Ifremer

Underwater Systems Unit

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Ifremer

Matisse 3D
Quick Start Guide

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1. Introduction

This document is a quick start guide to help you to process a complete dataset with Matisse, and that is oriented toward 3D reconstruction of underwater imagery (both still- and video). It deals with both pre-processing and processing, to render 3D terrain models with associated image texture.

The software provides several modules required to obtain textured 3D models.

The first step is the pre-processing of the dataset (still images of video). This step is mandatory when using video dataset, as it converts video to images and recommended for images only. The pre-processing tool allows to reduce resolution (for faster reconstruction), and to color correct images. This can be applied to still images.

The second step is the processing of the data. This requires the selection of a reconstruction algorithm, with its associated parameters, to obtain the reconstruction.

This software also provides the possibility of generating 2D photomosaics based on navigation only (i.e., no feature matching and renavigation of the camera), and geared towards sub-vertical imaging of the seafloor. Details of 2D processing are provided in Appendix E.

Matisse is open-source and publicly distributed. The software uses open-access libraries, and updated versions will be available at the Github Matisse project (https://github.com/IfremerUnderwater/Matisse). The release includes, in addition to the source code, a Windows executable version that can be executed on Windows7 and Windows10.

2. Installation of Matisse 3D

This software is available through Github at:

https://github.com/IfremerUnderwater/Matisse

Matisse can be compiled in Linux from the source code, and instructions are provided through the github pages for installation.

For Windows, a binary executable file can be downloaded and launched, and the executable includes instructions for the installation.

3. Pre-processing the dataset

Once Matisse installed, the first step, which is optional depending on the input data, is the preprocessing of the imagery. The Matisse Preprocessing tool can be launched from the Windows "start menu -> Matisse Preprocessing". It can also be launched from the Matisse software under Tools -> Launch Preprocessing tool.

The preprocessing allows the user to extract images or frames from the video for 3D processing, that will be stored and exploited in the subsequent 3D reconstruction.
For extracted video frames, and for input still images, Matisse Preprocessing can also carry out colour corrections, illumination corrections, and inpainting to remove portions of the frame (e.g., burned in text in the video or still images, frame of the vehicle in the view, among others)

The preprocessing tool provides a wizard with the following first window (Fig. 1):

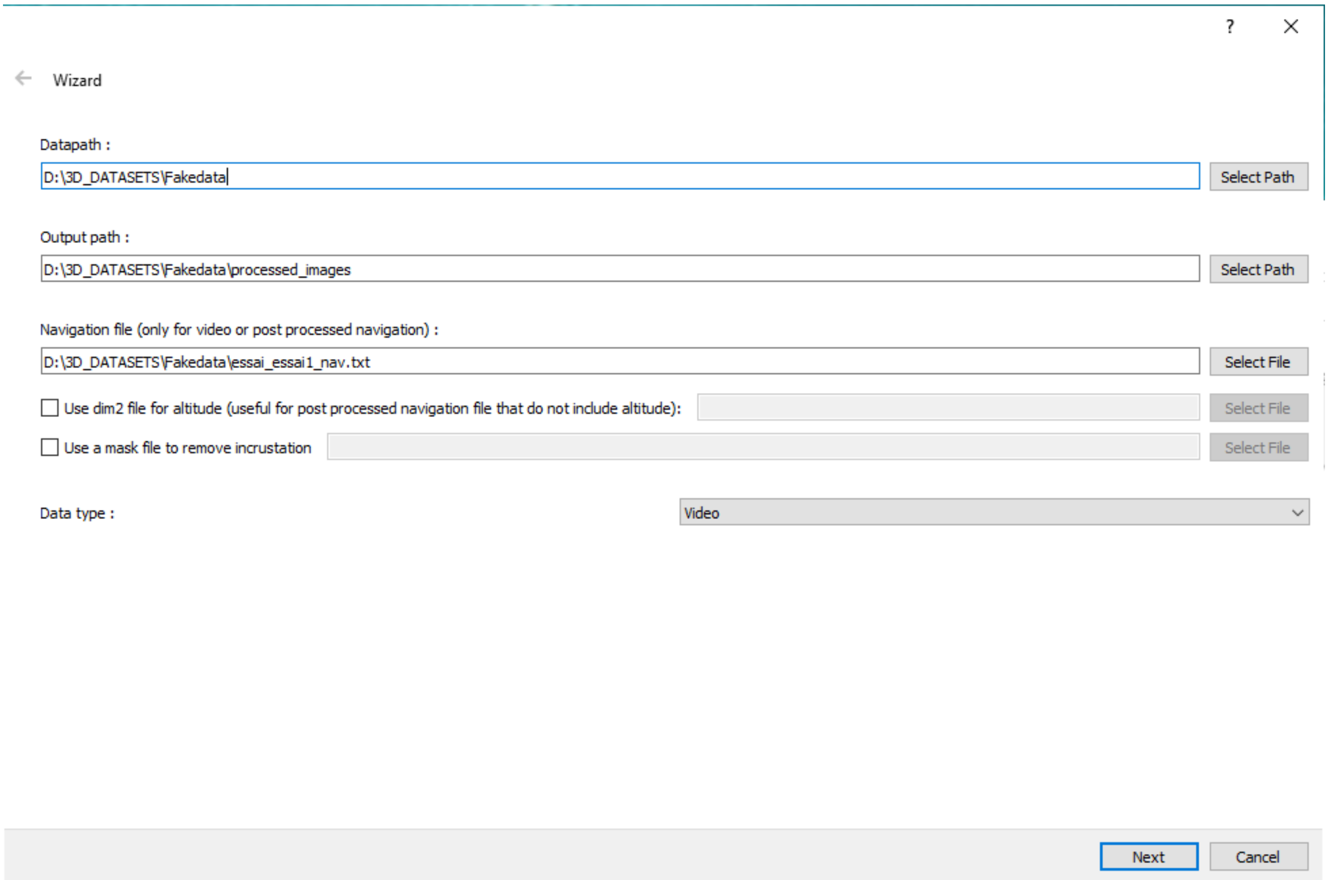


Fig 1. First Matisse Preprocessing wizard window

In the first page the user must enter the datapath with “Select path” and select the folder containing video(s) or images to be processed. Through this wizard the user can also provide the navigation file associated with the video, if scaled, oriented, and globally located 3D models are required.

To synchronize video and imagery with navigation the filenames and the navigation files require certain naming and formatting conventions. For navigation files, Appendix C provides indications on both Ifremer and user formats, and formatting requirements.

