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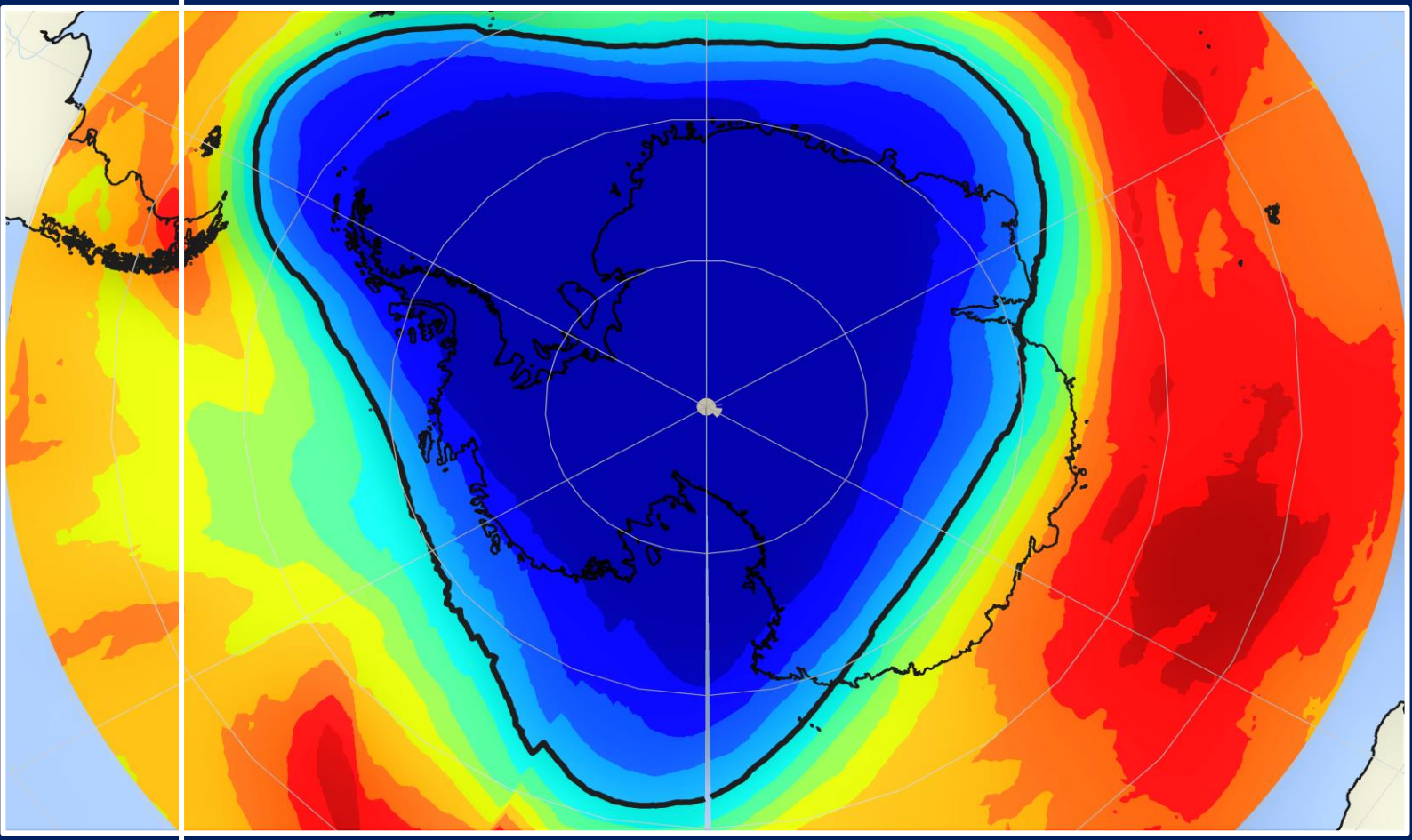

TRAINING KIT – ATMO04

OZONE LAYER MONITORING WITH SENTINEL-5P

Case Study: Antarctic Ozone Hole, October 2020

serco NOVELTIS ALONG-TRACK ROMANIA

Research and User Support for Sentinel Core Products

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Authors would be glad to receive your feedback or suggestions and to know how this material was used. Please, contact us on simon.b@rus-copernicus.eu

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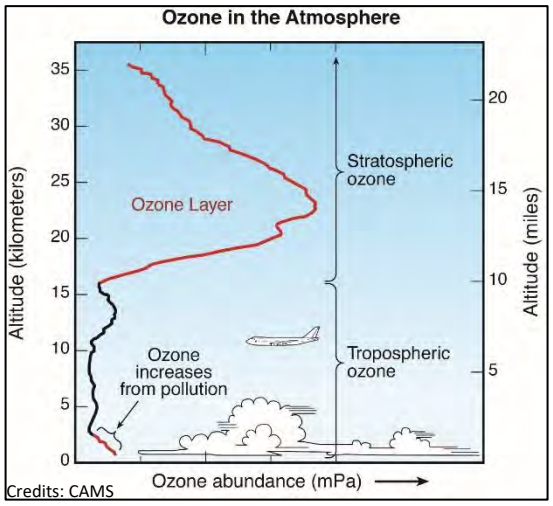
Table of Contents

1 Introduction to RUS

The **R**esearch and **U**ser **S**upport 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.

