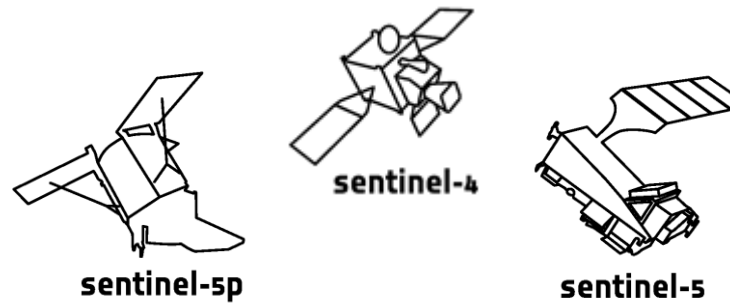


# EXPLORING THE ATMOSPHERE COMPOSITION WITH INNOVATIVE ONLINE DATA ANALYSIS SERVICES INTEGRATING NOVEL LEVEL-3 PRODUCTS FROM COPERNICUS SENTINEL MISSION

Julian Meyer-Arnek, Torsten Heinen, André Twele, Jonas Müller, Stephan Kiemle

EUMETSAT Conference 2023





**Copernicus Satellite**



**Data**

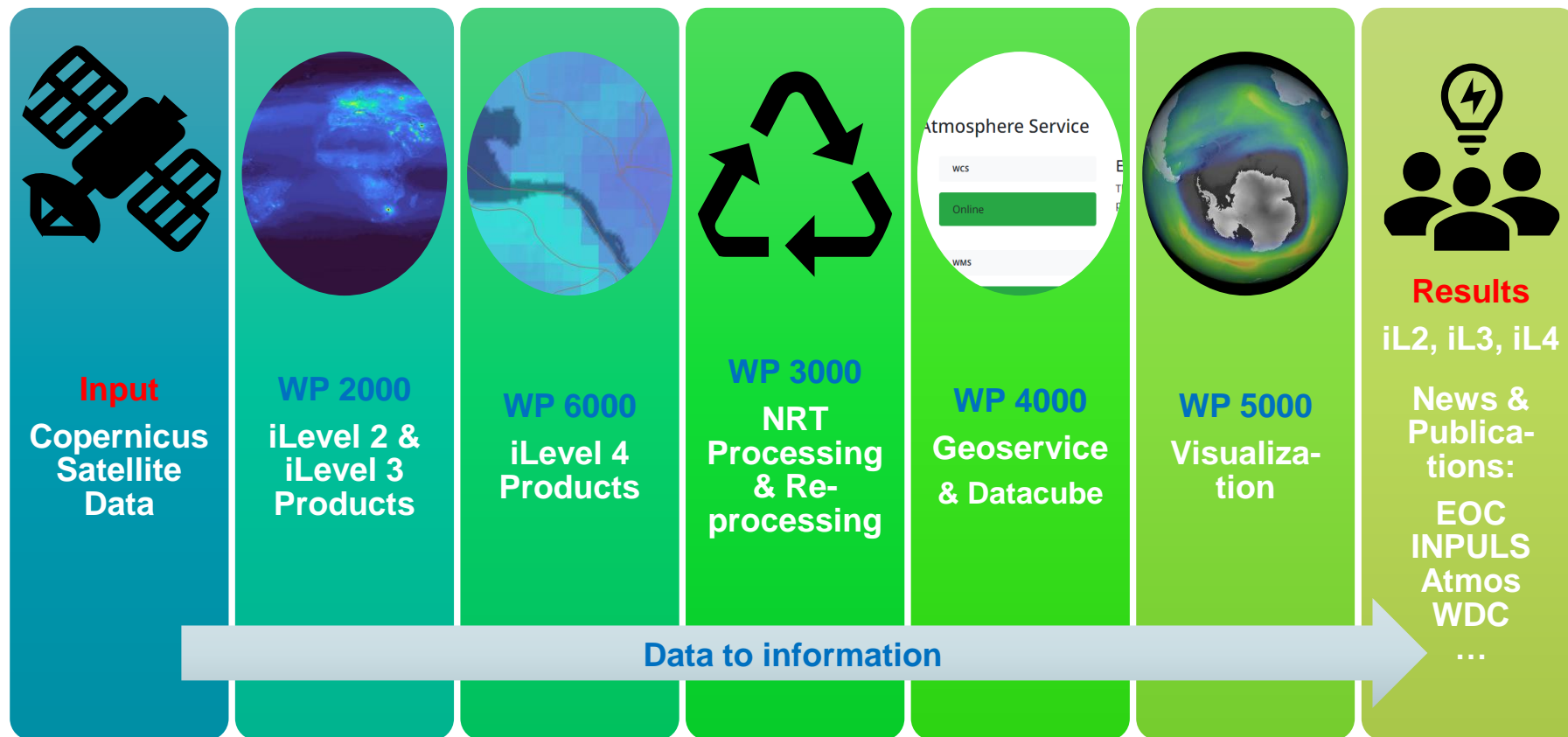


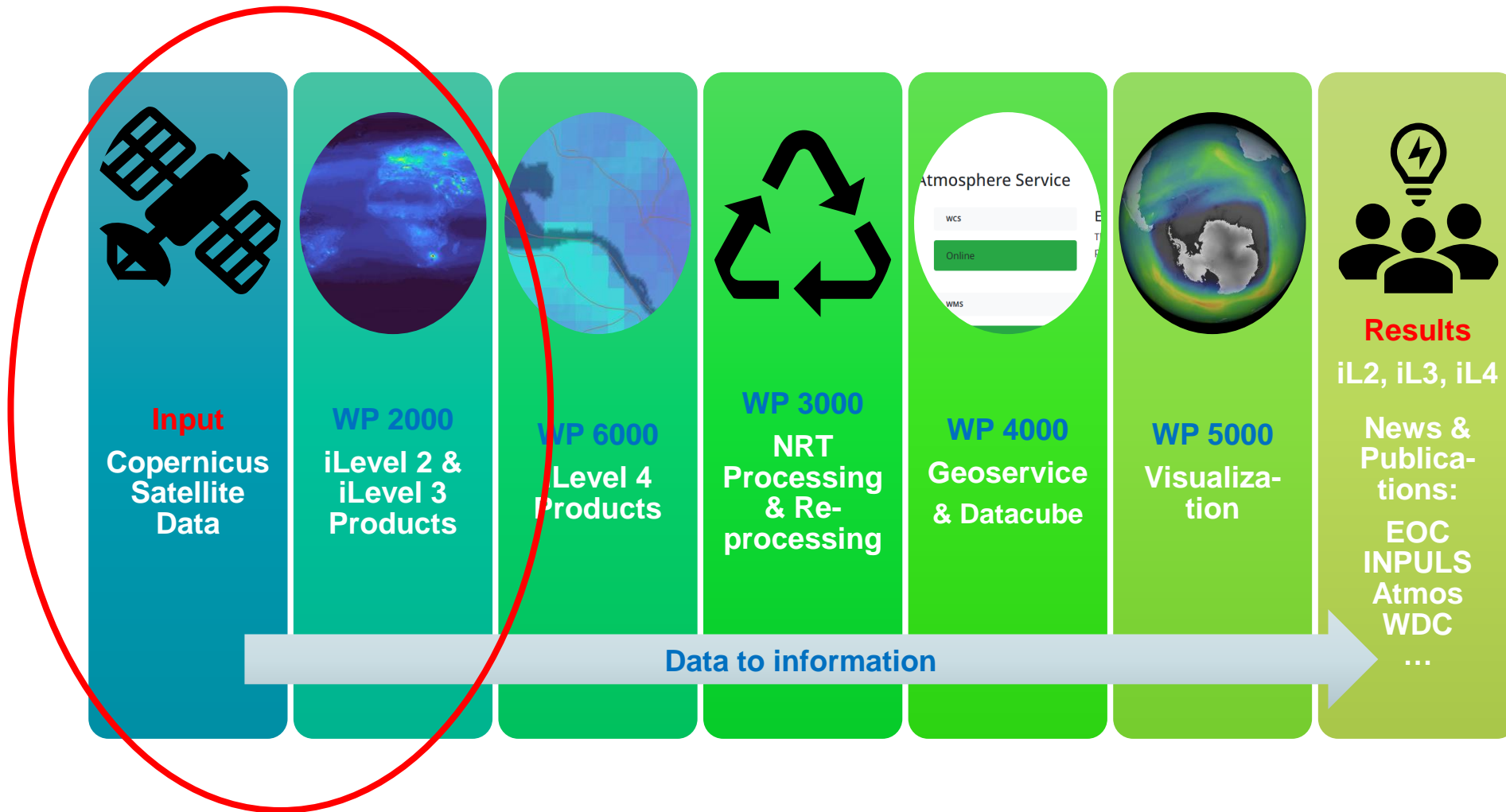
**Atmospheric Composition**



**Information (ARD)**

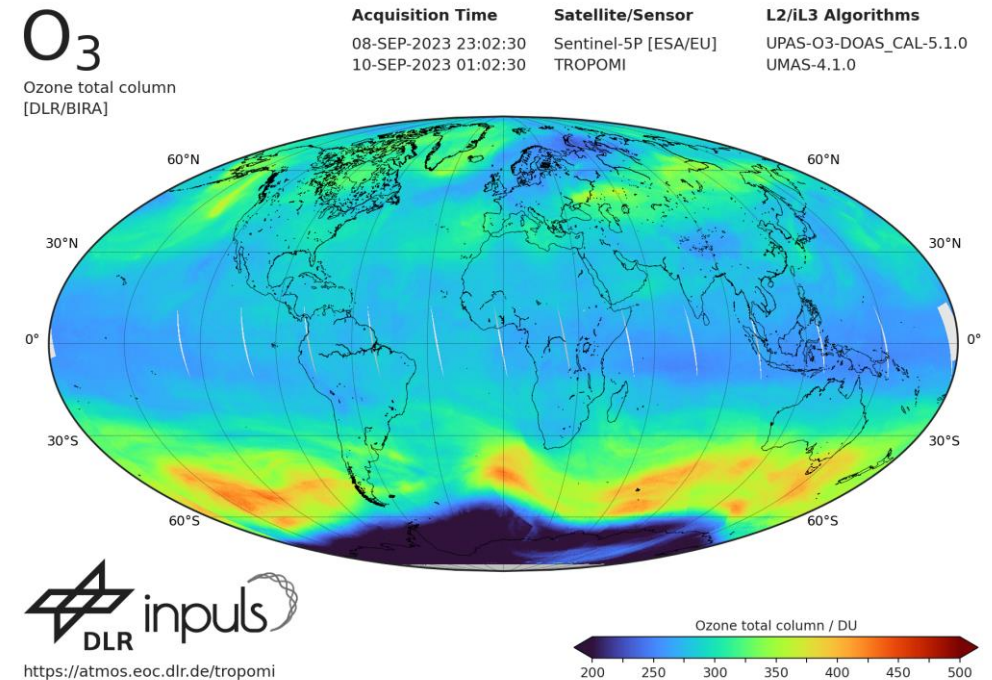
- Goal of the DLR-"inpuls"-project is to provide **user-friendly information about the state of our atmosphere** based on Copernicus missions.





