

TPU Estimation for Bathymetric LiDAR

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3D Underwater Mapping from Above and Below

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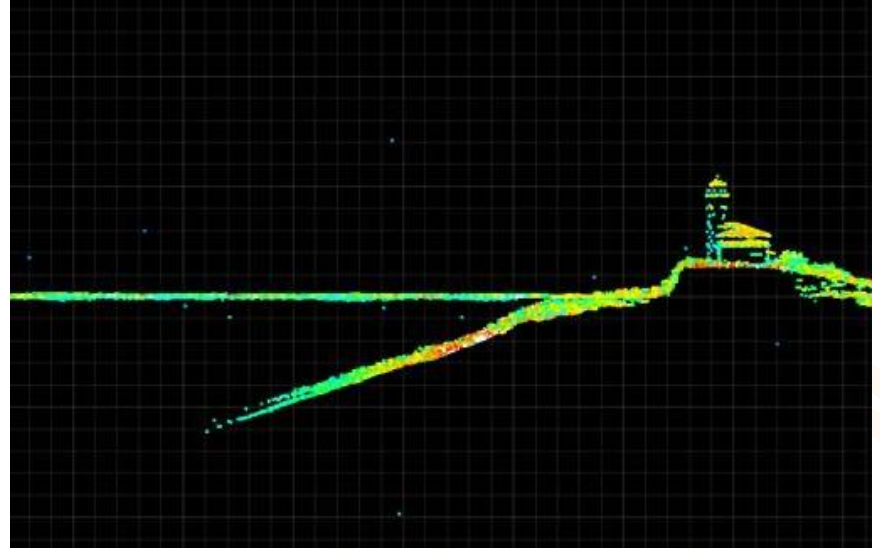
3rd International Workshop

July 2025



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- Workflow
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TPU– total propagated uncertainty

What is the use of TPU estimation?

demand for IHO order compliance in tenders
quality control based on other standards
or individual, application-related thresholds

IHO Standard defines **5 orders for hydrographic products or services**.

For compliancy with an order, specific requirements - ***Bathymetry, bathymetric coverage, feature detection*** - have to be met.

The stringency of the respective criteria corresponds to safety of navigation requirements.

The measurement equipment is a component of the overall assessment of whether an aspired order for the resulting survey product can be achieved.

- ***Performance specifications***
- ***Reference measurements***
- ***TPU estimation***

TPU calculation - Special Law of Propagation of Variance (SLOPOV)

$$\sigma_f = \sqrt{\left(\frac{\partial f}{\partial i_1} \cdot \sigma_{i_1}\right)^2 + \left(\frac{\partial f}{\partial i_2} \cdot \sigma_{i_2}\right)^2 + \dots + \left(\frac{\partial f}{\partial i_N} \cdot \sigma_{i_N}\right)^2}$$

$f(i_k)$...	function of n input parameters i_k
σ_{i_k}	...	uncertainties of these parameters
σ_f	...	uncertainty of the resulting function value

- $THU = 2.45 \cdot \sigma_r = 2.45 \cdot \sqrt{\frac{\sigma_x^2 + \sigma_y^2}{2}} = 1.73 \cdot \sqrt{\sigma_x^2 + \sigma_y^2}$
 - with 2.45 being the confidence radius (95%) of normalized 2D Gaussian
 - and σ_r describing the point's mean isotropic uncertainty within the xy plane (note: if $\sigma_x = \sigma_y$, then $\sigma_r = \sigma_x = \sigma_y$)
- $TVU = 1.96 \cdot \sigma_z$
 - with 1.96 being the symmetric confidence interval (95%) of normalized 1D Gaussian

TPU Estimator workflow

Sources of uncertainty

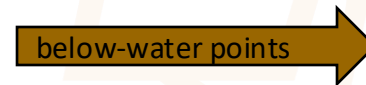
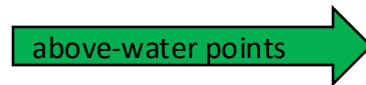
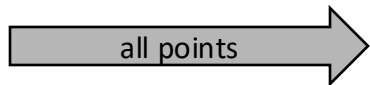
- Signal to noise ratio
- Angle measurement
- Trajectory
- ~~Turbidity~~
- ~~Wind~~