In this tutorial, we will assess and monitor the ozone hole extent over Antarctica thanks to processed Sentinel-5P products. We will carry out this study using Python code on RUS virtual machines.

2 Ozone layer and ozone hole - background



Ozone is a gas whose abundance varies in our atmosphere. While tropospheric ozone is an air pollutant and a greenhouse gas, the stratospheric ozone layer shields the biosphere from harmful solar UV radiation.

Invented in the 1930s, chlorofluorocarbons (CFCs) became widely used in the 1950s in various industries. Their remarkable properties (non-flammable, easily compressible, insoluble, stable) made them an ideally cheap alternative to noble gases. With their low chemical reactivity, CFCs were additionally believed to be of low environmental toxicity. Only a few decades later was it discovered that these substances were photochemically active and causing a major depletion of the ozone layer above Antarctica. The Montreal Protocol to ban CFCs was signed in 1987. Since then, the ozone layer has been gradually and slowly recovering.

Despite the ban on CFCs, an ozone hole still forms every year in late winter/early spring above Antarctica. The extremely cold winter temperatures coupled with a strong polar vortex enhance the ozone-depleting effects of the CFCs in this region. In 2020, the Antarctic ozone hole started by mid-August and ended in late December. It was unusually long and deep due to remarkably cold stratospheric temperatures and exceptionally powerful polar winds.

Monitoring the ozone layer is hence key to assessing the effects of the global efforts that have been carried out since the Montreal Protocol was signed in 1987. Data on the thickness of the ozone layer throughout the year and everywhere on Earth is also essential to estimate the recovery rate of this invisible layer that protects life on Earth. To this end, authorities and the scientific community rely on space-based technologies as they offer a unique and reliable way to monitor ozone daily and globally.

In this context, Sentinel-5P was launched in October 2017. Its main purpose is to screen the Earth's atmosphere and quantify different pollutants (O_3, CO, NO_2, SO_2, aerosols, etc.) with a great accuracy and spatial resolution. It also provides measurement continuity with precedent and ongoing atmospheric spatial missions (OMI, IASI and SCHIAMACHY). The data recorded by this satellite are free

of use and present a great interest to globally monitor air quality, greenhouse gas emissions and detect and assess the impact of polluting events.

3 Training

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

The Training Code for this tutorial is ATMO04. If you wish to practice the exercise described below within the RUS Virtual Environment, register on the RUS portal to request a Virtual Machine. Go to Your RUS Service → Your training activities and *Request a Webinar Training*.

3.1 Data used

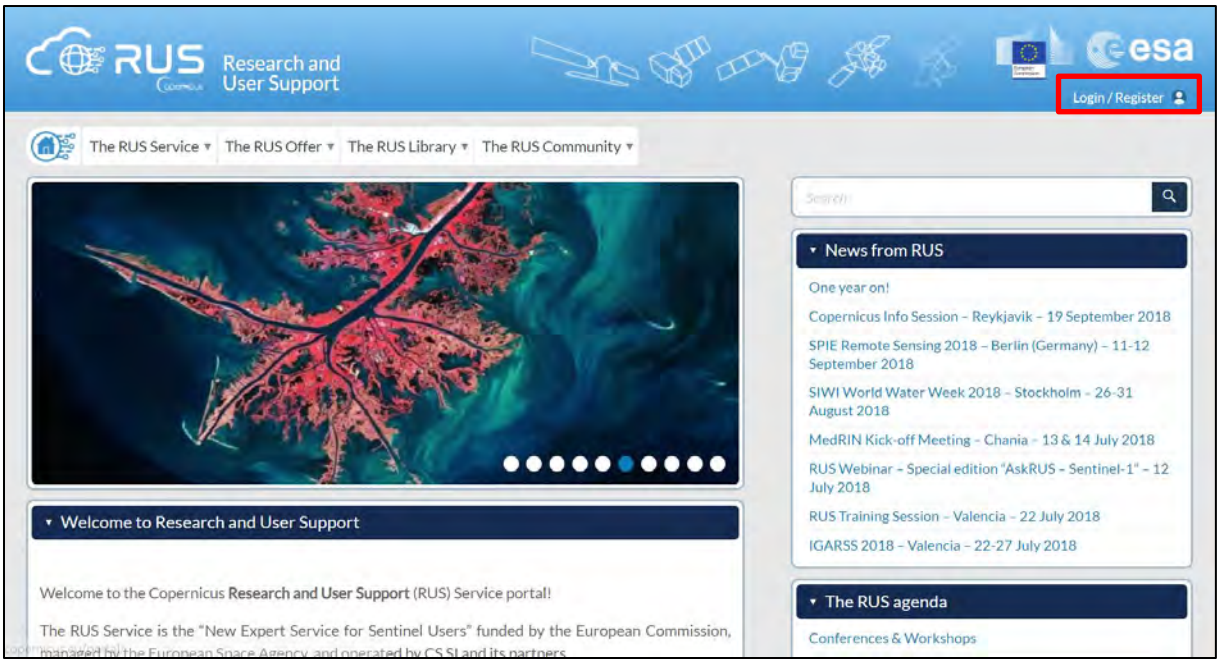
- 14 Sentinel-5P Ozone products acquired on October 1st 2020 (see section 6.1) [downloadable @ https://scihub.copernicus.eu/]
- Example file downloaded for the 1st October 2020 *@/shared/Training/ATMO04_OzoneHole_Antarctic/AuxData/file_exploration/*
- Pre-processed data available for the month of October 2020 *@/shared/Training/ATMO04_OzoneHole_Antarctic/AuxData/all_October_converted_files/*

