Project title**: Aerosol Optical Depth data Web Interface for data communication to scientists and the public (GAWaodIDC)**

Project duration**: 01.08.2021 – 31.01.2023**

Type of report**: Final report**

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Summary

The GAW PFR network is an aerosol optical depth (AOD) network operated by PMODWRC and supported by WMO-GAW and MeteoSwiss. The proposed project **GAWaodIDC** is aiming to report enhanced information on the processing chain and metadata for all GAW-PFR AOD measuring stations. This was achieved through the development of a website (https://gawpfr.pmodwrc.ch) that provides new and complete AOD information, at one place (**one-stop-shop**), together with the full processing chain and meta-data, according with the Swiss GCOS priorities 1.5 and 1.6. The interface is also a web tool that includes aerosol related applications for different users (scientists, local operators, public).

More specific, GAWaodIDC is a project aiming to ensure that standardized observations of AOD from the GAW-PFR network are archived and made freely available (under CC BY-NC 4.0 licence) to all interested users.

More specific and towards this direction, the activities that have been supported include:

- A complete data archiving of all GAW-PFR Data (existing since 1999), including calibration, uncertainty, raw and processed data;
- A free data sharing portal including all involved metadata in line with the GCOS monitoring principles;
- A science communication aspect including real time data and climatological data (e.g. daily, monthly averages, combined data, instrument comparisons).
- A user support section including standard operation procedures, software and processing guidelines and video tutorials for instrument maintenance.

Data archiving of GAW PFR data has been performed with the help of the PMOD/WRC IT team and hardware infrastructure that was purchased within the project. Archived data and real time data have been produced in a way to be compliant with a web interface technology.

Scientific report

Introduction

Multi-wavelength long term time series of AOD (a GCOS –Essential Climate Variable (ECV)) are crucial for observing the Climate and in addition, they are considered important for various organizations, including the World Meteorological Organization (WMO) within the Global Atmosphere Watch program (GAW) and the European Space Agency (ESA). PMOD/WRC is hosting the World aerosol Optical depth Research and Calibration Center (WORCC) that is responsible for the GAW-PFR (Precision Filter Radiometer) Network of long term AOD measurements.

Environmental research infrastructures are very important pillars for supporting their related communities but also for contributing to the Global Climate Observing System (GCOS). Thus, it is very important that data-related activities of measuring networks, follow specific policies related with data e-infrastructures and data workflows. In addition, climate data related systems need to ensure harmonization, data interoperability and applications within the measuring communities worldwide and especially in GCOS. The key aspect for the success of these e-infrastructures is to ensure that standardized observations, including traceable and transparent metadata of measured parameters, are archived, made freely available to all interested users and that they include the full data chain: from raw to processed observations, including uncertainties, to final data analysis. GCOS priorities requires that such information should be stored in a national or/and international level. An additional important aspect is data visualization and the use of auxiliary measurements and models in order, together with the related metadata, to provide a tool towards a one-stop-shop web information platform.

PMOD/WRC has deployed during the last 20 years, ground-based sun-photometers measuring in high temporal resolution (1 minute), spectral AOD (Kazadzis et al., 2018a). Currently, more than 30 PFR instruments are operating worldwide (Figure 1), 14 of them are located at sites defined by the WMO Scientific Advisory Group for aerosols and maintained/calibrated/processed by PMOD/WRC.

The aim of **GAWaodIDC** project is directly related with priorities 1.5 and 1.6 of the Swiss GCOS strategy plan. This project aims to provide free and open access to the full chain (raw data, calibration, final data, uncertainties) of standardized observations of AOD from the GAW-PFR network (resulted from the previous GCOS funded project), complemented with metadata information, together with simple tools for quality assurance (QA) and data analysis, through a web interface that includes information for scientists, instrument operators and the public.