Intermediate result

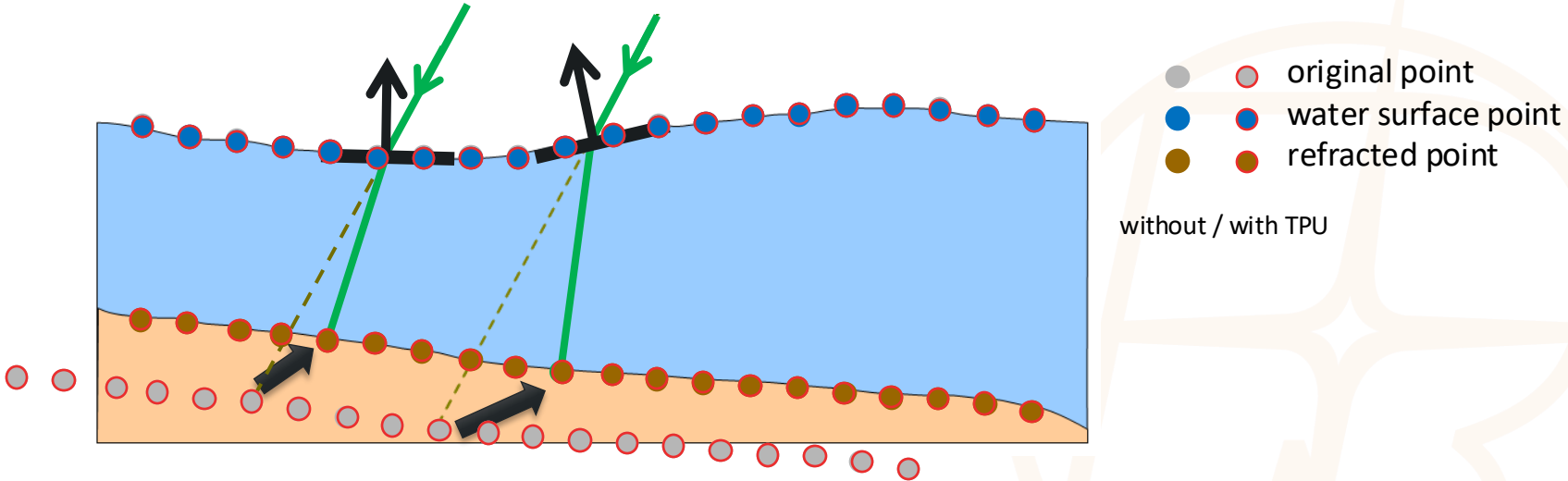
- All measurements:
 - x/y/z total propagated uncertainty
 - Total horizontal uncertainty
 - Total vertical uncertainty
- Water surface model
 - x/y/z uncertainty of cell origin
 - Uncertainty of normal vector

Output

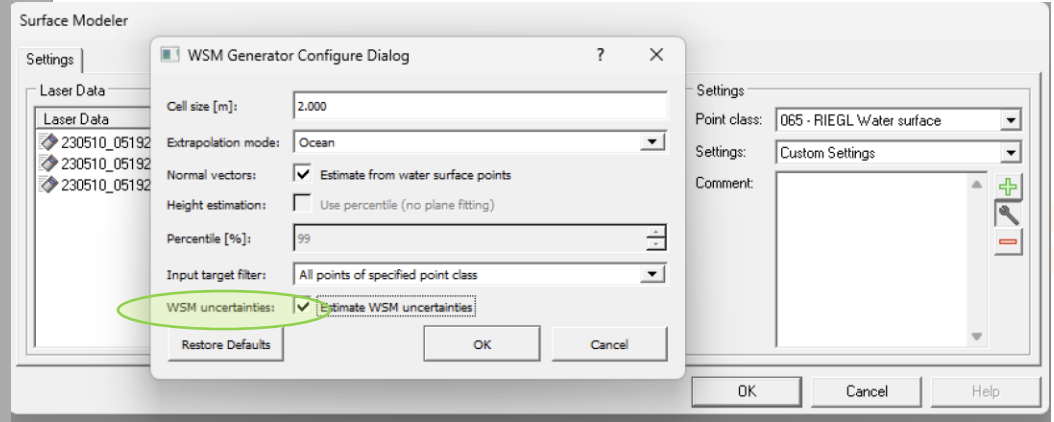
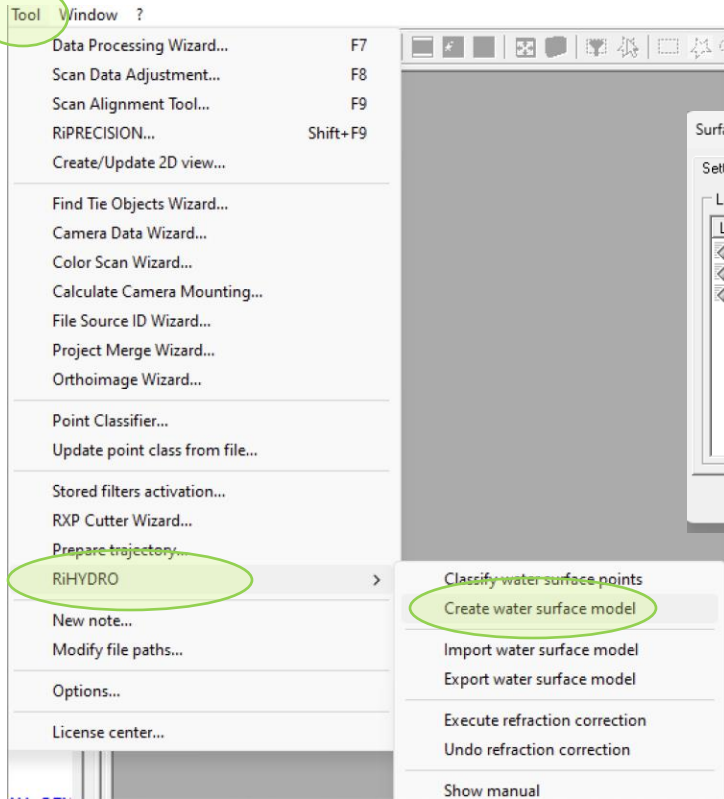
- Above-water points:
 - x/y/z total propagated uncertainty
 - Total horizontal uncertainty
 - Total vertical uncertainty
- Below-water points
 - x/y/z total propagated uncertainty
 - Total horizontal uncertainty
 - Total vertical uncertainty



