



Front Cover: Front view of the PMOD/WRC building during IPC-XIV. The fine weather was ideal for the participants.

Das PMOD/WRC ist eine Abteilung der Stiftung Schweizerisches Forschungsinstitut f. Hochgebirgsklima und Medizin in Davos, Schweiz.

The PMOD/WRC is a department of the Swiss Research Institute for High Altitude Climate and Medicine (SFI) in Davos/Switzerland.

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Physikalisch-Meteorologisches Observatorium Davos und Weltstrahlungszentrum PMOD/WRC

Unsere Mission

Wir sind ein international anerkanntes Kalibrierzentrum für meteorologische Strahlungsinstrumente. Zu diesem Zweck entwickeln wir Strahlungsinstrumente, sowohl für den Einsatz am Boden, als auch satellitengetragen im Weltraum. Unsere Forschung konzentriert sich auf den Einfluss der solaren Strahlung und der Sonnenaktivität auf das Klima der Erde und deren Atmosphäre.

Geschichte des PMOD/WRC

Das Physikalisch-Meteorologische Observatorium Davos (PMOD) erforscht seit seiner Gründung im Jahr 1907 den Einfluss der solaren Strahlung auf das Klima der Erde. Im Jahr 1926 schloss sich das Observatorium dem Schweizerischen Forschungsinstitut für Höhenklima und Medizin Davos an und ist seither Teil dieser Stiftung. Auf Antrag der Weltorganisation für Meteorologie (WMO) beschloss der Bundesrat 1970 die Finanzierung eines Kalibrierzentrums für Strahlungsmessungen als Beitrag der Schweiz an das Weltwetterbeobachtungsprogramm der WMO. In der Folge wurde das PMOD mit der Errichtung und dem Betrieb des World Radiation Center (WRC) beauftragt.

Kernaktivitäten

Das World Radiation Center unterhält den Primärstandard für die solare Bestrahlungsstärke, der aus einer Gruppe von hochpräzisen Absolutradiometern besteht. Als Reaktion auf weitere Anfragen der WMO wurde 2004 ein Kalibrierzentrum für Instrumente zur Messung der langwelligen atmosphärischen Strahlung und 2008 ein Kalibrierzentrum für spektrale Strahlungsmessungen zur Bestimmung der atmosphärischen Trübung eingerichtet. Seit 2013 wird auch das Weltkalibrierzentrum für UV von unserem Welt-Strahlungszentrum betrieben.

Heute besteht das Welt-Strahlungszentrum aus vier Abteilungen: Solare Radiometrie (WRC-SRS), Infrarot-Radiometrie (WRC-IRS), atmosphärische Trübung (WRC-WORCC) und UV-Radiometrie (WRC-WCC-UV).

Das PMOD/WRC ist vollständig in den Europäischen Verband der nationalen Metrologieinstitute (EURAMET) und in den Rahmen des Bureau International des Poids et Mesures (BIPM) integriert. Das PMOD/WRC ist assoziiertes Mitglied von EURAMET und wurde im September 2002 durch METAS beim BIPM als designiertes Institut (DI) für die Grösse "Solare Bestrahlungsstärke" im Rahmen des CIPM-MRA gemeldet.

Wir entwickeln und bauen Radiometer, die zu den genauesten ihrer Art auf der Welt gehören und sowohl am Boden als auch im Weltraum eingesetzt werden. Diese Instrumente sind auch käuflich zu erwerben und werden seit langem von den Wetter- und Klimadiensten weltweit eingesetzt. Darüber hinaus haben wir ein globales Netz von Stationen zur Überwachung der atmosphärischen Trübung mit Präzisionsfilterradiometern ausgestattet, die vom PMOD/WRC entwickelt wurden.

Die im Weltraum gesammelten Daten (Radiometrie und Solar Imaging) sowie die Bodenmessungen werden in Forschungsprojekten zum Klimawandel und zur Sonnenaktivität ausgewertet. Zu diesem Zweck haben wir mit der ETH Zürich ein eigenes globales Chemie-Klimamodell entwickelt, mit dem wir die Beziehung zwischen Sonne und Erde unter besonderer Berücksichtigung der mittleren Erdatmosphäre und der Ozonschicht untersuchen. Diese Forschungsaktivitäten und unsere internationalen Kooperationen sind weltweit anerkannt.

Schliesslich unterrichten wir an der ETH Zürich sowohl auf Bachelor- als auch auf Masterstufe innerhalb des Departements Physik und des Departements für Umweltsystemwissenschaften.

Physikalisch-Meteorologisches Observatorium Davos and World Radiation Center PMOD/WRC

Mission

Our core mission is to serve as an international calibration center for meteorological radiation instruments. To this end, we develop radiation instruments for use on the ground and in space. Our research focuses on the influence of solar radiation and solar activity on Earth's climate and its impact on the Earth's atmosphere.

PMOD/WRC History

Since its establishment in 1907, the Physikalisch-Meteorologisches Observatorium Davos (PMOD) has been studying the influence of solar radiation on the Earth's climate. In 1926, the Observatory joined the Swiss Research Institute for High Altitude Climate and Medicine Davos and has since become part of this foundation. At the request of the World Meteorological Organization (WMO), the Federal Council decided in 1970 to finance a calibration center for radiation measurement as Switzerland's contribution to the World Weather Watch Programme of the WMO. Following this decision, PMOD was commissioned to establish and operate the World Radiation Center (WRC).

Core Activities

The World Radiation Center maintains the primary standard for solar irradiance, which consists of a group of high-precision absolute radiometers. In response to further requests from WMO, a calibration center for atmospheric longwave radiation instruments was established in 2004, and the calibration center for spectral radiance measurements to determine atmospheric turbidity was established in 2008. Since 2013, the World Calibration Center for UV has also been operated by the World Radiation Center.

Today, the World Radiation Center consists of four sections: Solar Radiometry (WRC-SRS), Infrared Radiometry (WRC-IRS), Atmospheric Turbidity (WRC-WORCC), and UV Radiometry (WRC-WCC-UV).

PMOD/WRC is fully integrated into the European Association of National Metrology Institutes (EURAMET) and into the framework of the Bureau International des Poids et Mesures (BIPM). PMOD/WRC is an associated member of EURAMET and was nominated in September 2002 by METAS at the BIPM as the designated institute (DI) for the quantity "solar irradiance" within the framework of CIPM-MRA.

We develop and build radiometers that are among the most accurate of their kind in the world and are used both on the ground and in space. These instruments are also available for purchase and have long been used by Meteorological Services worldwide. Furthermore, a global network of atmospheric turbidity monitoring stations is equipped with precision filter radiometers developed by PMOD/WRC.

Data collected in space (radiometry and solar imaging) and by means of ground measurements are analysed in research projects on climate change and solar activity. For this purpose, we have developed with ETH Zürich our own dedicated global chemistry-climate model, devoted to investigating the Sun-Earth relationship with particular focus on the Earth's middle atmosphere and ozone layer. These research activities and our international collaborations are recognised worldwide.

Last but not least, we carry out teaching at both, the bachelor and master level at ETH Zürich, hosted within the Department of Physics and the Department of Environmental Systems Science.

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PMOD/WRC Introduction

Since its establishment in 1907, the Physikalisch-Meteorologisches Observatorium Davos (PMOD) has been studying the influence of solar radiation on the Earth's climate. In 1926, the Observatory joined the Swiss Research Institute for High Altitude Climate and Medicine Davos.

In 1971, the Federal Council financed a calibration center for radiation measurement as Switzerland's contribution to the World Weather Watch Programme of the World Meteorological Organisation (WMO). Since 1971, PMOD has been operating the World Radiation Center (WRC).

"Our core mission is to serve as an international calibration center for meteorological radiation instruments. We develop radiation instruments for use on the ground and in space. We research the influence of solar radiation and activity on the Earth's climate and its impact on the Earth's atmosphere."

World Radiation Center

The World Radiation Center (WRC) maintains the global primary standard for solar irradiance, on behalf of the World Meteorological Organization (WMO) and with financial contributions from the Swiss Federation, the Canton of the Grisons and the Commune of Davos. In addition, calibration centers for longwave radiation instruments, for spectral radiance measurements to determine the impact of particles and droplets in the atmosphere, and the World Calibration Center for UV have also been operated by the WRC.

Today, the WRC consists of four sections: Solar Radiometry (WRC-SRS), Infrared Radiometry (WRC-IRS), Aerosols (WRC-WORCC), and UV Radiometry (WRC-WCC-UV).

PMOD/WRC is integrated into the European Association of National Metrology Institutes and into the framework of the Bureau International des Poids et Mesures (BIPM).

Research

Climate change is one of the biggest risks to humankind. We hold the longest datasets in the world on irradiance and ozone* measurements – key for understanding the climate. Data collected in space and on the ground are analysed to understand and predict climate change. For this purpose, we have developed our own dedicated global chemistry-climate model, to investigate the Sun-Earth relationship with particular focus on the Earth's middle atmosphere and ozone layer.

We also research solar activity using high spatial and spectral resolution data. We are involved in the design, build and operations of these complex instruments. The key science questions are "what drives the solar wind?" and "What triggers solar flares?".

*Ozone instruments are operated on behalf of MeteoSwiss and exploited together with MeteoSwiss as part of the Swiss contribution to the WMO Global Atmosphere Watch programme.

Weltstrahlungszentrum

Das World Radiation Center (WRC) verwaltet im Auftrag der Weltorganisation für Meteorologie (WMO) und mit finanziellen Beiträgen des Bundes, des Kantons Graubünden und der Gemeinde Davos den globalen Primärstandard für die Sonneneinstrahlung. Darüber hinaus betreibt das WRC Kalibrierzentren für langwellige Strahlungsinstrumente, für spektrale Strahlungsmessungen zur Bestimmung des Einflusses von Partikeln und Tröpfchen in der Atmosphäre sowie das Weltkalibrierungszentrum für UV-Strahlung.

Heute besteht das Weltstrahlungszentrum aus vier Sektionen: Solar-Radiometrie (WRC-SRS), Infrarot-Radiometrie (WRC-IRS), Aerosole (WRC-WORCC) und UV-Radiometrie (WRC-WCC-UV).

Das PMOD/WRC ist in die European Association of National Metrology Institutes und in die Rahmenordnung des Bureau International des Poids et Mesures (BIPM) integriert.

Forschung

Der Klimawandel ist eine der größten Risiken für die Menschheit. Wir verfügen über die weltweit längsten Datensätze zu Einstrahlungs- und Ozonmessungen* – der Schlüssel zum Verständnis des Klimas. Im Weltraum und am Boden erhobene Daten werden in Forschungsprojekten zum Klimawandel ausgewertet. Zu diesem Zweck haben wir unser eigenes dediziertes globales Chemie-Klima-Modell entwickelt, um die Sonne-Erde-Beziehung mit besonderem Fokus auf die mittlere Atmosphäre und die Ozonschicht der Erde zu untersuchen.

Wir erforschen die Sonnenaktivität anhand von Daten mit hoher räumlicher und spektraler Auflösung. Wir sind an der Konstruktion, dem Bau und dem Betrieb dieser komplexen Instrumente beteiligt. Die wichtigsten wissenschaftlichen Fragen lauten "Was treibt den Sonnenwind an?" und "Was löst Sonneneruptionen aus?".

*Ozonmessgeräte werden im Auftrag von MeteoSchweiz betrieben und gemeinsam mit MeteoSchweiz im Rahmen des Schweizer Beitrags zum WMO Global Atmosphere Watch-Programm genutzt.

Technology

Technology is the key to building instruments for both ground and space-based applications.

We have world-recognised skills in the design of electronics and structures for harsh environments (all weather and in space). This also provides an ideal environment for the training of apprentices. We have seven instruments that are currently operational in space, including those that conduct irradiance, spectroscopic and imaging measurements of the Sun.

We are involved in the design and build of future space instruments and collaborate with industry, institutes, and space agencies around the world.

ETH-Zurich

Since 2019, the director at PMOD/WRC has an affiliated professorship located in the Department of Physics (D-PHYS) in the Institute of Particle Physics and Astronomy at ETH Zurich. This role provides strong collaboration in teaching (both lecture courses and projects), technology (complementary technologies are required for all research areas in IPA) and research.

We also have strong links with the Department of Environmental Systems Science (D-USYS) through our climate modelling expertise and provide teaching there.

Technologie

Technologie ist der Schlüssel zum Bau von Instrumenten für boden- und weltraumgestützte Anwendungen. Wir verfügen über weltweit anerkannte Fähigkeiten im Design von Elektronik und Strukturen für raue Umgebungen (bei jedem Wetter und im Weltraum). Dies bietet auch ein ideales Umfeld für die Ausbildung von Lernenden. Wir verfügen derzeit über sieben Instrumente im Weltraum, darunter solche, welche die Bestrahlungsstärke sowie spektroskopische und bildgebende Messungen der Sonne durchführen.

Wir sind an der Konstruktion und dem Bau zukünftiger Weltrauminstrumente beteiligt und arbeiten mit der Industrie, Instituten und Raumfahrtagenturen auf der ganzen Welt zusammen.

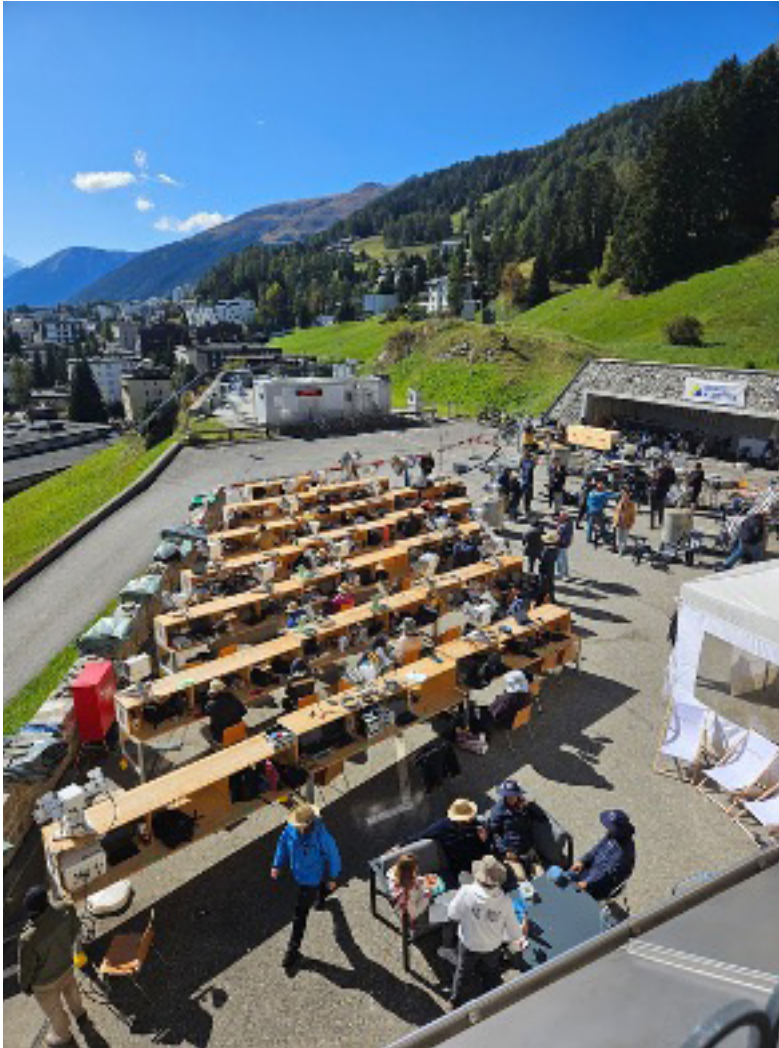
ETH-Zürich

Seit 2019 ist die Direktorin des PMOD/WRC eine afillierte Professorin im Departement Physik (D-PHYS) des Instituts für Teilchenphysik und Astronomie (IPA) der ETH Zürich. Diese Rolle bietet eine starke Zusammenarbeit in Lehre (sowohl Vorlesungen als auch Projektarbeiten), Technologie (komplementäre Technologien sind für alle Forschungsbereiche im IPA erforderlich) und Forschung.

Auch mit dem Departement Umweltsystemwissenschaften (D-USYS) sind wir durch unsere Expertise in der Klimamodellierung und durch die dortige Lehre eng verbunden.

Highlights 2025

2025 was a big year for PMOD/WRC as the 14th WMO International Pyrheliometer Comparisons IPC-XIV were held for 3 weeks in September/October. In parallel two other comparison campaigns took place: the 6th Filter-Radiometer Comparison (FRC-VI), used to measure atmospheric aerosols and the 4th International Pyrgeometer Comparison (IPgC-IV), which compares instruments that measure atmospheric longwave infrared radiation. There were 157 participating pyrheliometers with 64 institutions from 35 countries during the campaign.

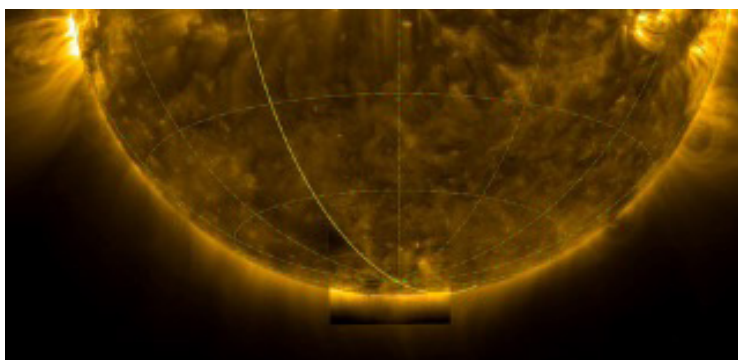


We have 7 instruments operational in space – we continue to operate them and plan coordinated science campaigns with other missions and telescopes on the ground.



The first light for our instrument DARA on the ESA Proba-3 space mission took place successfully in March this year. There are 2 spacecraft, with the upper one providing the means to occult the Sun for the lower spacecraft to measure coronal mass ejections. Our instrument DARA is operating well and has achieved the fastest time cadence ever for irradiance measurements – as well as for climate models these data can be used for space weather and to accurately model the solar radiation pressure noise profile for the future gravitational wave mission LISA. Image courtesy of ESA.

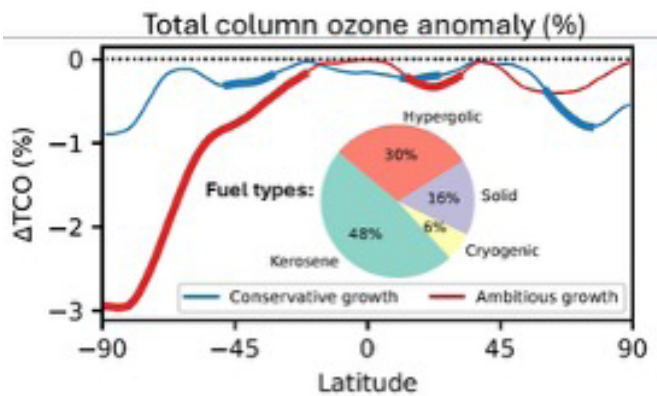
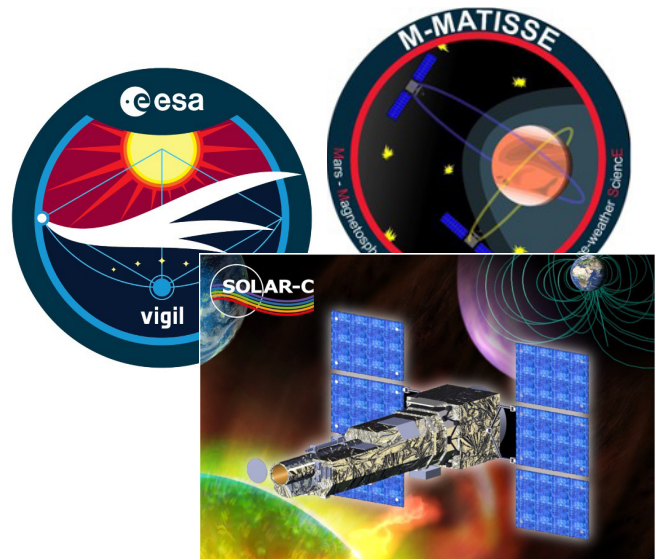
In March 2025, the ESA Solar Orbiter space mission had its first view of the solar poles, reaching 17 degrees out of the ecliptic. This is providing the first views of the solar poles. The mission will continue its journey reaching more than 30 degrees outside of the ecliptic plane, peering down at the poles each time it gets in close to the Sun (twice a year)-. Image courtesy of ESA and the EUI Solar Orbiter team.



Our WRC measurements campaigns were successful this year. More than 100 pyranometers, 18 field pyrhemeters and 6 cavity pyrhemeters were calibrated.

One of our infra-read cloud camera was installed at Geneva airport to measure the cloud cover below 1500 ft in collaboration with MeteoSwiss.

We have been developing the front-end electronics for the NASA contribution to the first ESA space weather mission, Vigil. Our instrument, the Joint EUV coronal Diagnostic Investigation, or JEDI (led by Don Hassler, SwRI), will capture images of the Sun in extreme ultraviolet light to understand and predict solar eruptions on the Sun. Some of the US team are shown below during a visit in September. The launch of Vigil is due in 2031. Our sub-system preliminary design review took place in November 2025. In addition, we are part of the competitive phase A study for a mission to Mars – we are developing our spectral irradiance concept for understanding space weather at Mars. We are also developing a radiometer concept for the Earth Climate Observatory - ECO is one of the four candidate mission concepts for the 12th Earth Explorer. Our instrument – the solar spectral irradiance monitor – has made great progress this year. Our instrument will provide the full Sun irradiance at sub-second time cadence to understand what drives solar flares and measure solar irradiance that impacts the Earth’s atmosphere.



The figure above shows an example of results from the Climate Modelling group. Rocket emissions thin the stratospheric ozone layer. They modelled different future scenarios including 2040 launches/year which produces a -0.29% depletion of the total column ozone in 2030 (Revell et al., 2025)

Our research continued to be successful, with over 43 refereed research papers published and over 40 talks given at international conferences. The research covered aspects of climate change such as future ozone layer evolution and how the Sun’s solar wind is formed. The research was recognised through the successful award of third-party funds.

Our tours and public talks continue to develop. We also had interactions with media including local and regional newspapers, and SRF. The photo shows the visit from SRF which was to discuss the Proba-3 mission.





We had 2 PhD students successfully pass this year (Xinyuan Hou, top left, on the topic of solar energy and Hannah Collier (top right, on the topic of solar flares). Andrea Battaglia who graduated in 2024 won the Edith Alice Müller Award 2025 from the Swiss Society of Astronomy and Astrophysics for outstanding PhD thesis (left).

We had 9 MSc and BSc students carrying out projects across all areas of research and technology including one from ETH Studio Davos.

Our three apprentices successfully completed their training year and have started into their next year successfully (see bottom left). In addition, we were pleased to welcome our new apprentice polymechanic EFZ in August.



“With a role to play in research that is recognised internationally and as the holder of an international Standard, PMOD/WRC seeks to maintain and increase the position and reputation of Switzerland for world-class research and technology. I would like to thank the staff at PMOD/WRC for their dedication and the Board of trustees and the Advisory commission for their constant support and advice. My ETH colleagues continue to provide excellent collaboration in teaching, space and technology. The students we teach are enthusiastic, smart and very engaged – thanks to them too.”

Louise Harra



Number of papers in non-reviewed papers or technical documents (e.g. space project documents for the agencies, white papers, conference papers)

160



Number of peer-reviewed research publications

43



Presentations (oral or poster) given at international meetings and conferences

49



Number of PhD students with PMOD/WRC supervisor

12



Numbers of lecture courses PMOD/WRC staff are involved in

4



Public events (local, cantonal, national e.g. open door events, school talks, public talks)

16



Interaction with media (interviews or articles in newspapers, TV)

29



International collaborations



Participation in national and international commissions, editorial boards

31



Number of employees

54



Number of calibrations
(number of Instruments)

217



Number of student projects supervised by PMOD/WRC staff (MSc and BSc)

12

World Radiation Center / Operational Services

Introduction

The World Radiation Centre (WRC) is a service centre which PMOD operates on behalf of the World Meteorological Organisation (WMO). The WRC was established in 1971 and was originally tasked with the standardisation of solar irradiance measurements and the world-wide dissemination of the standard. Toward this goal, the World Radiometric Reference (WRR) was defined in 1977 and has been maintained ever since by the WRC. Over the years, additional tasks have been added to the WRC mandate, including the standardisation of terrestrial (infrared) radiation, spectral UV, and aerosol optical depth measurements. Therefore, the WRC today consists of four sections: i) the Solar Radiation Section (SRS), ii) the Infrared Section (IRS), iii) the World Calibration Centre for UV (WCCUV), and iv) the World Optical Depth and Research Calibration Centre (WORCC).

Each section defines, maintains and disseminates the standards for their respective type of radiation measurements and data products. To this end, the WRC sections offer radiometric calibrations and engage in or organise instrument inter-comparisons, such as the quinquennial (five-yearly) International Pyrheliometer Comparison (IPC), the International Pyrgeometer Comparison (IPgC), the Filter Radiometer Comparison (FRC) and the international solar UV Calibration campaign (UVC).

In 2010, the WMO decided that its reference and calibration laboratories (such as the WRC) would adapt the concept of SI-traceability for all meteorological data products. As a result, the WRC became a so-called Designated Institute for solar irradiance. A quality management system according to ISO/IEC 17025 (General requirements for the competence of testing and calibration laboratories) had to be implemented to formally allow the WRC to file its "Calibration and Measurement Capabilities" in the BIPM key comparison database. The latter database is where all reference laboratories throughout the world, list their standards and achievable measurement uncertainties.

The WRC sections also run fundamental and applied research projects to develop, improve and maintain their radiometric standards, providing and benefiting from synergies with the solar physics, climate science, and space hardware groups at PMOD.



Quality Management System, Calibration Services

Ricco Soder, Wolfgang Finsterle, Julian Gröbner

Quality Management System (QMS)

Calibration and Measurement Capabilities (CMCs)

PMOD/WRC maintains eight Calibration and Measurement Capabilities (CMCs) in the Key Comparisons Database (KCDB) of the Bureau International des Poids et Mesures (BIPM). These CMCs form the basis for designation as a Designated Institute (DI) and are therefore essential to the laboratory's calibration activities. Depending on the wavelength range, the CMCs are assigned to the respective WRC calibration sections.

WRC-section	instrument (CMC)	quantity (CMC)	parameters (CMC)
SRS	pyranometer	responsivity, solar, irradiance	-
SRS	pyrheliometer	responsivity, solar, irradiance	-
WCC-UV	broadband detector	responsivity, solar, irradiance	λ : 280 nm to 400 nm
WCC-UV	broadband detector	responsivity, solar, irradiance	λ : 280 nm to 315 nm
WCC-UV	broadband detector	responsivity, solar, irradiance	λ : 315 nm to 400 nm
WCC-UV	broadband detector	responsivity, solar, irradiance	λ : 280 nm to 400 nm
WCC-UV	solar spectroradiometer	responsivity, solar, spectral, irradiance	λ : 300 nm to 310 nm
WCC-UV	solar spectroradiometer	responsivity, solar, spectral, irradiance	λ : 310 nm to 500 nm

Table 1. CMCs by WRC section at PMOD/WRC

Organization.

Following the gradual integration of the WORCC division into the existing quality management (QM) structure, further organizational adjustments were implemented during the reporting year. The three calibration laboratories WCC-UV, IRS, and WORCC,

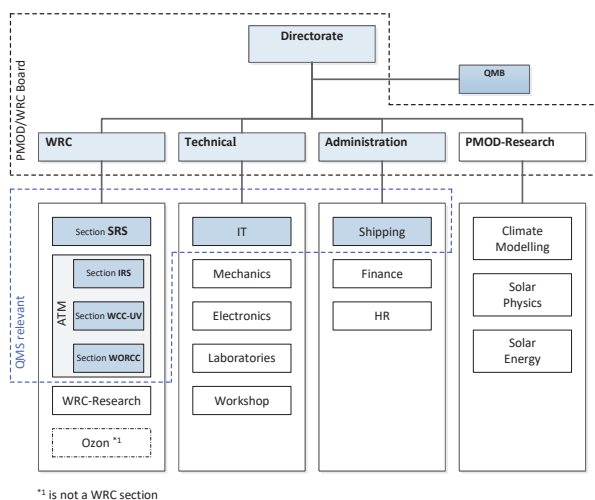


Figure 1. PMOD/WRC Quality Management System - Organizational chart.

all headed by Dr. Julian Gröbner, intensified their collaboration, particularly in the area of QM documentation, thereby improving efficiency and leveraging synergies.

Resources & Infrastructure

After the position of Deputy Quality Manager had remained vacant since 2024, Philipp Hiltbrunner was appointed to this role during the reporting year. In addition to his responsibilities in the technical department, he supports the calibration team in the Solar Radiation Section (SRS). This appointment reflects a strategic effort to strengthen cooperation between the technical department and the WRC sections and to improve operational efficiency.

As previously announced, Irene Keller's retirement is scheduled for the coming year. She kindly agreed to remain available during the 2025 main calibration season and supported the planning and implementation of IPC-IV. Her extensive experience contributed significantly to the successful execution of these activities.

Within the scope of section-specific budgets, all calibration sections continued to maintain and further develop their infrastructure through targeted projects.

Activities

In accordance with applicable standards, all four calibration departments continuously validate the performance of their infrastructure by participating in international measurement comparisons. During the reporting year, staff from the WRC sections took part in several such campaigns, as summarized in Table 2..

In the absence of an external peer audit, internal assessments were conducted in line with the annual audit plan. The focus during the reporting year was on systemic assessments, particularly

Datum (Periode) und Art der Kampagne	Feld / Subfield	Pilot lab and identification	Parameters / range of measurements	Status	Evaluation criterion	Result
September-Oktober, IPgC-IV (2025)	PR	PMOD/WRC	Responsivity, longwave irradiance	completed	Compatibility within uncertainty estimates	report in preparation
May 2025, QASUME, Poprad-Ganovce	PR	PMOD/WRC	Solar UV spectral irradiance	completed	Calibration of customer spectroradiometer	completed published
June 2025, QASUME, AEMET Madrid	PR	PMOD/WRC	Solar UV spectral irradiance	completed	Calibration of customer spectroradiometer	completed published
June 2025, QASUME, RBCCE, Spain	PR	PMOD/WRC	Solar UV spectral irradiance	completed	Calibration of customer spectroradiometer	completed published
July 2025, QASUME, Aosta	PR	PMOD/WRC	Solar UV spectral irradiance	completed	Calibration of customer spectroradiometer	completed published
July 2025, QASUME, BFS Munich	PR	PMOD/WRC	Solar UV spectral irradiance	completed	Calibration of customer spectroradiometer	completed published
22-Sep.2025 (4 weeks) FRC	PR (AOD)	PMOD/WRC	AOD	ongoing	WMO AOD tracability criteria	report in preparation
1.Jan.2025 (1 year) ACTRIS -IZO	PR (AOD)	PMOD/WRC	AOD	ongoing	Cert. of AOD differences to GAWPFR-TRIAD	report in preparation
1.Jan.2025 (1 year) ACTRIS -OHP	PR (AOD)	PMOD/WRC	AOD	ongoing	Cert. of AOD differences to GAWPFR-TRIAD	report in preparation
1.Jan.2025 (1 year) ACTRIS -Valladolid	PR (AOD)	PMOD/WRC	AOD	ongoing	Cert. of AOD differences to GAWPFR-TRIAD	report in preparation
22.09. – 10.10.2025 IPC-IV	PR	PMOD/WRC	DNI, 800-1000 Wm ²	Data evaluation	WRR factors, WRR stability	report in preparation

Table 2. Overview of measurement campaigns involving PMOD/WRC calibration sections.

regarding the ongoing implementation of WORCC documentation and the order processing workflow.

Systematic reviews of QM-relevant processes and documentation were complemented by the structured collection and evaluation of internal and external feedback. This feedback forms an integral part of continuous improvement and is periodically reviewed by a dedicated expert group.

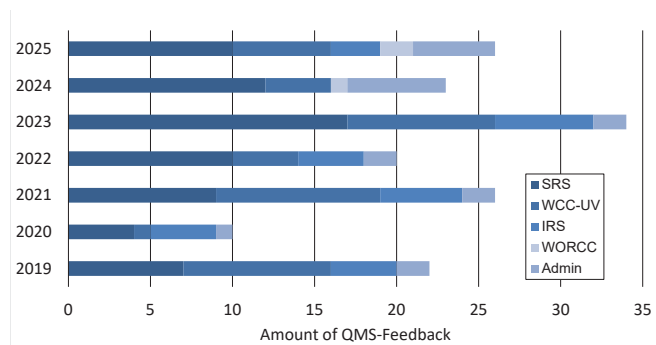


Figure 2. PMOD/WRC Quality Management System – Feedback chart.

Calibration Services

During the reporting year, a total of 217 instruments were calibrated across the various laboratories of the World Radiation Center (WRC). This figure is consistent with expectations based on recent years. No measurable impact, positive or negative, of the International Pyrheliometer Comparison (IPC-IV) was observed. Compared with the previous year, the number of calibrated instruments decreased slightly by ten.

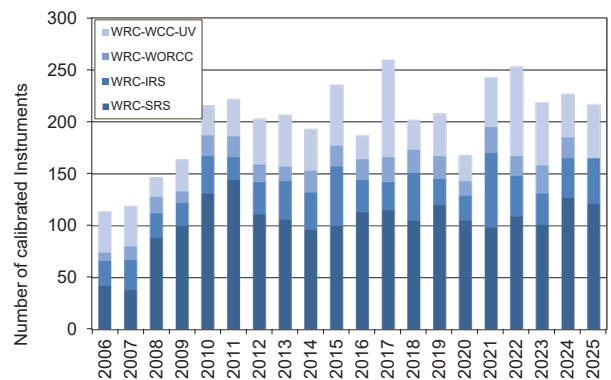


Figure 3. Statistics instrument calibrations at PMOD/WRC 2006-2025.

A detailed analysis shows that calibration activity in the SRS, IR, and UV sections remained stable. The overall decrease is primarily attributable to the absence of certificates approved from the WORCC section. Although calibrations were performed in this section, none of the certificates could be approved by the laboratory manager before year-end and are therefore not included in the current statistics.

section	type of instrument	amount of calibrated instruments	change to previous year	amount of certificates	
				w CIPM logo	w/o CIPM logo
WRC-SRS	Pyrheliometer	27	+2	11	16
	Pyranometer	94	-8	0	94
WRC-IR	Pyrgeometer	44	+7	46	0
	IRIS	0	-1	n/a	n/a
WORCC	Sunphotometer (PFR & others)	0	-19	n/a	n/a
	PSR	0	-1	n/a	n/a
WCC-UV	UV Broadband Radiometer	20	-11	40	21
	Spectroradiometer vs. QASUME	26	+15	0	26
	UV Lamps & Diodes & Spectroradiometer	6	+6	7	0

Table 3. Instruments calibrated during the reporting year and corresponding certificates issued.

Solar Radiometry Section (WRC-SRS)

Wolfgang Finsterle and Ricco Soder

The Solar Radiometry Section (SRS) of the WRC maintains and operates the World Standard Group (WSG) of Pyrheliometers which represents the World Radiometric Reference (WRR) for ground-based total solar irradiance measurements. In 2025 the SRS organized the 14th WMO International Pyrheliometer Comparison (IPC-XIV). The SRS also operates the ISO 17025 certified calibration laboratory for solar radiometers (pyrheliometers and pyranometers). The demand for calibration services has not changed compared to 2024.

In 2025 the SRS calibrated 124 (compared to 125 in 2024) solar radiometers: These consisted of 11 absolute pyrheliometers, 94 pyranometers, and 16 field pyrheliometers.

