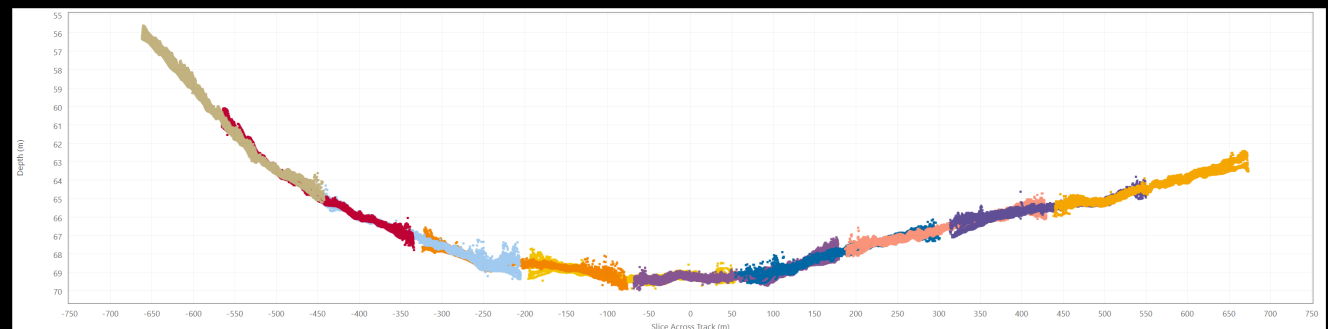
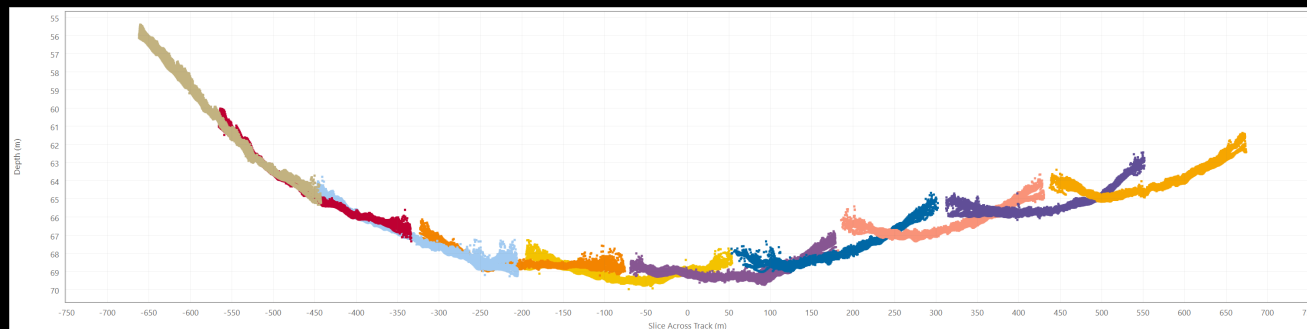
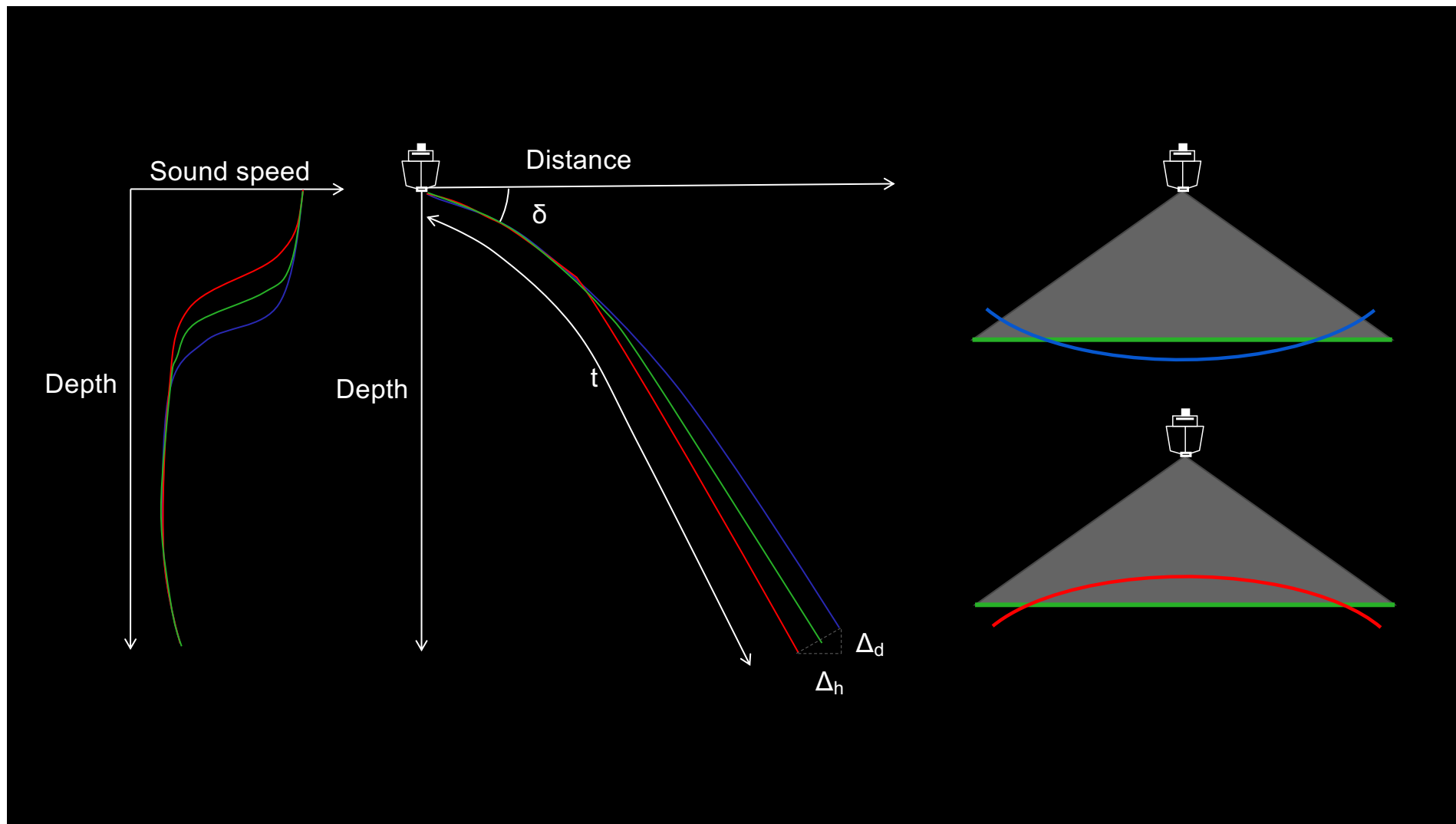


AUTOMATED CORRECTION OF REFRACTION RESIDUALS

Jonathan Beaudoin¹, Weston Renoud², Tannaz Haji Mohammadloo³, Mirjam Snellen³

1. QPS Canada Inc., Fredericton, NB, Canada
2. QPS B.V., Zeist, The Netherlands
3. Technical University of Delft, Delft, The Netherlands