TPU Estimator workflow



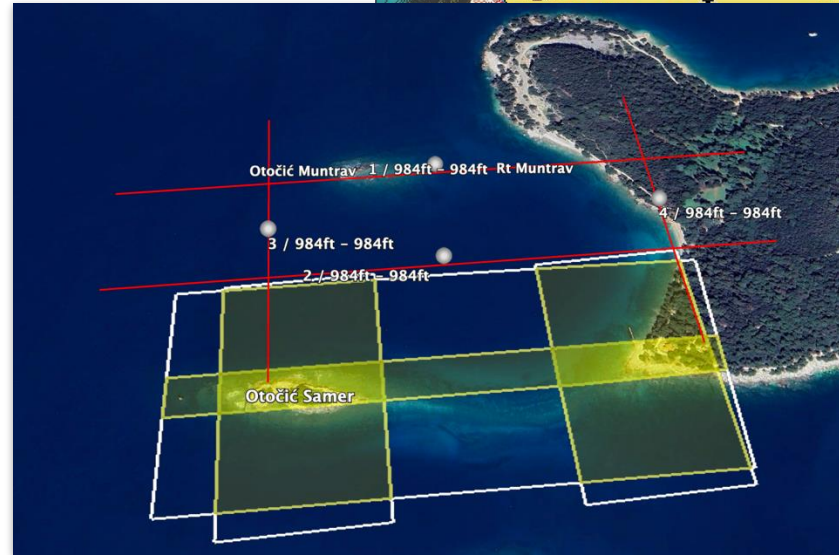
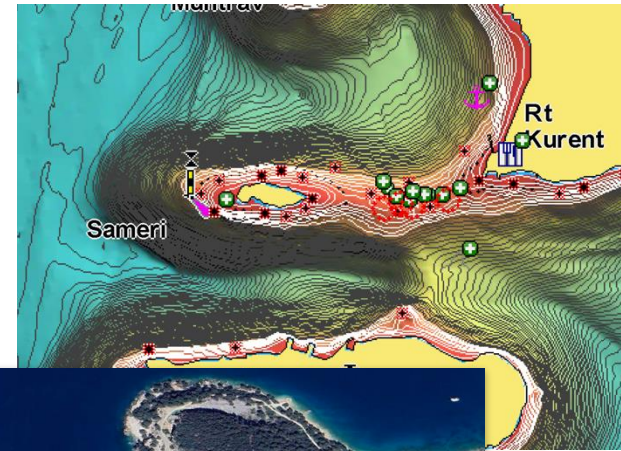
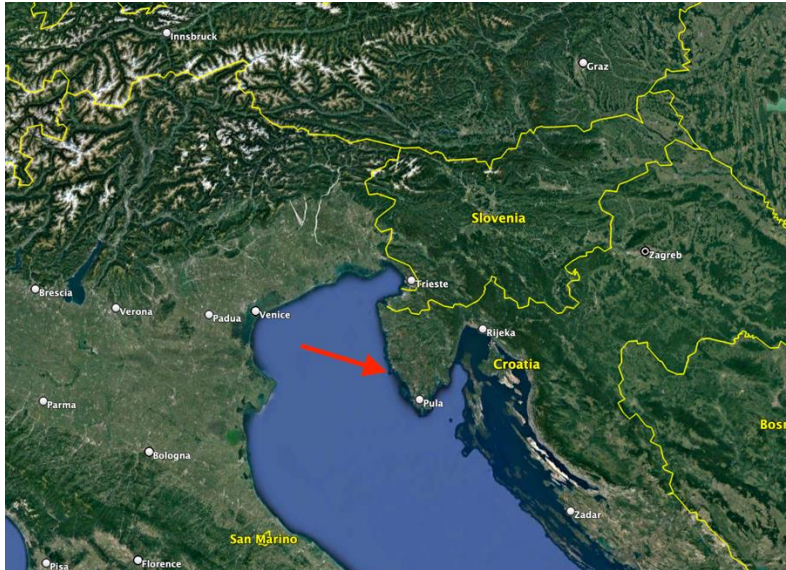
TPU Estimator RiHYDRO integration



Example dataset: VQ-860-G survey Samer Island (Croatia)

VQ-860-G
DA-62

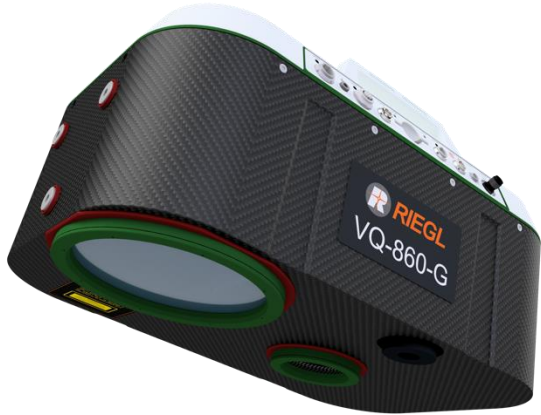
Flight altitude: 980 ft
PRR = 50 kHz and 100kHz
Laser beam divergence = 6 mrad
RCV FOV = 12 mrad