The WSG was operated on 121 days. The Cryogenic Solar Absolute Radiometer (CSAR) was operated on 23 days on the solar tracker and on 17 days in the optical laboratory.

From 26 September to 10 October the 14th WMO International Pyrheliometer Comparison were held at PMOD/WRC. Sixty-four institutions from 35 countries participated in the IPC-XIV with 157 pyrheliometers. The weather conditions allowed for solar irradiance measurements to be taken on 7 days during the comparison (Figure 1). On the remaining days the IPC-XIV symposium was held, where 53 presentations were given. The analysis of the IPC-XIV measurements is ongoing. Results will be presented in a



WMO technical report and the symposium talks will be published in WMO proceedings.

Between January and March extensive functional tests were conducted with the CSAR after receiving substantial upgrades of the cooling chain, radiation shields, and temperature monitoring capabilities. All tests were successful. Thanks to optimized thermal links and improved shielding much lower operating temperature of ~ 12 Kelvin can now be achieved (compared to ~ 35 Kelvin before the upgrades). Lower temperatures reduce the radiative cooling of the cavity, which minimizes the measurement uncertainty. The optimal temperature set point of the temperature stabilization system still needs to be determined. At cryogenic temperatures non-linear changes of material properties affect the thermal response time of the system. Numerical simulations based on a finite element model will be developed to further optimize the performance of the CSAR.

The entire month of August was used for comparing the CSAR against a calibrated transfer standard (trap detector) from the Physikalisch-Technische Bundesanstalt (PTB, Germany). For this comparison the CSAR was removed from the solar tracker and installed on the optics table. Substantial preparations were required for this experiment including a core drilling in the wall of the optical laboratory to feed the Helium lines for the cooling of the cryogenic radiometer. The comparison was conducted in optical power mode, i.e. with under-filled radiometric aperture. A narrow laser beam (wavelength 532 nm) was alternatingly directed on CSAR and the reference trap detector to determine the relative sensitivity of both sensors. Preliminary results confirm the agreement of both sensors within the uncertainty achieved by the experimental set up. The final analysis is ongoing, results will be published in a peer-reviewed publication

Figure 1. Participants of the 14th WMO International Pyrheliometer Comparison are collecting solar irradiance measurements during excellent weather conditions on October 2nd. Acoustic signals and a reference clock on the measuring field ensure strict adherence to the prescribed sequence and timing of the measurements, which is necessary for accurately comparing them to the reference values from the World Standard Group (WSG)

Infrared Radiometry Section (WRC-IRS)

Julian Gröbner and Christian Thomann

The Infrared Radiometry Section of the WRC maintains and operates the World Infrared Standard Group of Pyradiometers (WISG) which represents the world-wide reference for atmospheric long-wave irradiance measurements.

The WISG serves as atmospheric longwave irradiance reference for the calibration of pyrgeometers operated by institutes around the world. The WISG has been in continuous operation since 2004 and consists of four pyrgeometers which are installed on the roof platform of PMOD/WRC. The measurements of the individual WISG pyrgeometers with respect to their average are shown in Figure 1 for the period 2004 to the end of 2025. As can be seen in the figure, the long-term stability of the WISG is very satisfying, with measurements of the four pyrgeometers within ± 1 Wm^{-2} over more than 20 years..

Between January and December 2025, four IRIS radiometers (IRIS #4, #6, #9, #10) and one ACP (ACP96) belonging to PMOD/WRC were operated during 45 nights. The comparison of the WISG to these radiometers yielded an average difference of -4.7 Wm^{-2} , confirming the results obtained in previous years.

This year the fourth international Pyradiometer Comparison (IPgC-IV) took place from 22 September to 10 October. 26 participants with a total of 36 pyrgeometers participated at this inter-comparison. In addition, 6 Infrared Integration Sphere Radiometers (IRIS), 4 from PMOD/WRC, one from BOM, Australia and one from DWD, Germany and 6 Absolute Cavity Pyradiometers (ACP), 3 from NREL, USA, 1 from DWD, Germany, 1 from JMA, Japan, and 1 from PMOD/WRC were also operated.

Each pyrgeometer was characterised in the blackbody cavity of PMOD/WRC (Blackbody BB2007) to retrieve the pyrgeometer coefficients before being installed on the measurement platform on the roof of PMOD/WRC for an outdoor calibration relative to the

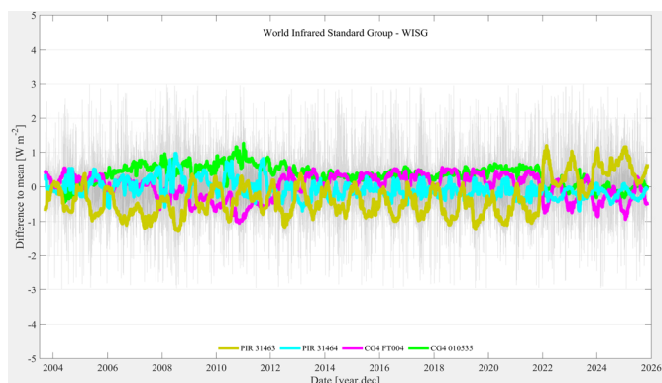


Figure 1. Night-time atmospheric longwave measurements of the WISG pyrgeometers relative to their average. The coloured lines represent a 30-day running mean of each WISG pyrgeometer, while the grey-shaded area represents daily averages.



Figure 2. Measurement platform on the roof of PMOD/WRC with IRIS radiometers in the front and ACP radiometers in the back.

WISG. Several cloud-free nights provided good conditions for the outdoor calibration. Calibration certificates for the pyrgeometers were produced and sent to all participants. A report describing the results of the comparison is being written and will be published as an IOM report in the course of 2026.

The comparison between the IRIS and ACP radiometers started on 15 August and lasted until 13 October. This comparison was held under the auspices of the Expert Team on Radiation References of the WMO. The objective is to validate the atmospheric downwelling longwave irradiances measured by the IRIS and ACP radiometers which independently are traceable to the SI. The aim is to submit a recommendation to the WMO congress by 2027 for the redefinition of the WISG based on the IRIS and ACP comparison during the IPgC-IV. More than 70000 measurements of nighttime downwelling longwave irradiances (1-minute averages) from the 12 participating IRIS/ACP instruments were obtained on 17 cloud-free nights during the comparison period. While a final analysis will only be available in the course of 2026, preliminary results indicate a good consistency between the majority of the IRIS and ACP radiometers.

The Thermal Infrared Remote Sensing (TIRlab) laboratory of the Department of Geography at the University of Zurich brought several thermal infrared sensors as well as thermal imaging cameras to be tested and calibrated at the blackbody facility of PMOD/WRC. The radiometers are used to measure the thermal emittance from forests and lakes at selected locations in Switzerland. A joint publication was published on this activity in 2025 (Adams et al., 2025).

Atmospheric Turbidity Section (WRC-WORCC)

Stelios Kazadzis, Natalia Kouremeti, Angelos Karanikolas and Julian Gröbner

The Atmospheric Turbidity Section of the WRC maintains a standard group of 3 Precision Filter Radiometers that serve as the reference for Aerosol Optical Depth measurements within WMO. WORCC also operates the global GAW-PFR AOD network and collaborates with other global aerosol networks. WORCC has participated in a number of projects and activities related to the homogenization of global aerosol networks, SI-traceable AOD retrievals, aerosol measurement, science and processes analysis and capacity building activities based on WMO-GAW goals.

The World Optical depth Research and Calibration Center (WORCC) calibration hierarchy consists of the use of the WORCC reference, based on the average of three (triad) well maintained Precision Filter-Radiometers (PFRs) that are located at Davos, Switzerland. In addition, instruments operating in high mountain stations such as Mauna Loa, USA and Izaña, Tenerife, Spain are performing Langley calibrations, and they are transported periodically to WORCC/Davos to check the PFR-Triad stability using an independent instrument. Minor changes in the scale of the GAWPFR-TRIAD have been applied in the 2nd half of 2025 with higher adjustment of 0.2 % at 368 nm after comparison to 3 Langley calibrated PFRs.

In addition, WORCC is responsible for the operation, maintenance and data processing of the PFR sun-photometers of the Global Atmospheric Watch GAW-PFR network. Annual quality assured data from GAW-PFR stations were updated and submitted to WDCA. In 2025, 12 instruments of the GAW-PFR network and 10 customer instruments part of the extended GAW-PFR and MeteoSwiss networks were calibrated against the reference GAWPFR-Triad.

Spectral AOD, by several spectroradiometers, was obtained in the spectral range 300nm to 2150nm (direct solar irradiance measurements) traceable to the SI (see scientific contribution page 61).

The 6th Filter Radiometer Comparison campaign for Aerosol Optical Depth (AOD) measurements were successfully held in Davos, from the 20th September to 17th of October 2025. For AOD measurements, A total of 32 sun-photometers and spectroradiometers from 14 institutes participated. These included reference instruments representing several major global initiatives, such as AERONET, GAW-PFR, and Skynet networks, and also national aerosol monitoring networks. The main objective of the campaign was the harmonization and traceability of ground-based aerosol optical depth measurements to the WMO AOD reference scale, as maintained by the PMOD/WRC reference Precision Filter Radiometers (PFRs). In addition to the PMOD/WRC reference PFRs, the reference QASUME spectroradiometer and laboratory calibrated PFR (EURAMET-1611) participated in the FRC as an ongoing effort to provide the AOD retrievals traceable to the SI system This effort supports both long-term intercomparisons and focused campaign-based common measurements to strengthen

consistency across European and global aerosol observation networks.

WORCC is participating in ACTRIS-CARS (Center for Aerosol Remote Sensing) through the ACTRIS-CH project providing a permanent traceability link between the ACTRIS AOD measurements and the WMO primary AOD reference. During 2025, 3 PFR instruments have been operated at Valladolid, Spain, OHP-France and Izaña, Spain. In October, the ACTRIS community met in Evora, Portugal for the ACTRIS week 2025.

Members of WORCC participate in various WMO related bodies including the Scientific Advisory group of Aerosols, The Expert team of Atmospheric Composition Measurement Quality and the one of the Atmospheric Composition and Network Evolution contributing to various reports on calibration facilities and reports such as the GAW Report No. 307 on the “Critical review of the atmospheric composition observing capabilities for monitoring and forecasting”. The lunar activities of WORCC include the continuous monitoring of AOD during the polar winter at Ny-Ålesund and providing low uncertainty lunar irradiance spectral measurements (QA4EO-WP2220, EURAMET-1611) at Davos with the Lunar-PFR and QASUME spectroradiometer for the validation of numerous lunar irradiance models.

WORCC is participating in various project on aerosol-cloud-radiation interactions (CERTAINTY and Panorama), has organized a field campaign in Thessaloniki Greece during spring 2025 within the project (Race ECV), scientific knowledge transfer (Excelsior and Atarri) and the Marie Curie Dust Doctoral Network). Also, WORCC members participated in publications related to the PFR AOD measurements (Karanikolas et al., 2025) and on the impact of NO₂ contribution on aerosol-optical-depth measurements at several sites worldwide (Masoom et al., under review). WORCC has been collaborating with SIAF and lead an overview publication on Aerosol Measurements and Decadal Changes (Kazadzis et al., 2025). WORCC is leading the COST action Harmonia.

PhD students X. Hu (Thesis in 2025), A. Karanikolas (ETHZ), M. Huertas (ETHZ), D. Kouklaki (NKUA, Greece), G. Charalampous (Tech. Un. Of Cyprus) and A. Moustaka (AUTH, Greece) are being supervised and collaborating with WORCC. There was one Master Thesis and two semester projects as a collaboration of WORCC and ETHZ.

References: Karanikolas, A., et al: Retrieval of aerosol properties from aerosol optical depth measurements with high temporal resolution and spectral range, *Atmos. Meas. Tech.*, 18, 7651–7677, <https://doi.org/10.5194/amt-18-7651-2025>, 2025.

Kazadzis, S., et al, *Aerosol Measurements and Decadal Changes: The Role of Climatic Changes and How It Reflects in Respiratory Allergies and Asthma*. *Allergy*. <https://doi.org/10.1111/all.16602>, 2025

World Calibration Centre for UV (WRC-WCC-UV)

Julian Gröbner and Gregor Hülsen

The objective of the World Calibration Center for UV (WCC-UV) of WMO GAW is to assess the data quality of the Global GAW UV network and to harmonise the results from monitoring stations in order to ensure representative and consistent solar UV radiation measurements on a global scale.

In 2025 our transportable reference spectroradiometer QASUME was used for 5 site audits in Europe. Between May and July we



Figure 1. All participants of the 20th RBCCE at INTA, Spain.

traveled to stations in Slovakia, Spain, Italy and Germany. Starting with the audit at the Slovak Hydrometeorological Institute (SHMU) in Poprad-Ganovce with participation by the Polish Institute of Geophysics and the Hungarian Meteorological Service, continued with a visit to the Agencia Estatal de Metrologia (AEMET) in Madrid and the National Institute of Aerospace Technology (INTA) near Mazgon, and finishing with the audit at the Bundesamt für Strahlungsschutz (BFS) in Munich, Germany.

During the 20th Regional Brewer Calibration Campaign-Europe (RBCCE), which was held at INTA, QASUME provided the global solar UV irradiance reference for the participating twenty Brewer and eight BTS spectrophotometers.

Results of all the QASUME site audits and reports of the campaigns can be found at the WCC-UV website <https://www.pmod-wrc.ch/en/world-radiation-center-2/wcc-uv/qasume-site-audits/>

The three European Partnership in Metrology (EPM) projects continued in 2025:

- **NEWSTAND:** New calibration standards and methods for radiometry and photometry after phaseout of incandescent lamps.
- **MeLiDos:** Metrology for wearable light loggers and optical radiation dosimeters.
- **S-CALe Up:** Self-calibrating photodiodes for UV and exploitation of induced junction technology.

In the frame of S-CALe-UP, PMOD mapped the two-dimensional spatial responsivity in the visible spectral range of detector samples with varying dopant types, dopant concentrations, and



Figure 2. Site visit to the UV monitoring station in ARPA-Aosta

wafer crystallinities after exposure to UV. Beyond the technical development of the core technology, PMOD increased the project's technological readiness level by successfully integrating the PQED into a primary standard proof of concept for spectroradiometer calibration.

As part of the NEWSTAND activities, we visited the Czech Metrological Institute (CMI) with QASUME in May and tested a prototype monochromatic irradiance source (TuPS-II) which is made traceable to the SI using Predictable Quantum Efficient Detectors (PQED) serving as absolute standard of optical power.

Within the MeLiDos Project we re-calibrated three UV dosimeters. This activity revealed significant sensitivity drifts of two dosimeters and only one remained stable from 2024 to 2025. Thereafter we exchange the different sets of instruments between the participating calibration facilities. A good practice guide for calibration UV dosimeter has been drafted and currently the intercomparison protocol and data exchange is going on.

References: Fountoulakis, I., Papachristopoulou, K., Kazadzis, S., Hülsen, G., Gröbner, J., Raptis, I.-P., Kouklaki, D., Masoom, A., Kouremeti, N., Kontoes, C., and Zerefos, C. S.: Assessment of the accuracy in UV index modelling using the UVIOS2 system during the UVC-III campaign, *Geosci. Model Dev.*, 18, 7451–7473, <https://doi.org/10.5194/gmd-18-7451-2025>, 2025.

Klotz, B., Gradl, R., Schenzinger, V., Schwarzmann, M., Schreder, J., Lorenz, S., Gröbner, J., Hülsen, G., & Kreuter, A. (2025). UV Map Nowcasting and Comparison with Ground-Based UV Measurements for the DACH Region. *Remote Sensing*, 17(4), 629. <https://doi.org/10.3390/rs17040629>.

Section Ozone: Total Column Ozone and Umkehr Measurements

Luca Egli, Franz Zeilinger and Julian Gröbner

At PMOD/WRC, operational total column ozone and Umkehr measurements are made using three Dobson and four Brewer spectrophotometers. These instruments monitor the ozone layer and are part of the Arosa–Davos record in Switzerland, the world's longest continuous total ozone time series, operating since 1926. Two array spectroradiometer systems (BTS Solar and Pandora) and the QASUME UV reference also retrieve ozone from direct sun UV spectra, enabling comparisons between modern and traditional methods. In total, 10 instruments for total column ozone observation are continuously operated in Davos.

The official Arosa–Davos time series (Figure 1) is based on three Brewer spectrophotometers (B040, B072, and B156) and three Dobson instruments (D051, D062, and D101) operated by PMOD/WRC on behalf of MeteoSwiss. These instruments routinely measure total column ozone and perform Umkehr observations to derive vertical ozone profiles. Dobson D051 is primarily dedicated to Umkehr measurements but is periodically operated in direct-sun mode to form a Dobson triad with D062 and D101. Monthly sunrise-to-sunset measurement sequences are conducted to identify potential air-mass-dependent biases, while weekly coordinated Umkehr observations enable cross-validation of ozone profiles. Overall, the six core instruments show excellent long-term consistency, agreeing within $\pm 1\%$ in total column ozone. (Figure 1).

The operational activities are closely linked to ongoing research initiatives such as the SNF-STOA project, which focuses on homogenized ozone datasets and trend analyses over Switzerland and Europe, and the GCOS-TOCUN project, which develops a rigorous uncertainty framework for total column ozone measurements. Together, they ensure that PMOD/WRC continues to deliver

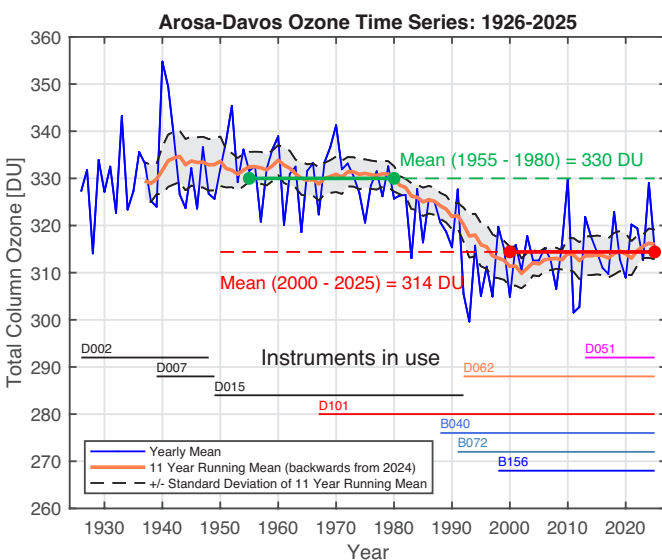


Figure 1. Total column ozone time series from 1926 to 2025. .



Figure 2. The WMO-BTS as guest at PMOD/WRC for comparison with first generation of TOC instruments (Dobsons in the container) and second generation of TOC instruments (Brewers).

high-quality, traceable ozone observations in support of national services and international programs such as WMO/GAW and GCOS.

In the same scientific framework, Brewer 038 from Environment Canada was first operated at PMOD/WRC, and later moved to the SLF experimental field at Weissfluhjoch (see page 62). Additionally, PMOD/WRC operates its own double monochromator Brewer B163, in continuous use since 2007, also routine global UV spectral scans to monitor surface ultraviolet radiation

In addition to the traditional Dobson and Brewer instruments, PMOD/WRC operates three complementary systems based on modern measurement technologies: QASUME – the world reference of UV radiation - was deployed intermittently to retrieve traceable total column ozone Egli et al (2022), providing an independent reference for quality assurance of the Arosa–Davos instruments.

Since the production of new Brewer instruments is critical, a WMO taskforce was established to assess the next generation of instruments. The WMO taskforce has selected the BTS-Solar instrument to be tested at high ozone slant columns occurring in the Arctic. For evaluating the improvements of the BTS-Solar on a spectral level (see page 48) and for comparison with the operational instruments of the Arosa-Davos time series, in spring 2025, the WMO-BTS was a guest instrument at PMOD/WRC. After the visit in Switzerland, the WMO-BTS participated at a field intercomparison in Spain and was finally installed in September 2025 in Sodankylä, northern Finland, for testing under Arctic conditions.

References: Egli, L., Gröbner, J., Hülsen, G., Schill, H., and Stübi, R.: Atmos. Meas. Tech., 15, 1917–1930, <https://doi.org/10.5194/amt-15-1917-2022>, March 2022.

Space Instrument Development

Space Missions in the Operations Phase

Krzysztof Barczynski, Louise Harra, Wolfgang Finsterle, Jean-Philippe Montillet, Margit Haberleiter, Silvio Koller and Daniel Pfiffner

PMOD/WRC is involved in the operations of Total Solar Irradiance (TSI) radiometers onboard four operational spacecraft. The ESA SOHO mission was launched back in 1995, and the PMOD/WRC instrument, Variability of solar IRradiance and Gravity Oscillations (VIRGO) is still operational. The Compact Lightweight Absolute Radiometer (CLARA) is a payload onboard the Norwegian NorSat-1 micro-satellite and is a new generation of radiometer to measure the Total Solar Irradiance (launched in 2017). The Chinese JTSIM mission was launched in July 2021, and our Digital Absolute Radiometer (DARA) instrument is onboard. Another DARA was launched on with the ESA PROBA-3 mission on 5. December 2025. In addition, we are involved in the scientific operations of two instruments onboard the ESA Solar mission mission - the EUV Imagers and the spectrometer SPICE.

The Total Solar Irradiance is an essential climate variable and PMOD/WRC has been measuring TSI from various space missions since the early 1990's. We currently operate four TSI radiometers in space, of which three actively produce data. Because of degraded attitude control of the NORSAT-1 spacecraft the CLARA can no longer point at the Sun accurately but still measures Outgoing Longwave Radiation (OLR) on the night side of the Earth.

VIRGO Onboard SOHO

The VIRGO experiment onboard the SOHO spacecraft has been providing total and spectral solar irradiance measurements almost continuously since February 1996. Degradation of the radiometric sensors is regularly assessed and corrected to update the VIRGO and composite TSI data products on the Astromat open archive <https://doi.org/10.60520/IEDA/113532> (Figure 1)

DARA onboard FY-3E

The DARA on the Chinese FY-3E satellite is providing regular TSI measurements since August 2021, although some operational challenges had to still be resolved in 2024. During September

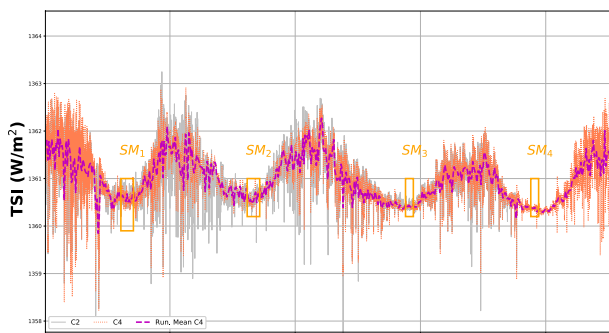


Figure 1. This TSI composite uses data fusion to combine the measurements from various space missions.

2025, the operator at CMA (Chinese Meteorological Agency) had an issue with restarting the instrument resulting in a loss of

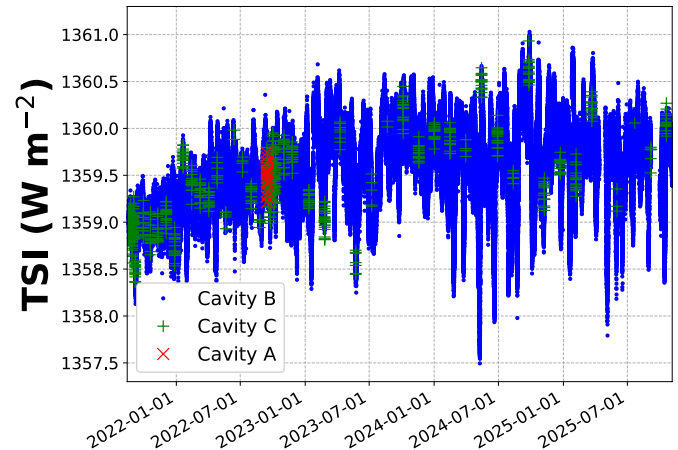


Figure 2. Time series of TSI recorded by the DARA instrument on board of the FY-3E/JTSIM spacecraft.

one month of data. The DARA/FY-3E TSI data product (JTSIM-DARAv1) is published on <https://www.pmodwrc.ch/en/research-development/space/fy-3e/> as well as on the ASTROMAT repository (<https://repo.astromat.org/>).

DARA Onboard PROBA-3

ESA's PROBA-3 mission was successfully launched on 5th December 2024 by the Indian Space Research Organisation's (ISRO) commercial branch NewSpace India Limited (NSIL) from the Sriharikota launch base on Satish Dhawan Space Centre. After a period of commissioning lasting until June 2025, the instrument is recording continuously. The current work is on the TSI pipeline converting the raw data to the data user-level product. At this time, we cannot make the data available to the community. We are working with the ESA data archive operators to deliver the product once the TSI data pipeline will be fully operational. However, anyone can contact the PMOD/WRC team to request the data. .

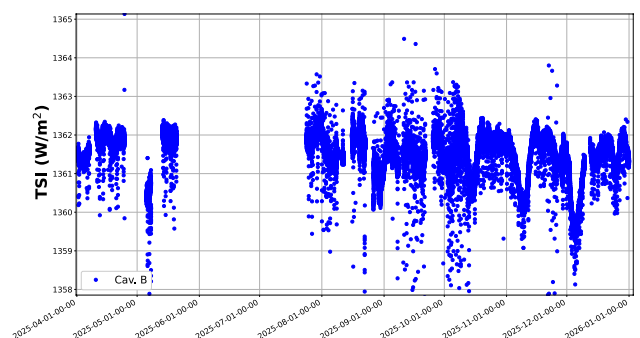


Figure 3. Time series of TSI recorded by the DARA instrument on board of PROBA-3 mission.

CLARA onboard NorSat-1

The CLARA operational pipeline has been updated in several ways. First, we have implemented the thermal emission of the precision aperture in the data processing chain. As this correction is temperature dependent the correction is applied to each (open) measurement cycle. The updated radiative loss model has been validated against the deep space measurements. In addition, the quality filtering of the CLARA data has been enhanced by implementing quality flags for the closed measurement cycles in the same way as it had been already done for the open shutter cycle. As expected, this method detects outliers in a more robust manner. Finally, the pipeline has been improved to determine the footprint of the CLARA OLR measurements for all viewing angles (see Figure 4 as an example). This step is essential for the upcoming routine OLR map production. The CLARA OLR data are accessible under ftp://ftp.pmodwrc.ch/pub/data/Earth_Observation/CLARA/OLR/:

References: Finsterle, W., Montillet J.-P., et al., 2021, Scientific Reports, 11, doi.org/10.1038/s41598-021-87108-y

Montillet, J.-P.; Finsterle, W.; Zhu, P.; Haberreiter, M.; Koller, S.; Pfiffner, D.; Wu, D.; Ye, X.; Yang, D.; Fang, W.; et al. Assessment of Instrument Performance of the FY3E/JTSIM/DARA Radiometer Through the Analysis of TSI Observations. Remote Sens. 2025, 17, 3902. <https://doi.org/10.3390/rs17233902>

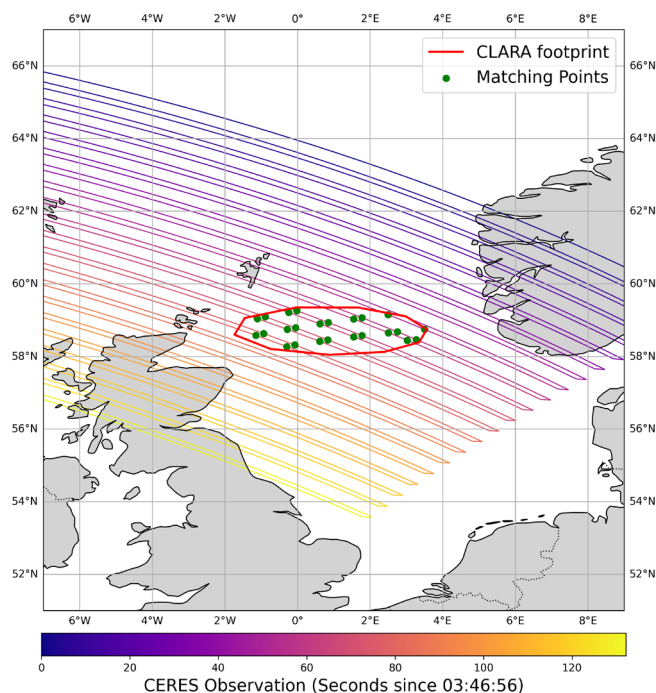


Figure 4. The red line indicates the CLARA footprint. The elongated shape results from CLARA's off-nadir pointing. Accurate knowledge of the CLARA footprint geometry is essential for generating CLARA OLR maps.

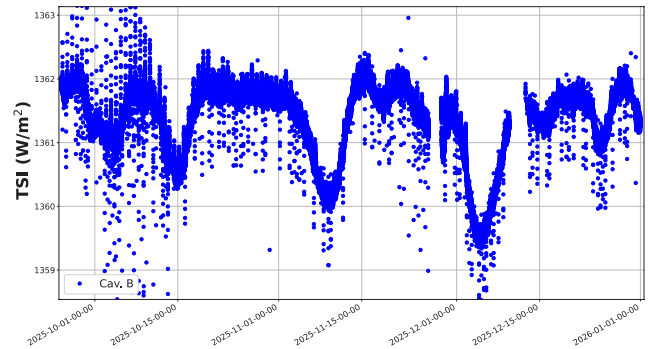


Figure 5. Time series of TSI recorded by the DARA instrument on board of PROBA-3 mission (Zoom).

EUI and SPICE Onboard Solar Orbiter

Solar Orbiter is a spaceborne solar physics observatory, launched in February 2020. The spacecraft carries a suite of six remote-sensing (solar imaging, spectroscopy, and photospheric magnetic field) and four in-situ instruments that measure the plasma properties of the solar wind, the interplanetary magnetic field, and energetic particles. We provide support for the operations, calibration and data analysis methodologies for two of these instruments: the Extreme Ultraviolet Imager (EUI), and the Spectral Imager of the Coronal Environment (SPICE) instrument. They provide imaging and spectroscopy data, respectively. Solar Orbiter observations are divided into observation campaigns, which are periods where the spacecraft's instruments focus on the same scientific goal. The operations support for EUI and SPICE on Solar Orbiter is provided by ESA PRODEX.

We provide assessment of the data return for EUI and SPICE. For EUI, we check that the campaign was carried out correctly. We use a semi-automatic code to compare the EUI expected observations and the EUI obtained observations for completeness. A visual inspection of the EUI data is performed, which provides input for improvements in the next campaigns. For SPICE observations, feedback is provided about: data completeness, anomalies, and interesting features (e.g., solar flares, plasma upflow regions) based on visual inspection.

We coordinated the Solar Orbiter Observing Plan (SOOP) for Long-Term Planning 19 (LTP19) on 1 April 2025. The scientific goal was to observe the Sun during the Solar Orbiter quadrature with respect to Earth. We used the observation plan: R_SMALL_HRES_HCAD_RS-burst. Solar Orbiter provides simultaneous observations the Earth orbiting satellites: Interface Region Imaging Spectrometer (IRIS) and Hinode; as well as the ground based-telescope - Daniel K. Inouye Solar Telescope (DKIST). The aims of this coordinated observation were to

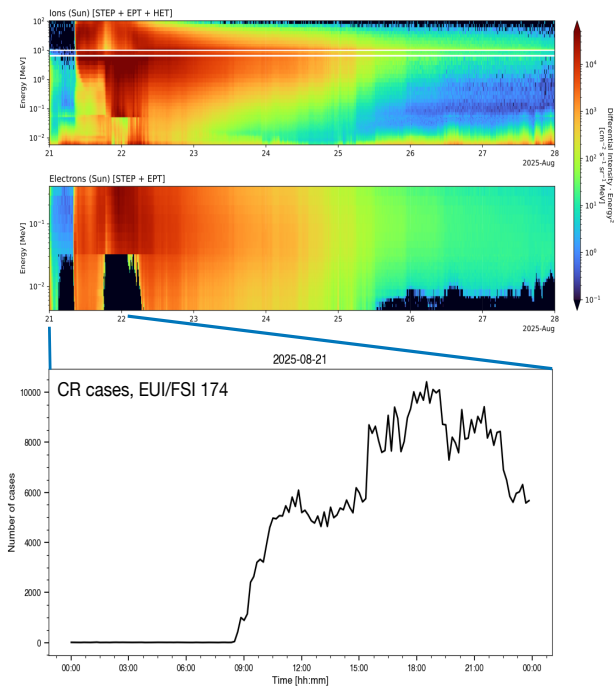


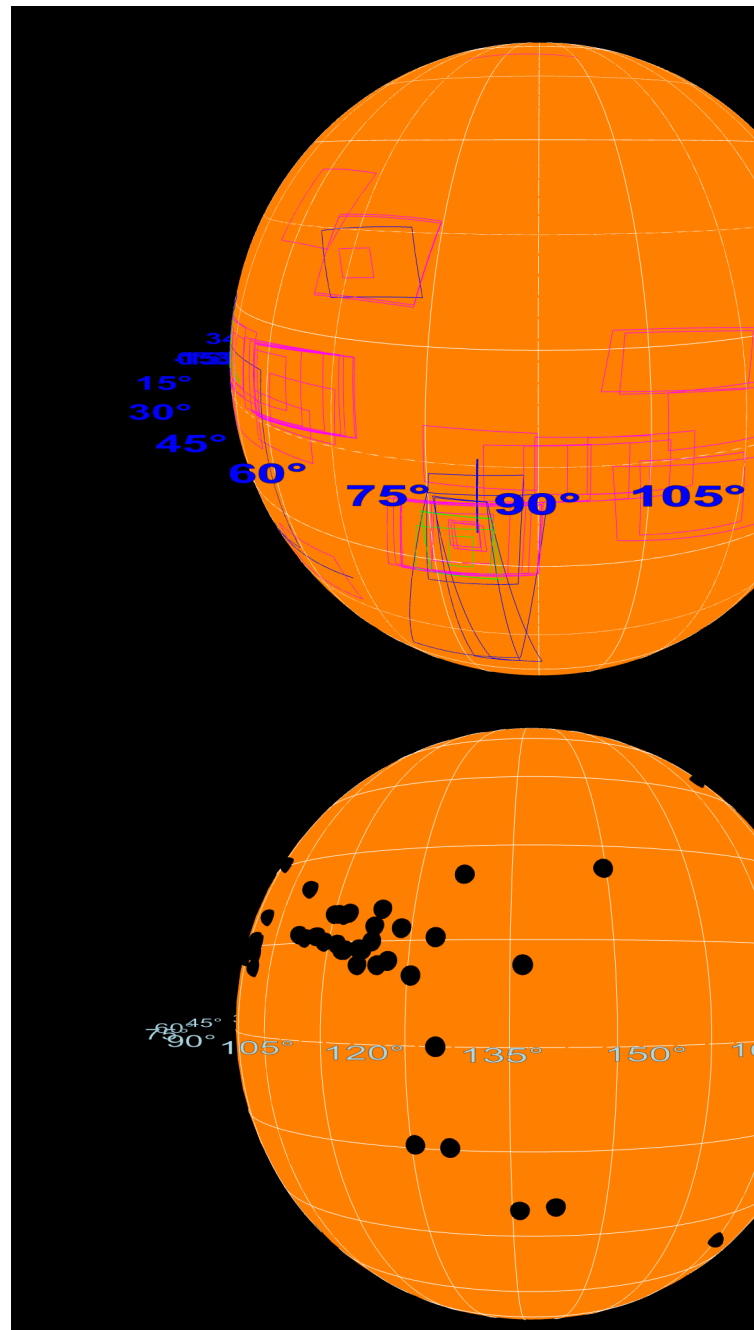
Figure 6. An example of a cosmic ray event observed on 21 August 2025. The upper two panels show ion and electron energies as measured from the EPD instrument, while the bottom panel shows a histogram of the number of cosmic rays cases as obtained from EUI.

study the active region and the plasma upflow regions at the border of active regions. The Solar Orbiter, IRIS and Hinode coordinated observations were successful. However, DKIST did not observe due to bad weather conditions in Hawaii. We conducted a second coordinated observation plan on 23 September 2025. We used the same space-based and ground-based telescopes as for the previous observing campaign. All expected observations from this campaign were obtained successfully. We are preparing the next coordinated observation campaign for February 2026.