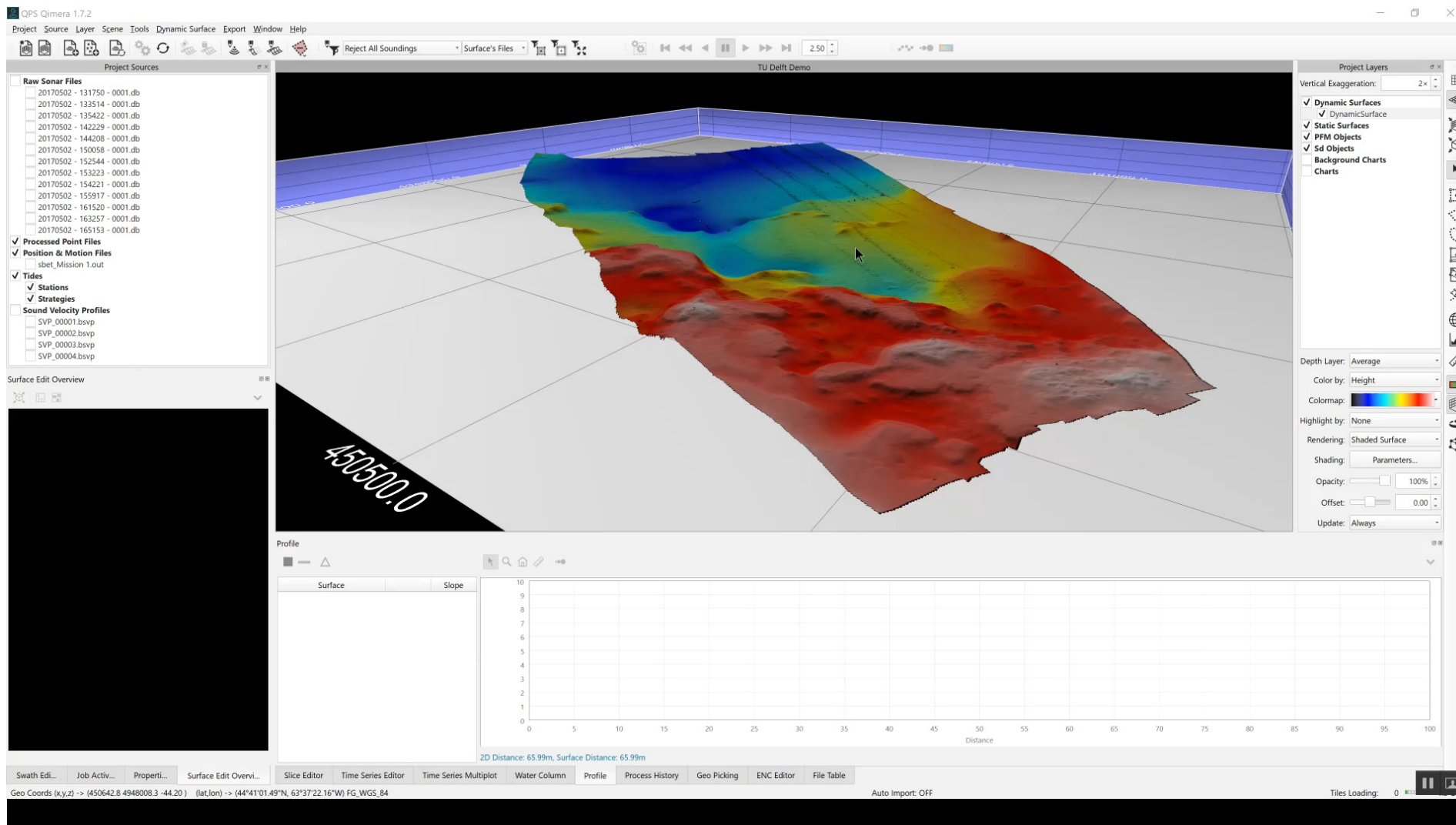


REFRACTION ERRORS: FIVE STAGES OF GRIEF

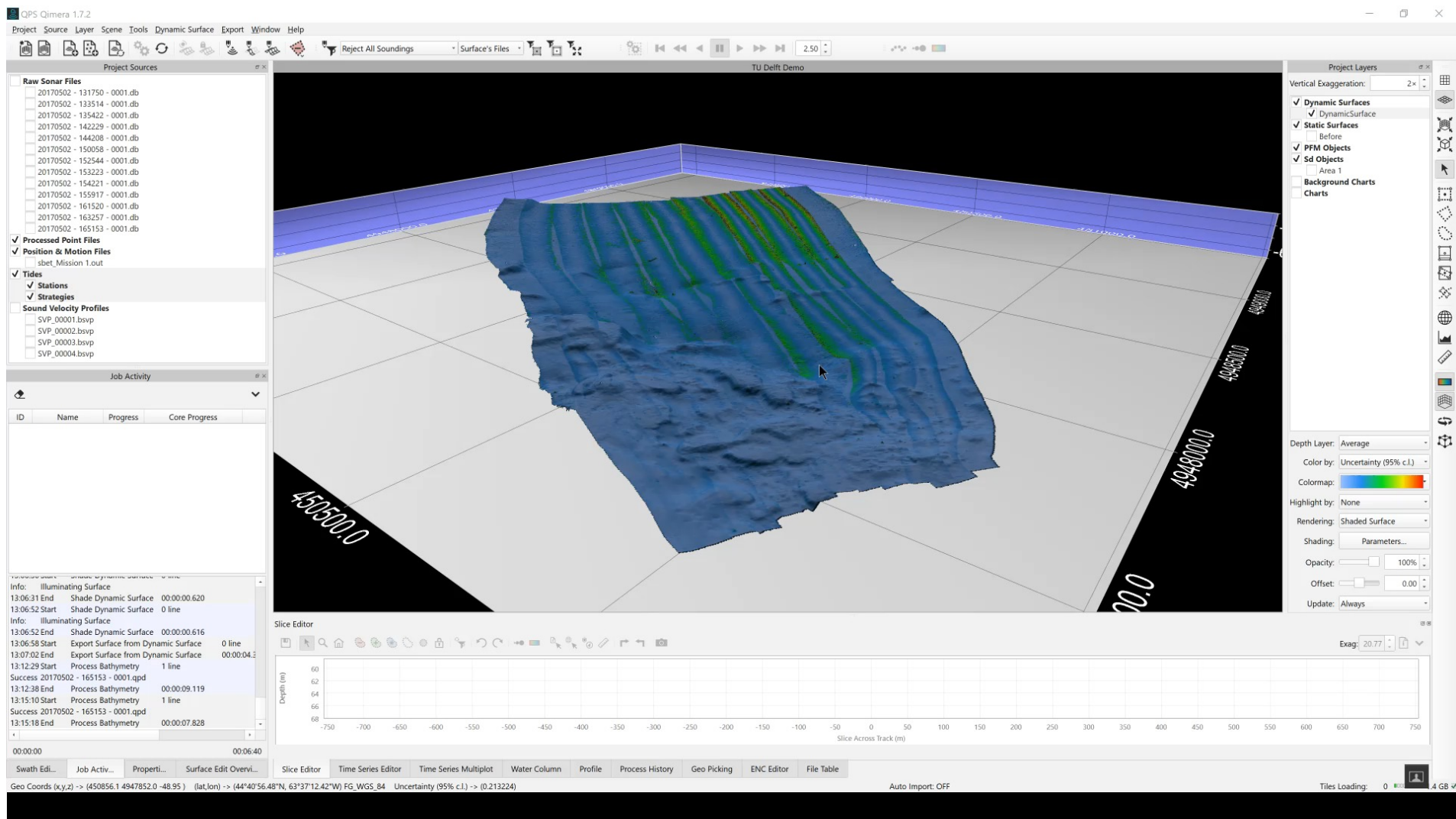
- Stage 1: Denial
- Stage 2: Anger
- Stage 3: Bargaining
- Stage 4: Depression
- Stage 5: Acceptance



