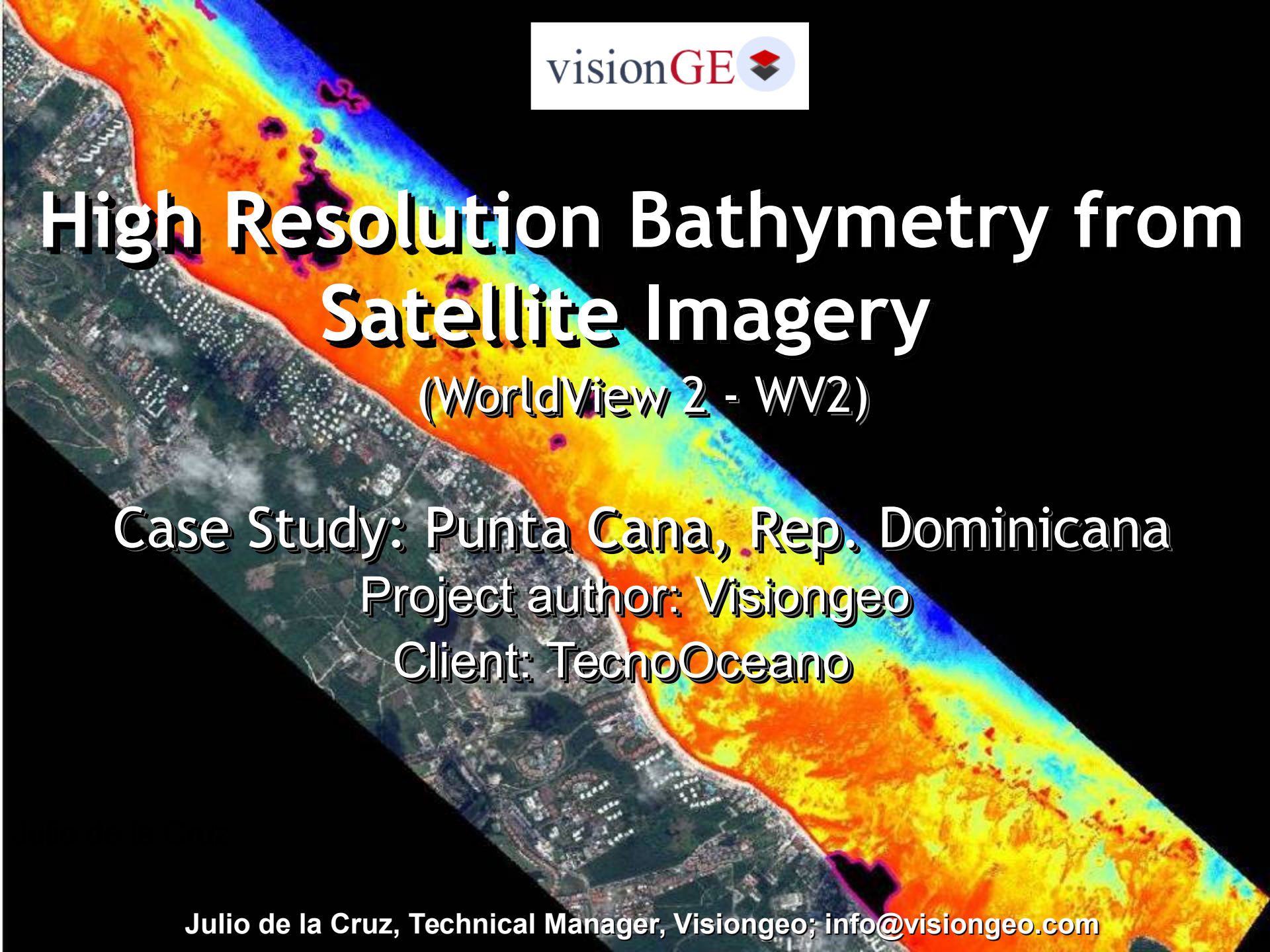


High Resolution Bathymetry from Satellite Imagery

(WorldView 2 - WV2)

Case Study: Punta Cana, Rep. Dominicana

Project author: Visiongeo

Client: TecnoOceano

Julio de la Cruz, Technical Manager, Visiongeo; info@visiongeo.com

Extensive use of coastal areas

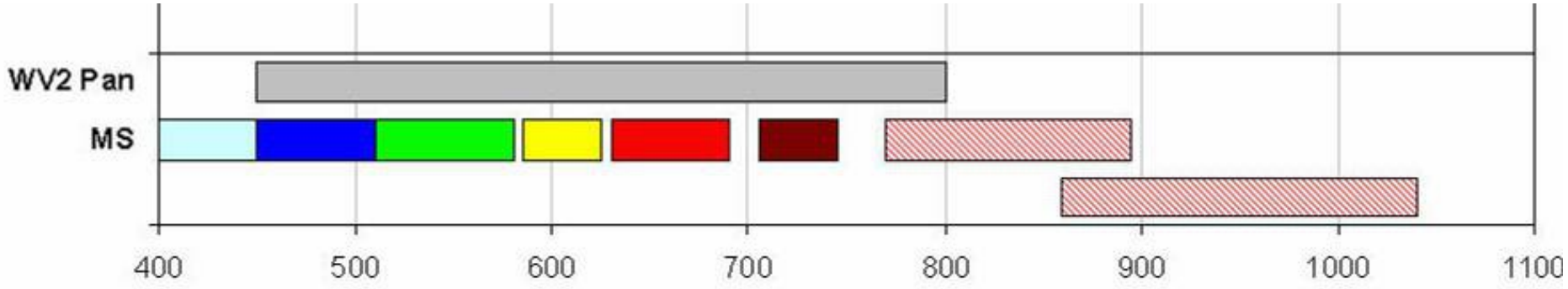
- The increasing use of the coastal environment (tourism, fishing, recreation, environment, infrastructure, security, etc.) requires detailed bathymetry as provided by the high resolution satellite (WorldView 2). This satellite bathymetry (WV2) has the following characteristics:
- Fast and detailed results, down to 30 m, from extensive marine areas at reasonable cost that can be integrated into a Geographic Information System (GIS). Including land satellite imagery to facilitate reference.
- Multitemporal results that allow to compare the differences between the destructive winter profile (storms) and constructive summer (less intensity waves).
- Identification of underwater sand deposits that can be exploited in dredging operations to replenish the loss of sand from beaches during winter storms.
- Identification of surf channels where sand beaches disappears by flowing rip currents which constitute a high risk to bathers that can not swim (even when rips are not developed).

Features of WorldView 2 imagery (WV2)

- Spatial resolution: 0.5 meter panchromatic and 2 meters multispectral. To preserve as much as possible the original spectral characteristics, the 2 m band was used for bathymetry analysis.
- Spectral resolution: 8 bands located approximately between 40 and 900 nm
- Radiometric Resolution: 11 bits, 2048 gray levels per band and pixel

Features of WV2 bands

Wavelengths of WV2 bands (Nm)



Features of WV2 bands

Refer to slide 4.

- Band 1: "Blue Coast". Located in the electromagnetic spectrum within the range of the visible blue (on the left).

  It can penetrate clear waters down to 30 meters. Particularly useful for bathymetric and benthic analysis, marine habitat mapping, improved atmospheric corrections (important for cover classification and change detection studies).
- Band 2: Visible Blue
- Band 3: Visible Green
- Band 4: "Yellow". Located in the visible spectrum (between the green and the red).

  Very important for cover classification studies, detects the "yellowness" of vegetation both on land and in water, improves the visual appearance of the image, it detects damaged by the oil and gas exploration vegetation. Assists in mineral geological mapping

Features of WV2 bands

Refer to slide 4.

- Band 5: Visible Red
- Band 6: "Red border." Located on the border between the visible and near infrared.

  Very important to measure the health of groundcovers even at the level of individual tree. Assistance in the classification of vegetation. Improvement of Vegetation Index studies so far made with the traditional red.
- Band 7: Near Infrared
- Band 8: "Near Infrared 2, or high wavelength".

  Improves the quantity and quality of analysis of vegetation and biomass studies. It is less affected by the influence of the atmosphere than the Near Infrared 1, which means more reliable results. Assistance in mapping and mineral exploration.

Features of WV2 bands

Standard bands:

- Band 2: Visible Blue. It is identical to the traditional visible blue. Of interest for coastal, marine and water studies.
- Band 3: Visible Green. Important to calculate the vegetation index, very important to classify types of vegetation if used in conjunction with the yellow band.
- Band 5: Visible red. Narrower than the traditional visible red, more focused on detecting red light by chlorophyll in healthy vegetation. Very useful in classifying bare soil, paths, roads and geological coverage.
- Band 7: Standard Near Infrared 1. Very effective for estimating biomass and moisture content of the vegetation. Support for separation of water bodies and vegetation, help in identifying vegetation types and the separation between soil types.

WV2 satellite images

Only the scene of the southern part was used due to the abundant cloud cover and haze of the northern scene and also due to excessive solar reflectance of another northern scene.

WV2 satellite images

Detail of the excessive solar reflectance of the northern scene compared to the southern scene that was finally used

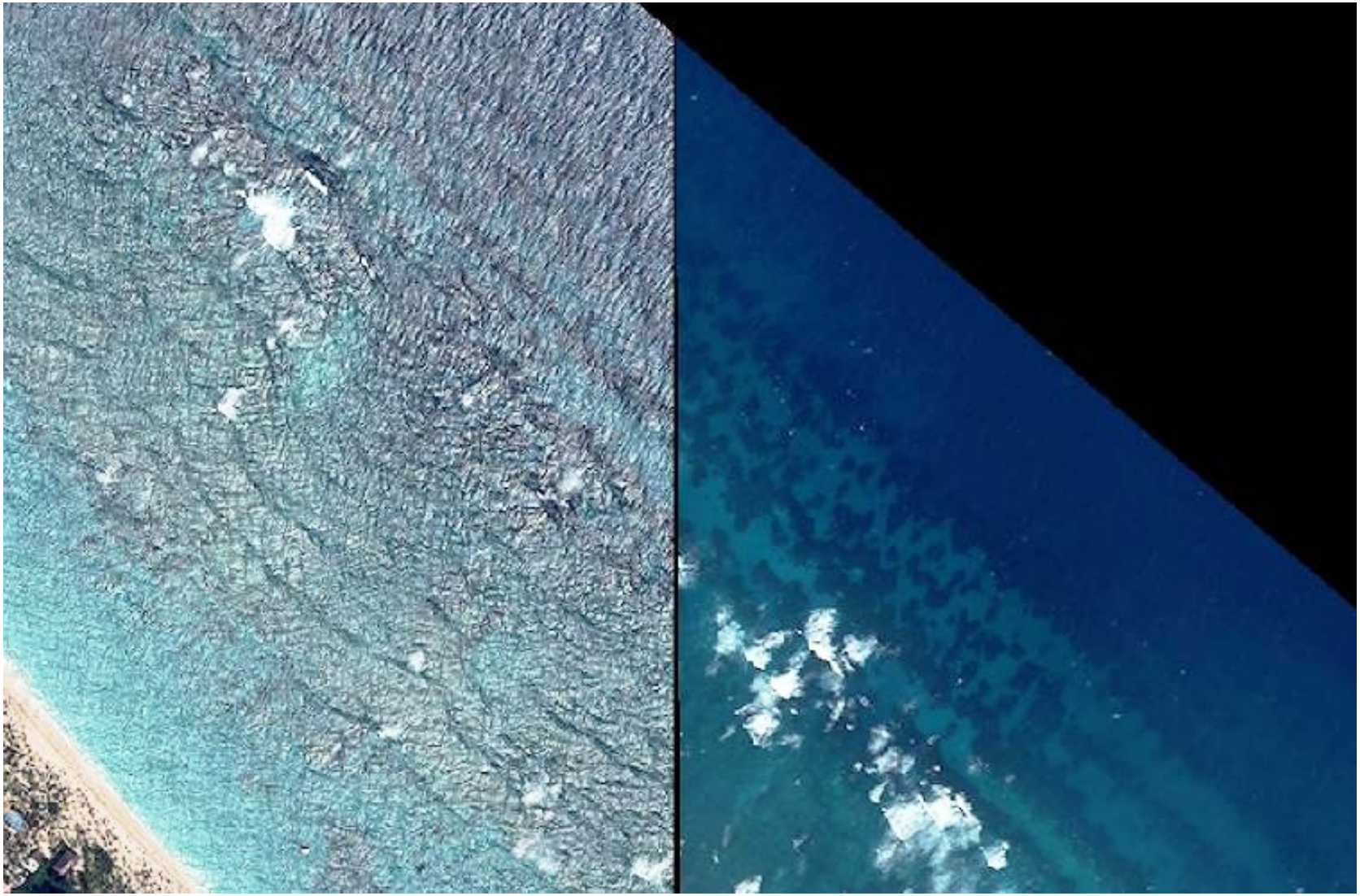
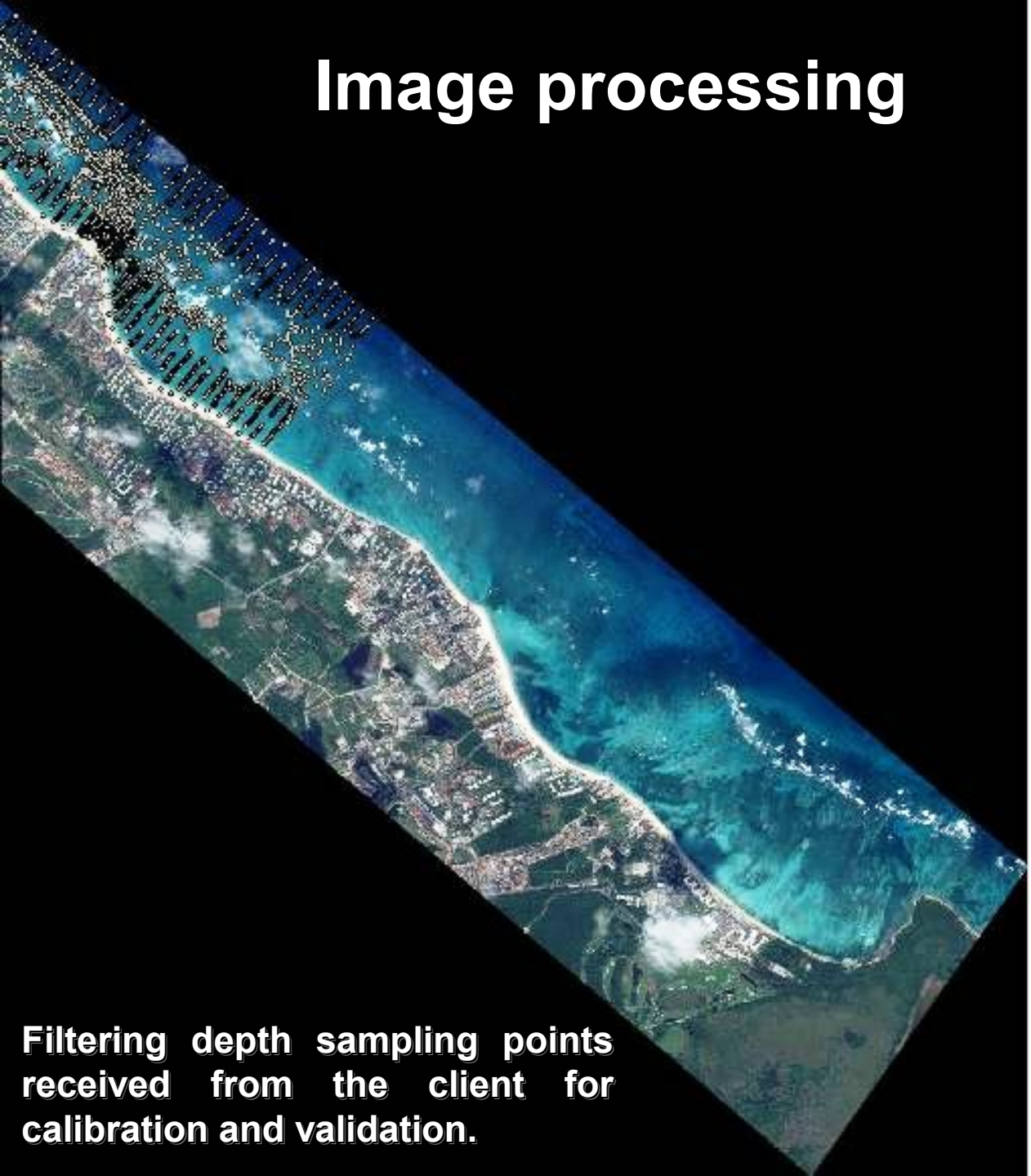


Image processing

The following processes were undertaken:

- Calibration and Atmospheric Correction. To reduce the influence of the atmosphere in the spectral values of the image.
- Orthorectification. For the coordinates of the image to be as accurate as possible to facilitate geographical reference.
- Filtering the sampling points depths received from the client and to eliminate points that:
  - Fall out of the picture
  - Fall on clouds and/or cloud shadows
  - Fall onto the white foam where the waves break
  - Reserve points for the subsequent verification of the accuracy of the bathymetry analysis

Image processing

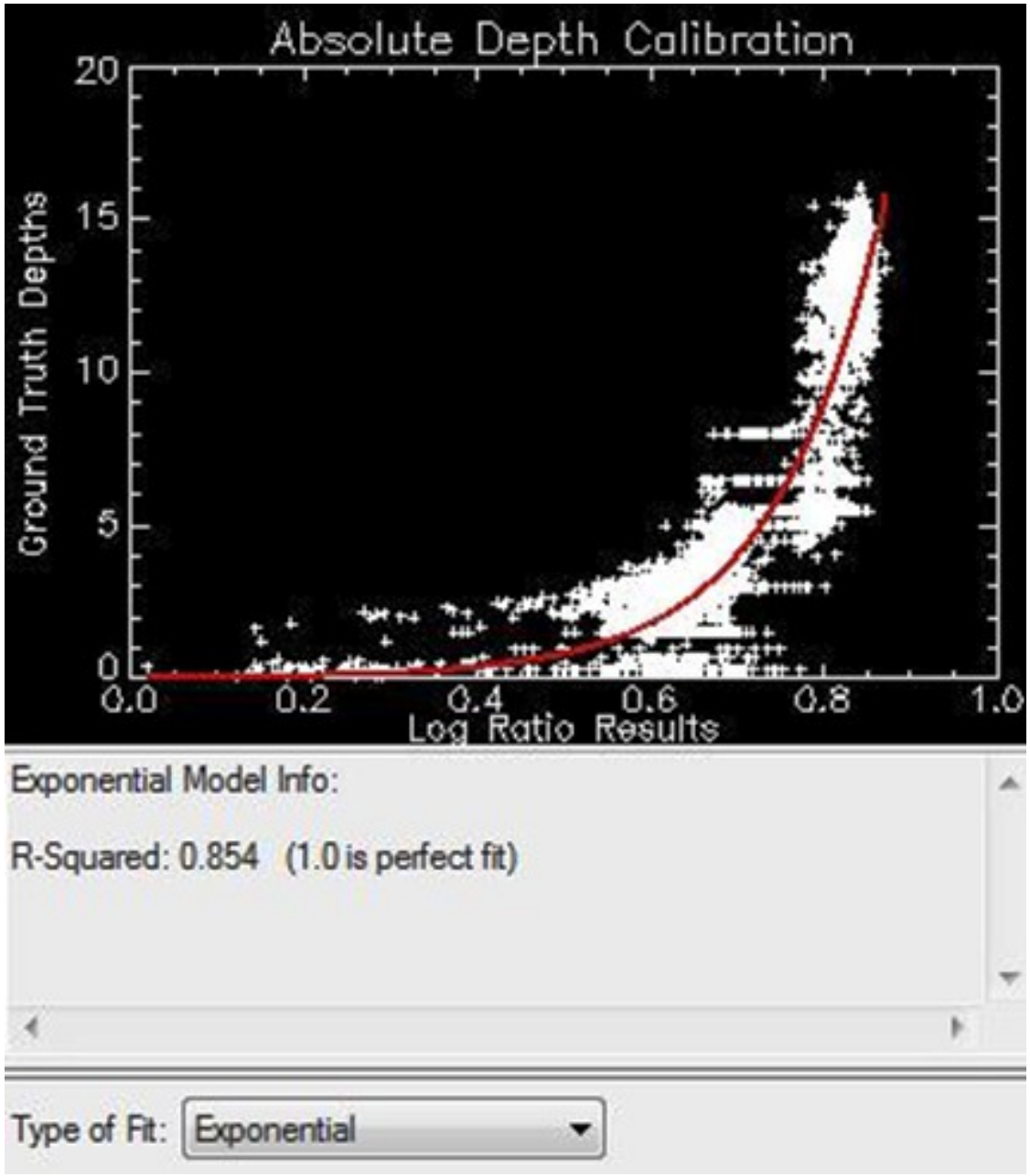


Filtering depth sampling points received from the client for calibration and validation.