3.2 Software in RUS environment

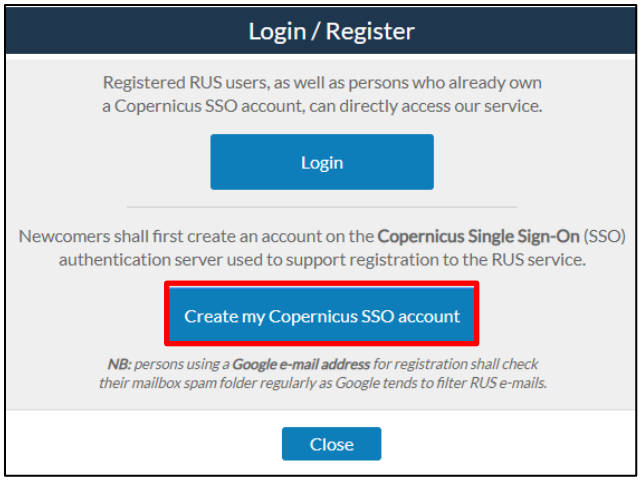
Internet browser, JupyterLab, Python

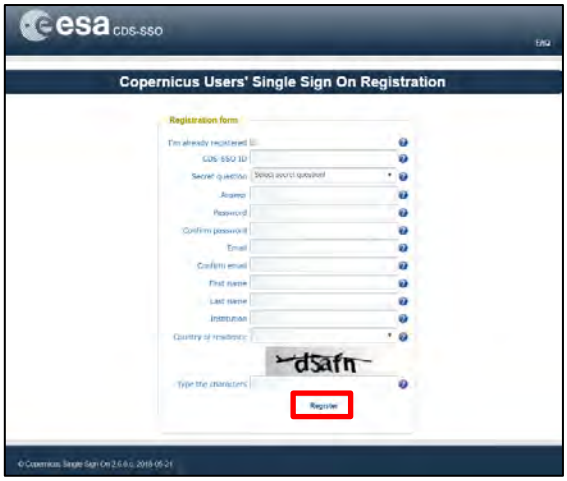
4 Register to RUS Copernicus

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.



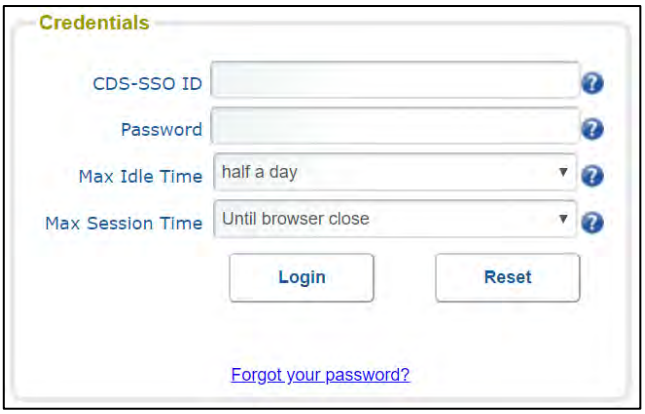
Select the option ***Create my Copernicus SSO account*** and then fill in ALL the fields on the **Copernicus Users' Single Sign On Registration**. Click ***Register***.



