Annual Report
Jahresbericht 2022

Front Cover: Brewer instruments during the 2022 Regional Brewer Calibration Campaign for Europe (RBCC-E) in the measurement field at PMOD/WRC with the participation of the World Brewer reference from Toronto (Canada).

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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pmod wrc

Annual Report
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2022

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 Bureau Internationale des Poids et Mesures (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 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 Bureau Internationale des Poids et Mesures (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 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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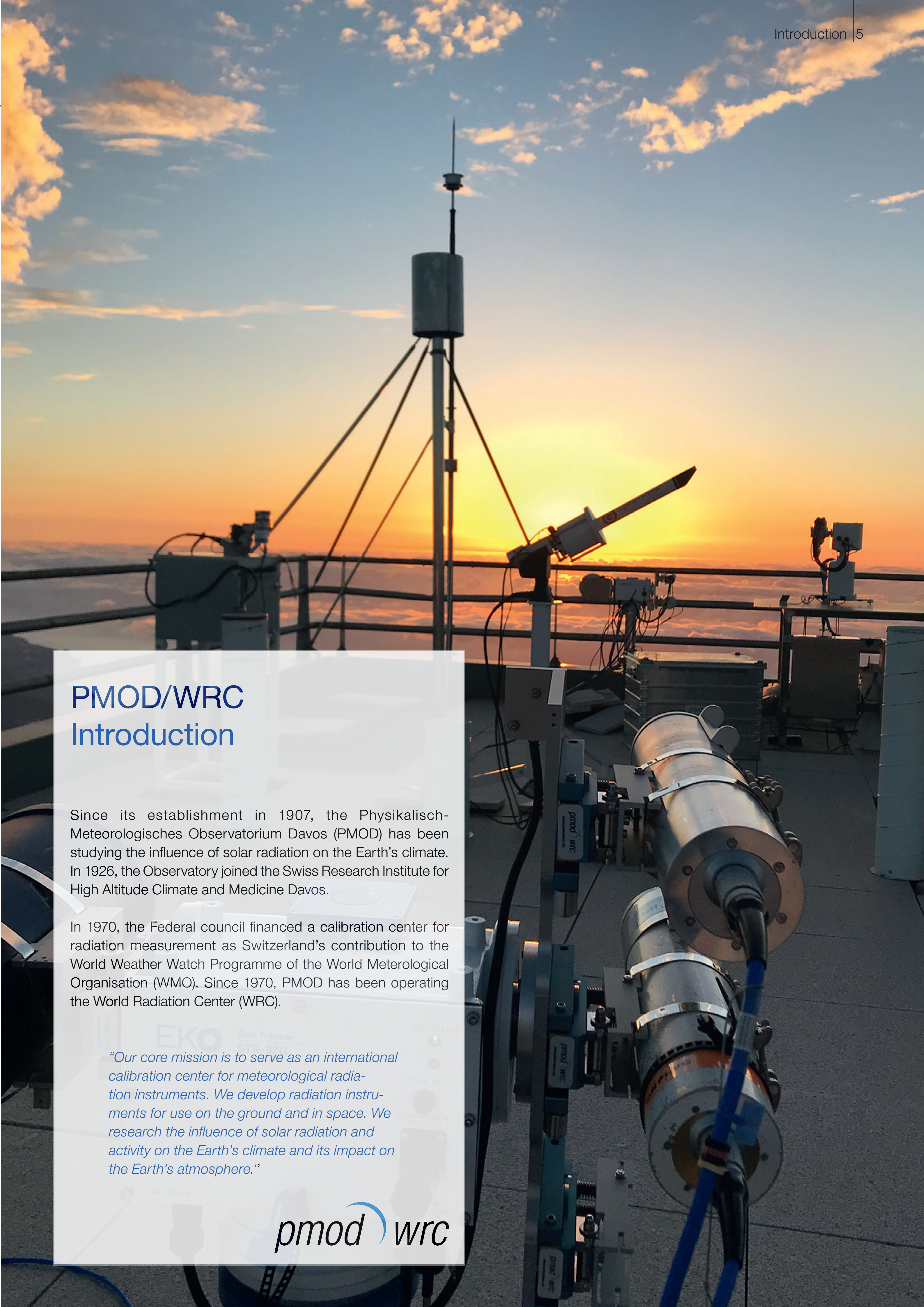


PMOD/WRC Introduction

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 1970, the Federal council financed a calibration center for radiation measurement as Switzerland's contribution to the World Weather Watch Programme of the World Meterological Organisation (WMO). Since 1970, 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 primary standard for solar irradiance. In addition, a calibration center for 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 WRC.

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

Weltstrahlungszentrum

Das Weltstrahlungszentrum (WRC) unterhält den primären Standard für die Sonneneinstrahlung. Darüber hinaus wurde 2004 ein Kalibrierzentrum für langwellige Strahlungsinstrumente und 2008 das Kalibrierzentrum für spektrale Strahlungsmessungen zur Bestimmung der atmosphärischen Trübung eingerichtet. Seit 2013 wird auch das Weltkalibrierzentrum für Ultraviolettstrahlung (UV) durch das WRC betrieben.

Heute besteht das WRC aus vier Sektionen: Solar-Radiometrie (WRC-SRS), Infrarot-Radiometrie (WRC-IRS), Atmosphärische Trübung (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.

Research

Data collected in space and on the ground are analysed in research projects on 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 research solar activity using high spatial and spectral resolution data. We are involved in the design, build and operation of these complex instruments. The key science questions are "what drives the solar wind?" and "what triggers solar flares?".

Forschung

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?".

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 tough environments (all weather and in space). This also provides an ideal environment for the training of apprentices. We have five 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.

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 fünf 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-Zurich

The PMOD/WRC director is an affiliated professor since 2019 in the Institute of Particle Physics and Astronomy (IPA) within the Department of Physics (D-PHYS). 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.

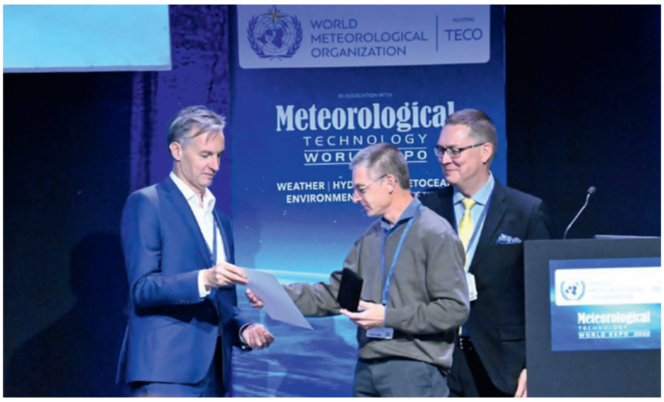
We also have strong links with the Department of Environmental Systems Science (D-USYS) through our climate modelling expertise and through teaching there.

ETH-Zürich

Seit 2019 ist die Direktorin des PMOD/WRC als affiliierte Professorin im Departement Physik (D-PHYS) des Instituts für Teilchenphysik und Astronomie (IPA) angesiedelt. 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.

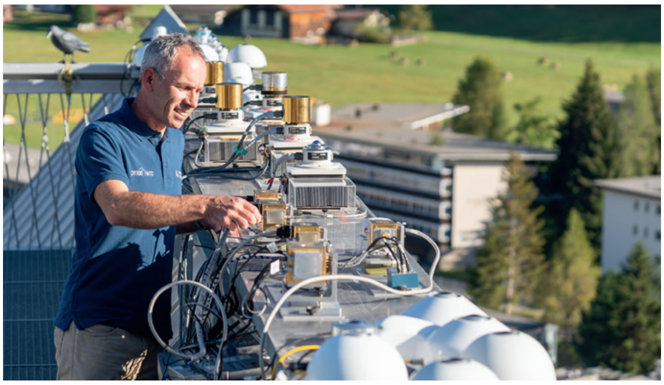
Auch mit dem Departement Umweltsystemwissenschaften (D-USYS) sind wir durch unsere Expertise in der Klimamodellierung und durch die dortige Lehre eng verbunden.

Highlights 2022

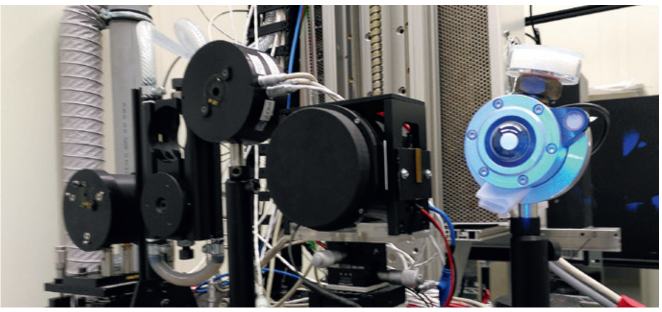


Thirty Precision Filter Radiometers (above) and five new IRIS radiometers (below) were built.

Julian Gröbner (above) and Natalia Kouremeti (left) received the Dr. Vilho Väisälä Award for an outstanding research paper on instruments and methods of observation.

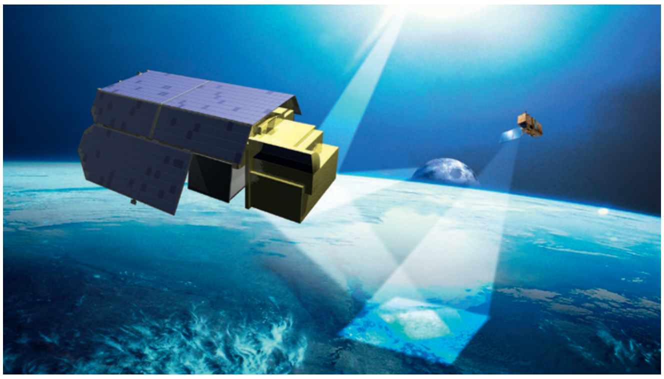


The Brewer campaign (above and right) took place successfully at Davos with six institutes from six countries.

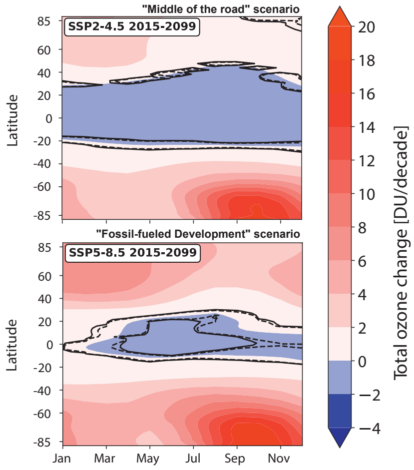


Ultra-Violet traceability to SI: A campaign at the German National Metrology Institute (PTB) was successful.

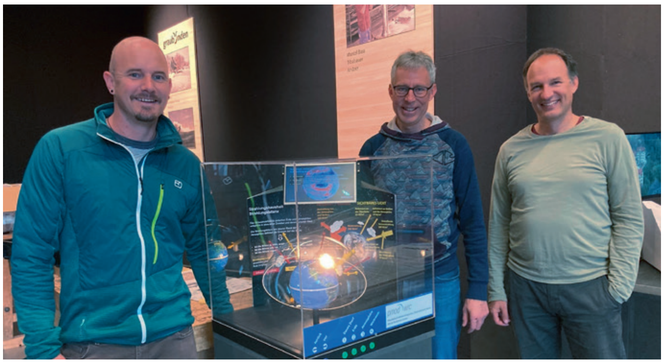
Renewed traceability for 103 pyrheliometers world-wide following the International Pyrheliometer Comparison XIII.



Our work on the ESA "Traceable Radiometry Underpinning Terrestrial and Helio-Studies" (TRUTHS) mission continued with modelling and breadboarding of the cavity and electronics.

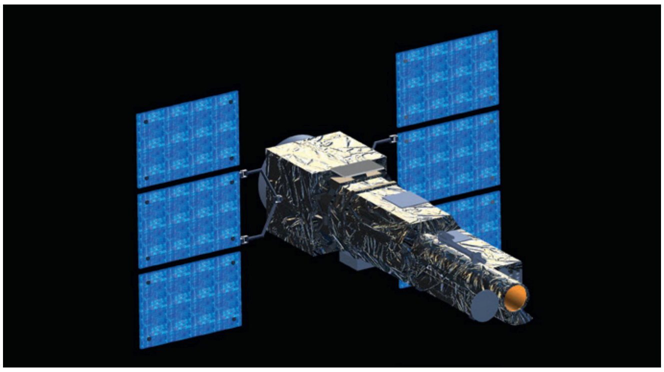


The climate group have investigated possible future trends in ozone under different climatic conditions.



Public outreach events included the "Nacht der Physik" at ETH Zurich (1000s of visitors) and the OLMA in St. Gallen with about 300,000 visitors.

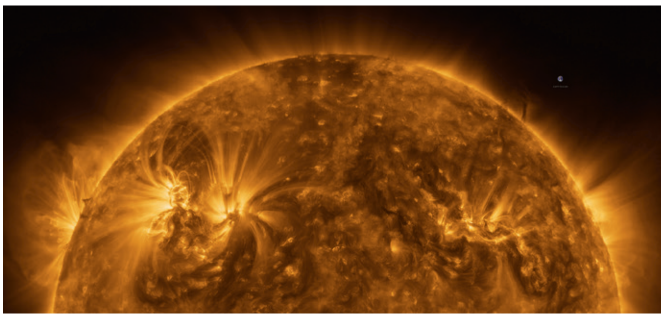
PMOD/WRC staff in the newly renovated workshop.



The Japanese JAXA mission Solar-C design work is well underway for the Solar Spectral Irradiance Monitor that is being led by PMOD/WRC.

"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 research and technology. Thank you".

Louise Harra, Director
PMOD/WRC and ETH Professor



The Solar Orbiter mission reached a major milestone in 2022, reaching its first science perihelion in March/April and the second one in October.

Lecture courses and project supervision continue. The above picture shows two of the first MSc project students who reported on Solar Orbiter data.

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 Infra-Red 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 benefitting from synergies with the solar physics, climate science, and space hardware groups at PMOD.

Quality Management System, Calibration Services, Instrument Sales

Ricco Soder, Wolfgang Finsterle, Julian Gröbner and Administration Department

Quality Management System

i) Calibration and Measurement Capabilities (CMCs)

Since there was no change regarding CMCs, PMOD/WRC still has eight different CMCs listed in the Key Comparison Database (KCDB) of Bureau International de Poids et Mesure (BIPM). These are summarised in Table 1.

Table 1. Details of the PMOD/WRC Calibration and Measurement Capabilities. WRC = World Radiation Center, SRS = Solar Radiometry Section, WCC-UV = World Calibration Center for UV.

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: 280-400 nm
WCC-UV	broadband detector	responsivity, solar, irradiance	λ: 280-315 nm
WCC-UV	broadband detector	responsivity, solar, irradiance	λ: 315-400 nm
WCC-UV	broadband detector	responsivity, solar, irradiance	λ: 280-400 nm
WCC-UV	solar spectroradiometer	responsivity, solar, spectral, irradiance	λ: 300-310 nm
WCC-UV	solar spectroradiometer	responsivity, solar, spectral, irradiance	λ: 310-500 nm

ii) Organisation and Human Resources

Eliane Tobler took over the position as Head of the Administration Department.

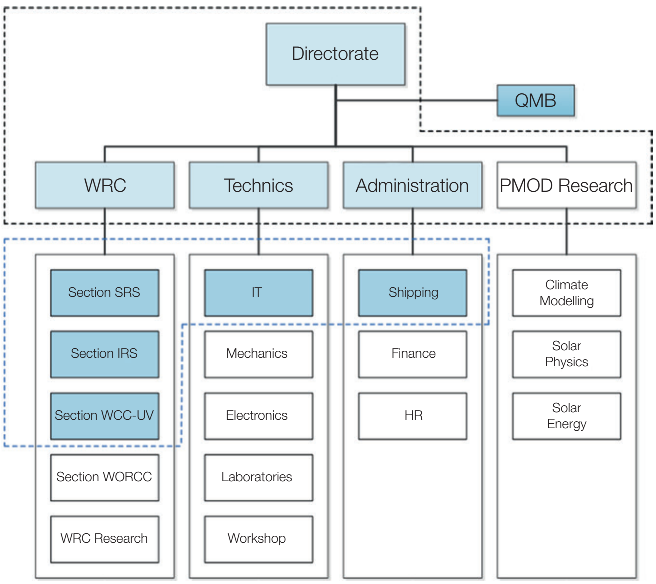


Figure 1. Organisational chart of the PMOD/WRC Quality Management System (QMS). The WRC Solar Radiometry Section (SRS), the World Calibration Center for UV (WCC-UV) and the Infrared Section (IRS) perform calibrations according to the EN ISO/IEC 17025 standard (shown in blue).

iii) Activities

According to the annual audit plan, two internal audits were conducted. The WRC-IRS section and the Administration Department were assessed with very positive outcomes.

Communication was strengthened in the past year. This led to an expansion of the already existing communication between the Quality Manager (QM) and Heads of the WRC sections, while a regular exchange between the QM and director was established in addition to the annual management review.

In 2022, the calibration sections of PMOD/WRC participated in six inter-laboratory comparisons and international measurement campaigns.

Furthermore, staff-training was performed in accordance with a section-specific schedule, while the QM-related documentation of all WRC sections was updated and continuously developed throughout the year.

Calibration Services

In 2022, the four WRC calibration sections (SRS, IRS, WCC-UV and WORCC) calibrated a total of 253 instruments, which is an increase of 4% compared to the previous year.

Solar Radiometry Section (WRC-SRS)

The WRC-SRS section calibrated a total of 109 instruments in 2022. Both the number of pyranometer and pyrheliometer calibrations slightly increased to 83 and 26 instruments, respectively.

Infrared Radiometry Section (WRC-IRS)

The WRC-IRS section performed 37 pyrgeometer calibrations, which is a decrease of 23 instruments.

Atmospheric Turbidity Section (WRC-WORCC)

The WRC-WORCC section calibrated 18 precision filter radiometers (PFR) against the WORCC Triad standard. One additional precision solar spectroradiometer (PSR) was calibrated against a reference standard, traceable to the German National Metrology Institute (PTB; Braunschweig, Germany). The WRC-WORCC section issued a total of 19 certificates.

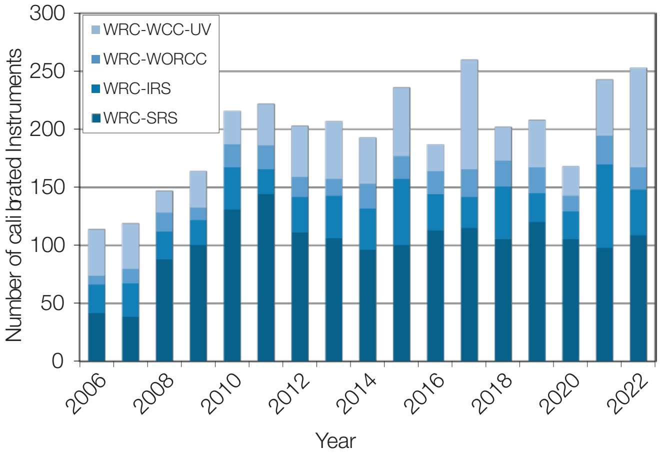


Figure 2. Statistics of instrument calibrations at PMOD/WRC for the 2006 - 2022 period. Remark: One instrument can result in more than one calibration certificate.

World Calibration Center for UV Section (WRC-WCC-UV)

Seventy-eight UVB broadband radiometers were calibrated in the WCC-UV section. This resulted in 245 certificates, which typically cover different measurement units. Furthermore, WCC-UV performed three lamp, diode and spectroradiometer calibrations, while five spectrometers were calibrated against the QASUME travelling reference. These calibrations resulted in nine certificates.

As it was not possible to issue all calibration certificates with a CIPM logo, a comprehensive summary of numbers over the last five years is shown in Table 2.

Table 2. Summary of calibration certificates issued by PMOD/WRC.