# Focusing L3: UMAS (Universal Mapper for Atmospheric Spectrometers)

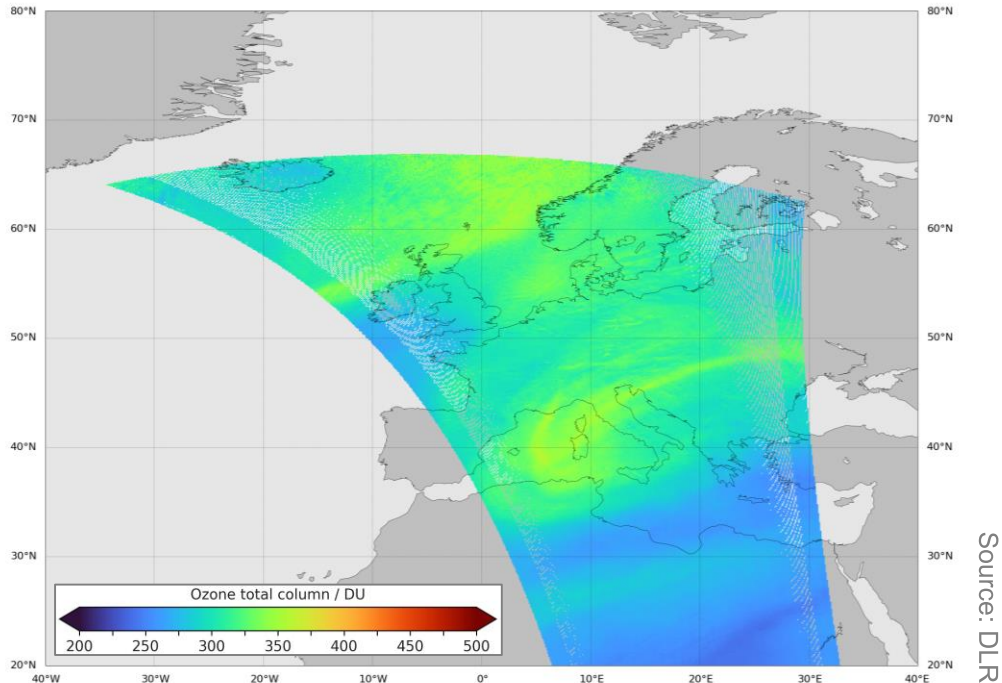
- UMAS generates Level 3 datasets from Level 2 input datasets
  - Level 2 dataset ingestion using a equirectangular projection regridding
  - Level 2 metadata aggregation
  - Level 3 statistics (number of observations, quality flags, standard deviation)
- UMAS also generates quicklooks for the Level 2 input datasets



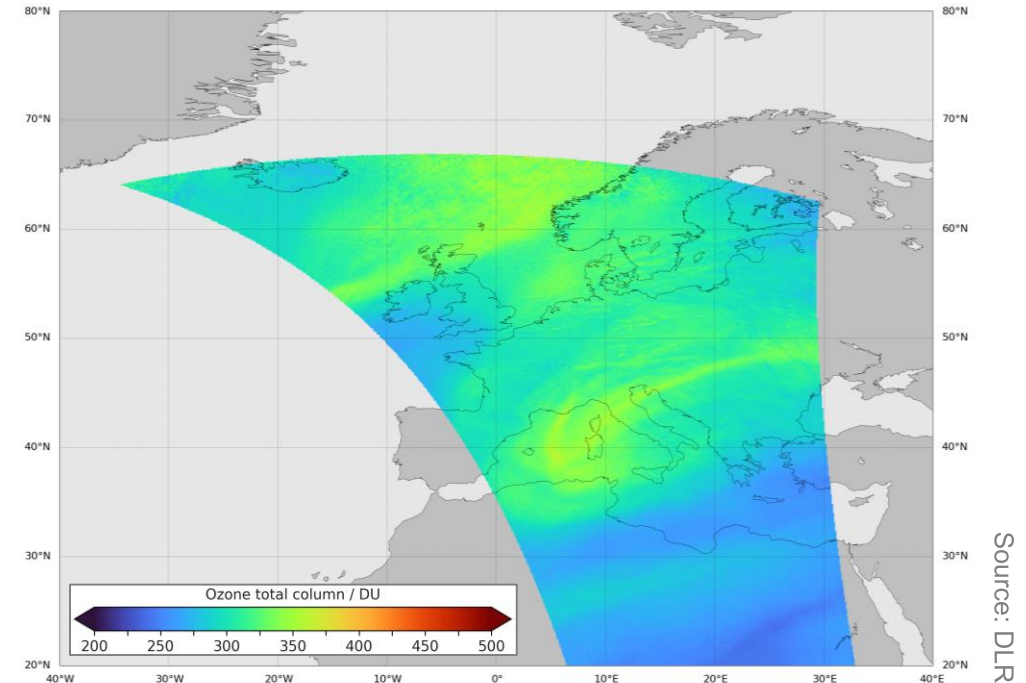
- The UMAS regridding reduces Level 2 measurements whose coordinate centers fall into the same equirectangular map cell using a mean kernel.
- Empty cells are filled with the neighbourhood if they belong to the dataset footprint.