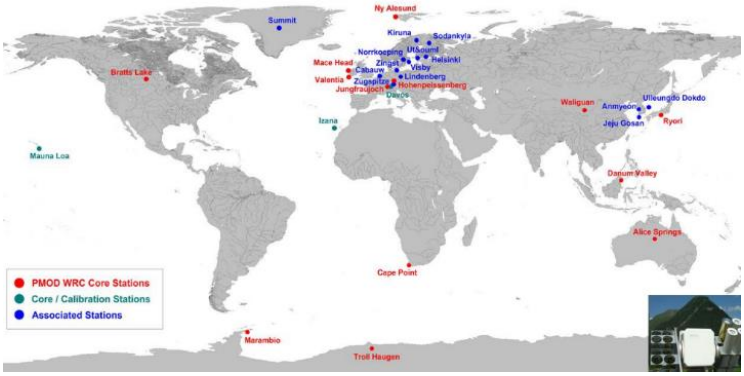
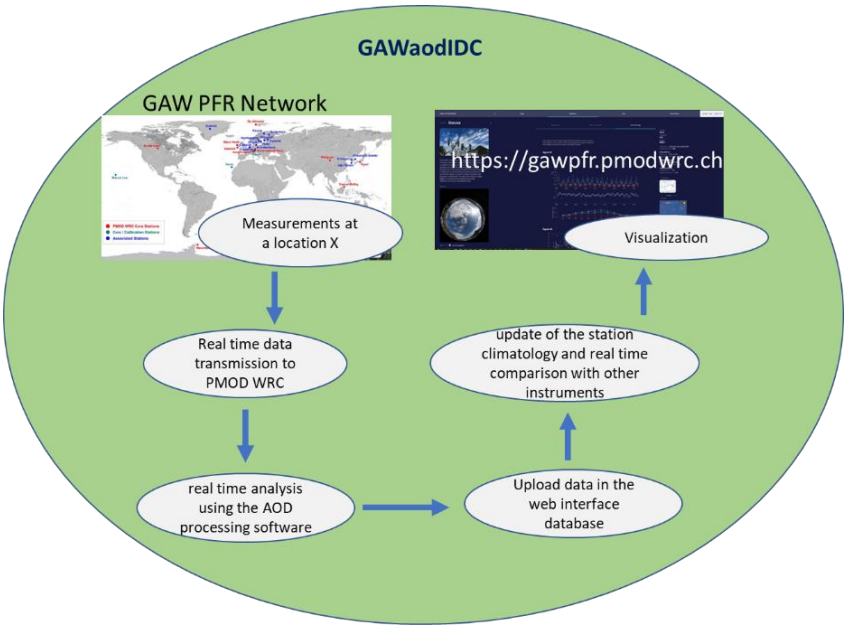


Figure 1: The GAW-PFR global Network for multi-wavelength AOD measurements

Methods and activities

In the following section we describe the methods and data used, and the completed activities according to the proposal. The main idea and the steps towards the goal of the web tool initialization is described in the following schematic S1.



S1. The GAWaodIDC methodology towards the web tool

Phase 1: Data and metadata archiving to a database

During this first phase we have created an internal PMOD/WRC database based on existing hardware and software data acquisition system but also with a purchase of a dedicated hardware/storage system to be used as the web interface baseline. In the database we have included information from GAW-PFR stations such as:

- Raw data (one-minute voltage in four wavelengths, time),
- transmittance and AOD data

In addition, metadata such as: Station information, calibration history, instrument optical characteristics, AOD and Ångström Exponent (AE) climatological statistics and the possibility to include results from collocated sun-photometers and/or satellite-based AOD climatological information.

Most work towards this project goal was to structure the database in a way that the web interface designers could easily and with no web/processing related delays, use the data for the interface. This includes the database organization and hierarchy using existing (WORCC PMOD/WRC) software related tools. In addition, real time data transmission (30 min to 1 h for key stations and once a day for the rest) from all GAW-PFR stations and the real time AOD processing tools developed at WORCC PMOD/WRC have been tailored in a way that they populate the database, directly translated to visualized results to the web interface dedicated web pages. An example for Davos can be found in: https://gawpfr.pmodwrc.ch/#/station/0

For these stations the data transfer is every 30 min, the signal, AOD and AE are shown in real time as well as the alignment of the instrument and other instrumental parameters (related with quality control and quality assurance procedures) to ensure the reliable operation of the instrument. Auxiliary information such as sky-camera images are also included when available.

To accommodate for the estimated ~6.5 Terabytes of project data, PMODWRC pre-existing storage system needed to be extended. The storage extension required the installation of an

additional disk shelf containing 18 additional hard disks. A virtual storage appliance has been deployed using this additional storage space. All storage is protected against hardware failures by means of RAID and multiple redundant components.

Phase 2: Web interface design and features

For this phase a professional web-designing company (WDC - https://blindstudio.gr/)) has been hired. WORCC PMOD/WRC scientists have been collaborating with the WDC on the web interface and database design and presentation strategy according to the project needs. The PMOD/WRC IT department has provided all the infrastructure and tools for realization of the site and database of the PMOD/WRC servers.

A video on practical information on instrument installation, operation and maintenance has been designed and recorded. The Guidelines for PFR operators page https://www.pmodwrc.ch/en/world-radiation-center-2/worcc/guidelines-for-pfr-operators/ contains the video, data acquisition software and guidelines for setting up the standard PFR data acquisition software (LoggerNet) and maintenance instructions. The video section will be continuously renewed according to PFR user needs and suggestions.

Phase 3: Implementation of near real time data and additional tools

Operational links between the database (WP1) and the developed website (WP2) have been optimized and evaluated. This work among PMOD/WRC scientist with the WDC, has been concluded and the web portal has been in operational mode in March 2023, with five months delay.

