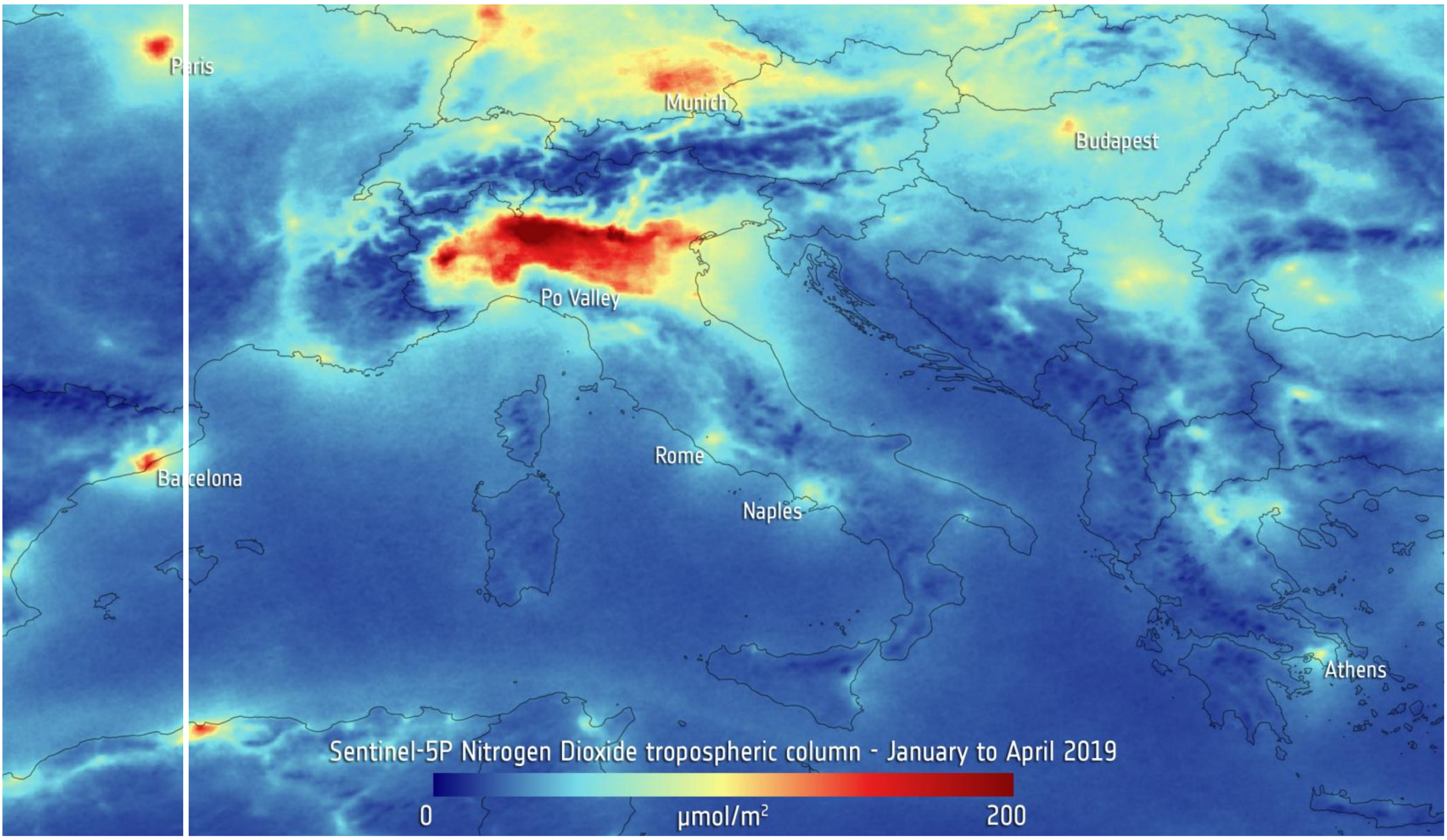

TRAINING KIT – ATMO01

AIR QUALITY MONITORING WITH SENTINEL-5p

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-copernicus.eu

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Table of Contents

1 Introduction to RUS

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 derived from the Copernicus Sentinel satellites constellation.

In this tutorial, we will employ RUS to monitor air quality using Sentinel-5p products as input data.

2 Air quality – background

Air pollution. Credits: Wikipedia Commons

Air pollution is a major environmental health problem that affects people in developed and developing countries alike. With millions of people dying prematurely every year as a direct result of poor air quality, it has never been more important to monitor the air we breathe.

Pollutants enter the air from a range of sources, although they are mainly a result of motor vehicle and industrial combustion processes. Governments and decision-makers rely heavily on satellite data and computer models to show how pollution accumulates and how it is carried in the air so that they can develop appropriate mitigation strategies.

A few years ago, the European Union (EU) started an ambitious program, Copernicus, which includes the launch of a new family of earth observation satellites known as Sentinels. Sentinel-5p provides timely data on a multitude of trace gases (CO, NO22, SO22, O33, aerosols…) with a great accuracy and spatial resolution. It also provides measurement continuity with precedent and ongoing atmospheric spatial missions (OMI, IASI and SCHIAMACHY).

3 Training

Approximate duration of this training session is **one** hour.

The Training Code for this tutorial is ATMO01. 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.

3.1 Data used

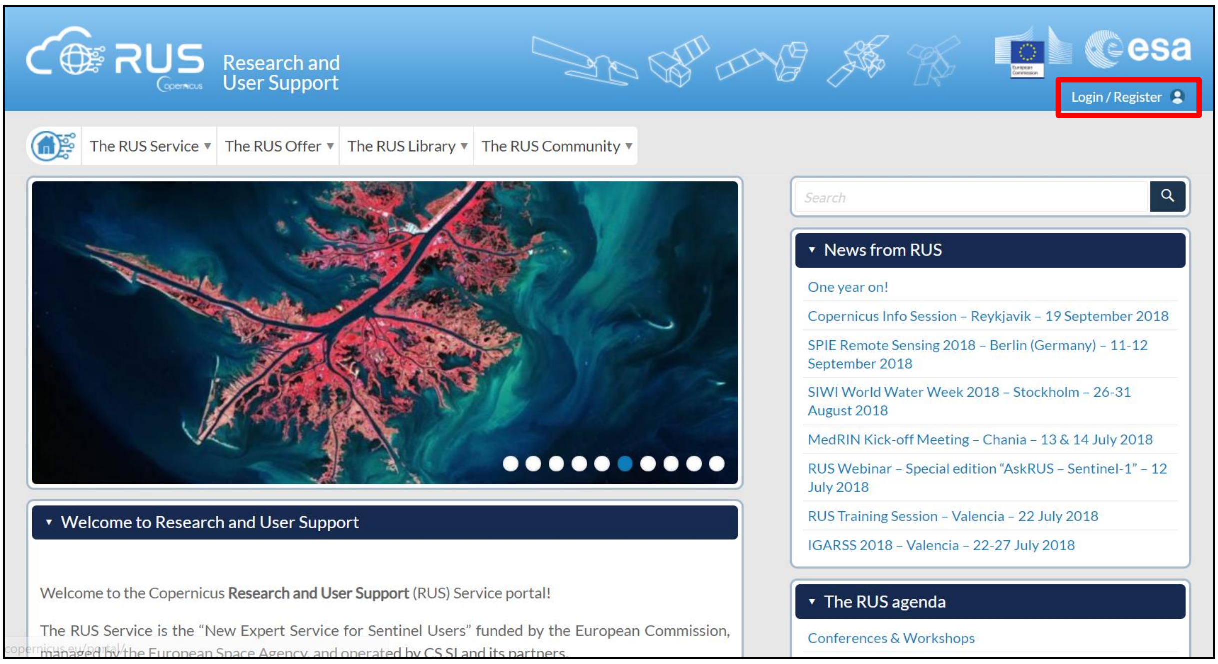
- 13 Sentinel-5p images acquired on May 17^{th} 2019
- Pre-processed data stored locally *@/shared/Training/ATMO01_AirQuality_Global/AuxData/*

3.2 Software in RUS environment

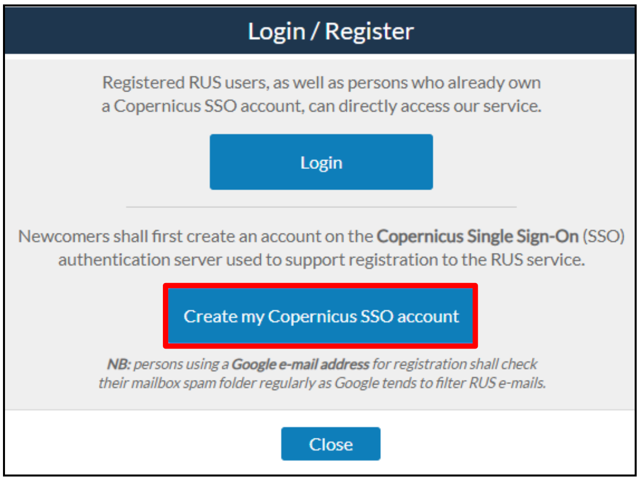
Internet browser, BEAT + QGIS

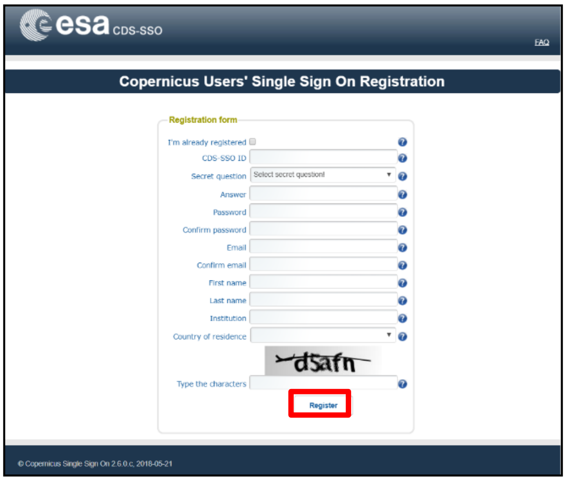
4 Register to RUS Copernicus

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) and click on ***Login/Register*** in the upper right corner.



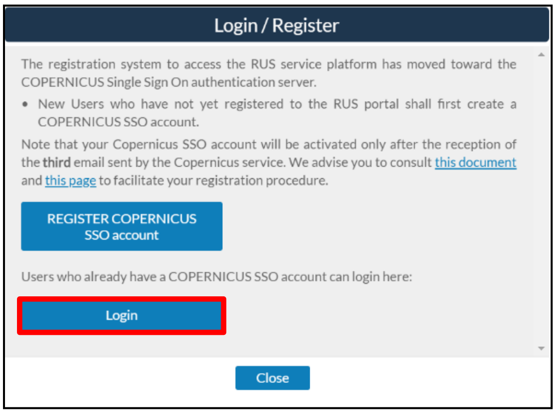
Select the option ***Create my Copernicus SSO account*** and then fill in ALL the fields on the **Copernicus Users' Single Sign On Registration**. Click ***Register***.

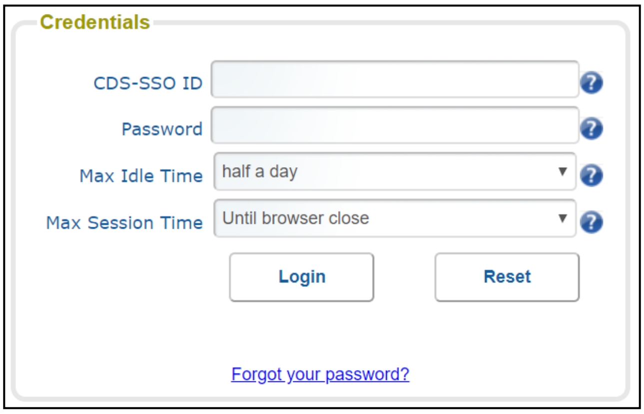




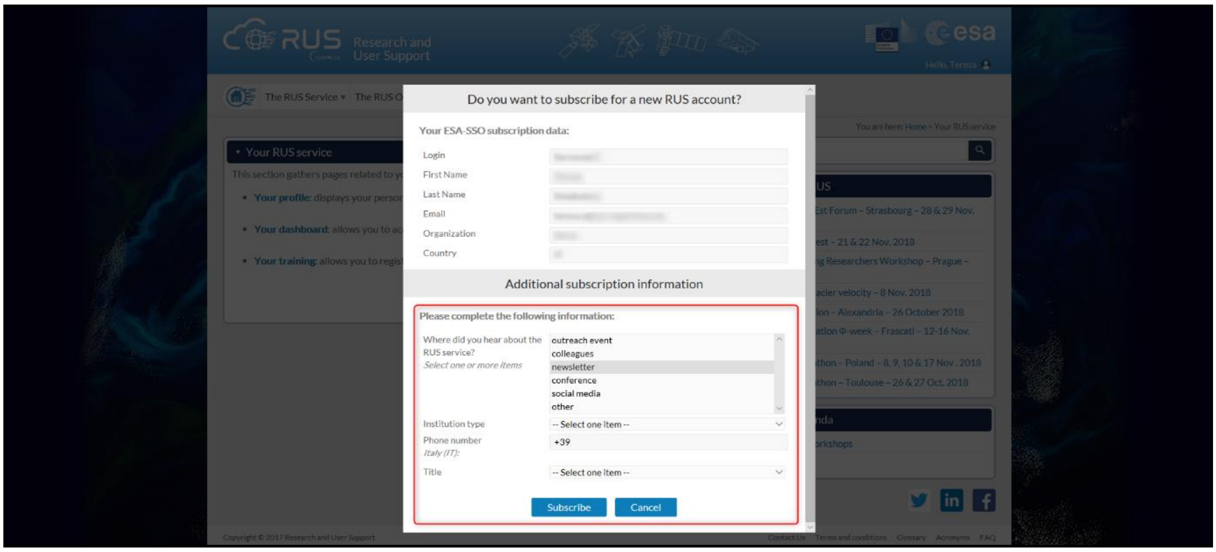
Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the e-mail to activate your account.

