Tutorial: basic corrections, parameter extraction

AFM images can show artifacts, often resulting in the presence of **horizontal lines**. The lines are due to an internal height compensation when there are areas with an important height difference (remember that while scanning we register a voltage value on the quad-core detector). On the picture, this generates **non-existing height difference** in regions that are supposed to be on the same plane therefore before extracting any relevant quantities we have to apply corrections. As well, during the scan there could be elements (ex. dirt particles) with a completely out-of-scale height compared to the surroundings, leading to a wrong estimation of some parameters like **roughness**. These out-of-scale features should be filtered out while analyzing the sample surface.

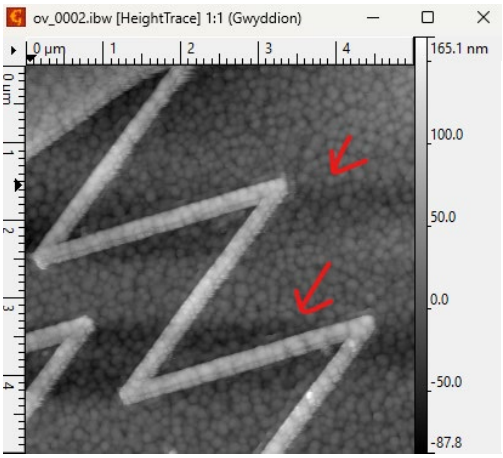
1) Import an image (ZigZag1.ibw)

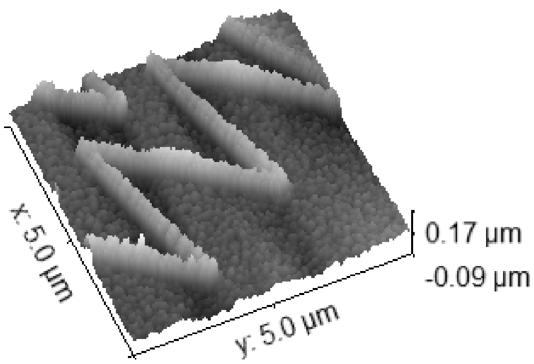
To import your image in Gwyddion, you can **drag and drop** it on the tools bar or you do **File > Open**. By default, we see the topography of the picture, but clicking on **Info > Show Data Browser** we can navigate among the different maps or the extracted plots (ex. a line profile).

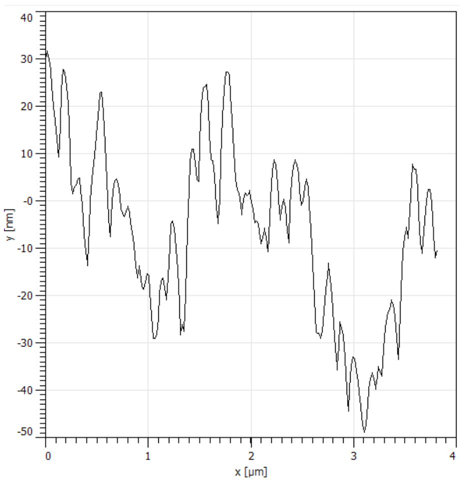
2) Identify the elements to correct

We see the presence of the horizontal lines. We observe different height regardless the surface is supposed to lie on the same plane. We can also see it by plotting the 3D image or a line profile.

2)







