US Hydro 2011

Producing Chart Data from Interferometric Sonars on Small AUVs

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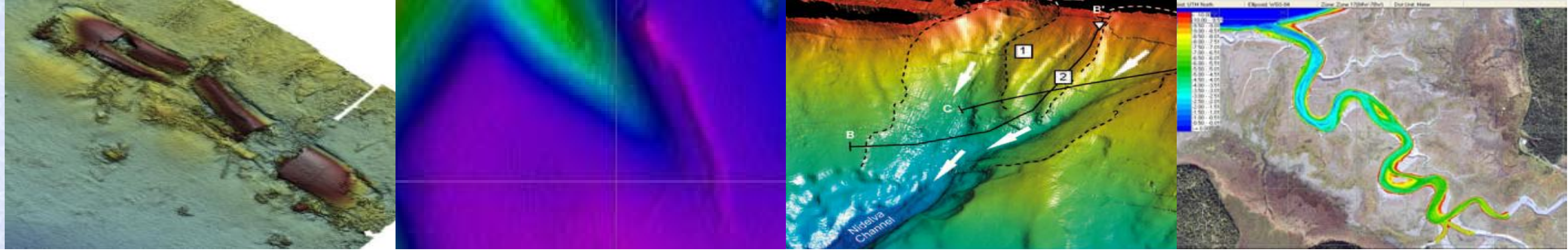

Presentation Objective:

Consider the question:

"Can the small AUV be a useful tool for collecting chart data?"

- Concentrate on current *commercial* systems
- Show *achieved* capability with field data
- Compare this capability with IHO specifications
- Comment on likely routes to improve performance

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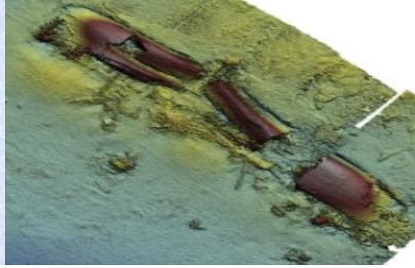
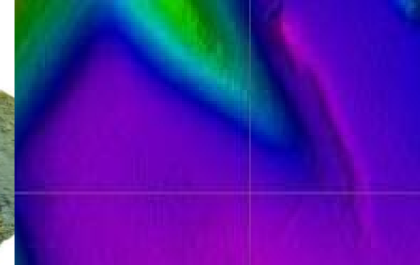
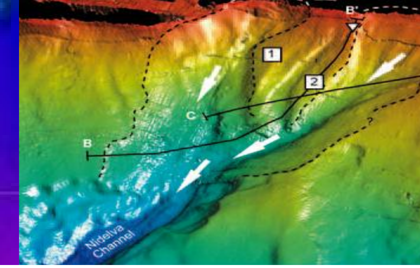
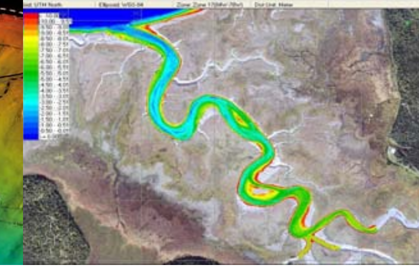





Why concentrate on *'small AUV'*?

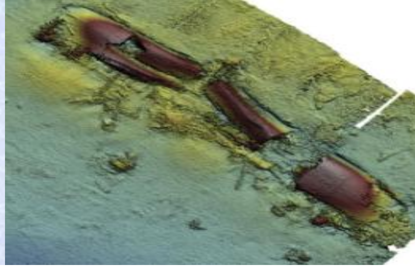
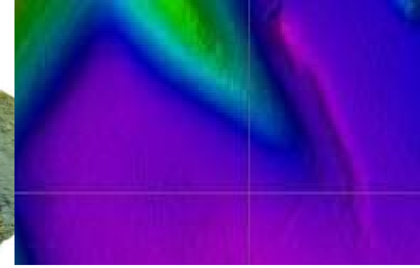
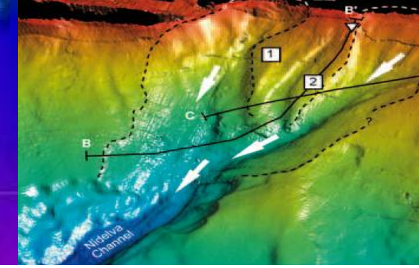
(small-AUV = less than 8-inch diameter)

Lower cost (less than US$1M)

Easier logistics

Safer operation

More useful in shallow water (=navigation depths)


Technology Timeline:

Chapter 1. 2005-2007 Putting a wide swath bathymetric capability on a small AUV:

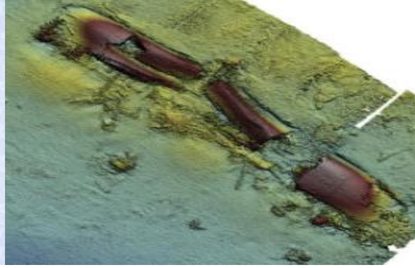
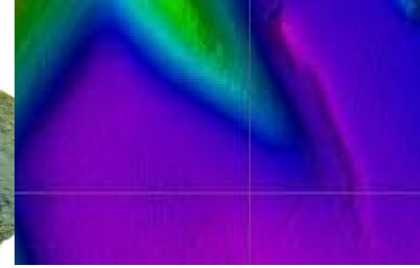
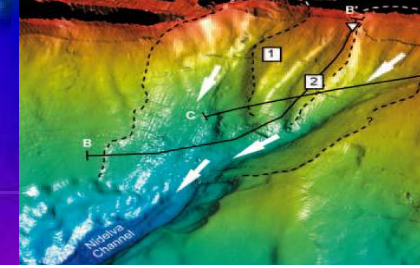
1999: Launch of GeoSwath sonar by GeoAcoustics Ltd.

2005: Shallow Survey 2005 (Plymouth, UK) GeoSwath interferometric sonar data accepted for charting by UKHO – chart BA1967.

2006: GeoAcoustics Ltd. and Hafmynd ehf. (Gavia AUV) sign co-operative agreement.

2007: GeoSwath sonar built into a Gavia payload module

Nov 2007: First system trials in Reykjavik, Iceland



Technology Timeline:

Chapter 2. 2008/09 Proving the capability:

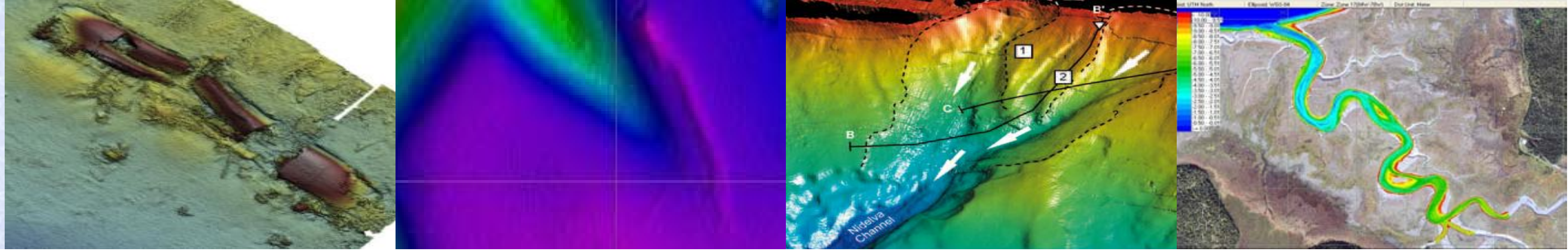
2008: NOAA signature expedition: Bonaire 2008

2008: First GeoSwath AUV sold to Harebin University, China

2008/9: GeoSwath/Gavia on hired operations in Caspian Sea (BP)

2009: April: APLIS under-ice deployment (University of Cambridge, UK)

2009: U. Delaware Gavia/GoSwath delivered (DORA)



Technology Timeline:

Chapter 3. 2009/11 Hydrography on small AUVs goes commercial

2010/11: Muliple commercial sales of Gavia AUVs for hydrographic work; e.g. Fugro Wodside, NCS (x2), Tetis Pro.

2010: UTEC Survey (Houston) signs cooperative agreement with U. Delaware to enhance capabilities and deploy commercially.

Oct 2010: GeoSwath/Remus 100 trials in San Diego

April 4th 2011: UTEC announce successful SBP trials on UDel Gavia

April 6th 2011: NCS survey announces purchase of 3rd Gavia

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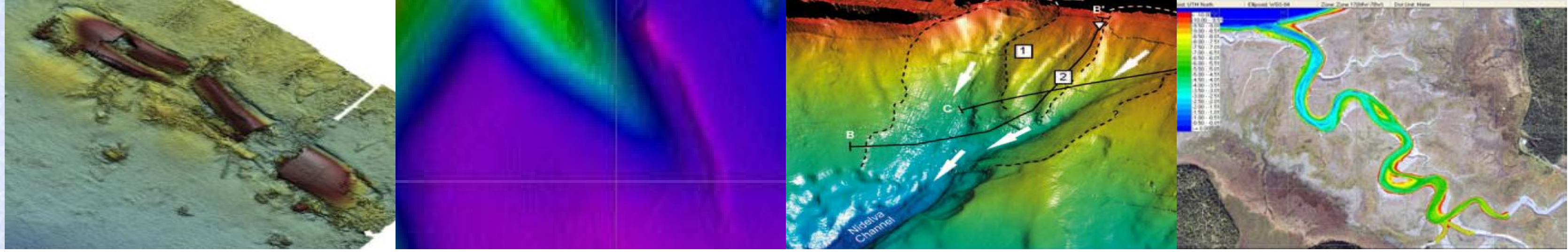
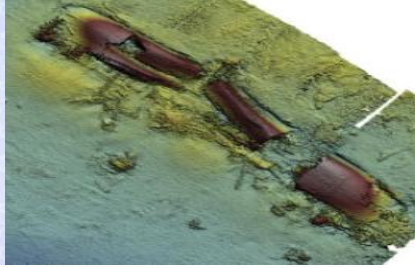
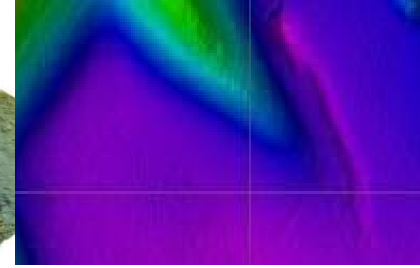
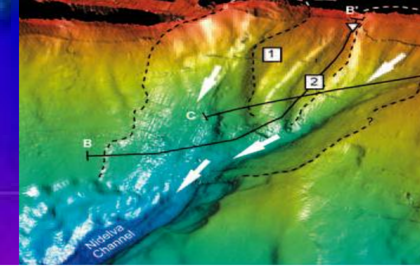


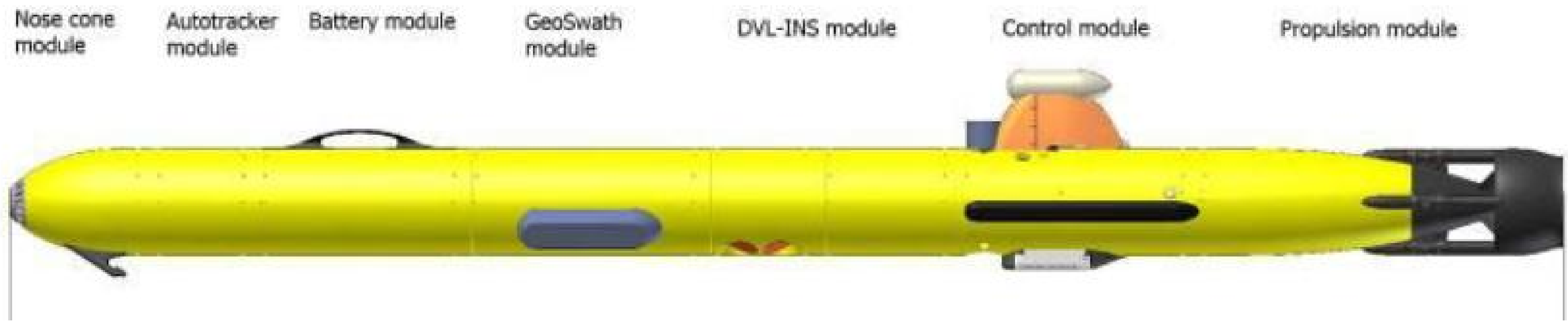
Since the table below went to press in early 2011, at least 4 additional Gavia systems have been ordered. As of April 2011 there exist at least 15 small AUVs with hydrographic capabilities.

Sonar	AUV and depth rating (if known)	End User	Received
GeoSwath-AUV 500kHz	Remus 100 (100m)	Kongsberg Maritime Aberdeen (rental)	2011
SwathPlus 475kHz	Gavia (500m)	Teledyne Gavia	2010
GeoSwath-AUV 500kHz	Gavia (500m)	NCS Survey Aberdeen	2010
GeoSwath-AUV 500kHz	Gavia (1000m)	NCS Survey Aberdeen	2010
GeoSwath-AUV 500kHz	(unknown)	Far East Academy of Sciences, Russia	2010
SwathPlus 475kHz	Gavia (1000m)	Tetis Pro	2010
GeoSwath-AUV 500kHz	Gavia (1000m)	Fugro Woodside, Australia	2010
SwathPlus 475kHz	Remus 100 (100m)	Hydroid Inc.	2009
GeoSwath-AUV 125kHz	(unknown)	SIA, China	2009
GeoSwath-AUV 500kHz	Gavia (500m)	University of Delaware	2008
GeoSwath-AUV 500kHz	Nezhna (3000m)	Harbin University, China	2008
GeoSwath-AUV 500kHz	Gavia (200m)	Hafmynd EHF, Iceland	2007

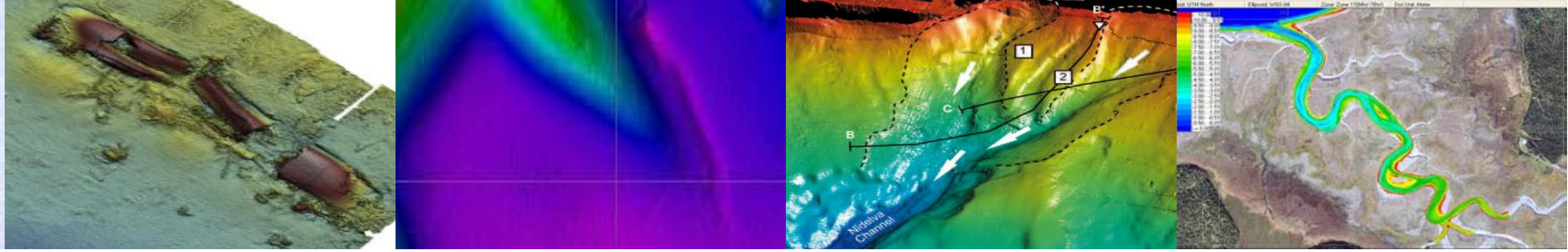
Table 1: **Interferometric Sonars Delivered for AUV Use** (from Cherkis, 2010, and press).


The Teledyne Gavia '*Surveyor AUV*'



- Man-portable: ~90kg in full survey configuration
- Modular system: can be check-in luggage (except batteries)
- Payload units upgradeable and flexible:
  - e.g. SeaNav, GeoSwath, Teledyne Chirp III SBP, Autotrack
- Battery unit can be swapped in 5 minutes (can carry 2)
- 4-5 hour endurance with 1 battery module, >8hr with 2



Examples of 'Easier Logistics':

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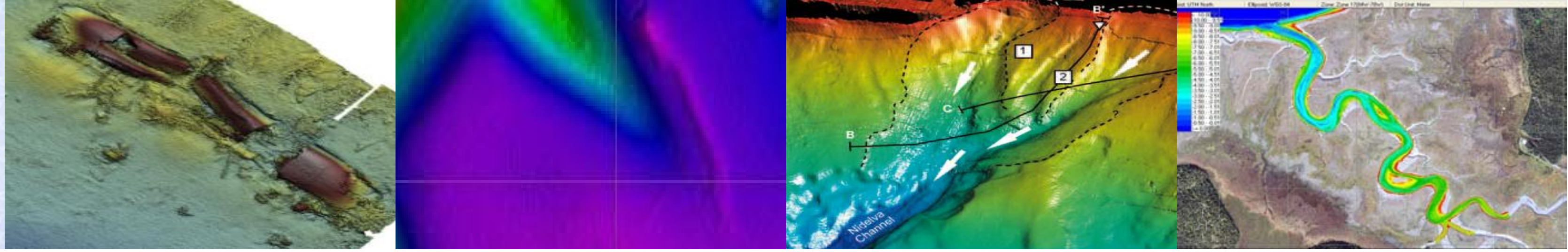
Image: NOAA Ocean Explorer, Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies



Easier Logistics:

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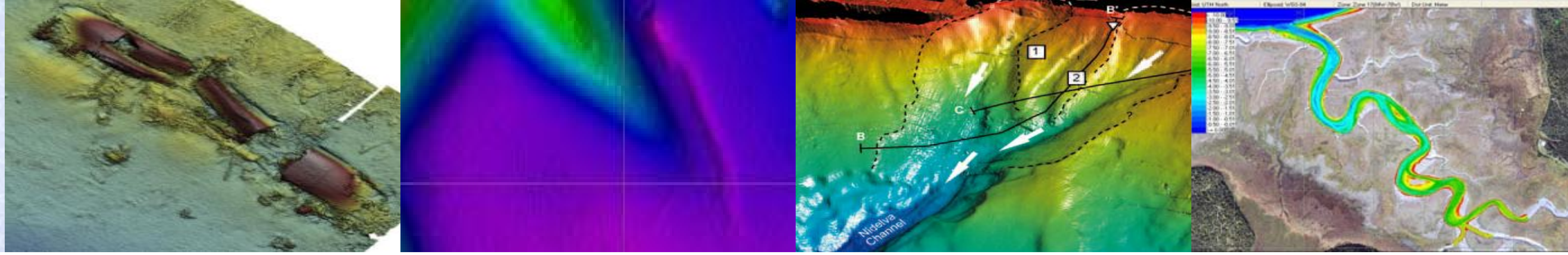

Easier Logistics:

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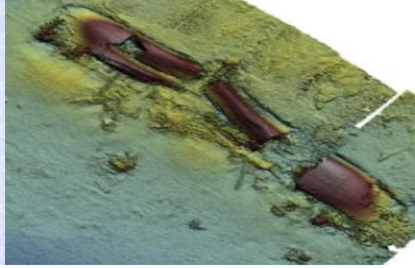

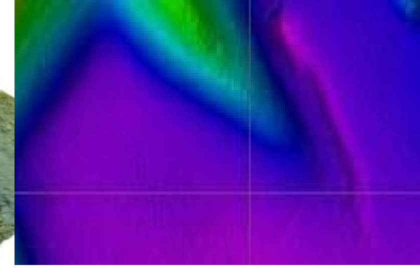

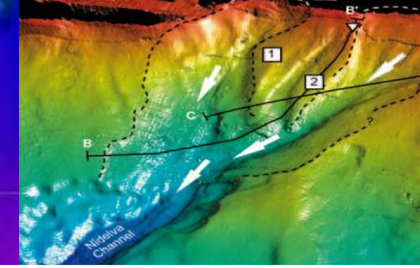

IHO requirements and key error sources:

Object Detection:

- Sonar characteristics

Horizontal Uncertainty:

- Sonar characteristics
- Positioning system

Vertical Uncertainty:

- Sonar characteristics
- Depth sensor

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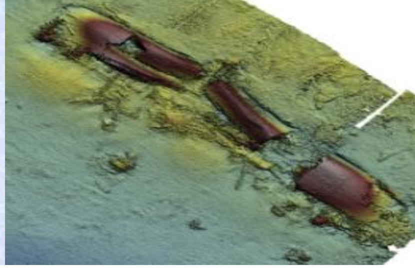
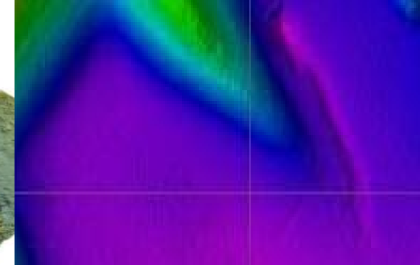
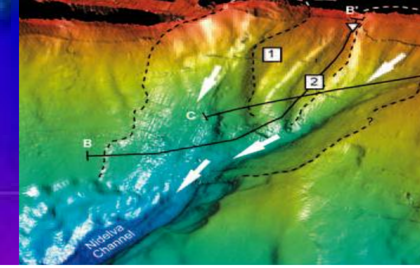






Interferometric Sonar Characteristics:

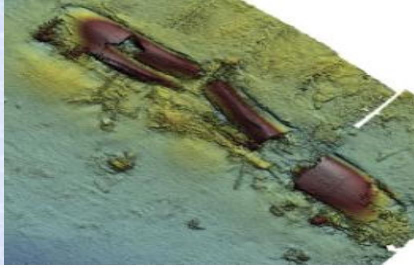
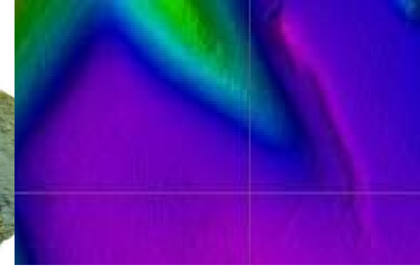
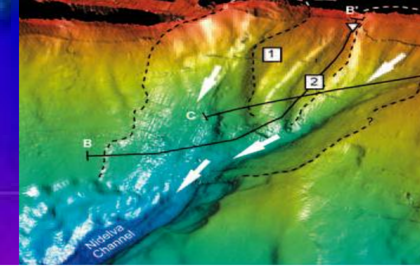
- It is a Side Scan (can be a very good side scan)
- There is a Lot of Data and the Data is Noisy
- Traditionally, hydrographers haven't liked them because you can't process the data as if it was a beamformer.
- If you try to pretend the data is like a beamformer, you'll experience a lot of pain and frustration.
- But there are many interferometers out there, working
- and there are appropriate interferometric Data Processing tools

E.g. OIC CleanSweep3:

www.oicinc.com

OCEANIC IMAGING Consultants

Seafloor mapping software and services by surveyors, for surveyors


There are Many Interferometers Out There,

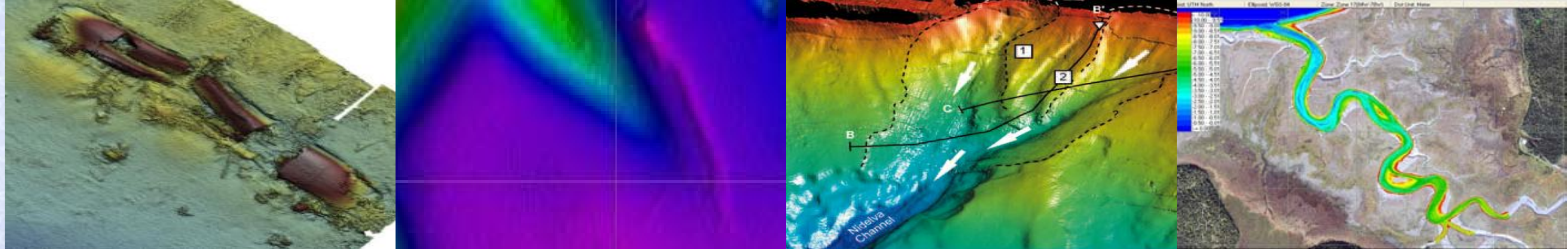
… and Lots of People Are Using Them ...

Over 250 high frequency (100kHz-500kHz) interferometers have been sold for boat mounted or towed work in 2000-2010.