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



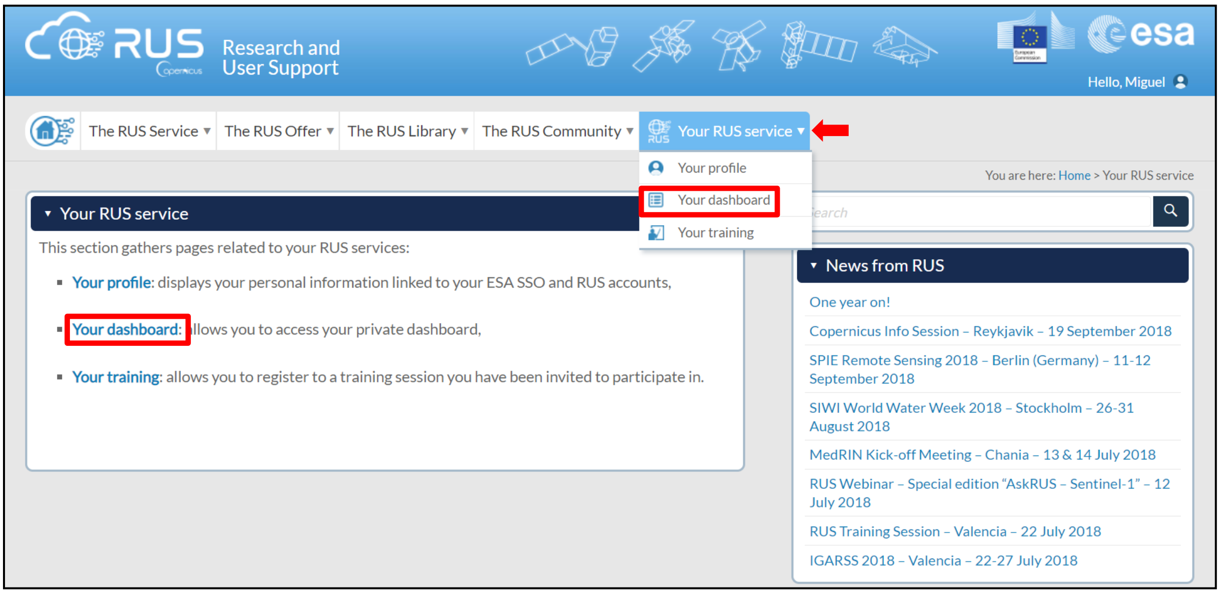


Upon your first login you will need to enter some details. You must fill all the fields.

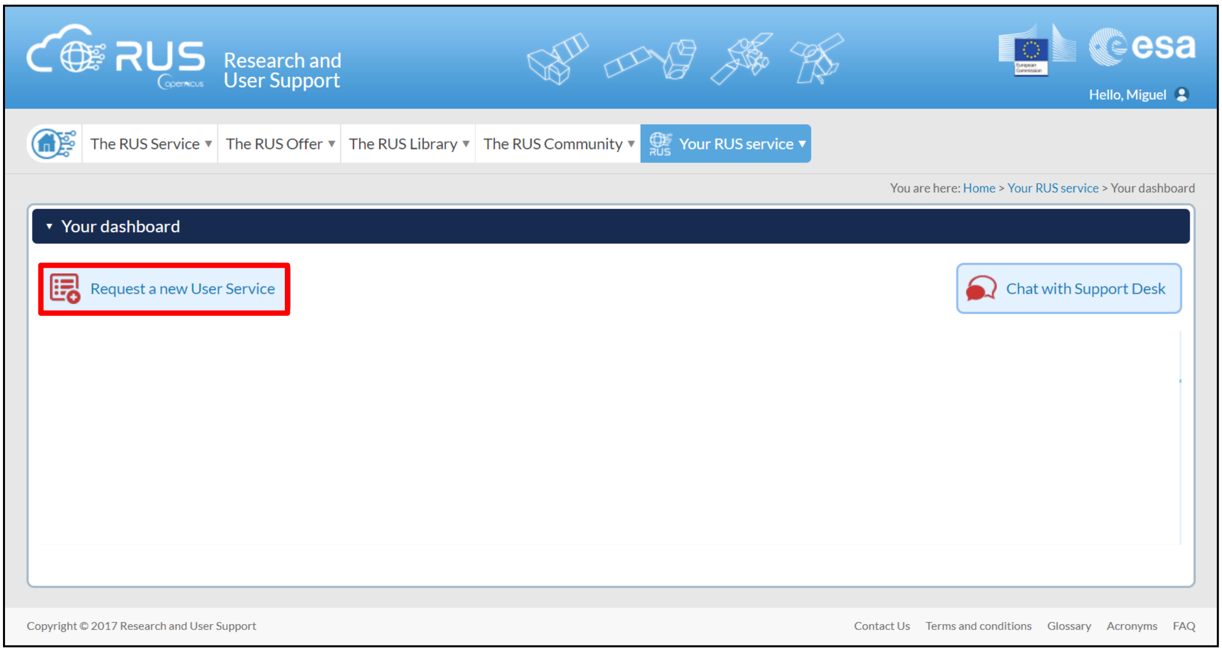


5 Request a RUS Copernicus Virtual Machine

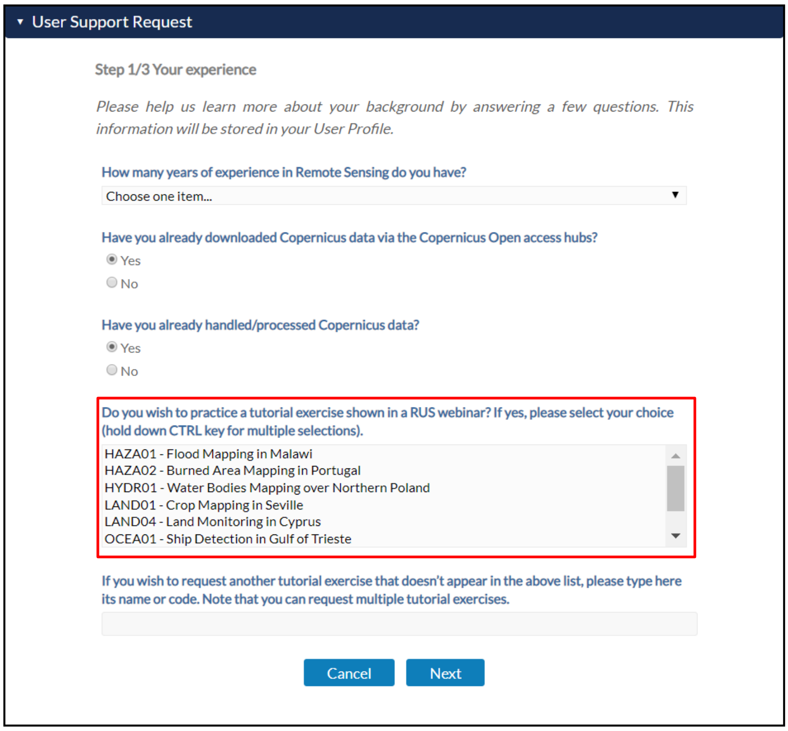
Once you are registered as a RUS user, you can request a RUS Virtual Machine to repeat this exercise or work on your own projects using Copernicus data. For that, log in and click on ***Your RUS Service → Your Dashboard***.



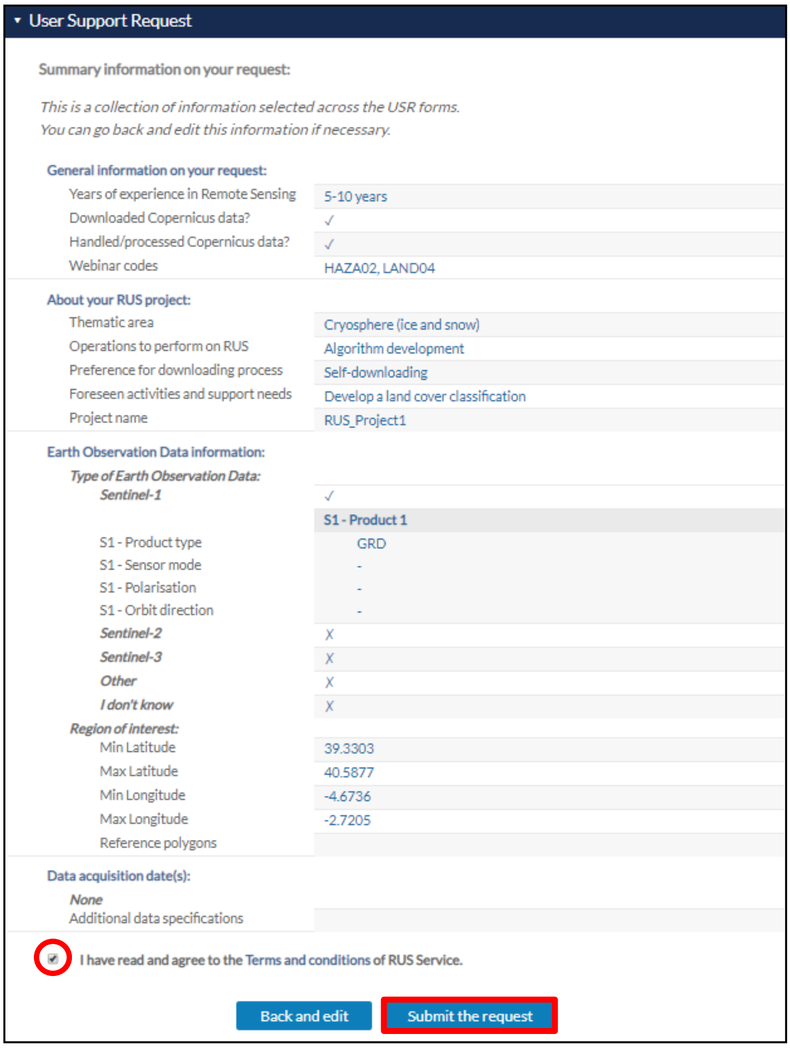
Click on ***Request a new User Service*** to request your RUS Virtual Machine. Complete the form so that the appropriate cloud environment can be assigned according to your needs.



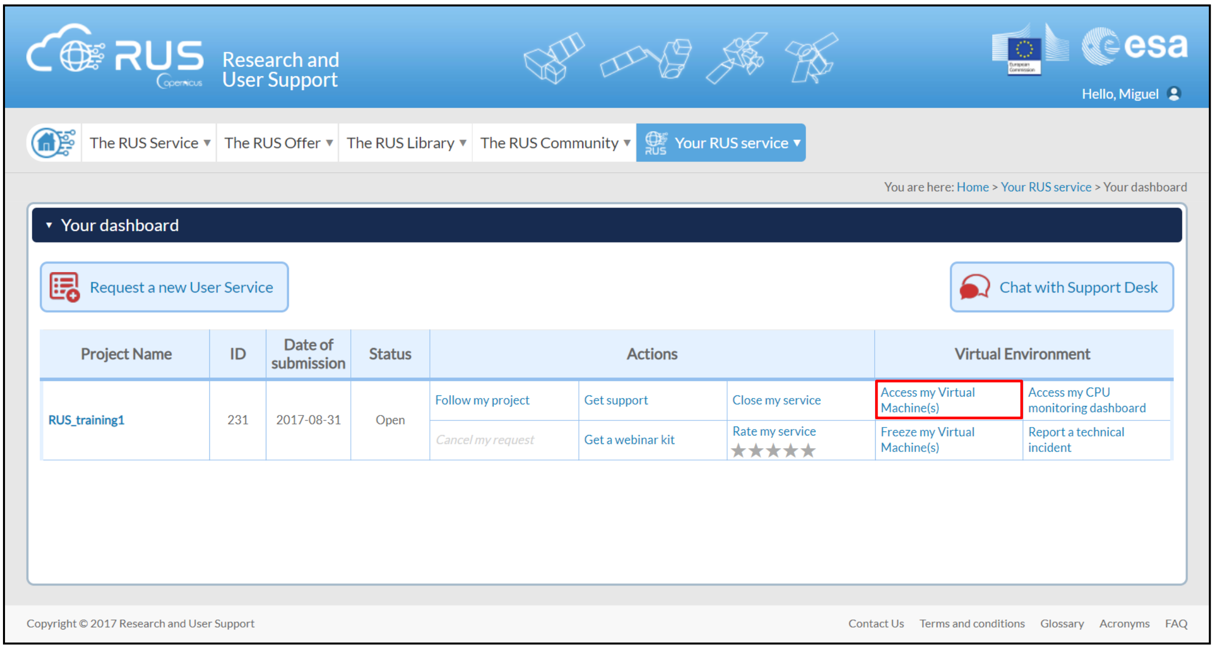
If you want to repeat this tutorial (or any previous one) select the one(s) of your interest in the appropriate field.