Two filename formats for video are supported:

- Ifremer historical format: ***missionname_divenumber_YYMMDDhhmmss_CAMID.ext***, where missionname, divenumber must be present but can be any alphanumeric string (with no special characters) as these are not considered, YY is year with 2 digits, MM is month, DD is day, hh is hour, mm is minutes, ss is seconds, CAMID, which is a number identifying the camera channel and that can also be any alphanumeric string, and ext can be almost any video extension.

- Second is ISO Time naming: ***YYYYMMDDThhmmss.fffZ.ext*** following the same convention as before but with fff representing milliseconds.

Same constraints apply to images: if the user wants to synchronize images with the navigation the photo must have a name corresponding to the date and time of image acquisition, with the following format: ***YYYYMMDDThhmmss.fffZ.ext*** (where ext can be jpeg, jpg, tiff, png).

The output path is automatically filled to datapath\processed_images, and may be changed by the user.

Finally, you can select a navigation file (again if you need navigation synchronization for scaling of the scene) and select the data type (video or photos). See appendix C for the supported navigation format.

For legacy video data containing incrustations, or for video streams where vehicle hardware appears in the frame, it is possible to remove these undesired image sections using inpainting. For this, the user can check “Use a mask file to remove incrustation” and provide a mask as a tiff image file, with black background for parts to be kept and full white for parts to be removed (see Figure 2 for example).

This mask has to be of the same size as that of the frames to process, and has to be provided by the user. To construct this mask, the user can use any image software (e.g., Photoshop, Affinity Photo, Inkscape, GIMP, etc.), and generate the corresponding tiff image to upload in Matisse.

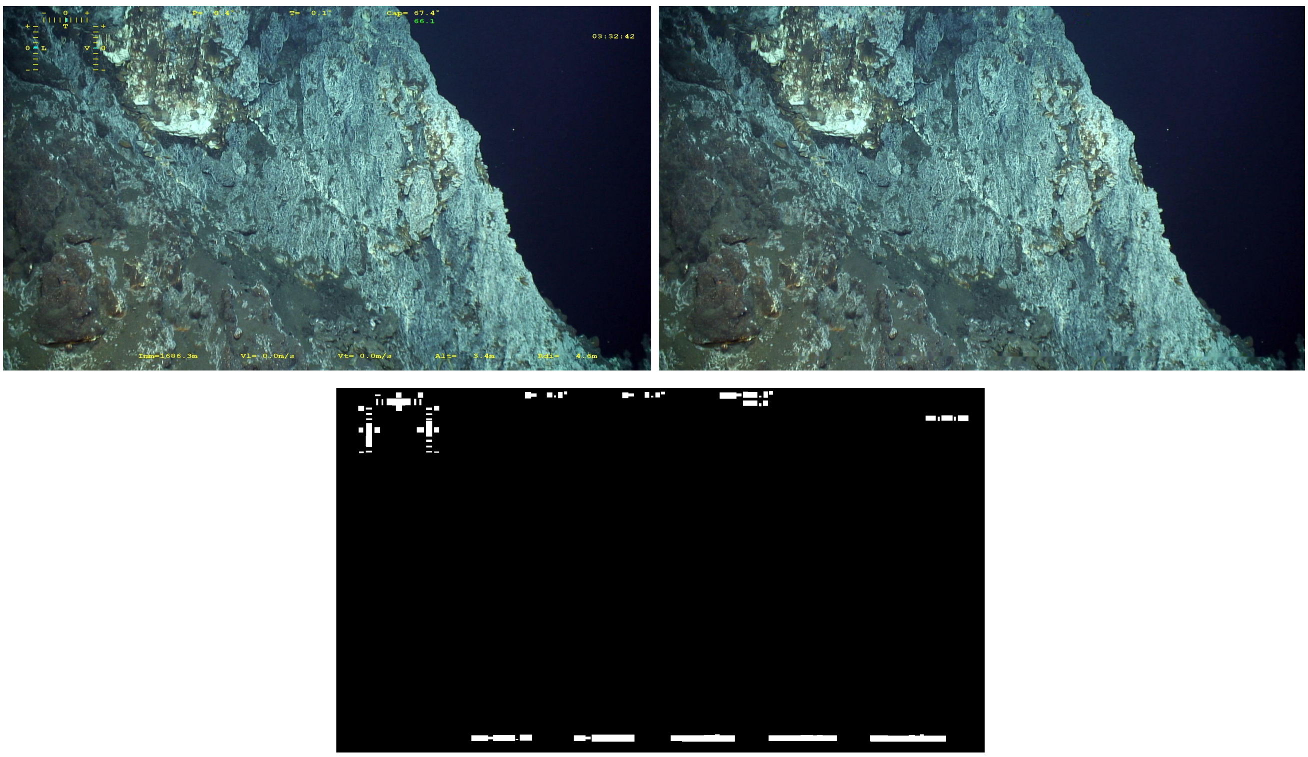


Fig. 2 Example of inpainting used to remove incrustation from images. At the top left is the image before inscrustation removal and on the top right after. The mask image used for inpainting is presented at the bottom. It is a tiff image file, with black background and full white for parts to be removed.

Once all the information completed, and upon pressing “Next”, the user reaches a second wizard page (Fig. 3):

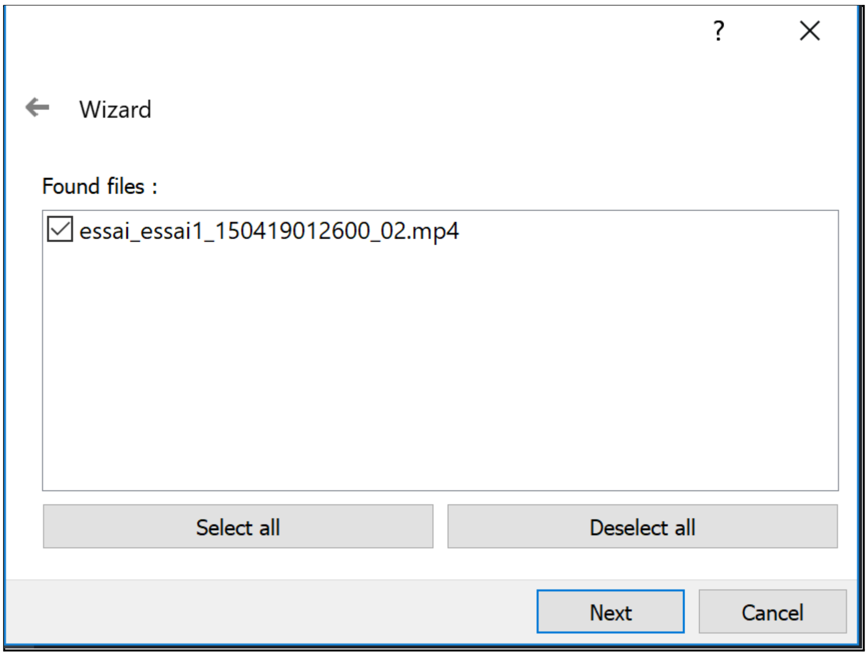


Fig. 3 Selection of files to be processed

This wizard page shows the files that have been identified in the data folder and that can be processed. The user can select one, a subset, or all of the files to process, either video files or images.

