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Satellite data validation with a focus on groundbased remote sensing capabilities, and satellite validation data center activities.

Ann Mari Fjæraa, NILU

Fifth Joint School on Atmospheric Composition

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Outline:

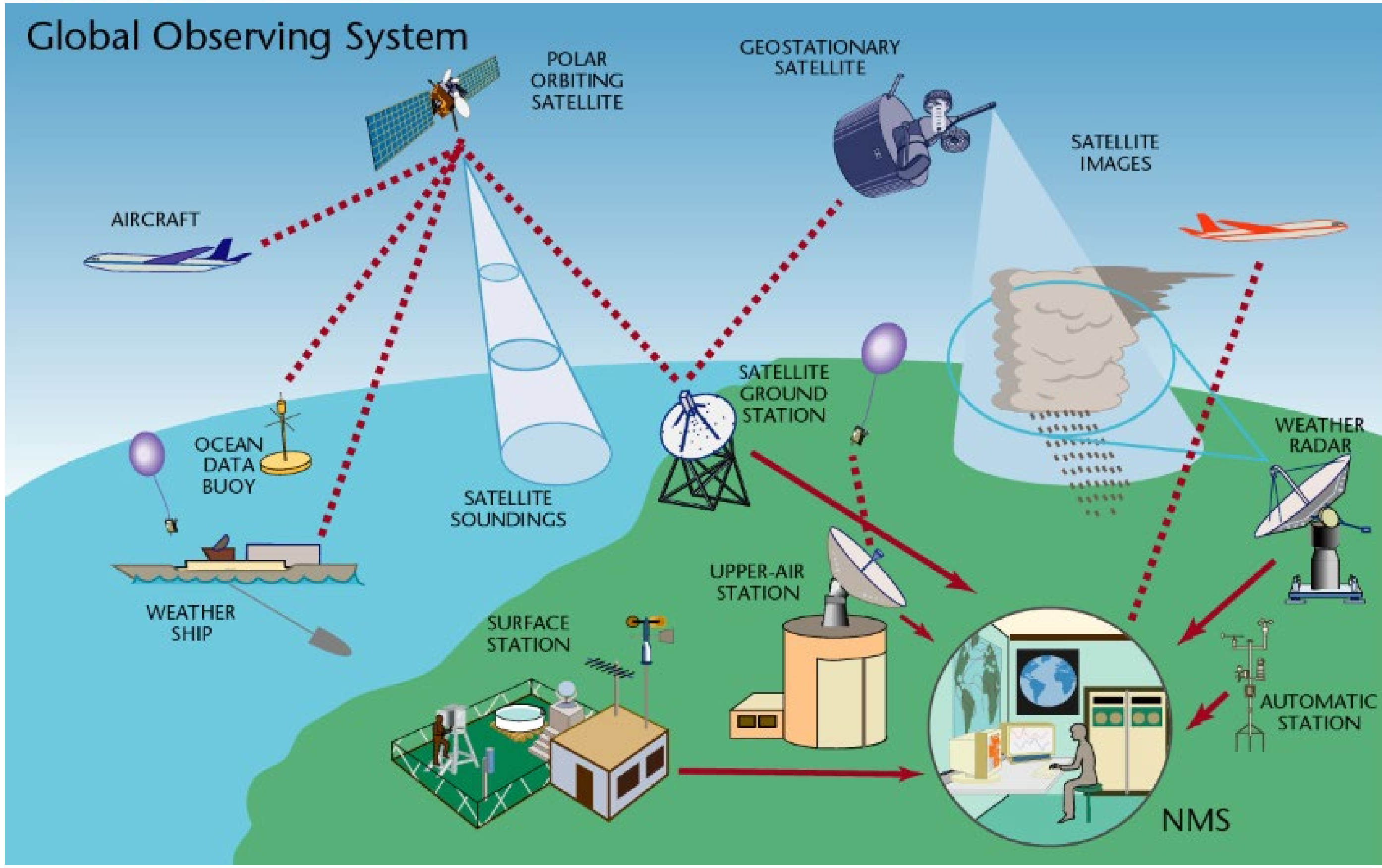
Satellite Data Validation and Ground-Based Remote Sensing Capabilities
EVDC - Satellite Validation Data Center Activities
Challenges in the Arctic

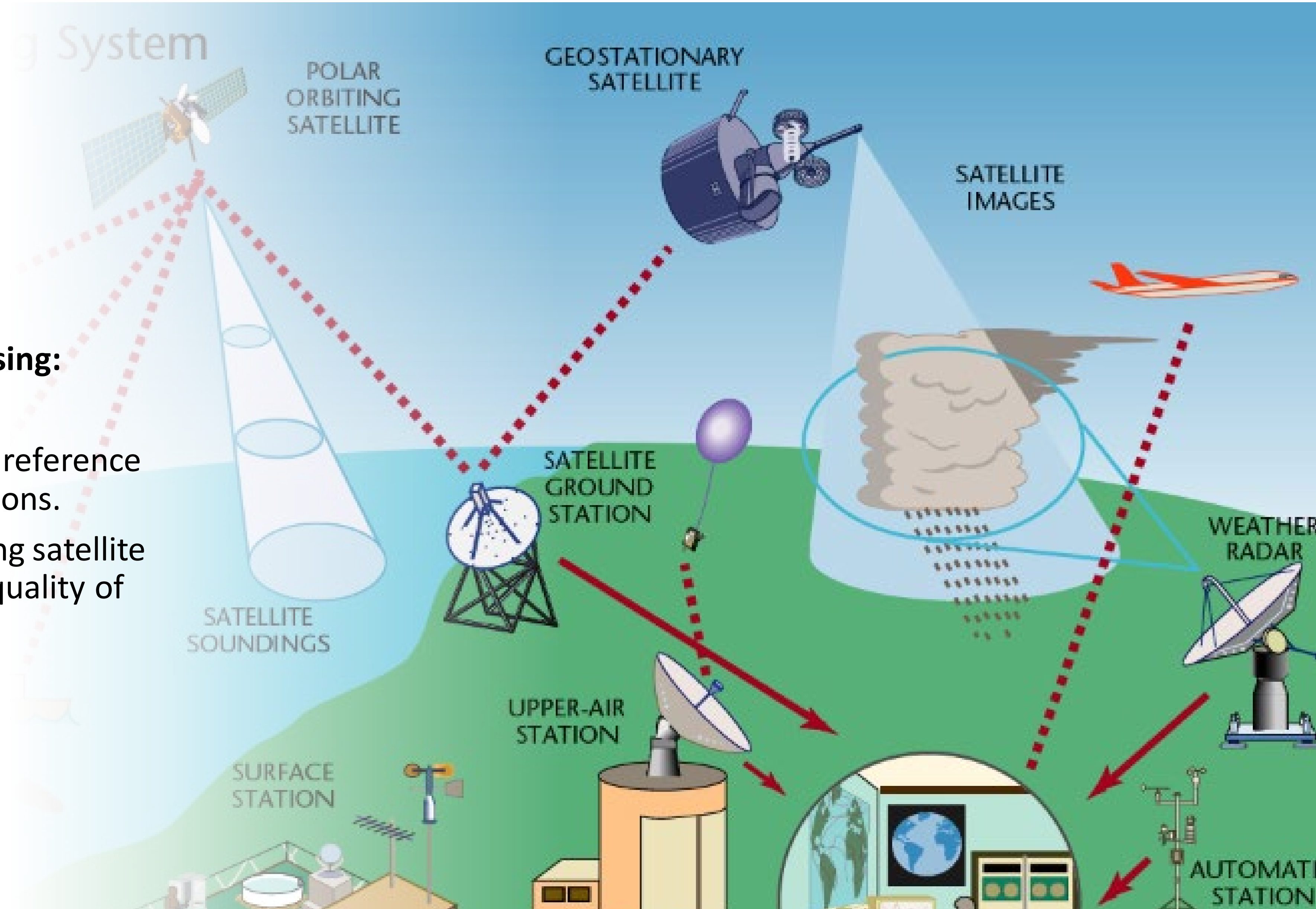
The Observing System

The harmonious synergy that exists among satellites, in-situ data, remote sensing systems, and (forecast) models play a pivotal role in Climate Monitoring and Air Quality research, offering a broad perspective on our planet.

In-situ data, collected at specific ground locations, validate and calibrate satellite information.

These diverse data sources converge in forecast models, and make predictions about weather, climate, and environmental changes.





The role of ground based remote sensing:

Groundbased measurements serve as reference points for validating satellite observations.

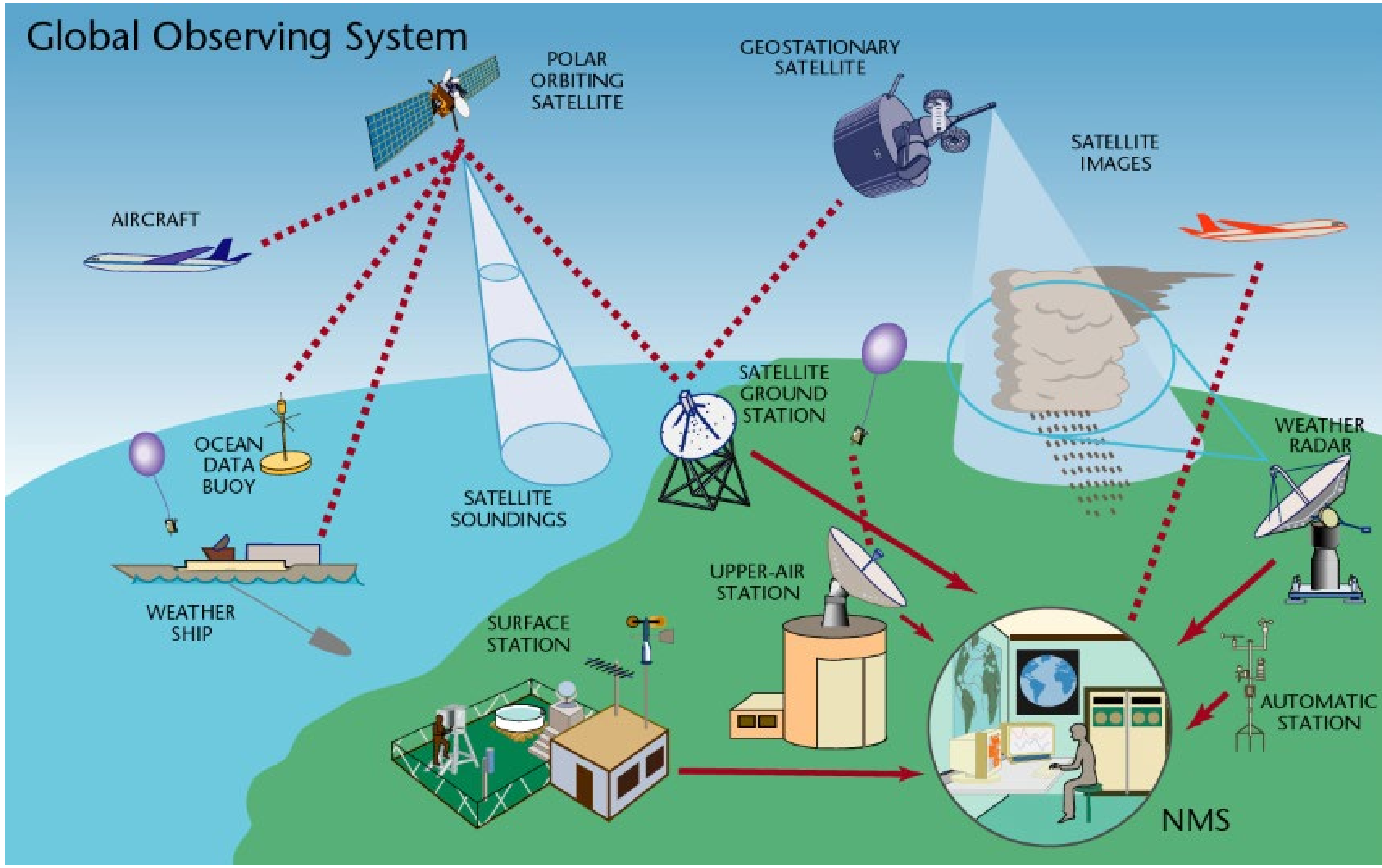
Some of the key objectives are verifying satellite sensor calibration and improving the quality of satellite-derived products.

Definitions:

In-situ refers to measurements or observations that are taken directly at a specific location.

In the context of atmospheric composition, "in-situ measurements" refer to **data collected from sensors, instruments, or devices** that are physically present in the atmosphere, **at the ground or within a specific atmospheric layer.**

In contrast to in-situ measurements, **remote sensing** techniques involve collecting data from a distance, often using satellites or other instruments that are not physically located within the atmosphere being studied.

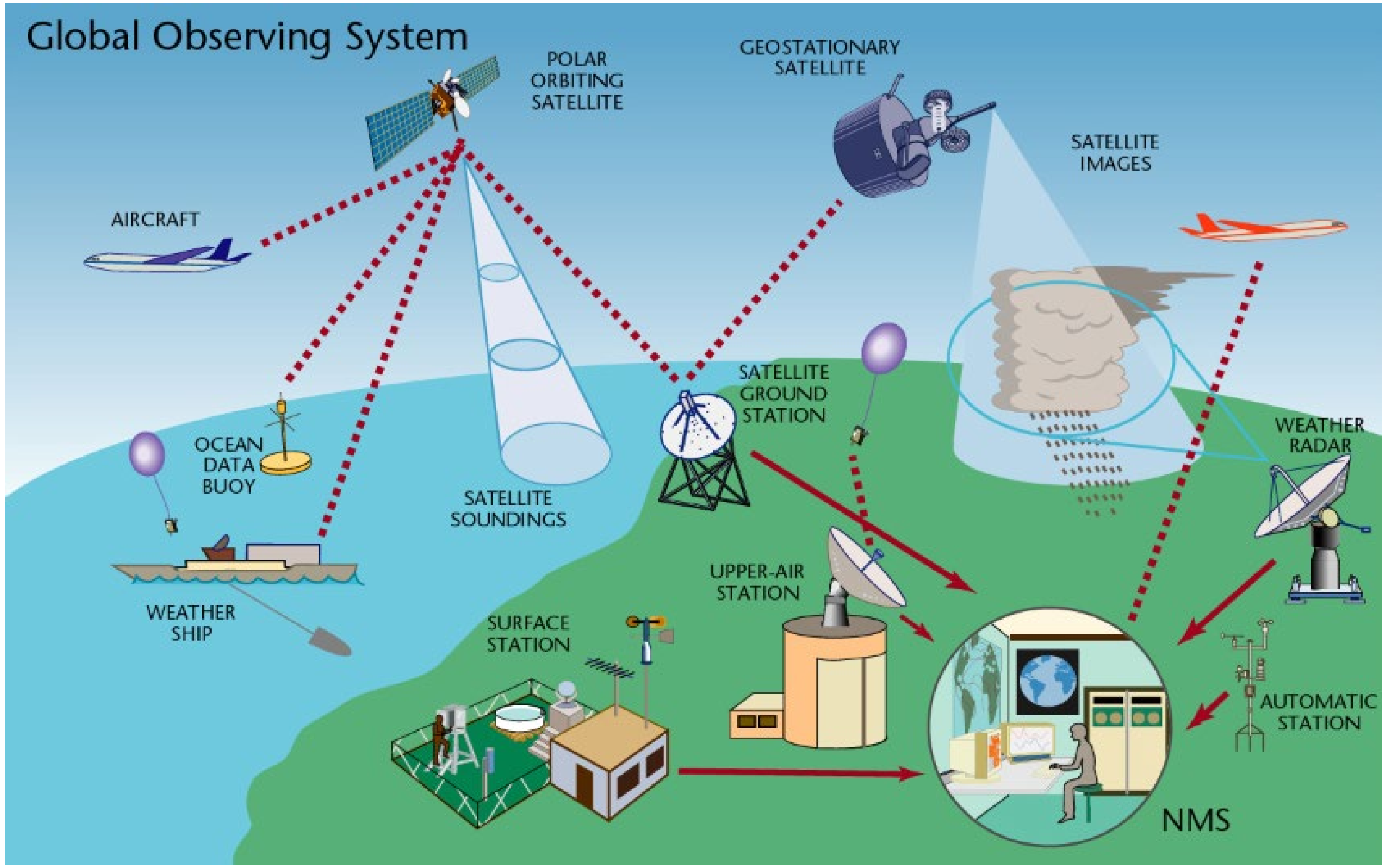


Definitions:

Measurement platform refers to the specific setup and can be for example

Groundbased stationary platform
Groundbased moving platforms
Airborne moving platforms

Station type refers to the classification of measurement stations based on their specific focus, locations and the types of measurements they perform, e.g. urban, regional, global background.