To gain an overview of solar events, such as flares and coronal mass ejections with potentially related energetic particle emission, a working group from several instruments compiles a catalogue of these events over the course of the Solar Orbiter mission. The catalogue is called Comprehensive Solar Energetic Electron event Catalogue (CoSEE-Cat). This catalogue serves as a starting point for combined case studies with several instruments and as a comprehensive basis for statistical event studies. With respect to EUI, we continuously update the event list together with the Energetic Particle Detector (EPD), the Spectrometer / Telescope for Imaging X-Ray (STIX), and Radio and Plasma Wave (RPW) instrument teams. We provide information about the EUI data availability, observation time, image cadence, and the approximate position of solar flares. In 2025, we published the catalogue (Warmuth et al. 2025) and prepared a webpage which shows events (<https://coseecat.aip.de>)

between 17 Nov 2020 and 31 Dec 2022. The list currently contains (January 2026) more than 1060 events observed between November 2020 and November 2025..

In 2025, the systematic study of so-called cosmic ray (CR) particle hits on the EUI/FSI sensor continued (Figure 6). The overall EUI detector damage from the cosmic rays is small compared to previous solar missions, which is mostly due to the sensor’s location behind the Solar Orbiter heat shield and the use of more robust detector technology. We have also started to study minor cosmic ray’s events where the hits do not fully saturate the sensor pixels. This might be due to secondary particle showers that



can be created in the spacecraft or instrument shielding, and a detailed investigation is ongoing. The results of these studies help to assess the expected impact of cosmic ray for the future instrument onboard the upcoming ESA Vigil mission, which is being built with contributions from PMOD/WRC.

We also began developing software that will use for two visualisation tools (Figure 7): one for coordinated observation visualisation and another for solar physics events. The software use a 3D interactive sphere (the solar surface) that can be rotated by the user. It will be used to visualise field-of-view of coordinated observations between Solar Orbiter instruments (EUI, SPICE)

and missions such as Hinode and IRIS. The second tool will focus on the visualisation of interesting solar events (e.g. solar flares) (Figure 2).

Publications in 2025:

Warmuth Alexander, et al., CoSEE-Cat: A Comprehensive Solar Energetic Electron event Catalogue obtained from combined in situ and remote-sensing observations from Solar Orbiter, *Astronomy and Astrophysics*, Volume 701, 2025, A20, ISSN: 0004-6361, <https://doi.org/10.1051/0004-6361/202554830>

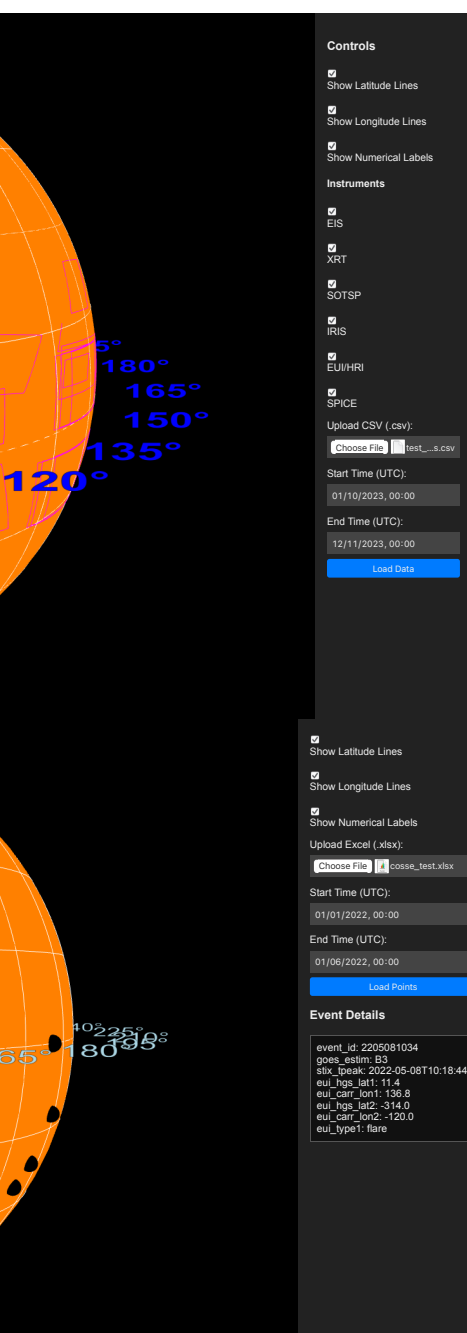


Figure 7. A preliminary version of the tools has been developed to support the search for and visualisation of coordinated observations between Solar Orbiter (EUI, SPICE) and the Hinode (EIS, XRT, SOT-SP) and IRIS missions (upper panel). A second tool (lower panel) focuses on identifying regions of interest.

Space Missions in the Build Phase

Krzysztof Barczynski, Valeria Büchel, Etienne de Coulon, Karim El Sammra, Wolfgang Finsterle, Matthias Gander, Manfred Gyo, Margit Haberleiter, Louise Harra, Markus Heim, Sarina Heim, Nils Janitzek, Silvio Koller, Patrik Langer, Christian Marty, Leandro Meier, Andri Morandi, Raphaël Naire, Daniel Pfiffner, Florian Reinhard, Pascal Schlatter, Oliver Schwahofer, Marcel Spescha, Jan Niklas Valär, and Stefan Wismer

PMOD/WRC has been involved in five space missions at different design and development stages. VIGIL is ESA's space weather mission at the L5 Lagrange point. JEDI, the Joint EUV Coronal Diagnostic Investigation, will capture images of the Sun in extreme ultraviolet light to understand and predict solar eruptions. We will provide the camera electronics. CSAR, part of the ESA TRUTHS (Traceable Radiometry Underpinning Terrestrial and Helio-Studies) mission, is a cryogenic absolute radiometer. We developed electronics and cavities for this instrument. The mission was cancelled towards the end of the prototyping phase. We successfully completed test campaigns on prototypes for SoSpIM, an extreme UV Solar Spectral Irradiance Monitor for the Japanese Solar-C mission. The instrument is now ready for the critical design review. We are part of the competitive phase A study for a mission to Mars – we are developing our spectral irradiance concept for understanding space weather at Mars. The mission is called M-MATISSE and our instrument is called M-SoSpIM. The team has prepared for the mission selection review. Furthermore, we are contributing to ECO (Earth Climate Observatory). This mission aims to measure the Earth's energy imbalance.

SoSpIM onboard Solar-C_EUVST

Solar-C is JAXA's next solar physics mission, with strong US and European participation, and is scheduled for launch in 2030. The mission will significantly advance our understanding of solar activity and its impact on Earth.

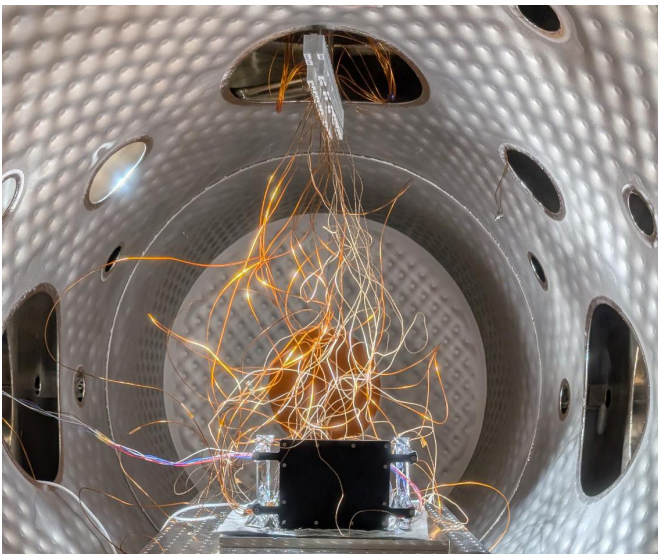


Figure 1. Test setup inside the thermal-vacuum chamber showing the instrument mounted on the support structure with thermocouple instrumentation for environmental testing.

The main payload, EUVST (EUV high-throughput Spectroscopic Telescope), provides high-resolution EUV spectroscopy from the chromosphere to the corona. The Swiss-led Solar Spectral Irradiance Monitor (SoSpIM), funded through ESA PRODEX, delivers spectrally resolved “Sun-as-a-star” irradiance measurements in two wavelength bands overlapping with EUVST. Together, the instruments link detailed solar flare processes to irradiance changes affecting Earth's atmosphere.

Following the successful PDR, 2025 we focused on instrument verification. Full compliance with electrical and interface requirements could be demonstrated with the Engineering Model, including successful interface testing in Japan. In parallel, all environmental tests were completed with the Structural Thermal Model, including vibration and thermal balance.

SoSpIM is developed in collaboration with Swiss industry and the Royal Observatory of Belgium. By year-end, the project reached Instrument Critical Design Review (i-CDR) readiness, with the formal kick-off and transition to Phase D planned for in 2026.

M-SoSpIM onboard M-MATISSE

M-MATISSE is the ‘Mars Magnetosphere ATmosphere, Ionosphere and Surface Science’ space mission. It will investigate the global dynamic response of the Martian plasma-atmosphere system to space weather activity with observations from two spacecraft. It will provide the first global characterisation of the dynamics of the Martian system at all altitudes, to understand how the atmosphere dissipates the incoming energy from the solar wind, including radiation, as well as how different surface processes are affected by space weather activity. Our instrument M-SoSpIM will be on each spacecraft. These two instruments will measure solar irradiance at three different wavelengths.

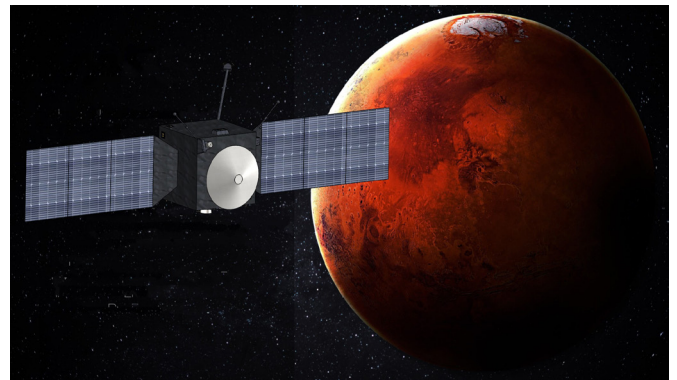


Figure 2. Artistic view of M-MATISSE (by Raphaël Naire).

M-MATISSE is led by Beatriz Sanchez-Cano from University of Leicester in the UK and has collaborations across Europe to develop the payloads.

M-MATISSE is one of the three final candidates for the ESA M7 mission. The team has successfully completed the Mission Consolidation Review in spring 2025 and has been working towards the Instrument Preliminary Requirements Review and the Mission Selection Review until the end of the year.

The final selection will take place between spring and summer 2026.

CSAR onboard TRUTHS

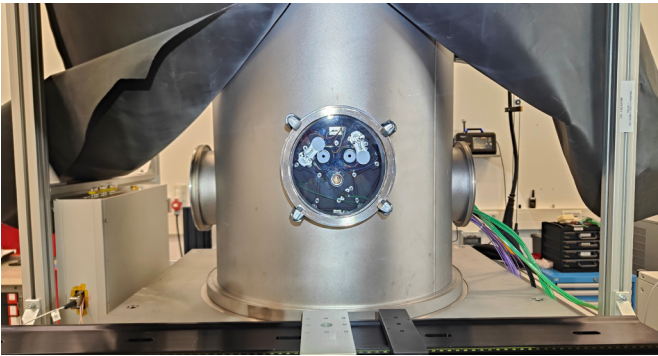


Figure 3. CSAR prototype in a thermal vacuum chamber. Image courtesy of Thales Alenia Space Switzerland

The Cryogenic Solar Absolute Radiometer (CSAR) aboard the ESA TRUTHS mission was designed to measure the Total Solar Irradiance (TSI) with unprecedented accuracy and to do in-orbit calibration of the Hyperspectral Imaging Spectrometer allowing for SI-traceable hyperspectral images of the earth.

In collaboration with Thales Alenia Space Switzerland, PMOD built a prototype of the CSAR, which was shipped to ESTEC in Noordwijk, The Netherlands where it was integrated into a thermal vacuum chamber for functional testing. The performed tests allowed us to demonstrate “Technology Readiness Level 6”, which was the major milestone of the Phase B2. The CSAR sensor head in combination with the front-end electronics designed by PMOD met the requirements to measure TSI at an unprecedented absolute accuracy.

Finally, the documentation for the Preliminary Design Review was prepared and delivered, which marked the end of Phase B2. At this point, unfortunately, TRUTHS was cancelled due to funding contributions being stopped.

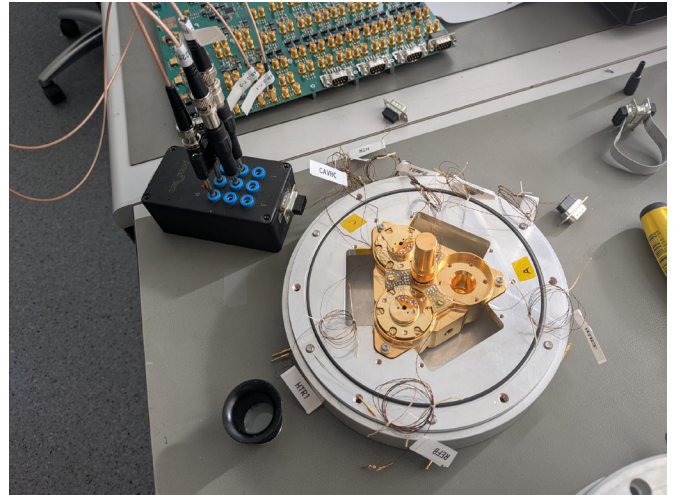


Figure 4. CSAR prototype sensor head during assembly at PMOD.

JEDI Front-End Electronics onboard Vigil

Vigil is ESA’s first operational space weather mission at the Sun–Earth L5 Lagrange point, providing enhanced early-warning capability for solar events. The NASA-provided Joint EUV coronal Diagnostic Investigation (JEDI) instrument will deliver continuous EUV observations of the solar disk and corona to track the initiation and propagation of solar eruptions.

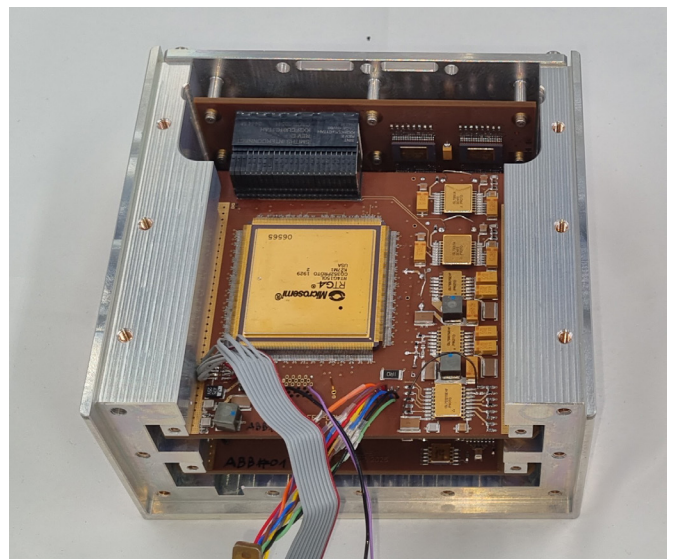


Figure 5. JEDI FEE Engineering Model integrated into its housing for electrical testing.

JEDI is led by Southwest Research Institute (SWRI) (PI, Don Hassler), with European contributions from Institut d'Astrophysique Spatiale, France (IAS, mirrors and filter wheels), Centre Spatial de Liège, Belgium (CSL, door and occulter mechanism), and PMOD/WRC, who develops the Front-End Electronics (FEE), which is needed to operate the sensor of the camera. The detector originates from Solar Orbiter flight spares, ensuring strong technical heritage.

In 2025, major milestones were achieved in FEE development and camera integration, including the successful completion of the Preliminary Design Review (PDR). Interface and power tests confirmed compliance with electrical specifications. Functional verification, including active pixel sensor integration, was successfully completed. Analog-to-digital converter characterization and analog performance validation were finalized, demonstrating a stable and compliant system performance.

Environmental verification (vibration, electromagnetic compatibility, and thermal-vacuum testing) is progressing according to plan. The project remains on track, with the Engineering Model (EM) and Proto-Flight Model (PFM) scheduled for development and delivery in the coming year. Launch is planned to be in 2031.

Earth Climate Observatory

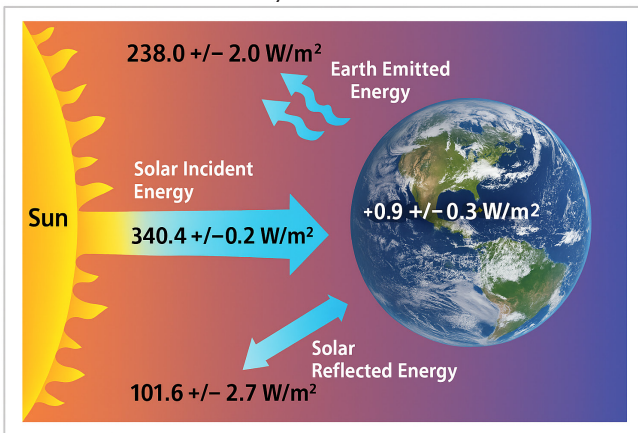


Figure 6. The Earth's energy budget.

The Earth Climate Observatory (ECO) is a new ESA Earth Explorer candidate mission. Its goal is to determine the Earth Energy Imbalance (EEI), which is the difference between Earth's incoming solar energy and the outgoing energy radiated into space. This difference is what fuels the current global warming.

ECO was proposed by a team of scientists led by the Royal Observatory of Belgium.

PMOD is involved in the development of the radiometers used to measure the Sun and Earth radiation led by the Liège Space Center. Adapting the proven solar radiometer design concepts to a wide field of view, Earth-facing instrument introduces new challenges, in particular due to the comparatively rapidly changing signal that we see when scanning the Earth versus the total solar irradiance in space.

The ECO mission is currently in Phase 0 (the mission definition phase), competing with three other Earth Explorer candidates. In 2026, two of the four candidates will be selected for continuation.

Launch is planned to be in the year 2035.

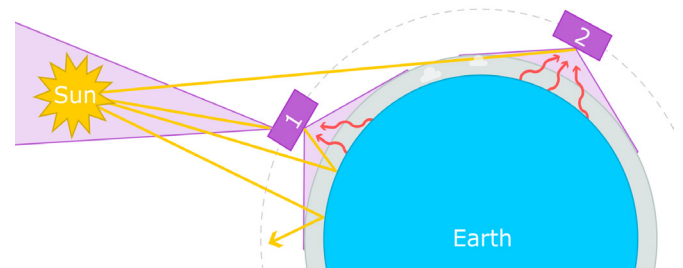


Figure 7. ECO mission concept with a two-satellite constellation scanning the Earth to capture its outgoing radiation while simultaneously measuring the solar irradiation.

Scientific Research Activities

Overview

Louise Harra

Projects at PMOD/WRC are related to solar radiation in which we address questions regarding the radiation energy budget in the terrestrial atmosphere, as well as problems in solar physics in order to understand the mechanisms concerning the variability of solar irradiance. Hardware projects at our institute are part of investigations into Sun-Earth interactions which involve measurements of solar irradiance and solar imaging.

There is strong synergy between the know-how obtained from the Operational Services of the World Radiation Center and other research activities. The same instruments are built for space-based experiments as are utilized for ground-based measurements. In addition, with the involvement in Solar Orbiter, the instrumentation extends to imaging and spectroscopy. The research activities can be grouped into four themes: climate modelling, atmospheric physics, development of reference instruments for meteorological radiation measurements and solar physics.

The majority of research activities are financed through third party funding. During 2025, there were a range of funding sources which included projects supported by the Swiss National Science Foundation, Karbacher Fonds, European COST action, SBFI, Meteoswiss, European H2020, ESA, EURAMET, SERCO and Simons Foundation. These funding sources supported twelve PhD thesis projects (eight of these at ETH and four students based at other universities and jointly supervised) and eight post-doctoral positions and three instrument scientists.

Swiss participation in ESA's PRODEX programme (PROgramme de Développement d'Expériences scientifiques) funds the hardware development of science space experiments and the operations of active space experiments. The institute's PRODEX projects paid for the equivalent of 2.7 technical department positions. An additional two are funded from a contract with Airbus UK for the ESA TRUTHS project.

In the area of climate modelling, the research studies both long and short-term changes in the Earth's atmosphere. The ozone layer evolution is being modelled and predicted. The impact of solar protons on the ionosphere has been assessed and particularly

strong historical events are analysed. In addition work is proceeding on understanding the top of the Earth's atmosphere outgoing radiation with the NORSAT-1 CLARA mission. The climate group is also modelling different scenarios for the Sun from the current day Sun to a highly active mode.

The Solar physics focus is on Solar Orbiter following the launch in 2020. These topics cover the creation of the slow and fast solar wind and the impact of flares, and are carried out in collaboration with an array of other space and ground-based missions including NASA's Parker Solar Probe and Solar Dynamics Observatory and JAXA's Hinode mission.

The institute's infrastructure and most of its overheads are paid for by the operational service of the World Radiation Center. We are proud of the fact that at the PMOD/WRC, the Center's services are based on research that is state-of-the-art in their respective fields. The WRC participated to several instrument intercomparisons in 2025, acting as reference for atmospheric longwave irradiance, total solar irradiance, spectral solar ultraviolet irradiance and aerosol optical depth. We hosted international comparison campaigns for total solar irradiance, longwave irradiance and aerosol optical depth.

We collaborated with a number of departments at ETH (D-PHYS, D-USYS, D-CHAB, D-ERDW, D-INFK) and resulting in 12 students carrying out projects with us. This includes through ETH studio Davos and departments in ETH covering environmental science, physics, informatics and engineering.

The research carried out at PMOD/WRC is intertwined with the instrumentation, both ground and space-based. In addition, a transfer of knowledge on solar radiation is being carried out through the development of a short-term forecast model of solar energy.

PMOD/WRC's citations for refereed publications are shown below, reaching more than 33,000. There are now over 880 refereed publications.

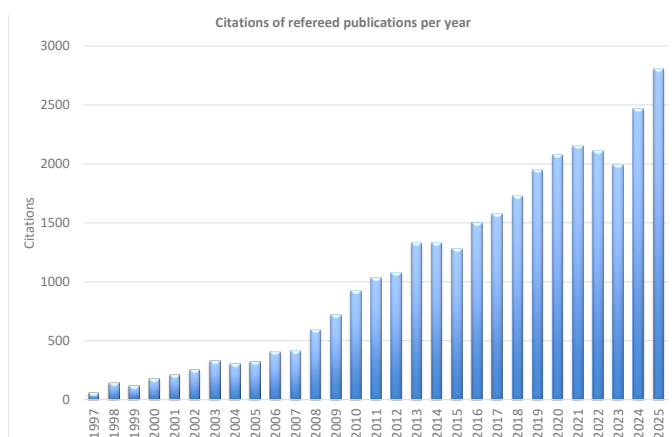


Figure 1. Number of annual citations to articles including an author with a PMOD/WRC affiliation. In December 2025, there were 33,531 citations to 884 articles included in Thomson Reuter's Web of Science. The articles were selected using the search criteria address = (World Rad* C*) OR (PMOD* NOT PMOD Technol* OR pmodak) OR (Phys* Met* Obs*).

How well do chemistry-climate models agree? (Part 1): Insights from the Interactive Stratospheric Aerosol Model Intercomparison Project (ISA-MIP)

Andrin Jörmann and Timofei Sukhodolov in collaboration with BOKU (Austria) and ISA-MIP

Large explosive volcanic eruptions eject gases into the stratosphere, where they go on to form aerosol particles that impact the climate. Modern chemistry-climate models include micro-physical aerosol processes, so they can simulate the aerosol evolution after such eruptions – based on real physics – and capture the effects. But how well do different models agree on the outcome? One experiment in ISA-MIP focuses on the response to the Mt. Pinatubo eruption in 1991. The intercomparison of several participating models shows that even in coordinated simulations, aerosol evolution and subsequent climate effects differ substantially.

The 1991 Mt. Pinatubo eruption is special for two reasons. It is the strongest recent explosive volcanic eruption and it was the first to be well-observed by satellites. This eruption injected the stratosphere with so much sulfur dioxide that the particles that formed from this gas enhanced the background aerosol layer by more than an order of magnitude. The stratospheric aerosol plays an important role in the atmospheric energy balance, because it modulates the amount of incoming solar and outgoing terrestrial radiation through scattering and absorption. Therefore, the Pinatubo eruption has been used as a test case for climate models in many studies in the past.

In recent decades our understanding of processes that shape the climate has evolved and climate models have been developed accordingly to now include interactive chemistry and aerosol modules. This generally improves projections, however, these complex model parts need to be tested and compared across different models. In this work, we participated in an analysis of multiple models that simulated the Pinatubo eruption and the subsequent atmospheric effects.

Figure 1 shows how 7 models react to the volcanic perturbation and how they compare to reanalysis and observational data (bottom right panel). The black contour lines indicate how the volcanic aerosol plume evolves after the eruption, with thicker lines showing a continuously more diluted aerosol cloud. Most models agree that the highest sulfate (SO₄) concentrations in the tropics move downward over time, somewhat matching observations. Still, there are significant differences in transport, including transport to higher latitudes (i.e. out of the tropics), which contributes to lower concentrations in this figure. With higher sulfate concentrations comes stronger absorptive heating. The color plot shows temperature anomalies, i.e. the difference between the volcanic simulations and identical control simulations without the eruption. While differences in plume evolution already suggest differences in heating, even models with similar transport produce strongly varying temperature anomalies. Possible reasons for this include that the respective aerosol modules produce different size distributions and that model-dependent radiative transfer schemes predict different heating efficiencies.

Remarkably, the mean temperature anomaly over all models agrees well with reanalysis data. This implies that while multi-model studies can produce robust results, caution is advised in studies with a single or few models. To better understand inter-model differences, idealized comparison studies that focus on single modules (like radiative transfer) are needed.

References: Perny, K., Sukhodolov, T., Kuchar, A., Arsenovic, P., Rosati, B., Brühl, C., Dhomse, S. S., Jörmann, A., Laakso, A., Mann, G., Niemeier, U., Pitari, G., Quaglia, I., Sekiya, T., Sudo, K., Timmreck, C., Tilmes, S., Visioni, D., & Rieder, H. E. (2025). Assessing the stratospheric temperature response to volcanic sulfate injections by Mt. Pinatubo: insights from the Interactive Stratospheric Aerosol Model Intercomparison Project. <https://doi.org/10.5194/egusphere-2025-5915>

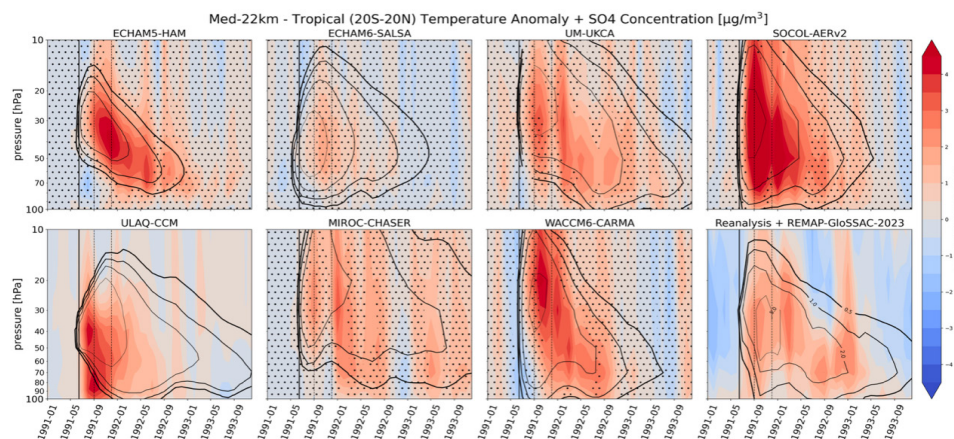


Figure 1. Tropical profile evolution of the temperature anomaly and SO₄ concentration after the Mt. Pinatubo eruption in June 1991 (black vertical line). The filled contour plot shows the 20° S to 20° N mean difference in temperature between the volcanic scenario with sulfate injection at 22 km altitude and the reference scenario. The black contour lines indicate the evolution of the SO₄ plume (levels are 0.5, 1, 2, 5 µg / m³). Dots indicate non-significant areas (p -value < 0.5). The "Reanalysis + REMAP-GloSSAC-2023" panel represents the observational data..

How well do chemistry-climate models agree? (Part 2): Results from the Chemistry Climate Model Initiative Experiment Phase 2 (CCMI-2022)

Andrin Jörmann, Timofei Sukhodolov, Eugene Rozanov, and Sandro Vattioni in collaboration with CCMI-2022

Some adverse effects of climate change could be temporarily alleviated by employing solar radiation management. By injection of a sulfuric aerosol precursor gas into the stratosphere, part of the incoming sunlight could be reflected back to space, which would have a cooling effect for the Earth's surface. There might, however, be strong side effects attached to this method. To investigate these we rely on the most sophisticated chemistry-climate models. While the average over results from multiple models is typically the best projection to use, we also need to understand the level of (dis-)agreement across different models.

Stratospheric aerosol injection (SAI) is a method in solar radiation management that works analogously to a large volcanic eruption. The injection strongly enhances the aerosol layer in the stratosphere, which cools the surface of the planet, but also affects the chemistry and circulation in the entire middle atmosphere. In the CCMI-2022 experiment a set of simulations was dedicated to capturing the effect of one SAI scenario. The scenario was designed to offset medium climate change exactly as much as needed to maintain surface temperatures at the 2025 level. This means the amount of material injected needs to increase continuously, as time goes on and climate change intensifies. Thus, the side effects also intensify over time.

There are two major basic implications of an enhanced stratospheric aerosol layer.

Dynamical: besides reflecting sunlight away, sulfuric aerosol particles also absorb radiation and heat the air around them. This intensifies the deep circulation in the middle atmosphere, especially over the tropics.

Chemical: aerosol particles provide surface area for heterogeneous reactions to occur, some of which directly facilitate ozone destruction.

Figure 1 shows the multi-model mean response due to the full (dynamical and chemical) effects of SAI (panel a) and due to only chemical effects (panel b).

Below the tropopause (black line) no anomalies are recorded, which is consistent with the experimental setup, where the climate at the surface (and most of the troposphere) in the SAI simulations is identical to the reference simulations. In the full SAI effects, the models agree on the sign of change in all numbered regions except region 5. The main driving force for the tropical anomalies (regions 6,1,2) are the aerosol heating-induced changes in circulation. Ozone mixing ratio anomalies arise from modulations in transport of air into and out of the main ozone formation region. The heating in models varies by up to a factor of two, causing significant differences in circulation changes. Therefore, the robustness of the signal location in Fig. 1 is somewhat surprising and suggests that – even though differences in magnitude remain – the processes that affect ozone under an SAI forcing are well represented in the models.

The chemistry-only contribution seems mostly minor, but also consistent across models. Chlorine activation on aerosol surfaces leads to catalytic ozone destruction in the lower stratosphere, causing a negative anomaly. Above, increases in water vapor and other gases lead to a suppression of the ozone-depleting nitrous oxides and thus a positive anomaly. Although these chemical effects only dominate the full signal in region 4, it is not only heating and circulation changes that control the SAI signal, but also the effect these changes have on chemistry. Dynamical changes can themselves alter chemical processes, making them stronger than they show up in chem-only. In this multi-model study, the models all seem to capture this complexity and provide a widely robust SAI signal. The results are described in Joerimann et al. (2026)

References: Tilmes, S., et al.: Stratospheric Aerosol Intervention experiment for the Chemistry–Climate Model Initiative, *Atmos. Chem. Phys.*, 25, 6001–6023, <https://doi.org/10.5194/acp-25-6001-2025>, 2025.

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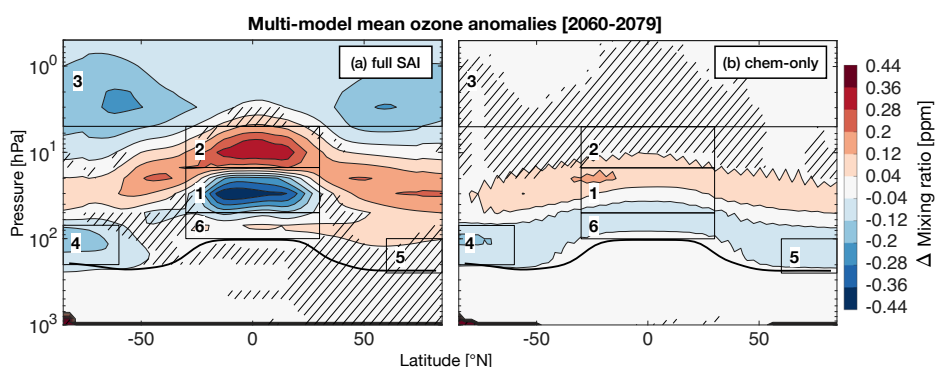


Figure 1. Multi-model mean zonal mean ozone mixing ratio anomalies due to full SAI (panel a, 5 models) and only chemical effects of SAI (panel b, 3 models). The black rectangles show regions with a dominant process shaping the ozone anomaly signal. The black line indicates the tropopause. Regions where the sign of all models do not agree are hatched.

Long-term variations in global aerosol optical depth and aerosol types based on Sun and sky photometer observations

Angelos Karanikolas, Anna Moustaka, and Stelios Kazadzis

Aerosols are a highly heterogeneous mixture of particles emitted by various sources. Different sources emit aerosols with different properties. For example, dust aerosols tend to be larger than smoke particles from wildfires. Observations of columnar aerosol properties related to size and radiation absorptivity can provide information about the sources of the most prevalent aerosols. In this study, we classify observations of aerosol properties by predominant type according to the source, study their effect on the aerosol optical depth (AOD — a parameter that describes the overall extinction of radiation due to aerosols) and assess how it changed over different periods.

Aerosols are a mixture of particles with different shapes, sizes and chemical compositions, which makes their study particularly complex. They are also very important because of their significant effects on climate and air quality. Aerosol classification is a useful tool for studying their sources, transport and effects. Classification methods and categorisation vary between studies (Hamill et al, 2016; Krishnaveni et al, 2025). It is common for aerosol-classification studies to focus on how often each type becomes predominant in various locations. However, an aerosol type may appear more frequently but at lower quantities and therefore correspond to low AOD when it is predominant, while other types may appear infrequent high-concentration episodes. Here we focus on the AOD levels related to predominance by type. We used the classification scheme of Hamill et al. (2016), which includes five source-based aerosol types: urban/industrial, biomass burning, desert dust, maritime and mixed. For classification we used observations of aerosol properties from the AERONET RObotic NETwork (AERONET). The values of these properties from selected stations for each type define the reference clusters, and all observations were classified according to their proximity to each cluster. For mixed aerosols we defined secondary types according to the second-nearest cluster. Finally, we calculated the percentage of AOD, corresponding to observations classified as each type. We selected several sites with long-term AERONET time series, each characterised by predominance of different aerosol types, and examined changes in both total AOD and the fractional AOD contribution (AOD%) associated with predominance of each type. We analysed two periods: the first extending from the beginning of station operation to 2012 (following Hamill et al., 2016), and the second from 2013 to the end of station operation or to 2024. This temporal separation allows assessment of long-term changes in aerosol loading and composition.