Upon clicking “Next” the user accesses a third and last window (see Fig. 4):

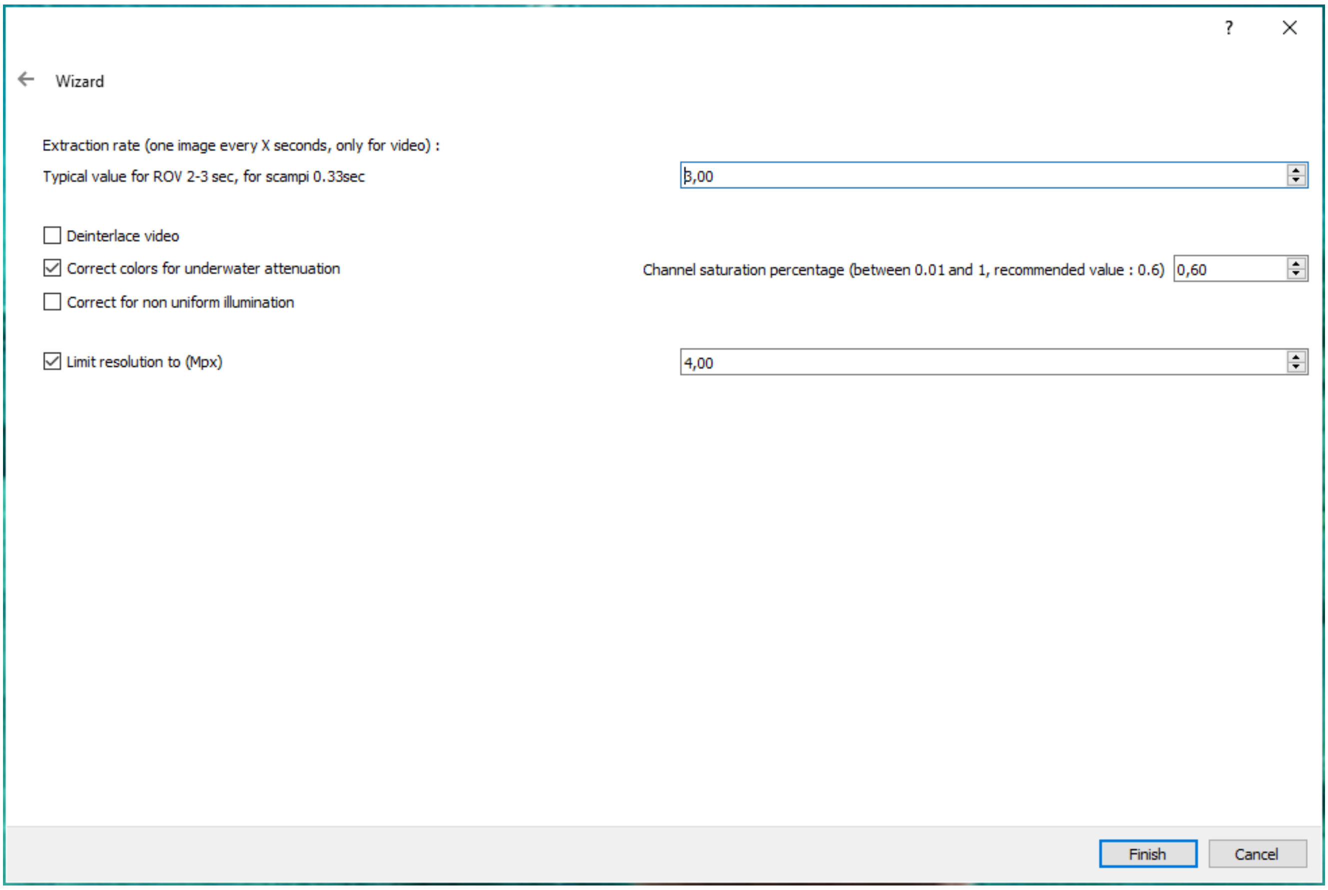


Fig. 4 selection of preprocessing parameters

In this window, the user can select 4 processing parameters:

- Extraction rate: This parameter is only used for video files, and corresponds to the time interval between two images extracted from the video. This time interval should be shorter for faster-moving surveys than for slower ones. A typical value is 2-3 seconds for videos acquired with ROV or submersible (e.g., Nautile), and 0.33 seconds for faster-moving platforms (e.g., typically for deep-towed systems such as Ifremer’s Scampi imaging sled).

- Deinterlace video: This parameter is only used for video. Must be checked if the input video is interlaced (eg. Scampi HD or older video formats, such as early Victor data)

- Correct colors: This can be checked if the user wants to correct images for color, intended to remove underwater colors artefacts. This parameter will apply to either selected images, or extracted frames from video using the two parameters above.

- Correct for non-uniform illumination: The user can check this case if the input imagery has a non-uniform illumination pattern (e.g., centered illumination that decreases towards the edges). This is the case for most deep-sea imagery, acquired with artificial lighting.

- Limit resolution (in Mpx): This option is useful to reduce image size and subsequently minimize the time of the 3D reconstruction.If images have a resolution that is higher than this value, then the images are scaled down to this value.

Finally the user can click on the ‘finish’ button and the dataset is then pre-processed. Processed images are saved into a separate folder that contains both these images, and the navigation file associated with the images in matisse dim2 format. This navigation file thus parses the original navigation files so that each image has the required navigation information for subsequent processing.

