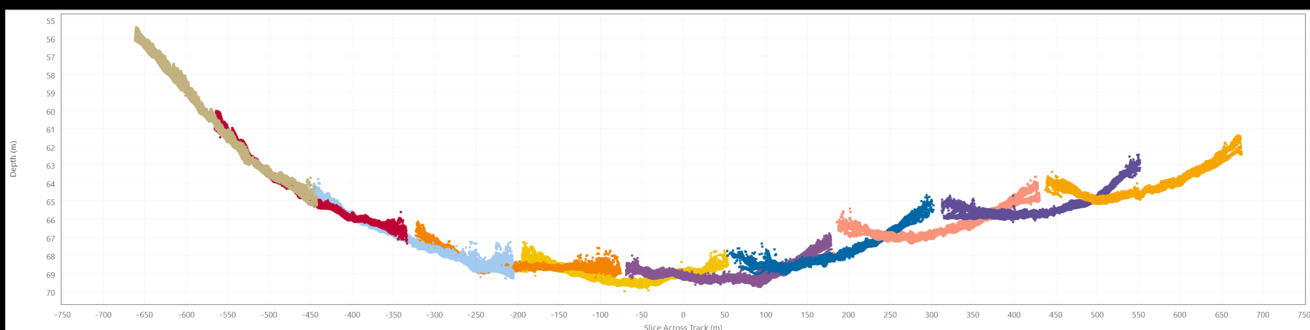
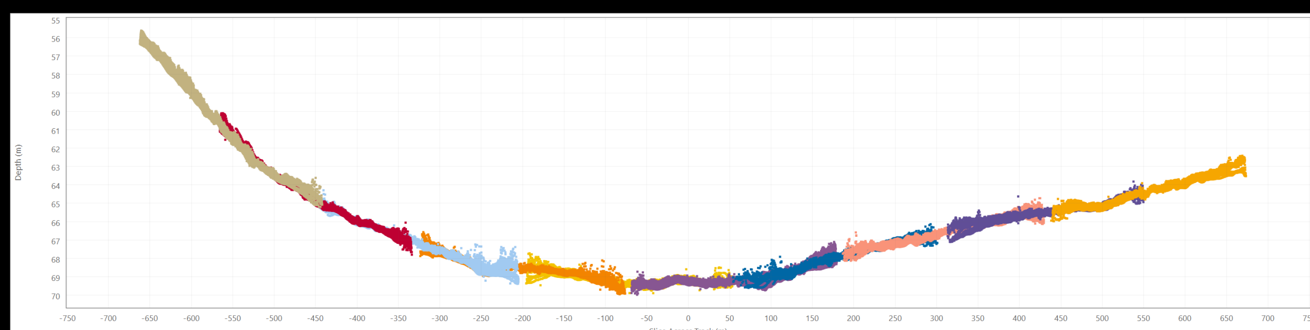
AUTOMATED CORRECTION OF REFRACTION RESIDUALS

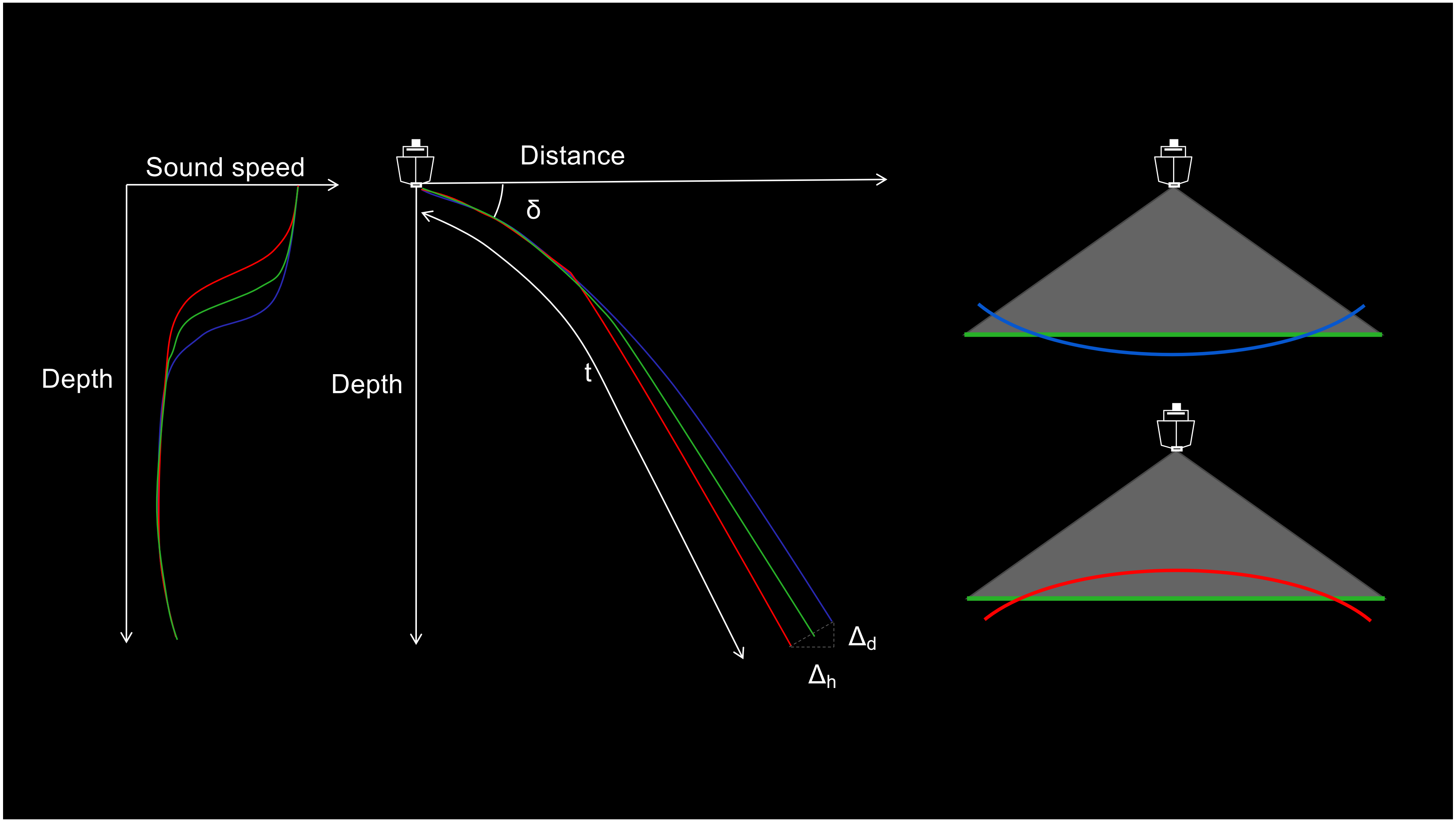
Jonathan Beaudoin[1], Weston Renoud[2], Tannaz Haji Mohammadloo[3], Mirjam Snellen[3]

