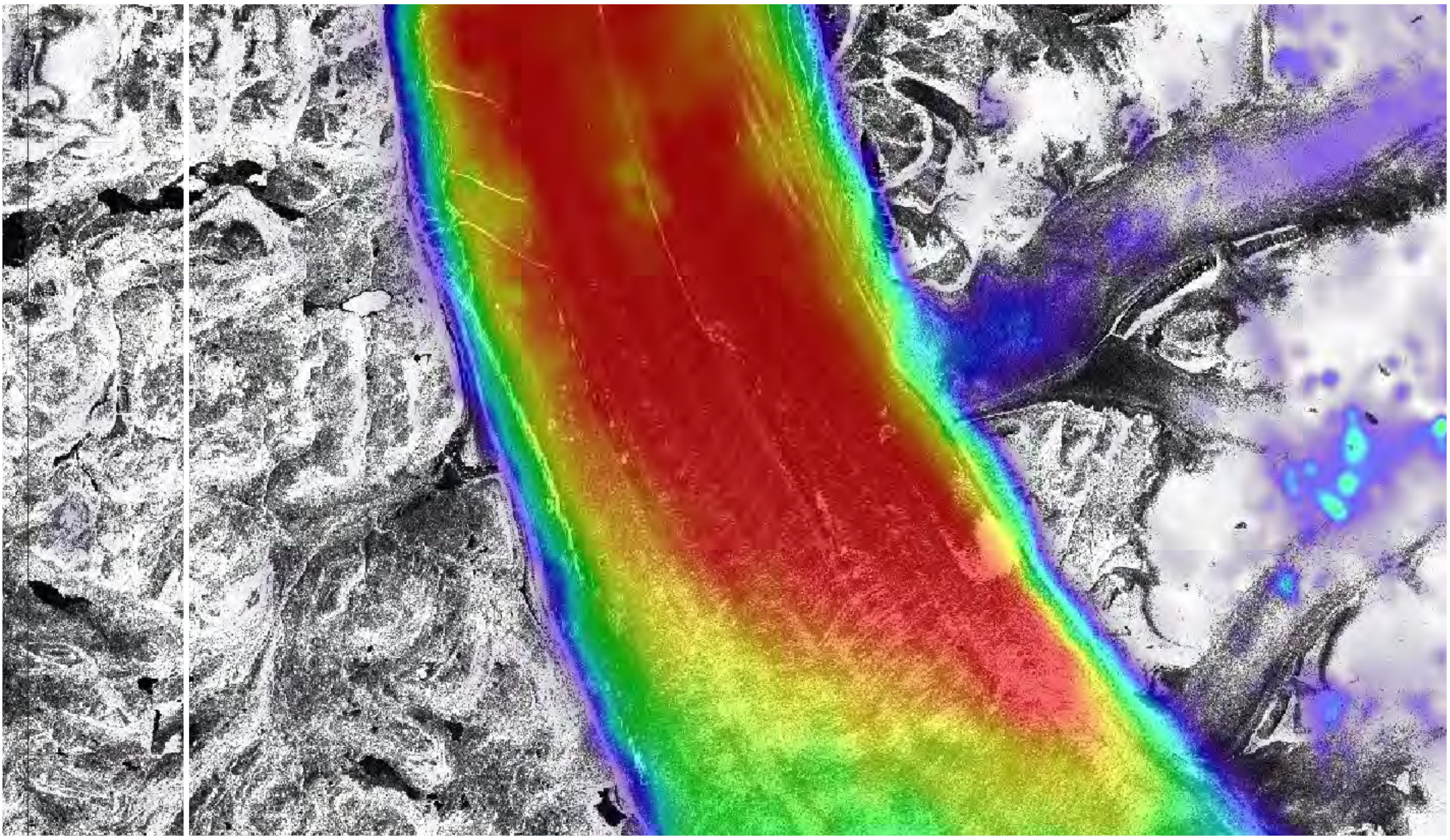

TRAINING KIT – CRYO02

# GLACIER VELOCITY WITH SENTINEL-1 USING SNAP S-1 TOOLBOX – PETERMAN GLACIER, GREENLAND

Research and User Support for Sentinel Core Products

The RUS Service is funded by the European Commission, managed by the European Space Agency and operated by CSSI and its partners.

Authors would be glad to receive your feedback or suggestions and to know how this material was used. Please, contact us on [training@rus-coperenicus.eu](mailto:training@rus-coperenicus.eu)

Cover images produced by RUS Copernicus

The following training material has been prepared by Serco Italia S.p.A. within the RUS Copernicus project.

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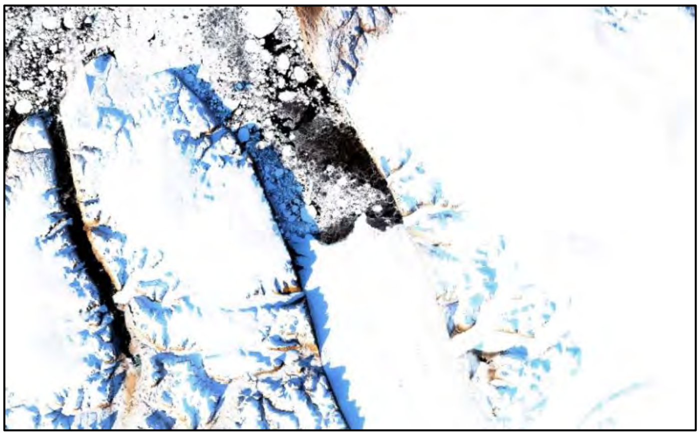
# Table of Contents

# 1 Introduction

The Research and User Support for Sentinel core products (RUS) service provides a free and open scalable platform in a powerful computing environment, hosting a suite of open source toolboxes pre-installed on virtual machines, to handle and process data acquired by the Copernicus Sentinel satellites constellation.



*Sentinel-2 image of Petermann Glacier tongue on 10 Sept. 2017 (Credits: contains modified Copernicus Sentinel data)*

Greenland ice sheet is the second largest ice mass on Earth. As climate changes, the ice sheet surface melt is increasing and more and more fresh-water flows to the ocean, contributing to the global sea-level rise.

Glacier velocity is a vital part of glacier monitoring and understanding the glacier system dynamics as well as its contribution to the global sea level. Satellite data is a perfect tool for monitoring glacier velocity over large areas. Two methods are commonly used to derive the speed of the ice flow from the satellite data: 1) SAR interferometry; 2) feature/speckle tracking (optical/SAR data) between consecutive acquisitions. In this tutorial we will use the second method applied to Sentinel-1 data.

The Petermann Glacier is a large tidewater glacier draining more than 4% of the Greenland ice sheet through the 90 km long Petermann Fjord and terminating in a floating ice tongue, which currently covers an area of 900 km$^2$. Estimated 12 billion tonnes of ice are drained to the ocean annually with estimated ice flow speed of 1 km/year.

# 2 Training

Approximate duration of this training session is one hour.

**The Training Code for this tutorial is CRYO02. If you wish to practice the exercise described below within the RUS Virtual Environment, register on the RUS portal and open a User Service request from Your RUS service → Your dashboard.**

## 2.1 Data used

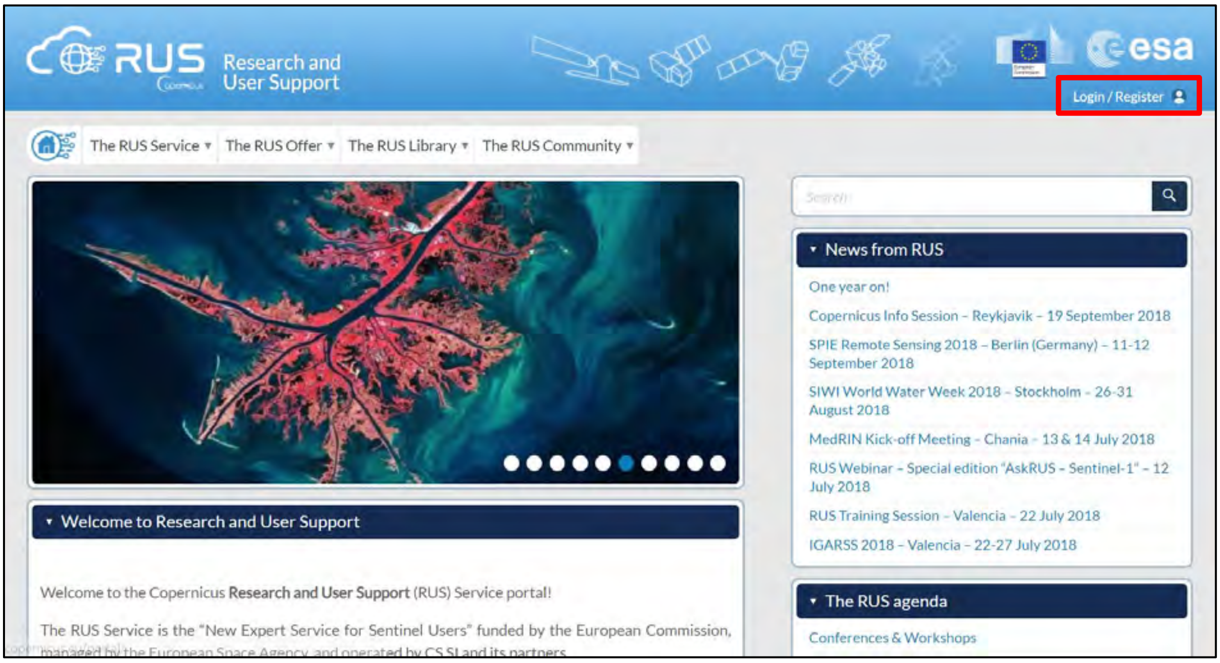
- Two Sentinel-1A IW GRDH images with HH & HV polarization acquired on 9 September 2017 and 21 September 2017 [downloadable @ https://scihub.copernicus.eu/]
  *S1A_IW_GRDH_1SDV_20170909T113539_20170909T113604_018298_01EC67_A5EC.zip*
  *S1A_IW_GRDH_1SDV_20170921T113539_20170909T113604_018473_01F1C7_1CE3.zip*

## 2.2 Software in RUS environment

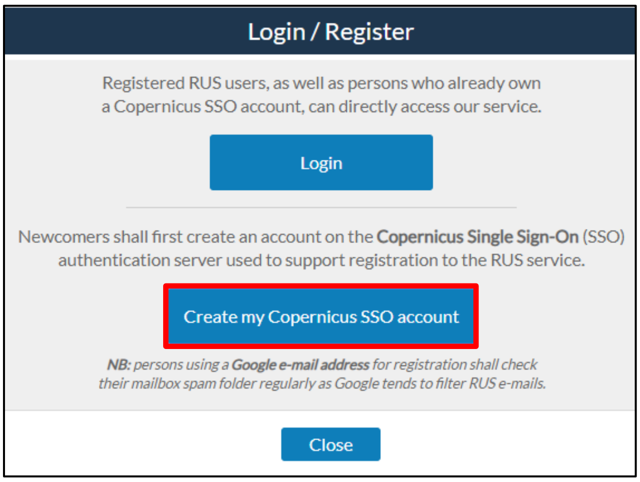
Internet browser, SNAP + Sentinel-1 Toolbox, (Extra steps: QGIS)

# 3 Register to RUS Copernicus

To repeat the exercise using a RUS Copernicus Virtual Machine (VM), you will first have to register as a RUS user. For that, go to the RUS Copernicus website ([www.rus-copernicus.eu](http://www.rus-copernicus.eu)) and click on ***Login/Register*** in the upper right corner.



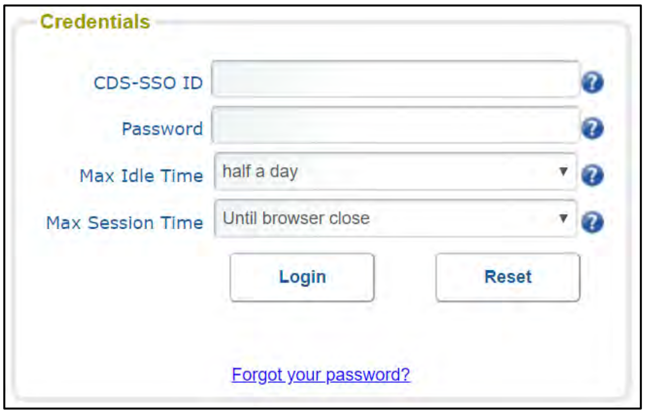

Select the option ***Create my Copernicus SSO account*** and then fill in ALL the fields on the **Copernicus Users' Single Sign On Registration**. Click ***Register***.



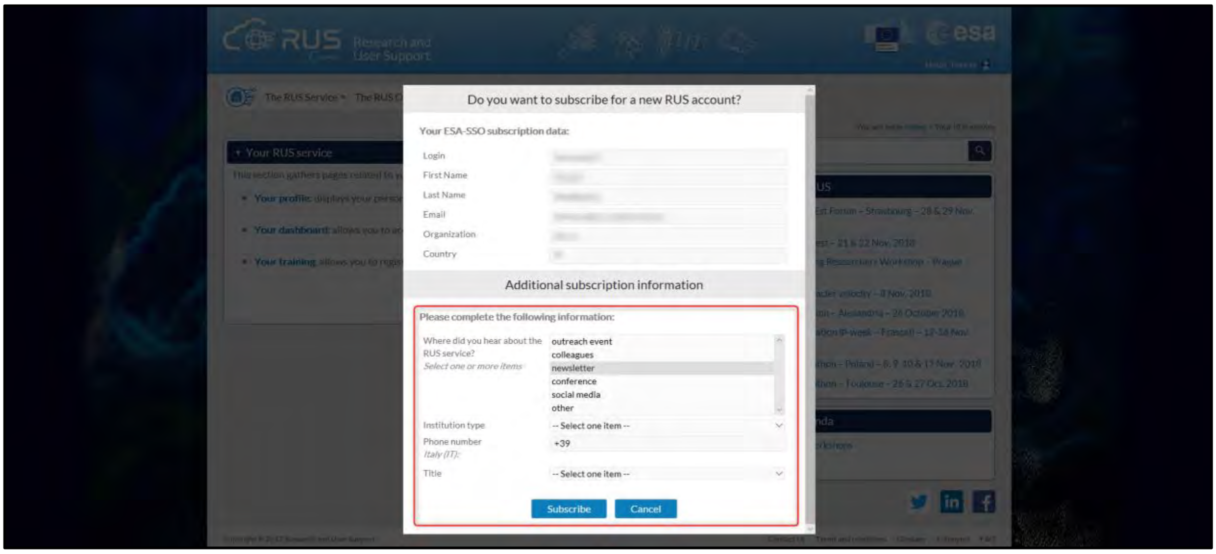


Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the e-mail to activate your account.

You can now return to [https://rus-copernicus.eu/](https://rus-copernicus.eu/), click on ***Login/Register***, choose ***Login*** and enter your chosen credentials.

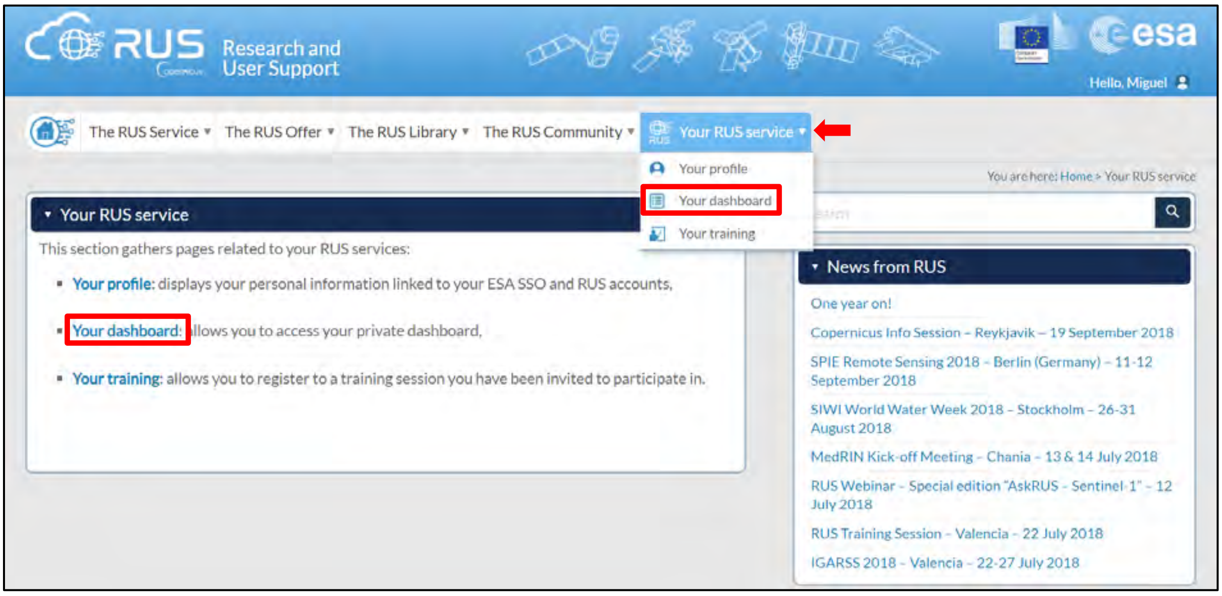




Upon your first login you will need to enter some details. You must fill all the fields.

