Tallinn University of Technology

Using airborne laser scanning profiles to validate marine geoid models

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Introduction

This study explores the usability of Airborne Laser Scanning (ALS) for measuring sea surface heights (SSH) and validating gravimetric geoid models over marine areas. ALS is a remote sensing technology for acquiring high-resolution and accurate spatial data about the 3D surface of measured object. A case study was carried out at the southern shores of Gulf of Finland, the Baltic Sea. Seven intersecting ALS profiles, which were flown at different altitudes, were used for SSH determination.

2. Case study

- The study area is located at the southern shore of Gulf of Finland in the Baltic Sea (Fig. 2).
- The ALS data were collected by the Estonian Land Board using a Leica ALS50-II airborne laser scanner.
- Two ALS campaigns were conducted in May 2013 (flight parametres in Table I).

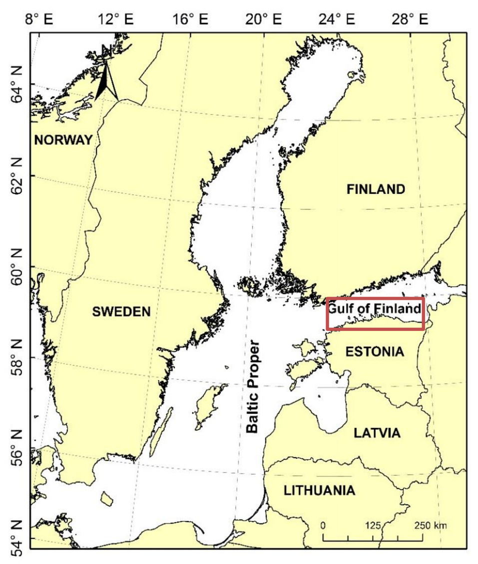

Fig. 2. Location of the study area in the Gulf of Finland, Baltic Sea

- Two flight lines (FL1 and FL4) were flown at an altitude of 2400 m and five flight lines (FL2, FL3, FL5, FL6 and FL7) at an altitude of 400 m.
- The weather and the sea surface were relatively calm at the time of the measurements.
- The sea level corrections are based on sea level observations conducted by the The Estonian Environment Agency at Tide Gauge stations (TG).

Table I
Flight parameters of ALS campaigns

Date	8 May 2013	14 May 2013
Flight height	2400 m	400 m
Field of view	55°	25°
Scanrate	32.6 Hz	57.1 Hz
Pulse rate	93.6 kHz	150 kHz
Corridor width	2498 m	177 m
Nadir point density	0.31 p/m²	6.67 p/m²
Average point density	0.46 p/m²	10.96 p/m²
Diameter of laser footprint	54 cm	10 cm
Flight lines	FL 1, FL4	FL 2, FL3, FL5, FL6, FL7

GRAV-GEOID2011

For the validation a high-resolution (1'x2') regional gravimetric GRAV-GEOID2011 model was used. This geoid model covers the entire area of Estonia and surrounding waters of the Baltic Sea. The fit between the geoid model and GNSS/levelling data within the Estonian dry land revealed RMS of residuals ±1…±2 cm.