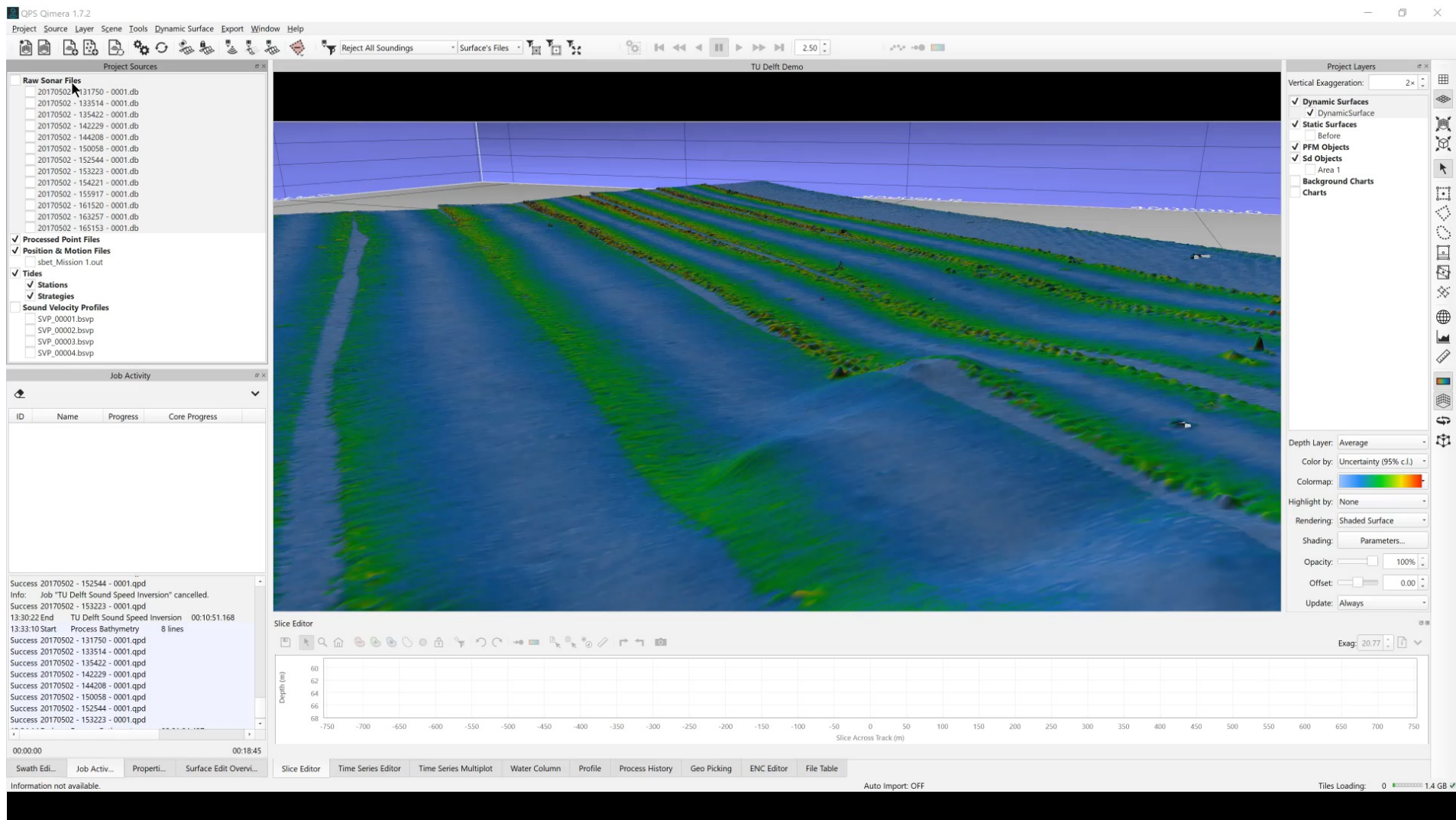
STAGE 1: DENIAL

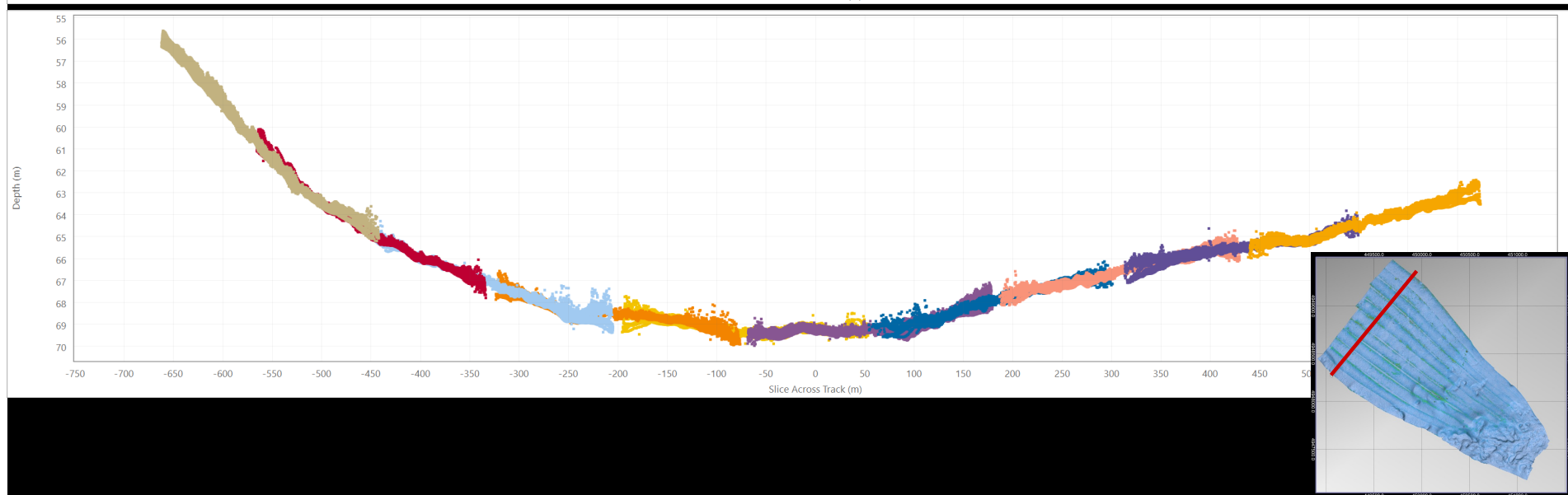
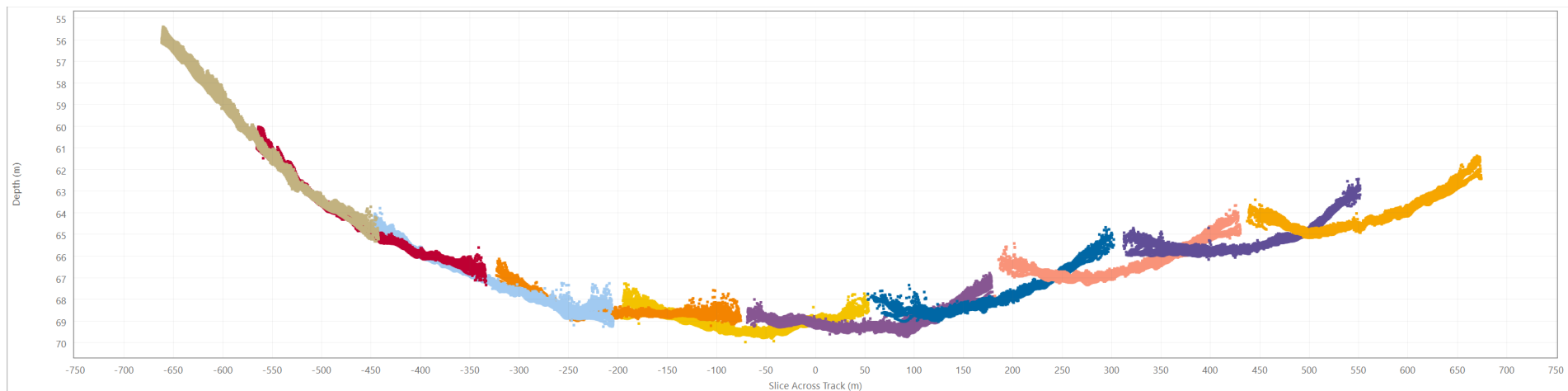


STAGE 3: BARGAINING



STAGE 5: ACCEPTANCE?





TU DELFT SOUND SPEED INVERSION

- Snellen et al. (2009)
- Funding available for commercial implementation (2016)
- Cooperative partnership with TU Delft and QPS (2017)
- Released exclusively in Qimera 1.6, February 2018



A model-based method for reducing the sound speed induced errors in multi-beam echo-sounder bathymetric measurements

Mirjam Snellen, Kerstin Siemes, Dick G. Simons
Delft University of Technology, Faculty of Aerospace Engineering, Acoustic Remote Sensing Group
Kluyverweg 1
2629 HS, Delft, the Netherlands

Abstract: We present a method for accurately estimating the bathymetry from multi-beam echo-sounder (MBES) travel-time measurements in environments with large variations in the water column sound speed (both temporally and spatially). In this type of environments the water column sound speeds at the time of the MBES transmission are often known, preventing a reliable conversion from the measured travel-times to bathymetry. In addition, accurate sound speed information is required for the MBES beamsteering process. Situations where information regarding the prevailing sound speeds is insufficient occur, for example, in situations where fresh river water mixes with seawater. The method fully exploits the redundancy in the MBES measurements obtained from the overlap of adjacent swaths. It maximizes agreement in the bathymetry along the overlapping swaths. The Gauss-Newton method is employed for the optimization. This method is very efficient, requiring a few iterations only and therefore very well suited for processing the large datasets as typically obtained by the MBES. From simulations it is shown that the method performs well and offers for an almost exact determination of the bathymetry and sound speeds. In principle, the method eliminates the need for sound speed measurements, as long as sufficient overlap exists.

INTRODUCTION
Employing multi-beam echo-sounder (MBES) systems has proven to be a cost-efficient technique to map the bathymetry of sea- and river-floors within limited time. In order to cover a large area of the seafloor at once, an MBES sends out an acoustic pulse along a wide swath perpendicular to the sailing direction. Beamsteering at reception allows for determining both the angle and the corresponding (two-way) travel-time of the received signals. For each ping, water depths along the swath can be derived from the combination of travel-time and angle, provided that the local sound speed in the water column is known [1].
When conducting MBES measurements, typically two sets of sound speed measurements are taken. The first set consists of the sound speeds at the MBES transducer position which are usually measured continuously using a sensor under the keel of the ship. These sound speeds are employed for the

beamsteering process. The second set consists of sound speed profiles acquired using, for example, a Conductivity-Temperature-Depth (CTD) device. These sound speed profiles are required for determining the sound propagation through the water column, needed for deriving the bathymetry from the measured travel-times [2], [3].

Due to algae growth and other types of contamination on the sensor, the quality of the sound speed measurements at the transducer position sometimes gets degraded, resulting in beamsteering in directions that differ from those aimed for and which are unknown. In addition, due to time constraints, only a few sound speed profile measurements are conducted during a survey. For environments where the water column sound speed profiles vary rapidly (both temporally and spatially) this can result in errors in the derived bathymetry.

Both above mentioned errors result in a bathymetry that shows only a *dropy* like effect. In these cases, the depths measured in the outer parts of swaths are under- or overestimated. This is most obvious when parts of the swaths overlap, since then the measured depths in the overlap regions are not consistent with each other.

