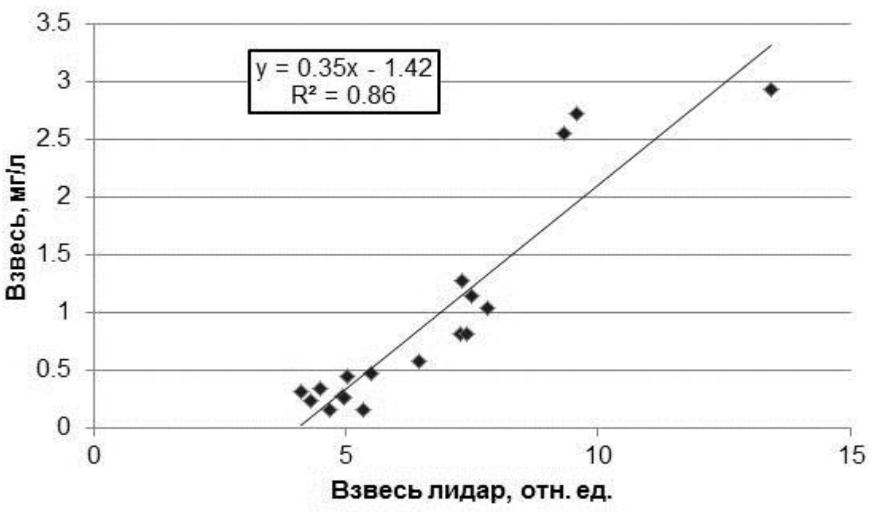
UFL-8 calibration, the Lake Balaton, Hungary, 2008