The data base has been designed and realized on mySQL serving as second storage of all levels of information for future possibility of providing the data to GAW-station operators through the website. Raw and processed data as well as metadata are stored in 1 min resolution for 1 instrument of each station. For optimizing the speed of the visualization of the data on the web subset tables are created containing the real-time data updated every 30 min for each site. Core GAW-PFR calibration stations (Davos, Jungfraujoch (Switzerland), Izaña (Spain), Mauna Loa (USA)) and ACTRIS (EU research infrastructure project - Aerosol, Clouds and Trace Gases Research Infrastructure) related stations (OHP (Observatoire de Haute-Provence, France) and VLD (Valladolid)) will be transferred and processed in real time (hourly).

Phase 4: Demonstrating the use of the new web-site to a specific user community

The web interface includes a number of features that all visitors and data users can identify, such as:

- The analysis and statistics of time series of AOD and AE in real time.
- Real time comparisons with other networks/instruments (e.g. AERONET)
- Day to day overview in order to serve as quick looks during major aerosol events (e.g. fires, dust events etc)

Concerning outreach of the web page and the tools.
In a university level they will be disseminated and used for relevant exercises in aerosol related lectures at ETH Zurich (MSc students - Institute of Atmospheric and Climate Science – Atmospheric Remote sensing course – Fall semester 2023), through personal communication with all GAW PFR operators and related scientists. Also, in related schools such as the WMO-organized GAWTEC (e.g. GAWTEC 41 “Aerosols” (16-27 Oct. 2023, https://www.gawtec.de/). Finally, at workshops and schools organized by the COST Networking Action HARMONIA (https://harmonia-cost.eu/ International network for harmonisation of atmospheric aerosol retrievals from ground-based photometers) that is led by this project PI.

Finally, we aim to disseminate the web page to various aerosol related user portals (GAW, SDSWAS (Sand and dust warning system), GCOS, OSCAR, CAMS) and also through existing projects collaborators (ACTRIS, MAPP (Metrology of Aerosol Optical properties, ESA-QA4EO (Quality assurance for Earth observations) and others.

The accomplished milestones deliverables can be summarized in the following table:

WP num.	Month	Type	Description	Progress
1	2	M1	Purchase of hardware infrastructure needed	Purchased
1	4	D1	Database with data and metadata completion	Has been completed
2	4	M2	Hiring the WDC collaborators	Company Blind Studio hired (https://blindstudio.gr/)
2	9	M3	Presentation of the web tool design	Blind Studio has presented different versions of the web design
2	9	M4	Development of the online Video tutorials	Video has been designed and shot in month 18 at PMOD/WRC, Davos.
3	12	M5	Real time data inclusion in the web portal	Real time data have been included in the current portal interface
3	15+5	D2	Web portal finalization for GAW-PFR data	The website has been finalized with a delay of 6 months
4	18+5	D3	Inclusion of data demonstration tools into the web portal	Will be continuously updated with new information and latest versions.
4	18	M6	Communication of the web portal to OSCAR and to various aerosol related user portals and GAW-PFR local scientists and technicians	The PIs and operators of the GAW-PFR stations have been informed about the new website.

Results

Database

The data base has been designed on mySQL serving as storage of all levels of information for future possibility of providing the data to GAW-station operators through the website.

The database has been organized in the following type of tables:

- PFR_NET_SITES
  - Containing information about each site location, collaboration institutes and personnel, long term AOD and AE statistics and tends, links to available sky/web-cameras. Part of this information are presented in https://gawpfr.pmodwrc.ch/#/stations.
- Data with 1min time resolution
  - RealTime_LOC (where LOC is the abbreviation of each station)
    - This table contains raw and processed data as well as meta data, as atmospheric pressure, ozone, nitrogen dioxide, optical depth of trace gases and Rayleigh scattering, in 1 min resolution for one instrument of each station. For optimizing the speed of the visualization of the data on the table RealTime_LOC contains only data of the current day and is updated every 30 min to 1 h for the core sites.
  - LOC
    - This table contains the same information as the RealTime_LOC, but for the whole operational time of the station.
  - LOC_yyyymm
    - These tables are views of the the LOC table containing only the information over one month (mm) of the year (yyyy) and columns that are used in the visualization page to optimize the speed.

- RealTime_Daily_LOC
    - Daily mean values of the table LOC. This table is used in the “Daily Overview” tab, in the interactive figure of AOD at 500 nm and AE as a function of date.
- QA_DailyMean_LOC, QA_MonthlyMean_LOC, Climatology_LOC
    - Daily, Monthly mean values and climatology of each station after quality assurance processes. Currently they contain the results of the GCOS-1 project and will be updated in yearly bases along with the submissions to to the WMO database (WDCA-NILU).