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.

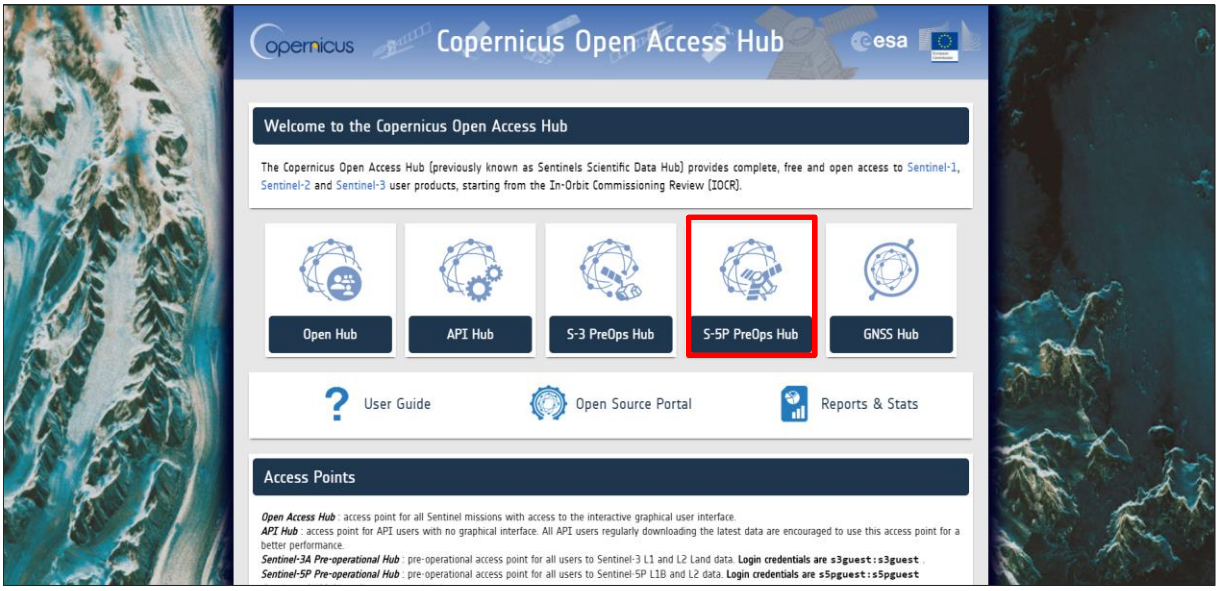
This is the remote desktop of your Virtual Machine.

6 Step by step

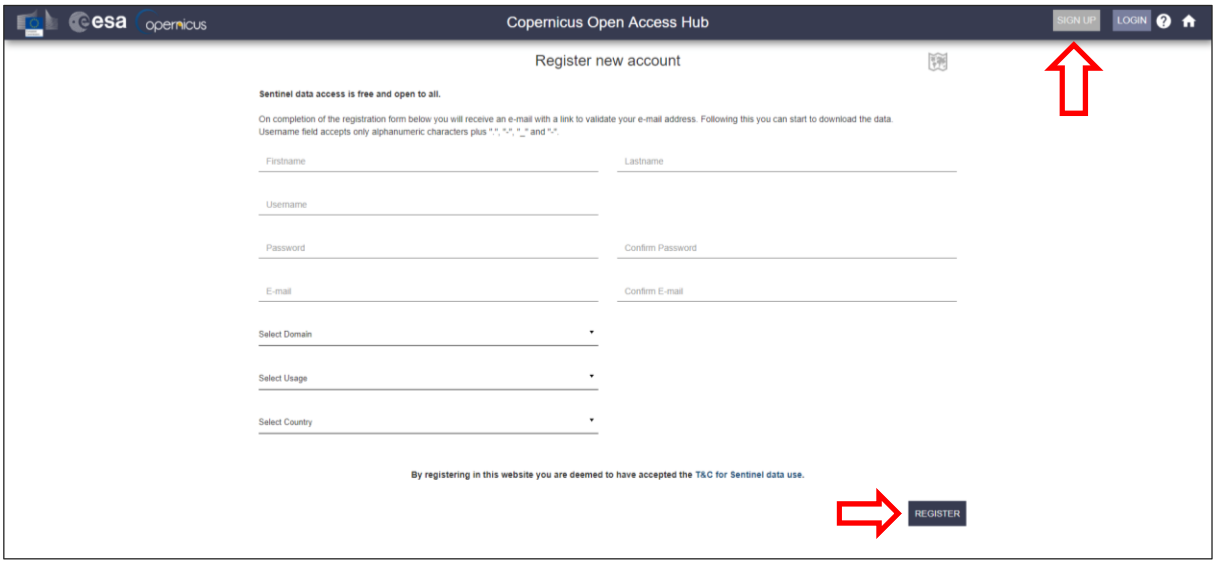
6.1 *Data download – ESA SciHUB*

Before starting the exercise, make sure you are registered in the Copernicus Open Access Hub so that you can access the free data provided by the Sentinel satellites.

Go to https://scihub.copernicus.eu/



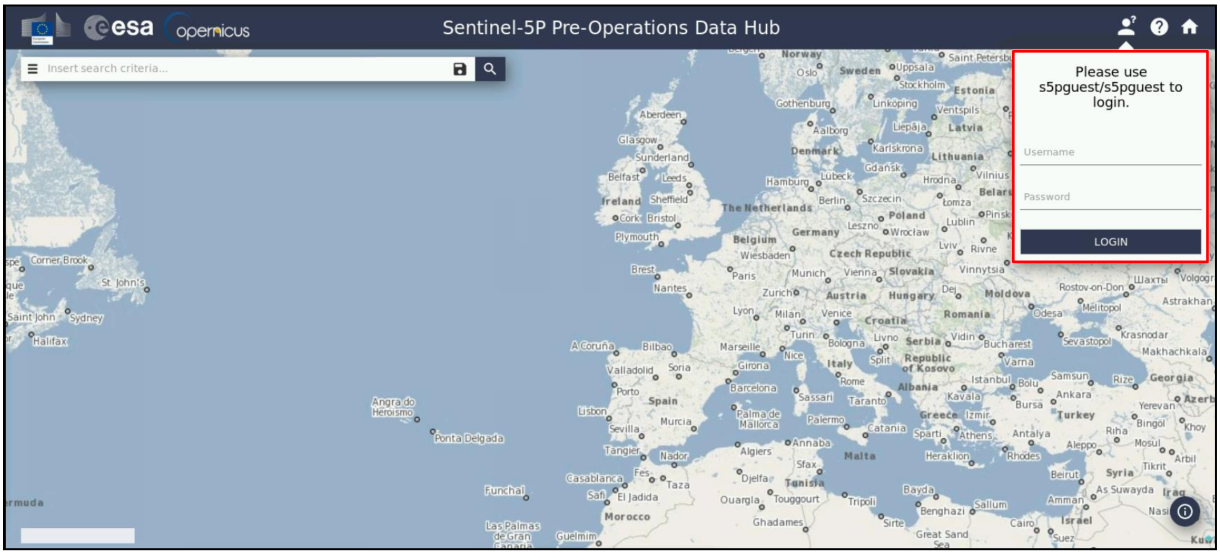
Go to *Open Hub*. If you do not have an account, sign up in the upper right corner, fill in the details and click register.



You will receive a confirmation email on the e-mail address you have specified: open the email and click on the link to finalize the registration.

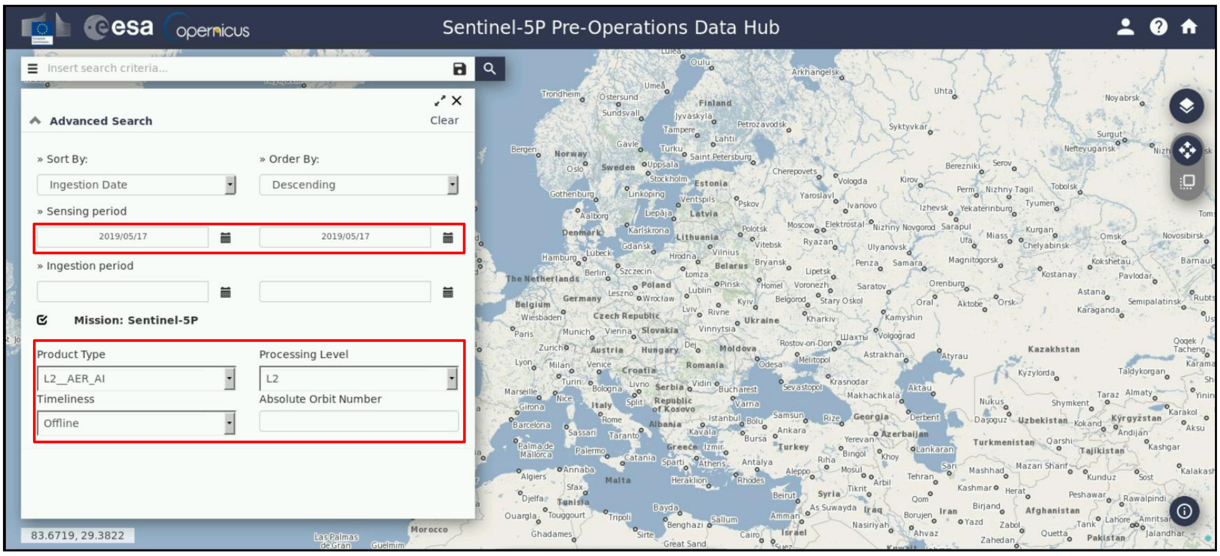
Once your account is activated – or if you already have an account – log in (See NOTE 1).

NOTE 1: At the time of creation of this tutorial (June 2019), Sentinel-5p products are still only accessible through the Sentinel-5p Pre-Operations Data Hub. To download S-5p products, log in using *s5pguest* as username and password. In the near future, products will be moved to the regular Copernicus Open Access Hub where you will be requested to log in with your own credentials. For that, create an account as explained previously.



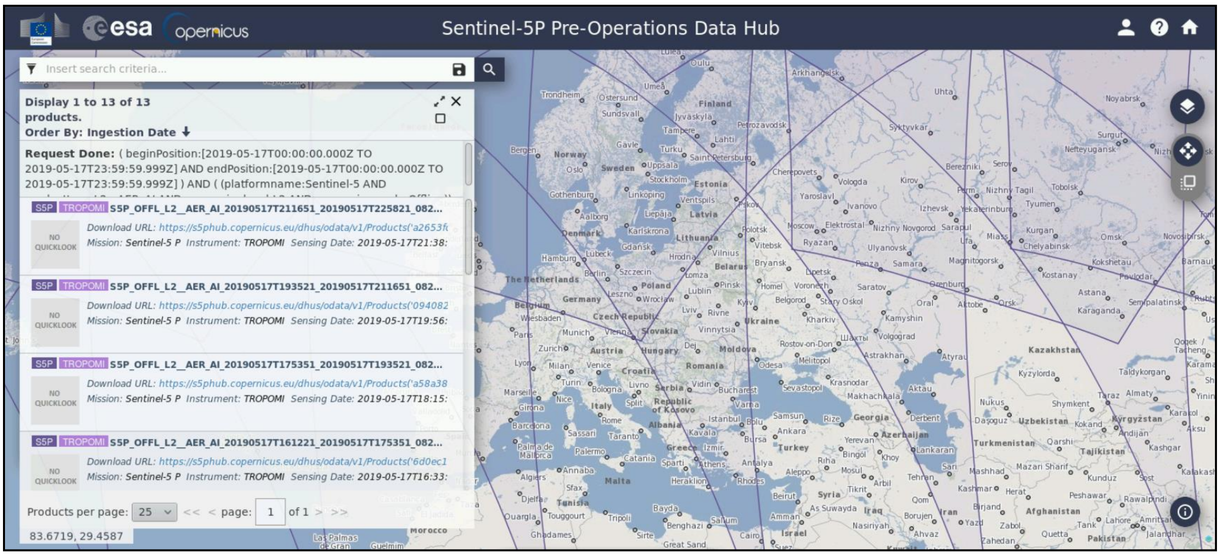
Since we are targeting the production of global maps, we do not need to define a specific study area in our search. Open the search menu by clicking to the left part of the search bar (☰) and specify the parameters below. Press the search button (🔍) after that.