	WRC-SRS Total	WRC-SRS with CIPM Logo	WRC-IRS Total	WRC-IRS with CIPM Logo	WRC-WORCC Total	WRC-WORCC with CIPM Logo	WRC-WCC-UV Total	WRC-WCC-UV with CIPM Logo
2018	105	99	46	0	23	0	76	23
2019	120	113	25	0	22	0	82	38
2020	105	94	25	0	14	0	82	24
2021	98	93	72	0	25	0	105	36
2022	109	99	39	0	19	0	254	89

Instrument Sales

In 2022, PMOD/WRC sold a larger number of instruments and accessories than in the previous two years (Figure 3). Seven Precision Filter Radiometers (PFR) were sold, which were all new-generation PFRN19 models (see Page 25).

In addition, two Universal Instrument Adapters (UIA) and two Ventilation and Heating Units (VHS) were sold.

Instrument sales increased in 2022 even though the production and sale of PMO6-cc absolute cavity pyrheliometers was outsourced to Davos Instruments (https://www.davos-instruments.ch/) in 2020. These type of radiometers have not appeared in the sales statistics (Figure 3) since 2020. Since then, Davos Instruments have developed a new generation of radiometer, the PMO8 series. PMOD/WRC will continue to be responsible for the calibration of absolute cavity pyrheliometers against the World Standard Group.

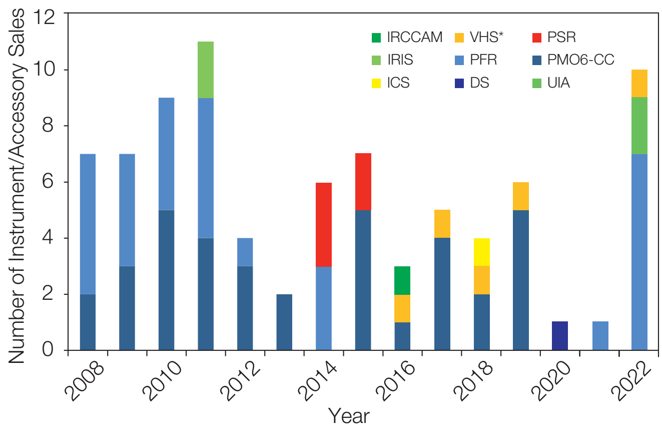


Figure 3. Number of PMOD/WRC instrument sales from 2008 up to and including 2022: i) IRCCAM = Infrared Cloud Camera, ii) VHS = Ventilation Heating Systems, iii) PSR = Precision Spectroradiometer, iv) IRIS = Infrared Integrating Sphere Radiometer, v) PFR = Precision Filter Radiometer, vi) PMO6-CC = absolute cavity pyrheliometer, vii) ICS = Irradiance Calibration System, viii) DS = Diffuser System for UV spectroradiometers, and ix) UIA = Universal Instrument Adapter.

**Note: VHS sales/year shown as a single unit for ease of interpretation. Actual VHS units sold: 2016 = 7; 2017 = 2; 2018 = 36; 2019 = 5; 2022 = 2.*

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. The SRS operates the ISO 17025 certified calibration laboratory for solar radiometers (pyrheliometers and pyranometers). During the 2022 calibration season, 109 certificates were issued compared to 108 in 2021. Other important activities included the evaluation of the 13th International Pyrheliometer Comparisons (IPC-XIII), which took place in 2021, publishing of the final report, and strategic planning for the future of the World Radiometric Reference.

In 2022, the WRC-SRS calibrated 107 radiometers. These consisted of eight absolute solar radiometers, 83 pyranometers, and 16 pyrheliometers with thermopile sensor. The WSG was operated on 72 days. The Cryogenic Solar Absolute Radiometer (CSAR) was operated for two weeks and the Monitor for Integrated Transmittance (MITRA) on 41 days in 2022. Additional tests were performed with MITRA in the climate chamber (see page 39).

A new data acquisition computer was installed and commissioned in the WRC-SRS calibration laboratory. The old computer is kept as a redundant back-up. The travelling standard group was enlarged with a PMO8 radiometer and now consists of four modern absolute cavity radiometers.

The travelling standard group represented the WRR at the National Pyrheliometer Comparison (NPC), which took place from 25 September to 1 October at the National Renewable Energy Laboratory at Golden, USA (Figure 1). The NPC serves as an interlaboratory comparison to confirm the mutual agreement of the WRR with the US national standard, thus adding to confidence in the stability of both standards. The results from the NPC-2022 were published in an NREL Technical Report (Reda et al., 2022).

A two-year strategy for the future replacement of the WSG was developed and presented to the Advisory Board meeting in November. Under the working title “WSG 2.0” the WRC-SRS plans to technically and formally establish CSAR/MITRA as an SI primary standard for solar irradiance measurements, while the WSG would continue to serve as a working standard for calibrating solar radiometers. The WSG 2.0 concept also contains a contingency plan to cover the premature failure of the WSG, in which case the travelling standard group will be used as a substitute for the WSG. The travelling standard group consists of four modern-type absolute cavity radiometers which are regularly compared to regional and national references world-wide during Regional, sub-Regional, and National Pyrheliometer Comparisons. The WSG 2.0 strategic plan was approved by the Advisory Board, and the work on the project started according to the workplan. It includes the characterisation and calibration of all components in the CSAR/MITRA measurement chain to SI-traceable standards and the formulation of the detailed uncertainty budget (Figure 2). The work is generously sponsored by Karbacher Funds.

Figure 1. The WRC-SRS travelling standard group against the backdrop of the Rocky Mountains at the National Pyrheliometer Comparison (NPC) in Golden, USA. The travelling standard group consists of the four absolute cavity radiometers mounted on the right-hand side of the solar tracker. The radiometers on the left belonged to Davos Instruments AG.

References:

Finsterle W.: 2023, WMO International Pyrheliometer Comparison IPC-XIII, WMO IOM Report No. 140, in press.

Reda I., et al.: 2022, NREL Pyrheliometer Comparisons: September 25 - October 1, 2022 (NPC-2022), NREL/TP-1900-84219, https://www.nrel.gov/docs/fy23osti/84219.pdf

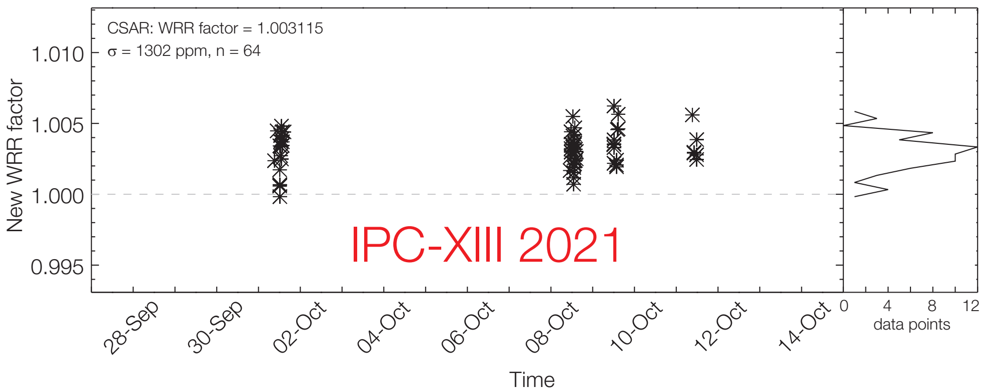


Figure 2. CSAR/MITRA results during IPC-XIII (Finsterle, 2023) confirmed the previously published WRR-to-SI offset of 0.3%. CSAR/MITRA is foreseen to replace the WSG to realise the WRR in an SI-traceable manner by the end of 2024 (WSG 2.0 strategy).

Infrared Radiometry Section (WRC-IRS)

Julian Gröbner, Christian Thomann and Stephan Nyeki

The Infrared Radiometry Section of the WRC maintains and operates the World Infrared Standard Group of pyrgeometers (WISG) that represents the world-wide reference for atmospheric longwave irradiance measurements.

The WISG serves as the 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 that are installed on the PMOD/WRC roof platform.

The measurements of the individual WISG pyrgeometers with respect to their combined average are shown in Figure 1 for the period from 2004 to the end of 2022. As can be seen in the figure, the long-term stability of the WISG is very satisfactory, with measurements of all four pyrgeometers within ±1 Wm^{-2} over the whole time period. As mentioned in the previous annual report, the WISG coefficients were slightly updated as of 1 January 2022 to increase their consistency during the spring to autumn calibration period, as is confirmed by the comparison shown in Figure 1.

The traceability of the WISG to SI was investigated through a comparison (Gröbner et al., 2023) with several independently calibrated radiometers: 1) the Infrared Integrating Sphere Radiometer (IRIS), 2) the Absolute Cavity Pyrgeometer (ACP), and 3) the Atmospheric Emittance Radiance Interferometer (AERI). These comparisons (Figure 2) were conducted over the last few years and have shown that the WISG irradiances in cloud-free conditions are consistently lower by about 4 Wm^{-2} than the IRIS radiometers. A slight dependence on the atmospheric Integrated Water Vapour (IWV) content is also evident in Figure 2.

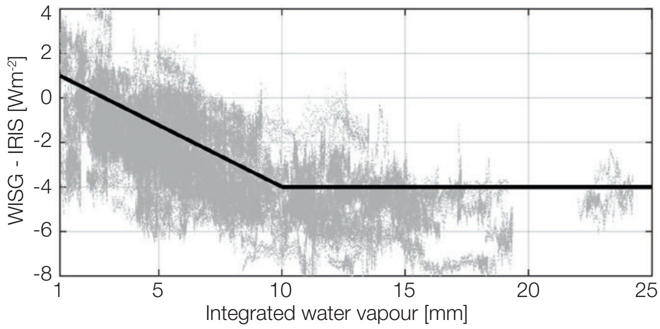


Figure 2. Differences between WISG and IRIS with respect to Integrated Water Vapour (IWV) during cloud-free nights for the period 2011 to 2022. The thick black line represents the average offset between the WISG and IRIS for values of IWV larger than 10 mm, and a linear fit between the residuals and IWV below 10 mm.

The BB2007 blackbody is the primary standard for longwave infrared irradiance at PMOD/WRC (Gröbner, 2008). In the framework of the EMPIR METEOC-4 project, this blackbody was compared to the Hemispherical Blackbody (HSBB), which was developed, built and operated at PTB (Feierabend et al., 2023). The agreement between BB2007 and the HSBB using IRIS#4 as a transfer radiometer was within their combined standard uncertainties and within the target uncertainty of 0.5 Wm^{-2}.

References:

Feierabend, M., Gröbner, J., Müller, I., Reiniger, M., Monte, C.: 2023, Bilateral comparison of irradiance scales between PMOD/WRC and PTB for longwave downward radiation measurements, Metrologia, 60, 025010, 14pp, https://doi.org/10.1088/1681-7575/acbd51

Gröbner, J., et al.: 2023, IRS 2022 proceedings, in print.

Gröbner, J.: 2008, Operation and investigation of a tilted bottom cavity for pyrgeometer characterizations, Applied Optics, 47, 4441-4447.

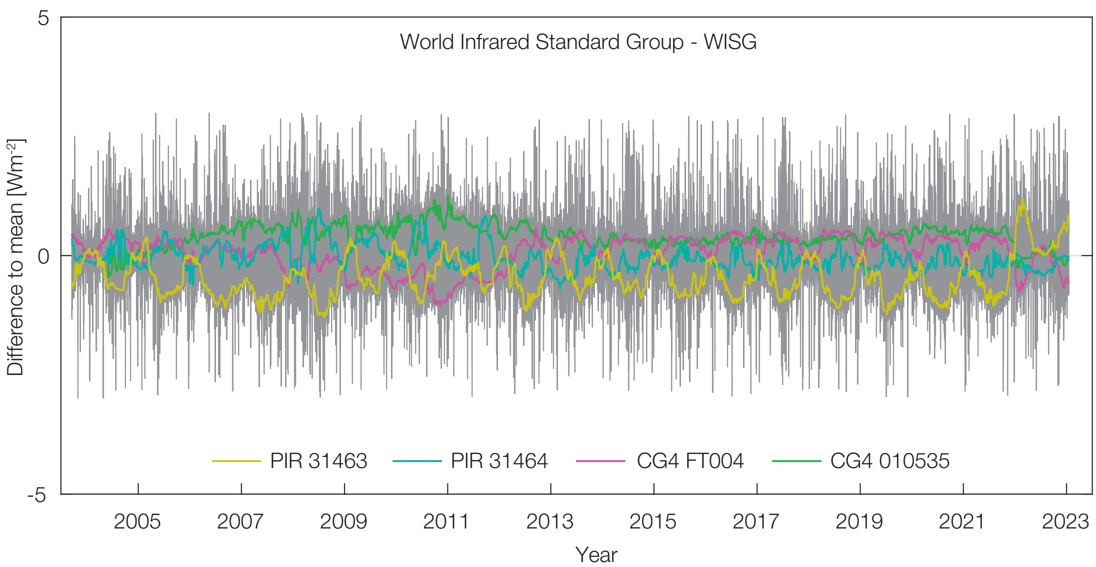


Figure 1. Night-time atmospheric longwave measurements of the WISG pyrgeometers relative to their average. The coloured lines represent a 30-day running mean of each WISG pyrgeometer while the grey-shaded area represents daily averages.

Atmospheric Turbidity Section (WRC-WORCC)

Stelios Kazadzis, Natalia Kouremeti and Julian Gröbner

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

The World Optical Depth Research and Calibration Center (WORCC) calibration hierarchy uses the WORCC reference. This is based on the average of three well-maintained Precision Filter-Radiometers (PFRs), collectively known as the Triad, that are located in Davos (Switzerland). In addition, instruments operating at high mountain stations such as Mauna Loa (USA) and Izaña (Spain) perform Langley calibrations and are then sent (one instrument every six months) to WORCC to check the Triad stability with an independent instrument. No changes were introduced to the Triad after analysing the Langley transfer-related data.

Annual quality assured data from GAW-PFR stations were updated and submitted to the World Data Centre for Aerosols (WDCA). In 2022, seven instruments from GAW-PFR and 11 customer instruments were calibrated against the reference Triad in Davos. WORCC is participating in ACTRIS-CARS (Center for Aerosol Remote Sensing), providing a permanent traceability link between the ACTRIS AOD measurements and the WMO primary AOD references. During 2022, an instrument was installed at Valladolid (Spain), and measurements of WORCC reference instruments and CARS sun-photometers at OHP (France) as well as Izaña and Valladolid (Spain) were performed.

Within the QA4EO/ESA project, WORCC scientists have been collaborating with Serco (CNR, Italy, and the National Observatory of Athens (Greece). The main results deal with the investigation of a correction algorithm that accounts for the real-time concentration of NO_2 when calculating AOD. WORCC is involved in the activities of the Metrology of Aerosol Optical Properties (MAPP) project. The main goal was to enable the traceability of AOD to the International System of Units (SI) using SI-traceable direct solar spectral irradiance measurements. This major step towards moving from the "traditional" Langley calibration method to SI-based traceability was conducted using a PFR instrument at the PTB calibration facilities. Major results were published by Kouremeti et al. (2022) and are shown in Figure 1.

Within the MAPP project, the Lunar-PFR was characterised at the German National Metrology Institute (PTB) and is able to provide lunar irradiance measurements with an uncertainty of 0.5%. The instrument participated in the MAPP-Izaña campaign, collecting a benchmark dataset over one lunar cycle to be used for a performance comparison of top-of-atmosphere lunar irradiance models e.g. ROLO, RIMO, LIME. The activity is supported by the QA4EO ESA project. In addition, in the framework of the Joint Aeolus Tropical Atlantic Campaign (JATAC), the ASKOS experiment (supporting the Aeolus mission), was implemented in the Cape Verde islands during the summer of 2022. Aerosol and solar radiation measurements were supported by PMOD/WRC.

WORCC received funding from the MeteoSwiss GCOS office to develop a website and webtool for GAW-PFR station data. This project (GAWaodIDC) reported information on the processing chain and metadata for all GAW-PFR AOD measuring stations. This was achieved and is demonstrated through the development of a website (https://gawpfr.pmodwrc.ch/) that provides new and complete AOD information in one place (one-stop-shop), together with the full processing chain and meta-data, in accordance with the GCOS Switzerland strategic priorities. The website and database will be ready in spring 2023.

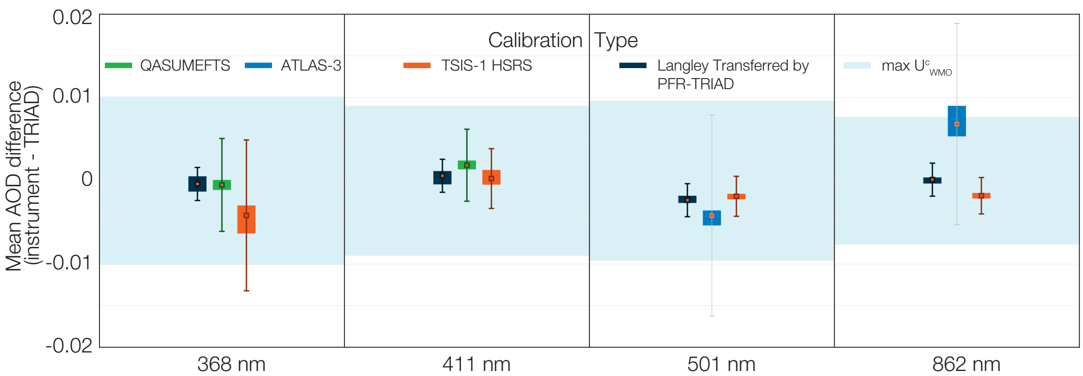


Figure 1. Panels for the four PFR channels showing the median AOD differences of the three methods: Langley transferred by the PFR-TRIAD, PTB calibration in combination with the top-of-atmosphere (ToA) high resolution spectra from QASUMEFTS, ATLAS-3 and TSIS-1 HSRS, to the PFR-TRIAD (red dots). The coloured squares represent the 5^{th} and 95^{th} percentiles of the differences, while error bars show the expanded uncertainty U (k = 2) in AOD from each method accounting for the uncertainty of the ToA spectrum and PFR calibration. The light blue area represents the adjusted WMO criterium during this campaign.

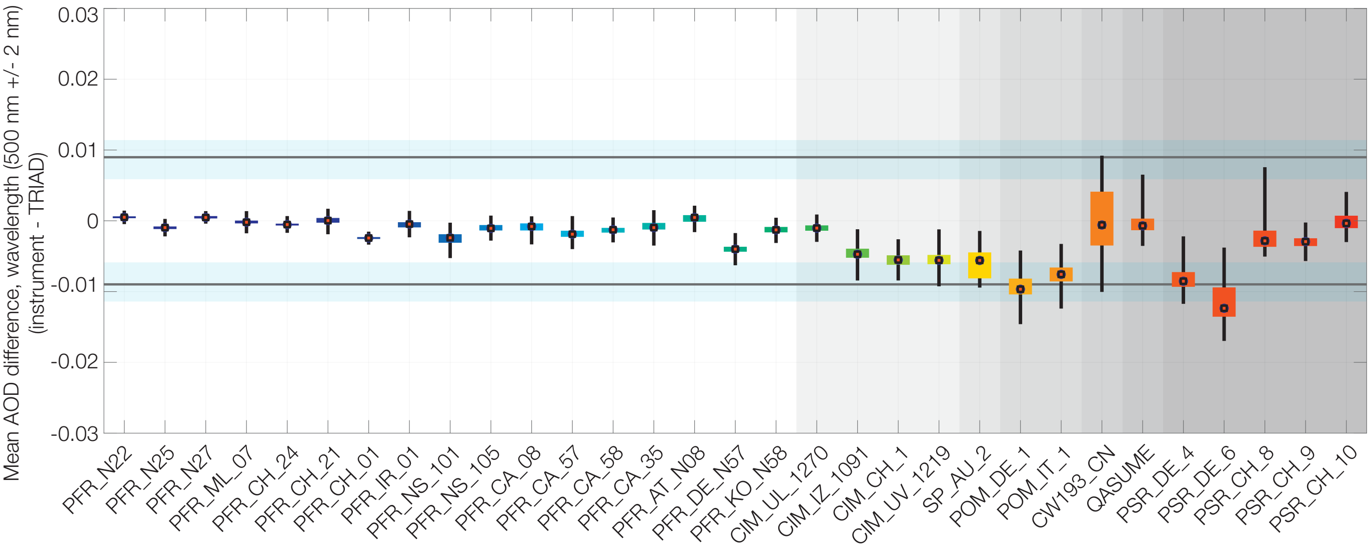


Figure 2. Comparison of AOD results at 500 nm. The open circles represent the median of the difference of each instrument from the mean of the triad at each wavelength over the 11 FRC-V selected days. The coloured boxes represent the 10th and 90th percentiles while the black lines represent the minimum and maximum values of the distribution excluding the outliers. Black horizontal lines represent the average WMO limits and cyan represents the range of these limits, based on the air mass change during each day.