# UMAS (Universal Mapper for Atmospheric Spectrometers)

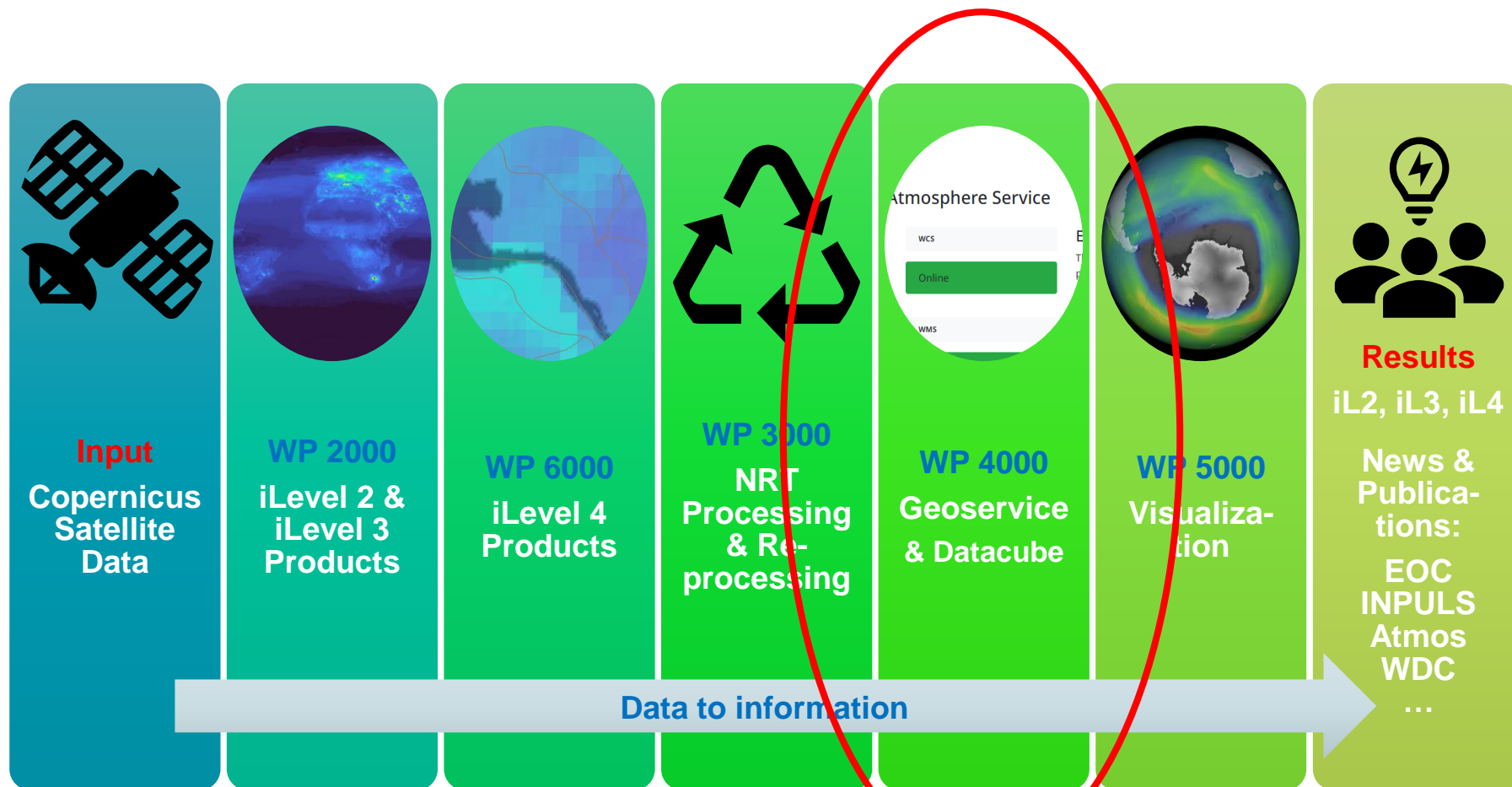
Step 1: data regridding



Step 2: cell filling

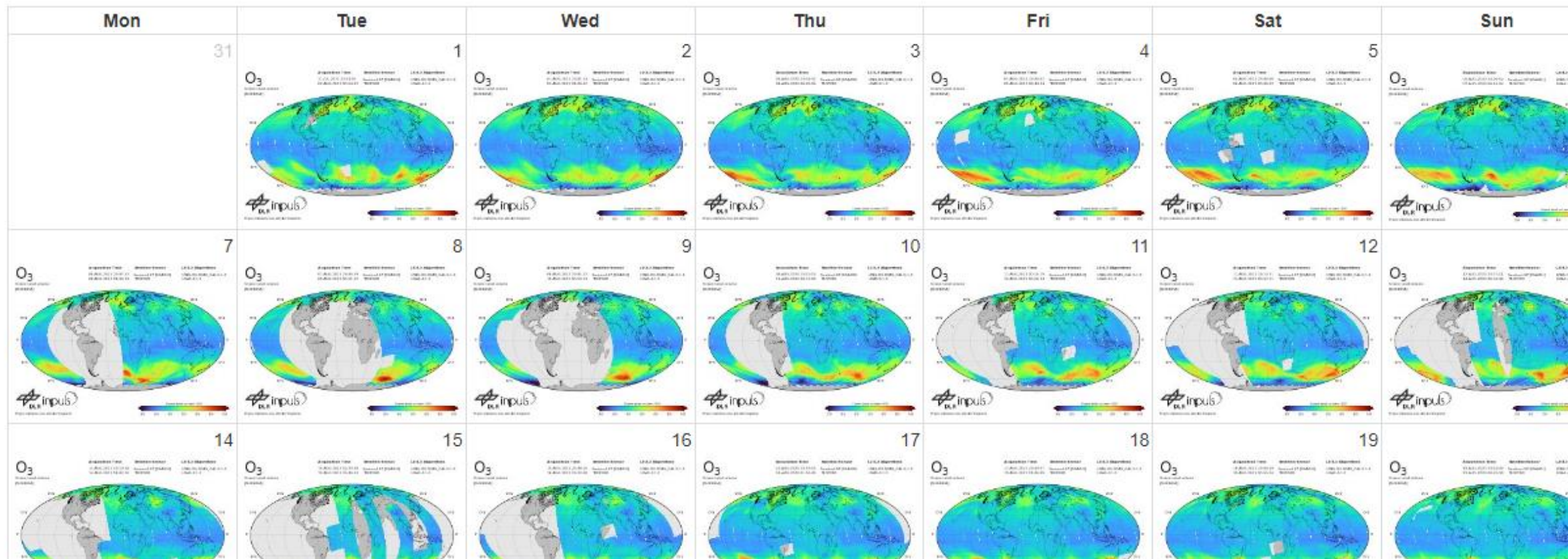


- The UMAS regridded reduces Level 2 measurements whose coordinate centers fall into the same equirectangular map cell using a mean kernel.
- Empty cells are filled with the neighbourhood if they belong to the dataset footprint.



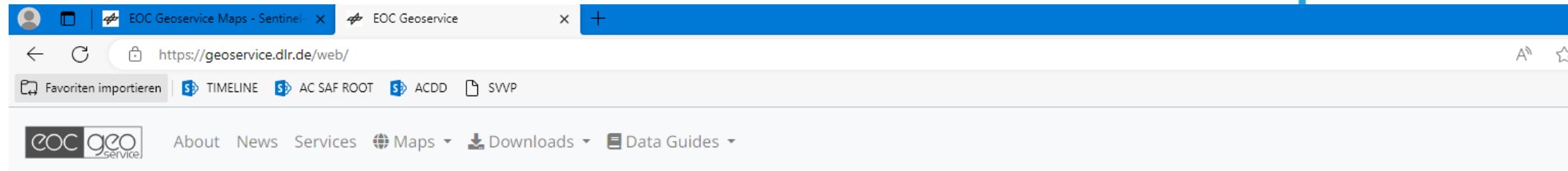
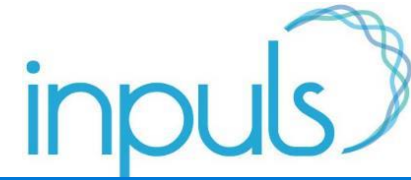
# Calendar

⏪
⏴
August
2023
⏵
⏩
TROPOMI / S5P
Ozone





# Data Access and Interactive Exploration

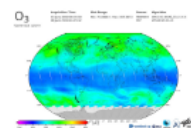


## Welcome to the EOC Geoservice

The EOC Geoservice of the Earth Observation Center (EOC) of the German Aerospace Center (DLR) provides discovery, visualization, and direct download services for a selection of the geospatial data hosted by the German Satellite Data Archive (D-SDA). Based on web technologies and running on high-performance hardware large geospatial datasets can be accessed through the EOC Geoservice. To find out more, see the [About](#) page or take a look at the [Geoservice Flyer](#).

[Browse Maps](#)[Check Services](#)[Contact us](#)[Read News](#)