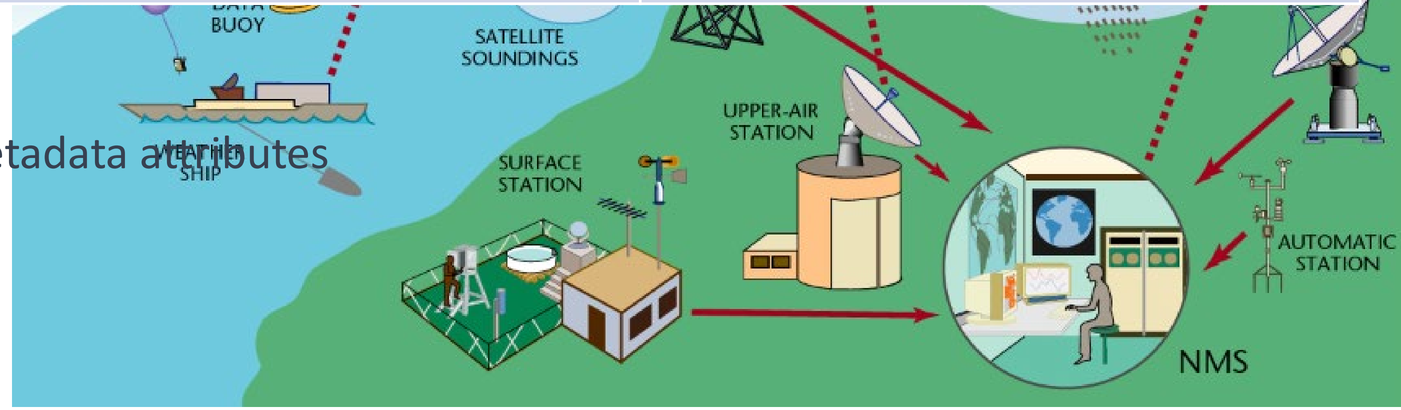


Definitions:

These classifications help to
- organize and standardize the data collected
- make it easier for researchers and scientist to analyze and compare atmospheric conditions across different regions and environments.

Definition	Attribute
Point in-situ	One point is space-time
Remote sensing in-situ	Total column or remote profile
Platform	Stationary, Moving
Platform setting	Groundbased, Aircraft, Ship, Drone
Station type	Urban, Rural, Regional, Global

Metadata attributes



Ground remote sensing capabilities;

Validation is fundamental work before the proper use of remote sensing (RS) products.

The validation should be implemented prior to the use of RS products - some products might overestimate/underestimate the accuracy of target variable.

The validation of satellite derived products is necessary so that an estimate of the product's accuracy and precision can be provided.

Best practices for ground remote sensing validation includes:

- Serving as an independent data source
- Be stable over time
- Being large enough to represent the pixel being validated

Stage	Description
Stage 1 Validation	Product accuracy has been estimated using a small number (typically < 30) of independent measurements obtained from selected locations and time periods and ground-truth/field program effort.
Stage 2 Validation	Product accuracy has been assessed over a widely distributed set of locations and time periods via several ground-truth and validation efforts. The spatial and temporal consistency of the product has been evaluated over globally representative locations and time periods. Results are published in peer-reviewed literature.
Stage 3 Validation	Product accuracy has been assessed over a globally distributed set of locations and time periods via several ground-truth and validation efforts. Product uncertainties have been well-established via independent measurements made in a systematic and statistically robust way that represents global conditions. Results are published in peer-reviewed literature.
Stage 4 Validation	Validation results for Stage 3 are systematically updated when new product versions are released and as the time-series expands.

(Ref.: CEOS work plan)

Ground remote sensing capabilities;

The ground networks

- have capability to be a continuous component operating in tandem with EO campaigns
- provide an independent check on the performance of space-based sensors and processing algorithms using high quality surface-based measurements
- adhering to international guidelines and protocols.

(Ref.: CEOS work plan)

Stage	Description
Stage 1 Validation	Product accuracy has been estimated using a small number (typically < 30) of independent measurements obtained from selected locations and time periods and ground-truth/field program effort.
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Stage 4 Validation	Validation results for Stage 3 are systematically updated when new product versions are released and as the time-series expands.

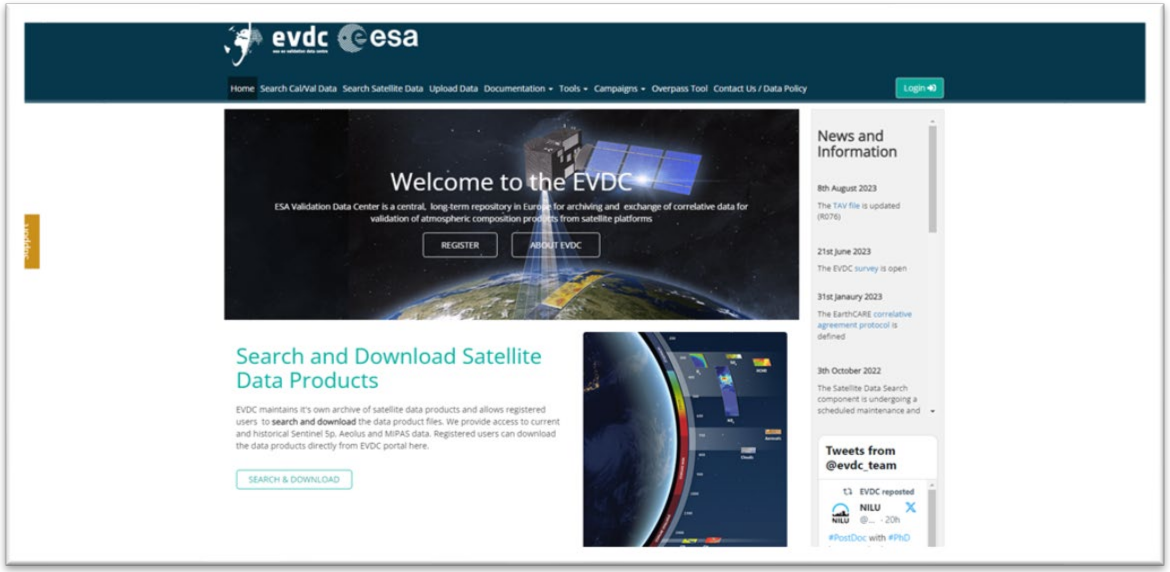
Challenges faced in ground based validation of satellite data;
Atmospheric interference, sensor calibration, cloud cover, and geographic variation, access to data;
These challenges can impact the accuracy of the in-situ data, still need for better ground-based validation capacities.

Importance of Research Infrastructures and **Satellite Validation Data Centers:**

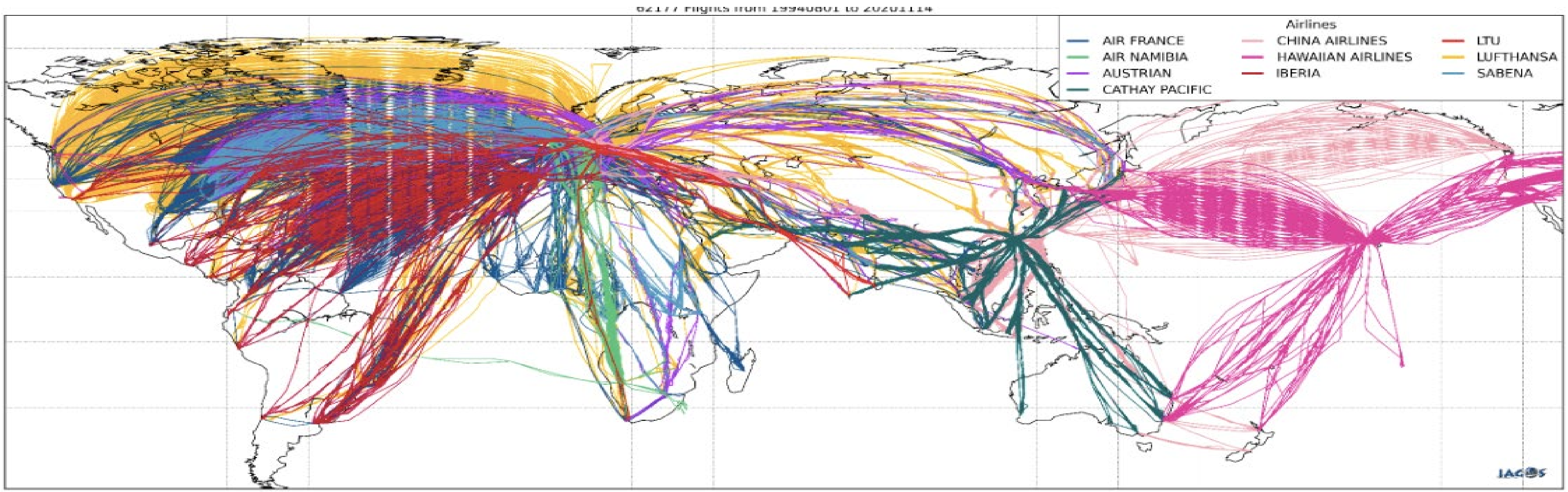
Data Centers serve as centralized hubs for collecting, archiving, and disseminating ground-based validation data.

They facilitate collaboration among researchers, institutions, and agencies involved in satellite data validation.

EVDC is ESA's "in-house" database for ENVISAT, Sentinel-5P, AEOLUS and upcoming EarthCARE mission.
EVDC is also linking to data from other World Data Centres.



Aircraft measurements



In-Service Aircraft for a Global Observing System (IAGOS) is a distributed infrastructure for long-term observations of atmospheric composition, aerosol and cloud particles on a global scale. The data is collected via a fleet of long-range in-service aircraft belonging to airlines operating internationally.

Data access through : https://www.iagos.org/iagos-data/

Each payload provides reactive gases, GHG and aerosol ECVs

Network for the Detection of Atmospheric Composition Change

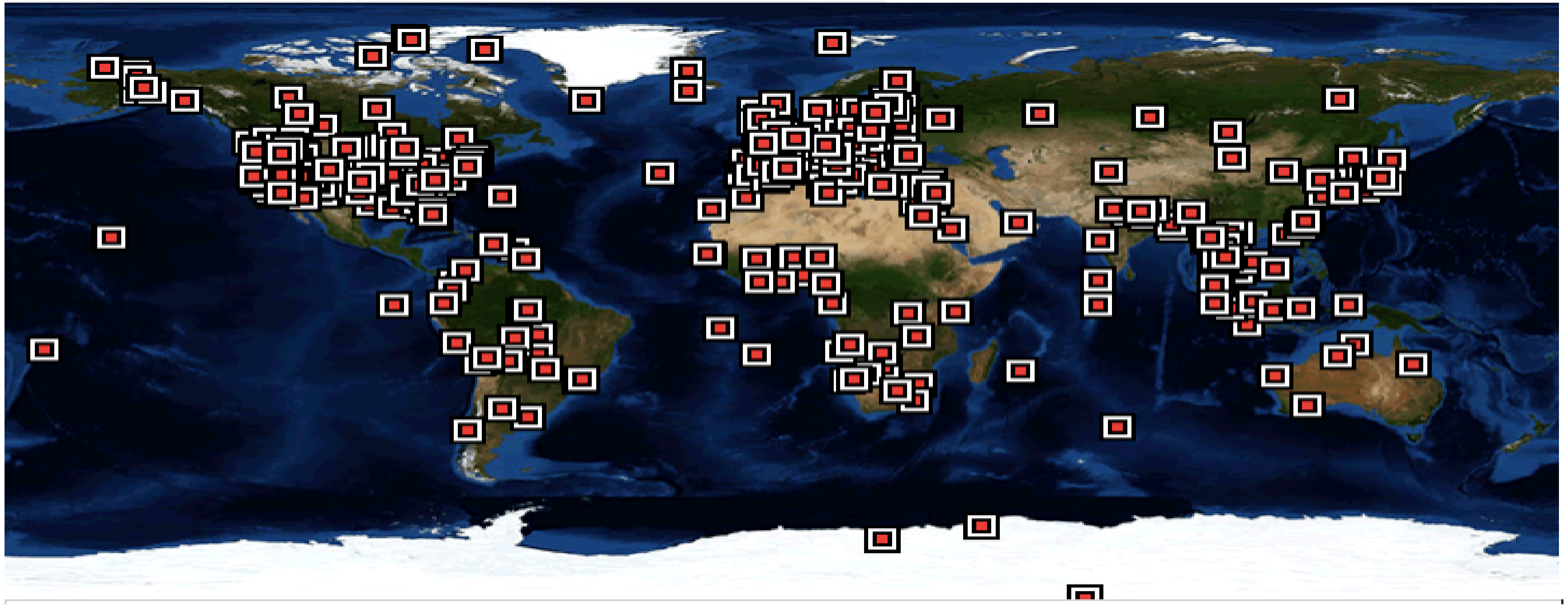
NDACC is composed of more than 70 globally distributed, ground-based, remote-sensing research stations with more than 160 currently active instruments.

