“Unravel”
An ImageJ Macro to aid conversion of interface roughness to planar roughness

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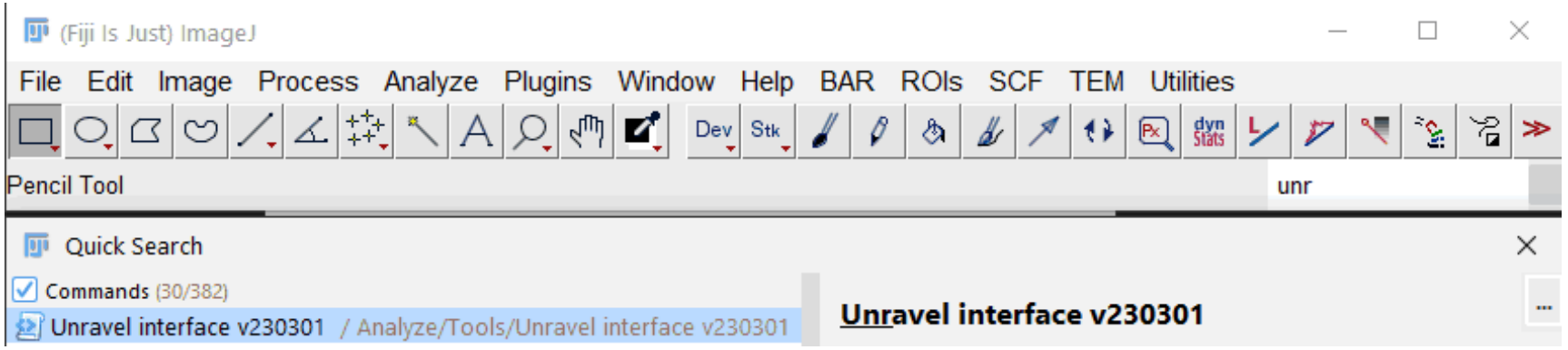
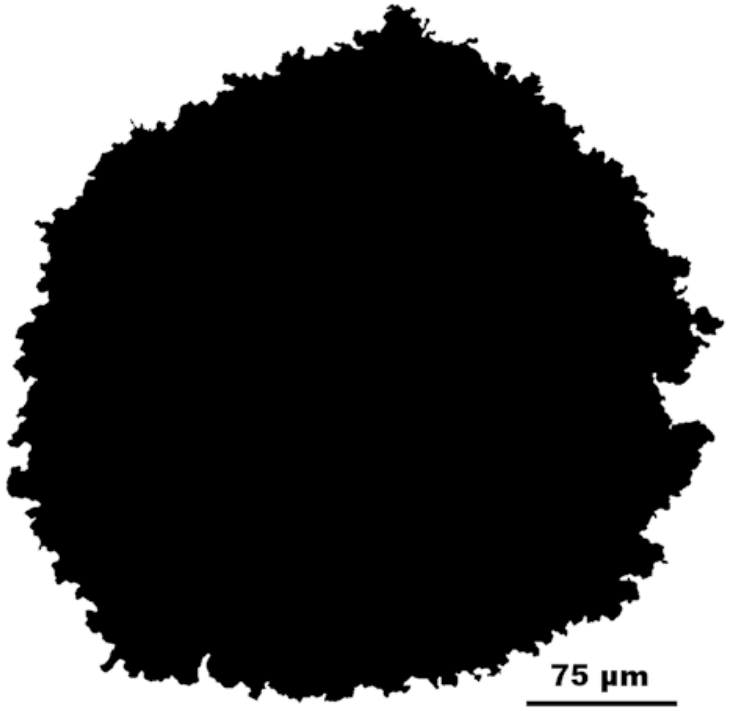


Issue: How do you obtain roughness from a cross-section of an interface?



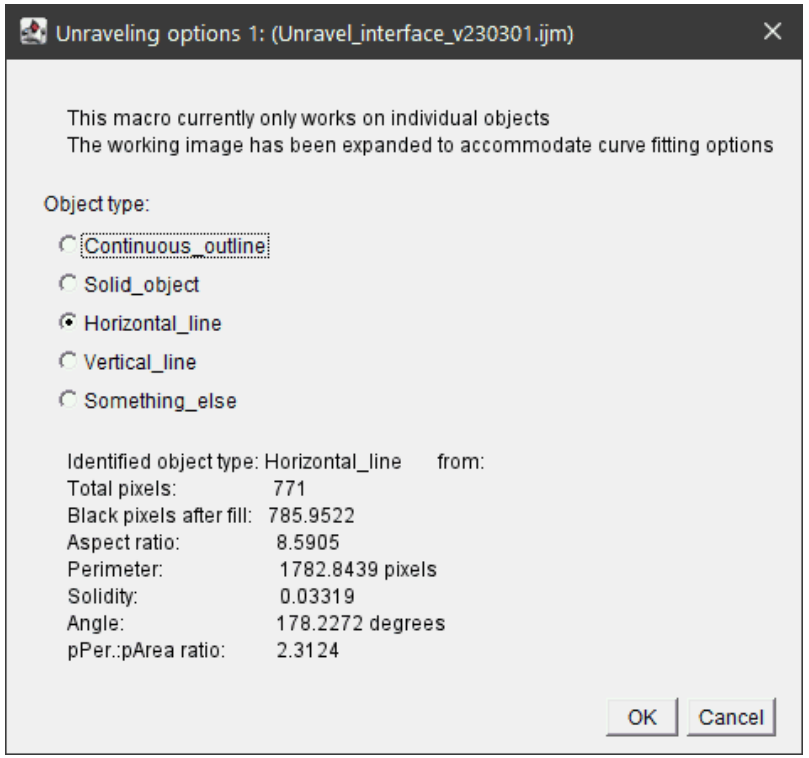
- Image above is a filament cross-section with a rough interface
  - How can the surface roughness be measured?

- Image above is an interface
  - Can the interfacial roughness be measured?

Menu 1: Choose object type

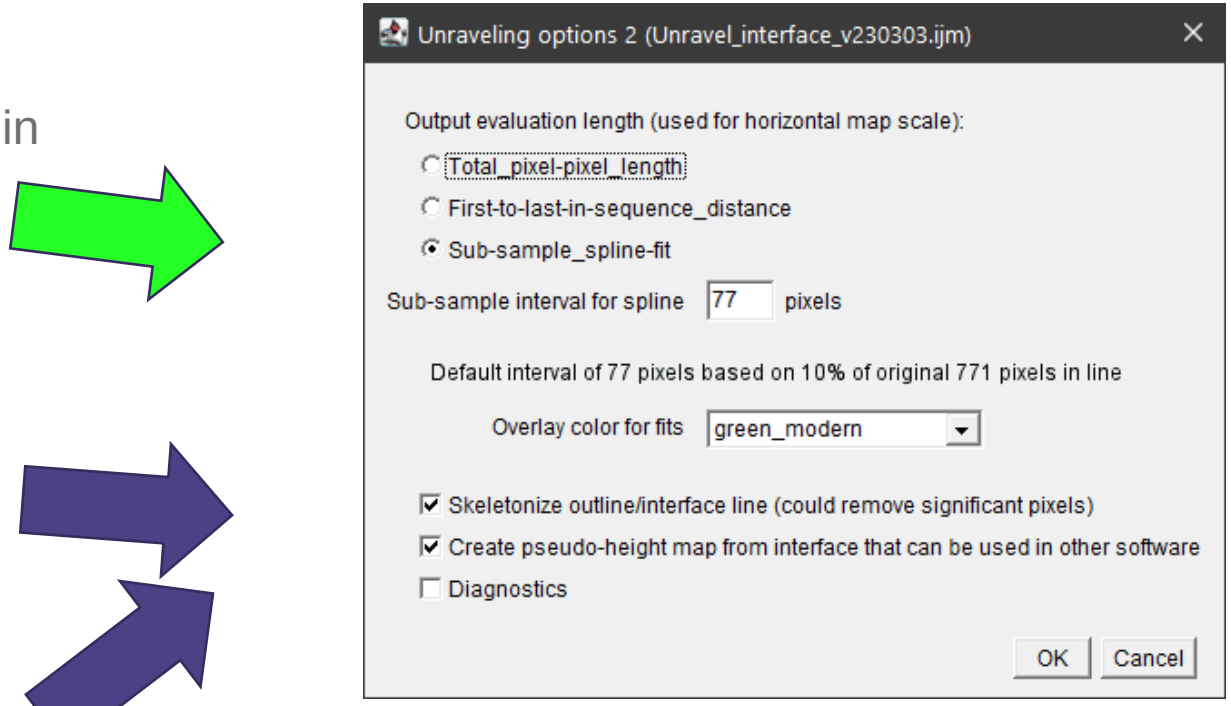
- Current version works on continuous outlines or solid objects