A new station for GAW-PFR at Ushuaia (Argentina) was established. Results from the 5th Filter Radiometer Comparison FRC-V, held at PMOD/WRC, were sent to the WMO to be published as a WMO report. Researchers from different AOD global networks were invited to participate, resulting in 32 instruments that took part. An example of the results is shown in Figure 2. WORCC participated in a publication related to a multi-sectoral impact assessment of an extreme African dust episode in the Eastern Mediterranean in March 2018. The main impacts analysed were linked to hospitalisation, solar energy and aviation-related socio-economic impacts (Monteiro et al., 2022).

An analysis of 12 years of parallel AOD measurements with CIMEL and PFR at PMOD/WRC was published (Karanikolas et al., 2022). In addition, a 15-year analysis of the direct effects of total and dust aerosols in solar radiation/energy over the Mediterranean Basin showed that annual GHI and DNI mean values were attenuated by 1% - 13% and 5% - 47% by aerosols, respectively. Over North Africa and the Middle East, attenuation by dust was found to contribute 45% - 90% to the overall attenuation (Papachristopoulou et al., 2022). Finally, the effect of the aerosol vertical distribution on the modelling of solar radiation was studied. Analysis of the results showed that under cloudless skies, changing the altitude of an artificial aerosol layer has a minor impact on the levels of shortwave radiation at the top and bottom of the atmosphere, even for high aerosol loads. Differences of up to 30% were, however, detected for individual spectral bands (Fountoulakis et al., 2022).

Long-term observations of AOD and their relation to in-situ aerosol properties in the Svalbard region, including PFR measurements, were presented within the LOAD-RIS project (https://zenodo.org/record/7376140). The monitoring of night-time AOD at Ny-Ålesund during the polar winter continues and is supported by SIOS and NILU. WORCC results and an overview were presented in various workshops and meetings. Such meetings included the Scientific Advisory Group for Aerosols and the Expert team of Atmospheric Composition Measurement Quality and GAW/GCOS-CH and GAW-DACH meetings. In addition, ACTRIS-CARS members met at the ACTRIS week in November 2022. WORCC leader, S. Kazadzis, was successful in a COST action proposal and will chair the COST action Harmonia project entitled "International network for harmonisation of atmospheric aerosol retrievals from ground-based photometers" (https://harmonia-cost.eu/) from 2022 to 2026. PhD students, X. Hu, A. Karanikolas (ETHZ), K. Papachristopoulou and D. Kouklaki (NKUA, Greece), are being supervised and are collaborating with WORCC. In addition, Dr. A. Masoom started her work on the ACTRIS-CH project. There was one Master Thesis and three semester projects related to aerosol research as a collaboration of WORCC/PMODWRC and ETHZ.

References:

Fountoulakis, I., et al.: 2022, Effect of aerosol vertical distribution on the modeling of solar radiation, Remote Sens. 14, 1143.

Karanikolas, A., Kouremeti, N., Gröbner, J., Egli, L., Kazadzis, S.: 2022, Sensitivity of aerosol optical depth trends using long-term measurements of different sun photometers, Atmos. Meas. Tech., 15, 5667-5680, https://doi.org/10.5194/amt-15-5667-2022

Kouremeti, N., et al.: 2022, SI-traceable solar irradiance measurements for aerosol optical depth retrieval, Metrologia, 59, 4, https://doi.org/10.1088/1681-7575/ac6cbb

Monteiro, A., et al.: 2022, Multi-sectoral impact assessment of an extreme African dust episode in the Eastern Mediterranean in March 2018, Sci. Tot. Environ., 843, 156861, https://doi.org/10.1016/j.scitotenv.2022.156861

Papachristopoulou, K., et al.: 2022, Remote Sens., 14, 1535, https://doi.org/10.3390/rs14071535

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 the WMO Global Atmosphere Watch (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.

The main activity during 2022 was the organisation of the 3rd International Solar UV Radiometer calibration. A total of 74 solar UV radiometers from 29 countries participated in the campaign of which 17 were from Europe. The nine different radiometer types represented at the campaign were Kipp & Zonen UV-S (18), CUV5 (3), SUV (5), Yankee UVB-1 (7), analog and digital Solar Light V. 501 (16/10), EKO MS (5) and five other miscellaneous types. The filter weighting functions mostly approximated the erythemal action spectrum and some the UVB, UVA and UVG spectra.

The standard calibration methodology, using the instrumental spectral as well as the angular response functions measured in the laboratory, provided remarkable agreement with the reference spectroradiometer, with expanded uncertainties (k = 2) of around 4% for most instruments.

The measurements of the solar UV radiometers were analysed both with the PMOD/WRC calibration as well as the calibration used by the home institutes. The average date of calibration of the user calibrations was three years prior to this campaign (i.e. 2019). In addition, 34 out of the 74 instruments used a single calibration factor, instead of the recommended calibration matrix in dependence on the solar zenith angle and total column ozone (Webb et al., 2007). The relative differences between the measurements using the user calibration and that from PMOD/WRC varied from 0.8% up to 50% for specific instruments.

Three quality assurance site visits with the transportable reference spectroradiometer, QASUME, were conducted in 2022. In

Figure 1. The UVC-III campaign at PMOD/WRC lasted from June to August 2022. UV radiometers from the campaign are seen in the above picture on the roof platform.

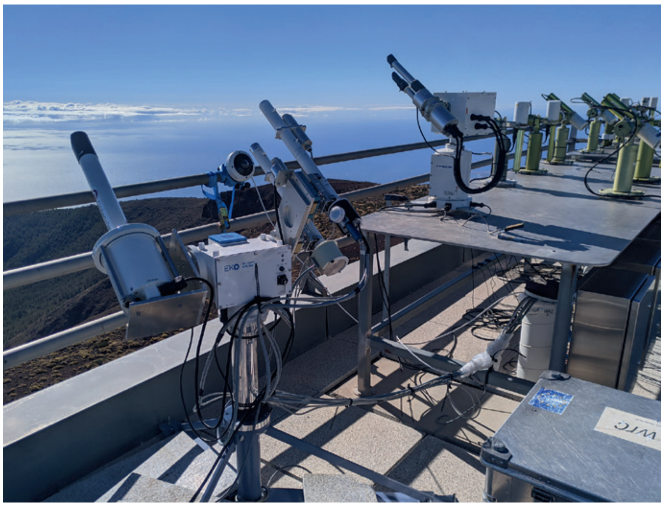


Figure 2. EMPIR MAPP campaign at Izaña (Spain) with the Qasume and QasumeIR spectroradiometers in the centre of the picture.

May, we visited the University of Reading (England). It was the 4th audit in Reading after 2003, 2012 and 2018. In June, we organised the 2nd visit to the Laboratoire d´Optique Atmospherique at the University of Lille (France). Furthermore, during the 17th RBCCE at PMOD/WRC, QASUME provided the global solar UV irradiance reference for the participating 10 Brewer spectrophotometers. In addition, direct solar UV irradiance measurements were used to derive total column ozone values which were compared to the reference data from the reference Brewer #185, operated by the Izaña Atmospheric Research Center of the Spanish Meteorological Agency (AEMET) in Spain.

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/

In April 2022, QASUME was taken to the German National Metrology Institute (PTB; Braunschweig, Germany) to validate the traceability chain of spectral solar UV irradiance to SI. This was the fourth campaign at the PTB after 2004, 2013, and 2014. QASUME was compared to the primary spectral irradiance standard, a high temperature blackbody as well as against the cryogenic irradiance reference in the TULIP laser facility at PTB. More details can be found in the Scientific Research Section (see page 42).

As part of the EMPIR 19ENV04 MAPP project, QASUME and QASUMEIR participated in a 3-week field campaign at Izaña. Both spectroradiometers recorded direct solar spectral irradiance in the wavelength range from 280 nm to 1700 nm. The data and retrieved AOD were compared against other spectroradiometers and filter radiometers participating in the campaign.

References: Webb, A., Gröbner, J., Blumthaler, M.: 2007, A practical guide to operating broadband instruments measuring erythemally weighted irradiance, EUR 22595, ISBN 92-898-0032-1

Section Ozone: Total Column Ozone and Umkehr Measurements

Julian Gröbner, Luca Egli and Franz Zeilinger

Operational total column ozone and Umkehr measurements are operationally performed at PMOD/WRC with three Dobson and four Brewer spectrophotometers. The objective of these instruments is to monitor the stratospheric ozone layer and to extend the world's longest continuous total ozone time-series from Arosa-Davos in Switzerland, which began in 1926. In addition to the Dobson and Brewer instruments, two array spectroradiometer based systems (Pandora and Koherent) and the portable world reference for ultraviolet radiation, QASUME, are operated at PMOD/WRC. The three supplementing instruments measure total column ozone with modern technology, which are compared with the performance of the traditional instruments. In total, 10 instruments are located at PMOD/WRC to monitor the total atmospheric column ozone at Davos.

The six instruments forming the Arosa-Davos time-series are operating continuously at PMOD/WRC. The long-term time-series come from three Dobson (D051, D062 and D101) and three Brewer (B040, B072 and B156) instruments from MeteoSwiss, which conduct direct sun (total column ozone, Figure 1) and Umkehr (vertical ozone profiles) measurements. Dobson D051 is mainly dedicated to Umkehr measurements. Occasionally, D051 is used for direct sun observations to compare with D101 and D062, forming a triad to monitor the stability across the three instruments. For the Umkehr cross-validation of D051, the Dobson D101 and D062 were occasionally set to Umkehr measurements as well.

The 17th Regional Brewer Calibration Campaign for Europe (RBCC-E) took place from 22 - 31 August 2022 at PMOD/WRC (Figure 2), with the support of the Izaña Atmospheric Research Center (Spain) and the Global Atmosphere Watch (GAW) programme. As in the previous calibration campaign in 2021, the

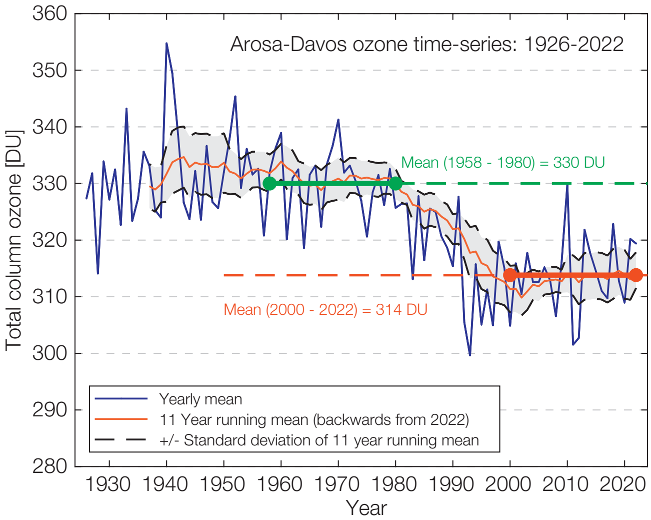


Figure 1. Total column ozone time-series from 1926 to 2022 are shown. Since 2010, the 11-year running mean appears to have stabilised to within a 2% limit (dashed line).

Figure 2. Brewer instruments during the 2022 Regional Brewer Calibration Campaign for Europe (RBCC-E) in the measurement field at PMOD/WRC with the participation of the World Brewer reference from Toronto (Canada).

RBCC-E travelling reference (B185) provided reference total column ozone measurements. Besides B185 and the four Davos Brewers, two Brewers from Ott Hydrotechnics (Delft, Netherlands), one Brewer from KNMI (Netherlands), one instrument from BOKU-Met (Austria) and the World Brewer reference B145 from Environment Canada (Canada) participated in the campaign. The World Brewer reference, B145, participated in a RBCC-E for the first time. This will allow a direct comparison of the European Brewer reference with the World reference.

The Arosa-Davos instruments performed well during the campaign and did not require any maintenance. The comparison with the European Brewer reference, B185, revealed that all instruments were within ±1% for total column ozone measurements.

The World portable reference for UV radiation, QASUME, was introduced as a new instrument for traceable total column ozone retrievals from direct solar spectral irradiance measurements (Egli et al., 2022). QASUME is used to monitor the operational Dobsons and Brewers as an independent instrument. The development ensures that the PMOD/WRC Ozone Section also measures total column ozone with state-of-the-art instruments and contributes to international efforts for improving total column ozone measurements.

In 2022, Herbert Schill retired after more than 40 years of quality assurance of the Dobson and Brewer Arosa-Davos ozone measurements. We thank Herbert for his diligent long-term engagement in the field of ozone monitoring and research in Switzerland.

References: Egli, L., Gröbner, J., Hülsen, G., Schill, H., Stübi, R.: 2022, Traceable total ozone column retrievals from direct solar spectral irradiance measurements in the ultraviolet, Atmos. Meas. Tech., 15, 1917-1930, https://doi.org/10.5194/amt-15-1917-2022

Instrument Development

Space Missions in the Build Phase

Andrea Alberti, Krzysztof Barczynski, Valeria Büchel, Wolfgang Finsterle, Matthias Gander, Louise Harra, Silvio Koller, Patrik Langer, Leandro Meier, Daniel Pffifner, Pascal Schlatter, Werner Schmutz, Marcel Spescha, Daniel Tye, Liviu Zambila

PMOD/WRC is involved in three space missions at different stages of development. The Digital Absolute Radiometer (DARA) is onboard the ESA PROBA-3 mission (to be launched in 2024). DARA is a follow-on to JTSIM-DARA onboard the Chinese FY-3E mission, which was launched in July 2021. Both radiometers are designed to measure the total solar irradiance (TSI). Development is underway for the ESA Traceable Radiometry Underpinning Terrestrial and Helio-Studies (TRUTHS) mission, due to be launched in the 2030s. We are also developing a solar spectral irradiance monitor for the JAXA Solar-C mission, due to be launched in 2028.

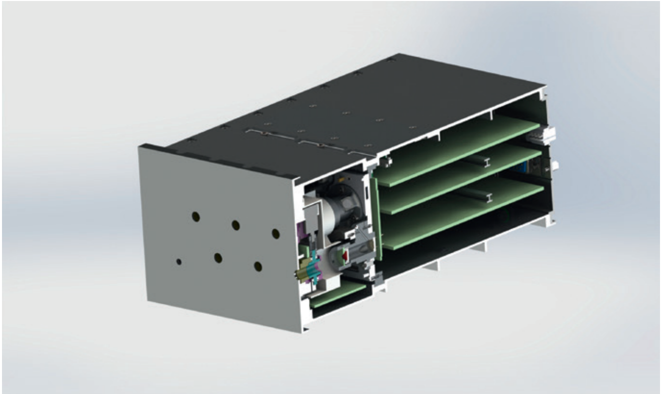


Figure 2. Cross-section view of SoSpIM.

DARA onboard PROBA-3

The DARA Flight Model was delivered to QinetiQ Space NV (Antwerp, Belgium) in late 2021. Integration into the spacecraft was scheduled for 2022 but was delayed until early 2023. Nevertheless, the end of the integration and test phase is approaching. PROBA-3 is currently scheduled for launch in the first quarter of 2024 from a site in India. An identical instrument to the Flight Model, the so-called Flight Spare, is shown in Figure 1.

In 2022, only a few additional technical tasks were conducted on DARA. Some changes had to be made to the multilayer insulation (MLI) for the flight model. The MLI will be supplied by an Italian supplier and assembled with the MLI of the spacecraft. In addition, PMOD/WRC must remain available during the various integration and test activities at spacecraft level. Since the communication between the instrument and the spacecraft has not yet been extensively tested, occasional details need to be verified. Regarding programming aspects, PMOD/WRC had to provide a so-called End-Item Data Package containing all relevant design and engineering documents, test and qualification reports, and integration and user manuals.

As the original PROBA-3 schedule has been delayed, DARA can now benefit from the experience gained with the JTSIM-DARA radiometer on the Chinese FY3-E mission. Raw data from JTSIM-DARA is being converted into higher-level information using new software routines, which will also be used later for DARA. We now look forward to the successful environmental test campaign of the spacecraft and launch in 2024.

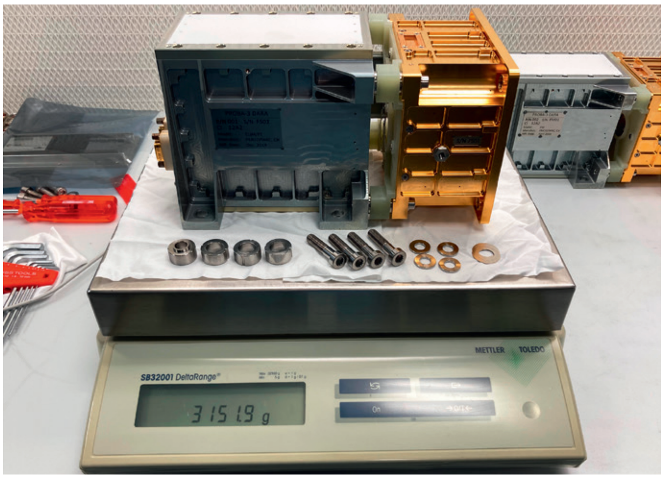


Figure 1. Physical properties (mass) verification of the DARA Flight Spare model.

SoSpIM onboard Solar-C

Solar-C is the next Japanese solar physics mission to be developed with significant contributions from US and European countries. The mission carries an EUV imaging spectrometer with a slit-jaw imaging system called EUVST (EUV High-Throughput Spectroscopic Telescope) as the mission payload. The mission will take a fundamental step towards answering how the plasma universe is created and evolves, and how the Sun influences the Earth. Solar-C is the fourth in the series of competitively chosen M-class missions by the Japan Aerospace Exploration Agency (JAXA), and will be launched with an Epsilon launch vehicle in 2028. A second instrument, led by PMOD/WRC, provides a spectral irradiance capability through the Solar Spectral Irradiance Monitor (SoSpIM), shown in Figure 2. This provides both scientific and calibration capabilities. SoSpIM and EUVST will work hand-in-hand. EUVST will provide consistent spectral observations from the chromosphere to the corona, tracking the energy flow on small spatial scales. SoSpIM will provide “Sun-as-a-star” measurements in two wavelength bands that overlap EUVST. This provides measurements of all solar flares visible from Earth, not just those within the EUVST field-of-view. The SoSpIM instrument provides the connectivity between the flare processes captured in detail on the Sun by EUVST and the impact of those irradiance changes in different layers of the Earth’s atmosphere. Solar-C passed its System Requirement Review at JAXA in December 2022.

SoSpIM is being developed in a consortium with the Royal Observatory of Belgium (ROB), Swiss industry (Art of Technology and dlab) and PMOD/WRC. The preliminary design of the instrument is well advanced. The engineering model is in the manufacturing and assembly phase. The next major step is achieving the instrument Preliminary Design Review.

CSAR onboard TRUTHS

Overview

The Traceable Radiometry Underpinning Terrestrial and Helio-Studies (TRUTHS) is a climate-focused ESA Earth Observation mission on behalf of the UK Space Agency (UKSA) in partnership with several European states. Delivered by the European Space Agency (ESA), it will facilitate an improved understanding of changes in the Earth's climate and the response to the world's "net zero" agenda. This will be achieved through both its own observations, and its capability to improve the Earth observation (EO) system as a whole, through the in-flight cross-calibration of other satellites. TRUTHS will help to improve the confidence in EO data gathered from space and the forecasts driven by this data. PMOD/WRC is supporting the instrument development for the Cryogenic Solar Absolute Radiometer (CSAR) that will serve as TRUTHS' primary radiometric reference.