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

a SAAB group company





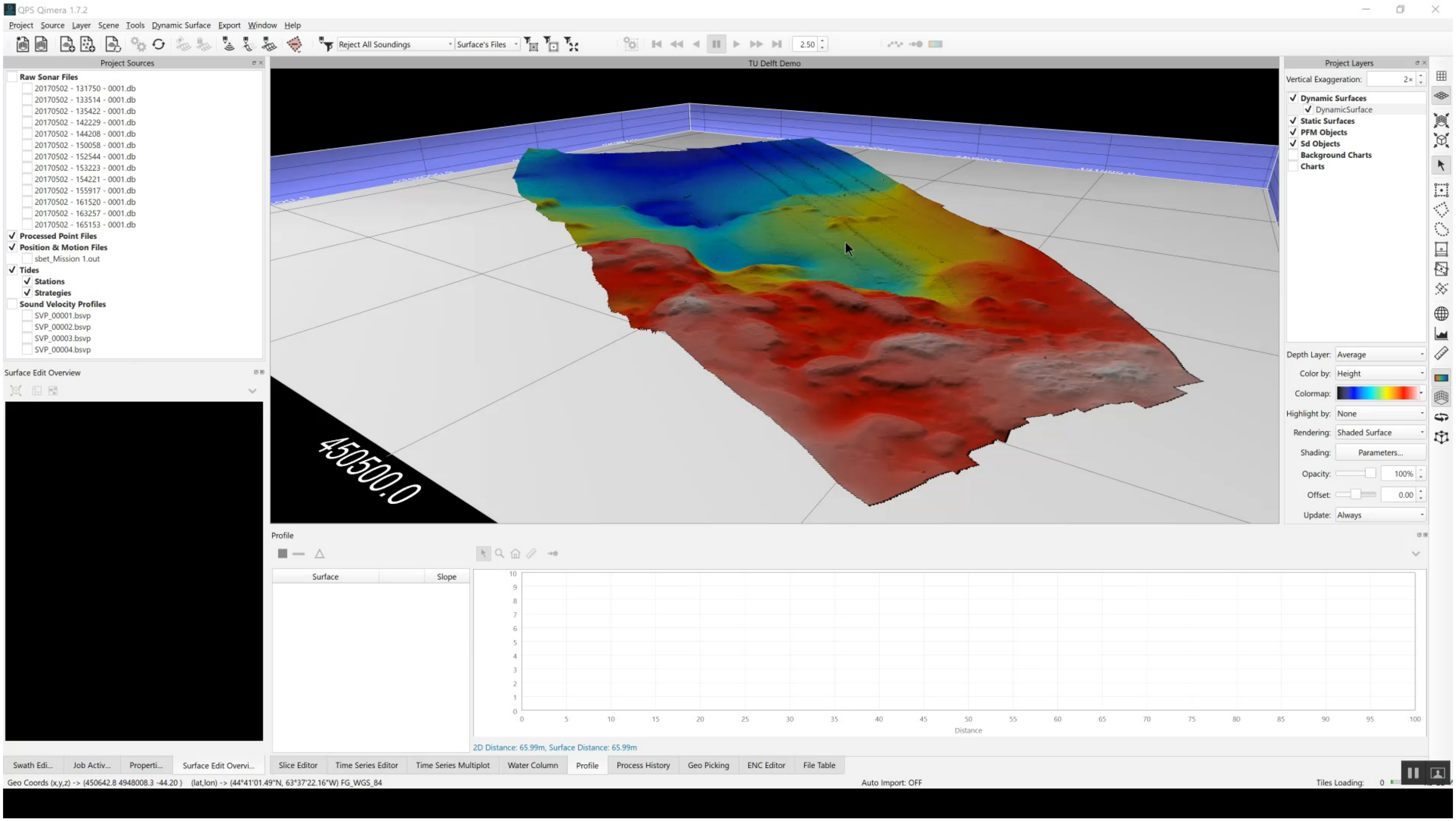


Sound speed
Depth
Distance
δ
Depth
t
Δd
Δh

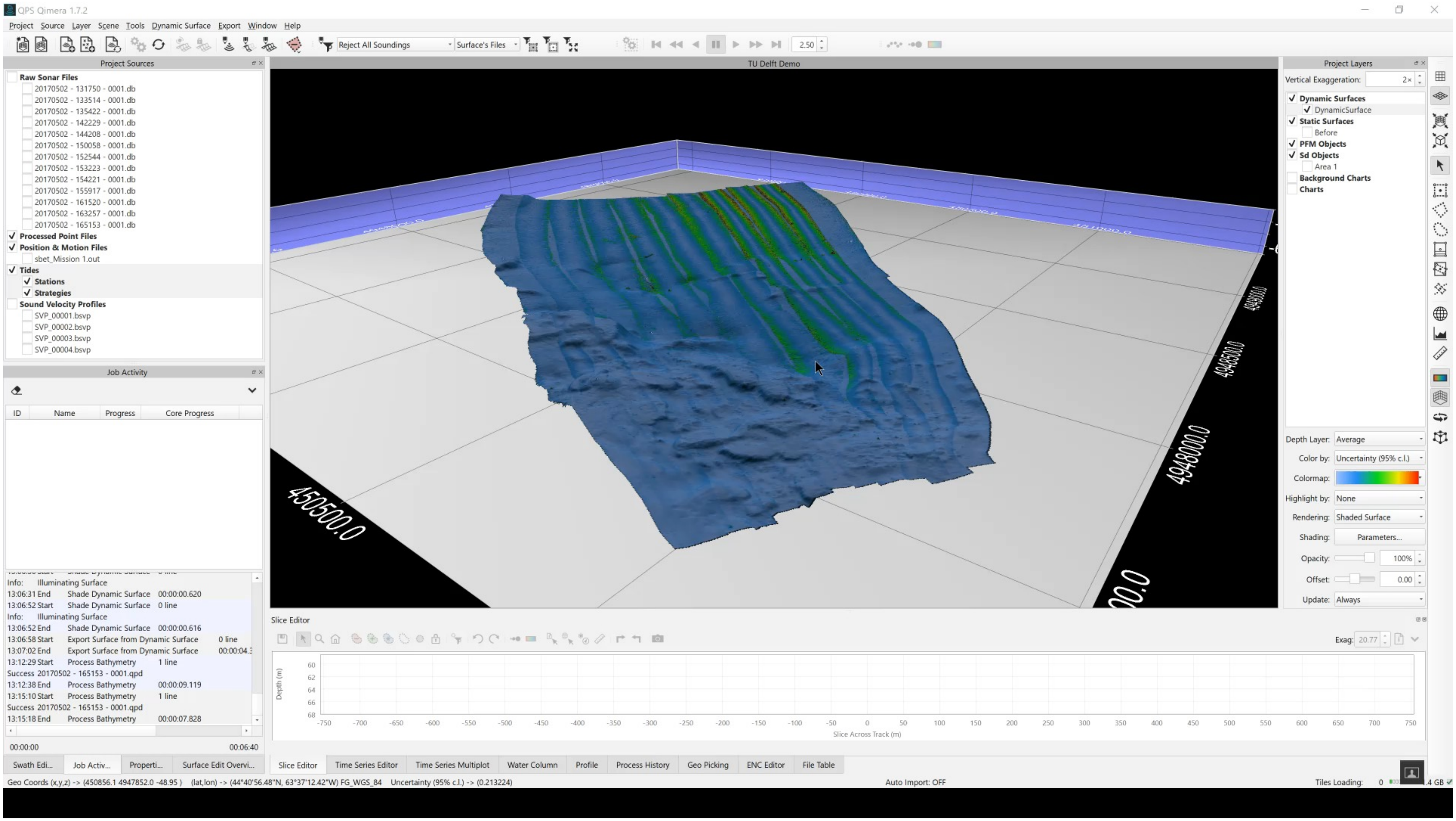
REFRACTION ERRORS: FIVE STAGES OF GRIEF

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

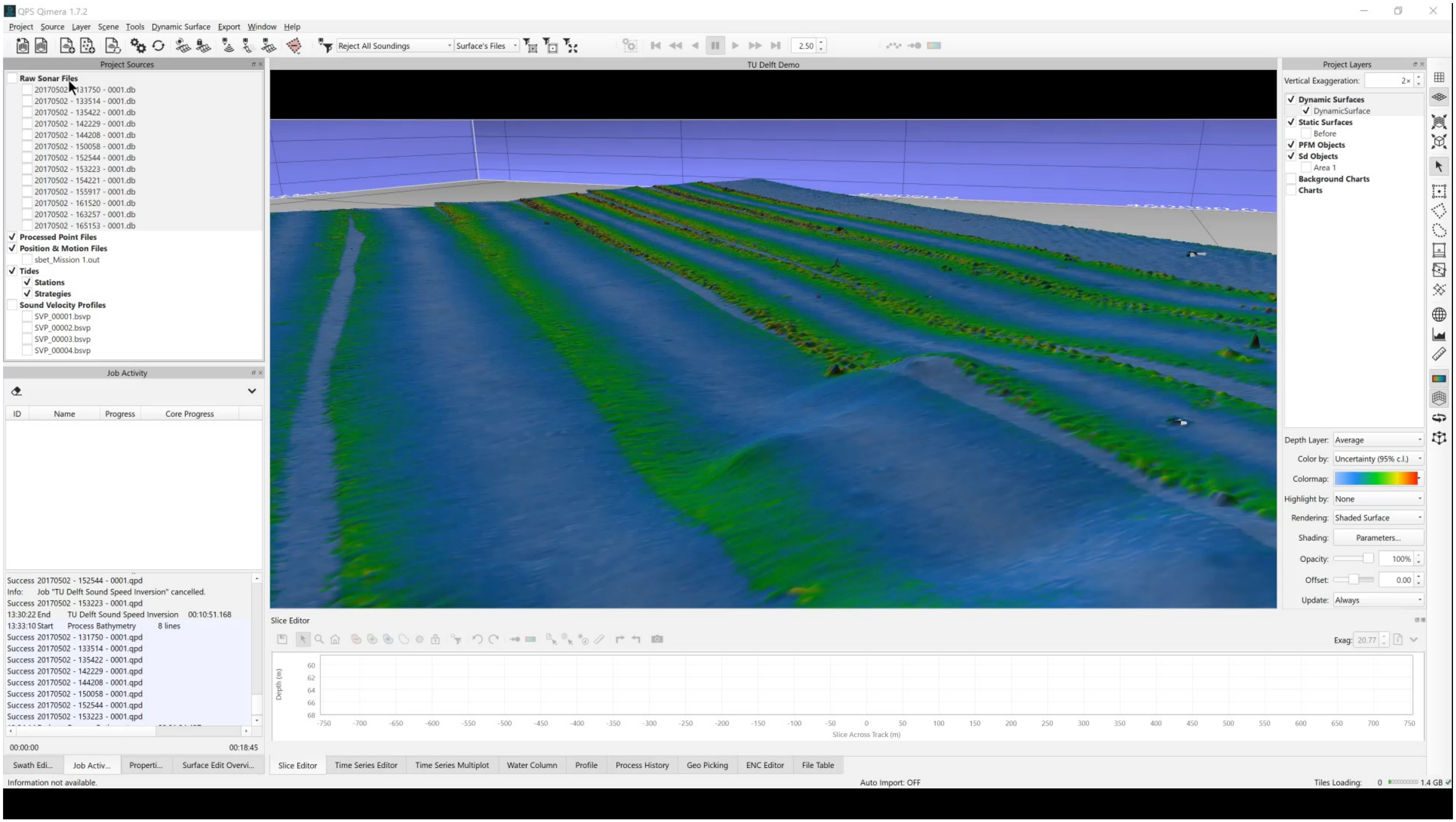
STAGE 1: DENIAL

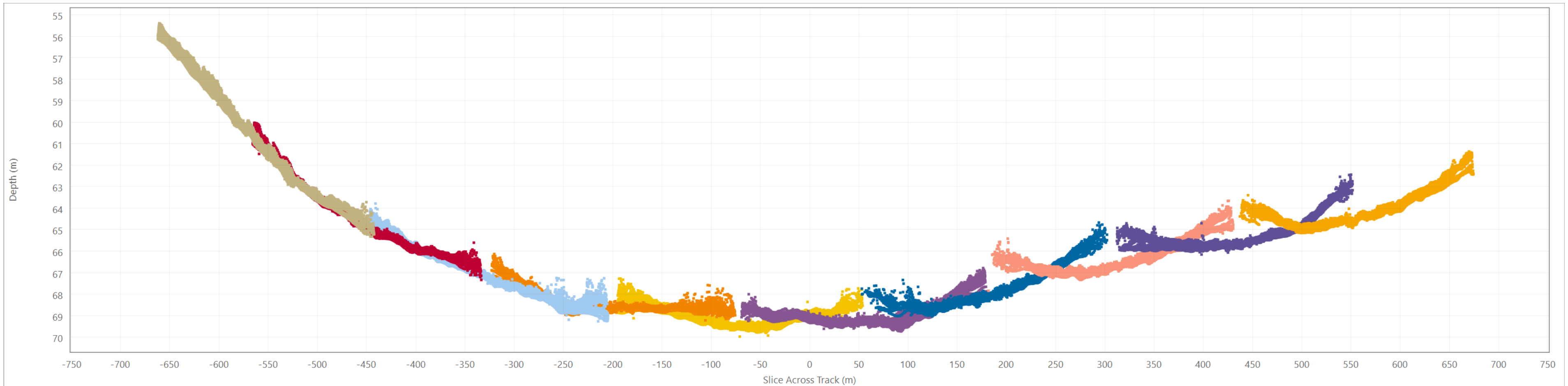

QPS Qimera 1.7.2
Project Source Layer Scene Tools Dynamic Surface Export Window Help
Reject All Soundings
Surface's Files
2.50
Project Sources
Raw Sonar Files
20170502 - 131750 - 0001.db
20170502 - 133514 - 0001.db
20170502 - 135422 - 0001.db
20170502 - 142229 - 0001.db
20170502 - 144208 - 0001.db
20170502 - 150058 - 0001.db
20170502 - 152544 - 0001.db
20170502 - 153223 - 0001.db
20170502 - 154221 - 0001.db
20170502 - 155917 - 0001.db
20170502 - 161520 - 0001.db
20170502 - 163257 - 0001.db
20170502 - 165153 - 0001.db
Processed Point Files
Position & Motion Files
sbet_Mission 1.out
Tides
Stations
Strategies
Sound Velocity Profiles
SVP_00001.bsvp
SVP_00002.bsvp
SVP_00003.bsvp
SVP_00004.bsvp
Surface Edit Overview
TU Delft Demo
450500.0
Project Layers
Vertical Exaggeration: 2x
Dynamic Surfaces
DynamicSurface
Static Surfaces
PFM Objects
Sd Objects
Background Charts
Charts
Depth Layer: Average
Color by: Height
Colormap:
Highlight by: None
Rendering: Shaded Surface
Shading: Parameters...
Opacity: 100%
Offset: 0.00
Update: Always
Profile
Surface
Slope
Distance
2D Distance: 65.99m, Surface Distance: 65.99m
Swath Edi... Job Activ... Properti... Surface Edit Overvi...
Slice Editor Time Series Editor Time Series Multiplot Water Column Profile Process History Geo Picking ENC Editor File Table
Geo Coords (x,y,z) -> (450642.8 4948008.3 -44.20) (lat,lon) -> (44°41'01.49"N, 63°37'22.16"W) FG_WGS_84
Auto Import: OFF
Tiles Loading: 0

STAGE 3: BARGAINING

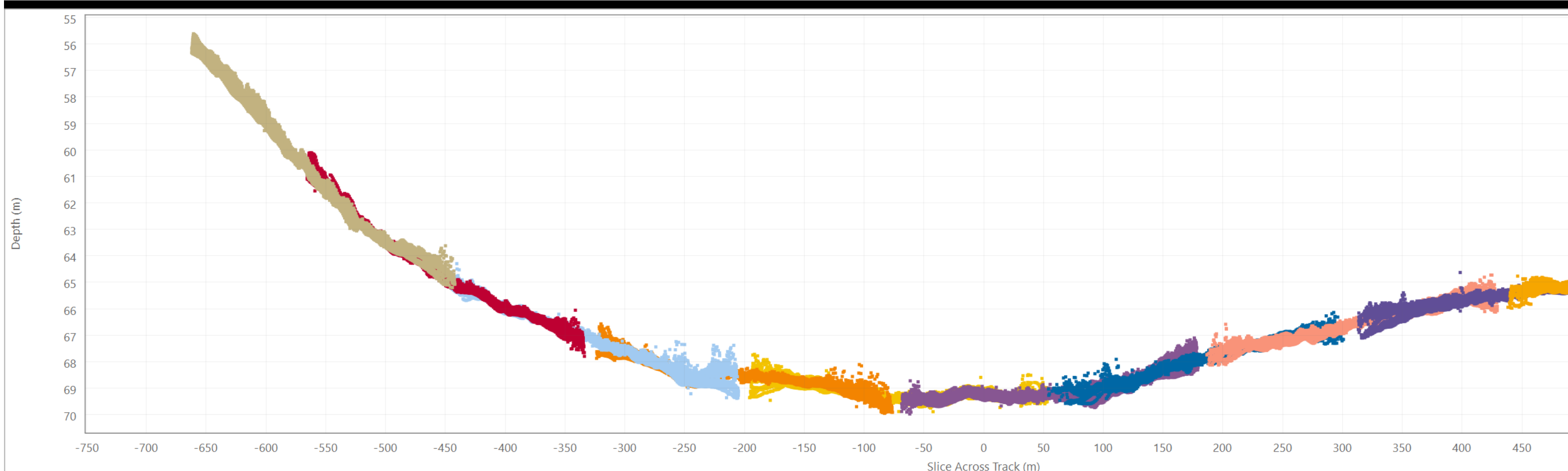

QPS Qimera 1.7.2
Project Source Layer Scene Tools Dynamic Surface Export Window Help
Reject All Soundings
Surface's Files
Project Sources
Raw Sonar Files
20170502 - 131750 - 0001.db
20170502 - 133514 - 0001.db
20170502 - 135422 - 0001.db
20170502 - 142229 - 0001.db
20170502 - 144208 - 0001.db
20170502 - 150058 - 0001.db
20170502 - 152544 - 0001.db
20170502 - 153223 - 0001.db
20170502 - 154221 - 0001.db
20170502 - 155917 - 0001.db
20170502 - 161520 - 0001.db
20170502 - 163257 - 0001.db
20170502 - 165153 - 0001.db
Processed Point Files
Position & Motion Files
sbet_Mission 1.out
Tides
Stations
Strategies
Sound Velocity Profiles
SVP_00001.bsvp
SVP_00002.bsvp
SVP_00003.bsvp
SVP_00004.bsvp
Job Activity
ID Name Progress Core Progress
Info: Illuminating Surface
13:06:31 End Shade Dynamic Surface 00:00:00.620
13:06:52 Start Shade Dynamic Surface 0 line
Info: Illuminating Surface
13:06:52 End Shade Dynamic Surface 00:00:00.616
13:06:58 Start Export Surface from Dynamic Surface 0 line
13:07:02 End Export Surface from Dynamic Surface
13:12:29 Start Process Bathymetry 1 line
Success 20170502 - 165153 - 0001.qpd
13:12:38 End Process Bathymetry 00:00:09.119
13:15:10 Start Process Bathymetry 1 line
Success 20170502 - 165153 - 0001.qpd