~60% GeoSwath
~30% Teledyne Benthos C3D
~15% SEA SwathPlus
+ several from the newer generation:
EdgeTech 4600, Klein Hydrochart (5000 v2)

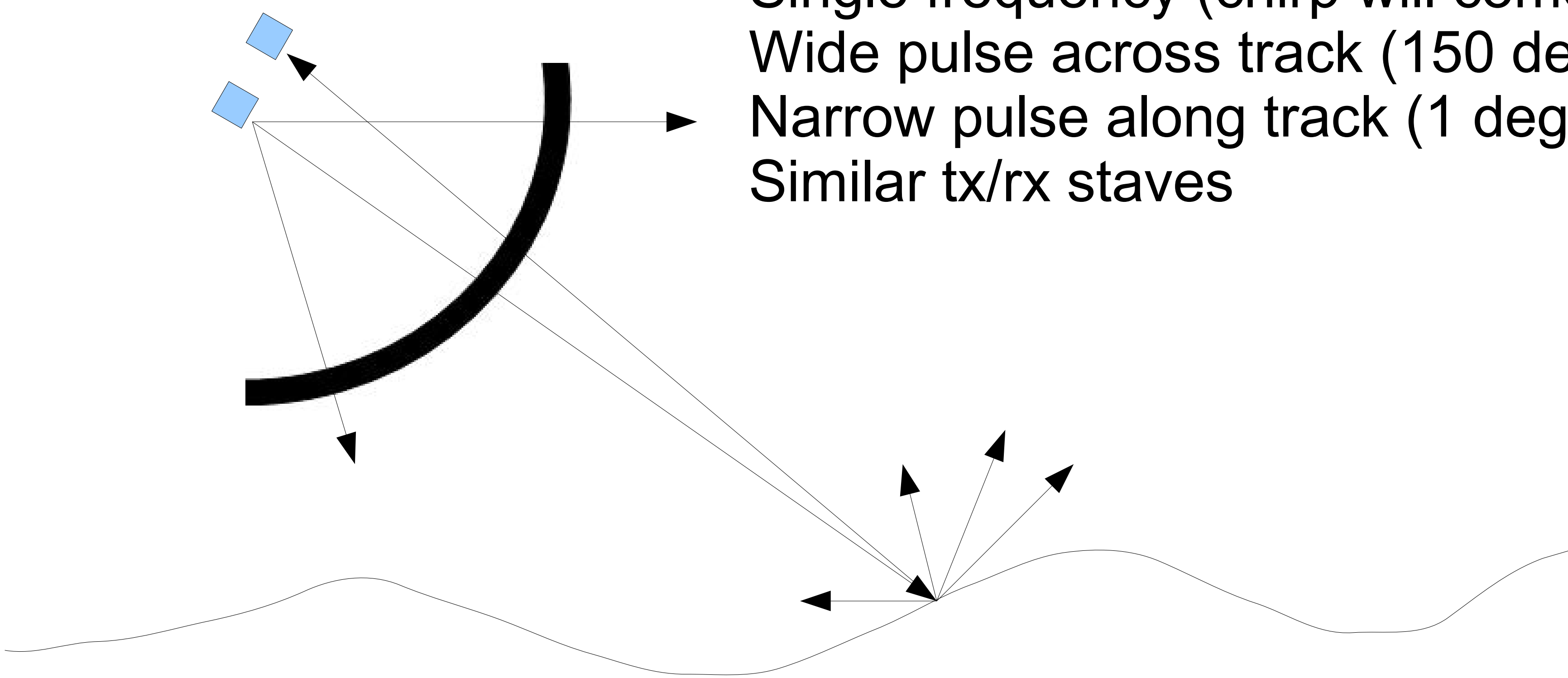
… and more are coming: Sonardyne Solstice, Marport, etc., etc.

Note: Traditionally not good penetration in the US market:
30+ GeoSwaths in China, 10+ in Australia, 6+ in Nigeria, ~5 in USA.

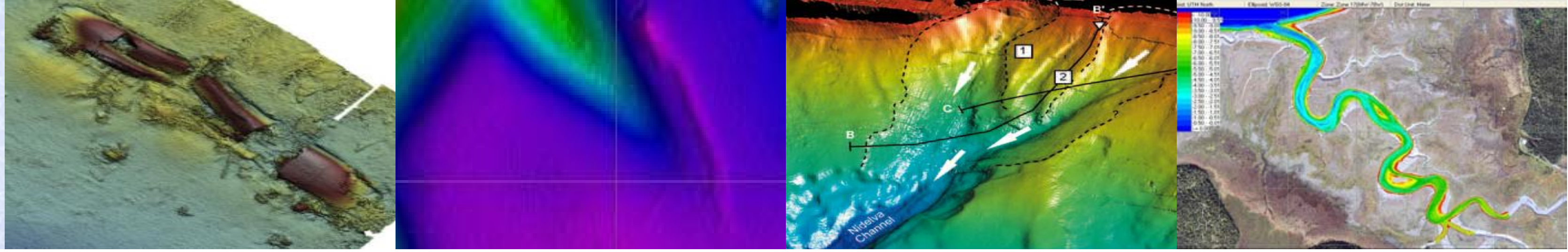


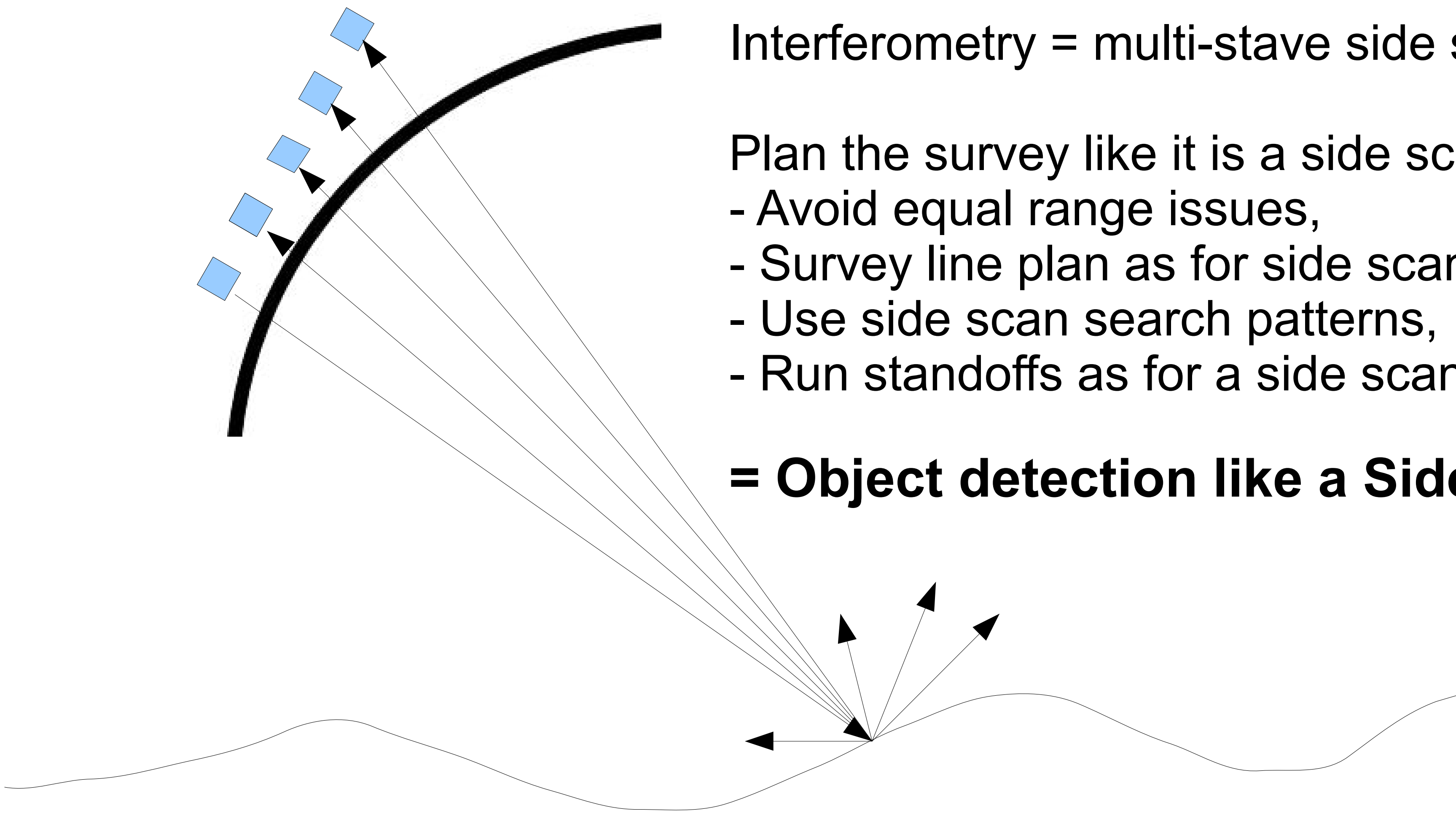
1. It is a Side Scan

Short pulse of sound (~15 cycles)
Single frequency (chirp will come)
Wide pulse across track (150 deg/txd)
Narrow pulse along track (1 deg)
Similar tx/rx staves



Footprint: Along track it depends on the beampattern
Across track: the way the pulse length intersects the seabed



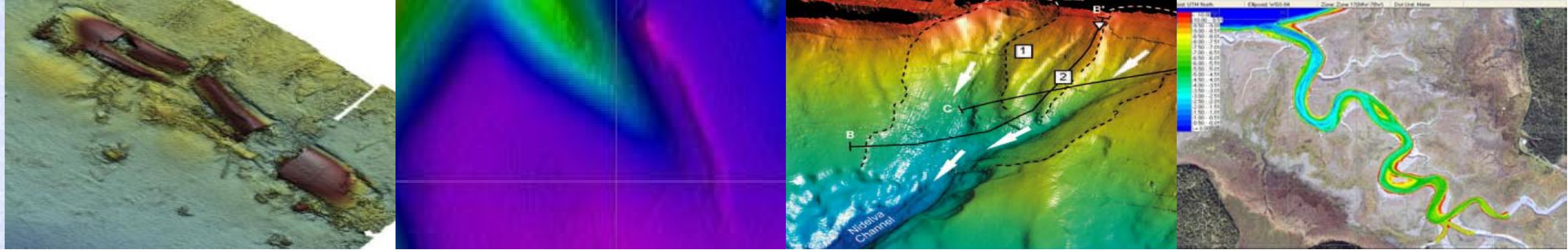


Interferometry = multi-stave side scan

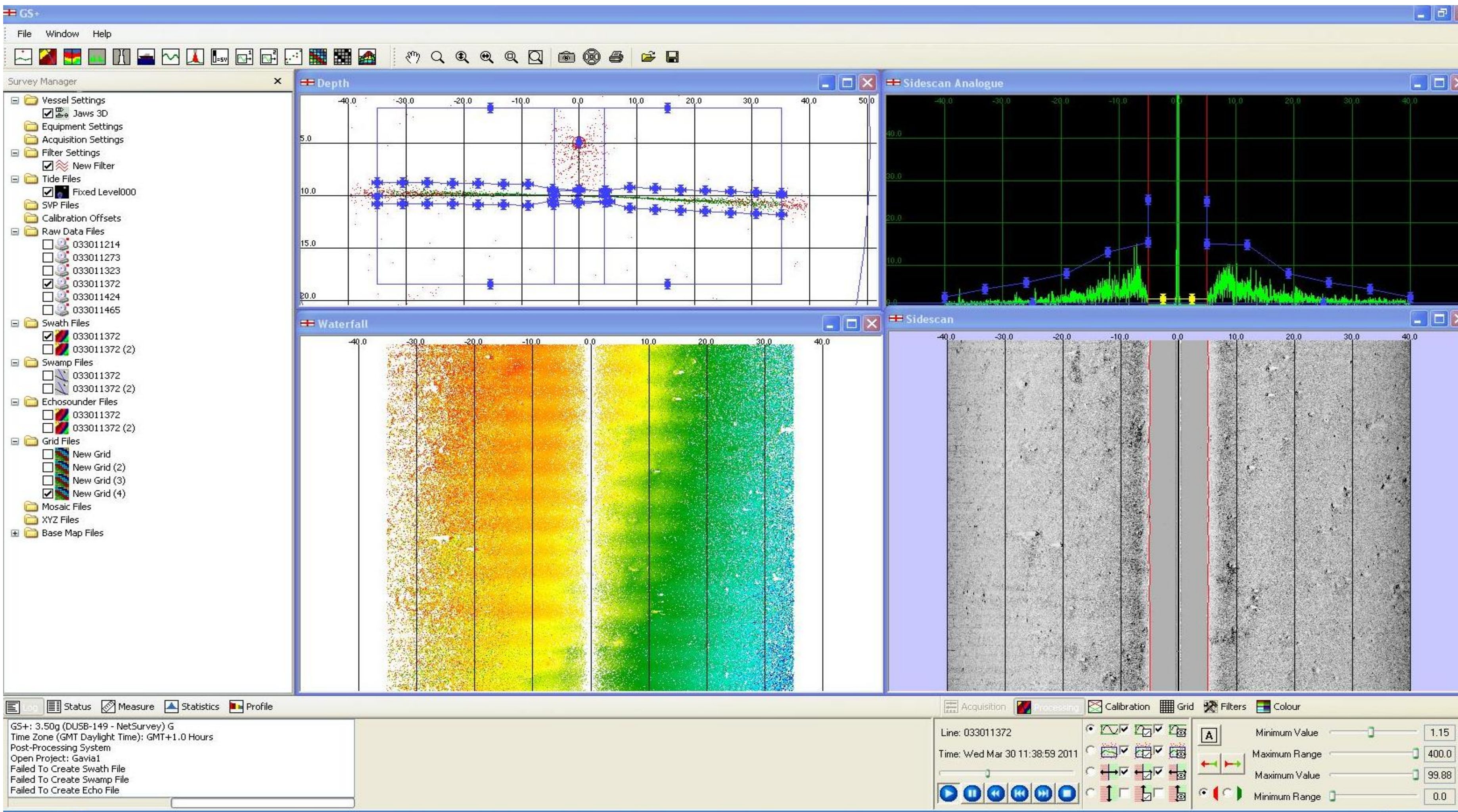
Plan the survey like it is a side scan:
- Avoid equal range issues,
- Survey line plan as for side scan,
- Use side scan search patterns,
- Run standoffs as for a side scan.

= Object detection like a Side Scan

Some issues at equal range, just like a side scan (possible exception of multi angle systems where signal to noise is high enough).
Has issues at nadir, just like a side scan - but only if it is flat: you'll see a wreck at nadir.



IHO Question 1: object detection capability

- 

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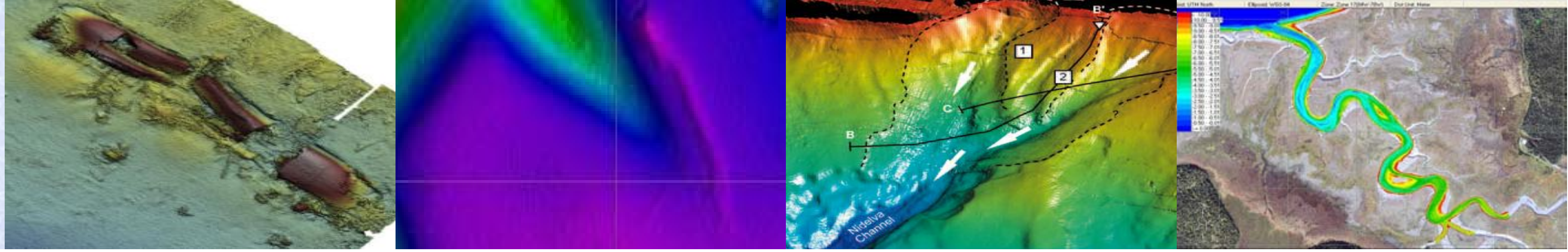

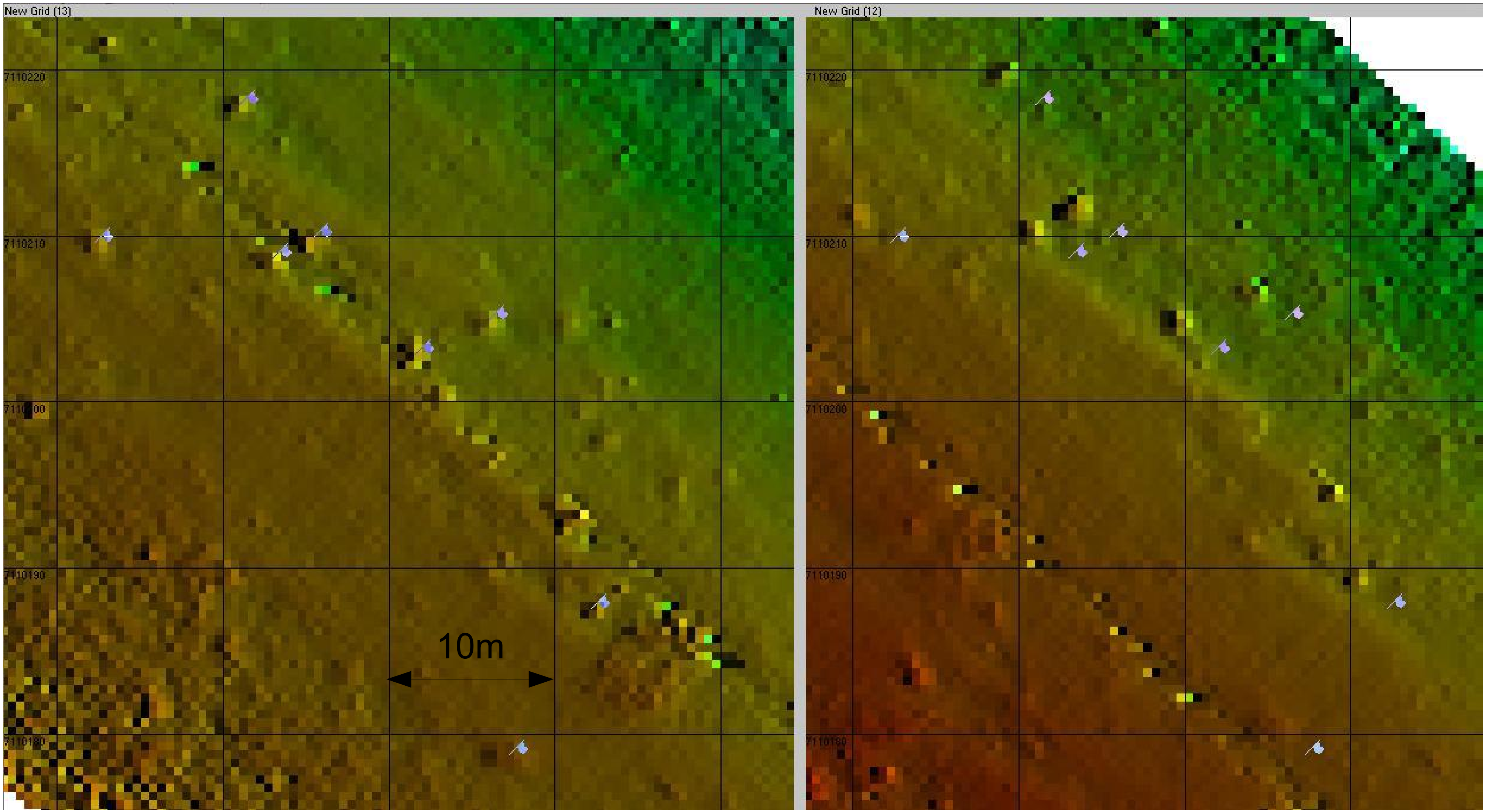

Resolved small objects seen in two lines, and shift in navigation resolved to sub-meter levels

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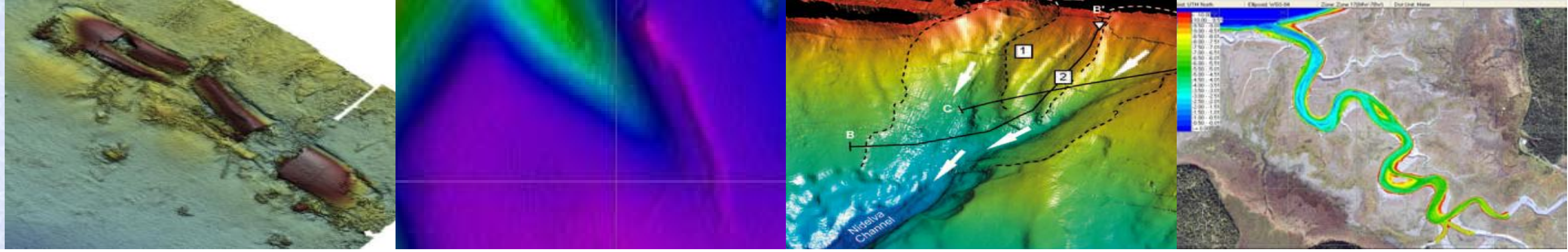
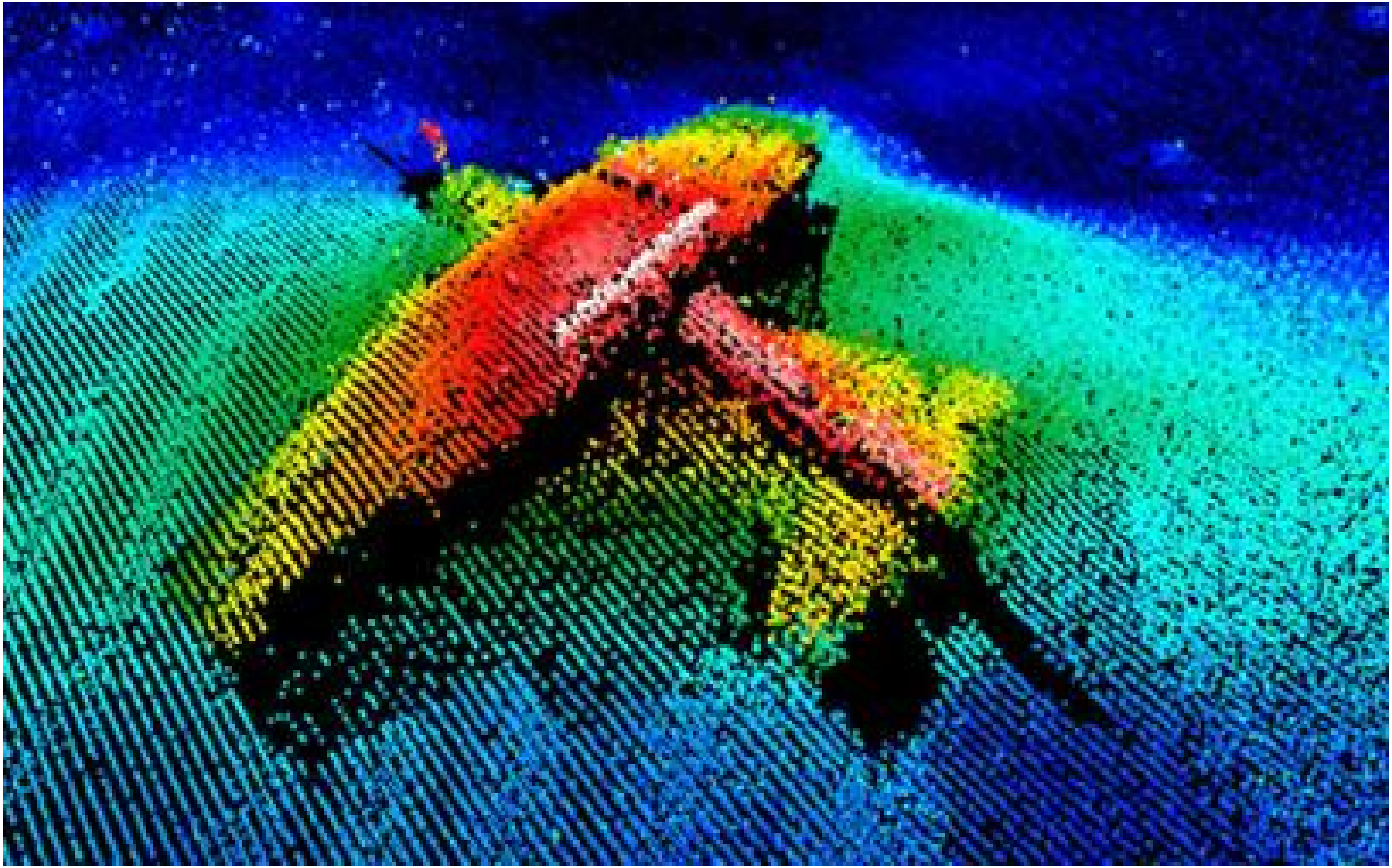
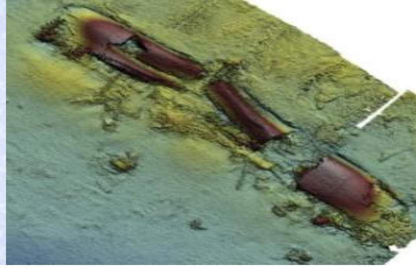
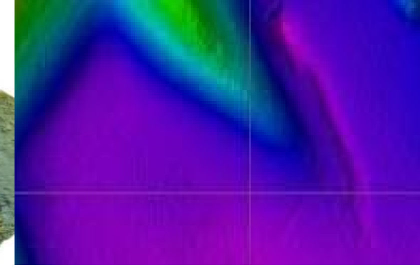
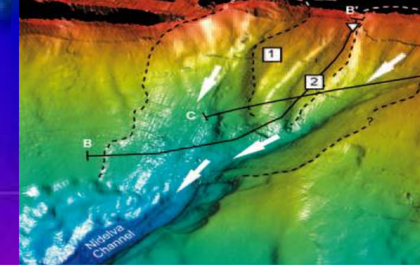


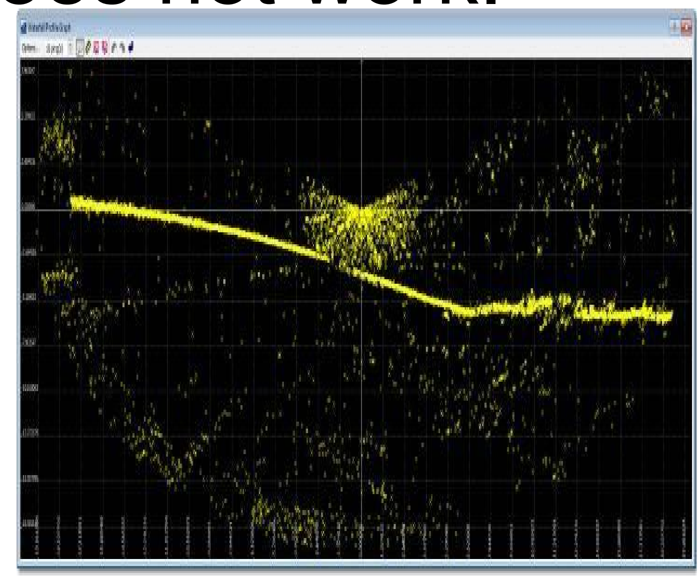


9.8m long plane wreck, prop resolved. 500kHz interferometric data collected on a Gavia AUV


Some hydrographers traditionally haven't liked them:

The concept of 'shoalest sounding' does not work.