## Latest News and Announcement



### Sentinel-5P TROPOMI L3 Daily Composites - Processor update and STAC

Posted on Sep 6, 2023 by Administrator

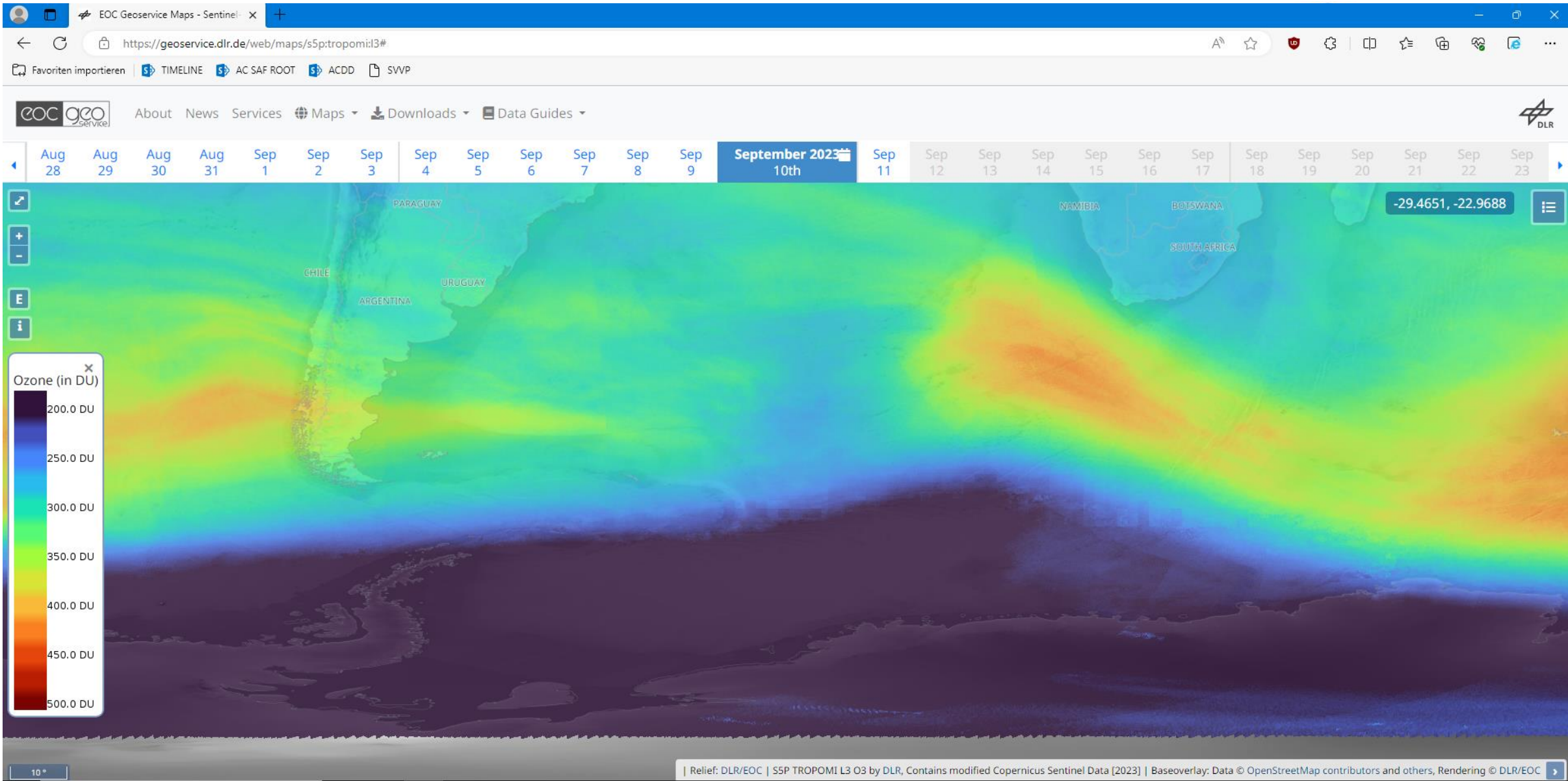
Since August 1, 2023, the Sentinel-5P L3 datasets are being generated with the new UMAS: 4.1.0 processor. These products are being published via our STAC Catalog endpoint [\[9\]](#). At current (06.09.2023) these atmospheric trace gases and cloud

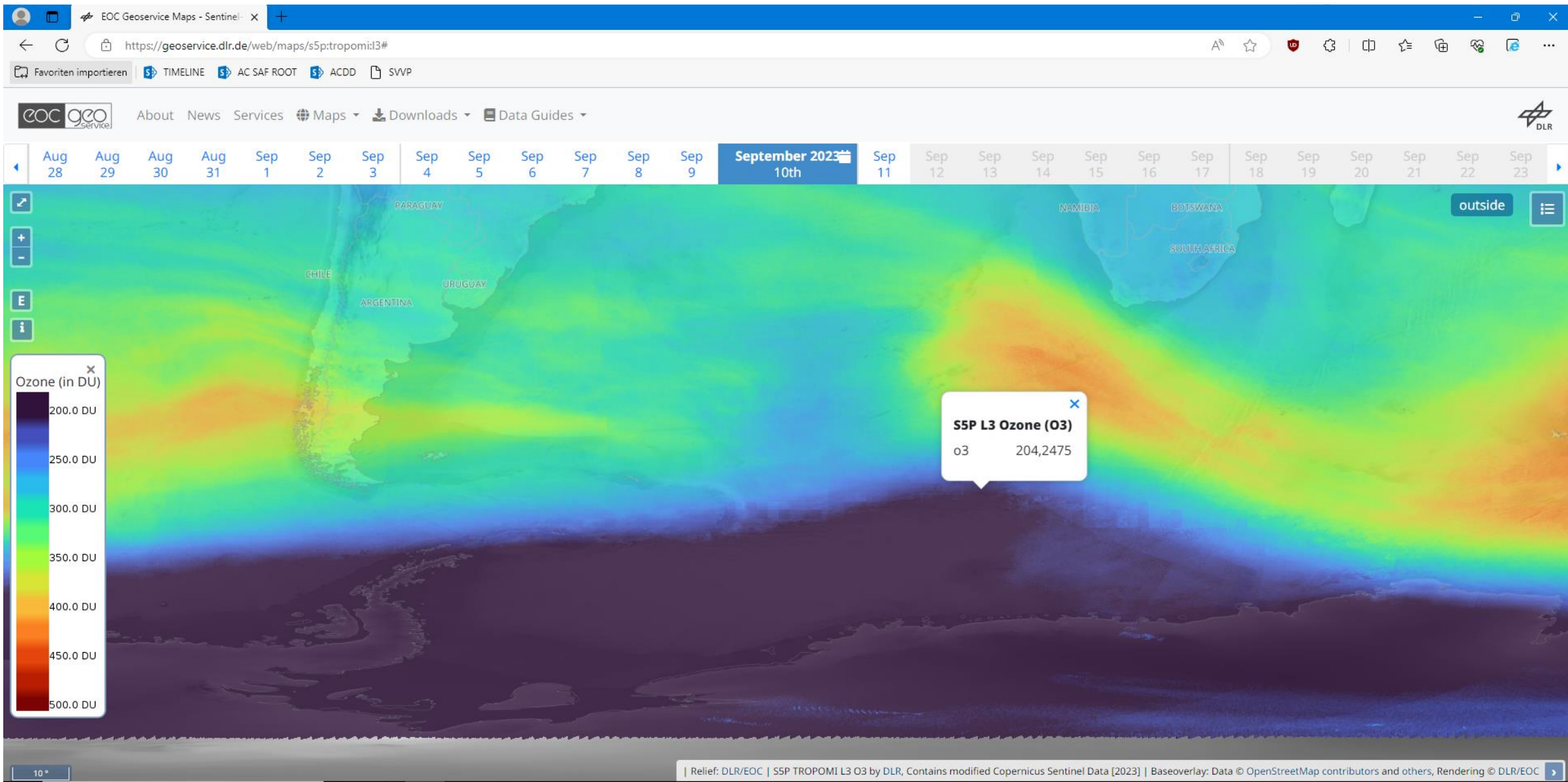
### Related Links

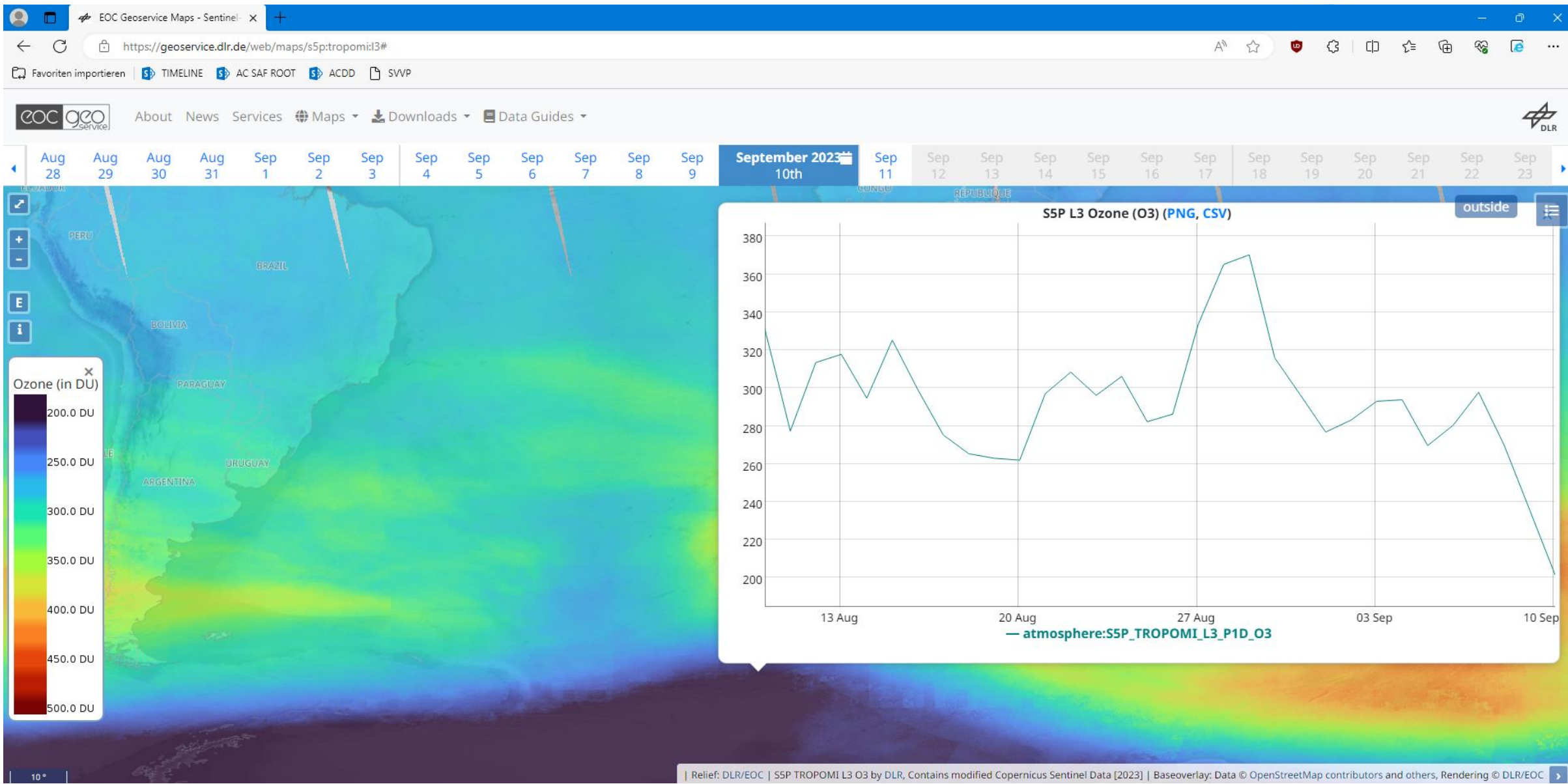
[\[1\] EOC STAC Catalog - SSP L3 Cloud Fraction](#)