13:15:18 End Process Bathymetry 00:00:07.828
00:00:00 00:06:40
TU Delft Demo
450500.0
4948000.0
4948500.0
Project Layers
Vertical Exaggeration: 2x
Dynamic Surfaces
DynamicSurface
Static Surfaces
Before
PFM Objects
Sd Objects
Area 1
Background Charts
Charts
Depth Layer: Average
Color by: Uncertainty (95% c.l.)
Colormap:
Highlight by: None
Rendering: Shaded Surface
Shading: Parameters...
Opacity: 100%
Offset: 0.00
Update: Always
Slice Editor
Exag: 20.77
Depth (m)
60
62
64
66
68
-750 -700 -650 -600 -550 -500 -450 -400 -350 -300 -250 -200 -150 -100 -50 0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750
Slice Across Track (m)
Swath Edi... Job Activ... Properti... Surface Edit Overvi...
Slice Editor Time Series Editor Time Series Multiplot Water Column Profile Process History Geo Picking ENC Editor File Table
Geo Coords (x,y,z) -> (450856.1 4947852.0 -48.95) (lat,lon) -> (44°40'56.48"N, 63°37'12.42"W) FG_WGS_84 Uncertainty (95% c.l.) -> (0.213224)
Auto Import: OFF
Tiles Loading: 0

STAGE 5: ACCEPTANCE?

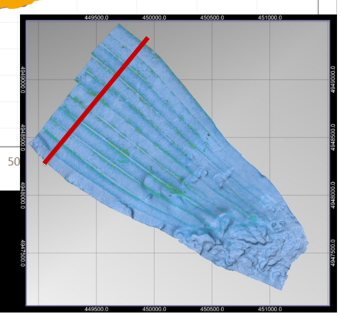

QPS Qimera 1.7.2
Project Source Layer Scene Tools Dynamic Surface Export Window Help
Reject All Soundings
Surface's Files
2.50
Project Sources
Raw Sonar Files
20170502 - 131750 - 0001.db
20170502 - 133514 - 0001.db
20170502 - 135422 - 0001.db
20170502 - 142229 - 0001.db
20170502 - 144208 - 0001.db
20170502 - 150058 - 0001.db
20170502 - 152544 - 0001.db
20170502 - 153223 - 0001.db
20170502 - 154221 - 0001.db
20170502 - 155917 - 0001.db
20170502 - 161520 - 0001.db
20170502 - 163257 - 0001.db
20170502 - 165153 - 0001.db
Processed Point Files
Position & Motion Files
sbet_Mission 1.out
Tides
Stations
Strategies
Sound Velocity Profiles
SVP_00001.bsvp
SVP_00002.bsvp
SVP_00003.bsvp
SVP_00004.bsvp
Job Activity
ID Name Progress Core Progress
Success 20170502 - 152544 - 0001.qpd
Info: Job "TU Delft Sound Speed Inversion" cancelled.
Success 20170502 - 153223 - 0001.qpd
13:30:22 End TU Delft Sound Speed Inversion 00:10:51.168
13:33:10 Start Process Bathymetry 8 lines
Success 20170502 - 131750 - 0001.qpd
Success 20170502 - 133514 - 0001.qpd
Success 20170502 - 135422 - 0001.qpd
Success 20170502 - 142229 - 0001.qpd
Success 20170502 - 144208 - 0001.qpd
Success 20170502 - 150058 - 0001.qpd
Success 20170502 - 152544 - 0001.qpd
Success 20170502 - 153223 - 0001.qpd
00:00:00 00:18:45
Swath Edi... Job Activ... Properti... Surface Edit Overvi...
TU Delft Demo
Project Layers
Vertical Exaggeration: 2×
Dynamic Surfaces
DynamicSurface
Static Surfaces
Before
PFM Objects
Sd Objects
Area 1
Background Charts
Charts
Depth Layer: Average
Color by: Uncertainty (95% c.l.)
Colormap:
Highlight by: None
Rendering: Shaded Surface
Shading: Parameters...
Opacity: 100%
Offset: 0.00
Update: Always
Slice Editor
Exag: 20.77
Depth (m)
60
62
64
66
68
-750 -700 -650 -600 -550 -500 -450 -400 -350 -300 -250 -200 -150 -100 -50 0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750
Slice Across Track (m)
Slice Editor Time Series Editor Time Series Multiplot Water Column Profile Process History Geo Picking ENC Editor File Table
Information not available.
Auto Import: OFF
Tiles Loading: 0 1.4 GB