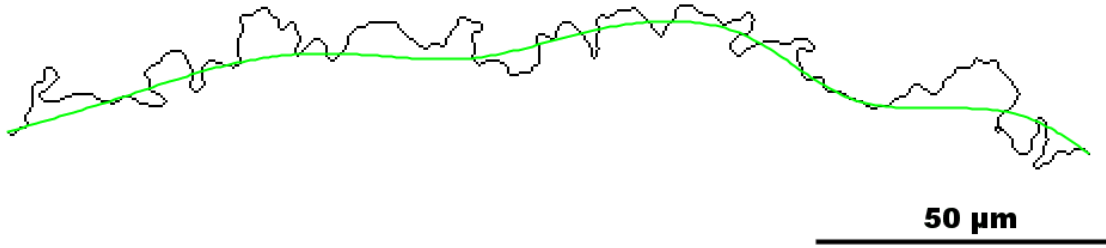
- The macro guesses the object type from measured parameters
  - In this case a horizontal line



Menu 2 (line): Sample length and basic options

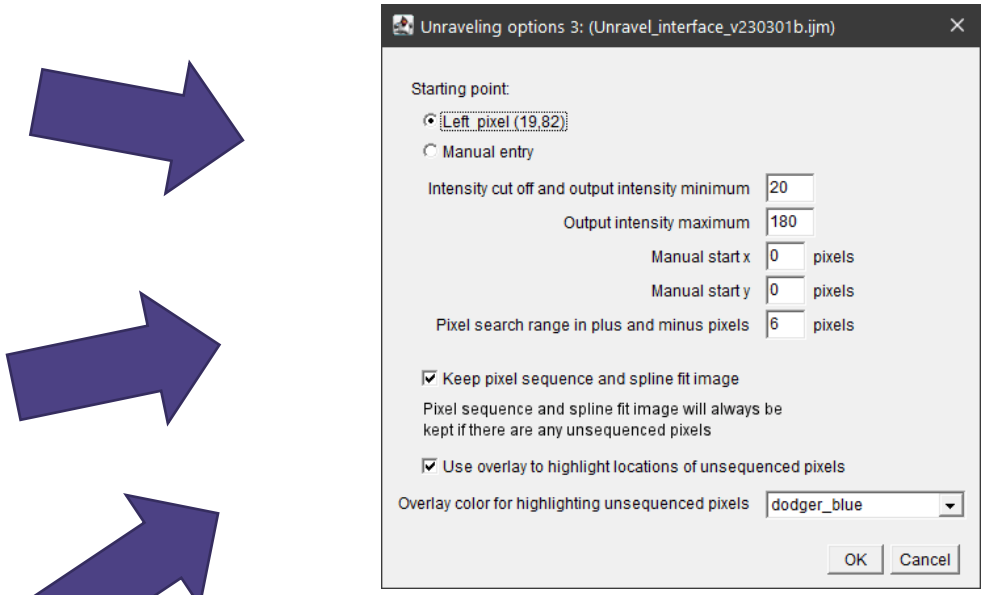
- 3 options for providing measuring the total evaluation length are provided:
  - This evaluation length will be embedded in the exported map
- The outline can be skeletonized to minimum pixel width but at the risk of losing significant pixels. Fewer skeletonized pixels will be missed from the unraveled sequence, so it is the default setting.
- A pseudo height map can be exported that can be used in 3rd party topographic software like Gwyddion

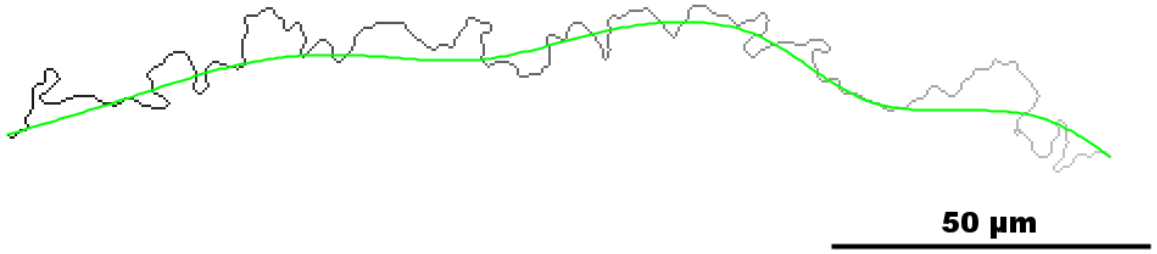




Menu 3 (line): Unravelling options

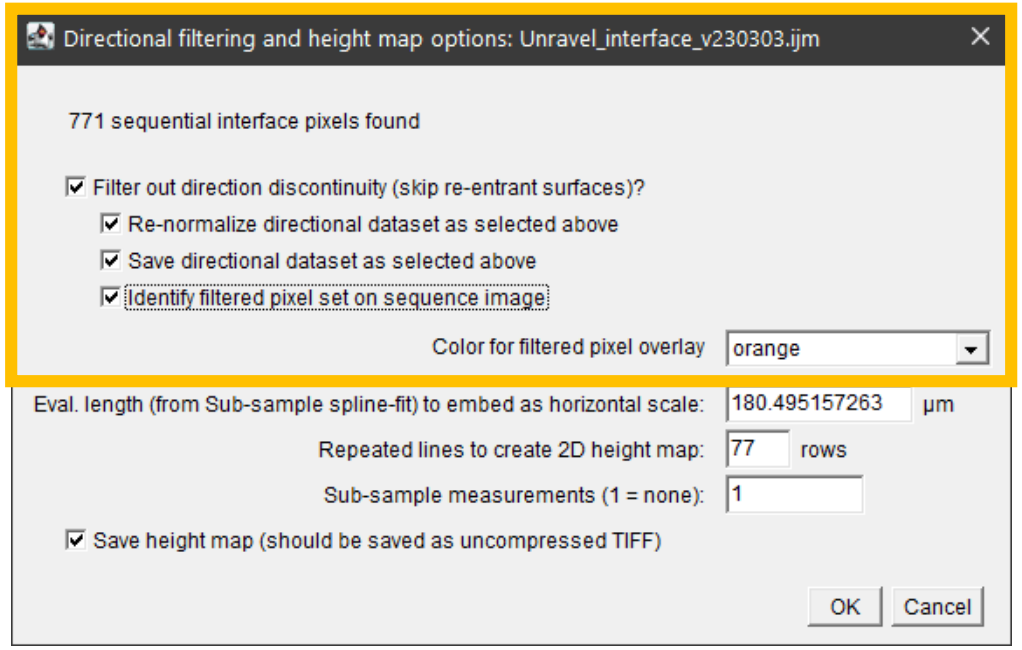
- The starting point of the unravelling can be selected
- The search range for the next pixel can be adjusted
- A map can be created to show the pixel sequence order and the spline fit

