Applications of Airborne Laser Scanning for Water Surface Altimetry on Lake Balaton

→ 8th COASTAL ALTIMETRY WORKSHOP

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Teaser slide :~)

If someone would offer you

- 500 km^2 of water surface altimetry data
- 1 meter horizontal resolution
- 2 cm vertical precision
- In 1 measurement day

What would you do with it?

Some frequent questions of coastal altimetry (a non-experts impression)

- I have a new processing method, how to verify whether it is better than the state of the art?
- We need to understand coastal sea surface height better in high resolution (tides, currents, effect of shore topography)
- How to bridge the gap between single-point reference measurements (buoys, pressure sensors, tide gauges) and satellite altimetry (resolutions at km scale, difficult near shore)

- We have a number of coastal applications where high spatial resolution without compromising accuracy is essential and regional (non-global) data coverage is OK

Introduction and objectives

How can Airborne Laser Scanning (ALS) be of use in coastal altimetry?

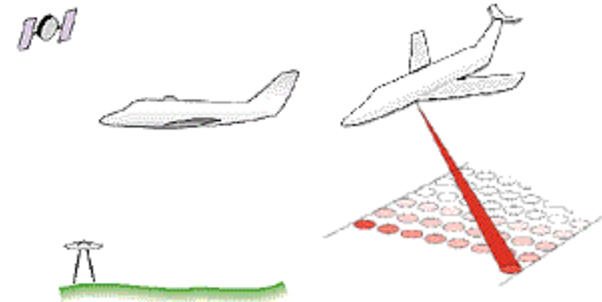
- Laser ranging already in use: ICESAT GLAS ; Harvest platform static LIDAR (Haines 2003) ; ALS for Internal Solitary Waves (Magalhaes 2013 GRL)

Objectives:

- Can ALS be used to measure water surface heights?
- What can we observe in ALS measurements?
- To what extent can a shallow and large lake resemble a gravity isosurface?

ALS works with a similar principle to satellite altimetry

Typical measuring frequencies 0,1-1 mHz
Wavelength: 1064 nm
Footprint diameter: 0,2-1,5 m
Swath widths ~ 1 km @ 1 pt/m^2



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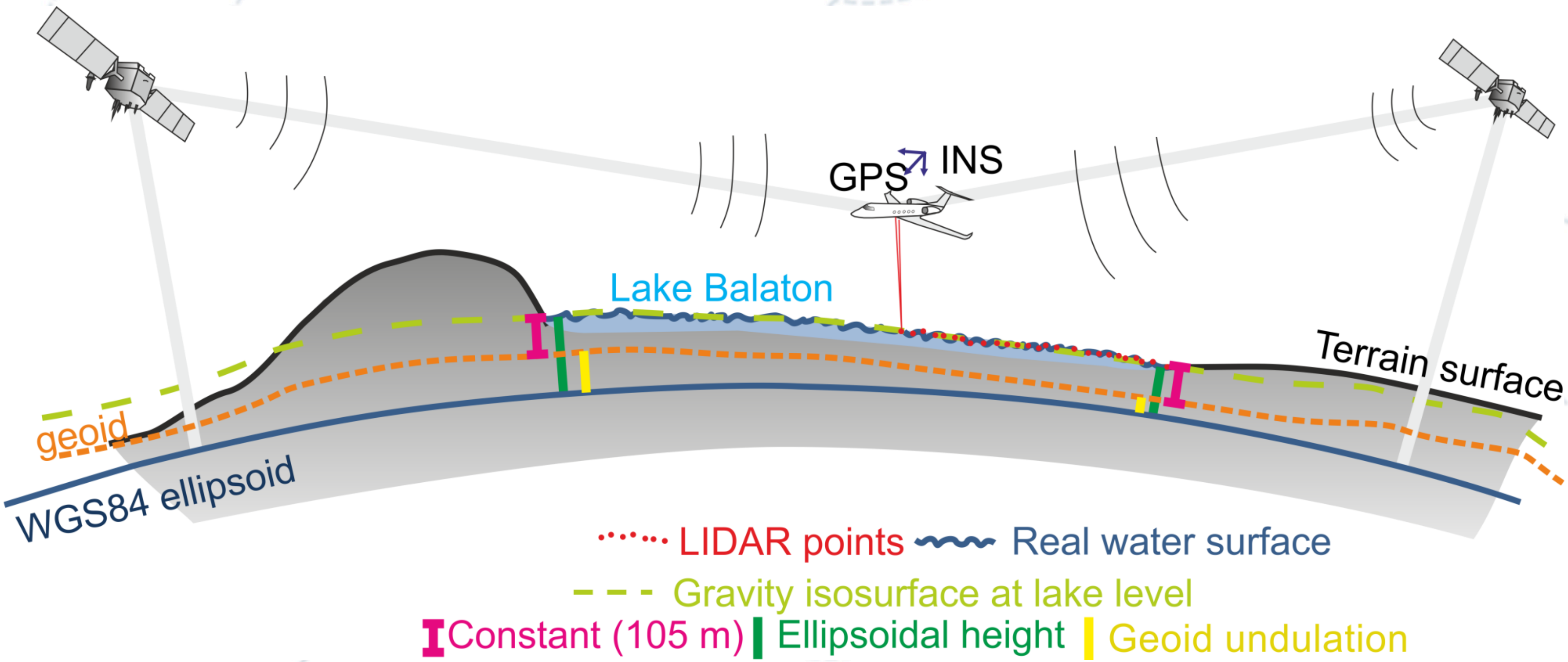
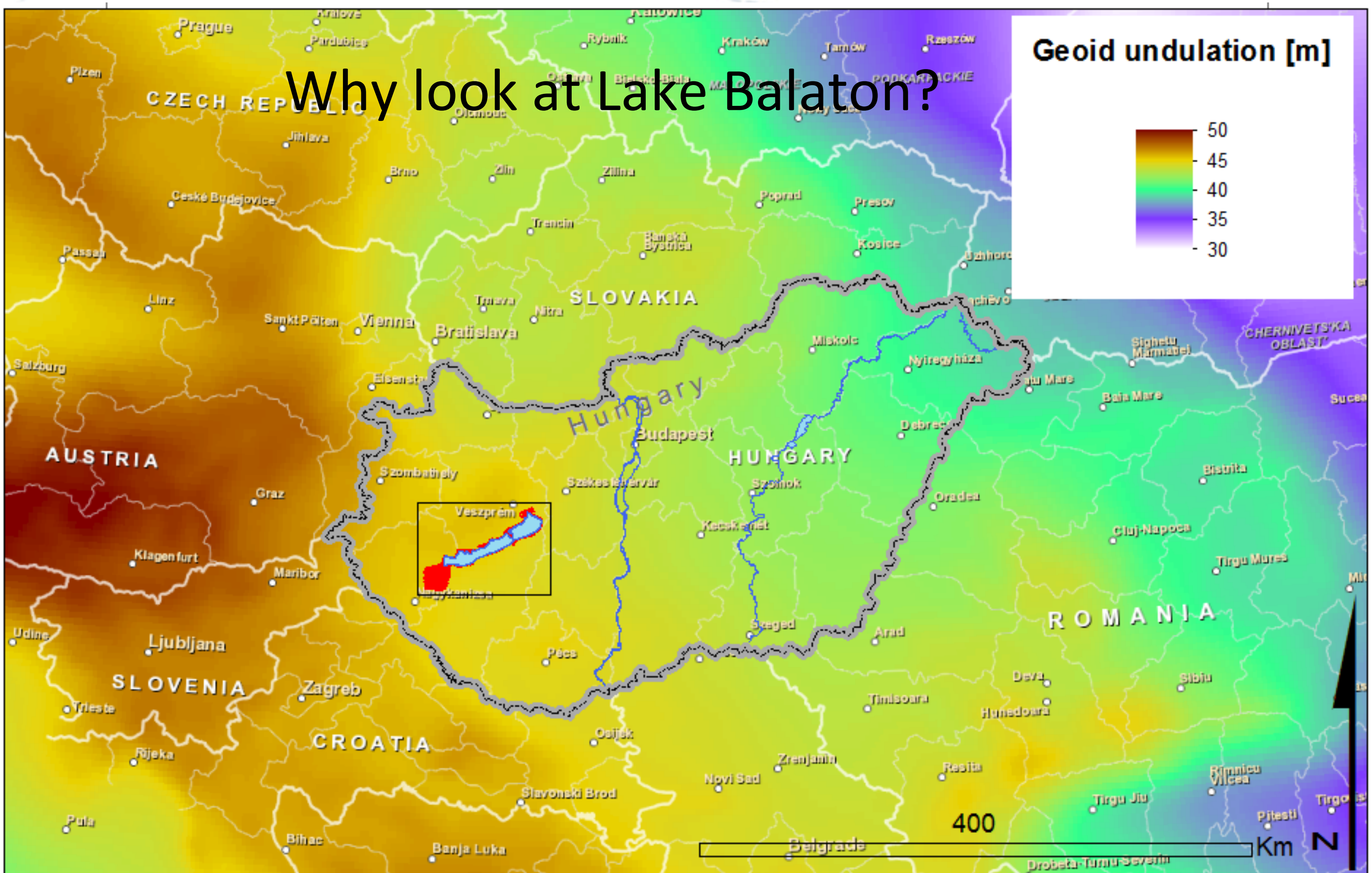
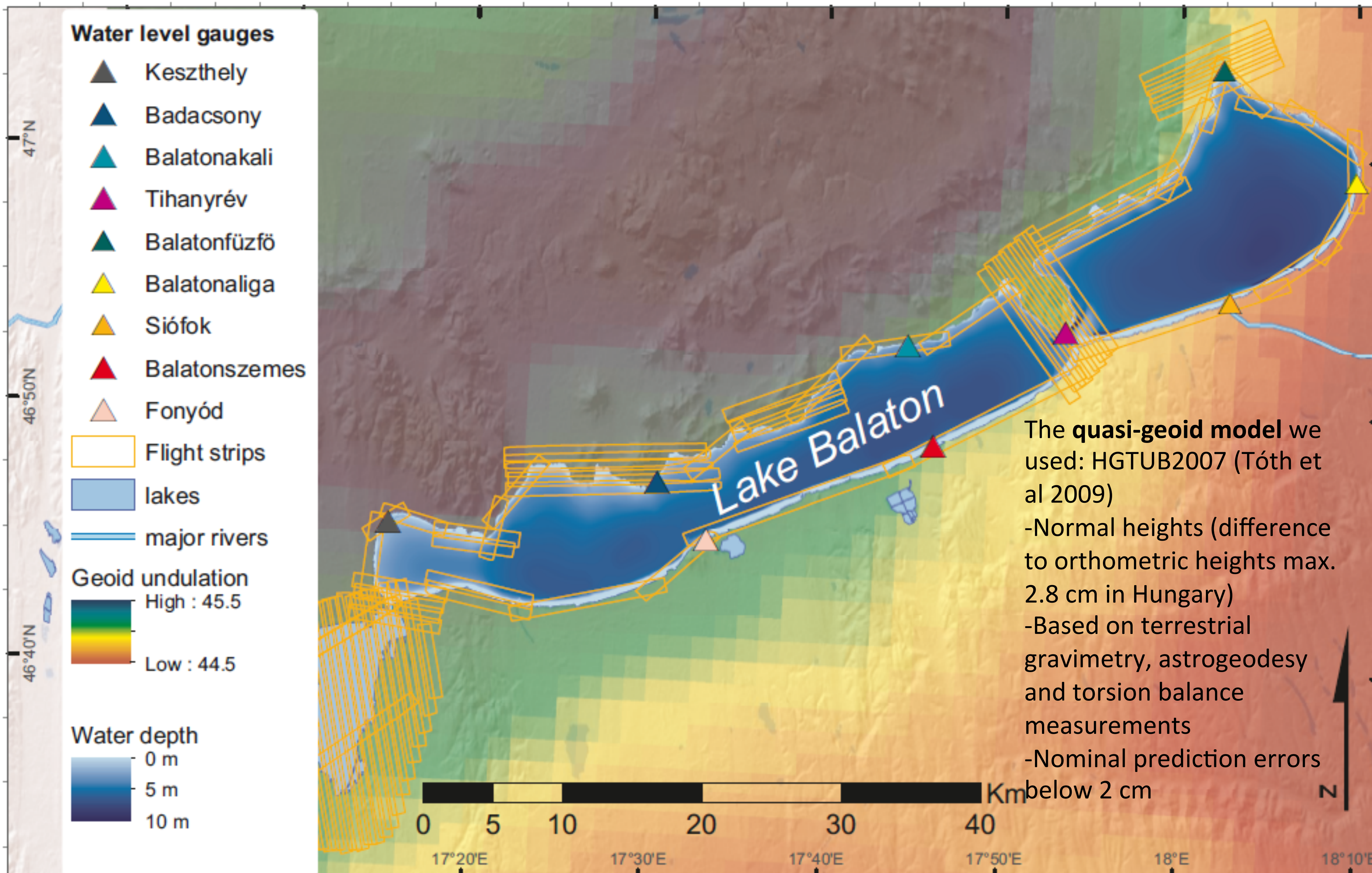


