





TRAINING KIT – ATMO04

OZONE LAYER MONITORING WITH SENTINEL-5P Case Study: Antarctic Ozone Hole, October 2020

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 <u>simon.b@rus-copernicus.eu</u>

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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 preinstalled 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, SentineI-5P was launched in October 2017. Its main purpose is to screen the Earth's atmosphere and quantify different pollutants (O₃, CO, NO₂, SO₂, 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 <u>RUS portal</u> to request a Virtual Machine. Go to Your RUS Service \rightarrow 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 @ <u>https://scihub.copernicus.eu/</u>]
- 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 (<u>www.rus-copernicus.eu</u>) 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 <u>https://rus-copernicus.eu/</u>, click on *Login/Register*, choose *Login* and enter your chosen credentials.

Login / Register	Credentials			-
Login / Register Discrete platform has moved toward the COPERNICUS Single Sign On authentication server. New Users who have not yet registered to the RUS portal shall first create a COPERNICUS SSO account. Note that your Copernicus SSO account will be activated only after the reception of the third email sent by the Copernicus service. We advise you to consult this document and this page to facilitate your registration procedure. REGISTER COPERNICUS SSO account Users who already have a COPERNICUS SSO account can login here: Login	CDS-SSO ID Password Max Idle Time Max Session Time	half a day Until browser close	v v t	000000000000000000000000000000000000000
Close		Forgot your password?		

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** \rightarrow **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.

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The RUS Service The RUS	Offer * The RUS Library * The RUS Community *	Your RUS service 🔻	
		You are here: Home	> Your RUS service > Your training activities
	Your training activities Webinar Training Request You wish to practice a tutorial exercise shown in a RUS webit Please select your choice Select one or more items: CRY003 - Snow Cover Mapping with Sentinel-2 CRY003 - Sea lex Monitoring with Sentinel-1 ATM001 - Air Quality Monitoring with Sentinel-5P ATM002 - Monitoring Pollution with Sentinel-5P ATM004 - Antarctic Ozone Hole Monitoring I have read and agree to the Terms and conditions of RUS	nar? with SentineI-5P 5 Service. Request Webinar Training	

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** \rightarrow **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.

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US_training1		submission	Open	Follow my project Conselver request View history	Get support Get a webinar kit	Close my service Rate my service ★★★★★	Access my Virtual Machine(s) Freeze my Virtual Machine(s)	Access my CPU monitoring dashboard Report a technical incident mentioning confidence

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/

welcome to the cop	ernicus Open Access Hub			Reports & Stats			
The Copernicus Open Access Sentinel-1, Sentinel-2, Senti Sentinel Data are also availa	Hub (previously known as Sentir nel-3 and Sentinel-5P user produc able via the Copernicus Data and I	nels Scientific Data Hub) provides con cts, starting from the In-Orbit Commi nformation Access Services (DIAS) th	uplete, free and open access to ssioning Review (IOCR). rough several platforms .	Data updated ho			
Please visi create scrip and asynch For further details or reques	Please visit our User Guide for getting started with the Data Hub Interface. Discover how to use the APIs and create scripts for automatic search and download of Sentinels' data, with synchronous access to the latest data and asynchronous access to historic data via the API and GUI.						
			A	Reports			
Open Hub	API Hub	S-5P Pre-Ops	POD Hub	DHUS Open Source Portal			
				Opernicus Copernicus Portal			

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.

Copernicus O	pen Access Hub	201
Register n	ew account	
Sentinel data access is free and open to all. On completion of the registration form below you will receive an e-mail with a link to valid Username field accepts only abuncase aphaniment characters plus $T_1 = 2^{-1} \sigma^2 - \alpha \sigma^2_{-1}$. Password fields retilintum length is 8 characters	ite your e-mail address. Following this you can start to download the data or γ_{c} or c_{c} , we say that c_{c} , c_{c}	
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Ernal	Cotilium E-mail	
Select Domain		
Select Usage		
Belied your country	to have accepted the TAC for Sentinel data use.	

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 1^{st} October 2020. Open the search menu by clicking to the left part of the search bar (\blacksquare) and specify the parameters below. Press the search button (\square) after that.

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

Check mission: Sentinel-5P

Product type: L2__03___

Processing level: L2

Timeliness: Offline

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Insert search oriteria		B Q		and Tobago Colombia	Nigeria Ethiopia	Haldives	Malaysia
Advanced Search		Clear		Peru Brazil Bolivia	Republic of the Congo		0
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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 2 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 <u>UniData website</u>.

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 \rightarrow Accessories and hit **Xfce Terminal**.

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

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File	Edit	View	Terminal	Tabs	Help				
(bas	ie) r	us@fi	ront:~\$	jupy'	ter lab				11

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: <u>https://www.anaconda.com/distribution/</u>

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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