VQ-860-G Installation in DA-62 Nosepod

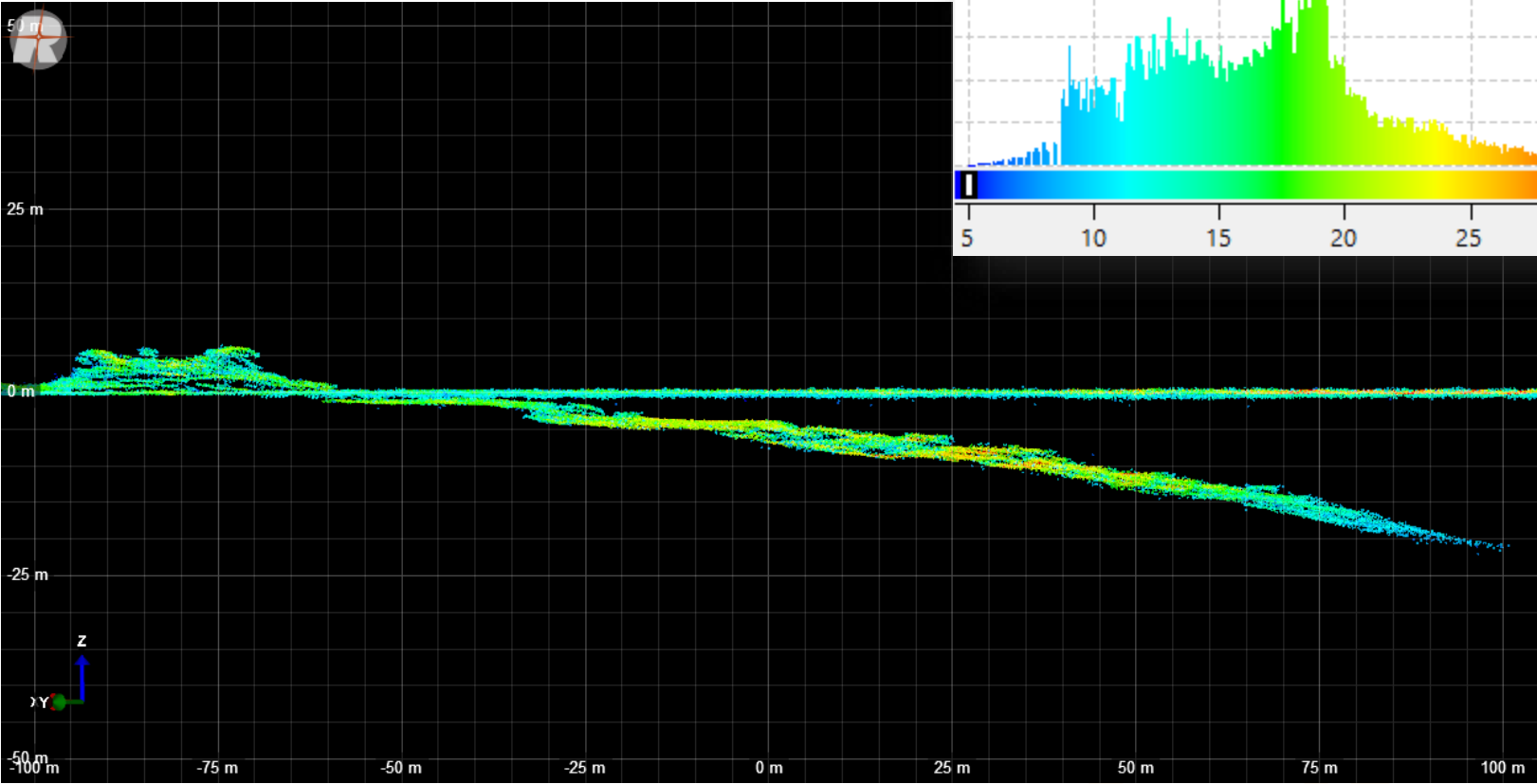


RIEGL VQ-860-G

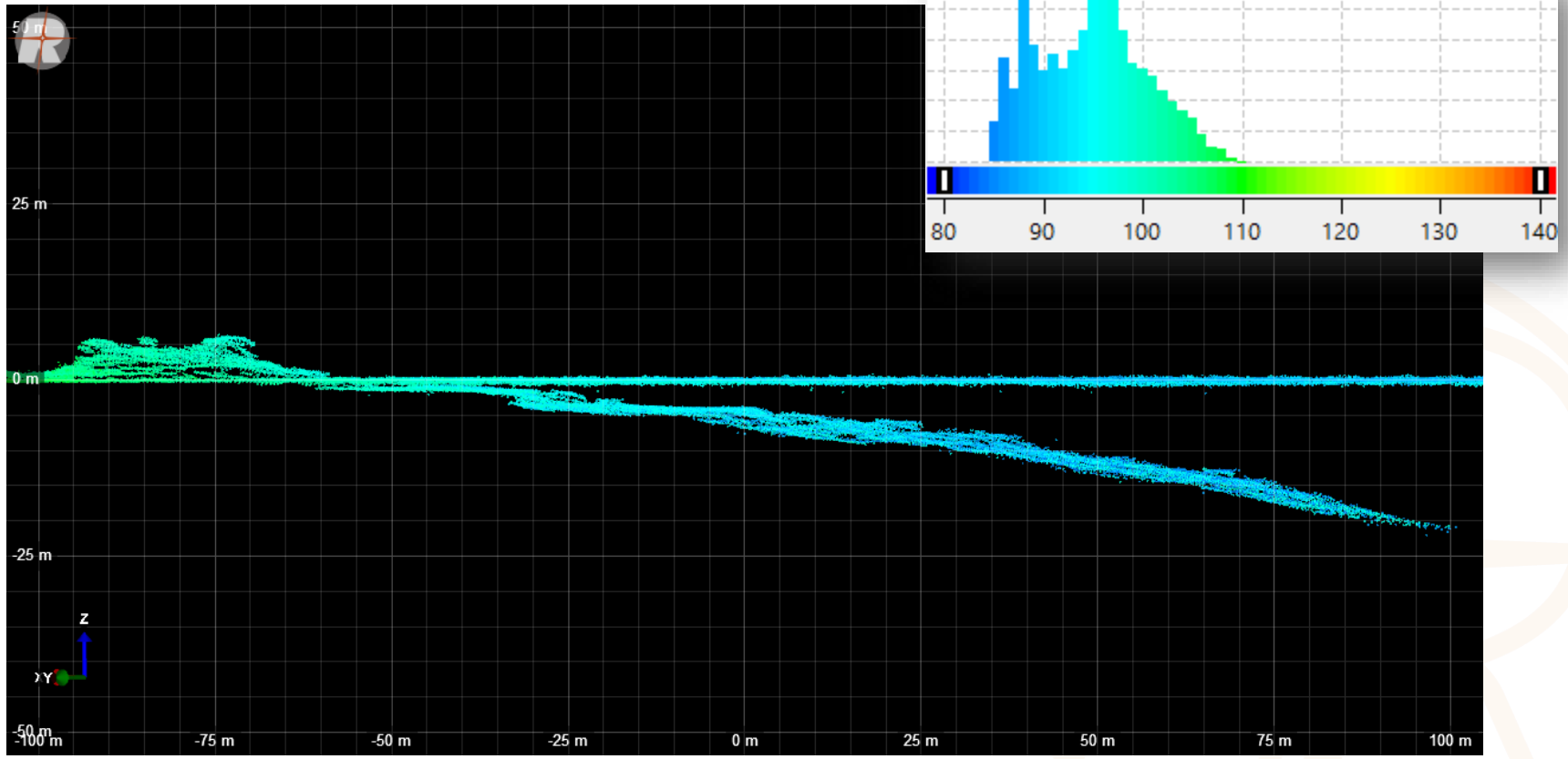


wavelength	532 nm (visible green light)
max. depth penetration	2.5 Secchi depth bright ground