Sensing period: From 2019/05/17 to 2019/05/17
Check Mission: Sentinel-5p
Product type: L2__AER_AI
Processing level: L2
Timeliness: Offline



In this case the search returns 13 results. Download all the products (products will be saved in */home/rus/Downloads)* and move them to the following path.

Path: */shared/Training/ATMO01_AirQuality_Global/Original/*



In this case the search returns 13 results. Download all the products (products will be saved in */home/rus/Downloads)* and move them to the following path (See NOTE 2 and 3).

Path: */shared/Training/ATMO01_AirQuality_Global/Original/*

NOTE 2: Sentinel-5p counts 14 orbits per day. Due to the starting (d) and end acquisition time (d+1) during the last orbit, when looking for all the products of a day the result may output 13 products instead of 14. To complete the global coverage, you may need to increase by one day the sensing time to find the last product.

NOTE 3: Sentinel-5p products are delivered as netCDF files. The Network Common Data Form, or netCDF, is an interface to a library of data access functions for storing and retrieving data in the form of arrays. An array is an n-dimensional (where n is 0, 1, 2, ...) rectangular structure containing items which all have the same data type (e.g., 8-bit character, 32-bit integer). A scalar (simple single value) is a 0-dimensional array. a large amount of free software as well as commercial or licensed packages is available at the UniData website.

6.2 VISAN – open and explore data

In this exercise we will use the Basic Envisat Atmospheric Toolbox (BEAT) toolbox to analyse the Sentinel-5p data and run our analysis. The ESA Atmospheric Toolbox project (BEAT) aims to provide scientists with tools for ingesting, processing, and analyzing atmospheric remote sensing data.

The project consists of several components, with the main components being CODA, HARP, and VISAN. These components are made available by means of several software packages.

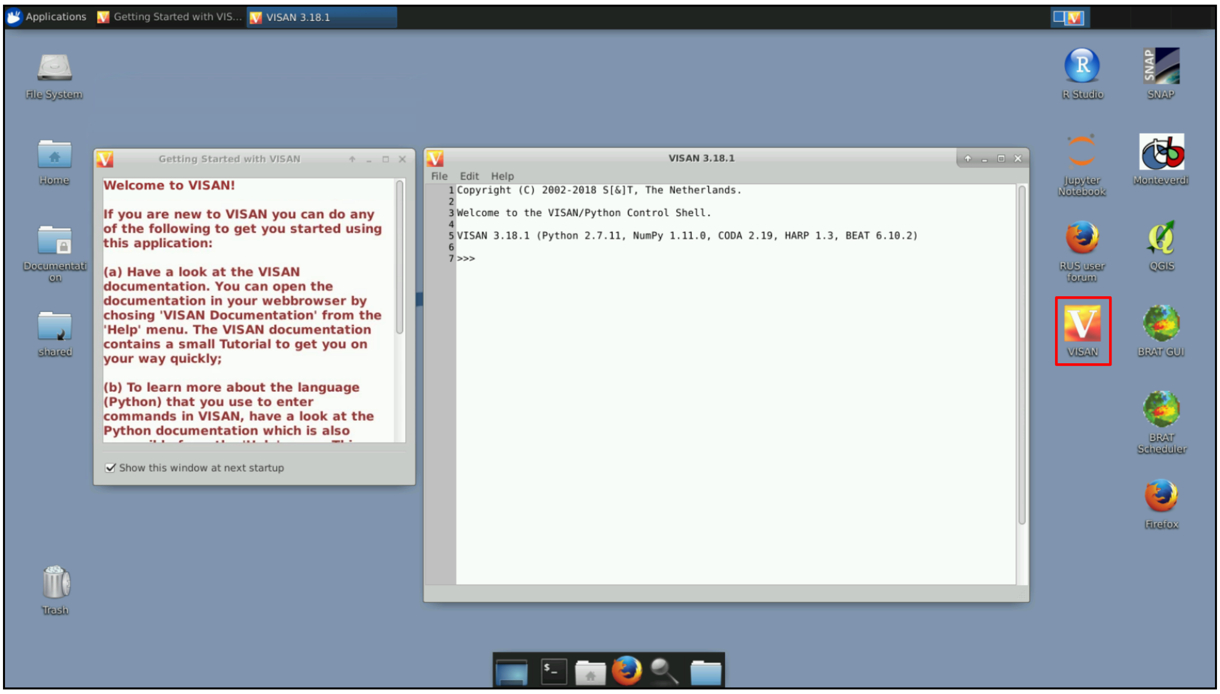
- CODA: allows direct reading access to product data, supporting a very wide range of products. All product file data is accessible via the CODA C library. On top of this, there are several interfaces available to directly ingest product data using e.g. Fortran, IDL, MATLAB, and Python.

- HARP: toolset for ingesting, processing and inter-comparing satellite or model data against correlative data. The toolset provides a set of command line tools, a library of analysis functions, and direct import/export interfaces for Python, IDL, and MATLAB. By appropriately chaining calls to the HARP command line tools one can preprocess satellite and correlative data such that the two datasets that need to be compared end up having the same temporal/spatial grid, same data format/structure, and same physical unit.

- VISAN: cross-platform visualization and analysis application for atmospheric data. The application uses the Python language as the means through which you provide commands to the application. The Python interfaces for CODA and HARP are included so you can directly ingest product data from within VISAN (HARP interfaces will be added once the HARP Python interface becomes available). Finally, VISAN provides some very powerful visualization functionality for 2D and world plots.

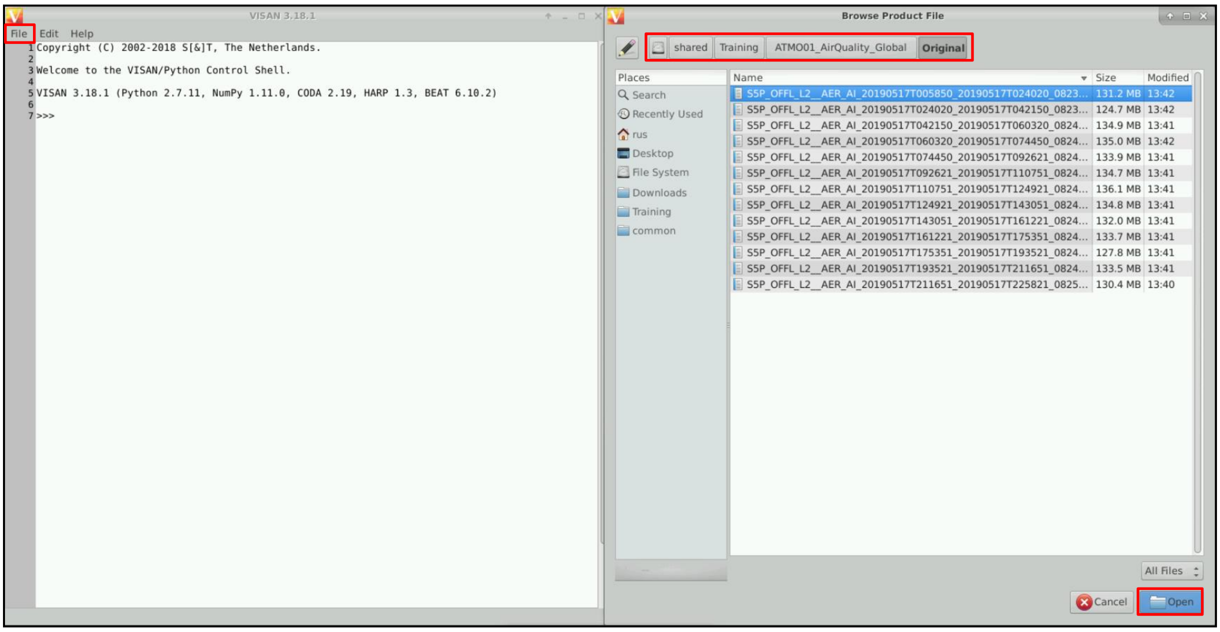
The primary instruments supported by BEAT are Tropomi (Sentinel-5P), GOME-2 and IASI (MetOp), OMI, TES and MLS (Aura), GOMOS, MIPAS, and SCIAMACHY (ENVISAT), and GOME (ERS-2). More information on the BEAT project can be found at http://www.stcorp.nl/beat/

In the desktop, double click on the VISAN icon - - to open it. The command line interface will appear together with the help window (if it is the first time you use VISAN, read the help window and close it afterwards).

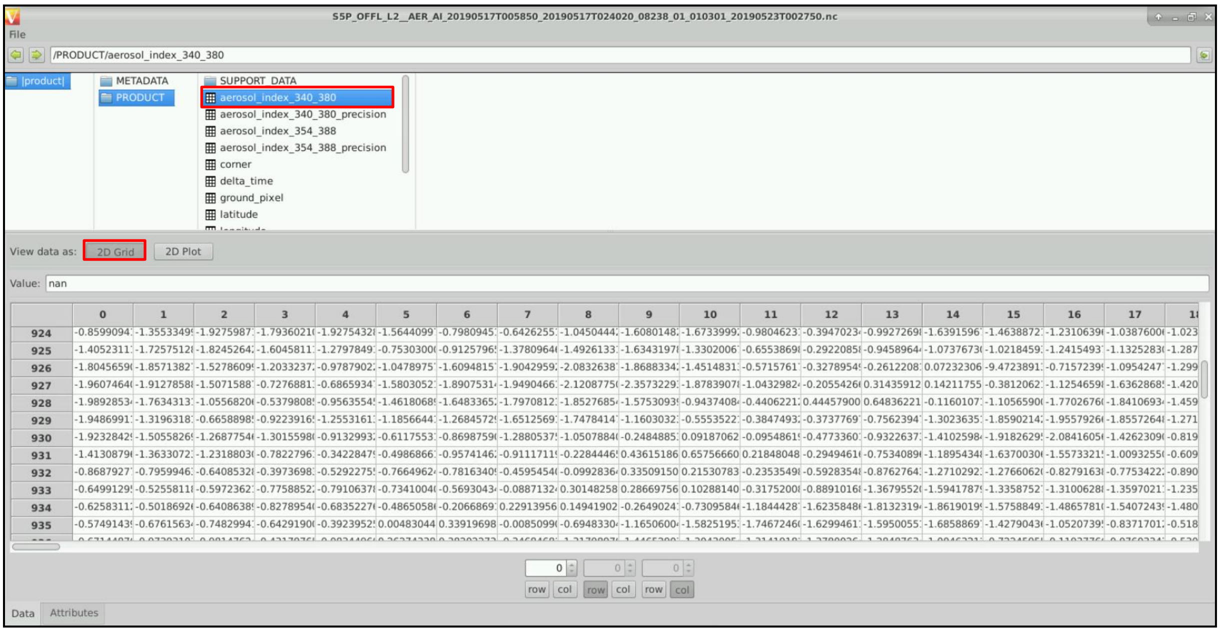


In the *File* menu, click on *Browse Product*, navigate to the following path and open the first Sentinel-5p product – S5P_OFFL_L2__AER_AI_20190517**T005850**_20190517**T024020**_08238_01_010301_20190523T002750.nc