Image processing

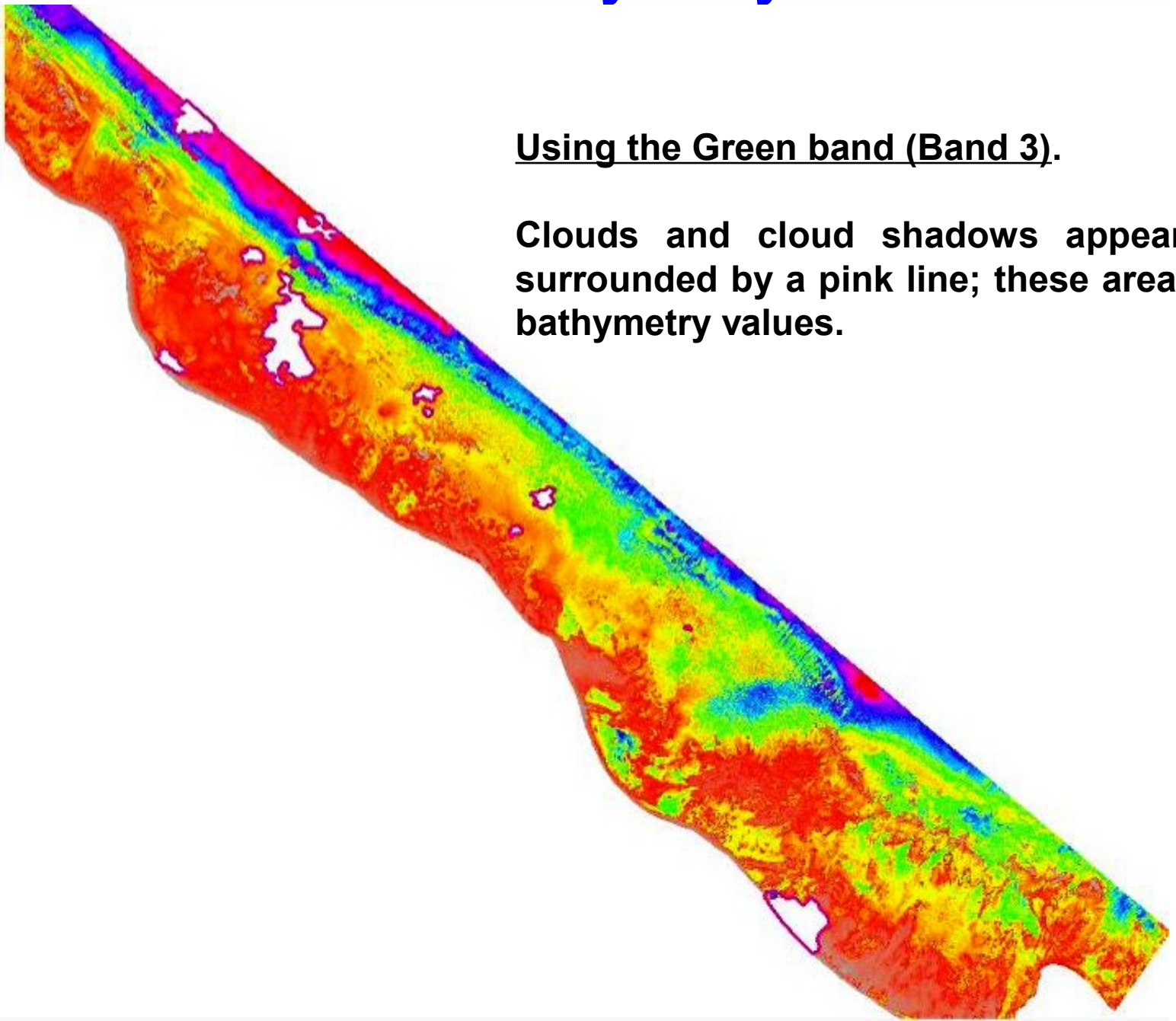
- Various color tables were tested in the visible range of the WV2 image and its correspondence to the bathymetry points provided.
- Logarithmic transformation band ratios. The following three methods were tested:
- Using band 1 (“blue coast”) as a fixed band and also using the band 3 Visible Green
- Using band 1 (“blue coast”) as a fixed band and also using band 4 yellow
- Using band 1 (“blue coast”) as a fixed band and also using band 4 yellow; clouds and cloud shadows were previously subtracted to the image.
- Calibration for absolute depths.
- In cases 1 and 2, subtraction of clouds and cloud shadows were made. Areas where white foam is formed where the waves break were not detracted. These areas can show errors.

Image processing



An exponential function was used for the calibration of absolute depth values

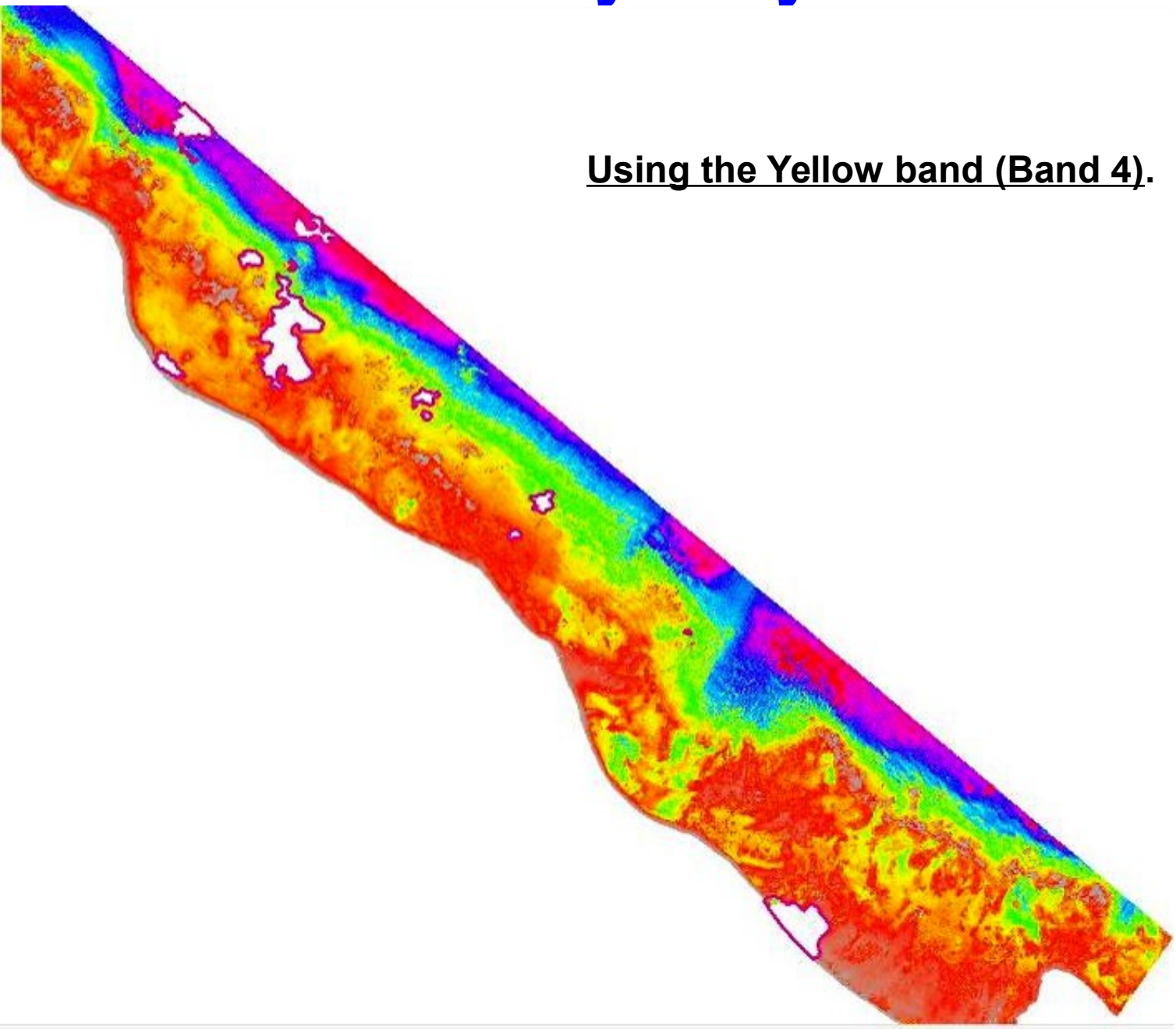
Bathymetry results



<u>Using the Green band (Band 3)</u>.

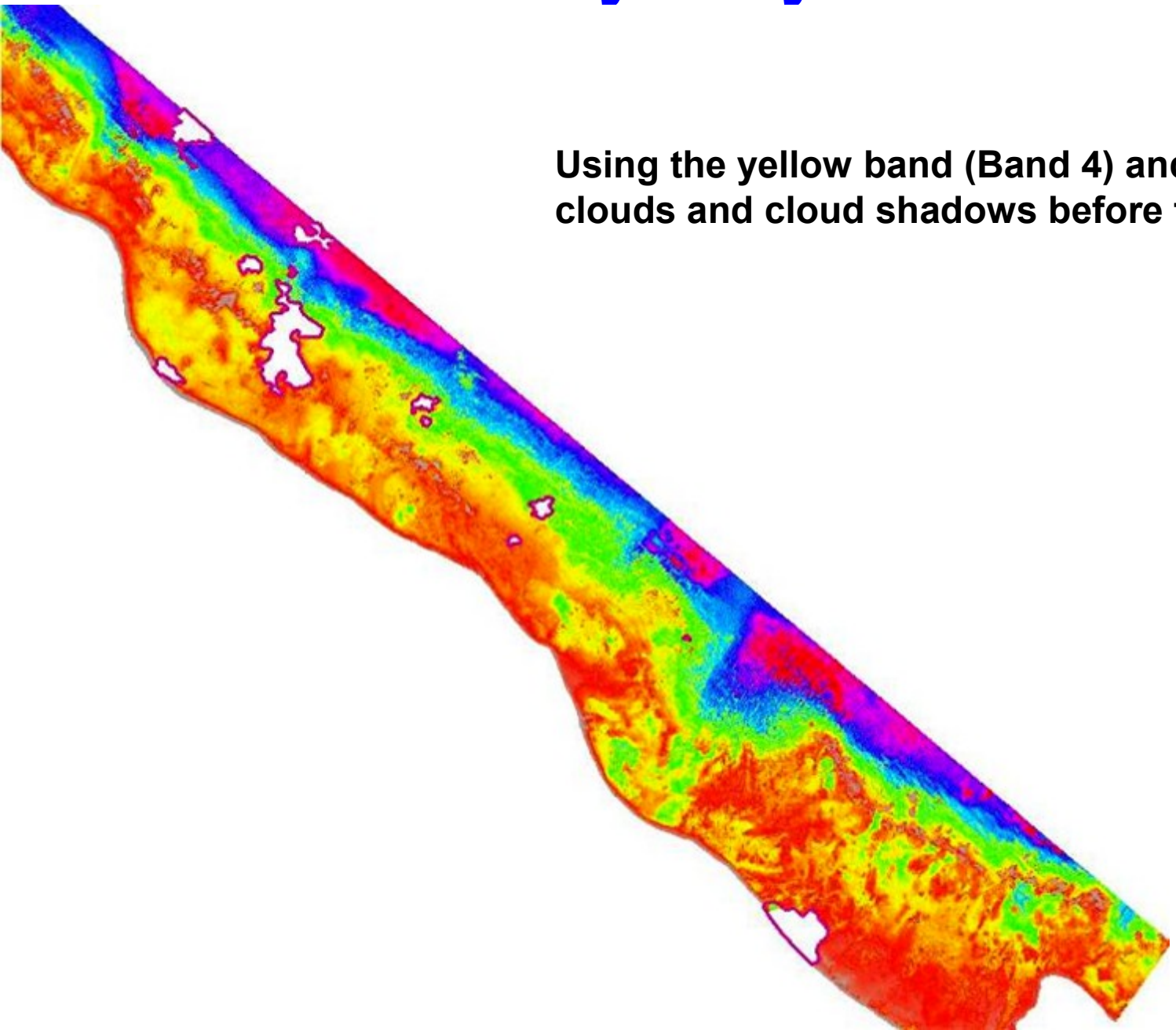
Clouds and cloud shadows appear in white surrounded by a pink line; these areas do not have bathymetry values.

Bathymetry results



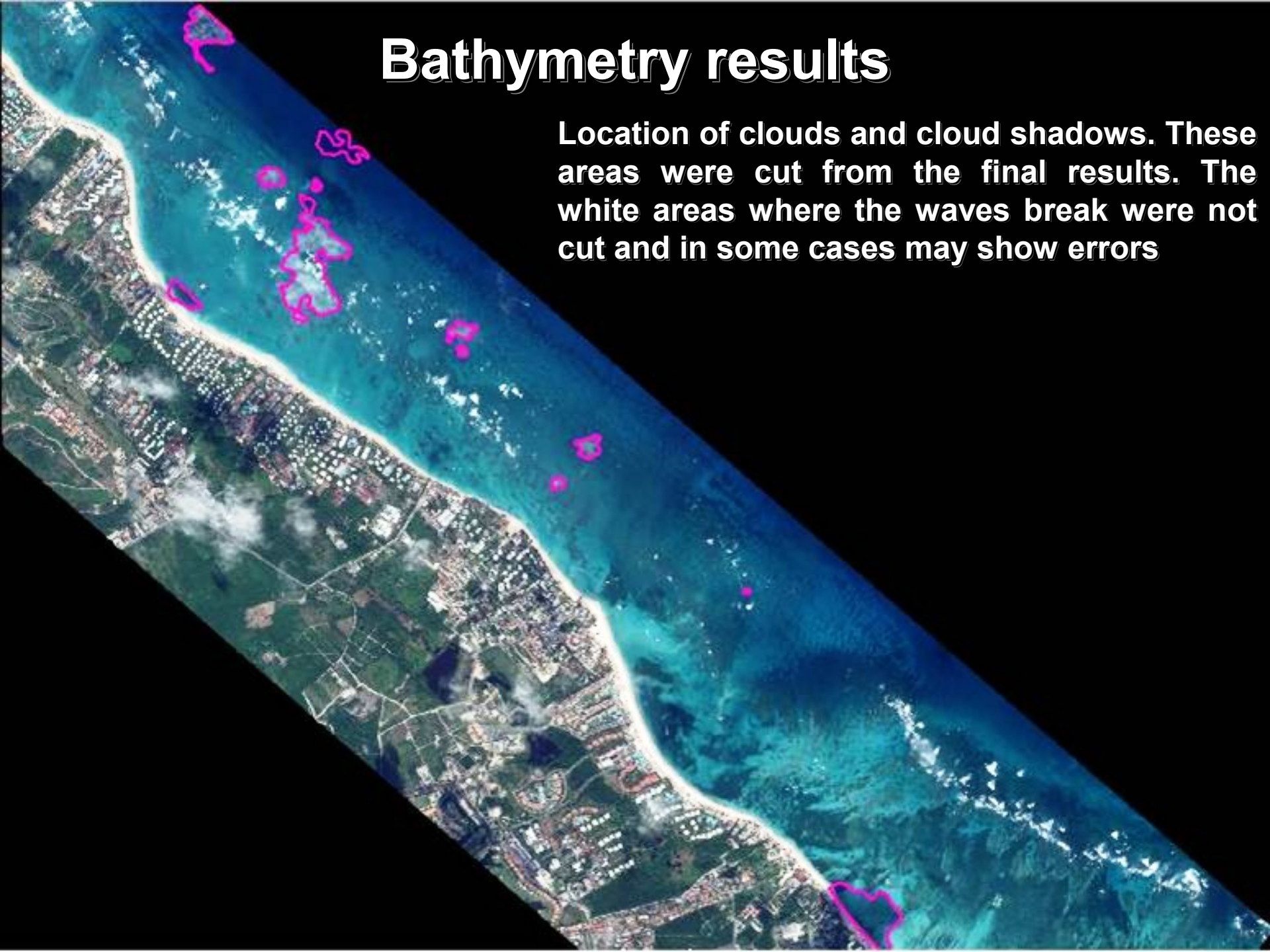
<u>Using the Yellow band (Band 4)</u>.