Website Description

The data display webpage is linked to the main PMOD/WRC webpage thought the pages:

https://www.pmodwrc.ch/en/world-radiation-center-2/worcc/gaw-pfr/
https://www.pmodwrc.ch/en/world-radiation-center-2/worcc/

by clicking the world map.

The initial page (https://gawpfr.pmodwrc.ch/) of the data display website is a map of the stations of the GAW-PFR network. The funding of the webpage from GCOS and MeteoSwiss is acknowledged by the logos located at the bottom right corner, linked to the Info tab where detailed information about the GAWaodIDC is provided.
The station can be selected on the map or through the drop-down menu.
The colour of the dots shows the status of the station

1. Active: data flow ok, last calibration date is within 1.8 years (cyan).
2. Uncalibrated: data flow ok, last calibration date has exited the 1.8 years (blue).
3. No data: data flow not ok (red).
4. Inactive: Station closed, or operation suspended due to technical reasons (black)

Upon selection of a station, some basic information, a photo of the station and the last AOD at 500 nm value and AE are shown, as well as a preview of a sky/web-camera if available.

Pressing “VISIT STATION” the user will be redirected to to the “Real Time” tab of the selected station.

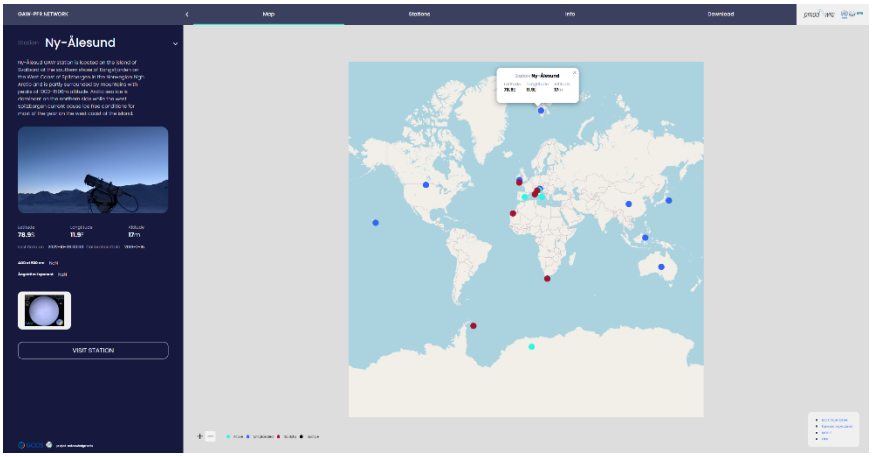


Figure 2: Snapshot of webpage initial page.

Real Time data tab

The short description of the station and a side bar with available sky/web – cameras remain, and the logos of the hosting institutes and projects supporting the activity are added. The side bar can be hidden with the arrow “<” net to the GAW-PFR NETWORK.
The content of the webpage is (snapshot in Annex, Figure 9):

1. Information about the serial number of the instrument and daily mean parameters related with the status of the instrument (sensor and housing temperature, reference voltages

and internal pressure and leakage of N_2) as well values related with the AOD retrievals (atmospheric pressure at the location of the instrument, and total column of ozone).

2. Plot of the signal of the four PFR channels normalized at 1AU (Astronomical Unit) as a function of local time of the station.
3. AOD of the PFR at four wavelengths as a function of of local time of the station. The data are selected based on the automatic quality assurance and cloud flagging algorithms. If there is a co-located Cimel instrument part of AERONET, or a second PFR or any other sun-photometer that provides online data, hereafter referred as device under test (DUT), the AOD of the DUT at 4 wavelengths is over plotted. By pressing on the legend of each wavelength the AOD time series can be hidden/shown.
4. If DUT is available, the AOD difference (DUT-PFR) as a function of the local time of the station is shown. The compared pair of wavelengths are described in the legend. The grey dots represent the maximum uncertainty of AOD based on WMO recommendations (0.05+0.01/air mass).
5. Ångström exponent (AE) as a function of local time of the station. If a DUT is available, a selected AE is overplotted.
6. Alignment of the PFR to the sun. The four-quadrant sensor of the PFR provides information for the hardware alignment of the PFR and the quality of the sun-tracking of the solar tracker. The Left-Right (LR) azimuthal and Up-Down (UD) zenithal parameters should be within ±10 arcmin to provide accurate results. In 6a the LR, UD are plotted against the local time of the station and in 6b on a target with 4 levels of 5, 10, 15, 20 arcmin.

On the right panel there is information about the location of the station, calibration date of the instrument, and daily mean values of AOD and AE as well are their long term mean values for an immediate identification of a possible high AOD event or malfunction of the PFR.

Moreover, there are backward air mass trajectories to help the user have an extra information of the airmasses arriving at the station and identify the source of AOD load. The trajectories are calculated using the HYSPLIT - NOAA open access software [*Stein et al.*, 2015].