In Figure 1, we present the results for the GSFC station (Washington, USA). Total AOD during the second period is consistently lower than in the first for all months, with the most pronounced reductions occurring in summer. For most months, the AOD attributed to urban/industrial sources has decreased and is largely replaced by the mixed urban/industrial category. This shift is primarily associated with decreases in the extinction Ångström Exponent and single scattering albedo, indicating changes in aerosol size and absorption properties. The results suggest that

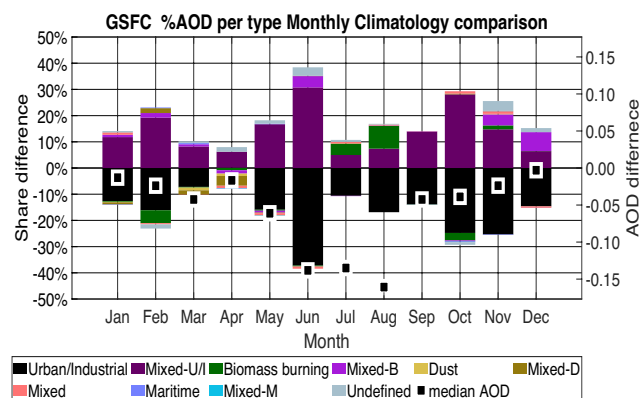


Figure 1. Panel a: Climatologies of median AOD and AOD percentage per type (and sub-type) for GSFC, 1993–2024. Panel b: Changes in AOD and AOD percentage per type between 1993–2012 and 2013–2024. The graphs include the secondary types mixed-urban/industrial (mixed-U), mixed-biomass burning (mixed-B), mixed-dust (mixed-D) and mixed-maritime (mixed-M).

while urban/industrial aerosols remain the predominant type, their compositional “purity” has declined. A likely explanation is a reduction in anthropogenic emissions without substantial changes in other aerosol sources, leading to both a lower overall aerosol burden (reflected in reduced AOD) and a diminished dominance of purely urban/industrial aerosol characteristics within the mixture. Overall, this analysis highlights the importance of considering not only the frequency of aerosol-type predominance when assessing long-term aerosol changes but also the AOD levels associated with that predominance. By focusing on the combination of occurrence and AOD contributions, we gain deeper insight into how emission controls and source mixtures affect aerosol loading and optical properties. In our example, the observed transition toward more mixed aerosol characteristics at GSFC underscores that reductions in emissions or transport may alter aerosol composition even when the dominant source category remains unchanged. This approach provides a more complete framework for interpreting aerosol trends and their implications for climate forcing and air quality.

Acknowledgements: This work received financial support through the ACTRIS Switzerland 2025–2028 grant (Swiss contribution to the ACTRIS ERIC) funded by the Swiss State Secretariat for Education and Research and Innovation (SERI).

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Two Decades of Aerosol Changes: Insights from CAMS reanalysis

Anna Moustaka, and Stelios Kazadzis in collaboration with ECMWF, Academy of Athens, and Aristotle University of Thessaloniki

Atmospheric aerosols are tiny particles from natural and human sources that affect climate, air quality, visibility, and health. Their presence in the atmosphere is often expressed through Aerosol Optical Depth (AOD), which measures how much sunlight is attenuated by these particles. Understanding long-term AOD trends is important for monitoring climate change and evaluating pollution-control efforts. In this study, we analyse global and regional AOD trends during 2003–2024 using the Copernicus Atmosphere Monitoring Service Reanalysis (CAMSRA). We then examine trends across 18 key regions influenced by different aerosol species, and assess the role of satellite data assimilation. These results improve our understanding of how and why aerosol levels are changing worldwide.

Aerosol optical depth (AOD) is a key metric for assessing global climate change, and its long-term evolution offers valuable insight into the changing climatic influence of atmospheric aerosols. In this study, we analyze the 2003–2024 aerosol dataset from the Copernicus Atmosphere Monitoring Service Reanalysis (CAMSRA), produced by ECMWF, to investigate global and regional AOD trend patterns across multiple sub-periods. For the regional analysis, 18 regions of interest (ROIs) were selected to represent areas dominated by dust, biomass burning, anthropogenic emissions, sea salt, and mixed aerosol types (Fig. 2). Trends were calculated for both total AOD and the five individual aerosol species included in CAMSRA—dust (DU), sea salt (SS), black carbon (BC), organic matter (OM), and sulfates (SU)—enabling an assessment of the contribution of each species to total AOD trends and their potential climatic implications. Evaluation of the CAMS AOD trends against ground-based AERONET measurements (Fig. 1) shows strong agreement for stations with statistically significant trends (above

the 95% confidence level). Overall, the comparison indicates a high correlation ($R = 0.89$), a low error ($RMSE = 0.0021$), and correct identification of the trend direction at 96.7% of stations. Negative trends are particularly well captured, whereas positive trends tend to be more frequently underestimated.

Across the 22-year study period, a significant decline in AOD was detected over China, while India exhibited persistent increases, consistent throughout all examined subperiods. Furthermore, when comparing the two decades (2003–2013 and 2014–2024), many regions worldwide displayed trend reversals (e.g., eastern China, the Taklamakan Desert, etc.).

The aerosol-specified trend analysis over the 18 ROIs reveals that OM and SU are the main contributors to AOD trends in biomass-burning and pollution-dominated regions (Fig. 2). Conversely, in several other regions, the dominant aerosol subtype does not necessarily control the total AOD trend, highlighting the need for further investigation into the mechanisms driving these regional changes.

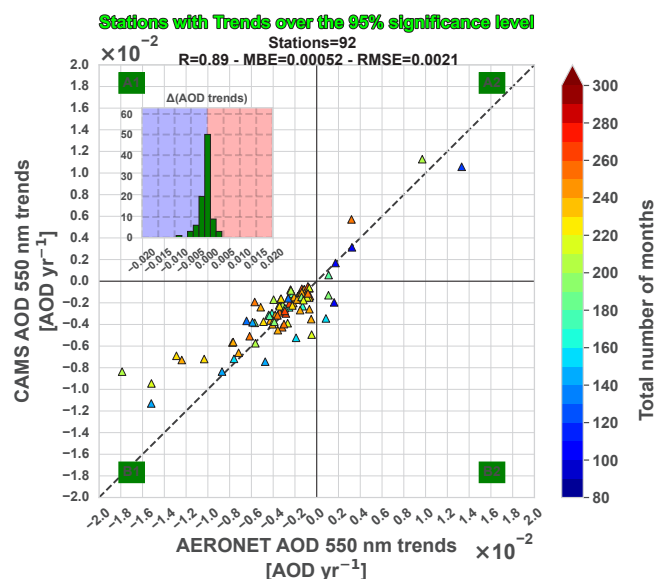


Figure 1. Intensity and Doppler shifts of spectral lines emitted by Fe XII (Panels a and b) and Ne VIII ions (Panels c and d). One of the two upflow regions are outlined at the east boundary of the active region. Adapted from Zhu et al. (2025, in preparation).

Regional AOD Trends based on CAMSRA 2003–2024

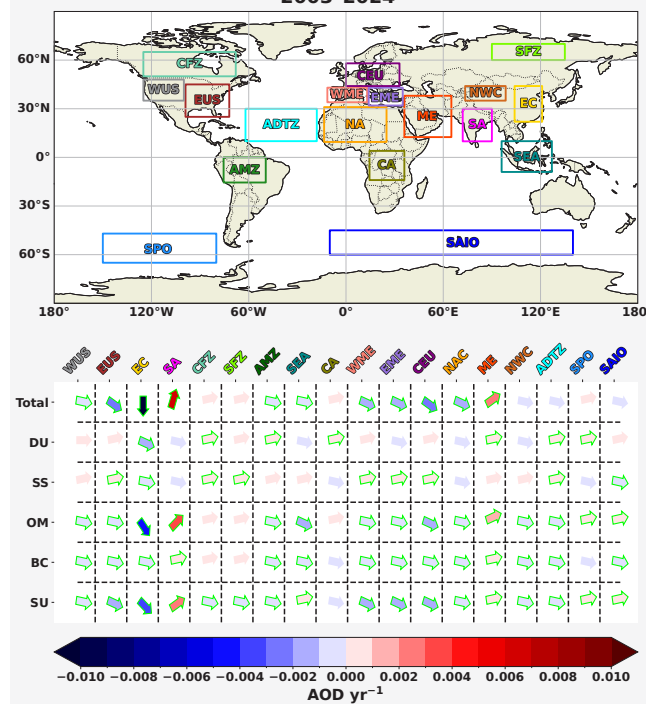


Figure 2. Regional aerosol optical depth (AOD) trends from CAMSRA for 2003–2024. The map shows the 18 regions of interest (ROIs) used in the analysis. The arrow panels illustrate the annual AOD trends for total AOD and for individual aerosol species (DU, SS, BC, OM, and SU) within each region

Acknowledgement: This work received financial support through the ACTRIS Switzerland 2025-2028 grant (Swiss contribution to the ACTRIS ERIC) funded by the Swiss State Secretariat for Education and Research and Innovation (SERI). Part of this work was supported by the COST Action Harmonia (CA21119) by COST (European Cooperation in Science and Technology).

The Role of Satellite AOD Assimilation in CAMS Aerosol Optical Depth and Its Long-term Trends

Anna Moustaka, and Stelios Kazadzis in collaboration with ECMWF, Academy of Athens, and Aristotle University of Thessaloniki

Atmospheric aerosols are tiny particles in the air that affect climate, air quality, and health. Their loading is commonly described by Aerosol Optical Depth (AOD), which indicates how strongly aerosols attenuate sunlight. The Copernicus Atmosphere Monitoring Service (CAMS) produces global aerosol datasets by combining atmospheric models with satellite observations. In the CAMS EAC4 (ECMWF Atmospheric Composition Reanalysis 4) product, satellite-derived AOD is assimilated into the model, while a corresponding control run (CTRL) is produced without AOD assimilation. In this work, we compare EAC4 and CTRL to quantify the impact of satellite AOD assimilation on the representation of aerosols and their long-term trends.

AOD is a key parameter for assessing climate-relevant aerosol loading, and its long-term behaviour provides insight into changes in atmospheric composition. In the Copernicus Atmosphere Monitoring Service (CAMS), satellite-retrieved AOD has been assimilated since 2003 to constrain the model aerosol fields, producing the CAMS reanalysis (EAC4). The assimilated observations include AOD from the MODIS instruments on Terra and Aqua, with additional contributions from AATSR on Envisat satellite. In parallel, a control simulation (CTRL) is generated without AOD assimilation, allowing the direct effect of assimilation to be isolated. In this study, we compare AOD and AOD trends from EAC4 and CTRL over 2003–2024 to quantify how satellite AOD assimilation influences the representation of aerosol levels and their long-term evolution.

To clearly assess the effect of satellite AOD assimilation, we ana-

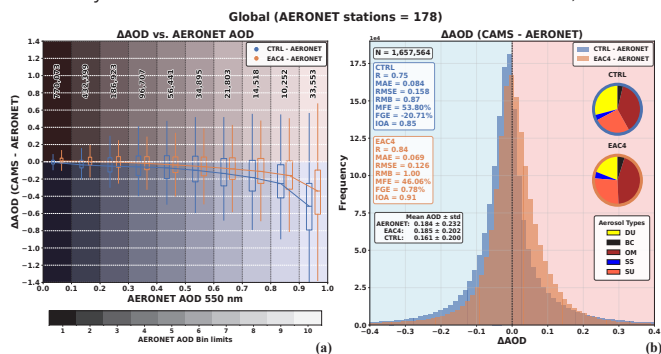


Figure 1. (a) Box-whisker plots of AOD differences ($\Delta AOD = CAMS - AERONET$) for CTRL (blue) and EAC4 (orange) as a function of AERONET AOD. AOD values are grouped into equal-width bins, with the number of pairs shown above each bin. (b) Histograms of ΔAOD for CTRL and EAC4, together with the main evaluation statistics. Pie charts show the fractional contribution of the different CAMS aerosol components to total AOD. Mean AERONET AOD and the mean \pm standard deviation for CTRL and EAC4 are also reported.

lyse AOD differences (ΔAOD), defined as $EAC4 - AERONET$ and $CTRL - AERONET$, as a function of AERONET AOD across 178 AERONET stations (2003–2024). Figure 3a shows ΔAOD box-whisker plots in AOD classes of width 0.1. At low AOD (0.0–0.2), both products agree well with AERONET, with ΔAOD centred near zero and representing $\sim 72\%$ of the data. As AOD increases, both

systems increasingly underestimate AOD, but the underestimation is clearly stronger in CTRL. EAC4 systematically reduces this bias across all AOD ranges, and its ΔAOD spread is consistently narrower, indicating greater stability of the assimilated product. At very high AOD (>0.7), underestimation becomes large for both systems, although EAC4 still performs noticeably better than CTRL. Figure 3b further summarizes the evaluation statistics. EAC4 shows markedly improved performance compared with CTRL, with higher correlation, lower RMSE and MAE, and an Index of Agreement (IOA) of 0.91. The mean bias is almost completely removed ($RMB \approx 1.00$), and the ΔAOD distribution is sharply centred near zero with fewer extremes. The largest improvement appears in the fractional gross error, which decreases from -20.7% in CTRL to 0.78% in EAC4, demonstrating that assimilation of MODIS and AATSR AOD largely eliminates the CTRL underestimation. The aerosol-component fractions also differ between the two products. CTRL attributes $\sim 29\%$ of total AOD to dust, whereas this fraction decreases to $\sim 19\%$ in EAC4, indicating that CTRL overestimates dust contribution. In contrast, the share of organic matter increases from 38% to 44% in EAC4, with smaller increases in sea salt, sulfate, and black carbon.

Additionally, assimilation of satellite aerosol observations in CAMS

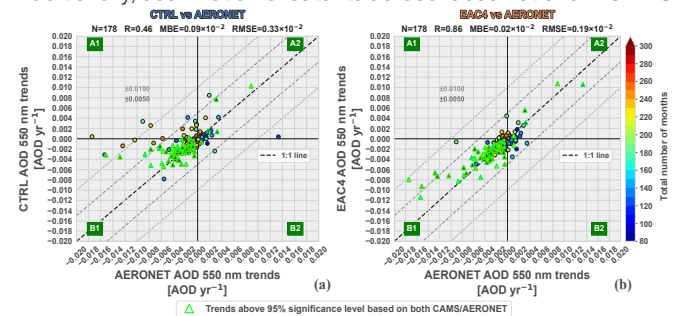


Figure 2. Scatter plots of AOD trends ($AOD\ yr^{-1}$) between AERONET and CAMS for (left) the EAC4 reanalysis (assimilation) and (right) the CTRL simulation (no assimilation). Green triangles indicate stations where both datasets show significant trends at the 95% level.

EAC4 leads to a substantial improvement in the representation of long-term AOD trends compared to the control simulation (Fig. 4). The correlation with AERONET increases from 0.46 (CTRL) to 0.86 (EAC4), while the RMSE is nearly halved. The distribution of trend differences also narrows considerably, and a larger fraction of stations exhibit statistically significant trends consistent with AERONET. These results demonstrate that data assimilation not only improves the instantaneous AOD fields but also helps constrain the long-term behaviour of aerosol loading in the reanalysis.

Acknowledgement: This work received financial support through the ACTRIS Switzerland 2025–2028 grant (Swiss contribution to the ACTRIS ERIC) funded by the Swiss State Secretariat for Education and Research and Innovation (SERI). Part of this work was supported by the COST Action Harmonia (CA21119) by COST (European Cooperation in Science and Technology).

A new method for atmospheric precipitable water vapor retrieval using BTS Spectroradiometer

Autor
Dhrona Jaine and Julian Gröbner

Accurate estimation of precipitable water vapour in the atmosphere (integrated water vapour, IWV) is essential for radiative-transfer studies, climate research, and solar energy applications. This study presents a new water vapor retrieval algorithm based on direct solar spectral irradiance measurements from a compact BTS spectroradiometer, with the retrieved IWV validated against independent reference observations. The BTS derived IWV shows good agreement with GPS (Agnes) Water vapor measurements, with a mean bias of -1.01 mm and a standard deviation of 0.80 mm over the analyzed period. In comparison, the co-located AERONET water vapor retrieval exhibits larger discrepancies, with a bias of -2.60 mm and the standard deviation of 1.82 mm relative to GPS. These results demonstrate that these low cost spectroradiometers can provide reliable IWV estimates suitable for long term atmospheric monitoring and solar radiation studies.

Atmospheric water vapor is a fundamental component in atmospheric radiative transfer studies, global climate observations and forecasting applications. Despite this importance, achieving accurate retrievals remains challenging due to the strong variability of water vapour and the complexity of near-infrared absorption features. Furthermore, the challenges become even more significant when working with a compact instrument such as Bi-Tec Sensor (BTS) spectroradiometer where the limited spectral resolution and the instrument line shape (ILS) can distort the absorption features.

This study aims to assess the response of direct solar spectral irradiance at individual wavelengths between 883 nm and 1008 nm to the changes in atmospheric water vapor, and to determine if a combination of wavelengths could yield a more stable and accurate retrieval compared to relying on a single wavelength absorption feature. To achieve this, we performed a detailed synthetic-spectra analysis using the radiative transfer model (libradtran). Analysing the seasonal datasets allowed us to quantify the sensitivity, stability, and bias characteristics in the selected spectral region. An appropriate selection criterion was developed based on the statistical analysis of these synthetic radiative transfer simulation data across the seasons as well as incorporating the existing literatures (Raptis et al. (2018)). Thereby, isolating the wavelength regions that consistently showed strong water vapor dependence across all atmospheric conditions. The analysis revealed several clusters, particularly between 933 nm to 936 nm and 943 nm to 949 nm, where the retrieval residuals remained low and stable throughout all seasons. The wavelength optimization forms the foundation of the formulation of the retrieval algorithm. The optimized wavelength set was subsequently applied to BTS measurements under real atmospheric conditions.

The resulting IWV derived from BTS and the AERONET were then evaluated through direct comparisons with co-located GPS IWV observations. Across all four key statistical error metrics such as Bias, Root mean square error (RMSE), Standard Deviation, and Mean absolute error (MAE); the proposed BTS IWV retrieval

demonstrated improved agreement with GPS IWV observations compared to the co-located AERONET IWV retrieval. As shown in Fig. 1a, the BTS derived IWV closely follows the 1:1 line over the full range of observed conditions, whereas the AERONET retrieval exhibits a systematic negative offset, indicating a consistent underestimation of atmospheric water vapor. Quantitatively, the BTS retrieval shows a bias of -1.01 mm, which is approximately 61% smaller than the bias observed for the AERONET retrieval (-2.60 mm) relative to GPS IWV measurements. This reduction in systematic error is accompanied by a narrow spread of the residuals, with a standard deviation of 0.80 mm for BTS retrieval compared to 1.82 mm for AERONET, corresponding to a reduction of approximately 56%. The RMSE, which incorporates both systematic and random error components, shows a reduction of about 59% for the BTS retrieval, confirming that it remains consistently closer to GPS-derived IWV across various atmospheric conditions. The error distributions shown in Fig. 1b further illustrate the improved

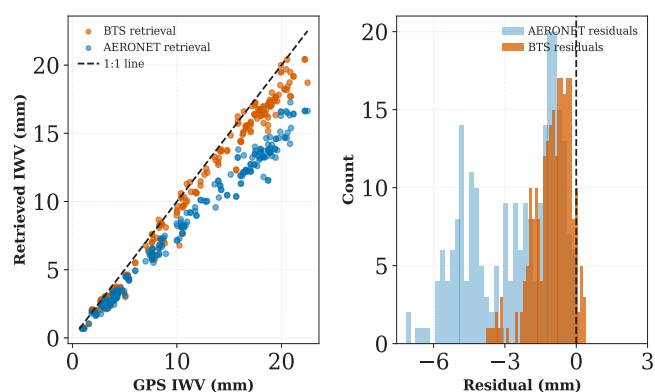


Figure 1. (a) Comparison between GPS IWV measurements and IWV retrieved from BTS and AERONET observations. The dashed line indicates the 1:1 relationship. (b) Distribution of retrieval residuals relative to GPS, illustrating the reduced bias and narrower spread of the BTS residuals compared to AERONET, indicating improved accuracy and stability of the BTS based retrieval.

stability of the BTS retrieval. The narrower residual distribution and lower MAE (1.03 mm) indicate reduced bias as well as enhanced accuracy. These results demonstrate that the careful selection of physically meaningful and spectrally stable wavelengths identified through synthetic radiative-transfer modelling and subsequently applied to real atmospheric measurements leads to a substantial improvement in retrieval performance. Overall, the proposed BTS based algorithm is providing a more consistent IWV product than the co-located AERONET retrieval, thereby demonstrating the potential of compact spectroradiometers for accurate and long-term atmospheric water vapor monitoring.

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Evaluating the impact of relocating ozone measurements from Arosa to Davos

Fernanda Cabello, Julian Gröbner

The differences in the Total Column Ozone between Arosa and Davos were assessed. An independent analysis was performed and compared to previous analyses. The TOC retrieval from the Brewer and Dobson spectroradiometer was improved by quantifying the systematic differences between the instruments. Additionally an ozone slant column constraint was applied to cover summer and winter measurements. Our findings suggest a constant transfer function of total column ozone from Arosa to Davos equal to the climatological tropospheric ozone column differences.

The analysis presented was realised within the framework of the Quantifying the past, present and future Stratospheric and Tropospheric Ozone over the Alps and Europe (STOA) project with the aim to developing an homogenized ozone time-series.

The Total Column Ozone (TOC) measurements in Switzerland started in 1926 at the LichtKlimatische Observatorium in Arosa. However, between 2011 and 2021 the relocation of the instruments to PMOD/WRC was undertaken. The relocation of the instruments was performed with great care to avoid any possible rupture of the world longest continuous ozone time-series. Due to this, the relocation lasted over 10 years and the analysis comparing each site was performed by Rene Stübi and collaborators during this overlapping period. These studies showed that the instruments exhibited an opposite seasonal behaviour of about 1% in magnitude, which led to a new analysis to investigate and to reconcile the measurements at both locations.

Synchronized measurements within a 5-minute temporal window were used for the analysis. To add consistency between the measurements performed by the Dobson and Brewer spectroradiometer the data were corrected following the methodology explained in Gröbner et al., .

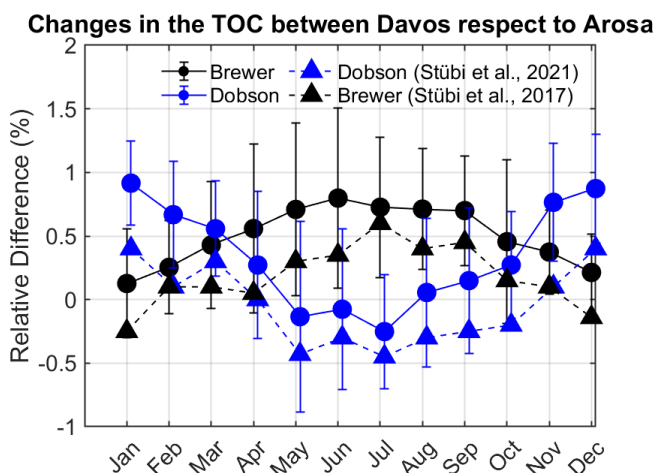


Figure 1. Relative TOC differences between Davos and Arosa for Brewer (black) and Dobson (blue) instruments. Triangles show reference results from Stübi et al.(2017,2021).

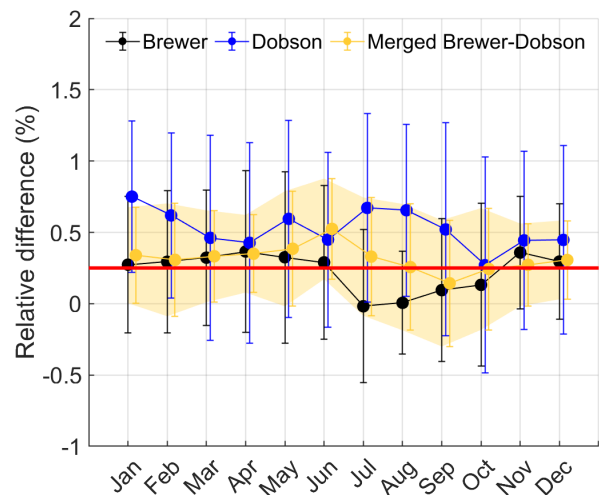


Figure 2. Relative differences between in TOC measurements obtained from Brewer (black), Dobson (blue) and merged instruments (yellow) following the implementation of comparison improvements. The shaded area corresponds to 95% confidence level of the dataset and the red line indicates the difference in the tropospheric ozone column between Arosa and Davos (Stübi et al.,2017).

2021 and Voglmeier., et al 2024. The relative monthly mean differences of the Brewer and Dobson instruments were used to assess the climatological differences in total column ozone between Arosa and Davos. The results were compared with the analysis from Stübi et al., 2017 and 2021.

Our findings are in good agreement with the previous studies as illustrated in the Figure 1, also demonstrating the opposite seasonal difference in TOC. In order to reduce the observed seasonal dependency shown in Figure 1, an additional constraint was applied to the comparison data to try to reduce the observed seasonal dependence: a common ozone slant column range from 850 DU to 950 DU.

The results of applying this additional constraint can be seen in Figure 2. This figure highlights the absence of seasonal behaviour and regarding the median mean of the distribution shows similar magnitude with the climatological tropospheric ozone column differences corresponding to a different height of 260 m (Stübi et al., 2017), which is the height difference between Arosa and Davos, indicated as red line in the Figure 2.

From our analysis we suggest a constant transfer function equal to the climatological differences in the tropospheric ozone column to transform the Arosa TOC measurement to the measurement carried out in Davos.

Acknowledgement: We would like to thank the financial support by the Swiss National Funding for STOA project.

24 years of QASUME Site Audits

Gregor Hülsen and Julian Gröbner

In the past 24 years the portable reference spectroradiometer QASUME was used to assess the quality of spectral solar UV measurements around the world. During the more than 330 site audits, 120 instruments at 38 stations (2 outside of Europe) could be compared to QASUME. Brewer spectrophotometers measure on average 3% lower irradiances with a variability of $\pm 4\%$ whereas scanning double monochromator systems from other manufacturers compare very well with the reference with a variability of $\pm 3\%$. In general, the performance of solar UV irradiance measurements is improving.

The EU funded project Q.A.S.U.M.E. started in 2002 with quality assurance of solar UV measurements using a Bentham DM150 spectroradiometer as transfer standard (Gröbner, 2006). In 2005 this task was transferred to PMOD/WRC, and in 2016 the WCC-UV was established as a section of the WRC. In total 330 site audits could be carried out until the end of 2025. The majority of the stations are in Europe, in addition two NDACC stations in New Zealand and La Reunion were also visited. The summary of the calibrations is:

- 245 Brewer spectrophotometers.
- 74 Scanning spectroradiometers of other manufacturers
- 21 Diode Array spectroradiometers (incl. 8 BTS)

All results of these QASUME site audits can be found at the WCC-UV website <https://www.pmodwrc.ch/en/world-radiation-center-2/wcc-uv/qasume-site-audits/>. Brewers typically underestimate solar UV irradiance mostly due to the imperfect cosine response of their input optic. In the last decades algorithms were developed to correct this error. However, as seen in Figure 1 the year to year variability and under-estimation of solar irradiance has not been generally improved. In contrast the performance of scanning spectroradiometers from other manufacturers with custom-made entrance optics shows much improved consistency with QASUME (Fig. 1, red line).

In 2014 the first large intercomparison of array spectroradiometers measuring solar UV irradiance took place in Davos in the frame of the European Metrology Project SolarUV. This activity revealed the need for significant improvements of this type of instruments to

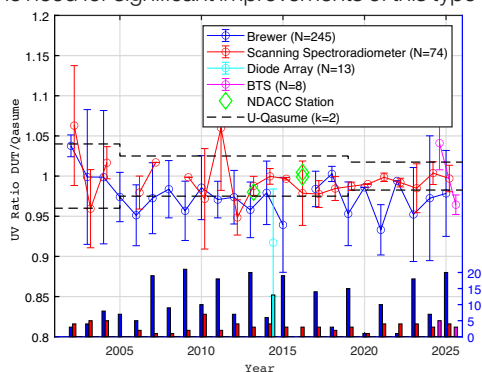


Figure 1. Yearly results of the 330 QASUME site audits.

achieve reliable measurements in the UV part of the solar spectrum.

The site visits of the two NDACC stations at Lauder, New Zealand and La Reunion, France, demonstrated good consistency with QASUME. Several of the instruments were audited multiple times – most of those on a regular frequency. Some at different locations or during large intercomparison activities. Examples are shown in Figure 2. Highlighted is the good performance of the two spectroradiometers of the WCC UV, Brewer #163 and QASUMEII (blue lines), which are well within the uncertainty of the reference standard (Hülsen, 2016) (dashed lines). Regular audits show drifts, instabilities or malfunctioning of the local instruments, like

- mounting error after a relocation (black-circles),
- calibration error (red-circles),
- instrument or calibration instabilities (green-crosses),

but also improvements, like Br1 (red-crosses) or Inst2 (green-circles).

Acknowledgement: We would like to thank all local operators for supporting the site visits and their institutes. Many thanks to the Qasume operators over this long time period: Julian Gröbner, Josef Schreder, Stelios Kazadzis, Natalia Kouremeti, Gregor Hülsen, Luca Egli, Christian Thomann and Franz Zeilinger.

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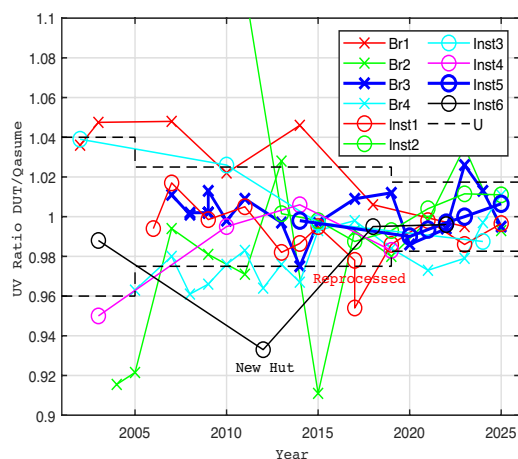


Figure 2. Repeated QASUME site audits show the long term stability of solar UV measurements at a specific station. The uncertainty of QASUME ($k=2$) is shown as black dashed lines.

Near-continuous tracking of a super active solar region for over three solar rotations

I. Kontogiannis, Y. Zhu, K. Barczynski, and L.K. Hara in collaboration with ETH Zurich, IRSOL, MPS, UCL and Uni Austria

In May 2024, Earth experienced the strongest geomagnetic storm of the past two decades, with spectacular aurora sightings reported as far south as the Mediterranean. This storm resulted from eruptions originating in active region NOAA 13664, a region characterized by a highly complex and strong magnetic field. By combining data from the Solar Orbiter and the Solar Dynamics Observatory space missions, we were able to continuously track the evolution and eruptive activity of this super active region for the first time.

Active regions are regions on the Sun characterized by extended, strong, and complex magnetic fields. They often host strong eruptive events such as flares and coronal mass ejections (CMEs), during which some of the stored magnetic energy is converted into electromagnetic emission, plasma, and accelerated particles. These events can be harmful to space missions and can cause geomagnetic storms, impacting various technological activities and ground-based infrastructure.

In May 2024, one of the most eruptive active regions of the past two solar cycles appeared on the Earth-facing side of the Sun. This was active region National Oceanic and Atmospheric Administration (NOAA) 13664; its flares and coronal mass ejections led to the strongest geomagnetic storm since 2003, causing aurora sightings as far south as Switzerland and the Mediterranean Sea. Super active regions like NOAA 13664 evolve over several months and produce adverse space weather effects. Since most solar observatories are located along the Sun–Earth line, we can observe such regions for only about two weeks before they disappear on the far side of the Sun due to solar rotation. However, the Solar Orbiter, with its orbit around the Sun, can extend our view of solar phenomena.

Between April and July 2024, the Solar Orbiter spacecraft was located roughly opposite Earth observing the far side of the Sun. This favorable configuration provided the opportunity to combine observations of the photospheric (surface) magnetic field and the corona (upper atmosphere) of the Sun to produce the first near-continuous, 94-day-long dataset for NOAA 13664. To this end, data from the Helioseismic and Magnetic Imager and the Atmospheric Imaging Assembly onboard the Solar Dynamics Observatory, as well as the Polarimetric and Helioseismic Imager and the Extreme Ultraviolet Imager onboard the Solar Orbiter, were utilized.

The combined dataset (Figure 1) illustrates how a series of new magnetic flux emergence events formed a highly compact and complex structure, whose complexity peaked around 20 May. The region then began to decay slowly, while maintaining considerable complexity. During the last two weeks, the decay process accelerated, and the region was barely detectable by around 18 July. This formation process and the evolution of complexity can explain the eruptive activity of the region. In Figure 2, we present

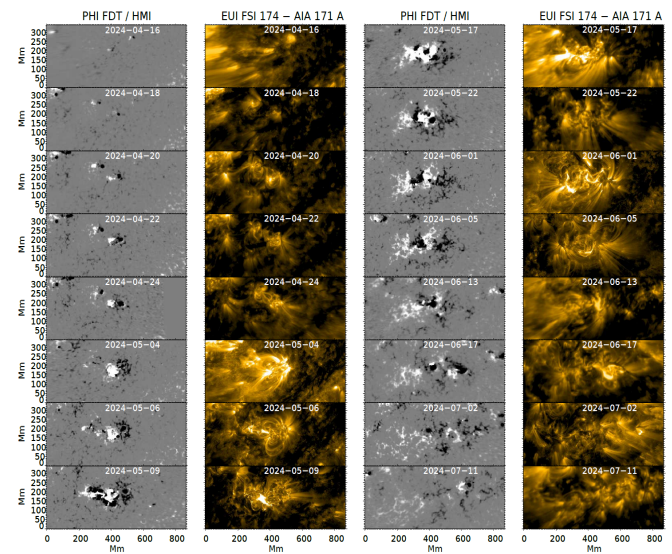


Figure 2. Snapshots of the evolution of NOAA13664 from 16 April 2024. Columns 1 and 3 show the maps of the line-of-sight magnetic field at the photosphere, where black and white patches denote regions with strong negative and positive magnetic field, respectively. Columns 2 and 4 show the corresponding maps of emission from one-million-degree plasma.

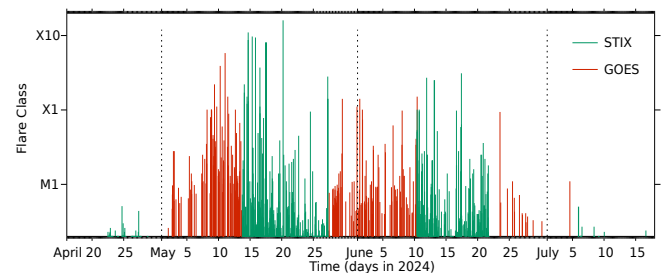


Figure 2. Total flare output of the region, as recorded by GOES (red) and STIX (green). Each line represents the magnitude of a flare.

the total flare output, including recordings from both the near and far sides of the Sun over the 94-day interval. The flare events were detected by the Geostationary Operational Environmental Satellite (GOES) and the Spectrometer Telescope for Imaging X-rays (STIX) onboard the Solar Orbiter. The flaring activity peaks between 15 and 20 May and remains high until mid- to late June, before dropping considerably.