scanner field of view	+/-20° across track +/- 14° along track
laser beam divergence	selectable, 1-6 mrad
measurement rate	50 kHz, 100 kHz
scan speed	up to 100 revolutions/second
laser safety	Laser Class 3B
weight	15 kg

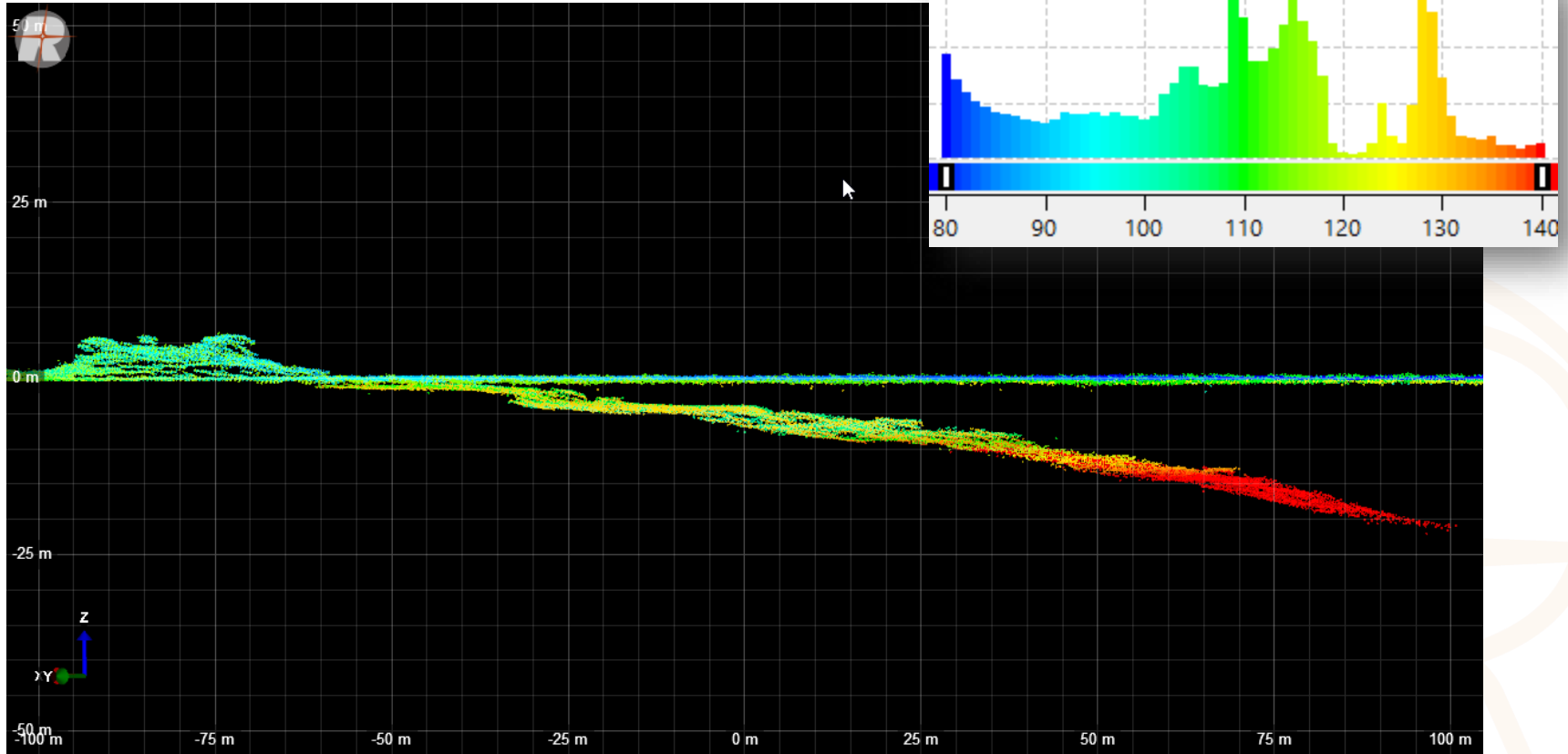
Amplitude [dB]