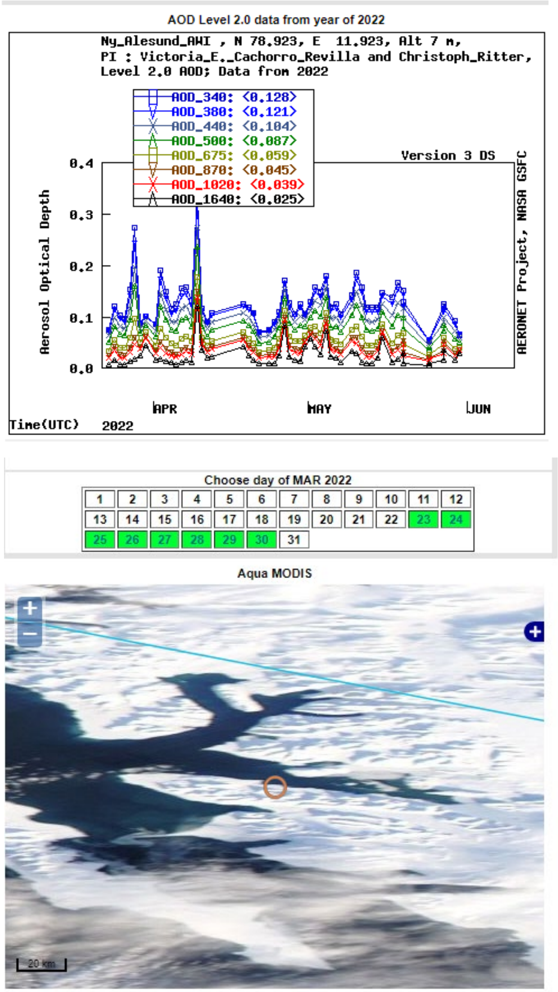
Key elements

- Stratosphere measurements
- Different instruments (lidar, microwave, radiometers, FTIR)
- Harmonized procedures
- Long term measurements

Major contributor to the Global Atmosphere Watch (GAW) program of the World Meteorological Organization (WMO)

https://www-air.larc.nasa.gov/





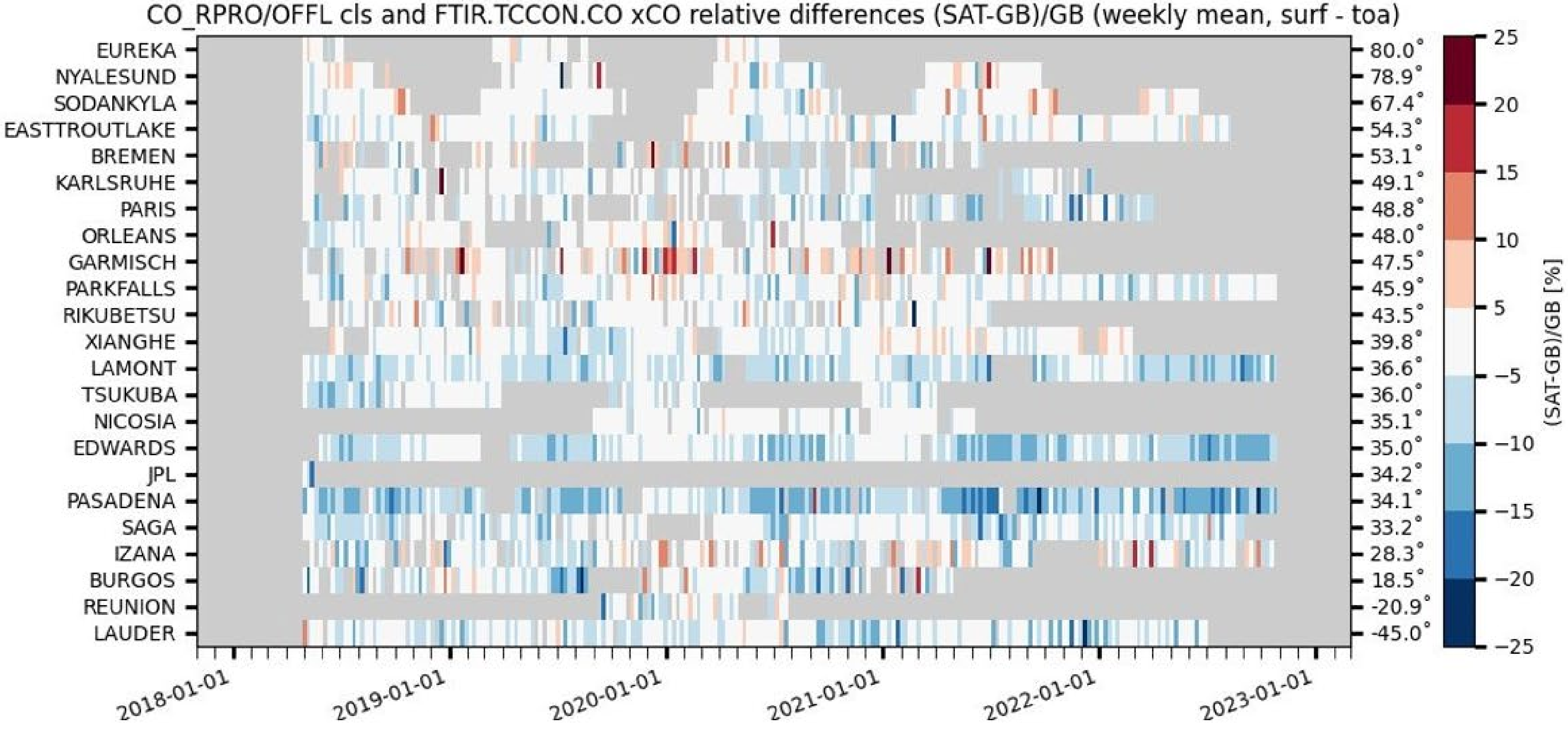
Aeronet (NASA) is the most operational and widely used aerosol network and provides AOD and retrieves other aerosol ECVs
Data access through : https://aeronet.gsfc.nasa.gov/

L2_CO (B. Langerock, M.K. Sha)

Validation using TCCON GGG2020 data

Comparison with **closest** co-located s5p pixels: **COLLECTION 3 results**

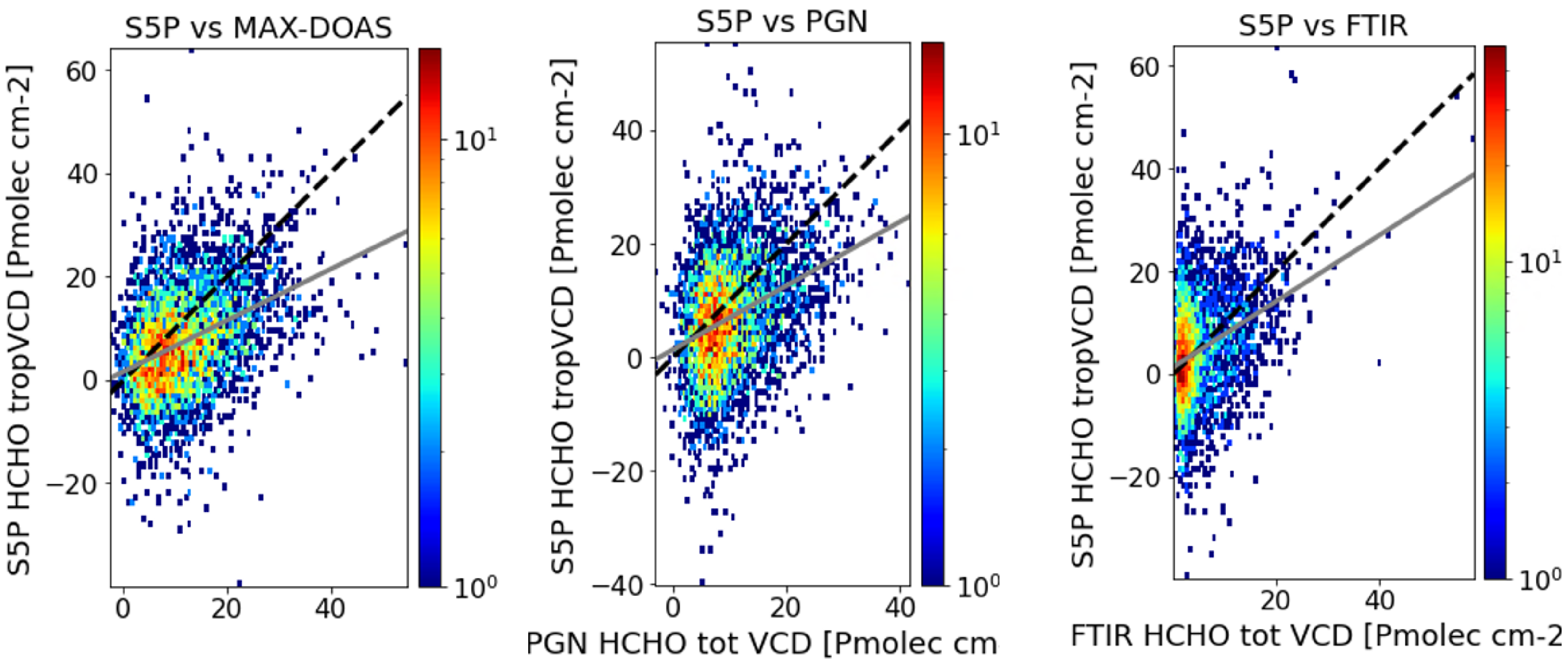
GB vs SAT direct comparison



Mean –> Bias = **-2.48%** ; STD = **6.97%** ; correlation coefficient = **0.86** (April 2018 – Dec 2022)

Mean –> Bias = -2.48% ; STD = 6.97% ; correlation coefficient = 0.86 (April 2018 – Dec 2022) – last report

S5P HCHO vs MAXDOAS, FTIR, Pandora



count=4556,R=0.38
meanΔ=-4.3,medianΔ=-4.4
medianΔ/GND=-42%
stdΔ=9.6,1/2IP68Δ=8.7
yvsx:y=0.49*x+1.60

count=4721,R=0.34
meanΔ=-3.1,medianΔ=-3.2
medianΔ/GND=-33%
stdΔ=9.4,1/2IP68Δ=8.9
yvsx:y=0.56*x+1.34

count=4048,R=0.33
meanΔ=-0.3,medianΔ=-0.4
medianΔ/GND=-11%
stdΔ=8.9,1/2IP68Δ=7.9
yvsx:y=0.64*x+1.39

Challenges faced in operating a Data Center:

Diversity among users and user needs.

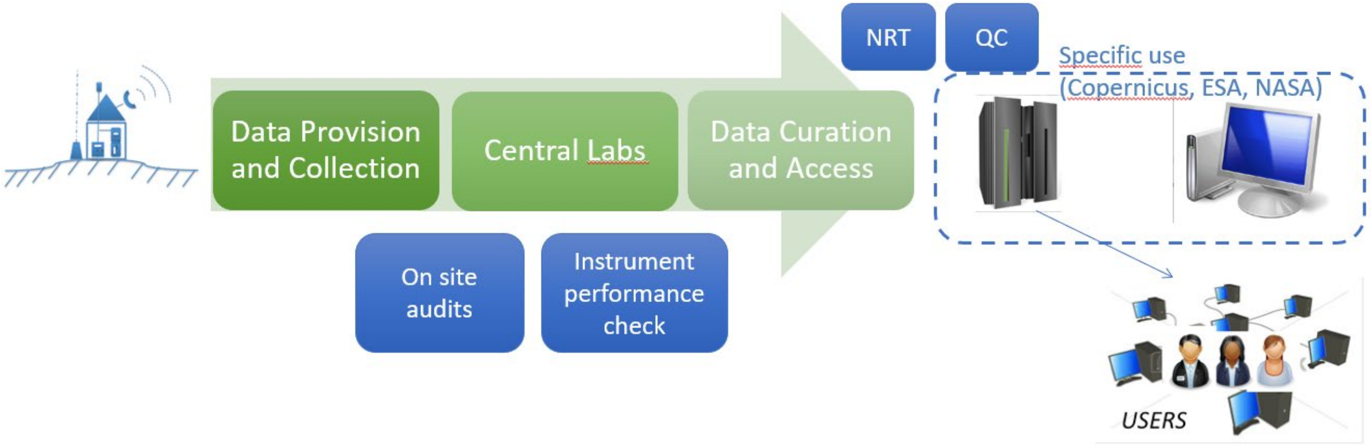
- EVDC users range from data submitters (PIs), data users (individual scientists and as input for forecast models) to stakeholders.

- Wide range of Infrastructure networks and FRMs, each created to serve several different and diverse purposes.

- Each Research Infrastructure and country runs its own network, sometimes with several operators per country and/or managed at different administrative levels –

- Data exchange between countries may be difficult, slow or even non-existent.

Regional differences both in terms of data access and data availability, e.g. Africa, Arctic…



Vocabulary

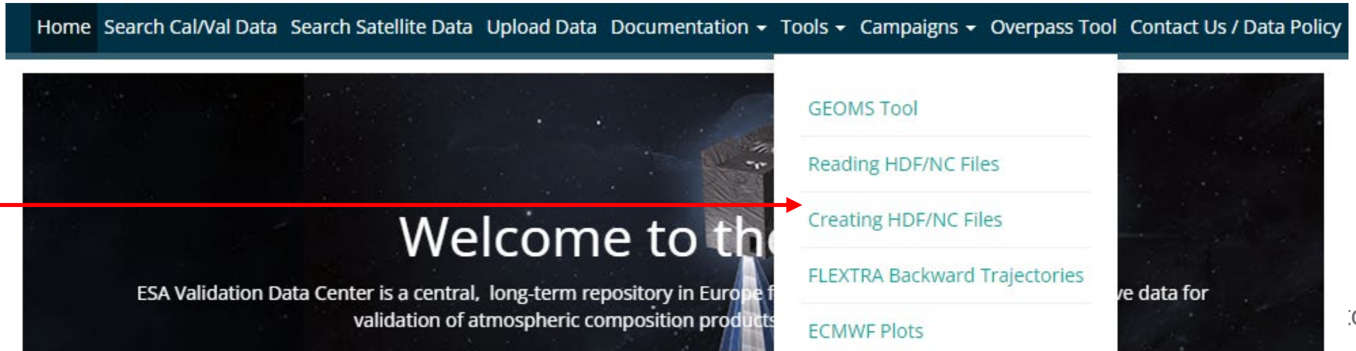
The ESA atmospheric Validation Data Centre, or EVDC for short, is over time set up to serve all these users and purposes. (Current version 2017-2025)

EVDC provides services and tools for data providers and users.