Here, we present a method for eliminating these errors, without the need for additional information on the sound speed profile. To this end, use is made of the fact that the seafloor will in general not vary much during the survey (several hours). By requiring the derived bathymetry along overlapping regions to coincide, the prevailing water column sound speeds and thus the bathymetry can be estimated by iteration. In theory, this approach eliminates the need for sound speed measurements as long as sufficient overlap along adjacent swaths is available [4], [5].

As a first step for assessing the feasibility of the proposed method simulations, have been carried out. Section II provides a description of the approach towards eliminating sound speed induced errors as proposed in this contribution. Section III presents the results of applying this method to simulated data. Conclusions regarding the applicability of the method are presented in Section IV.

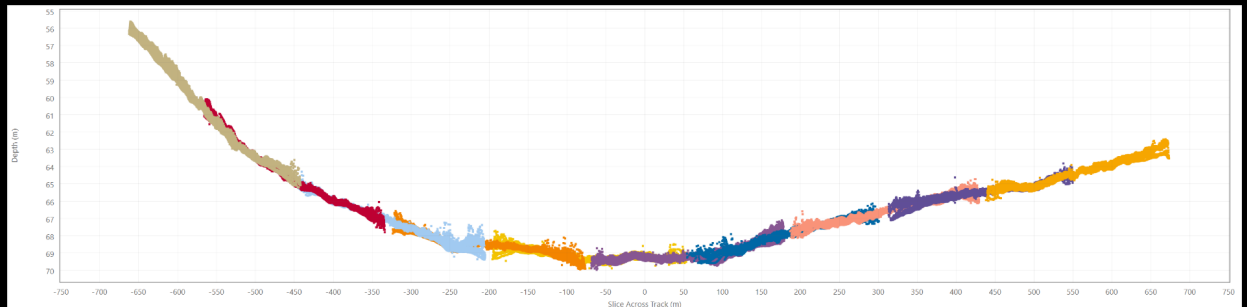
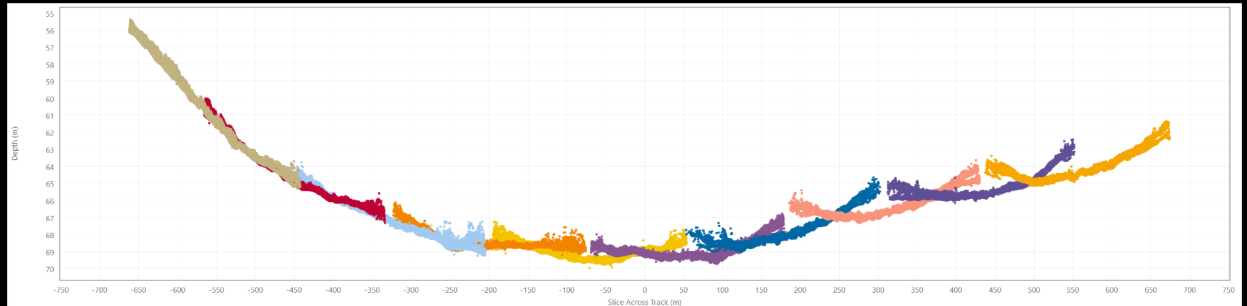
1-4244-2523-5/09/\$20.00 ©2009 IEEE



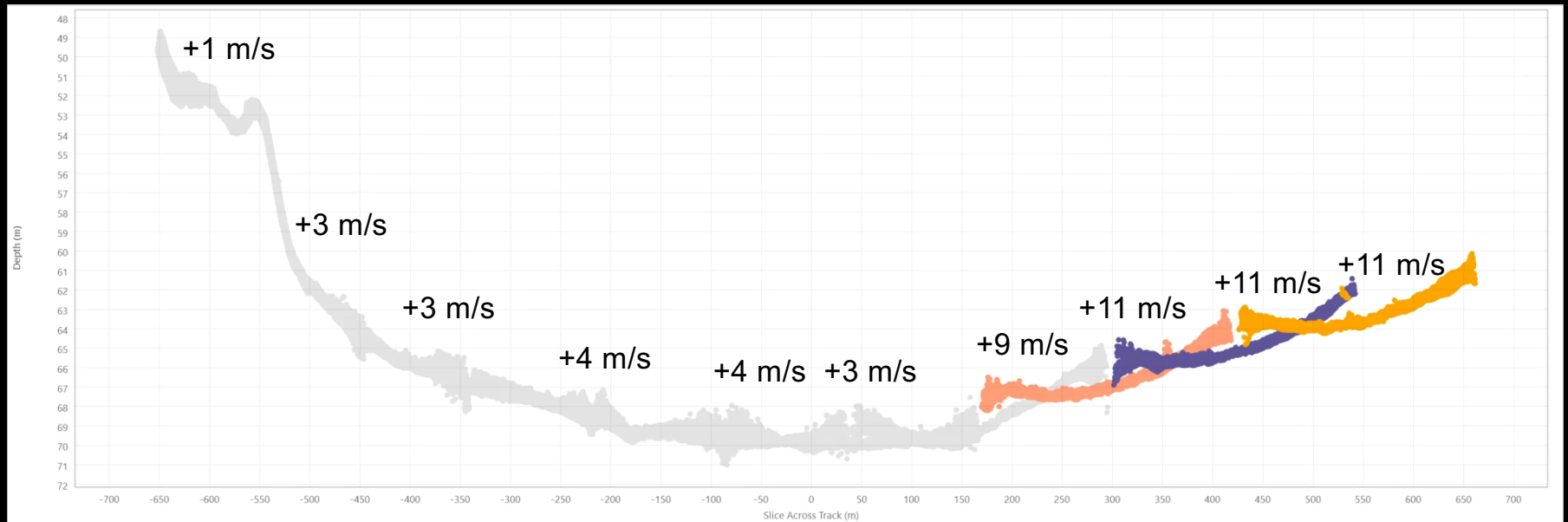
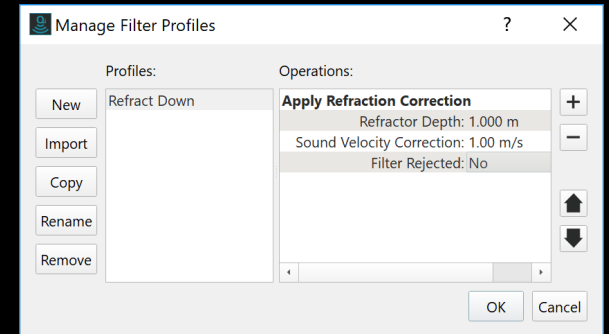
Snellen, M., Siemes, K. and D. G. Simons (2009). A model-based method for reducing the sound speed induced errors in multi-beam echo-sounder bathymetric measurements. OCEANS 2009 - EUROPE, pp. 1-7.

BENEFITS

- Objective
- Automated
- Physics-based
- Accountable

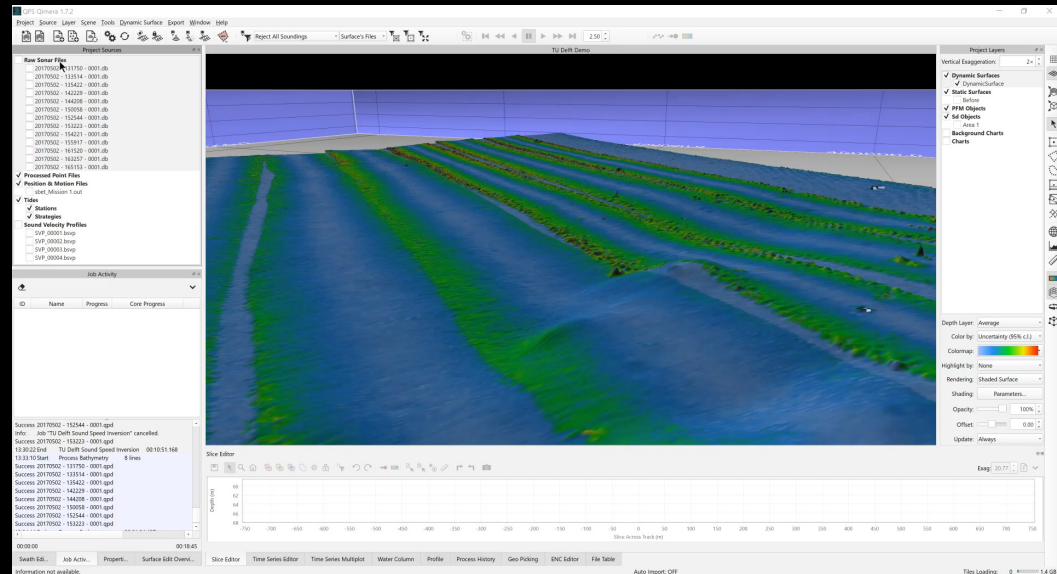
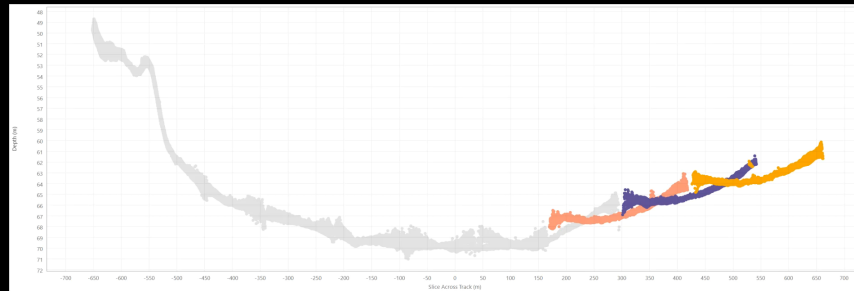