Path: */shared/Training/ATMO01_AirQuality_Global/Original/*

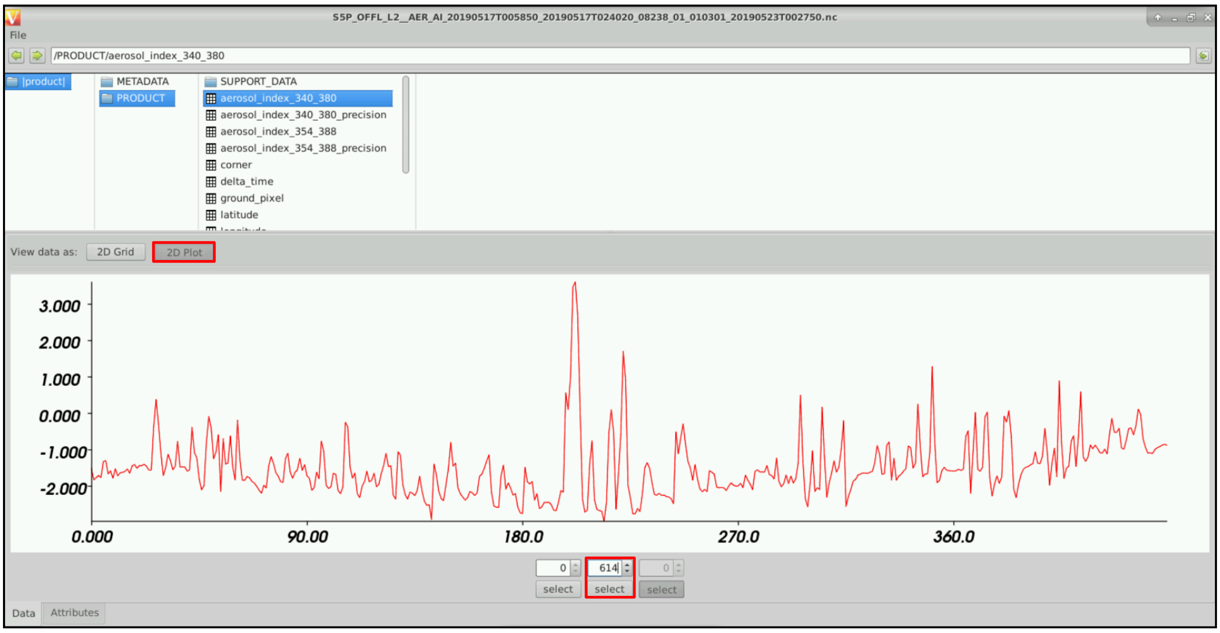


Once opened, VISAN gives you the option to navigate the Sentinel-5p product (*PRODUCT* folder) and access metadata (*METADATA* folder) information. The *PRODUCT* folder contains data of interest as 2D arrays (Aerosol index, error estimates, quality index…). The *SUPPORT_DATA* subfolder contains additional and auxiliary data (geolocation flags, lat/lon bounds, satellite position, etc.). Within the *PRODUCT* folder, select the *aerosol_index_340_380* file.



Click on the *2D Grid* to visualize the 2D array. For each variable, it is possible to check the whole product (all rows/columns), a specific row/column and its attributes (*Attributes* tab).

Next, click on the *2D Plot.* Set the x-axis coordinates to 0; 614; 0 to visualize a 2D plot.



After visualizing the data as an array and 2D graph, we will create a 3D visualization of the product. Close the browse product window on the main VISAN page and go to *File -> Harp Import.* This menu will create the Python command to perform an import on a product.

In the *Path* option, navigate to the following path and select the same product as before (Sixth from the top - S5P_OFFL_L2__AER_AI_20190517**T092621**_20190517T110751_08243_01_010301_20190523**T085237**.nc)

Path: */shared/Training/ATMO01_AirQuality_Global/Original/*

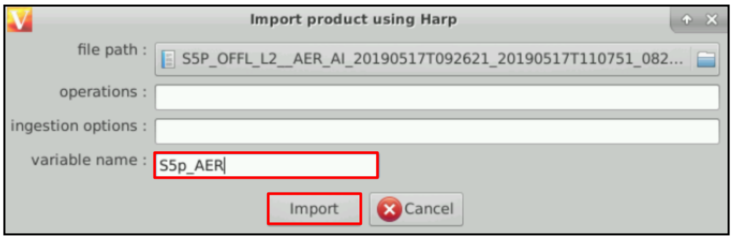
The *Operations* tab gives the possibility to provide a single string where individual operations are separated by a semi colon (i.e. 'latitude>-55[degree_north];bin()'). For this exercise, leave the Operations tab empty (See NOTE 4).

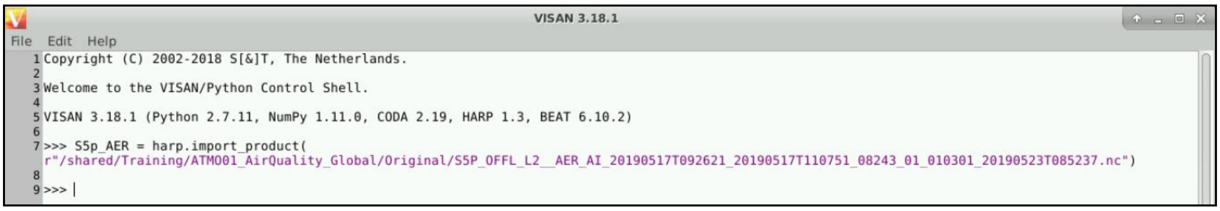
NOTE 4: HARP provides a simple expression syntax with which one can specify operations that need to be performed on a product. A list of operations is always provided as a single string where individual operations are separated by a semi-colon (;). Each operation can be either a comparison filter, a membership test filter, or a function call. Strings used in operations should be quoted with double quotes. More information at: http://stcorp.github.io/harp/doc/html/operations.html

The *Ingestion options* gives the option to ingest different variables from the Sentinel-5p product to the HARP converted product (i.e. which aerosol index to keep in the ingested product). For this exercise, leave the Ingestion options empty (See NOTE 5).

NOTE 5: HARP can ingest data from various types of products. HARP will try to automatically determine the product type of each file that you pass to the ingest function. An error will be raised if the product type of a file cannot be determined. For each ingestion, HARP will return a single HARP product. Each variable in a HARP product represents a specific quantity (e.g. O3 number density, cloud fraction, altitude, longitude, latitude, time, et cetera). You can customize which variables you want to include using the include() and exclude() operations that can be passed to the ingest function. More information at: http://stcorp.github.io/harp/doc/html/ingestions/

Next, in the *Variable* name tab, write *S5p_AER* to name the imported product. Finally, click *Import.* The python command used can be seen in the main VISAN window.

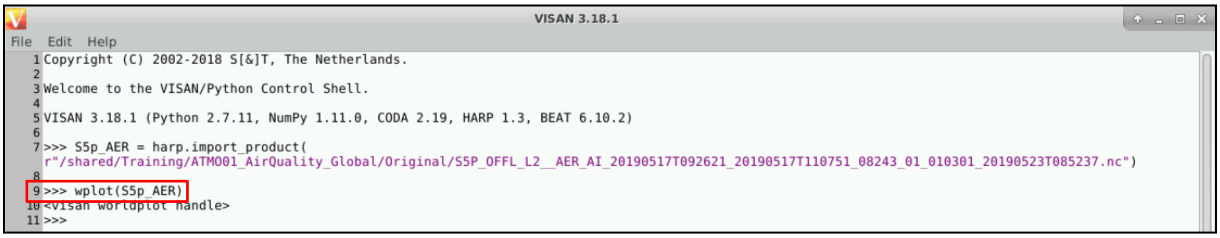


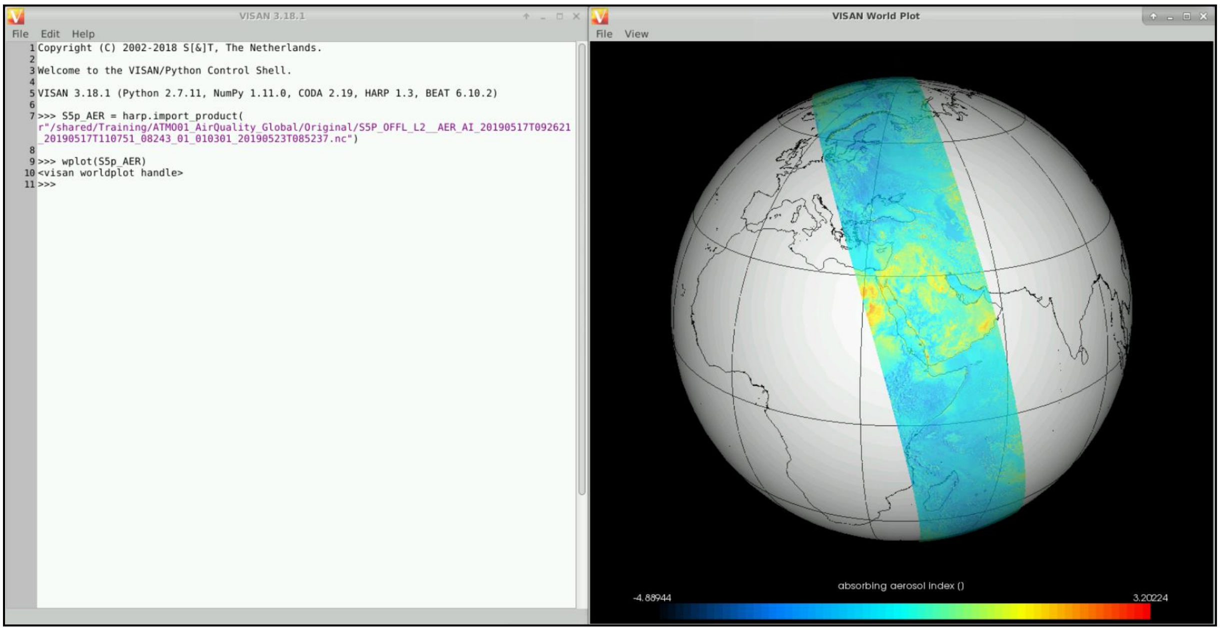


Once the product has been imported, we can use specific code to manipulate and visualize the data. In the VISAN window write the following command and press enter. (See NOTE 6).

NOTE 6: Much of VISAN's functionality is provided by Python and the Numpy package, which are both part of VISAN. For an overview of the functions provided please look at the Python and Numpy documentation. More information at http://www.stcorp.nl/beat/doc/visan/reference.html

```
wplot(S5p_AER)
```





To move on the VISAN World Plot window, maintain the left button of your mouse and move it in the appropriate direction. To zoom in/out, maintain the right button of the mouse and move it to the top/bottom of the window. Invalid data is present in the poles.

You can change the display settings (color table, color bar, projection, etc.). For that, go to *View -> Properties* in the plot window and change the parameters according to your preference. When changing a parameter, press the *ENTER* key of your keyboard to validate the change.

6.3 Level 3 Aerosol Index gridded product

With the objective to create a world map of the aerosol index, we first need to process the Sentinel-5p Level 2 products to keep a single grid per orbit (level 3 – L3). The conversion is done combining several operators in a single call. The sub-chapters below give more information on each step.

6.3.1 HARP bin_spatial operation

The HARP bin_spatial() tool maps all time samples onto a regular spatial lat/lon grid for all variables in a product. It follows a specific sequence of parameters shown below:

```
bin_spatial(lat_edge_length,lat_edge_offset,lat_edge_step,lon_edge_length,lon_edge_offset,lon_edge_step)
```

For example:

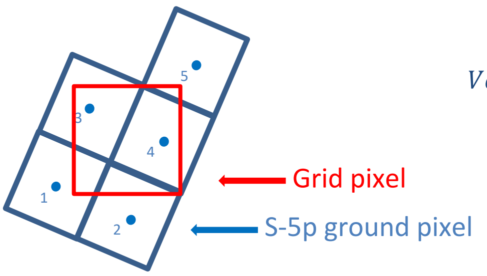
```
bin_spatial(271,-55,0.5,721,-180,0.5)
```

The choice of the spatial resolution (lat/lon_edge_step) and the boundaries (lat/lon_edge_offset, lat/lon_edge_length) can be chosen by the user. Please note that a higher spatial resolution and a larger area of interest increase the processing time (See NOTE 7).

NOTE 7: if only lat/lon center coordinates of ground pixels in the products, the HARP *bin_spatial()* tool performs an average of all values whose center point falls in the grid cell

$$Value = \frac{Pixel_3 + Pixel_4}{2}$$

Sentinel-5p products are delivered with lat/lon_bounds variable. In this case, the HARP *bin_spatial()* tool proceeds to an area weighted average based on ground pixel areas and grid cell intersection (a_i)



$$Value = \frac{\sum_{i=1}^{5} a_i * Pixel_i}{\sum_{i=1}^{5} a_i}$$

6.3.2 HARP derive operation

When spatially binning a product with *bin_spatial()*, only the lat/lon_bounds of the grid cells will be saved in the output product. To write the lat/lon center coordinates of the spatial grid in the output we use the *derive* operation.

Example: 'derive(longitude{longitude}); derive(latitude{latitude})'

6.3.3 HARP Comparison filter operation

This operator filters a dimension for all variables in the product such that items for which the value of the provided variable does not match the expression get excluded.

Example: 'latitude>-55 [degree_north]; longitude <70 [degree_east]'

6.3.4 HARP Convert Command line tool

Once the concept of the steps we will combine is clear, we will use the command line tool to combine all of them and apply it to our product. The tool allows to define a list of operations (in our case, *bin_spatial() ; derive() ; comparison*) to apply to each product using the -a parameter, to define ingestion options using the -o parameter and to define the output format using the -f parameter (the default NETCDF format will be used in this exercise).