The Windy.com open access weather forecast module helps the user organize better the daily maintenance to the PFR instrument (e.g., station visit for cleaning, adjustments in alignment).

Daily Overview

In the Daily Overview tab, the user has the ability to see the time series of the measured daily mean AOD and AE over the current year as a function of date. A day of interest can be selected on the interactive plot or thought the calendar. Upon day selection the user can see the same information as in the Real Time tab for that day (Figure 3).

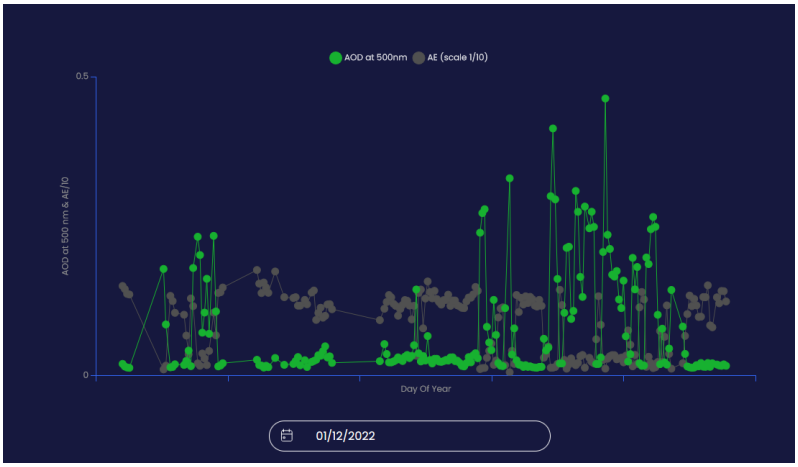


Figure 3: Snapshot of the interactive time series plot of daily mean AOD and AE (scaled by 0.1) as a function of date for Izaña station

Climatology tab

The Climatology tab contains information about the climatology of the GAW-PFR stations as have been calculated during the MeteoSwiss GCOS project “The Global Atmosphere Watch Precision Filter Radiometer (GAW-PFR) Network for Aerosol Optical Depth long term measurement. Figure 4 shows an example for Davos station.

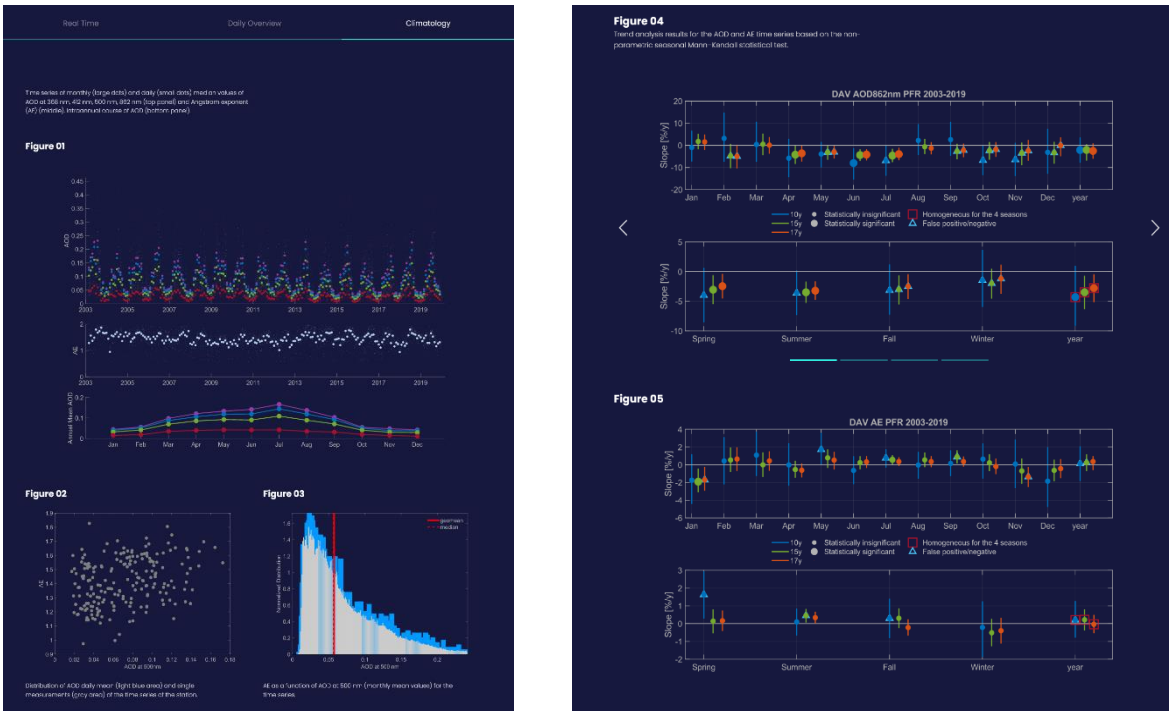


Figure 1: Snapshot of the climatology page of DAVOS.