Bathymetry results



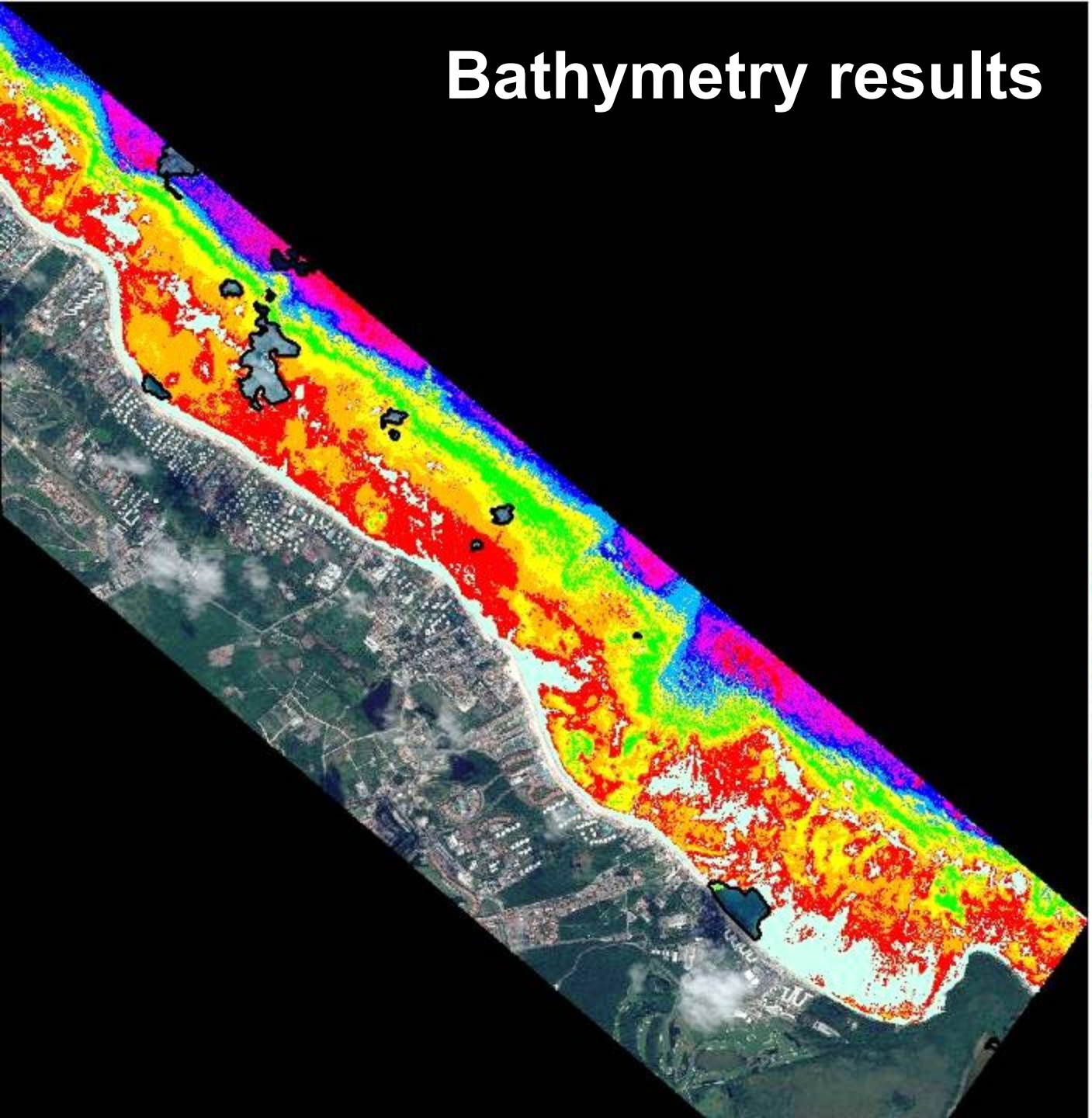
Using the yellow band (Band 4) and subtracting clouds and cloud shadows before the analysis

Bathymetry results



Location of clouds and cloud shadows. These areas were cut from the final results. The white areas where the waves break were not cut and in some cases may show errors

Bathymetry results

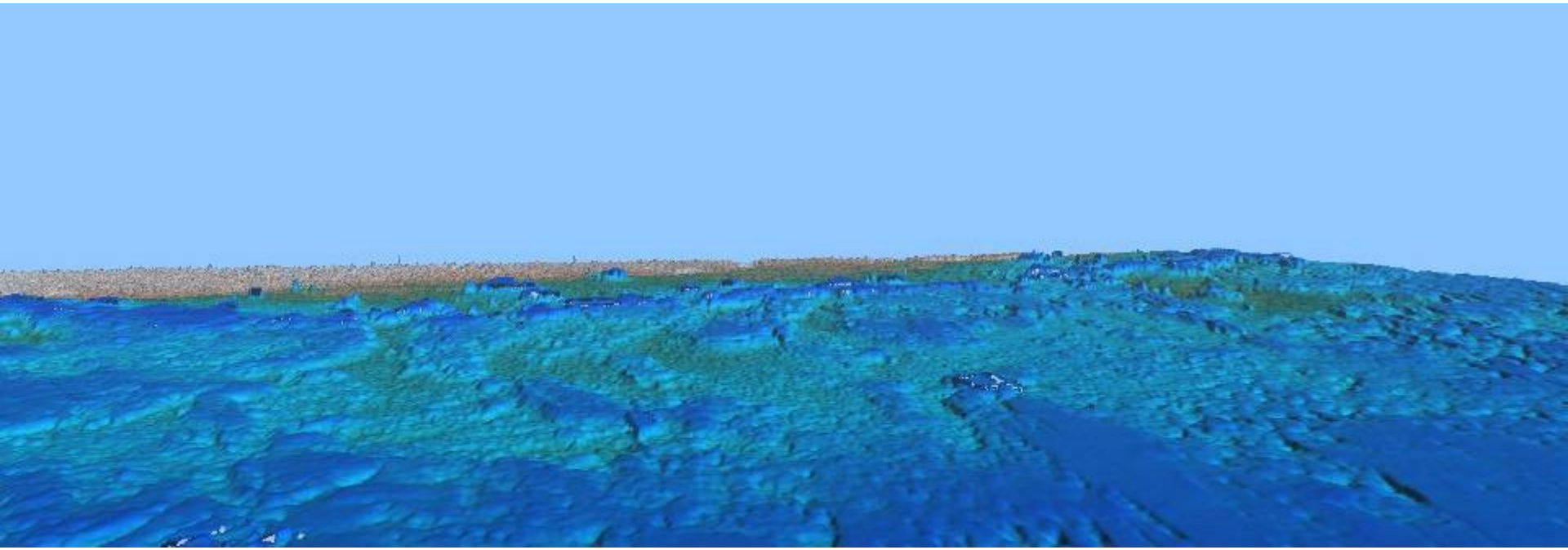


Bathymetry scale (m)

0.109543483 - 1.643152237
1.643152238 - 2.957674026
2.957674027 - 4.381739299
4.3817393 - 6.024891535
6.024891536 - 7.668043772
7.668043773 - 9.201652527
9.201652528 - 10.73526128
10.73526129 - 12.04978307
12.04978308 - 13.25476138
13.25476139 - 16.97923978

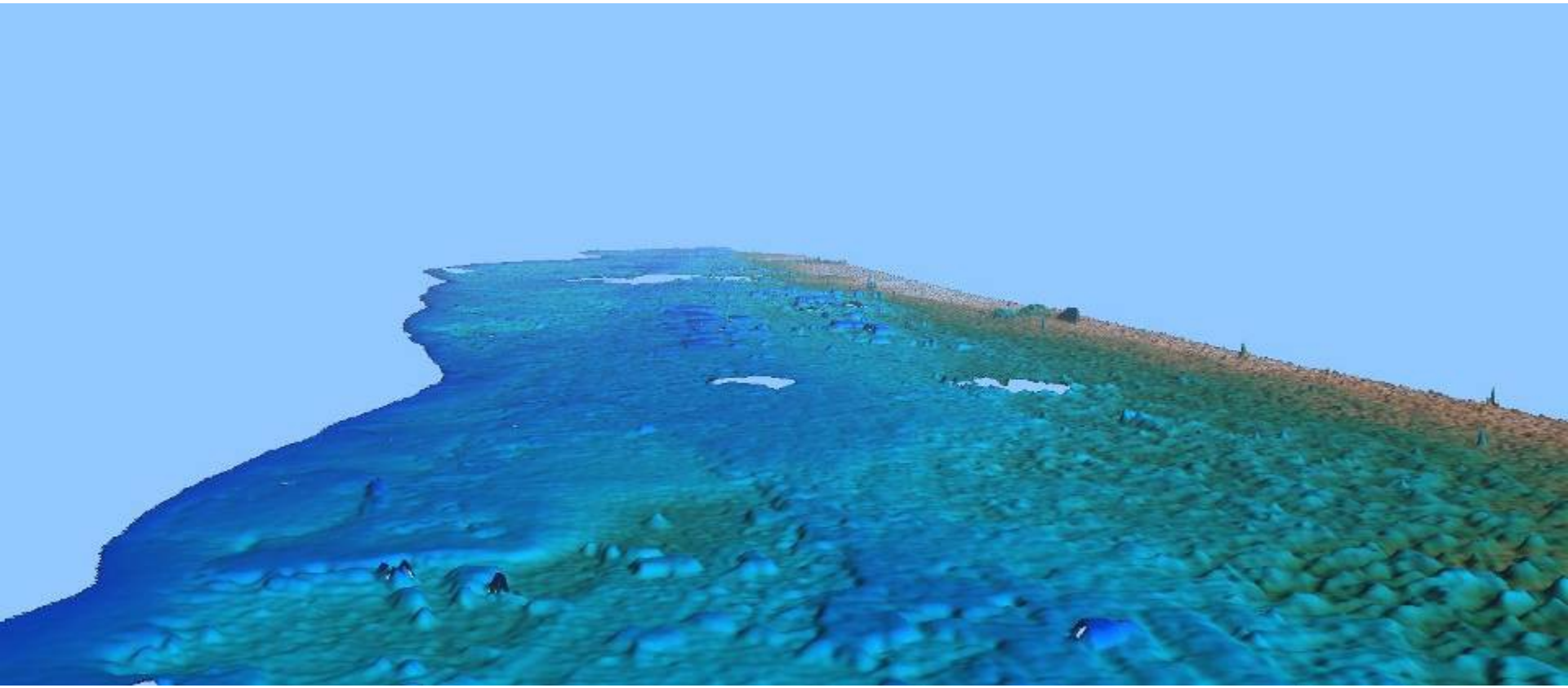
Bathymetry results

Detailed 3D bathymetry looking to land showing reef development (the Z is exaggerated for better appreciation)



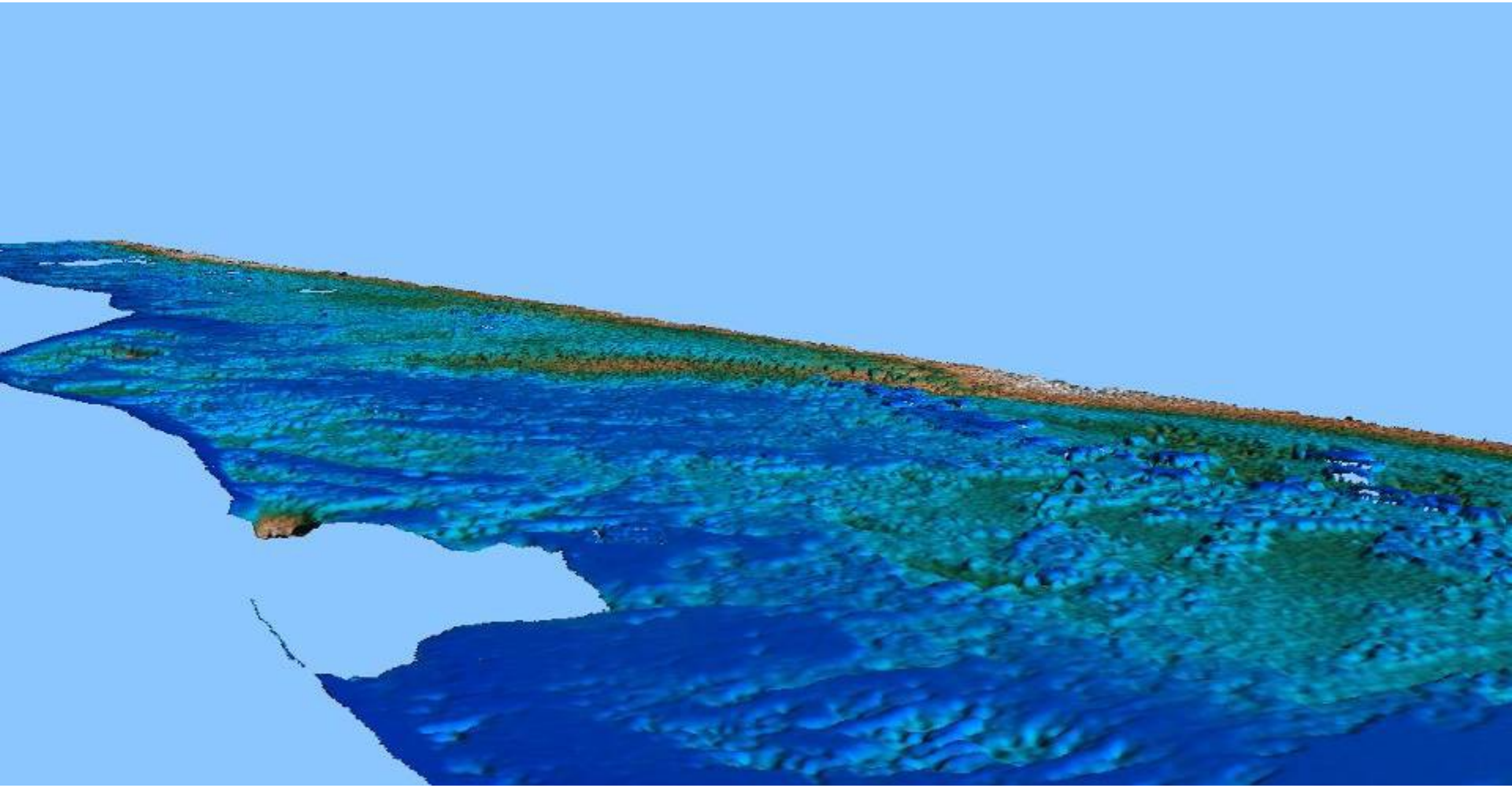
Bathymetry results

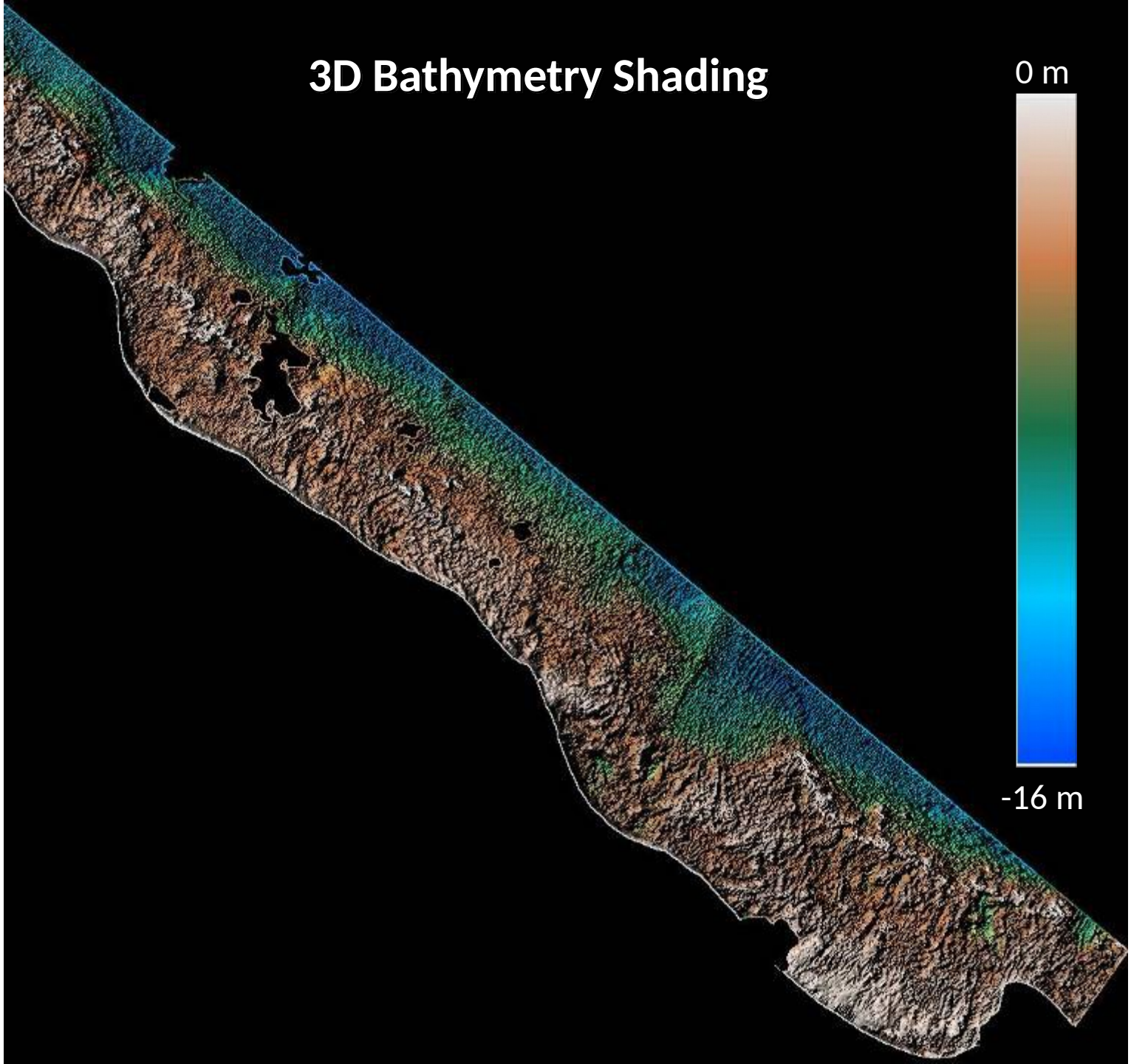
Detailed 3D bathymetry showing reef development (the Z is exaggerated for better appreciation)