[\[2\] EOC STAC Catalog - SSP L3 Cloud Optical Thickness](#)

[\[3\] EOC STAC Catalog - SSP L3 Cloud Top Height](#)







# STAC Collections

This document lists all the collections available in the SpatioTemporal

## Sentinel-5P - Daily Ozone

O<sub>3</sub>

Ozone total volume  
(DU/KM<sup>2</sup>)

Acquisition Time

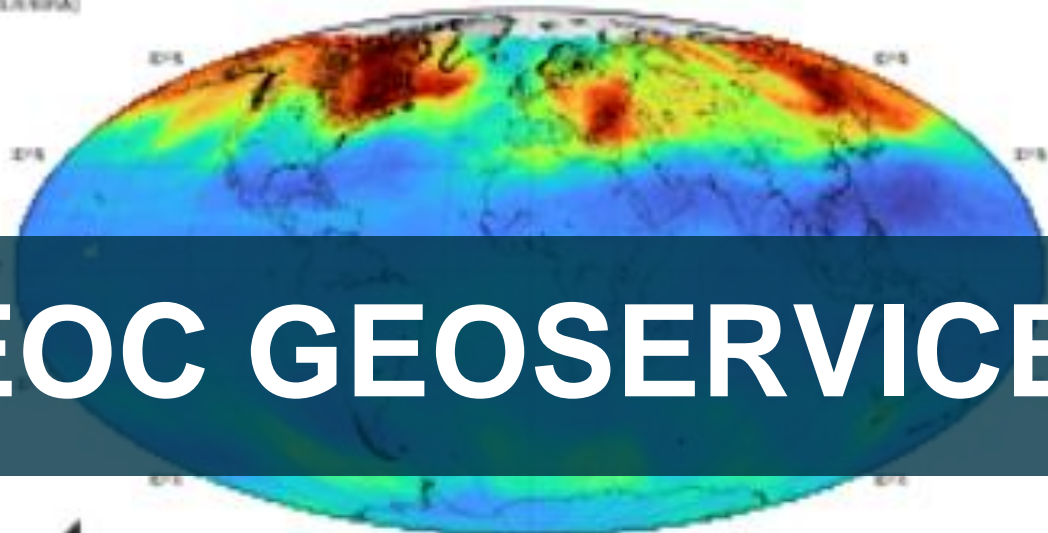
02.FEB.2023 23:00:00  
02.FEB.2023 00:20:12

Satellite/Sensor

Sentinel-5P (TROPOMI)  
TROPOMI

L2/L3 Algorithms

LPMS\_O3\_DIAS\_CAL\_V1.0  
LPMS\_V1.2.1



**DATA CUBE AT EOC GEOSERVICE**

# STAC Metadata for Simplified Discovery and Access

## How does it work?

- Start at <https://geoservice.dlr.de/eoc/ogc/stac/>.

A screenshot of a web browser displaying the landing page for the EOC EO Products Service. The browser's address bar shows the URL https://geoservice.dlr.de/eoc/ogc/stac/. The page features the EOC geo service logo, a search format dropdown menu, and a main heading "EOC EO Products Service". Below the heading, there is a paragraph of introductory text and four service cards: "API definition", "Search", "Queryables", and "Collections".

Home

## EOC EO Products Service

\*BETA\* Provides interoperable access to metadata from EO collections and products of DLR's Earth Observation Center (EOC). \*BETA\*

This is the landing page of the SpatioTemporal Asset Catalog 1.0.0 service, providing links to the service API and its contents.

### API definition

The [API document](#) provides a machine processable description of this service API conformant to OpenAPI 3. This API document is also available as [application/vnd.oai.openapi+json;version=3.0](#), [application/x-yaml](#), [text/html](#).

### Search

The [search page](#) provides a searchable list of all the STAC items available in this service.

### Queryables

The [Queryables](#) page list all properties that can

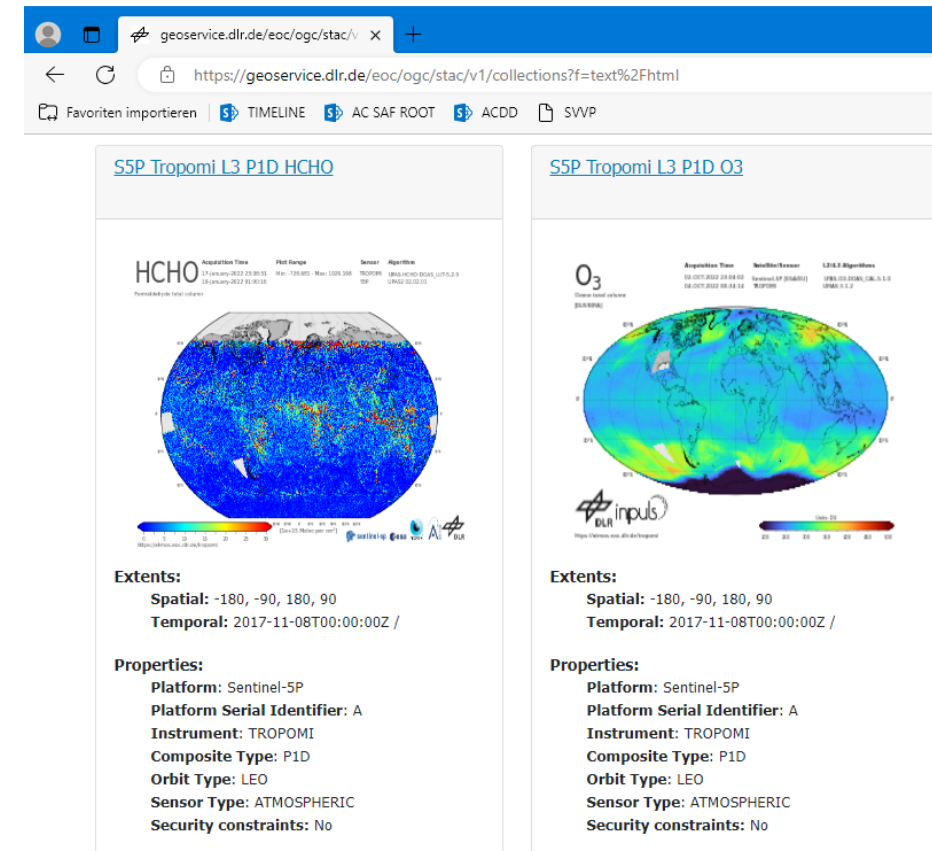
### Collections

The [collection page](#) provides a list of all the

# STAC Metadata for Simplified Discovery and Access

How does it work? → Visually explore analysis data.

- Start at <https://geoservice.dlr.de/eoc/ogc/stac/>.
- „Collections“ → „S5P Tropomi O3“



# STAC Metadata for Simplified Discovery and Access

How does it work? → Visually explore analysis data.