1. ALS principles for validating marine geoid models

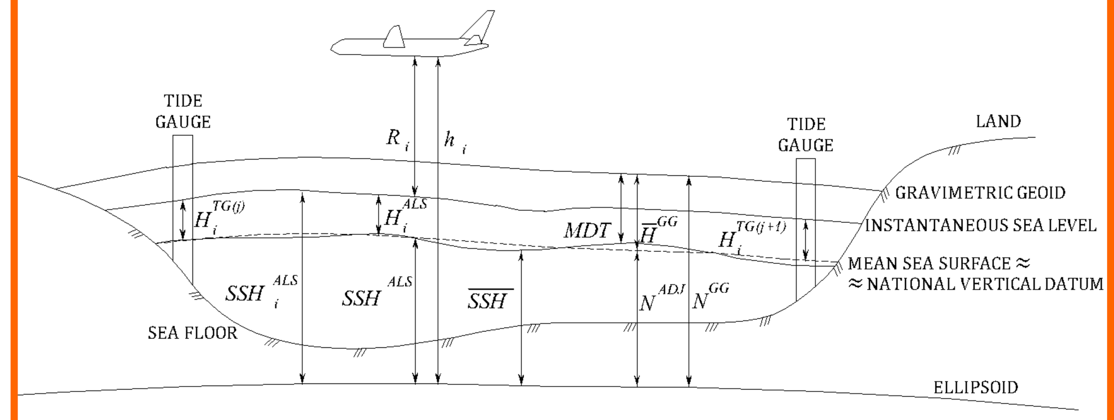

Fig. 1. Principle of sea surface height determination by using airborne laser scanning and the connection with geoid models.

The instantaneous sea surface height is found by:

$$SSH_i^{ALS} = h_i - R_i$$

Sea level corrected ALS-derived SSH is found by:

$$SSH^{ALS} = SSH_i^{ALS} - H_i^{ALS}$$

The mean sea surface height is the sum of gravimetric geoid height and mean dynamic topography:

$$\overline{SSH} = N^{GG} + MDT$$

Gravimetric geoid models do not coincide with mean sea surface. If MDT is considered constant, then the mean elevation difference can be found by:

$$\overline{H}^{GG} = \frac{\sum (N^{GG} - SSH^{ALS})}{n}$$

The adjusted geoid heights are found by:

$$N^{ADJ} = N^{GG} - \overline{H}^{GG}$$

The mean SSH, ALS-derived SSH and adjusted geoid heights roughly coincide:

$$\overline{SSH} \approx SSH^{ALS} \approx N^{ADJ}$$

4. Comparison between ALS-derived SSH and GRAV-GEOID2011 model

The comparisons (Fig. 6 and 7) demonstrated relatively good agreement over large portions of the profiles. The detected discrepancies between sea level corrected ALS-derived SSH and GRAV-GEOID2011 did not exceed 15 cm. Standard deviations of discrepancies between the gravimetric GRAV-GEOID2011 model and each profile remain reasonably within 6 cm (Table III).