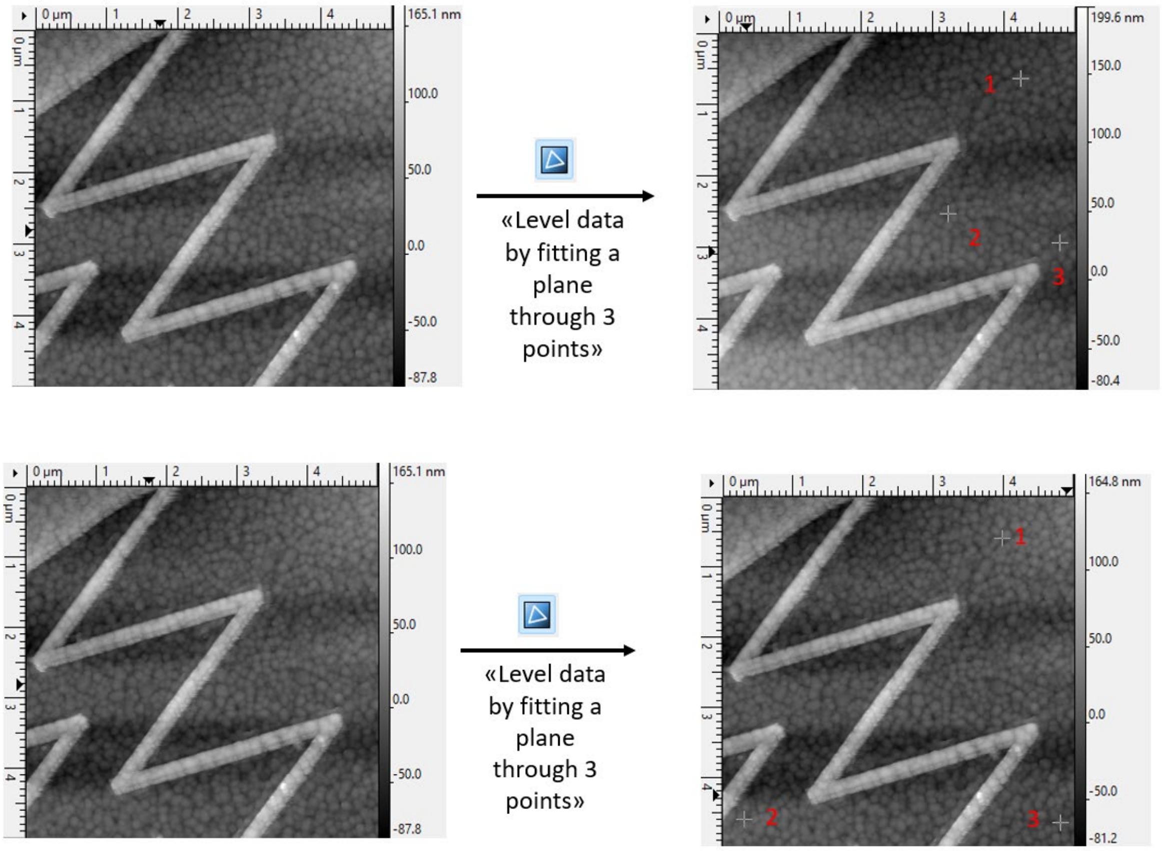
We have to remove the horizontal lines:

- Mask regions of interest
- Level data
- Correctly adjust the scale bar

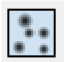
After that we can extract the quantities we need and export the picture