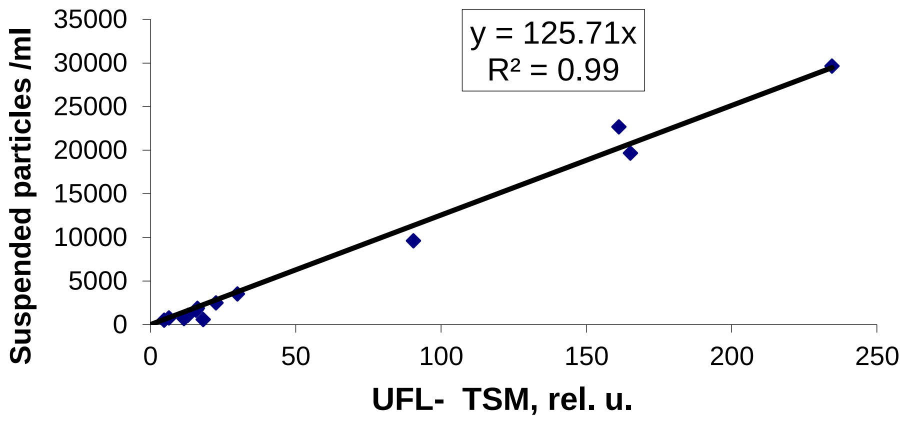




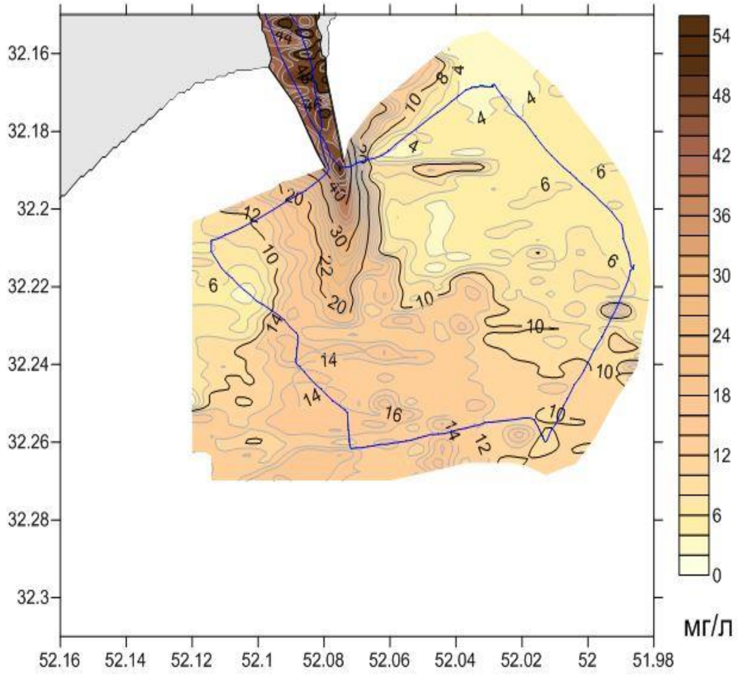
UFL-9 calibration, the Kara Sea, 2011