Depth (m)
55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70
-750 -700 -650 -600 -550 -500 -450 -400 -350 -300 -250 -200 -150 -100 -50 0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750
Slice Across Track (m)



Depth (m)
55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70
-750 -700 -650 -600 -550 -500 -450 -400 -350 -300 -250 -200 -150 -100 -50 0 50 100 150 200 250 300 350 400 450
Slice Across Track (m)



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

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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 speeds (both temporally and spatially). In this type of environments the water column sound speeds at the time of the MBES transmission are often not 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 estuaries where fresh river water mixes with seawater. The method fully exploits the redundancy in the MBES measurements obtained from the overlap of adjacent swathes. It searches for those water column sound speeds that result in a maximum agreement in the bathymetry along the overlapping swathes. 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 allows 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.**

I. 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 swathe 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 swathe 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 *smiley*- or *droopy*-like effects. In these cases, the depths measured in the outer parts of swathes are under- or overestimated. This is most obvious when parts of the swathes 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 inversion. In theory, this approach eliminates the need for sound speed measurements as long as sufficient overlap along adjacent swathes is available [4], [5].

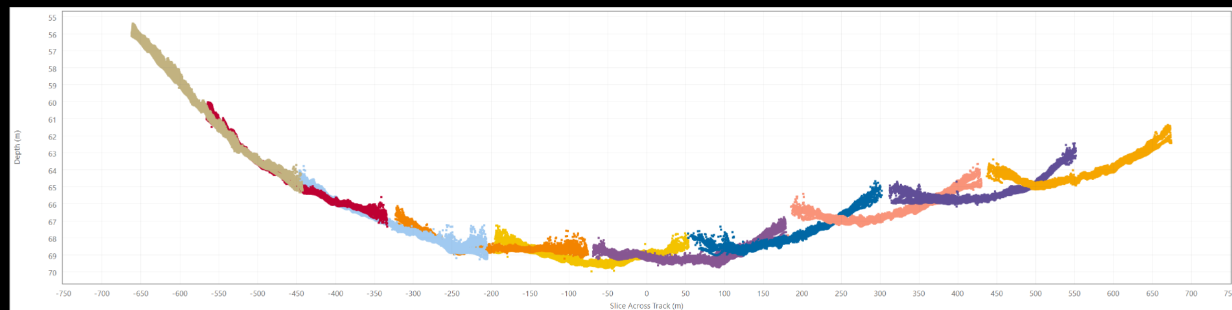
As a first step for assessing the feasibility of the proposed method simulations, have been carried out. Section II provides a description of the approach towards eliminating sound speed induced errors as proposed in this contribution. Section III presents the results of applying this method to simulated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

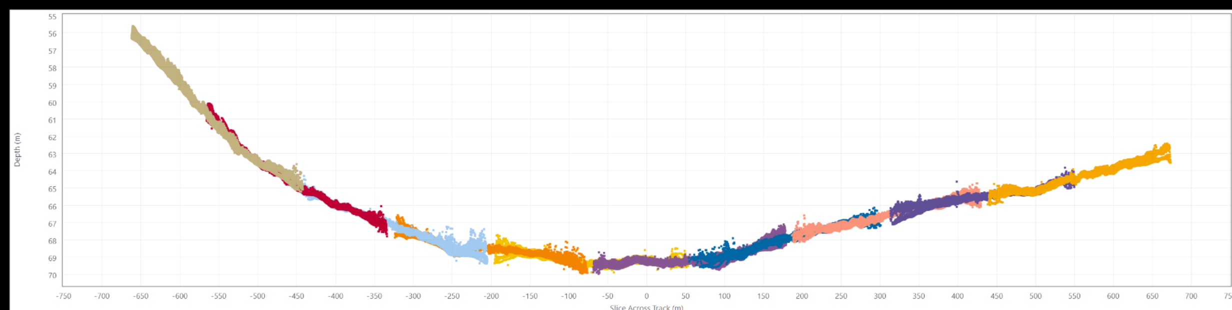
1-4244-2523-5/09/$20.00 ©2009 IEEE

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.

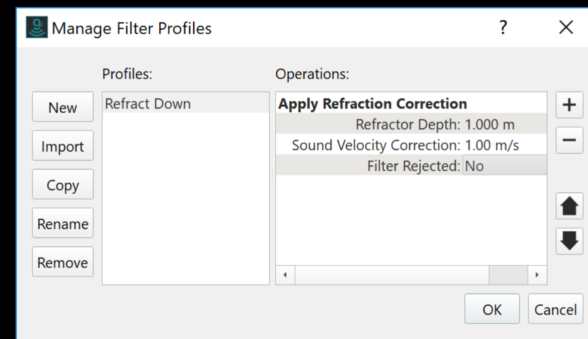
BENEFITS

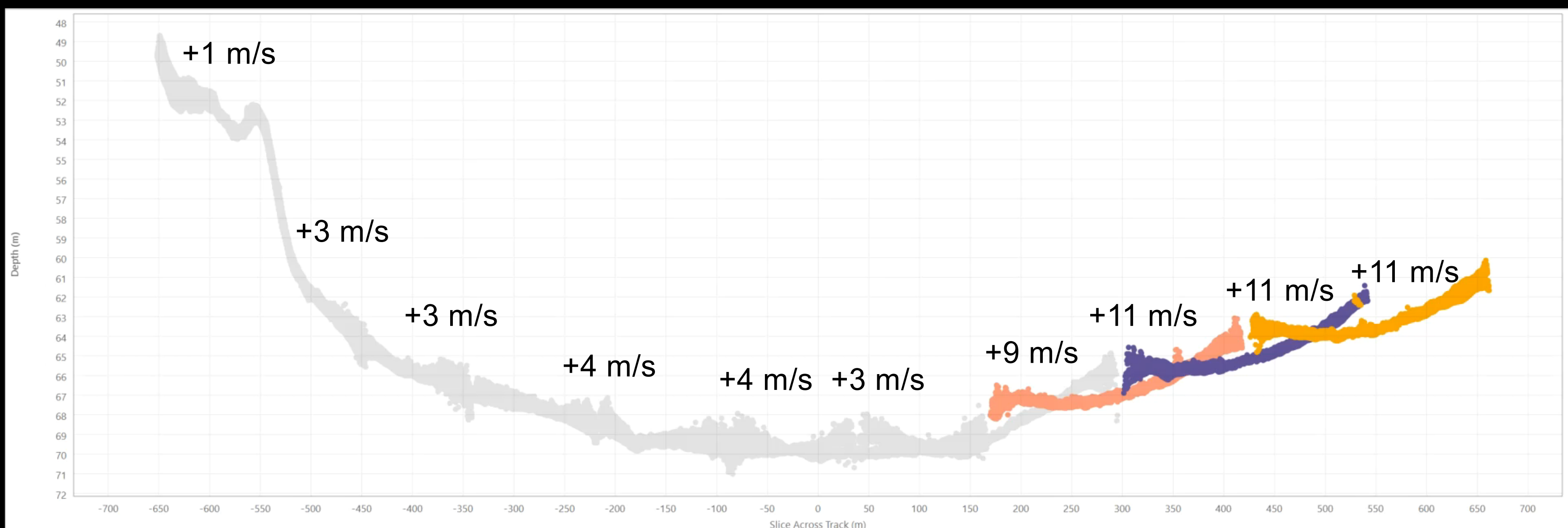
- Objective
- Automated
- Physics-based
- Accountable





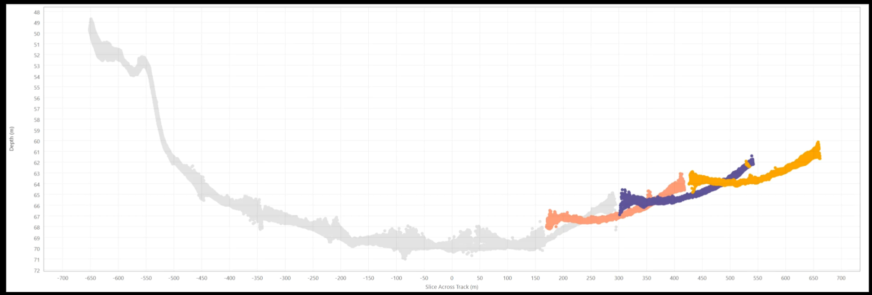
OBJECTIVE

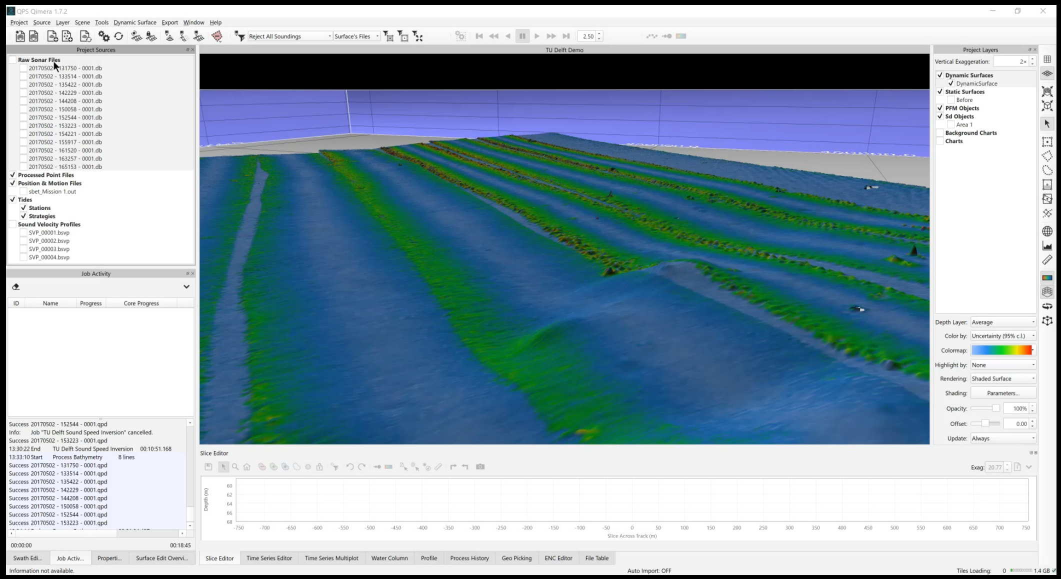

Manage Filter Profiles
Profiles:
Operations:
New
Import
Copy
Rename
Remove
Refract Down
Apply Refraction Correction
Refractor Depth: 1.000 m
Sound Velocity Correction: 1.00 m/s
Filter Rejected: No
OK
Cancel