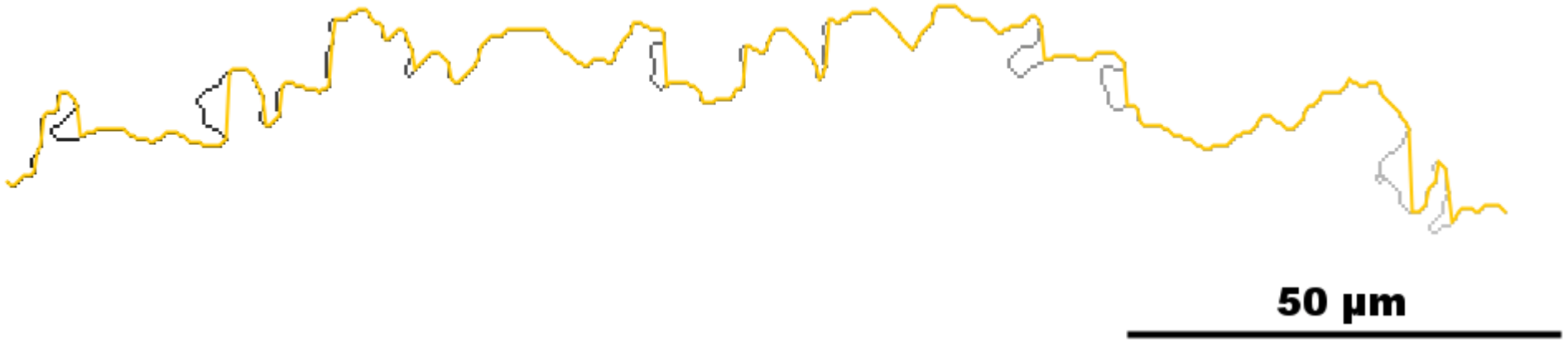




Directional continuity and other output options

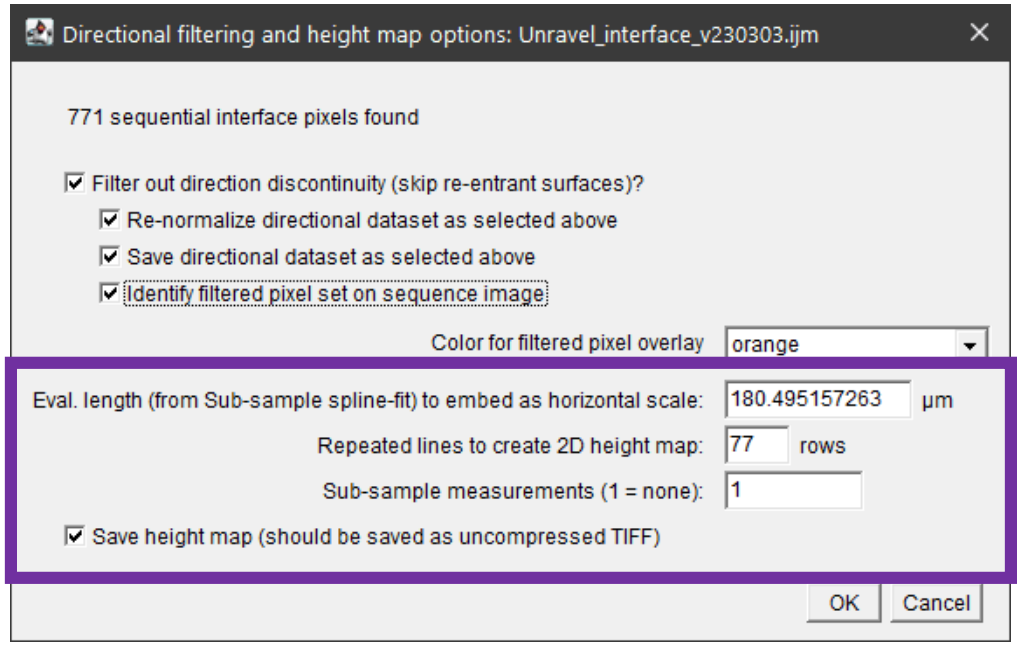
- A directional filter can be applied to remove reentrant features so results are more like that from a stylus
- Orange line below shows unidirectional set

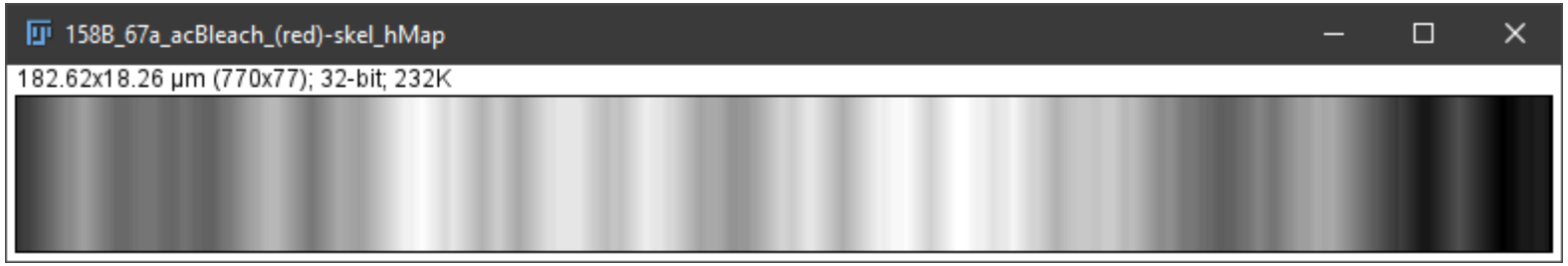




Pseudo height map from horizontal or vertical lines

- The 2D line data can be stretched vertically to create a 32-bit pseudo height map that can be imported into 3rd party topological analysis software
  - Unit-scaled “Heights” are directly stored in the 32-bit data
  - The measured evaluation length is embedded in the horizontal scale





“Heights” from horizontal or vertical lines

- For horizontal or vertical lines, “heights” are simply obtained from the *y* coordinates or *x* coordinates respectively
  - For horizontal lines the *y* coordinate is subtracted from the maximum *y* so that increasing “height” is upwards

Horizontal_interface_segment_unrav+Sub-sample_77pixel-spline-fit_outputCSV.csv

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Seq_coord_x	Seq_coord_y	Incr_dist(px)	Seq_dist(px)	Incr_dist(µm)	Seq_dist(µm)	Vert_dist(px)	Vert_dist_norm(px)	Vert_dist_norm(µm)	Vert_dist_norm_from_Mean(µm)	Vert_dist_norm_from_Mean^2(µm^2)	Seq_dist_NormToEval(µm)	Directional_continuity	Fourier_amps_uni-dir.
19	82	0.000000000	0.000000000	0.000000000	0.000000000	53	15	5.813957958	10.581755388	111.973547101	0.000000000	1	16.395713806
20	83	1.414213562	1.414213562	0.548145213	0.548145213	52	14	5.426360761	10.969352586	120.326696149	0.282564757	1	11.117042542
21	83	1.000000000	2.414213562	0.387597197	0.935742410	52	14	5.426360761	10.969352586	120.326696149	0.482368214	1	2.167309523
22	82	1.414213562	3.828427125	0.548145213	1.483887623	53	15	5.813957958	10.581755388	111.973547101	0.764932971	1	0.988444865
23	81	1.414213562	5.242640687	0.548145213	2.032032836	54	16	6.201555156	10.194158191	103.920861228	1.047497729	1	0.609142721
24	80	1.414213562	6.656854249	0.548145213	2.580178049	55	17	6.589152353	9.806560994	96.168638529	1.330062486	1	1.855682015

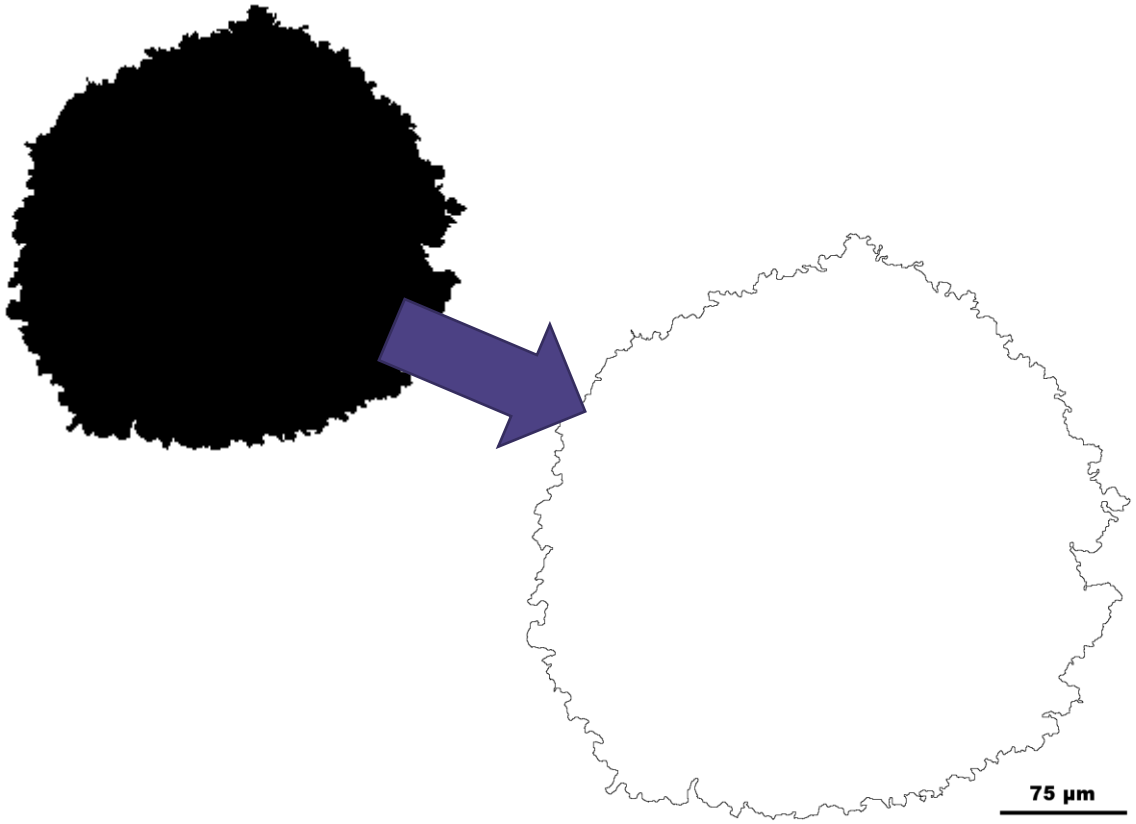
Note:
The Fourier sequence is calculated for the entire sequence (column is for convenience).