OBJECTIVE

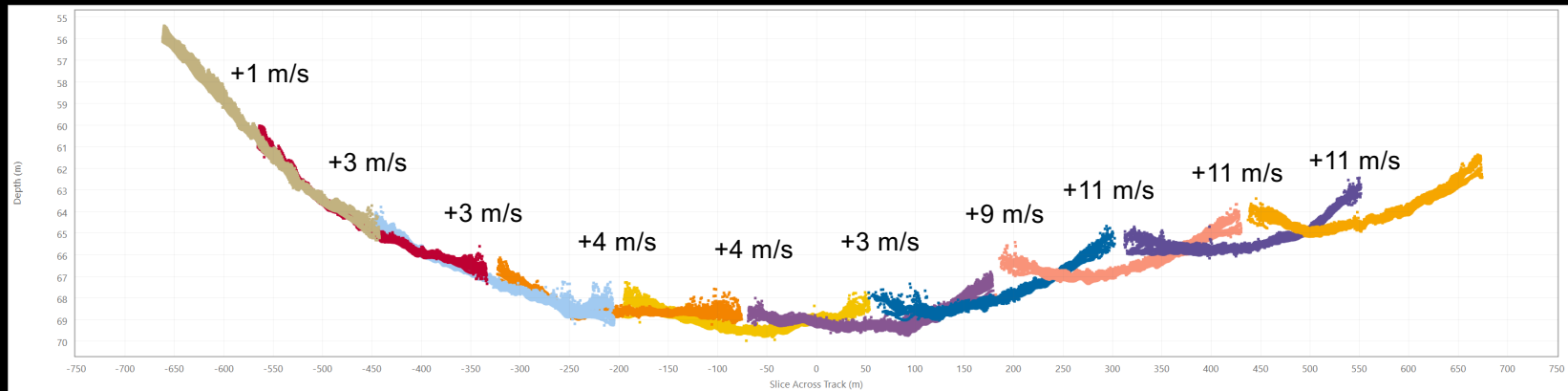


AUTOMATED

- Does not require data review
- Select lines, run algorithm
- Small number of parameters to choose from
 - Speed
 - Spatial Scale
 - Smoothing

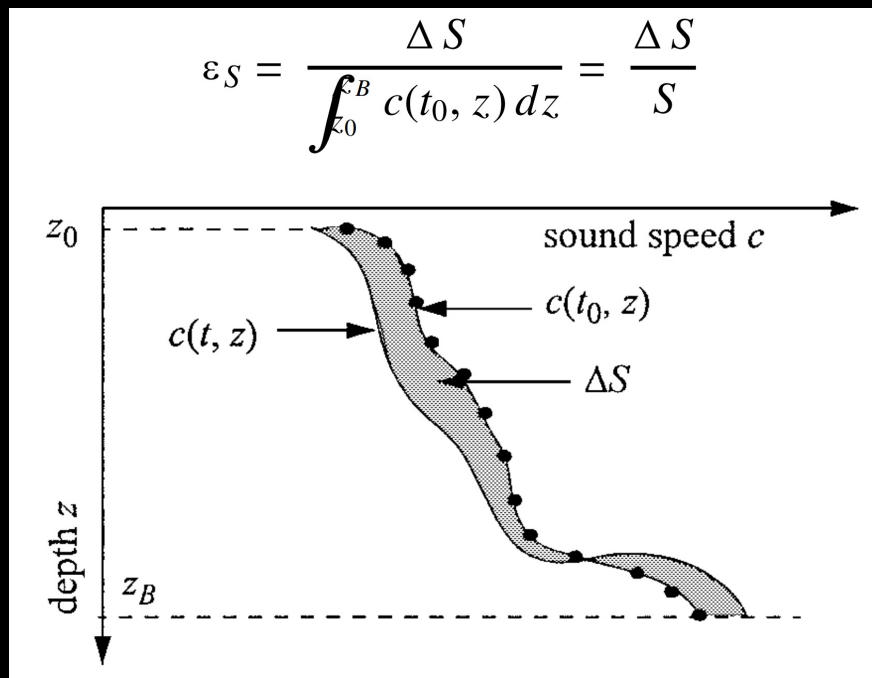


PHYSICS BASED



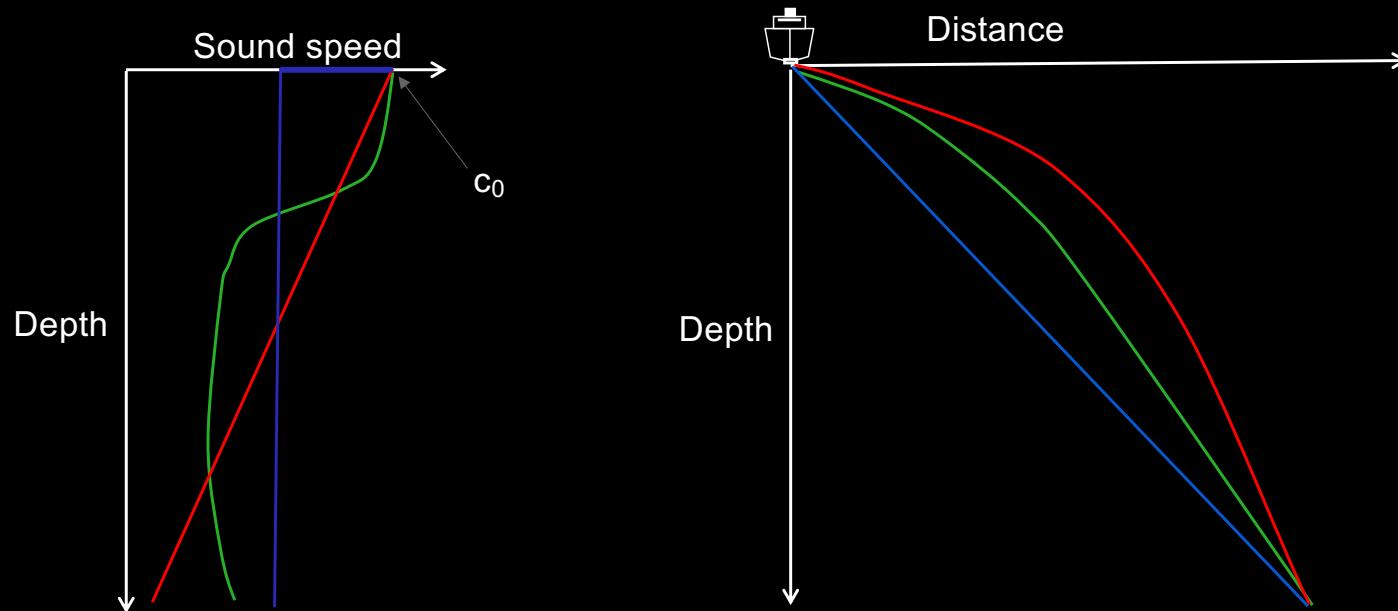
$$E(\mathbf{x}) = \sum_{c=1}^C \sqrt{\frac{\sum_{n=1}^N \sum_{b=1}^{B_{c,n}} (z_{c,n,b}(\mathbf{x}) - \bar{z}_c(\mathbf{x}))^2}{\sum_{n=1}^N B_{c,n}}}$$

PHYSICS BASED: HARMONIC SOUND SPEED



“...the depth estimate difference related to these two sound speed profiles is almost a function of only the relative area difference ε_S . The difference is zero when $\varepsilon_S = 0$.”