Why look at Lake Balaton?



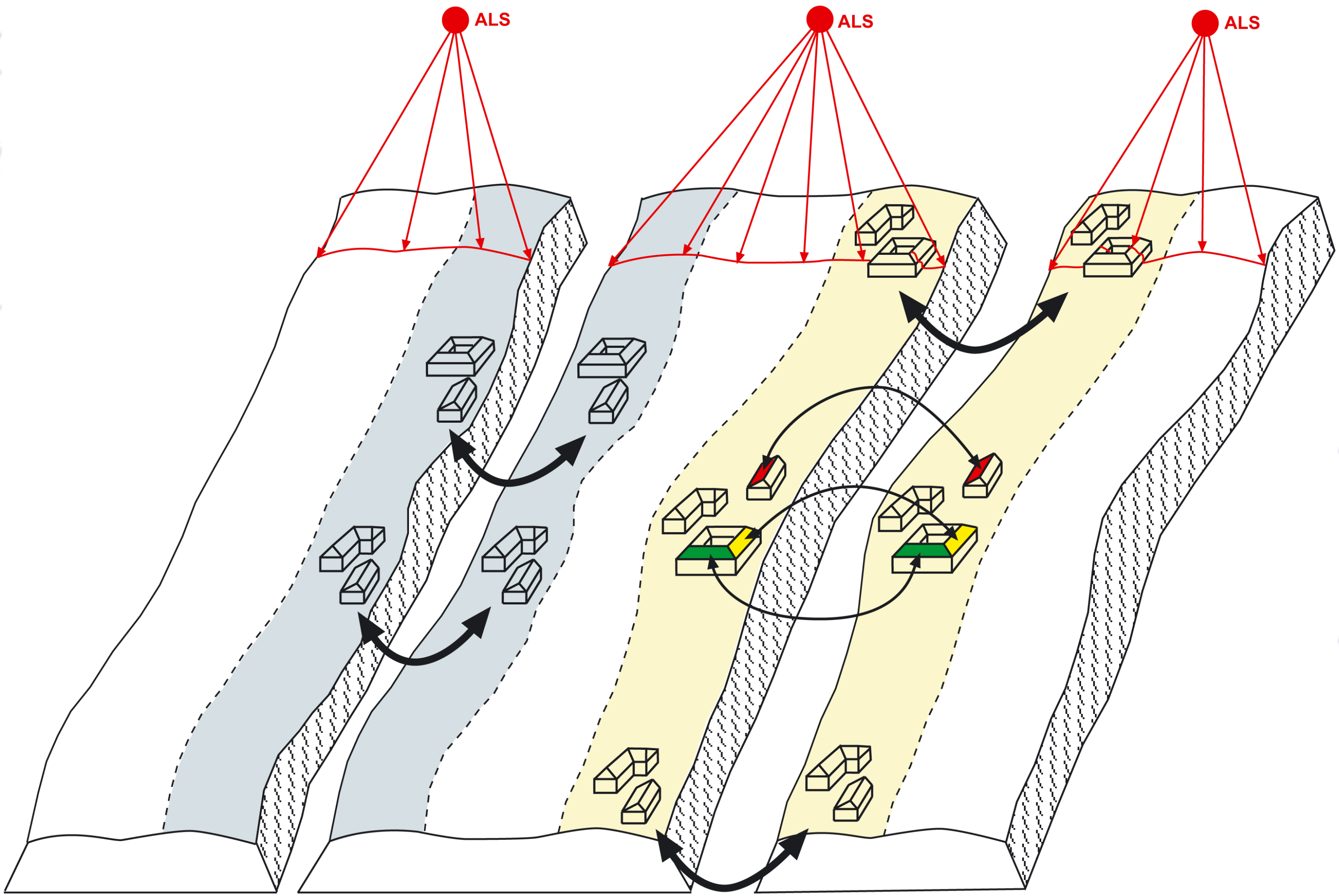
National Oceanography Centre cnes NOAA EUMETSAT NASA OSU Oregon State University University of New Hampshire esa