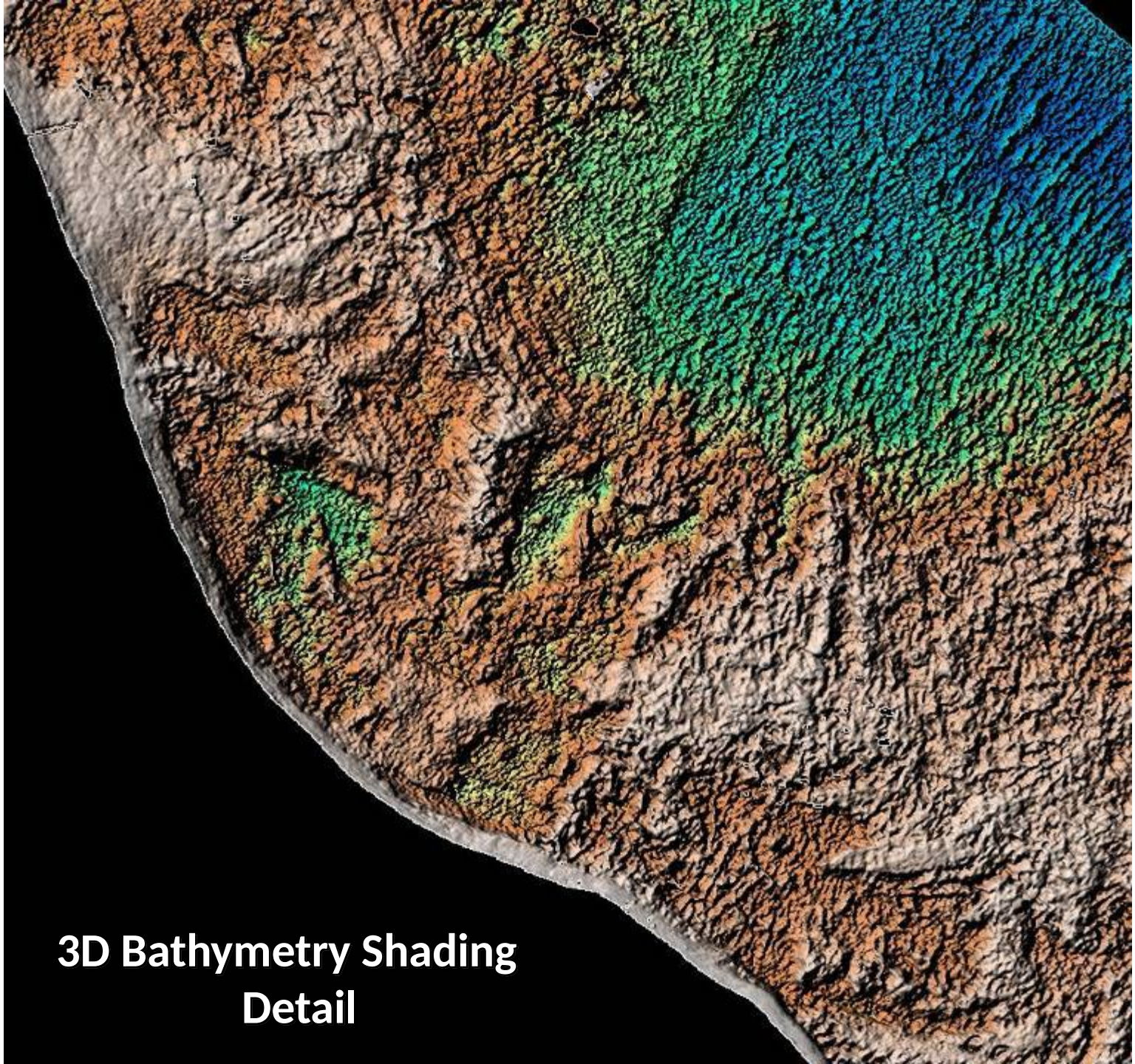


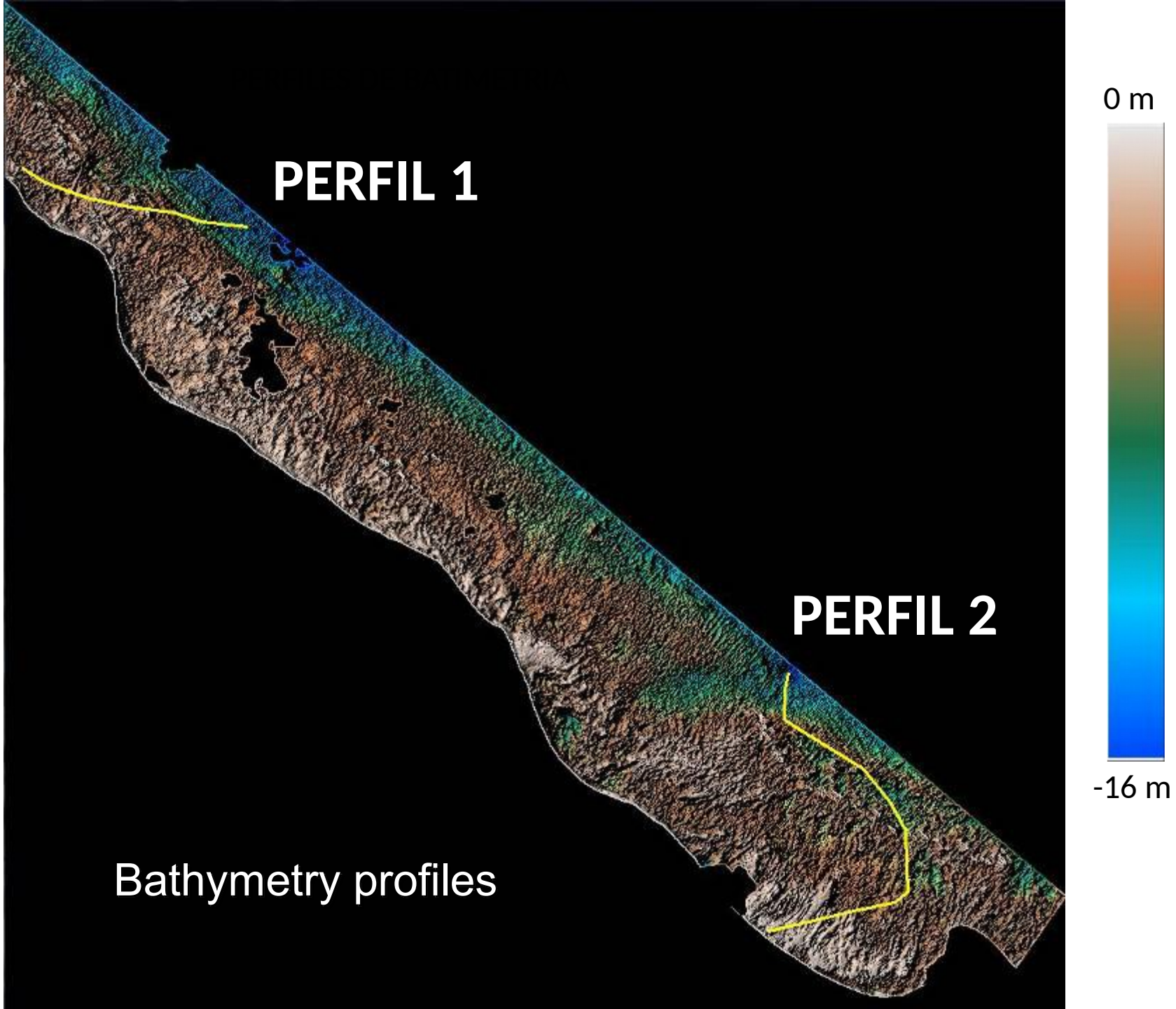
Bathymetry results

Detailed 3D bathymetry showing reef development (the Z is exaggerated for better appreciation)