Example:

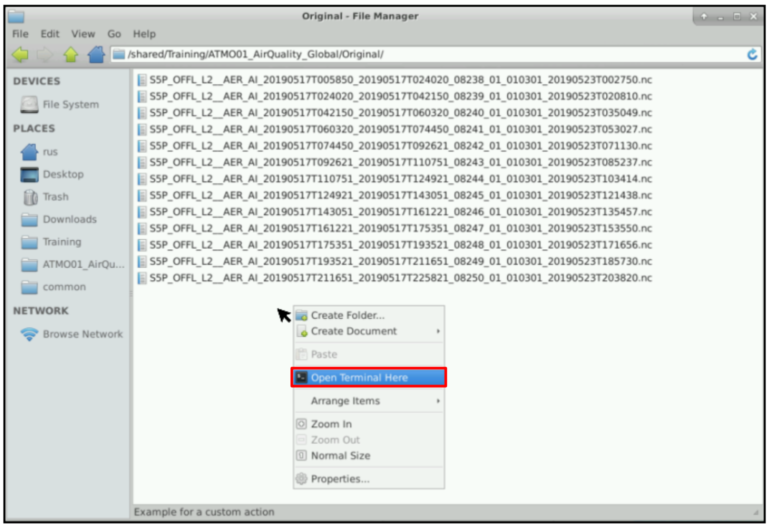
-a 'bin_spatial(…);derive(…)'

-o 'wavelength_ratio=354_338nm'

harpconvert -a 'operations_list' -o 'ingestion_option' input_file output_Directory/output_file

To run the command, go to the following path where all the input Sentinel-5p level 2 UV Aerosol Index products are stored. Right click anywhere on the folder and select *Open Terminal Here.*

Path: */shared/Training/ATMO01_AirQuality_Global/Original/*



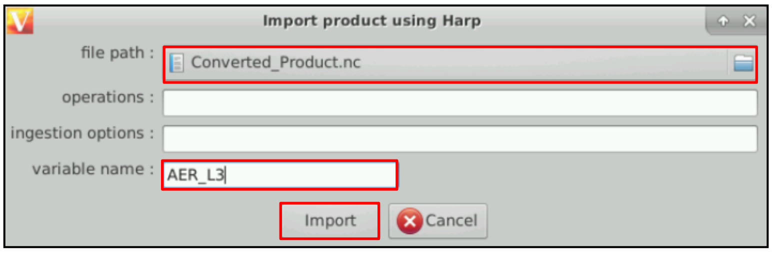
Copy/Paste the following command in the Terminal window and press *Enter* to run it. The output directory where the result will be saved has been set to the following path:

Path: */shared/Training/ATMO01_AirQuality_Global/Processing/L3_GriddedProducts/*

```
harpconvert -a 'latitude > -55 [degree_north]; latitude < 80 [degree_north]; bin_spatial(271,-55,0.5,721,-180,0.5); derive(latitude {latitude}); derive(longitude {longitude})' /shared/Training/ATMO01_AirQuality_Global/Original/S5P_OFFL_L2__AER_AI_20190517T092621_20190517T110751_08243_01_010301_20190523T085237.nc /shared/Training/ATMO01_AirQuality_Global/Processing/L3_GriddedProducts/Converted_Product.nc
```

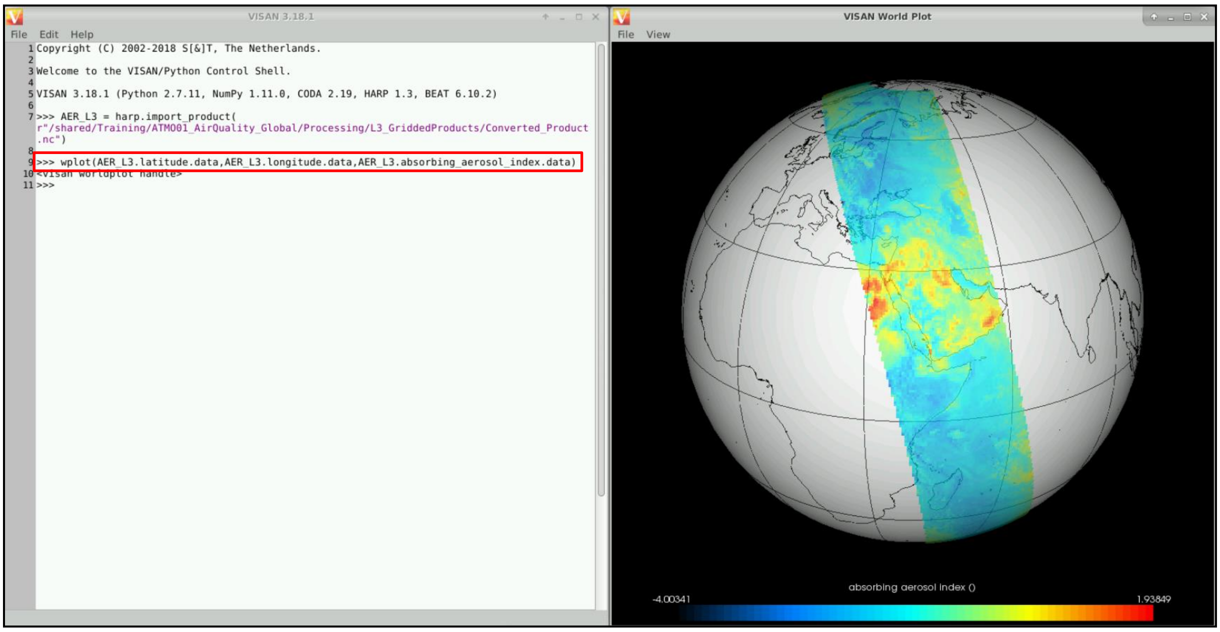
Once run, go to *File -> Harp import* in the main VISAN window to import the output product and visualize it. In the file path, navigate to the output path specify before and select the output product.

Leave the *operations* and *ingestion options* as default and change the *variable name* to *AER_L3.* Next, click *Import.*



As before, once the product has been imported, we can use specific code to manipulate and visualize the data. In the VISAN window write the following command and press enter (See NOTE 8).

```
wplot(AER_L3.latitude.data,AER_L3.longitude.data,AER_L3.absorbing_aerosol_index.data)
```



NOTE 8: Go to *View -> Properties* to change the display settings such as the color bar name, min/max values, color palette, etc. in the

6.4 *Daily averaged Aerosol Index product*

Sentinel-5p Offline products are delivered as single file orbits. To create a world map using the all the products available within a day, they all need to be processed as explained before and merged. Once each Sentinel-5p product is processed to keep a single grid per orbit, we will concatenate all the output files to create a World Map.

For this we will use the HARPMERGE operator, which combines multiple products from files or directory by appending them across the time dimension and storing the result into a single output file. When running HARPMERGE, we will include to code to:

- Define a list of operations to apply to each product before it is appended (-a): same processing as HARPCONVERT done in the previous chapter
- Define a list of operations to apply to the merged product (-ap): operation to properly export the merged product. The *bin()* operation will average each of the lat/lon grid cells over time

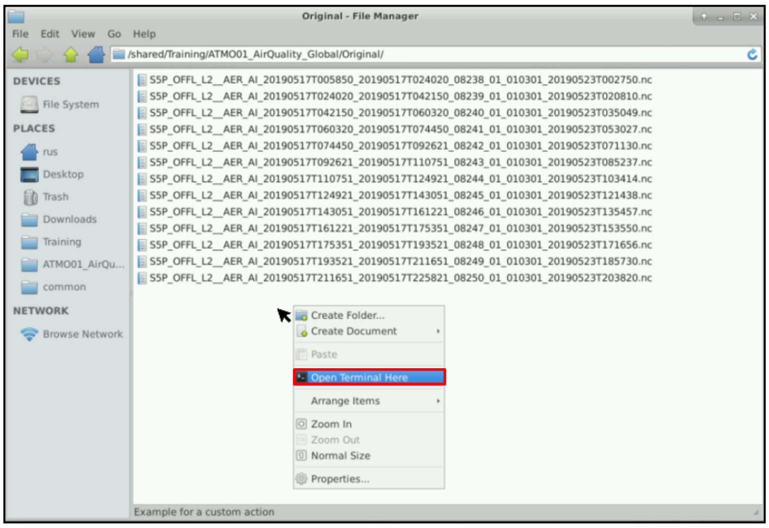
so that we have {1,lat,lon} elements. The *squash(time, (latitude, longitude))* will remove the *time=1* dimension created by the *bin()* operation from lat/lon variables to have proper georeferenced products for further use in other software (i.e. QGIS, Panoply…)

- In addition, ingestion options (-o) and output format (-f) could be defined

```
harpmerge -ap ‘operations_list’ -a ‘operations_list’ -o ‘ingestion_option’ input_file output_Directory/output_file
```

Go to the following path where all the input Sentinel-5p level 2 UV Aerosol Index products are stored. Right click anywhere on the folder and select *Open Terminal Here.*

Path: */shared/Training/ATMO01_AirQuality_Global/Original/*

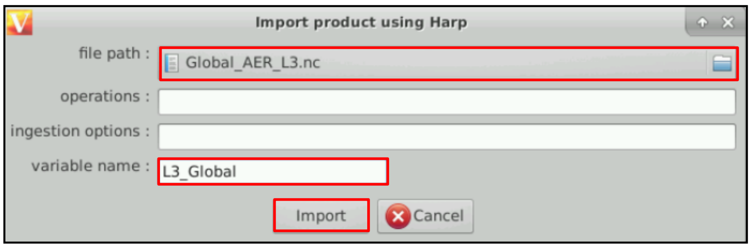


Copy/Paste the following command in the *Terminal* window and press *Enter* to run it. The code will create an average World Map for latitudes between [-55,80] for UV Aerosol Index on the 17/05/2019 for the 354/388 wavelength pair. The output directory where the result will be saved has been set to the following path:

Path: */shared/Training/ATMO01_AirQuality_Global/Processing/L3_GriddedProducts/*

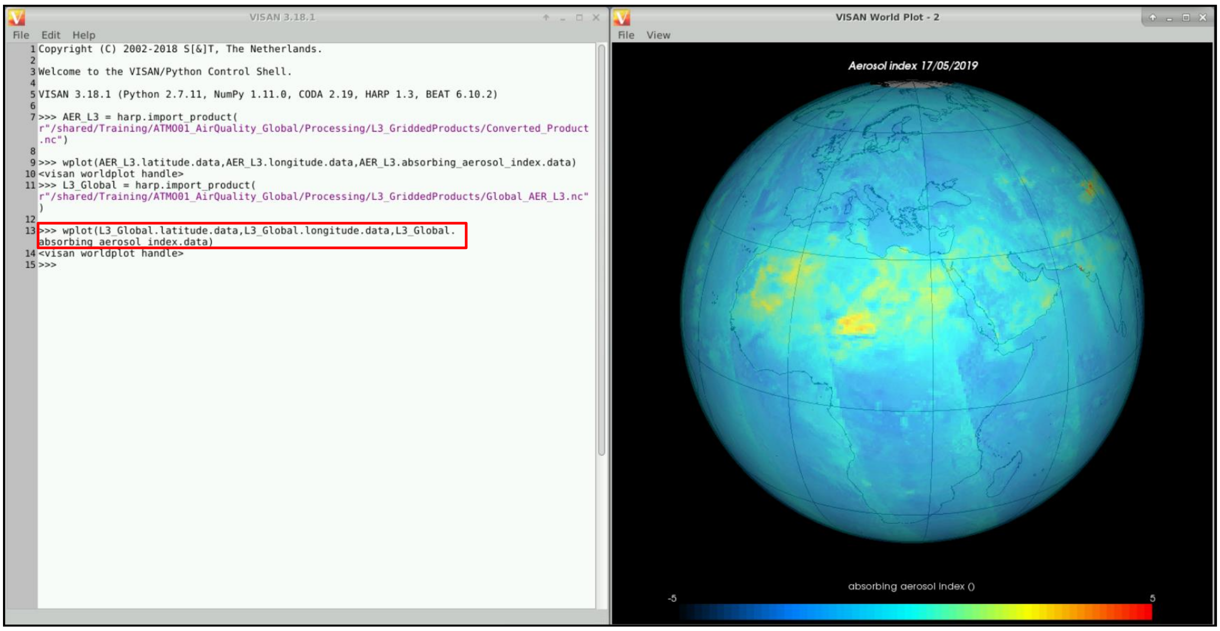
```
harpmerge -ap 'bin(); squash(time, (latitude,longitude))' -a 'latitude > -55 [degree_north]; latitude < 80 [degree_north]; bin_spatial(271,-55,0.5,721,-180,0.5); derive(longitude {longitude}); derive(latitude {latitude})' S5P_OFFL_L2__AER*.nc /shared/Training/ATMO01_AirQuality_Global/Processing/L3_GriddedProducts/Global_AER_L3.nc
```

Once run, go to *File -> Harp import* in the main VISAN window to import the output product and visualize it. In the file path, navigate to the output path specify before and select the output product. Leave the *operations* and *ingestion options* as default and change the *variable name* to *L3_Global.* Next, click *Import.*



As before, once the product has been imported, we can use specific code to manipulate and visualize the data. In the VISAN window write the following command and press enter.

```
wplot(L3_Global.latitude.data,L3_Global.longitude.data,L3_Global.absorbing_aerosol_
index.data)
```



Single orbit products have been re-gridded and properly concatenated into a single averaged Aerosol Index product (See NOTE 9).