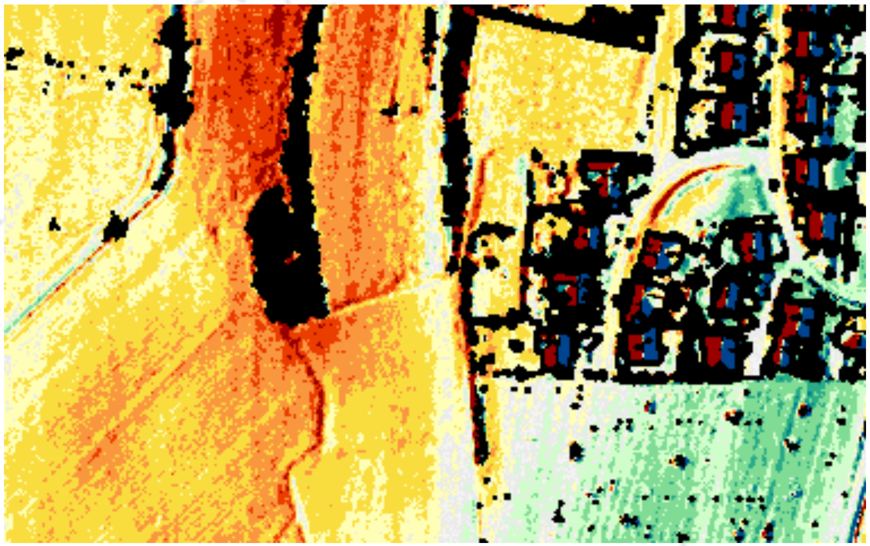
The **quasi-geoid model** we used: HGTUB2007 (Tóth et al 2009)

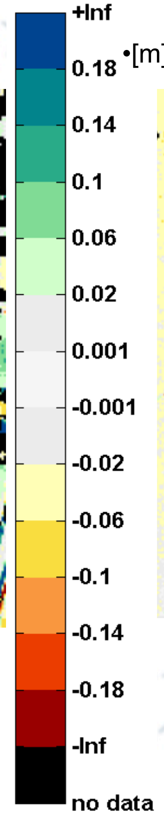
- Normal heights (difference to orthometric heights max. 2.8 cm in Hungary)
- Based on terrestrial gravimetry, astrogeodesy and torsion balance measurements
- Nominal prediction errors below 2 cm

Strip adjustment for improved georeferencing

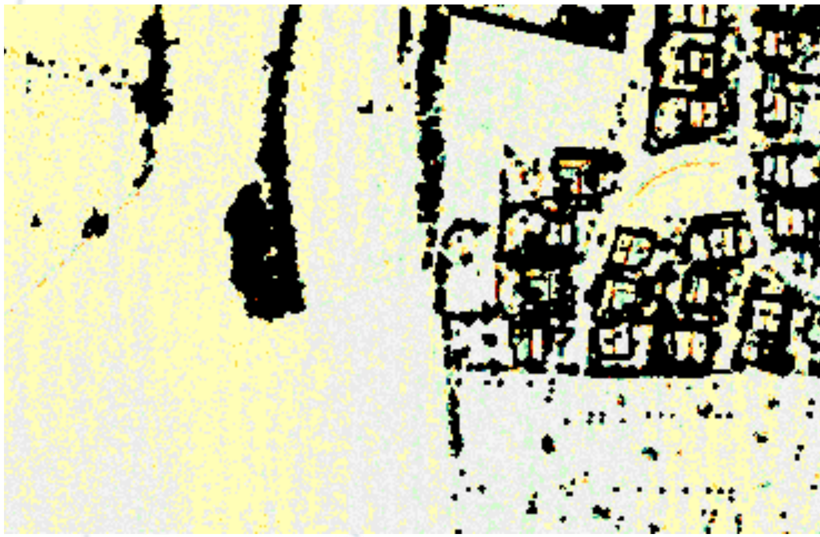


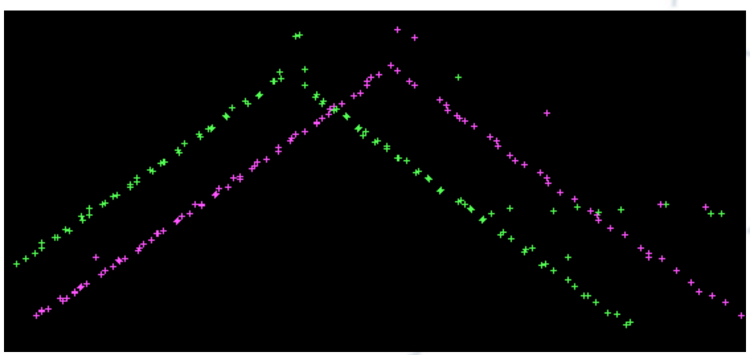
Original:

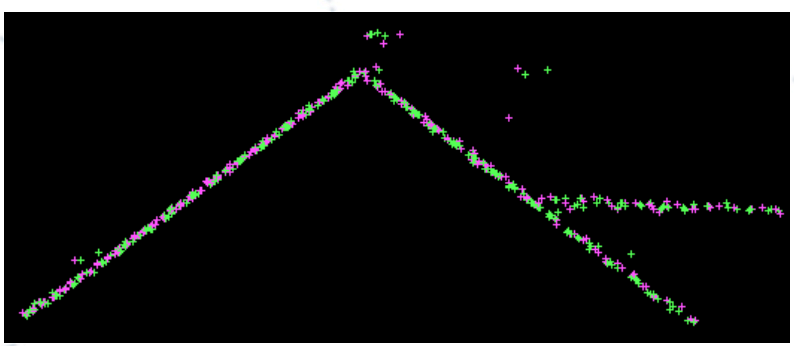




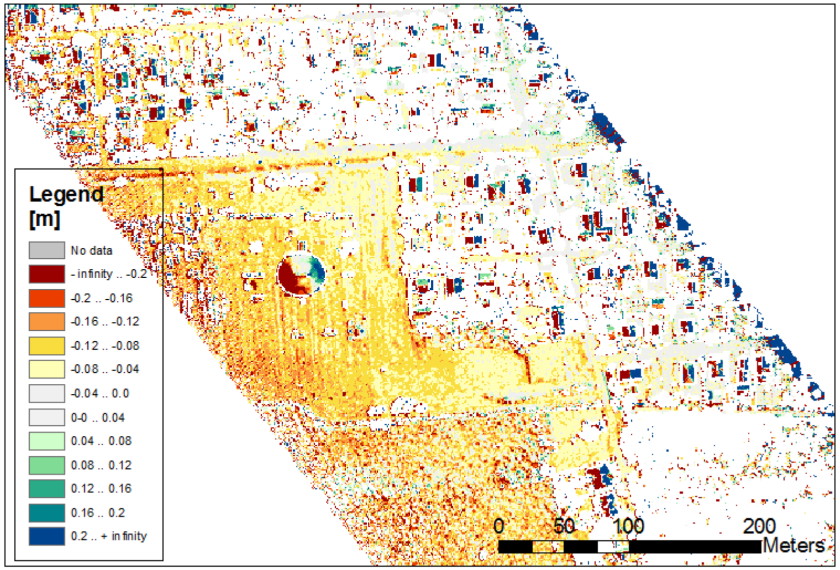
Improved:

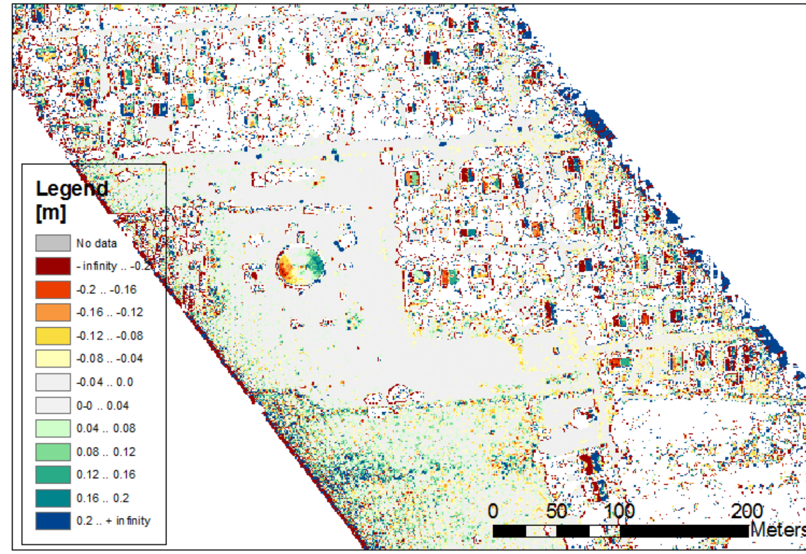






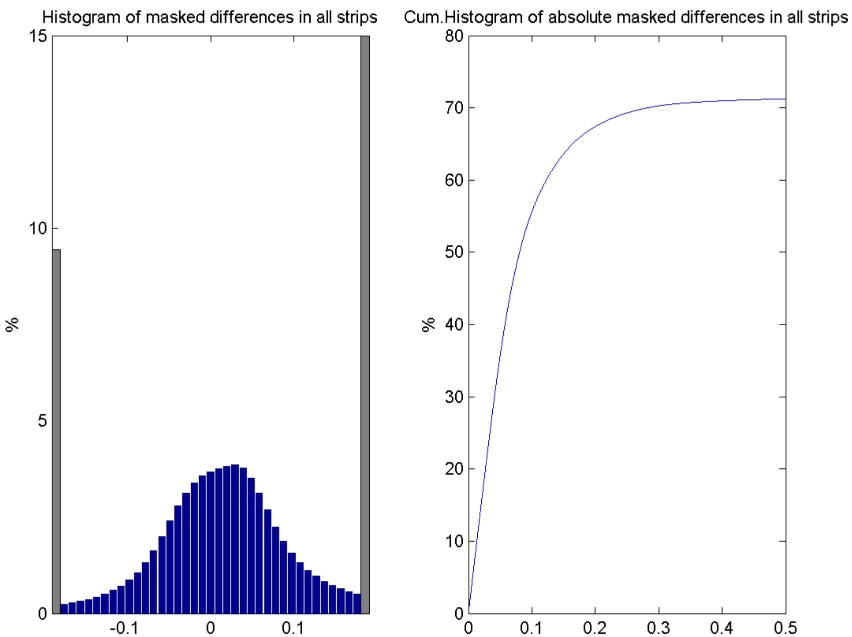
In cooperation with
Vermessung
Wenger-Öhn & AVT



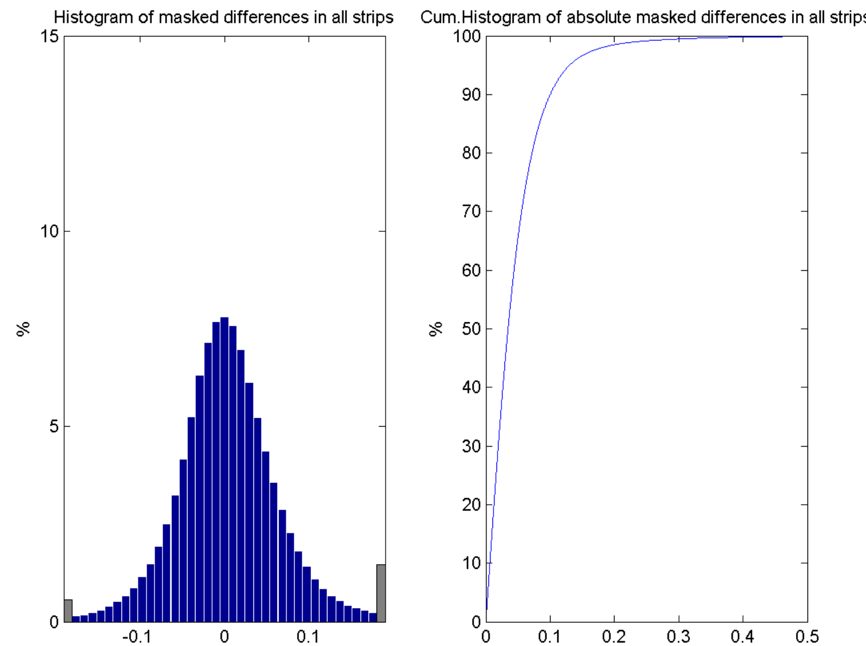


Height differences in overlapping ALS strips
Before strip adjustment correction

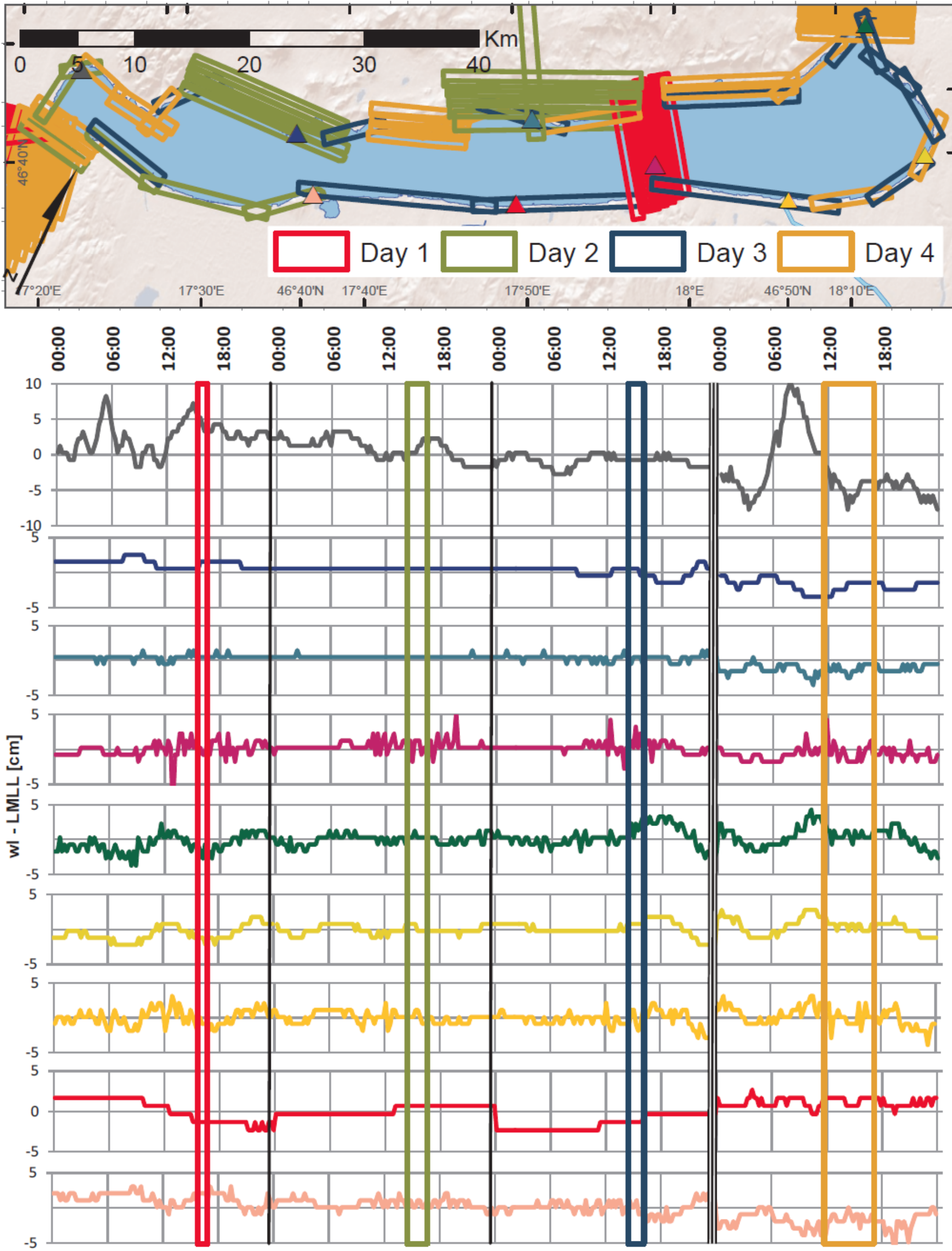
Height differences in overlapping ALS strips
After strip adjustment correction