Different problems to a multibeam

Different software is needed:

- Multibeam software can't cope

- Multibeam filters not appropriate

- Manufacturer's software usually OK for demos and small areas, but can be frustrating on larger jobs.

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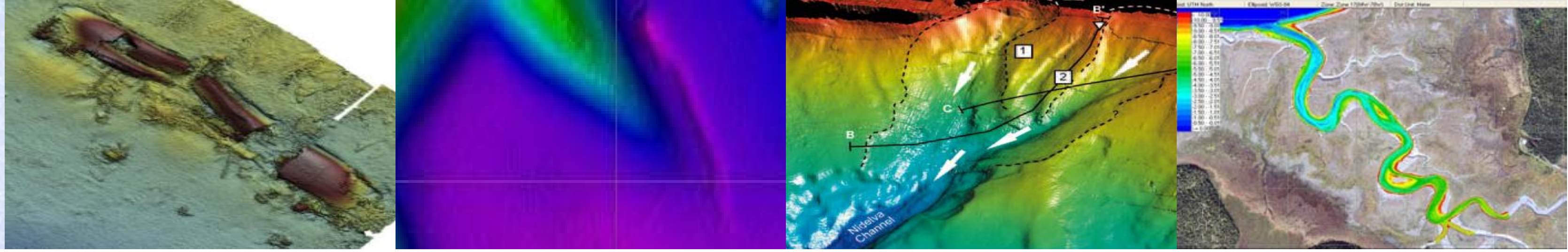
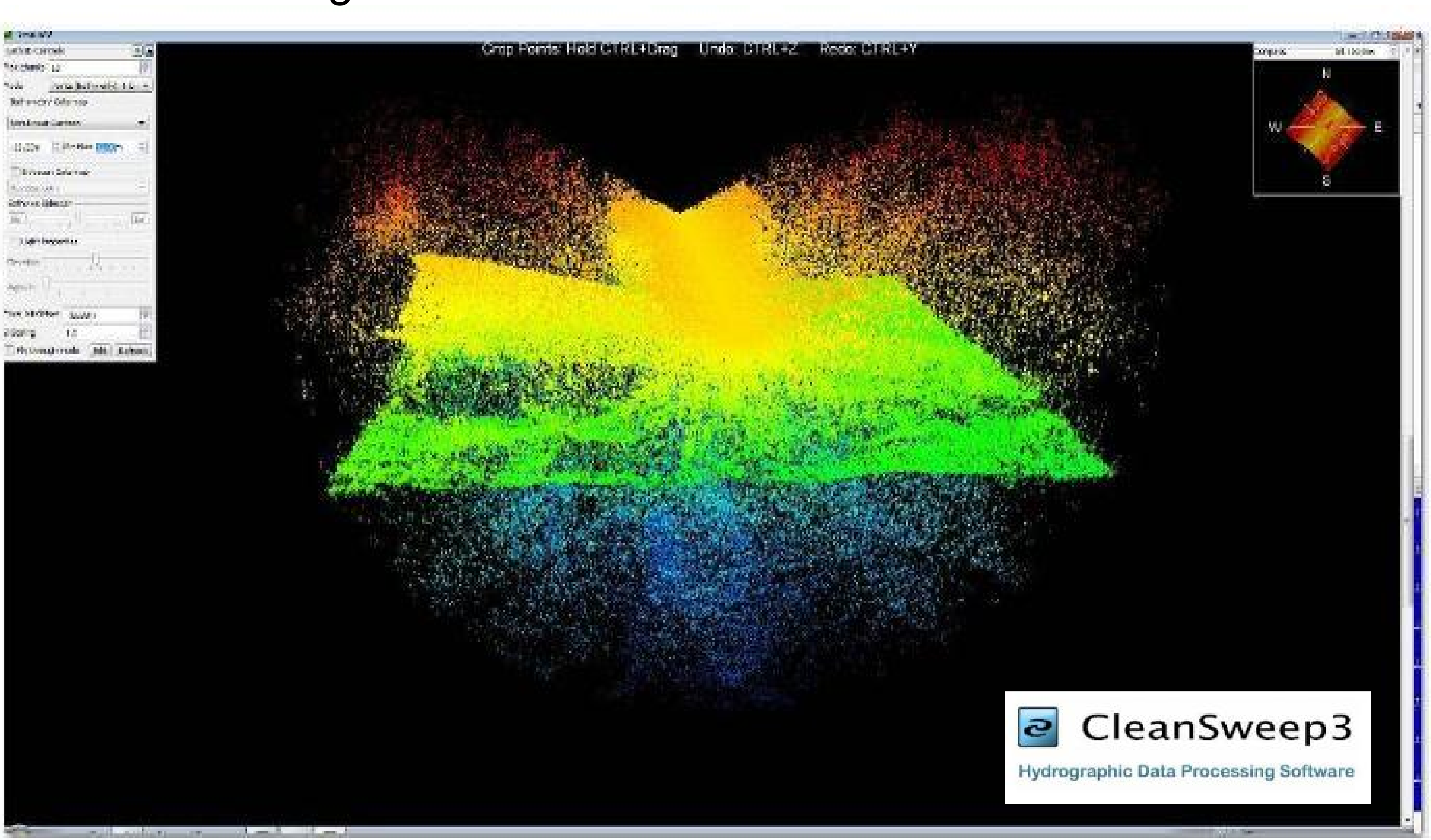


Manual data cleaning is not an option.
Image below shows ~10seconds of raw data



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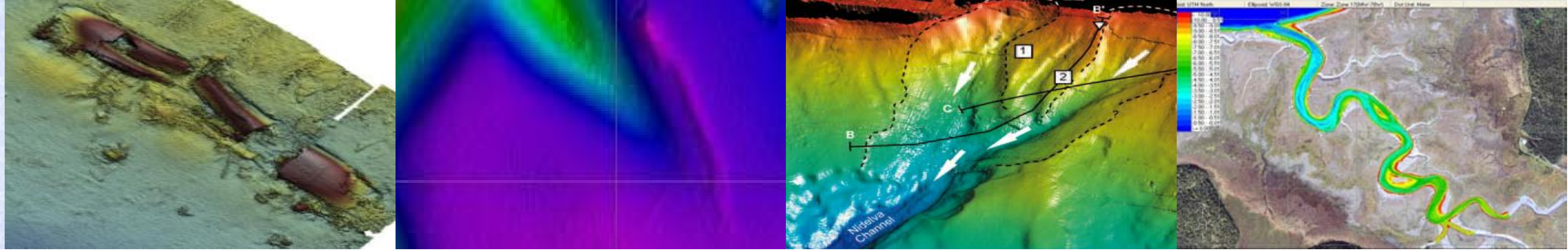
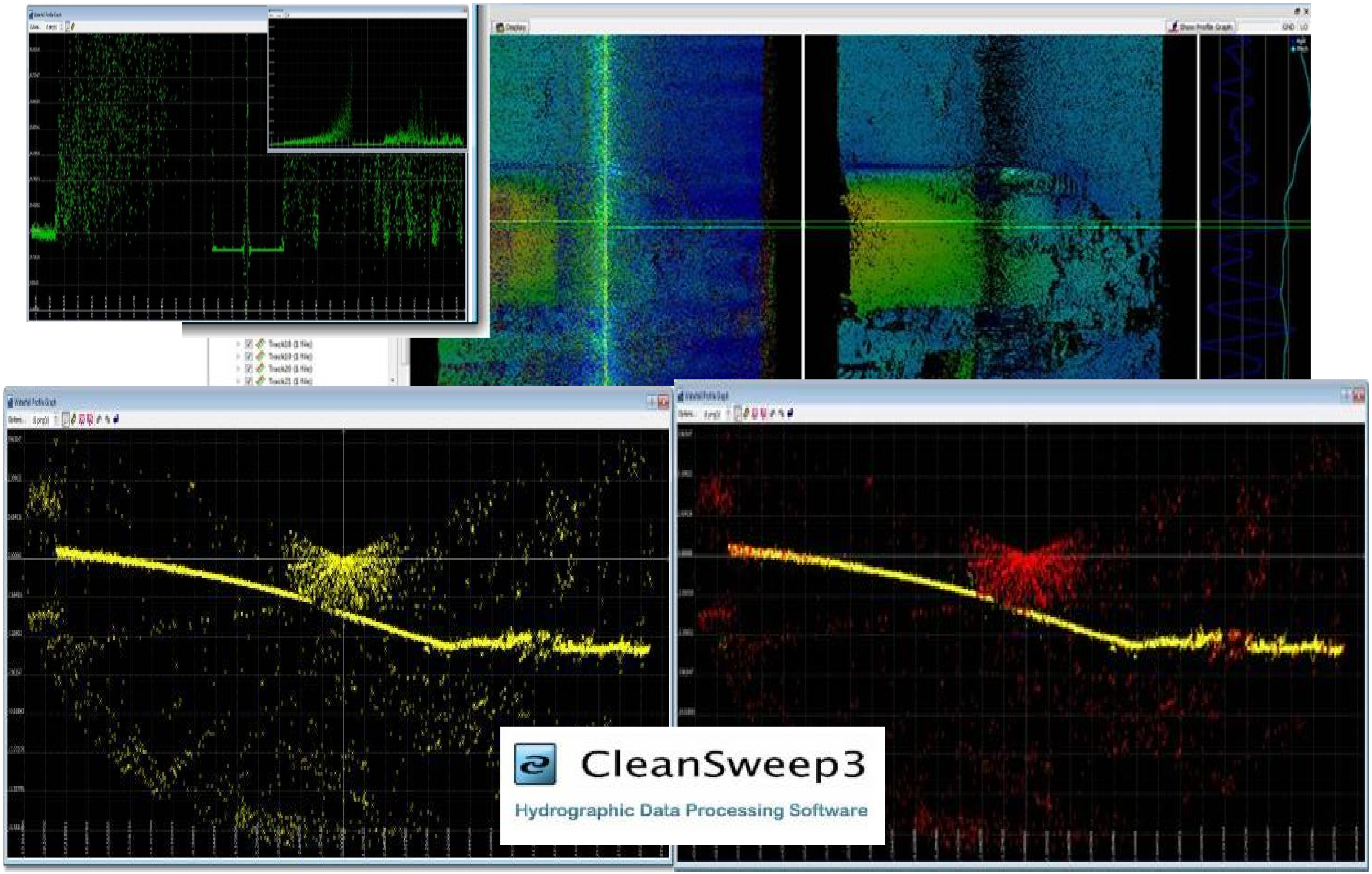
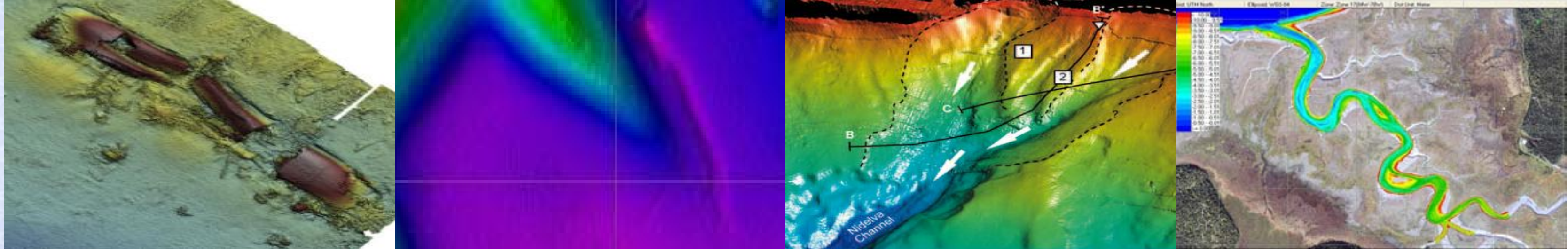
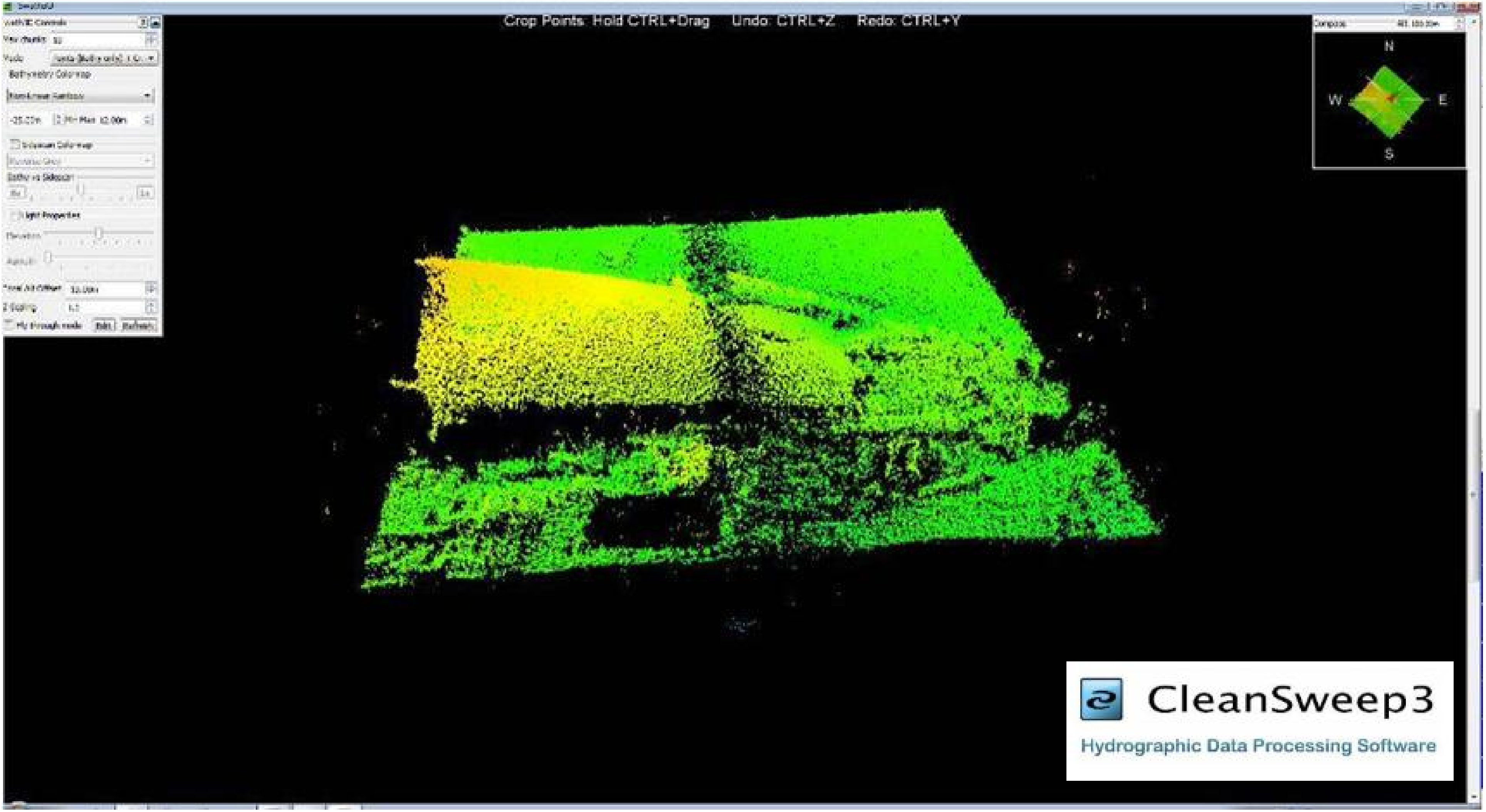


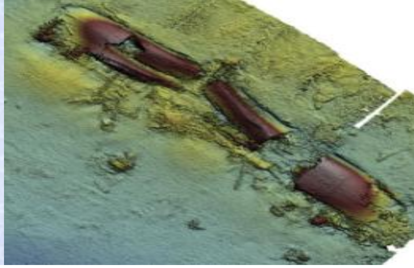
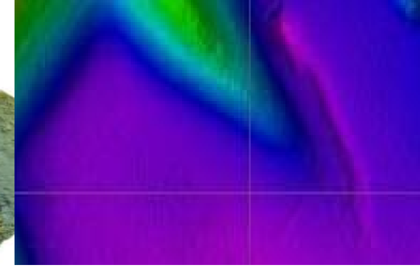
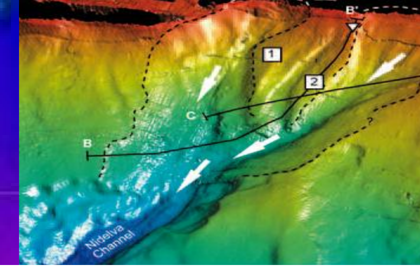
Appropriate data cleaning is effective:





Same data as previous image, cleaned data




Sonar Depth Accuracy Tests:

500kHz GeoSwath on Gavai AUV:

Found ± 3cm (1SD) at 15m fly height, 50cm bins.

GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L01501, doi:10.1029/2007GL031921, 2008

Digital terrain mapping of the underside of sea ice from a small AUV

P. Wadhams[1,2] and M. J. Doble[1,3]

Cold Regions Science and Technology 56 (2009) 90–97

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journal homepage: www.elsevier.com/locate/coldregions

Through-ice AUV deployment: Operational and technical experience from two seasons of Arctic fieldwork

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[a] Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge, UK
[b] Environmental Fluid Mechanics, Department of Civil Engineering, University of British Columbia, Vancouver, Canada
[c] Laboratoire d'Océanographie de Villefranche, Université Pierre et Marie Curie, Villefranche-sur-Mer, France

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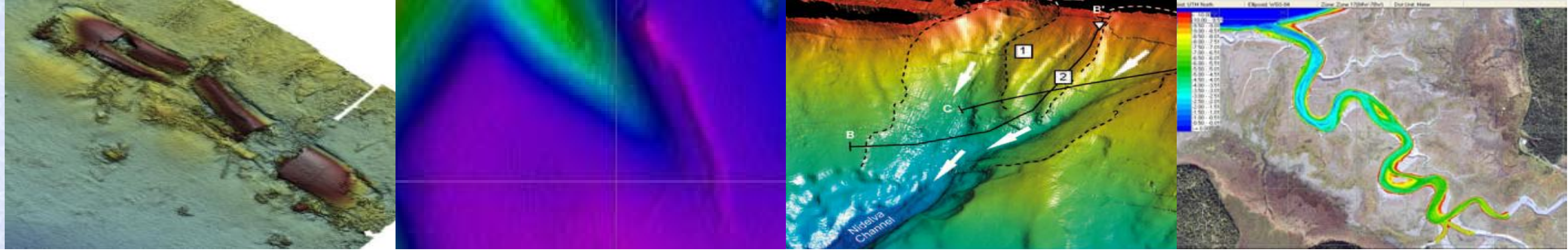


IHO Requirements and key error sources:

Object Detection:

Sonar characteristics

Horizontal Uncertainty:

Sonar characteristics

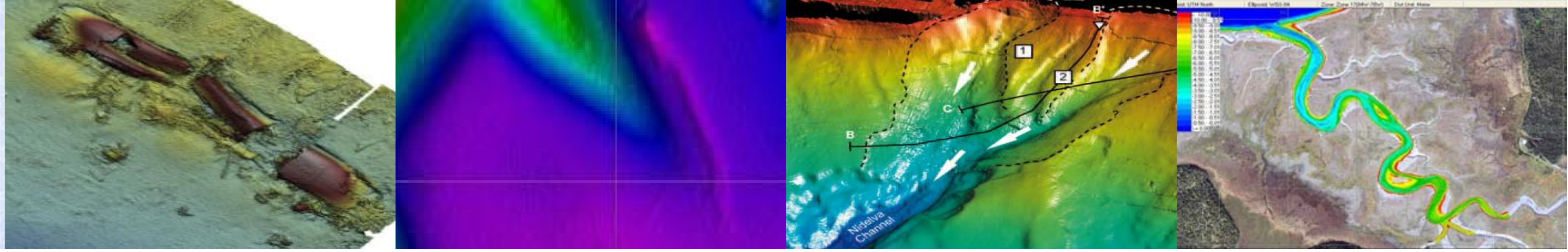
Positioning system

Vertical Uncertainty:

Sonar characteristics

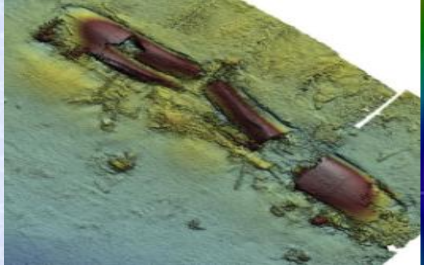
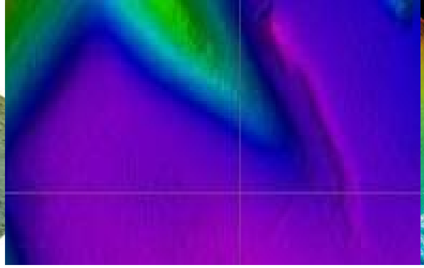
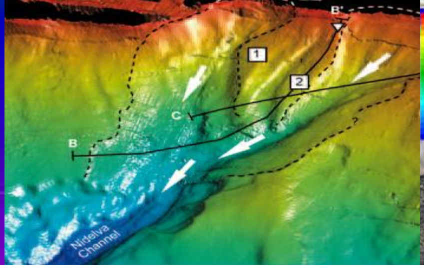
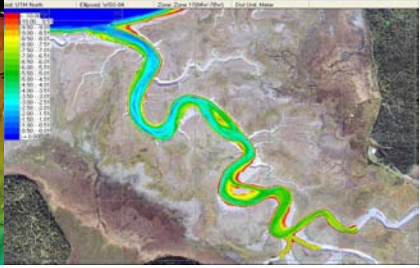
Depth sensor

OK, if you can accept interferometry



Vertical Uncertainty:

- The unique contribution to the vertical error budget (e.g. ex. tides, etc.) is the depth measurement.
- This should be achieved using pressure aiding of the INS: currently there are some issues with the aiding (Kalman sensor models) so pressure-depth is being used 'raw'
- Keller-Druck 33XE sensor: specification is 0.01% FS.
- (Pressure-to-depth conversion is critical).