Progress

PMOD/WRC was asked to support the development of the CSAR instrument for TRUTHS based on its experience with the ground-based CSAR and space radiometry. In 2022, a pre-development study was conducted to identify critical instrument components, and to align the operational concepts with the mission requirements. It was decided to develop an active cavity controller and to proof-test it on the ground-based CSAR. Additional tasks included developing a numerical model of the diffraction effect on the CSAR aperture system. The ground-based CSAR will also benefit from these developments as we carefully co-align the TRUTHS/CSAR and CSAR-ground developments to maximise the synergies.

PMOD/WRC is also developing new space qualified cavities for CSAR, featuring C-nanotube black coatings. The cavities will be manufactured and optically characterised at PMOD/WRC. Longwave (infrared) characterisation will most probably be performed at the Federal Institute of Metrology (METAS, Switzerland) and/or the National Metrology Institute (PTB, Germany).

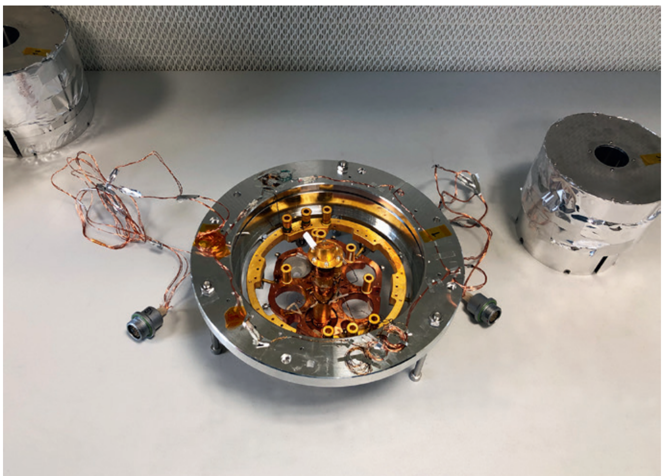


Figure 3. The Cryogenic Solar Absolute Radiometer was disassembled in the PMOD/WRC clean room to install new thermistors required for active cavity control. Seen here are the cryogenic reference block and two radiation shields which isolate the cold stage from ambient heat.

Figure 4. Voltage references mounted on a test jig used in a proton irradiation test.

In addition, a voltage reference pre-study was performed by PMOD/WRC. It is essential to precisely reproduce the SI unit for voltage, the volt, over short as well as long time periods during the mission duration. Providing electrical traceability is a crucial aspect and an important uncertainty component in an absolute solar radiometer, such as CSAR. A number of high-precision voltage references (one-chip electronics components) were tested in a representative printed circuit board design (Figure 4), which means that the following aspects need to be considered: no mechanical stress due to thermal variations, appropriate shielding, noise filters, etc. These samples underwent thermal cycling, vibration and ionising radiation tests. A batch of the selected components is now in operation in a dedicated setup to assess their long-term behaviour.

The TRUTHS mission requires quasi-continuous scans of the solar spectrum to be performed within only a few minutes. In this so-called OBCS mode, the CSAR shutter will remain open while the external monochromator performs a wavelength scan of the incoming solar radiation, thus sending a continuously varying signal to the CSAR cavity sensor. In order to derive the spectral intensities from the CSAR measurements, the signal needs to be deconvolved numerically using the CSAR response function as the kernel. In 2023, PMOD/WRC will use the ground-based CSAR to produce an empirical dataset, which will be used to derive the deconvolution model.

Space Missions in the Operations Phase

Wolfgang Finsterle, Krzysztof Barczynski, Manfred Gyo, Margit Haberreiter, Louise Harra, Silvio Koller, Jean-Philippe Montillet, Daniel Pfiffner

PMOD/WRC is involved in the operations of instruments onboard seven 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 ESA PROBA-2 mission, launched in 2001, hosts the LYRA instrument with PMOD/WRC involvement, and measures the solar spectral irradiance. 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 ESA/NASA Solar Orbiter mission, launched in 2020, has ten instruments onboard of which two have PMOD/WRC involvement. The Chinese JTSIM mission was launched in July 2021 and our Digital Absolute Radiometer (DARA) instrument is onboard.

PMOD/WRC have operational, calibration and scientific responsibilities for all the instruments we have developed. These include irradiance measurements (VIRGO, LYRA and CLARA), and more recently imaging and spectroscopic measurements (Solar Orbiter). We have been funded through Karbacher Funds to support these efforts since the end of 2019 to the end of 2022. As of 2023, funding comes from the ESA Prodex programme.

VIRGO onboard SOHO

The VIRGO experiment onboard the SOHO spacecraft has been providing total and spectral solar irradiance (TSI, SSI) measurements almost continuously since February 1996. Over the years, the active sensor has degraded in terms of accuracy due to long exposure to UV/EUV light. The back-up sensor that operates at a much lower rate (once every 10 days) is used to monitor the alteration of the high recording rate sensor. A machine-learning based algorithm was developed in order to correct this degradation in the recorded measurements. Since then, the PMOD/WRC team have been providing an update of the new PMO6v-v8 product on a regular basis of about every 4 months (Finsterle et al., 2021).

The data pipeline for the VIRGO data on the SOHO archive is currently being updated at:

https://soho.nascom.nasa.gov/data/archive/

Information about the mission and new products are also available on our website:

https://www.pmodwrc.ch/en/research/development/space/soho/#SOHO-VIRGO

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

CLARA onboard NorSat-1

Overview

The Compact Lightweight Absolute RAdiometer (CLARA) experiment (Finsterle et al., 2014; Walter et al., 2017) onboard the Norwegian micro satellite NorSat-1 was launched on 14 July 2017 and first light measurements were taken on 21 August 2017. CLARA's primary science goal is to measure total solar irradiance (TSI) in space and contribute to the long-term TSI record. CLARA is traceable to the National Institute of Standards and Technology (NIST) radiometric scale. Since November 2019, CLARA also measures the outgoing longwave radiation (OLR) during the part of the orbit when CLARA is on the night-side of Earth.

CLARA Operation

In 2021, CLARA was operational until August 2021, when a second reaction-wheel stopped working, this time due to a problem of the wheel software. After software development by the University of Toronto Institute for Aerospace Studies (UTIAS; Canada), the upgraded firmware was uploaded to the spacecraft and the solar pointing of the NorSat-1 platform continued in June 2022. However, some issues with solar pointing occurred again on 7 November 2022, which were resolved in April 2023.

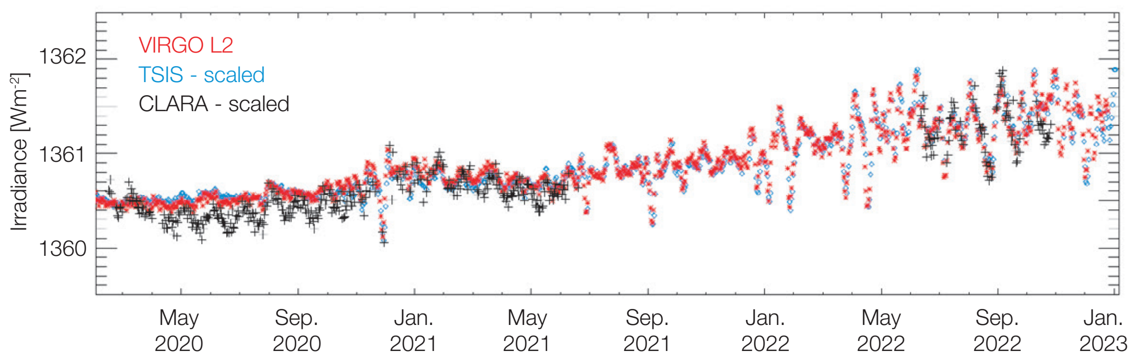


Figure 1. CLARA TSI time-series (black) compared to the VIRGO L2 (v8) TSI measurements (red). All datasets are shown with a daily resolution.

After investigation, solar measurements restarted in January for a short time until February, after which solar pointing was no longer possible. After detailed investigations with intermittent solar measurements in January 2023, we are happy to report that regular TSI measurements have again been possible since 2 April 2023.

Data Pipeline
The CLARA processing pipeline has been updated. The updates include a verified pointing filter and an improved electrical calibration. In addition, the temperature-dependent radiative loss to deep space, the angle-dependent radiative loss of the cavity and the radiative contribution of the precision aperture can now be corrected.

The CLARA Level 0 to Level 1 pipeline runs automatically every hour. The TSI and OLR Level 1 to Level 2a data processing is performed on a regular (about weekly) basis to provide CLARA data in physical units. This pipeline is not yet fully automated. The Level 2a to Level 2b transformation, i.e., taking account of the instrument degradation, is currently being implemented.

Improved Electronic Temperature Correction
A spurious increase of TSI, which started to occur in July 2022, was investigated and the temperature correction based on the electrical calibration was improved. Specifically, the temperature dependence of the heater and shunt voltages has been updated by using a multi-regression analysis based on the temperature sensors of the reference voltmeter and the analogue to digital converter (ADC), respectively. With this methodology, the spurious increase of TSI was corrected.

Figure 1 shows the latest version of the TSI measurements, which are based on the improved reference and ADC temperature corrections. As of June 2022, CLARA nicely follows the increasing solar activity as measured by the VIRGO instrument onboard the SOHO mission. As a final step, the improved temperature correction also needs to be applied to the calibration at the TSI Radiometer Facility (TRF) at the Laboratory for Atmospheric and Space Physics (LASP, Boulder, USA). This is currently being implemented.

References: Finsterle, W., Koller, S., Beck, I., et al.: 2014, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 9264, Earth Observing Missions and Sensors: Development, Implementation, and Characterization III, 92641S

Walter, B., Levesque, P.-L., Kopp, G., et al.: 2017, The CLARA/NORSAT-1 solar absolute radiometer: Instrument design, characterization and calibration, Metrologia, 54, 674-682.

EUI and SPICE onboard Solar Orbiter

Solar Orbiter is an orbiting solar physics observatory, launched in February 2020. Solar Orbiter has a suite of six remote-sensing (sun and surroundings imaging, spectroscopy, magnetic field) and four in-situ instruments that measure plasma properties of the solar wind. We provide support for the operations, calibration and data analysis methodologies for two of these instruments: the Extreme Ultraviolet Imager (EUI), and Spectral Imager and Coronal Environment (SPICE). EUI and SPICE provide imaging and spectroscopy data, respectively. Solar Orbiter observations are divided into observation campaigns, which are periods when the ten Solar Orbiter instruments focus on the same scientific goal.

We provide assessment of the data return for EUI and SPICE. For EUI, we check that the campaign was carried out correctly. A semi-automatic code was developed to compare the EUI expected observations and the EUI obtained observations lists. A visual inspection of the EUI data is performed, which provides input for improvements in the next campaigns. For SPICE observations (e.g. Figure 2), feedback is provided about: data completeness, anomalies, and interesting features (e.g., flares, upflow region) based on a visual inspection.

Solar Orbiter allows us to observe the Sun simultaneously with other Earth-orbiting telescopes and ground-based telescopes with different viewing angles. These observations provide information about the three-dimensional structures of solar features. Our input helps to develop and coordinate observations between Solar Orbiter and: i) the Interface Region Imaging Spectrograph (IRIS), and ii) Hinode/EIS. In October 2022, we co-managed the first coordinated observation between Solar Orbiter and the Daniel K. Inouye Solar Telescope (DKIST). DKIST is the largest ground-based telescope that provides solar observations as of February 2022 with an unprecedented spatial resolution. We proposed and successfully obtained observations of two projects of coordinated observations between DKIST and Solar Orbiter. In the first project, we observed the active region directly after the Solar Orbiter-Sun-Earth quadrature. The second project was dedicated to the long-term observation of an active region.

The EUI detector and filters degrade with time and can also have artifacts. The correction of artifacts is necessary for proper data calibration. For example, the Full Solar Imager (FSI) image data contains artificial vertical black bars in the off-limb area. We applied tests to identify the source of these artificial patterns. Based on the correlations, we put forward a preliminary correction method and suggested additional laboratory tests of EUI-type detectors.

The EUI team prepared instructions in the Python software language to analyse EUI data. In addition, we prepared complementary instructions in the IDL software language. The instructions provide constraints on how to analyse EUI data, which were presented during the 8th Solar Orbiter meeting in Belfast in September 2022.

An important aspect of our EUI operation activity is collaboration with the operation teams of other instruments onboard Solar Orbiter. The Spectrometer/Telescope for Imaging X-rays (STIX) onboard Solar Orbiter provides information about X-ray flux. We are in the process of developing a list of EUI observations that contain the coordinated information for both STIX and the energetic particle detector flare measurements (https://datacenter.stix.i4ds.net/).

JTSIM-DARA onboard FY-3E

The satellite was launched on 4 July 2021 from the SLS-2 launch site at the China Jiuquan Satellite Launch Centre. After a short commissioning phase (up to 17 August 2021), DARA began total solar irradiance observations (Montillet et al., 2022). Details of the mission can be found on our website at: https://www.pmodwrc.ch/en/research-development/space/fy-3e/

The data pipeline is at the moment still under construction. A dataset will also be released in the near future.

References: Montillet, J.-P., Finsterle, W., Haberreiter, M., Schmutz, W., Pfiffner, D., Koller, S., Gyo, M., Fang, W., Ye, X., Yang, D., Wu, D.: 2022, Total Solar Irradiance monitored by DARA/JTSIM: first light observations, EGU General Assembly 2022, Vienna, Austria, 23-27 May 2022, EGU22-616, https://doi.org/10.5194/egusphere-egu22-616

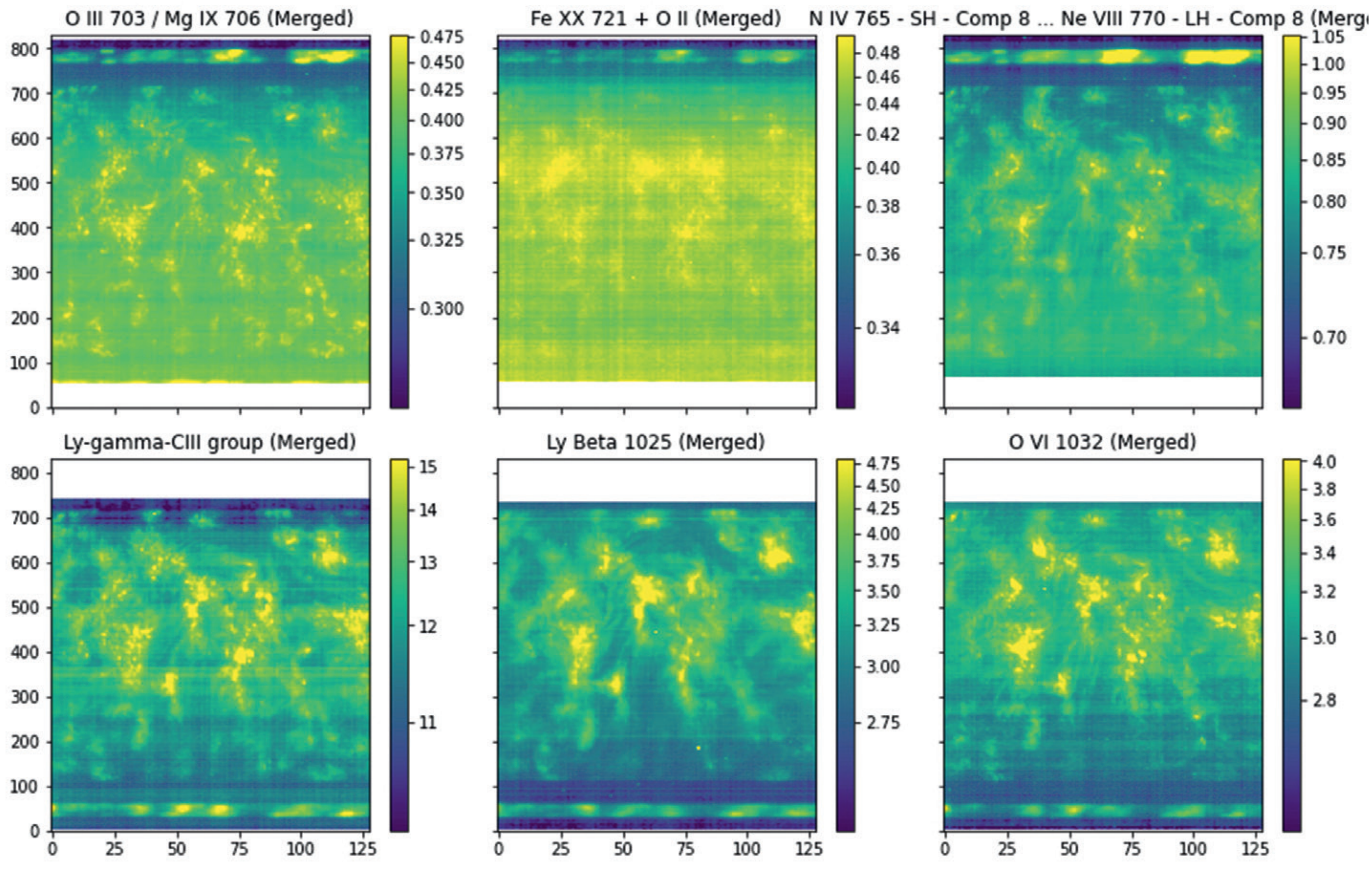


Figure 2. An example of SPICE data that are being analysed. The six panels show the maps of integrated intensity along the wavelength for six different spectral lines. These maps show the solar atmosphere from the chromosphere through the transition region up to the solar corona. We provide a visual inspection of SPICE data. The aim of visual inspection is to search for anomalies and interesting features (e.g., flares, upflow regions).

Instrument Development and Maintenance

Lloyd Beeler, Pascal Schlatter, Patrik Langer, Marcel Spescha, Jakob Föller, Nic Matthes, Christian Fringer and Linus Luzi

PMOD/WRC builds its own tailor-made, high accuracy, long-term stability instruments for specific scientific applications. In small numbers, these instruments can also be purchased. Together with PMOD/WRC's calibration capabilities, our instruments allow high quality and traceable radiation measurements. The latest development project was the re-design of the Infrared Integrated Sphere Radiometer (IRIS). Furthermore, a second batch of Precision Filter Radiometers (PFR19) and associated electronic boxes were manufactured. Among instrument maintenance and repairs, some minor retrofit kits were developed in order to extend the working-life of older instruments.

Infrared Integrated Sphere Radiometer (IRIS)

Functionality: The IRIS instrument-head consists of a pyroelectric sensor and two rotating shutters integrated into a gold-plated sand-blasted integrating sphere (Figure 1). The integrating sphere has a hemispherical acceptance angle with a cosine-weighted response to allow irradiance measurements. The sphere has two openings, one facing up, for incoming longwave radiation, and one facing down, which views a blackened reference cavity. The two shutters, one for each opening, rotate with a phase shift of 90° to each other i.e., the pyroelectric detector is alternately exposed to the incoming radiation or the reference cavity. Thus, the output signal of the sensor is a periodically varying function, which is amplified and detected by a lock-in amplifier. The temperature of the black reference cavity is constantly monitored using a precision thermistor.

History: The first IRIS instrument prototype was developed and built by PMOD/WRC in 2007, and was designed as a new reference radiometer to measure downward longwave irradiance.

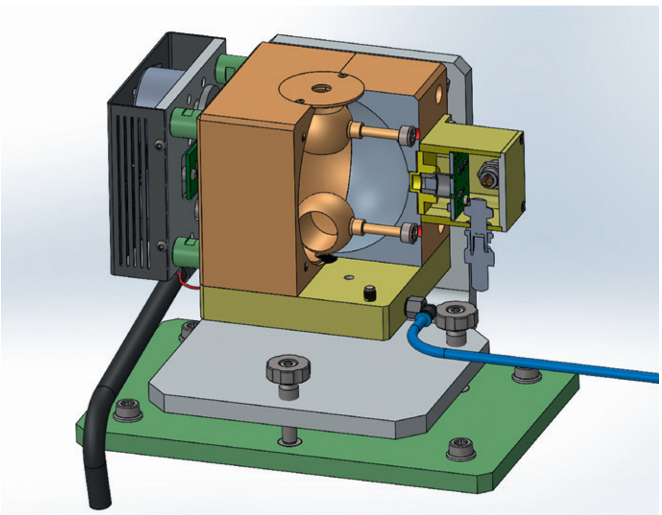


Figure 1. Cross-section view of the IRIS21 instrument-head showing the shutter blades and sensor.