> NOTE 9: For no apparent reasons some spots over the ocean have high aerosol index values caused by the sun glint. Pixels affected by sun glint can be filtered out by applying a quality filter when executing the HARPMERGE command line tool (-*absorbing_aerosol_index_validity > 80*) (0: worst quality | 100: full quality).

6.5 *Monitoring fire using Aerosol Index*

Taking advantage of the Sentinel-5p temporal resolution, in this section we will explore the capabilities to monitor a fire event in California (U.S.A.) using the aerosol index level 2 product.

The 2018 wildfire season was the deadliest and most destructive wildfire season on record in California, with a total of 8,527 fires burning an area of 766,439 ha. In November 2018, strong winds aggravated conditions in another round of large, destructive fires that occurred across the state. This new batch of wildfires included the Woolsey Fire and the Camp Fire, becoming both California's deadliest and most destructive wildfire on record.

Close the *Terminal* window. In the file browser, navigate to the following path, right click anywhere in the folder and click on *Open Terminal Here* (See NOTE 10).

Path: /shared/Training/ATMO01_AirQuality_Global/Original/Fire_California/

> NOTE 10: Images for this exercise must be downloaded in advanced. Go to <ins>*8.1 Extra data download – Fire monitoring*</ins> and follow the instructions.

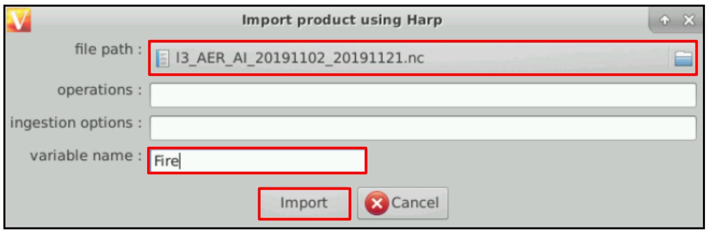
Copy/Paste the following command in the Terminal window and press *Enter* to run it. The output directory where the result will be saved has been set to the following path:

Path: /shared/Training/ATMO01_AirQuality_Global/Processing/Fire_California/

```
harpmerge -a 'latitude > 32 [degree_north]; latitude < 42 [degree_north]; longitude > -126 [degree_east]; longitude < -116 [degree_east]; absorbing_aerosol_index_validity>80; bin_spatial(101,32,0.1,101,-126,0.1); derive(longitude {longitude});derive(latitude {latitude})' S5P_OFFL_L2__AER*.nc /shared/Training/ATMO01_AirQuality_Global/Processing/Fire_California/l3_AER_AI_20191102_20191121.nc
```

In this case, the *-ap 'bin(); squash(time, (latitude,longitude))'* command is not used as we want to keep the time dimension in the merged product to create an animated plot.

Next, go to *File -> Harp import* in the VISAN window to import the output product and visualize it. In the file path, navigate to the output path specify before and select the output product. Leave the *operations* and *ingestion options* as default and change the *variable name* to *Fire.* Next, click *Import.*



As before, once the product has been imported, we can use specific code to manipulate and visualize the data. In the VISAN window write the following command and press enter.

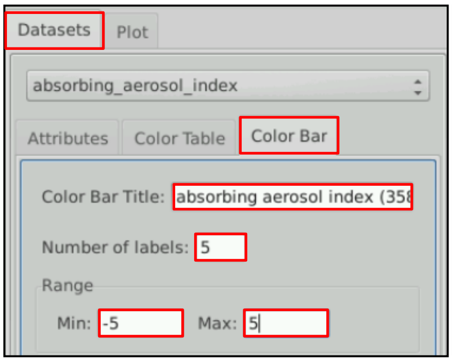
```
wplot(Fire)
```

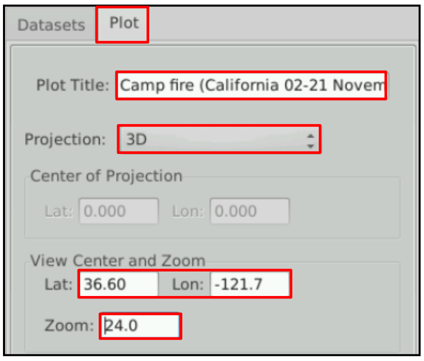
To create the animated plot, in the plot window go to *View -> Properties.* In the *Plot* tab, change the title to: *Camp fire (California 02-21 November 2018) UV Aerosol Index.* Next, navigate to the Camp Fire location (California, U.S.A.) and zoom in using your mouse (you can also set the coordinates as shown in the screenshot).

In the *Dataset -> Color Bar* tab, change the following parameters:

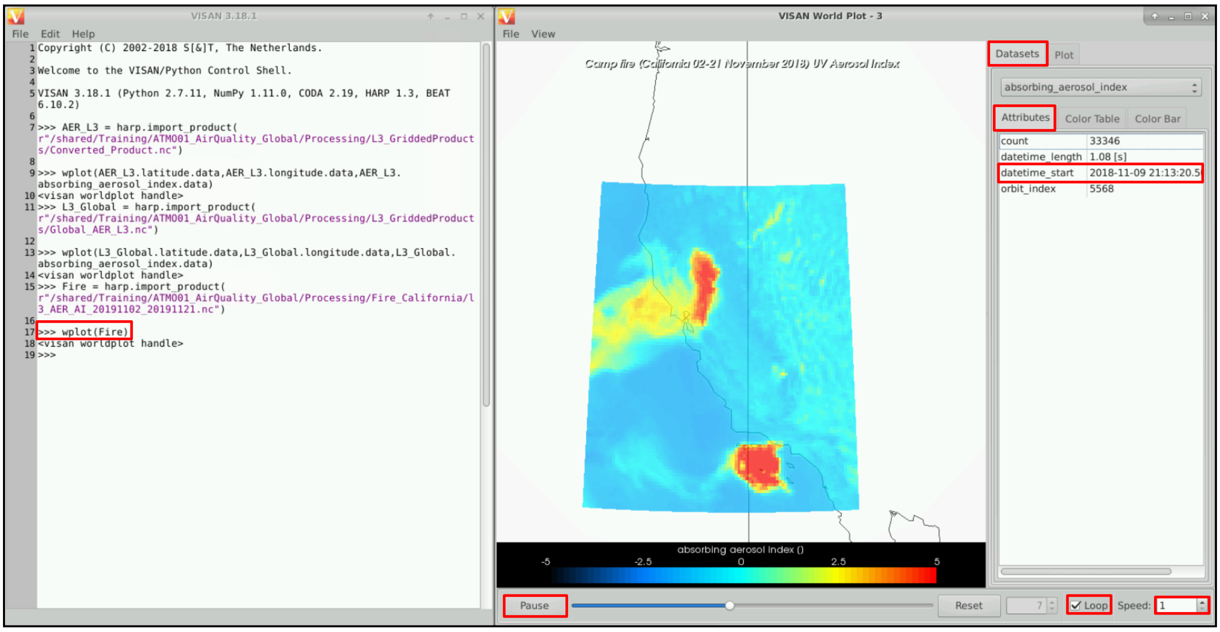
- Color bar tittle: Absorbing aerosol index (354/388 nm)
- Number of labels: 5
- Range Min: -5
- Range Max: 5

In the *Attributes* tab you can visualize the timeframe of the product being displayed.





At the bottom of the VISAN world plot window, select the *Loop* option. Set the *Speed* to 1 and press *Play.* The plot displays the evolution of the generated aerosol plume.



6.6 Tropospheric vertical NO2 column

6.6.1 Daily averaged tropospheric NO_2 vertical column

To explore the capabilities of Sentinel-5p to detect and monitor other air pollutants, we will create a daily averaged tropospheric vertical NO_2 column using Sentinel-5p level 2 NO2 products. For that, close the current *Terminal* window. Open a file browser and navigate to the following path (See NOTE 11).

NOTE 11: Images for this exercise must be downloaded in advanced. Go to *8.2 Extra data download – NO2 Monitoring* and follow the instructions.

Path: /shared/Training/ATMO01_AirQuality_Global/Original/N02/

Right click anywhere in the folder and click *Open Terminal Here.*

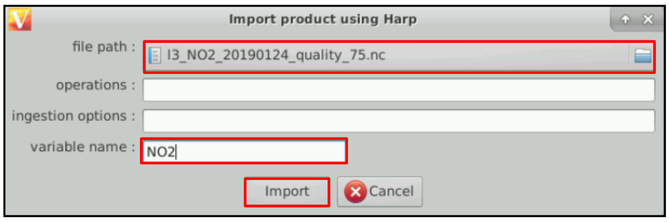
Copy/Paste the following command in the Terminal window and press *Enter* to run it. The output directory where the result will be saved has been set to the following path:

Path: /shared/Training/ATMO01_AirQuality_Global/Processing/NO2/

```
harpmerge -ap 'bin(); squash(time, (latitude,longitude))' -a 'latitude > -55 [degree_north]; latitude < 60 [degree_north]; tropospheric_NO2_column_number_density_validity > 75; bin_spatial(231,-55,0.5,721,-180,0.5); derive(longitude {longitude});derive(latitude {latitude})' S5P_OFFL_L2__NO2*.nc /shared/Training/ATMO01_AirQuality_Global/Processing/NO2/l3_NO2_20190124_quality_75.nc
```

The command builds a daily averaged world map for latitudes between [-55,60] of tropospheric vertical column of NO_2 on 24/01/2019 with full quality data. The value of the *tropospheric_NO2_column_number_density_validity* is set to 75 as it is the recommended pixel filter to remove cloud/snow/ice covered scenes, errors and problematic retrieval.

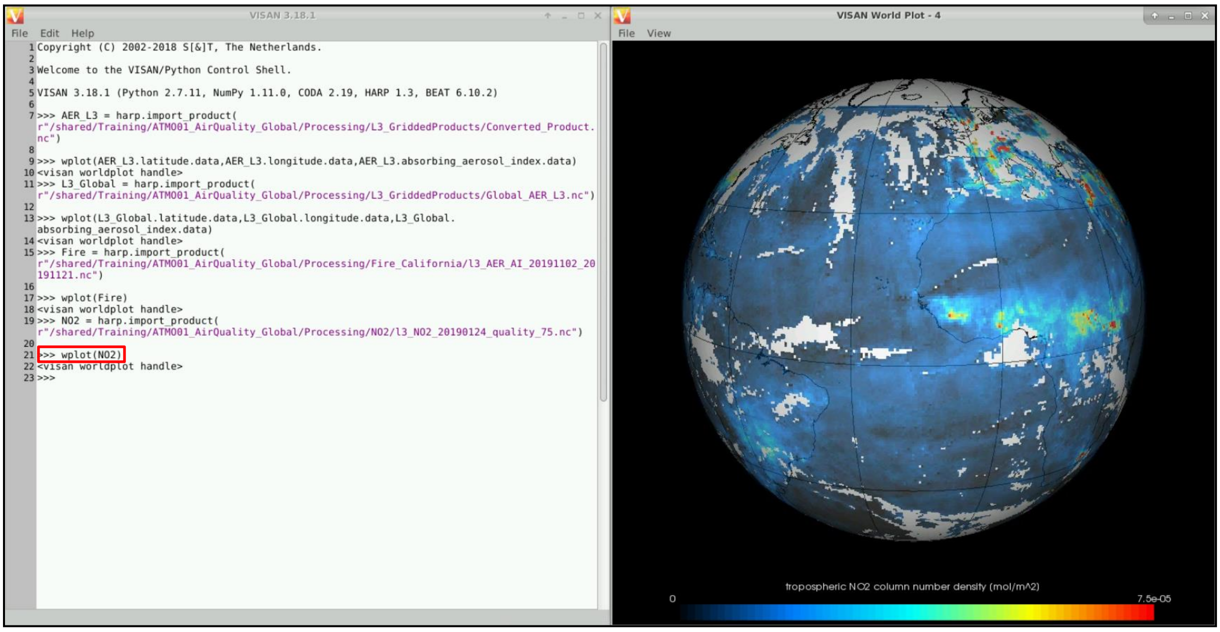
Once run, go to *File -> Harp import* in the main VISAN window to import the output product and visualize it. In the file path, navigate to the output path specify before and select the output product. Leave the *operations* and *ingestion options* as default and change the *variable name* to *NO2*. Next, click *Import.*



As before, once the product has been imported, we can use specific code to manipulate and visualize the data. In the VISAN window write the following command and press enter.

```
wplot(NO2)
```

Single orbit products have been re-gridded and properly concatenated into a single averaged tropospheric vertical column of NO_2 products. To improve the visualization, change the *Min/Max* values of the color bar to 0 and 0.000075 mol/m^2 respectively.