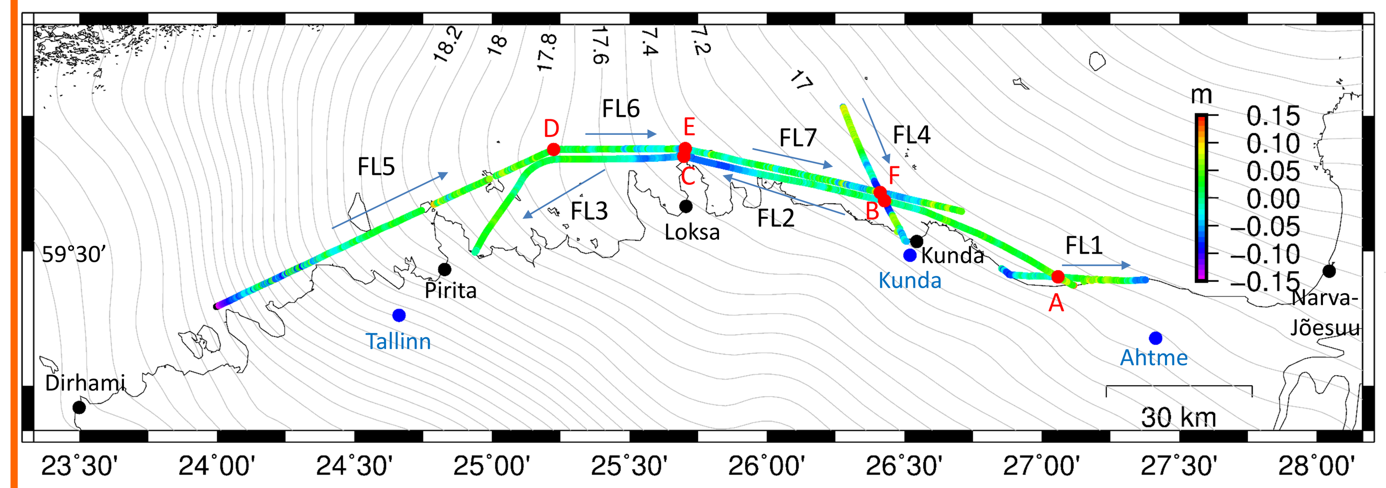

Fig. 6. Discrepancies between ALS-derived sea level corrected SSH and adjusted GRAV-GEOID 2011 model. GRAV-GEOID2011 contours with interval 0.1 metres are depicted in the background. ALS flight lines (FL1-FL7), tide gauge stations (black dots), CORS (Continuously Operating Reference Stations) (blue dots), intersections (red dots) between flight lines (A-F). The direction of flight is indicated with arrows.

Table III
Statistics of elevation differences between the mean ALS-derived sea surface height and GRAV-GEOID2011 model

	FL1	FL2	FL3	FL4	FL5	FL6	FL7
n[1]	348	1211	805	349	882	334	718
$\overline{H}^{GG}$ [2] [m]	-0.388	-0.456	-0.405	-0.431	-0.378	-0.377	-0.440
Min[3] [m]	-0.082	-0.078	-0.096	-0.091	-0.166	-0.056	-0.069
Max[3] [m]	0.108	0.139	0.068	0.105	0.149	0.047	0.109
Stdev[3] [m]	0.043	0.037	0.034	0.062	0.049	0.027	0.037

[1] Number of filtered ALS-derived SSH points
[2] Mean elevation difference between SSH and GRAV-GEOID2011.
[3] Results after the removal of the mean difference in third row.