KELLER

Highly Precise (0,01%) Pressure Transmitters

MATHEMATICALLY COMPENSATED / PROGRAMMABLE

Series 33 X
Series 35 X

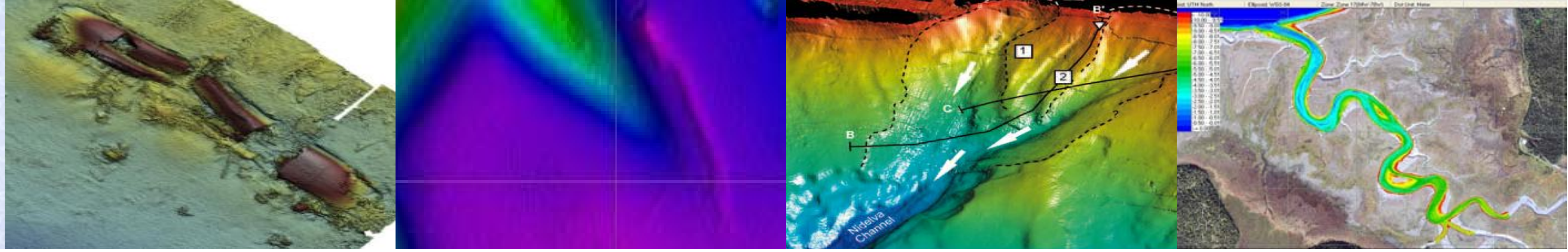
Digital Output of Transmitter

This high precision of 0,01 %FS is available as an option (the standard Series 33 X has an accuracy of 0,05 %FS). These Series are based on the stable, floating piezoresisitive transducer and the newly developed XEMICS micro-processor with integrated 16 bit A/D converter. Temperature dependencies and non-linearities of the sensor are mathematically compensated. With the READ30 software and the KELLER cable K-107, the calculated pressure can be displayed on a Laptop or PC. The READ 30 software also allows the recording of pressure signals and the graphic display on the PC. Up to 128 transmitters can be hooked together to a Bus-system.

Series 33 X
G1/4" thread

Specifications

	Standard Pressure Ranges (FS) and Overpressure in bar								
PR 33 X / PD 33 X / PR 35 X		1	3	10	30				
PA(A) 33 X / PA(A) 35 X	0,8…1,2	1	3	10	30	100	300	700	1000
Overpressure	2	2	5	20	60	200	400	1000	1000
Overpr. referential pressure side PD		2	5	7	20				
PD, static line pressure* standard / high Pressure	200 bar / 600 bar								



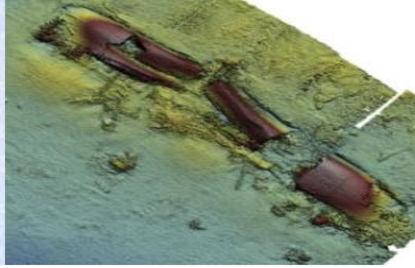
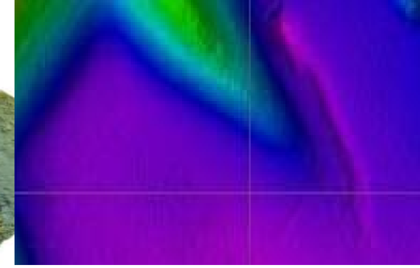
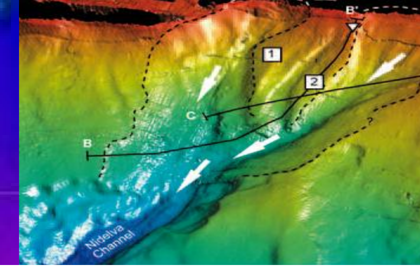
Approximate contribution to error budget:

~6cm at 95% confidence for the 30bar sensor.

~20cm at 95% confidence for the 100bar sensor.

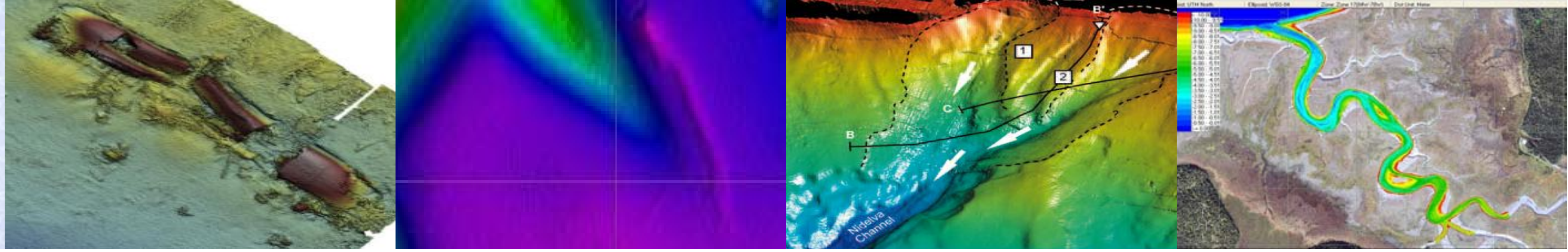
Full error budget is fairly complex:

- Tide measurement
- Atmospheric pressure
- Depth-to-pressure conversion
- Issues from swell (see later images)



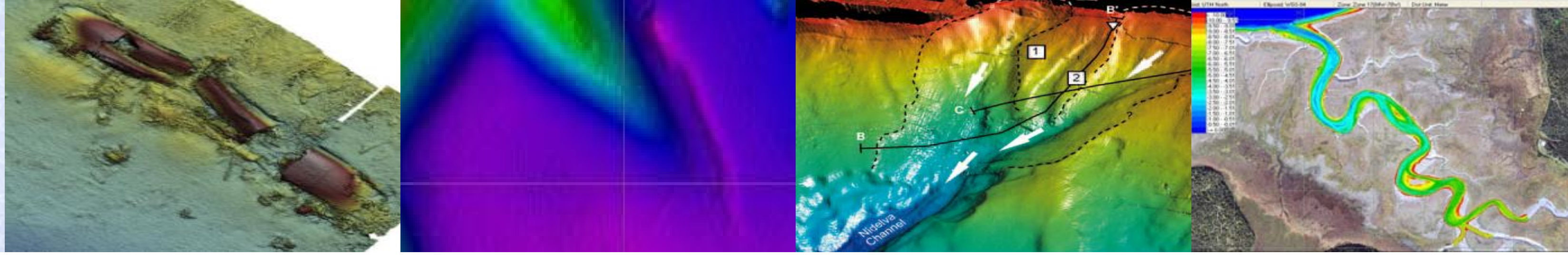
Horizontal Uncertainty

- Issue 1 – where did you start from?
- GPS location of submergence point?
- Very low antenna when getting fixes on surface
- Possible solutions:
  - direct feed of position
  - Subsea launch from cradle
  - USBL



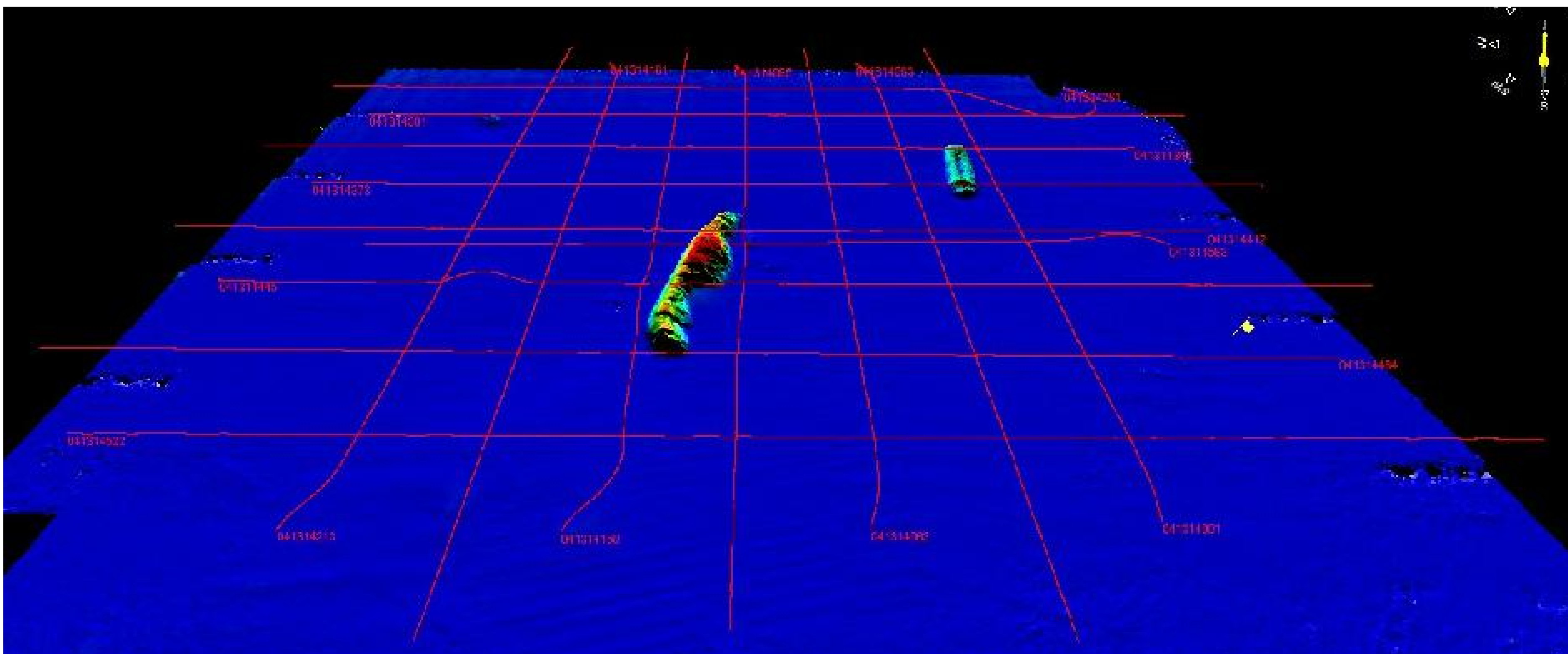
Horizontal Uncertainty

- Issue 2 – positioning underwater
- Uses Inertial Navigation System (INS)
- On Gavia this is the Kearfott/RDI SeaNav
- Uses 'T24' INS with RDI Doppler Velocity Log aiding.
- Possible solutions to INS/DVL drift:
  - USBL
  - ZUPT
  - SLAM



Measurement of INS Drift in the Field

- Using multiple passes over fixed objects over ~1 hour (grid survey over a wreck)



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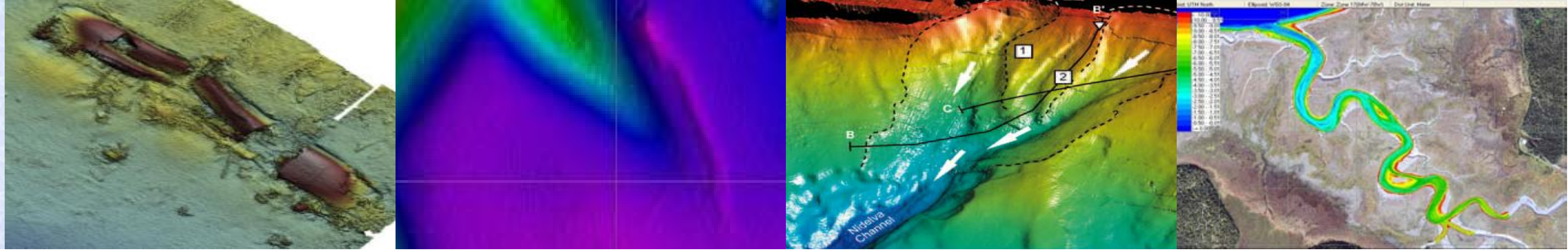

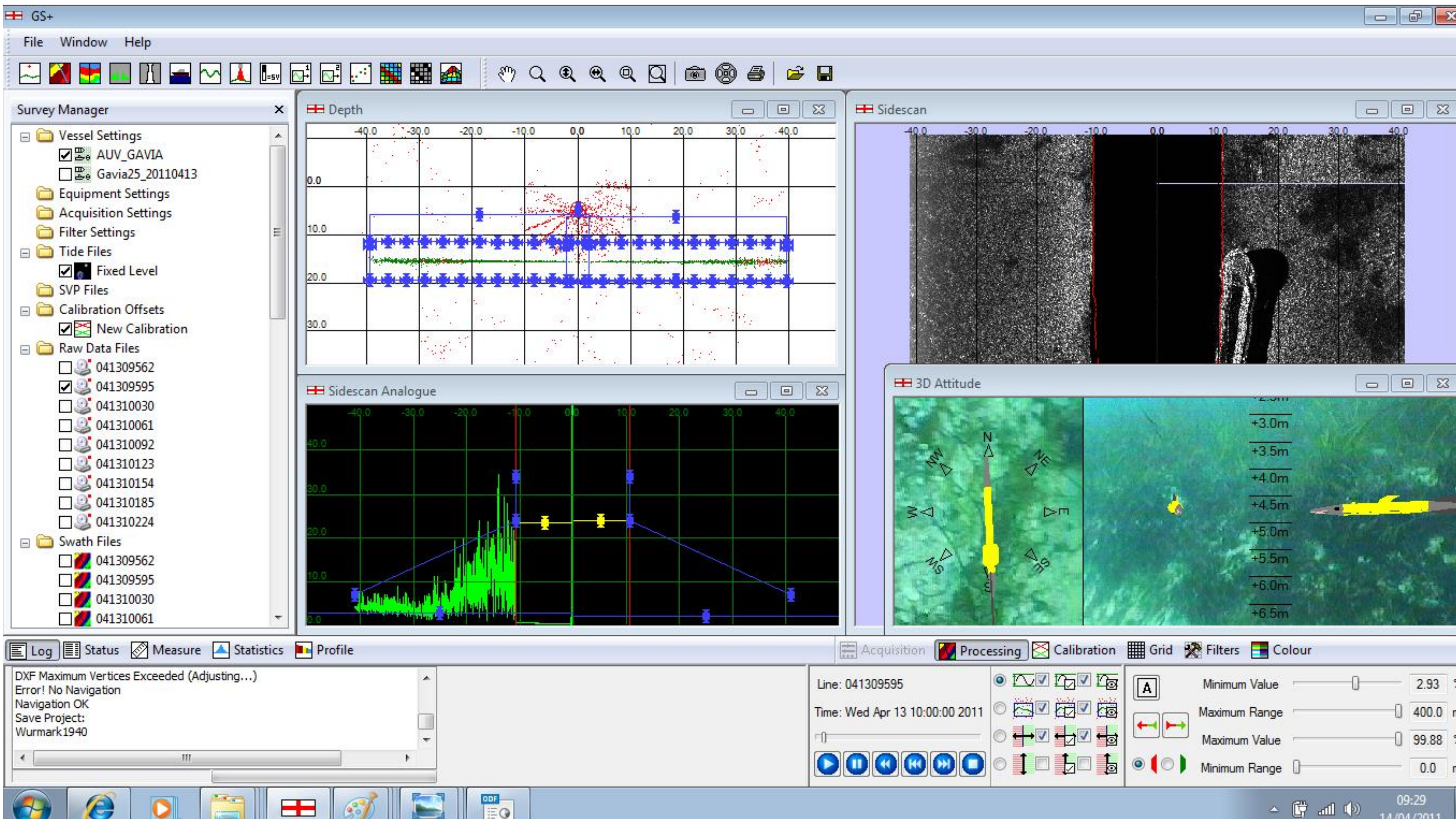

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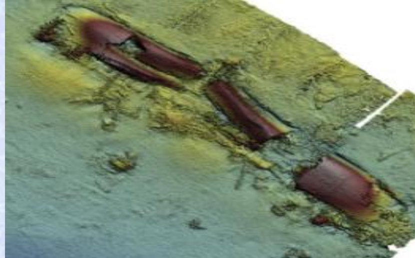

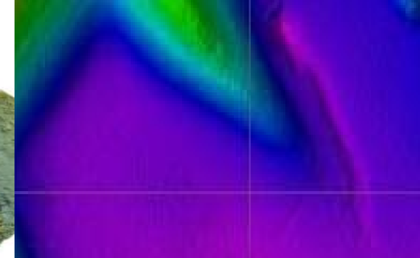

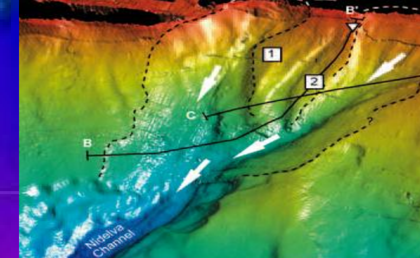

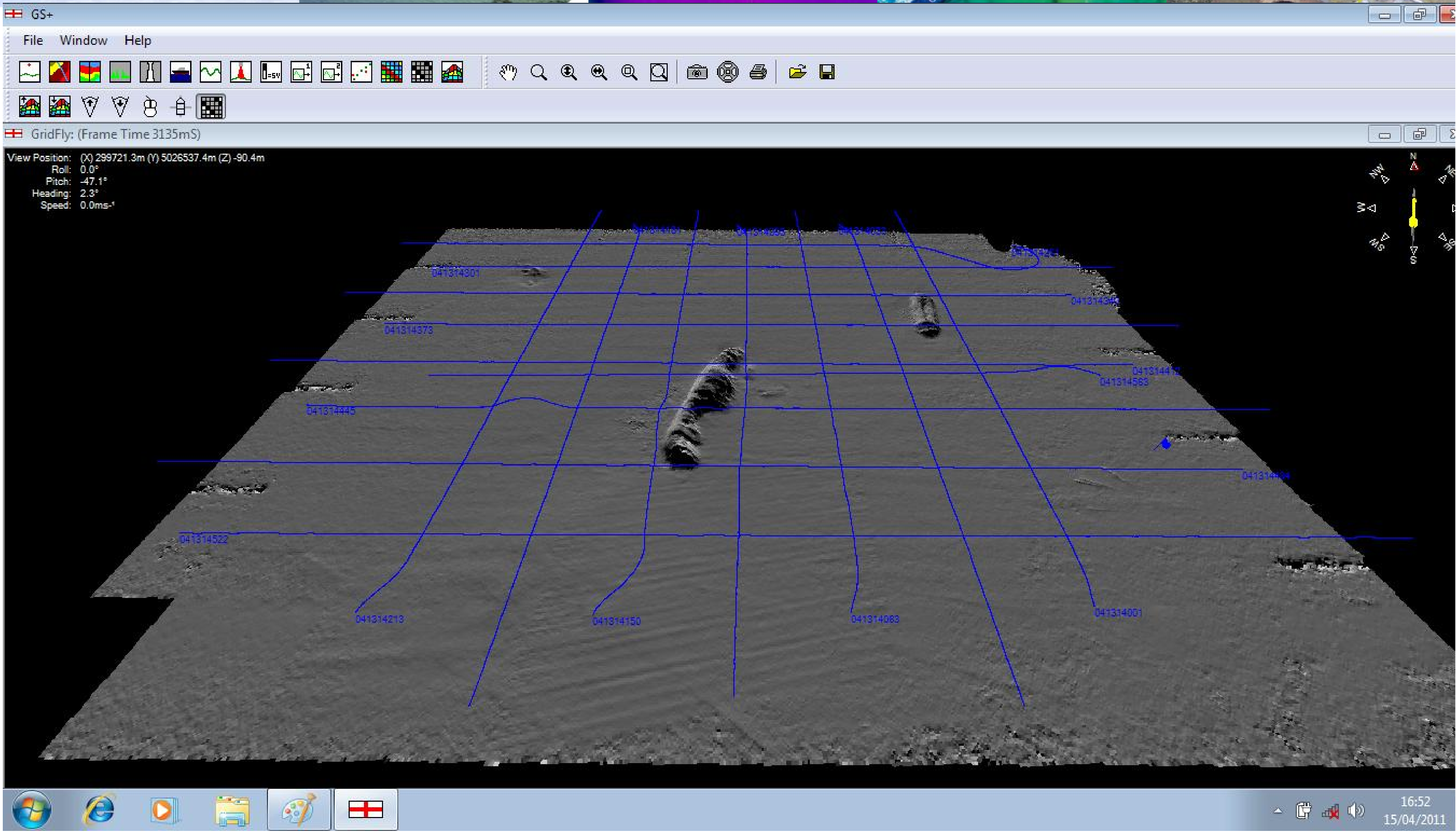

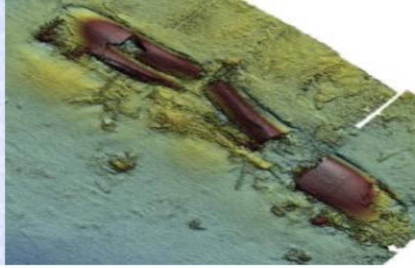

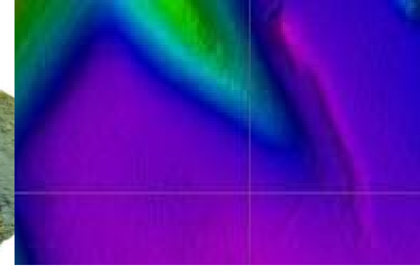

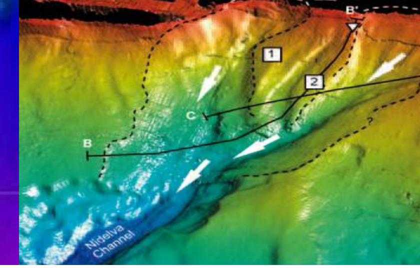

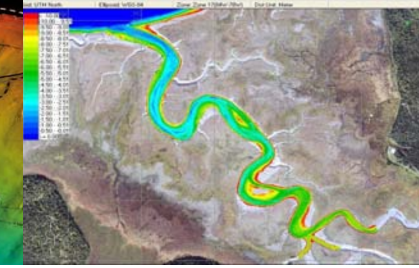

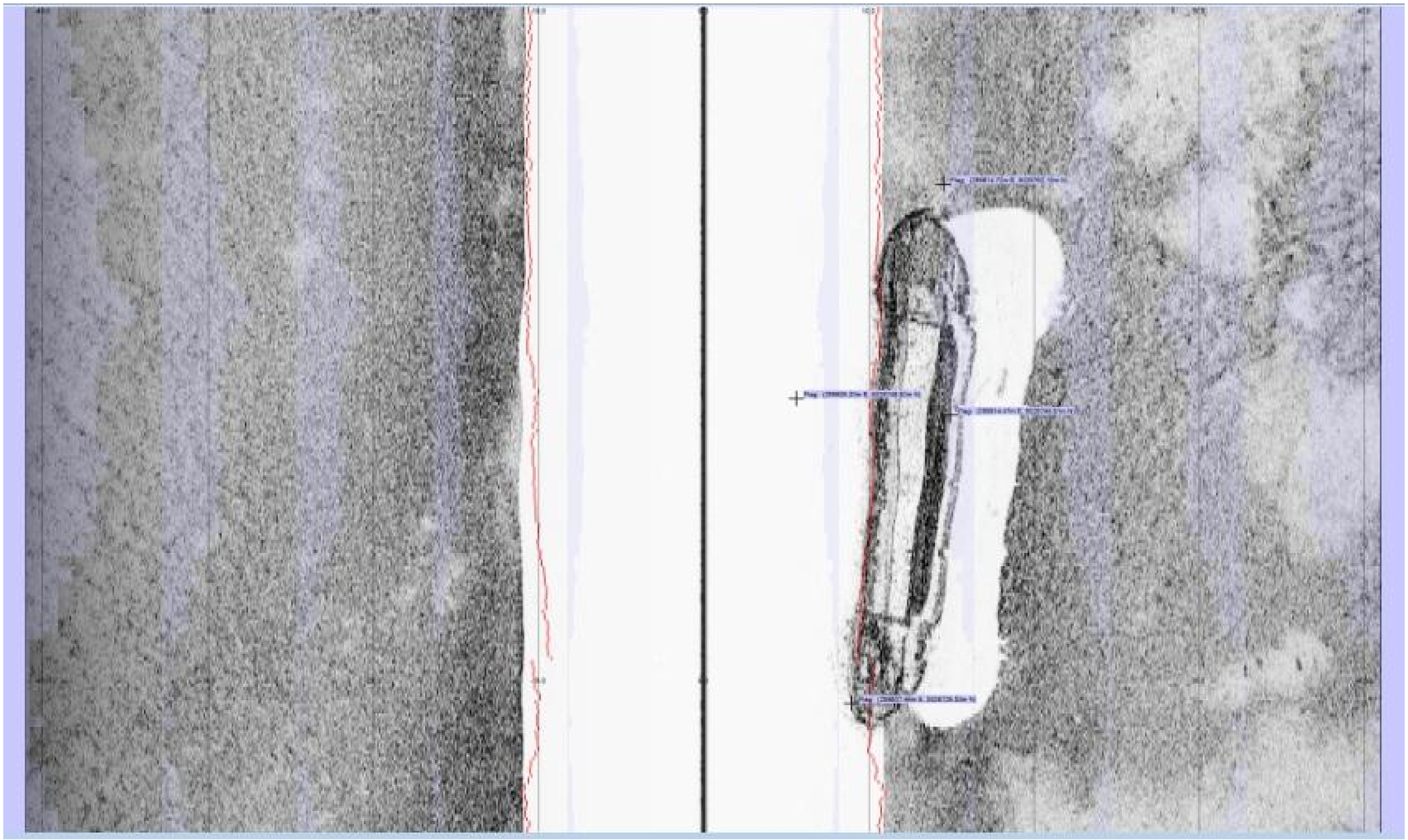

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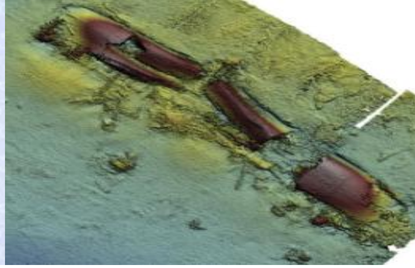