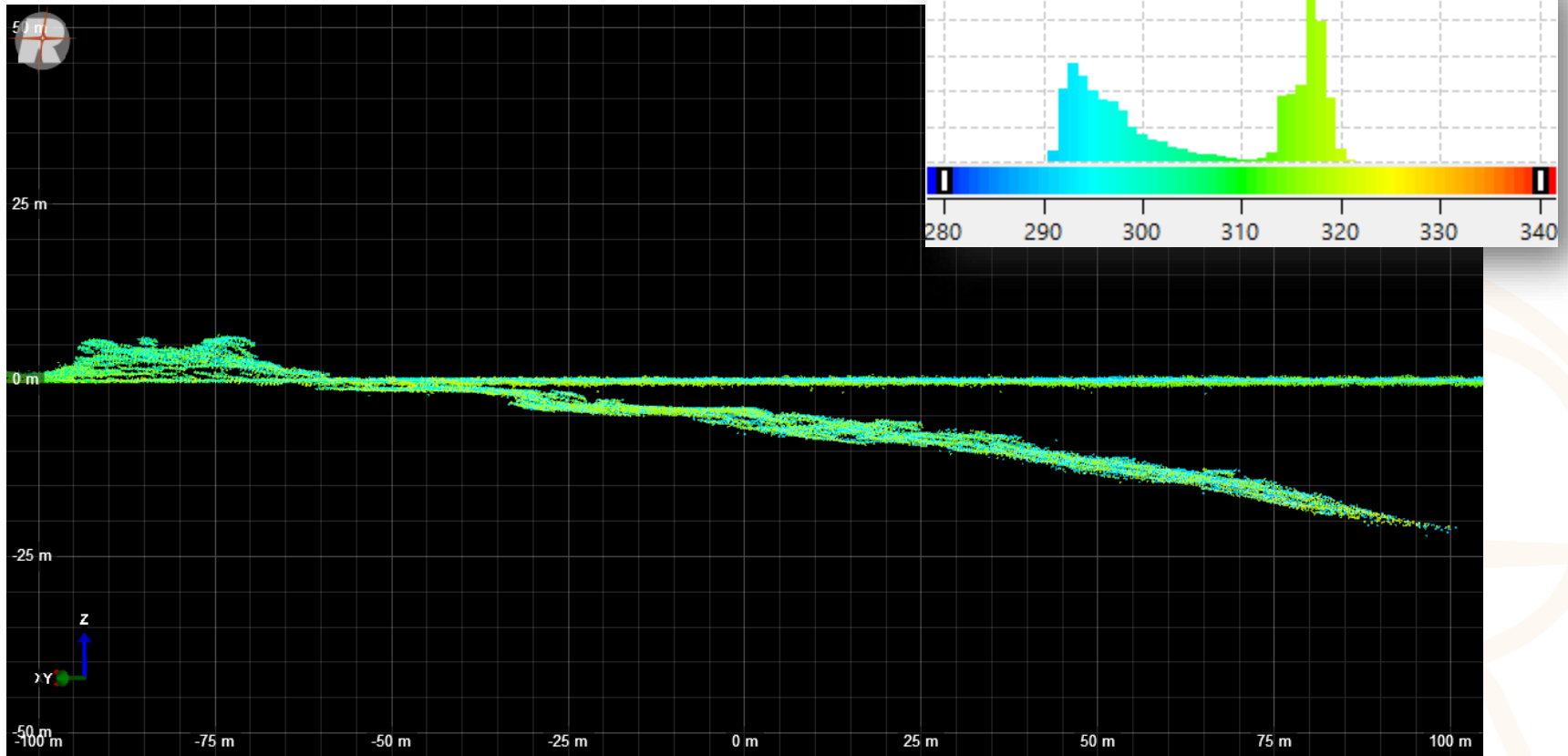
RIEGL TVU [mm]



cBLUE TVU [mm]