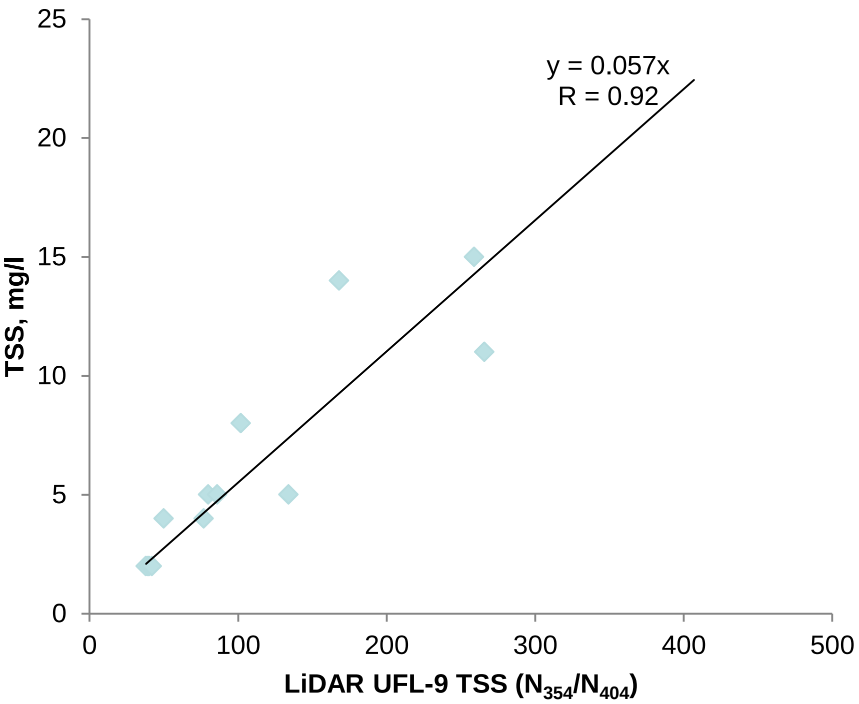




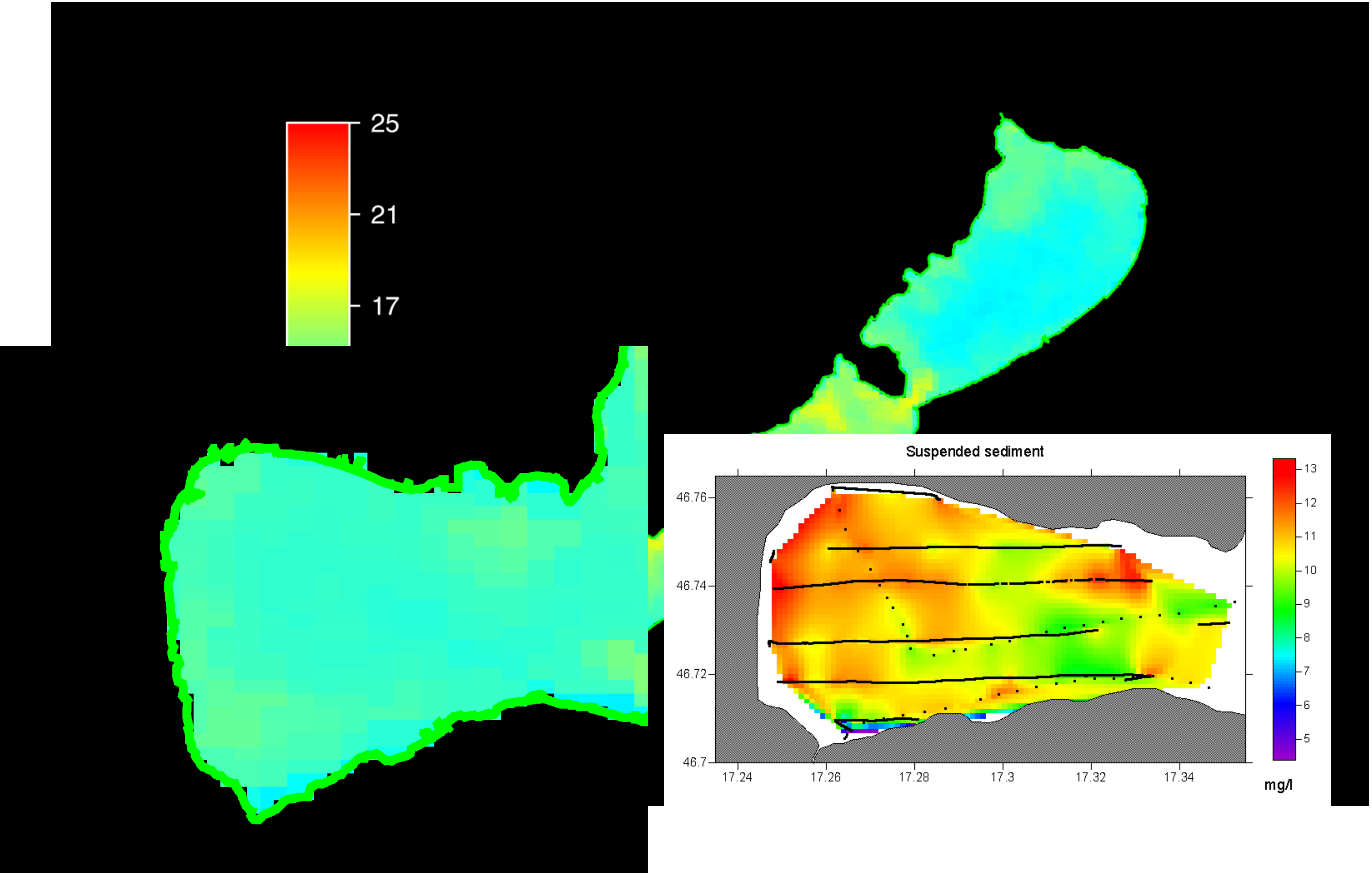


UFL-9 calibration, Riu-Grandi, Brasilia, the Atlantic Ocean, 2016