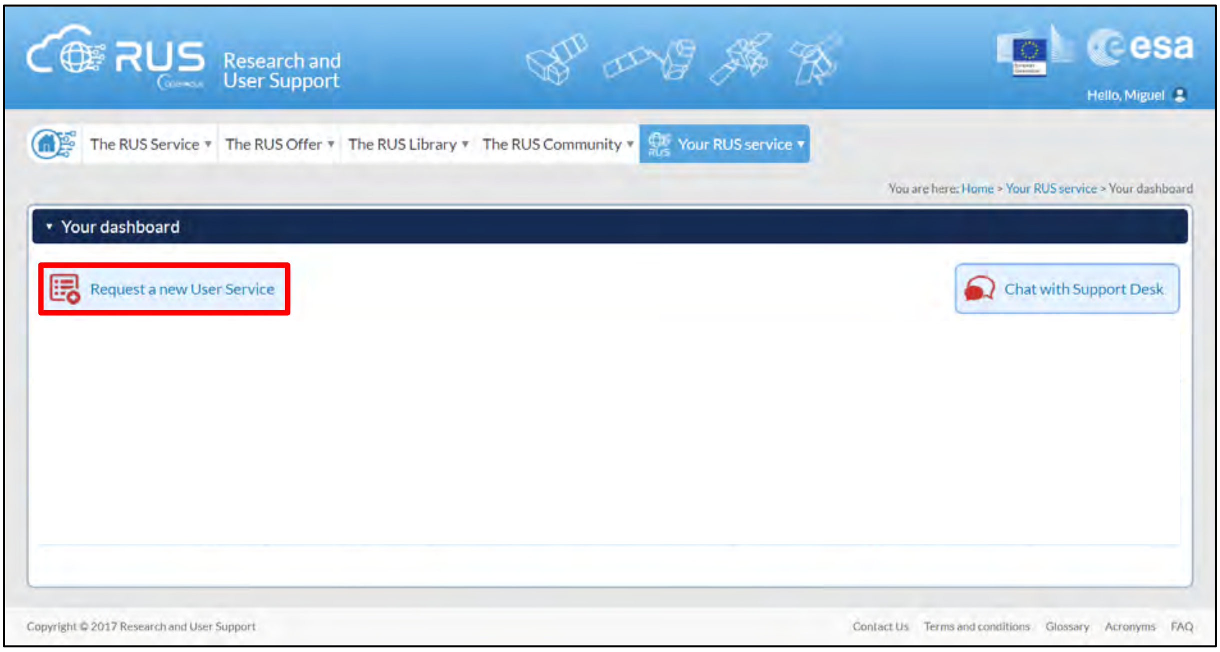



# 4 Request a RUS Copernicus Virtual Machine

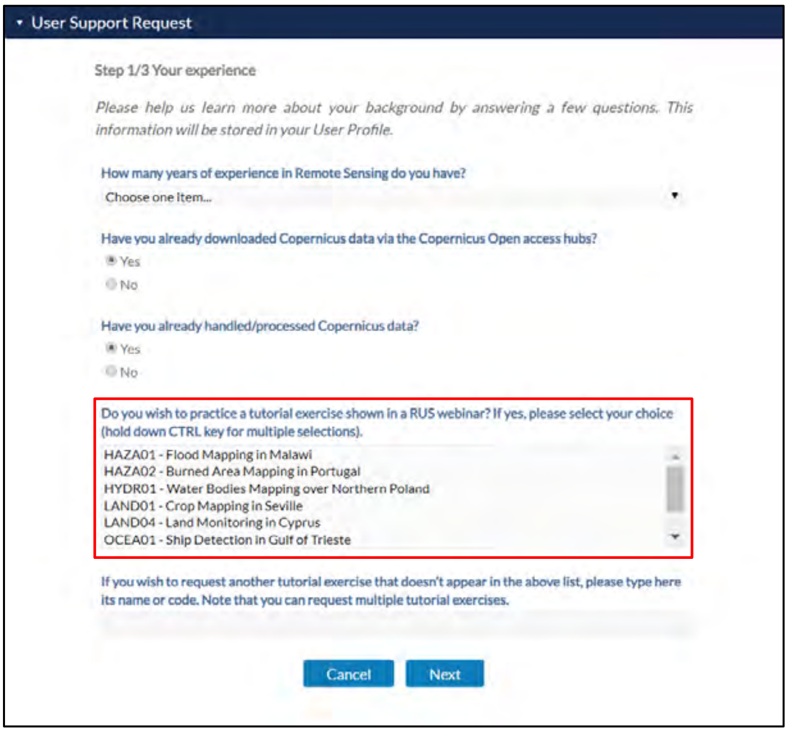
Once you are registered as a RUS user, you can request a RUS Virtual Machine to repeat this exercise or work on your own projects using Copernicus data. For that, log in and click on ***Your RUS Service* → *Your Dashboard***.



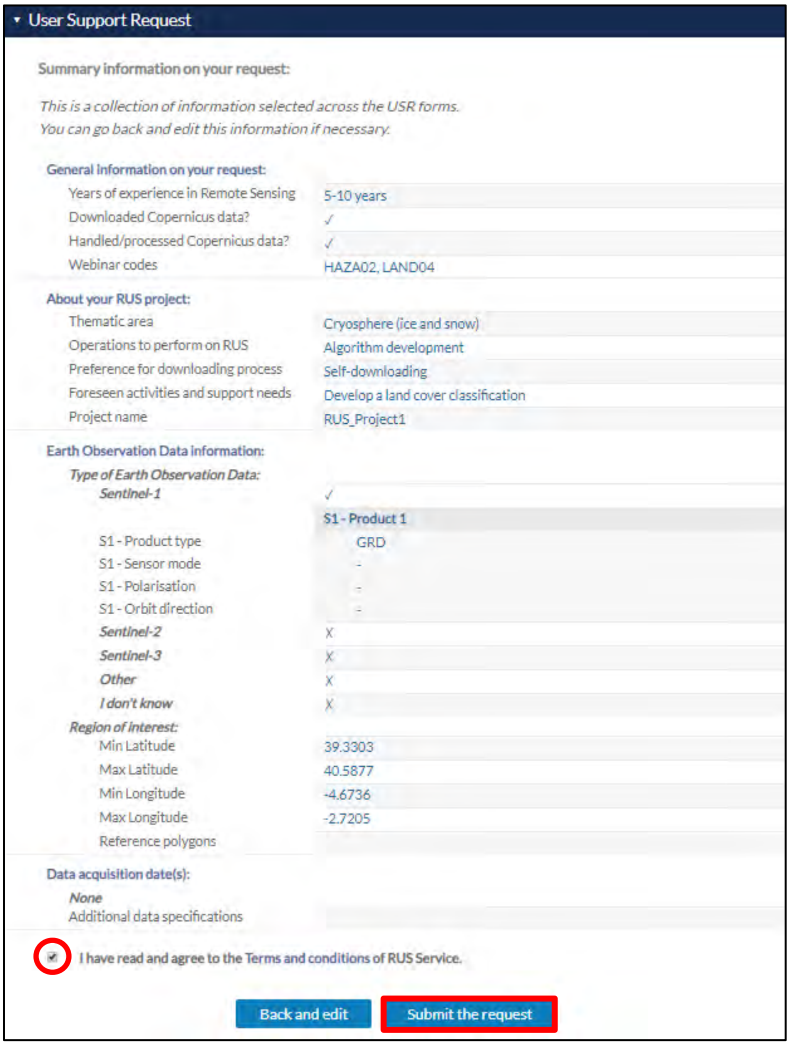
Click on ***Request a new User Service*** to request your RUS Virtual Machine. Complete the form so that the appropriate cloud environment can be assigned according to your needs.



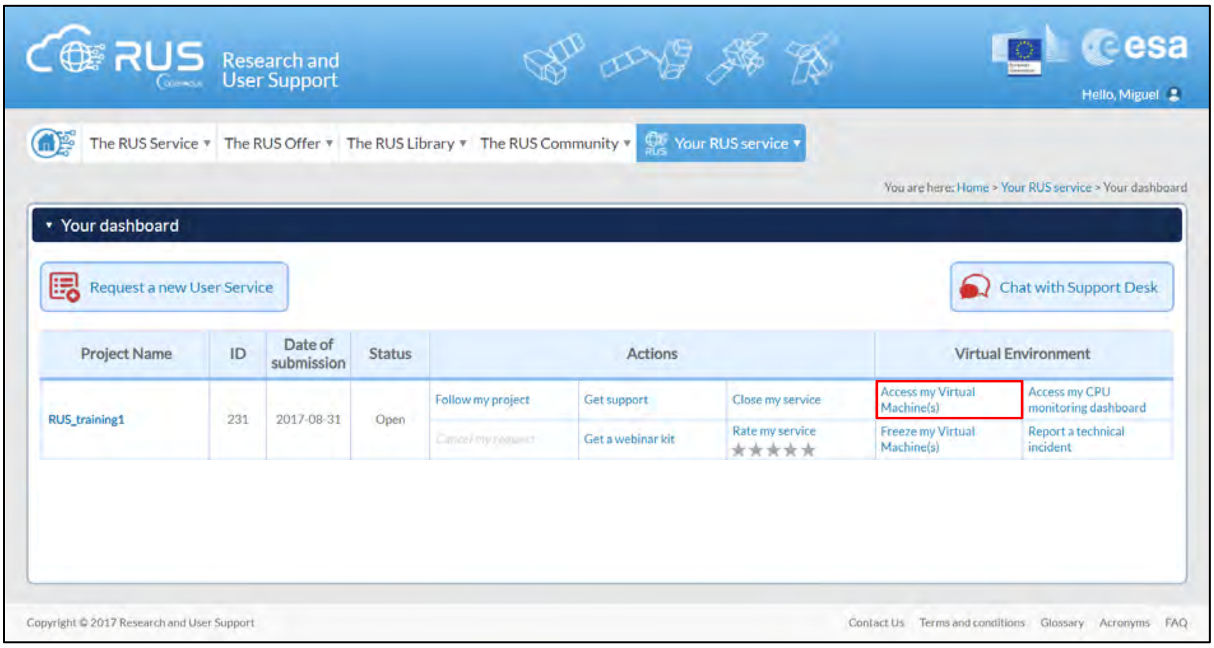

If you want to repeat this tutorial (or any previous one) select the one(s) of your interest in the appropriate field.




Complete the remaining steps, check the terms and conditions of the RUS Service and submit your request once you are finished.




Further to the acceptance of your request by the RUS Helpdesk, you will receive a notification email with all the details about your Virtual Machine. To access it, go to ***Your RUS Service → Your Dashboard*** and click on ***Access my Virtual Machine***.



Fill in the login credentials that have been provided to you by the RUS Helpdesk via email to access your RUS Copernicus Virtual Machine.


This is the remote desktop of your Virtual Machine.

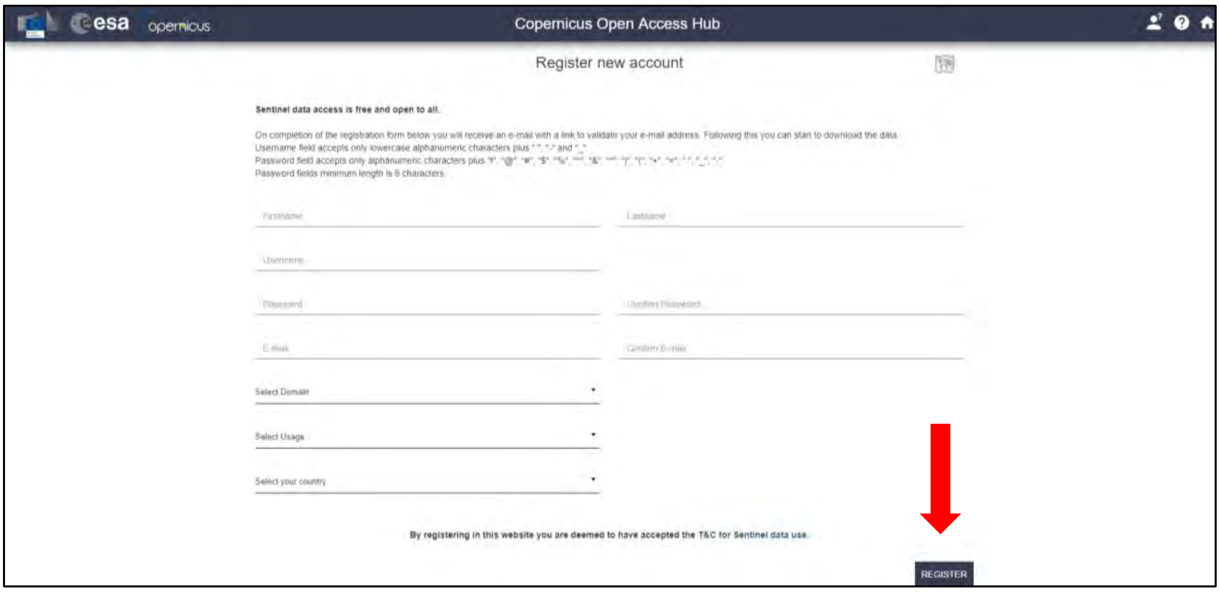

# 5 Step by step

## *5.1 Data download – ESA SciHUB*

In this step, we will download the Sentinel-1 scenes from the Copernicus Open Access Hub using the online interface. Go to **Applications → Network → Firefox Web Browser** or click the link below.

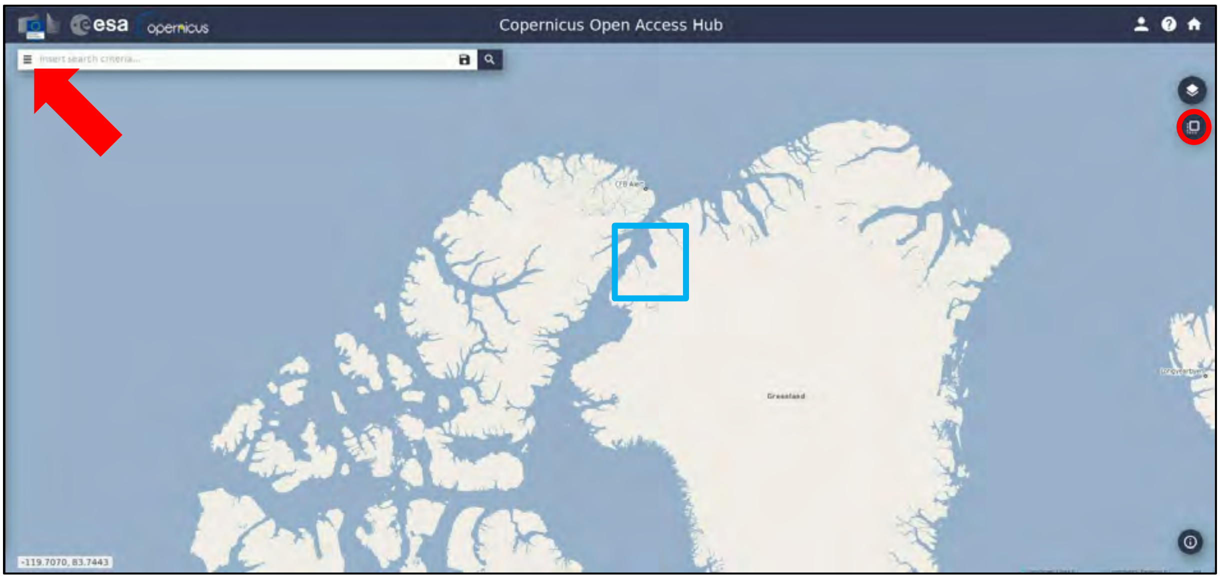
Go to [https://scihub.copernicus.eu/](https://scihub.copernicus.eu/)


Go to "**Open HUB**", if you do not have an account please register by going to "**Sign-up**" in the LOGIN menu in the upper right corner.

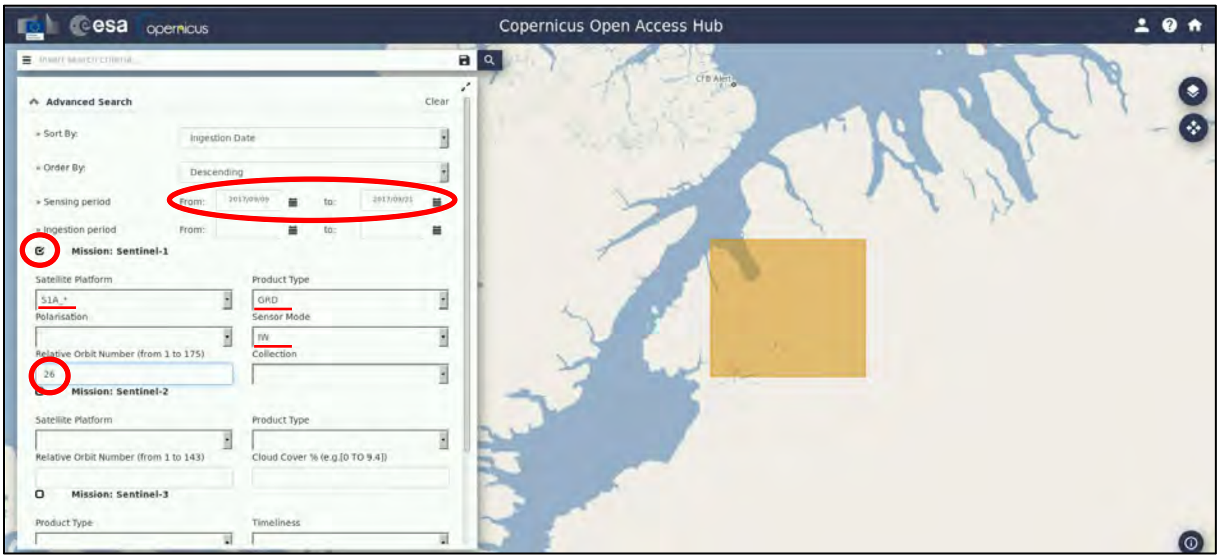
After you have filled in the registration form, you will receive an activation link by e-mail. Once your account is activated or if you already have an account, "**LOGIN**".

Navigate to the north of Greenland (**approximate area – blue rectangle**). Switch to drawing mode and draw a search rectangle approximately as indicated below.