4. Post-Processing with Matisse

To build reconstruction from your images you can run Matisse 3D in post-processing mode, which is the default launching mode (see appendix A for other available modes of post-processing). The user should access a purple/gray interface window (Fig. 5):

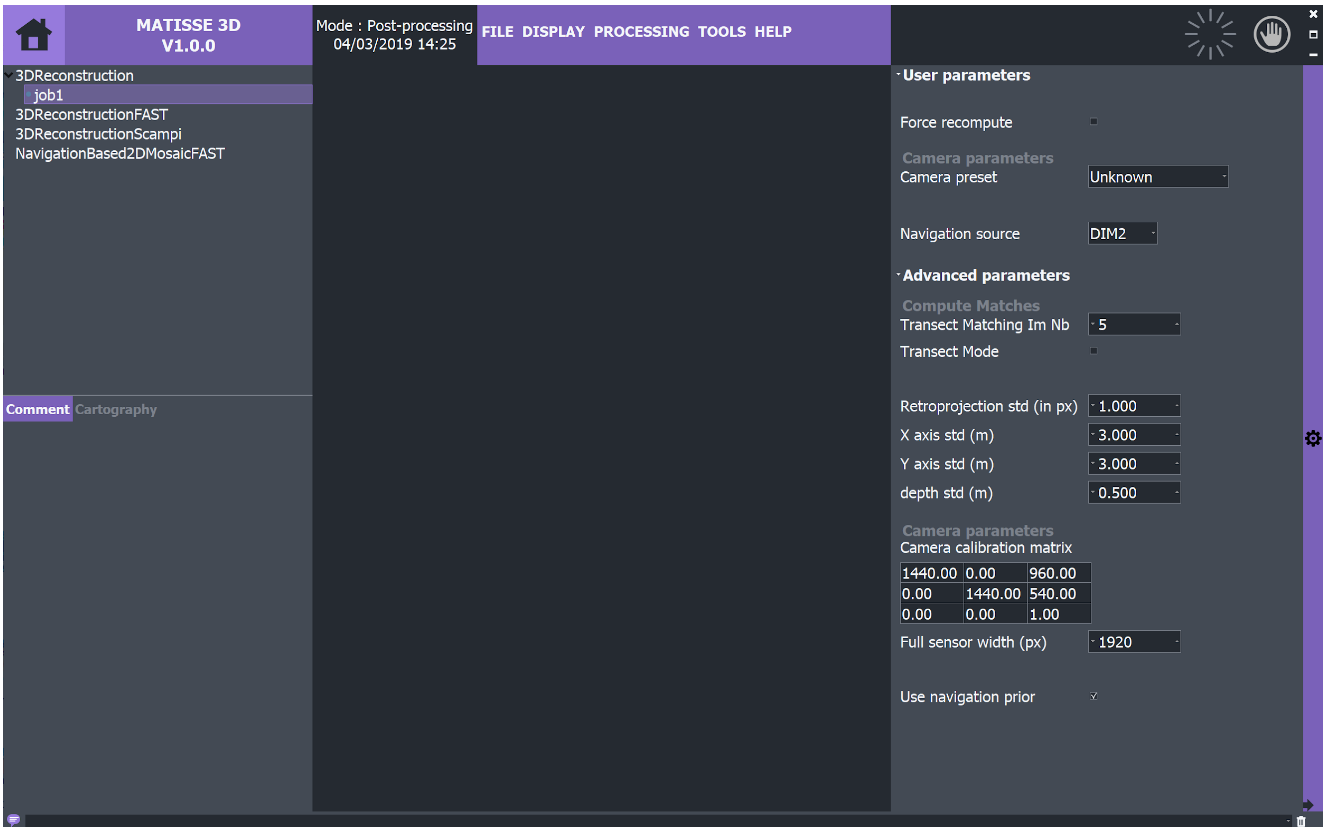


Fig. 5 Matisse post processing main interface window.

The left panel lists the available processing methods, and the header horizontal bar at the top includes the main menu, a wheel to indicate if processing is taking place, and a hand to stop the current process. The right panel provides tuning algorithm parameters. Parameters are classified in two categories: ‘user’ with some basic parameters, and an ‘advanced parameters’ menu, that includes default values and that requires deeper understanding of the 3D reconstruction method and processing.

The first required user action is to select the algorithm that is best suited for the purposes of the user’s processing. The choice is straightforward, based on a broad description of the available algorithms:

- 3D Dense: This is the most generic algorithm for 3D reconstruction. The user can process images acquired with an underwater vehicle or a diver.

- 3D Dense FASTER: Same as the previous one but faster. This algorithm is useful for low-capacity computers but the resulting resolution will be lower than that from the prior method 3D Dense.

- 3D Sparse FASTEST: This is the fastest technique but provide the less 3D details about the scene. It can be used for low power computer or when overlap between images is too low or just to simply have a result as fast as possible.

To apply an algorithm to a dataset the user must **right click** on the algorithm of choice (left panel) then click “create new task”. This will open the following window:

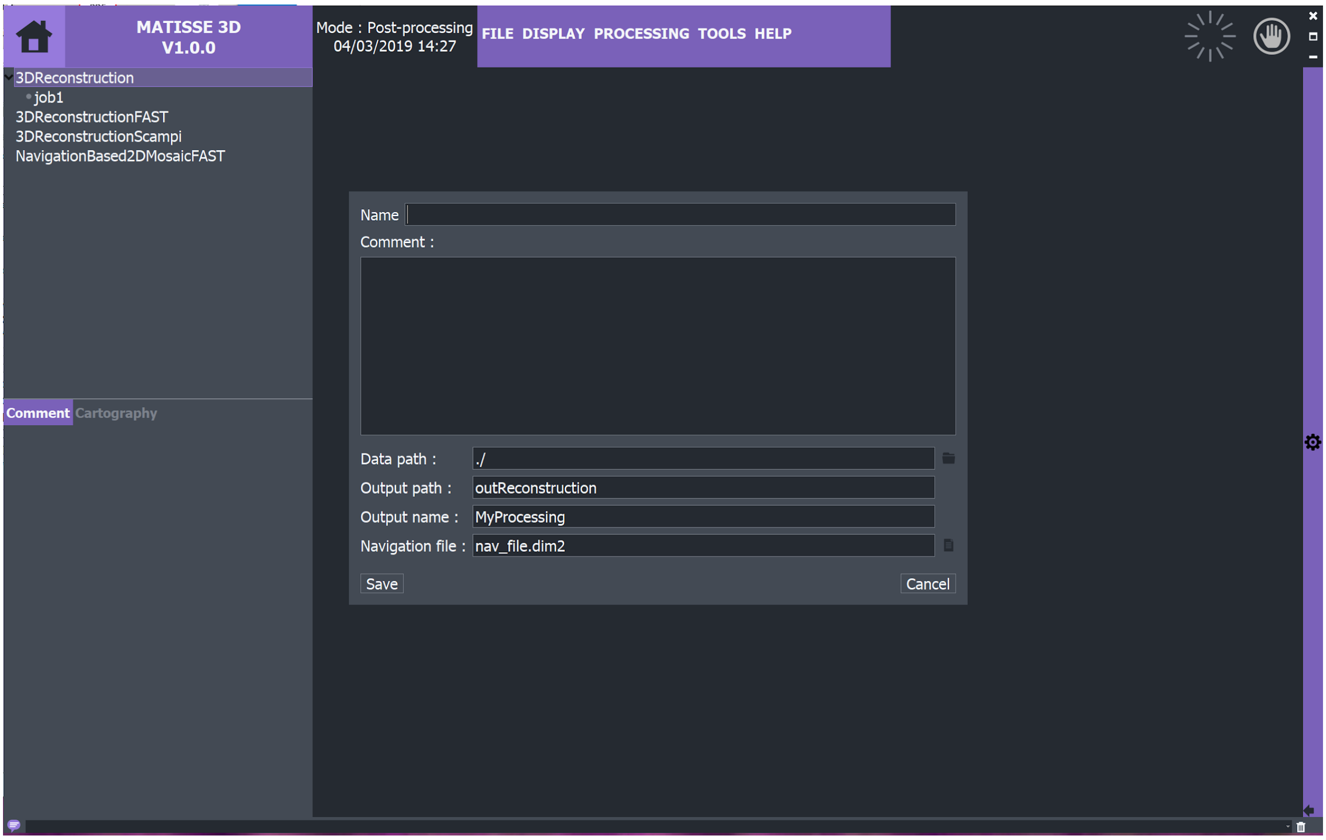


Fig. 6 Required information to start processing.