- Start at <https://geoservice.dlr.de/eoc/ogc/stac/>.
- „Collections“ → „S5P Tropomi O3“
- „Items“ → „Item“ (specific day)



A screenshot of a web browser displaying the STAC metadata page for 'S5P Tropomi L3 P1D O3'. The browser address bar shows the URL 'https://geoservice.dlr.de/eoc/ogc/stac/v1/collections/S5P\_TROPOMI\_L3\_P1D\_03'. The page header includes the 'eoc geo service' logo and navigation links. The main content area shows the collection name 'S5P Tropomi L3 P1D O3' with a selected 'items' tab. Below this, there are buttons for 'Parent', 'Collection', 'Items', and 'Queryable', each with 'html' and 'json' options. There are also 'OpenSearch' buttons for 'geojson', 'atom/xml', and 'ISO 19139'. The 'Properties' section lists metadata such as Name, Title, Description, License (CC-BY-4.0), Platform (Sentinel-5P), Instrument (TROPOMI), and Sensor Type (ATMOSPHERIC). The 'Assets' section includes links for 'Thumbnail', 'Overview', and 'Map Preview'. On the right side, there is a thumbnail map of the Earth showing ozone concentration data, with a color scale ranging from 0 to 400 DU. The map is titled 'O3' and includes technical details like 'Acquisition Time', 'Sensor/Processor', and 'L2/L3 Algorithm'.



# STAC Metadata Discovery and

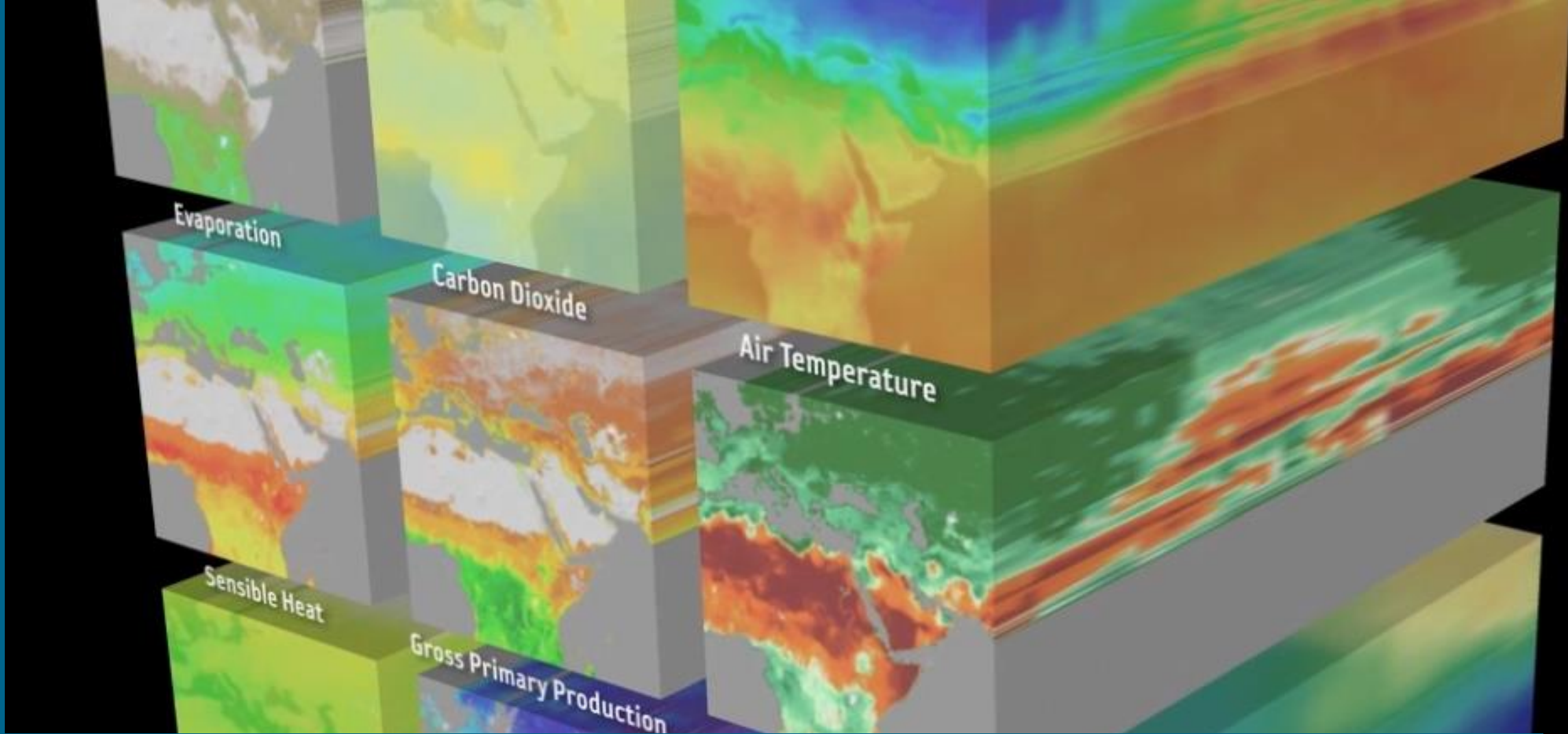
## How does it work

- Start at [https://geoservice.dlr.de/eoc/ogc/stac/v1/collections/S5P\\_TROPOMI\\_L3\\_P1D\\_03](https://geoservice.dlr.de/eoc/ogc/stac/v1/collections/S5P_TROPOMI_L3_P1D_03)
- „Collections“ → „Items“
- „Items“ → „Items“
- Chose the assets

The screenshot shows a web browser window with the URL [https://geoservice.dlr.de/eoc/ogc/stac/v1/collections/S5P\\_TROPOMI\\_L3\\_P1D\\_03](https://geoservice.dlr.de/eoc/ogc/stac/v1/collections/S5P_TROPOMI_L3_P1D_03). The page displays the following information:

- Composite Type:** P1D
- Sensor Type:** ATMOSPHERIC
- Extents:**
  - Spatial:** -180, -90, 180, 90
  - Temporal:** 2023-09-09T00:00:00Z / none
- Properties:**
  - Parent Identifier:** [S5P\\_TROPOMI\\_L3\\_P1D\\_03](#)
  - Crs:** [4326](#)
  - Created:** Sep 9, 2023, 4:00:49 AM
  - Updated:** Sep 10, 2023, 6:00:52 AM
  - Processing Center:** Remote Sensing Technology Institute (IMF)
  - Processing Level:** L3
  - Processor Name:** UMAS
  - Processor Version:** 4.1.0
  - Constellation:** Sentinel-5P
  - Instruments:** TROPOMI
  - License:** CC-BY 4.0
  - Platform:** Sentinel 5 Precursor
  - [PROCESSING] Facility:** Remote Sensing Technology Institute (IMF)
- Assets:**
  - Metadata (metadata, data)
  - Overview (overview)
  - O3 (data)
  - Thumbnail (thumbnail)
  - Quicklook (quicklook)

The page also features a world map and a footprint map showing the spatial extent of the collection. A color scale for the footprint map ranges from 0 to 100. The DLR inputs logo is visible in the bottom right corner of the footprint map.



# PROGRAMMATIC DATA ACCESS

intranet.dlr.de | Projekte - Canva | UV-Bodyguard 300x2 | 2023-06-27\_EUSPA\_Pr | EOC Geoservice Maps | My Interactive Sessio | ozone\_hole\_v... (2) - | Google Translate

https://portal.terrabyte.lrz.de/node/hpdar03c02s02.cos.lrz.de/20511/lab/tree/Projekte/impuls-s5p-ozone-hole-size/ozone\_hole\_v02.ipynb

File Edit View Run Kernel Tabs Settings Help

Filter files by name

/ Projekte / impuls-s5p-ozone-hole-size /

Name	Last Modified
20230209_INPULS_WP4000_v003.p...	13 days ago
20230223_INPULS_WP4000_v001.p...	13 days ago
ozone_column_density.ipynb	13 days ago
ozone_hole_edited.ipynb	13 days ago
ozone_hole_v02.html	13 days ago
ozone_hole_v02.ipynb	10 seconds ago
ozone_hole.ipynb	13 days ago
README.md	13 days ago

Launcher | test\_openeo.ipynb | Launcher | ozone\_hole\_v02.ipynb

Python 3 (ipykernel)

### Now let's connect to the STAC catalog

Import library and connect to the EOC STAC catalog service.  
This is just a "connect", no data is going to be downloaded.

```
[3]: from pystac_client import Client
```

```
[4]: catalog = Client.open(
      url="https://geoservice.dlr.de/eoc/ogc/stac/"
    )
```

### Let's discover datasets

Data discovery is performed according to our settings

```
[5]: %%time

stac_items = catalog.search(
    collections=collections,
    datetime=dates_from_to,
    method="GET",
    filter_lang="cql2-text",
    max_items=1000
).item_collection()

CPU times: user 14.9 ms, sys: 1.29 ms, total: 16.2 ms
Wall time: 1 s
```

```
[6]: stac_items
```