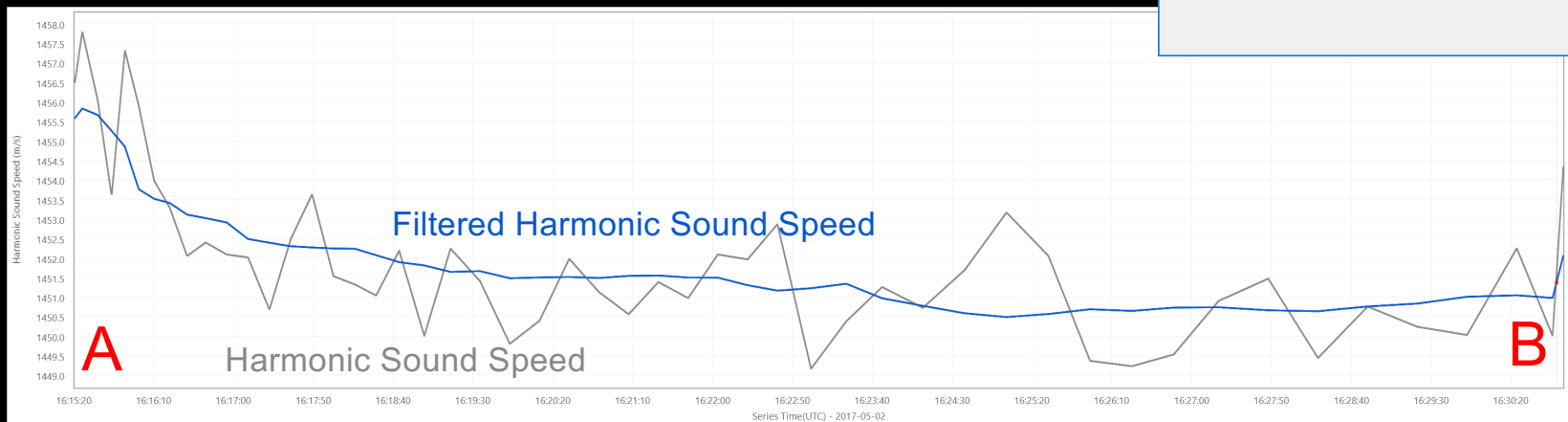
PHYSICS BASED: HARMONIC SOUND SPEED



“for the same propagation time, the position at which a sound pulse impinges on the seafloor is almost the same for a family of sound speed profiles with the **same surface value c_0** and the same area under them, which is defined as an integral of $c(z)$ with respect to depth z .”

Geng and Zielinski (1999), *Precise Multibeam Acoustic Bathymetry*, Marine Geodesy, 22:157–167, 1999

ACCOUNTABLE



TU Delft Sound Speed Inversion Settings ? X

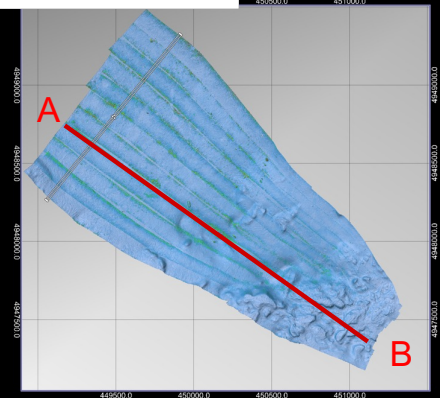
Algorithm: Full Search

Configuration: Coarse

☒ Smooth results?

OK Cancel

- HSS time-series results for every survey line
- Different runs preserve different results
- User can review, vet, edit or even reject entirely



ACCOUNTABLE

Harmonic Sound Speed

☒ Use harmonic sound speed as override strategy where available

Harmonic Sound Speed Priorities:

☒ Full Search - Coarse (20170502 - 161520 - 0001_11)

Processing Settings Editor

Sound Velocity Position, Motion, Heading Vertical Referencing Depth Son

Sound Velocity Strategy

☒ Specific sound velocity profile: SVP_00003.bsvp

☐ Fixed Velocity from surface sensor

☐ Fixed velocity: 1500.0 m/s

☐ Real-time scheduling

☐ Nearest in time

☐ Nearest in distance

☐ Nearest in distance, within time: 720 minutes

Surface Sound Speed

☐ Use as first entry in raytrace profile

Surface Sound Speed Priorities:

☒ Applied Surface Sound Speed (20170502 - 161520 - 0001_11)

Harmonic Sound Speed

☒ Use harmonic sound speed as override strategy where available

Harmonic Sound Speed Priorities:

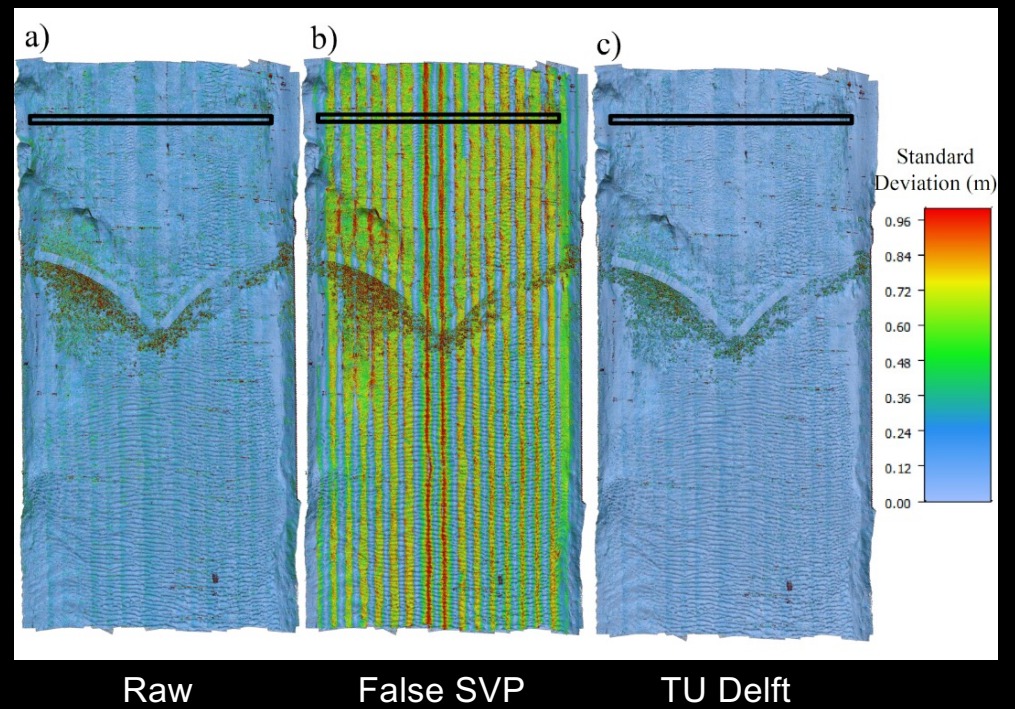
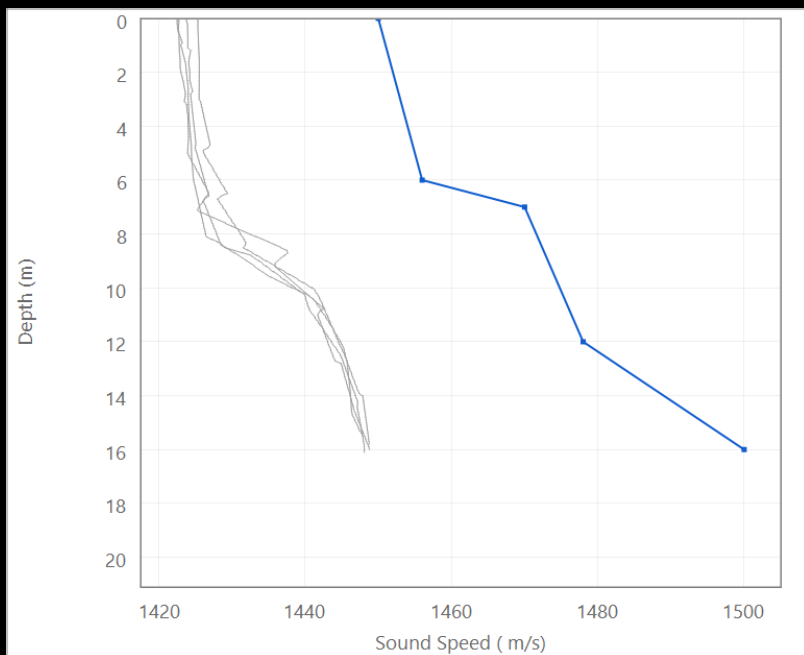
☒ Full Search - Coarse (20170502 - 161520 - 0001_11)