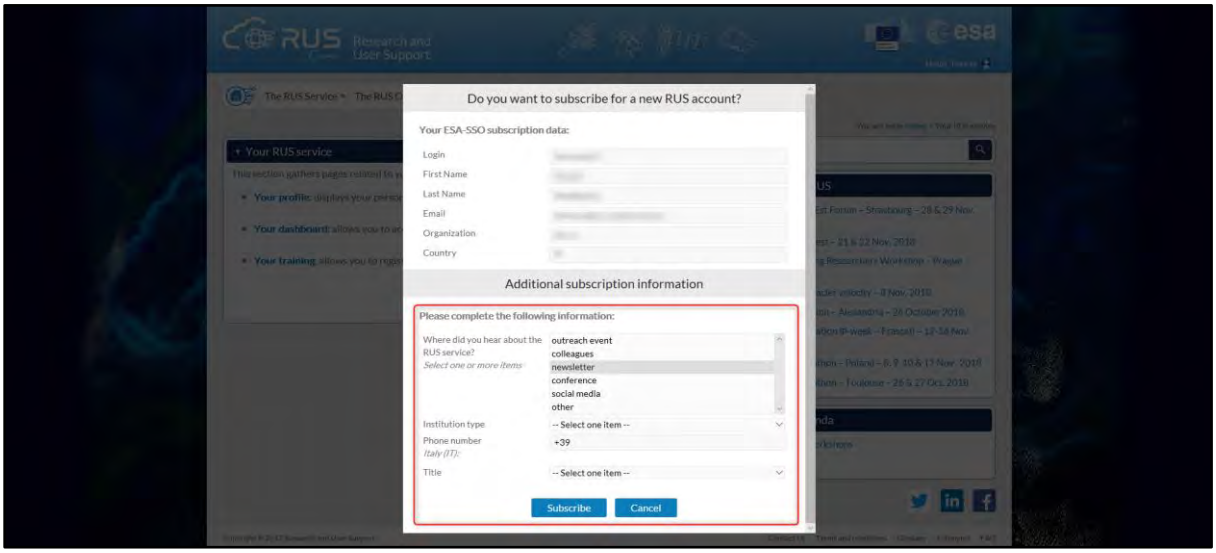


Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the e-mail to activate your account.

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

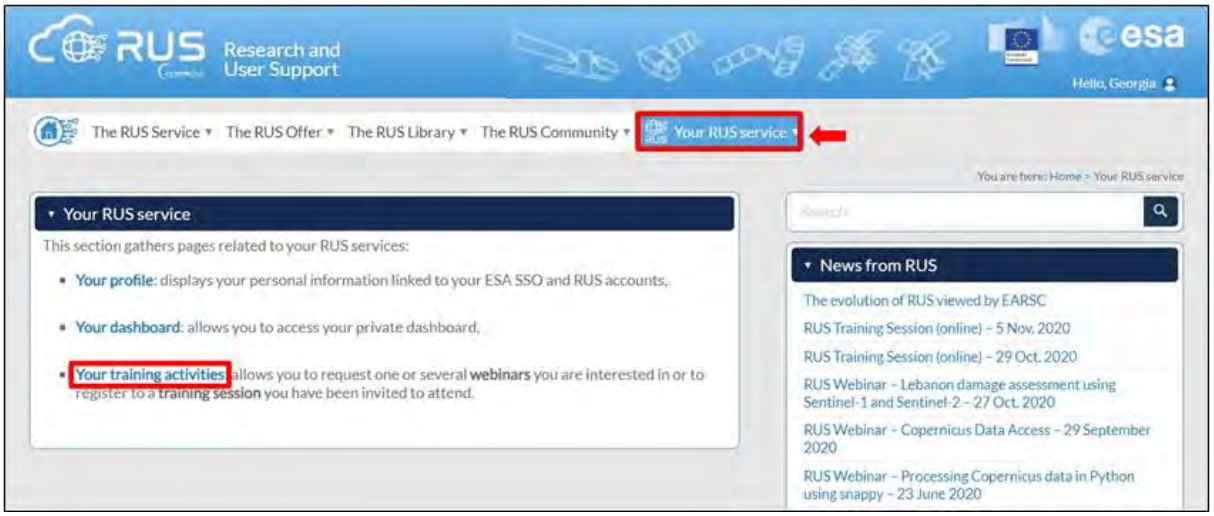


Upon your first login you will need to enter some details. You must fill all the fields.