This work, which was published in *Astronomy & Astrophysics* (Kontogiannis et al. 2025, A&A 704, A105) illustrates how future missions offering multi-vantage-point solar observations can enable monitoring of all evolutionary stages of complex active regions and their activity, thereby widening our forecasting window for solar eruptions and broadening our understanding of how magnetic flux emerges and evolves on the Sun.

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Model intercomparison for small volcanic eruptions

Jan Sedlacek, Timofei Sukhodolov in collaboration with MPI (Germany), IPSL (France), University of Oslo (Norway)

The ESA STATISTICS project aims to examine solar radiation modification (SRM) techniques from a different angle. One major focus is on how spaceborne Earth observations can be integrated with models to advance our understanding of these techniques. The project also investigates monitoring capabilities and defines requirements needed to detect SRM deployment. Our contribution is based on modelling small amounts of sulfate in the stratosphere and understanding differences from different models in the framework of a small modelling intercomparison project.

Stratospheric Aerosol Injection (SAI) is one of the most investigated and promising techniques of solar radiation modification (SRM). The method is inspired by large volcanic eruptions where aerosols are transported to the stratosphere and are reflecting back to space solar radiation. In the volcanic setting the material is sulfur although recently several alternative materials are proposed to be used for SAI (Vattioni et al, 2024).

Comparison with measurements taken after a volcanic eruption is currently the only way to validate the evolution of stratospheric sulfate aerosols in atmospheric and climate models. The most prominent of these eruptions was that of Mount Pinatubo in June 1991. This was also the largest eruption in the last 150 years. The observations following this eruption provide many opportunities for observation-model comparisons. However, the large sulfur emissions of about 16 Tg SO₂ within 3 hours is not comparable to SAI conditions. Here, injections of up to 10 Tg SO₂ per year are discussed. Since aerosol microphysics is non-linear and the final particle size depends strongly on the SO₂ concentration, smaller volcanic eruptions with an eruption height just reaching the stratosphere provide more realistic conditions to compare to

SAI conditions. The Raikoke and Ulawun eruptions in 2019 were such eruptions.

Four different models are collaborating in a small modelling intercomparison: SOCOL, ECHAM5-HAM, NorESM, and IPSL-ESM. The models include aerosol microphysics, such as nucleation, condensation, coagulation, and sedimentation processes. However, the details differ. The simulations started in 2018 with the eruption of the Ambae volcano. Including this eruption is important to achieve a reasonable sulfate background concentration. However, the models show quite some differences between the simulated background radii and concentrations in June, with only ECHAM-HAM and NorESM showing an area with increased particle size in the tropics (Fig. 1). SOCOL simulates relatively small particle sizes in June and shows small particle sizes for the other months as well. The observations show a decrease in particle size in the Southern Hemisphere's lower stratosphere in August (see Fig. 1, third column). This decrease is due to increased nucleation following the eruption of the Ulawun volcano. In the Northern Hemisphere, particle size increased compared to June due to the Raikoke eruption. Raikoke is located at higher latitudes where lower stratospheric temperatures result in less frequent nucleation. The models simulate this feature with less separation between the Northern and Southern Hemispheres.

Acknowledgment: This work is supported by the ESA Statistics project.

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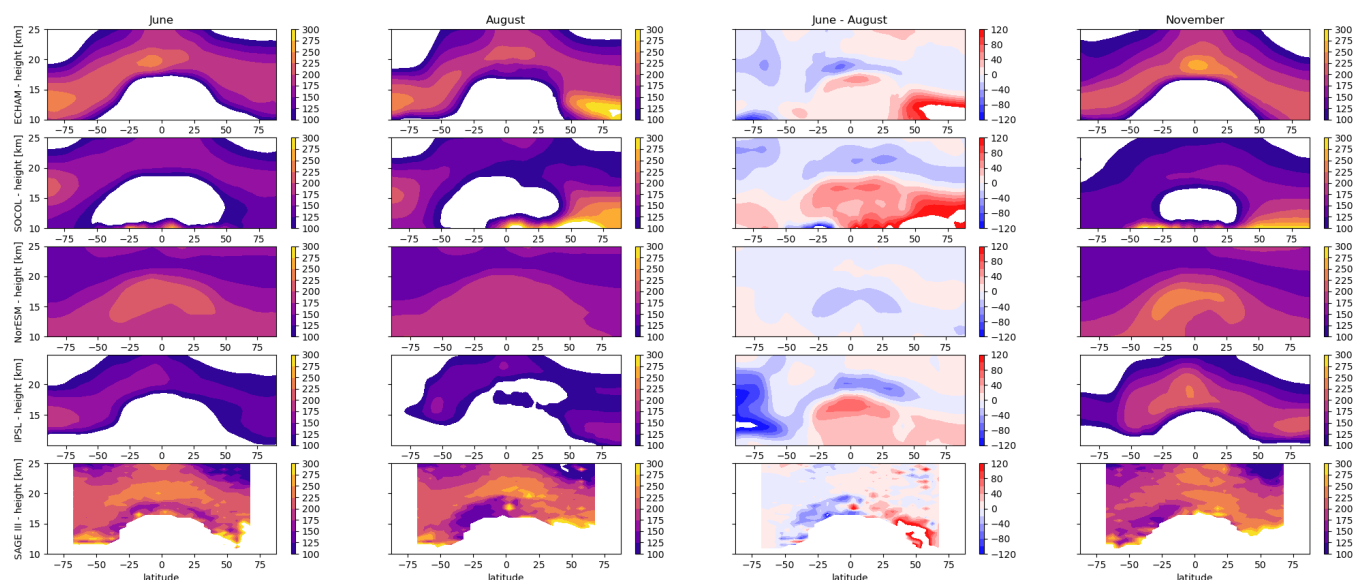


Figure 1. Zonal means of the monthly averaged effective radius (nm) for four models (ECHAM-HAM, 1st row; SOCOL, 2nd row; NorESM, 3rd row; IPSL-ESM, 4th row) and SAGE III observations (last row) for the months June, August and November and the anomaly between June and August. All models simulated the Raikoke and the two Ulawun eruptions.

The Global Energy Balance Archive (GEBA)

Jan Sedlacek, Pascale Smith, Julian Gröbner in collaboration with ETH Zürich (Switzerland)

The Global Energy Balance Archive (GEBA) is a central storage database which collects worldwide measured surface energy fluxes. GEBA was initiated by Atsumu Ohmura and collaborators at ETH Zürich in the 1980's. The data originates from various sources, such as operational data, measurement from campaigns, data reports, monographs, and personal communication, just to name a few. The database is hosted by ETH Zürich but in recent time the maintenance work has shifted to PMOD/WRC. Currently a big task is the change in database technology. GEBA is funded by Meteoswiss in the framework of GCOS Switzerland and is freely accessible after registration.

In the early 1980's Atsumu Ohmura and collaborators at ETH Zürich started collecting surface energy flux data and building a central storage system. The idea became a World Climate Program project (WCP - Water Project A7). The first digital database was released in 1986 and opened to the scientific community in 1991. The data is collected from various sources, such as operational measurements, data reports, published and unpublished manuscripts, monographs, and personal communications. In the earlier times the data was still in paper form and had to be digitized. The database contains 19 different variables such as the standard quantities global radiation, direct and diffuse shortwave radiation, and incoming and outgoing longwave radiation. A few variables are also less popular quantities such as subsurface heat flux, latent heat to melt, and absorbed global radiation. GEBA only contains ground based and directly measured data. Today, data from more than 2700 measurement sites are incorporated into the database (see Fig. 1). The oldest record in GEBA is from Stockholm and dates back to 1922.

Since the first public release several major changes to the database were carried out. One of the bigger changes was surely the accessibility through the internet in 1997. In recent years a major change in the database structure has started where PMOD/WRC is increasingly involved. The database changed underlying technology from an Oracle database to a Postgres database. In parallel several adaptations are done. The structure of the database is changed and is adapted to today's standards. In addition, several quality checks are being implemented, not only checking the measured values but also the metadata. Over the years and with changing staff several inaccuracies have slipped into the database. The change in structure is a good opportunity to revise the data and correct erroneous entries if necessary. Additionally, a new user registration system has to be implemented on demand of ETH Zürich.

During this funding period, three main topics were identified by the strategic committee: i) licensing, ii) versioning and iii) strategic perspective. For the licensing, a lawyer was mandated and several agreement forms were developed for data providers. This ensures compliance with the respective license regulations of the data provider.

Concerning the second point, the implementation of a versioning system has started. After evaluation of different concepts and

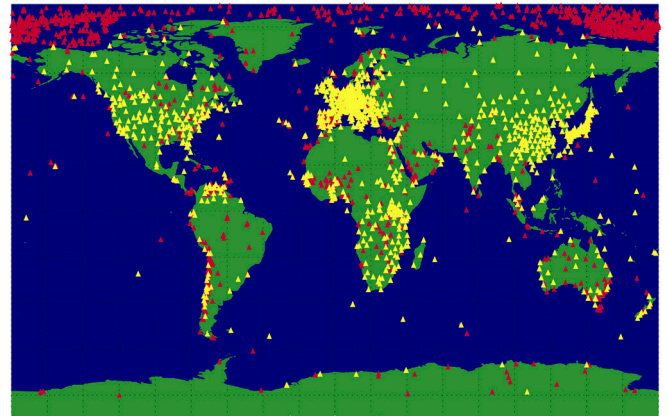


Figure 2. Map of the different measurement sites which provided data to GEBA. Red triangles denote site with at least 1 monthly entry; the yellow triangles denote sites with multiyear records (from Wild et al (2017))

standards, the framework of 'slowly changing dimensions' was chosen. The basic algorithms are already implemented, and first tests are looking promising. There are still several details and exceptions that need to be analyzed and solved.

Martin Wild, the project leader at ETH, will retire in the next few years. Thus, to ensure that GEBA will also be available to the community in future, there are several discussions ongoing. The plan is to slowly move the archive from ETH to PMOD/WRC. The transition has already started with PMOD/WRC being actively involved in the development of new features and maintenance.

Acknowledgement: The maintenance and development of the GEBA database is supported by Meteoswiss in the framework of GCOS Switzerland.

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Total Solar Irradiance (TSI) Data Analysis

Jean-Philippe Montillet, Wolfgang Finsterle, Margit Haberleiter, Daniel Pfiffner

Our recent activities focused on three key areas: (i) Product Dissemination: Continued distribution of the PMO6v8 product (from VIRGO/PMO6 processing) and the updated Total Solar Irradiance (TSI) composite, incorporating all satellite observations from 1978 to the present. (ii) FY-3E in operational phase: Processing of observations from the DARA radiometer onboard the Chinese FY-3E satellite and delivering the JTSIMDARAv1 product. (iii) PROBA-3 Analysis: Post-launch calibration of the DARA radiometer aboard and analysis of the first light measurements.

VIRGO onboard SOHO and the TSI composite time series

The VIRGO/PMO6v-V8 (PMO6v8) product: Following the development in 2020-2021 of the algorithm performing the degradation correction based on machine-learning (ML), PMOD/WRC now releases in each quarter the PMO6v8 product on: the Astromat repository [1]; since February 2025, the data are also available on the Geo Knowledge Hub [2] a repository maintained by the Group of Earth Observations. The 44-year TSI Composite produced by PMOD/WRC: Since the late 70's, successive satellite missions have been monitoring the sun's activity, recording the total solar irradiance (TSI). We produce a TSI composite that is updated quarterly and made available via the public data repository [3].

JTSIM-DARA / FY-3E mission

Data Analysis of the Observations: The JTSIM-DARA produces TSI measurements since-August 2021. The radiative losses to deep space have been re-analysed, leading us to the update first light measurements of $1363.76 \text{ W/m}^2 \pm 404 \text{ ppm}$ for the main cavity (Cavity B), and $1363.88 \text{ W/m}^2 \pm 412 \text{ ppm}$ for the reference cavity (cavity A) and $1363.71 \text{ W/m}^2 \pm 404 \text{ ppm}$ for the back-up cavity (cavity C) in WRR scale [4, 5]. The degradation is so far estimated at 49 ppm for the whole period covering August 2021 – May 2025. The DARA-JTSIM data are released a public repository [6]. Figure 1 shows the PMO6v8 and JTSIM-DARAv1 products in WRR scale for a daily sampling.

PROBA3 - DARA /ESA-PROBA3 mission

The Project for On-Board Autonomy-3 (PROBA3) is the fourth satellite technology development and demonstration precursor

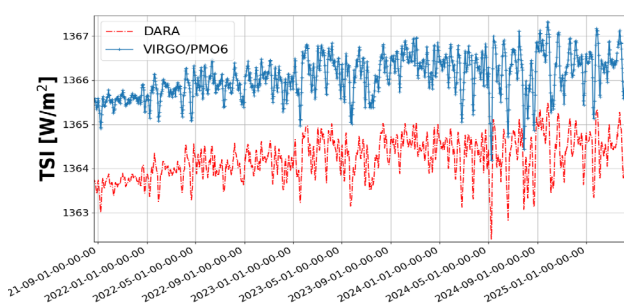


Figure 1. PMO6v8 and JTSIM-DARAv1 products in WRR scale for a daily sampling

mission within ESA's GSTP (General Support Technology Program) series. The PROBA3 mission concept comprises two independent satellites in highly elliptical Earth Orbit in Precise Formation Flying. One of the satellites carries the Digital Absolute Radiometer (PROBA3-DARA) developed and manufactured in Switzerland by the PMOD/WRC. We measured the first light measurements on the 25.02.2025 [7] for each cavity $1362.19 \text{ W/m}^2 \pm 123 \text{ ppm}$ for the main cavity (Cavity B), and $1361.45 \text{ W/m}^2 \pm 130 \text{ ppm}$ for the reference cavity (cavity A) and $1362.40 \text{ W/m}^2 \pm 135 \text{ ppm}$ for the back-up cavity (cavity C) in SI scale. Figure X3 shows the first measurements on 25.02.2025 for cavity B and a comparison with the Pmo6v8 product. On 13 August 2025, we conducted the first measurements at 20 Hz, paving the way for capturing rapid solar features that influence solar irradiance. At the time of writing this report, deep space measurements for the back-up and reference cavities (cavities C and A, respectively) are still ongoing.

Acknowledgement: J.-P.M., W.F., and M.H. gratefully acknowledge the support from the Karbacher-Funds. J.-P.M. also thanks the Swiss Space Office for support via the PRODEX funds.

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Quantification of how stratospheric aerosol injection could affect surface solar irradiance

Kevin Kilchhofer, Kyriaki Papachristopoulou, Manouk Geurts, Timofei Sukhodolov and S Kazadzis

This study aims to estimate the effects of stratospheric aerosol injection (SAI) scenarios in clear-sky (cloudless) solar radiation at the surface (SSR) using benchmark radiative transfer calculations. SAI is one solar radiation modification (SRM) method, which is increasingly viewed as a potential backstop against global warming. If SRM techniques are implemented in the future, it will be important to understand their potential financial and societal implications, particularly regarding reduced solar energy production. Currently, little is known about how SRM could affect photovoltaic (PV) output or what strategies might help to mitigate any reductions in surface solar radiation.

Here, to produce estimates of solar radiation at the surface (SSR) we used the libRadtran radiative transfer model (Mayer & Kylling, 2005; Emde et al., 2016). The SAI scenario includes an aerosol layer of sulphuric acid particles at a height of 19 km. We parameterized their optical properties as described in Hummel et al., 1988. The computed SSR data were further utilized to simulate the energy production of PV panels at a location close to Paris (SIRTA), hence we have modelled radiation with (additional to SAI) ambient tropospheric composition profiles obtained by Copernicus Atmosphere Monitoring Service (CAMS). We calculate downwelling surface shortwave irradiance with and without SAI scenario and for different solar PV geometries. This allows us to compute highly resolved irradiance data on top of results obtained by large-scale climate model studies such as Baur et al., 2024

Figure 1 depicts measured (dashed lines) and modelled (solid for CAMS and dotted for AERONET) irradiances for a day (date) with clear-sky conditions in Paris. The results agree well in most cases and thus, the model is suitable to investigate the influence of different SAI scenarios. Results of percentage differences

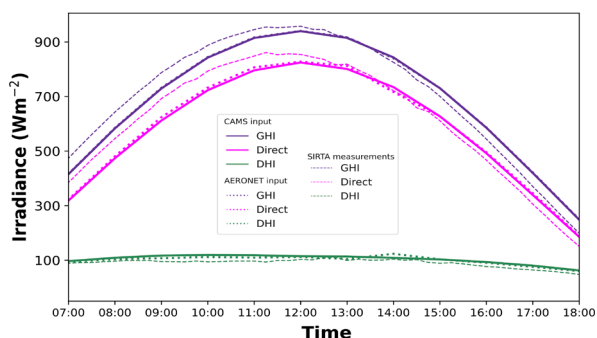


Figure 1a. Diurnal data for a clear-sky day (June 7th, 2024) irradiance (direct, diffuse horizontal (DHI) and global horizontal (GHI)) for the SIRTA station in Paris (Lat = 48.713, Lon = -2.208). The dashed lines represent ground-based pyranometer measurement, and the solid (dotted) show the simulated results from a radiative transfer model with aerosol optical properties taken from CAMS (AERONET).

between a SAI scenario with an aerosol optical depth equal to 0.07 (AODSAI = 0.07) and without is depicted in Figure 2.

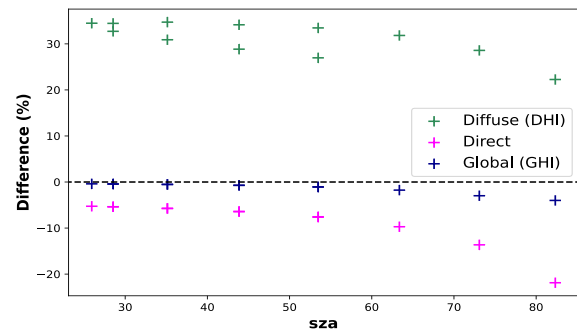


Figure 1a. Figure 2. Difference for horizontal irradiance components as a function of solar zenith angles of the SAI layer versus the control scenario of the same day as presented in Figure 1 for direct (pink) and diffuse (green) and global (blue).

Intuitively, the direct component (pink) of the irradiance is decreasing with a SAI layer as the sulfuric acid particles will attenuate the incoming solar radiation. However, the diffuse downwards (green) increases by up to 33% in the case of a SAI layer compared to the scenario without SAI. Overall, this only results in a small decrease of the global horizontal (blue) slightly bigger towards higher solar zenith angles. In the next step, we will derive the direct and diffusive irradiance components as a function of tilting and rotational angles of PV panels. This is further being used as the basis for a PV energy production model. Additionally, we will simulate the dependence of irradiance changes on other potential SAI aerosol types with different optical properties and evaluate it regarding the PV power output and Earth's radiation budget.

Acknowledgement: This work was supported by ESA as part of the STATISTICS project.

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Active region evolution under the spotlight, with unprecedented coordinated high-resolution stereoscopic observations and numerical simulations

Krzysztof Barczynski, Yingjie Zhu, Louise Harra and the International Space Science Institute (ISSI) International team members of team titled: "Active region evolution under the spotlight, with unprecedented coordinated high-resolution stereoscopic observations and numerical simulations"

Since September 2022, we have coordinated several solar-disk observation campaigns using the space missions Solar Orbiter, IRIS, and Hinode, with three successful campaigns also including the ground-based DKIST telescope. In February 2025, we brought together a team at the International Space Science Institute (ISSI) in Bern to study solar active regions using these unprecedented high-resolution, stereoscopic observations combined with numerical simulations. The aim is to understand how different layers of the solar atmosphere interact and how small-scale structures drive the evolution of active regions. This effort resulted in a team of 19 researchers from around the world working on four focused projects addressing key properties of solar active regions and leading by Krzysztof Barczynski (PMOD/WRC).

Solar Orbiter is a multi-instrument space mission that observes the Sun from a heliocentric orbit. When combined with observations from other space-based missions such as IRIS and Hinode, it provides complementary views of the solar atmosphere. The Daniel K. Inouye Solar Telescope (DKIST) in Hawaii adds unprecedented ground-based, highest-resolution observations, allowing us to study the smallest structures in the solar atmosphere.

Our team (Fig.1) focuses on the physics of solar active regions—among the most dynamic structures in the solar corona (Fig.2). We use coordinated observations to study physical processes across the solar atmosphere, with emphasis on four main topics grouped around two key questions. The first scientific question is how does the coupling between the corona and underlying solar atmosphere evolve in active regions over different time scales?

To answer this question, we focused on magnetic-field intensity relation. We study how the intensity of spectral lines formed at different atmospheric heights relates to magnetic field strength. We extended previous studies to many new spectral lines and much higher spatial and spectral resolution using Solar Orbiter and DKIST observations. This allows us to understand the

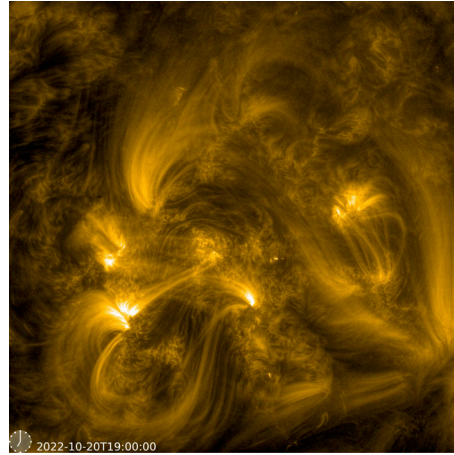


Figure 2. One of the active regions investigated by ISSI Team, observed at high resolution by the Solar Orbiter. The extended bright structures are coronal loops.

relationship between the structures in the different parts of the solar atmosphere.

Moreover, we study the properties of coronal rain. Coronal rain consists of cool, dense plasma that forms in the hot corona and falls back along magnetic loops. Using coordinated imaging and spectroscopy from Solar Orbiter and DKIST, we analyse its motion, structure, and thermal properties. We then relate these characteristics to the magnetic conditions at loop footpoints, providing new insights into the coupling between magnetic fields and plasma dynamics.

The second question is how do small-scale features in the solar atmosphere affect the active region's evolution?

To this aim, we investigate thin, thread-like structures called fibrils in magnetically active regions. High-resolution observations from DKIST and Solar Orbiter are used to trace how these features connect different atmospheric layers and how they respond to the magnetic field. We also study wave-like motions in fibrils and nearby coronal loop footpoints (so called moss) to understand energy transport through the solar atmosphere.

We also focus on wave activity that propagates in the solar atmosphere and especially slow magnetohydrodynamic (MHD) waves observed in coronal loops. By comparing observations with theoretical and numerical models, we examine how these waves are generated, how their properties change with height, and how much energy they carry. We also explore their temporal evolution and possible links to different type of waves.

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Figure 1. Members of our ISSI International Team during in person meeting in Bern (February 2025).

Cloud-aERosol inTeractions & their impActs IN The earth sYstem (CERTAINTY)

Kyriaki Papachristopoulou and Stelios Kazadzis in collaboration with National Observatory of Athens (Greece)

The CERTAINTY project has received funding from the European Union's HORIZON Research and Innovation Actions (January 2024 – December 2027) and aims to advance knowledge of interactions between clouds, aerosols, and radiation, which are key regulators of earth's climate. Within CERTAINTY, a consortium of 18 partners bring together observational and model-based expertise to achieve its scientific objectives.

Cloud, aerosols and their interactions are key regulators of climate. CERTAINTY aims to reduce key uncertainties in aerosol–cloud–radiation interactions that limit climate and extreme-event predictions. By integrating advanced observations, next-generation satellite data (e.g., EarthCARE), machine learning, and high-resolution Earth system modeling, the project aims to improve process understanding and predictive capability to support climate mitigation and adaptation strategies.

PMOD/WRC participates in several working groups aimed at advancing understanding of aerosol–cloud–radiation interactions and validating the new EarthCARE observations using ground-based measurements and radiative transfer modeling.

Within CERTAINTY, the EarthCARE (EC) validation task focuses on preparing EarthCARE observations for scientific applications. Validation measurements contribute to large-scale international efforts. PMOD/WRC contributes to the validation of EarthCARE products using ground-based observations from validation campaigns conducted by PMOD/WRC (for more details please see project RACE-ECV on page X), as well as data from established networks such as the Baseline Surface Radiation Network (BSRN).

Satellite-based retrievals of aerosol and cloud direct radiative effects (DREs) are essential for quantifying the Earth's radiative

energy budget. The EC mission aims to improve understanding of how aerosols and clouds modify radiative fluxes by providing collocated observations of aerosols, clouds, precipitation, and radiation, enabling a three-dimensional representation of the atmosphere. However, DRE quantification in models predominantly relies on one-dimensional (1D) radiative transfer (RT) simulations, which neglect important three-dimensional (3D) cloud effects. Using EarthCARE's novel datasets, we quantify differences in aerosol shortwave DREs between 1D and 3D RT simulations (Fig. 1) under clear- and cloudy-sky conditions. Aerosol DREs are calculated using 1D and 3D RT solvers from the libRadtran package (Mayer & Kylling, 2005; Emde et al., 2016; Mayer 2009). Our results show substantial differences in the radiation field between 1D and 3D simulations, particularly when strongly scattering aerosol layers are located above cloud layers.

Acknowledgement: This project has received funding from Horizon Europe programme under Grant Agreement No 101137680 via project CERTAINTY (Cloud-aERosol inTeractions & their impActs IN The earth sYstem).

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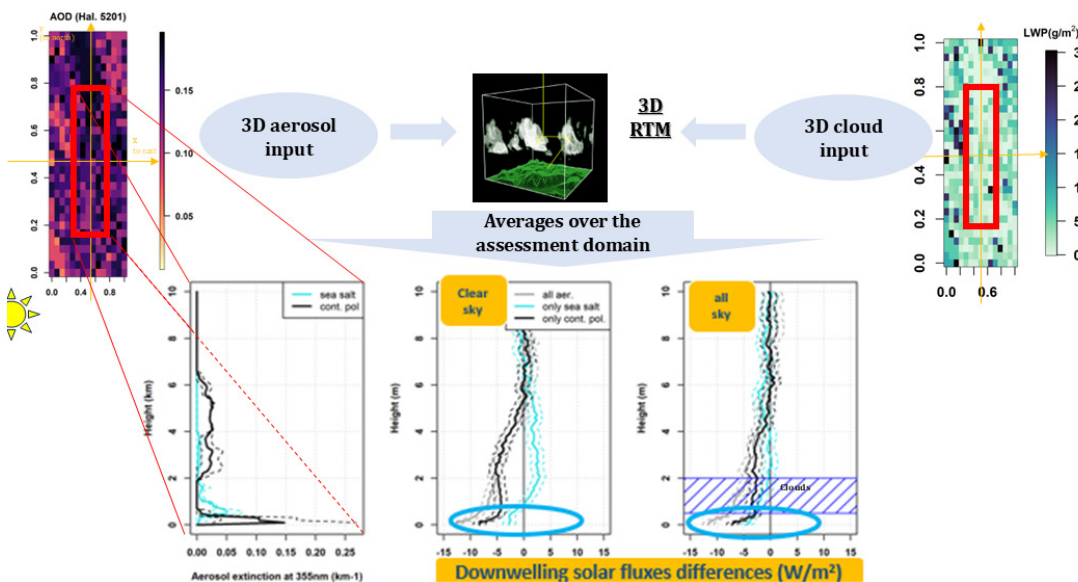


Figure 1. Schematic overview of the methodology for deriving aerosol direct radiative effects in a 3D domain.

Radiation closure experiments for EarthCARE validation (RACE-ECV)

Stelios Kazadzis, Kyriaki Papachristopoulou, Natalia Kouremeti, Angelos Karanikolas, Anna Moustaka, and Yannis Gschwind, in collaboration with UZH (Switzerland)

The Earth Cloud, Aerosol and Radiation Explorer (EarthCARE) is a recently launched satellite mission (May 2024) that, for the first time, provides concurrent observations of aerosols, clouds, precipitation, and radiation. This unique capability offers an unprecedented opportunity to investigate in detail the properties of these climatic agents, their interactions, and their impacts on the Earth-atmosphere energy balance. Within the framework of EarthCARE validation activities, PMOD/WRC conducted the RACE-ECV field campaign in collaboration with the University of Zurich (UZH). The campaign involved the deployment of high-accuracy spectral solar radiation and sun-photometer measurements, operated in synergy with other ground-based remote sensing instruments.

The EarthCARE satellite mission delivers valuable insights into the three-dimensional structure of clouds, precipitation, and aerosols, together with co-located radiative flux measurements. These simultaneous observations are used to assess the representation of clouds, precipitation, aerosols, radiative fluxes, and derived heating rates in weather and climate models, while simultaneously improving our understanding of cloud and aerosol radiative effects and their interactions (Wehr et al., 2023).

The RACE-ECV project has the following objectives:

- To directly validate EarthCARE products related to total-column, multi-wavelength aerosol and cloud optical thickness
- To perform radiative closure studies through intercomparisons with high-quality solar irradiance measurements and radiative transfer model (RTM) simulations
- To provide a high quality observational dataset of aerosol optical properties and spectral solar irradiance to support a wide range of atmospheric studies and European projects focusing on aerosol–cloud interactions (e.g. CERTAINTY).

To fulfill the objectives of the RACE-ECV project, two intensive field campaigns were planned. The first campaign was conducted in spring 2025 (16 April to 22 May 2025) in Thessaloniki, Greece, and included two EarthCare overpasses. The campaign

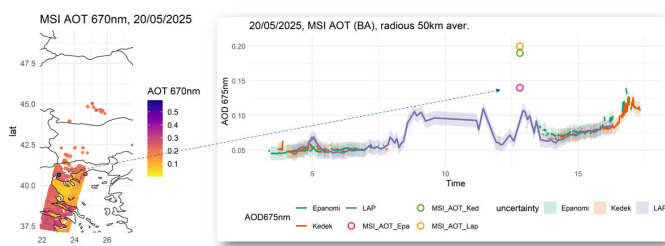


Figure 1. Direct validation of the EC total-column aerosol optical thickness (AOT) product at 670 nm. The left panel shows the EarthCARE AOT at 670 nm during the overpass on 20 May 2025, while the right panel presents surface-based observations with associated uncertainties at the three main sites. EarthCARE observations are indicated by circles.

was supported by ESA EVID 44 and the RACE-ECV project, with the participation of seven institutes. Three main coordinated sites equipped with sophisticated instrumentation were established in alignment with EC satellite overpasses (distance ~15 km), along with six additional sites operating handheld instruments during the overpasses. At the three main sites, high-accuracy sun photometers were deployed in synergy with other ground-based remote-sensing instruments, providing comprehensive observations of aerosols, clouds, and surface spectral solar radiation. This campaign also served as a pilot study, paving the way for a second campaign planned for 2026.

The direct validation of the EC total-column aerosol optical thickness (AOT) product at 670 nm using ground-based observations (Fig. 1) revealed a slight underestimation for both overpasses. Radiative closure experiments were also performed. These experiments provide an indirect assessment of the EC synergistic aerosol and cloud products by comparing measured surface spectral/broadband solar radiation with radiative transfer model simulations driven by EC products. In addition, an intercomparison was conducted using ground-based aerosol inputs to the radiative transfer model. For the second overpasses (Fig. 2), the results show that simulations based on EC inputs reproduce the measured spectral ultraviolet irradiance with accuracy comparable to that achieved using ground-based aerosol measurements.

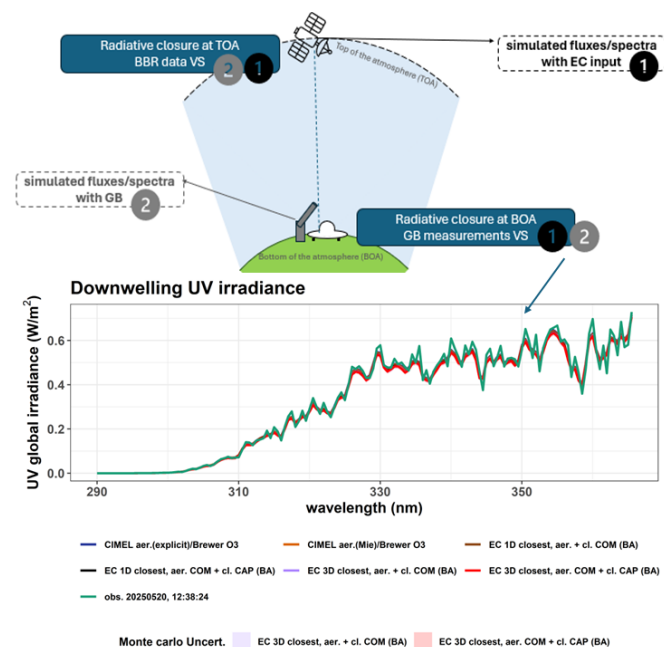


Figure 2. Indirect validation of EC products through radiative closure experiments using spectral solar measurements.

Acknowledgement: The project RACE-ECV has received funding by SBFI (SBFI-633.4-2021-2024/PMOD - EarthCARE 202/2).

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Spectral improvements of BTS-Solar Array Spectroradiometer for Total Column Ozone Retrieval

Luca Egli and Julian Gröbner in collaboration with Gigahertz Optik

PMOD/WRC is testing a new, compact instrument to keep global ozone monitoring reliable as older Brewer instruments are phased out. Since 2019, the BTS-Solar spectroradiometer in Davos has delivered ozone results closely matching trusted Brewer and Dobson references, using the KoherentTOC method. However, at high ozone slant columns, the comparison reveals biases to the reference instruments. Therefore, improvements on the spectral level addressing the stray-light and sensitivity were investigated. A field intercomparison in Spain revealed the total column ozone from the improved instruments are within 1% also for high ozone slant columns.

Since 2019, PMOD/WRC has been evaluating a compact, potential next-generation instrument for measuring total ozone column (TOC) from direct sunlight. The work focused on the Gigahertz Optik BTS2048-UV-S-F array spectroradiometer, operated first with a weatherproof fiber-optic setup that enables stable, continuous outdoor measurements [Egli et al. 2023]. Later, the array spectroradiometer was integrated into the standard BTS-Solar housing as delivered by the manufacturer and used worldwide. It was confirmed that TOC quality remained consistent as the system moved from a research setup toward operational deployment.



Figure 1. The BTS from Davos on a sun tracker at the regional Brewer intercomparison 2025 in Spain.

To translate the instrument's UV spectra into ozone values, PMOD/WRC developed the retrieval software KoherentTOC, which includes a custom double-ratio retrieval. The retrieval is designed for the ability to be calibrated against Brewer or Dobson reference instruments in co-located field campaigns. The resulting TOC data since 2019 were assessed against the long-term Arosa/Davos reference record, built on established Brewer and Dobson measurements (see page 23). As reported by Egli et al. [2023] TOC from the BTS array spectroradiometer showed good agreement with the Brewer at low airmasses using KoherentTOC.