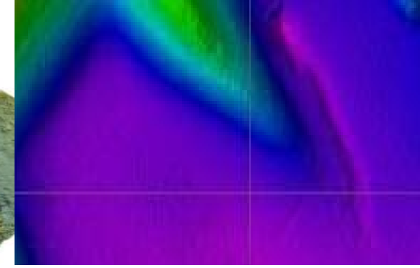

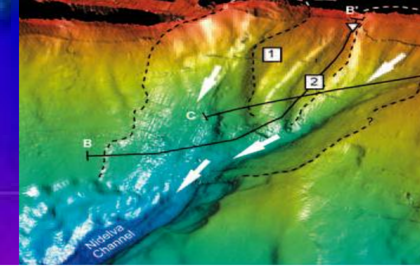

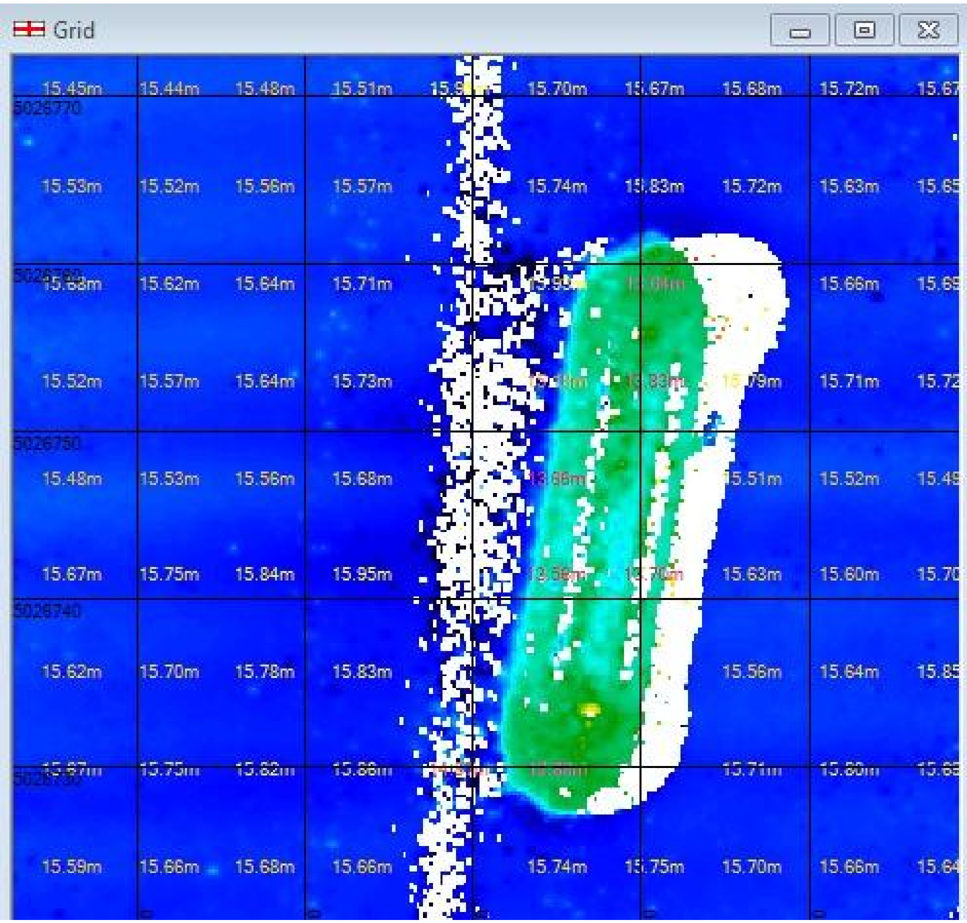

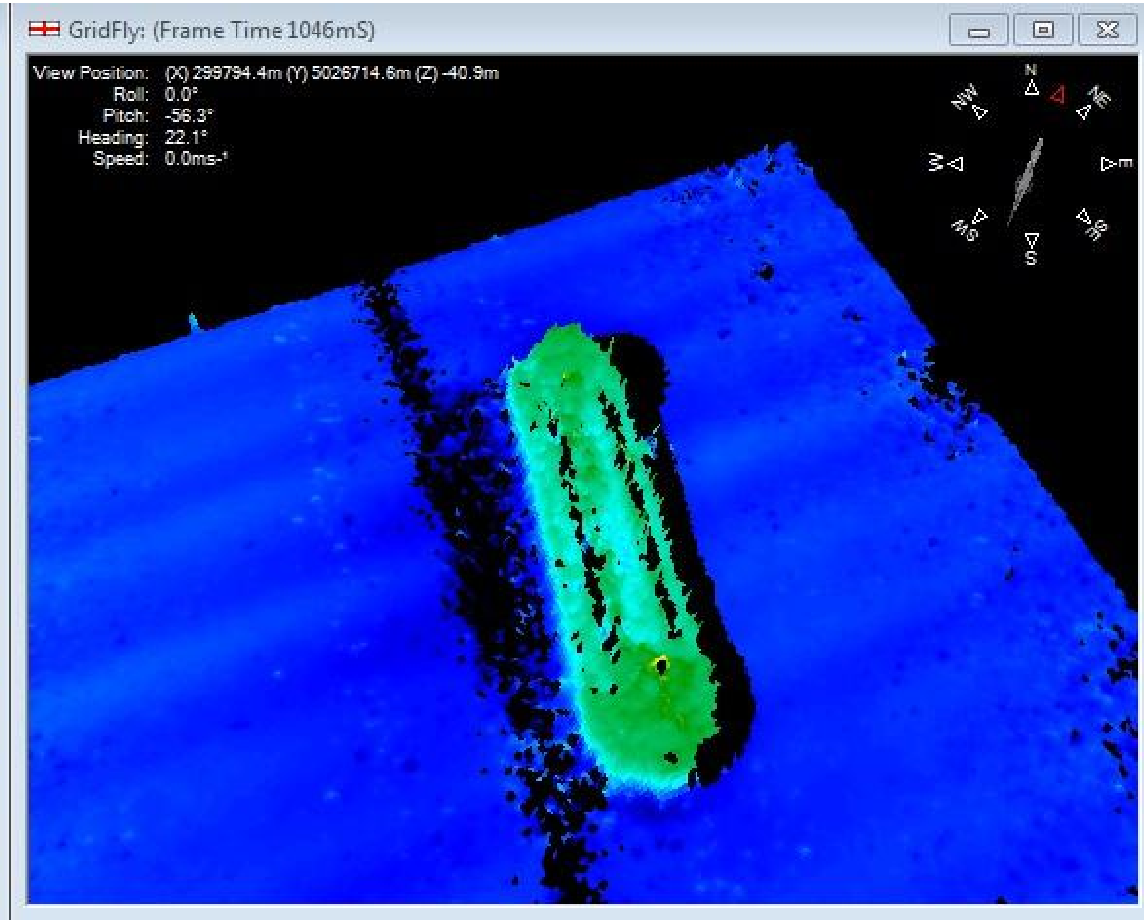

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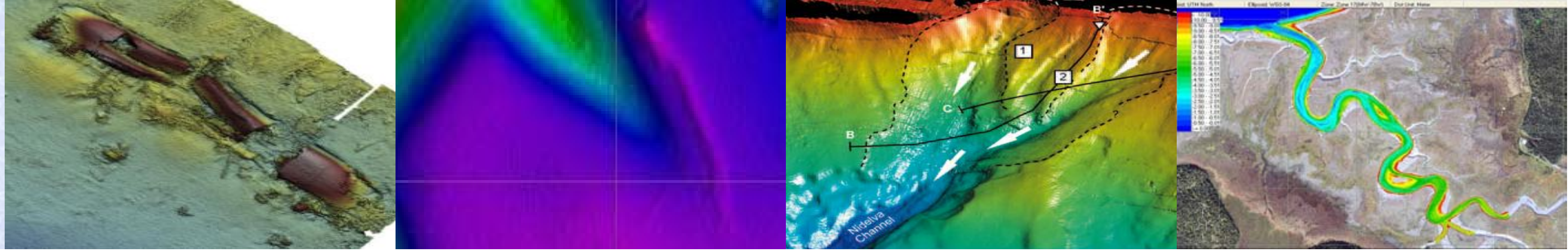

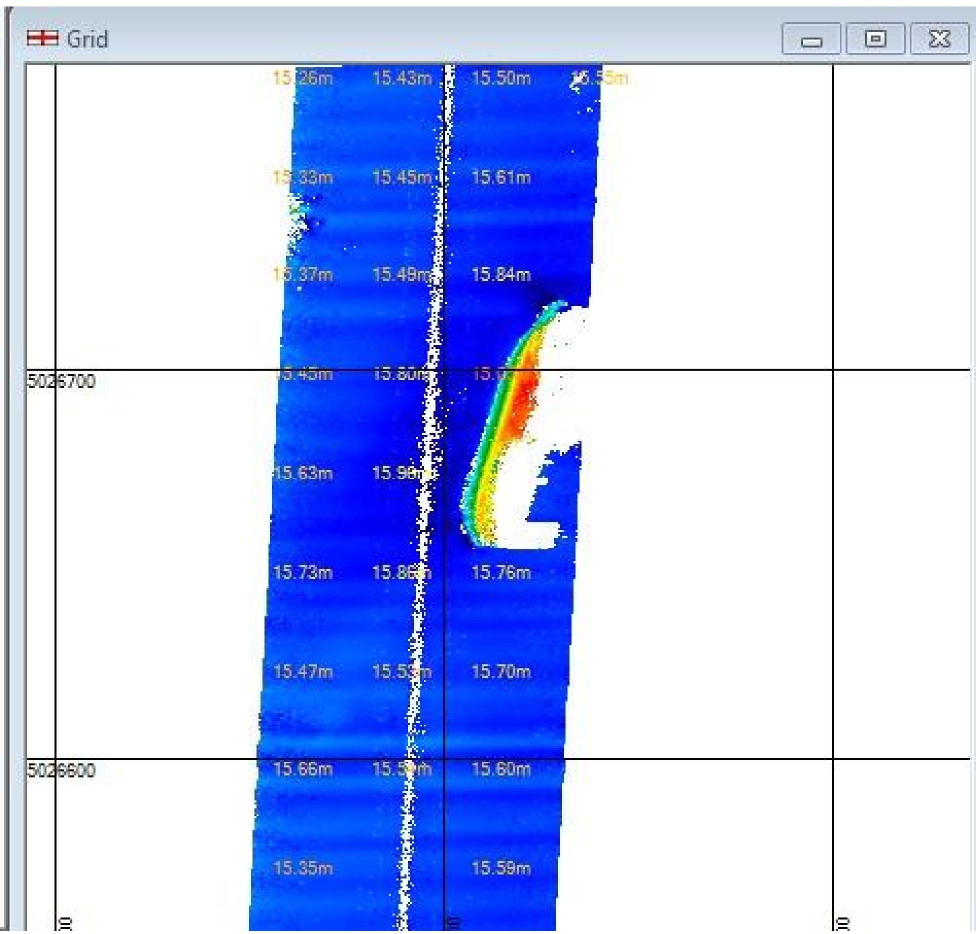

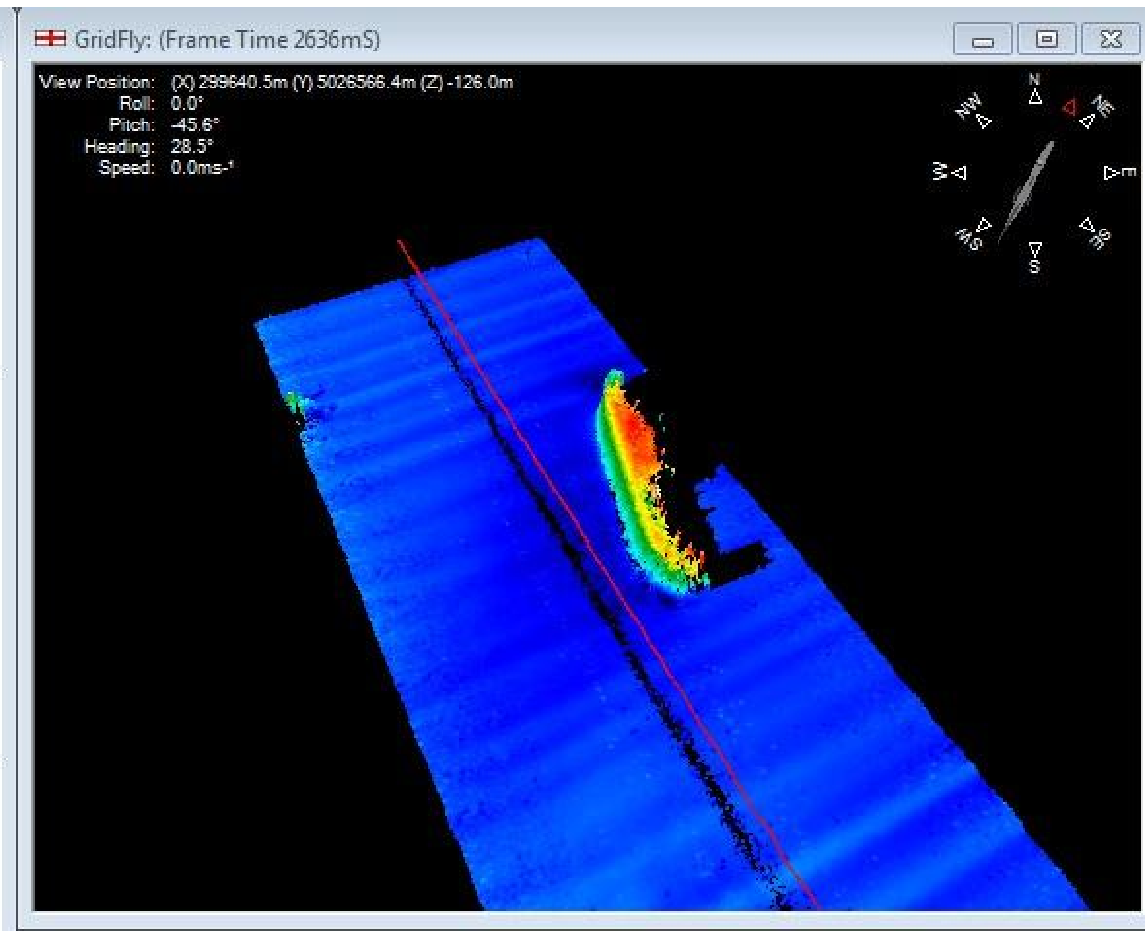

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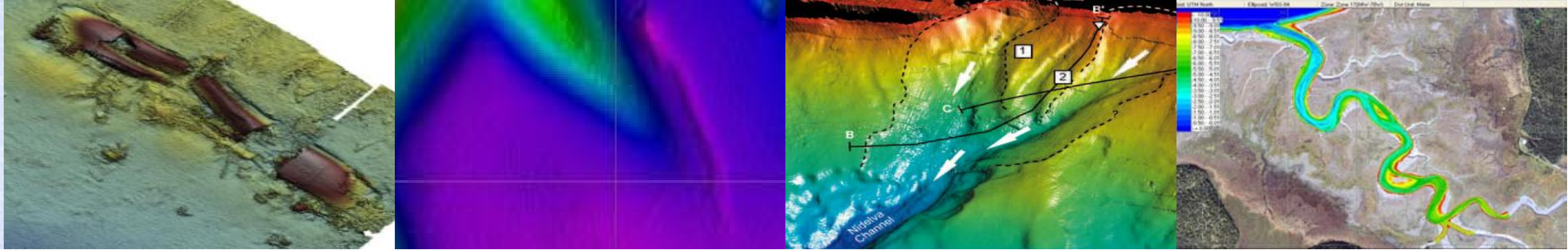
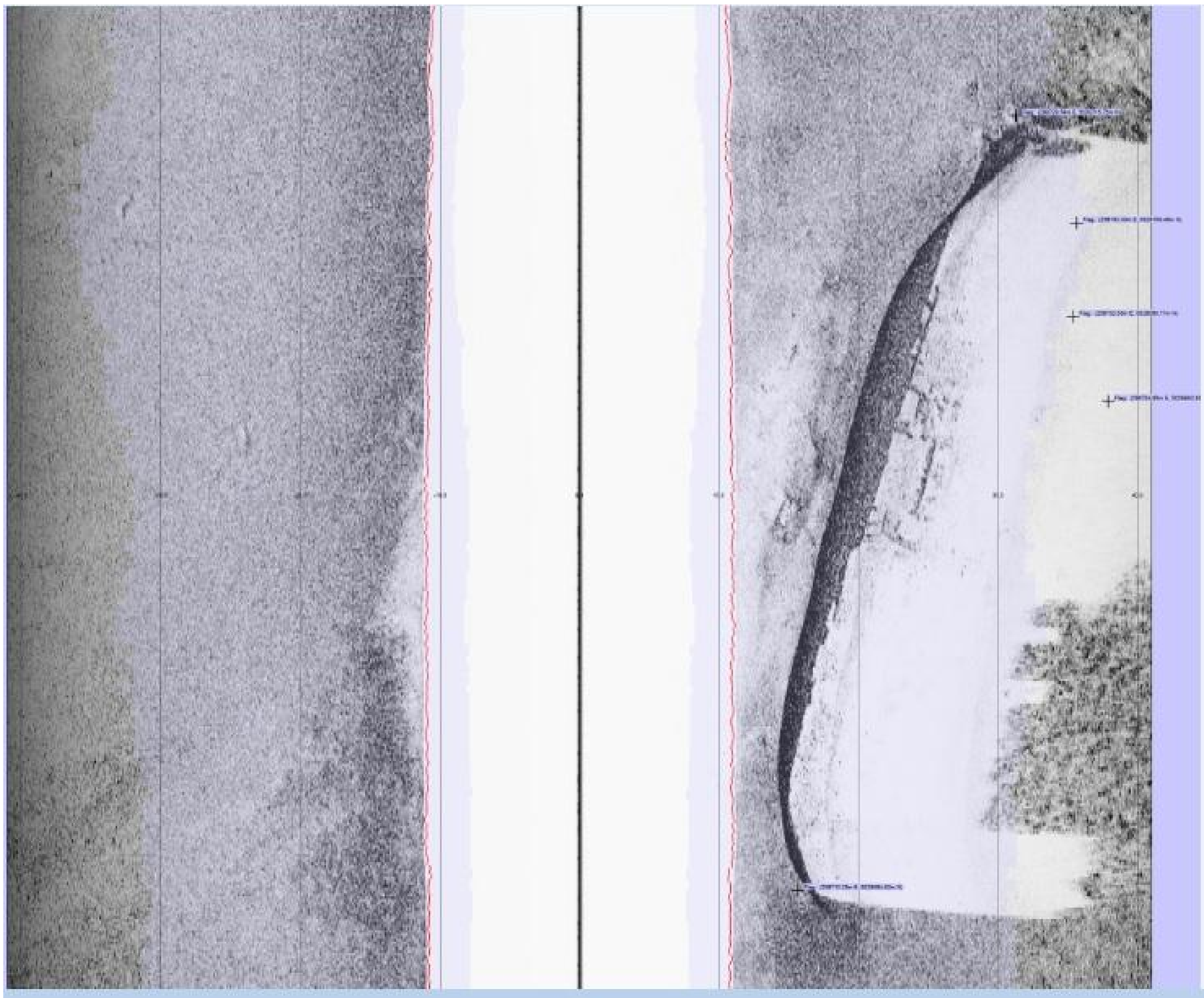
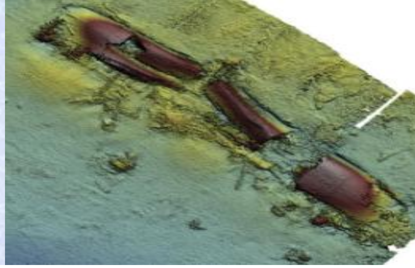
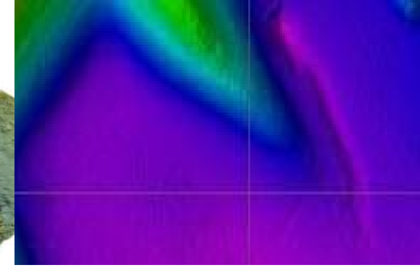
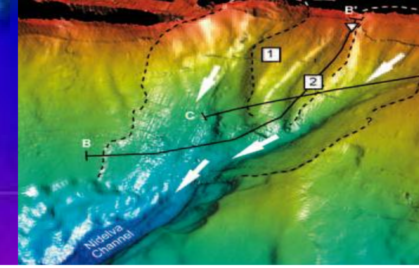
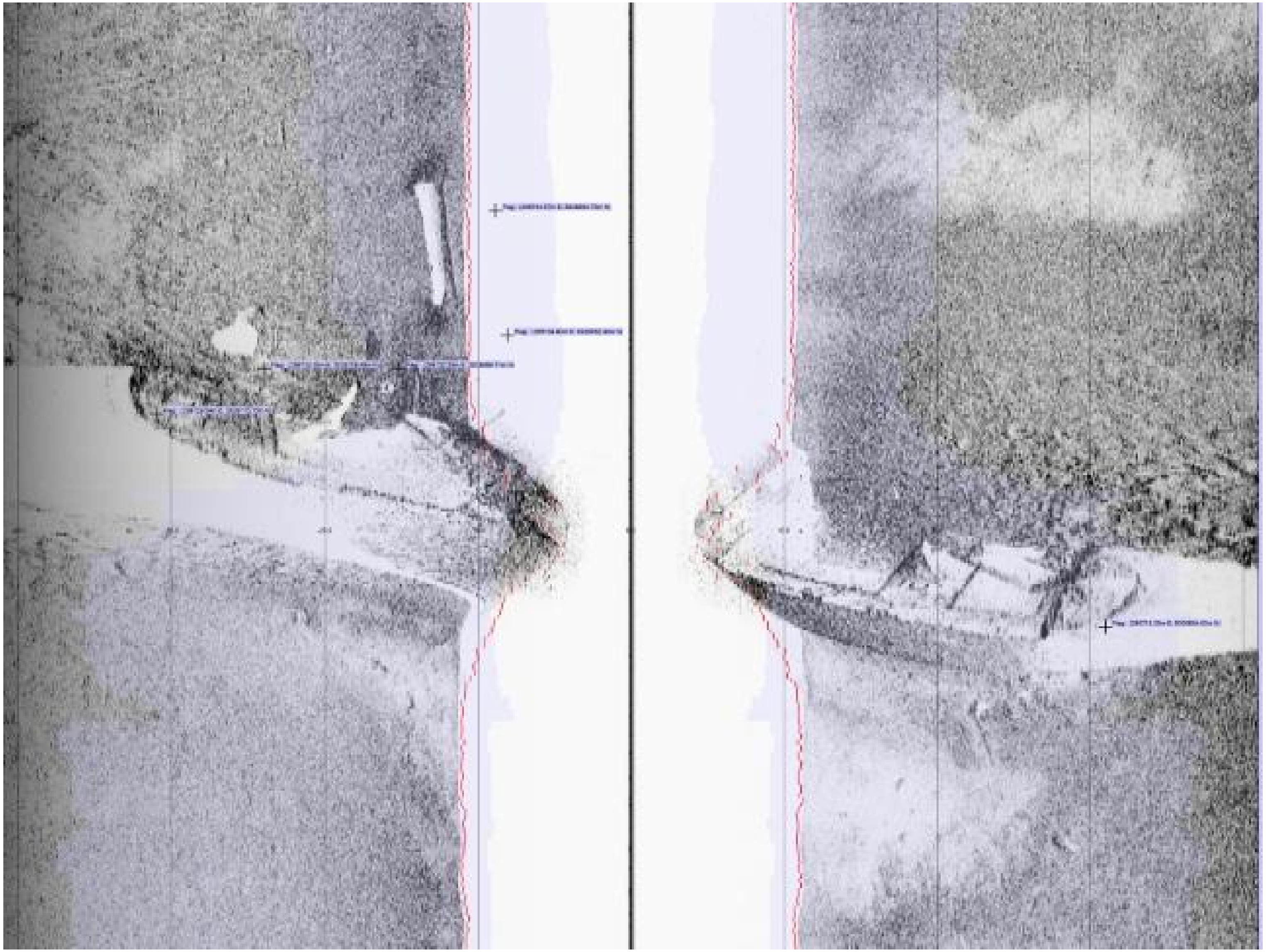