+1 m/s
+3 m/s
+3 m/s
+4 m/s
+4 m/s
+3 m/s
+9 m/s
+11 m/s
+11 m/s
+11 m/s
Depth (m)
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
-700 -650 -600 -550 -500 -450 -400 -350 -300 -250 -200 -150 -100 -50 0 50 100 150 200 250 300 350 400 450 500 550 600 650 700
Slice Across Track (m)

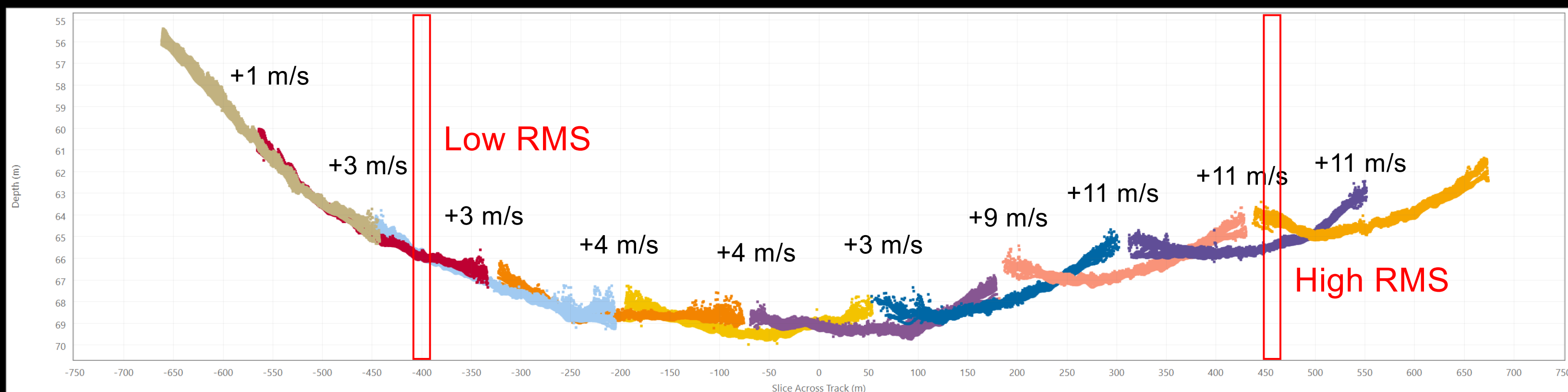
AUTOMATED

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



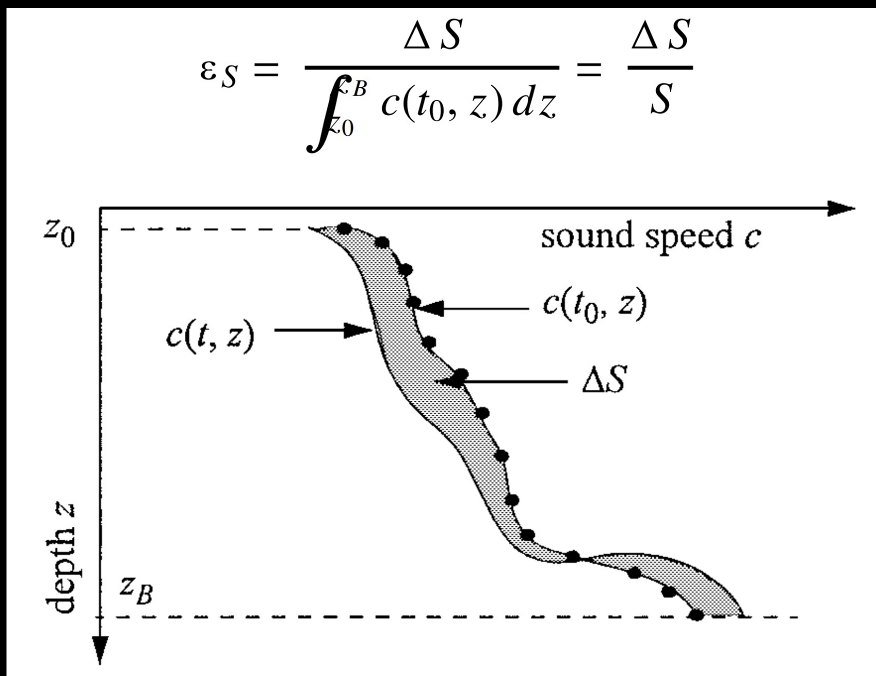


PHYSICS BASED



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

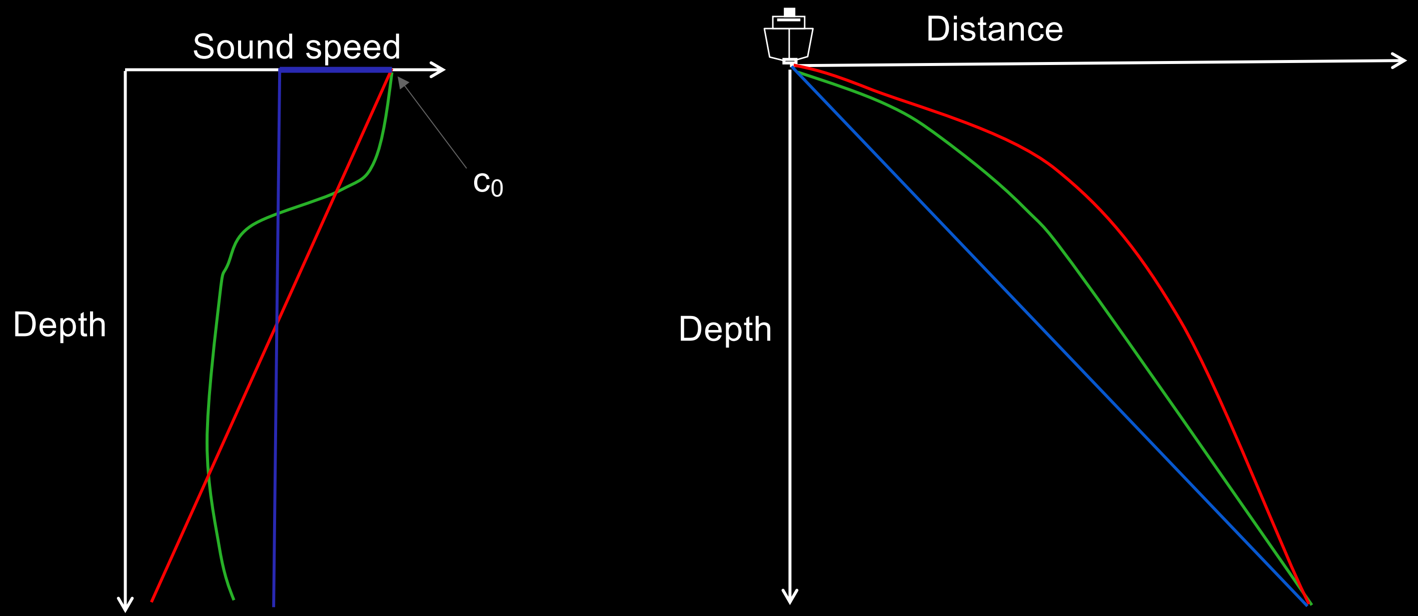
PHYSICS BASED: HARMONIC SOUND SPEED



"…the depth estimate difference related to these two sound speed profiles is almost a function of only the relative area difference e_S. The difference is zero when $e_S = 0$."