At the same time, the evaluations revealed an important limitation: under conditions of very high ozone and high solar zenith angles - typical occurring in Arctic spring - the TOC retrievals show biases to reference instruments. These situations are particularly challenging because sunlight travels a longer path through the atmosphere and therefore more absorption due to atmospheric ozone occurs. This implies greater demands on spectral sensitivity and stray-light suppression in the instrument. Furthermore, the production of Brewer instruments, which have underpinned global

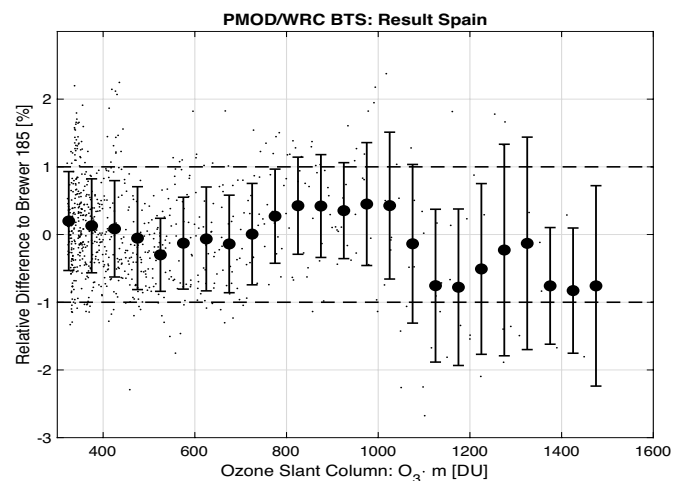


Figure 2. Relative difference between BTS Solar (applying custom double technique from the KoherentTOC retrieval software) compared to the World reference of total column ozone Brewer 185 during the regional Brewer intercomparison in Spain.

ozone monitoring for decades, is announced to be phased out. A WMO taskforce was established to evaluate potential third generation instruments, for monitoring TCO in a worldwide network - also for Arctic conditions.

Since BTS-Solar is a promising candidate for such a new instrument, in 2025, PMOD/WRC and Gigahertz Optik GmbH collaborated to tackle key technical challenges: improving spectral detectability, reducing stray light, and minimizing dependence on slant path effects. A new spectral-level correction using a stray-light correction matrix and enhanced internal filter analysis was developed and tested. The improvements were implemented through upgraded firmware based on the BTS platform's existing capabilities.

The improvements on the spectral level and using KoherentTOC were tested and calibrated at the regional Brewer intercomparison in El Arenosillo Spain (Figure 1). The comparison with the world reference Brewer 185 show that the relative differences between both instruments are within 1% also for higher ozone slant columns near 1500 DU. This rather flat ozone slant path dependency indicates that BTS with the improved spectra may be deployed also in Arctic spring total column ozone conditions.

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Hydrological response to stratospheric aerosol injections using less absorptive solid particles

Manouk Geurts, Timofei Sukhodolov, Sandro Vattioni, Jan Sedlacek in collaboration with CSIC (Spain) and IAC ETH

Sulfur-based stratospheric aerosol injections (SAI) can reduce greenhouse gas induced global warming, but also causes undesirable side effects, such as lower stratospheric warming and enhanced precipitation reduction, due to the absorptivity of sulphate aerosols. To mitigate these effects, alternative solid particles with similar shortwave (SW) scattering but lower absorptivity have been proposed. We compared the hydrological response of sulfur-based SAI with three alternative materials, alumina, calcite, and diamond dust, using transient simulations with the fully coupled atmosphere-ocean-aerosol-chemistry-climate model SOCOLv4. Following the G6 experimental setup of the Geoengineering Model Intercomparison Project, SAI is applied to offset warming in a high-emission scenario (SSP5-8.5) to SSP2-4.5 surface temperatures.

The hydrological cycle is linked to the global energy balance (Q) (Ricke et al., 2023). Changes in the net atmospheric radiation balance (F_a) are primarily compensated by changes in latent heat flux (LH) (Equation 1), as the sensible heat flux (H) is four to five times smaller than LH. Because LH and evaporation are directly linked via the heat of vaporization, and global precipitation must equal global evaporation to maintain water balance, precipitation is constrained by the energy balance

$$\Delta Q = \Delta F_{a} + \Delta LH + \Delta H = 0$$

More absorptive materials produce larger reductions in net radiative fluxes at the top of the atmosphere (TOA), as shown in Figure 1a. For SWnet this occurs because more absorptive materials require increased scattering to achieve the same cooling. For net long wave radiation (LWnet) the larger reductions reflect enhanced LW trapping. At the surface, a similar pattern is observed for SWnet, again due to increased scattering, associated with lower stratospheric warming. In contrast, LWnet increases are similar across all SAI materials, because surface temperatures are the same in each experiment. The larger increase in SSP2-4.5 results from lower atmospheric CO₂ concentrations. Under clear sky conditions (Figure 1c and d), patterns are like all sky conditions but with higher values for SWnet and LWnet, highlighting the key role of clouds modulating SAI efficacy.

The strongest increase in F_a occurs for the most absorptive materials, indicating radiative trapping for more absorptive materials. To restore atmospheric energy balance, these materials exhibit the largest reduction in LH and therefore the highest hydrological sensitivity (Figure 1b, and f).

All SAI experiments show a higher hydrological sensitivity than SSP2-4.5, because SAI directly alters the surface energy balance by reducing incoming solar radiation. SSP2-4.5 modifies the energy balance indirectly through LW trapping by GHGs in the atmosphere. This difference in the vertical structure of radiative forcing explains the weaker hydrological response in SSP2-4.5. Among the SAI experiments, higher aerosol absorptivity leads to

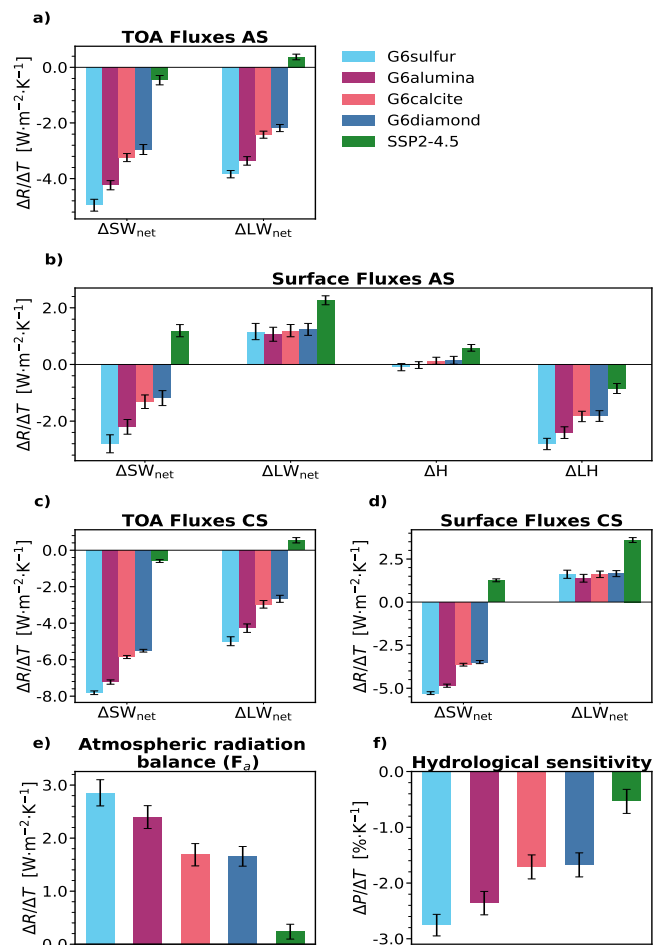


Figure 1. Global mean differences for G6sulfur, G6alumina, G6calcite, G6diamond and SSP2-4.5 relative to SSP5-8.5 for the energy balance under all sky (AS) conditions at the TOA (a), and at the surface (b), energy balance under clear sky (CS) conditions at the TOA (c), and at the surface (d), F_a (e), and Hydrological sensitivity (f), all normalized with the global mean cooling between experiment and SSP5-8.5. Fluxes are expressed in $Wm^{-2} K^{-1}$, and hydrological sensitivity in $\%K^{-1}$. The error bars indicate the ensemble standard deviation from the global mean, calculated over the last 20 years (2080-2099) of the simulations and the three ensemble members..

stronger perturbations of the energy balance and greater suppression of the hydrological cycle.

Despite uncertainties in stratospheric interactions, aerosol cloud interactions, and plume-scale micro-physical processes of solid particles, our results show that using less absorptive materials could reduce hydrological side effects associated with sulfur-based SAI.

A paper discussing these results is in preparation for submission to the Environmental Research Letters journal.

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Advances in Determining the Earth Radiation Budget

Margit Haberreiter, Wolfgang Finsterle in collaboration with ROB, Belgium and NPL, UK.

The Earth's energy budget is determined by the balance between incoming and outgoing radiation within the Earth system. All components of the Earth Radiation Budget (ERB) — namely Total Solar Irradiance (TSI), reflected Outgoing Shortwave Radiation (OSR), and Outgoing Longwave Radiation (OLR) emitted by the Earth — are designated as Essential Climate Variables (ECVs) by the World Meteorological Organization's Global Climate Observing System (GCOS). Specifically, the Earth Energy Imbalance is a key observable to determine the state and future trajectory of the Earth climate system.

AVID Project

First, within the AVID Project we make use of the CLARA TSI and OLR data to advance our understanding of the measurement of the important ERB components with the state-of-the-art space radiometer CLARA. Whilst the TSI measurements from space has a long heritage at PMOD/WRC, the measurement of the OLR with an SI-traceable absolute radiometer is a rather new avenue. Within the AVID project have advanced the tool to determine the co-location of the CLARA and CERES Single Scanner Footprint data (Haberreiter et al., 2025). This allows us to compare in detail the CLARA and CERES observations for the same time and geolocation. The detailed comparison is still ongoing. Furthermore, we have improved the radiometric model of the CLARA space radiometers by including the thermal emission of the precision aperture to the cavity. This is an important component in the correction to the radiative loss of the cavity when the shutter is open and is validated via the deep space measurements. The new correction is important for both, the TSI and OLR measurements with CLARA as well as all other space radiometers built at PMOD/WRC.

TRUTHS TACOS

Within the TRUTHS Accompanying Consolidation and Operations Study (TACOS) we investigate the effects of solar spectral irradiance variations on the terrestrial atmosphere. Specifically, we are interested in the effects the new solar reference spectrum implemented in the CMIP7 solar forcing dataset as compared to the previous spectrum as part of CMIP6. In collaboration with the Academy of Athens we performed sensitivity studies on the effects of ozone, and heating rates in the Earth's atmosphere. The modelling results indicate that there is a considerable change in the tropospheric ozone of up to 5%. Currently a publication is in preparation for the validation of the CMIP7 solar irradiance forcing dataset.

Earth Climate Observatory (ECO)

The Earth's climate system is governed by the small imbalance between incoming solar radiation at the top of the atmosphere (ToA) and outgoing radiation as described above. Current observations indicate an energy imbalance of approximately 1 Wm^{-2} , implying that the Earth system is presently gaining energy. This excess energy constitutes the fundamental driver of ongoing climate change (see also Figure 1 for illustration).



Figure 1. The ECO mission is designed to precisely determine the Earth Energy Imbalance to be able to reveal tomorrow's climate.

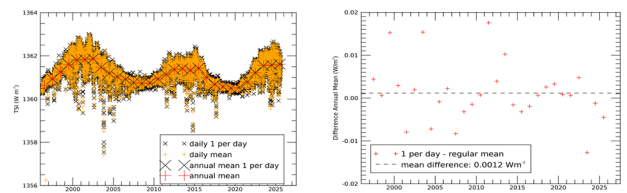


Figure 2. Evaluation of the sampling error for the incoming solar radiation using the SOHO/VIRGO data. The difference of the sampling of 1 measurement per day compared to a 1-minute cadence sampling is less than 0.02 W/m^2 for TSI, or a factor of 4 less for the incoming solar radiation (ISR), yielding 0.005 W/m^2 . The 2-sigma standard deviation is 1.4 W/m^2 for TSI and 0.35 W/m^2 for ISR.

However, the accurate quantification of this imbalance and its temporal evolution remains challenging. Addressing this issue is the primary scientific objective of the Earth Climate Observatory (ECO) mission, selected as one of four candidate missions of the 12th Earth Explorer Programme. Dewitte et al. (2025) summarizes the science case of the ECO mission. Currently, the MAG evaluates key scientific requirements for the ECO mission. This includes for example the evaluation of the annual sampling error for the incoming solar radiation as shown in Figure 2. Currently, ESA and the ECO Mission Advisory Group prepare the Report for Mission Assessment in preparation for the upcoming User Consulting Meeting in July 2026.

Acknowledgement: MH acknowledges support by Karbacher-Fonds.

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Traceability of Aerosol Optical Depth Measurements and Links with the Clouds and Trace Gases Research Infrastructure (ACTRIS) / Calibration of Aerosol Remote Sensing (CARS)

Natalia Kouremeti, Stelios Kazadzis, Gregor Hülsen, Angelos Karanikolas and Julian Gröbner

The World Optical Depth Research and Calibration Center (WORCC) is participating in the Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS-CH, 2025 – 2028, <https://www.actris.ch>), and collaborates with the Centre for Aerosol Remote Sensing (CARS) of ACTRIS. After receiving the approval of the ACTRIS General Assembly in November 2023, PMOD/WRC is now officially a new sun-photometric unit of ACTRIS/CARS.

The main task of the CARS-PMOD/WRC unit is to link the aerosol optical depth (AOD) calibrations from ACTRIS/CARS with the WMO scale and SI traceable measurements. This goal is being achieved through the continuous operation of PMOD/WRC reference Precision Filter Radiometers (PFRs) at the ACTRIS/CARS calibration sites: Izaña (IZO) in Spain, Observatoire de Haute Provence (OHP) in France and the University of Valladolid (VLD) in Spain. The aim of this collaboration is: i) to link CARS with the WMO defined AOD scale maintained by WORCC, ii) the homogenization of AOD retrievals, and iii) the provision of standard operating procedures and process documents on the comparison of PFR (WORCC) and CIMEL (ACTRIS/CARS) sun-photometers. ACTRIS-CH activities have been linked to the validation of Sentinels 4 and 5 and ongoing efforts for relevant MoUs, as WORCC is co-leading the ACTRIS Expert Team on Satellite validation in collaborations with ESA/EUMETSAT.

WORCC is working on standardizing and homogenizing AOD reference scales and improving the calibration and processing algorithms for consistent long-term measurements of AOD. Based on the results of SI traceable AOD retrievals obtained within the MAPP (Metrology of Aerosol Optical Properties) project, which continues within the EURAMET-1611 project, WORCC collaborates with the German National Metrology Institute (PTB) to form an SI traceable pool of PFR references. The 4th calibration for PFR N01 is scheduled for February 2026. This activity will, in turn, provide SI traceability to the ACTRIS/CARS reference CIMEL sun-photometers.

The traceability to the WMO AOD scale is checked via comparisons of co-located, synchronous AOD measurements between PFRs and AERONET-Europe Cimel CE318(T) sun-photometers at the calibration sites. All Cimel channels in the UV to NIR range are validated, extrapolating the PFR AOD data using the

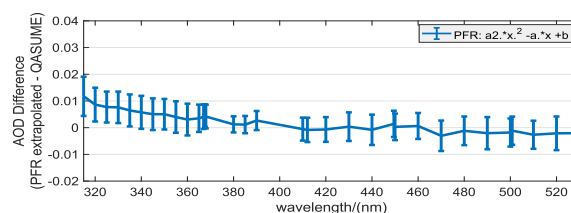


Figure 1. Median difference and standard deviation of spectral AOD from the QASUME spectroradiometer and PFR-N01 AOD calculated with a second-degree fit of the logarithm of AOD for the four PFR channels at 368 nm, 412 nm, 500 nm, and 862 nm against the logarithm of wavelength.

Ångström law for atmospheric conditions that lead to uncertainties of less than 0.01 in AOD.

The uncertainties and limitations of the extrapolation have been investigated using the reference spectrometer QASUME and the PFR N01, analyzing synchronous measurements over the period 2024-2025 at PMOD/WRC. For low aerosol loads, a second-degree polynomial fit of AOD and wavelength gives the most consistent results in terms of offsets and spread due to different AOD loads and types (excluding heavy dust and smoke events). Figure 1 shows the average spectral AOD difference between QASUME and fitted PFR AOD. The uncertainties have been included in the ACTRIS performance certificates of the reference CIMELs.

The overall performance for the Izaña calibration site is shown in Figure 2 as a time series of the AOD differences at 500 nm and normalized distributions of AOD differences for all CIMEL wavelengths. For this site, all AOD differences are consistent with the WMO limits by more than 95%, while for VLD and OHP, this level of agreement is achieved for wavelengths longer than 440 nm.

Acknowledgement: This research has been funded .by ACTRIS Switzerland 2025-2028 grant (Swiss contribution to the ACTRIS ERIC) funded by the Swiss State Secretariat for Education and Research and Innovation (SERI).

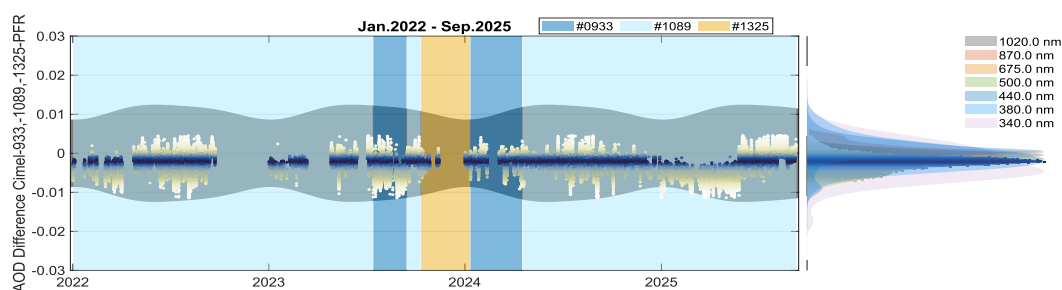


Figure 2. Left panel: Time series of AOD differences between Cimel #933, #1089, and #1325 and PFR at 500 nm. The AOD differences (dots) are colored based on the probability density function shown in the colored distributions for the 7 Cimel wavelengths on the right panel. The highlighted wavy area on the left panel represents the WMO limit for AOD differences between two instruments with calibration uncertainties of less than 1%.

6th WMO Filter Radiometers Campaign (FRC-VI) Traceability of Aerosol Optical Depth Measurements

Natalia Kouremeti, Julian Gröbner, Stelios Kazadzis, Gregor Hülsen, Angelos Karanikolas and Miguel Huerta

The 6th Filter Radiometer Campaign (FRC-VI) has been organised at PMOD/WRC Davos on behalf of the World Meteorological Organization (WMO) from 22 September to 20 October 2025. The FRC aims to assess the consistency across different networks with respect to the WMO AOD reference every five years.

The Filter Radiometer Campaigns (FRC) are organised every five years by the World Optical Depth Research and Calibration Centre (WORCC) of PMOD/WRC on behalf of the WMO. These campaigns play a crucial role in harmonising ground-based aerosol optical depth (AOD) measurements globally, as several international and national AOD networks participate with different types of filter radiometers and spectroradiometers. The goal of the FRC is to assess the consistency across different networks with respect to the WMO AOD reference, known as GAWPFR-TRIAD.

The 6th Filter Radiometer Campaign (FRC-VI) took place from 22 September to 20 October 2025. This campaign brought together 33 instruments, including filter-radiometers (CIMEL, Prede-POM, SP02, MFRSR), spectroradiometers (QASUME-UV & IR, BTS, CAS PSR, HSR1, SSIM), and handheld sunphotometers (Microtops, Calitoo), representing nine international and national AOD networks (AERONET, GAWPFR, SKYRAD EU & JP, SURFRAD, China, Finland, Germany, Sweden) and three research institutes. The campaign was extended by 10 days due to adverse weather conditions. Twelve nearly clear sky days with low aerosol loads will be used for comparison (aerosol optical depth (AOD) at 500 nm ranging from 0.01 to 0.04 and Ångström exponent 1.0 to 1.8) (Figure 2).

The GAWPFR-TRIAD consists of three Precision Filter Radiometer (PFR), for 2025: N01, N22, and N25. The GAWPFR-TRIAD has been checked and adjusted against five travelling standards, Langley calibrated at Izaña (28.3° N, 16.5° W, 2.4 km) and Mauna Loa (19.5° N, 155.6° W, 3.4 km) observatories. Adjustments of -0.07%, -0.03%, 0.01%, and -0.22% for the wavelengths 862 nm, 500 nm, 412 nm, and 368 nm, respectively, have been applied for the FRC-VI period based on the analysis of data from September to December 2025. The data will be finalised after the 4th calibration of N01 at the TULIP facility of PTB, where discrepancies of 0.01 to 0.02 in AOD between the SI traceable AOD retrievals and Langley ones at 368 nm will be further investigated. The combined expanded relative uncertainty of the GAWPFR-TRIAD for 2025



Figure 1. FRC-VI, Davos, PMOD/WRC. Hosted filter radiometer and spectroradiometers installed at the PMOD/WRC garden.

has been accessed to 0.4% for 862 nm and 500 nm, and 0.6% for 412 nm and 368 nm.

The GAW report of FRC-VI will be released in 2026, where the intercomparison results of spectral AOD will be presented, and the level of agreement between the networks will be assessed and compared to previous FRC campaigns (GAW Report No. 231 and 280). An uncertainty analysis based on the information provided by each instrument will be performed and compared to the WMO traceability level of agreement, which represents calibration uncertainties of 1%. Furthermore, building on the work of the EMPIR 19ENV04 MAPP project, which focuses on AOD retrievals based on laboratory calibration of spectroradiometers and filter radiometers, emphasis is placed on these comparisons since the methodology has been operationally adapted by a few commercial instruments. In addition, the reference spectroradiometer QASUME will be used to validate extrapolation techniques for AOD outside the spectral range of 368 nm to 863 nm covered by the GAWPFR-TRIAD reference instruments.

Acknowledgement: The authors and PMOD/WRC would like to express their heartfelt gratitude to the participants of FRC-VI for their invaluable support of this WMO homogenization activity. Their enthusiasm and commitment to extending the campaign have been instrumental in the success of FRC-VI. Thank you for your dedication and collaboration!

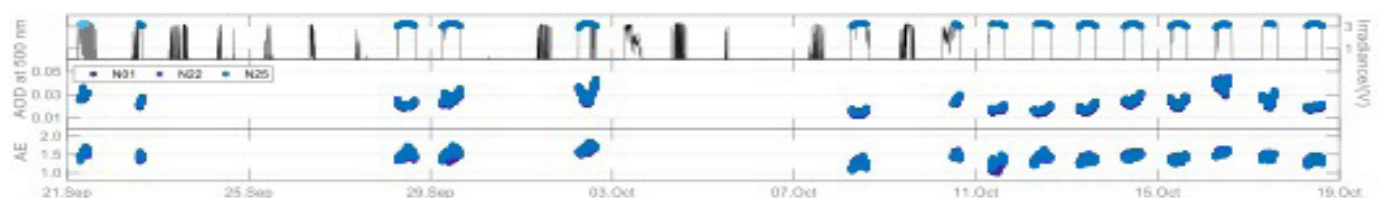


Figure 2. 6th Filter Radiometer Campaign - PMOD/WRC- Davos 22 September - 19 October 2025. PFR irradiance (V) (top) AOD at 500 nm (middle) and Ångström exponent (AE) (bottom) from the GAWPFR-TRIAD.

Traceability of Lunar Direct Irradiances Measured with Precision Filter Radiometer and QASUME Spectroradiometer

Natalia Kouremeti, Julian Gröbner, Gregore Hülsen in collaboration with PTB (Germany) and USGS (USA)

A Precision Filter Radiometer (PFR) measuring lunar direct irradiances for the retrieval of aerosol optical depth (AOD) has been characterized and calibrated at PTB and PMOD/WRC. The spectral irradiance responsivities of the instruments are used in the Langley extrapolation method to assess the precision of the Top-of-Atmosphere (ToA) lunar spectral irradiance provided by known lunar irradiance models.

Atmospheric aerosols are known to impact the climate and represent one of the essential climatic variables with the largest uncertainties in climate change studies. Within the framework of the Global Atmospheric Watch (GAW), Aerosol Optical Depth (AOD) is monitored based on direct solar irradiance measurements performed by Precision Filter Radiometers (PFRs). Growing interest in nocturnal observations of AOD, to fill the gap in the annual cycle of Arctic aerosol climatology, led to the development of the Lunar PFR in 2014.

The Lunar PFR was calibrated at PTB following the same procedures as the sun-PFR [1], aiming to provide a benchmark dataset for lunar model developers. The laser-based calibration at the TULIP setup of PTB led to calibration factors with combined expanded uncertainties of 0.26%, 0.27%, 0.18%, and 0.25% at the four PFR channels with centroid wavelengths of 861.75 nm, 675.39 nm, 501.39 nm, and 411.95 nm, respectively, at the minimum PFR gain. The second calibration of the Lunar PFR at PTB in August 2024 revealed changes in responsivity as well as in centroid wavelengths after necessary service on the instrument, resulting in minor changes to the optical axis and thus changes in the relative responsivity of the instrument. The determination of the maximum PFR gain (lunar gain) was verified for all four channels during the latest calibration leading to a combined expanded uncertainty of lunar irradiance calibration factors of less than 0.4%. The dataset used for the retrieval of the Top-of-the-Atmosphere (ToA) lunar irradiance consists of measurements performed at the Izaña Observatory (28.3° N, 16.5° E, 2.4 km) during the MAPP project campaign from September 3 to 23, 2022. This dataset has been used to assess differences between the Lunar PFR irradiance and the models ROLO [3], RIMO [4] and LIME [5]. Seven Langley-based ToA lunar irradiance retrievals were possible during one lunar cycle with lunar phases ranging from 6° to 58°. The ROLOT ToA lunar irradiance accounts for the relative responsivity of the PFR and the TSIS-1 HSRS ToA solar spectrum [6], while ROLOAirL is in addition adjusted based on the 2019 dataset of AirLUCI [7]. Additionally, two versions of the LIME model (LIME: 20231120, LIME25: 20250608) have been analyzed. The mean difference of ToA lunar irradiance retrieved during the campaign by the Langley extrapolation method and the models show excellent agreement for the most recent versions of lunar models ROLOAirL and LIME25 at 862 nm, with a difference of 0.5% (Figure 1). For the rest of the wavelengths, the differences have been significantly reduced compared to the older versions (RIMO, ROLOT, and LIME) but still show differences on the order of 2% to 5%, which

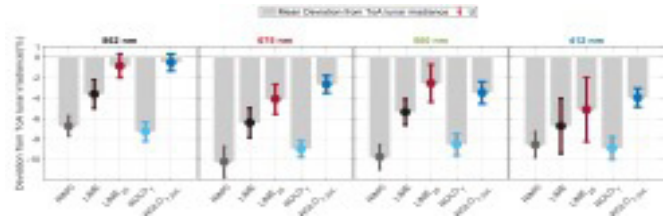


Figure 1. Mean difference of ToA lunar irradiance between Lunar-PFR and lunar irradiance models. The error bars represent the standard deviation of the 7 retrievals over the lunar cycle from September 3 to 23, 2022, at the Izaña Observatory.

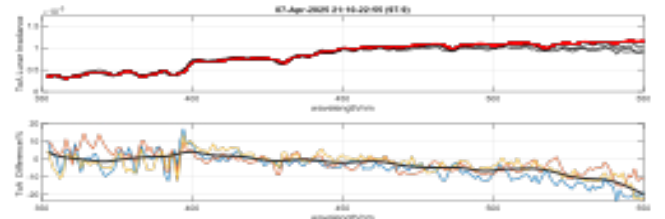


Figure 2. Top: Example of lunar irradiance ToA spectrum retrieved from QASUME lunar irradiance on April 7, 2025, and interpolated daytime AOD (red line) along with the ToA lunar irradiance from the LIME (v5) model over the duration of the scan (30 min). Bottom: Difference between LIME (median-smoothed: black) and individual spectra (coloured lines).

are well within the combined expanded relative uncertainty of the comparison; however, they are far from the requirements of 1% for an SI-traceable AOD retrieval from lunar irradiance. Within the ESA-QA4EO project, additional spectral measurements have been performed using the reference spectroradiometer QASUME, utilizing the already validated entrance optics for direct solar irradiance measurements [7]. An example of a spectrum measured in Davos on April 7, 2025, and extrapolated to ToA using daytime AOD and ozone data is shown in Figure 2. The lunar activity at PMOD/WRC will continue, focusing on optimizing lunar irradiance measurements and reducing the uncertainties of ToA lunar irradiance retrievals. High-quality spectral data will contribute to resolving the discrepancies between lunar models, which are valuable for nighttime AOD retrievals as well as for satellite calibration activities.

Acknowledgement: We would like to thank Tom Stone (USGS) the PTB team Saulius Nevas, Schneider, Kerstin Schwind for making this work possible. This work has been supported by the European Metrology Program for Innovation and Research (EMPIR) within the joint research project EMPIR 19ENV04 MAPP and ESA-QA4EO project, contract QA4EO/SER/SUB/09.

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Laser-based Primary Standard for Absolute Spectral Irradiance Calibration

Salim Ferhat, Gregor Hülsen and Julian Gröbner in collaboration with SINTEF (Norway), JV (Norway), PTB (Germany)

Current SI-traceable calibration methods of spectroradiometers are based on transfer-standard lamps from National Metrology Institutes (NMIs), which have several disadvantages and increased uncertainties. We present a proof-of-concept optical facility that provides an alternative approach to lamp-based methods by combining a Predictable Quantum Efficient Detector (PQED) with an ultra-stable, homogeneous monochromatic beam. This results in an in-lab primary spectral irradiance standard with reduced uncertainties and a shorter traceability chain.

High temporal stability, spatial uniformity, and monochromaticity are important parameters for various optical metrology applications, particularly for calibrating spectroradiometers used in Spectral Solar Irradiance (SSI) measurements. To achieve this, as a first step we developed a diffraction-based computational model to generate and predict monochromatic irradiance spatial distributions in the visible and NIR ranges. Using Fresnel diffraction and Fourier analysis, the model accurately predicts beam behaviour from the input parameters of micro-optical components and the laser source. The model was used to design a beam homogenizer, which was experimentally validated and integrated into a stabilized laser system. With an expanded ($k=2$) generated irradiance uncertainty of below 0.5%, the system provides a practical and precise platform for radiometric and metrological applications using commercially available components. The work has been disseminated to the optics community through publication in *Optics and Laser Technology* (Ferhat and Gröbner, 2025).

As part of the S-CALe Up (22IEM06) project, we demonstrated that PQED (exceptionally stable photodiodes with near-ideal quantum efficiency assembled in a trap-like configuration) can be a key component of an in-lab primary reference for spectral irradiance. To assess how closely PQED approximates a lossless detector, further analysis of PQED's behaviour under expanded, overfilling beams has been carried out to quantify the detector's two main loss mechanisms: optical reflection losses and charge-carrier losses. A reflectance model of the trap photodiode structure combined with thin-film optics and materials data has been developed to estimate optical losses of an incident expanded beam. Charge-carrier losses were determined experimentally from photocurrent I-V characteristics at multiple wavelengths and

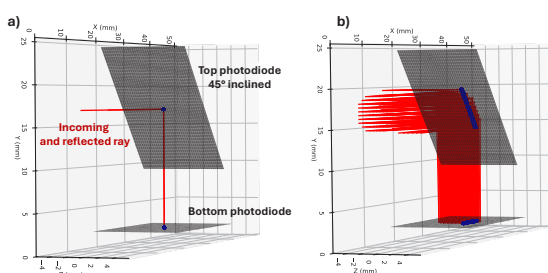


Figure 1. 3D ray tracing simulations of incident light and reflections in a trap detector PQED. a) A single collimated parallel ray. b) Expanded, overfilling beam composed of multiple rays.

Wavelength (nm)	Detector	Measured Irradiance (mWm^{-2})	Relative Difference (%) PQED/detector
473	PQED	34.6	0.77
	ACTON	34.9	
	PQED	114.5	0.13
	QASUME II	114.4	
	PQED	225.5	0.8
	ACTON	223.7	
633	PQED	678	0.32
	ACTON	680.2	
	PQED	184	0.64
	QASUME-IR	184.3	
	PQED	249.1	0.63
	ACTON	250.7	
633	PQED	358.16	0.31
	ACTON	356.95	

Figure 2. Comparisons of measured irradiances obtained with the Laser-PQED and lamp-calibrated systems.

flux levels. The results show that, with these losses, the PQED responsivity relative to an ideal detector exceeds 99.95%. The corresponding uncertainty in linking photocurrent to fundamental constants is thus below 0.05%. Model estimates were compared with a calibrated three-photodiode trap detector (T13, PTB; 0.01% SI-traceable uncertainty), with the relative difference in measured fluxes between the two remaining around 0.1%, validating the loss model and the near-ideal performance of the PQED. Integration of the precision-aperture PQED into the ultra-stable laser system allows highly accurate irradiance measurements in the visible and NIR ranges. The resulting Laser-PQED system achieves an expanded ($k=2$) relative uncertainty of 0.46%, less than half the uncertainty typical of lamp-based transfer standard methods.

Validation was performed by comparing Laser-PQED irradiances to those obtained with FEL-calibrated spectroradiometers: QASUMEII (473 nm), QASUMEIR (633 nm), and the in-lab ACTON double-monochromator system for both wavelengths. The Laser-PQED measurements closely matched the reference spectroradiometers with relative differences consistently below 0.8%. The close agreement with lamp-based systems and the lower intrinsic uncertainties show the Laser-PQED system to be a proof of concept for an in-lab spectral irradiance primary standard with a significantly shortened traceability chain. Current limitations of this new approach, primarily its spectral range and applicability at a set of discrete wavelengths, will be addressed in the upcoming EPM project S-CALe-IIT. PMOD/WRC validated the system's applicability for spectroradiometer calibration, supporting PQED's technological readiness for broader metrological use. These results are currently under review for publication in *Metrologia*.

Acknowledgement: This work has been supported by the European Partnership in Metrology (EPM), co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States, within the project 22IEM06 S-CALe Up.

References: Ferhat, S. and Gröbner, J.: Ultra-Stable, spatially uniform monochromatic beam generation via active flux stabilization and fractional Talbot Self-Imaging, *Optics & Laser Technology*, 192, 113964, <https://doi.org/10.1016/j.optlastec.2025.113964>, 2025.

X-ray Photoelectron Spectroscopy and Elastic Recoil Detection Analysis for quantifying HNO₃ and HCl uptake on calcite surfaces

Sandro Vattioni and Timofei Sukhodolov in collaboration with PSI (Switzerland), IAC ETHZ (Switzerland) and IBL ETHZ (Switzerland)

Recent studies suggest that climate intervention using stratospheric aerosol injection (SAI) of calcite particles instead of SO₂ could reduce harmful side effects, such as changes in precipitation patterns and stratospheric ozone loss (Vattioni et al, 2025). The latter is strongly influenced by calcite's uptake of HNO₃ and HCl, which control the strength of catalytic ozone depletion cycles. Using X-ray photoelectron spectroscopy (XPS) and heavy ion elastic recoil detection analysis (HI-ERDA), we measured the uptake of HNO₃ and HCl by calcite and determined their transformation into calcium nitrate and chloride as function of penetration depth underneath the gas-solid interface.

XPS was performed at temperatures, humidities and HNO₃ and HCl concentrations representative for the lower stratosphere, for up to 72 hours, revealing nitrate and chloride penetration to depths of a few nanometers within the first hours of exposure and a slowdown thereafter. ERDA investigations of samples exposed for 10 days to HNO₃ or HCl concentrations 3-4 orders of magnitude higher and temperatures 30 K higher than for XPS show diffusion-like penetration of nitrogen- or chlorine-containing species to depths of more than 250 nm.

We conclude that uptake decreases with exposure time due to the increasing accumulation of reaction products near the surface. This passivation can be described by exposure-dependent uptake coefficients (see Figure 1). The exposure is defined as the product of the concentration of the reacting acid and the duration of each experiment. Reported uptake coefficients initially start at high values of about 0.1, but rapidly drop to values of 10⁻⁴ for HNO₃ and 10⁻⁵ for HCl for characteristic stratospheric exposures assuming an average residence time of one year to these acids in the lower stratosphere. This greatly limits the influence of HNO₃ and HCl uptake on the optical

properties of the particles and on the abundance of stratospheric nitrogen and chlorine reservoir gases, as well as the associated impact on ozone.