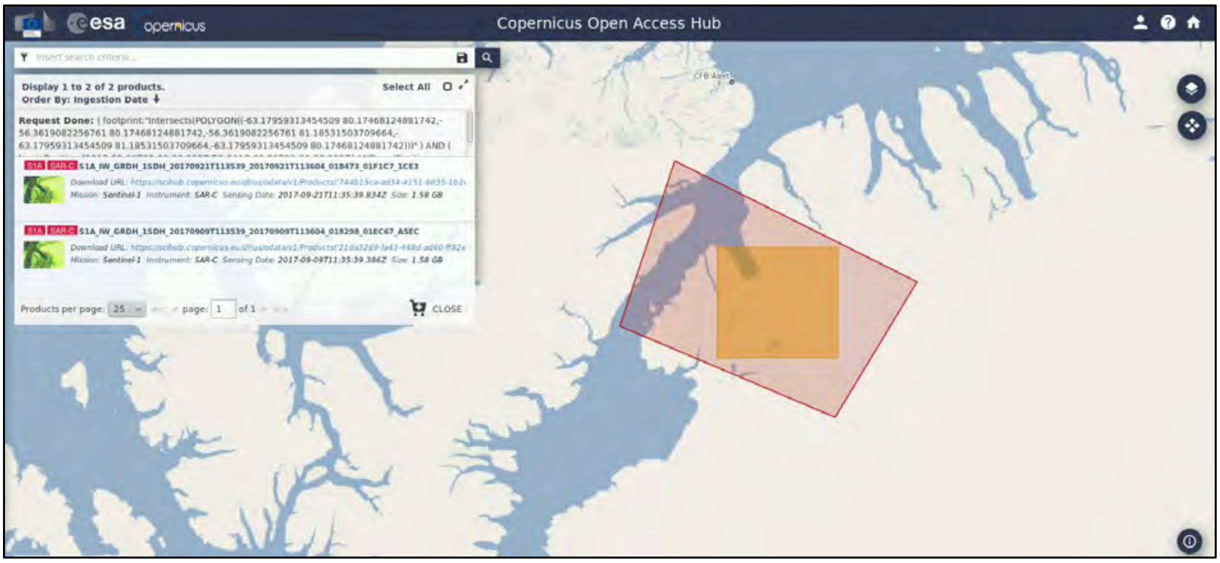



Open the search menu by clicking to the left part of the search bar and specify the following parameters:

**Sensing period:** From 2017/09/09 to 2017/09/21
**Mission:** Sentinel-1
**Satellite Platform:** S1A*
**Product Type:** GRD (Ground-range-detected product)
**Sensor Mode:** IW
**Relative Orbit Number:** 26




In our case, the search returns 2 results, depending on the exact search area defined. Download scenes:
*S1A_IW_GRDH_1SDV_20170909T113539_20170909T113604_018298_01EC67_A5EC.zip*
*S1A_IW_GRDH_1SDV_20170921T113539_20170909T113604_018473_01F1C7_1CE3.zip*



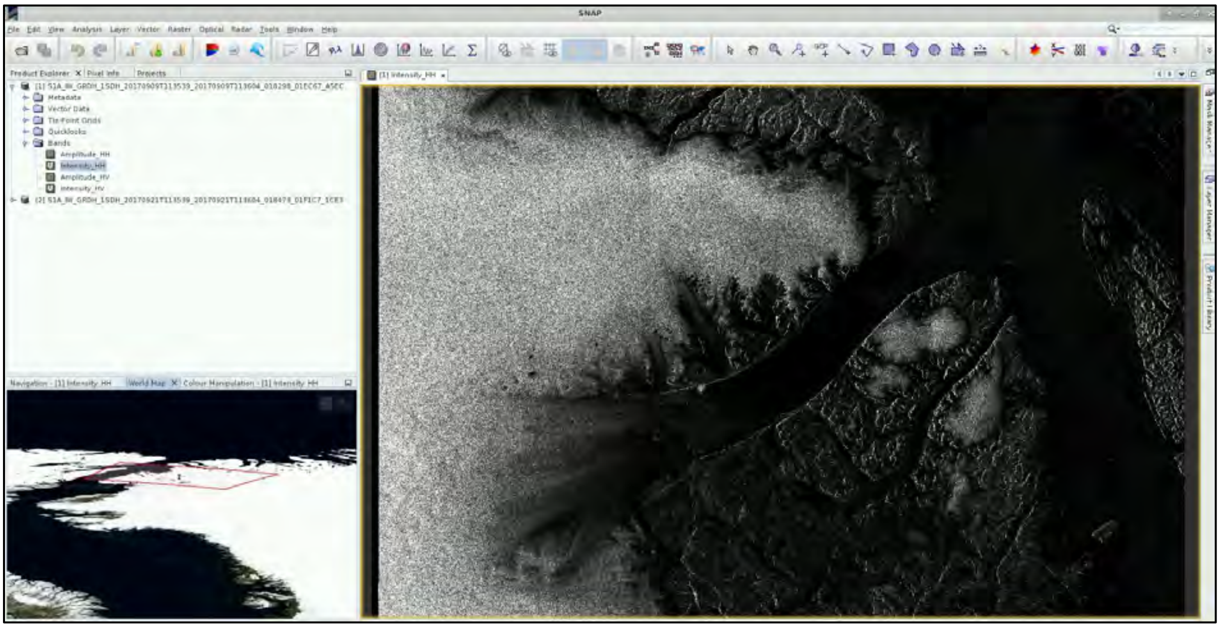

Move downloaded scenes from desktop (*/home/rus)* to:
***/shared/Training/CRYO02_GlacierVelocity_Greenland_TutorialKit/Original***

> TIP 1: It may sometimes happen that the data used to create this exercise are temporarily unavailable. In such case, you can use other date period for the same location to find two images 12 days apart in the same orbit.

## *5.2 SNAP – open and explore data*

Open **SNAP Desktop** (icon located on the desktop); click **Open Product**, navigate to: ***/shared/Training/CRYO02_GlacierVelocity_Greenland_TutorialKit/Original***
and open both downloaded products:
*S1A_IW_GRDH_1SDV_20170909T113539_20170909T113604_018298_01EC67_A5EC.zip*
*S1A_IW_GRDH_1SDV_20170921T113539_20170909T113604_018473_01F1C7_1CE3.zip*

The opened products will appear in **Product Explorer** window. Click **+** to expand the contents of product [1] from 9 September 2017, then expand **Bands** folder and double click on ***Intensity_HH*** band to visualize it.



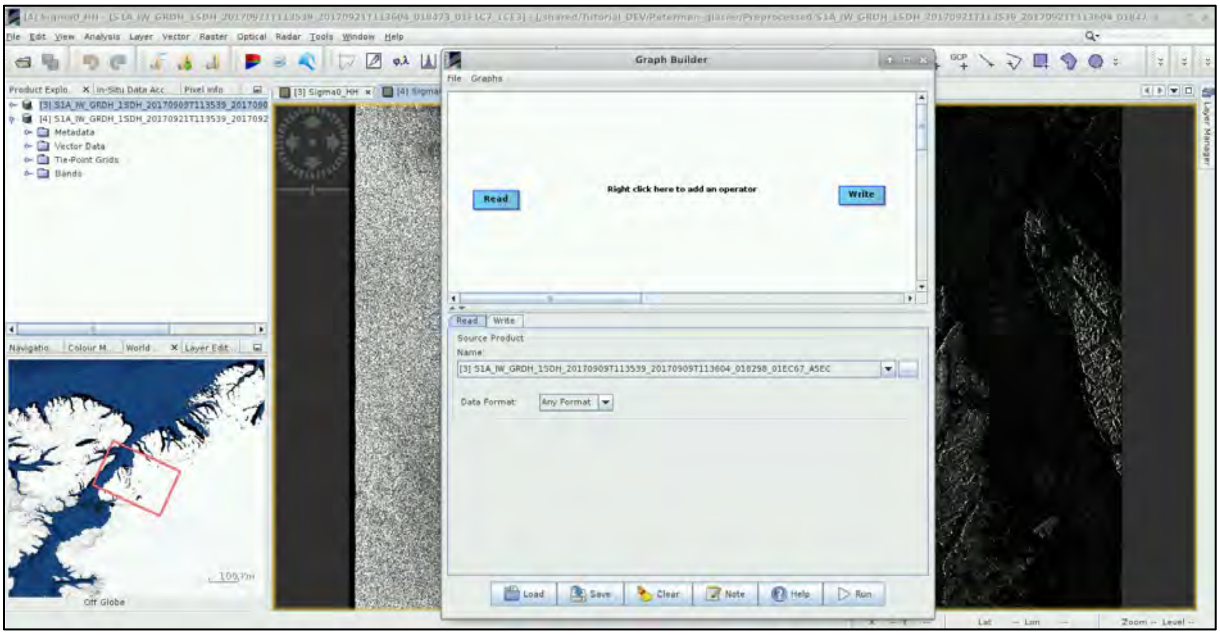
We can see that the view appears as if “mirrored”: this is because the scene was acquired during **descending** pass (the satellite was moving in direction from north to south, looking to the right (in this case west)) and the view shows the pixels in order of the data acquisition, as the image is not yet projected into cartographic coordinates.

## *5.3 Pre-processing*

We need to apply identical pre-processing steps to both of our scenes. However, processing the data step by step and product by product would be time consuming and inconvenient, luckily, we can use the **Batch Processing** tool available in SNAP to apply all steps to both images in one go (this also saves disk space as only the final product is physically saved).

To use the tool, we first need to define the process we want to apply and all its steps. We can do this using the **GraphBuilder** tool.

So let’s build our graph. Go to **Tools → GraphBuilder**.

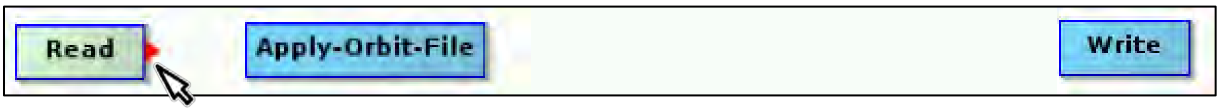



At the moment, the graph has only two operators: **Read** (to read the input) and **Write** (to write the output).

In the first step, we will update the orbit metadata (See NOTE 1). To add the operator right-click the white space between the existing operators and go to **Add → Radar → Apply-Orbit-File.**

> NOTE 1: The orbit state vectors provided in the metadata of a SAR product are generally not accurate and can be refined with the precise orbit files which are available days-to-weeks after the generation of the product. The orbit file provides accurate satellite position and velocity information. Based on this information, the orbit state vectors in the abstract metadata of the product are updated. (*SNAP Help*)

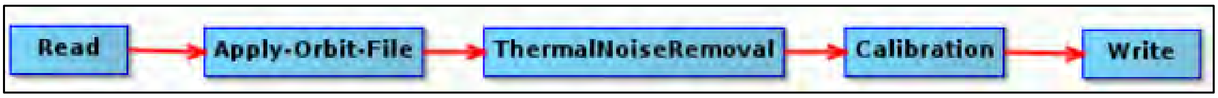
A new operator rectangle appeared in our graph and new tab appeared below. Now connect the new **Apply-Orbit-File** operator with the **Read** operator by clicking to the right side of the **Read** operator and dragging the red arrow towards the **Apply-Orbit-File** operator.



In the next step we will remove the thermal noise (See NOTE 2). We do this by right-clicking the white space somewhere left of the resample operator and going to **Add → Radar → Radiometric → ThermalNoiseRemoval.** Connect the **ThermalNoiseRemoval** operator with the **Apply-Orbit-File** operator.


NOTE 2: Thermal noise in SAR imagery is the background energy that is generated by the receiver itself (*SNAP Help*). It skews the radar reflectivity to towards higher values and hampers the precision of radar reflectivity estimates. Level-1 products provide a noise LUT for each measurement dataset, provided in linear power, which can be used to remove the noise from the product.

Now we can add the **Calibration** operator. The objective of SAR calibration is to provide imagery in which the pixel values can be directly related to the radar backscatter. Though uncalibrated SAR imagery is sufficient for qualitative use, calibrated SAR images are essential to quantitative use of SAR data (See NOTE 3). To add the operator go to **Add → Radar → Radiometric → Calibration.** Connect the Calibration operator, to both the **ThermalNoiseRemoval** operator and **Write** operator.




NOTE 3: Typical SAR data processing, which produces level-1 images, does not include radiometric corrections and significant radiometric bias remains. The radiometric correction is necessary for the pixel values to truly represent the radar backscatter of the reflecting surface and therefore for comparison of SAR images acquired with different sensors or acquired from the same sensor but at different times, in different modes, or processed by different processors. (*SNAP Help*)

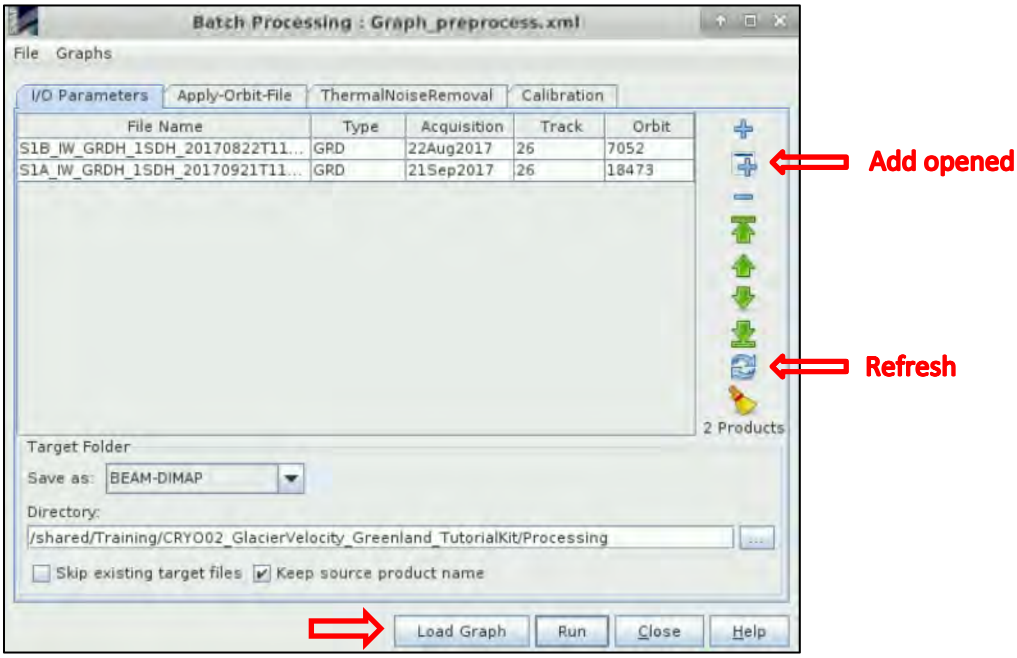
For the moment, do not change anything in the parameter tabs and save the graph as ***Graph_preprocess.xml*** to: ***/shared/Training/CRYO02_GlacierVelocity_Greenland_TutorialKit/Processing*** by clicking **Save** at the bottom of the window. After you have saved it, close the **GraphBuilder** window.

In the **Product Explorer** window, select (highlight) the product [1] (9 September 2017). Open the **Batch Processing** tool (**Tools → Batch Processing**).

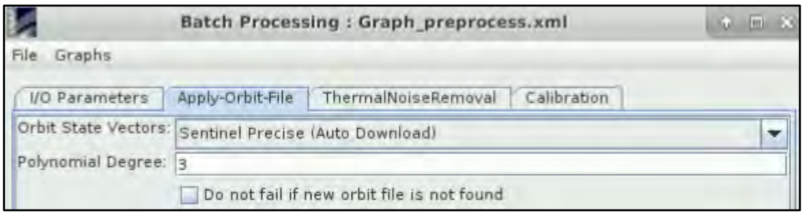
We will add both opened products by clicking **Add Opened** on the upper right (second icon from the top) and then click **Refresh** (second icon from the bottom). Then we click **Load Graph** at the bottom of the window and navigate to our saved graph and open it. We see that new tabs have appeared at the top of window corresponding to our operators with the exception of **Write**; this is correct as these parameters will be set in the **I/O Parameters** tab.

In the **I/O Parameters** tab set "**Directory**" to ***/shared/Training/CRYO02_GlacierVelocity_Greenland_TutorialKit/Processing*** and make sure the "**Keep source product name**" option is selected ✓ (See NOTE 4).

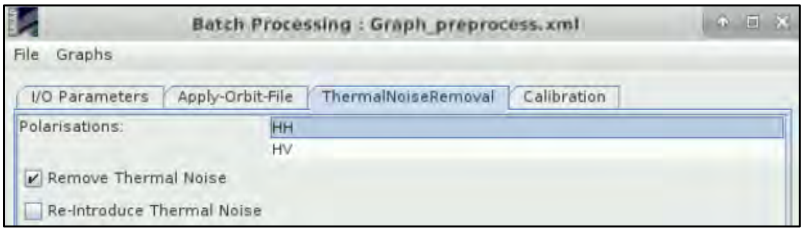
NOTE 4: The product file names will be identical to the input file names. If you set your output directory to the folder that contains your input data the input data will be overwritten.



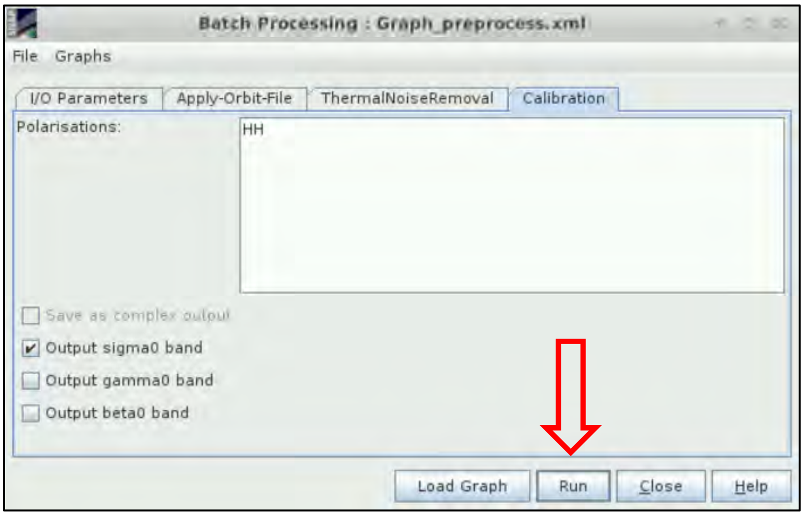

In the **Apply-Orbit-File** tab we can accept the default settings.




In the **ThermalNoiseRemoval** tab select HH polarization and make sure that the "**Remove Thermal Noise**" option is selected.




In the **Calibration** tab we will also accept all default settings and then click **Run**.



You should have 2 new products in the **Product Explorer** window. Close the **Batch Processing** window.

## *5.4 Coregistration and Offset tracking*

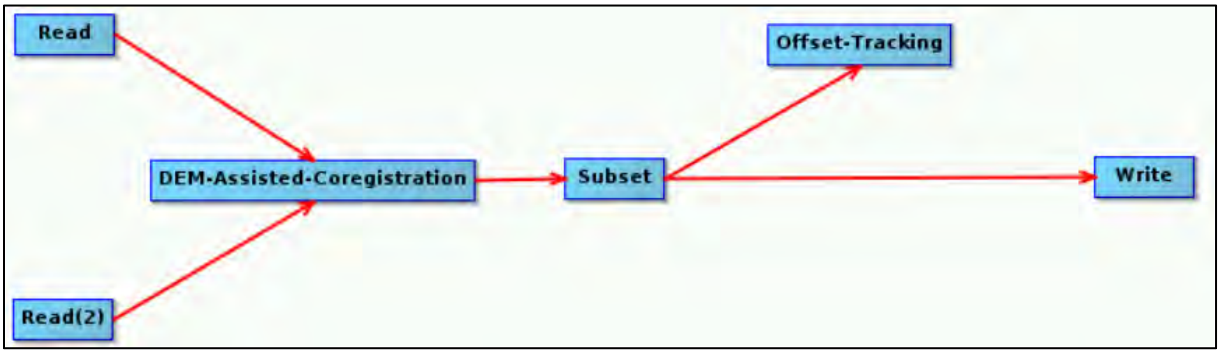
To simplify the process, we will also create a new graph for the next processing steps. Let's open the **Graph Builder** again (**Tools → Graph Builder**).

First, we need to delete the Write operator. Right click on it and select "**Delete**". Then we need to add a second Read operator. Right-click in the white space and go to **Add → Input-Output → Read**.

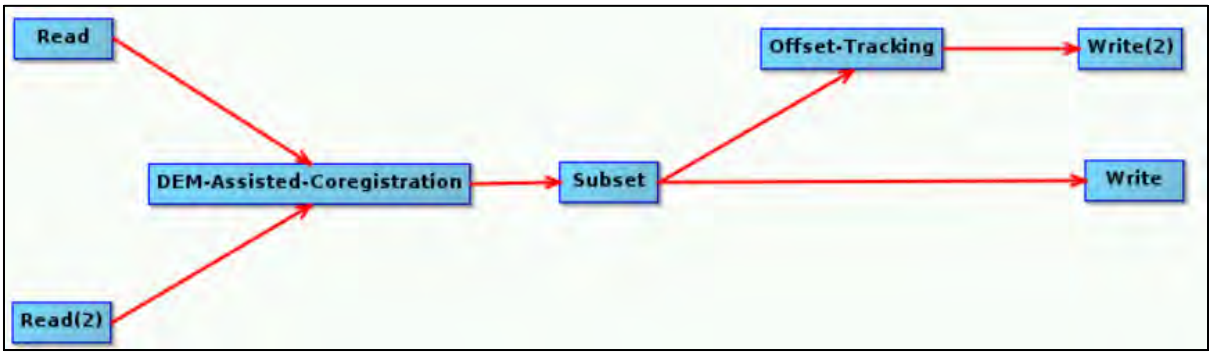
We will add the **DEM-Assisted Coregistration** operator by going to **Add → Radar → Coregistration → DEM-Assisted-Coregistration** and connect both **Read** operators to it.