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

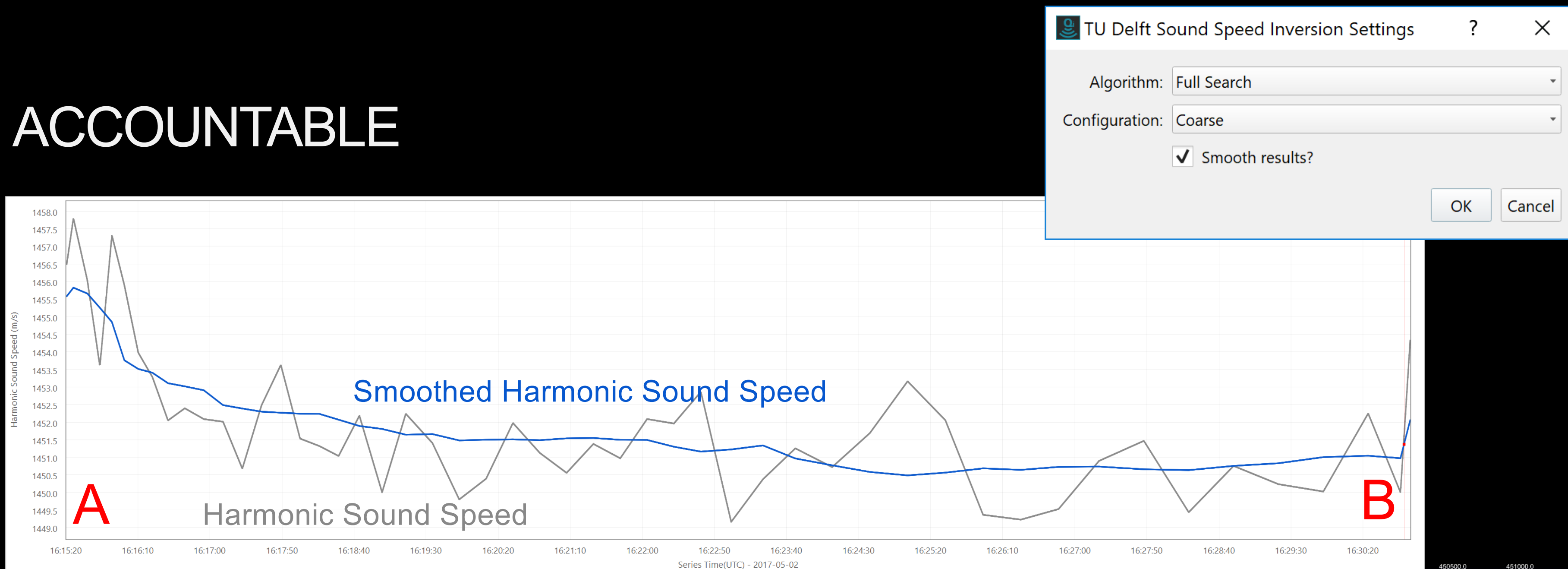
PHYSICS BASED: HARMONIC SOUND SPEED



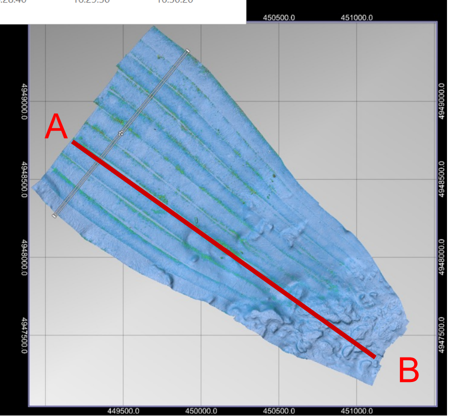
"for the same propagation time, the position at which a sound pulse impinges on the seafloor is almost the same for a family of sound speed profiles with the same surface value c_0 and the same area under them, which is defined as an integral of $c(z)$ with respect to depth z."

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

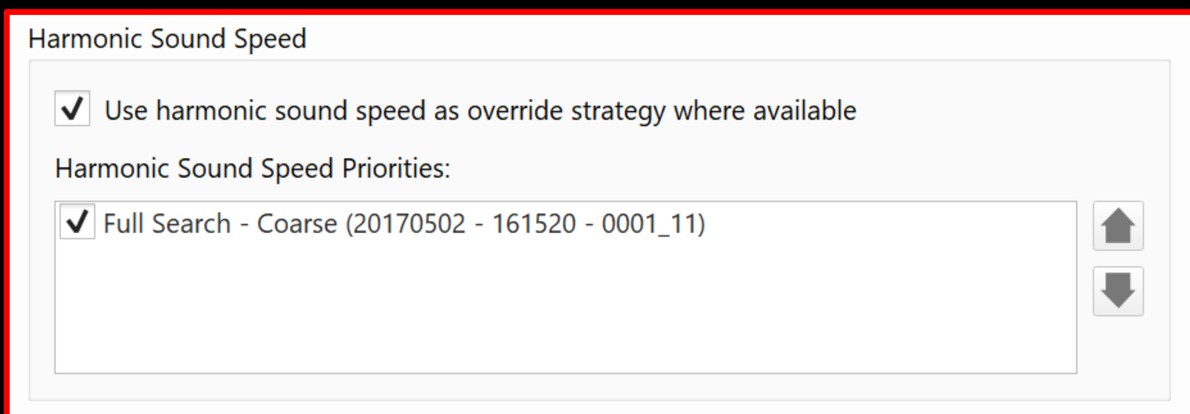
ACCOUNTABLE

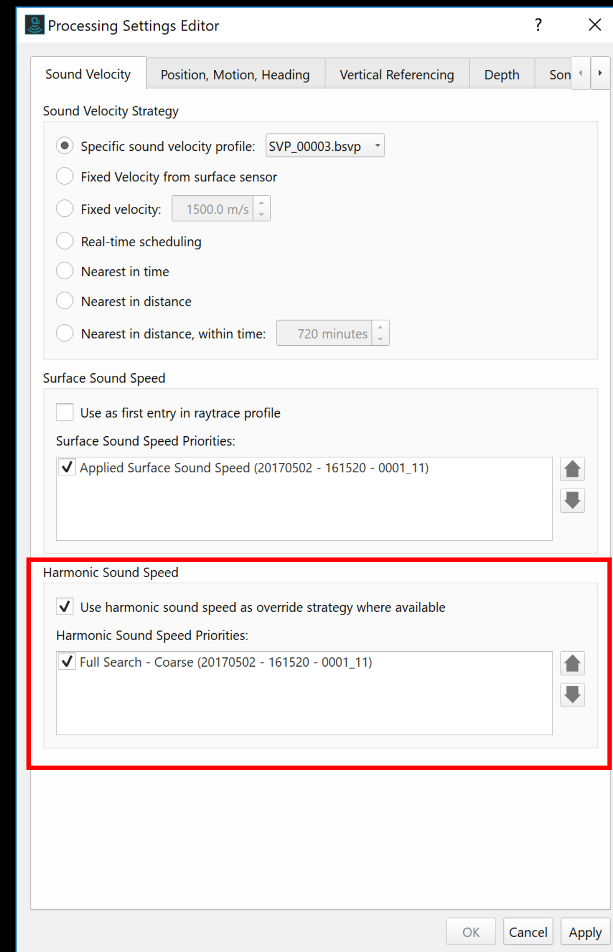


- HSS time-series results for every survey line
- Different runs preserve different results
- User can review, vet, edit or even reject entirely



ACCOUNTABLE

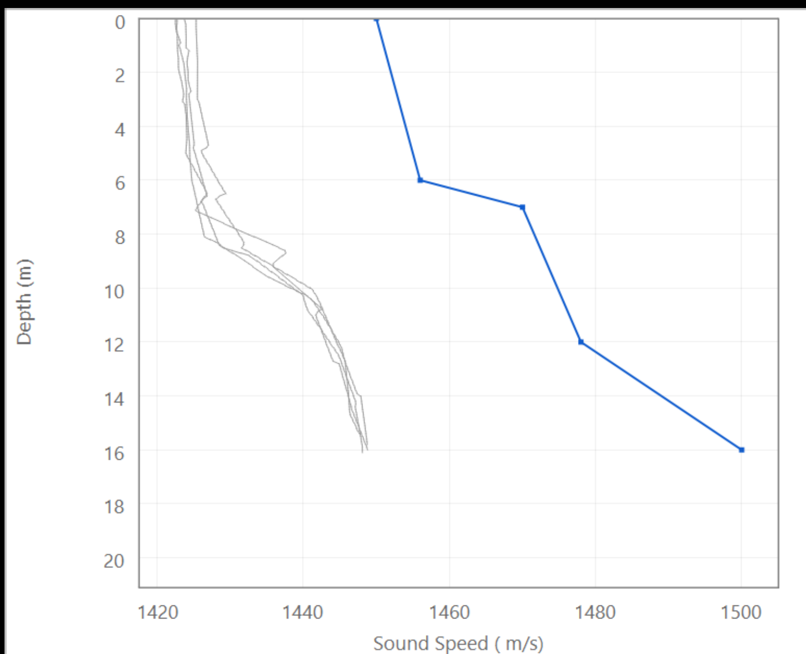


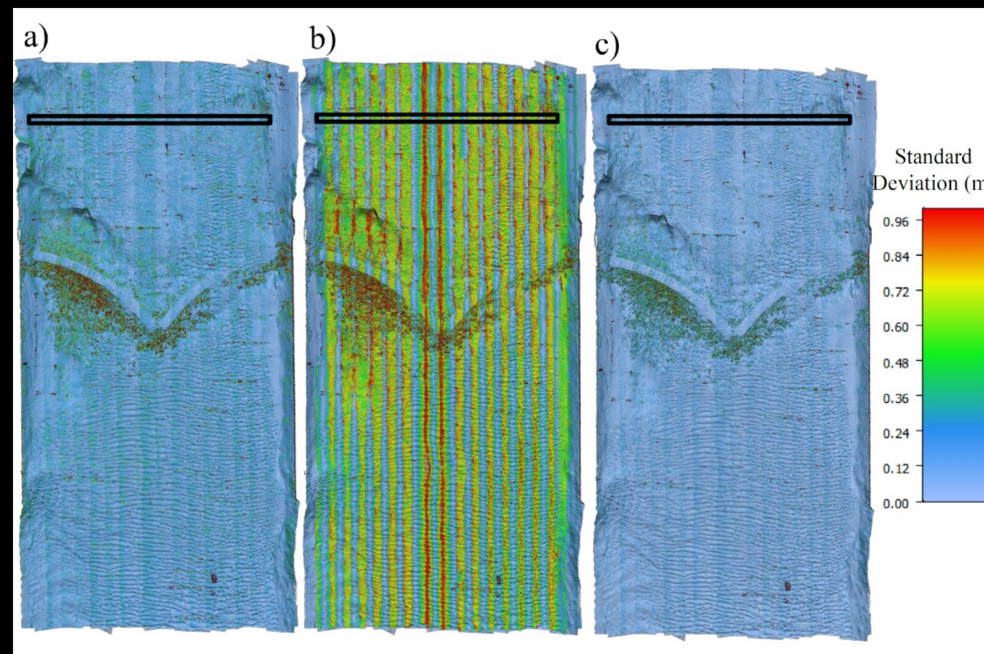


COMMUNITY ACCEPTANCE?