We performed sensitivity simulations using the aerosol chemistry climate model SOCOL-AER, in which these uptake coefficient for HNO₃ and HCl were applied to surfaces of calcite particles injected to the stratosphere between 30°N and 30°S with a injection rate of 5 Mt/yr. The simulations show zonal mean total ozone column anomalies of at most 2% over the polar regions. However, Figure 1 also shows large uncertainty ranges for the uptake coefficients derived for stratospheric exposures. Thus, larger uptake coefficients of up to 10⁻³ can not be confidently excluded. On the one hand, uptake coefficients of 10⁻³ for HCl on calcite particles could result in zonal mean ozone column increase of up to 26% over the south polar region and thus, to substantial recovery of the ozone hole due to removal of chlorine from the stratosphere. HCl is the main chlorine reservoir species and the end product of ozone destroying chloro-fluoro carbons. On the other hand, strong uptake of HNO₃ on calcite would result in zonal mean ozone column depletion of up to 14% due to removal of NO_x from the stratosphere, which is required for deactivation of active chlorine.

Acknowledgement: This work was partially performed at the in-situ Soft X-Ray Ambient Pressure Photoelectron Spectroscopy beamline of the Swiss Light Source at Paul Scherrer Institute in Villigen, Switzerland. This project received funding from the Simons Foundation (Nr. 00005208)

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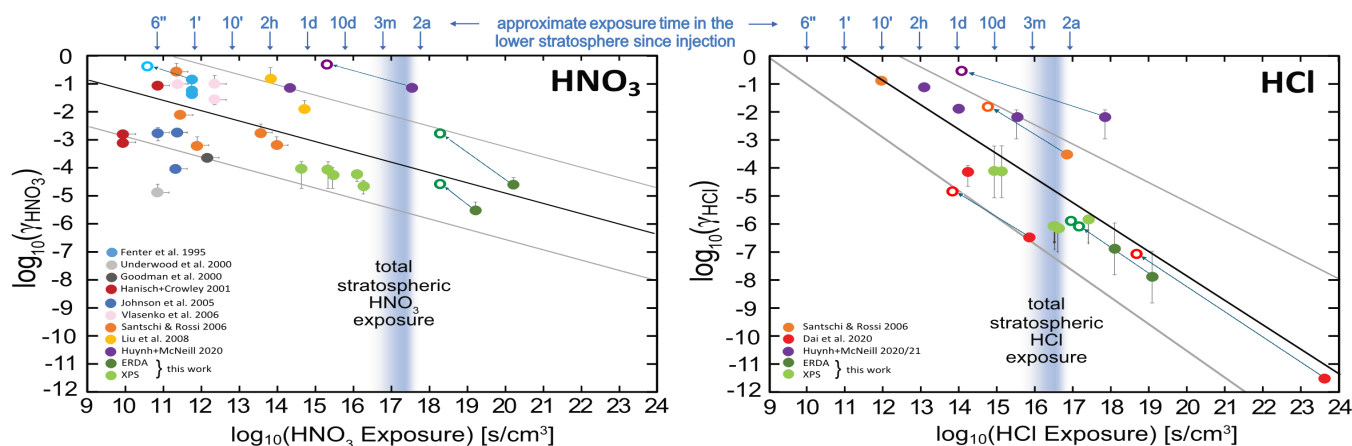


Figure 1. Uptake coefficients of HNO₃ (left) and HCl (right) measured in various studies including this study (labeled ERDA and XPS) as a function of exposure. Thick black lines: logarithmic least square fits to the experimental data. Thin gray lines for HCl: fit ± standard deviation of the slope of the fit. Blue shaded ranges: maximum stratospheric exposures of calcite particles injected into stratosphere after a characteristic residence time and concentrations in the lower stratosphere (i.e. one year at 70 hPa with 2 ppbv HNO₃ and 0.4 ppbv HCl).

Overview of activities of the COST Action Harmonia: “International network for harmonization of atmospheric aerosol retrievals from ground-based photometers”

Stelios Kazadzis and Harmonia COST Action Core group leaders and Collaborators

The Harmonia (International network for harmonization of atmospheric aerosol retrievals from ground based photometers) COST Action is a European Cooperation in Science and Technology funded project. Harmonia’s grand holder institute is PMODWRC. The main aim of the COST Action HARMONIA is: “to Establish a network involving institutions, instrument developers, scientific and commercial end users, in order to improve, homogenize and valorize aerosol columnar retrievals, using mainly solar and sky but also lunar and star photometers from different networks”.

Several global sun-photometric aerosol measuring networks exist. However, there are several instrumental, algorithm and hardware based differences on their related aerosol products and a global standardization is needed. In addition, in order to improve and optimize sun- and moon- photometric aerosol measurements, a network of aerosol scientists and operators, aerosol measurement users and software, hardware developers is needed. The objective of “HARMONIA” Action is to establish a network involving institutions, instrument developers, scientific and commercial end users, in order to improve and homogenize aerosol retrievals using mainly solar and sky but also lunar and star photometers from different networks.

Harmonia includes four working groups (WG):

WG1 aims to enhance pan- European and Global research coordination in order to optimize and homogenize aerosol columnar products from direct and diffuse irradiance measurements, and study their new related uncertainties; to improve already existing products and tools dealing with the new challenges at the limit of the aerosol retrieval techniques and to suggest standardization methodologies for calibration and post processing algorithms.

WG2 aims towards the establishment of a cooperation network working towards measurement improvement. In this WG data already stored in the datacenter of each international network of photometers, or of independent instruments, are checked to find co-located sites providing the same optical properties with different equipment and methods of analysis.

WG3 aims at fostering coordination between academia, operational agencies and industrial partners, in order to increase the applicability of the aerosol products. This includes a demonstration of the relevance of aerosol optical properties to various communities (satellite atmospheric composition validation, model evaluation (example fig. 1), solar energy, aerosol forecasting assimilation, aviation).

WG4 aims to create a hub among scientists and the industrial sector including instrument and software developers. The main aim is to demonstrate the possibilities of improvements based on synergistic and standardization aspects and also inform on the needs of new technologies towards specific end user goals.

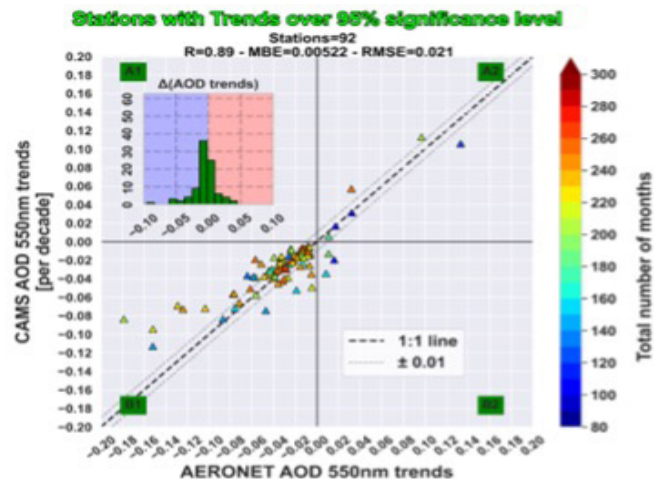


Figure 2. WG3 activities example on long term trend comparison/evaluation for Aerosol Optical depth at 500nm from 92 AERONET stations and the Copernicus Atmospheric Monitoring Service reanalysis data. (figure by A. Moustaka).

Harmonia Action has a network of 140 members dealing with aerosol sun photometry and aerosol remote sensing. During 2025, Harmonia has organized a school at Izaña, Tenerife, Spain (May 26-28, 2025, picture 1). In addition, till the end of 2025, 22 publications have been acknowledging Harmonia related work. Finally, a number of short term scientific missions, Virtual Mobility grants and IT conference Grants, has been awarded.



Figure 2. WG3 activities example on long term trend comparison/evaluation for Aerosol Optical depth at 500nm from 92 AERONET stations and the Copernicus Atmospheric Monitoring Service reanalysis data. (figure by A. Moustaka).

Relevant links for the Harmonia outcome:

All the Harmonia publications can be found here: <https://harmonia-cost.eu/publications/>

A list of all science awarded grants and their related reports can be found at: <https://harmonia-cost.eu/grantees/>

A link with all HARMONIA deliverables can be found here: <https://harmonia-cost.eu/deliverables/>

A link with all HARMONIA dissemination videos can be found here:

<https://www.youtube.com/@HARMONIA-COST>

<https://harmonia-cost.eu/videos/>

Interactive chlorine chemistry in modeling cosmogenic ^{36}Cl : A model update for the AEON project

Tatiana Egorova, Eugene Rozanov, and Timofei Sukhodolov, in collaboration with the Cosmic Rays Group, University of Oulu (Finland), and CEREGE (France)

Cosmogenic radionuclide ^{36}Cl tracks solar activity, geomagnetic fluctuations, and atmospheric transport. Many models ignore stratospheric chlorine chemistry. In the SNSF AEON project, we introduce SOCOL-AERv2-Cl, a climate model that includes an interactive stratospheric chlorine cycle. Focusing on 1894–1941, when ^{36}Cl is produced cosmogenically, we tested two methods: one based on full chlorine chemistry and another treating ^{36}Cl as a chemically passive tracer. Results show no significant differences, indicating that a simplified approach is enough for accurate pre-industrial ^{36}Cl modeling.

The importance of ^{36}Cl lies in its ability to accurately record signatures of extreme solar proton events (SPEs), surpassing other isotopes in precision. Cosmogenic ^{36}Cl , produced by cosmic-ray spallation of atmospheric argon, helps reconstruct past solar activity and atmospheric processes. Unlike ^{10}Be or ^{14}C , it is affected by both cosmic ray flux and chemical factors. This allows for precise detection of solar proton events (SPEs) in ice cores; however, volcanic aerosols can influence transport and mask SPE signals.

Despite advances in interpreting empirical data and modeling phase-dependent deposition, the role of chlorine chemistry itself and its involvement in stratospheric halogen cycles remain largely unexplored. To address this gap, we introduce a new configuration of the SOCOL-AERv2 chemistry–climate model (SOCOL-AERv2-Cl), which features a fully interactive stratospheric chlorine cycle. We conduct multi-decadal simulations for the pre-nuclear bomb testing period (1894–1941), during which ^{36}Cl is produced solely by cosmogenic processes. Two configurations are compared: one in which ^{36}Cl actively participates in chlorine chemistry, and another in which it is treated as a passive, non-reactive tracer.

Seasonal maps (Fig. 1) show the differences between the full chlorine cycle simulation and the simplified gas-phase transport model (^{36}Cl). Positive values indicate higher concentrations in the full-cycle simulation, while negative values indicate stronger removal due to additional phase partitioning and deposition processes. These differences are typically small (within 10%), but their patterns highlight circulation-driven variability.

During winter (DJF), positive anomalies cluster in the Southern Hemisphere, following the southward shift of the Intertropical Convection Zone (ITCZ) and increased storm activity in the Southern Ocean westerlies; negative anomalies mostly appear over the Northern Hemisphere midlatitudes. In spring (MAM), the ITCZ shifts northward, midlatitude baroclinicity peaks, and wet deposition rises in the Northern Hemisphere. In summer (JJA), strong positive anomalies occur in monsoonal regions (South and East Asia, West Africa) and parts of the high-latitude Northern Hemisphere; negative anomalies occur in the southern midlatitudes. During autumn (SON), transition patterns form, as anomalies weaken and move toward the equator, marking the decay of monsoons. Overall, the spatial and seasonal deposition patterns, along with the small (under 5%) differences between runs, are

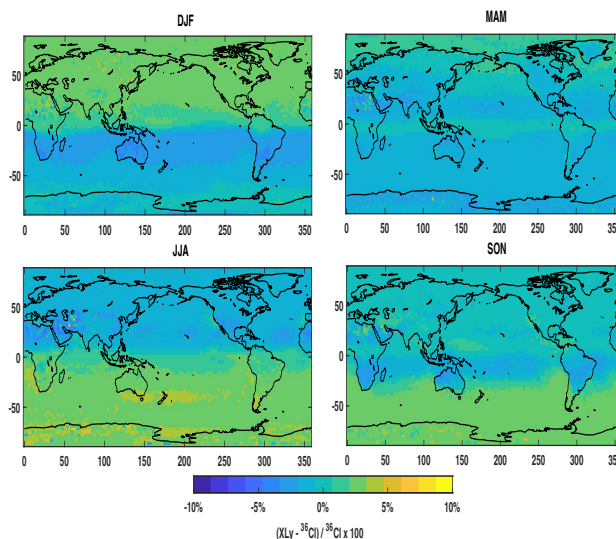


Figure 1. Seasonal variations in ^{36}Cl between two model experiments: one including the full chlorine cycle and the other with simplified gas-phase transport only.

Interactive chlorine chemistry has a marginal influence on pre-industrial ^{36}Cl , validating simplified models for efficiency. Antarctic discrepancies highlight needs for firn-air modules. Paper discussing these results is prepared for submission to the Geoscientific Model Development journal (Golubenko et al., prepared for submission).

Future work in this direction will focus on SPE effects, multi-isotope simulations, and variable climate scenarios.

Acknowledgement: Swiss National Science Foundation (SNSF) project AEON (grant no. 200020E_219166). Oulu group Partial support from the Research Council of Finland (Project no. 354280) is gratefully acknowledged.

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Influence of Atmospheric Scattering on Photolysis Rates Using the Cloud-J Module

Tatiana Egorova, Eugene Rozanov, and Timofei Sukhodolov, in collaboration with O3Lab (SPb University) and BOKU (Austria)

The formation and destruction of stratospheric ozone, which protects the biosphere from harmful ultraviolet radiation from the sun, are connected to photodissociation processes. Because of the critical role of photodissociation in atmospheric photochemistry, photodissociation is a key part of chemical climate models (CCMs) used to study the changing chemical composition of the atmosphere. For the STOA project, we are introducing a new photolysis scheme, Cloud-J 8.0. Simulations and comparisons with observations demonstrate that using the Cloud-J v.8.0 module improves photolysis rate calculations and provides a more reliable representation of the seasonal ozone cycle over the Southern polar region.

The severe ozone depletion over the Southern Hemisphere, known as the “ozone hole,” is a clear example of human-made chemicals causing global ozone loss that contributes to climate change and increases levels of harmful surface UV radiation. Some Chemistry–Climate models, including our SOCOLv3 model, tend to underestimate total column ozone (TCO) compared to satellite measurements over the Southern polar region. This underestimation can reach 50% in monthly-mean zonally average biases during cold seasons.

The method's accuracy in calculating photolysis rates may cause this underestimation. One technique that uses pre-calculated photodissociation coefficients is the “Look-up table” (LUT), which was previously used in SOCOLv3. Cloud and aerosol effects, which are very important in the troposphere, are not included in LUT calculations and are only incorporated into the photolysis rates as modification factors.

To model the processes governing the propagation of solar radiation through the atmosphere more accurately, we introduce the wide-band Cloud-J algorithm for calculating photolysis rates in the presence of cloud and aerosol layers, considering optical thickness, single-scattering albedo, and scattering phase function. It improves the accuracy of photolysis rate calculations by capturing the complex interactions between solar radiation and various atmospheric components. A comparison of data obtained with Cloud-J v.8.0 and libRadtran, as well as the module's sensitivity to atmospheric parameters, is presented in the paper (Imanova et al., 2025a).

To improve the model's photolysis rate estimation, the Cloud-J v.8.0 module was integrated into CCM SOCOLv3, and the simulation results were compared with those from the look-up table (LUT) approach. Because the spectral range of Cloud-J v.8.0 is limited to 177.5–778 nm and does not include gas components where photodissociation occurs at shorter wavelengths, such as O₂ (O+O(1D)), H₂O, and CH₄, the photolysis rates of these gases are calculated using the “old” LUT scheme.

We carried out multiple experiments from 2014 to 2018 and compared the results with IKFS-2 measurements. Figure 1

displays the absolute difference in total column ozone (TCO) between simulations using the LUT and those employing the Cloud-J v.8.0 photolysis scheme, in comparison with IKFS-2 satellite data. The findings show that applying Cloud-J v.8.0 significantly enhances TCO estimates over the Southern polar region from June to September. Specifically, the discrepancy with satellite data in July and August was reduced from 80 DU to 40 DU. In September, the model run with Cloud-J v.8.0 exhibited no statistically significant deviation from the IKFS-2 measurements.

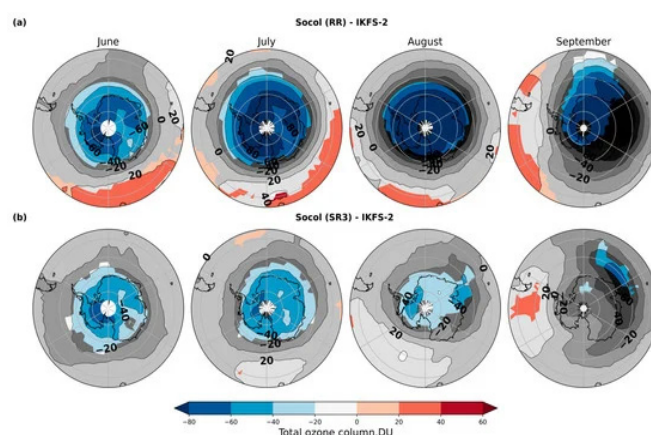


Figure 1. Difference in TCO (DU) between experiment with LUT(RR) (a), experiment with Cloud-J (b), and IKFS-2 data for months from June to September over the 2014–2018 period. Statistically significant results at the 95% level is highlighted in color.

The next step for the STOA project will be to introduce Cloud-J, with updates to tropospheric chemistry in SOCOLv4.2, and to use the results in regional simulations with the WRF model.

Acknowledgement: Swiss National Science Foundation (SNSF) project 200021L-22814 10001350 (STOA).

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Energetic particle precipitation impacts on the atmosphere and climate in idealized time-slice simulations

Timofei Sukhodolov, Silvan Wigger, Sandro Vattioni, Jan Sedlacek, and Andrin Joerimann

Energetic particle precipitation (EPP) is a key driver of chemical and dynamical processes in the middle atmosphere, influencing ozone concentrations, radiative heating, and large-scale circulation patterns. However, investigating EPP impacts in observations and historical simulations is complicated by the sporadic nature of EPP events, sparse and noisy datasets, and the presence of internal atmospheric variability and other forcings that can obscure EPP-driven signals. Trying to overcome these limitations, we performed long-term idealized time-slice simulations with the fully coupled chemistry-climate model SOCOLv4 (Sukhodolov et al., 2021) under different EPP forcing scenarios.

This study investigates the impact of energetic particle precipitation (EPP) on atmospheric chemistry, dynamics, and surface climate using 50-year-long time-slice simulations with the SOCOLv4.0 chemistry-climate model. Simulations were performed under pre-industrial conditions, using EPP forcings of the strong EPP year 2003, which culminated in the Halloween storms, and the weak EPP forcing reference year 2008.

Our results showed that EPP increased polar NO_x in the mesosphere and upper stratosphere, mainly via low- and medium-energy electrons, with minor solar proton contributions. Continuous and persistent EPP forcing also caused substantial global and inter-hemispheric transport, persisting beyond the events, spreading NO_x to lower altitudes and latitudes (Fig. 1a), resulting in almost world-wide statistically significant ozone changes (Fig. 1b). In the polar Northern Hemisphere (NH), ozone depletion is the most pronounced in the mesosphere, where NO_x is produced, and in the upper stratosphere due to the downward NO_x transport within the polar vortex. Previous studies showed that such pattern should produce a net cooling effect in the mesosphere and upper stratosphere, which then strengthens the meridional temperature gradient and intensifies the stratospheric polar vortex (e.g., Arsenovic et al., 2016). However, we found the reversed effect with a temperature dipole of positive stratosphere and negative upper stratosphere/mesosphere temperature anomalies (Fig. 1c). This pattern cannot be explained by the in-situ radiative effects of ozone alone and instead points to a dominant role of compression heating

associated with changes in the polar residual circulation. Our simulations indicate that the forcing for such dynamical changes is coming from the persistent cooling in the tropical troposphere associated with long-term transport of NO_x and related ozone depletion (Fig. 1a-c). The resulting temperature pattern weakens the stratospheric meridional temperature gradient, alters planetary wave propagation, and weakens the polar vortex (Fig. 1d), which triggers surface responses resembling shifts in the North Atlantic Oscillation. In additional simulations where we varied the Halloween Storm dates, we also identified that the interplay of polar and extra-polar EPP effects can result in temperature changes of a different sign depending on the seasonality of the events.

Our study confirms the robust atmospheric and surface effects of EPP but also highlights a potentially overlooked role of the extra-polar EPP impacts even in terms of the sign of the response depending on various factors. We show that the EPP signal in ozone can be present globally in the stratosphere, because of the long lifetime of NO_x, which provides an additional modulation to the related thermodynamical response of the polar middle atmosphere and its connection to the surface climate. This raises the question to which extent this mechanism is manifested under non-idealized realistic conditions, given that there are multiyear periods of enhanced EPP related to the maximum phase of the 11-year solar cycle.

A Paper discussing these results is in preparation for submission to the Geophysical Research Letters journal.

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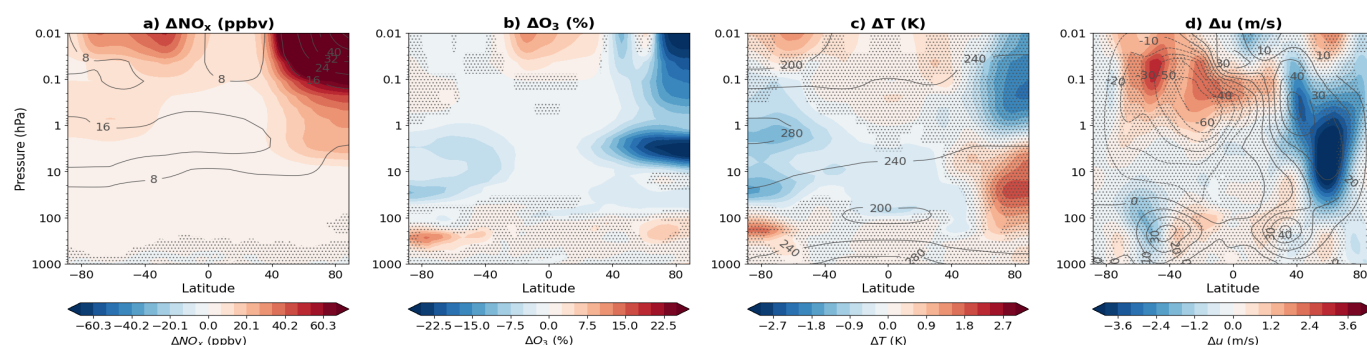


Figure 1. December-mean anomalies for NO_x mixing ratio, O₃ mixing ratio (in %), temperature, and zonal wind in one of the high-EPP experiments. Contours present the climatology of the reference experiment. Stippling indicates regions where anomalies are not statistically significant at the 90% confidence level.

Ozone layer impacts from interactions between a sulphate aerosol injection (SAI) scenario and potential future sources of halogens

Timofei Sukhodolov, Etienne Gilgien, Sandro Vattioni, Jan Sedlacek, and Andrin Joerimann

As the climate is warming, sulfate SAI has been proposed as a way of cooling down the planet's surface. One of the drawbacks of this method is the ozone destruction that it causes, which was projected to weaken over the 21st century due to phasing out of anthropogenic chlorofluorocarbons. However, there might be other sources of halogens in the future atmosphere such as chlorine emissions from solid rocket boosters and strong halogen-rich volcanic eruptions. In this study, we research the interactions of sulfate SAI with these two potential halogen sources in terms of their impacts on the ozone layer, using the estimates from historical volcanic eruptions and existing rocket emission data.

For the rocket halogens study, four different scenarios were simulated as time-slice experiments for 30 years. The REF experiment consisted of the projected 2060s conditions of the SSP5-8.5 scenario. The REFROC experiment consisted of the same conditions as the REF one, with rocket halogen emissions following the "ambitious growth" scenario of Revell et al. (2025), which is based on the reported emission of year 2019. The SAI experiment was based on REF, with the additional injection of 10 Tg of sulfur dioxide (SO₂) each year at $\pm 30^\circ$ latitude. Finally, the SAIROC experiment combined the sulfur injection of SAI and the rocket emissions of REFROC.

The scenarios used to study the impact of volcanic halogens followed a similar pattern. In this case, each simulation was run with three ensemble members over five years each. The REF and SAI scenarios are kept unchanged. For the two scenarios with a volcanic eruption under reference or SAI conditions, a Mt. Pinatubo-sized eruption was used. It corresponded to the co-injection of 12 Tg of SO₂ and 14% as much hydrochloric acid (HCl). This co-injection coefficient is on the upper end of usual estimates for large eruptions like Mt. Mazama (5677 BCE) and was chosen to evaluate a worst-case scenario. A second set of runs was also made with a co-injection of only 0.14% to verify the less extreme scenario consistent with the satellite measurements of more recent but much weaker eruptions.

Our results showed that sulfate SAI conditions amplify the ozone-depleting properties of halogens, both from rocket launches as well as volcanic eruptions. In the case of rockets, the strengthened polar vortex and an increased chlorine activation on the surface of SAI aerosols led to an additional deepening of the southern ozone hole by 4 DU in the annual mean. For volcanic emissions, the presence of sulfate aerosols in the atmosphere even flipped the slightly positive ozone volcanic impact in the northern hemisphere due to the weakened polar vortex (Fig. 1a) to a loss (Fig. 1b). Lower HCl co-injection scenario revealed qualitatively similar results. The addition of these ozone losses to those caused by sulfate SAI itself will be an important challenge when considering the implementation of SAI as a geoengineering method, as the loss of ozone can have serious consequences for human health and global environment.

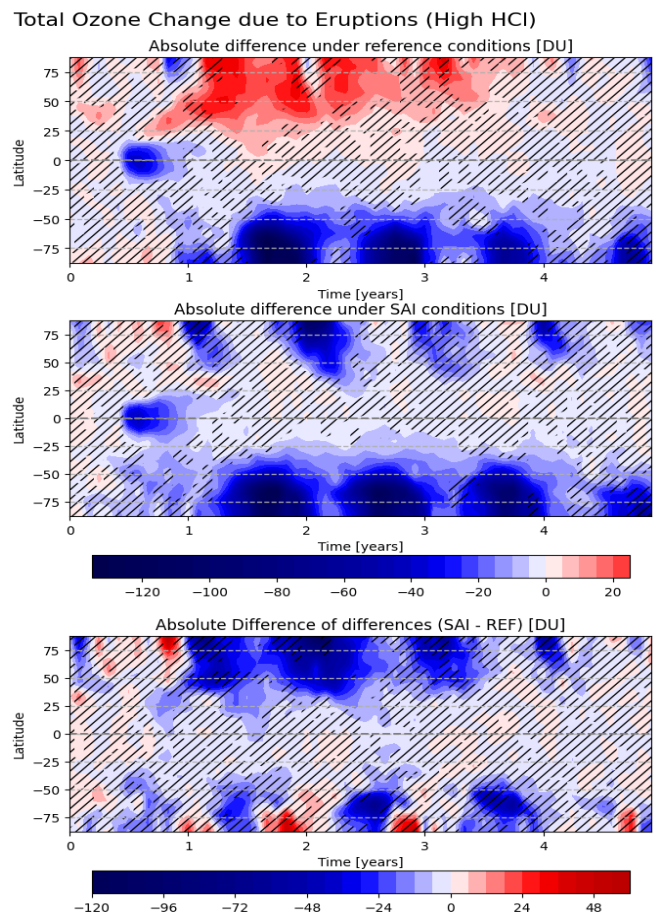


Figure 1. Ozone impact of a Pinatubo-like eruption with a high HCl co-injection coefficient near the equator in June of year 1. The top two panels show the impact under reference and SAI conditions respectively. The bottom panel shows the amplification of the impact due to SAI. The colors are equivalent in all panels. Hashing indicates statistically insignificant changes.

One potential way of minimizing this problem would be to restrict the halogen emissions of rockets, either by using fuels which do not release chlorine (e.g. hydrogen-based cryogenic), or by limiting the number of launches and objects delivered to the orbit, as those provide an additional flux of metallic compounds during de-orbiting, which will impact stratospheric composition, radiation, and dynamics. Volcanic eruptions cannot be predicted or avoided, so measures will have to be reactive.

A Paper discussing these results is in preparation for submission to the Geophysical Research Letters journal.

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Aerosol Optical Depth from spectroradiometers traceable to SI

Julian Gröbner, Natalia Kouremeti, Gregor Hülsen, and Stelios Kazadzis

Aerosol Optical Depth (AOD) was operationally retrieved from the QASUME, QASUME-IR and BTS spectroradiometers in the spectral range from 300 nm to 2150 nm during the whole year 2025. The spectroradiometers were regularly calibrated using portable small power lamps traceable to the QASUME spectral irradiance scale. The comparison to a PFR sunphotometer belonging to the GAWPFR Triad, as well as to a CIMEL sunphotometer belonging to AERONET produced very good agreement in AOD to better than 0.01 over all common spectral channels.

Up to now, global AOD measuring networks determine AOD using measurements of atmospheric transmission where the Top of the Atmosphere (ToA) reference irradiances are obtained from zero-airmass extrapolations. As shown in the EMPIR project Metrology for Aerosol Properties (MAPP), Kouremeti et al., 2022 and Gröbner et al., 2023, laboratory-calibrated spectroradiometers and filter radiometers use the satellite-based solar spectrum TSIS-1 as ToA reference to determine AOD with uncertainties comparable to those from Langley-based calibrations. One of the main advantages of laboratory-based calibrations are that these instruments can be recalibrated anytime without needing to be brought to locations suitable for performing Langley-calibrations.

In this study we show a long-term comparison of AOD between several spectroradiometers operated at PMOD/WRC, Davos relative to two sunphotometers belonging respectively to AERONET and the GAWPFR Triad, for most of the year 2025. The QASUME and QASUME-IR spectroradiometers are scanning spectroradiometers and were operated at PMOD/WRC during the spring, summer and fall seasons, while the BTS array spectroradiometers were operated continuously for the whole of 2025. The QASUME and QASUME-IR spectroradiometers were recalibrated on a weekly schedule using small power lamps traceable to the transfer standard lamps calibrated at the PTB, while the BTS spectroradiometers were recalibrated on a two-month basis.

The comparison was performed at the common spectral channels of the filter radiometers, 340 nm, 368 nm, 412 nm, 440 nm, 500

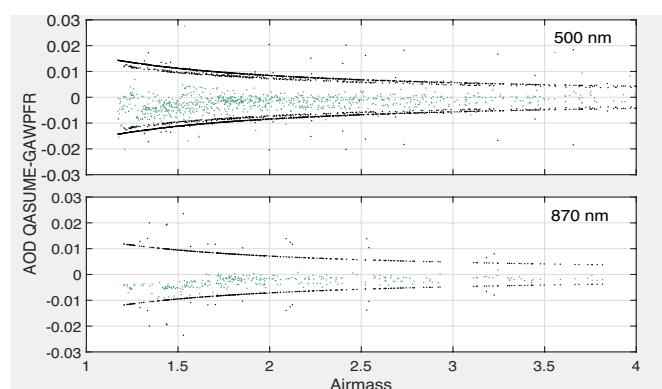


Figure 1a. AOD differences at 500 nm between QASUME and PFR N01 (top panel) and at 870 nm between QASUME-IR and PFR N01 (bottom panel). The black lines represent the combined expanded uncertainty ($k=2$).

Table 1 Average AOD difference at 500 nm (top) and 870 nm (bottom) for 2025. The values in parentheses represent the standard deviation.

500 nm / 870 nm	QASUME	BTS	AERONET	GAWPFR
QASUME		-0.0049 (62)	-0.0026 (46)	-0.0021 (39)
BTS	-0.0018 (23)		0.0018 (34)	0.0032 (41)
AERONET	-0.0035 (57)	-0.0024 (34)		0.0013 (43)
GAWPFR	-0.0026 (42)	0.0013 (46)	0.0034 (49)	

nm, 675 nm, 870 nm, 1020 nm, and 1640 nm. The comparison of AOD at 500 nm and 870 nm between QASUME and the GAWPFR Triad radiometer N01 is shown in Figure 1a with respect to air-mass, with the gray lines representing the combined expanded uncertainties of the measurements. Figure 1b shows the same comparison between the BTS spectroradiometers and a sunphotometer belonging to AERONET. Table 1 shows the average AOD differences and standard deviations between all instruments at 500 nm and 870 nm. As can be seen in the figures and the table, the agreement between the instruments is excellent, with average differences below 0.005 and standard deviations typically less than 0.005. The consistency is also excellent at the other common wavelengths channels, especially in the ultraviolet at 340 nm and the infrared at 1640 nm.

This comparison demonstrates that SI-traceable spectroradiometers can serve as reference instruments for spectral AOD and can therefore form the basis for a new traceability scheme of AOD with respect to SI.

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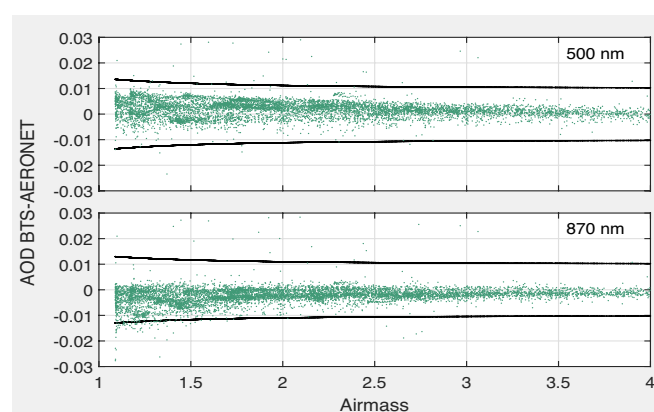


Figure 1b. AOD differences at 500 nm and 870 nm between BTS and AERONET. The black lines represent the combined expanded uncertainty ($k=2$).

Total column ozone and spectral solar UV measurements at Versuchsfeld Weissfluhjoch

Julian Gröbner, Fernanda Cabello, Franz Zeilinger, Luca Egli, with the collaboration of Environment and Climate Change Canada

A Brewer spectroradiometer was installed at the Versuchsfeld Weissfluhjoch to measure total column ozone and spectral solar UV radiation. The total column ozone measurements will be used to assess the amount of atmospheric ozone in the differential atmospheric column between the PMOD/WRC at Davos, at 1590 m.a.s.l., and the Versuchsfeld Weissfluhjoch, at 2536 m.a.s.l. These measurements will support the analysis of the impact of tropospheric ozone on the long-term evolution of the total column ozone above Davos.

A scientific collaboration was established between the PMOD/WRC and the Air Quality Research Division of Environment and Climate Change Canada in Toronto, Canada. The purpose of the loan of Brewer 038 is to perform research studies on climate change impact on stratospheric ozone and spectral solar UV radiation.

Brewer 038 arrived at PMOD/WRC in December 2024 and was installed at PMOD/WRC to measure collocated total ozone and solar UV data with the Brewers of PMOD/WRC. The total column ozone measurements lasted from January to August 2025 and were used to derive the calibration constants of Brewer 038 in comparison to the reference Brewers located at PMOD/WRC.

In July, Brewer 038 was moved to the optical laboratory of PMOD/WRC to determine the responsivity of spectral UV irradiance using 1 kW tungsten halogen lamps traceable to the SI. Furthermore, the angular responsivity of the global entrance optic of Brewer 038 was derived, in order to apply an angular response correction to the measurements of global solar UV radiation. The angular response measurements were performed in four planes and from the measurements a diffuse cosine error of 0.91 was obtained. A global solar UV cosine correction was calculated for clear sky conditions using a radiative transfer model to simulate the direct and diffuse solar irradiance components in dependence on solar zenith angle.