OK Cancel Apply

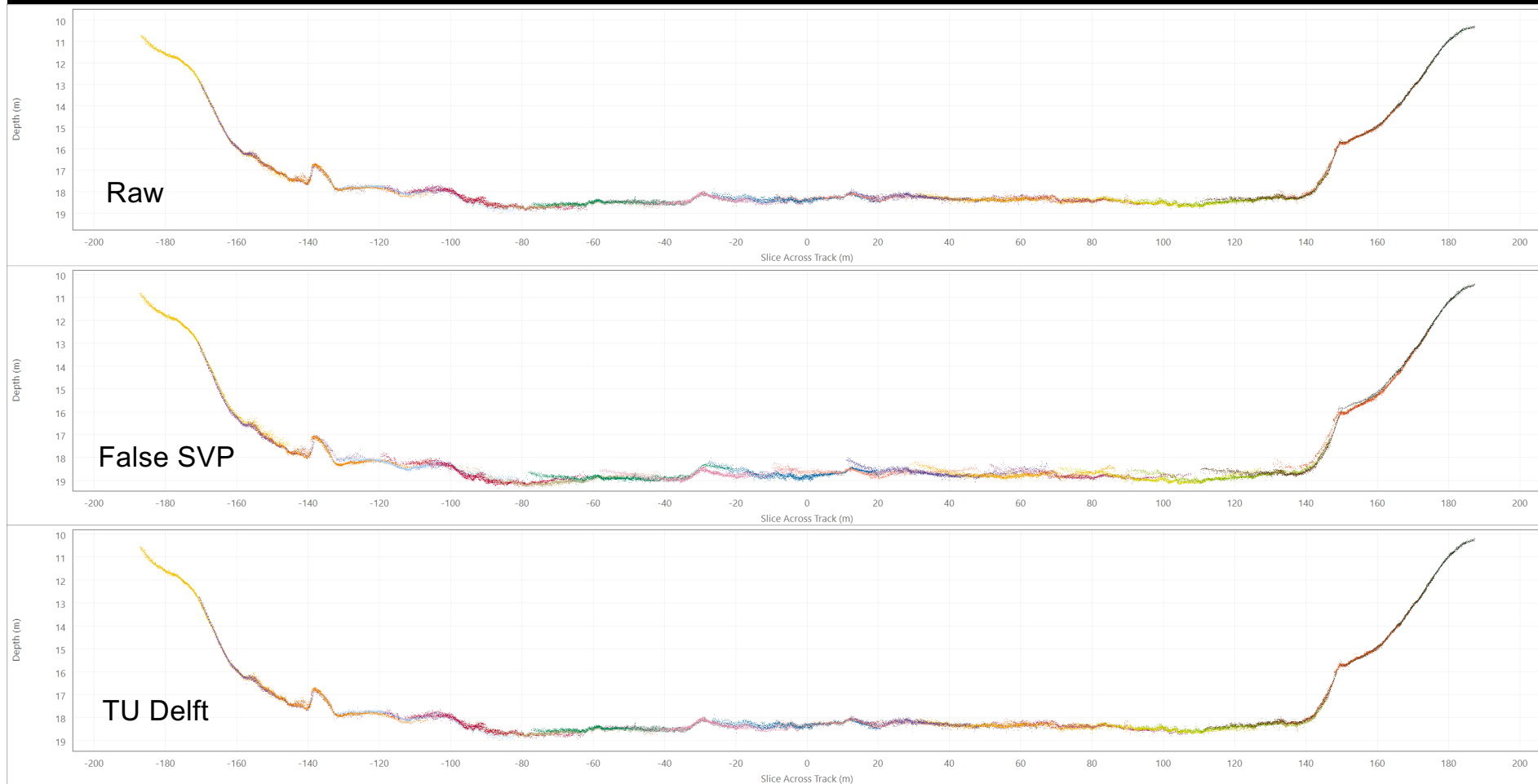
COMMUNITY ACCEPTANCE?

TEST AGAINST BASELINE

TEST AGAINST BASELINE



TEST AGAINST BASELINE



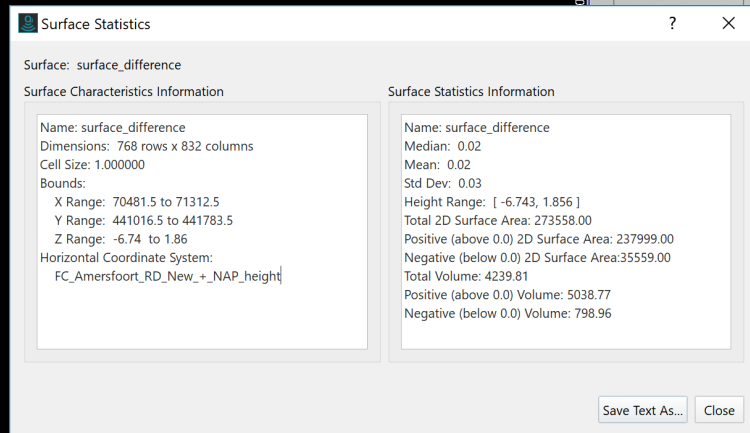
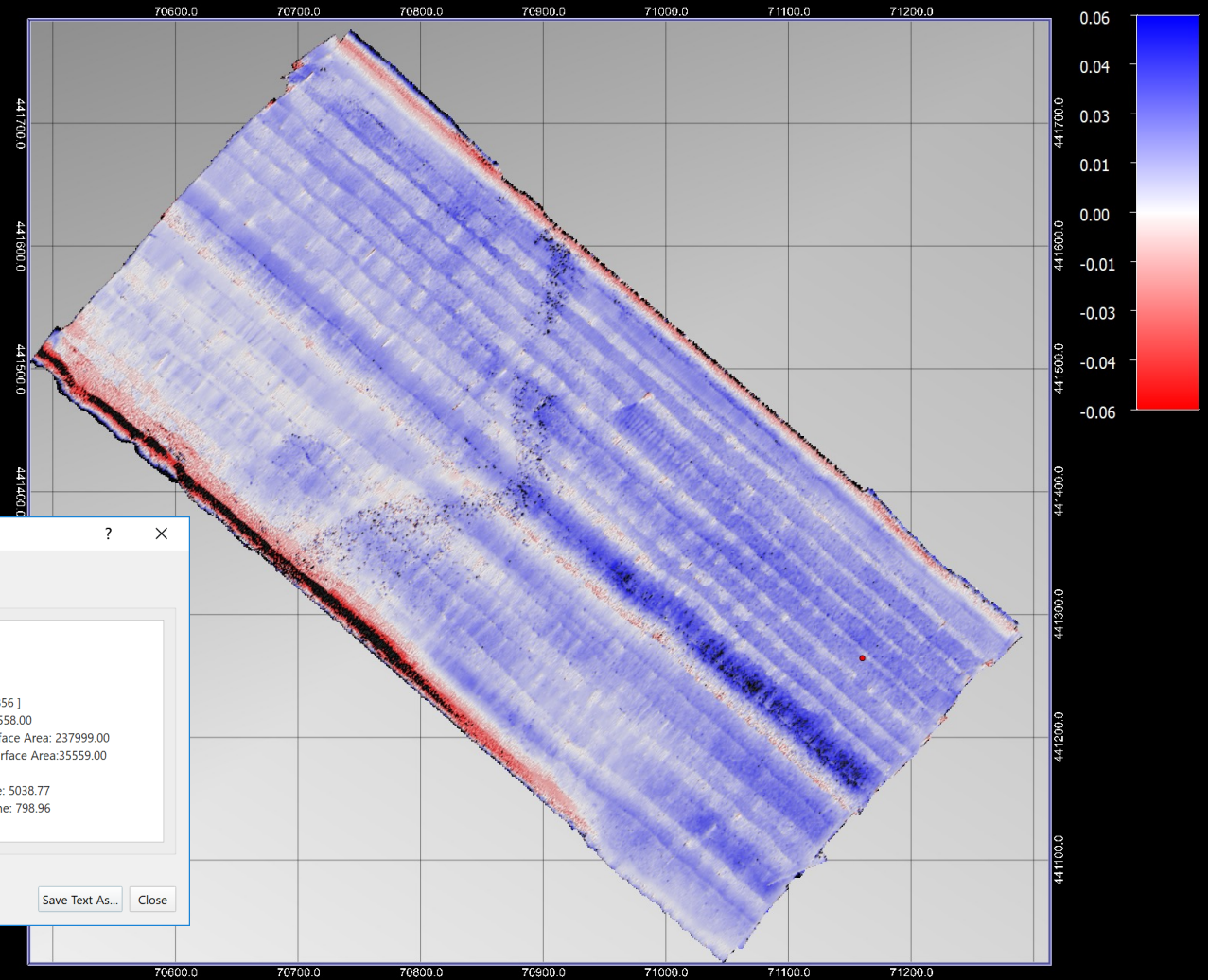
TEST AGAINST BASELINE