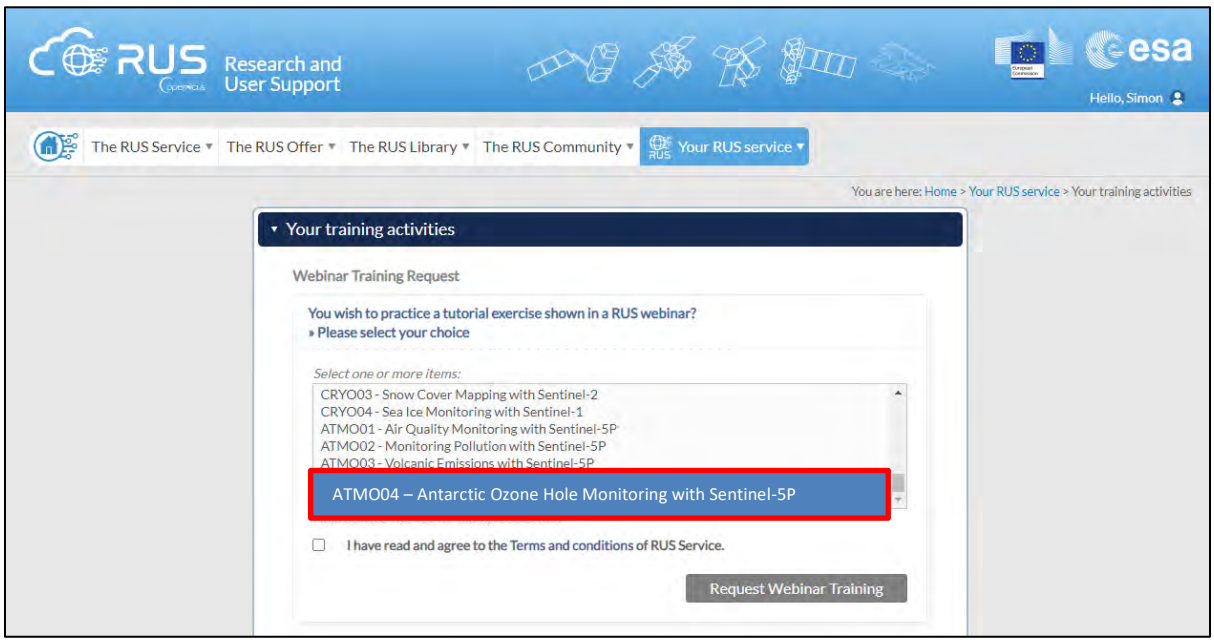


5 Request a RUS Copernicus Virtual Machine to repeat a Webinar

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 training activities***.



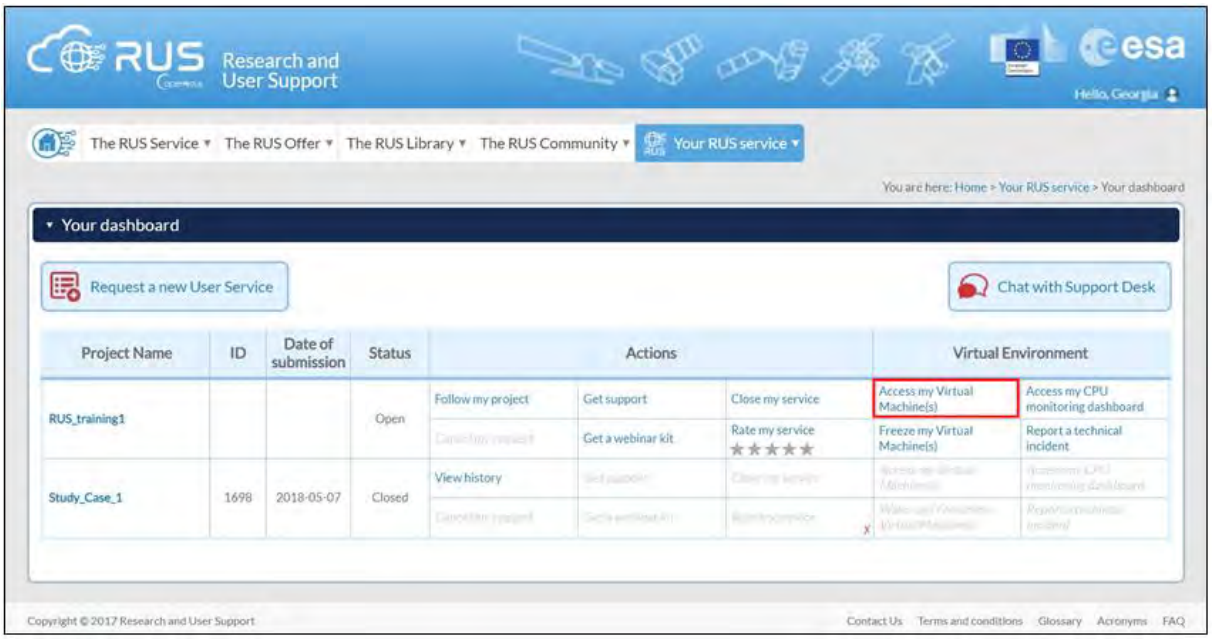
Select **ATMO04 – Antarctic Ozone Hole Monitoring with Sentinel-5P**, check the field *"I have read and agree to the Terms and conditions of RUS Service"* and then click on ***Request Webinar Training*** to request your RUS Virtual Machine.



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***.

NOTE: If the "***Access my Virtual Machine***" is greyed out, please access your VM from the direct link you have received at the email informing you about the creation of your VM.