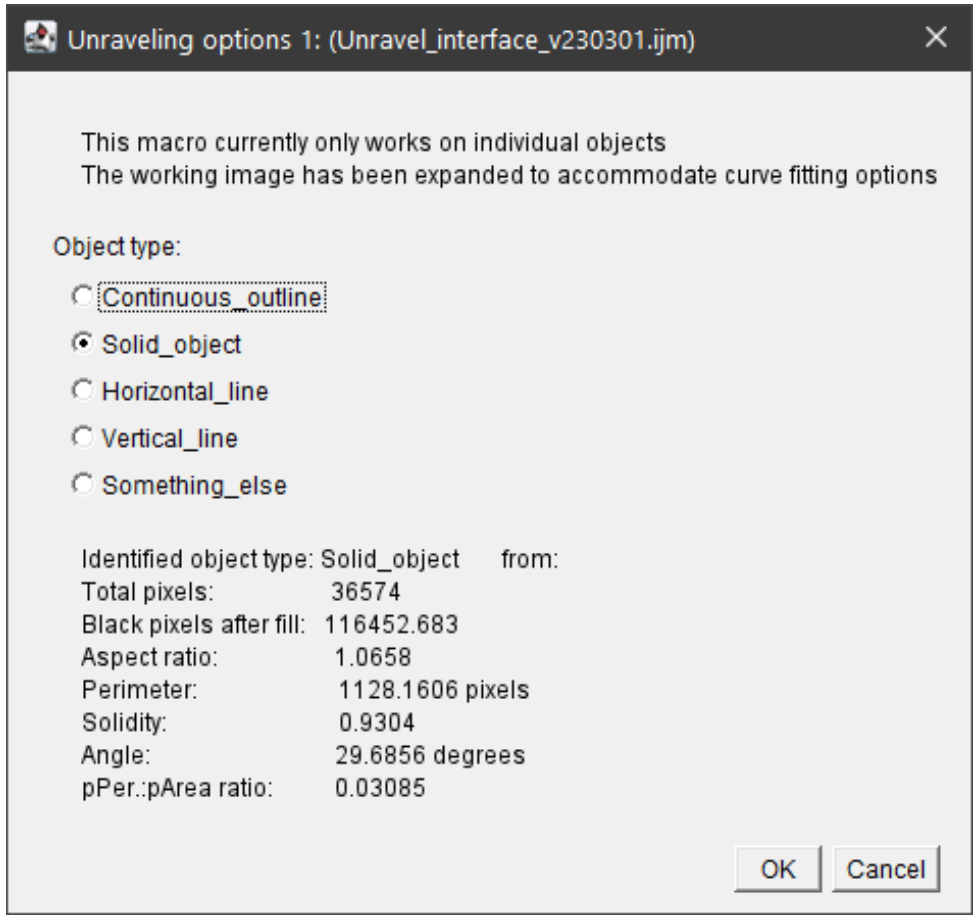
Ra and Rq of not have waviness extracted

```
Horizontal_interface_segment_unrav+Sub-sample_77pixel-spline-fit height statistics:
min = 0 µm
max = 25.1938 µm
range = 25.1938 µm
mean = 16.025 µm
std Dev = 6.2819 µm
_________Deviation from Mean_________:
min = 0.1335 µm
max = 17.1878 µm
mean = 5.2708 µm
std Dev = 3.6019 µm
_________The simple R values below do not have waviness extracted_____
Ra(full length) = 5.2708 µm
Rq(full length) = 6.3818 µm
_________
```

Menu 1: Choose object type – outline continuous

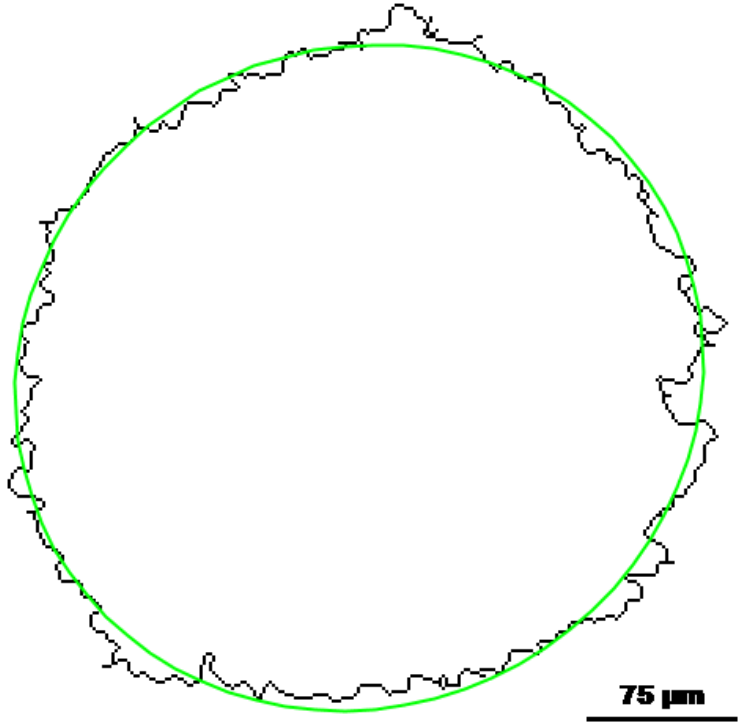
- This example: A continuous outline around an object will be created