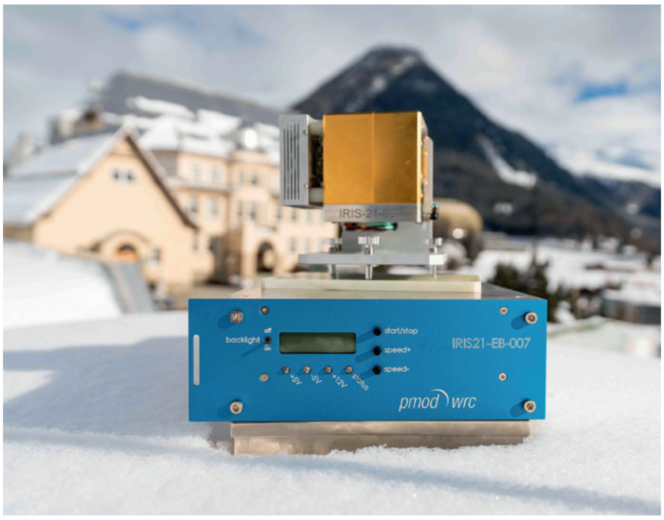


Figure 2. The IRIS21 prototype instrument.

IRIS is calibrated relative to the well-characterised PMOD/WRC blackbody cavity, thus providing traceability to SI units. A second instrument prototype followed in 2009 and a small series was finally released in 2011. All instruments have been in more or less continuous operation, and as a result have started to suffer from fatigue over the last few years. In 2021, it was decided to develop a new IRIS generation (IRIS21) to replace the existing instruments. A first prototype for testing was ready in summer 2022 (Figure 2).

IRIS21: The general instrument functionality of IRIS21 remains the same as for older versions. However, in terms of instrument operation, handiness and instrument reliability, improvements were made. The modularity of instrument device units was also a concern, but the units were designed to be individually replaced without a large overhead.

The power supply and control unit were accommodated in two different housings in older IRIS versions. Furthermore, the control unit had to be placed close to the head as the shutter motor cable had to be shorter than two meters for technical reasons. In IRIS21, the two units were combined into a single so-called electronic box and the connection cable to the head was lengthened by up to twelve meters. The D-sub connectors used previously were replaced with durable, outdoor Lemo connectors. This makes the IRIS21 handier, sturdier, and more convenient to operate.

The size of the instrument head was proportionally expanded so that the new shutter motors could be fitted on the side. The new shutter stepper-motors feature twice the torque and half the step size of the previous motors. This improves sensor signal quality and shutter reliability at temperatures as low as -20°C. The sphere's surface was changed from flame splattered aluminium to sandblasted gold plating. To be able to purge the head's sphere with nitrogen or dry air, a purge hook-up was added. The flywheel's material which connects the shutter motor to the actual shutter axle was changed from aluminium to stainless steel, which is much less thermally conductive and reduces the influence of the warm shutter motors on the measurement system. The detector housing socket on the side of the instrument-head remains compatible with older models.

Precision Filter Radiometer (PFR)

History: The very first Precision Filter Radiometer (PFR) series was developed and released in 1998. The main purpose was to provide radiometers for the Global Atmosphere Watch PFR (GAW-PFR) network. Follow-up series of radiometers were built on almost a yearly basis up until 2011. In 2019, it was decided to relaunch the instrument and a re-design was initiated. After prototyping and intense testing, the first batch of 10 radiometers was finished in 2021. These were all sold almost immediately, and it was decided to produce a second batch of 20 radiometers, which began production in winter 2021. The final instrument assembly and commissioning took place in spring 2022 followed by calibration.

PFR Electronic Box: The PFR head itself is not an autonomous instrument and requires a dedicated control unit, which supplies power and performs the data acquisition. For this purpose, PMOD/WRC provides the so-called PFR Electronics Box which was also developed along with the PFR19 instrument. As these boxes were soon sold out, another fourteen were manufactured in 2022. New firmware was written for the PFR Electronics Box that was optimised for repair work as well as for testing in a climate chamber.

Figure 3. The second batch of PFR19 radiometers, ready for delivery.

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.

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 utilised 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 2022, there were a range of funding sources which included projects supported by the Swiss National Science Foundation, Karbacher Funds, European COST action, SBFI, Meteoswiss, European H2020, ESA, EURAMET. These funding sources supported eight PhD thesis projects (four of these at ETH and four students based at other universities and jointly supervised) and three 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. The institute's PRODEX projects paid for the equivalent of around two technical department positions. An additional (nearly) two positions are funded from a contract with Airbus UK for the ESA TRUTHS project.

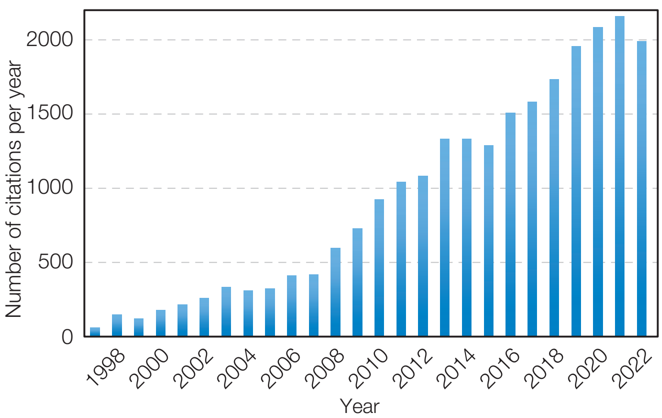
In the area of climate modelling, our research is concerned with both long and short-term changes in the Earth's atmosphere. The ozone layer evolution is being modelled and predicted. The impact of solar protons on the ionosphere has been assessed and particularly strong historical events are analysed. In addition, work is proceeding on understanding the outgoing radiation at the top of the Earth's atmosphere with the CLARA instrument aboard the NORSAT-1 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 cruise phase and first science perihelion in March 2022. These topics cover the creation of the slow and fast solar wind, 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, as well as 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 third international solar ultraviolet campaign took place between July and August 2022 with the QASUME reference spectroradiometer acting as a reference. The spectral irradiance reference was validated prior to that campaign by direct comparison to the primary spectral irradiance standard of the German metrology institute. During two weeks in August, several European institutes gathered in Davos to calibrate Brewer spectrophotometers to measure total column ozone, relative to the World standard reference Brewer, brought to Davos by the Spanish Meteorological Agency (AEMET). In addition, a large-scale field campaign was held in September 2022 at the high altitude laboratory at Izana (Tenerife, Canary Islands) in the framework of the Metrology for Aerosol Optical Properties (MAPP) project.

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. There are now 700 refereed publications.



Number of annual citations to articles including an author with a PMOD/WRC affiliation. In January 2022, there were a cumulative total of 23,082 citations to 700 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*).

A New View of Solar Flares from the Solar Orbiter Mission

Louise Harra, Andrea Battaglia, Muriel Stiefel, Krzysztof Barczynski, Conrad Schwanitz and Hannah Collier

Solar flares are the most energetic releases of energy in our solar system. The launch of the Solar Orbiter mission has provided us with not only a new view from the different orbital positions, but also higher resolution images and spectroscopy. During the cruise phase of Solar Orbiter, many flares were observed. We focussed firstly on a large flare that unusually has four hard X-ray sources. This is the first discovery of flare accelerated particles in a filament eruption. We then focused on smaller flares in which we showed how hot they can become and how reconnection of magnetic field lines can occur in the corona causing acceleration of highly energetic particles. These studies were carried out in collaboration with ETH MSc students.

The standard solar flare model is successful at explaining a number of key observations of flares. Solar flares show a rapid brightening across most of the electromagnetic spectrum in just minutes. The model predicts that magnetic reconnection occurs high in the corona which is triggered by the eruption of a magnetic flux rope. Some of the energy released during the reconnection process accelerates particles which flow along the magnetic field lines to the denser regions of the solar atmosphere. In these regions Bremsstrahlung takes place and hard X-rays emission is frequently seen at the ends of the magnetic loops. One of the challenging parts of the model is the observation of the magnetic flux rope which is a key part of the trigger process.

Work led by an MSc student, Muriel Stiefel, analysed a large solar flare, which was observed by four different spacecraft with multi-wavelength spectroscopic measurements. Key new observations were made by the Solar Orbiter mission in its cruise phase by the Spectrometer/Telescope for Imaging X-rays (STIX). Several instruments jointly monitored a large solar flare. For the first time, hard X-ray measurements have been made not only of the flare footpoints but also of the magnetic flux rope (see Figure 1).

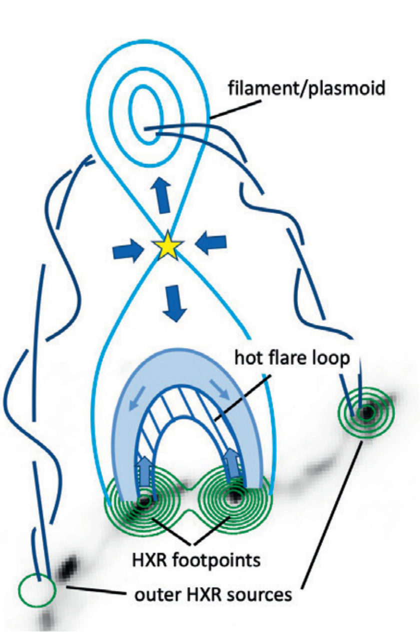


Figure 1. Cartoon of the analysed flare during its impulsive phase. The standard flare footpoints are seen at the bottom of the blue magnetic loops. In addition, there are two extra sources which are related to the footpoints of the elusive erupting magnetic flux rope. After Stiefel et al. (2022).

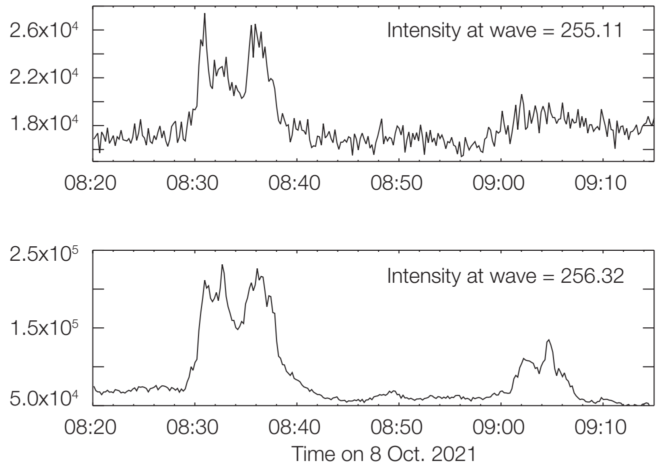


Figure 2. The top panel shows the extracted hot Fe XXIV emission from a series of small flares. The bottom panel shows the cooler He II emission. Fe XXIV emission is evident in all the flares and has a temperature of 15 MK. After Harra et al. (2022).

Another key parameter in understanding solar flares is how hot the temperature can reach. Solar flares show a relationship between the emission measure and temperature over four orders of magnitude, and stellar flares take this relationship a further four orders of magnitude. This strong correlation indicates similar energy sources from the smallest solar flare to the largest stellar flares. Although there have been temperatures measurements of small flares before, during the Solar Orbiter cruise phase we carried out a special campaign to obtain hard X-ray observations from STIX, soft X-ray and EUV spectroscopic data from the Hinode spacecraft. This special campaign had a high time cadence and used the overlap-programme mode of the spectrometer, allowing fast time cadence across the whole flaring active region. We observed small flares and found evidence of temperatures over 15 MK being reached through evidence of the Fe XXIV emission line (see Figure 2). Previous measurements of flares with temperatures of 15 MK have been found for more energetic flares. These new observations allow us to probe the smaller flares more accurately.

References:

Harra, L., Battaglia, A., Barczynski, K., Collier, H., Krucker, S., Reevs, K., Doschek, G.: 2022, How hot can small flares get?, Solar Physics, in press.

Stiefel, M., Battaglia, A., Barczynski, K., Collier, H., Massa, A., Schwanitz, C., Tynelius, S., Harra, L., Krucker, S.: 2022, Solar flare hard X-rays from the anchor points of an eruptive filament, Astron. Astrophys., in press, https://doi.org/10.48550/arXiv.2212.11327

Solar Wind Sources

Krzysztof Barczynski, Conrad Schwanitz and Louise Harra

The solar wind is a stream of charged particles generated continuously in the solar atmosphere. The solar wind affects space weather and the space environment in the Solar System. However, the origin and the properties of the solar wind source are still debated. Coronal holes, coronal hole boundaries, active region edges, and helmet streamers are the sources of the solar wind. Small-scale structures and jets are also considered as a potential source. Despite their small size, they are numerous in the solar atmosphere and hence can provide a substantial contribution to the solar wind. The high-resolution remote sensing data from the Solar Orbiter and simultaneous in-situ observation allow us to connect the solar disc features with the solar wind properties. In this report, the focus is on small-scale extreme ultraviolet brightenings, so-called campfires, which look like miniature solar flares. The distribution of solar jets in active regions is then discussed. Our focus is on small and compact upflow regions that are related to tiny X-ray jets and can be related to small-scale sudden reversal of the magnetic field in the solar wind, so-called switchbacks.

The extreme ultraviolet (EUV) brightenings, so-called campfires, are tiny (0.4 - 4 Mm) and short-lived (10 - 200 s) features that are observed in the quiet Sun at coronal temperatures (1 MK). The EUV brightenings are numerous in the solar atmosphere, and were observed with the High-Resolution Imager (HRI) telescope in the Extreme Ultraviolet Imager (EUI) instrument onboard the Solar Orbiter mission. We compared the basic geometrical (size, orientation) and physical properties (intensity, lifetime) of the EUV brightenings observed by EUI and those obtained from a non-potential coronal magnetic-field simulation (Barczynski et al., 2022). The simulation successfully reproduced the basic geometrical and physical properties with similarities >85%. Further studies based on the high-resolution magnetograms and other regions are planned.

Solar jets influence heating and can release particles into the solar wind. Active regions (ARs) are a well-known source of jets. In work led by an MSc student, Jonas Odermatt, we developed a method to identify jets and determine their position and length (Odermatt et al., 2022). We identified 239 jets in five ARs (example in Figure 1). We found that older ARs produce more jets than younger ones. The jets are not located uniformly in the ARs. Instead, they especially concentrate at the edges of the strong leading sunspots. This work is the first step to understanding the distribution of jets in ARs. The upflow region can release particles into the solar wind. Five compact sources of the strong upflow region were identified with Hinode/Extreme Ultraviolet (EUV) Imaging Spectrometer (EIS) Doppler data (Sterling et al., 2022). The solar corona observation with Hinode/X-ray Telescope (XRT) soft-X-ray (SXR) images and in Solar Dynamics Observatory (SDO)/Atmospheric Imaging Assembly (AIA) EUV images show faint and inconspicuous corresponding events. We found that these events are consistent with faint coronal X-ray jets. We suggest that jets can be more frequent in the solar atmosphere than suggested in previous studies. Thus, they can considerably contribute to solar wind and can also be related to the magnetic field reversal observed close to the Sun, so-called switchbacks.

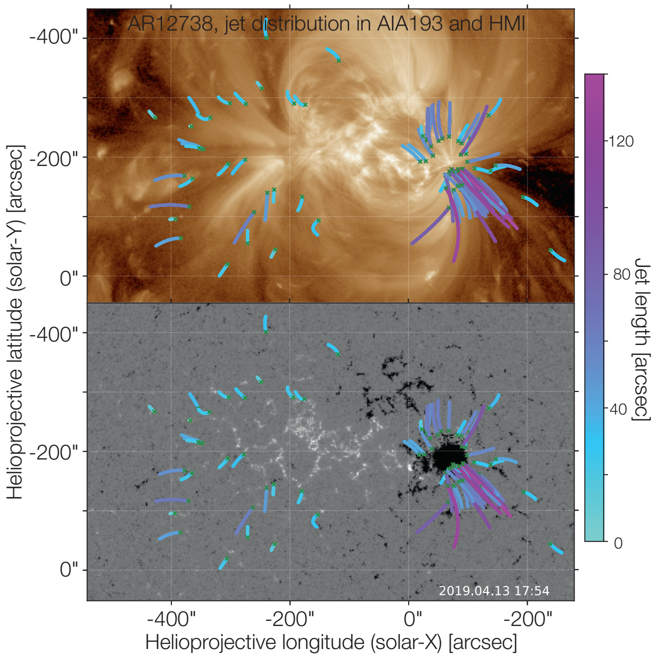


Figure 1. The jet locations marked in AR12738 observations obtained with Solar Dynamics Observatory. The top panel shows the extreme UV image of the solar corona obtained with the Atmospheric Imaging Assembly (AIA) at 193 Å. The bottom panel shows the corresponding underlying photospheric magnetic field measured with the Helioseismic and Magnetic Imager (HMI). The magnetogram range is (-300, 300) G. The colour lines code the length of the jets. The footpoint location is indicated by the green cross (Odermatt et al., 2022).

The Parker Solar Probe (PSP) space mission detected “magnetic switchbacks” below 0.2 AU. We used remote-sensing and in-situ observations to connect the switchbacks to their source region on the Sun. We focused on a small-equatorial coronal hole to which PSP was connected during the observation. Our analysis shows a strong linear correlation between the time-scale of the switchback-filled coronal wind and the time-scale of the solar corona processes. The results suggest that switchbacks are initiated in the solar corona and are then propagated into space (de Pablos et al., 2022).

References: Barczynski, K., et al.: 2022, A statistical comparison of EUV brightenings observed by SO/EUI with simulated brightenings in nonpotential simulations, Solar Physics, 297, 10, id. 141, https://doi.org/10.1007/s11207-022-02074-6

de Pablos, D., et al.: 2022, Searching for a solar source of magnetic-field switchbacks in Parker Solar Probe's first encounter, Solar Physics, 297, 7, id. 90, https://doi.org/10.1007/s11207-022-02022-4

Odermatt, J., et al.: 2022, Spatial distribution of jets in solar active regions, Astron. Astrophys., 665, id. A29., https://doi.org/10.1051/0004-6361/202243120

Sterling, A. C., et al.: 2022, Ap. J., 940, 1, id. 85, https://doi.org/10.3847/1538-4357/ac9960

Towards a Data Product of the Earth's Outgoing Radiation with CLARA Onboard NorSat-1

Margit Haberreiter, Wolfgang Finsterle and Jean-Philippe Montillet in collaboration with Statsat (Norway) and UTIAS (Canada)

Besides taking TSI measurements, the CLARA radiometer (Finsterle et al., 2014; Walter et al., 2020) onboard NorSat-1 also measures the Outgoing Longwave Radiation (OLR) on the night-side of the Earth since the end of 2019. In practice, this means that during each orbit there are alternating phases during which the TSI and OLR measurements are taken. CLARA can be considered as a technical demonstration towards determining the incoming and outgoing components of the Earth Radiation Budget.

While for the TSI measurements, the solar fine-pointing mode is required, the Earth outgoing radiation measurements are obtained without an active pointing mode. Therefore, to derive where CLARA points on the Earth, the exact knowledge of the position and attitude of NorSat-1 in space is required. In addition, the OLR measurements need to be filtered to make sure the Earth always fills the field-of-view of the instrument. To do this, we determine the angle between the nadir vector (i.e. the vector pointing to the center of Earth) and Line-of-Sight (LoS) vector, and select only those measurements where the LoS vector is less than 50° from the nadir vector. Figure 1 shows the OLR data for 11 January 2020. As can be seen, there is some substantial variation in the preliminary OLR data, and further analysis is needed to understand the source of these variations. In addition, we investigated whether the geographical location of the footprint showed any correlation with the OLR measurements. However, none were found.