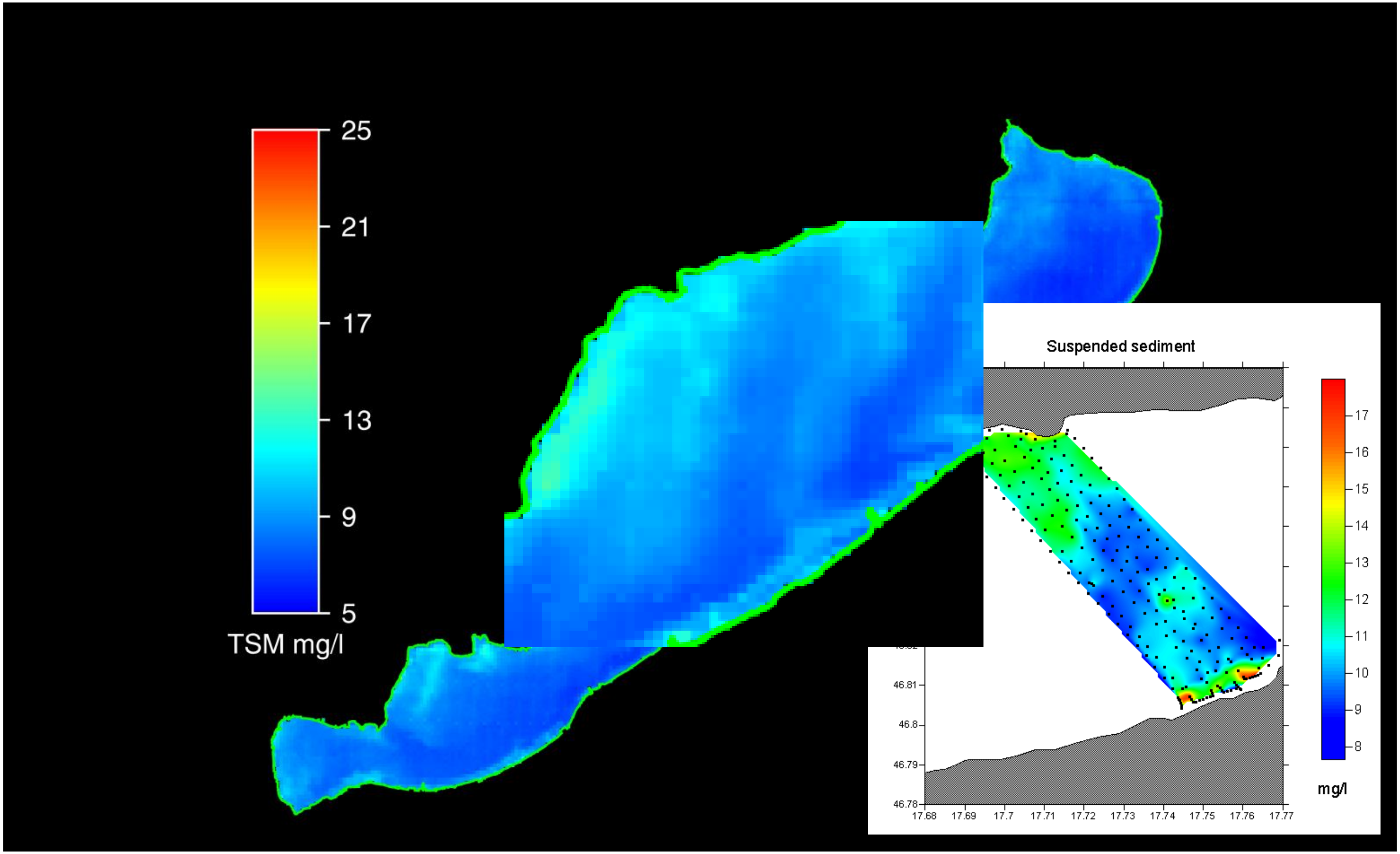




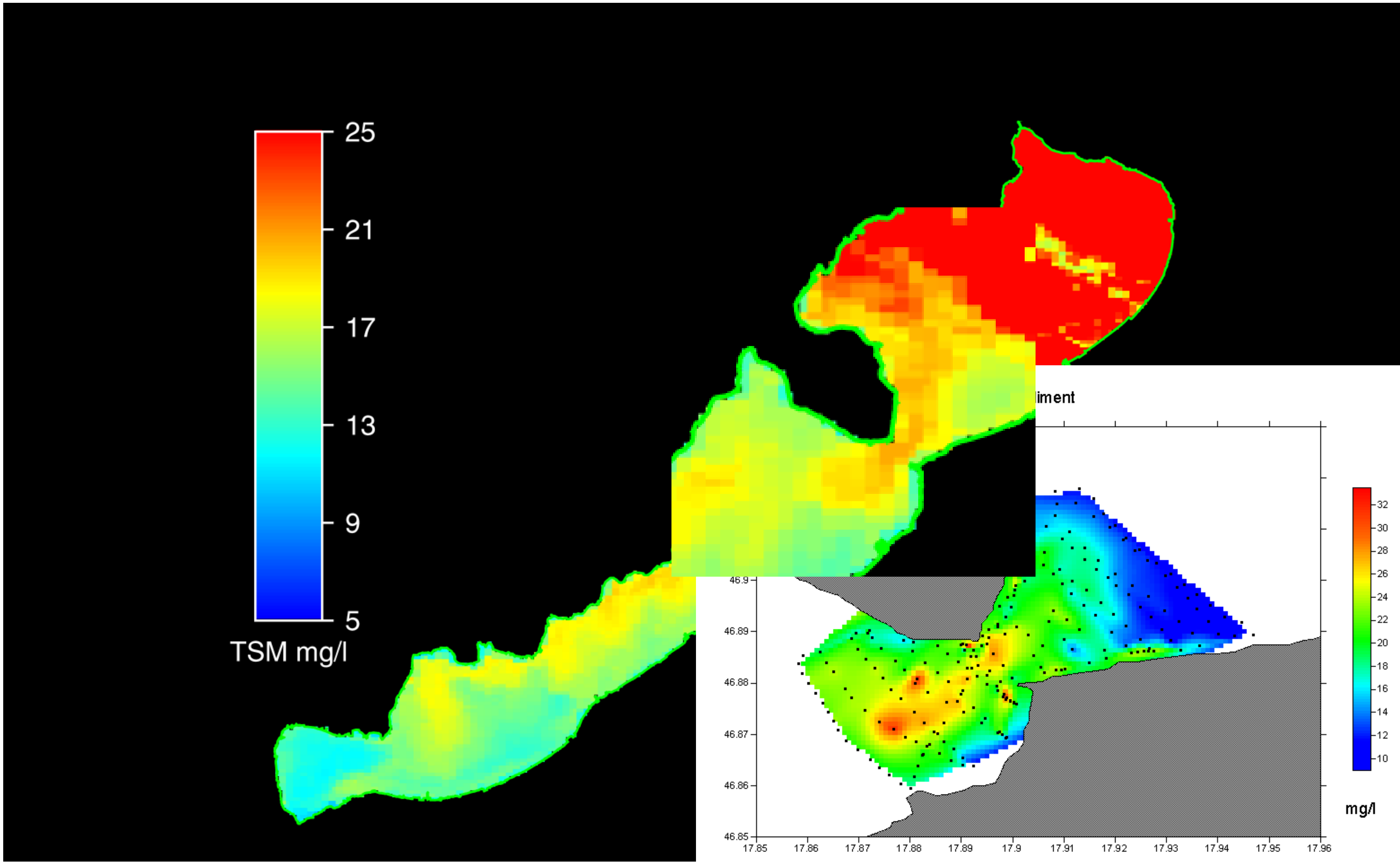
Total Suspended Matter (MODIS Terra & Lidar), 10.09.08.