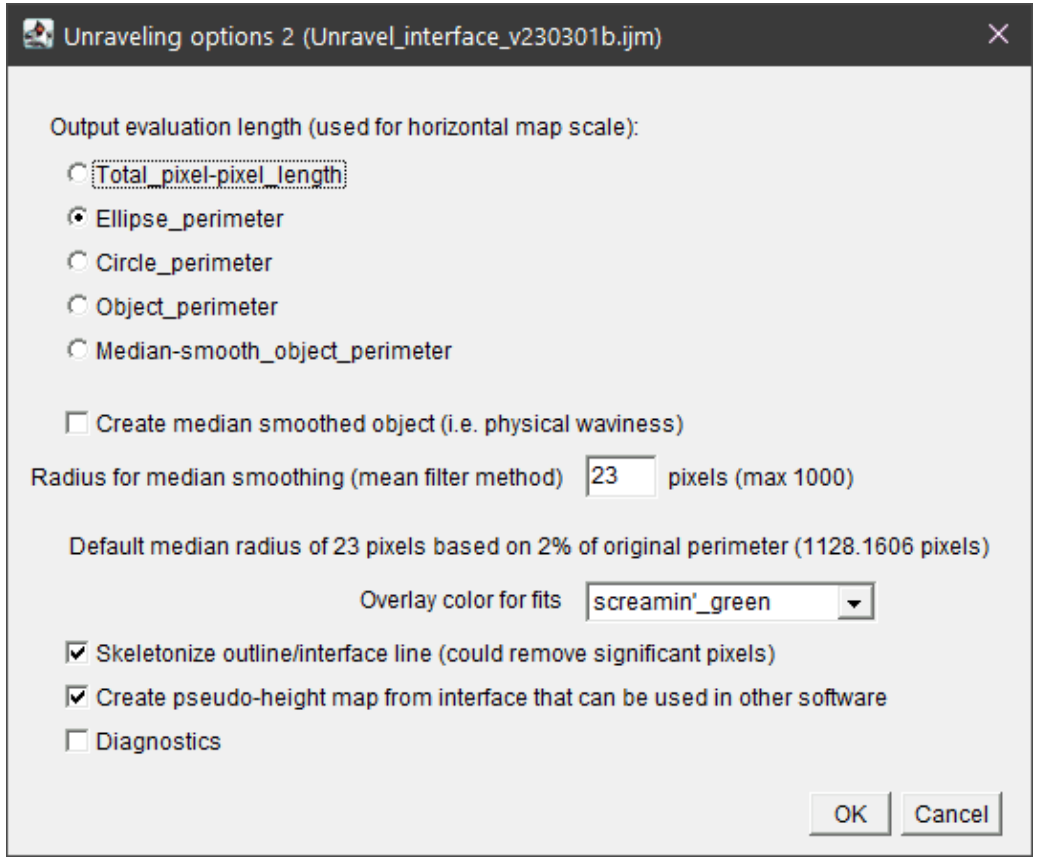




Menu 2 (continuous): Sample length and basic options

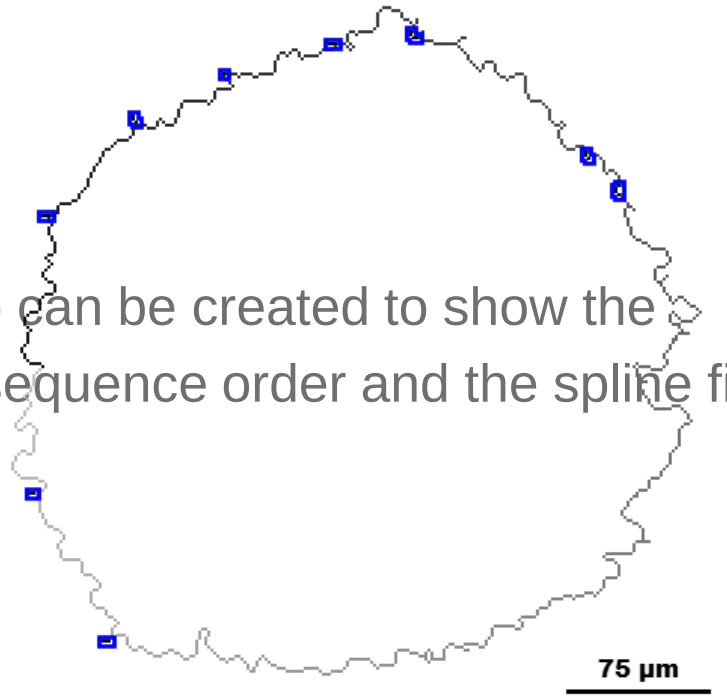
- 5 options for providing measuring the total evaluation length are provided:
  - This evaluation length will be embedded in the exported map



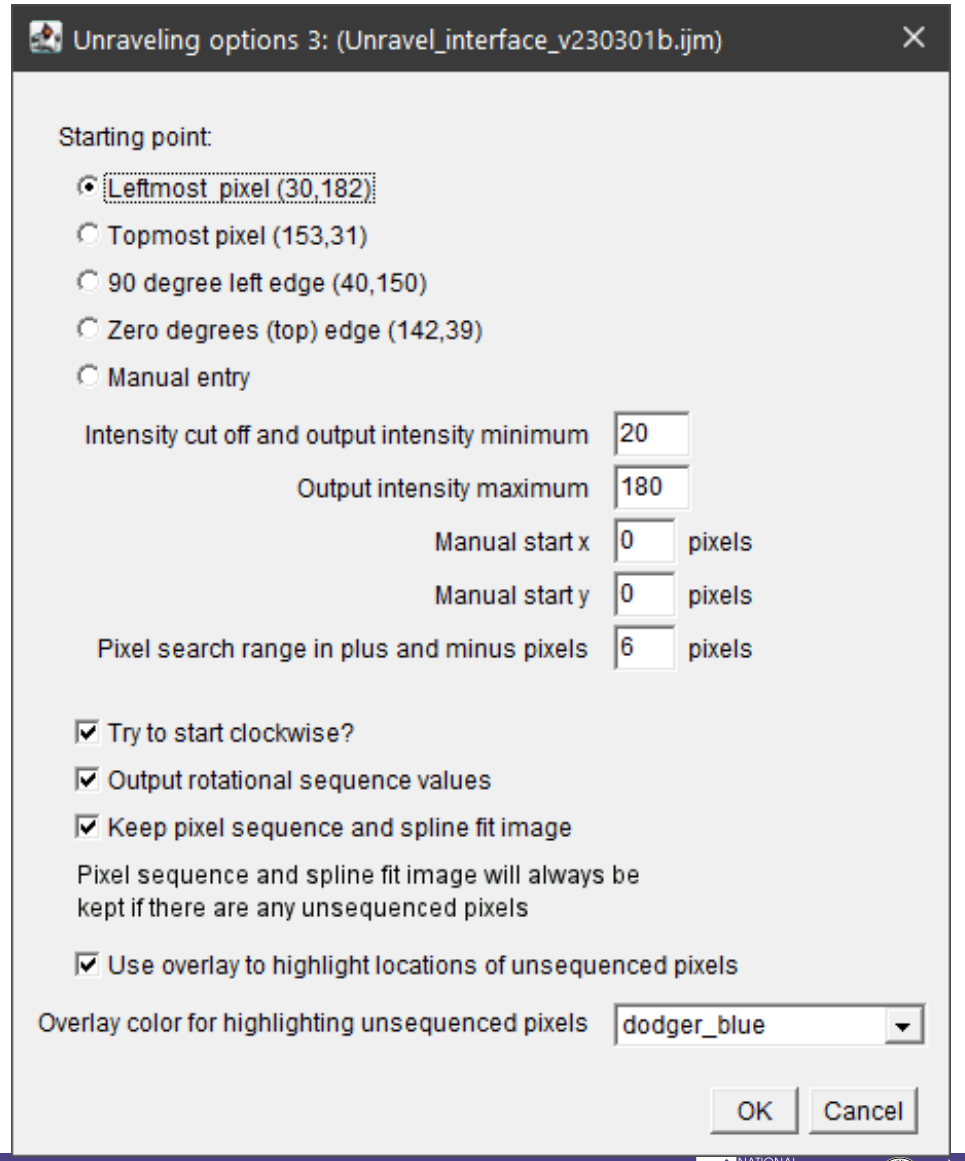


Menu 3 (continuous): Unravelling options

- The starting point of the unravelling can be selected
- The search range for the next pixel can be adjusted

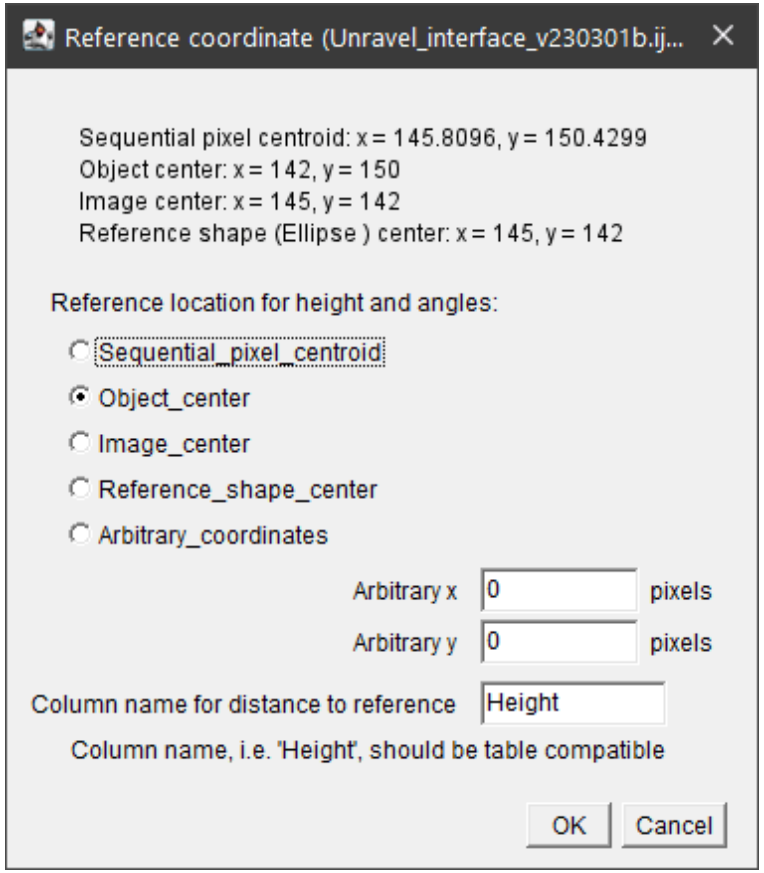


- A map can be created to show the pixel sequence order and the spline fit



“Height” reference menu (continuous

- For continuous objects, distances (“heights”) are calculated to a single reference point (default is the measured object center)



- The minimum distance value is subtracted to output the normalized values

158B_67a_acBleach(red)_OtsuThresh_crop-25pc_unrav+Ellipse_perimeter_full_output.csv