Next, we will add the **Subset** operator (**Add → Raster → Geometric → Subset**) and connect the **DEM-Assisted-Coregistration** operator to it.

Since we want to continue to Offset Tracking and save this subset separately as well, we will add the **Offset-Tracking** operator (**Add → Radar → SAR Applications → Offset-Tracking**) and the **Write** operator (**Add → Input-Output → Write)**. Connect the **Subset** operator to both **Offset-Tracking** and **Write** operator.

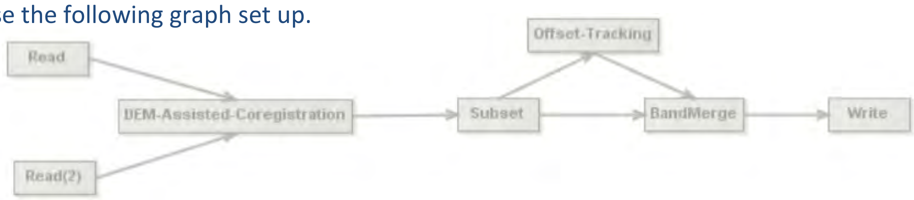



As the last step, we will add another **Write** operator (**Add → Input-Output → Write**) and connect the **Offset-Tracking** operator to it in order to save the final product (See TIP 2).



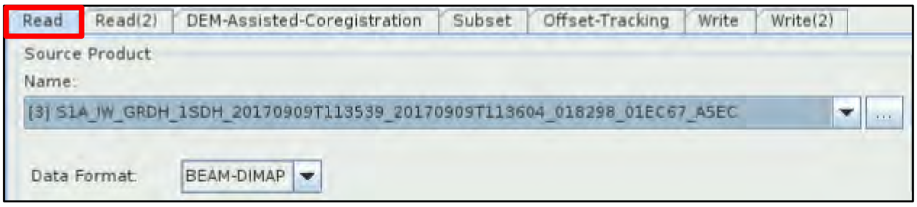
Tabs corresponding to each of the operators have appeared below the graph. We will go through them one by one to set all the parameters.

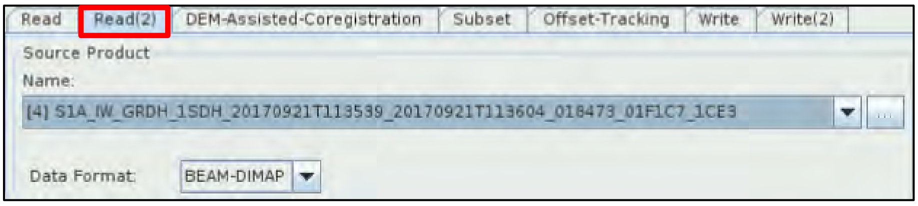
TIP 2: It may seem strange to write the two products separately, especially since we will stack them in the next step; however, the output of offset tracking is not only a raster but also a vector point layer containing the velocity at each Ground Control Point (GCP) and additional information that could be useful, such as heading (direction of the movement) and directional components. SNAP does not currently offer operator to export the vector layer in graph. If you do not need the vector layer, you can use the following graph set up.




### 5.4.1 Read

First let's go to the first **Read** tab and make sure that the pre-processed product [3] from 9-Sept 2017 is selected as the Source product. Then go to the **Read(2)** tab and set the pre-processed product [4] from 21-Sept 2017 as the Source product.

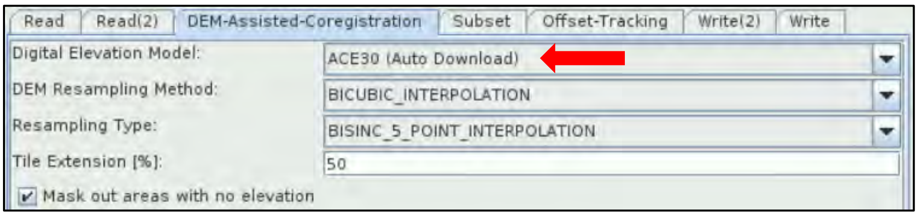



### 5.4.2 DEM-assisted coregistration

Image coregistration is the process of geometrically aligning two or more images so that corresponding pixels represent identical area on earth surface. It is possible to coregister two or more products using only orbit state vectors, however for the purpose of offset tracking we need more precise coregistration. Therefore, we use additional information provided by digital elevation model (DEM).

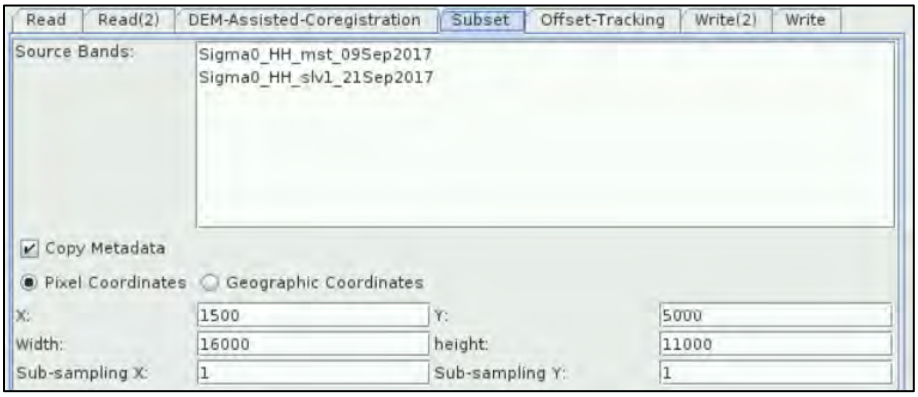
Go to the **DEM-Assisted-Coregistration** tab and set "Digital Elevation Model": **ACE30 (Auto Download)**




### 5.4.3 Subset

Since our Area of Interest (AOI) is quite small and there is no need to process the whole image, we start with sub-setting the scene to a more manageable size. This will reduce the processing time in further steps and is recommended when the analysis is focused only over a specific area and not at the complete scene. Go to the **Subset** tab and at “**Pixel Coordinates**” set:

X: **1500** Width: **16000** Y: **5000** Height: **11000**




### 5.4.4 Offset Tracking

Offset Tracking is used to estimate the motion of a feature between two acquisitions through cross-correlation on selected Ground Control Point (GCP) in coregistered images (master and slave) in both slant-range and azimuth direction. The movement velocity is then computed based on the offsets estimated by the cross-correlation (See NOTE 5). The velocities computed on the GCP grid are interpolated to create velocity map. It is a method frequently used for glacier motion estimation.

NOTE 5: The Offset Tracking is performed in the following sub-steps (*ESA Snap*):

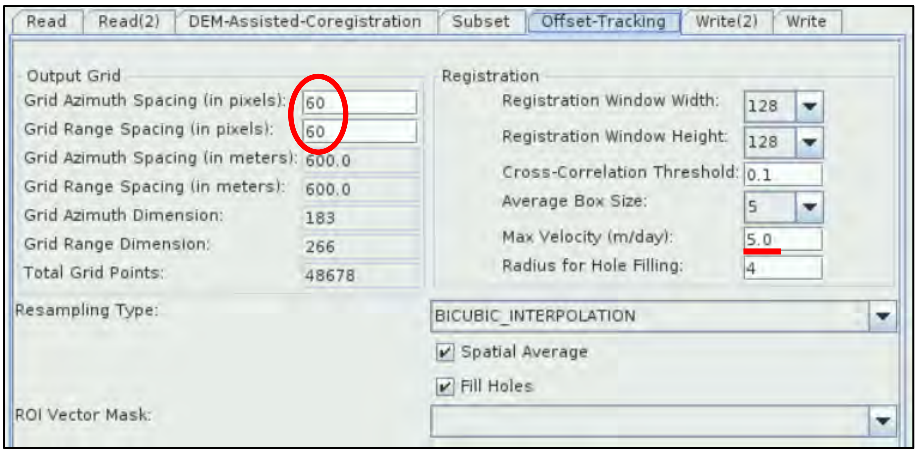
- For each point in the user-specified GCP grid in master image, compute corresponding pixel position in slave image using normalized cross-correlation.
- If the computed offset between master and slave GCP positions exceeds the maximum offset (computed from user specified maximum velocity), then the GCP point is marked as outlier.
- Perform local average for the offset on valid GCP points.
- Fill holes caused by the outliers. The offset at missing point will be replaced by a new offset computed by local weighted average.
- Compute the velocities for all points on GCP grid from their offsets.
- Finally, compute velocities for all pixels in the master image from the velocities on GCP grid by interpolation (final product has same pixel size as the input data).

To perform the **Offset-Tracking,** we need to set several parameters. First, we need to set the GCP grid spacing in pixels in range and azimuth directions (determines the resolution/level-of-detail of our velocity product). We will set the spacing to 60 pixels (600m) in both directions, this balance between the level of detail and smoothness of our output, is sufficient for our purposes (also: the higher the resolution => the longer the processing time).

Next, we need to set the Registration Window dimensions; the size of the registration window depends on the maximum velocity of the glacier (from literature of historical data) and the period between the data acquisitions. Our images were acquired 12 days apart and the maximum speed of the Petermann Glacier is close to 5 m/day, this means that the glacier surface will shift by maximum 60 meters. This means that we can keep the default setting of 128 pixels (1280x1280m). To filter out false high values we also set the known maximum glacier velocity to 5 m/day. So, we need to set:

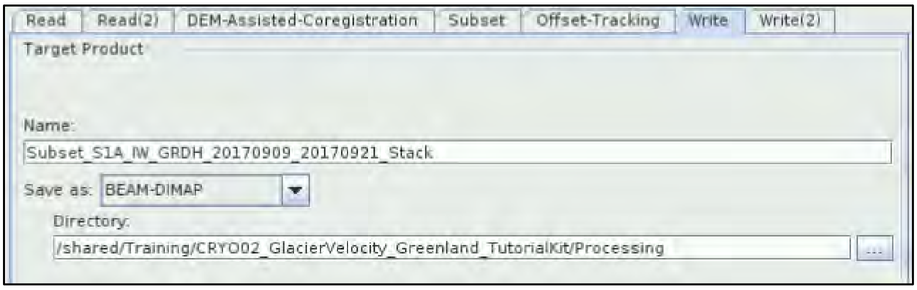
**Grid Azimuth Spacing (in pixels):** 60
**Grid Range Spacing (in pixels):** 60

**Max Velocity (m/day):** 5.0

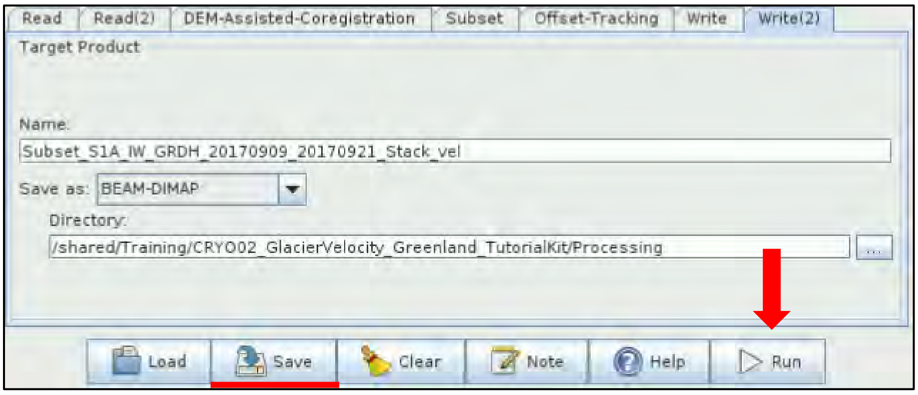



## 5.4.5 Write operators

In the **Write** tab (connected to the **Subset** operator), set the product name to ***Subset_S1A_IW_GRDH_20170909_20170921_Stack*** and the target directory to ***/shared/Training/CRYO02_GlacierVelocity_Greenland_TutorialKit/Processing***.



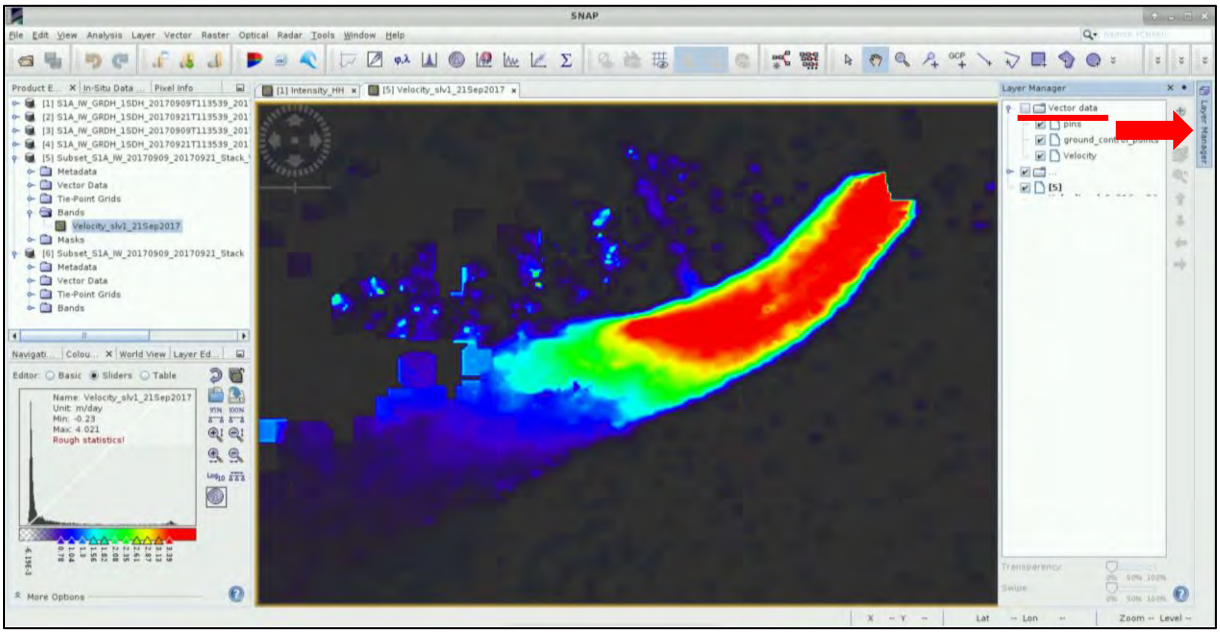

In the **Write(2)** tab (connected to the **Offset-Tracking** operator), set the product name to ***Subset_S1A_IW_GRDH_20170909_20170921_Stack_vel*** and the target directory to ***/shared/Training/CRYO02_GlacierVelocity_Greenland_TutorialKit/Processing***.




Click **Save** to save the graph with the name "**Graph_offset_tracking**", at the following directory: ***/shared/Training/CRYO02_GlacierVelocity_Greenland_TutorialKit/Processing***.

Click **Run**. This might take a while. *Approximate processing time: 35 minutes.*

After the processing is completed, close the **Graph Builder** window. Two new products [5] and [6] have appeared in the **Product Explorer** window. Expand the **velocity product** [5] and double click the ***Velocity_slv1_21Sep2017*** band to open it in the **View** window. On top of the velocity map we can see the geolocation point grid that obscures our view. We can hide it by going to **Layer Manager** on the right side (or go to **Layer → Layer Manager** to open it) and **deselect the vector folder**.

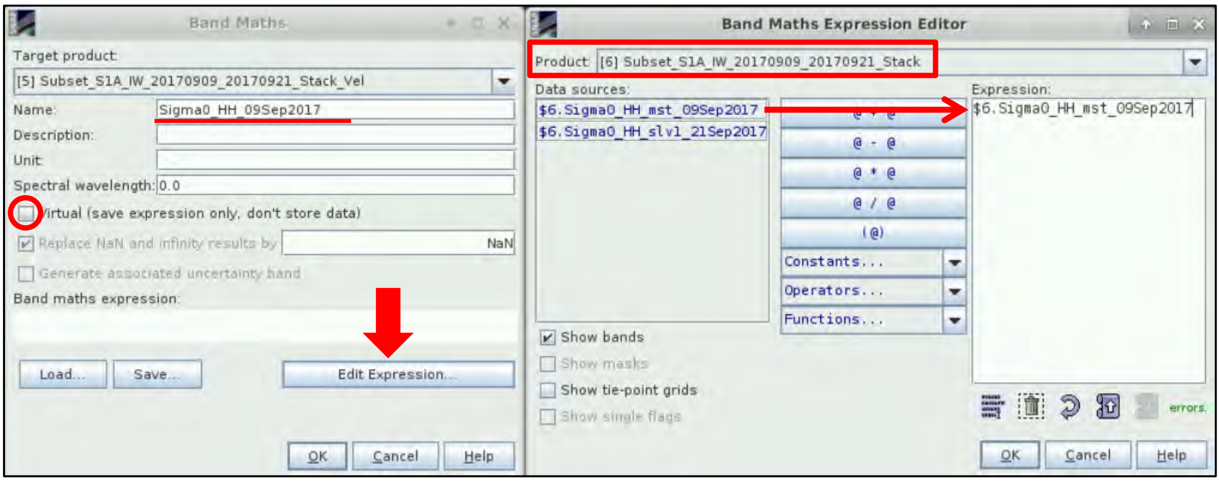


## 5.5 *Stack the products*

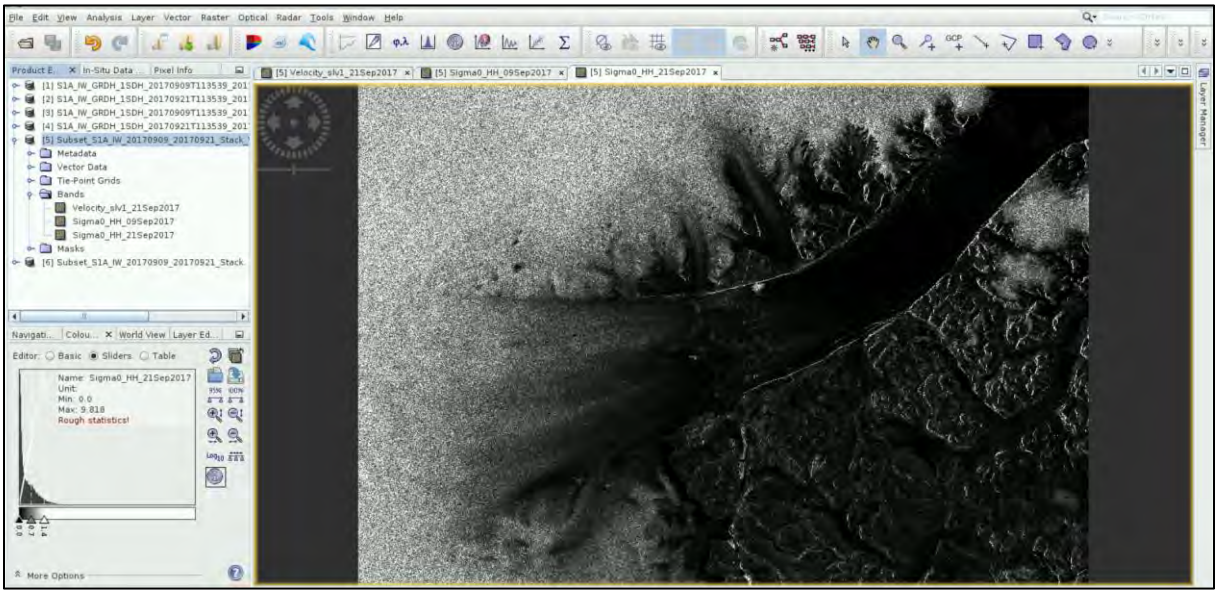
Let's join the two outputs to a single product, for this we will use the **Band Math** function. Right-click product [5] and open **BandMath** dialog. Set "Name" to ***Sigma0_HH_09Sep2017*** and **deselect** the **Virtual (save expression only, don't store data)** option because we want to store the data.