# PROGRAMMATIC DATA ACCESS: pystac

Filter files by name

/ Projekte / inpuls-s5p-ozone-hole-size /

Name	Last Modified
20230209_INPULS_WP4000_v003.p...	13 days ago
20230223_INPULS_WP4000_v001.p...	13 days ago
ozone_column_density.ipynb	13 days ago
ozone_hole_edited.ipynb	13 days ago
ozone_hole_v02.html	13 days ago
ozone_hole_v02.ipynb	10 seconds ago
ozone_hole.ipynb	13 days ago
README.md	13 days ago

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    method="GET",
    filter_lang="cql2-text",
    max_items=1000
).item_collection()

CPU times: user 14.9 ms, sys: 1.29 ms, total: 16.2 ms
Wall time: 1 s
```

```
[6]: stac_items
```

```
[6]: type "FeatureCollection"
      features [] 30 items
```

--> Now we identified the relevant datasets which we need for our research.

## Load the data to local storage

Now the data of the identified data sets is going to be downloaded to the local client. You can concentrate on your work. All ugly work such as

intranet.dlr.de | Projekte - Canva | UV-Bodyguard 300x2 | 2023-06-27\_EUSPA\_Pr | EOC Geoservice Map | My Interactive Sessio | ozone\_hole\_v... (2) | Google Translate

https://portal.terrabYTE.lrz.de/node/hpdar03c02s02.cos.lrz.de/20511/lab/tree/Projekte/inpuls-s5p-ozone-hole-size/ozone\_hole\_v02.ipynb

File Edit View Run Kernel Tabs Settings Help

Filter files by name

/ Projekte / inpuls-s5p-ozone-hole-size /

Name	Last Modified
20230209_INPULS_WP4000_v003.p...	13 days ago
20230223_INPULS_WP4000_v001.p...	13 days ago
ozone_column_density.ipynb	13 days ago
ozone_hole_edited.ipynb	13 days ago
ozone_hole_v02.html	13 days ago
ozone_hole_v02.ipynb	1 minute ago
ozone_hole.ipynb	13 days ago
README.md	13 days ago

Launcher | test\_openeo.ipynb | Launcher | ozone\_hole\_v02.ipynb

Python 3 (ipykernel)

## Load the data to local storage

Now the data of the identified data sets is going to be downloaded to the local client. You can concentrate on your work. All ugly work such as

- re-projection or
- area-slicing

is done on the server.

```
[7]: from odc.stac import stac_load
import xarray as xr
```

```
[9]: %%time

ozone_column = stac_load(
    stac_items,
    bands=["o3"],
    crs="EPSG:4326",
    resolution=resolution,
    lon=(bbox[0], bbox[2]),
    lat=(bbox[1], bbox[3]),)

print ("Data is extracted on the server and downloaded to local storage.")

Data is extracted on the server and downloaded to local storage.
CPU times: user 3.71 s, sys: 448 ms, total: 4.15 s
Wall time: 8min 42s
```

```
[10]: ozone_column
```

```
[10]: xarray.Dataset
```

► Dimensions: (latitude: 667, longitude: 4000, time: 30)

▼ Coordinates:

latitude	(latitude)	float64	-30.02 -30.11 ... -89.86 -89.95
longitude	(longitude)	float64	-180.0 -179.9 ... 179.9 180.0
spatial_ref	()	int32	4326
time	(time)	datetime64[ns]	2023-08-01T12:00:00 ... 2023-08-...

Simple 0 2 Python 3 (ipykernel) | Idle Mem: 476.17 MB Mode: Command Ln 1, Col 1 ozone\_hole\_v02.ipynb

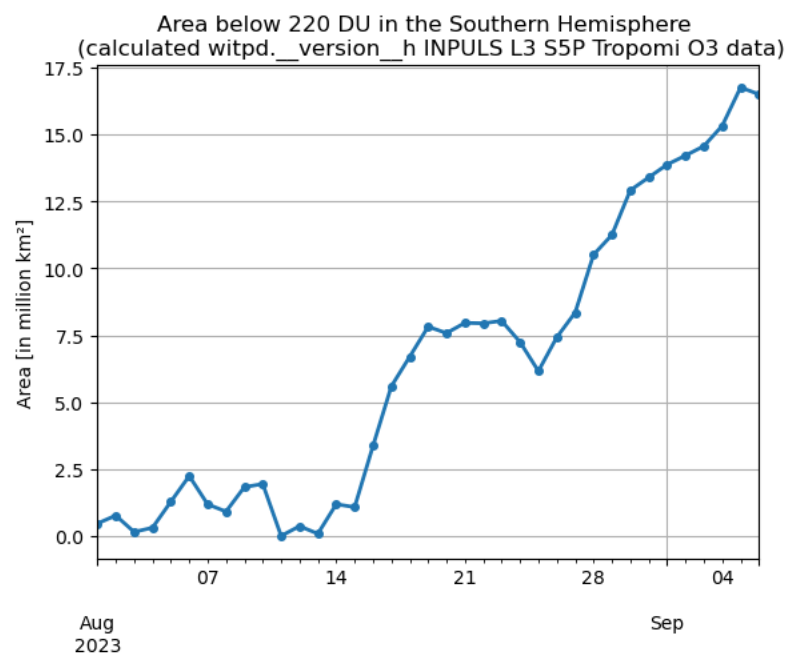
Filter files by name

/ Projekte / inpuls-s5p-ozone-hole-size /

Name	Last Modified
20230209_INPULS_WP4000_v003.p...	13 days ago
20230223_INPULS_WP4000_v001.p...	13 days ago
ozone_column_density.ipynb	13 days ago
ozone_hole_edited.ipynb	13 days ago
ozone_hole_v02.html	13 days ago
ozone_hole_v02.ipynb	1 minute ago
ozone_hole.ipynb	13 days ago
README.md	13 days ago

```
[13]: import matplotlib.pyplot as plt

df_ozone_hole.plot(
    x='datetime',
    y='size_ozone_hole',
    legend=None,
    kind='line', marker='o', markersize = 4, lw = 2,
    title = "Area below 220 DU in the Southern Hemisphere \n (calculated witpd.__version__h INPULS L3 S5P Tropomi O3 data)")
plt.xlabel('')
plt.ylabel('Area [in million km²]')
plt.grid()
plt.show()
```



```
[16]: pd.__version__
[16]: '2.0.3'
```

The screenshot displays a JupyterLab environment with the following components:

- Browser:** The address bar shows the URL `https://portal.terrabyte.lrz.de/node/hpdar03c02s02.cos.lrz.de/20511/lab/tree/Projekte/inputs-s5p-openEO/test_openeo.ipynb`.
- File Browser:** Located on the left, it shows a directory structure under `/ Projekte / inputs-s5p-ozone-hole-size /`. The file `ozone_hole_v02.ipynb` is selected, with a last modified time of 10 minutes ago.
- Code Editor:** The main area contains Python code for loading and processing data:

```
[4]: local_conn = LocalConnection("./")
[5]: stac_url = "https://geoservice.dlr.de/eoc/ogc/stac/v1/"
    url = stac_url + "collections/S5P_TROPOMI_L3_P1D_03/"
    spatial_extent = {"east": 180.0, "south": -90.0, "west": -180.0, "north": 90.0}
[6]: s5p_datacube = local_conn.load_stac(
    url=url,
    spatial_extent=spatial_extent,
    temporal_extent=["2023-08-01", "2023-08-15"],
    bands=["o3"]
)
[8]: task_reduce_time = s5p_datacube.reduce_dimension('time', reducer='mean')
[9]: task_reduce_lon = task_reduce_time.reduce_dimension('x', reducer='mean')
[10]: task_reduce_lon
```
- Variable Inspector:** At the bottom, it shows three variables: `load_stac #loadstac1`, `reduce_dimension #reducedimension1`, and `reduce_dimension #reducedimension2`. The first variable has attributes `bands: o3`, `spatial_extent: Bounding Box`, and `temporal_extent: 2023-08-01, 2023-08-15`. The second and third variables have `dimension: time` and `dimension: x` respectively, and both have `reducer: mean`.

# PROGRAMMATIC DATA ACCESS: openEO

Browser tabs: intranet.dlr.de, Projekte - Canva, UV-Bodyguard 300x2, 2023-06-27\_EUSPA\_P, EOC Geoservice Map, My Interactive Sessio, test\_openeo.... (2), Google Translate

URL: [https://portal.terrabite.lrz.de/node/hpdar03c02s02.cos.lrz.de/20511/lab/tree/Projekte/inputs-s5p-ozone-hole-size/test\\_openeo.ipynb](https://portal.terrabite.lrz.de/node/hpdar03c02s02.cos.lrz.de/20511/lab/tree/Projekte/inputs-s5p-ozone-hole-size/test_openeo.ipynb)

File Edit View Run Kernel Tabs Settings Help

Filter files by name

/ Projekte / inputs-s5p-ozone-hole-size /

Name	Last Modified
20230209_INPULS_WP4000_v003.p...	13 days ago
20230223_INPULS_WP4000_v001.p...	13 days ago
ozone_column_density.ipynb	13 days ago
ozone_hole_edited.ipynb	13 days ago
ozone_hole_v02.html	13 days ago
ozone_hole_v02.ipynb	10 minutes ago
ozone_hole.ipynb	13 days ago
README.md	13 days ago

Launcher test\_openeo.ipynb Launcher ozone\_hole\_v02.ipynb

Python 3 (ipykernel)