TEST AGAINST BASELINE

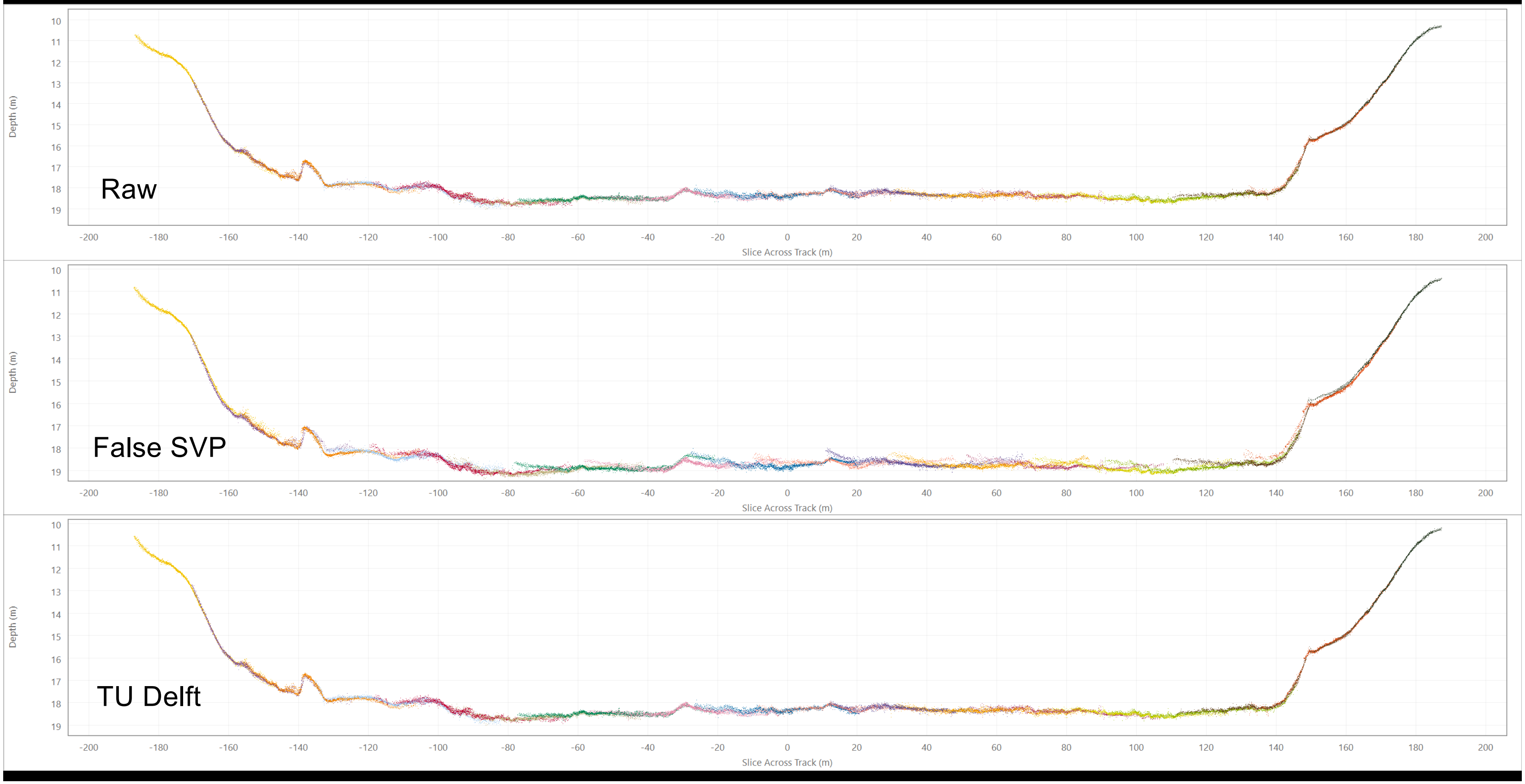
TEST AGAINST BASELINE





Raw False SVP TU Delft

TEST AGAINST BASELINE



TEST AGAINST BASELINE

Fake SVP	TU Delft
Median: -0.33	Median: 0.02
Mean: -0.33	Mean: 0.02
Std Dev: 0.06	Std Dev: 0.03

Surface Statistics

Surface: surface_difference

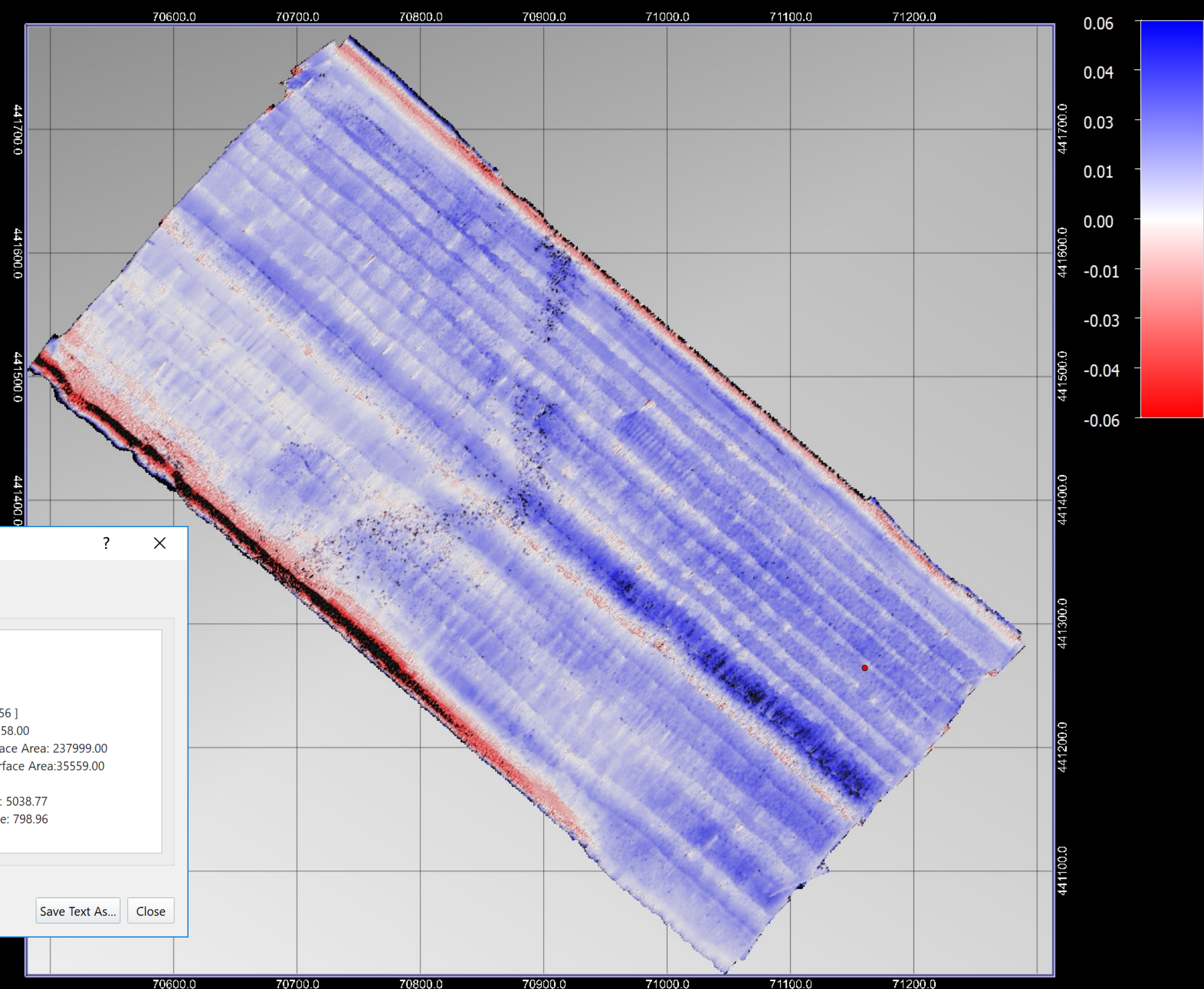
Surface Characteristics Information

Name: surface_difference
Dimensions: 768 rows x 832 columns
Cell Size: 1.000000
Bounds:
X Range: 70481.5 to 71312.5
Y Range: 441016.5 to 441783.5
Z Range: -6.74 to 1.86
Horizontal Coordinate System:
FC_Amersfoort_RD_New_+_NAP_height