Then click on the **Edit Expression...** and a new dialog will open. Set **Product** to:
***[6] Subset_S1A_IW_20170909_20170921_Stack***.

Then in **Data Sources**, click on ***$6.Sigma0_HH_mst_09Sep2017*** band.




Click **OK** in both windows. Repeat the process to add also the second band. This time set "Name" to ***Sigma0_HH_21Sep2017*** and in **Data Sources**, click on ***$6.Sigma0_HH_slv1_21Sep2017*** band. The new bands will automatically open in the view. Go to the **Layer Manager** in the upper right corner and **deselect the Vector folder** in both images.

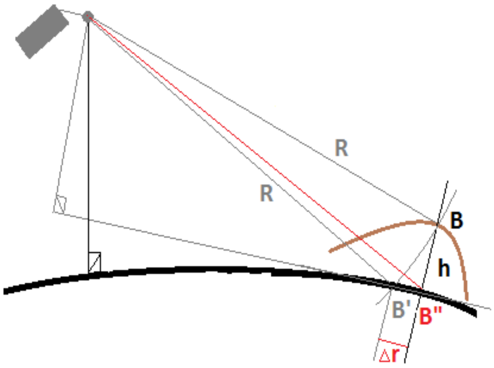


In the **Product Explorer** Window, select products [1] to [4]; right-click and select **Close 4 Products**.

### *5.6 Terrain correction*

Our data are still in radar geometry, moreover due to topographical variations of a scene and the tilt of the satellite sensor, the distances can be distorted in the SAR images. We need to apply **Terrain Correction** to compensate for the distortions and reproject the scene to geographic projection. (See NOTE 6)

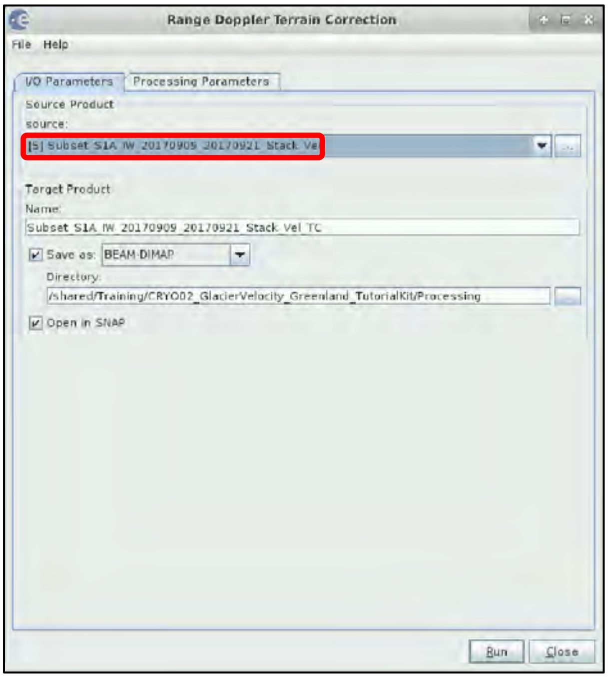
NOTE 6: The geometry of topographical distortions in SAR imagery is shown on the right. Here we can see that point **B** with elevation **h** above the ellipsoid is imaged at position **B'** in SAR image, though its real position is **B"**. The offset **Δr** between **B'** and **B"** exhibits the effect of topographic distortions. *(SNAP Help)*

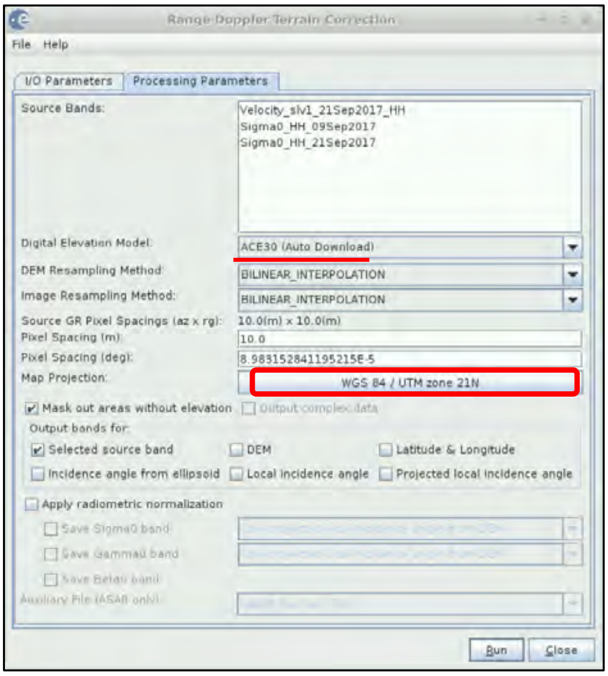


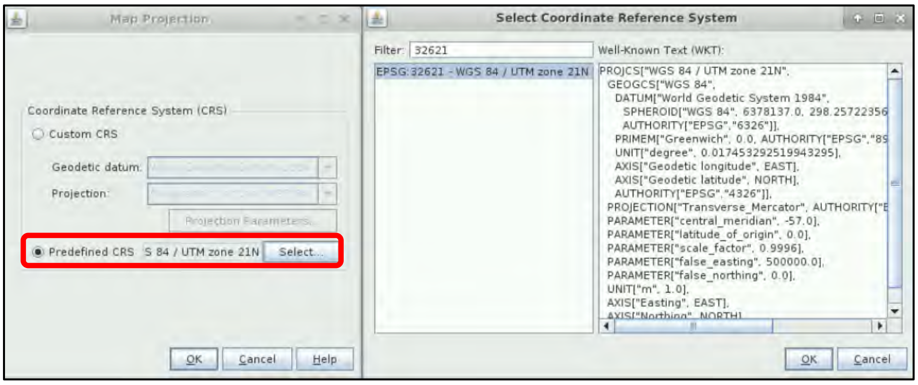

Click **Radar → Geometric → Terrain Correction → Range-Doppler Terrain Correction**

In the **I/O Parameters** tab set as "Source Product" the **product [5] (velocity product)**. In "Target Product", keep the default name and set the "Directory" to:
***/shared/Training/CRYO02_GlacierVelocity_Greenland_TutorialKit/Processing***.

In the **Processing Parameters** tab set:
**Digital Elevation Model**: ACE30 (Auto Download)
**Map Projection**: Click on it, choose Predefined CRS and click on "**Select**". In "Filter" search for **32621** (EPSG: 32621 – WGS84 / UTM Zone 21N) and when you find it click **OK** to both windows.



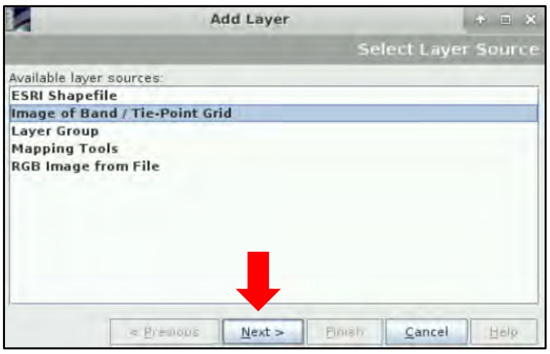



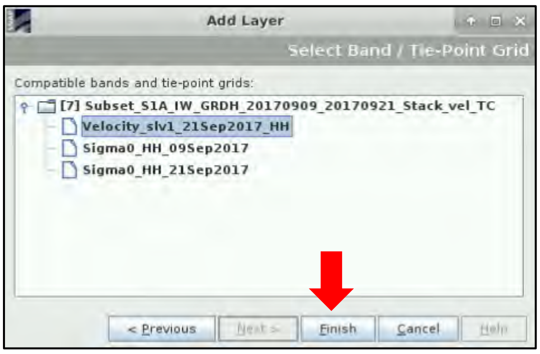

Keep defaults values for the other parameters. Click **Run**. *Approximate processing time: 2.5 minutes.*

## *5.7 Visualize*

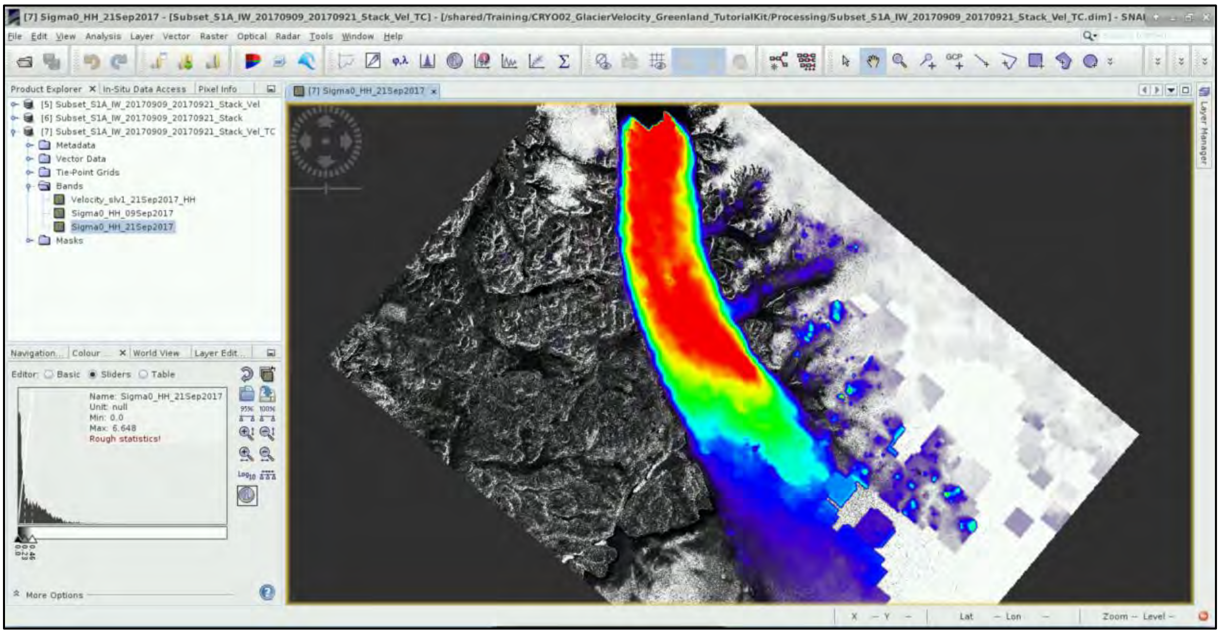
Close **Range Doppler Terrain Correction** window. Let's overlay the velocity data on top of the original data. Expand the new georeferenced product [7] and open the ***Sigma0_HH_21Sep2017*** band in **View** window. We can stretch the histogram a little in the **Colour Manipulation** tab (move the white slider on the right, to approx. 0.45).

Then go to the **Layer Manager** in the top right corner and in the **Vector data** folder **deselect Velocity**. Then click on ⊕ to add an overlay layer, select **Image of Band / Tie-Point Grid** and select the ***Velocity_slv1_21Sep2017_HH***. Then click **Finish**.

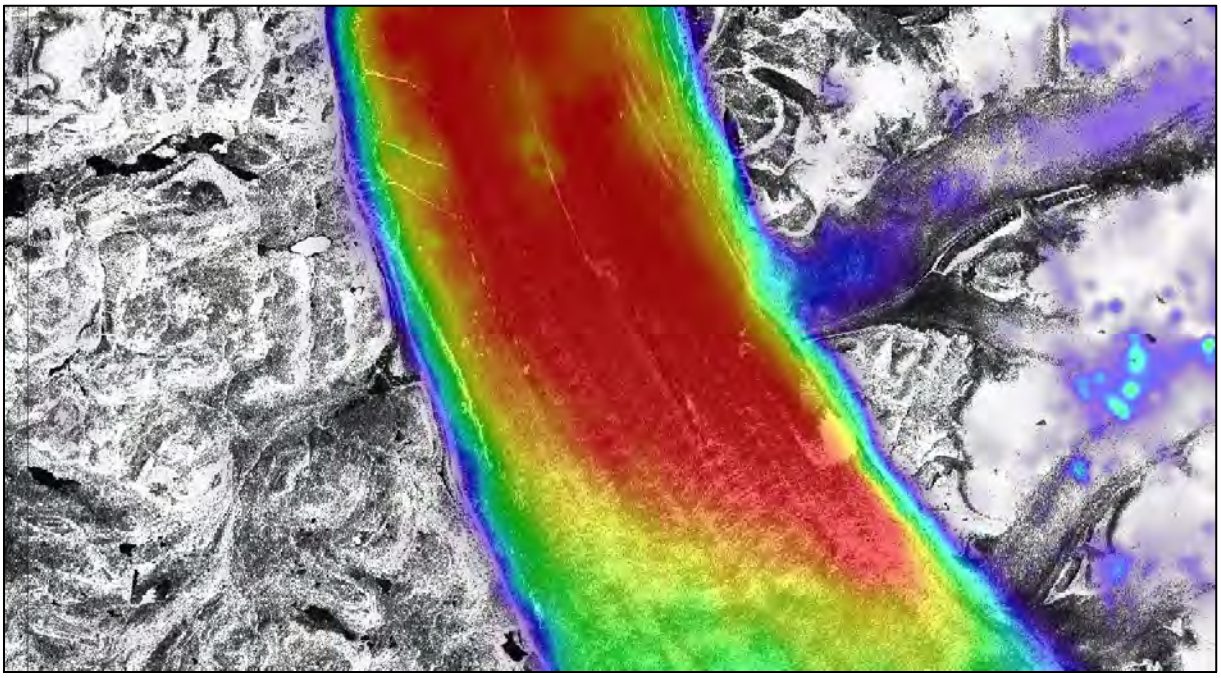


Now, we can see the velocity band overlaid over the original image, we can adjust the **transparency** by going to the **Layer Manager**, selecting the ***Velocity_slv1_21Sep2017*** and moving the transparency slider on the bottom of the tab.




We can also make the layer semi-transparent. In **Layer Manager,** select the overlaid *Velocity* layer and move the transparency slider at the bottom of the tab.



## *5.8 Compare to existing velocity datasets*

In the ***Auxdata*** folder you can find a CSV file (tab delimited) containing a velocity data from two external sources, both also based on Sentinel-1. Let's see how our results compare to them.

The first dataset was acquired from the *CPOM Ice Sheet Outlet Glacier Velocity Service* (Centre for Polar Observation and Modelling Data Portal), a portal providing near real-time velocity maps produced by tracking moving features (offset-tracking) in Sentinel-1 data between two consecutive acquisitions

(Hogg, Shepherd, & Gourmelen, 2015). The CPOM velocity data we will use here, correspond to period 15 -21 September 2017 (our results correspond to 9-21 September 2017).

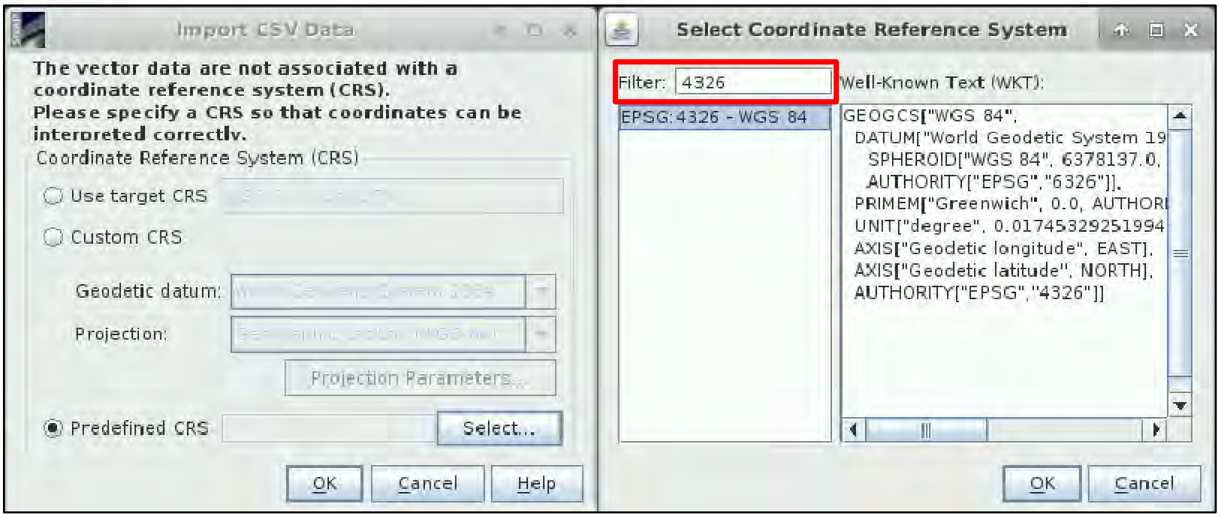
The second dataset contains values extracted from the *ENVEO Greenland ice velocity map 2016/2017 from Sentinel-1* (ENVEO Cryoportal) also derived using feature tracking in Sentinel-1 data. Compared to the CPOM dataset, the ENVEO velocity uses 12 day period between image pairs and the final product is generated by pixel-scale averaging of velocities estimated from image pairs acquired between 23 December 2016 and 22 February 2017 (Nagler, Rott, Hetzenecker, Wuite, & Potin, 2015).

The final product is then resampled to 250m grid. Apart from the overall horizontal velocity product we will use, the dataset also includes separate velocity components (vx, vy, vz) valid pixel count and uncertainty estimates.