Due to the air pollution present in urban areas, the world's major cities are highlighter (specially over China). Furthermore, due to cloud coverage, large invalid areas are visible.

6.6.2 Monthly averaged tropospheric NO_2 vertical column

In the last step, we will derive a monthly averaged tropospheric vertical NO_2 column using Sentinel-5p level 2 NO2 products. For that, close the current *Terminal* window. Open a file browser and navigate to the following path. There, all averaged daily maps of tropospheric vertical column of NO_2 for January 2019 have been created following the same method as before.

Path: /shared/Training/ATMO01_AirQuality_Global/Original/NO2_GlobalAverage/

Right click anywhere in the folder and click *Open Terminal Here.*

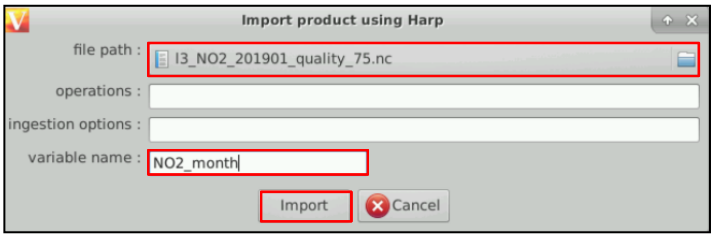
Copy/Paste the following command in the Terminal window and press *Enter* to run it. The output directory where the result will be saved has been set to the following path:

Path: /shared/Training/ATMO01_AirQuality_Global/Processing/NO2/Global/

```
harpmerge -ap 'bin(); squash(time, (latitude,longitude))' l3_201901*.nc /shared/Training/ATMO01_AirQuality_Global/Processing/NO2/Global/l3_NO2_201901_quality_75.nc
```

The command builds a monthly averaged world map for latitudes between [-55,60] of tropospheric vertical column of NO_2

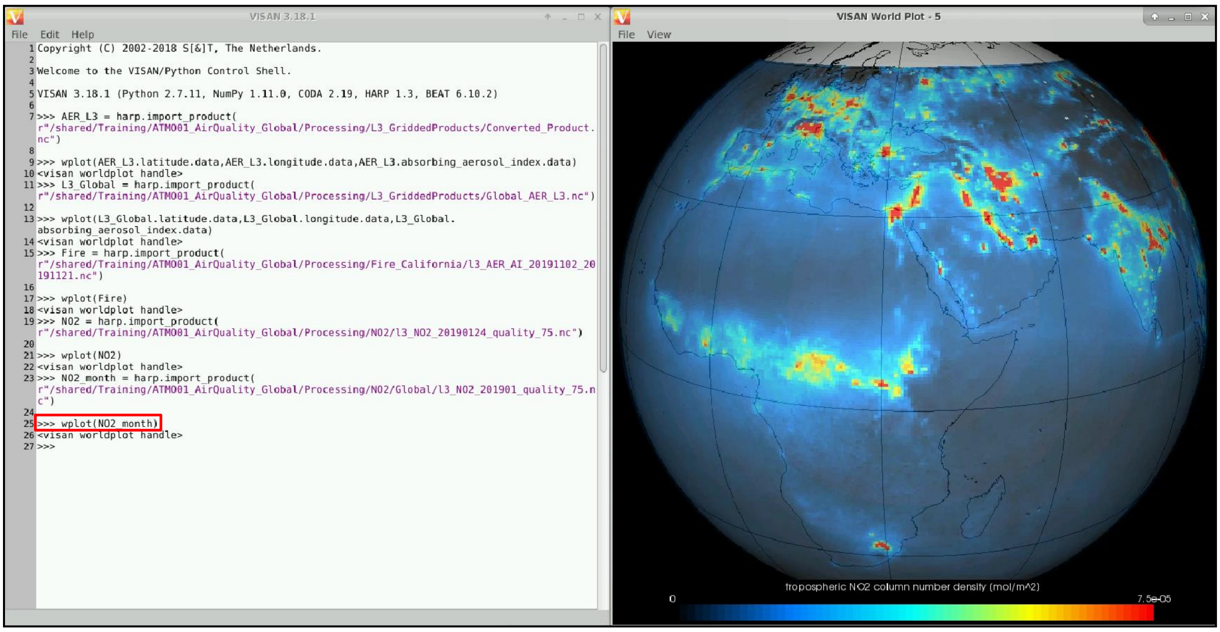
Once run, go to *File -> Harp import* in the main VISAN window to import the output product and visualize it. In the file path, navigate to the output path specify before and select the output product. Leave the *operations* and *ingestion options* as default and change the *variable name* to *NO2_month*. Next, click *Import.*



As before, once the product has been imported, we can use specific code to manipulate and visualize the data. In the VISAN window write the following command and press enter.

```
wplot(NO2_month)
```

Daily averaged products have been properly concatenated into a single monthly averaged tropospheric vertical column of NO_2 products. To improve the visualization, change the *Min/Max* values of the color bar to 0 and 0.000075 mol/m^2 respectively.

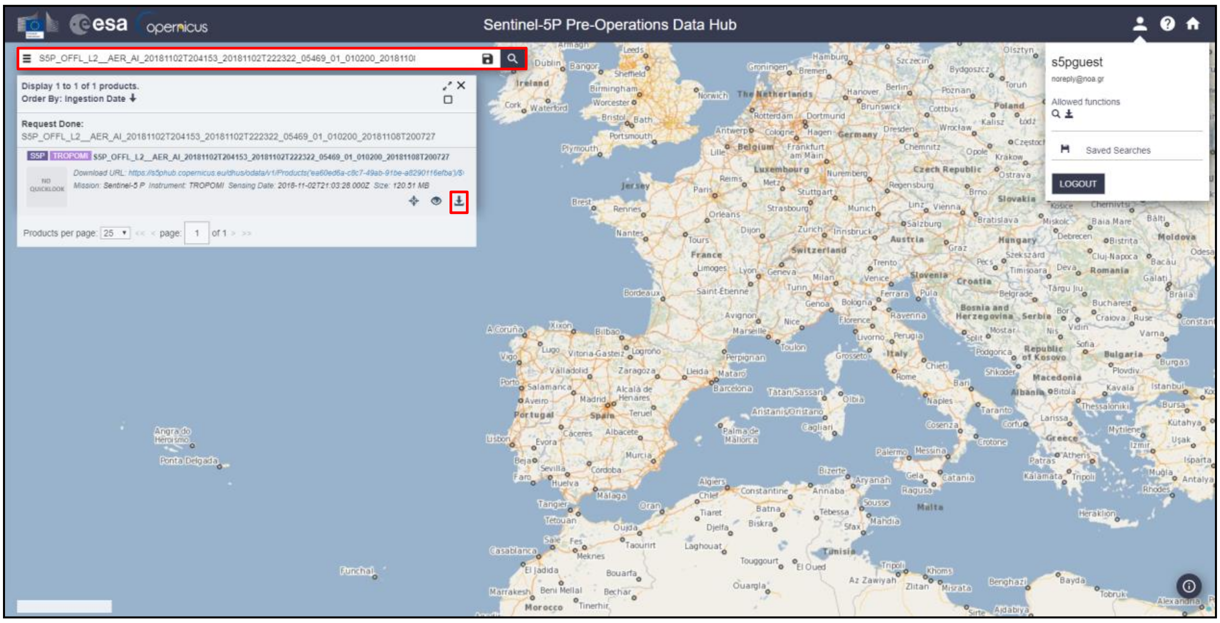


8 Extra steps

8.1 Extra data download – Fire monitoring

To download the data for the fire monitoring exercise go to the Sentinel-5p Pre-Operations Data Hub, log in as explained before and copy paste the following product names in the search bar. Then, click on search and download to product. Once downloaded (in home/rus/downloads) move it to the following path.

Path: /shared/Training/ATMO01_AirQuality_Global/Original/Fire_California/



Date	Product ID
2018-11-02	S5P_OFFL_L2__AER_AI_20181102T204153_20181102T222322_05469_01_010200_20181108T200727
2018-11-03	S5P_OFFL_L2__AER_AI_20181103T202245_20181103T220415_05483_01_010200_20181109T194206
2018-11-04	S5P_OFFL_L2__AER_AI_20181104T200338_20181104T214507_05497_01_010200_20181110T192244
2018-11-05	S5P_OFFL_L2__AER_AI_20181105T194430_20181105T212600_05511_01_010200_20181111T190324
2018-11-06	S5P_OFFL_L2__AER_AI_20181106T192523_20181106T210652_05525_01_010200_20181112T184406
2018-11-07	S5P_OFFL_L2__AER_AI_20181107T204745_20181107T222915_05540_01_010200_20181113T201448
2018-11-08	S5P_OFFL_L2__AER_AI_20181108T202838_20181108T221007_05554_01_010200_20181114T195528
2018-11-09	S5P_OFFL_L2__AER_AI_20181109T200931_20181109T215100_05568_01_010200_20181115T193606
2018-11-10	S5P_OFFL_L2__AER_AI_20181110T195023_20181110T213153_05582_01_010200_20181116T191647
2018-11-11	S5P_OFFL_L2__AER_AI_20181111T193116_20181111T211246_05596_01_010200_20181117T185728
2018-11-12	S5P_OFFL_L2__AER_AI_20181112T191210_20181112T205339_05610_01_010200_20181118T183807
2018-11-14	S5P_OFFL_L2__AER_AI_20181114T201526_20181114T215655_05639_01_010200_20181120T193926

2018-11-16	S5P_OFFL_L2__AER_AI_20181116T193712_20181116T211842_05667_01_010200_20181122T185737
2018-11-17	S5P_OFFL_L2__AER_AI_20181117T191806_20181117T205936_05681_01_010200_20181123T184418
2018-11-18	S5P_OFFL_L2__AER_AI_20181118T204029_20181118T222159_05696_01_010200_20181124T200555
2018-11-20	S5P_OFFL_L2__AER_AI_20181120T200217_20181120T214347_05724_01_010200_20181126T192906
2018-11-21	S5P_OFFL_L2__AER_AI_20181121T194311_20181121T212441_05738_01_010200_20181127T191033

8.2 Extra data download – NO2 Monitoring

To download the data for the NO2 monitoring exercise go to the Sentinel-5p Pre-Operations Data Hub, log in as explained before and copy paste the following product names in the search bar. Then, click on search and download to product. Once downloaded (in home/rus/downloads) move it to the following path.

Path: /shared/Training/ATMO01_AirQuality_Global/Original/N02/

Date	Product ID
2019-01-24	S5P_OFFL_L2__NO2____20190124T010650_20190124T024820_06635_01_010202_20190130T024317
	S5P_OFFL_L2__NO2____20190124T024820_20190124T042951_06636_01_010202_20190130T043730
	S5P_OFFL_L2__NO2____20190124T042951_20190124T061121_06637_01_010202_20190130T061522
	S5P_OFFL_L2__NO2____20190124T061121_20190124T075251_06638_01_010202_20190130T080926
	S5P_OFFL_L2__NO2____20190124T075251_20190124T093421_06639_01_010202_20190130T094112
	S5P_OFFL_L2__NO2____20190124T093421_20190124T111551_06640_01_010202_20190130T113605
	S5P_OFFL_L2__NO2____20190124T111551_20190124T125722_06641_01_010202_20190130T143915
	S5P_OFFL_L2__NO2____20190124T125722_20190124T143852_06642_01_010202_20190130T151234
	S5P_OFFL_L2__NO2____20190124T143852_20190124T162022_06643_01_010202_20190130T161125
	S5P_OFFL_L2__NO2____20190124T162022_20190124T180152_06644_01_010202_20190130T182515
	S5P_OFFL_L2__NO2____20190124T180152_20190124T194322_06645_01_010202_20190130T201724
	S5P_OFFL_L2__NO2____20190124T194322_20190124T212452_06646_01_010202_20190130T214447
	S5P_OFFL_L2__NO2____20190124T212452_20190124T230622_06647_01_010202_20190131T080338
	S5P_OFFL_L2__NO2____20190124T230622_20190125T004753_06648_01_010202_20190131T004111

THANK YOU FOR FOLLOWING THE EXERCISE!

9 Further reading and resources

Sentinel-5 User Guide

https://sentinel.esa.int/web/sentinel/user-guides/sentinel-5p-tropomi

Sentinel-5 Technical Guide

https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-5p/products-algorithms

Tropomi

http://www.tropomi.eu/

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