Nidelva Channel



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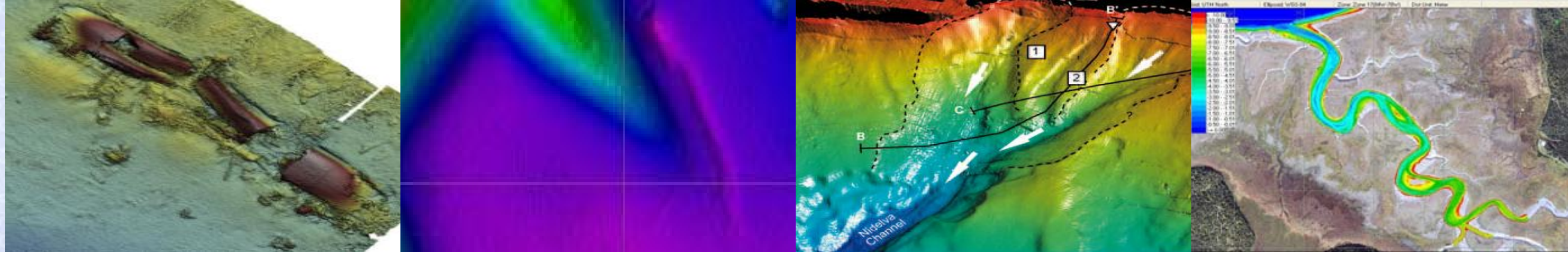
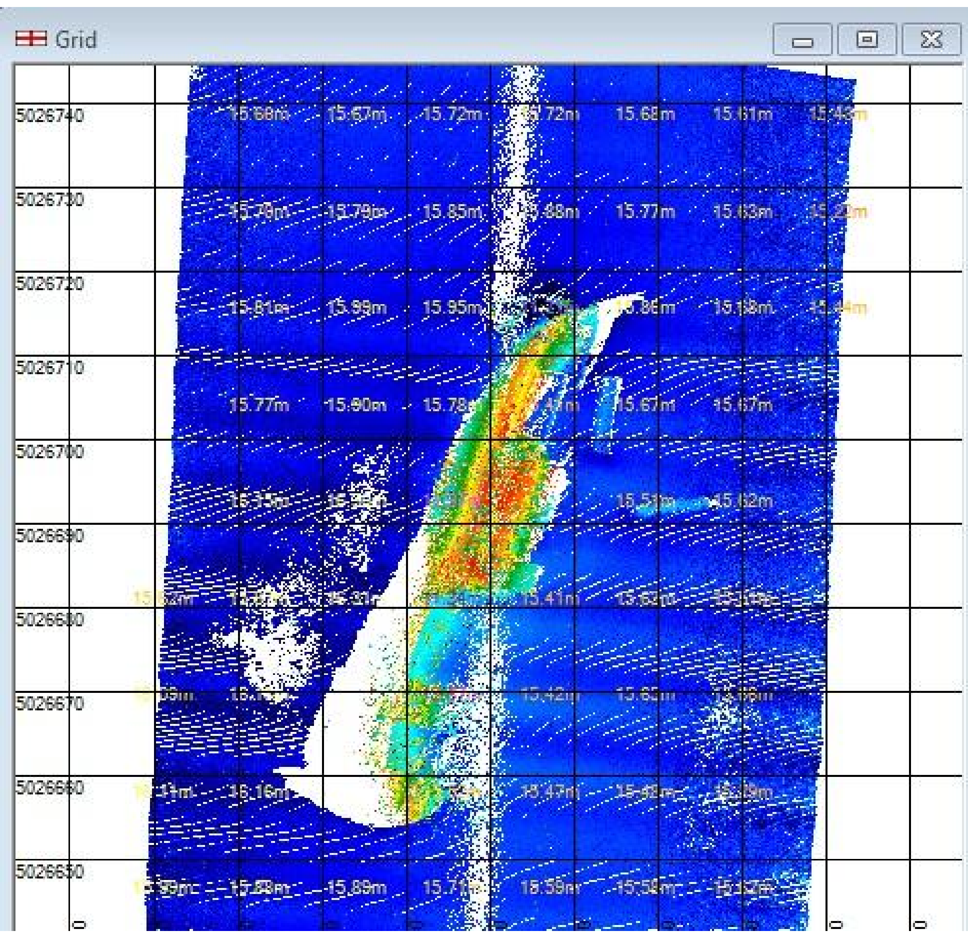
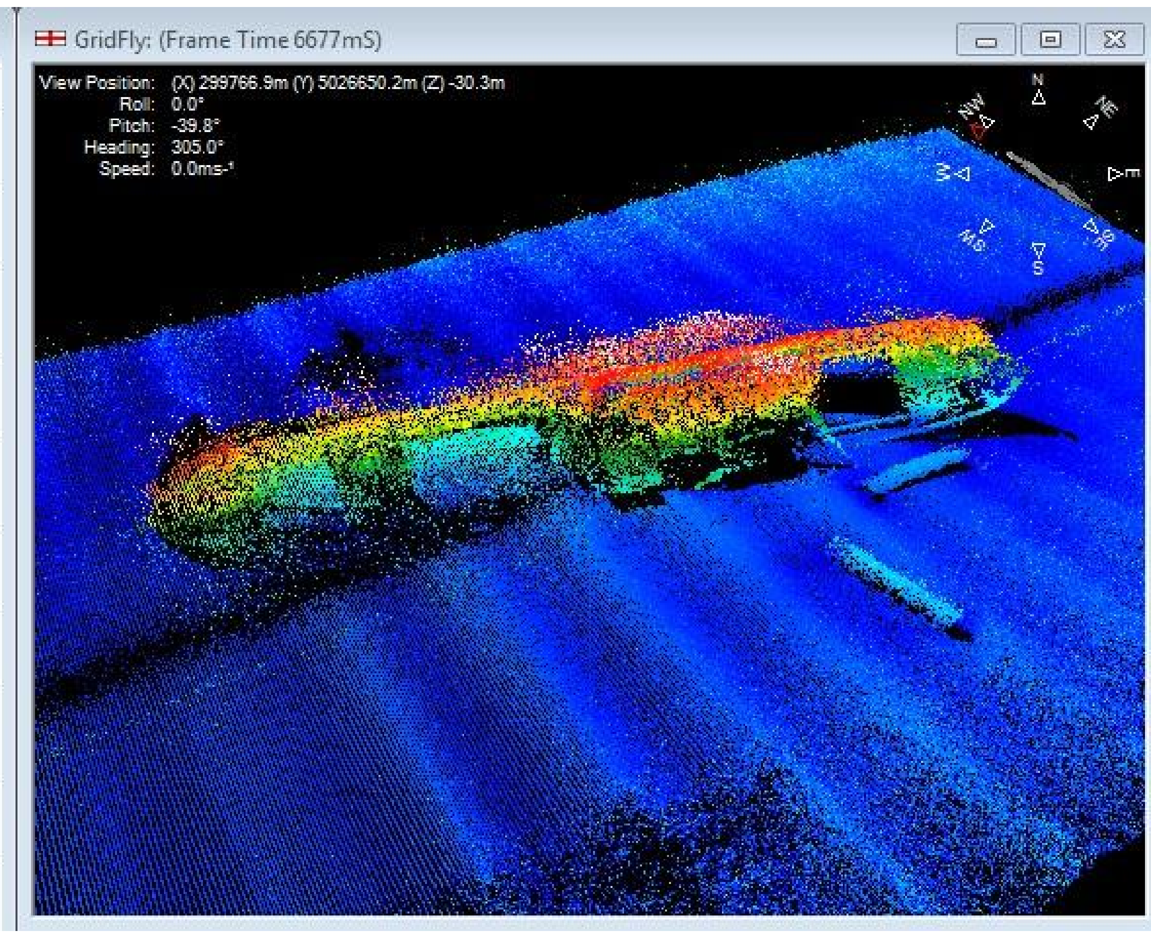
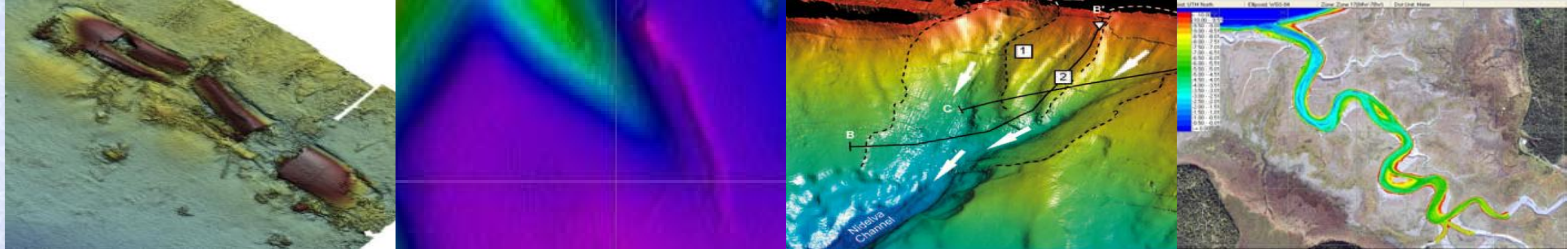
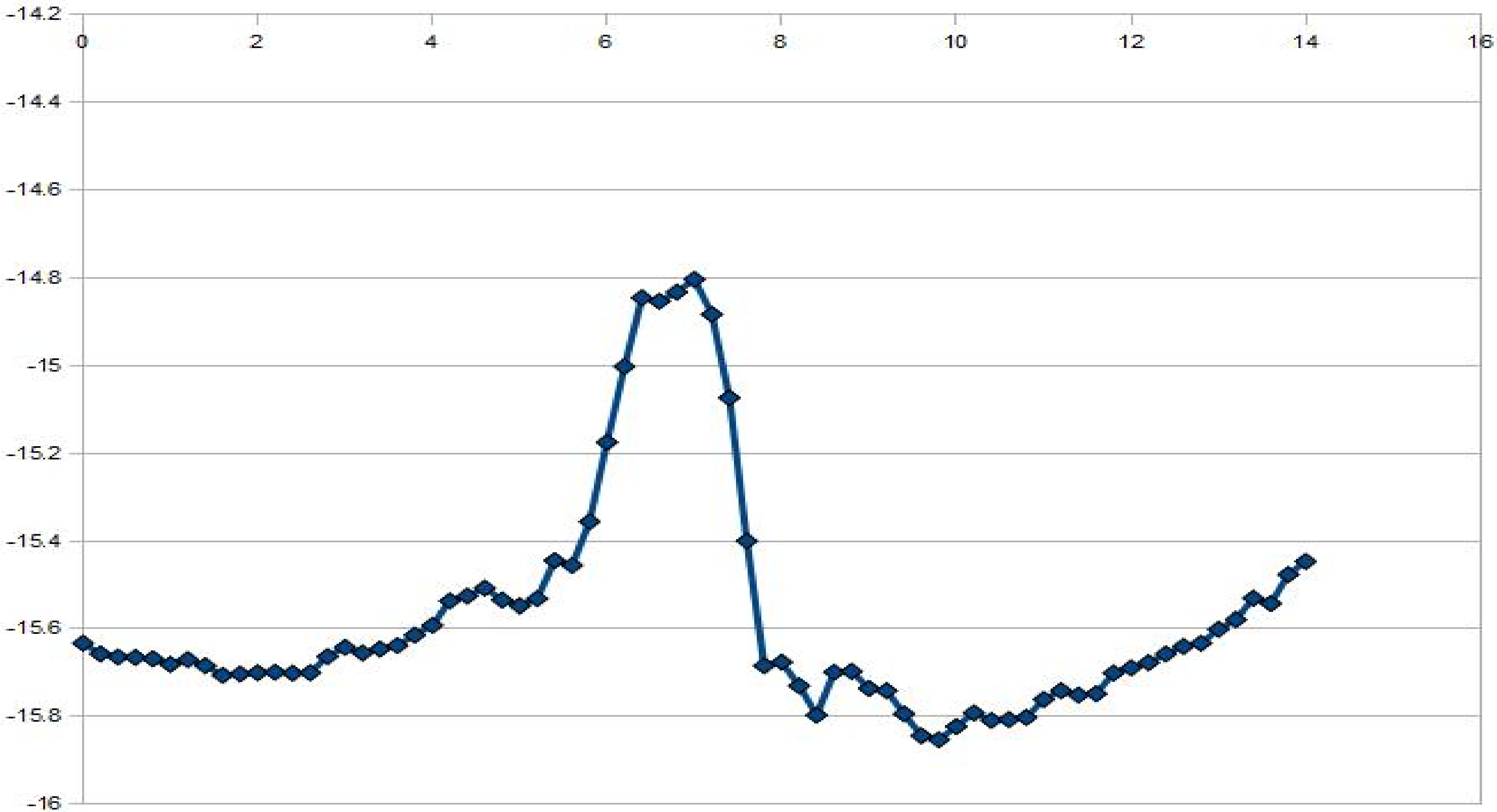


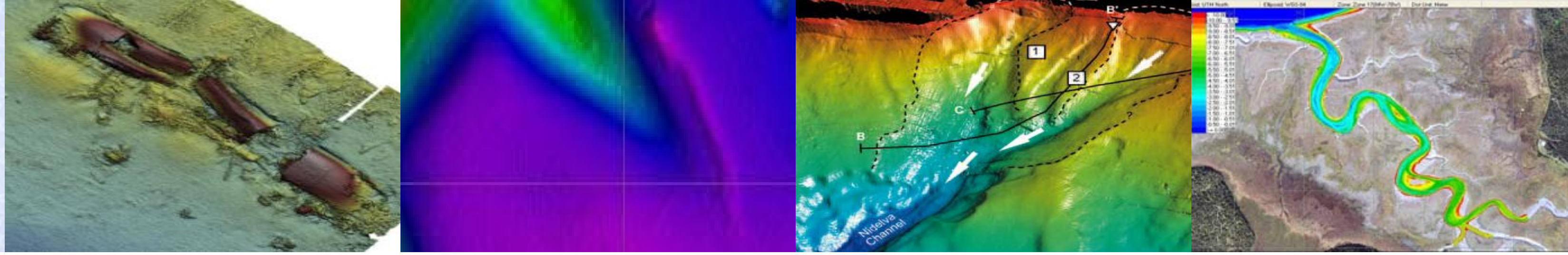


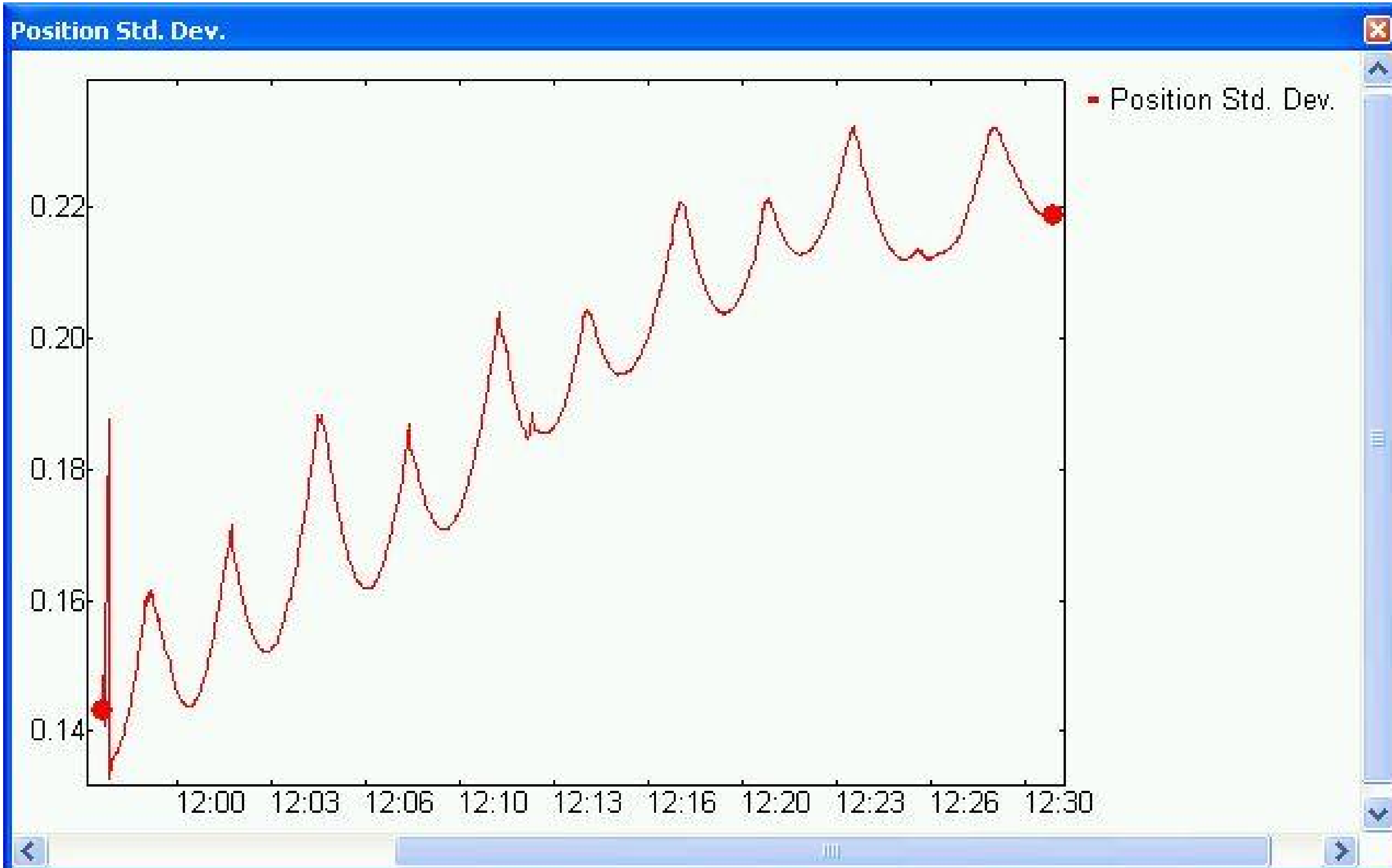






Profile over the funnel. Approx resolution of position ~ 0.2m.





SEANAV position quality report.

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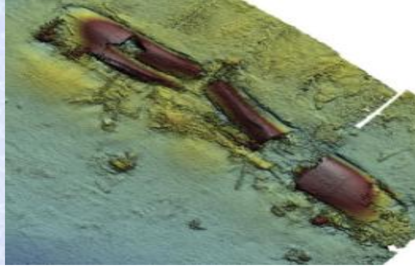

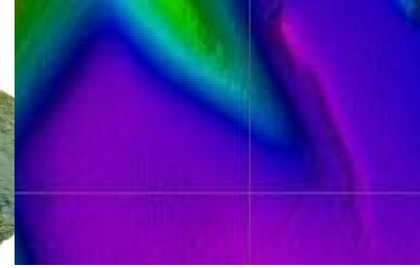

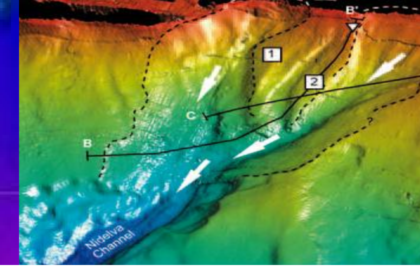

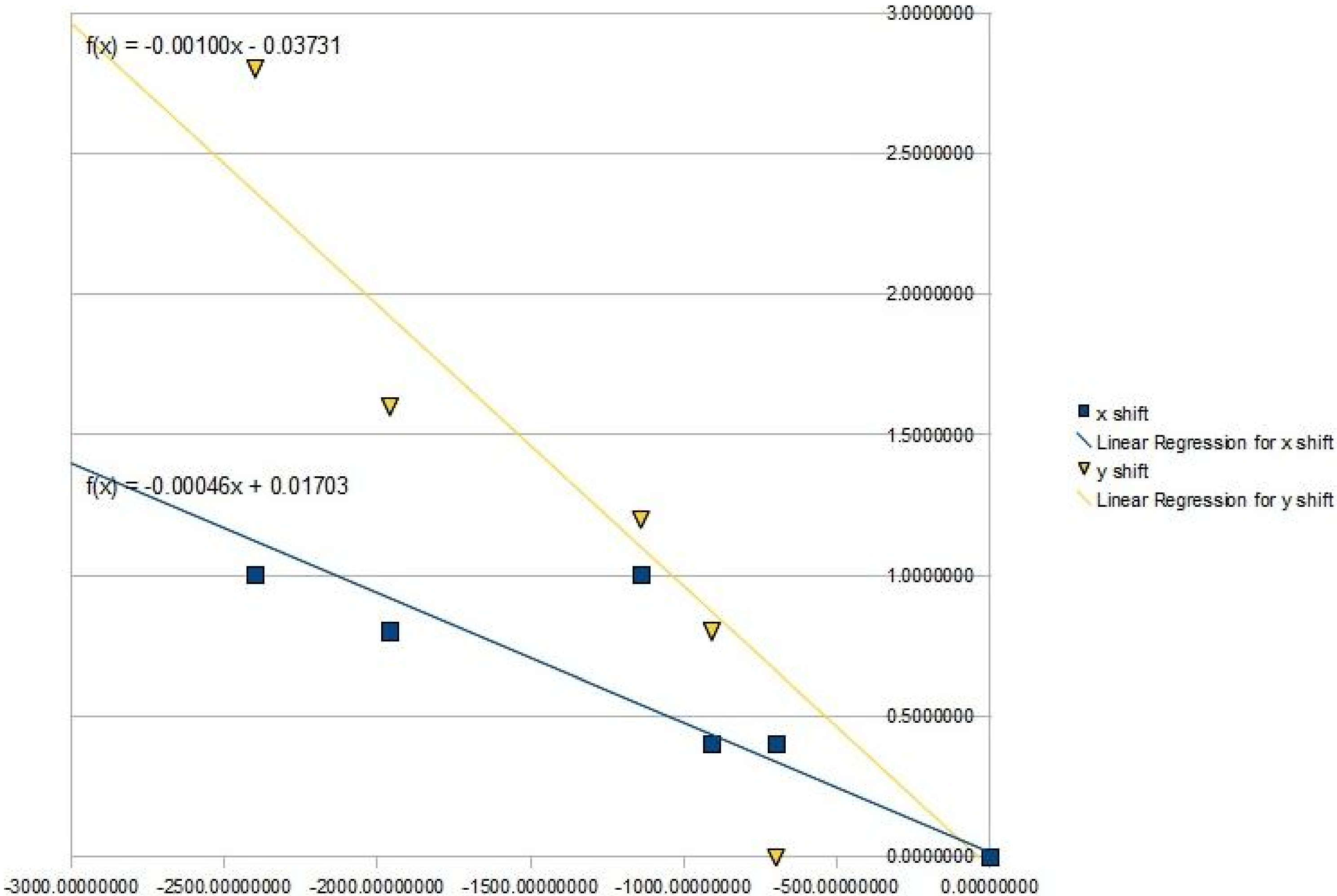

Postion drift of reference objects, horizontal axis in seconds, vertical in m offset.