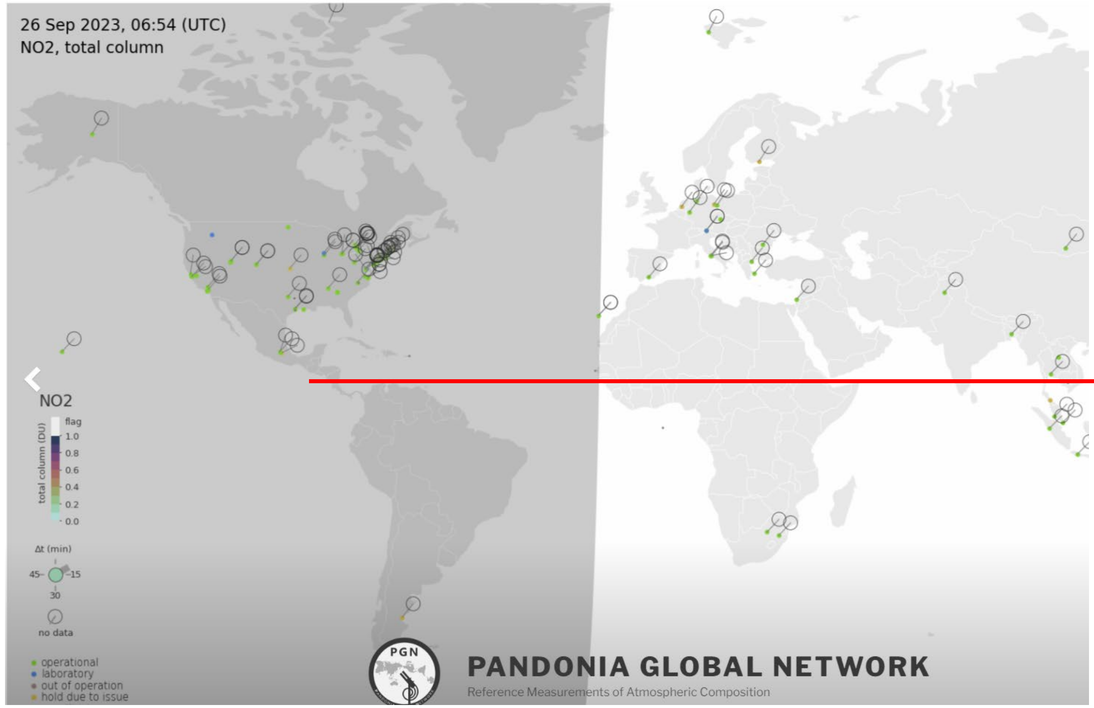
EVDC for data providers:
Support on data formatting according to the ***GEOMS***, which defines the structure, content, and naming of variables and attributes for different instrument types and measurement principles.

EVDC also performs quality checks on the data and metadata, and provides feedback and error messages to the data submitters.

Forward of data to ESA-ATM-MPC.



The PGN data and EVDC



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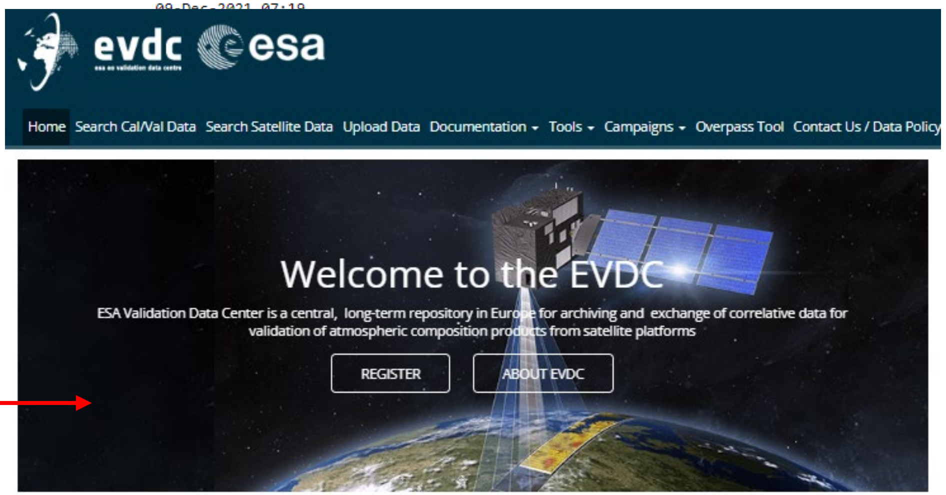


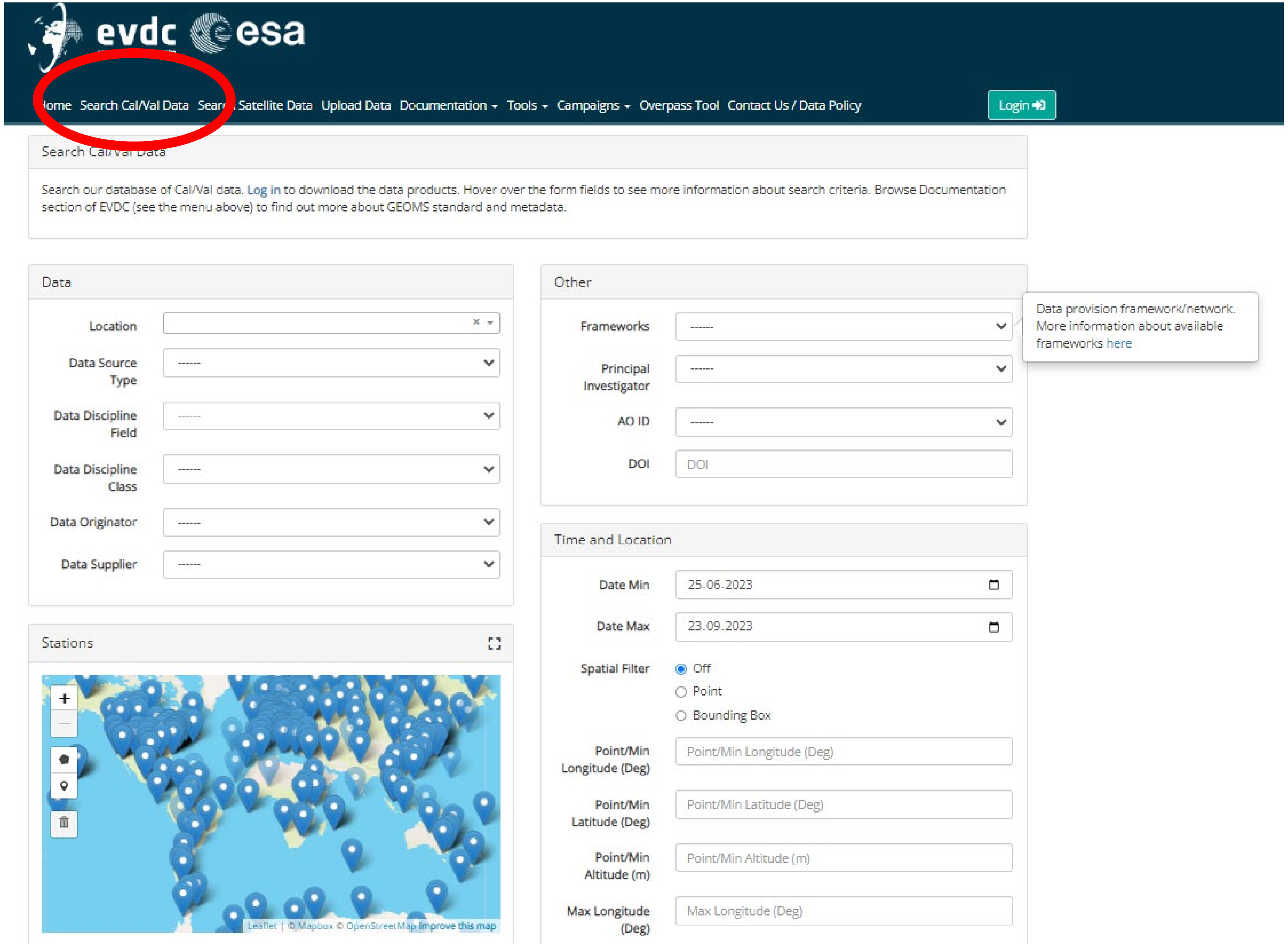
Search for ground based Cal/Val data

EVDC offers search and download of time series of Cal/Val data through a dissemination web system.

Users can select parameters from a long list of predefined variables from (currently) around

1.8 mill individual measurement time series, from 20+ networks and more than 500 ground stations. Longest time series span over more than 70 years.

.HDF4, .H5 and .netCDF



Use of ground based Cal/Val data:

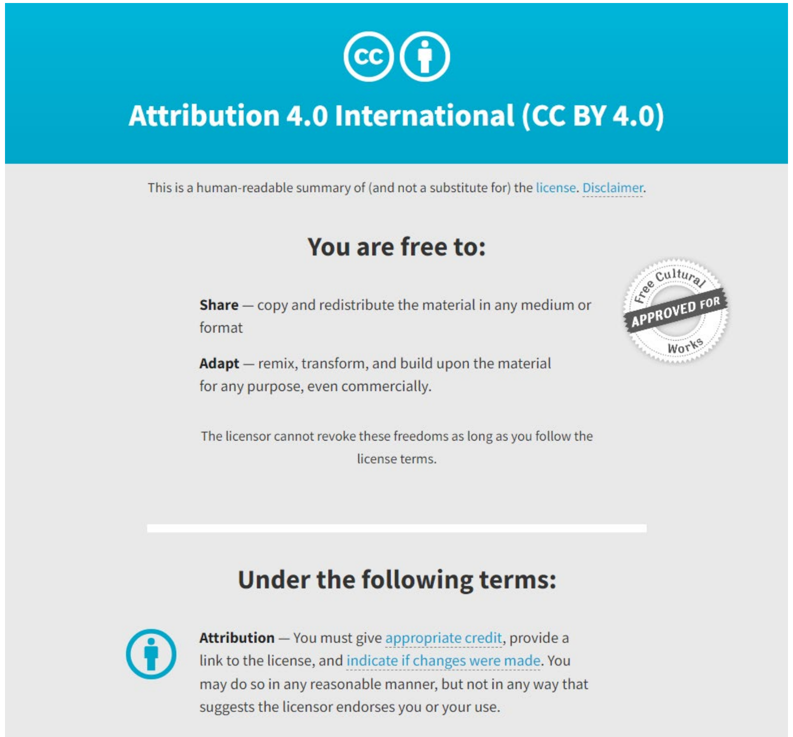
License agreements:

Aims to

- encourage dissemination of data and results for scientists involved in measurement campaigns and contributing networks/stations
- protect the rights of the individual scientists involved in these

Example 1: Re-distribution of data by others than the owner to third parties, or partners outside the ECVT and the ESA algorithm developers is not allowed and requires written permission from the data originator with copy to the EarthCARE project”

Example 2: Co-authorship is the decision of the primary author of a manuscript. If the PGN data from a few sites are a major component of the paper co-authorship to PI(s) should be offered. In any case an acknowledge should be made.



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Adapt — remix, transform, and build upon the material for any purpose, even commercially.

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Under the following terms:

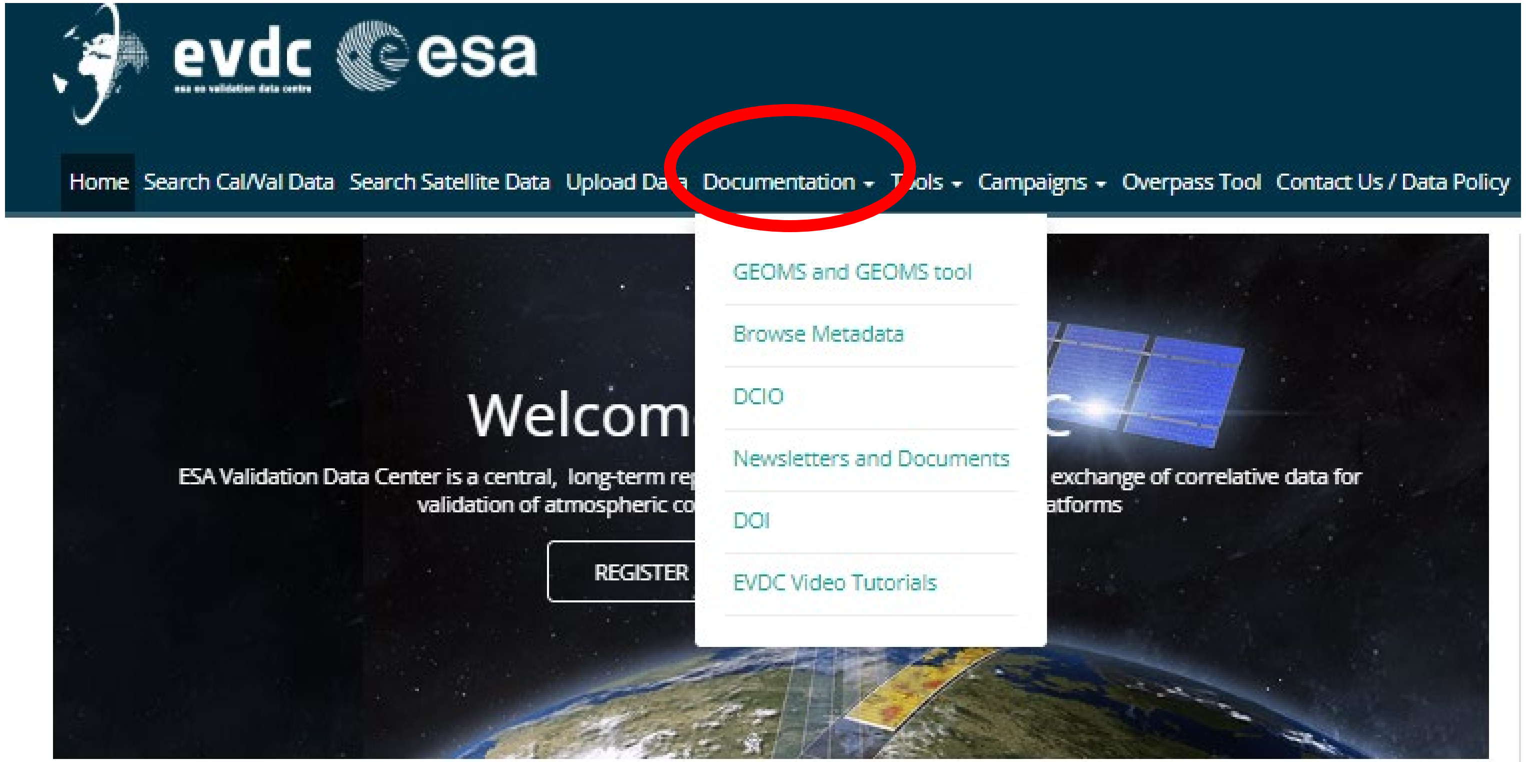
Attribution — You must give appropriate credit, provide a link to the license, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.

Documentation

Documentation of datasets and its capabilities/performance and “fit for purpose” is essential for Cal/Val.