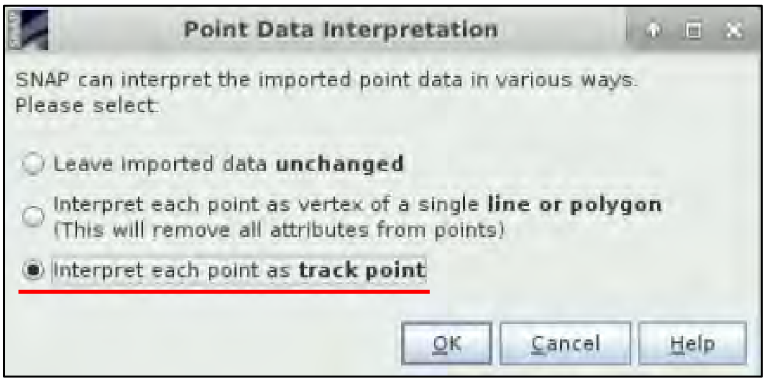
We can load the CSV file by going to the **Product Explorer** window and selecting the product [7]. Then go to **Vector → Import → Vector from CSV**.

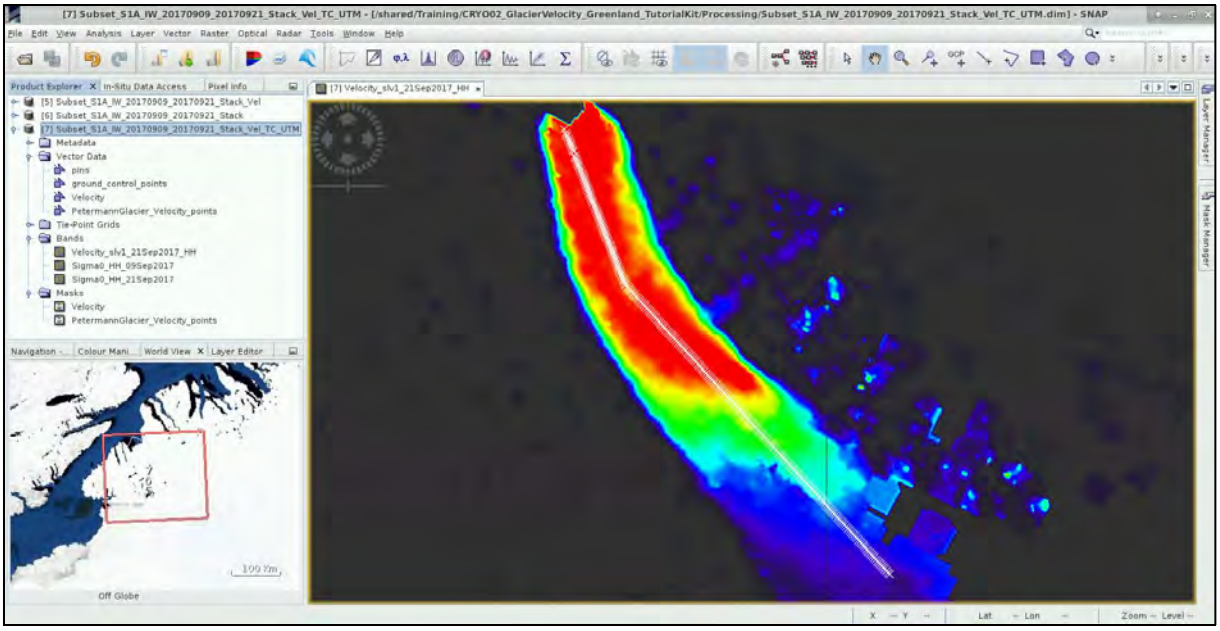
Navigate to ***/shared/Training/CRYO02_GlacierVelocity_Greenland_TutorialKit/Auxdata*** and select ***PetemannGlacier_Velocity_points.csv***

In the **Import CSV Data** window selected **Predefined CRS,** click on "**Select**" and in the **"Filter"** search for "**4326**", select "**EPSG: 4326 - WGS 84**" and click **OK only** to the 2 first windows.




In the **Point Data Interpretation** window, select "**Interpret each point as track point**" and then click **OK**.





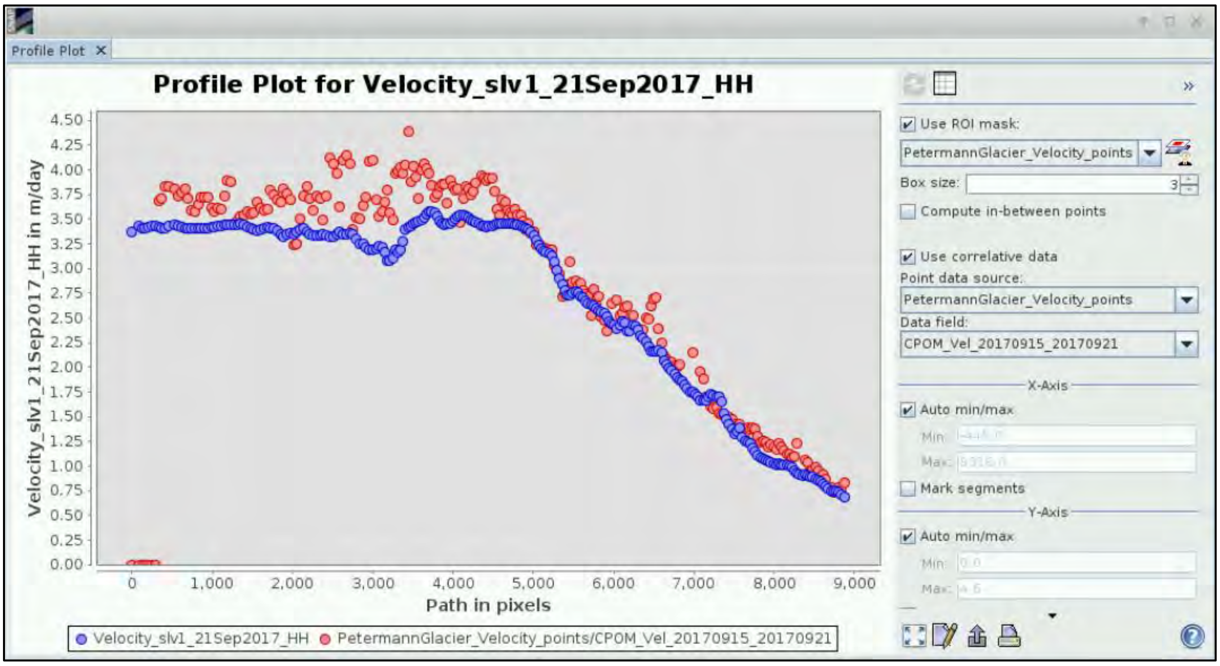
Now let's compare the profiles. In the **Product Explorer** window, in the product [7], highlight the ***Velocity_slv1_21Sep2017_HH*** band. Then go to **Analysis** and click on **Profile Plot**.

Select ✓ the **Use ROI mask** and choose ***PetermannGlacier_Velocity_points***
Deselect **Compute in-between points**.

Select ✓ **Use correlative data** and set:

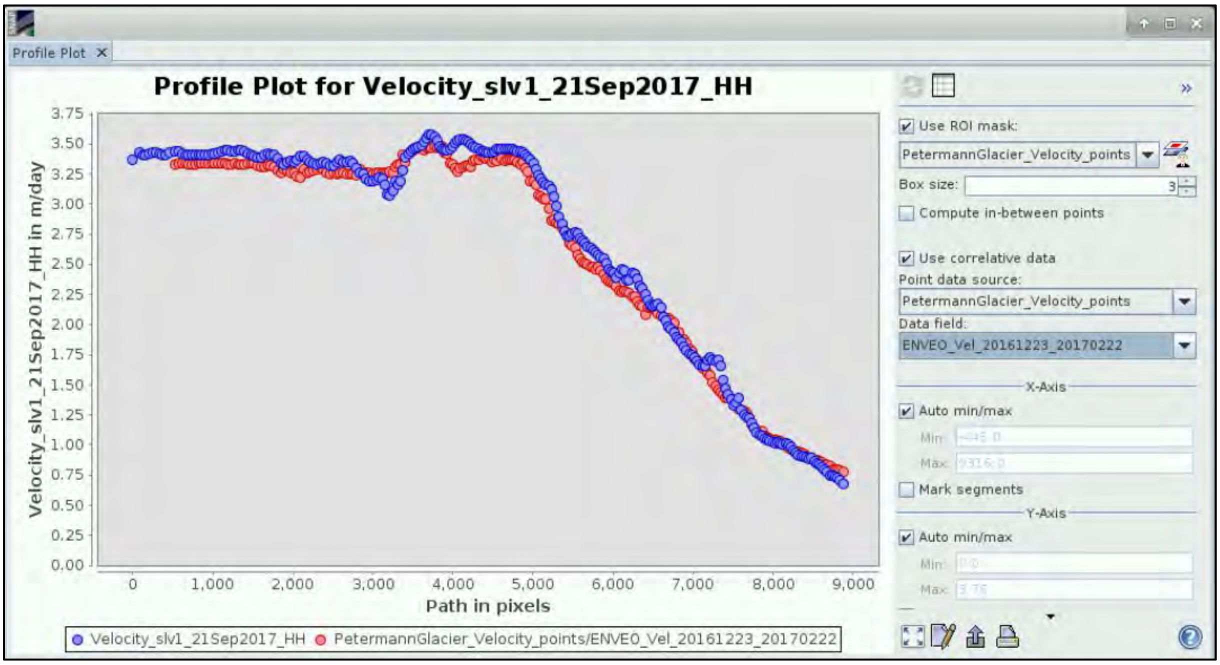
Point data source: ***PetermannGlacier_Velocity_points***

Data field: ***CPOM_Vel_20170915_20170921***




We can see that the CPOM data show more variability but otherwise agree quite nicely with our estimation. The increased variability is likely a result of shorter time period between used acquisitions (6 days, compared to 12 days period for our input images) and much finer GCP grid spacing (100 m, compared to our 600 m).

Now change the correlative **Data field** to ***ENVEO_Vel_20161223_20170222***.




We can see that our estimation agrees with the ENVEO velocity almost perfectly. The ENVEO velocity uses the same time period between images (12 days), but the estimated velocities are averaged over 3-month period which is likely responsible for the minor differences. Glacier velocity changes over time as it is partly driven by the melt, therefore we can expect that the velocity would be slightly lower during the winter months compared to early fall.

# 6 Other suggested steps

## 6.1 *Export velocity*

Now we can export our results to an ESRI Shapefile (.shp) format that is more manageable and can be processed and visualized further in software such as QGIS. The shapefile will contain following information:

- Coordinates of GCP point in master image (9 Sept)
- Coordinates of corresponding point in slave image (21Sept)
- The distance travelled
- Velocity in m/day
- Heading in degrees (East from North)
- Range shift
- Azimuth shift

In order to view this, expand the "**Vector Data**" folder of the product [7] and **double click** on **Velocity**.

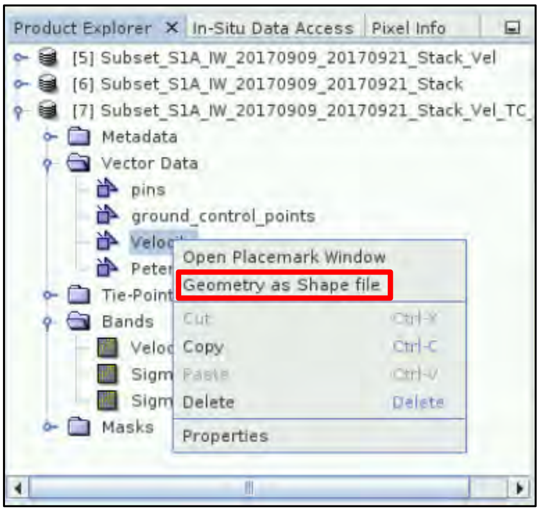
[7] Velocity_slv1_21Sep2017_HH × [7] Velocity ×

| Velocity | mst_lat | mst_lon | slv_lat | slv_lon | distance | velocity | heading | range_shift | azimuth_shift | geometry | style_css |
|---|---|---|---|---|---|---|---|---|---|---|---|
| post_0 | 80.569 | -54.166 | 80.569 | -54.166 | 0.613 | 0.05 | 36.865 | 0.061 | 0.602 | POINT (55… | fill:#0000f… |
| post_1 | 80.571 | -54.194 | 80.571 | -54.194 | 0.578 | 0.047 | 36.371 | 0.053 | 0.567 | POINT (55… | fill:#0000f… |
| post_10 | 80.596 | -54.448 | 80.596 | -54.448 | 1.807 | 0.15 | 253.27 | -1.224 | -1.316 | POINT (54… | fill:#0000f… |
| post_100 | 80.834 | -57.058 | 80.834 | -57.058 | 0.851 | 0.07 | 201.03 | 0.108 | -0.834 | POINT (49… | fill:#0000f… |
| post_1000 | 80.68 | -55.602 | 80.68 | -55.602 | 0 | 0.063 | -1 | 0.369 | -0.655 | POINT (52… | fill:#0000f… |
| post_10000 | 80.95 | -62.261 | 80.95 | -62.261 | 0.435 | 0.036 | 215.802 | -0.104 | -0.422 | POINT (40… | fill:#0000f… |
| post_10001 | 80.952 | -62.293 | 80.952 | -62.293 | 0.514 | 0.043 | 216.655 | -0.13 | -0.496 | POINT (40… | fill:#0000f… |
| post_10002 | 80.954 | -62.324 | 80.954 | -62.324 | 0.596 | 0.05 | 216.28 | -0.148 | -0.577 | POINT (40… | fill:#0000f… |
| post_10003 | 80.956 | -62.356 | 80.956 | -62.356 | 0.903 | 0.075 | 216.59 | -0.229 | -0.87 | POINT (40… | fill:#0000f… |
| post_10004 | 80.958 | -62.387 | 80.958 | -62.387 | 0.835 | 0.069 | 212.744 | -0.157 | -0.816 | POINT (40… | fill:#0000f… |

Depending on the version of SNAP you have there might be a reoccurring bug that prevents simple export of the detections to ESRI shapefile format. Outlined below is a method to export for **versions without the bug (OPTION 1)** and a work-around method for **versions with the bug (OPTION 2)**.

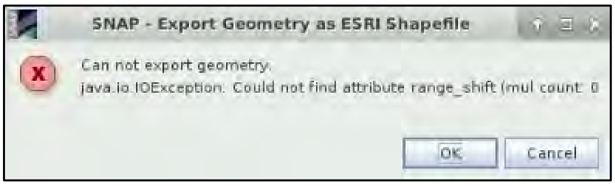
### 6.1.1 OPTION 1 – No error

In **Product Explorer** window, expand the product [7] and open the **Vector Data** folder. Right-click on the ***Velocity*** layer and select **Geometry as a Shapefile**. Save the layer to the ***Processing*** folder with the name "**Velocity.shp**".




### 6.1.2 OPTION 2 – SNAP versions with error

If the approach described in OPTION 1 does not work for you then the version of SNAP installed on your machine likely contains the mentioned error.



Click **OK** and make the following steps.

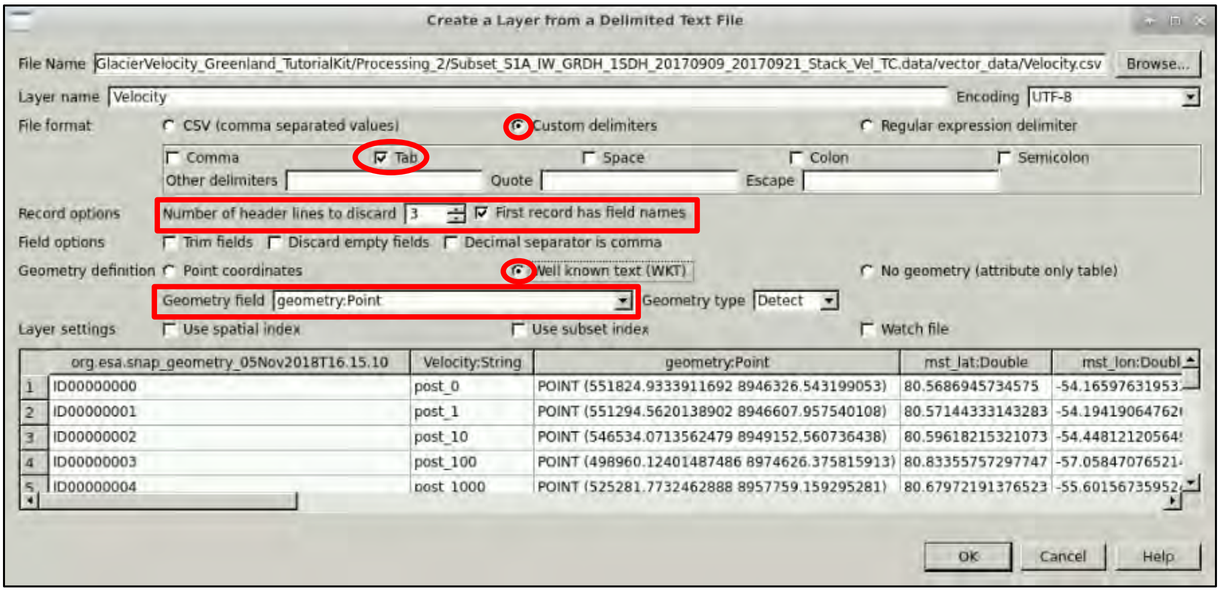
The detections are stored in the output product folder as a CSV file. The CSV file can be loaded directly to QGIS and converted into shapefile.

In your VM, go to **Applications → Processing** and open **QGIS Desktop.** Now, click on the **"Add Delimited Text Layer"**  in the vertical menu on the left of the window. In the window that opens, click **Browse** and navigate to:

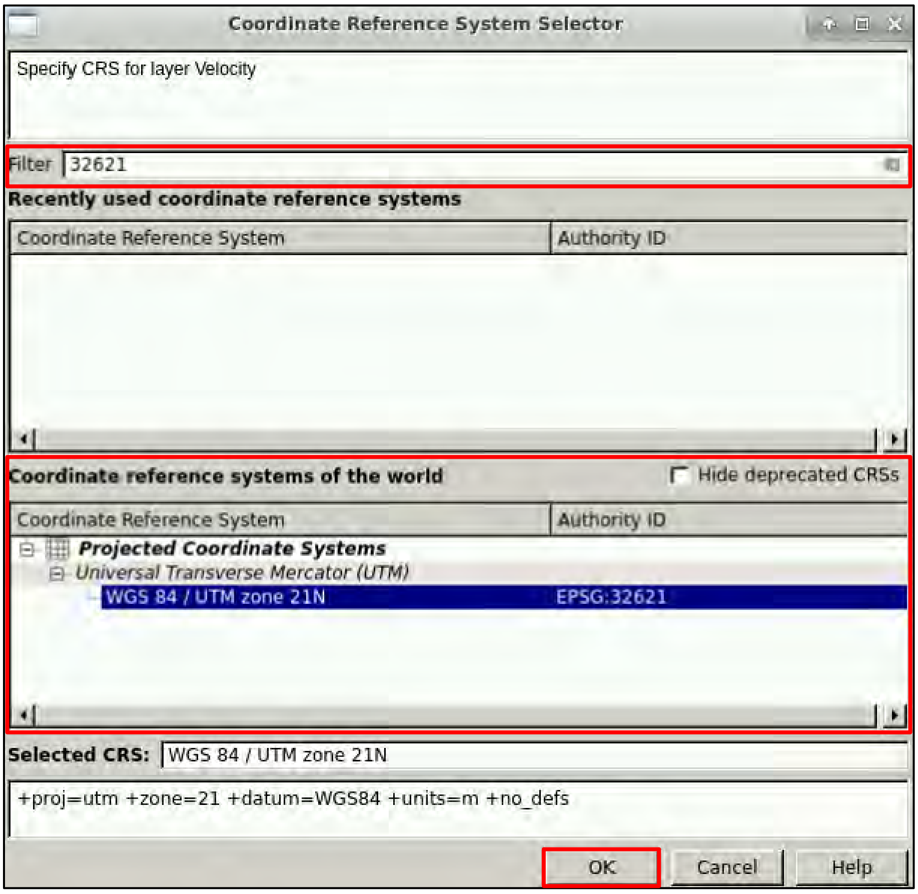
***/shared/Training/CRYO02_GlacierVelocity_Greenland_TutorialKit/Processing/***, open ***subset_S1A_IW_GRDH_1SDV_20170909_20170921_Stack_Vel_TC.data*** folder, then open ***vector_data*** folder, select ***Velocity.csv*** and click "**Open**".