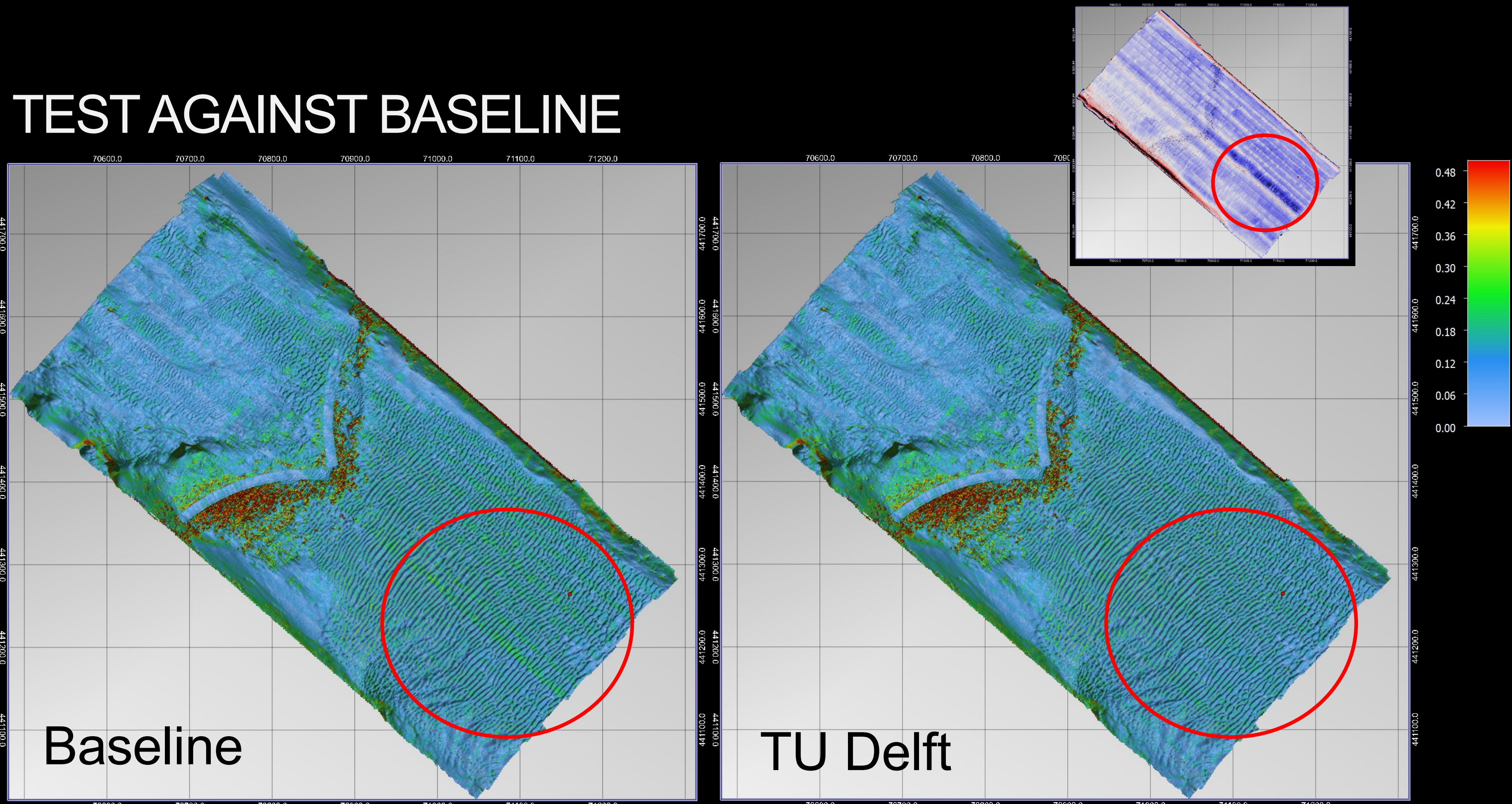
Surface Statistics Information

Name: surface_difference
Median: 0.02
Mean: 0.02
Std Dev: 0.03
Height Range: [-6.743, 1.856]
Total 2D Surface Area: 273558.00
Positive (above 0.0) 2D Surface Area: 237999.00
Negative (below 0.0) 2D Surface Area:35559.00
Total Volume: 4239.81
Positive (above 0.0) Volume: 5038.77
Negative (below 0.0) Volume: 798.96

Save Text As... Close

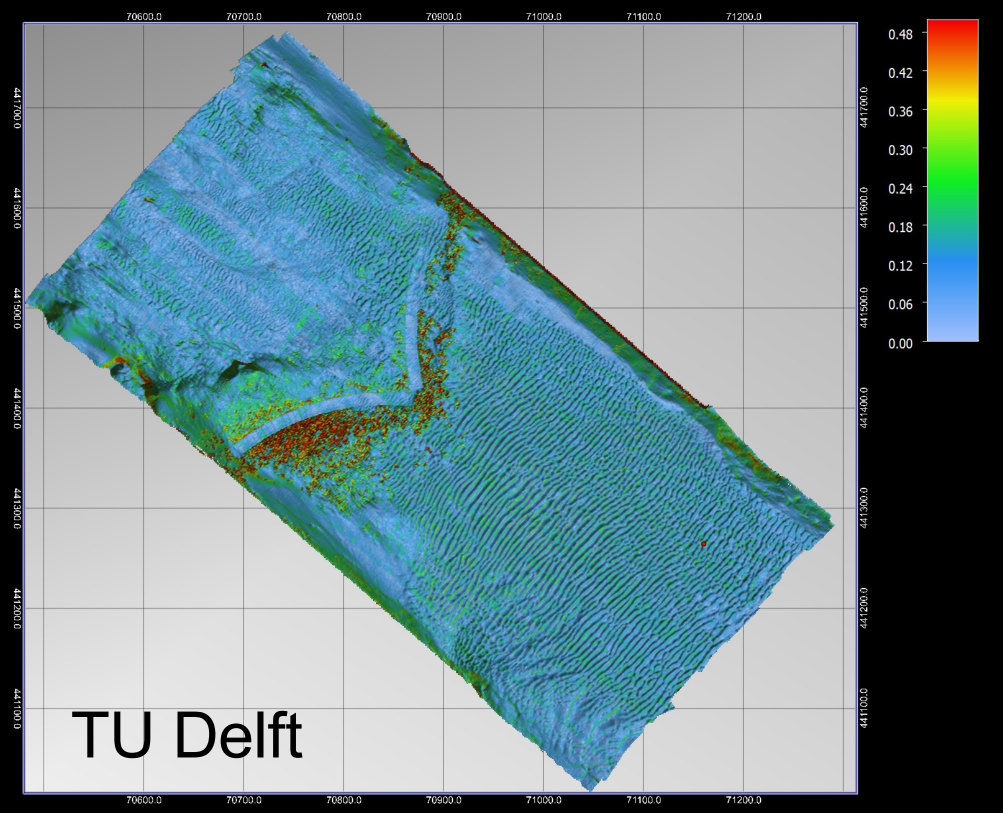


TEST AGAINST BASELINE

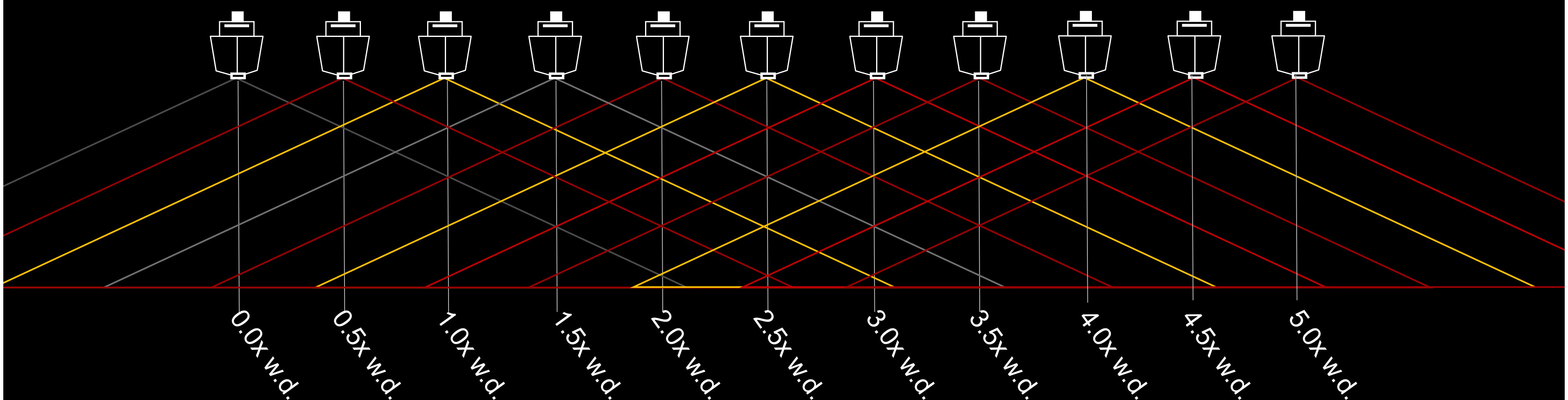


FUTURE WORK

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



SENSITIVITY TO LINE SPACING



- 11 survey lines, as long as normal for a patch test
- Space lines at ½ water depth, e.g. 10 m spacing in 20 m of water
- Good vertical control, RTK or SBET
- Need SVP cast immediately before and after
- QINSy .db, Kongsberg .all/.kmall, Hypack .hsx, Reson .s7k
- Email beaudoin@qps.nl

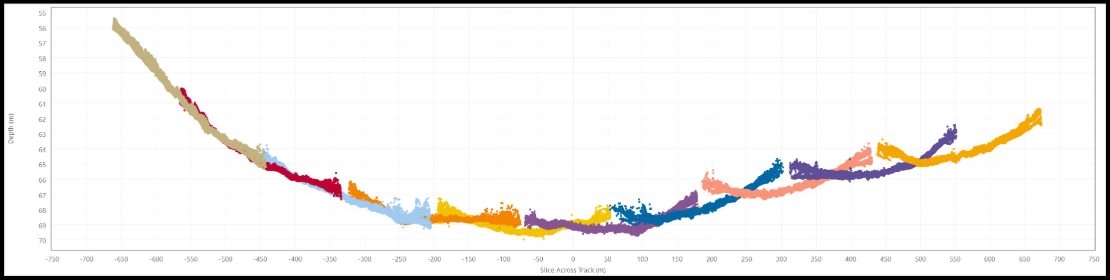
What's in it for you?
Free TU Delft add-on for 1 year

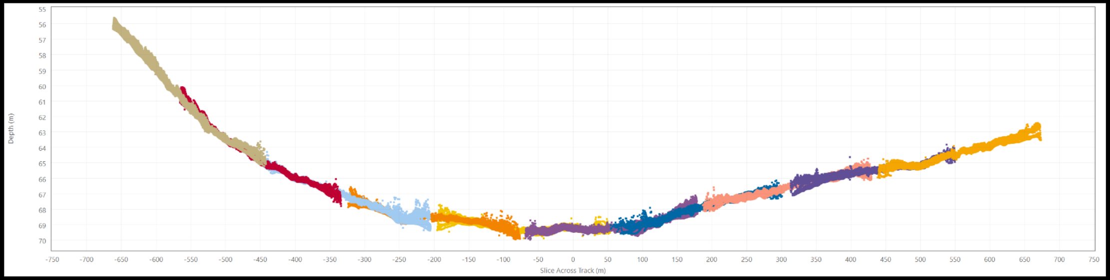
SUMMARY

QPS
a SAAB group company

TU Delft

- 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?