Stations tab

The station tab contains the list of station available on the website along with some information about the location of the station, WMO classification, length of time series, long term means and trends of AOD at 500 nm and AE.

Figure 5: Example of station details

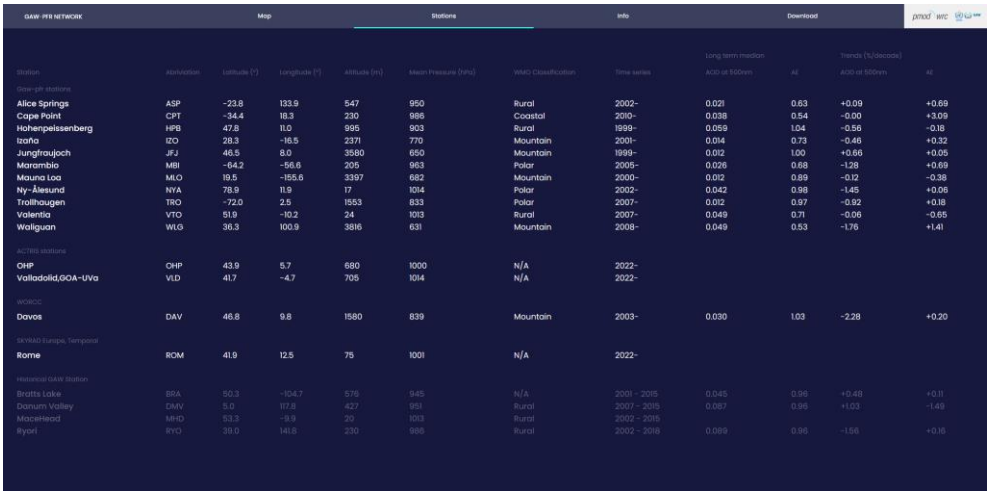


Figure 6: snapshot of the Station tab.

Info tab

The Info tab contains basic information of the GAW-PFR network, acknowledgments of the funding agencies of the webpage and the GAW-PFR network collaborator, hosting institutes and projects related to the operation of the sites.

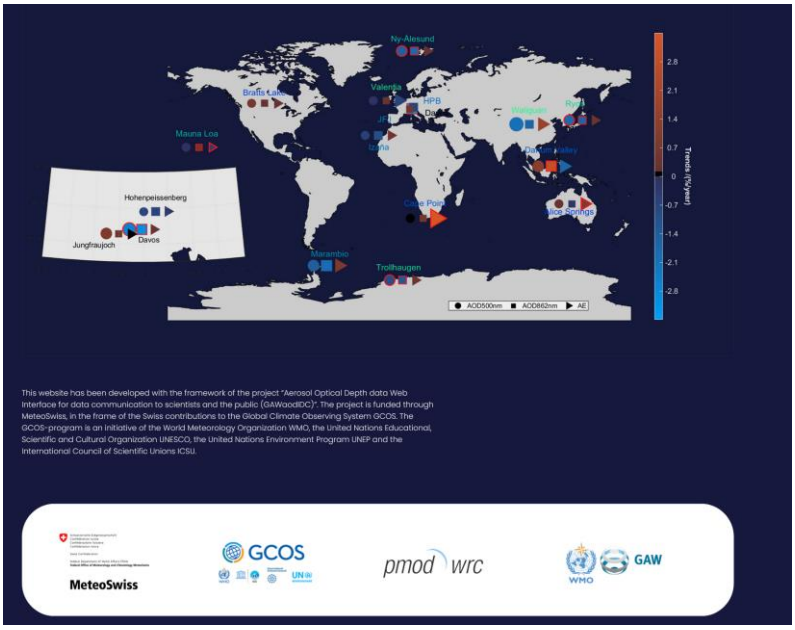


Figure 7: Snapshot of the Info tab.

Guidelines of PFR operators

The link for this page is located currently in the Info tab. The Guidelines for PFR operators page https://www.pmodwrc.ch/en/world-radiation-center-2/worcc/guidelines-for-pfr-operators/ will be continuously updated with the latest version of software as well as with help full documents and videos.

Download tab

The download tab gives the ability to the user to download data from the GAW-PFR Network in different time resolutions.

All measurements refer to the 1 min resolution available for the PFR instruments, the default option is download AOD and Ångström parameters along with their uncertainties. The user can also add the information about the concentration of trace gasses and atmospheric

pressure used in the AOD retrievals. Moreover, there is an option to select only clear sun and quality assured data.

The daily, monthly mean and climatology datasets are the datasets produced in the previous GCOS project “The Global Atmosphere Watch Precision Filter Radiometer (GAW-PFR) Network for Aerosol Optical Depth long term measurement”. The download function is currently operational on a provisional mode, to be gradually finalized for all network stations.