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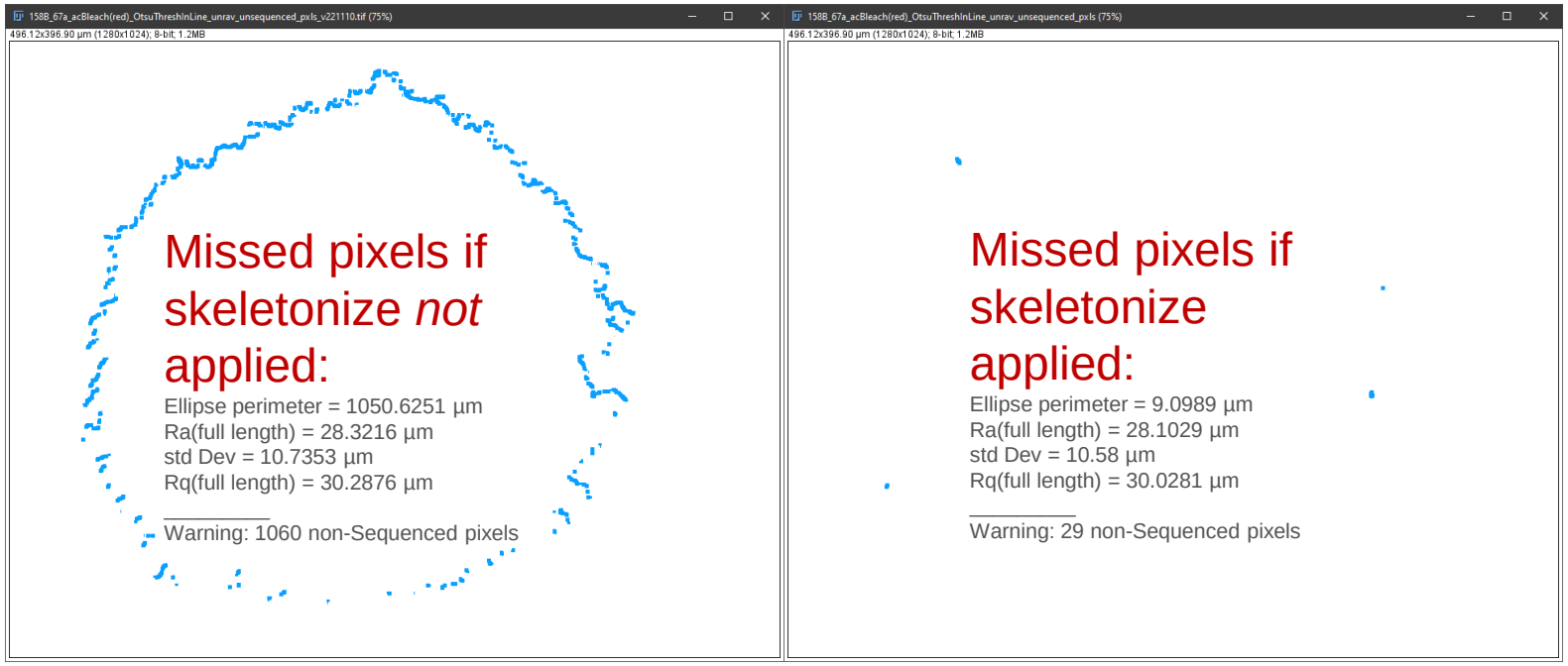
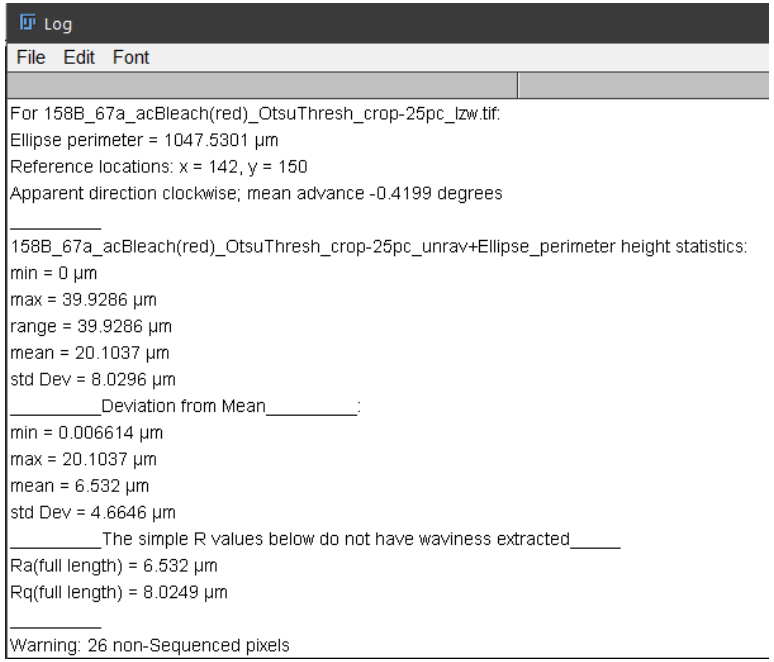
Seq_coord_x	Seq_coord_y	Incr_dist(px)	Seq_dist(px)	Incr_dist(µm)	Seq_dist(µm)	Height(px)	Height_norm(px)	Height_norm(µm)	Height_norm_from_Mean(µm)	Height_norm_from_Mean^2(µm^2)	Angle (radians)	Angle (degrees)	Angle Offset (radians)	Angle Offset (degrees)	Angle Incr. (radians)	Angle Incr. (degrees)	Seq_dist_NormToEval(µm)	Directional_continuity	Fourier_amps_uni-dir.
40	150	0.000000000	0.000000000	0.000000000	0.000000000	102.000000000	8.000000000	12.403119481	7.700595150	59.299165664	1.570796327	90.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	1	20.103713989
39	149	2.000000000	2.000000000	3.100779870	3.100779870	103.004854255	9.004854255	13.961035403	6.142679227	37.732508092	1.561087894	89.443747773	6.273476874	359.443747773	-0.009708433	-0.556252227	2.026377620	1	4.282462120
38	149	1.000000000	3.000000000	1.550389935	4.651169805	104.004807581	10.004807581	15.511352976	4.592361654	21.089785564	1.561181238	89.449096021	6.273570219	359.449096021	0.000093345	0.005348248	3.039566430	0	5.744721413
37	149	1.000000000	4.000000000	1.550389935	6.201559740	105.004761797	11.004761797	17.061671928	3.042042703	9.254023806	1.561272805	89.454342407	6.273661786	359.454342407	0.000091567	0.005246386	4.052755240	0	5.408189774
36	149	1.000000000	5.000000000	1.550389935	7.751949675	106.004716876	12.004716876	18.611992219	1.491722412	2.225235755	1.561362644	89.459489813	6.273751625	359.459489813	0.000089839	0.005147406	5.065944050	0	5.375229836

Additional output

- A basic summary is sent to the log window
- Note: The Fourier amplitudes are calculated for the entire sequence (column is for convenience).
- Note: Ra and Rq are not adjusted for waviness





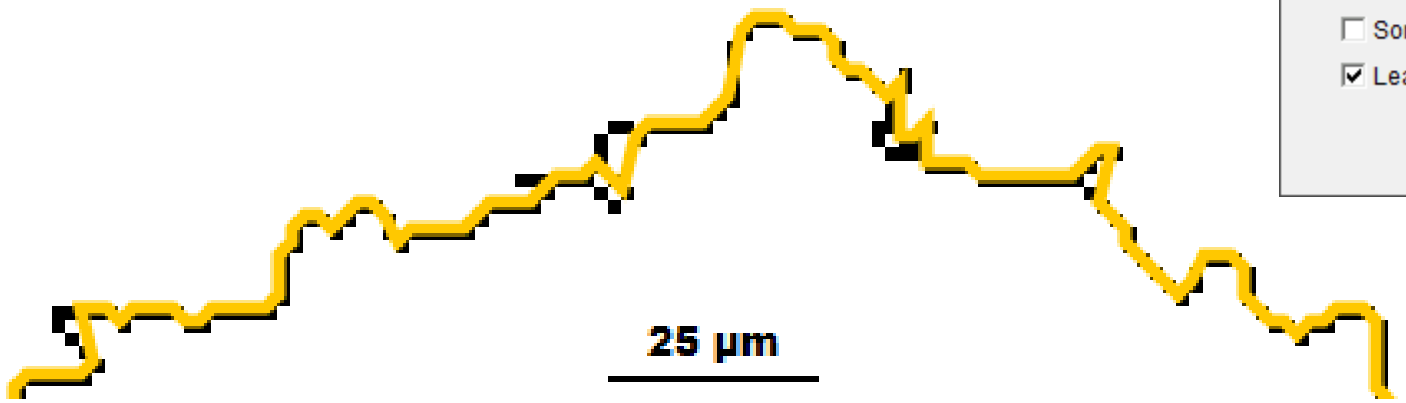
Note: If not all pixels are captured in the sequence the missing count as reported and an image (left) is created with the missing pixels highlighted.
The pixel capture is not uniform because the search matrix looks for the first-nearest pixel with the search sequence the same for all searches