At Davos, the measurements of total column ozone agreed to better than 1% with the measurements of the other Brewers, while the UV index values of Brewer 038 agreed to within 3% with the UV index values measured with Brewer 163 when the cosine correction was applied to the measurements of Brewer 038.

Brewer 038 was relocated to the Versuchsfeld Weissfluhjoch on 13 August 2025, as shown in Figure 1. Measurements of spectral solar UV irradiance and total column ozone have been measured continuously since 14 August. The top panel shows the UV index values, obtained by calculating the erythemally weighted irradiance from the measured solar spectra. The bottom panel shows the daily mean total column ozone.

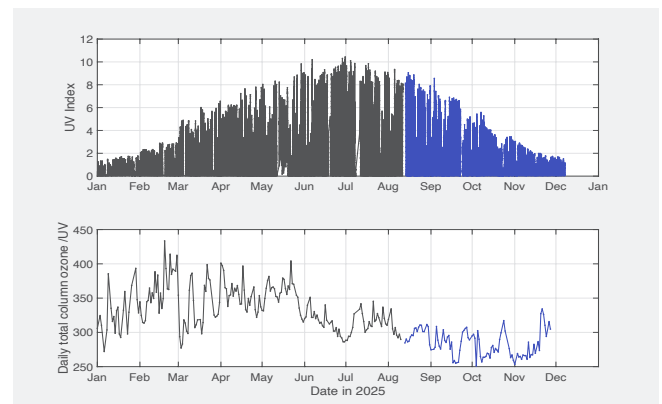


Figure 1. Measurements of Brewer 038 at Davos in black, and at Versuchsfeld Weissfluhjoch in blue. Top panel: UV index values. Bottom panel: daily average of total column ozone.

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A preliminary analysis of the measurements show that the UV index values are about 10% higher at Versuchsfeld Weissfluhjoch than the measurements at PMOD/WRC, which correspond to a UV enhancement of 10% per km. A comparison of UV Index values between a collocated broadband UV radiometer yields excellent agreement, as shown in Figure 3.

In the investigated period between August and November, the differential ozone column contains on average between 3 DU and 5 DU of ozone. This comparison will be extended over the next years in order to observe the seasonal variability and possible long-term evolution of the atmospheric ozone column over Davos.

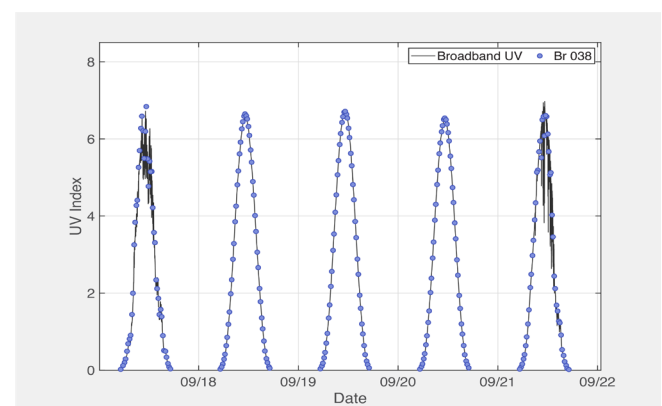


Figure 2. UV Index measurements of Brewer 038, blue dots, and a collocated broadband UV radiometer (black curve) at Versuchsfeld Weissfluhjoch.

Acknowledgement: We would like to thank Environment and Climate Change Canada for providing Brewer 038 and the WSL-Institut für Schnee- und Lawinenforschung for hosting the instrument.

Small-scale Dynamics in the Solar Upper Atmosphere

Yingjie Zhu, Louise Harra, Krzysztof Barczynski, Adriana De-Sassi, and in collaboration with MPS (Germany), NSO, NASA, and CU (United States), UCL (United Kingdom), IAFE (Argentina), ROB (Belgium), and IAS (France)

The solar atmosphere is far from calm, with short-lived bursts spanning hundreds to thousands of kilometers. These events occur across the Sun, from magnetically active regions to quieter areas. Although each event is small, together they may play a major role in shaping the solar atmosphere and the space environment. New high-resolution observations from the Solar Orbiter spacecraft and advanced ground-based telescopes allow scientists to study these dynamic processes in detail, bringing us closer to understanding the heating of the solar outer atmosphere and its continuous plasma outflow into space, known as the solar wind.

The outer atmosphere of the Sun, the corona, is a highly turbulent and structured environment at millions of degrees, shaped by the magnetic field. High-resolution observations in extreme ultraviolet (EUV) light reveal frequent small-scale bursts, brightenings, and jet-like motions, releasing energy intermittently. A review of these events is given by Harra et al. (2025) in the new era of observations from the Solar Orbiter mission.

Below the corona lies the chromosphere, where thin, thread-like features called fibrils (Fig. 1a, dark hair-like features) are observed by the largest solar telescope, the Daniel K. Inouye Solar Telescope (DKIST). By comparing these features with coronal observations from Solar Orbiter (Fig. 1b; small bright blobs), Zhu et al. (in prep) found that both long, static fibrils and shorter dynamic fibrils are linked to brightening features by the magnetic field, revealing a strong connection between different atmospheric layers.

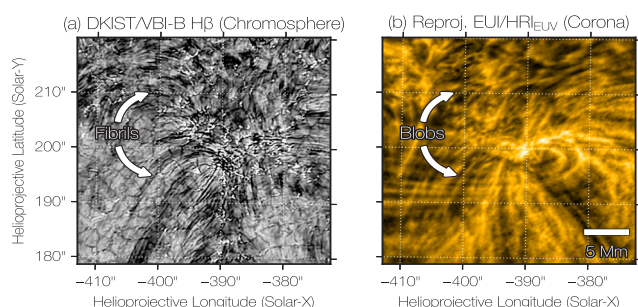


Figure 1. The Sun's atmosphere at two very different heights but at the same place and time. Hair-like dark fibrils (left) and their coronal counterparts, bright blob-like features (right) observed by DKIST and Solar Orbiter. Adapted from Zhu et al. (in prep).

Similar dynamic behavior was identified by Zhu et al. (2025) and Barczynski et al. (in prep) in regions where plasma flows upward at the boundary of active regions. They might be related to the release of solar wind plasma in these regions.

Chitta et al. (2025) found widespread jet-like features in coronal holes. Coronal holes appear as dark regions (see Fig. 2 for an example), where plasma flows outwards. They are known as the source regions of the fast (> 500 km/s) solar wind. Remote observations and direct measurement of the solar wind, both made by Solar Orbiter, suggest that the birth of the solar wind is tightly linked to frequent jet activity in coronal holes.

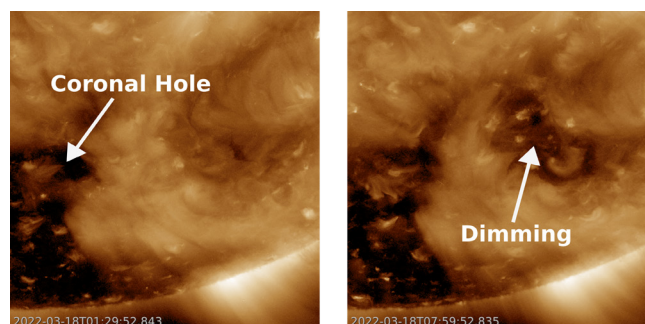


Figure 2. View of the Sun's corona observed in a wavelength that highlights plasma at about 1.6 million degrees. It shows a large polar coronal hole (dark region) and on the right image a dimming (second dark region) that formed over the 6.5 hours between the two images. Taken by NASA's Solar Dynamics Observatory (SDO) with the Atmospheric Imaging Assembly (AIA).

We also examined a region on the Sun where a large solar eruption occurred, which left behind a dark dimming (Fig. 2). De-Sassi et al. (in prep) found that the dimming behaves like a coronal hole in the upper corona, whereas the lower layers show little response. For example, we found that small structures near the base of the corona remain relatively unchanged, indicating the dimming mainly lies at high altitudes. Together, these findings highlight the importance of small-scale, short-lived events in shaping the solar atmosphere and driving the solar wind in various regions.

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Media - Selected Highlights

7. Jan 2025

Timofei Sukhodolov

Stratospheric injection of solid particles could reduce climate change impacts

<https://usys.ethz.ch/en/news-events/news/archive/2024/12/stratospheric-injection-of-solid-particles-could-reduce-climate-change-impacts.html>

6. Mar 2025

Wolfgang Finsterle

First Light of DARA/PROBA3. Schweiz Aktuell, SRF.

<https://www.srf.ch/play/tv/-/video/-?urn=urn:srf:video:9d5b287f-937c-4f6c-806a-4065927c2eeb>

17. Apr 2025

Timofei Sukhodolov

Tonga-Vulkanausbruch kühlte noch den nächsten Winter

<https://www.sn.at/panorama/oesterreich/tonga-vulkanausbruch-kuehlte-noch-den-naechsten-winter-art-589926>

15. May 2025

Timofei Sukhodolov

Record-Breaking Solar Storm Strikes Earth in 12,350 BC, Scientists Reveal

<https://scienmag.com/record-breaking-solar-storm-strikes-earth-in-12350-bc-scientists-reveal/>

11. Jun. 2025

Timofei Sukhodolov

Tagesanzeiger article about our paper on rocket impacts on ozone:

<https://www.tagesanzeiger.ch/eth-zuerich-emissionen-von-raketenstarts-bedrohen-ozonschicht-584146905168>

29. Jul. 2025

Timofei Sukhodolov

Davoser Zeitung Article: Das globale klima kuenstlich veraendern?

15. Sept. 2025

Julian Gröbner

Wie in den letzten beiden Jahren werden wir im Rahmen der Marke graubünden eine Kampagne umsetzen zum Thema Bilden und Forschen. Der inhaltliche Aufhänger ist «Willkommen in Graubünden der unbegrenzten Möglichkeiten»

25. Oct. 2025

Timofei Sukhodolov

Rocket launches are blasting a new hole in our ozone layer

<https://newatlas.com/environment/rocket-launch-hole-ozone-layer/>

12. Nov 2025

Louise Harra

Interview with 20 Minuten about the solar storms and northern lights.

12. Nov. 2025

Sandro Vattioni

Interview with swissinfo.ch about emotions of climate scientists on lacking climate action "10 Jahre nach dem Paris-Areement"

<https://www.swissinfo.ch/ger/klimaschutz/die-klimaangst-unter-klimaforschenden/90271340>

25. Nov. 2025

Wolfgang Finsterle

Article in Davos Zeitung: "Weltweite STRahlungsvergleiche in Davos"

31. Dec. 2025

Julian Gröbner

Beitrag im ORF " Unterwegs bei m Nachbarn" - Interview von Julian Gröbner am Dach des PMOD/WRC., Gesendet am 25/10, 16:20 ORF 2

Administration

Personnel Department

Eliane Tobler and Kathrin Anhorn

External Outreach

Once again, the year 2025 began with the ETH@WEF event in our seminar room, held under the theme “Rethinking Exploration.”

In addition to numerous guided tours at the institute, a major public outreach highlight was the International Pyrheliometer Comparison XIV, hosted in September and October 2025. Nearly all staff members contributed to the event, demonstrating exceptional dedication and teamwork.

Beyond public events and in-house tours, our apprentices continue to engage actively with the wider community through our Instagram channel, sharing weekly posts that showcase our work and achievements. In mid-November, our electronics apprentices proudly represented the institute at the “Fiutscher” fair in Chur.

Team Highlights

In late July, the PMOD team participated in a workshop led by external coaches on the important topics of bullying and mobbing in the workplace. The team-building evening concluded with a shared dinner and board games, fostering a positive and supportive working atmosphere.

Team Changes

We are pleased to welcome new and returning colleagues who joined our team in 2025:

February	Fernanda Cabello, PhD Student
April	Kevin Kilchhofer, PostDoc
July	Markus Heim, Electronics Engineer
August	Tomas Bartko, Apprentice Polymechnics Anton Müller, Apprentice Administration Sandro Vattioni, PostDoc (former student and Zivi)
September	Miguel Huerta, PhD Student Christian Marty, Electronics Engineer (former Zivi) Jan Niklas Valär, Electronics Engineer

At the same time, we extend our best wishes to our departing colleagues - Patrik Langer, Leandro Meier, Nils Janitzek, and Stephan Nyeki - for success and fulfilment in their future endeavours.

Work Anniversaries

We take great pride in seeing former long-term employees and apprentices return to the institute. In keeping with our tradition, we celebrated our jubilarians during the annual Christmas dinner:

- Julian Gröbner, 20 years
- Irene Keller, 15 years
- Stylianos Kazadzis, 10 years
- Jean-Philippe Montillet, 5 years
- Fabrizio Vignali, 5 years
- Wolfgang Finsterle: 20 years

We extend our sincere gratitude for your continued loyalty and dedication to the institute, and we look forward to celebrating many more anniversaries together.

Appreciation

Our heartfelt thanks go to everyone for their ongoing commitment, outstanding work, and numerous contributions to publications, public engagement, digitalization initiatives, and process improvements. Your efforts and teamwork continue to define our success and drive our mission forward.

Finally, we'd like to thank all our civil servants for their commitment: Louis Bischof, Sydney Escher, Lukas Eugster, Adrian Jäggi, Ian Jacob, Tom Pichler and Yann Roth.



Figure 1: During the team-building session, employees showcased creativity and teamwork by building towers from pasta and sweets.

Personnel

Scientific Personnel

Prof. Dr. Harra, Louise	Director, affiliated Prof. at ETH-Zurich, Head of Solar Astrophysics Group, Solar Physicist
Dr. Barczynski, Krzysztof	Postdoc, Solar Physics Group, Physicist
Dr. Janitzek, Nils	Postdoc, Solar Physics Group, Physicist, (until 03.2025)
Dr. Zhu, Yingjie	Postdoc, Solar Physics Group, Physicist
Soder, Ricco	CCO, Quality Systems Managert
Dr. Gröbner, Julian	Co-Head WRC, Head WRC-Sections IR, WORCC, WCC-UV and Ozone Section, Physicist
Cabello, Fernanda	PhD student, WRC Section (since 02.2025)
Dr. Egli, Luca	Scientist, WCC-UV and Ozone Sections, Physicist
Dr. Ferhat, Salim	Scientist, Optical Radiometry, WRC Section, Physicist
Dr. Hülsen, Gregor	Scientist, WCC-UV Section, Physicist
Jaine, Dhrona	PhD student, WRC-WORCC Section, (since 01.06.2024)
Dr. Kouremeti, Natalia	Scientist, WRC-WORCC Section, Physicist
Thomann, Christian	Technician
Zeilinger, Franz	Technical Engineer, BSc, Ozone Section
Dr. Kazantzis, Stylianos A.	Scientist, WRC-WORCC Section, Physicist
Hou, Xinyuan	PhD student, WRC-WORCC Section, (until 04.2025)
Huerta, Miguel	PhD student, WRC Section, (since 09.2025)
Karanikolas, Angelos	PhD student, WRC-WORCC Section
Dr. Kilchofer, Kevin	Postdoc, WRC-WORCC Section, (since 04.2025))
Moustaka, Anna	PhD student, WRC-WORCC Section
Dr. Papachristopoulou, Kyriakoula	Postdoc, WRC-WORCC Section, Physicist
Dr. Finsterle, Wolfgang	Co-Head WRC, Head WRC-Section Solar Radiometry, Physicist
Dr. Haberreiter, Margit	Project Manager/Scientist Space, Instrument Scientist, WRC-SRS Section
Dr. Montillet, Jean-Philippe	TSI Instrument Scientist, Geoscientist
Dr. Sukhodolov, Timofei	Head of Climate Group, Climate Scientist
Dr. Rozanov, Eugene	Scientist, Climate Group, Physicist, (former Head of Climate Group)
Dr. Egorova, Tatiana	Scientist, Climate Group, Climate Scientist
Jörimann, Andrin	PhD student, Climate Group, (since 01.04.2024)
Dr. Sedlacek, Jan	Scientist, Climate Group, Climate Scientist
Vattioni, Sandro	Postdoc, Climate Group, (since 08.2025)

PhD and Project Students

Akhmim, Saad-eddine	BSc student, ETH Zurich, (until 12.2025)
Barba Matta, Estephany	MSc student, UCD Dublin, (until 10.2025)
Geschwind, Yiannis	MSc student, ETH Zurich, (until 09.2025)
Geurts, Manouk	MSc student, ETH Zurich, (until 08.2025)
Gilgien, Etienne	BSc student, ETH Zurich, (until 07.2025)
Jentgens, Henrik	MSc student, ETH Zurich, (until 03.2025)
Kirner, Lukas	BSc student, ETH Zurich, (since 09.2025)
Maier, Nicolas	MSc student, ETH Zurich, (until 12.2025)
Mittaine, Diane	MSc student, ETH Zurich, (since 02.2025)
Wigger, Silvan	MSc student, ETH Zurich, (until 08.2025)
Zeng, Xuying	MSc student, ETH Zurich, (until 11.2025)
De Sassi, Adriana	PhD student, ETH Zurich
Charalambous, Georgia	PhD student, Cyprus University of Technology
Collier, Hannah	PhD student, ETH Zurich, FHNW, (until 09.2025)

Kouklaki, Dimitra	PhD student, National and Kapodistrian Un. Athens, Greece
Stiefel, Muriel	PhD student, ETH Zurich, FHNW I

Baumann, Luca	ETH studio Davos student (until 06.2025)
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Technical Personnel

Büchel, Valeria	Co-Head Technical Department, Project Manager Space
Pfiffner, Daniel	Co-Head Technical Department, Project Manager Space
Bartko, Tomas	Polymechanic Apprentice, 1st year)
Dr. De Coulon, Etienne	Systems Engineer
El Sammra, Karim	Electronics Apprentice, 4 th year
Gander, Matthias	Electronics Engineer
Gyo, Manfred	Electronics Engineer
Heim, Markus	Mechanical Engineer, (since 07.2025)
Heim, Sarina	Electronics Apprentice, 2 nd year, (since 01.08.2024)
Hiltbrunner, Philipp	Technician, since, (01.08.2024)
Langer, Patrik	Mechanical Engineer, (until 06.2025)
Dr. Marty, Christian	Electronics Engineer, (since 09.2025)
Meier, Leandro	Electronics Engineer, (until 08.2025)
Morandi, Andri	Project Manager Space
Reinhard, Florian	Project Manager Space
Schlatter, Pascal	Mechanic, Head of Workshop, Safety Officer
Schwahofer, Oliver	Mechanics Engineer
Senft, Marco	IT Systems Administrator
Spescha, Marcel	Technician / Mechanics Dept.
Valär, Jan Niklas	Electronics Engineer, (since 09.2025)
Vignali, Fabrizio	IT Systems Administrator

Administration

Tobler, Eliane	Head HR / Finances, Accountant, MSc
Anhorn, Kathrin	Senior Financial Project Coordinator
Keller, Irene	Administration, Import/Export
Mark, Nina	Administration Apprentice, 2 nd year
Dr. Nyeki, Stephan	Media Officer (until 04.2025)

Caretaker

Ferreira Pinto, Maria Sofia	General caretaker, cleaning
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Civilian Service Conscripts

Bischof, Louis	08.02.2025 - 29.07.2025
Escher, Cyrill	31.03.2025 - 27.06.2025
Eugster, Lukas	01.09.2025 - 04.12.2025
Jacob, Ian	22.09.2025 - 04.11.2025
Jäggi, Adrian	25.08.2025 - 18.12.2025
Pichler, Tom	10.02.2025 - 28.03.2025
Roth, Yann	30.06.2025 - 29.08.2025

Participation in Commissions, Editorial Boards, International Consortia

Louise Harra	<p>Member of the editorial board of RAS instruments and techniques Member of scientific board of Congressi Stefano Franscini Member of SNSF postdoc mobility committee Secretary of Swiss Committee on Space Research Chair of ESA Heliophysics User archive committee Subject editor for Proceedings of the Royal Society A: Mathematical, Physical & Engineering Sciences Board of Davos Science City Member of the Presidium of the Platform MAP (Mathematics, Astronomy, and Physics, map.scnat.ch) of the Swiss Academy of Sciences co-chair of science advisory board of MPS Swiss Commission for Astronomy (SCFA) of the Swiss Academy of Sciences (SCNAT) GCOS JSG 3: Space Weather Monitoring and Prediction study group Member of ETH Global Strategy Committee expert in the habilitation proceedings at University of Graz Board of Dublin Institute of Advanced Studies Member of SNSF project funding panel. External examiner for PhD thesis - Harry Greatorex (May 2025) PhD examiner at IAS, Paris for Slimane MZERGAT</p>
Wolfgang Finsterle	<p>Guest Editor for several special issues in the AGU journal Earth Space Science - https://agupubs.onlinelibrary.wiley.com/hub/journal/23335084/call-for-papers/si-2025-001540 Member of WMO Expert Team on Radiation References (ET-RR) Member of IRC Solar Irradiance Working Group (SIWG)</p>
Julian Gröbner	<p>Member of the Expert Team on Radiation References of the Standing Committee on Measurements, Instrumentation and Traceability (SC-MINT) of the WMO, since 2014 Member of the WG-IR of the Baseline Surface Radiation Network (BSRN), since 2006 Member of the Regional Brewer Scientific Group - Europe (RBCC-E, 2005 - ongoing) Elected member of the International Radiation Commission, and Chair of the Working Group on Solar UV Radiation, IAMAS, since 2009 Member Beirat für Umwelt und Klima der Physikalisch-Technischen Bundesanstalt (PTB), since 2024. Technical committee for photometry and radiometry of EURAMET, observer. Member of the Dobson Ad-Hoc Committee, http://www.o3soft.eu/dobsonweb/committee.html since 2021 Member of the Scientific Advisory Group for Ozone and UV in the Global Atmosphere Watch programme of the WMO, since 2016 Chair of the Scientific Committee of the Conference "New Developments and Applications in Optical Radiometry" (NEWRAD), since 2014 Member of the Swiss Global Atmosphere Watch Programme managed by Meteoswiss, since 2005</p>
Margit Haberreiter	<p>President Swiss Society for Astronomy and Astrophysics Swiss Representative WMO Expert Team on Space Weather Member of Mission Advisory Group of the Earth Explorer 12 Candidate Mission Earth Climate Observatory Topical Editor Annales Geophysicae</p>
Stelios Kazadzis	<p>Editor in Copernicus: Atmospheric Chemistry and Physics Editor/coordinator Special issue interjournal ACP/AMT Sun-photometric measurements of aerosols: harmonization, comparisons, synergies, effects, and applications https://acp.copernicus Co PI ACTRIS Expert group on Satellite validation Co PI Energy Action group of EuroGeos https://eurogeosec.eu/action_group_single</p>

[html?slug=energy-action-group](#)
 Member of WMO Scientific advisory group for Aerosols
 Expert team of WMO of data quality management
 Expert Team of Atmospheric Composition and Network Evolution of WMO
 International Radiation Committee member
 ACTRIS CARS Unit leader

- Timofei Sukhodolov
 Member of the APARC project “High Energy Particle Precipitation in the Atmosphere”, HEPPA-4
 Co-lead of the APARC activity “Interactive stratospheric aerosol model intercomparison”, ISA-MIP
 PI of the SOCOLv4 model in the APARC activity “Chemistry-climate model initiative phase 2”, CCMI-2
 Member of the International Commission on the Middle Atmosphere, ICMA
 Co-leader of the SCOSTEP COURSE program Focus Area 3 “External impacts and internal dynamics of the Earth atmosphere”
- Krzysztof Barczynski
 Co-I EUI instrument onboard Solar Orbiter
 Co-lead of Solar Orbiter – DKIST-IRIS-Hinode coordinated observations group
 Member EPD – STIX – EUI coordinated flare observations team
 Member of Program Committee of Academia Raetica
 Representative of Akademischer Mittelbau am Physikdepartement ETH Zurich (AMP, Scientific Staff Association) to Departementskonferenz (DK) at ETH Zurich
 Member of Solar-C Science Working Group
 Member of M-MATISSE Science Study Team
 Board member of European Solar Physics Division of the European Physical Society
- Jean-Philippe Montillet
 Editorial Member of Discover Data, Springer
 Member of the subgroup Law & policy subgroup - Group of Earth Observations - Geneva.
 Vice chair & member of the executive committee (at the start of 01.2026) - IEEE foundation - Switzerland chapter
 Guest Editor for several special issues in the AGU journal Earth Space Science - <https://agupubs.onlinelibrary.wiley.com/hub/journal/23335084/call-for-papers/si-2025-001540>
- Sandro Vattioni
 Co-Author of Chapter 6 (on Stratospheric Aerosol Injection) of the 2026 WMO ozone assesment report (Scientific Assessment of Ozone Depletion 2026)
- Tatiana Egorova
 Editor in Geoscientific Model Development
 Member of Editorial Board of MPDI Atmosphere
- Jan Sedlacek
 Guest Editor for several special issues in the AGU journal Earth Space Science - <https://agupubs.onlinelibrary.wiley.com/hub/journal/23335084/call-for-papers/si-2025-001540>

Meetings, Symposia, Workshops, Public Events (selected highlights)

16 Jan. 2025	ACCTRIS Sun photometer workshop.
25 Feb. 2025	Harmonia MC meeting in Un. of Sarajevo, Bosnia and Herzegovina
27 May 2025	Harmonia sun photometry school at Izana, Tenerife, Spain.
15 Jun. 2025	Workshop on aerosol users, Limassol Cyprus
02 Sept. 2025	Workshop of the project STOA (Quantifying past, present and future Stratospheric and Tropospheric Ozone over the Alps and Europe)
08 Sept. 2025	Workshop on aerosol sun photometer industrial actors.
22 Sept. 2025	WMO IPC-XIV
24 Sept. 2025	IPC-XIV/FRC-VI/IPgC-IV Symposium
08 Oct. 2025	ISO TC180 annual meeting

Bilanz per 2025 (inklusive Drittmittel) mit Vorjahresvergleich

	31.12.2025	31.12.2024
Aktiven	CHF	CHF
Flüssige Mittel	4'208'418.21	3'385'384.29
Forderungen	77'389.70	28'035.60
Aktive Rechnungsabgrenzungen	508'653.56	810'349.80
Warenvorräte	1'000.00	1'000.00
Total Aktiven	4'795'461.47	4'224'769.69

Passiven

Verbindlichkeiten	131'609.69	134'951.58
Passive Rechnungsabgrenzung	2'240'227.43	1'885'279.01
Rückstellungen	1'871'475.75	1'780'000.00
Eigenkapital	552'148.60	424'539.10
Total Passiven	4'795'461.47	4'224'769.69

Erfolgsrechnung 2025 (inklusive Drittmittel) mit Vorjahresvergleich

Ertrag	CHF	CHF
Beitrag Bund Betrieb WRC	1'459'400.00	1'459'400.00
Beitrag Bund (BBL), Unterhalt Gebäude	76'111.00	85'824.50
Beitrag Kanton Graubünden WRC	550'000.00	550'000.00
Beitrag Kanton Graubünden für ETH Prof.	270'000.00	240'000.00
Beitrag Gemeinde Davos	710'000.00	710'000.00
Beitrag Gemeinde Davos, Mieterlass	160'000.00	160'000.00
Dienstleistungsauftrag MeteoSchweiz OZON	263'622.58	293'283.18
Dienstleistungsauftrag WMO Genève	21'881.00	21'881.00
Anstellungsverhältnisse	103'234.45	180'325.65
Overhead Projekte	252'266.72	368'999.85
Instrumentenverkäufe	144'766.01	233'574.70
Reparaturen und Kalibrationen	264'532.73	262'043.30
Ertrag Dienstleistungen	155'190.81	72'857.67
Mittelverwaltung für Projekte	806'562.71	0.00
Übriger Ertrag	8'092.18	8'231.10
Finanzertrag	0.00	8'632.13
Ausserordentlicher Ertrag	103'268.25	2'814.67
Drittmittel	3'546'812.65	3'350'796.04
Total Ertrag	8'895'741.09	8'008'663.79

Aufwand

Personalaufwand	5'556'053.19	5'344'004.70
Investitionen Observatorium	260'694.76	268'346.41
Investitionen Drittmittel	55'132.17	49'351.44
Unterhalt Gebäude (Beitrag Bund)	79'573.34	85'824.50
Unterhalt	68'820.68	83'557.93
Verbrauchsmaterial Observatorium	96'311.21	143'291.88
Verbrauchsmaterial Drittmittel	504'959.90	511'898.98
Verbrauch Commercial	10'484.95	67'228.02
Reisen, Kurse	154'175.78	137'048.64
Raumaufwand/Energieaufwand	215'309.31	213'890.57
Versicherungen, Verwaltungsaufwand	187'045.48	261'477.16
Mittelverwaltung fuer Projekte	1'110'322.71	0.00
Finanzaufwand	3'050.43	8'149.56
Übriger Betriebsaufwand	280'446.59	360'350.06
Ausserordentlicher Aufwand	1'751.09	0.05
Total Aufwand	8'584'131.59	8'069'579.90
Jahresergebnis vor Bildung/Auflösung Rückstellungen	311'609.50	474'243.89
Bildung Rückstellungen	184'000.00	400'000.00
Jahresergebnis	127'609.50	74'243.89
	8'895'741.09	8'008'663.79

Abbreviations

ACTRIS-CARS	Aerosols, Clouds, and Trace gases Research Infrastructure Network, Center for Aerosol Remote Sensing
AERONET	Aerosol Robotic Network, GSFC, USA
AOD	Aerosol Optical Depth
APARC	Atmospheric Processes and Their Role in Climate
AU	Astronomical Unit (1 AU = 149,597,870.7 km; used to measure distances within the Solar System or around other stars)
BIPM	Bureau International des Poids et Mesures, Paris, France
BSRN	Baseline Surface Radiation Network of the WCRP
CCM	Chemistry-Climate Model
CIMO	Commission for Instruments and Methods of Observation of WMO, Geneva, Switzerland
CIOMP	Changchun Institute of Optics, Fine Mechanics and Physics
CIPM	Comité International des Poids et Mesures
CLARA	Compact Light-weight Absolute Radiometer (PMOD/WRC instrument onboard the NorSat-1 micro-satellite mission)
CMA	Chinese Meteorological Administration
CMC	Calibration and Measurement Capabilities
CME	Coronal Mass Ejections
COSI	Code for Solar Irradiance (solar atmosphere radiation transport code developed at PMOD/WRC)
COST	European Cooperation in Science and Technology
CSAR	Cryogenic Solar Absolute Radiometer (PMOD/WRC research instrument, ground-based)
DARA	Digital Absolute Radiometer (PMOD/WRC instrument onboard the ESA PROBA-3 formation flying mission)
ECV	Essential Climate Variable
EMRP	European Metrology Research Programme
ESA	European Space Agency
EUI	Extreme Ultraviolet Imager (PMOD/WRC participation in EUI instrument onboard the Solar Orbiter mission)
EUV	Extreme Ultraviolet region of the light spectrum
FM	Flight Model
FRC	Filter Radiometer Comparisons, held at PMOD/WRC every 5 years
FS	Flight Spare
FY-3E	Chinese weather satellite, Fengyun-3
GAW	Global Atmosphere Watch, a WMO Research and Operational Programme focussing on atmospheric composition
GCM	General Circulation Model
GCR	Galactic Cosmic Rays
IACETH Zurich	Institute for Climate Research, ETH Zurich, Switzerland
IPC	International Pyrheliometer Comparisons, held at PMOD/WRC every 5 years
IPgC	International Pyrgeometer Comparisons, held at PMOD/WRC every 5 years
IRCCAM	Infrared Cloud Camera (PMOD/WRC research instrument)
IRIS	Infrared Integrating Sphere Radiometer (PMOD/WRC research instrument)
IRS	Infrared Section of the WRC at PMOD/WRC
ISO/IEC	International Organisation for Standardisation/International Electrotechnical Commission
ISO 17025	General requirements for the competence of testing and calibration laboratories
JTSIM-DARA	Joint Total Solar Irradiance Monitor – DARA (experiment onboard the Chinese FY-3E mission)
METAS	Federal Office of Metrology, (Eidgenössisches Institut für Metrologie), Bern-Wabern, Switzerland
MeteoSwiss	Federal Office of Meteorology and Climatology MeteoSwiss, Zurich, Switzerland

MITRA	Monitor to Determine the Integrated Transmittance (PMOD/WRC research instrument)
MRA	Mutual Recognition Arrangement
NASA	National Aeronautics and Space Administration, Washington DC, USA
NIST	National Institute of Standards and Technology, Gaithersburg, MD, USA
NorSat-1	Norwegian Satellite-1
NPL	National Physical Laboratory, Teddington, UK
NREL	National Renewable Energy Laboratory, Golden, CO, USA
PFR	Precision Filter Radiometer (manufactured by PMOD/WRC)
PMO6-cc	Type of absolute cavity radiometer (previously manufactured by PMOD/WRC)
PROBA	ESA Satellite Missions (PROBA-1 to 3)
PRODEX	PROgramme de Développement d'Expériences scientifiques, ESA
PSR	Precision Spectroradiometer (manufactured by PMOD/WRC)
PTB	Physikalisch-Technische Bundesanstalt, Germany; The German National Metrology Institute
QASUME	Quality Assurance of Spectral UV Meas. in Europe (portable World reference for UV radiation constructed by PMOD/WRC)
QMS	Quality Management System
SCNAT	Swiss Academy of Sciences
SFI	Schweiz. Forschungsinstitut für Hochgebirgsklima und Medizin, Davos, Switzerland
SIAF	Schweiz. Institut für Allergie- und Asthma-Forschung, Davos, Switzerland
SKYNET	Sky Radiometer Network
SNSF	Swiss National Science Foundation
SOCOL	Combined GCM and CTM Computer Model developed at PMOD/WRC
SOHO	Solar and Heliospheric Observatory (ESA/NASA space mission)
Solar Orbiter	SoIO; An ESA mission to conduct solar research (PMOD/WRC are participating with the EUI and SPICE instruments)
SoSpIM	Solar Spectral Irradiance Monitor (PMOD/WRC co-experiment onboard the JAXA Solar-C mission)
SPE	Solar Proton Events
SPICE	Spectral Imaging of the Coronal Environment (PMOD/WRC co-experiment, onboard the Solar Orbiter mission)
SRS	Solar Radiometry Section of the WRC at PMOD/WRC
SSI	Solar Spectral Irradiance
TRF	The Total Solar Irradiance Radiometer Facility (TRF) at the Lab. for Atmospheric and Space Physics (LASP), Boulder, USA
TRUTHS	Traceable Radiometry Underpinning Terrestrial and Helio-Studies (ESA space mission)
TRUTHS/CSAR	Cryogenic Solar Absolute Radiometer (CSAR; PMOD/WRC space-based instrument) onboard the TRUTHS mission
TSI	Total Solar Irradiance
VHS	Ventilation Heating System (manufactured at PMOD/WRC)
VIRGO	Variability of Solar Irradiance and Gravity Oscillations (PMOD/WRC instrument onboard the SOHO mission)
WCC-UV	World Calibration Center for UV in the WRC of the PMOD/WRC
WDCA	World Data Centre for Aerosols, NILU, Norway
WISG	World Infrared Standard Group of pyrgeometers (maintained by WRC-IRS at PMOD/WRC)
WMO	World Meteorological Organisation, a United Nations Specialised Agency, Geneva, Switzerland
WORCC	World Optical Depth Research and Calibration Center of the WRC at PMOD/WRC
WRC	World Radiation Center at PMOD/WRC, composed of the Sections: IRS, SRS, WCC-UV, and WORCC
WRR	World Radiometric Reference
WSG	World Standard Group of pyrheliometers (realises the WRR; maintained by WRC at PMOD/WRC)

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