The user has to give a name to the task, with the option to enter a comment. The user must also select the appropriate data path (where images to process are located). The user can leave the default output folder which is “outReconstruction”. You can select a name for the reconstruction; this is also the name that will be given to 3D files resulting from the processing. And finally, and optionally the user can select the navigation file. This navigation file is mandatory to obtain scaled reconstructions. Click “Save” once all the information is completed.

The task (named also a job) appears under the algorithm name on the left panel. The right panel opens and gives the user the opportunity to tune some parameters for the acquisition. The main ones are:

- Camera preset: select the camera you used for the acquisition. If the user ignores the camera information or has no access to it, “unknown” can be selected instead. This choice, however, may result in lower quality reconstructions relative to those with well calibrated cameras, or the reconstruction may fail , depending on survey conditions. The default available cameras are those from Ifremer vehicles, but Appendix B provides information on how to add additional cameras by the user.

- Navigation source: Use dim2 navigation file or EXIF. If EXIF is selected, the standard GPS data is used from image metadata (see Appendix for navigation file format).

- Navigation and image quality parameters (they can differ for USBL only vs PHINS):
  - Reprojection std (in px), this is the confidence of point localization in camera frame
  - X axis std, standard deviation in navigation x axis.
  - Y axis std, same as X for Y
  - Depth std, same as X for depth

Then the user can right click on the task to save parameter with “Save” button. Then another right click again over the job or task allows the user to run it with the “Run button”.

As long as the wheel is turning, the program is being executed, and has not crashed. Depending on the size of the image dateset, this process can take a very long time, depending also on computer power, and the user should not assume that the software is frozen. For example, with a 2018 gen core i7, 4000 thousand images in HD resolution require somewhat above 1 week of processing time. In some cases, with insufficient RAM memory, the system may terminate Matisse, and the processing will not be completed. Here is an example of log of a 3D reconstruction that terminated normally :

[MODULE Init3DRecon]: Initialize Sfm from data

[MODULE Init3DRecon]: usable #File(s) listed in sfm_data: 367

usable #Intrinsic(s) listed in sfm_data: 1

[MODULE Init3DRecon]: took 0.111 seconds

[MODULE Matching3D]: Features matching started

[MODULE Matching3D]: took 771.904 seconds

[MODULE SfmBundleAdjustment]: Bundle adjustment started

[MODULE SfmBundleAdjustment]: took 182.109 seconds

[MODULE Meshing3D]: Meshing started

[MODULE Meshing3D]: took 40.646 seconds

[MODULE Texturing3D]: Texturing started

[MODULE Texturing3D]: took 24.766 seconds

We see that the last module, here Texturing3D ended and took 24.766 seconds, so the reconstruction should be complete.

5. Description of the output files of the reconstruction

Upon successful processing, the Matisse log will indicate ‘Texture reconstruction finished’. Matisse will return a single reconstruction, or several if the program is unable to join different sets of images into a single 3D model. Multiple files will be found in each destination folder, for each of the models in the output. As an example of files that can be found for a reconstruction named “MyProcess” (corresponding to the default name as shown in Figure 5), the resulting files include:

- **cloud_and_poses.ply** -> 3D sparse reconstruction, first step of the reconstruction
- **MyProcess_X_dense.ply** -> same as the previous one but with more points (densification)
- **MyProcess_X_dense_mesh.ply** -> meshing (surface) made with the previous one

- Final reconstruction files (with texture reconstruction). The user needs all these files for further processing:
    - **MyProcess_X_texrecon.kml**: geo-localization file
    - **MyProcess_X_texrecon.obj**: 3D data of the model
    - **MyProcess_X_texrecon.mtl**: list of textures
    - **MyProcess_X_texrecon_materialYYYY_map_Kd.png**: images required for 3D scene texturing

- Temporary files are in a separated “temp” folder that can be removed if the user is satisfied with the result, but that are useful for troubleshooting:
    - All mvs files
    - Files beginning with xxxx_Resection.ply (where xxxx is a number)
    - spt and vec files
    - MVE folder
    - “Matched” and “splitted_matches” folders

Appendix A : Application modes

Matisse can be run in different modes for different purposes. The user can change the current mode by clicking on the house icon in the top left, and the following window appears:

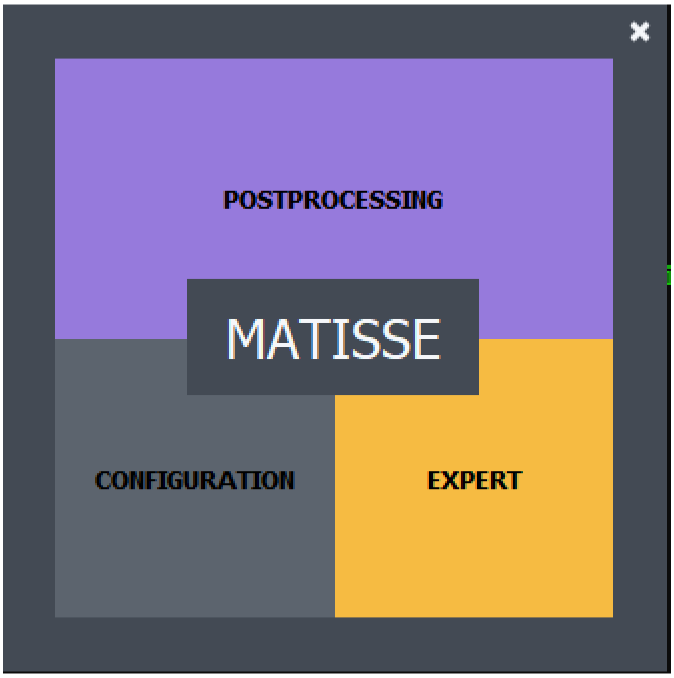


Fig. 7 Matisse welcome dialog. It lets the user choose the running mode

There are two launching modes:

Expert mode, corresponding to yellow bottom right square in figure 7, which, as the name suggests, is mainly for experts, giving access to all Matisse settings and processing chain creation. This mode is grayed by default and can be activated in the configuration (bottom left in grey). Standard users should not need to access this mode, but technical support can ask the user to go into this mode mainly for troubleshooting and provide help, solving specific user problems or issues.