Result: 1mm/s drift.

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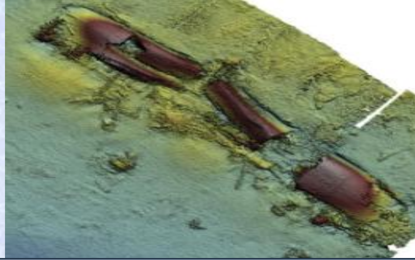

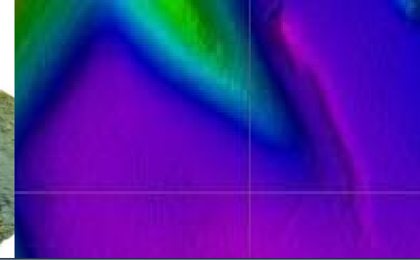

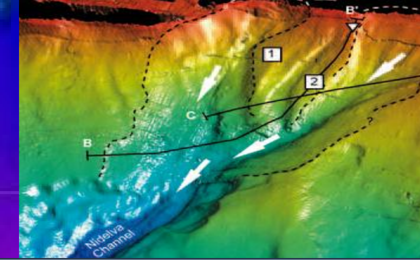

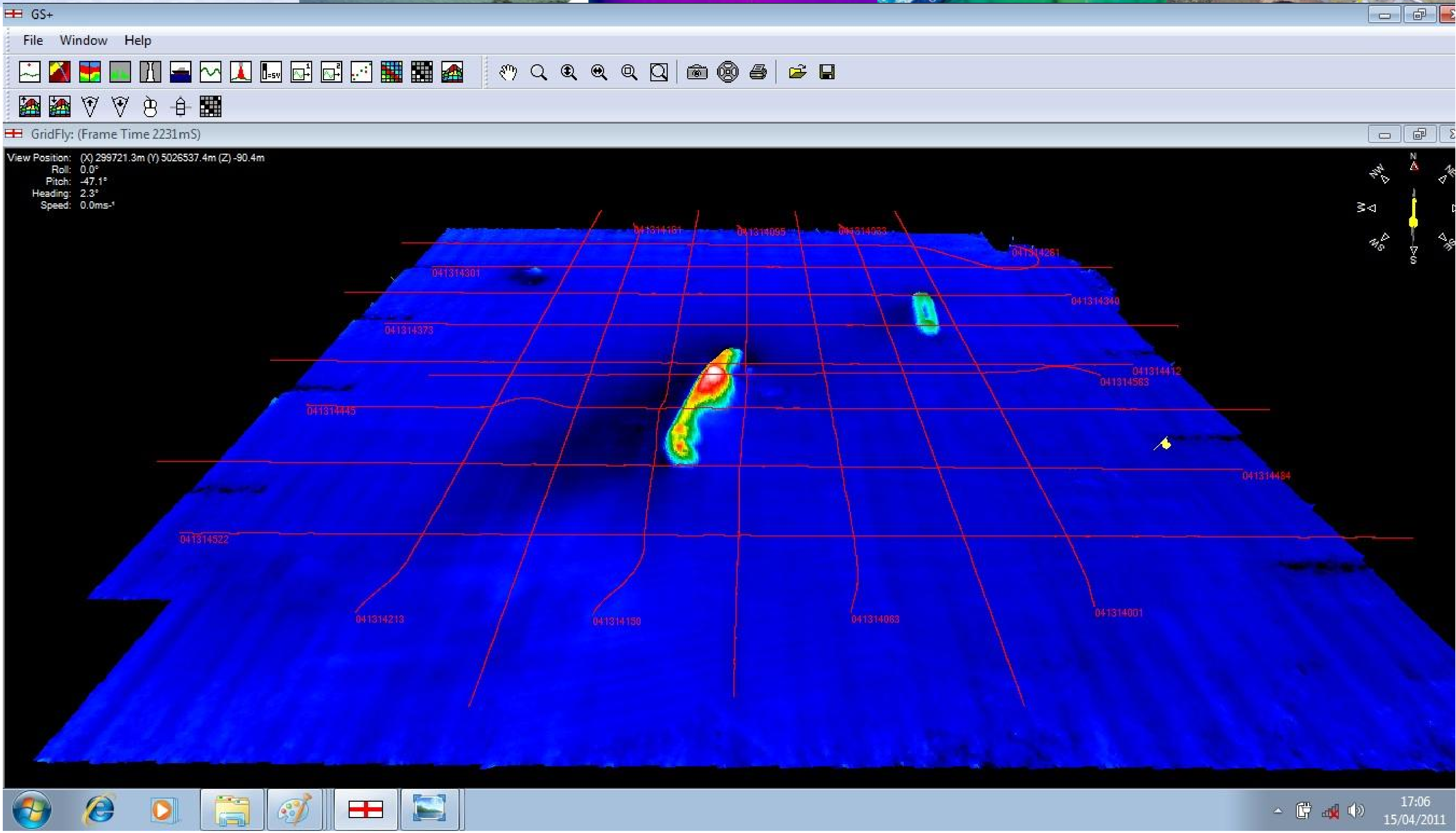

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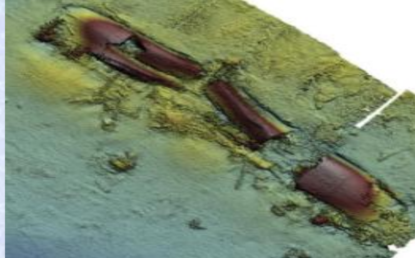
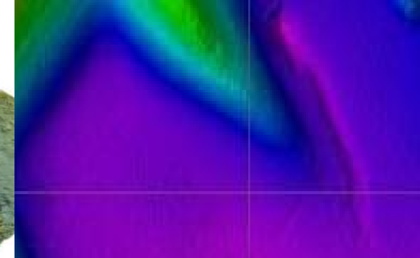
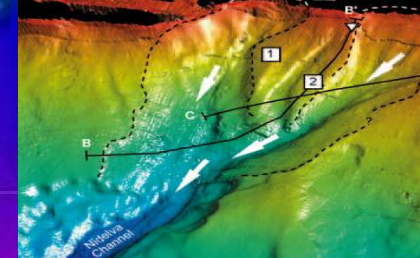
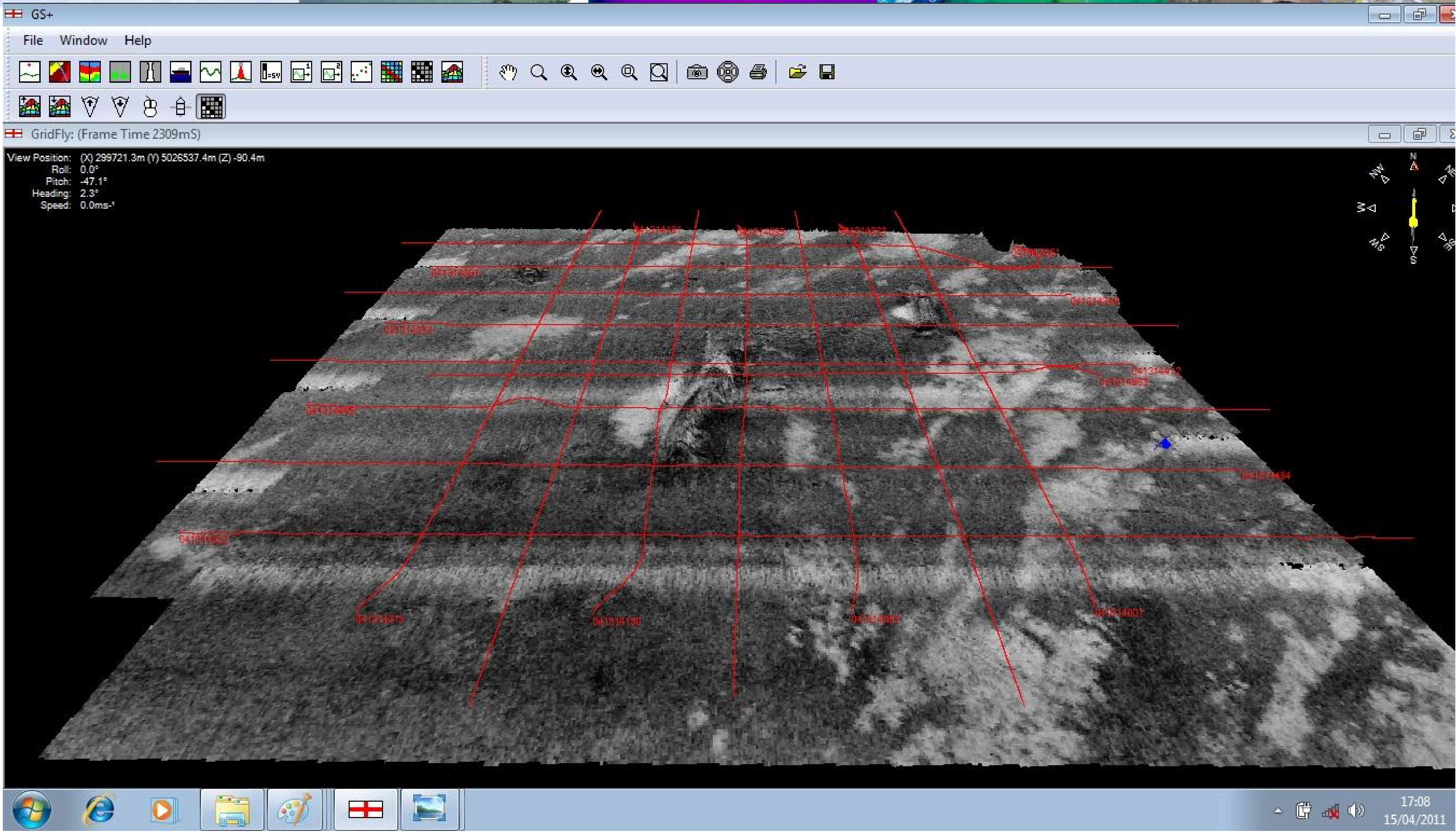
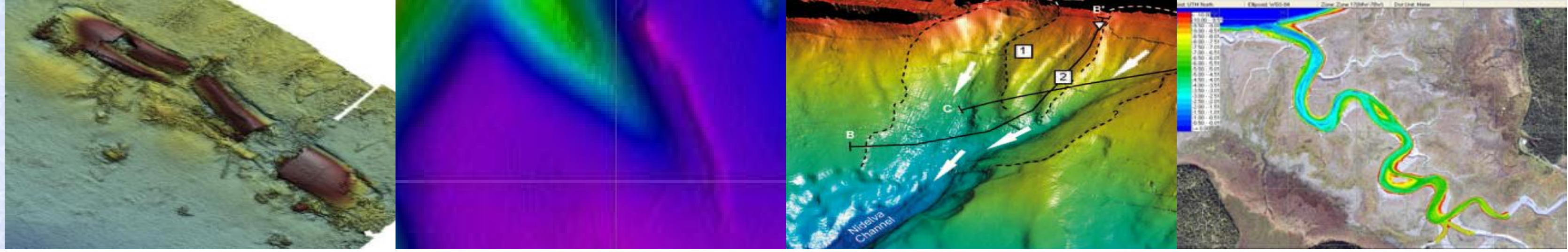


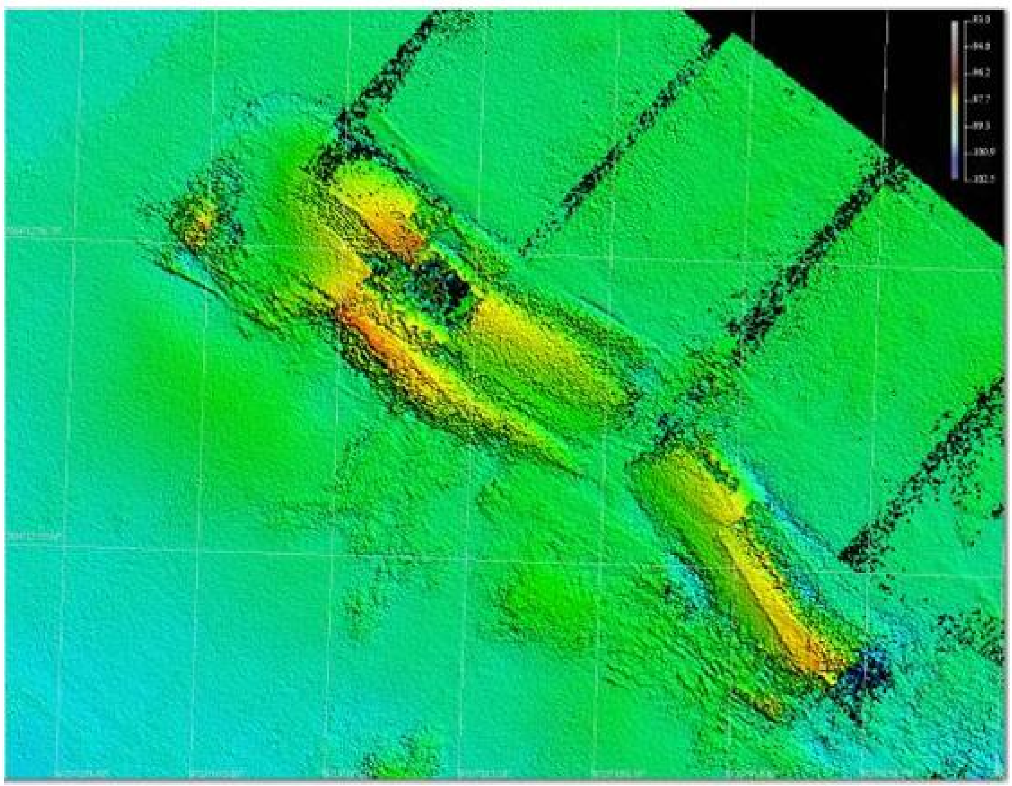


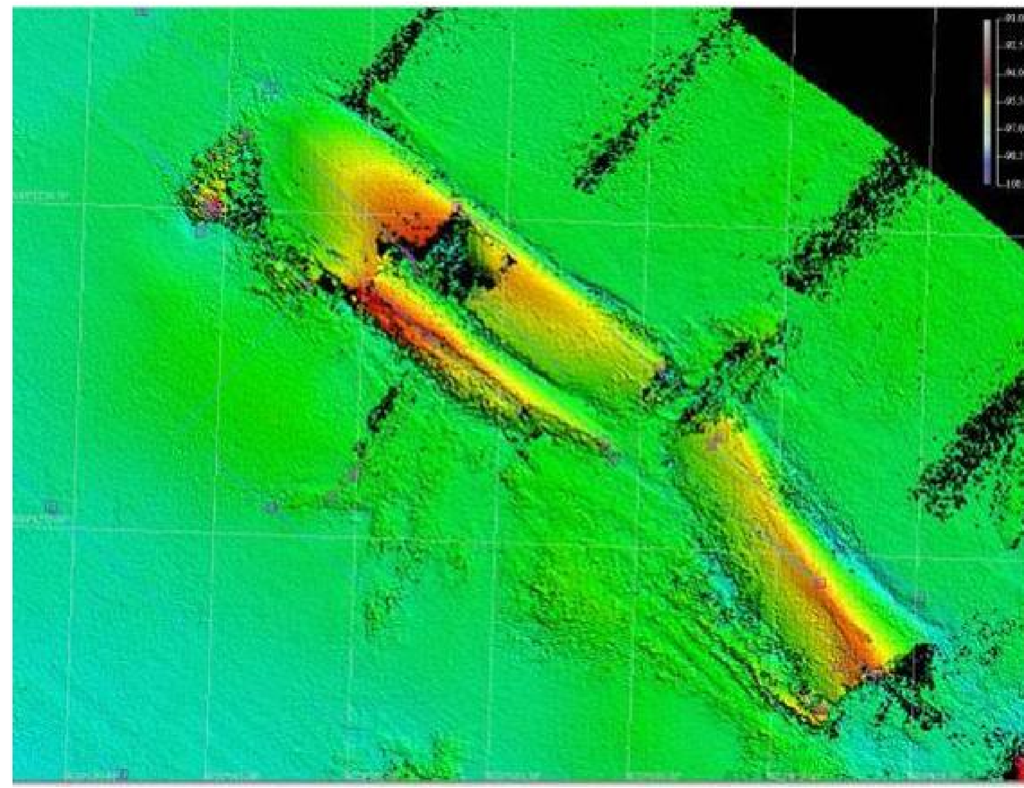






Second Example: SS Shirvan, Iceland



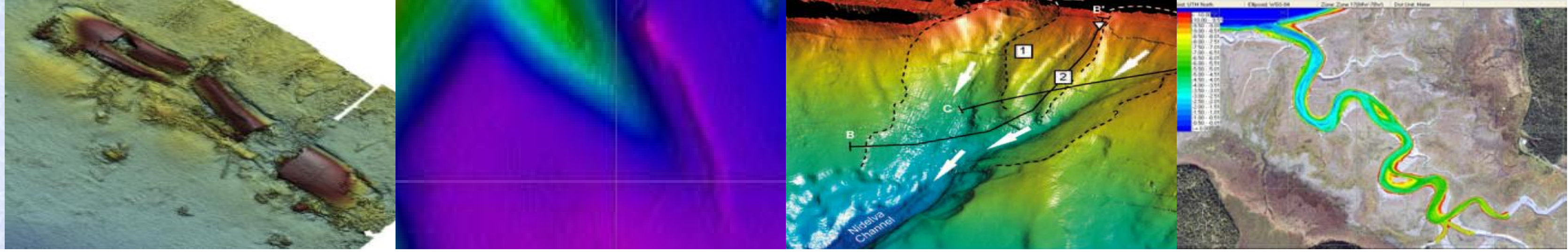


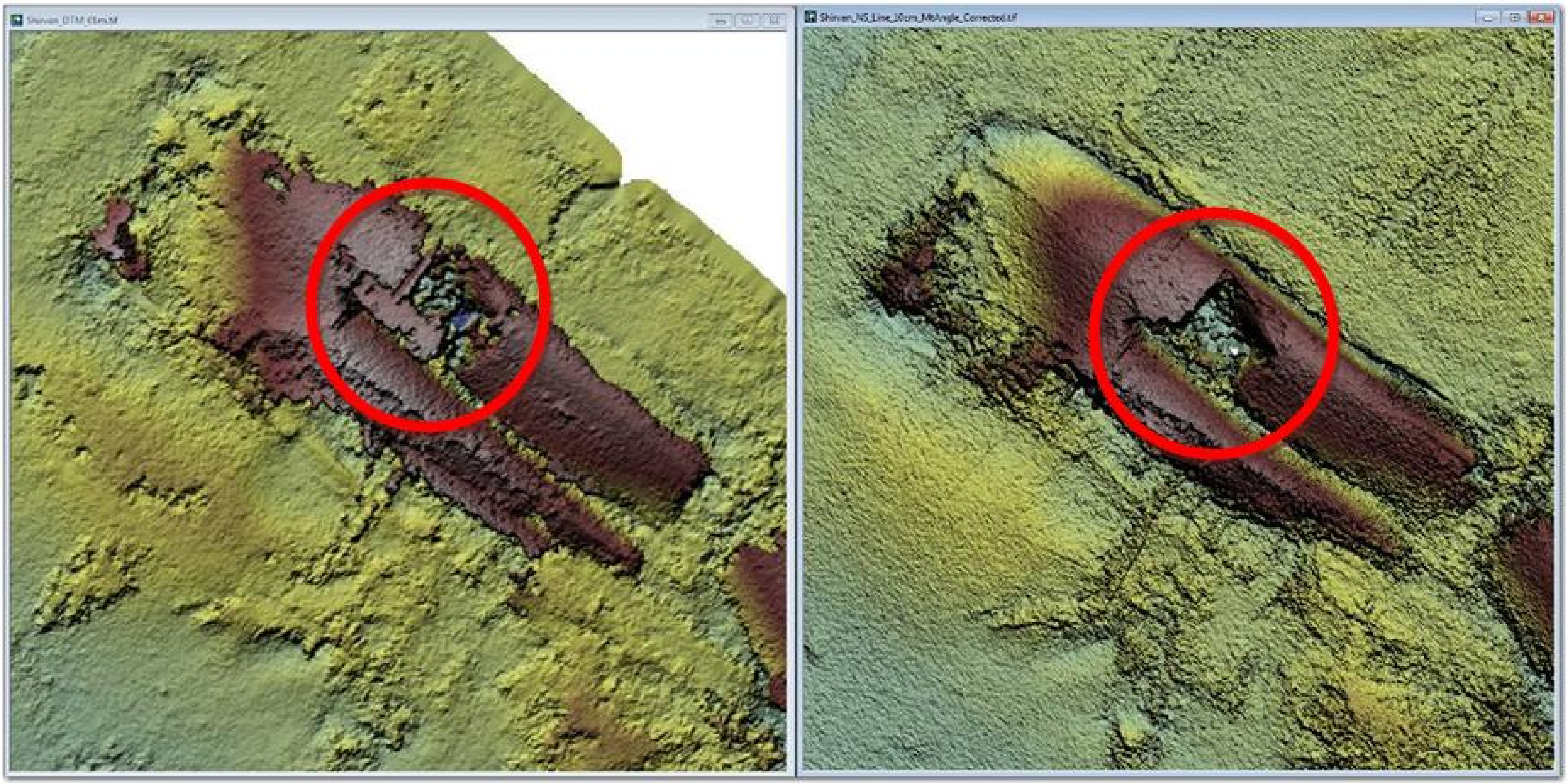
SLAM navigation correction using Internav