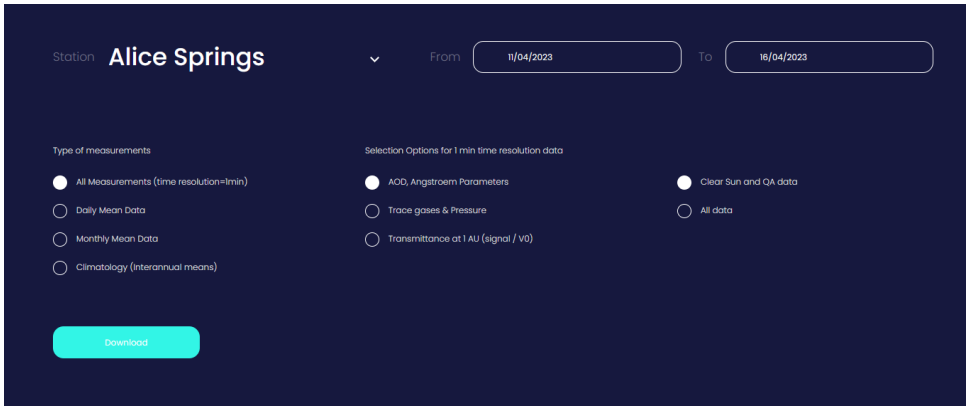


Figure 8: Snapshot of download page.

Conclusions and limitations

The project is based on an international activity, the Global Atmospheric Watch Precision filter Radiometer (GAW-PFR) network that directly supports WMO-GAW and GCOS objectives and goals. GAW-PFR is a monitoring program maintained from PMOD/WRC and deals with a GCOS and WMO defined ECV (multi-wavelength aerosol optical depth). The aim of this project was directly related with priorities 1.5 and 1.6 of the Swiss GCOS strategy.

The main goal of the project was the development of the GAW-PFR web-interface:

https://gawpfr.pmodwrc.ch/

that contains:

- Quality assurance and control features for GAW PFR operators
- Real time measurements
- Climatology of all measurements for each station

As described the work included:

- the output of the previous funded project “GAW PFR network” and the data reanalysis that have been performed.
- Technical upgrades on the hardware and storage system of PMOD/WRC,
- the collaboration with the external web developing company for building the interface and a number of other technical aspects described in the previous section.

With the main outcome, the provided service/website that is available for all interested parties on GAW PFR AOD data, quality assurance, climatology statistics and instrument comparisons.

Limitations to the project and brief explanation

Main objectives of the project have been achieved. However, the web site needs a period of optimisation to identifying possible improvements on the data visualization and provision based on the web page users’ comments and recommendations. The recommended and planed upgrades such as cover page, map optimization, will be performed from WORCC PMOD/WRC during the next two years in collaboration with the WDC. Part of the agreement with the web developers includes the option on improving the page in case of certain user requirements. Improving and disseminating the web portal information will be a continuous task for PMODWRC as long as GAW-PFR continue to operate.

Explanation in case of deviations from the activities planned.

Web developing has been delivered with a 5 months delay and the project had to be extended for two and a half months. This delay also brought inability to finalize the population of all past data from all stations (download option), a task to be completed till September 2023. In addition, the proper dissemination of the web page (e.g. to OSCAR surface) has not been performed during the course of the project. The action is foreseen to be completed May - June 2023.

Outreach work, publication of data and results

The GAW PFR Network has been presented at the Swiss National GAW/GCOS Symposium – September 13 to 14th 2021. Results included aspects of the previous funding project on data homogenization and recalibration (project: The Global Atmosphere Watch Precision Filter Radiometer (GAW-PFR) Network for Aerosol Optical Depth long term measurements).

Results of the project including calculated statistics on daily, monthly, yearly AOD and Angstrom Exponent data and also trends has been presented in the International Radiation Symposium, July 4-8, Thessaloniki, Greece. The poster presentation is attached in Annex 2.

Outlook

The GAWPFR web page development is the starting phase of a long/term operation of this product/web site and database. PMOD/WRC is going to continuously improve the web page information and data provision, based on new developments, ideas and user-oriented requirements.

The web tool is going to be also used as a quality control tool for the scientists responsible for the GAW-PFR smooth operation and for local instrument operators. In addition, the web tool includes a real time comparison tool and interface for the collaboration of with the Calibration of Aerosol Remote Sensing group of ACTRIS and other activities and also a database for any interested person to download and use the data for various atmospheric studies.