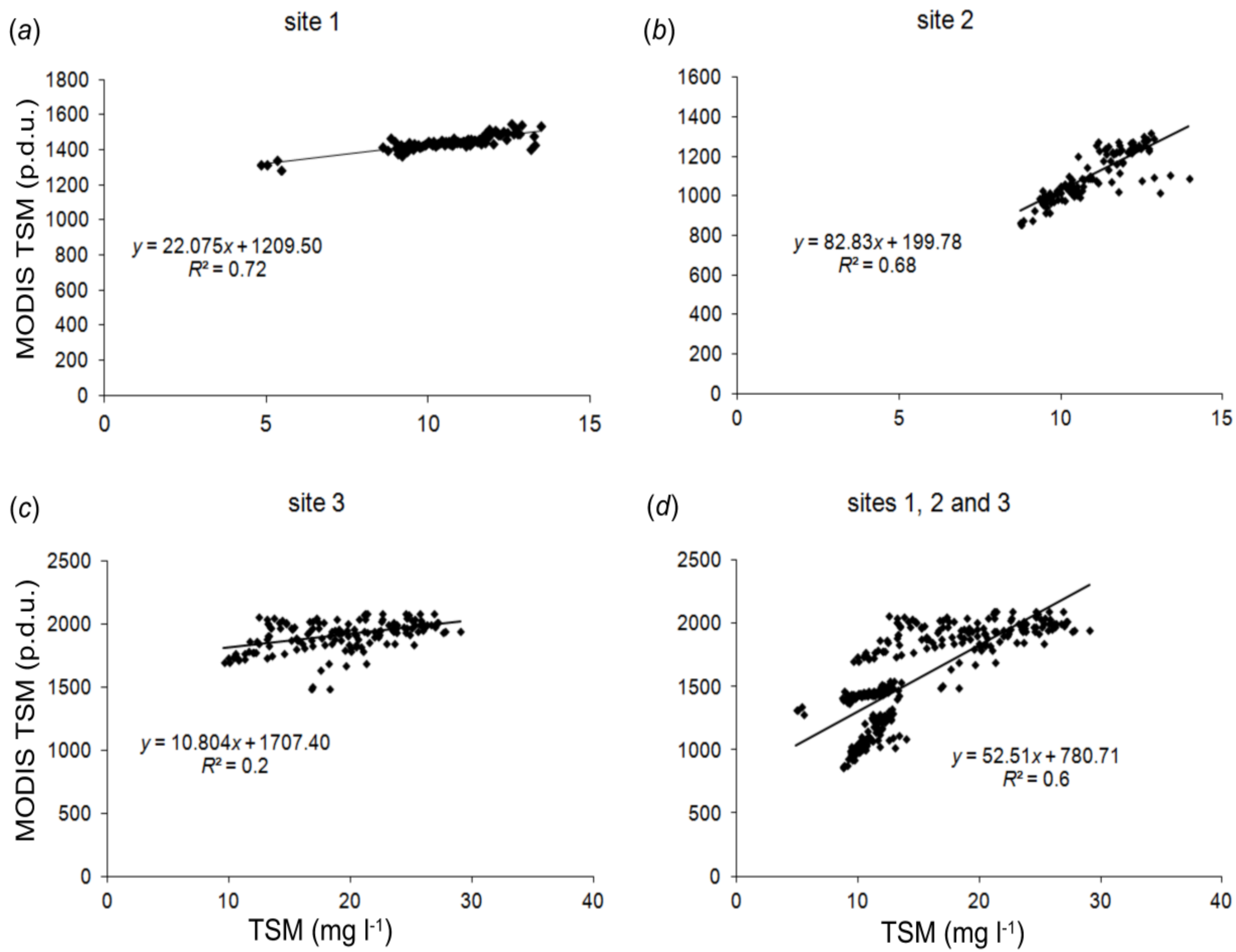
Total Suspended Matter (MODIS Terra & Lidar), 11.09.08.