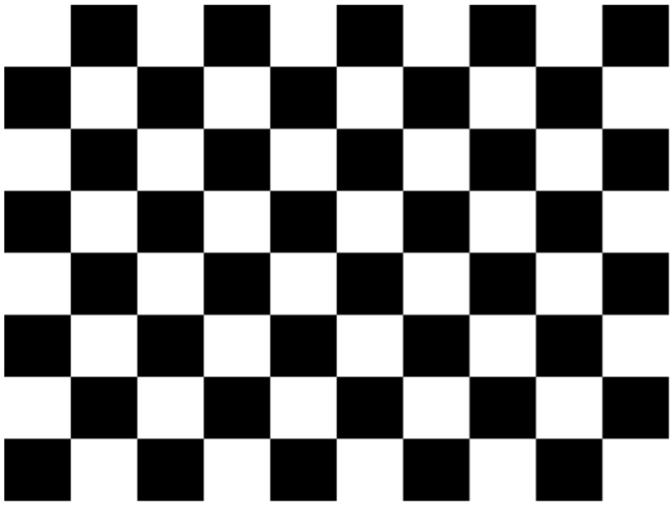
Postprocessing mode, which is the main user mode for launching reconstructions on already acquired data. This quick guide (see above) focuses mainly on this mode.

Appendix B : Camera calibration and management

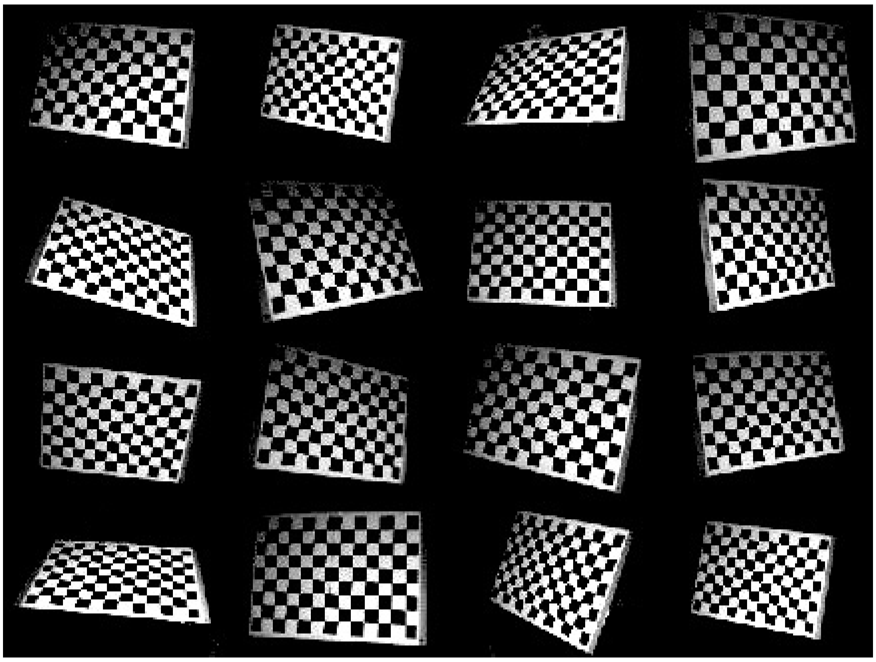
In order to obtain the best possible results for your reconstructions it is highly recommended to calibrate the cameras used in surveys and subsequent 3D processing. If the user's camera has a zoom, it must be calibrated at the same level of zoom as the one used for the reconstruction. If the user's camera is used for underwater images, then it must be calibrated with images taken underwater. It is recommended to calibrate the camera at full resolution and Matisse will handle any rescaling. If the user already has a calibrated camera, it can be directly added to the software using matisse camera manager.

A. How to calibrate your camera

For the calibration the user will need a chessboard calibration pattern (see below)



This particular calibration pattern is a 9 by 7 chessboard pattern. Numerous other calibration patterns are available on the web, and that can be printed to calibrate cameras. It is critical to leave a white space around any of the patterns, so that the edges can be fully detected by the Matisse processing. Then the user must acquire multiple images of this pattern in different positions and orientations, as shown in the example below with 16 images:



The pattern should not be too far from the camera, so as to fit as much as possible entirely in the camera field (not cropped at the corners) and with varying angles from one image to the other. At least 10 images are recommended, more images provide more robust results. When in doubt, users may contact the authors of the software.

Once the calibration images have been acquired, the user can launch the Matisse camera calibration tool from the main menu in Maisse (Tools -> Launch camera calibration tool). A window similar to that in Figure 8 should appear, where the user can provide the required information and settings.

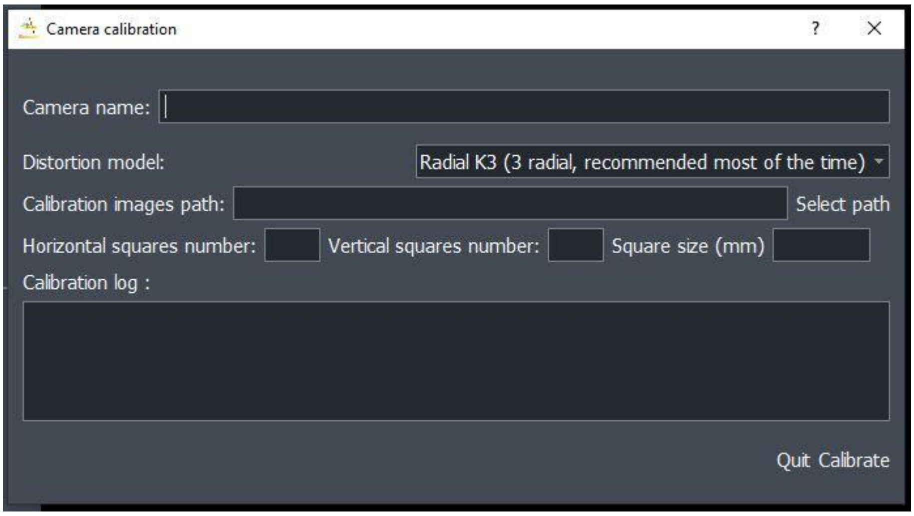


Fig. 8 Calibration window

Here is a description of the settings that the user needs to enter:

- Camera name: This is the camera name that will be incorporated into the Matisse calibration library after the camera parameters are acquired
- Distortion model: Most cameras will give good results with Radial K3. If the user used a fisheye camera then, in general, it is best to use the fisheye model. In any case users may try

multiple models and retain the one with the lower calibration error. If Radial K3 and Brown T2 yield the same error then the user should use Radial K3, given that it is a simpler model and it will hence improve the stability of the reconstruction.