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

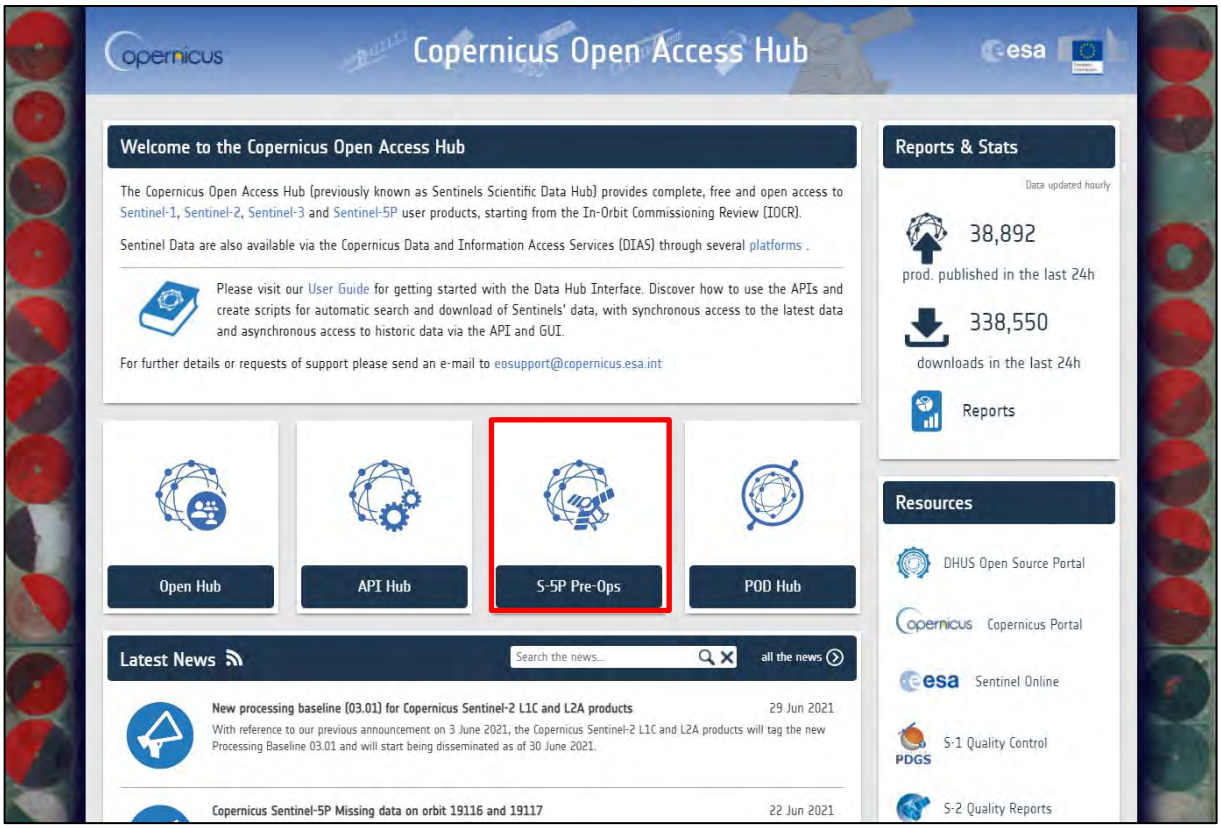
This is the remote desktop of your Virtual Machine.

6 Step by step

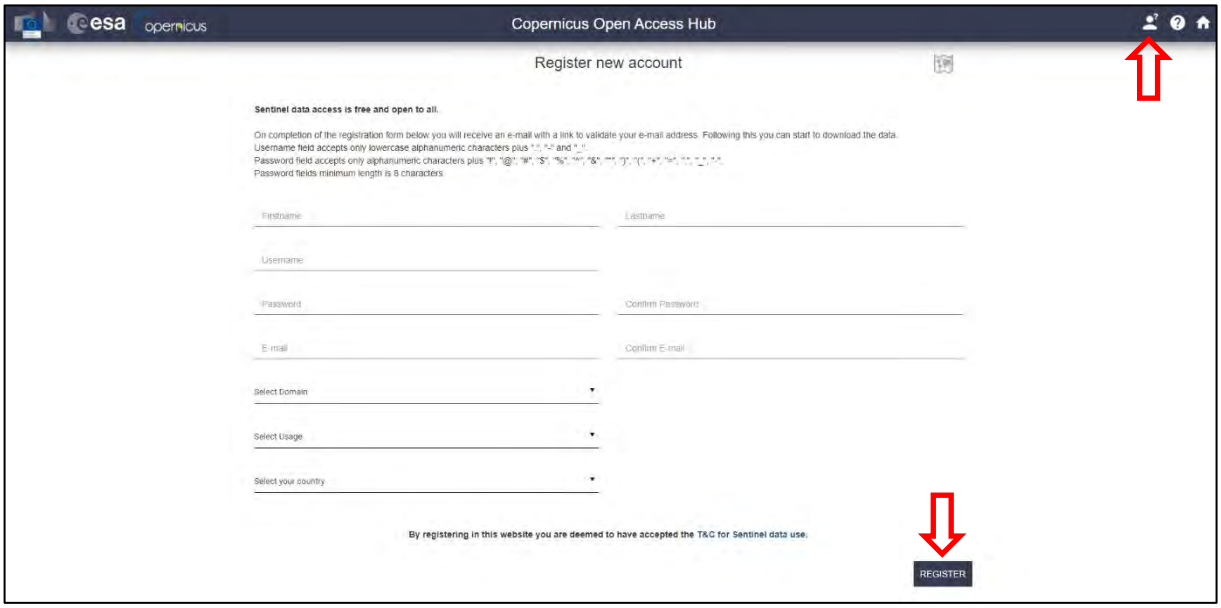
6.1 Data download – ESA SciHUB

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 (August 2021), 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.