CleanSweep3

Hydrographic Data Processing Software

Thurne Hydro.com



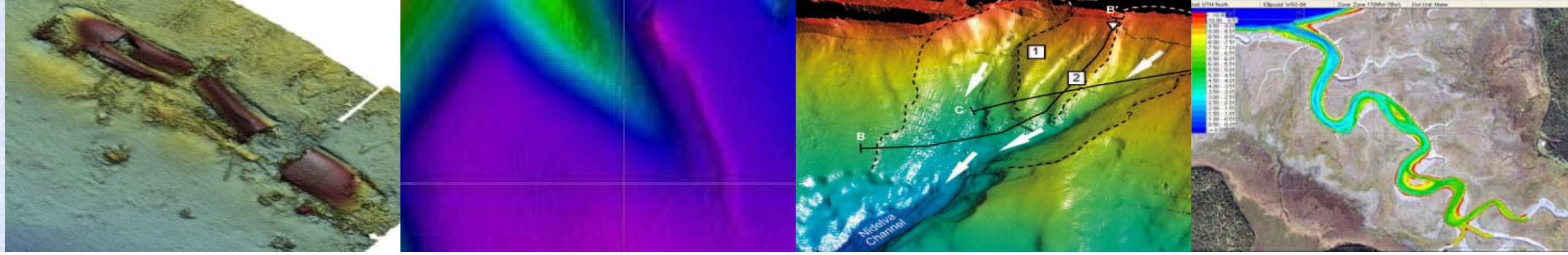


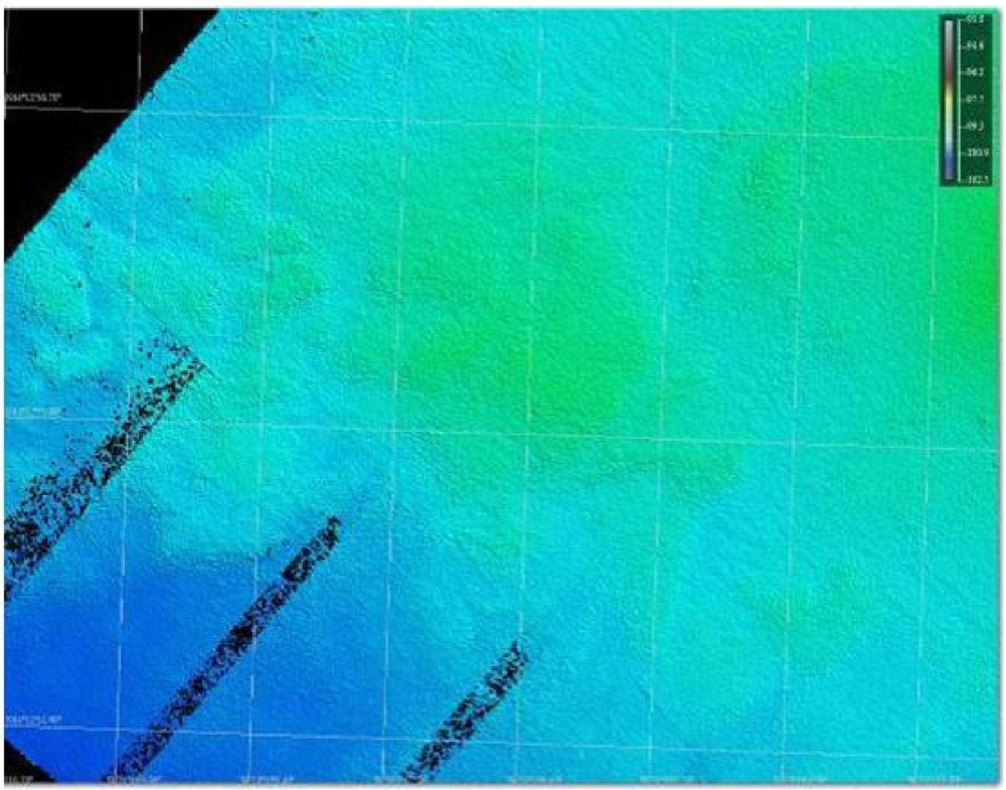
SLAM navigation correction using Internav

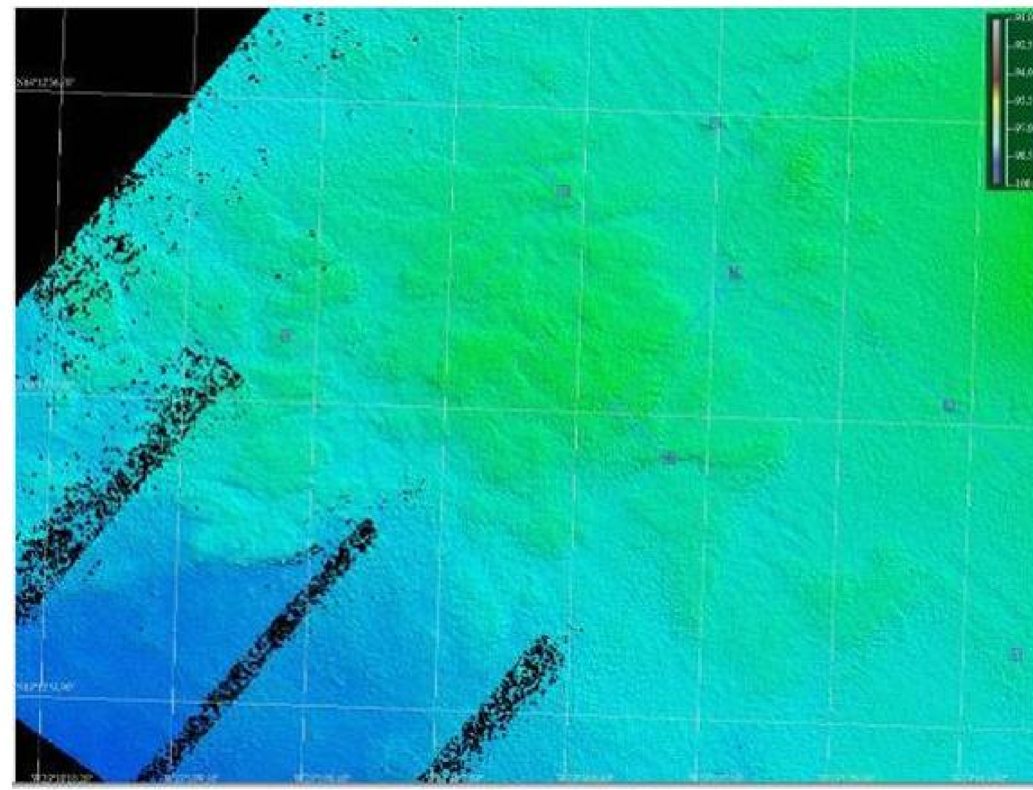
CleanSweep3

Hydrographic Data Processing Software

Thurne Hydro.com





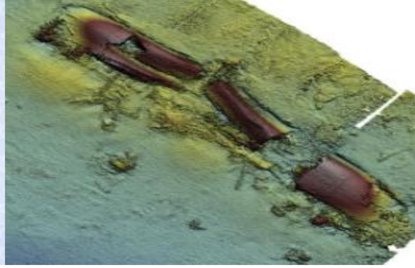


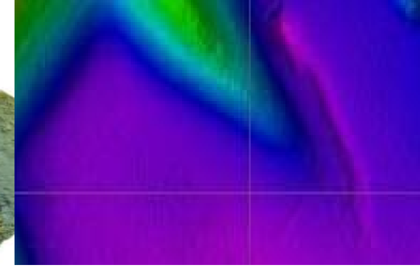
SLAM navigation correction using Internav

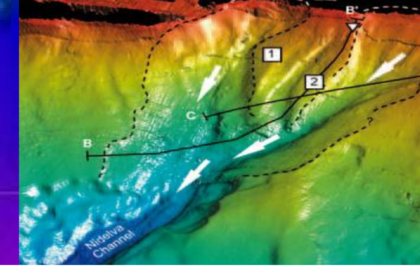
CleanSweep3

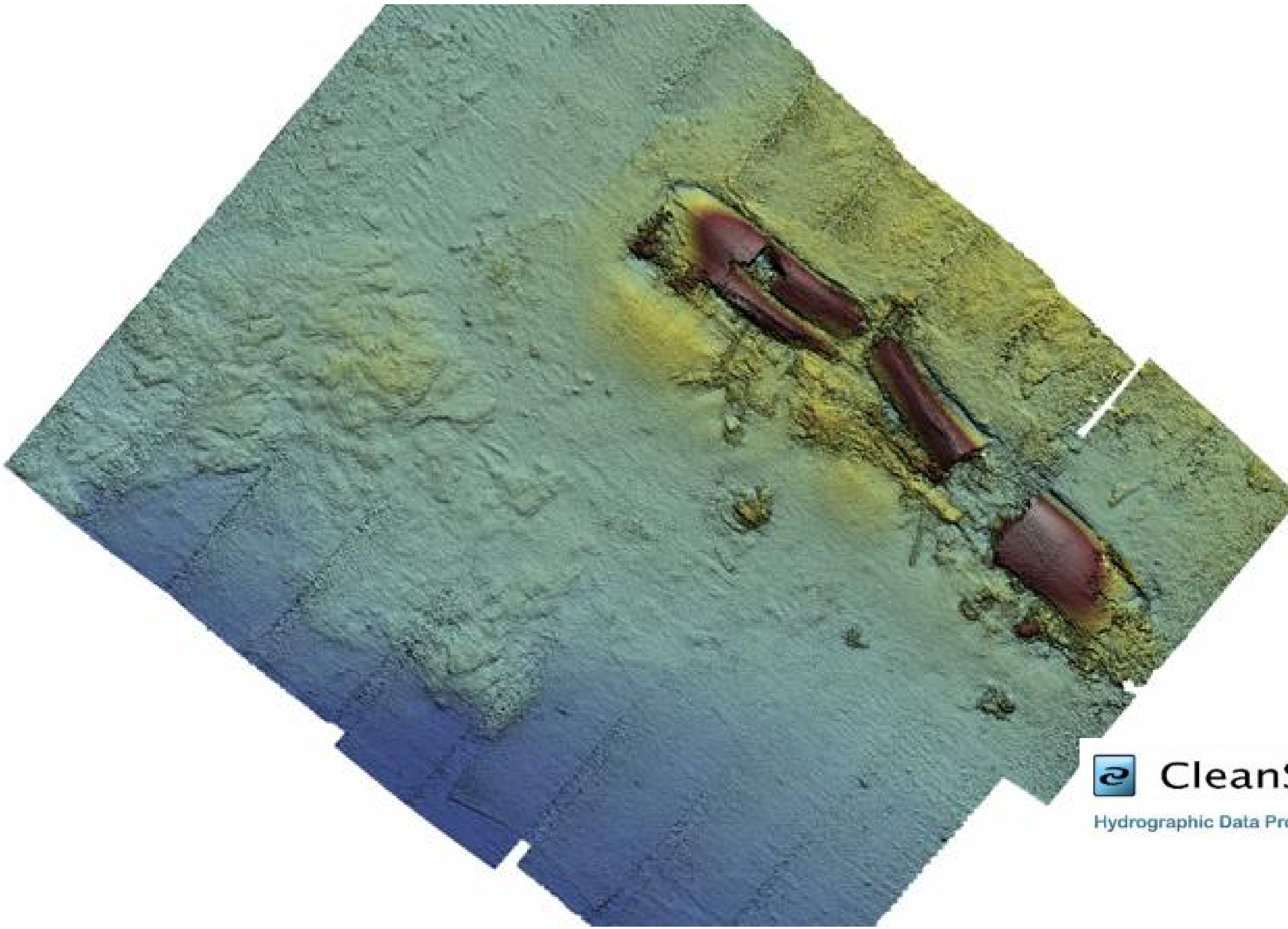
Hydrographic Data Processing Software

Thurne Hydro.com









CleanSweep3

Hydrographic Data Processing Software

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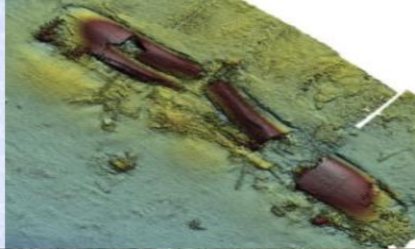
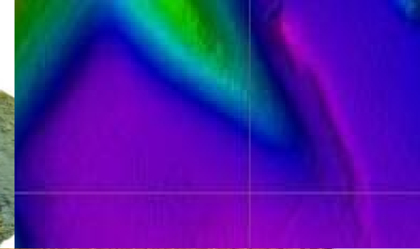
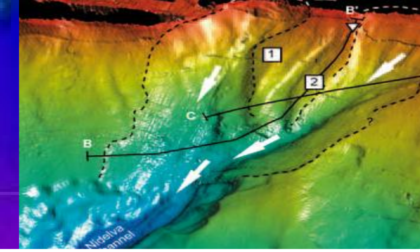


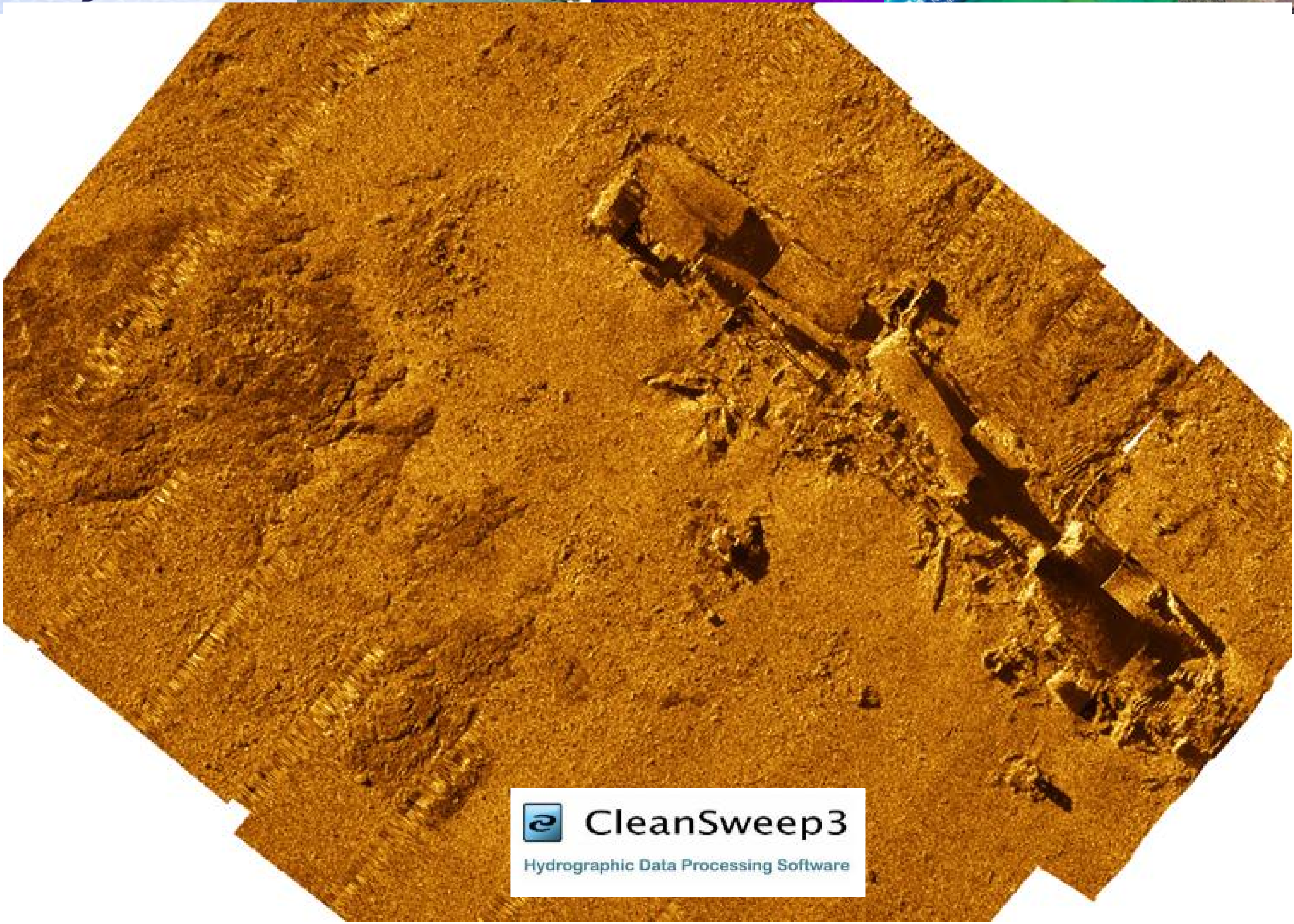

CleanSweep3

Hydrographic Data Processing Software

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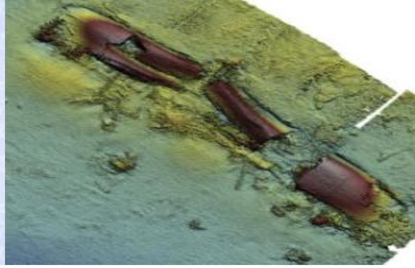
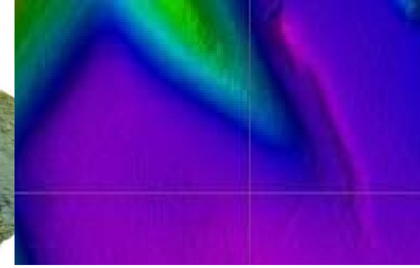
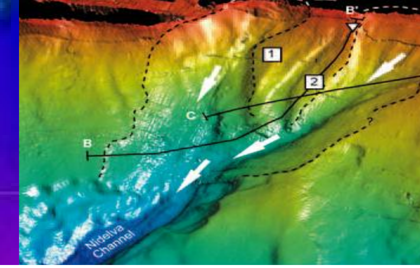
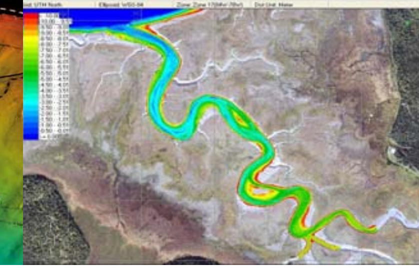
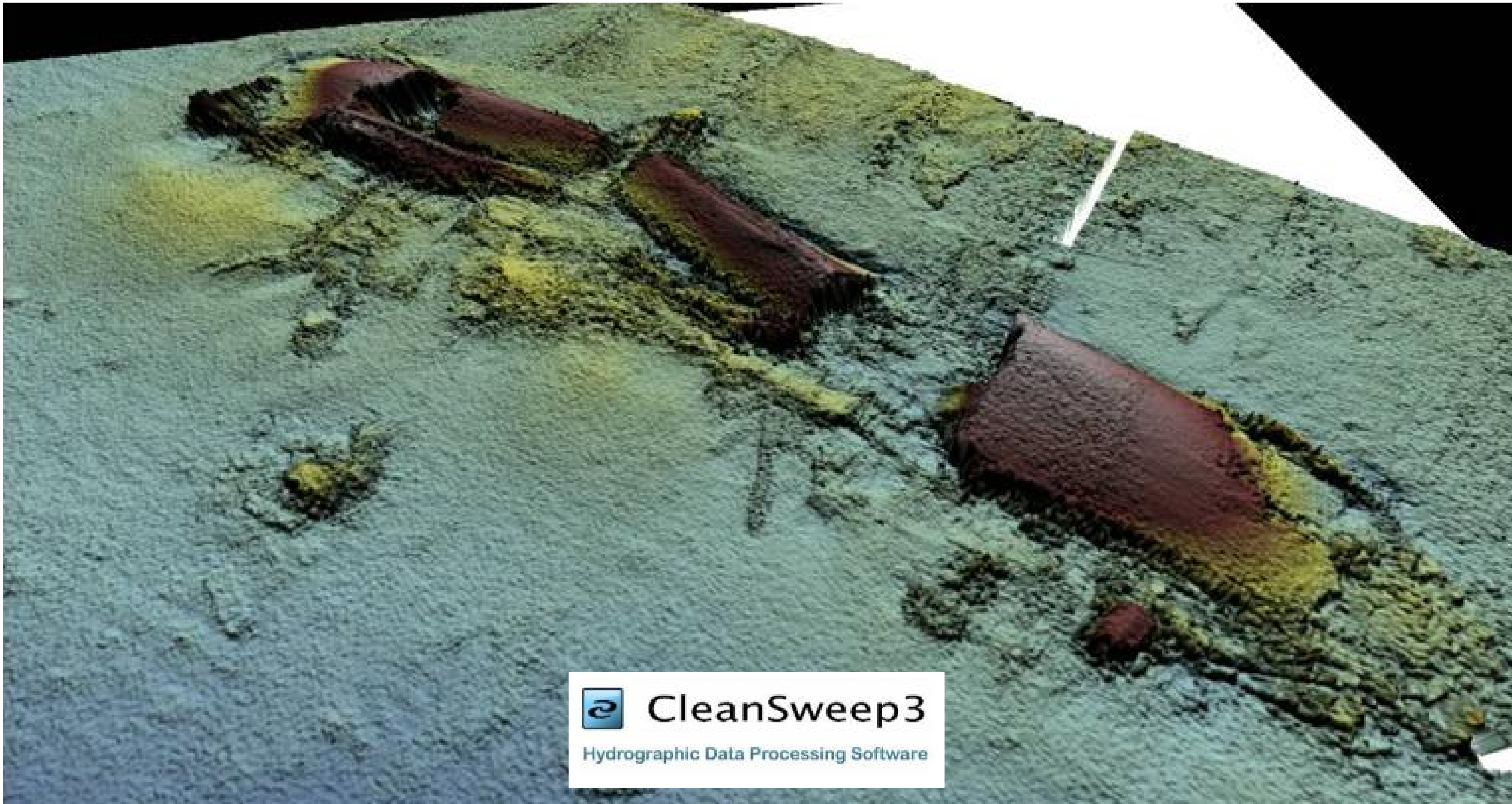
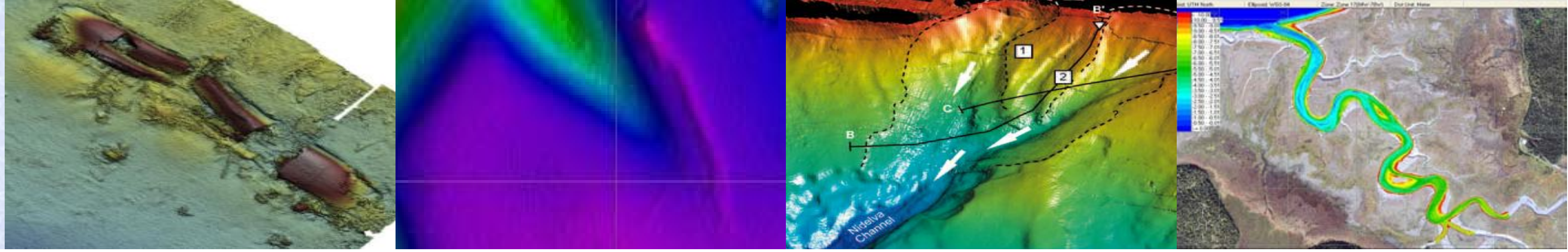












Conclusions:

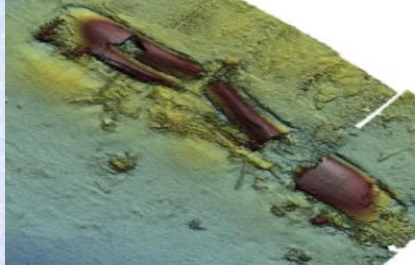
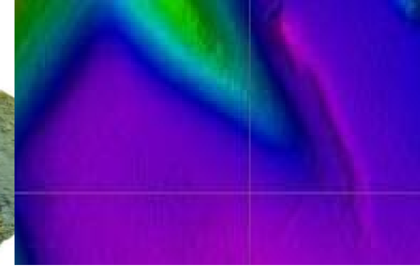
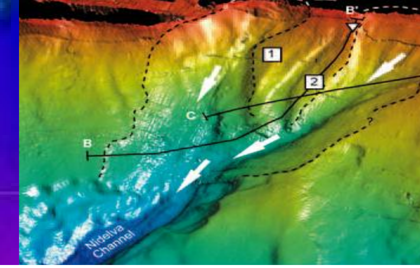
““Can the small AUV be a useful tool for collecting chart data?””

- Small-AUV logistics suit some hydrographic tasks.

- Current AUV capability delivers data that can be qualified as IHO Order 1 and possibly Special Order.

- Small AUV hydrography is being used for engineering.

- Performance limitations exist, solutions are on the way.



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