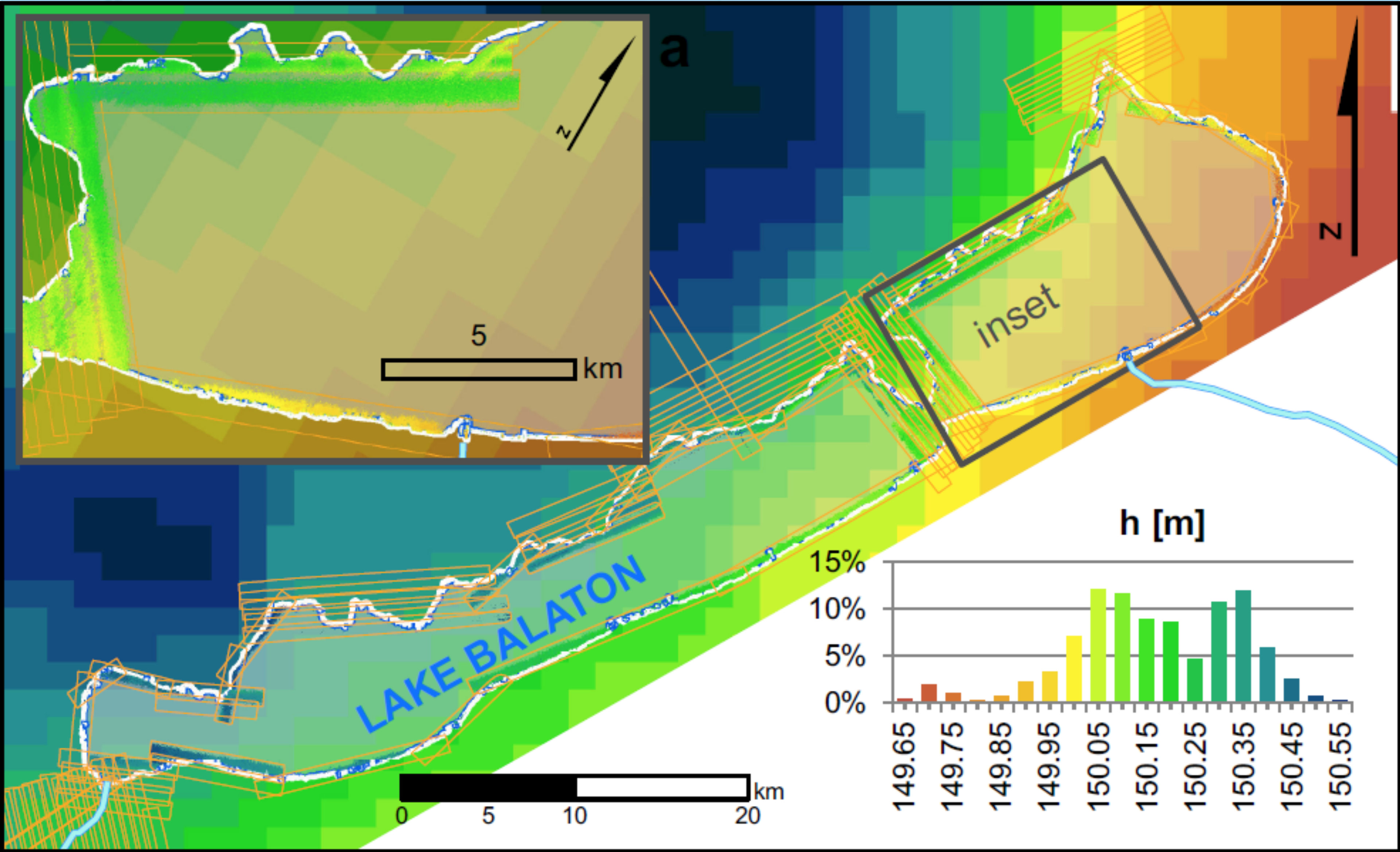
n_{used}/n_{data}: 160906909/= RMS: 2.0023 median: 0.0336 sig_{MAD}: 0.1225
min: -1048.8835 max: 1093.0327 mean: 0.7645 sig: 1.6764

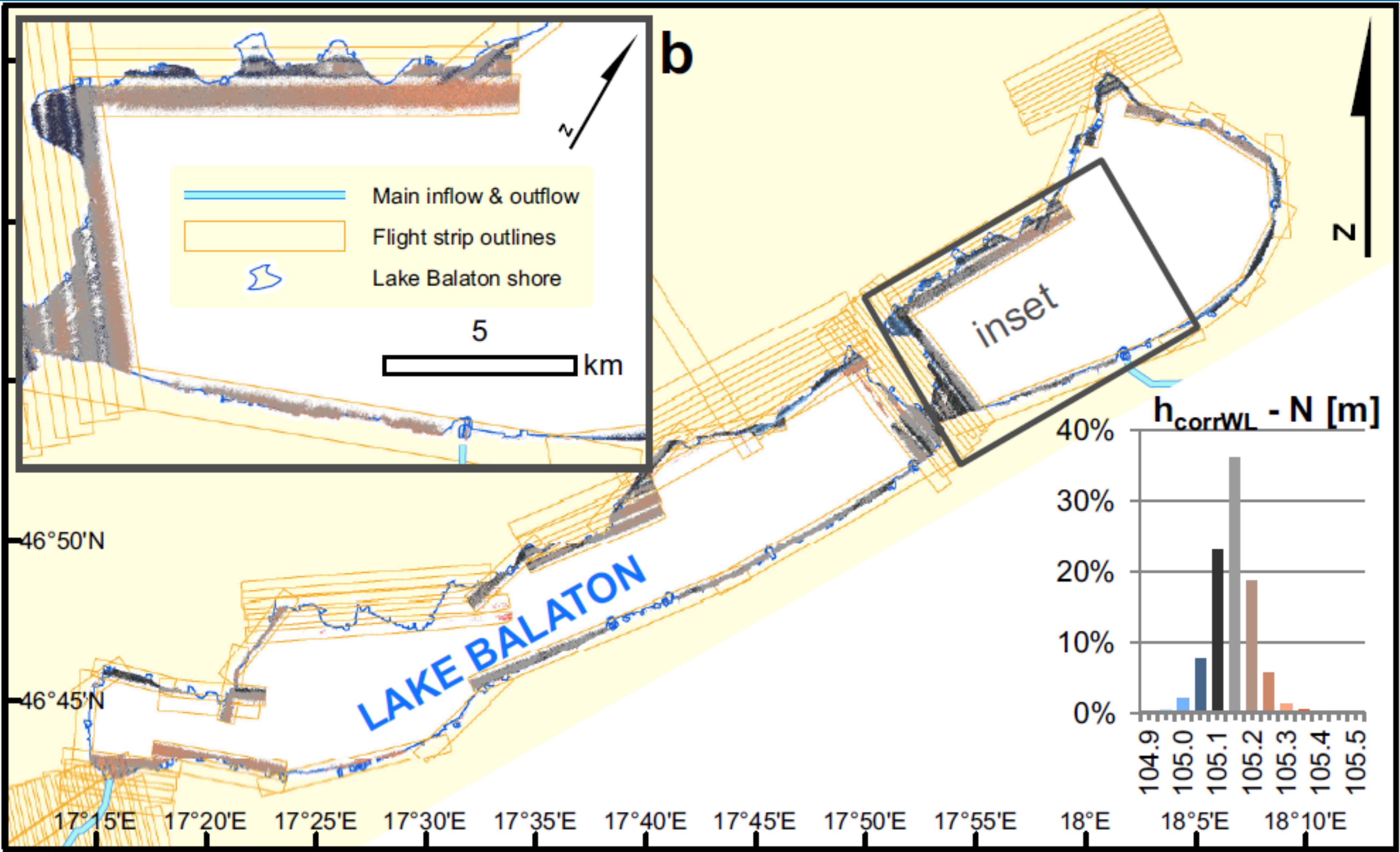


n_{used}/n_{data}: 163257522/= RMS: 0.6989 median: 0.0021 sig_{MAD}: 0.0512
min: -982.7828 max: 1038.7267 mean: 0.0129 sig: 0.6985