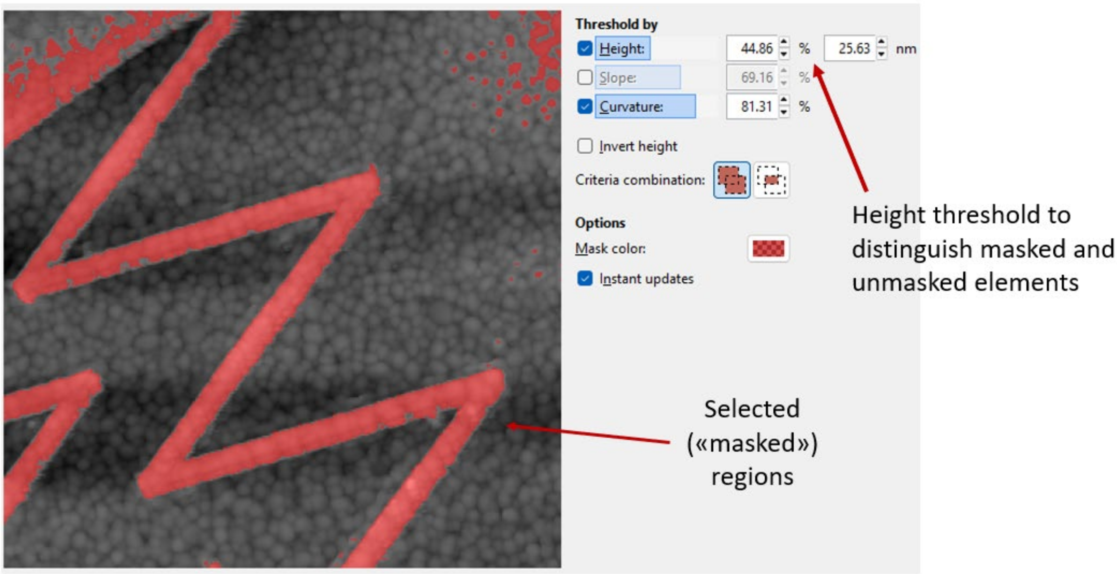
3) Mask regions of interest

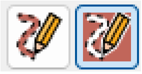
We are looking at a thin film (about 40/50 nm thick) surface with some metal contacts on top (about 100 nm thick), therefore we have elements of a very different height. There are several ways we can correct for height deviation of the surface, however depending on the features we have some methods are more effective than others. Let's see an example:

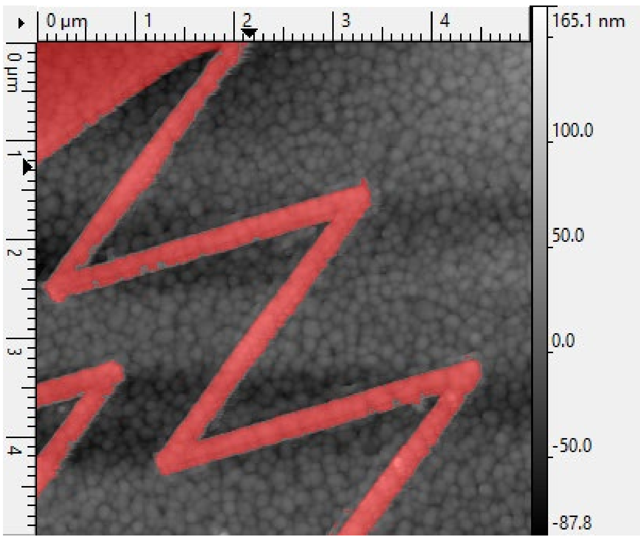


In this case we selected 3 points that are supposed to lie on the same plane and we try to planarize the surface. However, it is not effective at all regardless of the way we choose the points. The reason in this case is the presence of the contact, which in first place created the line artefact. In fact, this method is more efficient in presence of a simple drift.

An alternative solution is to mask the disturbing element (the contact in our case) and to correct "ignoring" its presence. We have to select all the elements belonging to the contact region: we can use  ("**Edit Mask**") command to select them manually, or we can use a small trick exploiting the height difference between the contact and the surface. Click  ("**Mark grains by threshold**") bottom. This command allows for selecting the elements depending on their properties (z-height in this case). This will save us time rather than drawing by hand the zig-zag lines 😊