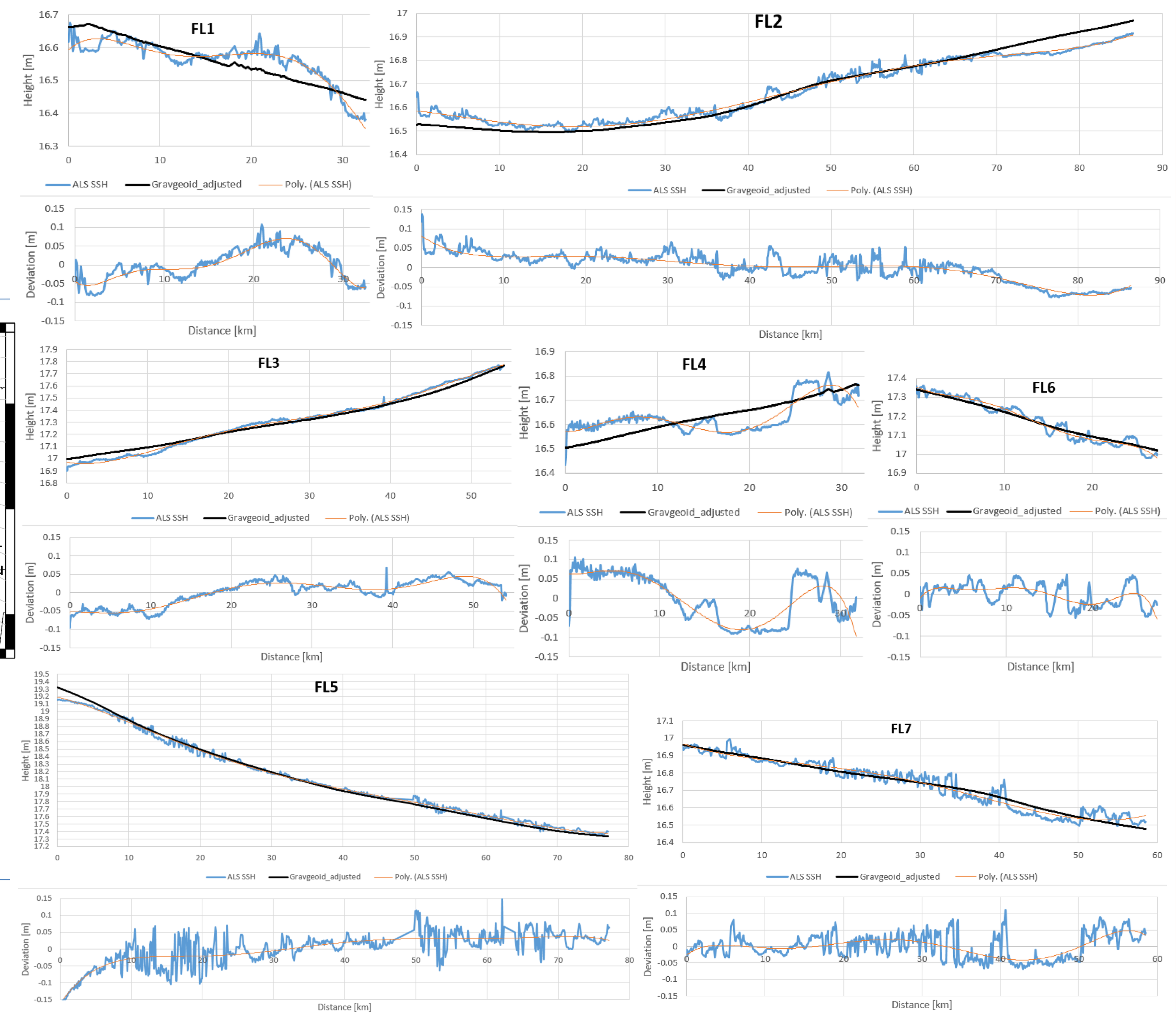

Fig. 7. Profiles of discrepancies between ALS-derived sea level corrected SSH (blue lines) and adjusted GRAV-GEOID 2011 model (black lines) (cf. Table III) – the absolute heights (above) and the deviation (below). ALS SSH is also represented with a 4th degree polynomial trend line (orange lines). On the x-axis is the distance from the beginning of the flight line. The flight direction is shown on Fig. 6 .

3. Data processing

- The anomalous points above and below the sea surface (Fig. 3.) in the point cloud were removed.
- The dry-land points (reflecting from islets and the coast along the flight route) were removed (Fig. 4). A shape-file containing contours of Estonian coast was used to automatically cut out points falling on dry-land.
- The ALS data were corrected according to Tide Gauge station (TG) readings (Fig. 5). Because all the avalaible TGs were located to the south of the test area, the sea level correction was found by using longitudinal interpolation.
- The ALS data were averaged to find a single sea level corrected SSH value for each flight second (GPS time). One second of flight time corresponds to ~70…90 m of along-track distance.
- Cross-validation of ALS measurements was carried out by comparing SSH at flight line intersections (Fig. 6.). The discrepancies are generally ~6 cm (Table II).

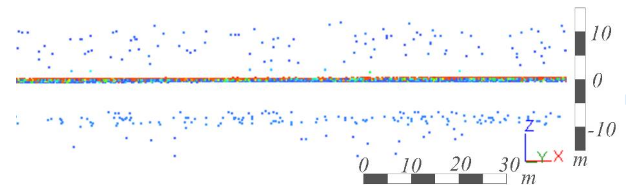

Fig. 3. Anomalous points in the point cloud

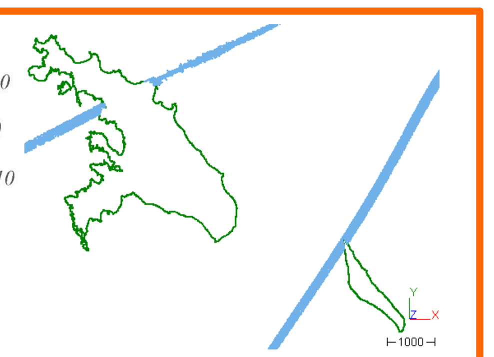

Fig. 4. Dry-land points removed.