- Calibration images path: Select path to the calibration image set.
- Horizontal squares number: number of horizontal squares in the calibration pattern.
- Vertical squares number: number of vertical squares in the calibration pattern.
- Square size: size of square edge (side) in the calibration pattern.

Once all the needed information has been entered, clicking on ‘Calibrate’ will start the calibration procedure. At the end of the process, if completed successfully, the user’s camera will be added to the Matisse camera list and be subsequently available for processing.

B. Camera manager: This functions allows the user to Add/Remove/Check the available cameras in Matisse

The user can launch the camera manager from Tools->Launch camera manager. The opened window is as follows (Figure 9):

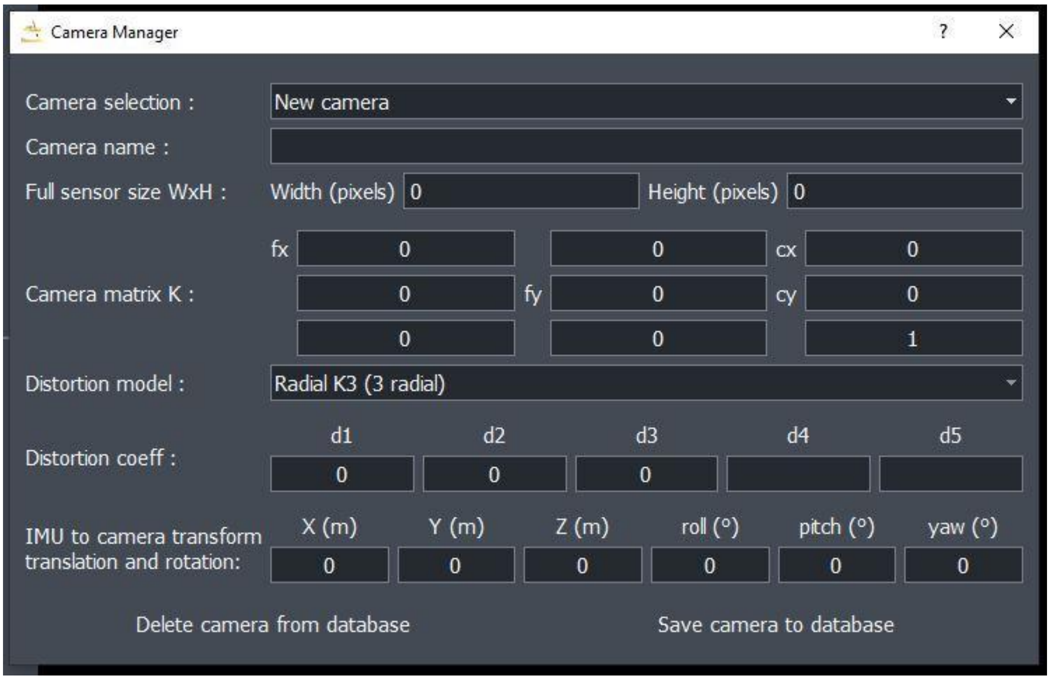


Fig 9. Window showing the camera calibration parameters, camera position (if available) and menus to save/edit/erase cameras in Matisse.

The user will find in the camera selection list all the cameras calibrated with Matisse or added through this manager. One can modify and save it, or can create a new one by selecting “New camera”. The parameters in display are standard, and correspond to the intrinsics.

The last line is the position of the camera relative to the center of navigation of the vehicle. If the navigation output is that of the camera location, or if the user does not have this information, then all parameters should be left set to 0 as in Figure 9.

Appendix C: Supported navigation format

Navigation files can be provided in two formats. First, Matisse can process the standard IFREMER navigation format. Second, the user can provide a csv file with mandatory and optional parameters, ase described below.

IFREMER format

The IFREMER format provides fields in the following order, in a comma-separated file:

Date (format, detects if YYYY/MM/DD or DD/MM/YYYY)
Time (format, detects of hh:mm:ss.zzz or hh:mm:ss)
Latitude (in decimal degrees)
Longitude (in decimal degrees)
Depth (positive down and negative up (note: opposite notation relative to altitude in airborne applications)
Altitude (positive distance to the seafloor)
Heading (positive clockwise, angles in degrees)
Pitch (positive down, angles in degrees)
Roll (positive starboard, angles in degrees)

Matisse verifies that the file has 8 fields, and ignores additional fields that are common in IFREMER format files. Matisse also ignores the first line with the field headers.

The 5 mandatory fields for 3D reconstruction are date, time, latitude, longitude, and depth; other fields can be set to zero.

The 6 mandatory fields for 2D navigation-based reconstruction are date, time, latitude, longitude, altitude, and depth; other fields can be set to zero.

Important note: both latitude and longitude must have high accuracy, so that local photomosaics can be built and georeferenced, and be free of any rounding)

```
DATE,TIME,LATITUDE,LONGITUDE,DEPTH,ALTITUDE,HEADING,PITCH,ROLL
19/10/2020,23:09:44.125,-12.845238667,45.681603333,50.9,2.80,322.7,-4.2,2.2
19/10/2020,23:09:45.250,-12.845238733,45.681603222,50.9,2.80,324.1,-4.2,2.4
19/10/2020,23:09:46.360,-12.845238800,45.681603111,50.9,2.80,324.8,-4.3,2.5
19/10/2020,23:09:47.754,-12.845238867,45.681603000,50.8,2.80,325.1,-4.4,2.8
```

User format

In addition to the Ifremer format, Matisse supports a comma-delimited text format, with one header line. Parameters can be provided in any order, but indicated in the text with adequate text labels as indicated below, and with the hashtag '##' as the first character sequence of the line so that it can be identified as the header.