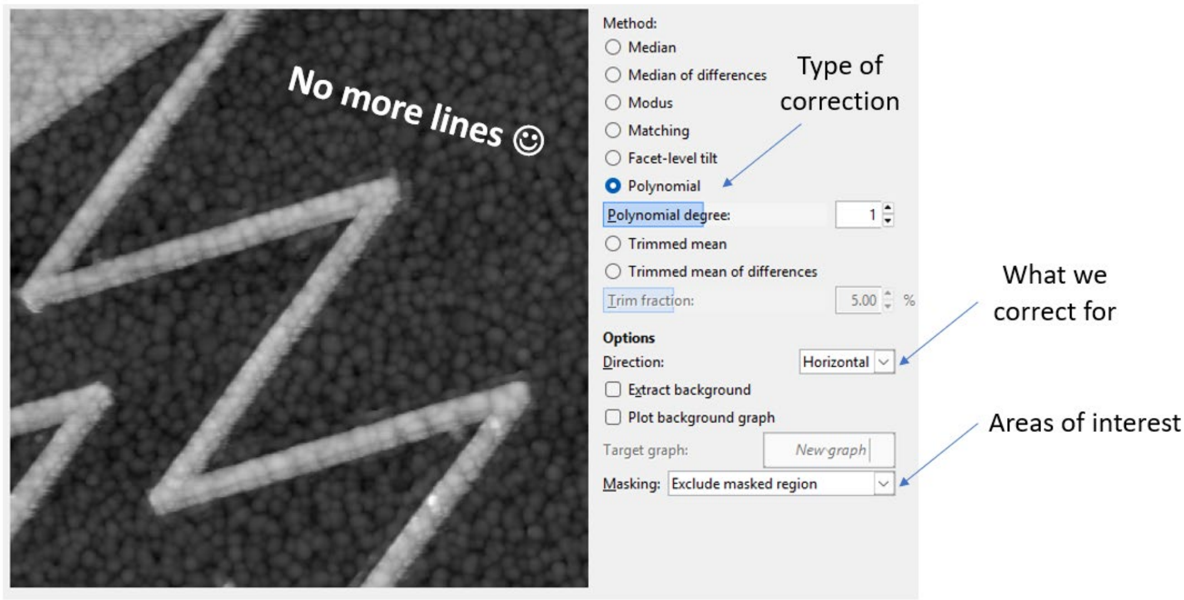


However, we can see that the mask we created is not perfect. We can adjust it by using  manually adding and removing features using the  tool. At the end we should have something like this, with only the contacts selected:

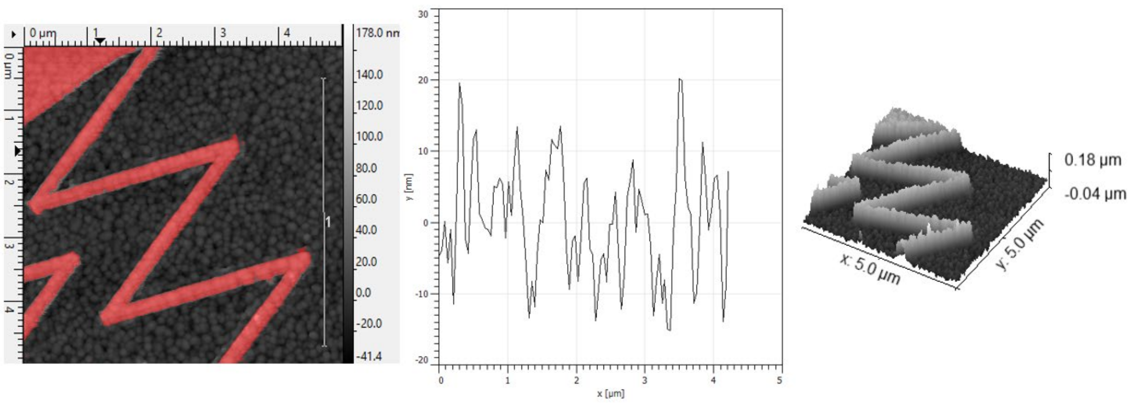


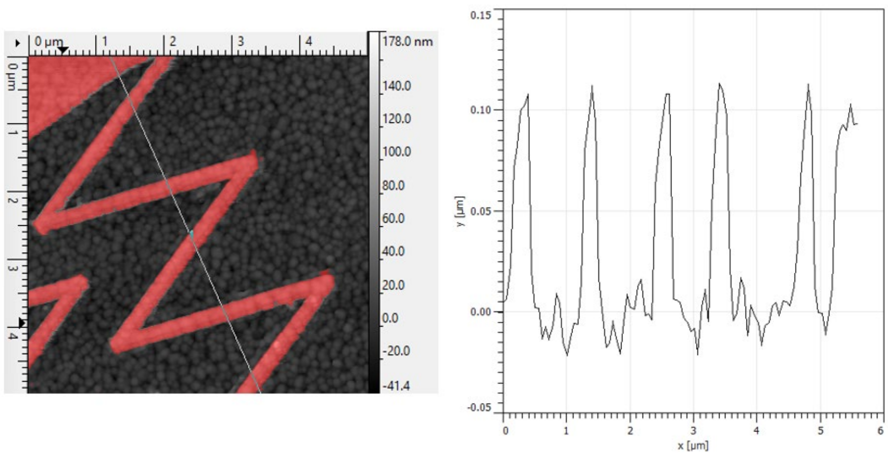
4) Level data

Now it is possible to apply our correction. Gwyddion offers a very simple way to correct for this horizontal (or sometimes vertical) lines. Press  (“**Align rows using various methods**”). This command allows for correcting both horizontal and vertical lines in the scan by using different methods to extract the background and to subtract it from your picture. We have to select the correct option for the masking, excluding our contact regions. From the preview we can immediately see the effectiveness of this method:



Now we are in principle good to go to extract what we need. In fact, if we try to plot a line scan on the surface  or we generate the 3D plot  we can see there are no more major artefacts:

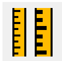


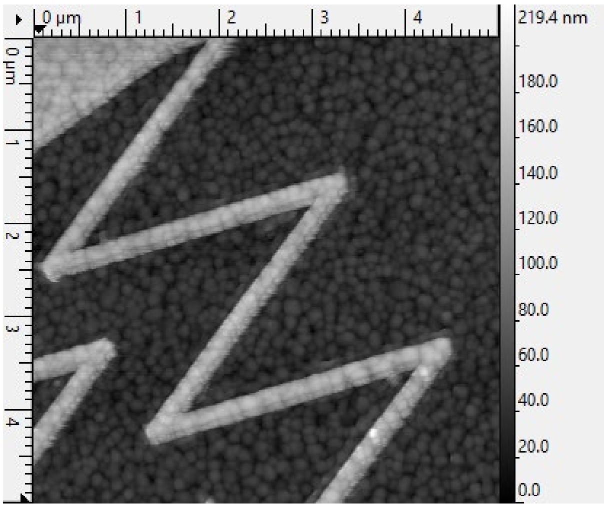


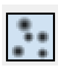
Contact thickness is about 100 nm as we were expecting to see