Technical documentation, Intercomparison results, Validation outcome…

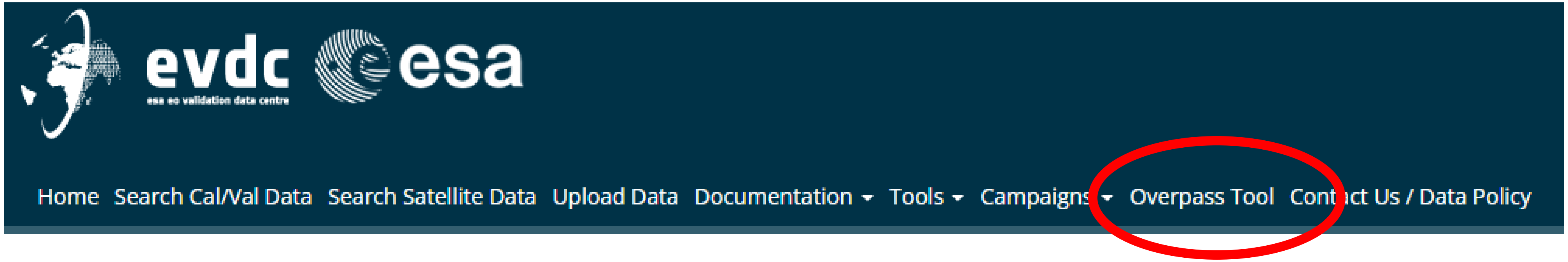
EVDC holds, or links to the native documentations of the provided datasets.



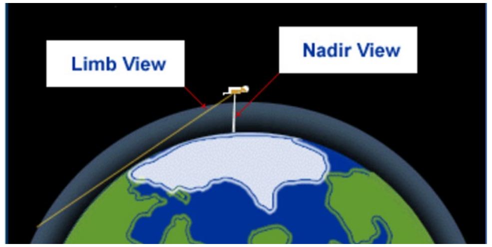
Data are provided via **Data Centers**, e.g.
GAW-WDCA, GAW-WDCRG, GAW-WDCGG, AVDC, JAXA, Airbase, WOUDC or
Research Infrastructures or Networks, e.g.
ICOS, ACTRIS, IAGOS, NDACC, Pandonia Global Network, EUBREWNET, TCCON, COCCON, AERONET, EARLINET, MPL-NET, CloudNET, SHADOZ, GALION, GRUAN, among others

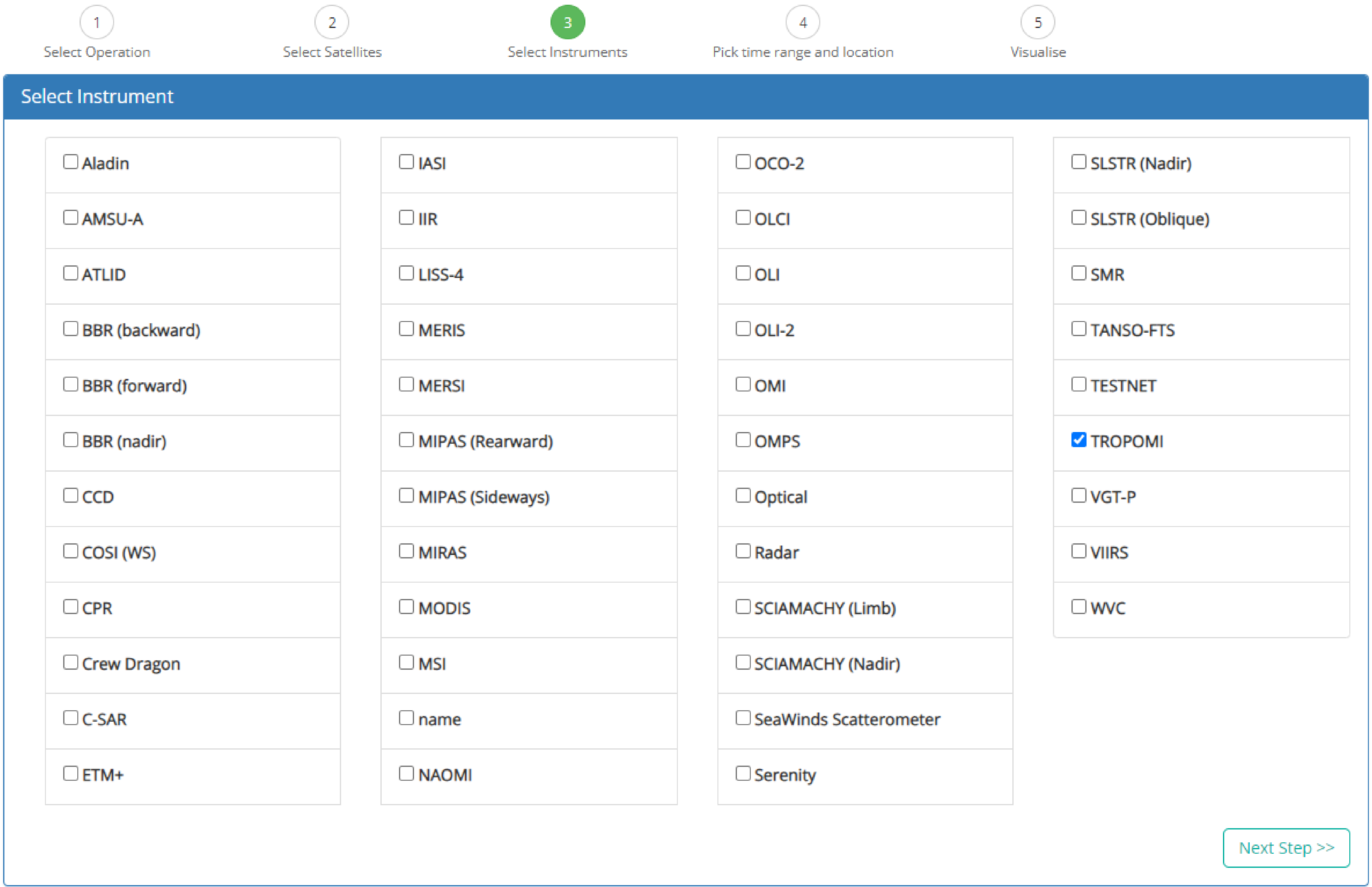
Data analysis and visualization:
EVDC provides online interface to the tools for download of and work with atmospheric data.

EVDC provides ***the orbit tool***, that allows users to predict satellite orbits of most of existing (and virtual/upcoming) satellites, visualize satellite overpasses and sensor footprints on 3D globe and download the orbit data in CSV, KML and JSON format https://evdc.esa.int/orbit/.



An overpass is defined as when the field of view of a satellite instrument passes over an area of interest.





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BBR (nadir)
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COSI (WS)
CPR
Crew Dragon
C-SAR
ETM+
IASI
IIR
LISS-4
MERIS
MERSI
MIPAS (Rearward)
MIPAS (Sideways)
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SCIAMACHY (Limb)
SCIAMACHY (Nadir)
SeaWinds Scatterometer
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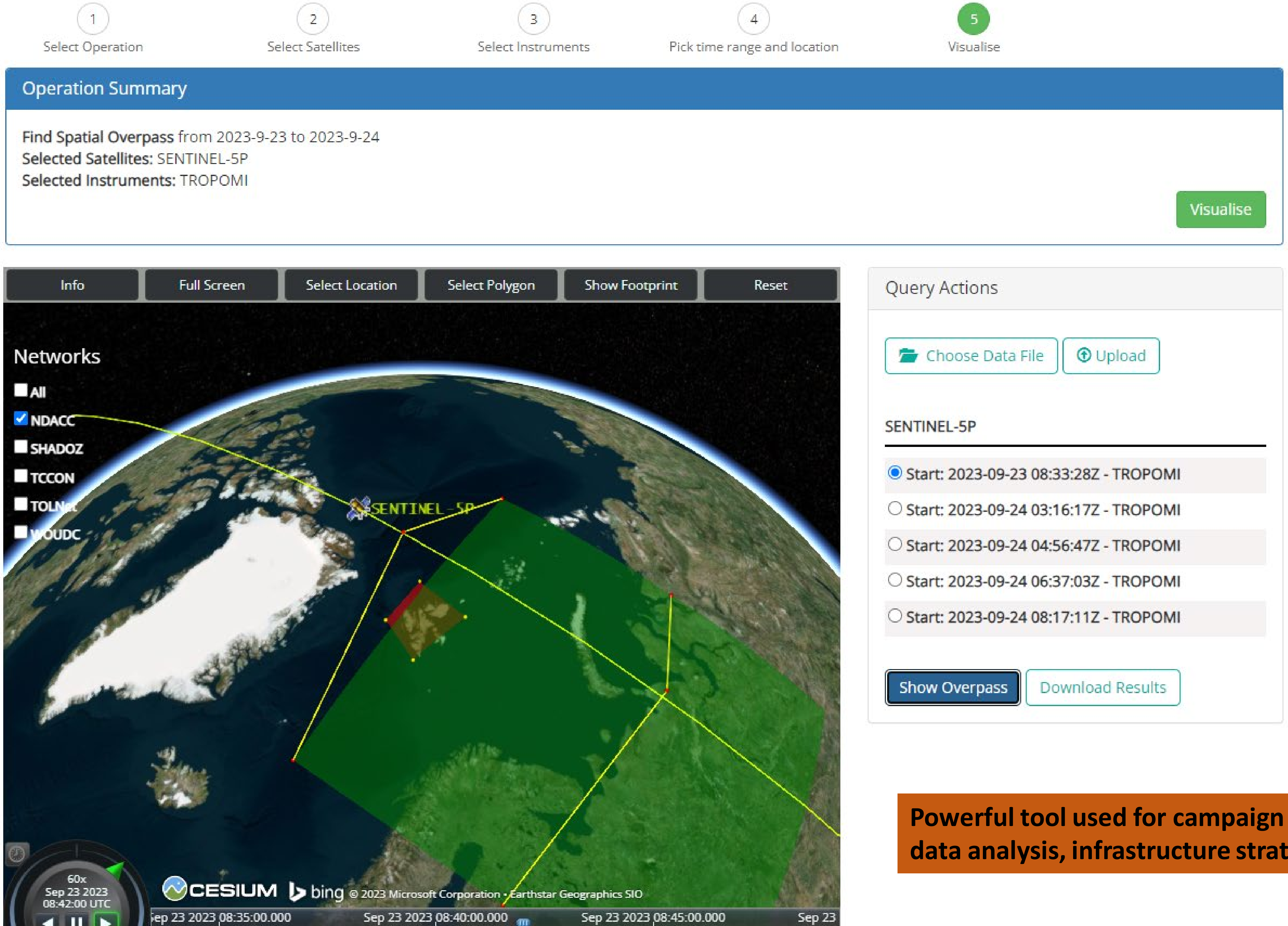
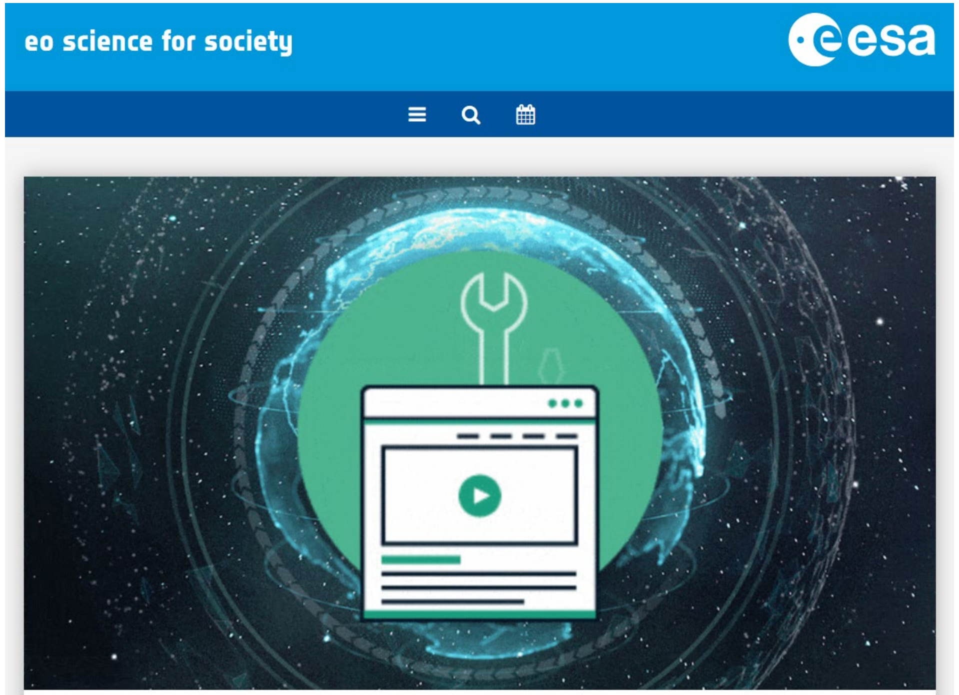
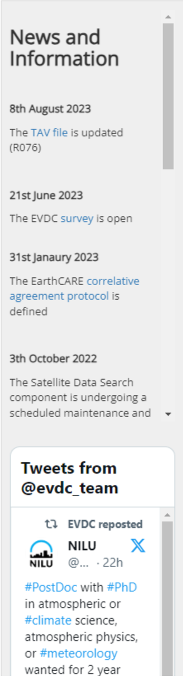


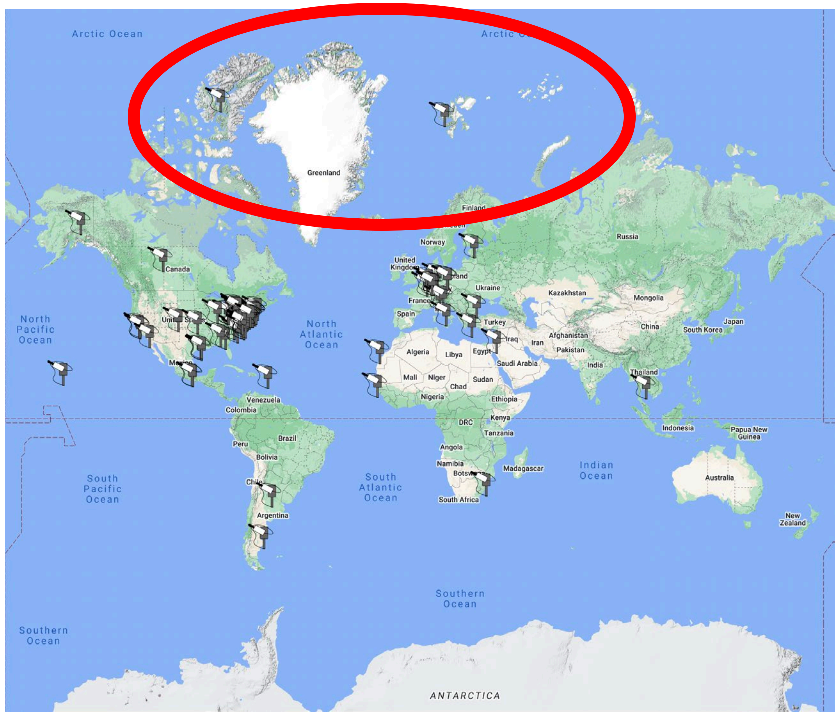
Powerful tool used for campaign planning, data analysis, infrastructure strategies.