In this guide, we describe the procedure to download the Sentinel-5P images for 1st October 2020. 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.

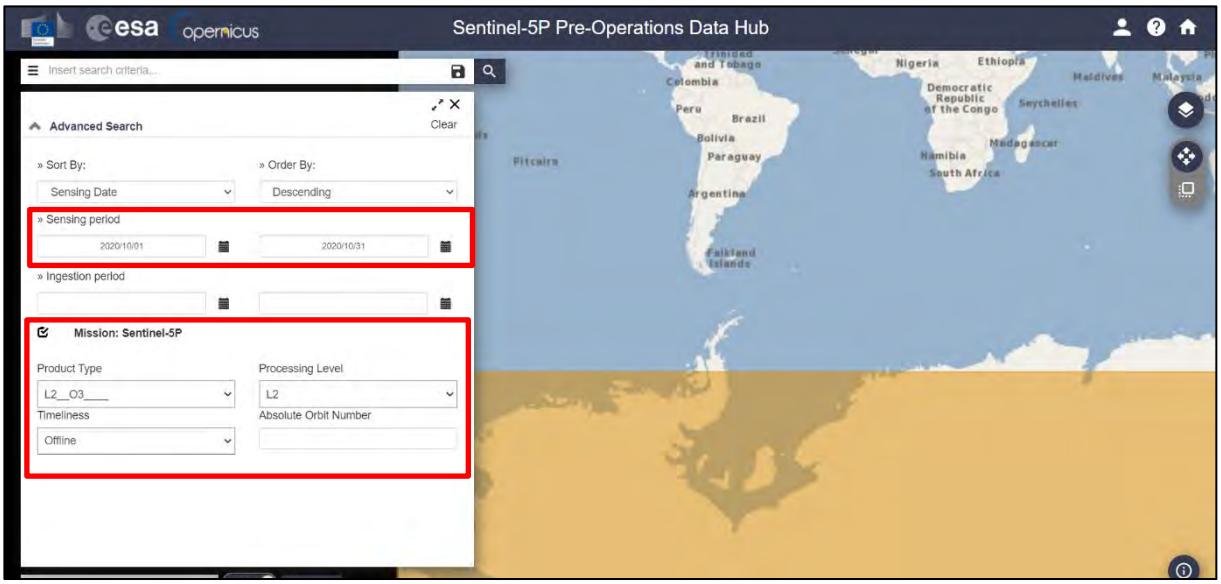
Sensing period: From 2020/10/01 to 2020/10/01

Check mission: Sentinel-5P

Product type: L2__O3___

Processing level: L2

Timeliness: Offline



In this case, the search returns 14 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/ATMO04_OzoneHole_Antarctic/Original/*

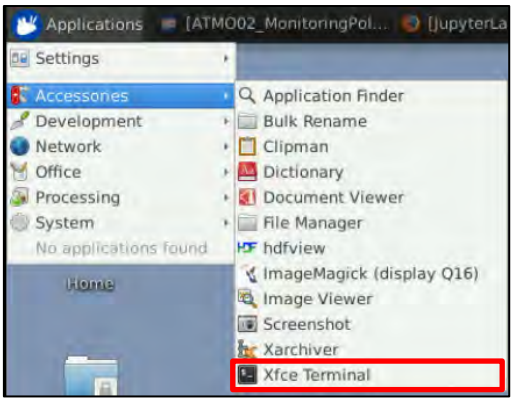
> NOTE 2: Sentinel-5P counts 14 orbits per day. Due to the starting (d) and end acquisition time (d+1) during the last orbit, when looking for all the products of a day the result may output 13 products instead of 14. To complete the global coverage, you may need to increase by one day the sensing time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

> NOTE 3: Sentinel-5P products are delivered as netCDF files. There is a single NetCDF file per orbit. *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 (From NetCDF User's Guide).* A large amount of free software as well as commercial or licensed packages is available at the UniData website.

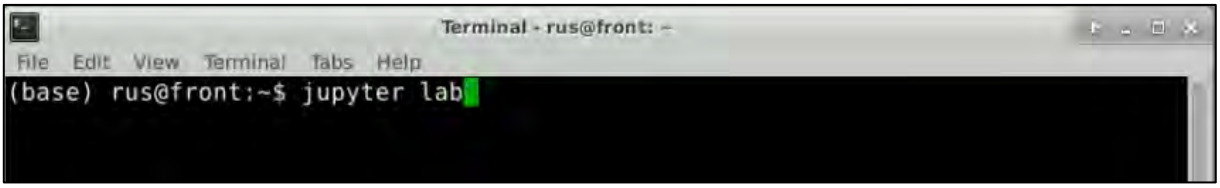
6.2 Sentinel-5P Python Processing – Jupyter Notebook

Further processing and instructions to continue the analysis of Sentinel-5P images will be performed using Python code in JupyterLab (Anaconda Distribution) (see NOTE 4 and NOTE 5) provided with this training kit.

We are going to launch JupyterLab from a terminal. To open a Terminal, go to *Applications* → *Accessories* and hit **Xfce Terminal**.