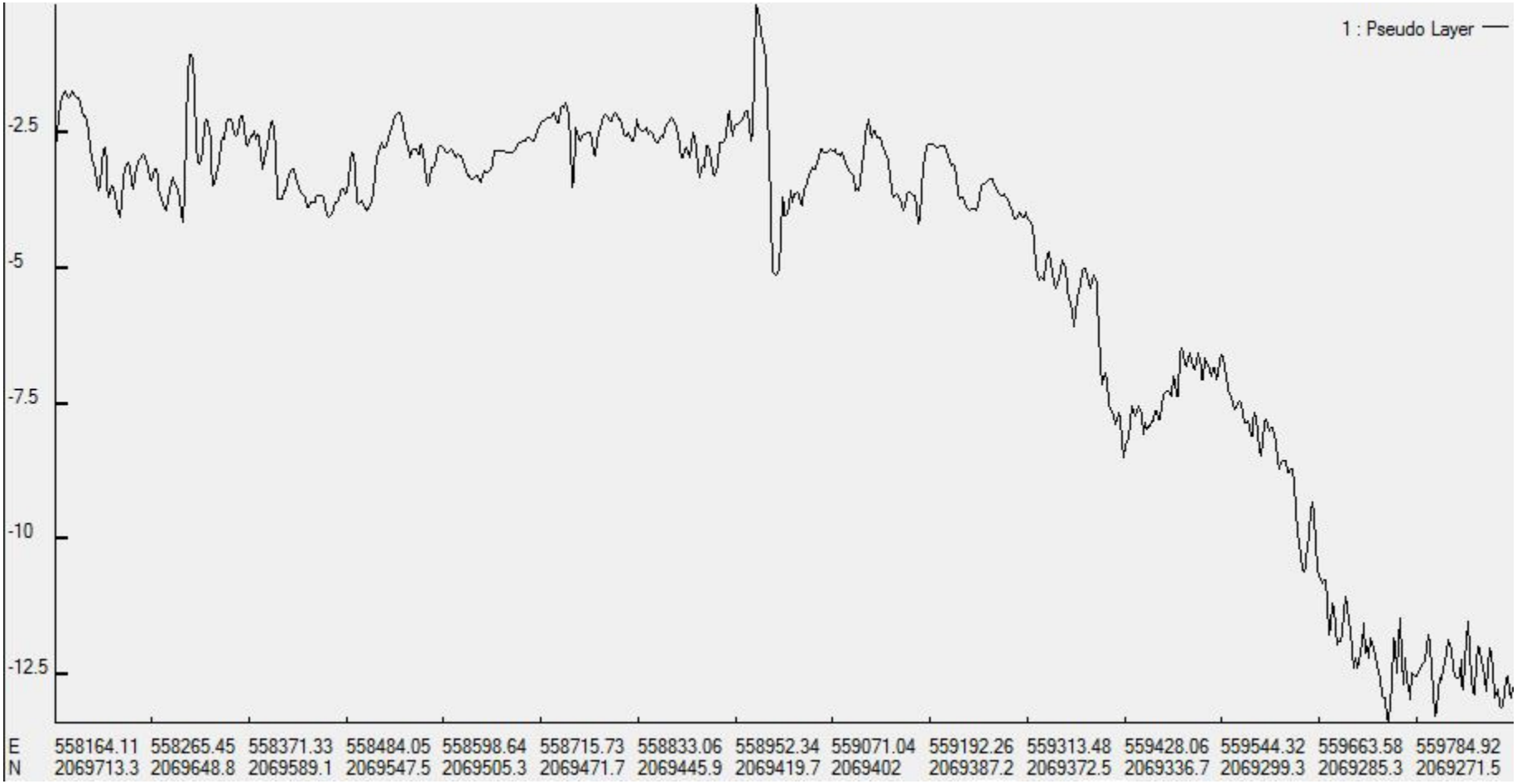

3D Bathymetry Shading
0 m
-16 m


0 m
-16 m
3D Bathymetry Shading
Detail


PERFIL 1
PERFIL 2
Bathymetry profiles
0 m
-16 m

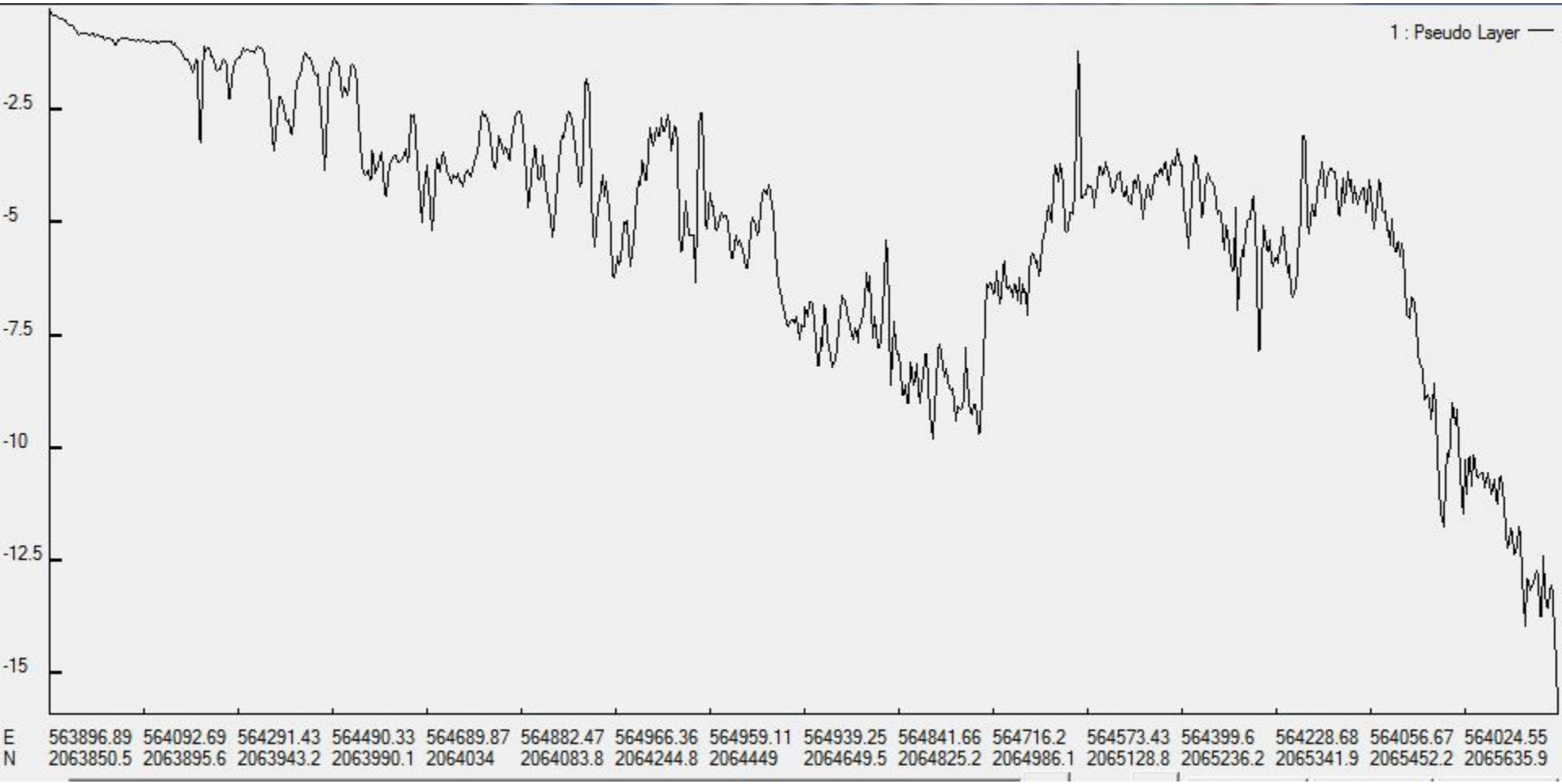
PERFIL 1

Bathymetry profile 1

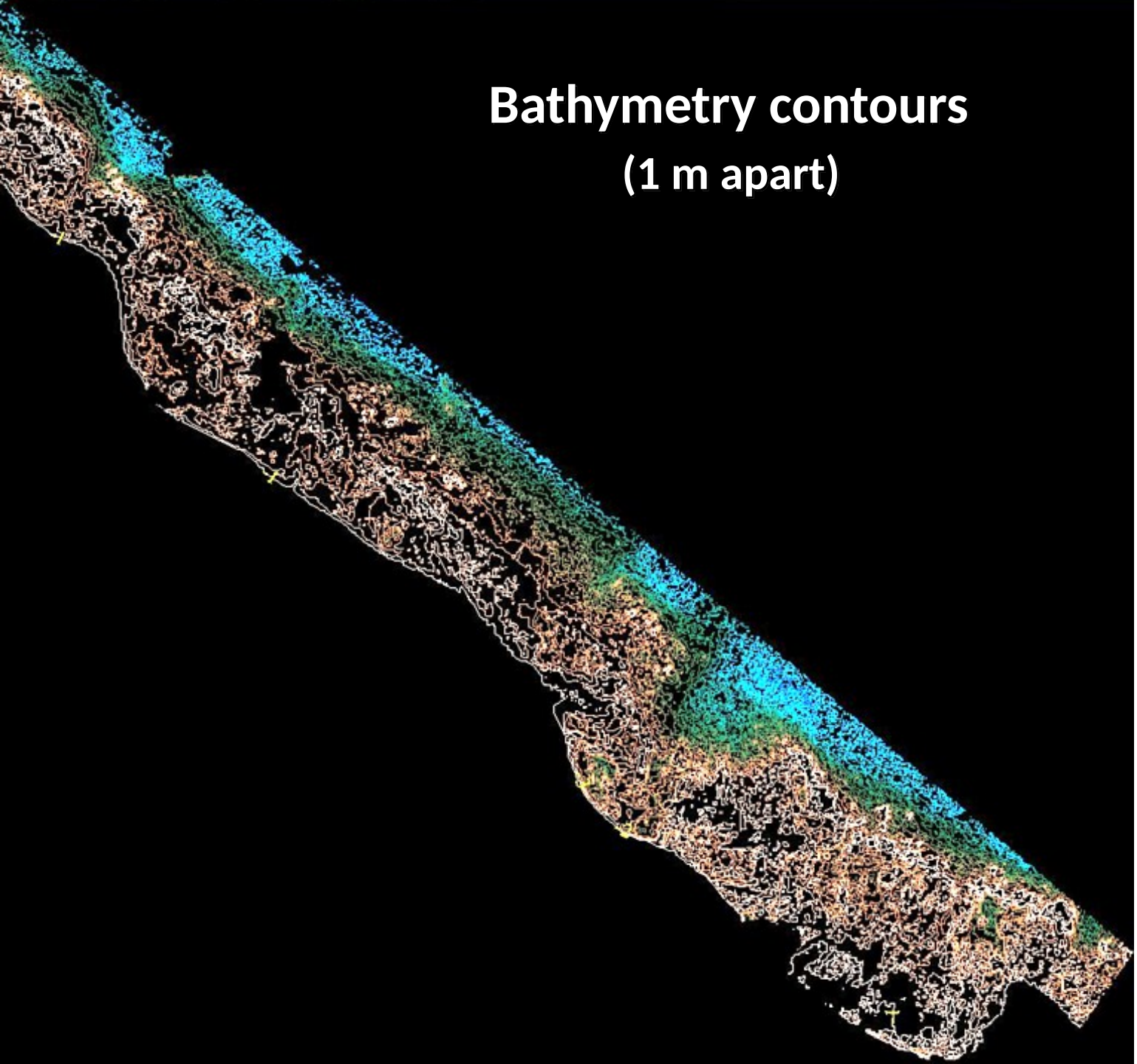


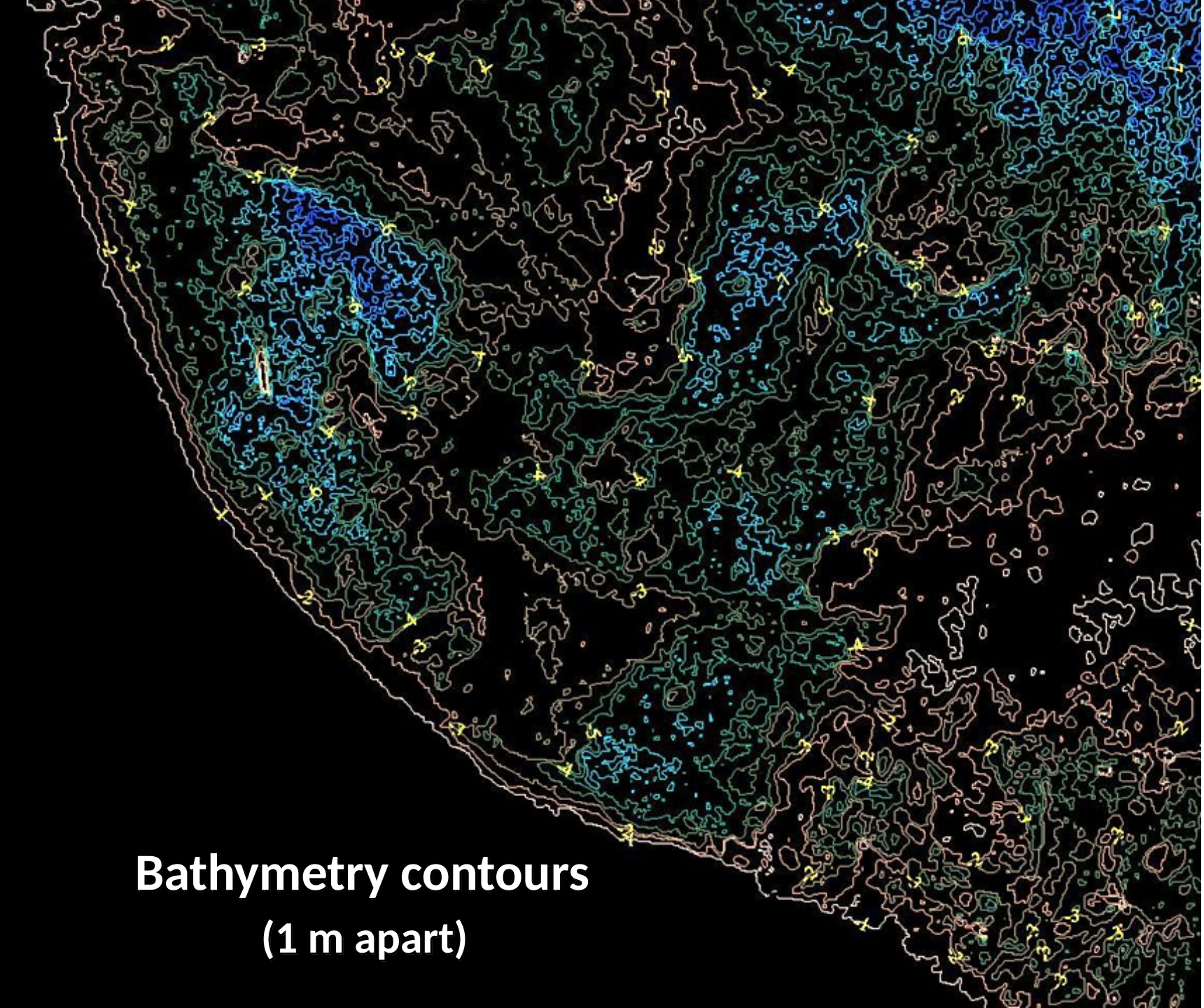
PERFIL 2

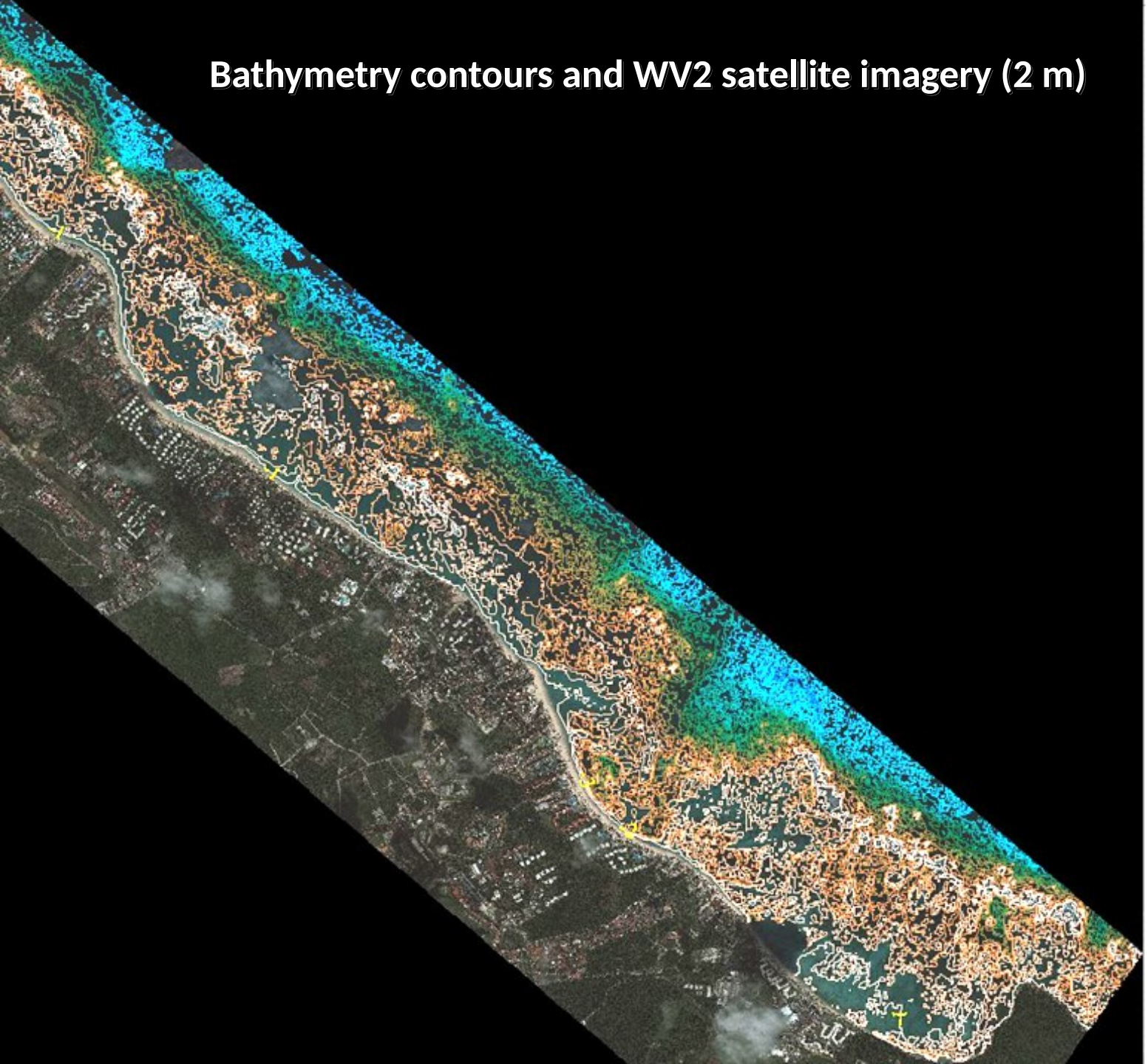
Bathymetry profile 2



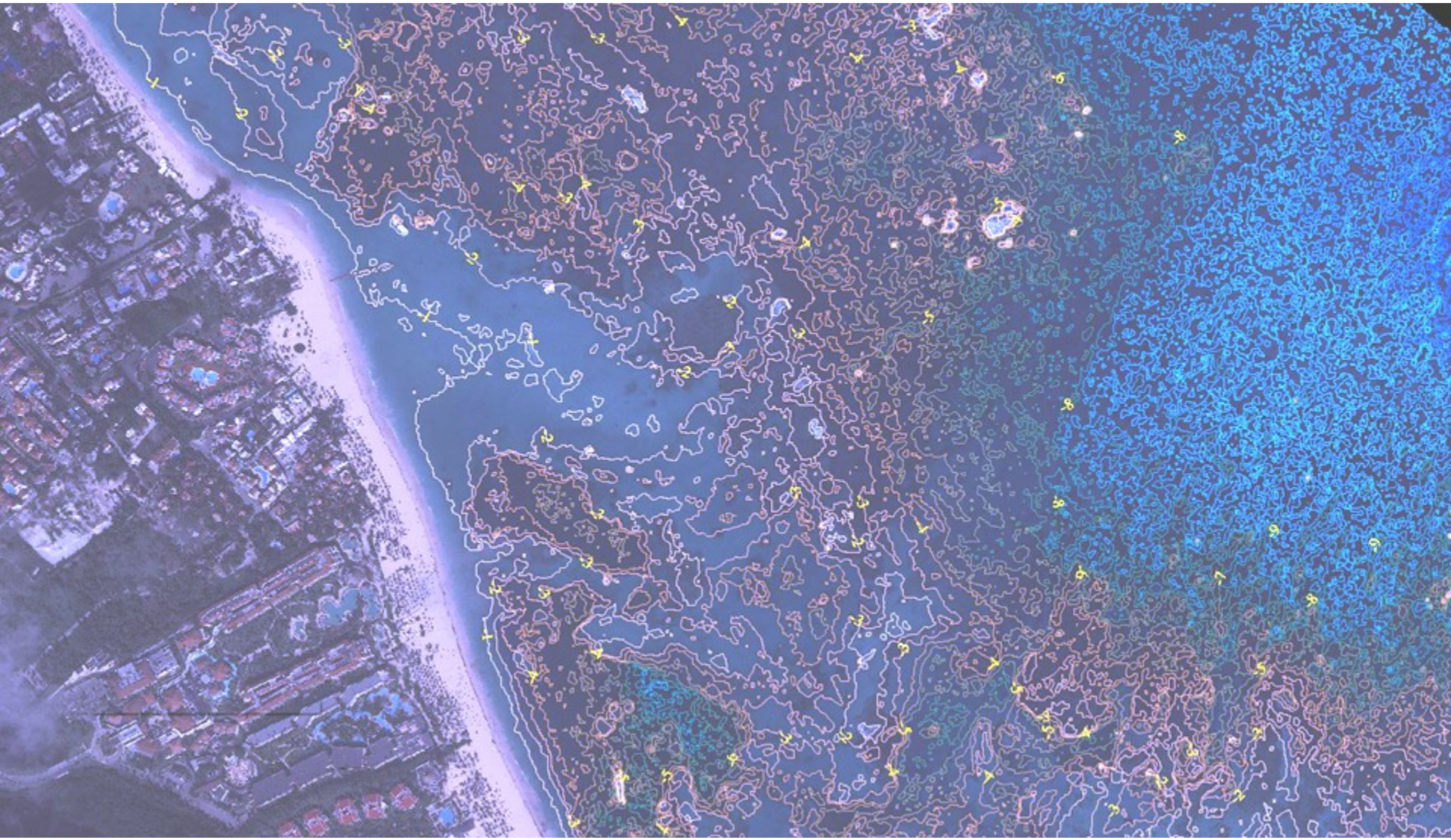
Bathymetry contours
(1 m apart)




Bathymetry contours
(1 m apart)

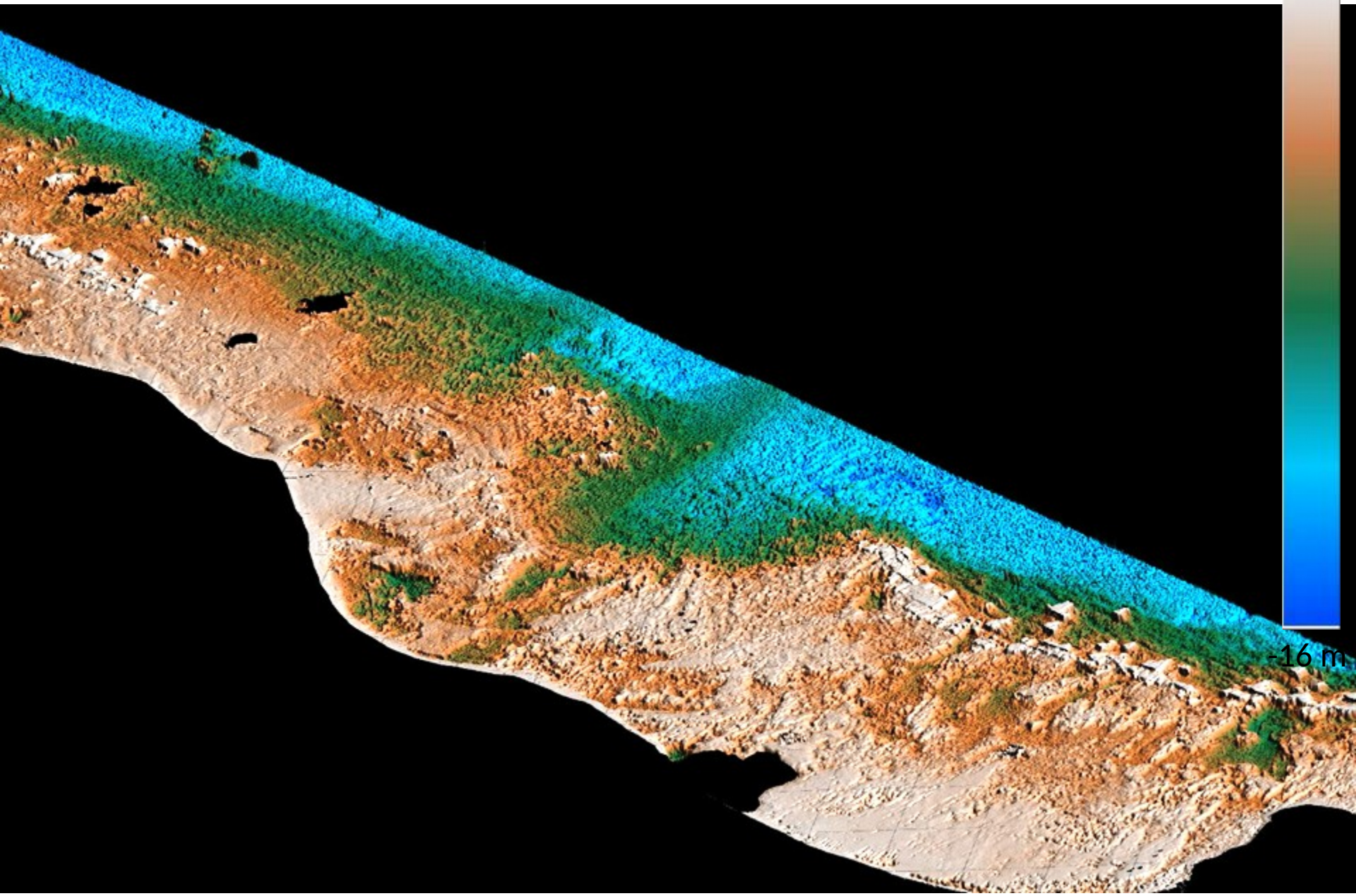

Bathymetry contours and WV2 satellite imagery (2 m)
0 m
-16 m

Bathymetry contours and WV2 satellite imagery (2 m)

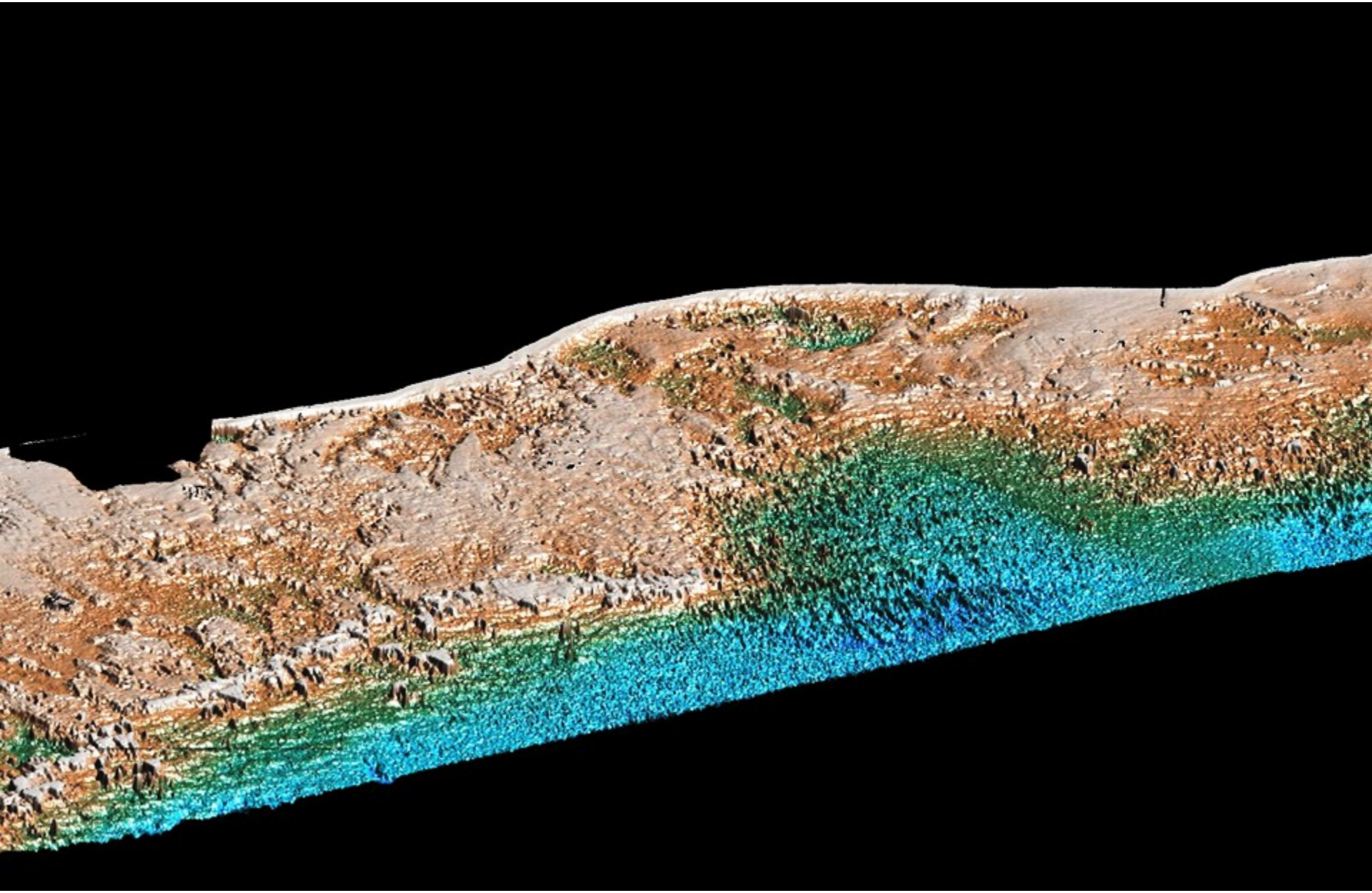


Bathymetry contours and WV2 satellite imagery (2 m)