A table will appear in the bottom of the window. Select **Custom delimiters**, and select **Tab**, unselect all other delimiters and in **Other Delimiters** type delete all.

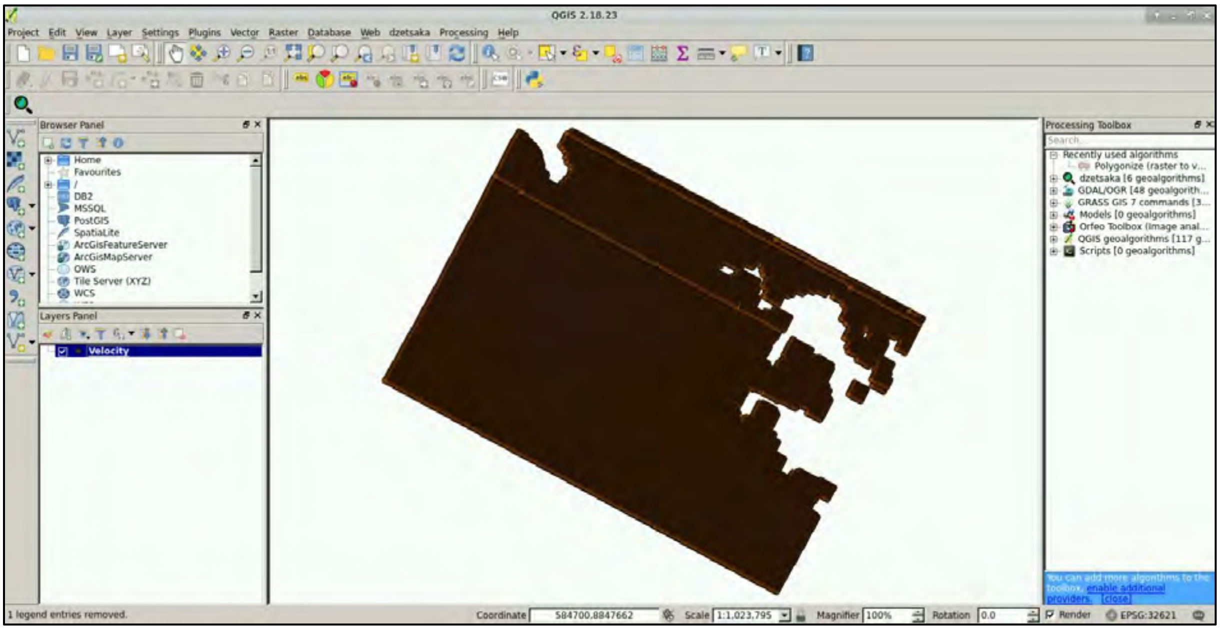
In **Record options**, set **Number of header lines to discard** to **3** and **select** the "**First record has field names**" option. Finally, in the **Geometry definition**, select "**Well known text (WKT)**" and set **Geometry Field** to "**geometry:Point**".



Then, click **OK**. The following window will appear. In “**Filter**”, type **32621** and you will see that in the “**Coordinate reference systems of the world**” tab, the “**WGS 84 / UTM zone 21N**” Coordinate Reference System will appear. Select it and click **OK**.

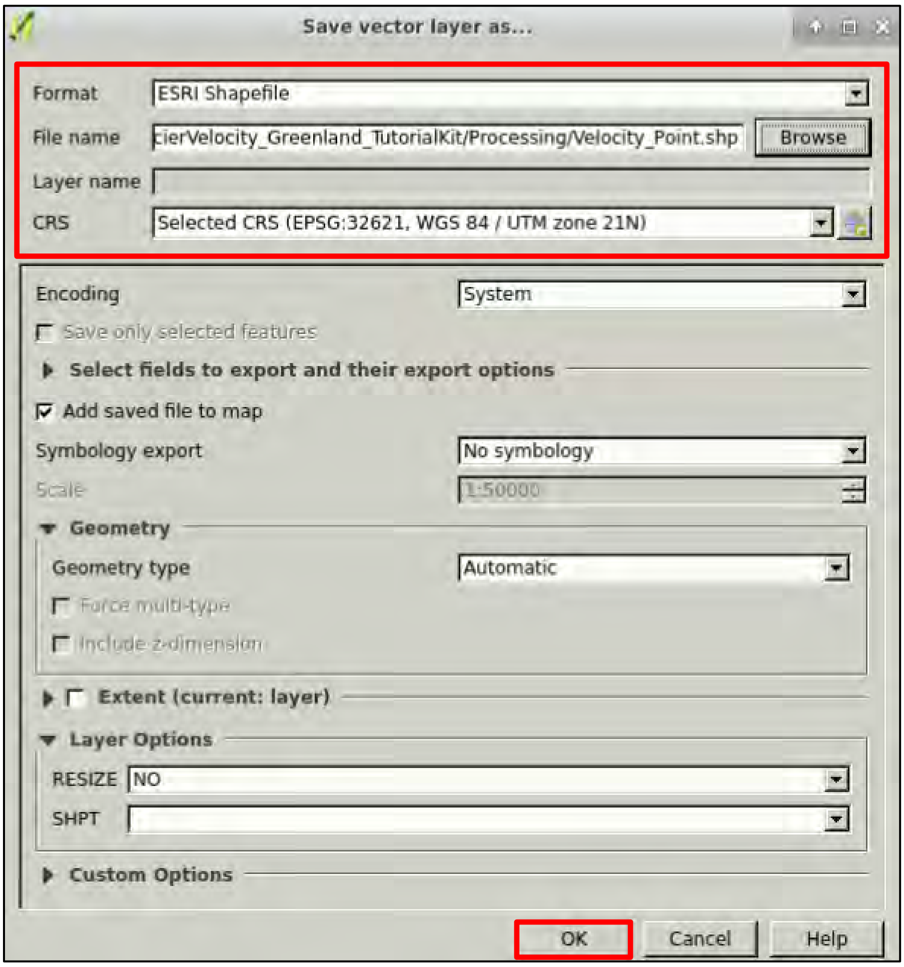



The new layer Velocity will appear in the **Layers Panel**.



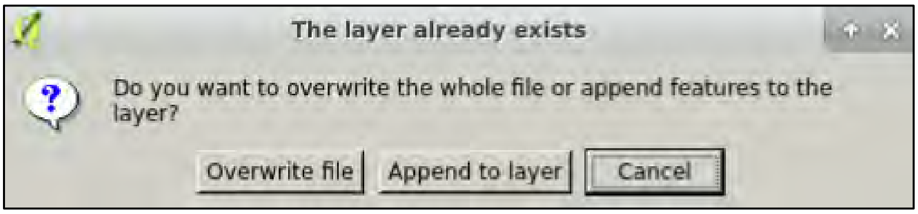

Click **OK**. Then right-click on the layer again and go to **Save as**. In the window that opens, set:

**Format: ESRI Shapfile**
**Filename: *\/shared/Training/CRYO02_GlacierVelocity_Greenland_TutorialKit/Processing/Velocity_Point.shp*** (Click "**Browse**", navigate to the following path: ***\/shared/Training/CRYO02_GlacierVelocity_Greenland_TutorialKit/Processing/***, select the ***Velocity_Point.shp*** file and click **Save**.)
**CSR: Selected CRS (EPSG:32621, WGS 84 / UTM zone 21N)**




Then click **OK**.

To the following window that appears, click “**Overwrite file**”.



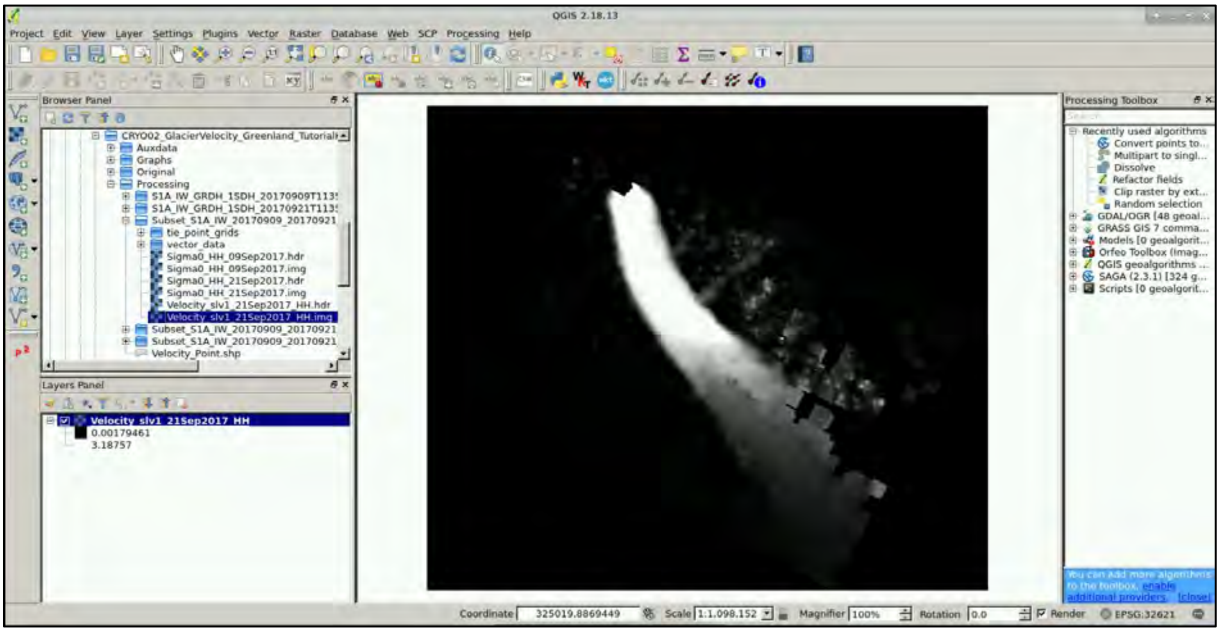

Now you have the layer saved as an ESRI Shapefile. Close QGIS.

## *6.2 Visualize in QGIS*

Minimize the SNAP window and open or re-open QGIS (**Applications → Processing → QGIS Desktop**). Once the QGIS is loaded let’s open the **Velocity raster** band.

Navigate to the ***Processing*** folder in the **Browser Panel** on the left side of the window, expand the ***Subset_S1A_IW_20170909_20170921_Stack_Vel_TC.data*** folder and double-click the ***Velocity_slv1_21Sept2017_HH.img***.

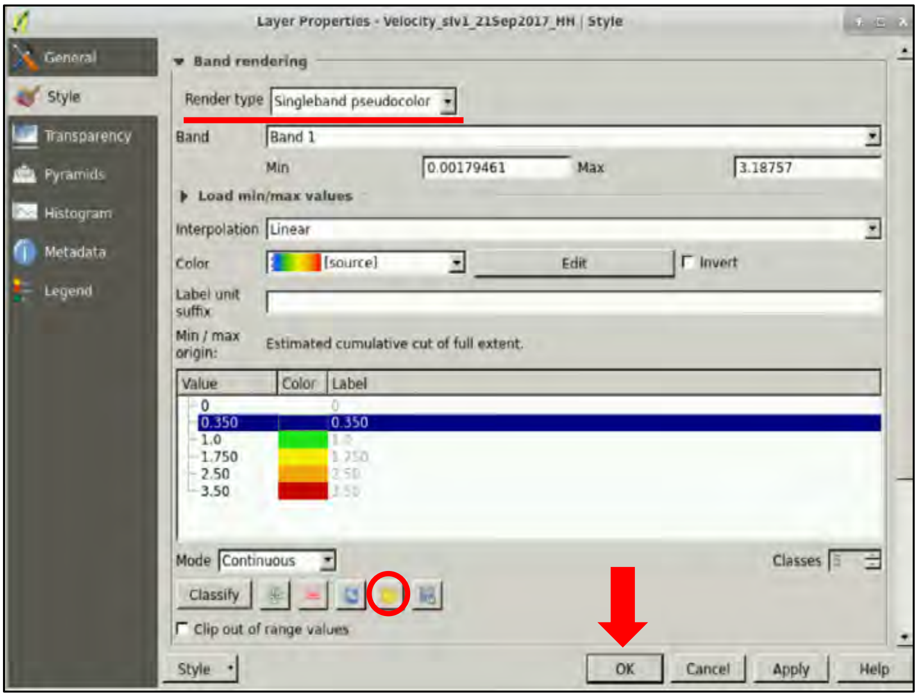
The raster layer will be opened and added to the **Layers Panel** below the **Browser Panel**.

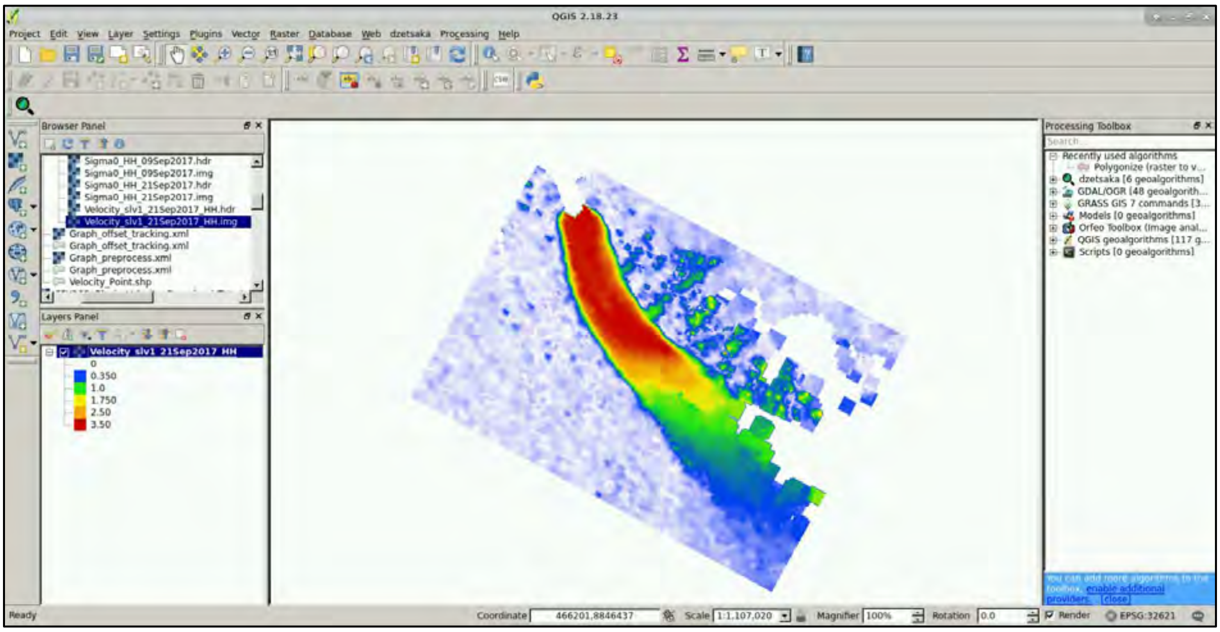



To change the appearance right-click the layer in **Layer Panel**, go to “**Properties**” and in **Style** tab set: **Render type**: “**Singleband pseudocolor**”

You can select any colour pallet and adjust the classes to your liking, however for our purposes we will use predefined colour pallet and classes saved as a text file in the ***Auxdata*** folder. To load it, click “**Load color map from file**” (indicated on the image below), then navigate to ***/shared/Training/CRYO02_GlacierVelocity_Greenland_TutorialKit/Auxdata*** and select ***Glacier_velocity_ColourPallet.txt***

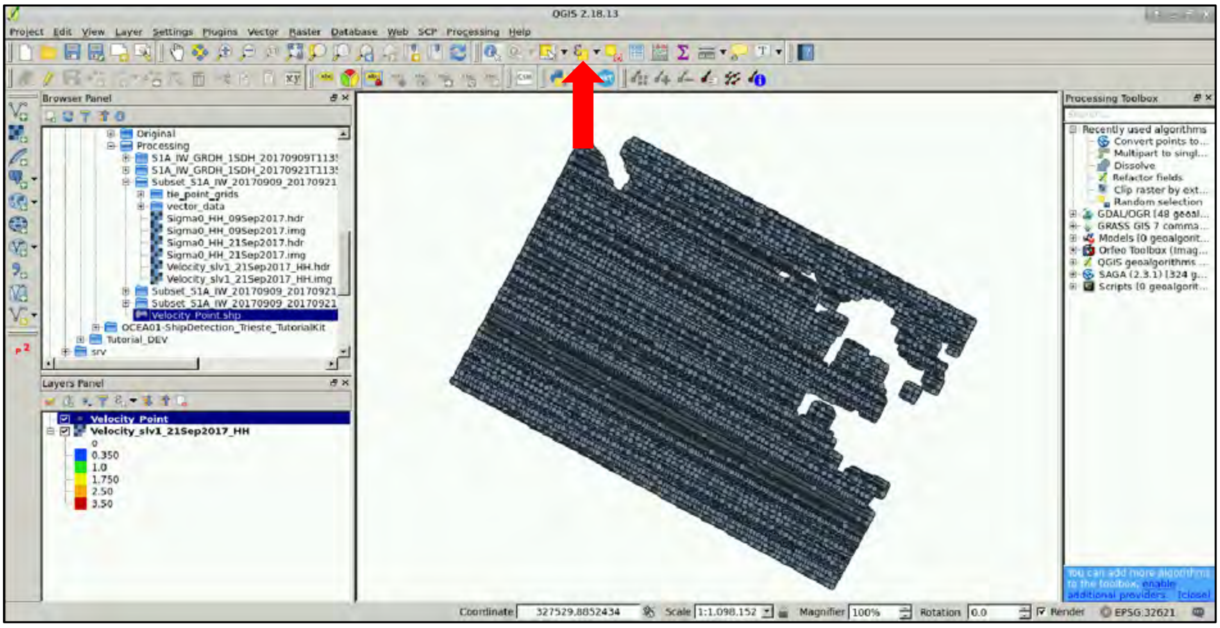
Click **OK**.