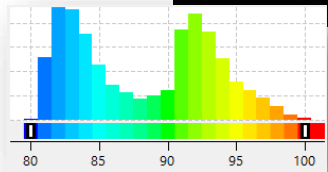
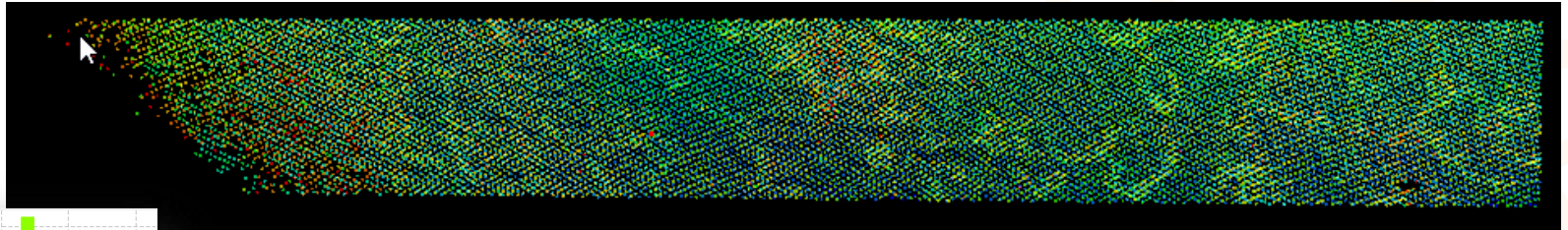
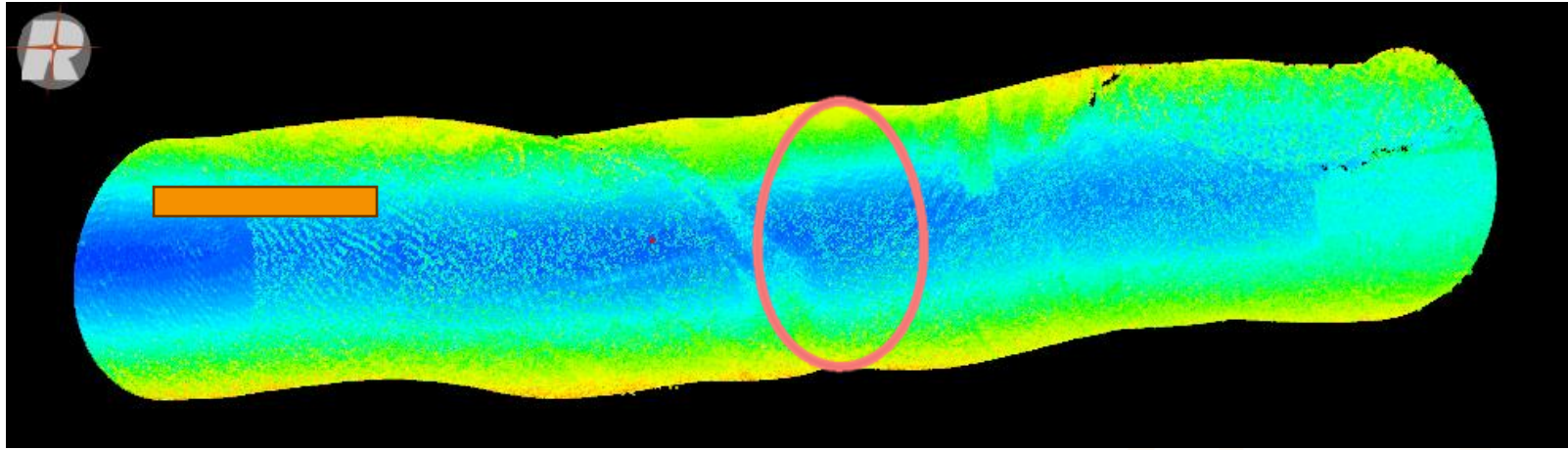
RIEGL THU [mm]



cBLUE THU [mm]