From theoretical considerations, no dependency of OLR on the LoS angle is expected to the first order if the emission is perfectly Lambertian (Haberreiter and Finsterle, 2022). However, CLARA only measures the thermal emission from Earth. In reality, some deviation from an isotropic thermal emission is to be expected. Ultimately, we are interested in obtaining the outgoing radiation for different surface types on Earth, i.e., land, ocean, clouds, etc., as seen by CLARA. To achieve this, the geographical areas CLARA points to, need to be determined. As an example, Figure 2 shows the longitude and latitude of CLARA's footprint on 26 June 2022. This information will be used to determine the exact geometry of CLARA's footprint.

Acknowledgements: MH acknowledges support by the PMOD-CIOMP Collaborative Project and Karbacher Funds.

References:

Haberreiter, M., Finsterle, W.: 2022, CIOMP PMOD Collaborative Resarch Project, Final Report, V1.1.

Finsterle, W., Koller, S., Beck, I., Spescha, M., Suter, M., Walter, B., Schmutz, W., 2014: The new TSI radiometer CLARA, Proceedings of the SPIE, 9264, id. 92641S, 5, htttps://doi.org/10.1117/12.2069614

Walter, B., Andersen, B., Beattie, A., Finsterle, W., Kopp, G., Pfiffner, D., Schmutz, W.: 2020, First TSI results and status report of the CLARA/NorSat-1 solar absolute radiometer, Astronomy in Focus, in press.

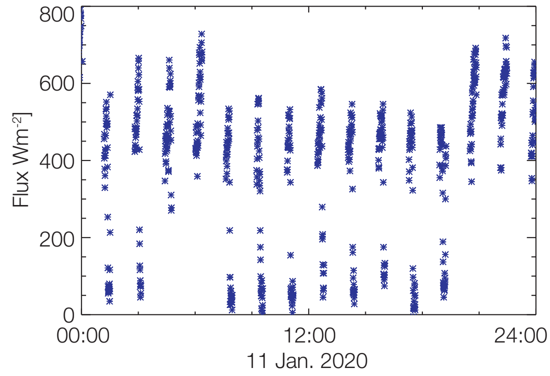


Figure 1. Earth outgoing radiation as measured with CLARA for individual orbits over the entire day on 11 January 2020.

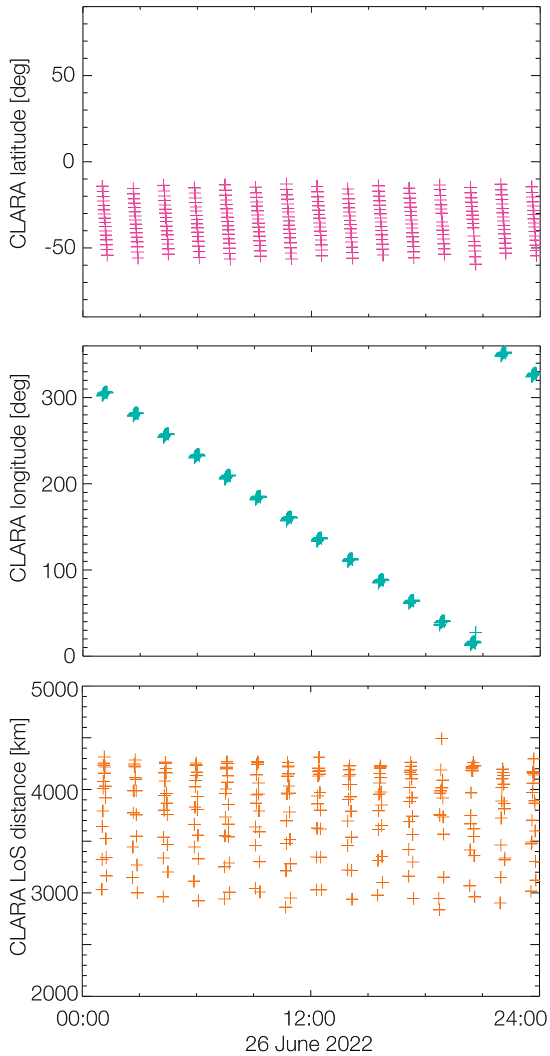


Figure 2. Longitude (top panel), latitude (middle panel) of the CLARA footprint, and the LoS distance from CLARA to the footprint (bottom panel) over the entire day on 26 June 2022.

Total Solar Irradiance (TSI) Data Analysis

Jean-Philippe Montillet, Wolfgang Finsterle, Margit Haberreiter, Daniel Pfiffner and Silvio Koller

We have continued the development of several algorithms to: i) produce a new Total Solar Irradiance (TSI) composite time-series using observations recorded by successive satellite missions launched since 1978 to the present, and ii) process new observations recorded by the DARA radiometer from the latest missions. This includes an analysis of the first light by the radiometer onboard the Chinese FY-3E satellite, iii) perform the pre-flight calibration of the DARA radiometer, which will fly on the next ESA PROBA-3 mission.

VIRGO onboard SOHO and the TSI composite time-series

The VIRGO/PMO6v-V8 product: Following the development in 2020 - 2021 of the algorithm that performs the degradation correction based on machine-learning, PMOD/WRC now releases the VIRGO/PMO6v-V8 product on our ftp server every three months (https://www.pmodwrc.ch/en/research-development/space/soho/#SOHO-VIRGO).

The new 41-year TSI Composite produced by PMOD/WRC: Since the late 1970s, successive satellite missions have been monitoring the sun's activity and recording the total solar irradiance (TSI). Some of these measurements last for more than a decade. In order to analyse the solar cycle and for climate studies it is crucial to homogenise the individual TSI records and merge them into a seamless record whose duration exceeds that of the individual instruments. Climate models can be better validated using such long TSI records, which can also help provide stronger constraints on past climate reconstructions (e.g., back to the Maunder minimum; Egorova et al., 2018, Shapiro et al., 2011). We have developed a 3-step method based on data fusion, including a stochastic noise model to take into account short and long-term correlations, which characterise the noise within the combined TSI observations (Montillet et al., 2021; 2022a). Compared with previous products (Dudok de Wit et al., 2017) scaled at the nominal TSI value of ~1361 Wm^{-2}, the difference in terms of mean value over the whole time-series is below 0.2 Wm^{-2}. Similar results are obtained when comparing the various composites in terms of solar minima. Figure 1 shows the new TSI composite time-series. The analysis also includes the time-frequency analysis of the time-series, which is useful for studying solar variability at different time-scales. The algorithm together with the full analysis of the TSI composite was recently published (Montillet et al., 2022a), and is part of a special issue in the Journal of Geophysical Research Atmospheres (Montillet et al., 2022b). The time-series is updated regularly (every quarter) on a public data repository (Montillet et al., 2023) and the PMOD/WRC ftp server via our website (https://www.pmodwrc.ch/en/research-development/solar-physics/tsi-composite/).

JTSIM-DARA / FY-3E mission

Data Analysis of the Observations: The FY-3E mission was successfully launched into space on 5 July 2021. Since the commissioning phase that lasted until mid-August 2021, PMOD/WRC has routinely analysed the observations from the DARA radiometer. The basic processing focuses on converting the raw observations recorded by the instrument (Level0) to irradiance measurements (Level2). Level 2 observations are corrected for various factors, including: shutter aperture, reflectance, diffraction, the World Radiometric Reference factor, etc (Song et al., 2021; 2022). This processing also includes checking several additional corrections such as the Earth-Sun distance of the satellite, the doppler effect (also called orbital correction), and the deep space or dark correction. Once corrected, the TSI time-series from JTSIM-DARA (Figure 2), allows us to estimate the first light value on 18 August 2021. This is 1361.13 ± 0.16 Wm^{-2} for the main cavity (Cavity B),

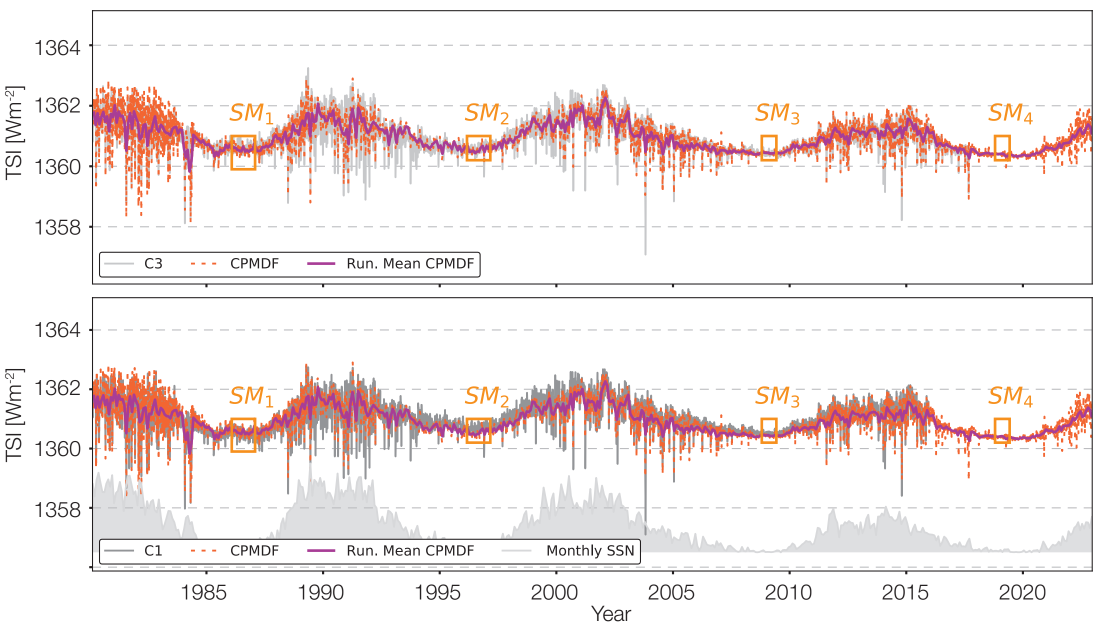


Figure 1. The new composite (CPMDF, orange) based on merging 41 years of TSI measurements. For comparison, C3 (Fröhlich, 2006) and C1 (Dudok de Wit et al., 2017) are also shown (grey line). A 30-day running mean of CPMDF is shown as a yellow/purple dashed line. The orange boxes are associated with the solar minima (SM) for each solar cycle. For context, the monthly sunspot number (SSN) is also displayed.

and 1361.5 ± 0.15 Wm^{-2} for the back-up cavity (cavity C). For the second back-up cavity (cavity A), the estimate is 1361.02+/-0.12 Wm^{-2} (Zhu et al., 2023). These preliminary values and uncertainties are still being worked on. The JTSIM-DARA data are released on-demand on the PMOD/WRC ftp server via our website (https://www.pmodwrc.ch/en/research-development/space/fy-3e) but will eventually be available on the FY-3E data portal.

PROBA3-DARA /ESA-PROBA3 mission

The Project for On-Board Autonomy-3 (PROBA-3) is the fourth satellite technology development and demonstration precursor mission within ESA's GSTP (General Support Technology Program) series. The PROBA-3 mission concept comprises two satellites in a highly-elliptical Earth orbit in precise formation, flying close to one another and with the ability to accurately control the attitude and separation of both satellites. The mission launch is scheduled for 2024. One of the satellites has a DARA radiometer to record TSI. We have finished the pre-flight calibration campaign in the facilities at PMOD/WRC and those at the Lab. for Atmospheric and Space Physics (LASP; Boulder, USA). We have calibrated all relevant parameters that are used to transform the raw measurements (i.e., voltage, current) into calibrated irradiance observations.

Acknowledgements: 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.

References:

Dudok de Wit, T., et al.: 2017, Methodology to create a new total solar irradiance record: Making a composite out of multiple data records, Geophys. Res. Lett., 44, 1196-1203, https://doi.org/10.1002/2016GL071866

Egorova, T., Rozanov, E., Arsenovic, P., Peter, T., Schmutz, W.: 2018, Contributions of natural and anthropogenic forcing agents to the early 20th century warming, Frontiers in Earth Science, 6, 206, https://doi.org/10.3389/feart.2018.00206

Fröhlich, C.: 2006, Solar irradiance variability since 1978, Space Sci. Rev., 125, 53-65, https://doi.org/10.1007/s1121400690465

Montillet, J.-P., et al.: 2021, Solar noise in 40 year long TSI composite time series, AGU Fall Meeting 2021, https://doi.org/10.1002/essoar.10509108.1

Montillet, J.-P., et al.: 2022a, Data fusion of Total Solar Irradiance composite time series using 41 years of satellite measurements, J. Geophys. Res. Atmos., https://doi.org/10.1029/2021JD036146

Montillet, J.-P., Haberreiter, M., Rozanov, E.: 2022b, Monitoring the Earth Radiation Budget and Its Implication to Climate Simulations: Recent Advances and Discussions, Special Issue, https://agupubs.onlinelibrary.wiley.com/doi/toc/10.1002/(ISSN)2169-8996.RDTNBGDT1

Montillet, J.-P., et al.: 2023, Composite PMOD data fusion, Version 1.0, Interdisciplinary Earth Data Alliance (IEDA), https://doi.org/10.26022/IEDA/112763

Shapiro, A., et al.: 2011, A new approach to the long-term reconstruction of the solar irradiance leads to large historical solar forcing, Astron. Astrophys., 529, A67, https://doi.org/10.1051/0004-6361/201016173

Song, B., Ye, X., Finsterle, W., et al.: 2021, The Fengyun-3E/Joint Total Solar Irradiance Absolute Radiometer: Instrument design, characterization, and calibration, Sol. Phys., 296, 52, https://doi:10.1007/s11207-021-01794-5

Song, B., Ye, X., Finsterle, W., et al.: 2022, correction to: The Fengyun-3E/Joint Total Solar Irradiance Absolute Radiometer: Instrument design, characterization, and calibration, Sol. Phys., 297, 77, https://doi.org/10.1007/s11207-022-02028-y

Zhu, P., et al.: 2023, The first light from the joint total solar irradiance measurement experiment onboard the FY3-E meteorological satellite, to be submitted.

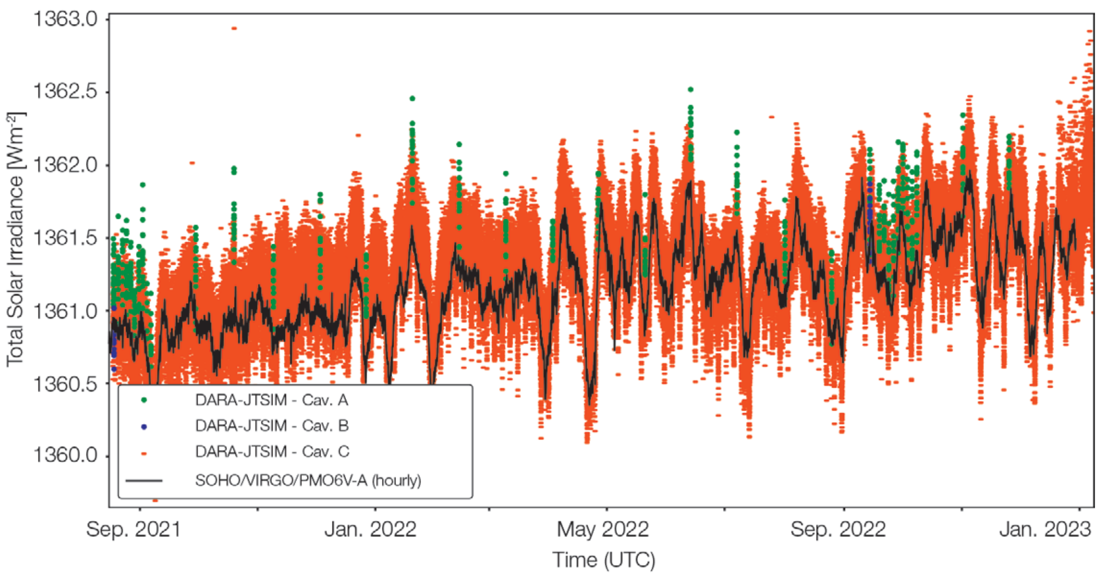


Figure 2. The minute-rate data recorded by all cavities is shown. DARA observations are compared with the hourly average of the VIRGO PMO6v-V8 product.

Simple Parameterisation of GCR/SEP-Produced ^{10}Be Transport and Deposition Using CCM SOCOL-AERv2-BE

Eugene Rozanov and Timofei Sukhodolov in collaboration with Oulu University (Finland)

The chemistry climate model (CCM), SOCOL-AER2-BE, was used to define areas responsible for the accumulation of ^{10}Be in ice cores from Antarctic and Greenland stations. We pay attention to all possible sources of cosmogenic ^{10}Be in the atmosphere for the period 1980 - 1992 covering one full solar activity magnetic cycle (~22 years). We found that for polar regions, the dominant source of ^{10}Be produced by galactic cosmic rays (GCR) is located in the stratosphere (25 - 40 km) roughly between tropical zones (0° - 30°N latitudes). While for ^{10}Be produced by solar electron precipitations (SEP), the dominant source is located in the middle stratosphere over the polar zone (60°N - 90°N). The obtained parameterisation allows an estimate of the ^{10}Be deposition in the ice archives for the events with different particle spectra without running complicated and expensive CCM.

In this study, we use the CCM SOCOL-AERv2-BE version (Golubenko et al., 2021) to model ^{10}Be produced by GCR and SEP separately, from the boundary layer up to the upper atmosphere, to obtain a realistic beryllium transport. In addition to the full modelling runs, we also perform a simplified parameterisation study based on these. The entire atmosphere was divided into 96 zones: six latitude zones (S1 = 90°S - 60°S, S2 = 60°S - 30°S, S3 = 0 - 30°S, N3 = 0 - 30°N, N2 = 30°N - 60°N, N1 = 60°N - 90°N), four longitude zones (0°E - 90°E, 90°E - 180°E, 180°E - 270 °E, 270°E - 360°E) and four altitude zones (Tr = 0 - 25 km, St1 = 25 - 40 km, St2 = 40 - 55 km, and St3 = 55 - 80 km). Beryllium produced in each zone was traced individually so that in the final deposition we can distinguish the location of its production. The results were analysed and parameterised to define the dominant contribution of the source zones to the final deposition of ^{10}Be.

The dominant source of ^{10}Be in Greenland, for the GCR scenario (Figure 1a), is the tropical lower stratosphere (~70% and 17% for the northern tropics, N3St, and southern tropics, S3St) followed by the northern tropical troposphere N3Tr (~10%). Other sources constitute only a few percent together. A similar pattern is observed for ^{10}Be in Antarctica in the GCR scenario (Figure 1b), i.e. the dominant contribution of about 70% is from the S3St

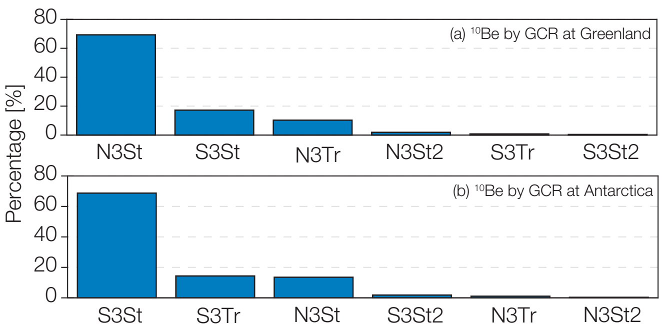


Figure 1. Percentage contribution of the main source regions (longitudinally averaged) of ^{10}Be to the near-ground concentration in polar regions for galactic cosmic rays (GCR).