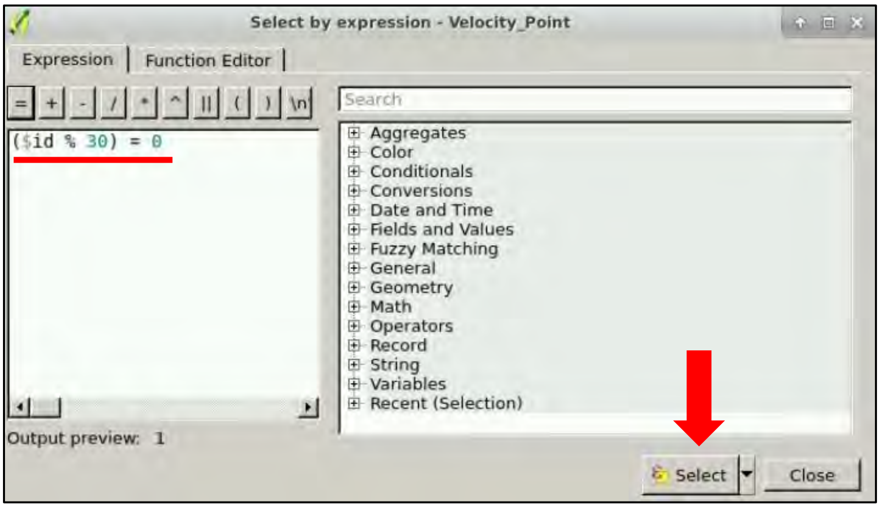




## 6.3 Add vector Velocity fields

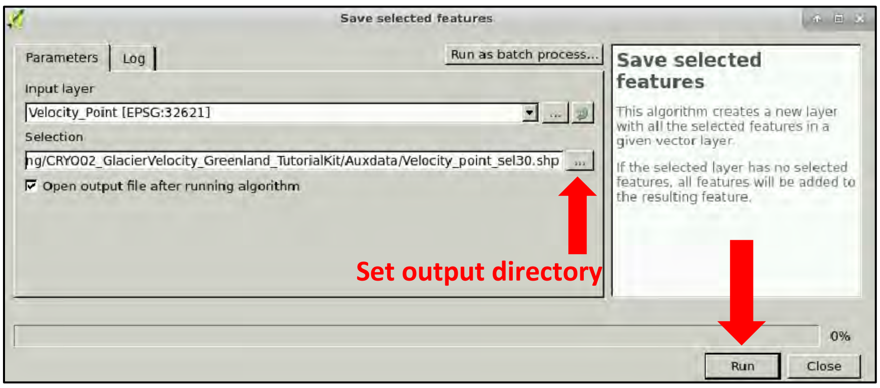
In the **Browser Panel** double click the ***Velocity_point.shp*** layer to load it. We need to filter the layer a little since the point grid is too dense for our purposes.



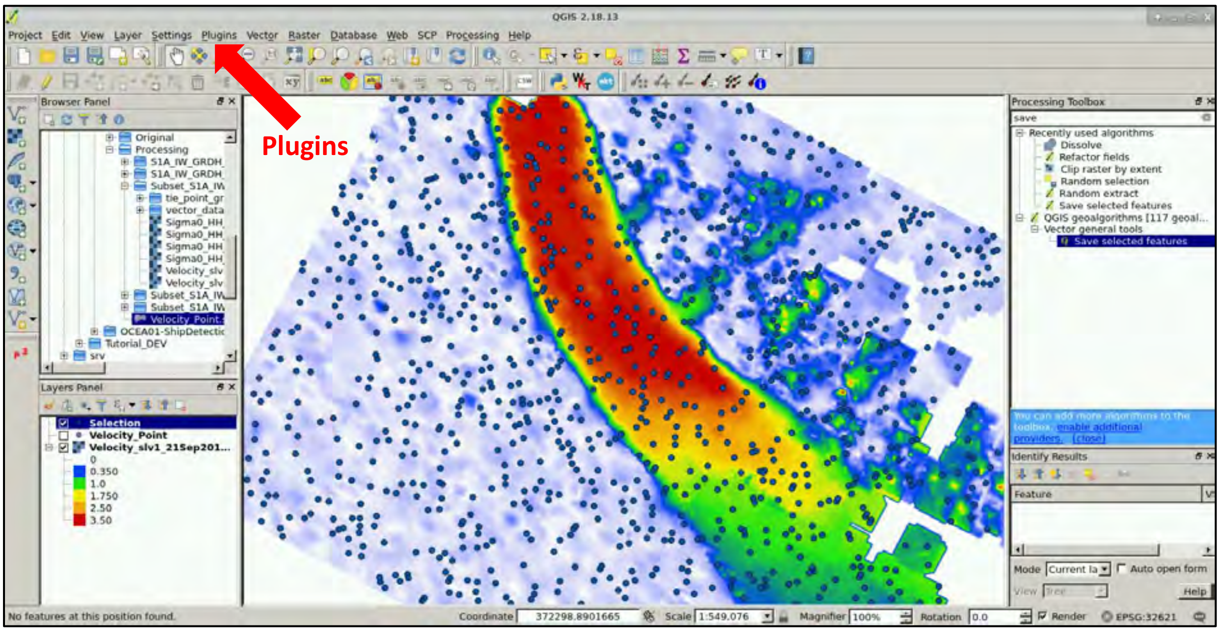

The simplest way to do this is to create subset with every n$^{th}$ point (or for example random selection). Select the *Velocity_point.shp* in the **Layer Panel** and in the upper tool panel click (above) and set **Expression**: `($id % 30) = 0`




Click **Select** and then close the window. Go to the **Processing Toolbox** at the right side of the window, in the search box type "**Save**" and press **Enter**. Then double-click on the **Save selected features** tool and set "**Selection**" to ***/shared/Training/CRYO02_GlacierVelocity_Greenland_TutorialKit/Processing*** (choose "**Save to file...**") and write as "**File name**": ***Velocity_point_sel30.shp***. Click **Save** and press **Run**.

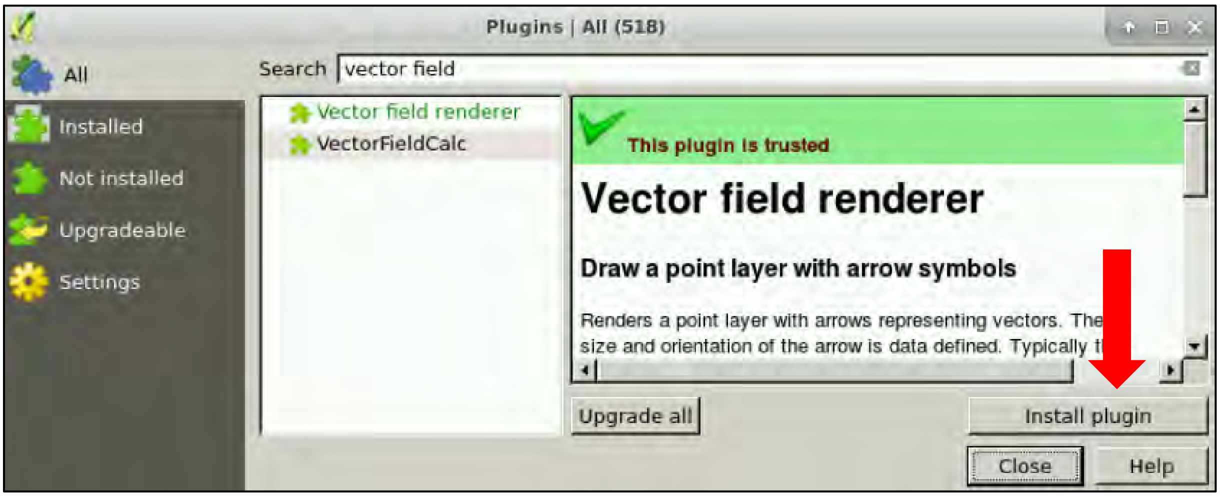


New point layer ***Selection*** appeared in **Layers Panel**. **Deselect** the original ***Velocity_point*** layer in the **Layers Panel** to hide it.




To visualize the velocity vector fields, we need to use the **Vector field renderer** plug-in or install it (if it is not already installed). We can do this by going to the **Plugins** menu on the top of the QGIS window (indicated above) and go to **Manage and Install Plugins…**

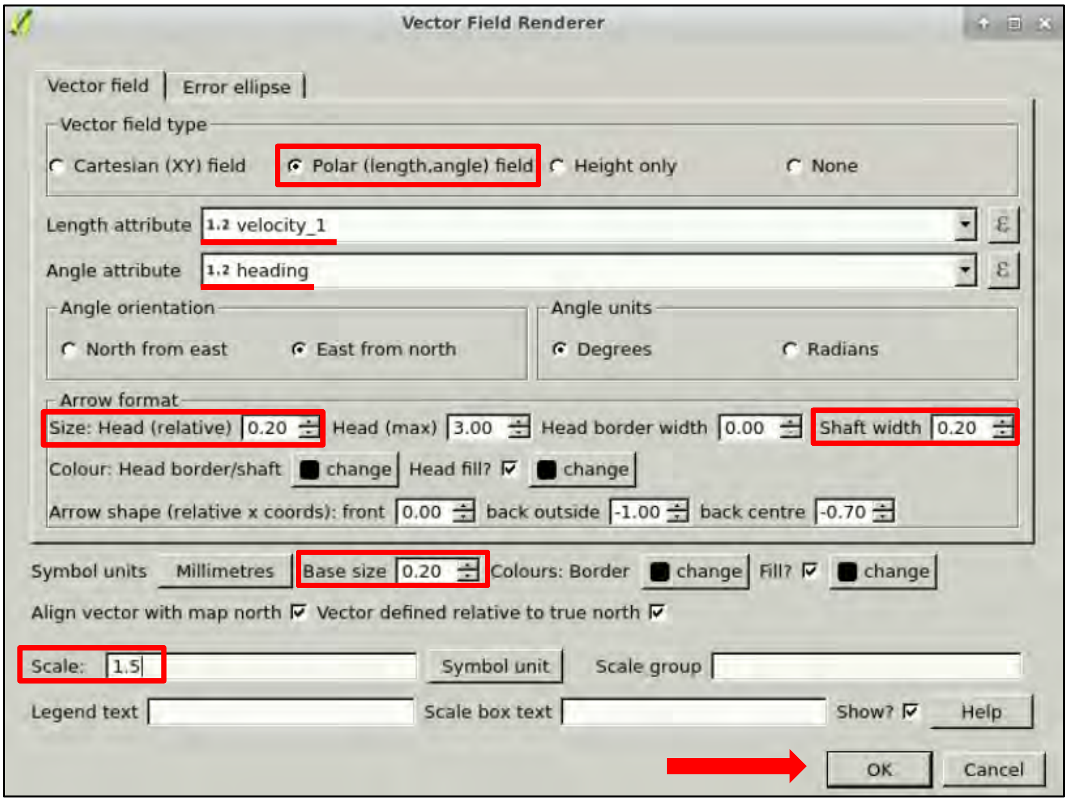
In the **Plugins** dialog search for ***Vector field***, select ***Vector field renderer*** and press **Install plugin**.



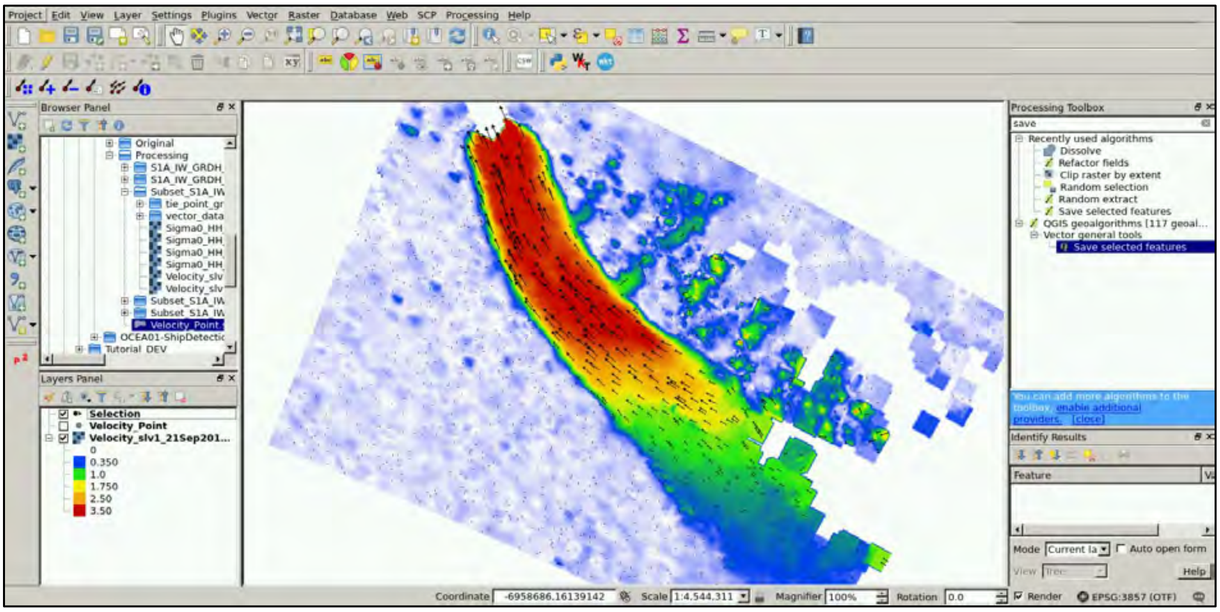

Close the dialog. Now make sure the ***Selection*** layer is highlighted in the **Layers Panel** and then click on **Apply vector renderer to current layer** in the toolbar at the top of the window.

At the **Vector field** tab, set as:

**Vector field type:** Polar (length, angle) field
**Length attribute:** velocity
**Angle attribute:** heading
**Arrow format:** Size: Head (relative): 0.20 and Shaft width: 0.20
**Base size:** 0.20
**Scale:** 1.5



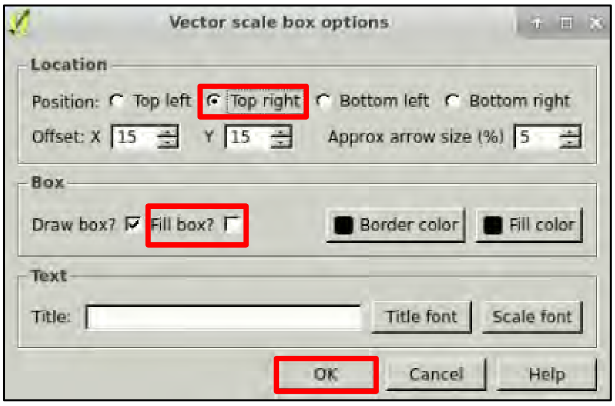

Click **OK**.

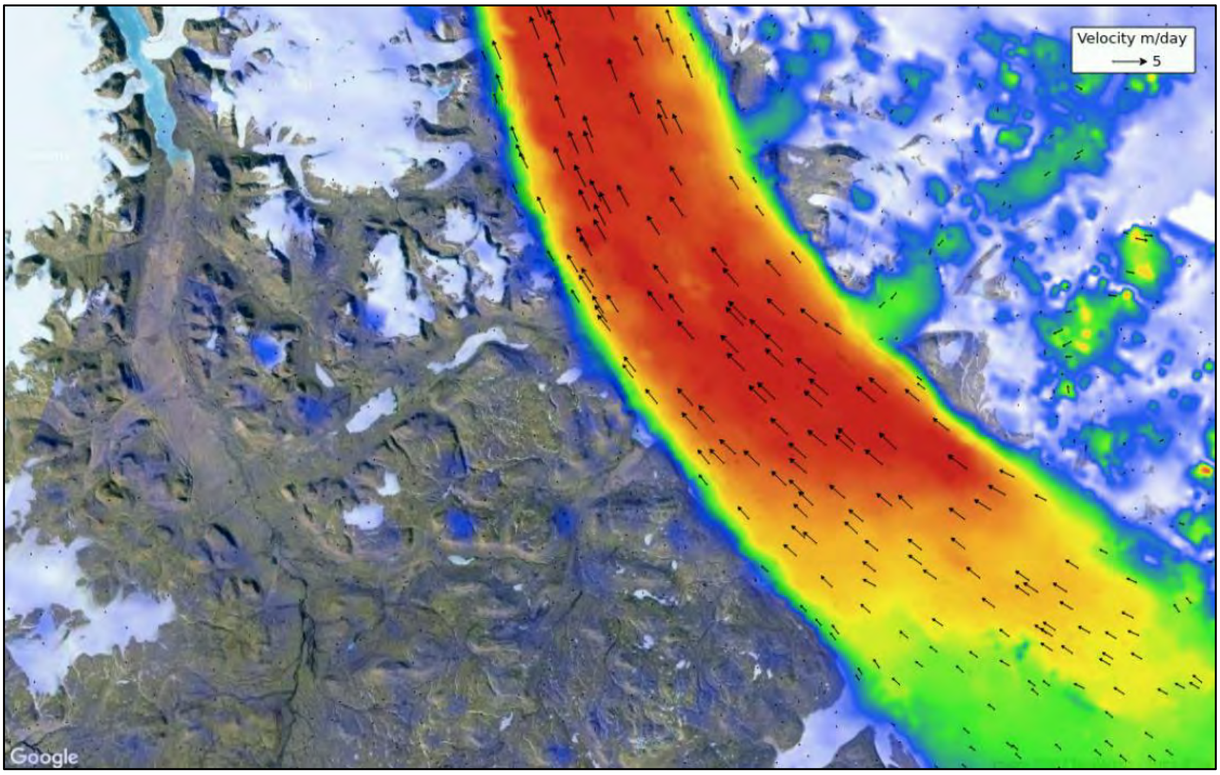



Now we can inspect the direction of the ice flow. As a last step we can add a base map. Go to **Web → OpenLayers plugin → Bing Maps → Bing Aerial**.

Drag the **Bing Aerial** layer **to the bottom** of all layers in the **Layers Panel** to visualize the result.

Click on the **Display the vector scale box**  icon, in **Location** choose **"Top right",** in **Box** deselect **"Fill Box"** and click **OK.**




THANK YOU FOR FOLLOWING THE EXERCISE!

## 7 Further reading and resources


Hogg, A., Shepherd, A., & Gourmelen, N. (2015). A first look at the performance of Sentinel-1 over the West Antarctic Ice Sheet. Presented at the FRINGE 2015, Frascati, Italy.

Nagler, T., Rott, H., Hetzenecker, M., Wuite, J., & Potin, P. (2015). The Sentinel-1 Mission: New Opportunities for Ice Sheet Observations. *Remote Sensing*, *7*(7), 9371–9389. https://doi.org/10.3390/rs70709371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