```
[4]: local_conn = LocalConnection("./")
[5]: stac_url = "https://geoservice.dlr.de/eoc/ogc/stac/v1/"
url = stac_url + "collections/S5P_TROPOMI_L3_P1D_03/"
spatial_extent = {"east": 180.0, "south": -90.0, "west": -180.0, "north": 90.0}
[6]: s5p_datacube = local_conn.load_stac(
url=url,
spatial_extent=spatial_extent,
temporal_extent=["2023-08-01", "2023-08-15"],
bands=["o3"]
)
[8]: task_reduce_time = s5p_datacube.reduce_dimension('time', reducer='mean')
[9]: task_reduce_lon = task_reduce_time.reduce_dimension('x', reducer='mean')
[10]: task_reduce_lon
[10]:
```

Zoom with STRG or Meta key and the mouse wheel.

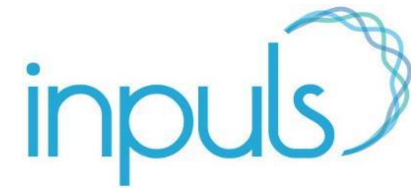
```

graph LR
    A["load_stac #loadstac1  
bands: o3  
spatial_extent: Bounding Box  
temporal_extent: 2023-08-01, 2023-08-15  
url: https://geoservice.dlr.de/eoc/ogc/s..."] -- data --> B["reduce_dimension #reducedimension1  
dimension: time  
reducer: mean"]
    B -- data --> C["reduce_dimension #reducedimension2  
dimension: x  
reducer: mean  
Result"]
  
```

Simple 0 2 Python 3 (ipykernel) | Idle Mem: 1.46 GB Mode: Command Ln 1, Col 73 test\_openeo.ipynb 1



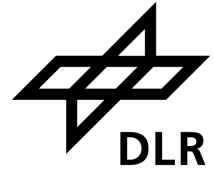
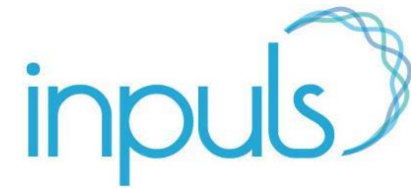
# Ingestion Process at DLR/DFD



- Extract information from NetCDF files automatically:
  - Flexible:  
Extract specified information from NetCDF attributes to create STAC for a multitude of different data products. Extraction tool can target NetCDF attributes in the source file, apply regular expressions to them or put a fixed string to STAC metadata.
  - Configurable:  
Tool can be adjusted to any specific dataset.

```
act.py  S5P_TROPOMI_L3.csv x
ngs > S5P_TROPOMI_L3.csv
|metadata;file;S5P_TROPOMI_L3;datatype
id;*.nc;filename;String
collection;static;S5P_L3_03;String
properties/version;static;Version 1.0;String
properties/created;*.nc;history:([\^\.]+);DateTime
properties/updated;*.nc;history:([\^\.]+);DateTime
properties/datetime;*.nc;time_coverage_start;DateTime
properties/start_datetime;*.nc;time_coverage_start;DateTime
properties/end_datetime;*.nc;time_coverage_end;DateTime
properties/platform;static;Sentinel-5P;String
properties/instrument;static;TROPOMI;String
properties/constellation;static;Sentinel-5P;String
properties/license;static;CC-BY 4.0;String
properties/proj;epsg;static;4326;Int
properties/sat:orbit_state;static;ASCENDING;String
properties/processing:facility;static;OP;String
properties/processing:level;static;L3;String
properties/s5p:resolution;static;7 x 3.5 km2 (original L2 resolution);S
properties/s5p:datasource;static;S5P TROPOMI L2 data;String
providers/name;*.nc;institution;String
providers/description;*.nc;creator_name;String
providers/roles;static;producer;String
providers/url;*.nc;creator_url;String
bbox/0;*.nc;geospatial_lon_min;Double
bbox/1;*.nc;geospatial_lon_max;Double
bbox/2;*.nc;geospatial_lat_min;Double
bbox/3;*.nc;geospatial_lat_max;Double
```

# Ingestion Process at DLR/DFD

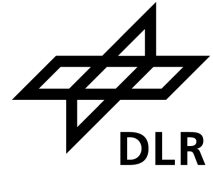
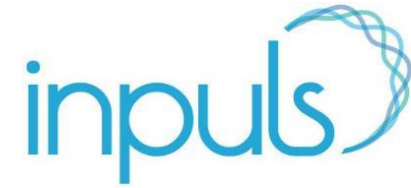


- Extract information from NetCDF files automatically:
  - Flexible:  
Extract specified information from NetCDF attributes to create STAC for a multitude of different data products. Extraction tool can target NetCDF attributes in the source file, apply regular expressions to them or put a fixed string to STAC metadata.
  - Configurable:  
Tool can be adjusted to any specific dataset.

```
act.py  S5P_TROPOMI_L3.csv x
ngs > S5P_TROPOMI_L3.csv
|metadata;file;S5P_TROPOMI_L3;datatype
id;*.nc;filename;String
collection;static;S5P_L3_03;String
properties/version;static;Version 1.0;String
properties/created;*.nc;history:([\^\.]+);DateTime
properties/updated;*.nc;history:([\^\.]+);DateTime
properties/datetime;*.nc;time_coverage_start;DateTime
properties/start_datetime;*.nc;time_coverage_start;DateTime
properties/end_datetime;*.nc;time_coverage_end;DateTime
properties/platform;static;Sentinel-5P;String
properties/instrument;static;TROPOMI;String
properties/constellation;static;Sentinel-5P;String
properties/license;static;CC-BY 4.0;String
properties/proj;epsg;static;4326;Int
properties/sat:orbit_state;static;ASCENDING;String
properties/processing:facility;static;OP;String
properties/processing:level;static;L3;String
properties/s5p:resolution;static;7 x 3.5 km2 (original L2 resolution);S
properties/s5p:datasource;static;S5P TROPOMI L2 data;String
providers/name;*.nc;institution;String
providers/description;*.nc;creator_name;String
providers/roles;static;producer;String
providers/url;*.nc;creator_url;String
bbox/0;*.nc;geospatial_lon_min;Double
bbox/3;*.nc;geospatial_lat_max;Double
```

EO MetadataExtract is available on GitHub.

# EOC Geoservice: Long lasting evolution



- Started in EVO-ODAS (2015-2018) as „EO-enriched geospatial index“



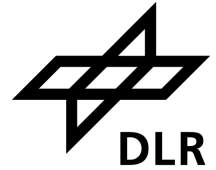
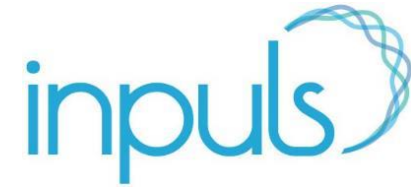
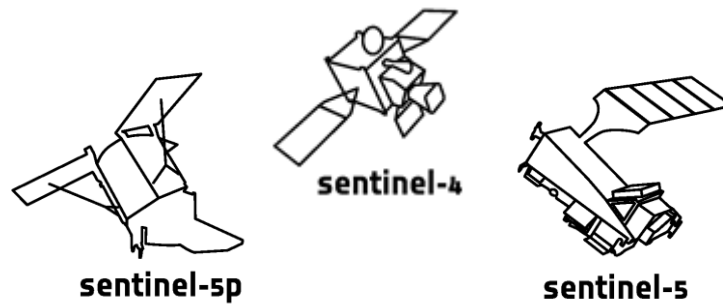
- Continued in 2020 with „LOOSE“.



Technologies for the Management  
of Long EO Data Time Series

- Required software for STAC published as Open Source in collaboration with GeoSolutions
- Service operational in EOC Geoservice
- STAC endpoint: <https://geoservice.dlr.de/eoc/ogc/stac>

# Thank you!



## STAC Metadata for selected S5P Tropomi L3 and L4 products available at

<https://geoservice.dlr.de/eoc/ogc/stac/>

Topic: Exploring the Atmosphere Composition with Innovative Online Data Analysis Services  
Integrating Novel Level-3 Products from Copernicus Sentinel Mission

Date: 13.09.2023

Authors: J. Meyer-Arnek (Julian.Meyer-Arnek@DLR.de), T. Heinen, A. Twele,  
J. Müller, S. Kiemle

Institute: DLR/DFD

Credits: „DLR (CC BY-NC-ND 3.0)“



# Thank you!



<https://geoservice.dlr.de/eoc/ogc/stac/>

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