Data dissemination and outreach:

EVDC lets researchers upload and register their data in the central repository and share it with the earth observation community. EVDC provides video tutorials, documentation, news, information, and surveys to engage with users and partners. Upcoming training courses in 2023 and 2024.





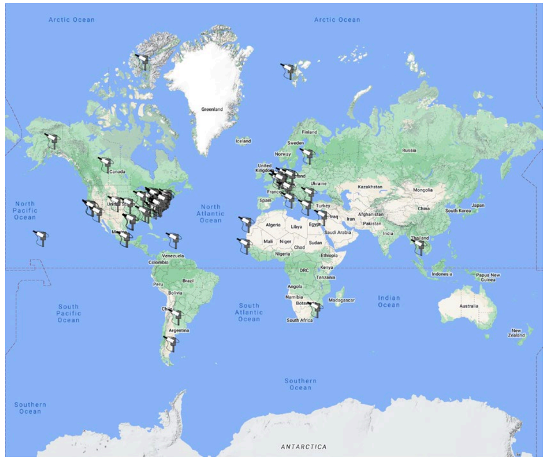


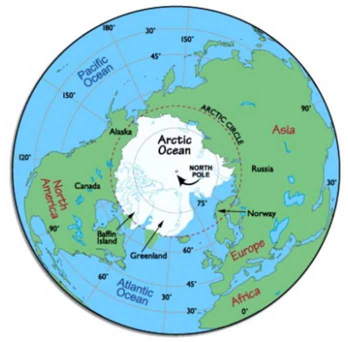
Throughout this course - you have learned that:

The Pandora instrument is a sophisticated tool used in atmospheric research and monitoring.
It plays a crucial role in assessing air quality and measuring various atmospheric constituents.
Pandora instruments are especially valuable for monitoring air quality, tracking pollutants and compounds like ozone (O3), nitrogen dioxide (NO2), and aerosols, and assessing their impact on the environment and human health.

What are the Pandora's capabilities in Arctic and Polar Areas?

Figure 1: Pandora at the PEARL Ridge Lab. The instrument pointed at the sun for measurements by its tracker. The PEARL-GBS is shown in the background in its dome. Photo Credit: Ramina Alwarda.





Arctic Map from Worldatlas.com

Definition of Arctic and Antarctica (Polar areas)

In the context related to satellite data validation and the challenges associated with it, the term "Arctic" typically refers to the geographical region situated around the North Pole. It encompasses the Arctic Ocean and the surrounding lands, including parts of several countries such as Canada, Greenland, Russia, the United States (Alaska), Iceland, Norway, Sweden, and Finland. The term “Antarctica” refers to the Antarctic ice shelf.

The Polar regions are characterized by extreme cold, polar night (a period of continuous darkness during the winter months), and polar day (a period of continuous daylight during the summer months). They are known for distinctive ecosystems, sea ice cover, and unique climate patterns.

When discussing GB satellite data validation in the Arctic, it usually involves addressing the specific challenges and conditions related to this northernmost part of the Earth, which can significantly differ from validation efforts in other regions due to its extreme environmental factors and geographical location.

Challenges in the Arctic

Satellite data validation with in-situ data in the Arctic presents a set of special challenges due to the extreme environmental conditions and remote location of this region.

Harsh Arctic Climate: The Arctic experiences extreme cold and harsh weather conditions. These conditions can make it challenging to operate and maintain ground-based instruments.

Polar Night: During the polar night, some Arctic regions experience continuous darkness for several months. This limits the availability of natural light sources for validation and affects the timing of measurements.

Limited Accessibility: Many parts of the Arctic are remote and difficult to access. Lack of infrastructure, transportation options, and harsh terrain can hinder the installation and maintenance of ground-based validation equipment.

Challenges in the Arctic

Snow and Ice: Snow and ice cover a significant portion of the Arctic, making it challenging to deploy and maintain ground-based instruments. Snow and ice can also affect the reflectivity of surfaces, which impacts the accuracy of satellite data.

Cloud Cover: The Arctic is frequently covered by clouds, which can obstruct satellite observations and limit the availability of clear-sky data for validation purposes.

In situ networks and research infrastructures are yet extremely essential for

- filling data gaps,
- improving our understanding of Arctic processes,
- supporting scientific research, climate modeling,
- policy decisions related to the Arctic's environment

Climate Change in Arctic Regions:

The Arctic is warming 3-4 times faster than the rest of the world.
Significant changes over the last years!

Need for Air Quality Monitoring in the Arctic:

Being a pristine and remote environment, the Arctic region is not immune to air quality issues, with increasing wildfires, seasonal changes, changes in global circulation patterns, pollution from various new sources, new shipping routes.

Pandora instruments can track pollutants like NO2 and particulate matter, offering valuable data for assessing air quality in the Arctic.
Many in-situ networks and Research Infrastructures provide good measurements from the Arctic.


Record-hot summer in Svalbard

This year's summer in Svalbard is the hottest ever recorded. The previous record from 2020 only lasted two years.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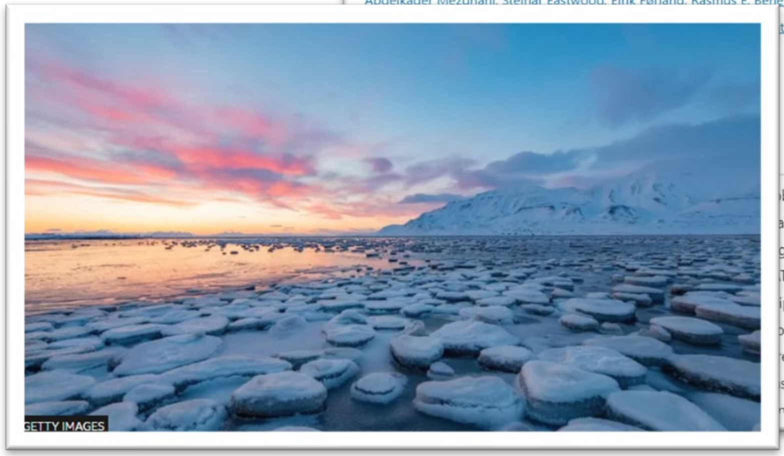
Exceptional warming over the Barents area

Ketil Isaksen, Øyvind Nordli, Boris Ivanov, Morten A. Ø. Køltzow, Signe Aaboe, Herdis M. Gjelten, Abdelkader Mezghani, Steinar Eastwood, Eirik Førland, Rasmus E. Benestad, Inger Hanssen-Bauer, Ragnar ... tiana Karandasheva

...bal reanalyses points to ... a scarcity of observations ... gion. Here, we study the ... T observations and a quality ... ipelagos in the Barents Sea. We ... of up to 2.7 °C per decade, with a ... e compared with the most ... s remote sensing data records ... nd high-resolution ice charts



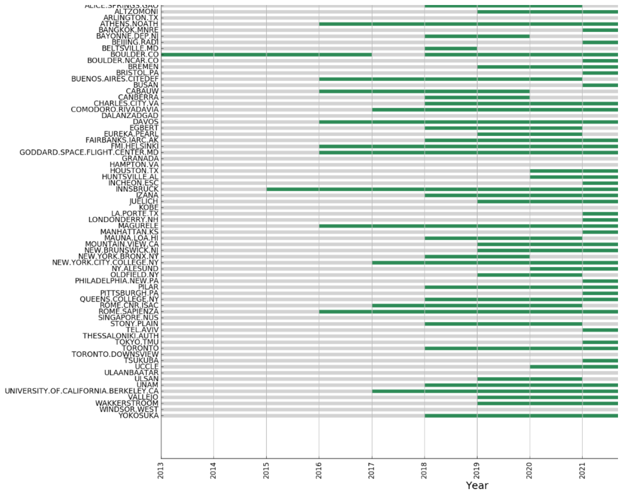
Dust and Aerosols in the Arctic:
Dust and aerosols in the Arctic atmosphere can originate from various sources, both natural (e.g., dust storms, wildfires) and anthropogenic (e.g., industrial emissions).

Concentrations are low, but in the Arctic, dust and aerosols can have significant consequences. They can influence atmospheric heating, ice melt rates, and air quality, which again triggers the warming and impact on human health.

Pandora instruments help, together with a long range of other in-situ measurements in quantifying concentrations and their composition, providing insights into the sources and transport of gases and particles in the Arctic atmosphere.

Validating data from multiple sensors and platforms, each with its own characteristics and limitations, can be particularly challenging in the Arctic.
Extremely important to have well documented,
long and harmonized data times of high quality.

evdc
esa eo validation data centre

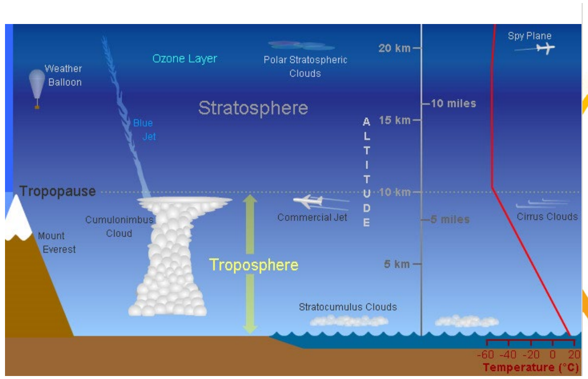


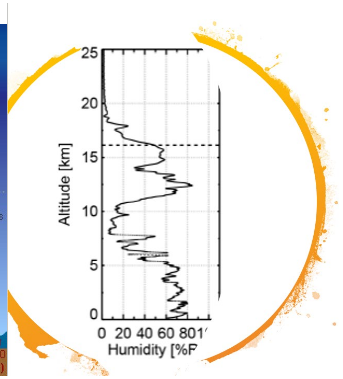
The added value of total column and profiling instruments:
O_3, NO_2, dust and aerosols in the Arctic atmosphere can originate from various sources, both natural (e.g., dust storms, wildfires) and anthropogenic (e.g., industrial emissions).

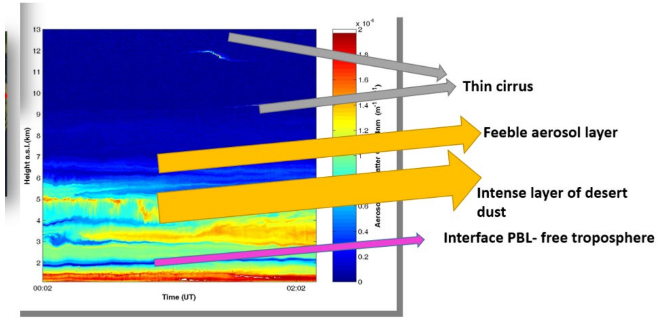
What makes this phenomenon particularly intriguing is that these pollutants often do not necessarily deposit at the ground level upon arrival. Instead, they can remain aloft in the atmosphere, suspended in aerosols or gases.

By cross-referencing ground-based Pandora instruments and other vertical distributed in-situ data with satellite observations, we can improve the accuracy of remote sensing data, aiding in the tracking of pollutant transport.

Ref. Lucia Mona, CNR
15.Sept



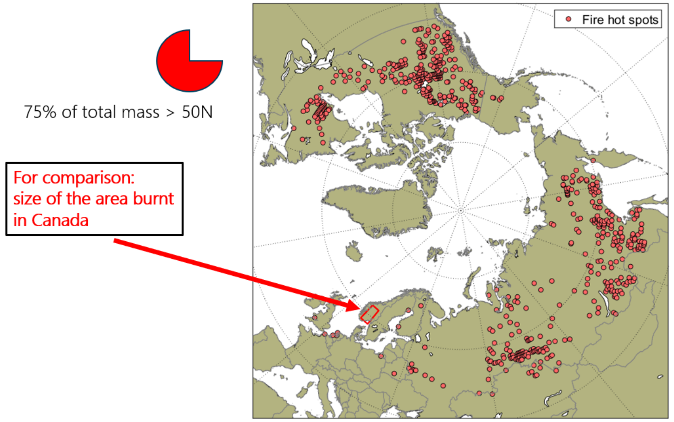




Aerosol lidar measurements @ 1064 nm CNR-Potenza-IT

Wildfires: As the Arctic experiences more rapid warming than other regions, the extended period of warmer temperatures creates favorable conditions for wildfires. Higher temperatures lead to drier vegetation and a longer fire season. Climate change disrupt Arctic precipitation patterns, permafrost melts, release of greenhouse gases like carbon dioxide and methane, exacerbating climate change in a dangerous feedback loop. This, in turn, contributes to more frequent and severe wildfires.

Canadian wildfires May-September 2023:

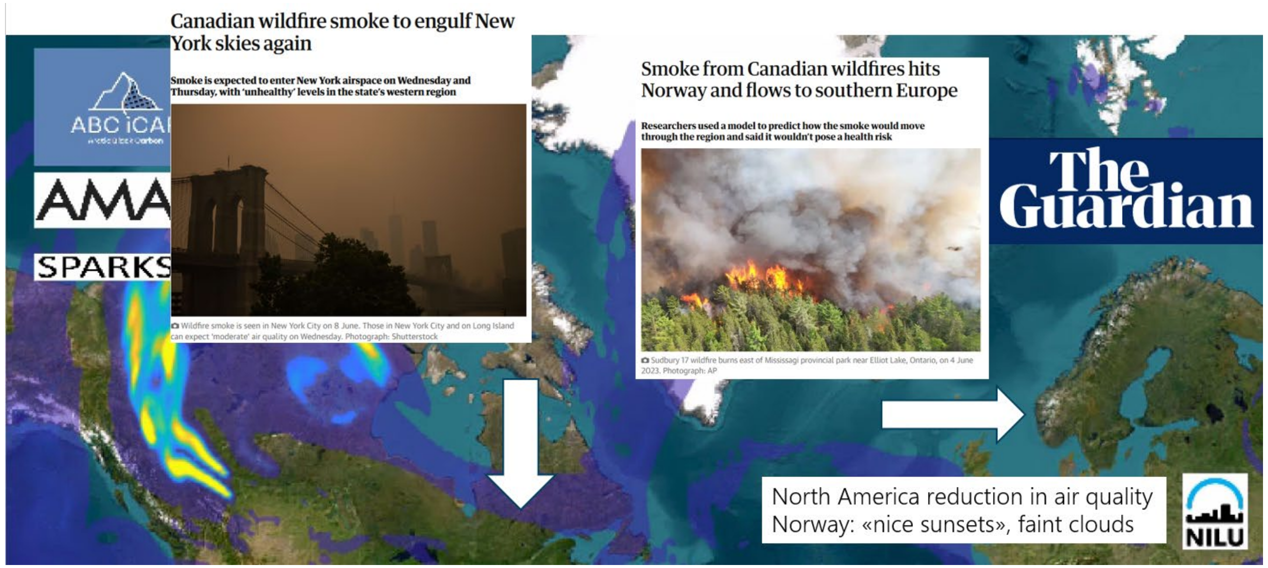


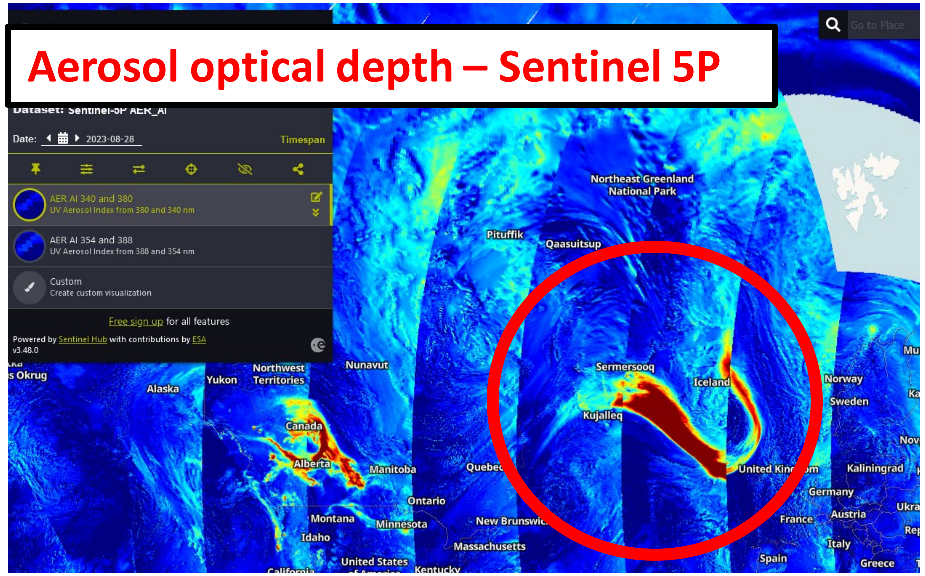
CNC: burnt area:

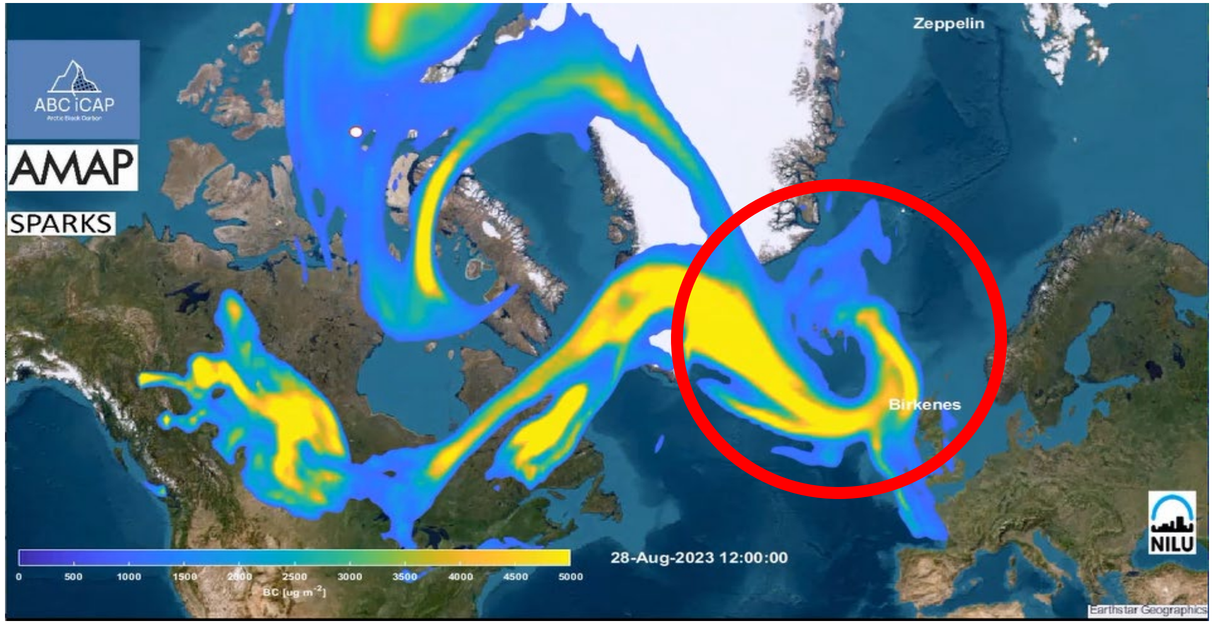
15 Mio ha,

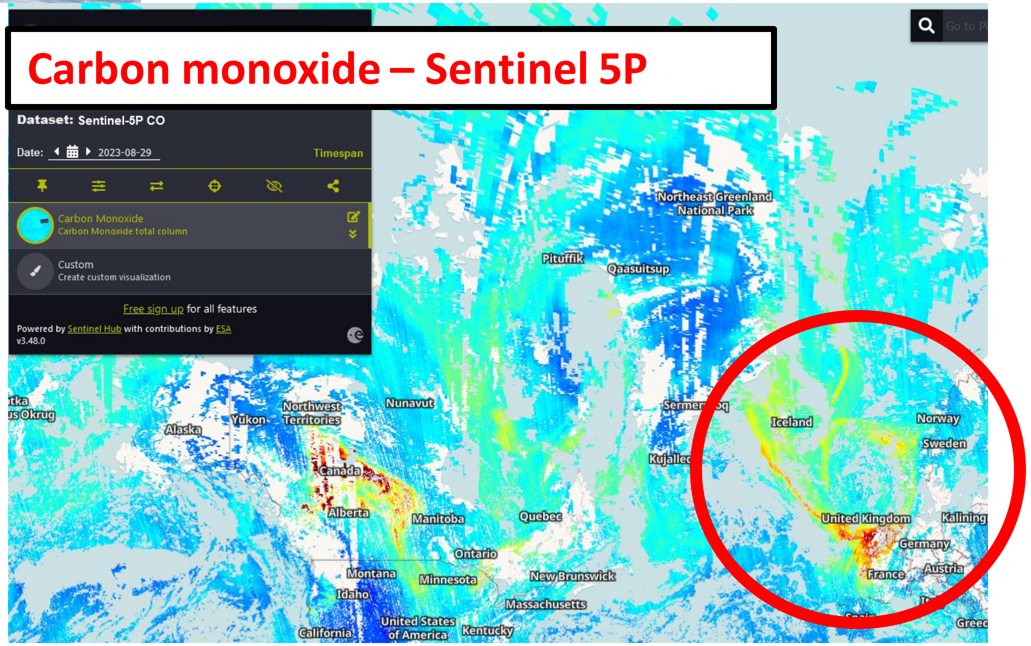
400 x 400 km,

1.5% of Canada

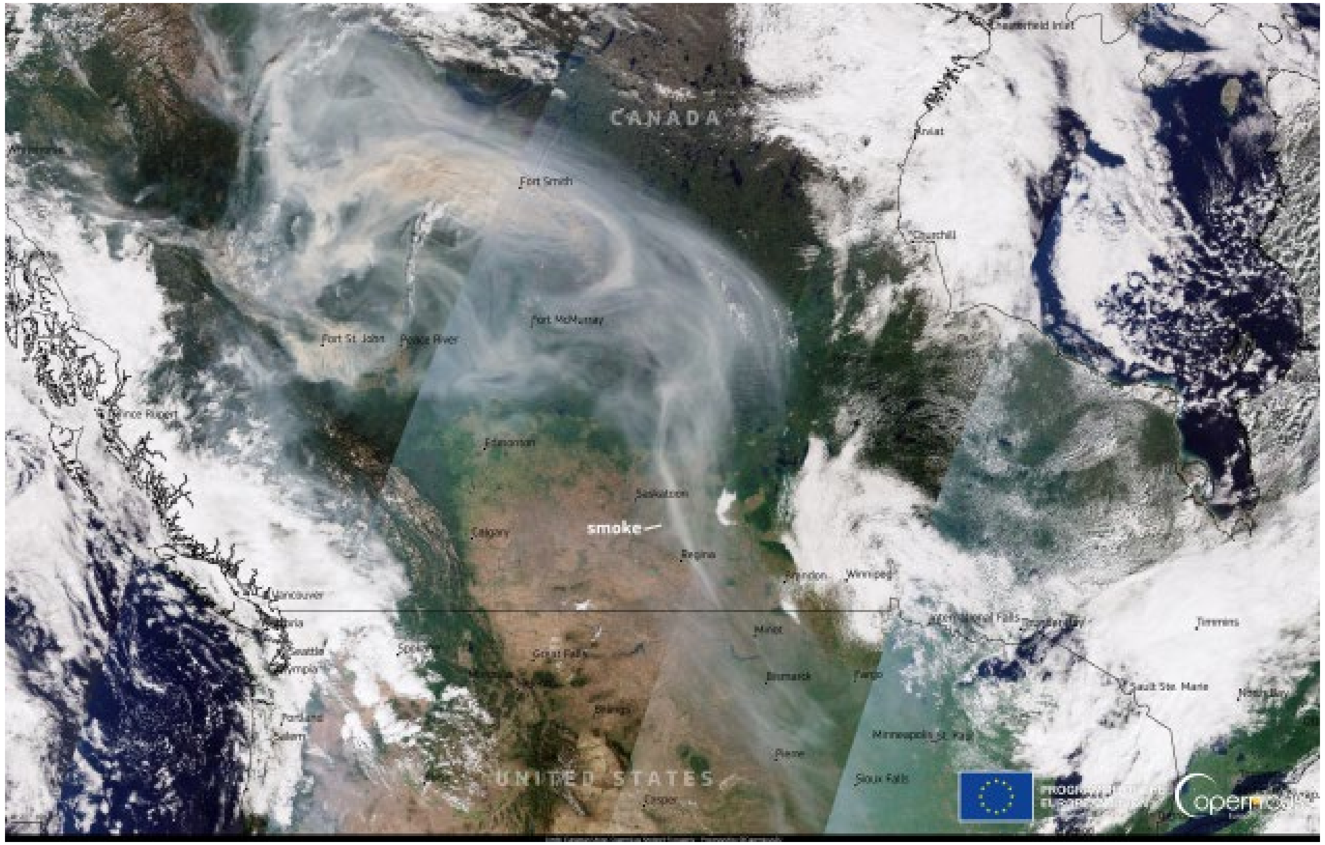




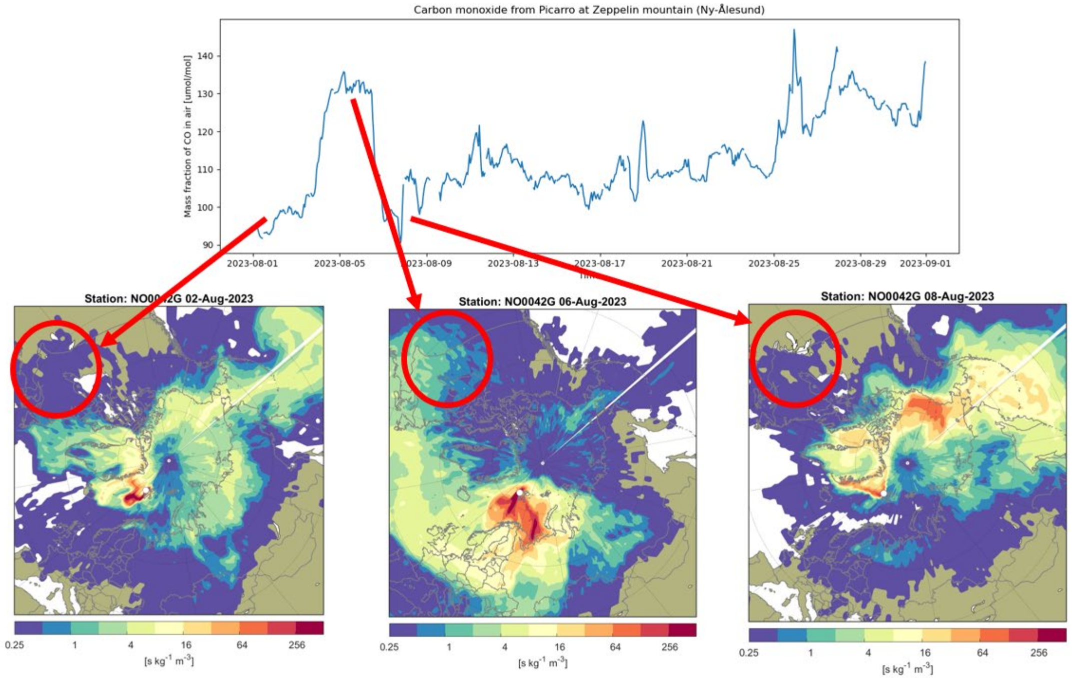




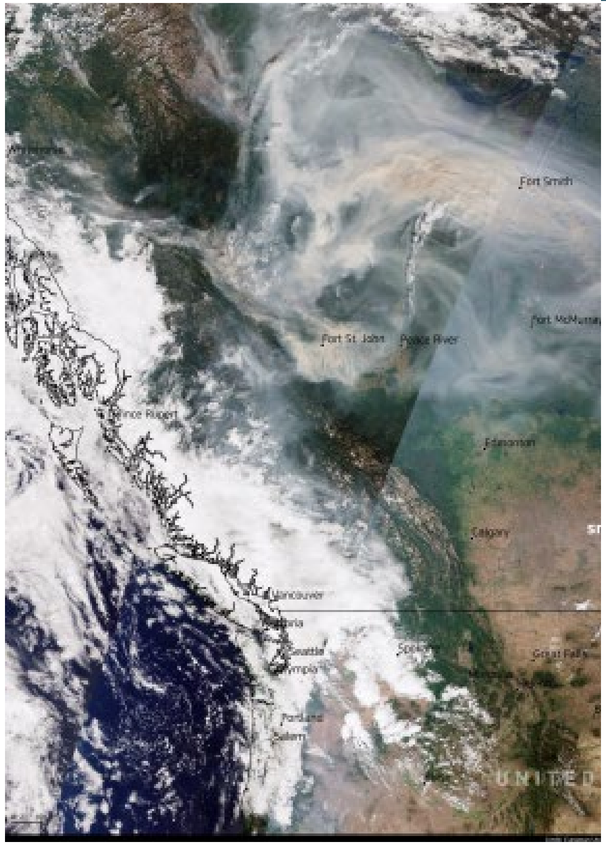
FLEXPART simulation



2023, August 29th
Credit: European Union, Copernicus Sentinel-3 imagery



FLEXPART
Footprint emission sensitivity performed for a passive air tracer.