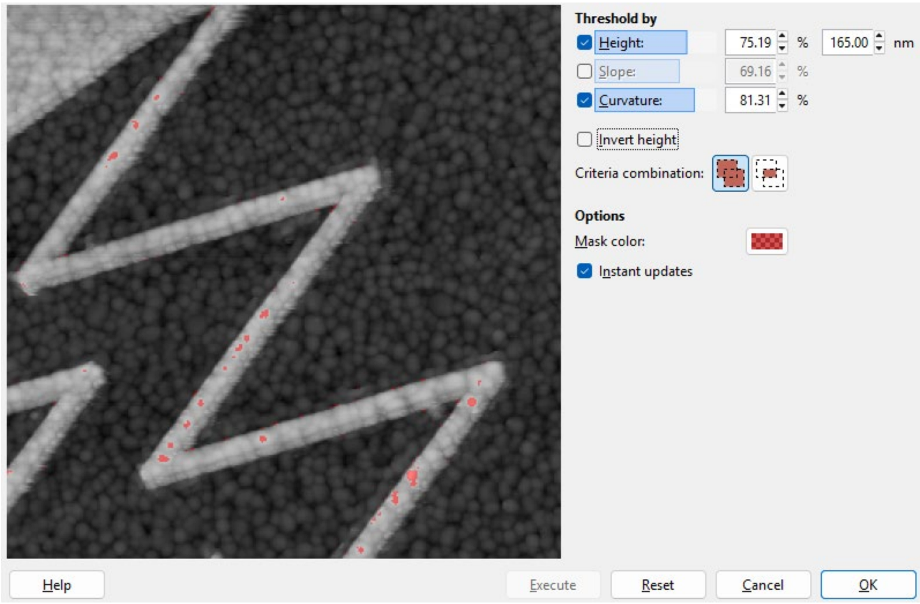
5) Correctly adjust the scale bar

If we pay attention to the scale bar in the top pictures, we have height between 180nm and -41 nm approximately, so about 220nm in terms of absolute difference. This range is automatically selected to correctly represent our surface features: AFM doesn't know the topography of the sample, what we register is a voltage difference compared to the reference position of the tip that we associate to the origin in the quad-core detector. We can adjust the scale bar depending on what we would like to represent.

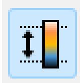
For simplicity, let's remove the mask in the image (**Edit Mask > Remove**). Our sample is made up of a substrate (thermal oxide, quite flat), a thin film and some contacts. For example, we may want to set the minimum level we register in the scan (the substrate surface in case of voids) as the 0 nm of our scale bar. This can be done either by pressing  ("**Shift minimum data value to zero**") or by pressing  ("**Change physical dimensions, units or value scale**"). The latter command allows to change the scale range (about 220 nm in our case) and to apply corrections shifting the data by defined quantity. Inserting a positive "Z shift" equal to our negative minimum height shifts everything to 0 nm. In the end, we obtain this:

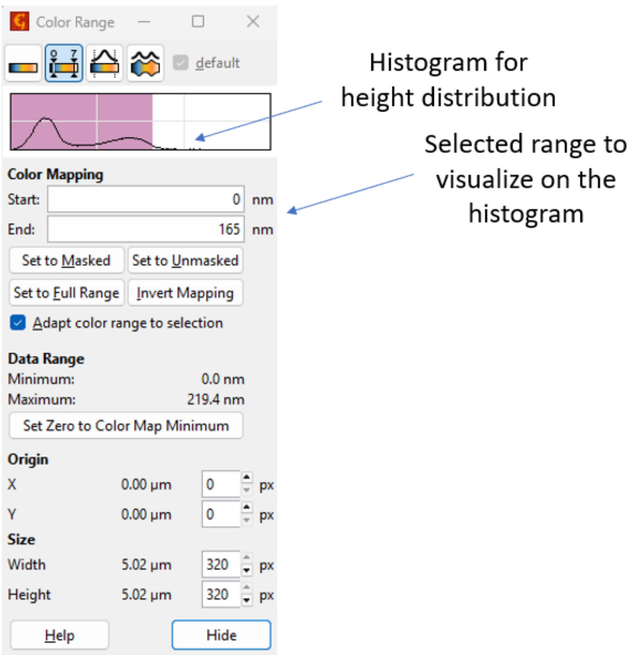


At this point, we might ask why the range is about 220 nm if our sample is supposed to be as thick as the sum of the thin film thickness (about 50 nm) and the metal contact (about 100 nm) compared to the substrate surface (0 nm). This can be related to a wrong estimation of the thickness, or by the presence of defects (ex. particles, voids) affecting the overall range. To understand it, we can go back to the threshold command  and play with the height threshold range to see if our "out-of-range" features are isolated elements on the surface. For example, let's mark all the elements higher than 10% of our estimated thickness (150 nm):



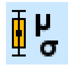
In this case, we can see that only few isolated features on top of the contact are over the set threshold, most likely because of particle incorporated beneath the metal or irregular point in the topography.