Fake SVP

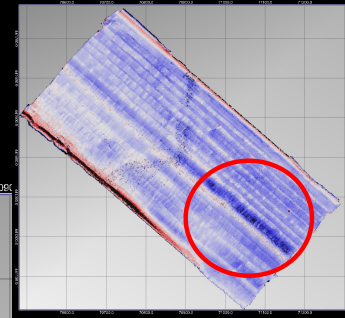
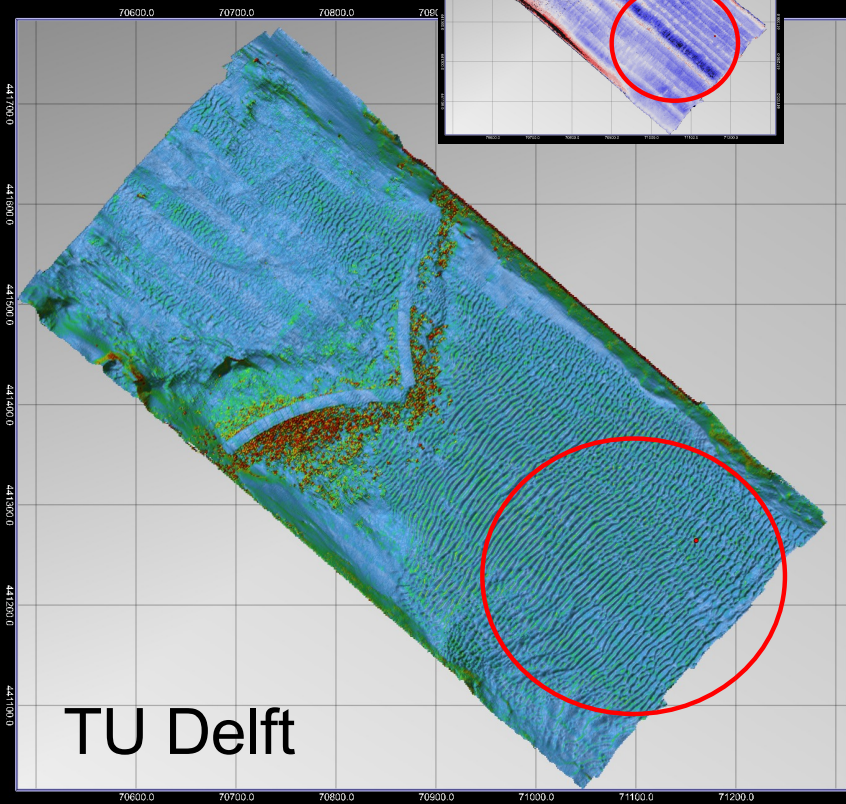
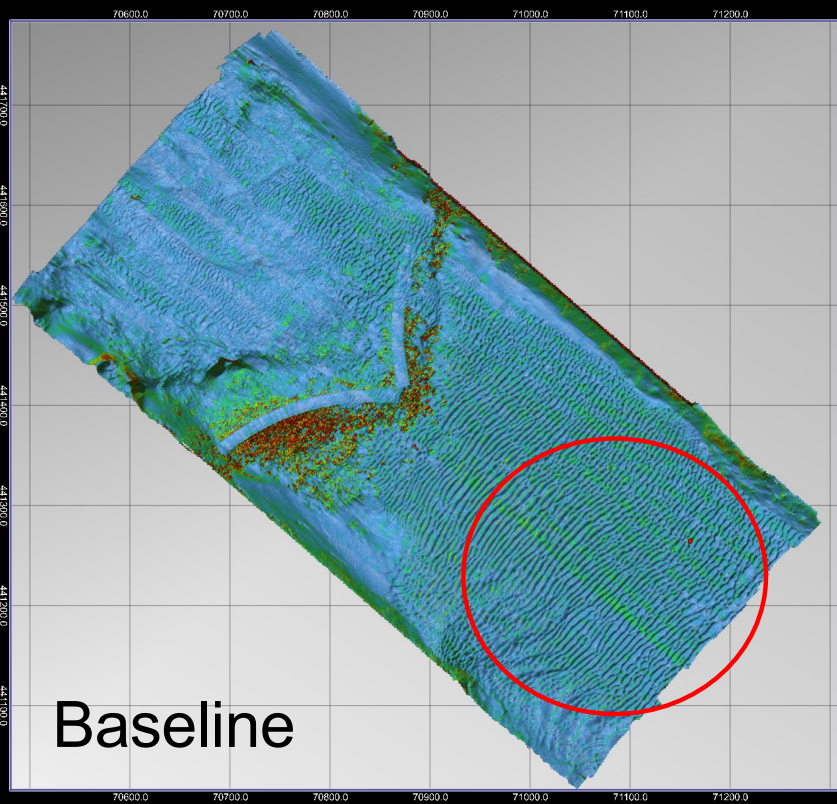
Median: -0.33
Mean: -0.33
Std Dev: 0.06

TU Delft

Median: 0.02
Mean: 0.02
Std Dev: 0.03

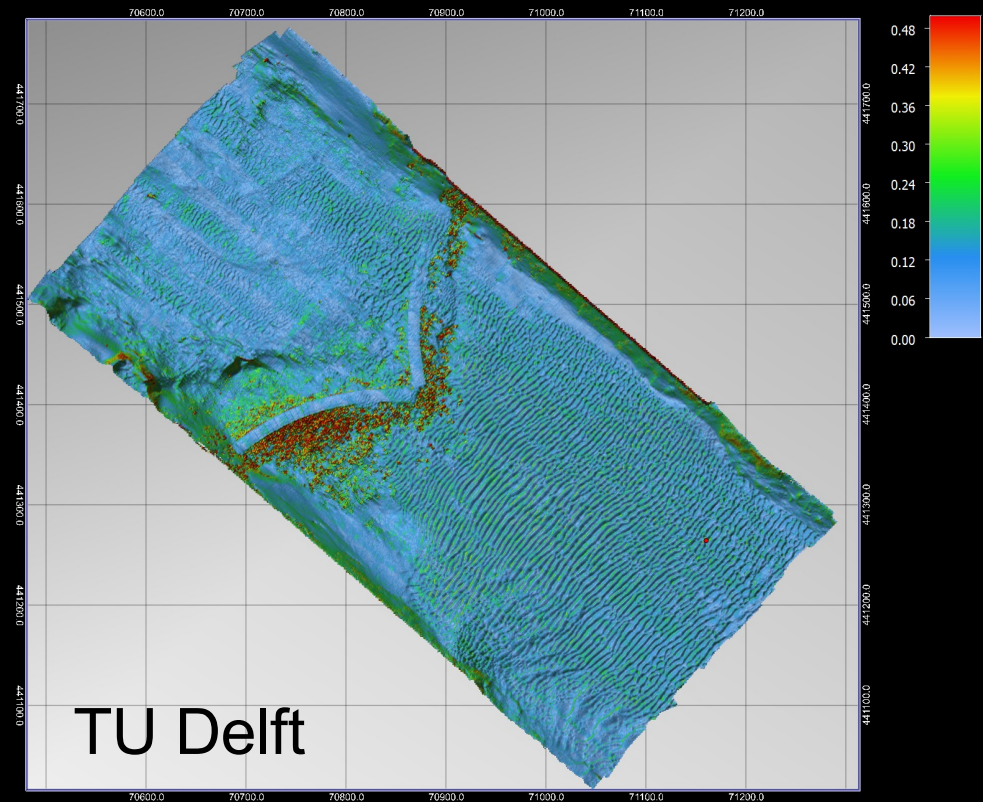


TEST AGAINST BASELINE



FUTURE WORK

- What can improve?
 - Dual-head with minimal line overlap
 - Case of sub-optimal vertical positioning
- Better understand sensitivity to
 - Survey line spacing
 - Seabed morphology
 - Oceanographic conditions

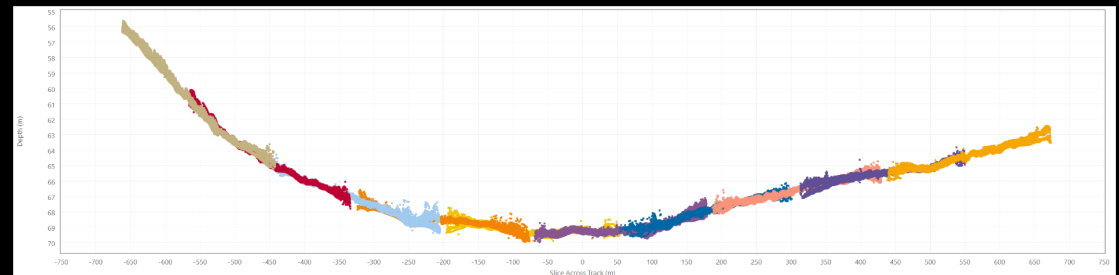
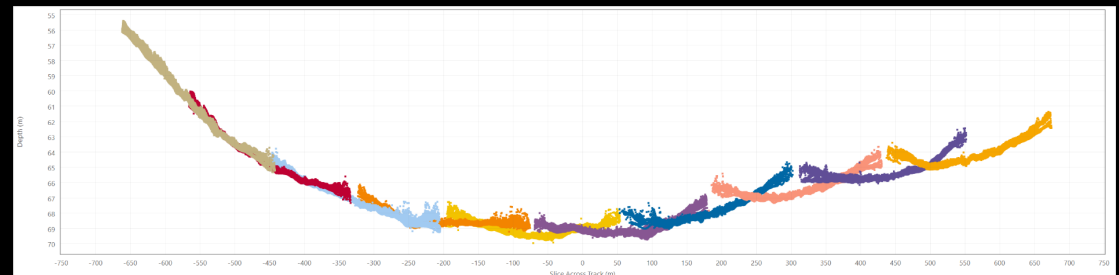


SUMMARY



- Partnerships work for transfer of research ideas to operational tools
- New tool that is
 - Objective
 - Automated
 - Physics-based
 - Accountable

“I just processed a client’s data with the Inversion Algorithm and ‘POOF!’ 95% of the refraction problems were gone.”



THANK YOU FOR
YOUR ATTENTION

QUESTIONS?