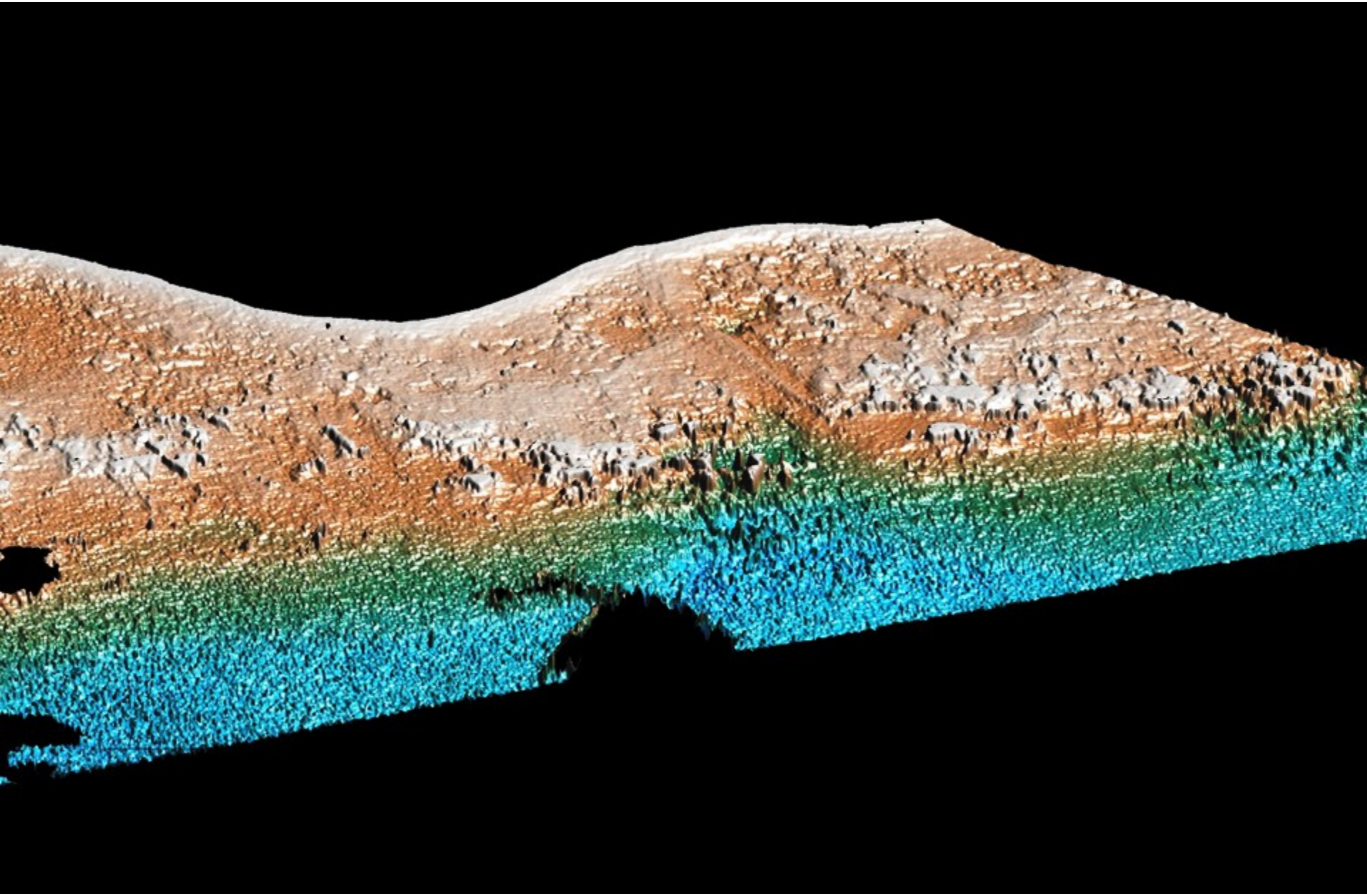
3D View

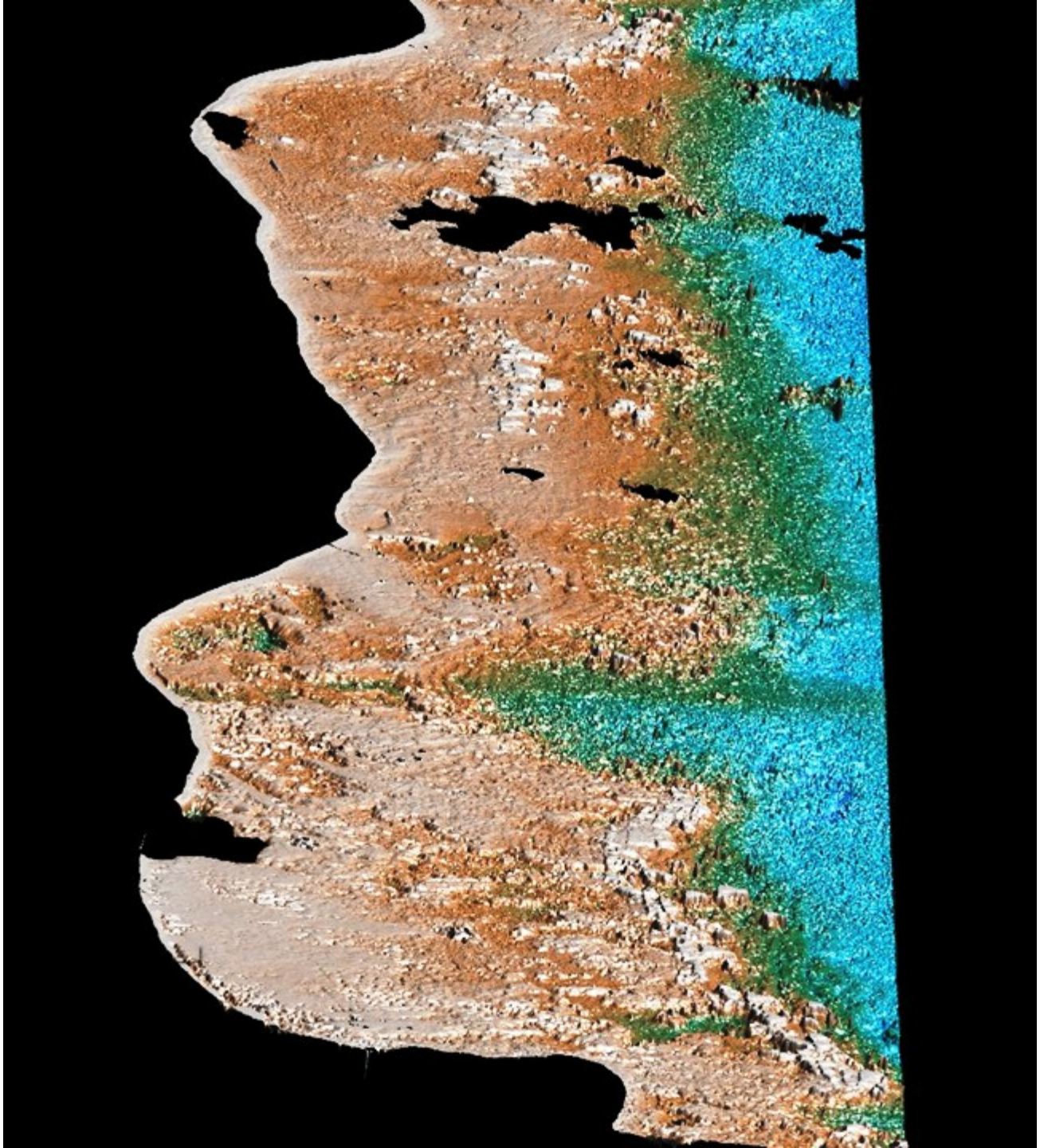


3D View



3D View



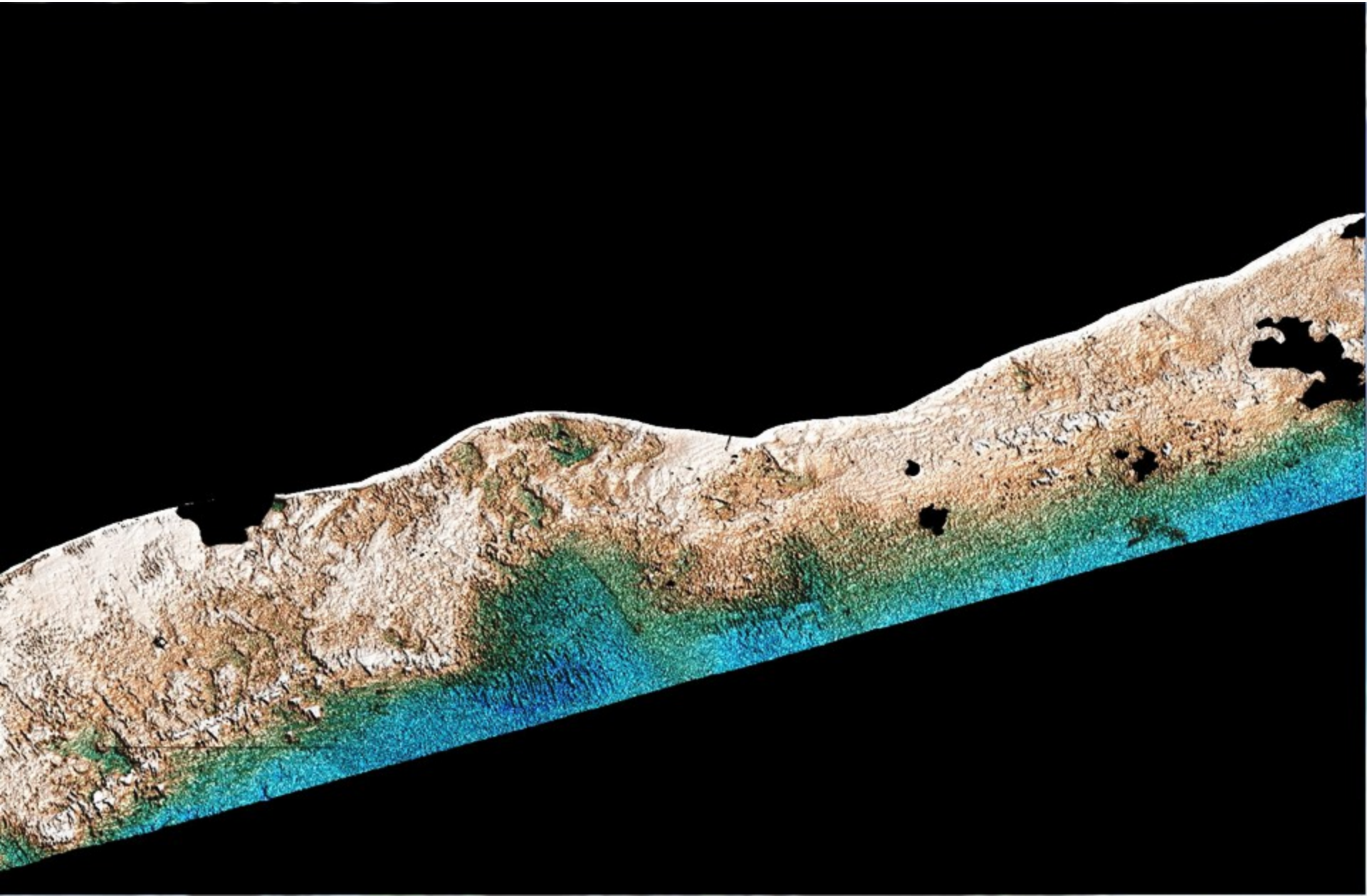


3D View

0 m

-16 m

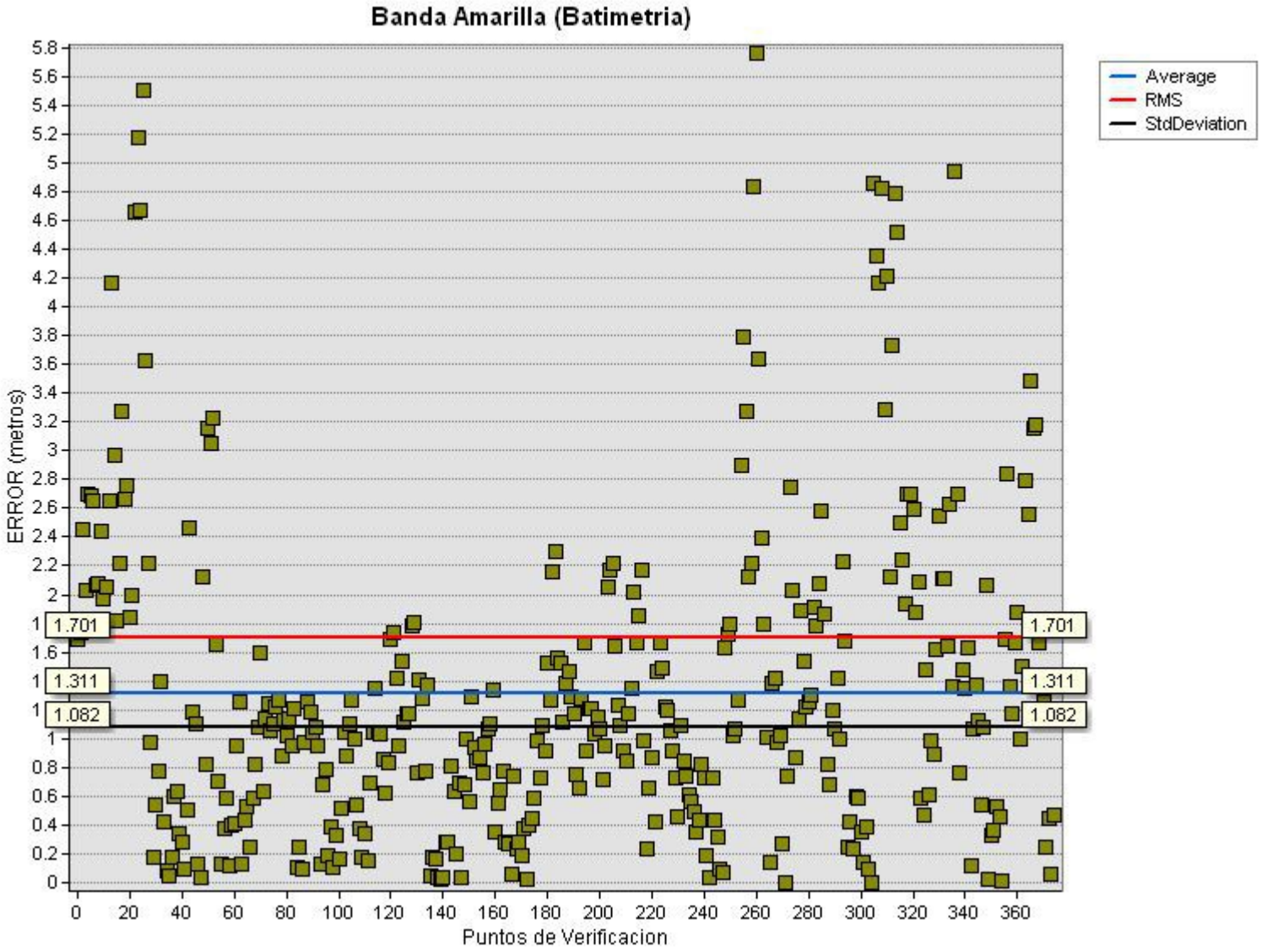
3D View



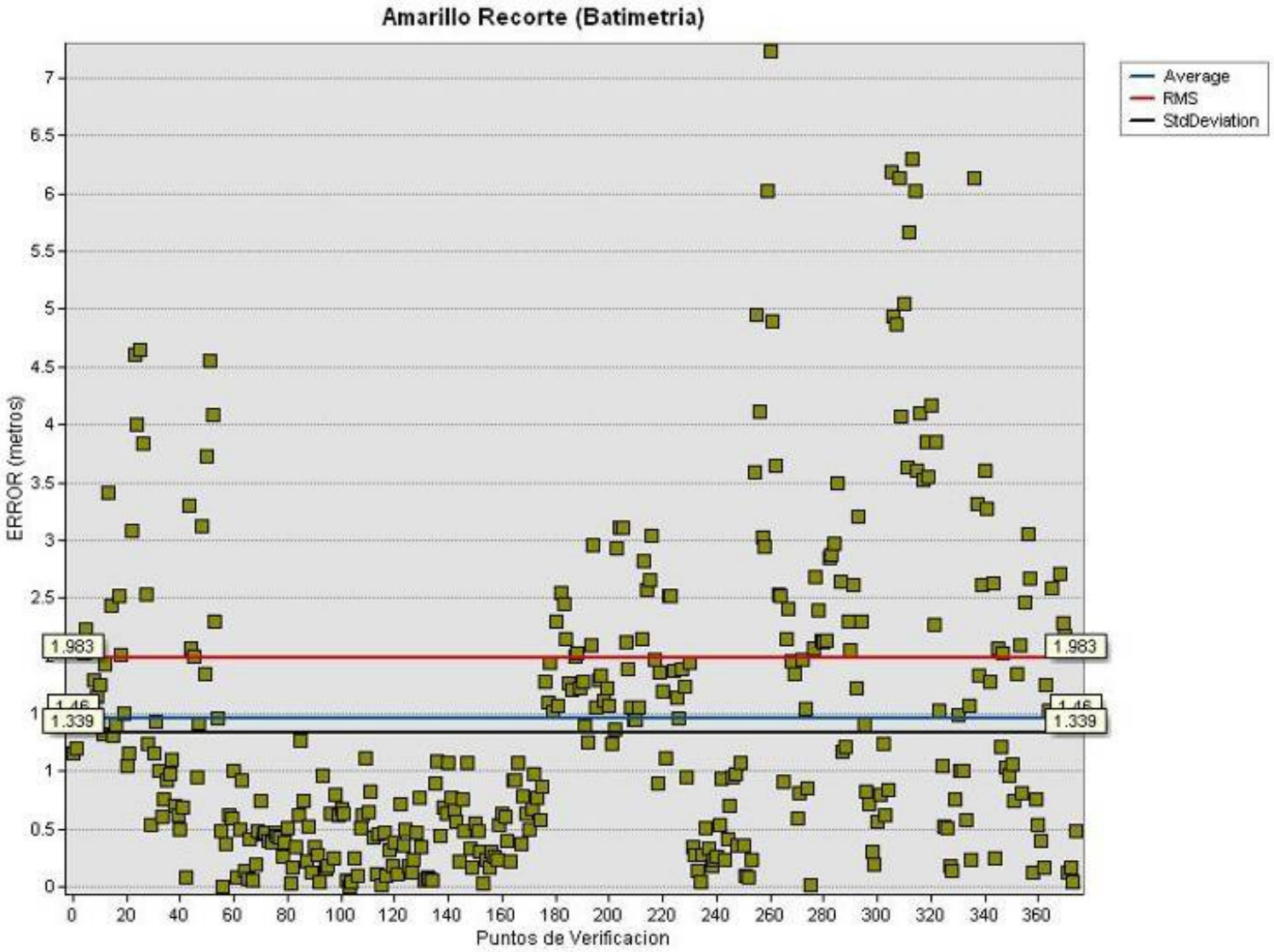
Validation of the results

- From all the bathymetry sampling provided by the client, 375 points were not used in the analysis. They were reserved for use as checkpoints for calibration and validation of the results. For each of the three results with the different bands used, the average error, RMS error and the standard deviation error, were calculated.
- The three errors above were calculated for the entire study area and also for three depth ranges: 0 to 3.5 meters; from 3.5 to 8 meters and greater than 8 meters.
- In general terms, the best-performing method is obtained using the yellow band without subtracting the clouds and cloud shadows with an RMS of 1.7 meters. However, for depths greater than 8 meters the method that gives less error is using the yellow band but previously subtracting clouds and their shadows with an RMS of 1.8 meters. The overall results can be improved by combining these two methods, taking into account depths greater than 8 meters.
- The use of the green band gives worse RMS values in all depth ranges but nevertheless seems to delineate better the entire seafloor.
- The results obtained are shown in the following slides:

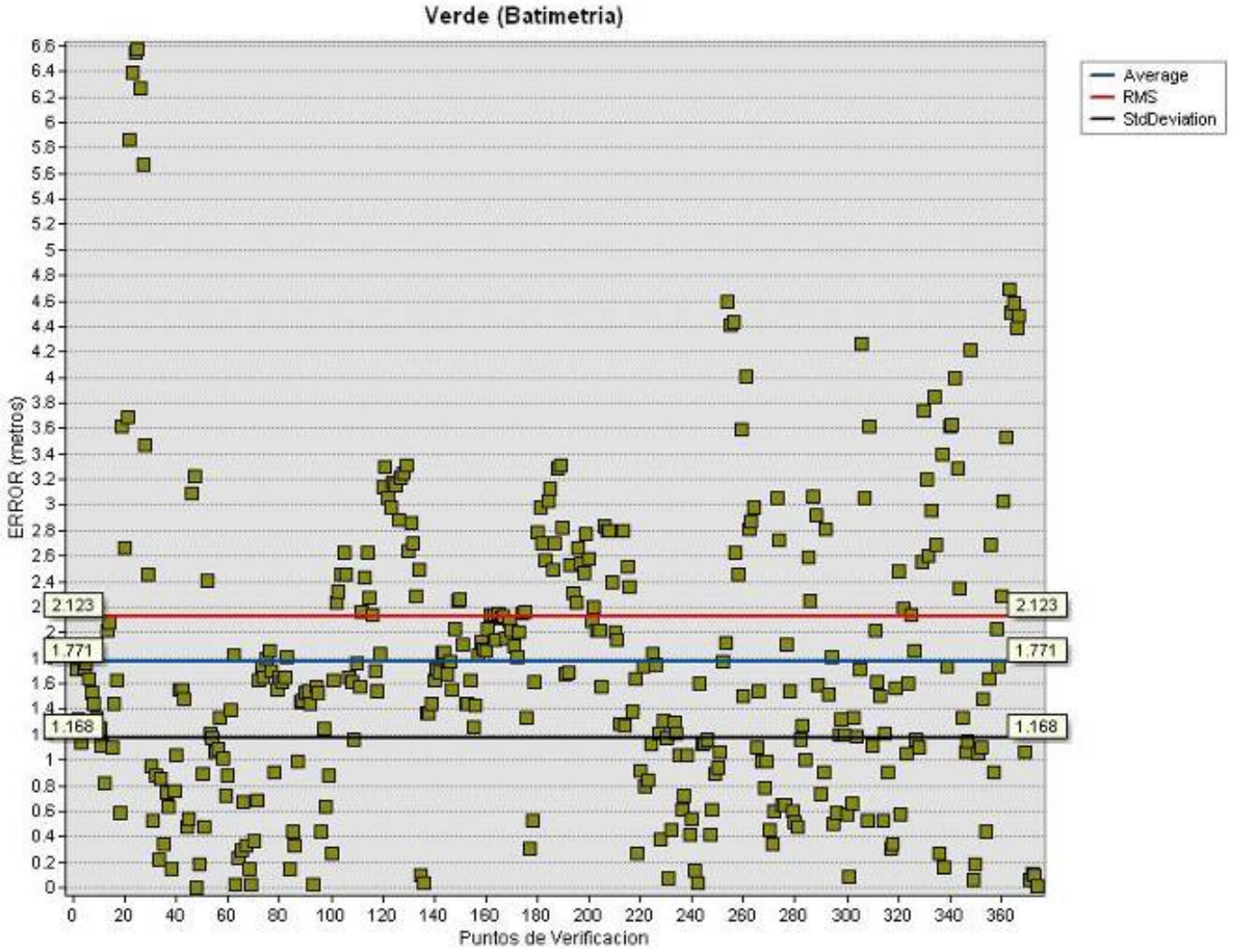
Validation of the results



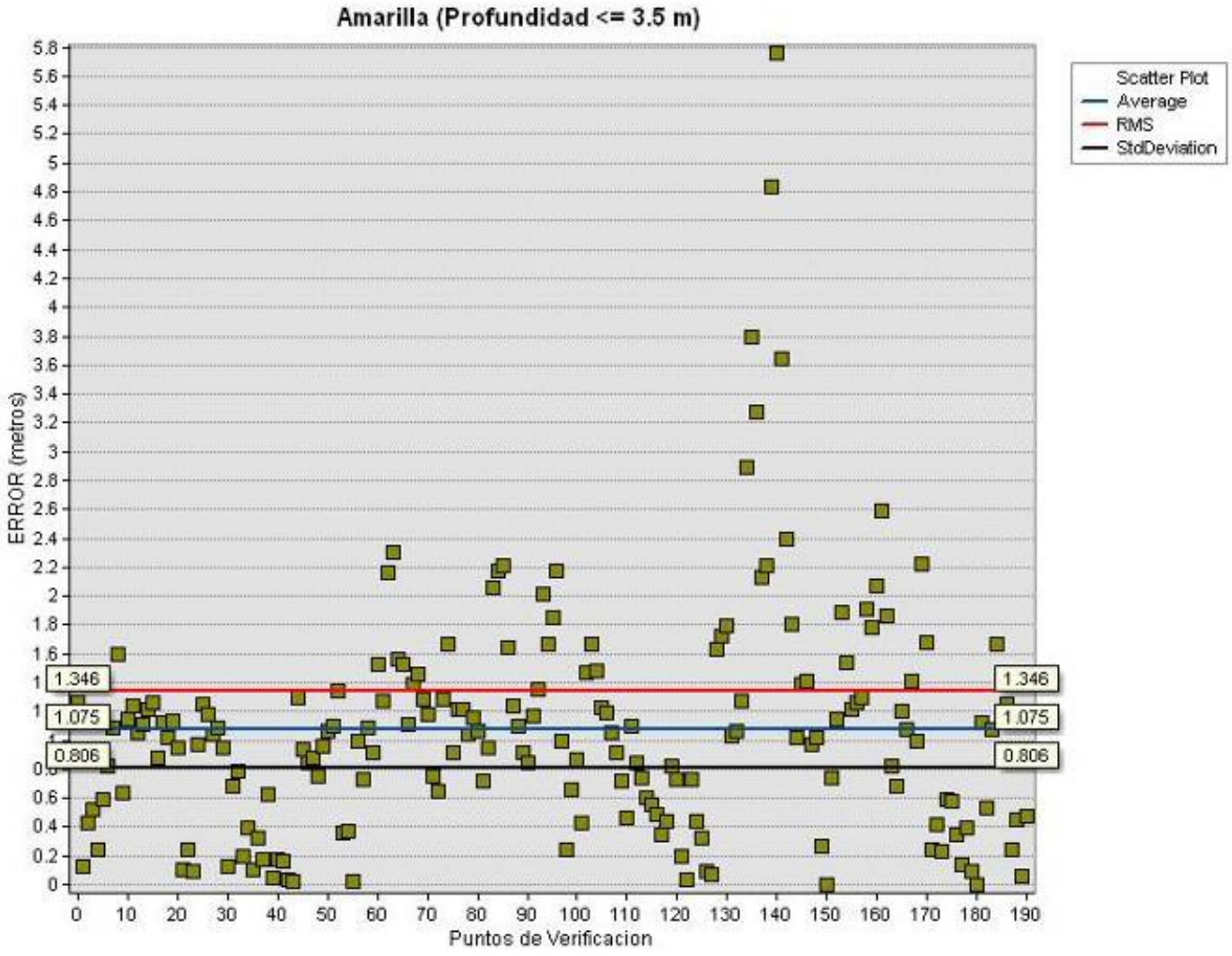
Validation of the results



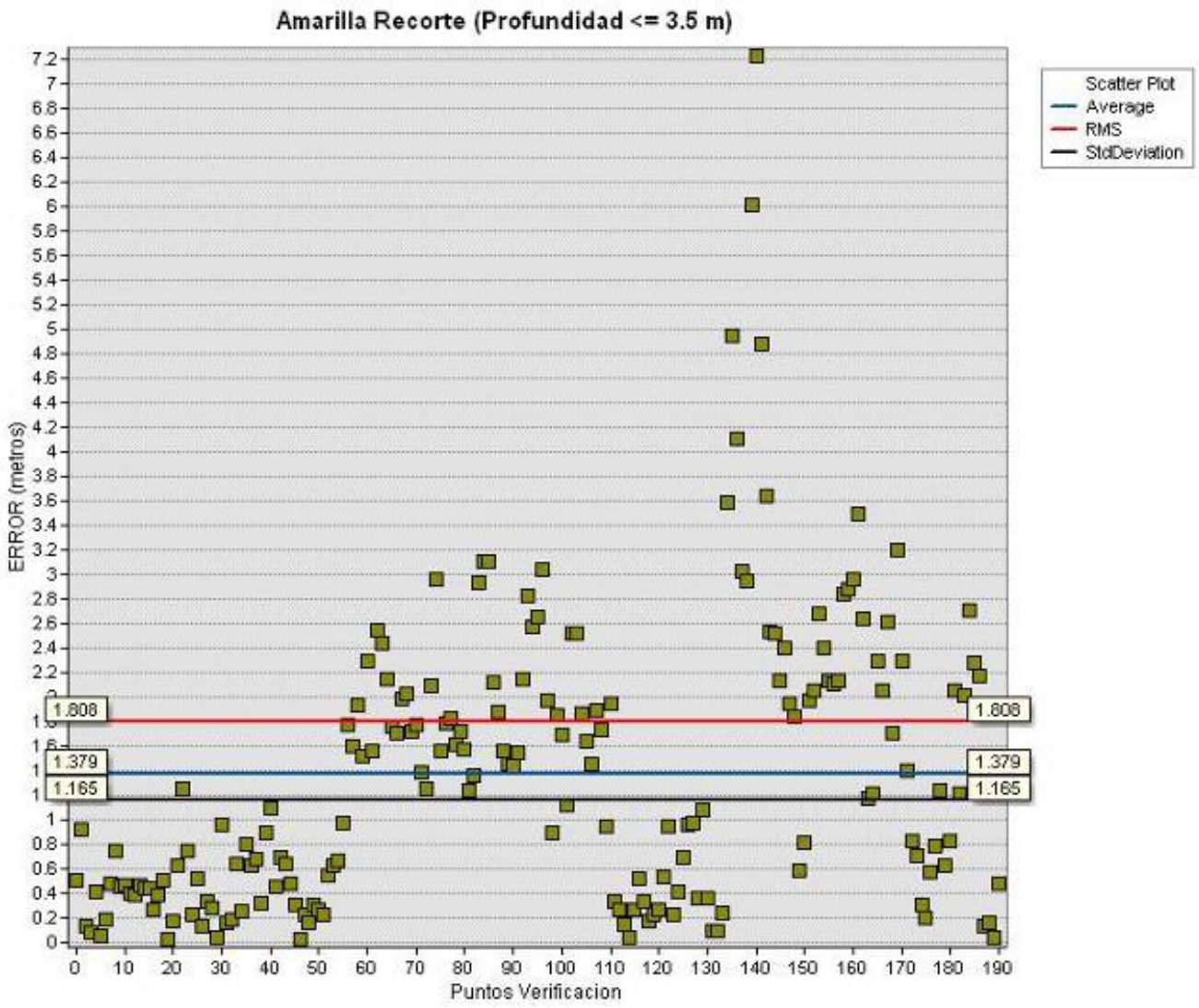
Validation of the results



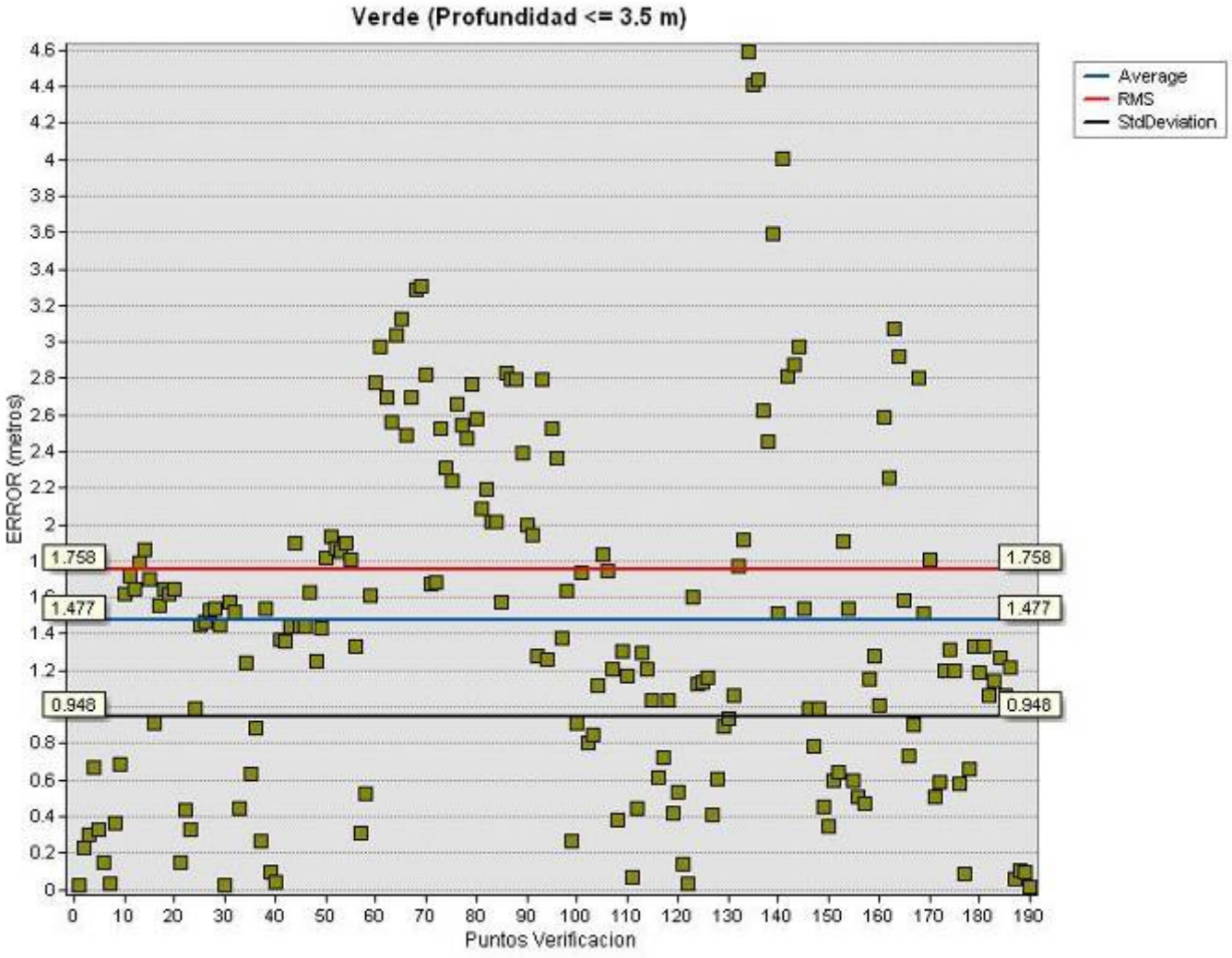
Validation of the results



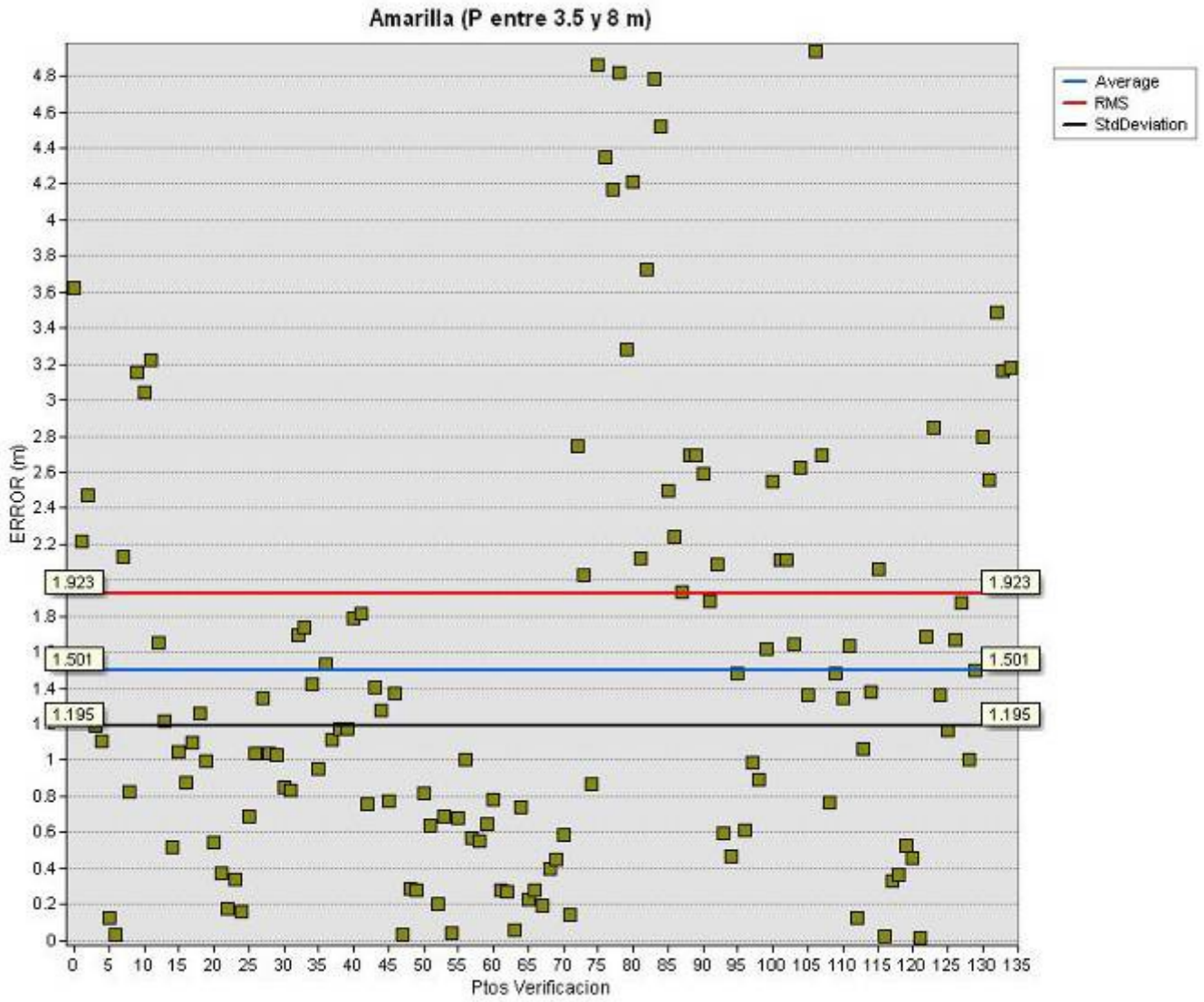
Validation of the results



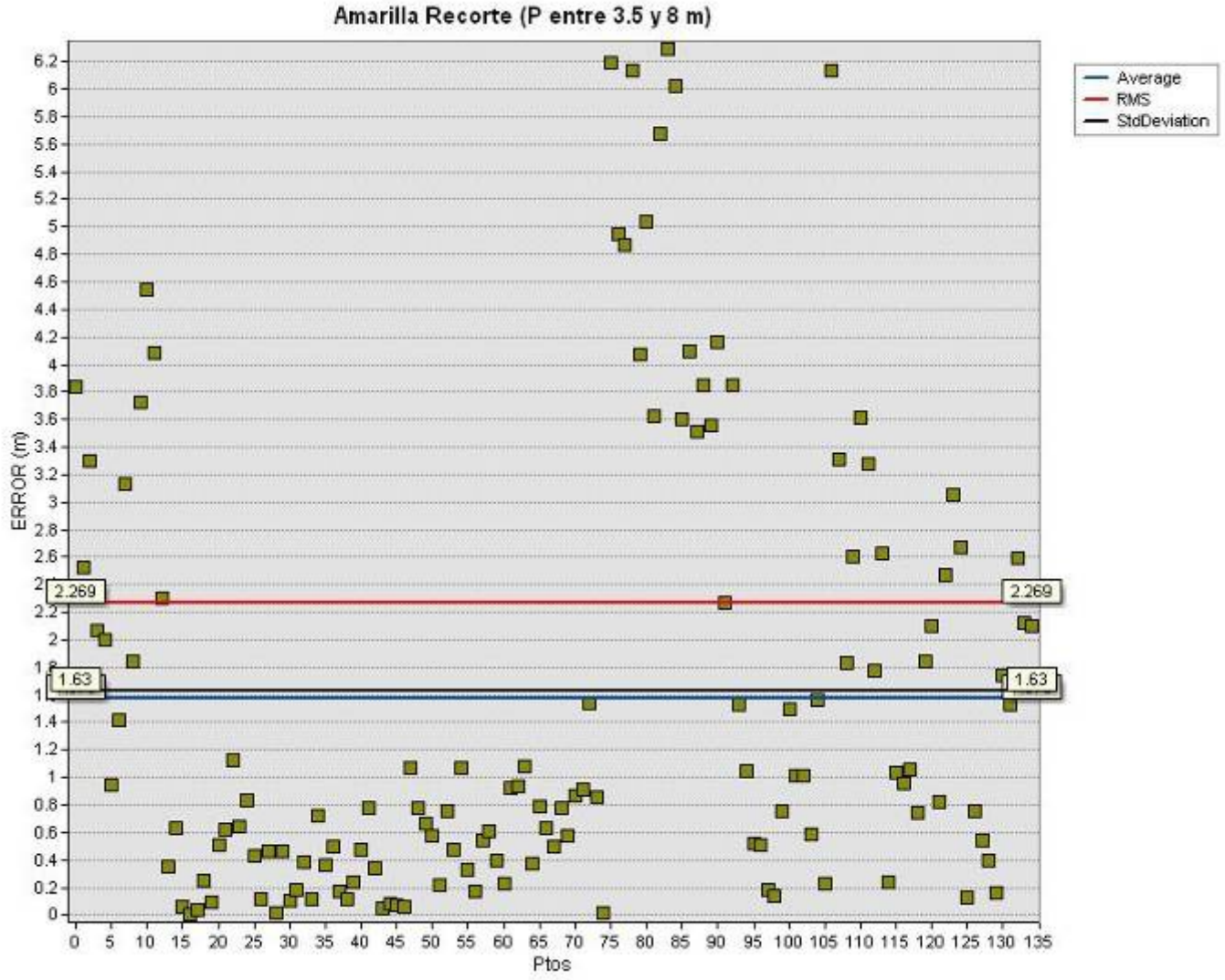
Validation of the results



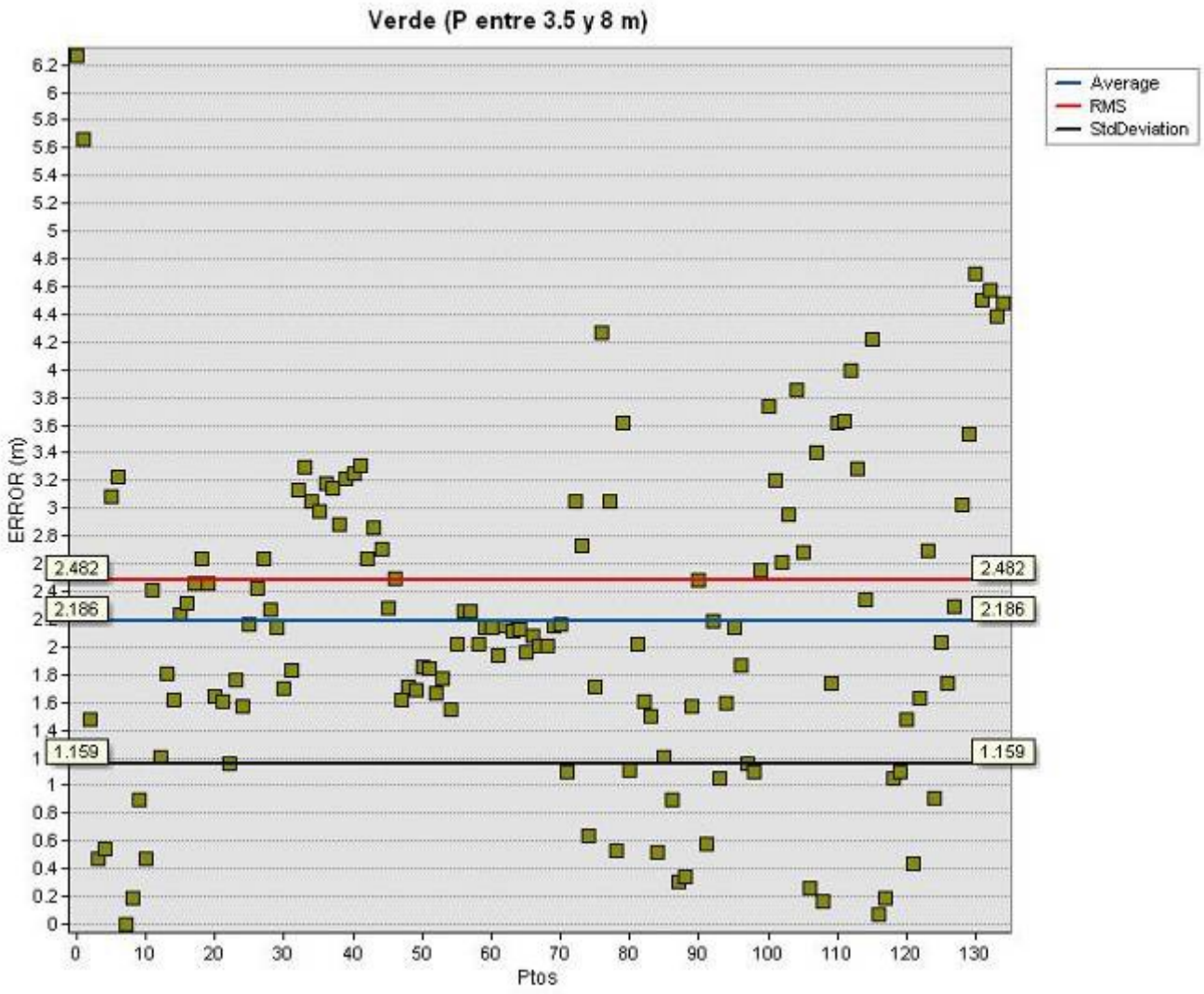
Validation of the results



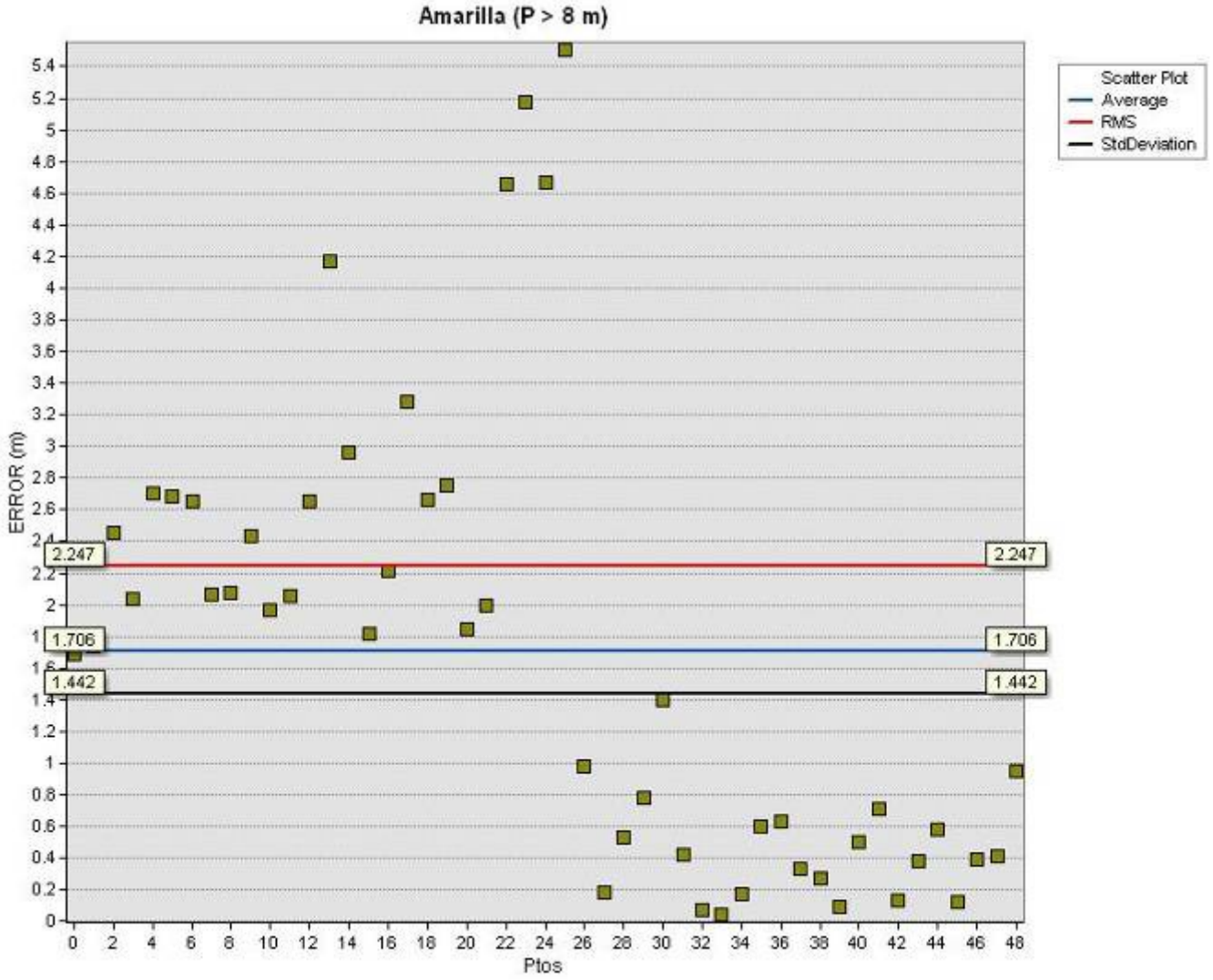
Validation of the results



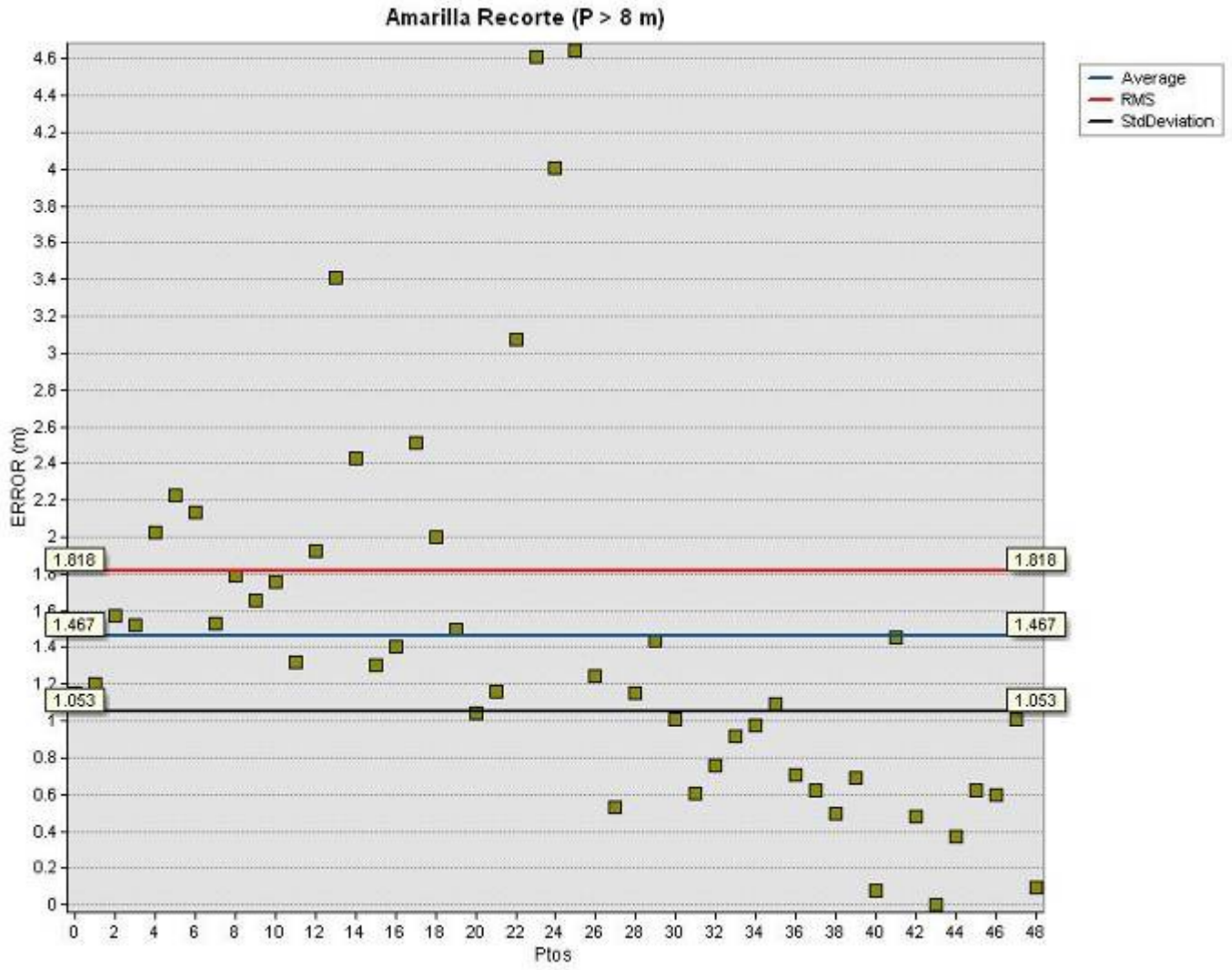
Validation of the results



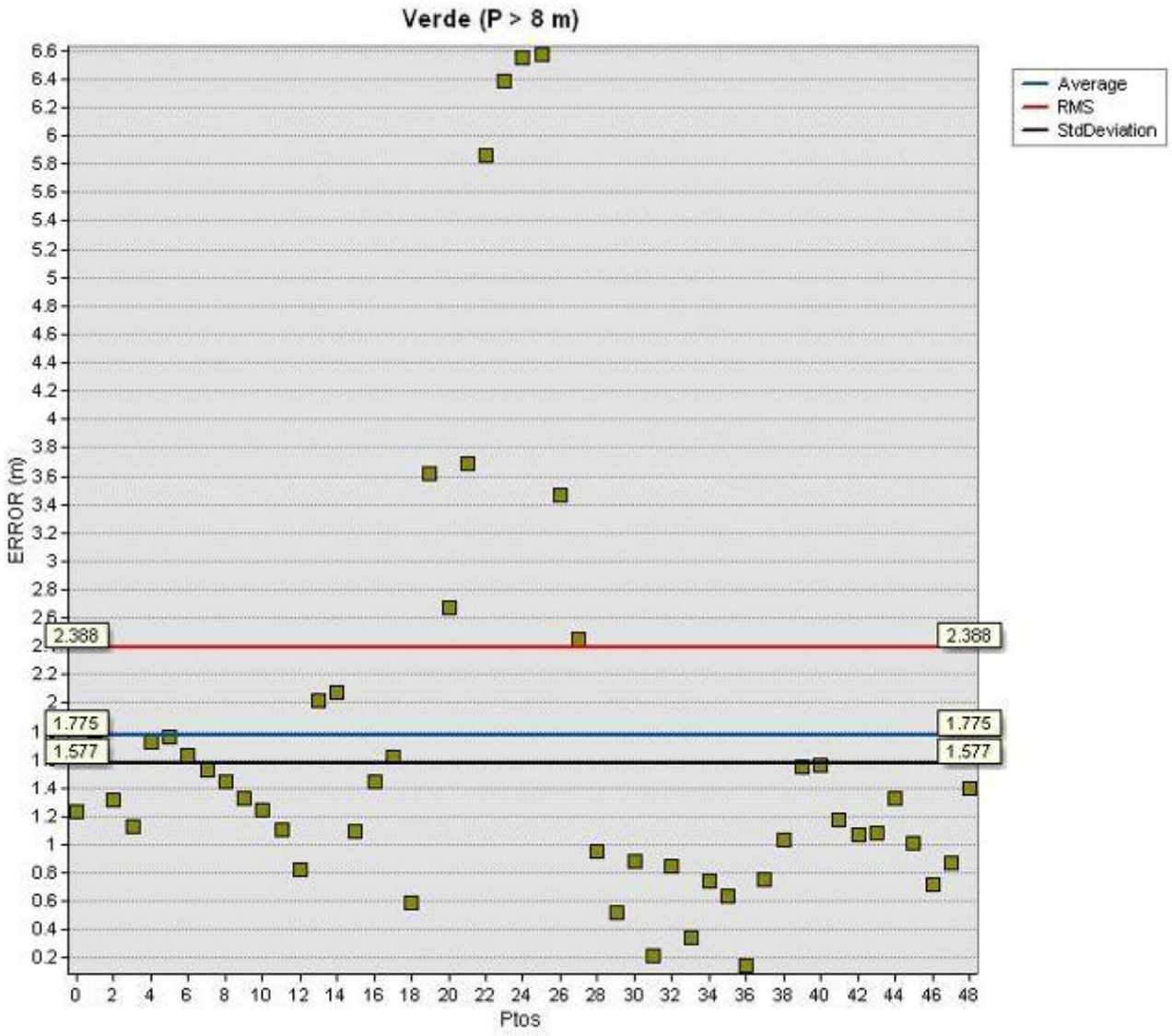
Validation of the results



Validation of the results



Validation of the results



Customer evaluation (TecnoOceano)

The bathymetry obtained by processing WorldView 2 satellite imagery has the following characteristics:

- Bathymetry of high detail due to the adequate spatial resolution satellite image of WV2 that was used (2 m).
- The bathymetry obtained by this methodology extends to large marine areas and therefore represents an economic saving compared with traditional techniques, although these are more accurate. The error in the satellite bathymetry is about 1 meter (by excess or by defect).
- The satellite bathymetry is a good choice when it comes to extensive marine areas where fast and detail results are required.
- The satellite bathymetry requires some precise bathymetric data with which to calibrate and validate the results (absolute values). Otherwise, only relative values (based on a color scale) pending calibration would be obtained.

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