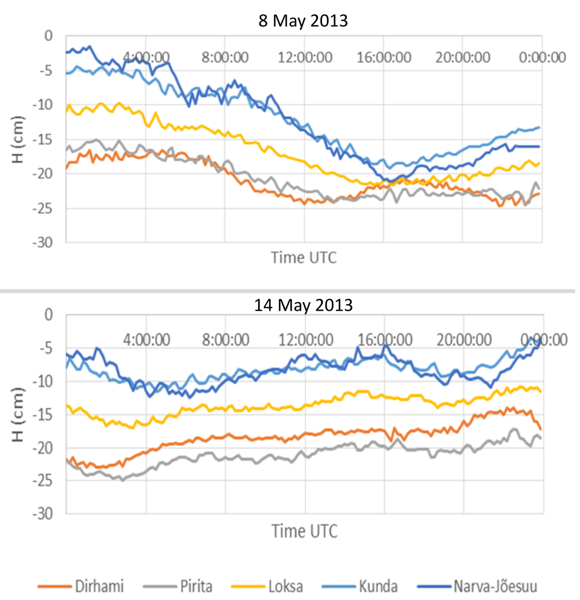

Fig. 5. Tide gauge station readings

Table II
Cross-validation of ALS measurements at flight line intersections

Intersection	ALS SSH difference [m]
A	0.009
B	0.102
C	0.060
D	0.060
E	0.064
F	0.035

5.ALS back-scattering on water

- More points registered near-nadir.
- The width of the corridor where points are registered (i.e. back-scattered) varies along the track even though the flight parameters remain the same.
- More points are registered from disturbed water surface than from calm water surface.

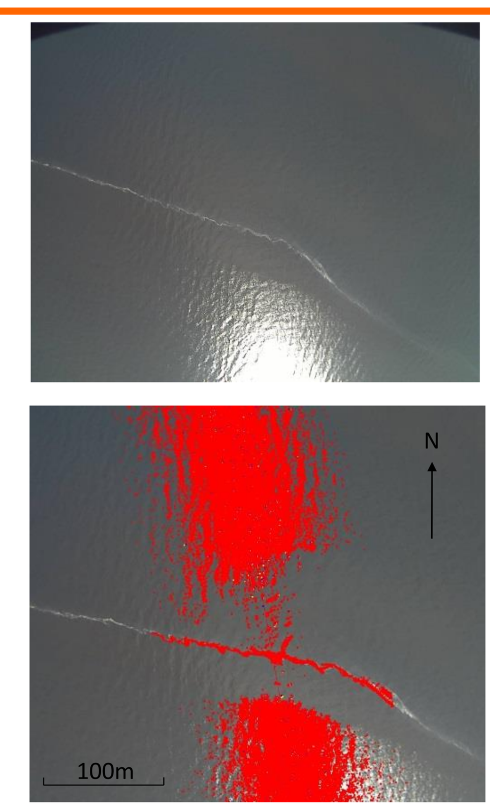

Fig. 8. ALS back-scattering on water

Conclusion

- This study has demonstrated that ALS can be used to measure instantaneous sea surface heights, which can be utilized to validate geoid models over marine areas.
- The accuracy of the method is estimated to be ~10 cm.
- The reasons behind variances of back-scattering on water need further research.

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Acknowledgements:

This study is supported by the Estonian Environmental Technology R&D Programme KESTA, research project ERMAS AR12052. The ALS data used in this study was received from the Estonian Land Board under the license contract ST-A1-2422, 22/06/2012. The prime author was supported by Erasmus programme Mobility for staff training, which is carried out by foundation Archimedes.