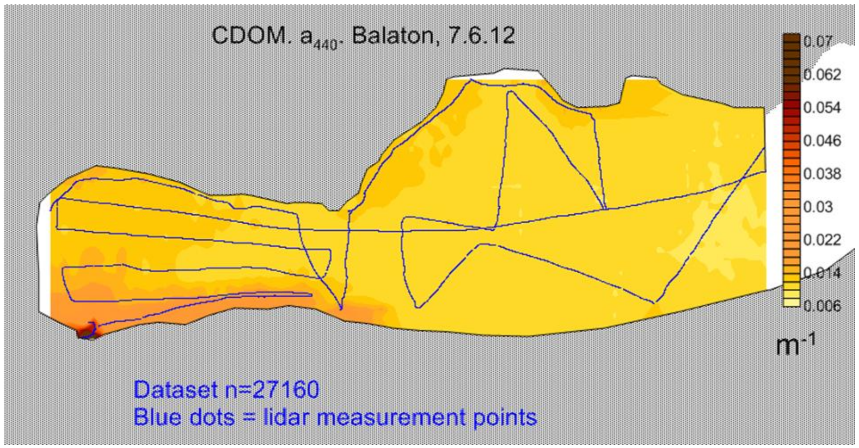
Total Suspended Matter (MODIS Terra & Lidar), 12.09.08.



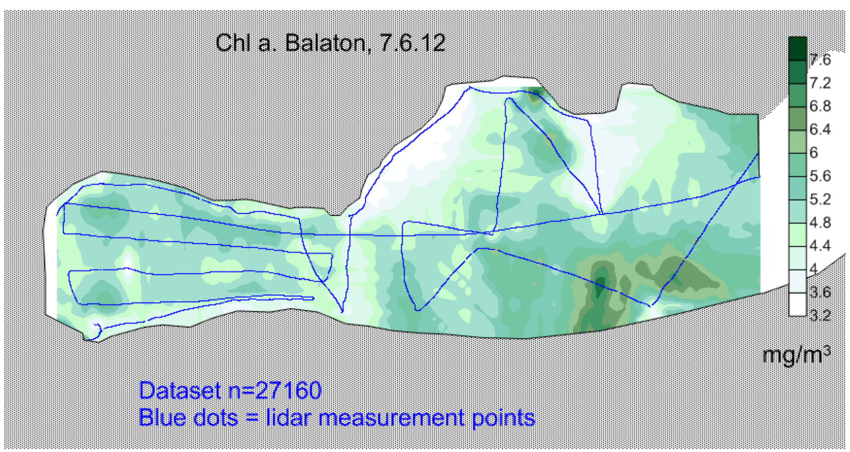
Correlation between MODIS band 1 and UFL8 TSS measurements

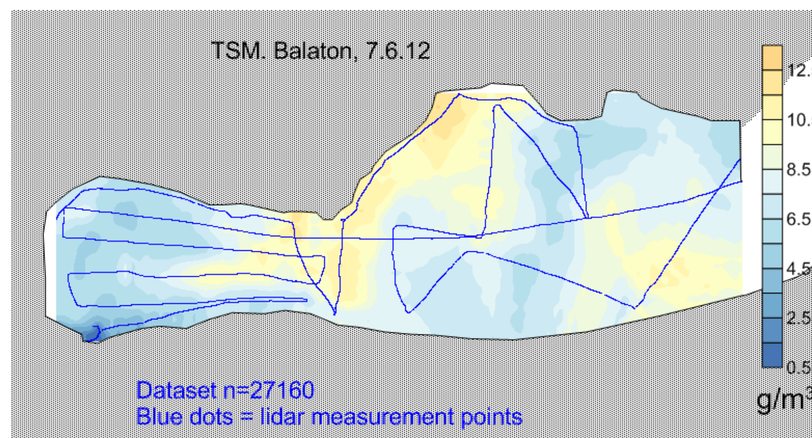


Small-scale variability of chlorophyll, CDOM, and suspended matter in the Lake Balaton as obtained by shipborne UV fluorescent lidar UFL-9