Contributions

Principle investigator: Stelios Kazadzis (SK), Co-PI Natalia Kouremeti (NK)

Webpage design: Charis Karantzas (blindstudio.gr) in collaboration with NK and SK

Webpage programming: Giorgos Rizos, Nikos Koukourouzis, Stelios Pelekis (kukarika.com)

Database design and realization, online GAW-PFR network analysis, data quality control and assurance, design realization and operation of prototype webpages, guidelines page: NK

Trajectories: NK, Akriti Masoom (PMOD/WRC)

Reporting: SK, NK, Julian Gröbner

Project management: SK, Eliane Tobler (PMODWRC)

Collaborators: PMODWRC IT team: Marco Senft and Fabrizio Vignali

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Stein, A. F., et al. (2015), NOAA's HYSPLIT Atmospheric Transport and Dispersion Modeling System,doi:https://doi.org/10.1175/BAMS-D-14-00110.1.

Annex 1

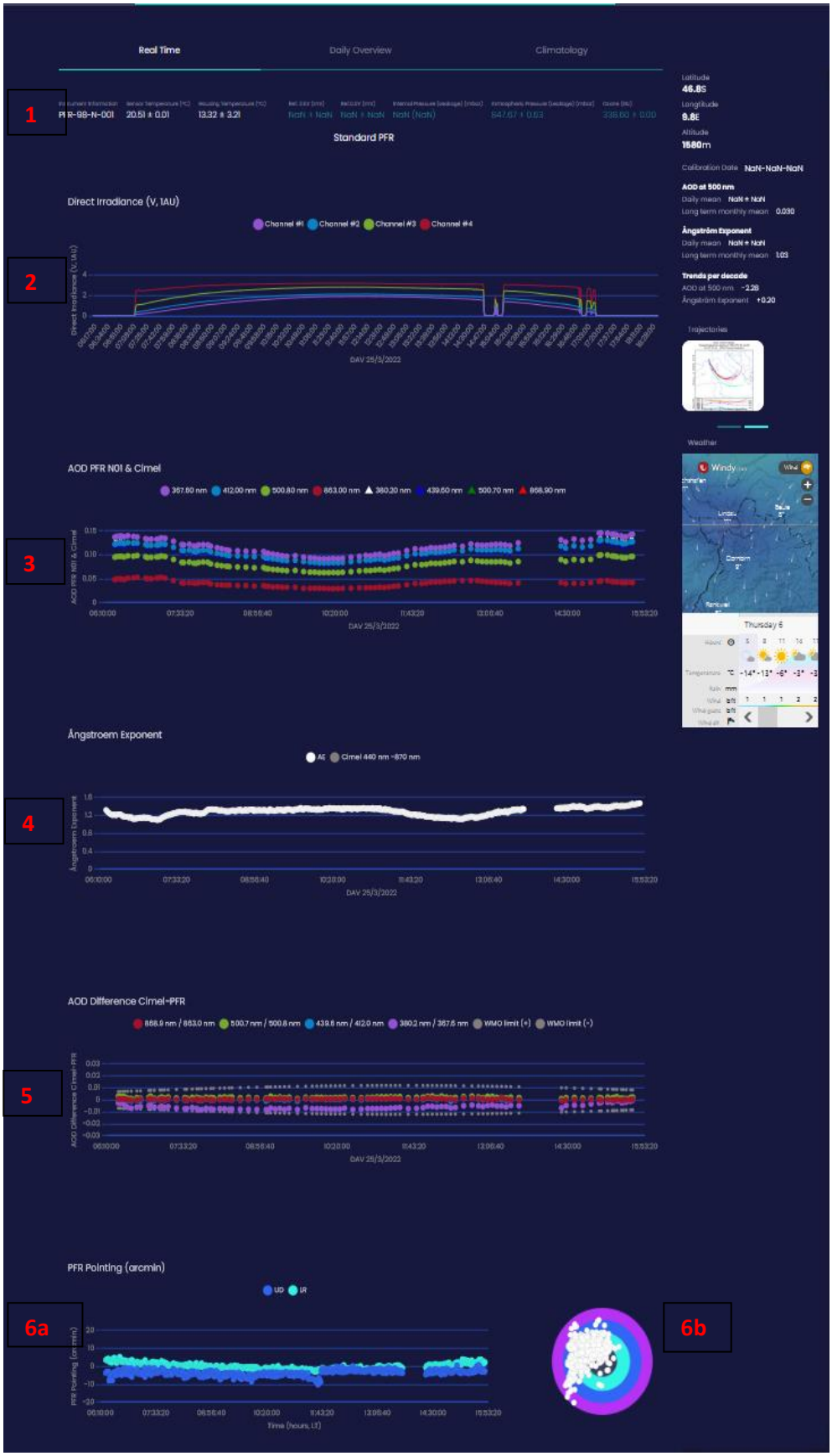

Figure 9: Snapshot of the Real Time tab for the Davos station

Annex 2

Poster presented in the International Radiation Symposium in Thessaloniki, Greece, July 2022