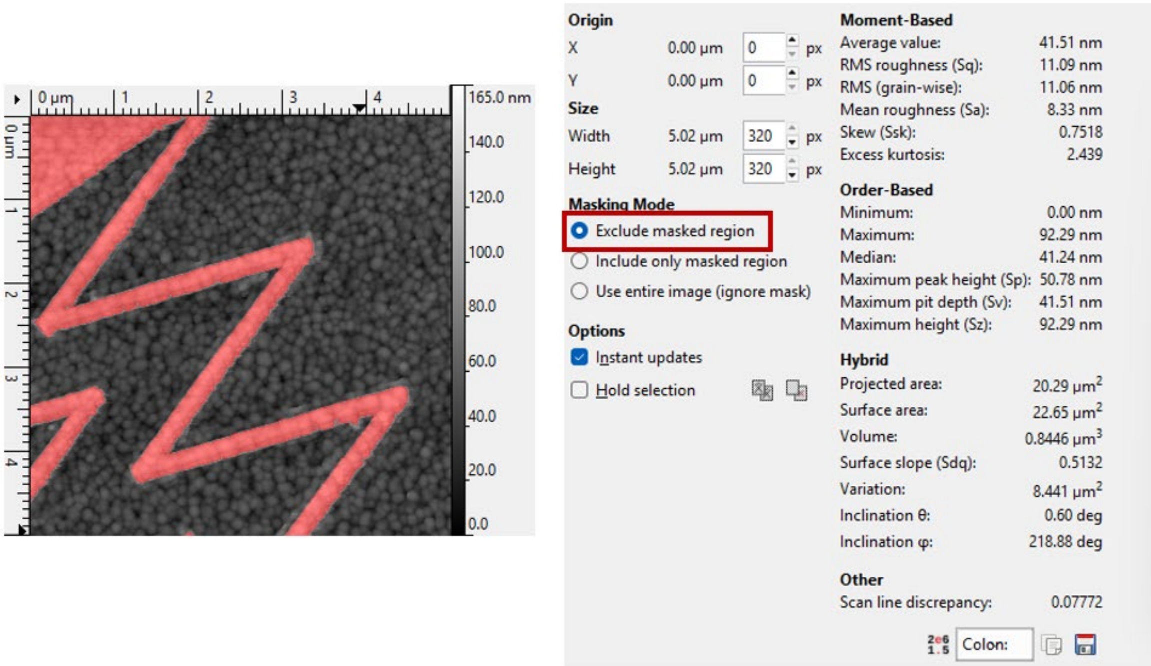
An alternative way to check the "quality" of the range is by pressing  (“**Stretch color range to part of data**”). In this case we can visualize the histogram of the height and adapt quite simply our range excluding extreme values:



6) Extraction of relevant quantities

After applying the due corrections, we are finally ready to save our picture or to extract all the information we need from it. We have already seen how to extract a basic line profile with . The plots can be saved in the Data Browser by pressing "**Apply**". To export a plot is sufficient to select it from the Data Browser, right-click on the plot and choose the preferred "**Export**" option.

Roughness parameters can be automatically computed. It is possible to check the roughness along a line using  ("**Calculate roughness parameters**") or on an area using  ("**Statistical quantities**"). The latter command allows for excluding masked regions from the computation of roughness parameters. In our case we must exclude the contact to analyze the surface of the thin film:



Alternatively, we can crop a portion of the original image without the contact using  ("**Crop data**") to compute the roughness without masking. However, keep in mind that in this situation we are averaging on a much smaller portion of our surface.

7) Exporting an image

Once we are satisfied with our corrections, we can export the picture. By default, Gwyddion shows the topography using a gray-scale coded bar. Possibly, the colors can be changed by right-clicking on the bar itself and selecting another color code. To save a picture press **File > Save As** and rename the image with another format like **.png** or similars.

Exercise:

Open the folder "**VO_2 surface**". Inside there are few images obtained from VO_2 samples deposited for a different amount of time. VO_2 is a complex oxide able to change its crystallographic phase and electrical properties depending on external stimuli (temperature or voltage for example). The sample analyzed in this tutorial is as well VO_2, but deposited with a different technique.

Using the images in the folder try to:

1. Apply the tutorial tips to correct for scan artefacts (lines, range, etc.)
    a. Do you use any particular structures appearing on the surface? If yes, can you guess what are these features?
2. Extract the roughness parameters correcting for the presence of out-of-scale features
    a. Is there any correlation between the average roughness and the deposition time?
3. Is there a difference in roughness between different regions of the sample? If yes, can you explain where it comes from?