The following parameters, with a name header indicated as in the bold character, and with the formatting as indicated here will be read by Matisse:

Mandatory fields

latitude - decimal degrees, positive for N, negative for S; XX.XXXX
longitude - decimal degrees, positive for E, negative for W
lepth - m (positive down)
leading - degrees from N (positive clockwise)
altitude - m (distance to seafloor, positive - note: mandatory for 2D navigation-based reconstructions)
date - several formats supported:

date_yyyy/MM/dd
date_dd/MM/yyyy
date_yy/MM/dd
date_dd/MM/yy
Note: 2 year digits are assume that if yy<70 correspond to the 2000's, and >70 to 1900's

time: autodetection of the format among hh:mm:ss.zzz and hh:mm:ss

Optional fields

Pitch - degrees (positive down)
Roll - degrees (positive starboard)
Altitude - m (non-mandatory for 3D, distance to seafloor, positive)

Here is an example of file:

##date_dd/MM/yyyy,time,latitude,longitude,depth,altitude,heading,pitch,roll
19/10/2020,23:09:44.125,-12.845238667,45.681603333,50.9,2.80,322.7,-4.2,2.2
19/10/2020,23:09:45.250,-12.845238733,45.681603222,50.9,2.80,324.1,-4.2,2.4
19/10/2020,23:09:46.360,-12.845238800,45.681603111,50.9,2.80,324.8,-4.3,2.5
19/10/2020,23:09:47.754,-12.845238867,45.681603000,50.8,2.80,325.1,-4.4,2.8

Appendix D: Training datasets

The users can access 4 different datasets on-line, that include imagery (still images and video), associated navigation files, and the resulting 3D textured models generataed with Matisse. These datasets are presented in Arnaubec et al. (submitted Computers and Geosciences)

Arnaubec A., Escartín J., Opderbecke J., Matabos M., Gracias N. (2021). Underwater 3D terrain reconstruction from video or still imagery: Processing and exploitation software (MATISSE & 3DMETRICS). Computers and Geosciences, Submitted.

The datasets, with the link to download them via the doi link, include:

- Seafloor with litter. This survey was acquired with HROV Arianne:over a flat seafloor area, with numerous debris of human origin. This dataset includes two different models, one without proprocessing of images including colour correction, and a second one calculated form images including colour correction.
  Doi: https://doi.org/10.17882/79024

- Fault scarp. This ROV Victor 6000 survey targeted a sub-vertical fault scarp for studies of faulting and seismicity (see Escartín et al., 2016, Earth and Planetary Science Letters).
  Doi: https://doi.org/10.17882/79217

- Hydrothermal chimney. This ROV Victor 6000 survey targeted a ~20 m high hydrothermal chimney, Tour Eiffel, from the Lucky Strike hydrothermal field at the Mid Atlantic Ridge. Original video data was pre-processed to remove incrustations. Processed imagery is provided in this dataset.
  Doi: https://doi.org/10.17882/79218

- Whipwreck. This HROV Arianne survey targeted a 1903 torpedo boat shipwreck off the French Mediterranean coast.
  Doi: https://doi.org/10.17882/79028

Appendix E : 2D photomosaics from navigation data

Seafloor mapping can exploit sparse imagery (e.g., towed systems, images acquired during transits) that otherwise are not suitable for 3D reconstructions. Matisse implements a mode to use navigation information, including vehicle altitude above the seafloor, to generate 2D photomosaics, where the images are scaled, rotated, and placed geographically (e.g., See Escartin et al., 2018). This processing mode does not perform any feature matching nor re-navigation but as the method is very fast it can help process very large areas to obtain a global overview of the environnement.

It works exactly as 3D algorithms, you just have to create a processing task based on the “NavBased 2D Mosaic Fast” algorithm. The only difference is that you cannot process a dataset without altitude of the vehicle from the seafloor nor with an unknown camera (You must select a camera from Matisse database or create one).

By default, Matisse outputs standard geotiff files forming a 2D mosaic (see figure 10). You can also make independent, non overlapping tiles by selecting the “disjoint drawing” option in the parameter panel.

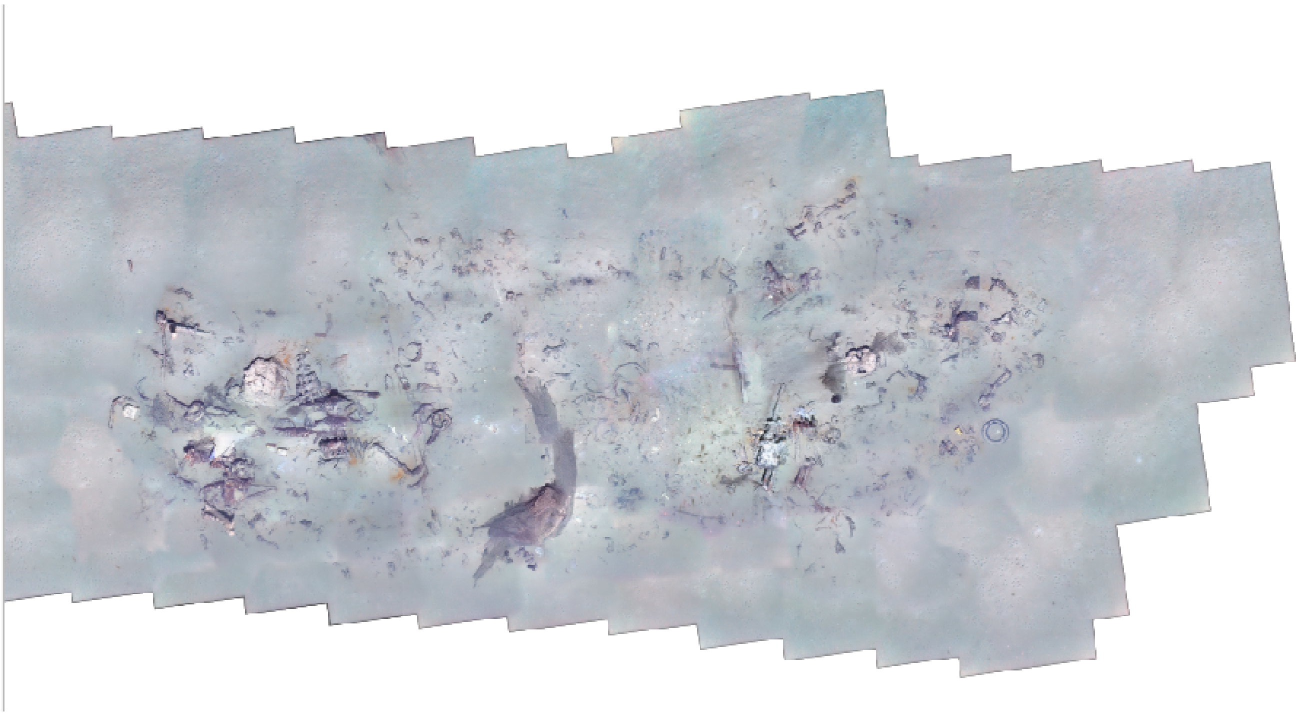


Fig 10. Example of 2D Mosaic produced with Matisse using one of the datasets we provided in openaccess (sea floor litter https://doi.org/10.17882/79024)