2023, August 29th
Credit: European Union, Copernicus

evdc esa
esa eo validation data centre

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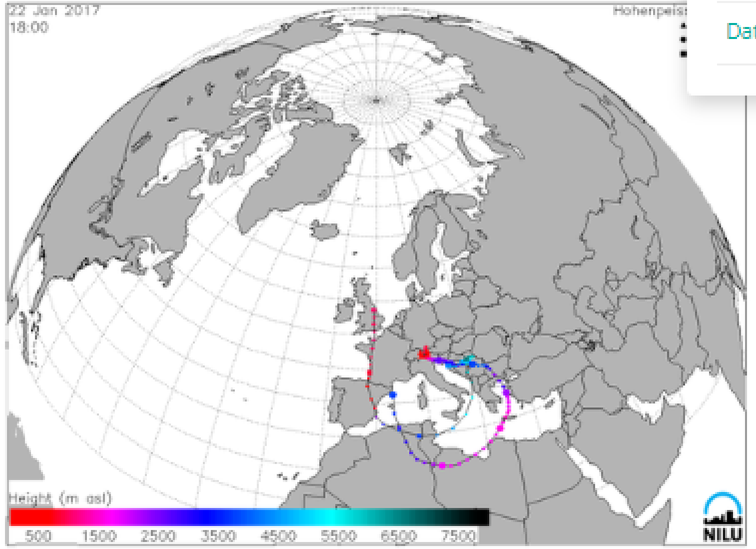
Tools
- GEOMS Tool
- Reading HDF/NC Files
- Creating HDF/NC Files
- FLEXTRA Backward Trajectories
- ECMWF Plots
- Data Formatting Templates

Updated: 06 Oct 2020

FLEXTRA Backward Trajectories

Air mass trajectories are calculated at NILU using the Flextra model de… …peration with Gerhard Wotawa og Petra Seibert (Institute of Meteorology and Geophysics, Wienna) and using meteorological data … …e for Medium Range Weather Forcast). Publications using FLEXTRA results are requested to include an acknowledgement of, and… …el developers.

A few EVDC stations are already added to the FLEXTRA trajectory syste… …s in case you want to access plots and data from other stations, these can be made available upon request. Please follow the … …o browse this tool.



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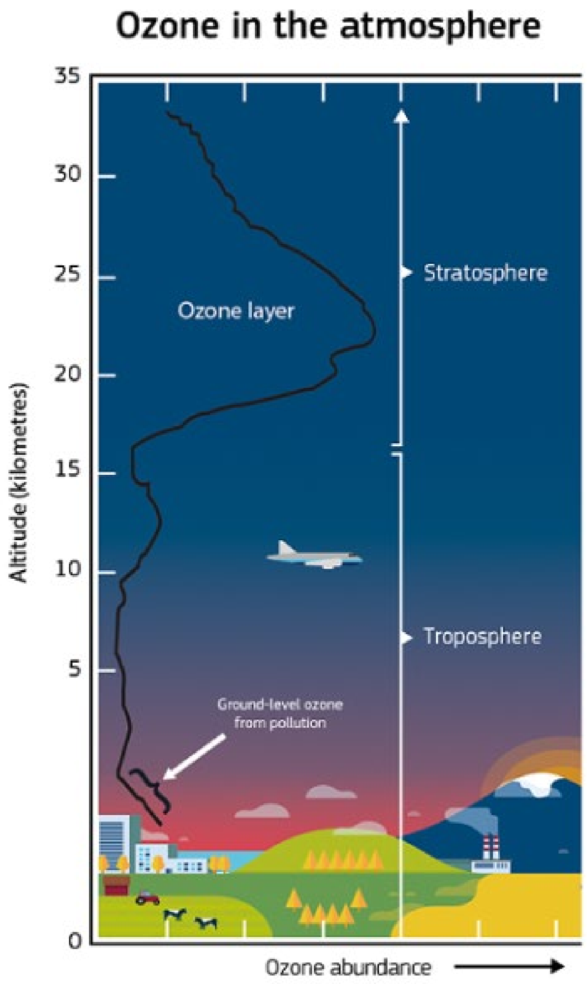
Contact: nadirteam@nilu.no

Ozone Depletion: Ozone depletion in the Arctic and Antarctica has been a significant environmental concern for decades. The primary cause of this depletion is the presence of human-made chemicals known as ozone-depleting substances (ODS), with chlorofluorocarbons (CFCs), halons, and other industrial chemicals being major culprits.

The most notorious example of ozone depletion occurs in the Antarctic region, where an annual phenomenon known as the "Antarctic Ozone Hole" forms during the Southern Hemisphere's spring (September to November). A rapid reduction in ozone concentration, result is a significant decrease in the protective ozone layer, allowing more harmful ultraviolet (UV) radiation to reach the Earth's surface.

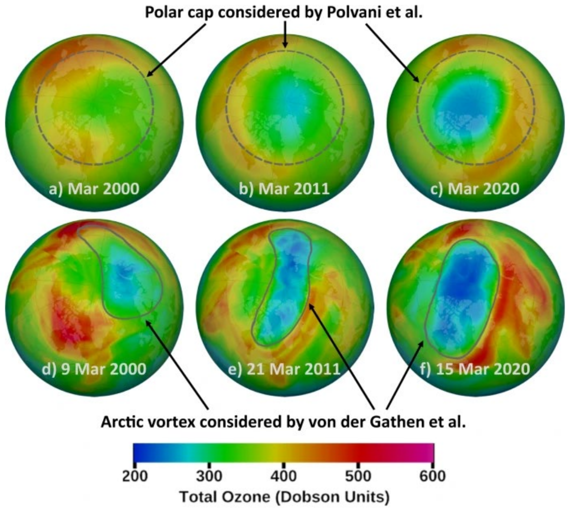
Thanks to efforts like the Montreal Protocol, the ozone hole is slowly recovering, though it is expected to persist for several decades.

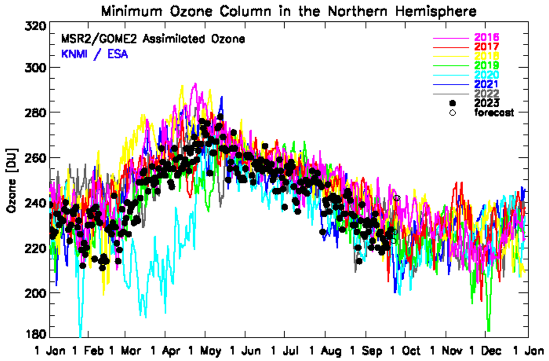


Ozone Depletion

The Arctic's ozone layer is not as consistently impacted as the Antarctic's, partly differences in atmospheric circulation patterns and temperatures, but it can vary more from year to year and is less predictable.

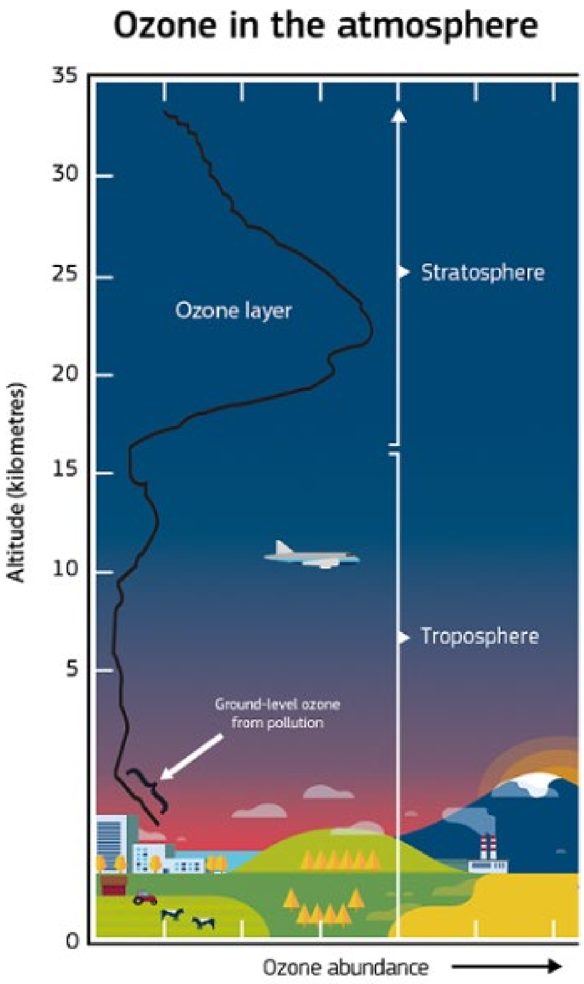
Continued monitoring and research are essential to better understand the dynamics of ozone depletion in the Arctic and Antarctic and to ensure that recovery remains on track.





https://www.temis.nl/

Courtesy: von der Gathen, P., Kivi, R., Wohltmann, I. *et al.* Reply to: No evidence of worsening Arctic springtime ozone losses over the 21st century. *Nat Commun* **14**, 1609 (2023). https://doi.org/10.1038/s41467-023-37135-2

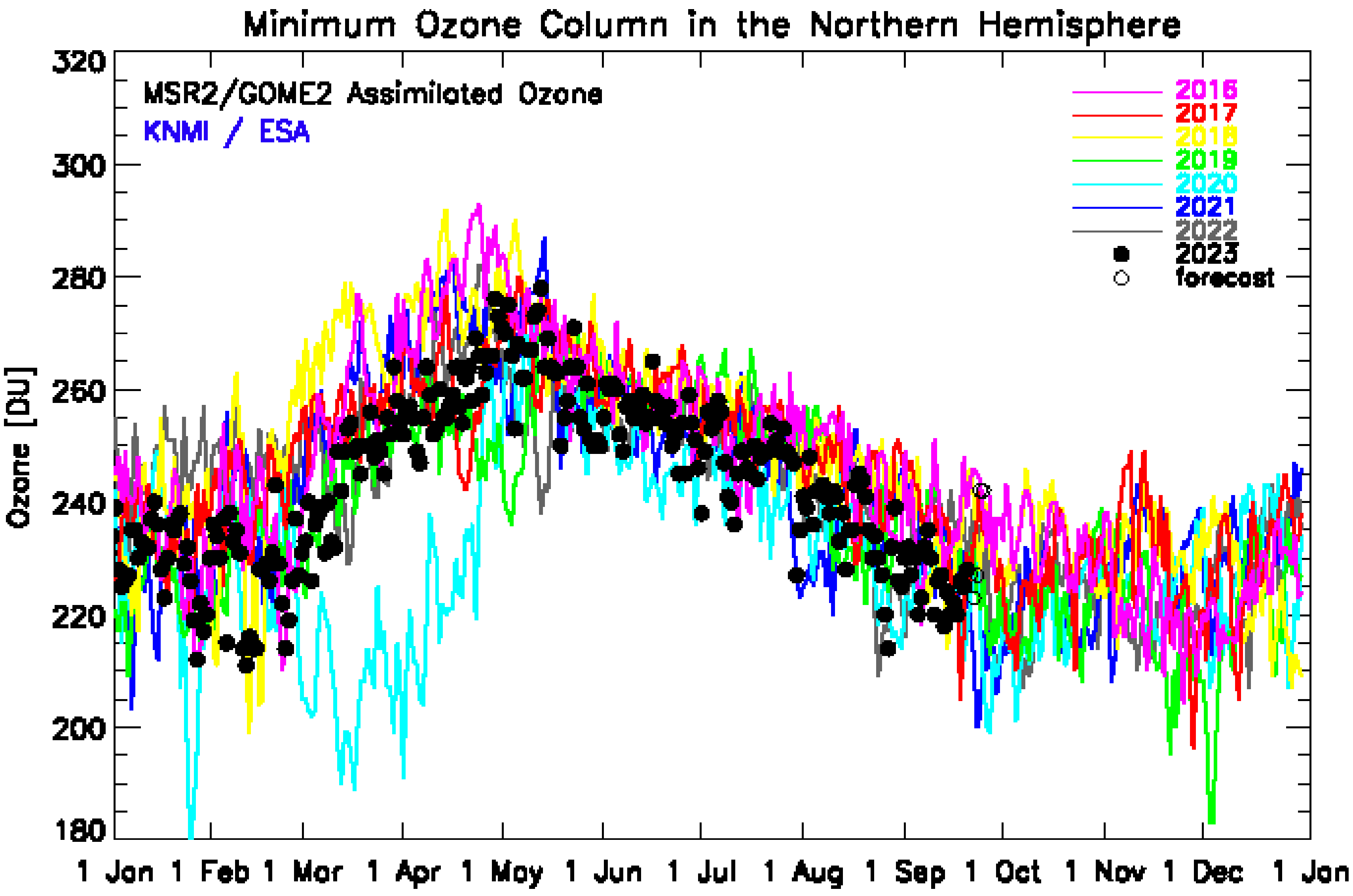


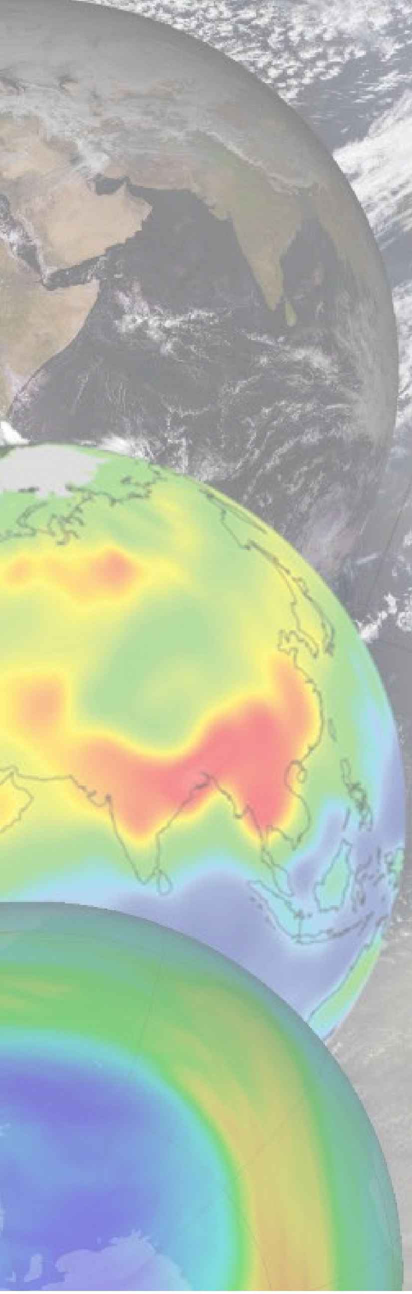
Summary and Conclusions:

The ground based remote sensing system is a complex world with many access points, and with many **capabilities.**
- it exists through the establishment of interoperable systems and FRMs,
- it is a key to produce, enrich and validate satellite products and improving their accuracy and reliability

There has been considerable improvements in the quality and time coverage for data the recent years although the lack of measurements in many regions of the world is still somewhat problematic and areas for improvements.

EVDC supports satellite validation activities, such as providing data from different sources and formats, facilitating data comparison and evaluation, and enables data sharing and collaborations.


Minimum Ozone Column in the Northern Hemisphere
MSR2/GOME2 Assimilated Ozone
KNMI / ESA
2016
2017
2018
2019
2020
2021
2022
2023
forecast
Ozone [DU]
320
300
280
260
240
220
200
180
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan



Thank you!

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ann.mari.fjaeraa@nilu.no
Senior Scientist at NILU