- Lake Balaton has well-studied seiche and setup effects due to wind, but hardly any wind during studied period
- Dynamic water surface height changes were observed from water gauges with 15 min frequency
- Differences with respect to Local Mean Lake Level (LMLL, over 4 days) was within ± 5 cm in all but 1 station
- During measurement flights, deviations were within ± 4 cm, flight strip height was corrected based on nearest gauge

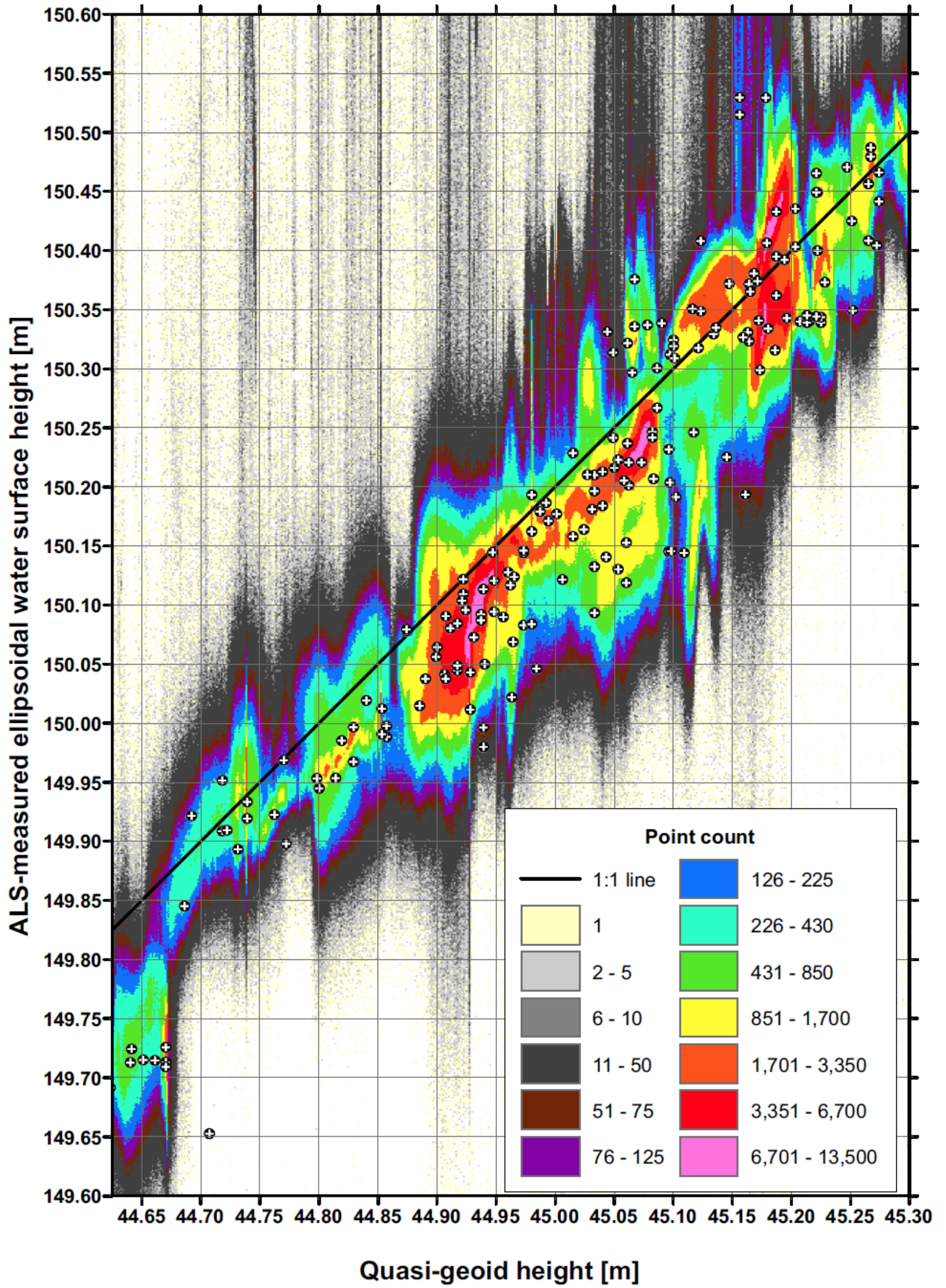

a
5
km
N
inset
LAKE BALATON
0
5
10
20
km
h [m]
15%
10%
5%
0%
149.65
149.75
149.85
149.95
150.05
150.15
150.25
150.35
150.45
150.55


b
Main inflow & outflow
Flight strip outlines
Lake Balaton shore
5
km
N
inset
LAKE BALATON
N
h_{corrWL} - N [m]
40%
30%
20%
10%
0%
104.9
105.0
105.1
105.2
105.3
105.4
105.5
46°50'N
46°45'N
17°15'E
17°20'E
17°25'E
17°30'E
17°35'E
17°40'E
17°45'E
17°50'E
17°55'E
18°E
18°5'E
18°10'E

- ALS-measured ellipsoidal water surface heights closely follow quasi-geoid height
- R^2= 0.906 when LIDAR heights resampled to quasi-geoid model resolution

However, in part of the lake, there is considerable difference between the quasi-geoid model and the measured lake surface height!

Graph shows point count for each ellipsoidal water height/quasi-geoid height interval of 1.25 × 1.25 cm. Bilinear interpolation of quasi-geoid height raster to ALS resolution was used for the scatterplot, crosses show ALS heights resampled to quasi-geoid resolution



Summary

- Airborne Laser Scanning of a water surface, combined with strip adjustment, can produce accuracies comparable to satellite altimetry
- Spatial resolution of ALS on the scale of meters, height differences in cm range can be resolved
- The surface of a large lake under favourable weather conditions is relatively close to a gravity potential isosurface.