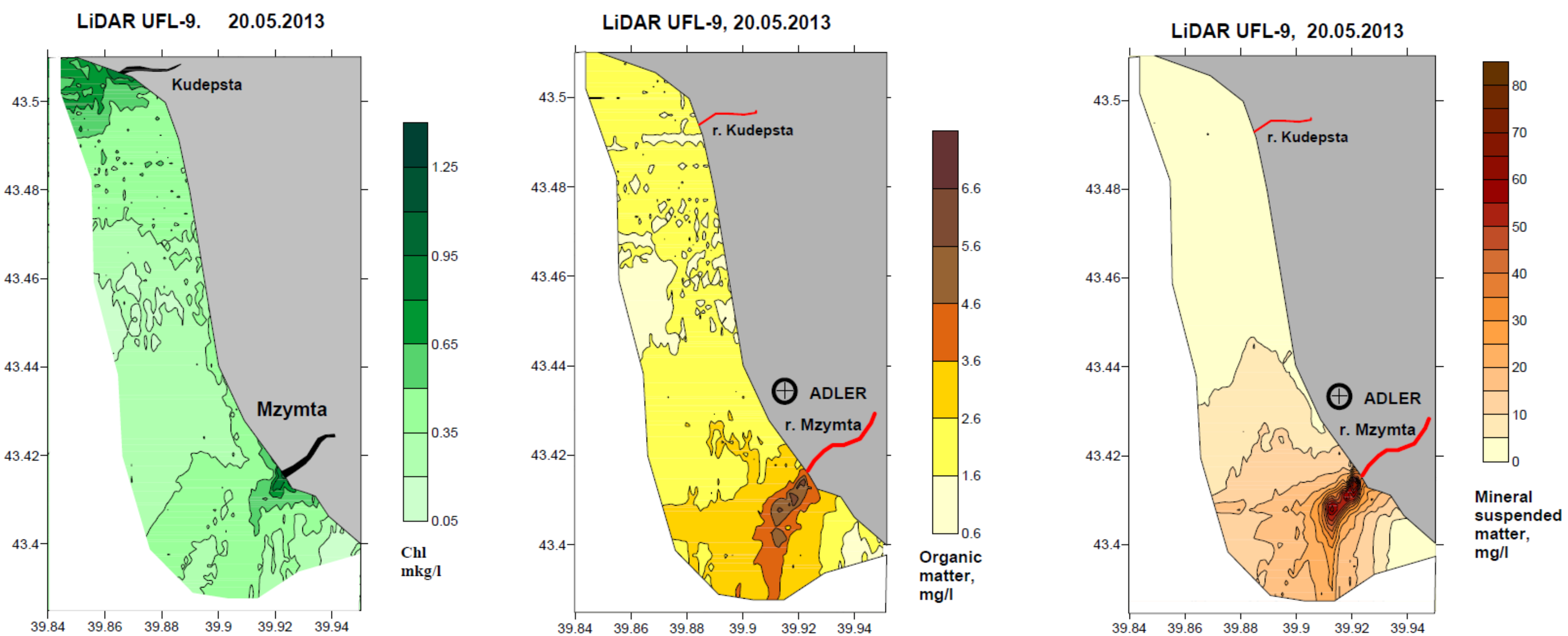


07.06.2012	Patchiness, scales		
	CHL	DOM	TSM
Mean, m	5.1	6.8	37.5
Max, m	32.6	72.4	332.1
Min, m	1.3	1.3	1.3
RMS, data	1.18	0.00154	6.01
RMS/10	0.12	0.00015	0.60





Mzymta River plume, the Black Sea, 2013
LiDAR UFL-9 DOM, chlorophyll, TSM simultaneous measurements



Thank you!