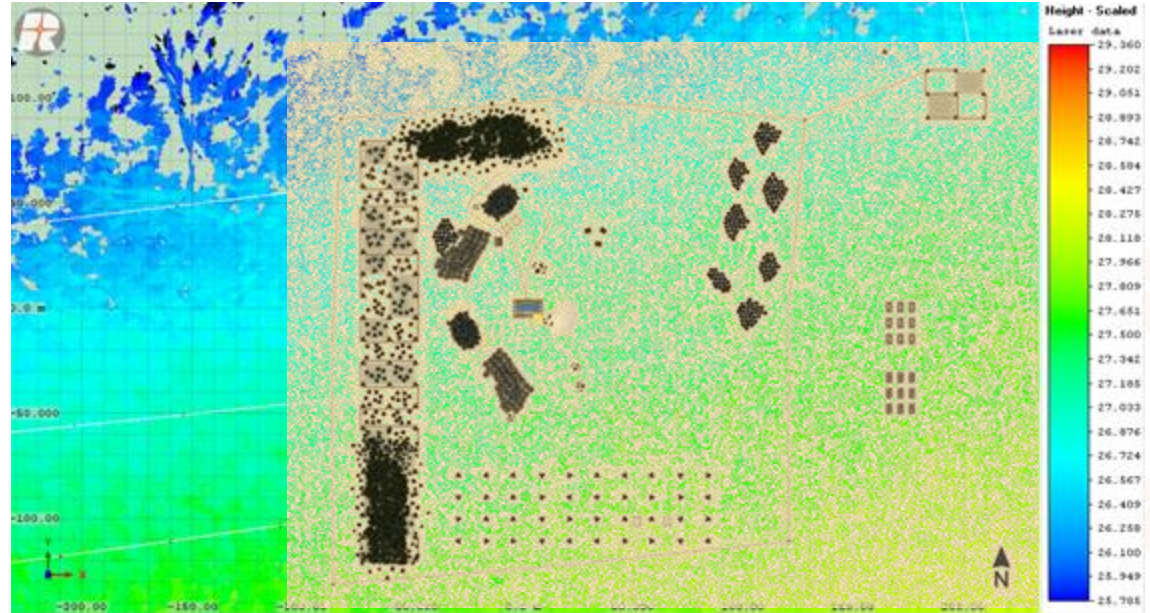


RIEGL TVU – dependencies



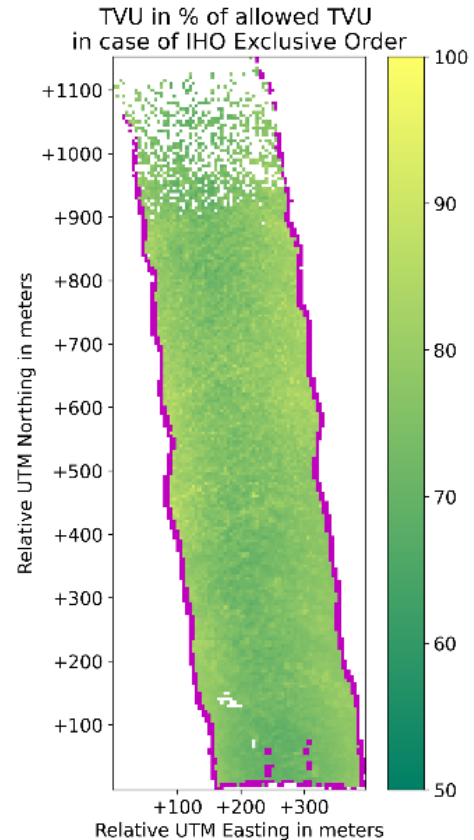
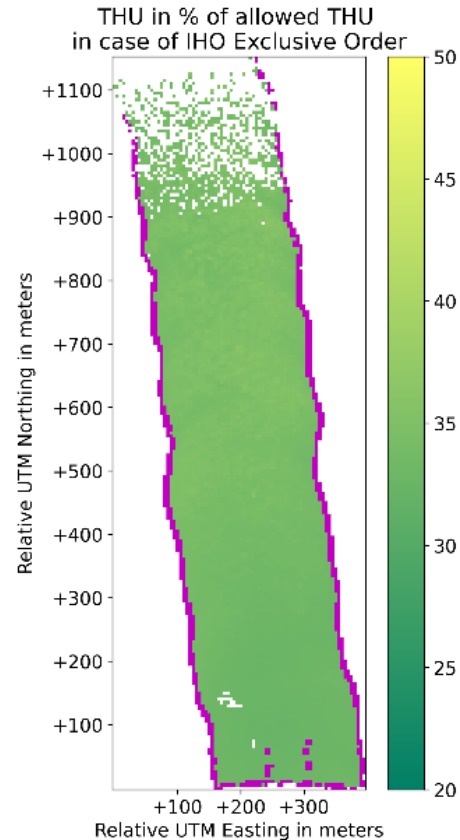
Test project Rostock Digital Ocean Lab Nienhagen

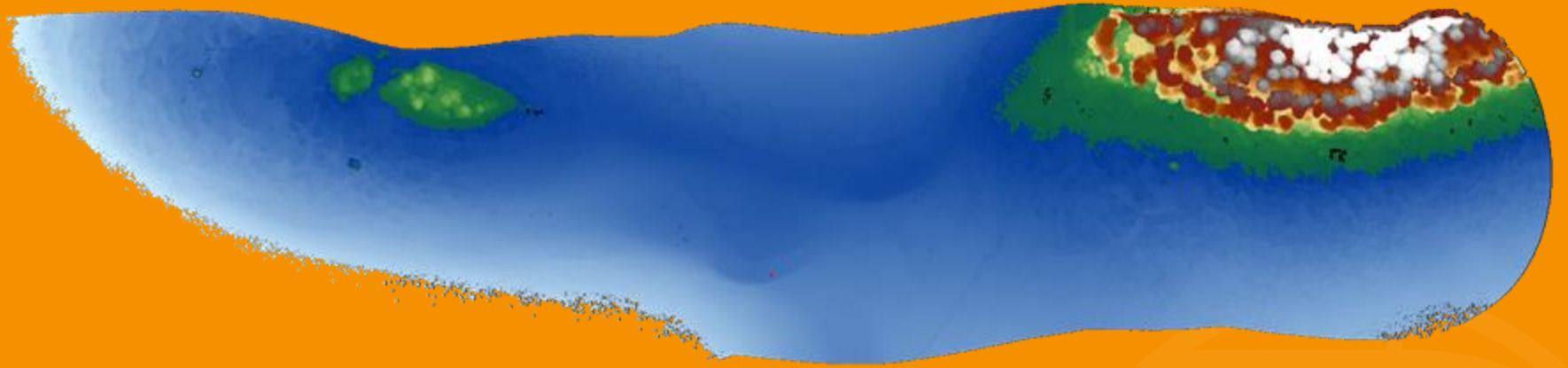
- platform: Diamond DA 62 OE FRW
- speed: 110 kts
- altitude: 300 m
- wave amplitude: 50 cm
- laser beam divergence: 3 mrad
- measurement rate: 100 kHz



Validation against IHO Standard

- IHO Exclusive Order
- estimated TPU values relative to allowed values in a raster model with 5 m resolution





**Thank you
for your kind
attention.**

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