Next write jupyter lab and press enter to launch the application.

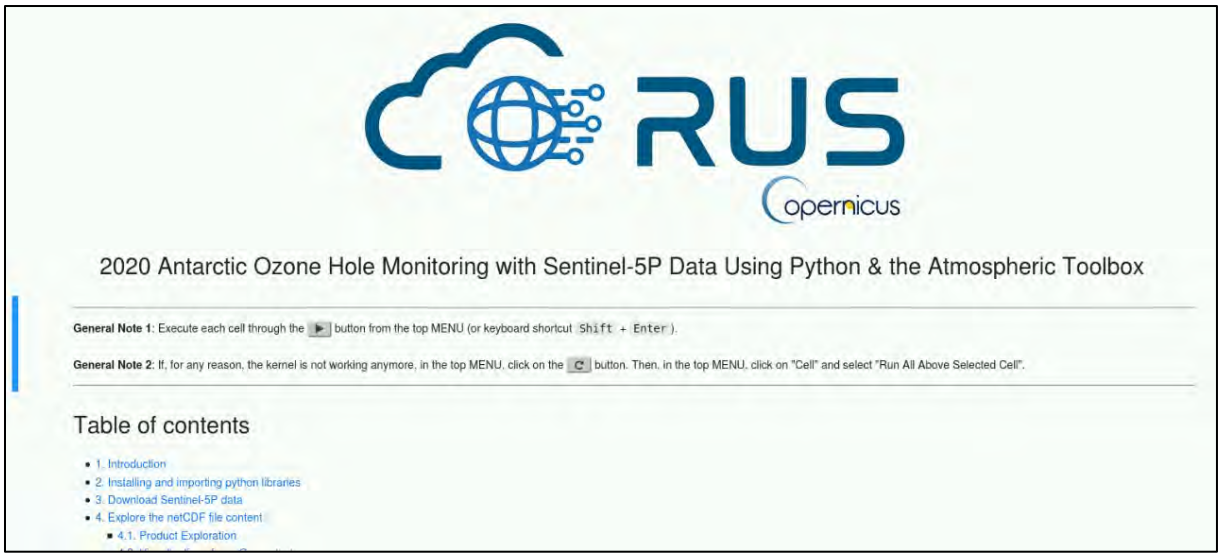


Once open, navigate to the following path inside the JupyterLab GUI and open the file *Code_ATMO04.ipynb*

Path:/shared/Training/ATMO04_OzoneHole_Antarctic/AuxData

NOTE 4: Python is an interpreted, high-level, general-purpose programming language. Created by Guido van Rossum and first released in 1991, Python's design philosophy emphasizes code readability through use of significant whitespace. Its language constructs and object-oriented approach aim to help programmers write clear, logical code for small and large-scale projects. Python is dynamically typed and garbage-collected. It supports multiple programming paradigms, including procedural, object- oriented, and functional programming. Python is often described as a "batteries included" language due to its comprehensive standard library. More info at: www.python.org

Anaconda is a free and open-source distribution of the Python and R programming languages for scientific computing (data science, machine learning applications, large-scale data processing, predictive analytics, etc.), that aims to simplify package management and deployment. Package versions are managed by the package management system *conda*. More info at: https://www.anaconda.com/distribution/



NOTE 5: Project Jupyter is a non-profit, open-source project, born out of the IPython Project in 2014 as it evolved to support interactive data science and scientific computing across all programming languages. Notebook documents (or "notebooks", all lower case) are documents produced by the Jupyter Notebook App, which contain both computer code (e.g. python) and rich text elements (paragraph, equations, figures, links, etc…). Notebook documents are both human-readable documents containing the analysis description and the results (figures, tables, etc..) as well as executable documents which can be run to perform data analysis. More info at: www.jupyter.org

Follow the instructions in the JupyterLab Notebook to continue the exercise.

THANK YOU FOR FOLLOWING THE EXERCISE!

7 Further reading and resources

Sentinel-5P User Guide
https://sentinel.esa.int/web/sentinel/user-guides/sentinel-5p-tropomi

Sentinel-5P Technical Guide
https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-5p/products-algorithms

Tropomi
http://www.tropomi.eu/

Sentinel-5P L2 Ozone Product User Manual
https://sentinel.esa.int/documents/247904/2474726/Sentinel-5P-Level-2-Product-User-Manual-Ozone-Total-Column

Sentinel-5P L2 OFFL Total Ozone Readme file
https://sentinel.esa.int/documents/247904/3541451/Sentinel-5P-Readme-OFFL-Total-Ozone.pdf

Twenty Questions and Answers about the Ozone Layer, Scientific Assessment of Ozone Depletion
https://csl.noaa.gov/assessments/ozone/2010/twentyquestions/

The 2020 Antarctic Ozone Hole Season
https://atmosphere.copernicus.eu/2020-antarctic-ozone-hole-season

A reminder on the Dobson Unit

https://sacs.aeronomie.be/info/dobson.php

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