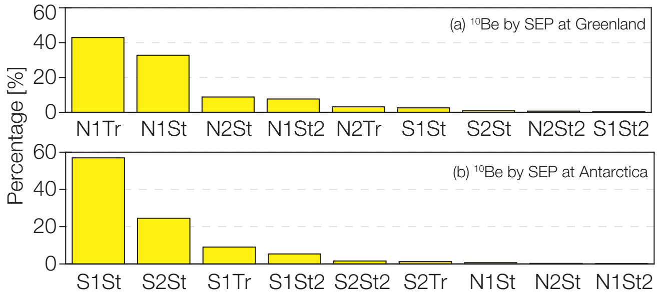


Figure 2. Percentage contribution of the main source regions (longitudinally averaged) of ^{10}Be to the near-ground concentration in polar regions for solar electron precipitations (SEP).

region (lower southern tropical stratosphere), while the southern tropical troposphere and the northern tropical stratosphere each contribute ~14%. Overall, ^{10}Be in polar near-surface air is mostly (≥99%) produced in the entire tropical-zone atmosphere. This is closer to the results of the model by Heikkila et al. (2013), but far from a simplified approach often used in cosmogenic isotope studies: globally mixed production or global stratosphere plus polar troposphere (e.g. McCracken, 2004). The situation is different for the SEP scenario (Figure 2a and b). The major fraction (about 84%) of ^{10}Be deposited on the Greenland ice cap originates from the local polar atmosphere (43%/34%/7% for the troposphere N1Tr, lower stratosphere N1St, and upper stratosphere N1St2, respectively) with ~12% originating from the northern mid-latitudes. For Antarctica, the polar atmospheric production also dominates (about 75%), with slightly different partitions (10%/58%/5% for the troposphere, lower and upper stratosphere, respectively), and about 25% from the south mid-latitudes. This is in general agreement with previous studies (Mazaud et al., 1994).

References:

Golubenko, K., Rozanov, E., Kovaltsov, G., Leppanen, A.-P., Sukhodolov, T., Usoskin, I.: 2021, Chemistry-climate model SOCOL-AERv2-be with the cosmogenic beryllium-7 isotope cycle, Geophys. Mod. Dev., 1-24, https://doi.org/10.5194/gmd-2021-56

Heikkila, U., Beer, J., Abreu, J. A., Steinhilber, F.: 2013, On the atmospheric transport and deposition of the cosmogenic radionuclides (^{10}Be): A review. Space Sci. Rev., 176, 321-332, https://doi.org/10.1007/s11214-011-9838-0

Mazaud, A., Laj, C., Bender, M.: 1994, A geomagnetic chronology for Antarctic ice accumulation, Geophys. Res. Lett., 21, 337-340, https://doi.org/10.1029/93GL02789449

McCracken, K.: 2004., Geomagnetic and atmospheric effects upon the cosmogenic ^{10}Be observed in polar ice, J. Geophys. Res. Atmos., 109, https://doi.org/10.1029/2003JA010060

Comparison of Arctic and Antarctic Stratospheric Cold Events in Chemistry Versus No-Chemistry Climate Models

Tatiana Egorova, Eugene Rozanov and Timofei Sukhodolov in collaboration with NIWA (New Zealand) and CCMI-2 teams

The results obtained with SOCOLv4 in the framework of the joint IGAC/SPARC Chemistry-Climate Model Initiative (CCMI) were used to study the importance of interactive chemistry for the Arctic and Antarctic stratospheric climate. We show that interactive ozone chemistry increases the persistence of low temperature anomalies over high latitudes and amplifies stratospheric cold biases in the models.

We use the output from nine chemistry-climate and eight associated no-chemistry models to investigate the stability and evolution of cold episodes appearing in the Arctic and Antarctic stratosphere during the 1980 - 2014 period. The SOCOLv4 (Sukhodolov et al., 2021) output was compared to that from MPI-ESM1-2-LR, which has a very similar set-up but uses prescribed ozone fields. Figure 1 illustrates the simulated monthly mean temperature bias at the 70 hPa pressure level averaged over the northern polar cap relative to observations (NCEP-DOE2 dataset). The SOCOLv4 performance, shown in the upper panel, is rather good. The simulated bias does not exceed 2 K for all months. Our no-chemistry counterpart (MPI-ESM-2-LR, lower panel) also performs well for all months except for the November - January period. Overall, our model is the best, showing the smallest bias in the Arctic lower stratosphere. In the Antarctic lower stratosphere (not shown), the situation is slightly worse because SOCOLv4 has a bias of about 5 K in springtime, which does not appear in the MPI-ESM-2-LR model. This can be explained by the known overestimation of the ozone mixing ratio in this area in SOCOLv4 results (see Sukhodolov et al., 2021). However, it should be noted that the SOCOLv4 negative bias is much lower in comparison with other participating models except for UKESM1-StratTrop and MRI-ESM2-0.

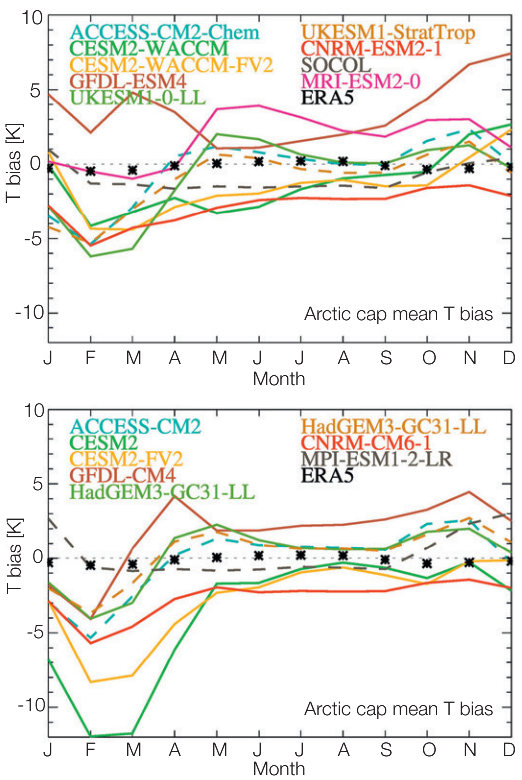


Figure 1. Monthly mean 70 hPa bias of polar-cap (poleward of 75°N) mean temperature (K) relative to NCEP-DOE2 for the period 1980 - 2014. After Morgenstern et al. (2022).

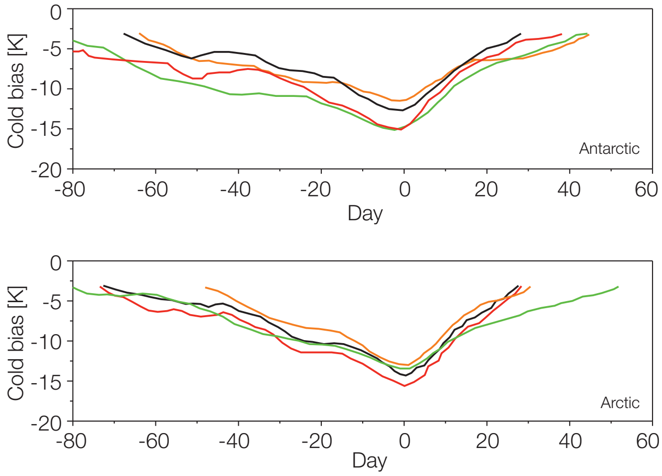


Figure 2. Evolution of cold anomalies in Antarctic (upper panel) and the Arctic (lower panel) relative to the point of coldest temperature. Black: NCEP-DOE2 re-analysis. SOCOLv4 and MRI-ESM2-0 data are shown in green and orange. The red line represents the ERA5 meteorological re-analysis. After Morgenstern et al. (2022).

Figure 2 illustrates the performance of SOCOLv4 and MPI-ESM1-2-LR in the simulation of the cold anomaly evolution in the lower stratosphere over Antarctica. Relative to NCEP-DOE2 data, the evolution of the cold anomalies in MRI-ESM2-0 is more realistic with respect to amplitude and duration. Treatment of the interactive chemistry leads to an increased duration and magnitude of the cold anomaly evolution. It can again be related to an overestimated ozone depletion in SOCOLv4. However, our results are much closer to ERA5 data, which makes any conclusions about the quality of our model to be inconclusive. Over the Arctic area, the situation is different. Cold anomalies in SOCOLv4 are close to NCEP-DOE2 data for both duration and magnitude for the time interval from 50 days before the maximum of the cold event to 10 days thereafter. After 10 days, SOCOLv4 still produces visible cold anomalies. MPI-ESM1-2-LR underestimates cold anomalies before the maximum but agrees well with NCEP-DOE2 data after the maximum is reached.

We show that interactive ozone chemistry increases the persistence of low temperature anomalies over high latitudes and amplifies stratospheric cold biases in the model. The solution to the problem is in the improvement of the accuracy of ozone field simulations.

References:

Morgenstern, O., et al.: 2022, Comparison of Arctic and Antarctic stratospheric climates in chemistry versus no-chemistry climate models, J. Geophys. Res. Atmos., 127, e2022JD037123, https://doi.org/10.1029/2022JD037123

Sukhodolov, T., et al.: 2021, Atmosphere–ocean–aerosol–chemistry–climate model SOCOLv4.0: description and evaluation, Geosci. Model Dev., 14, 5525-5560, https://doi.org/10.5194/gmd-14-5525-2021

Climate Implications of the Sun Transition to High Activity Mode (CISA)

Tatiana Egorova and Eugene Rozanov in collaboration with MPI-S (Germany)

It was suggested that the Sun could go through the epoch of high magnetic activity which would lead to unexpected behaviour of the solar irradiance (Shapiro et al., 2020). A noticeable 0.9% drop in the total solar irradiance (TSI) will be accompanied by a large increase in UV irradiance. In the CISA project, we analyse the possible consequences of the Sun's transition to the high magnetic activity mode for the terrestrial atmosphere.

We used the SOCOL model (Muthers et al., 2014; Sukhodolov et al., 2021) with an interactive ocean module (MPIOM). This allows the evaluation of possible implications of a change in activity of the Sun to be determined for the terrestrial climate and ozone layer. We performed four 90-year-long experiments driven by different prescriptions of solar spectral irradiance (SSI). A reference case, using SSI from the present-day solar maximum state, approximately the year 2000, was also used. Three experiments were then run: i) with monthly mean SSI calculated for the high activity mode (basic experiment), ii) with the changed SSI for chemical-only calculations (chemistry run), and iii) SSI for radiative balance (energy run) calculations. These experiments allowed the influence of different physical/chemical processes in the atmosphere to be distinguished.

The response of the near-surface temperature is demonstrated in Figure 1 for the "basic" and "chemistry" experiments. A weaker energy input caused by suppressed deep penetrating (wavelength exceeding 400 nm) radiation leads to global cooling, exceeding 0.5 K over land masses except over Northern Europe, Russia, and Alaska. Ocean surface cooling is present everywhere, but most pronounced over the tropical eastern Pacific. Over the northern high latitudes, the response is slightly positive but only marginally significant. Figure 1 (lower panel) shows that for the "chemistry" experiment, stratospheric ozone and temperature changes lead to a pronounced high latitude warming.

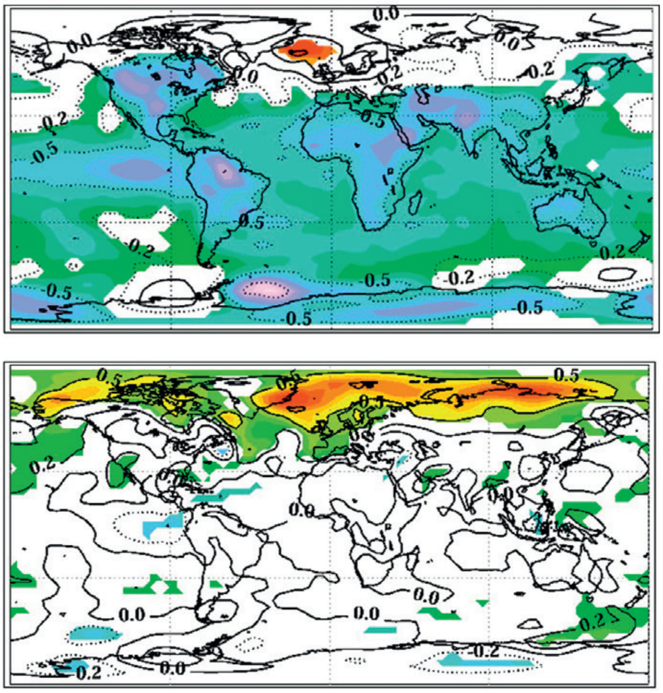


Figure 1. The change in annual mean near-surface temperature obtained with "basic" (upper panel) and "chemistry" (lower panel) relative to the "reference" simulation. The coloured areas show the response with a statistical significance of more than 95%.

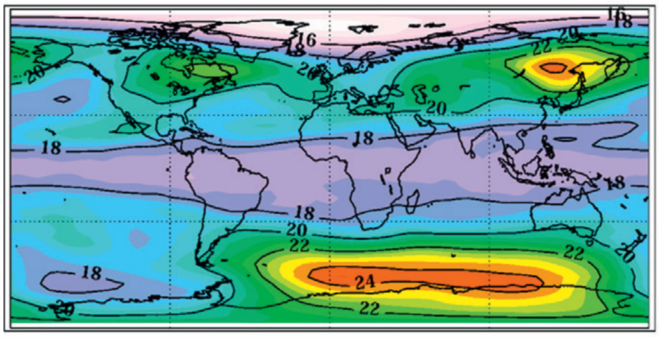


Figure 2. Changes (Dobson Units) of the annual mean total column ozone caused by the transition of the Sun to the high activity mode. The coloured pattern shows the statistically significant response at the 95% level.

The response of the total column ozone (TCO) is presented in Figure 2. The TCO response is positive everywhere and almost totally controlled by chemical forcing. The magnitude varies from 16 Dobson units (DU) over the northern to more than 24 DU over the southern high latitudes. There are also several areas over the northern middle latitudes where the TCO increase exceeds 20 DU. The relative TCO increase is within 5 - 10% which should decrease the surface UV radiation dose. More details of the study are available in Egorova et al. (2023).

Acknowledgement: The CISA project was funded by the Swiss Karbacher Fund, Canton Grison, Switzerland.

References:

Egorova, T., Shapiro, A.V., Shapiro, A.I., Arsenovic, P., Rozanov, E.: 2023, Climate implications of the Sun transition to higher activity mode, J. Atm. Sol.-Terr. Phys., 244, https://doi.org/10.1016/j.jastp.2023.106020

Muthers, S., Anet, J.G., Stenke, A., et al.: 2014, The coupled atmosphere–chemistry–ocean model SOCOL-MPIOM, Geosci. Model Dev., 7, 2157-2179, https://doi.org/10.5194/gmd-7-2157-2014

Shapiro, A.I., Amazo-Gómez, E.M., Krivova, N.A., Solanki, S.K.: 2020, Inflection point in the power spectrum of stellar brightness variations, Astron. Astrophys., 633, A32, https://doi.org/10.1051/0004-6361/201936018

Sukhodolov, T., et al.: 2021, Atmosphere–ocean–aerosol–chemistry–climate model SOCOLv4.0: description and evaluation, Geosci. Model Dev., 14, 5525-5560, https://doi.org/10.5194/gmd-14-5525-2021

Climatic Change Under the Extreme Conditions of the No-Montreal-Protocol Scenario

Jan Sedlacek, Timofei Sukhodolov, Tatiana Egorova and Eugene Rozanov in collaboration with ETH Zürich (Switzerland)

In 2022, the SNSF-funded POLE project came to an end. One of the major points of the investigation was to reassess the benefits and impacts that the Montreal Protocol and its Amendments have on the climate system. Partial results have already been presented in previous years. One of the final main tasks was to investigate in more detail the impact due to changes in the chemical composition of the atmosphere and changes due to radiative effects.

The need for the implementation of the Montreal Protocol and its Amendments (MPA) is undisputed. The ban on CFCs (Chlorofluorocarbons) has different impacts on the atmosphere and ultimately on the Earth's climate and human health. The impact on the climate of the MPA is not that straightforward. On the one hand, the decline in CFCs reduces the concentration of potent greenhouse gases and thus reduces the radiative forcing caused by them (Egorova et al., 2022). On the other hand, lower CFC concentrations in the atmosphere hinder certain chemical reactions, which are responsible for the destruction of the ozone layer. These changes in the chemical composition then also affect climate mainly through the modification of temperature gradients and subsequently the wind fields in the stratosphere, with further implications for the surface circulation patterns.

As an example of the changes due to the MPA, the surface pressure anomalies of the Northern Hemisphere winter are now discussed (see Figure 1). Without the MPA, the surface pressure over the central Arctic would be reduced and a band with higher surface pressure would be present at mid-latitudes. This pattern is called a positive Arctic Oscillation pattern (AO). Such a pressure distribution leads, for example, to a stronger jet-stream, to stronger trade winds, and to a stronger polar vortex. The AO is strongly coupled with the North Atlantic Oscillation (NAO) pattern, which is a pressure dipole between the Azores and Iceland. The NAO has an impact on the temperature and precipitation over Europe. The chemical effect would lead to a negative phase of the NAO. Consequently, the climate in northern Europe would be colder and dryer whereas over the Mediterranean, temperatures would be higher and more precipitation would be expected. On the other hand, the warming induced by the CFC properties as a greenhouse gas would shift the NAO to a positive phase. This would lead to a warmer and wetter northern Europe and a dryer and colder Mediterranean region. The overall pressure changes over the Atlantic of the increased CFC concentrations cancel the signal from the chemical properties and radiative forcing, leading to a neutral state of the NAO.

The equivalent of the AO in the Southern Hemisphere is the Southern Annular Mode (SAM). In austral winter and spring, the SAM is in antiphase, leading to a weak positive SAM if the radiative and chemical forcings are combined. However, in austral summer, both forcings are in phase, and the SAM becomes positive. Thus, without the MPA in summer, the westerlies around Antarctica would be shifted south and there would be increased precipitation in eastern Australia (see Zilker et al., 2023 for details).

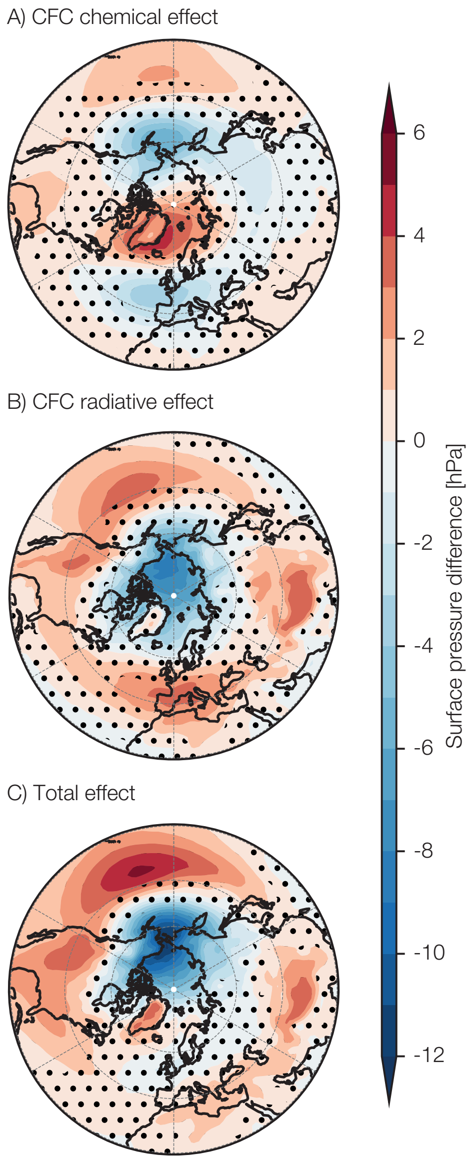


Figure 1. Arctic winter surface pressure differences during the 2080 - 2099 period. Stippling indicates where the differences are not significant at a 90% confidence level.

As illustrated above, the impact of the MPA has a strong seasonal and regional dependency. Through the changes in dynamics, the climate signals can be modified.

References: Egorova, T., et al.: 2022, Montreal Protocol's impact on the ozone layer and climate, acp-2022-730, accepted.

Zilker, F., et al.: 2023, Stratospherically induced tropospheric circulation changes under the extreme conditions of the No-Montreal-Protocol scenario, submitted to Atmospheric Chemistry and Physics.

The Impact of Different CO_2 and ODS Levels on the Mean State and Variability of the Springtime Arctic Stratosphere

Timofei Sukhodolov in collaboration with BOKU-Met (Austria) and IAC ETH (Switzerland)

Rising concentrations of greenhouse gases (GHG) and ozone are the main drivers of the stratospheric climate evolution in the 21st century. The focus of this study was to decompose the role of the two factors for temperature changes in the Arctic polar cap stratosphere, which has important implications for the northern surface mid-latitude climate. For this, we used two chemistry-climate models (CCMs) in a set of idealised experiments. Our results showed that in the upper/middle stratosphere, the CO_2 thermal cooling dominates, while in the lower stratosphere the effects of O_3 and CO_2 largely offset each other. In addition, the lower stratospheric temperatures are shown to be particularly sensitive to the presence of anthropogenic ozone-destroying substances (ODS).