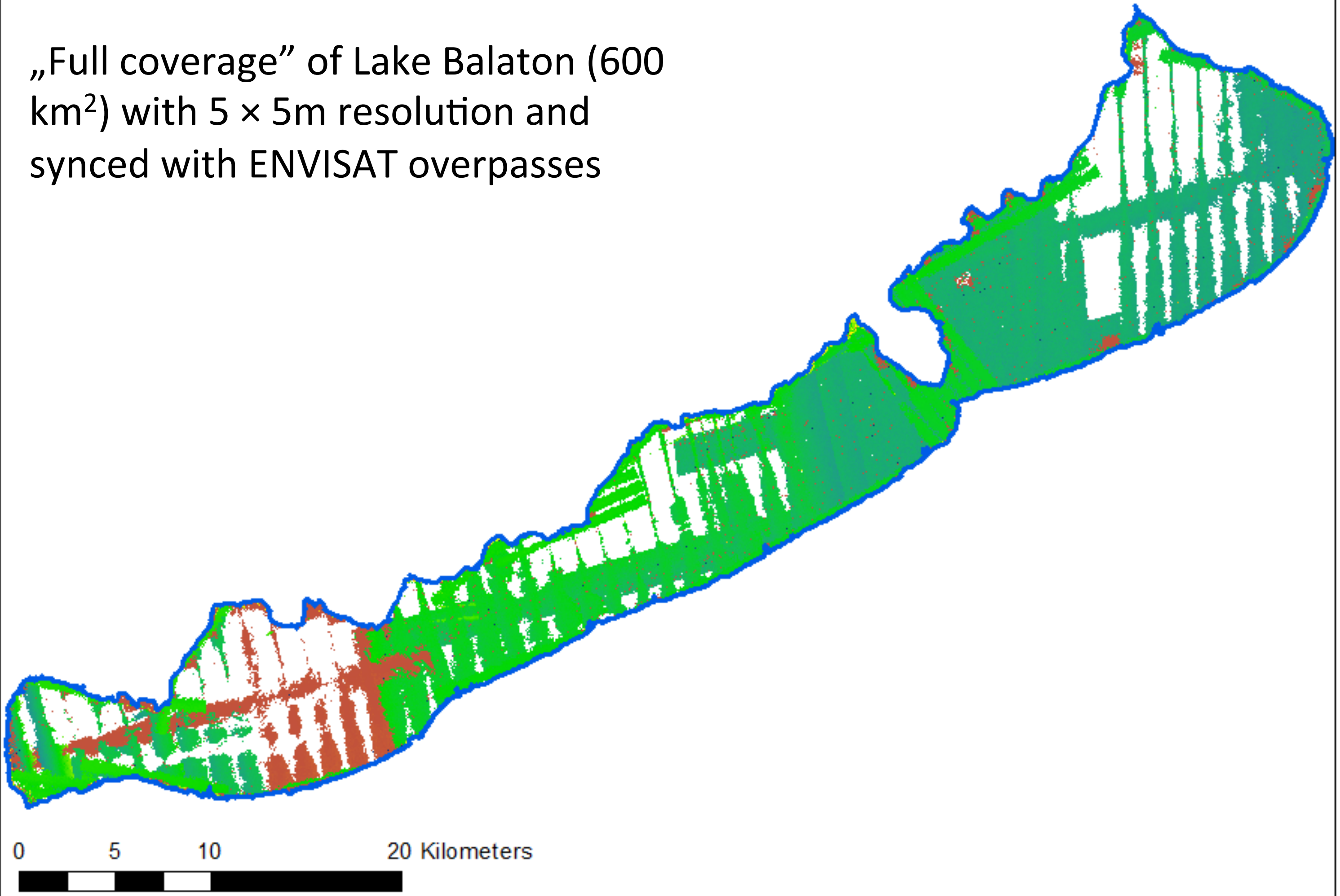
Airborne LIDAR vs. Satellite altimetry

- No comparison tried yet, but data available and synced with ENVISAT overpasses, so theoretically possible

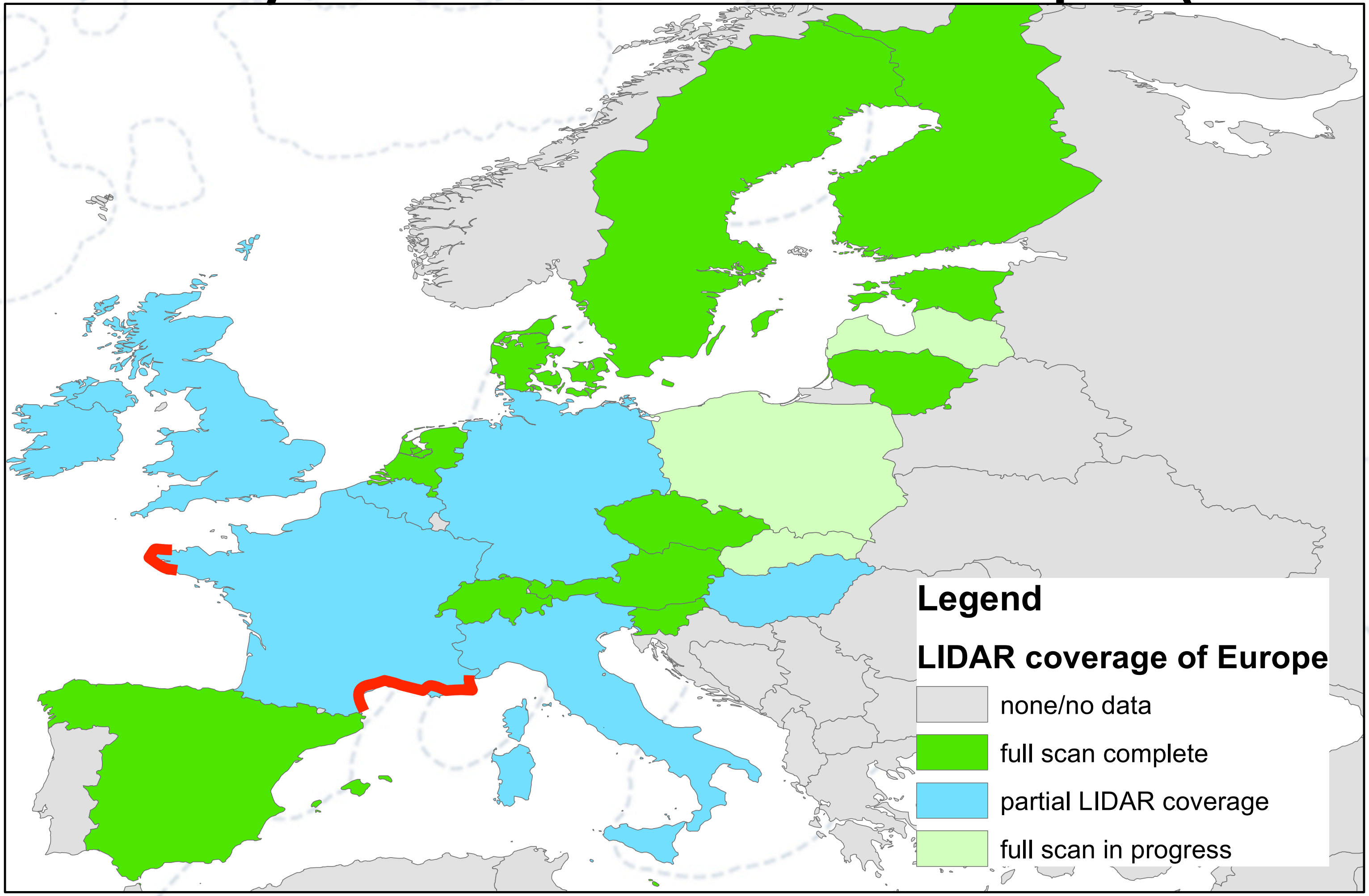
- Applications: Satellite altimetry cal/val
- Linking tide gauges to satellite altimetry
- Resolving spatial patterns observed by satellite altimetry with higher resolution

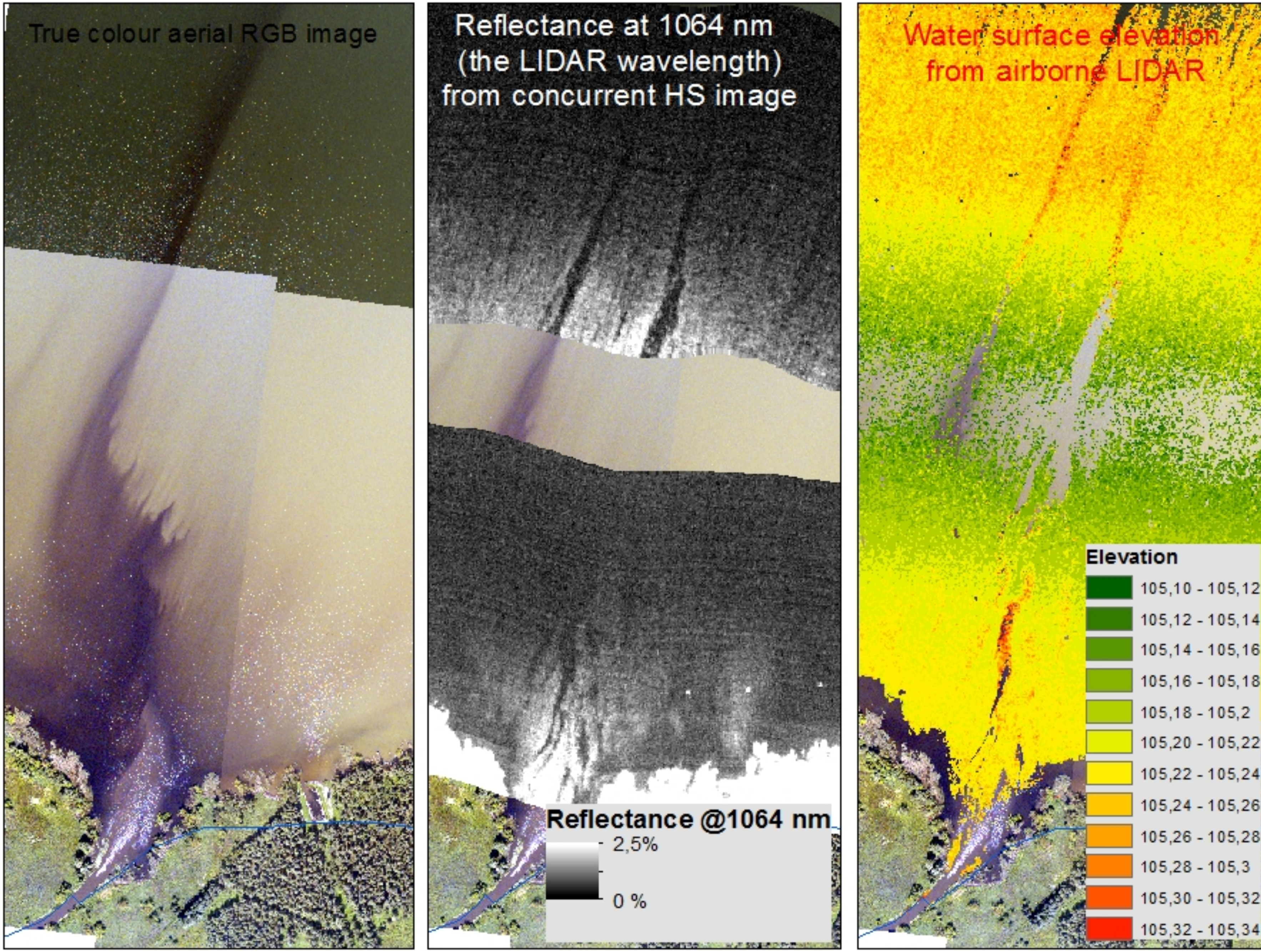
ALS data coverage of Lake Balaton during the EUFAR campaign