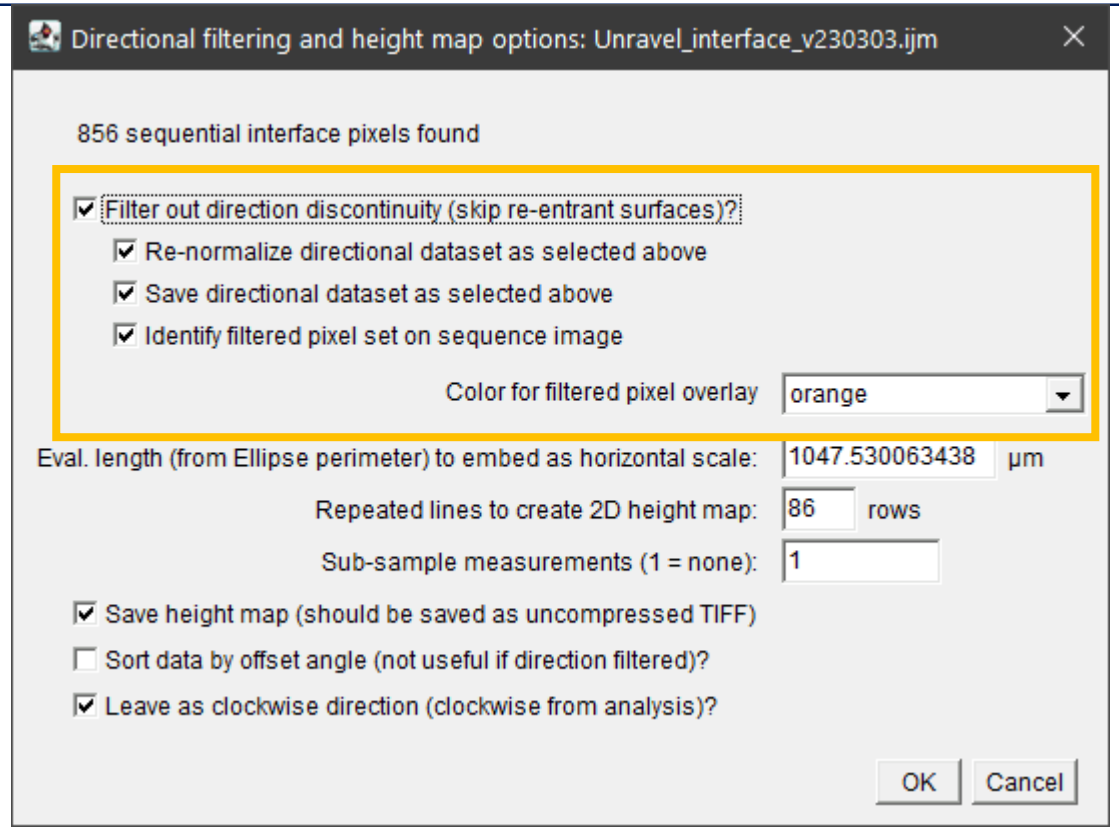
Some improvement might be useful here

The higher the image resolution for the interface, the less likelihood of error from this issue

Directional continuity and other options

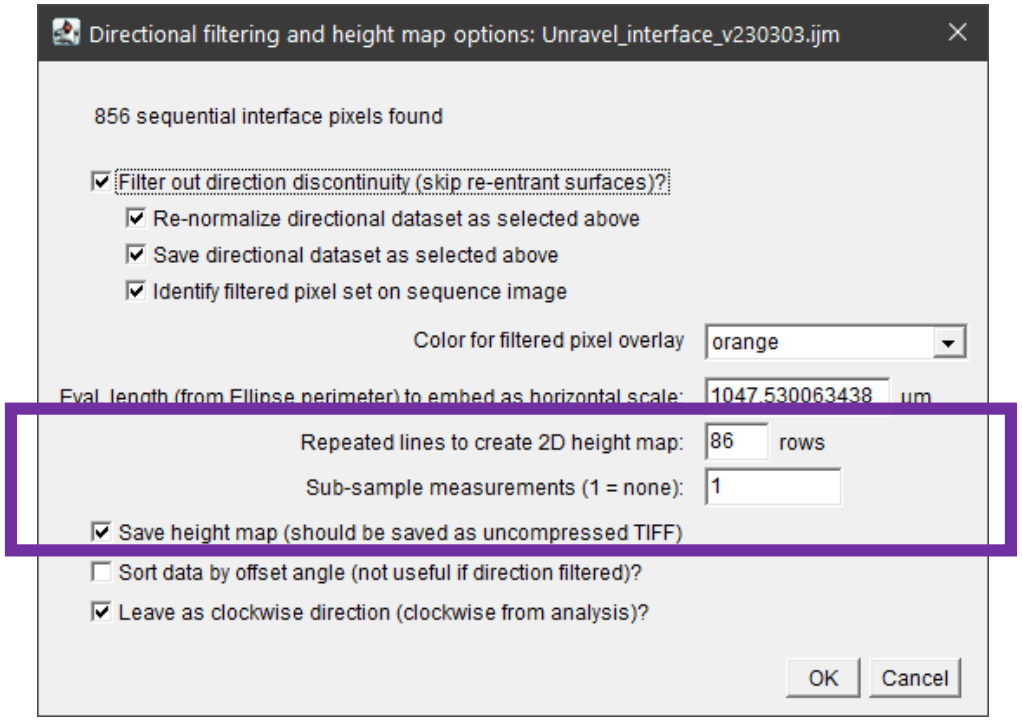
- Reentrant interfaces can be filtered out so the results are more those produced by a styles

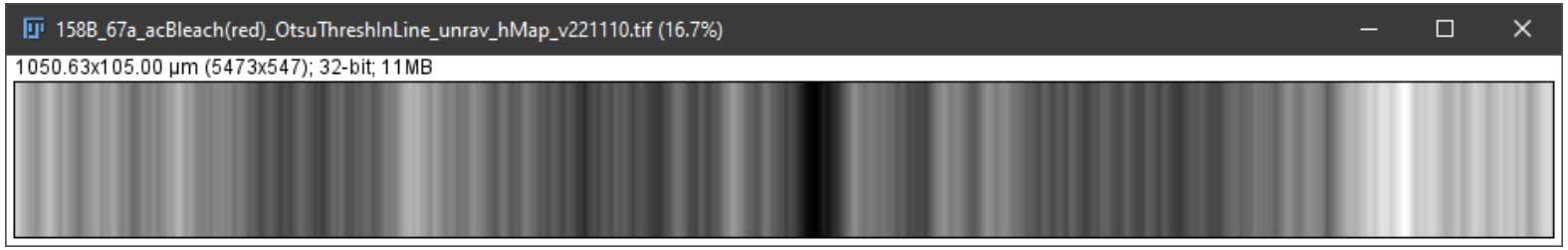




Pseudo height map from horizontal or vertical lines

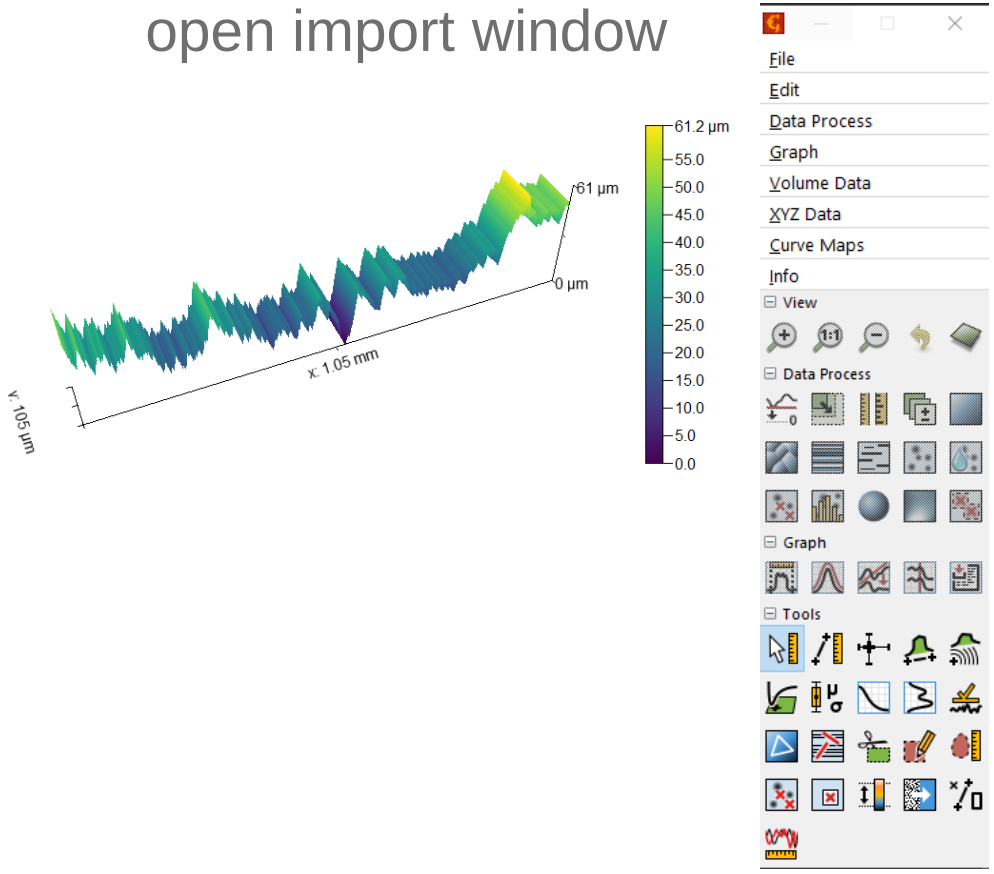
- The 2D line data can be stretched vertically to create a 32-bit pseudo height map that can be imported into 3rd party topological analysis software.
  - Unit-scaled “Heights” are directly stored in the 32-bit data
  - The measured sample length is embedded in the horizontal scale