„Full coverage" of Lake Balaton (600 km^2) with 5 × 5m resolution and synced with ENVISAT overpasses

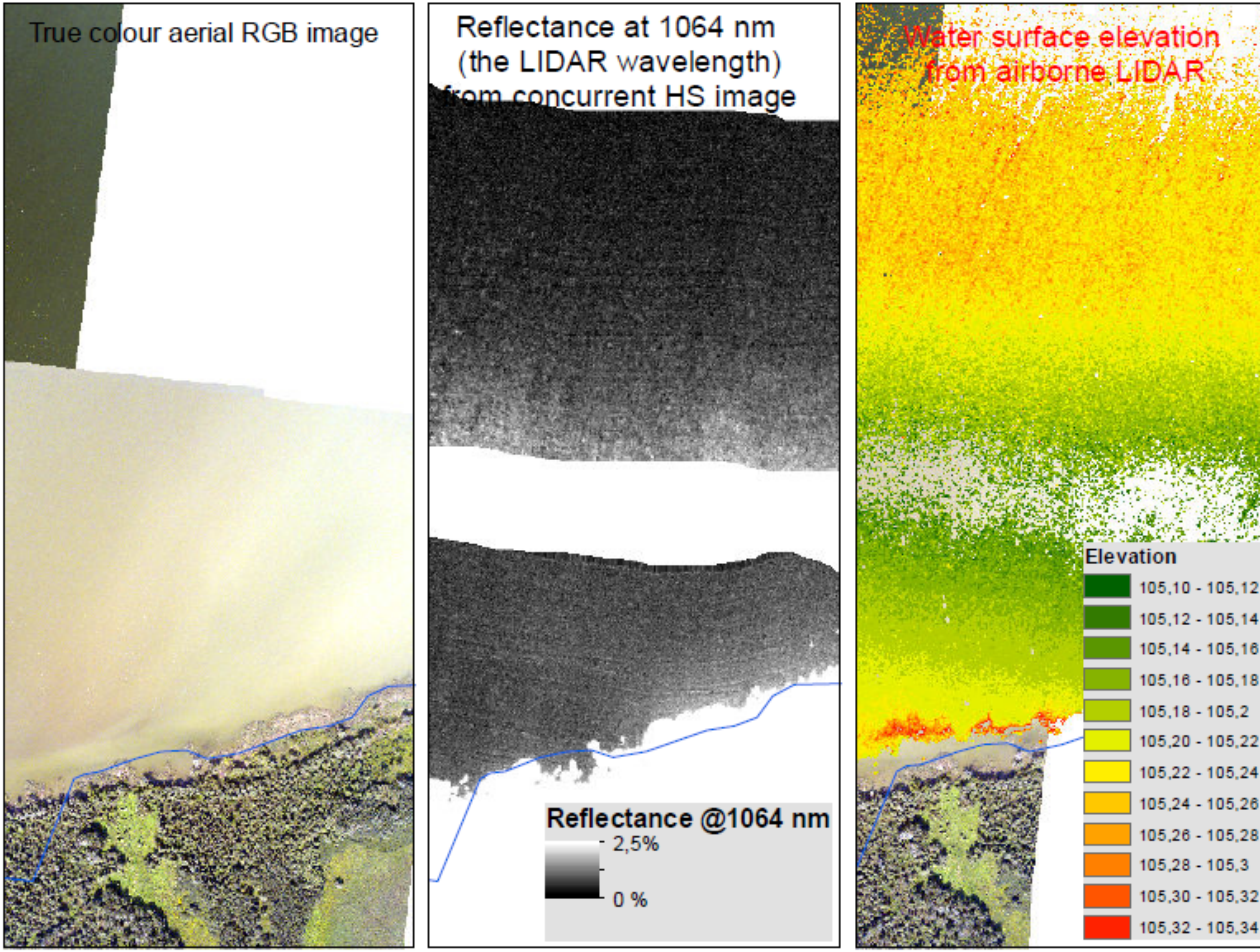


Availability of ALS data in Europe (2013)





True colour aerial RGB image
Reflectance at 1064 nm (the LIDAR wavelength) from concurrent HS image
Reflectance @1064 nm
2,5%
0 %
Water surface elevation from airborne LIDAR
Elevation
105,10 - 105,12
105,12 - 105,14
105,14 - 105,16
105,16 - 105,18
105,18 - 105,2
105,20 - 105,22
105,22 - 105,24
105,24 - 105,26
105,26 - 105,28
105,28 - 105,3
105,30 - 105,32
105,32 - 105,34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105,22 - 105,24
105,24 - 105,26
105,26 - 105,28
105,28 - 105,3
105,30 - 105,32
105,32 - 105,34

Conclusions and open questions

- ALS can deliver sufficient accuracies and resolutions for application in coastal altimetry
- Data is available for many European lakes and shores

- Can ALS be used to study dynamic water surface topography?
- How does ALS compare to satellite data?

- Zlinszky, A., Timár, G., Weber, R., Székely, B., Briese, C., Ressl, C., and Pfeifer, N.: Observation of a local gravity potential isosurface by airborne LIDAR of Lake Balaton, Hungary, Solid Earth, 5, 355-369, doi:10.5194/se-5-355-2014, 2014.

Estimated error budget

	Estimated error budget, individual height sources in cm				
		Standard deviation	Median	spatial distribution of error	source of value
Airborne LIDAR system	Absolute point vertical accuracy	8	0	systematic point error within each strip	Leica Geosystems (2006)
	Point accuracy after strip adjustment	5	0	mainly random except for strips with georeferencing artefacts	Measured for strip adjustment quality control
Water surface height effects	Waves (in 40% of the strips, no waves in the rest)	9	0	periodic systematic	Estimated from LIDAR quality control
	Total impact of waves on full dataset	4	0		
	Specular reflection (influencing ca. 10% strip area in 30% of the strips surveyed	5	15	systematic	
	Total impact of specular reflection on full dataset	0.15	0.45		
	Smile artefact (influencing ca. 20% strip area in 30% of the strips	2.5	-7		
	Total impact of smile artefact on full dataset	0.15	-0.35		
	Dynamic water topography	3	0		

estimated error budget, total effect of height error sources on data [cm]		
	Standard deviation	Median
Total impact of water as target surface	5	0
Total estimated height error budget	7.1	0
True total error budget (from measurement data, Fig 2.b)	5.6	-2.2