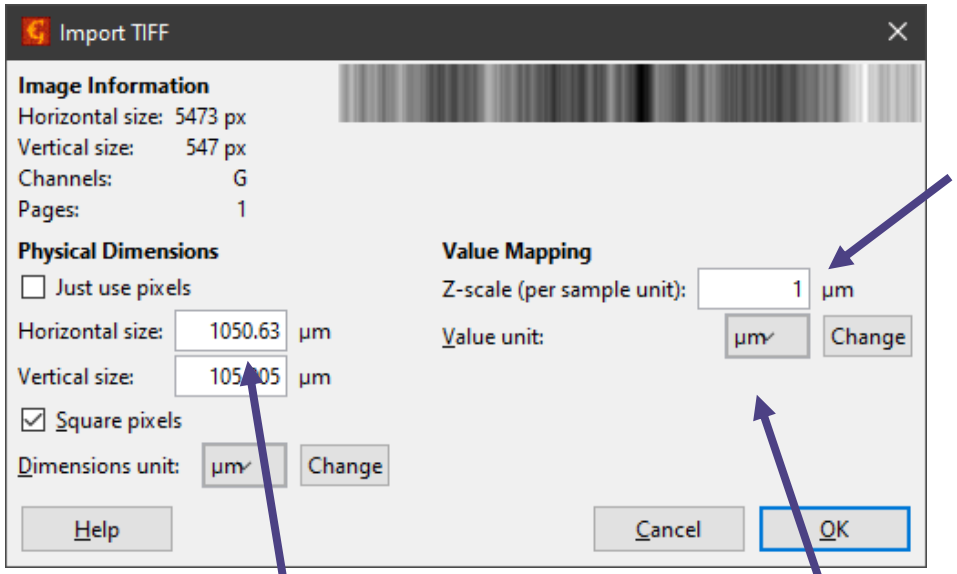




Gwyddion Import (http://gwyddion.net/)

- Drop TIFF format hMap file onto Gwyddion toolbar to open import window



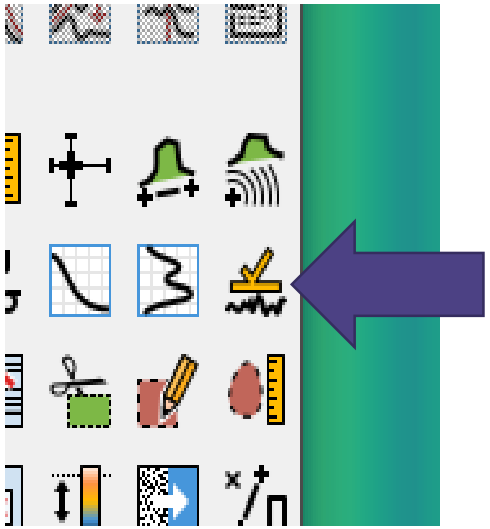


Leave as “1” to directly import 32-bit height data from the TIFF file

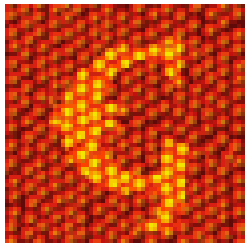
The last width is remembered so it is important to correct this to the current value. Should this value be the circle/ellipse perimeter or the smoothed surface?

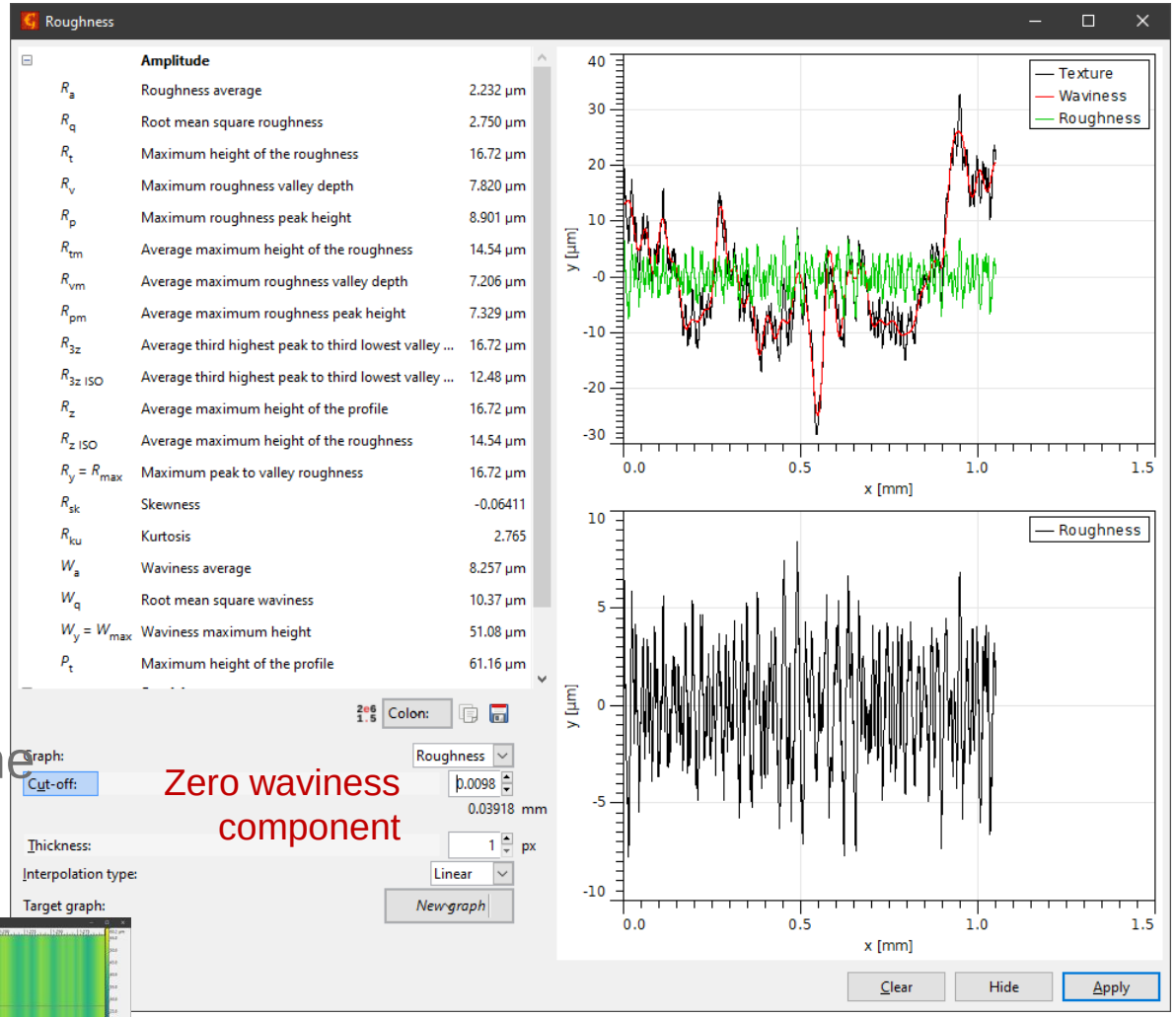
These are the units used for the 32-bit TIFF file

Import into Gwyddion to correct curvature and measure roughness parameters



Roughness values can be calculated by clicking on this icon on the Gwyddion toolbar





- After clicking on icon draw a horizontal line across the map (use shift key to enforce horizontal)