Ozone and CO_2 are the main contributors to the stratospheric radiative balance. Ozone strongly absorbs the solar radiation and thereby heats the stratosphere, while CO_2 emits in the infrared and cools it. Increased CO_2 also leads to higher ozone in the stratosphere, since cooling by CO_2 slows down the ozone destruction rates. Substantial attention in the science community has been paid to the influence of stratospheric processes on the tropospheric climate, driven by the context of future recovery and super-recovery of the stratospheric ozone layer due to declining ODS emissions and the increasing GHG emissions. However, the contribution of the two processes (CO_2 vs ozone increase) to the future mean state and variability of the stratosphere has not been properly addressed so far. In our study, we tried to fill this gap and focused on the contribution of CO_2 and ozone levels on the Arctic polar cap (60° - 90°N) mean temperature in the lower (70 hPa) and upper/middle stratosphere (10 hPa), with regard to both the mean state and variability. We analysed a set of six time-slice simulations performed with WACCM and SOCOL CCMs, explicitly tailored to represent past, present and potential future climate states (and varying ODS levels) and to explore the effects of interactive stratospheric chemistry. These comprise a pair (ODS-rich) of simulations with interactive chemistry vs. prescribed chemistry for the year 2000, a corresponding pair of simulations for a 1 × CO_2 climate, and a corresponding pair of simulations for a 4 × CO_2 climate.

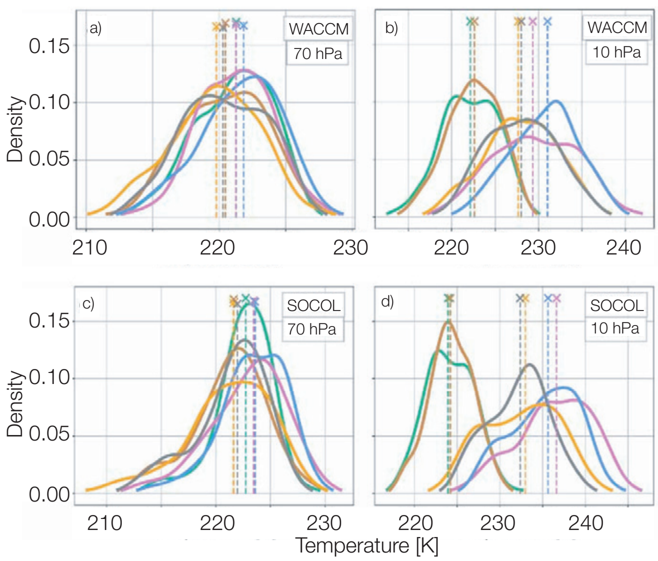


Figure 1. Monthly April absolute temperature probability density functions for WACCM and SOCOL at 70 hPa and 10 hPa. Yellow/grey pair: year 2000 runs with and without interactive chemistry. Blue/pink and brown/green: same pairs for 1 × CO_2 and 4 × CO_2 runs, respectively. After Kult-Herdin et al. (2022).

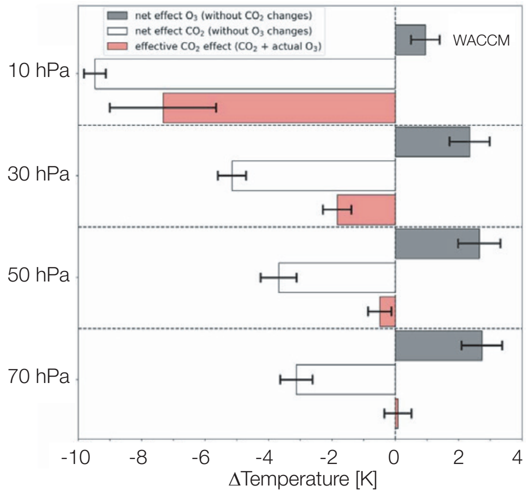


Figure 2. Net effects of CO_2 and ozone on the April stratospheric temperature in the Arctic polar cap, as derived from a combination of WACCM experiments. After Kult-Herdin et al. (2022).

Our simulations showed that at 10 hPa, there are clear separations between the experiments, depending on the corresponding CO_2 levels, and no clear difference between the runs with and without interactive chemistry (Figure 1b and d). This highlights the dominant importance of the cooling by CO_2 and the (only) minor contribution from the ozone increase. At 70 hPa, all experiments are grouped together for both models, meaning that CO_2 cooling effects are locally compensated by the warming effects from ozone. This is further confirmed in Figure 2, where we calculated the net effects of ozone and CO_2 on temperature at different stratospheric levels. One experiment that stands out in Figure 1a and c is the interactive chemistry run (yellow line) in the year 2000, which shows the appearance of the coldest April temperatures amongst all experiments. This is due to the feedback between the local temperatures, elevated ODS levels, polar stratospheric clouds, and heterogeneous ozone destruction. Such cold temperature conditions have been shown to be extremely important for the European springtime circulation patterns. Further details of our study can be found in Kult-Herdin et al. (2023).

References: Kult-Herdin, J., Sukhodolov, T., Chiodo, G., Checa-Garcia, R., Rieder, H.: 2022, The impact of different CO_2 and ODS levels on the mean state and variability of the springtime Arctic stratosphere, Environ. Res. Lett., https://doi.org/10.1088/1748-9326/acb0e6

Role of Internal Atmospheric Variability in the Estimation of Ionospheric Response to Solar and Magnetospheric Proton Precipitation in January 2005

Timofei Sukhodolov and Eugene Rozanov in collaboration with the EAGLE community

We investigated the importance of internal atmospheric variability for the detection of ionospheric response to external forcings from the precipitating protons of solar and magnetospheric origin for the period 17 - 23 January 2005. We analysed the results of ensemble runs with the whole-atmosphere model, EAGLE, and showed that internal atmospheric variability can strongly mask the forced signal, especially its after-effects, which can lead to false interpretation if only one model realisation is considered. We conclude that space weather studies require a proper consideration of the internal atmospheric noise to ensure statistical significance of the obtained results and a reliable interpretation of the observational data.

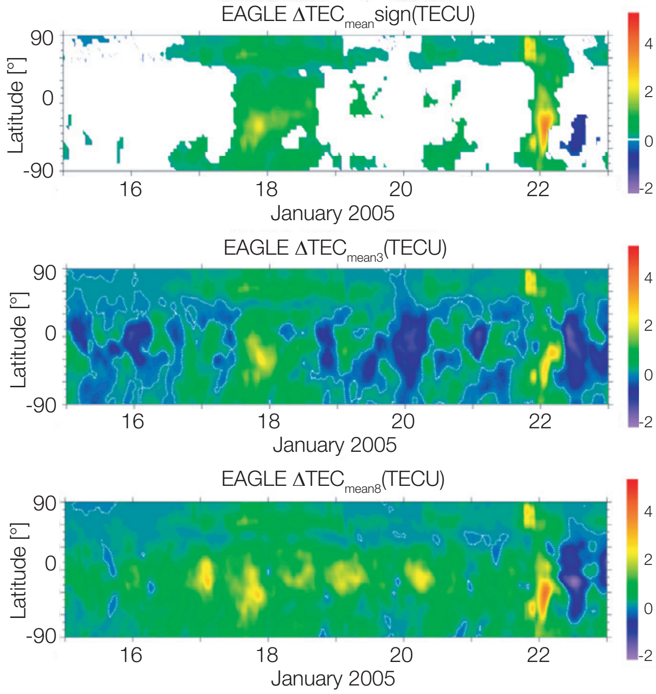


Figure 1. EAGLE-simulated temporal evolution of disturbances in zonal mean total electron content (ΔTEC): in TEC units (TECU, 10^{16} electrons/ m²) for the ensemble mean case (TEC_{mean}sign) and for two individual ensemble members (TEC_{mean3} and TEC_{mean8}). The white area shows a statistically insignificant response. After Klimenko et al. (2023).

In climate studies, the uncertainties related to the internal variability of a system are dealt with by using an ensemble approach. It implies having a range of modelling realisations that are slightly different from each other because of small changes in their initialisation, which triggers the dynamics of these realisations to follow different trajectories. In case studies, such an approach allows the statistical significance of the obtained results to be estimated. However, in space weather modelling applications, this has been rarely used, mostly because whole-atmosphere models with dynamics extending from the surface to the thermosphere have appeared only recently. Thus, there is currently no complete understanding of the importance of atmospheric variability for the ionospheric response to space weather events.

In our study, we aimed to investigate the influence of internal atmospheric variability on the detection of upper atmosphere response to external forcings, using the January 2005 proton precipitation event. We performed and analysed the 8-member ensemble pair of simulations with and without the proton precipitation forcing to see how the internal variability can modify the ionospheric response to the event and whether the event itself influences the ensemble spread. For the simulations, we used the whole-atmosphere model, EAGLE, that is able to calculate the dynamics of the atmosphere from the surface up to the upper thermosphere, and includes an interactive treatment of the ionosphere. Results of the simulations are presented in Figure 1, as a difference in total electron content (TEC) between the runs with and without the event. In the ensemble mean case (TEC_{mean}sign), only statistically significant areas are shown and illustrate large disturbances in the polar areas, mostly caused by the direct proton ionisation effects, as well as in the low latitudes due to the local change of atmospheric composition (O/N_2 ratio) caused by the adjustment of transport from high latitudes. Details of these mechanisms have been described by us in Bessarab et al. (2021).

While considering some of the individual ensemble member pairs (TEC_{mean3} and TEC_{mean8} in Figure 1), one can see that single simulations agree with each other in general during the peaks of the event (e.g., 17 and 22 January). However, the after-effects and the unperturbed period can be significantly masked by the internal atmospheric noise even in terms of the sign of the changes, especially in the low latitudes, making the potential conclusions very biased if only one model realisation or only observations are used for the analysis.

We have also investigated whether the considered space weather event can influence the atmospheric noise itself. We found that the ensemble standard deviation in TEC shows a clear universal time variation, which is connected with the internal atmospheric variability, namely daily regimes of generation of waves that propagate vertically and affect the thermosphere. Analysis of the noise level response to the forcing events revealed that it is also likely affected by the precipitating protons. However, this response can be event -specific and nonlinear, which also results in a different behaviour at high and low latitudes. Further details of our study can be found in Klimenko et al. (2023).

References:

Bessarab, F.S., Sukhodolov, T., et al.: 2021, Ionospheric response to solar and magnetospheric protons during January 15-22, 2005: EAGLE whole atmosphere model results, Advances in Space Research, ISSN 0273-1177, https://doi.org/10.1016/j.asr.2020.10.026

Klimenko, M.V., Klimenko, V.V., Sukhodolov, T., et al.: 2023, Role of internal atmospheric variability in the estimation of ionospheric response to solar and magnetospheric proton precipitation in January 2005, Advances in Space Research, https://doi.org/10.1016/j.asr.2023.01.012

Future Ozone Trends in a Changing Climate Simulated with SOCOLv4

Arseniy Karagodin-Doyennel, Tatiana Egorova, Timofei Sukhodolov, Jan Sedlacek and Eugene Rozanov in collaboration with the IAC ETH (Switzerland)

In this study, we evaluate the future evolution of atmospheric ozone between 2015 and 2099 simulated with the Earth System Model (ESM), SOCOLv4, using two potential future Shared Socioeconomic Pathways (SSP) via a dynamical linear model (DLM). Modelling results indicate that stratospheric ozone will mostly recover in the 21st century, governed by declining halogen concentrations (hODS) and increased greenhouse gas (GHG) forcing. The tropospheric column ozone is also expected to change substantially due to the changes in anthropogenic emissions of ozone precursors, which strongly affects the total column.

We analysed atmospheric ozone trends in two sets of ensemble simulations using SOCOLv4 (Sukhodolov et al., 2021), covering the period from 2015 to 2099. One simulation is based on the SSP2-4.5 scenario and the other on the SSP5-8.5 scenario, which differs in greenhouse gas and ozone precursor emissions. Future trends in ozone and non-hODS drivers of ozone evolution, such as NO_x, CO, and temperature, are evaluated for the first time using an advanced tool for multivariate regression analysis, namely the DLM. Figure 1 shows the near-global (60°N - 60°S) annual mean partial and total column ozone changes throughout the 21st century with respect to the 2015 - 2019 period in different atmospheric layers. Ozone in the entire atmosphere and stratosphere (Figure 1a and 1b) on a near-global scale shows signs of an increase until the middle of the century. Growth slowed over the second half of the century and ozone began to decline gradually, driven both by the intensification of transport from the tropics toward the mid-latitudes due to global warming and by a decline in tropospheric ozone. Yet, in general, ozone recovers throughout the entire period due to a decline in the hODSs level.

The evolution of tropospheric ozone (Figure 1c) is largely determined by changes in CH_4, CO, and NO_x. The contribution of CO plays a larger role under both scenarios due to the lower abundant of NO_x. Under the SSP5-8.5 scenario, the sharp decrease in O_3, starting after 2065, was mainly as a result of the decrease in NO_x, as both CH_4 and CO start to decrease later (for details see Karagodin-Doyennel et al. (2023)). Later in the century, tropospheric ozone will be lower than it is now in both scenarios. However, the difference in the zero crossing-point time is about 50 years between both scenarios.

Even though the anthropogenic halogen loading problem has been brought under control to date, our results showed that globally and regionally, the future evolution of ozone will still undergo substantial variations, which are also driven by diverse future human activities. This study is therefore important for the further refinement of future strategies for socioeconomic pathways. More analysis of the future ozone trends and the responsible drivers can be found in Karagodin-Doyennel et al. (2023).

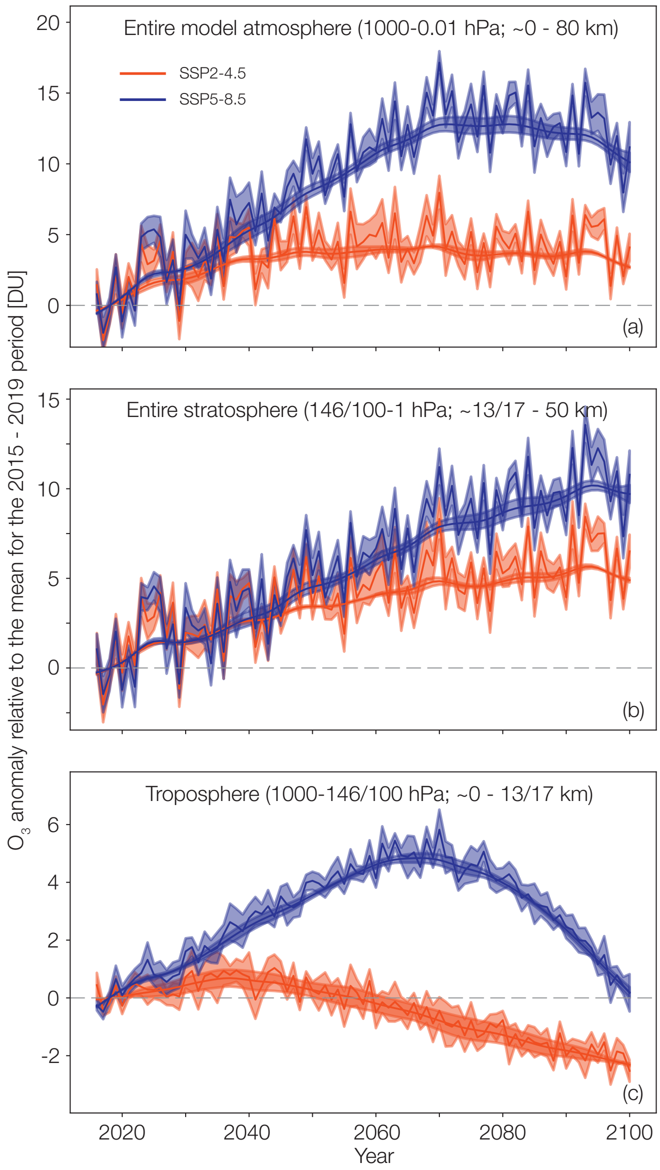


Figure 1. Near-global (60°N - 60°S) annual mean anomaly of column ozone and DLM fits (both in Dobson Units, DU) between 2015 and 2099 relative to the mean O_3 for the 2015 - 2019 period presented for: (a) the entire model atmosphere, (b) the entire stratosphere, and (c) the troposphere. Shading represents the 1σ standard deviation between ensemble members of the experiment.

Acknowledgment: The study was funded by the SNSF project POLE (200020_182239) and supported by CSCS under projects ID S-901 and ID S-1029.

References: Karagodin-Doyennel, A., Rozanov, E., Sukhodolov, T., Egorova, T., Sedlacek, J., Peter, T.: 2023, The future ozone trends in changing climate simulated with SOCOLv4, Atmos. Chem. Phys., 23, 4801-4817, https://doi.org/10.5194/acp-23-4801-2023

Sukhodolov, T., et al.: 2021, Atmosphere–ocean–aerosol–chemistry–climate model SOCOLv4.0: description and evaluation, Geosci. Model Dev., 14, 5525-5560, https://doi.org/10.5194/gmd-14-5525-2021

Towards a Cryogenic Standard for Ground-Based Solar Irradiance Measurements

Natalia Engler, Wolfgang Finsterle and Ricco Soder

The Cryogenic Solar Absolute Radiometer (CSAR), operated at the World Radiation Center at PMOD/WRC, aims to provide the traceability of Direct Normal Incidence (DNI) solar irradiance measurements to the International System of Units (SI), and to improve the accuracy of DNI measurements from currently 0.3% to 0.03%. The solar radiation enters the CSAR vacuum tank through the quartz window, which reflects and/or absorbs parts of the solar spectrum. Because the incoming solar spectrum is unknown and changes with atmospheric conditions, the transmittance coefficient of the window needs to be determined simultaneously with the CSAR operation. The transmittance coefficient is then used to correct the CSAR measurements. This task is performed by the Monitor of Integrated Transmittance (MITRA).

The MITRA instrument was developed and built at PMOD/WRC and has been in operation since 2010. MITRA operates at ambient temperature. It uses two parallel radiometric channels to determine the relative effect when the quartz window is placed in front of one of the channels. Several changes and improvements have been implemented to MITRA since the first design.

The latest improvement includes a dark receiver to compensate for changes in ambient temperature. Together with the solar radiometer, MITRA is installed on the solar tracking platform, allowing parallel operation of both instruments (Figure 1). Simultaneous measurements with CSAR and MITRA are necessary because the solar spectral irradiance, and thus the transmittance coefficient of the quartz window, change with airmass and atmospheric conditions. To characterise MITRA and to develop the best measurement procedures for achieving the highest accuracy of CSAR DNI readings (targeted uncertainty 0.03%), measurements of the window transmittance are performed and evaluated on a regular basis at PMOD/WRC.

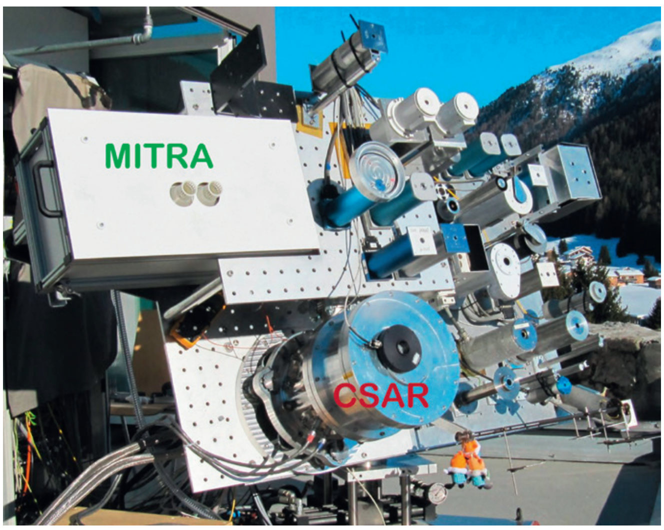


Figure 1. CSAR and MITRA are mounted on the PMOD/WRC solar tracking platform.

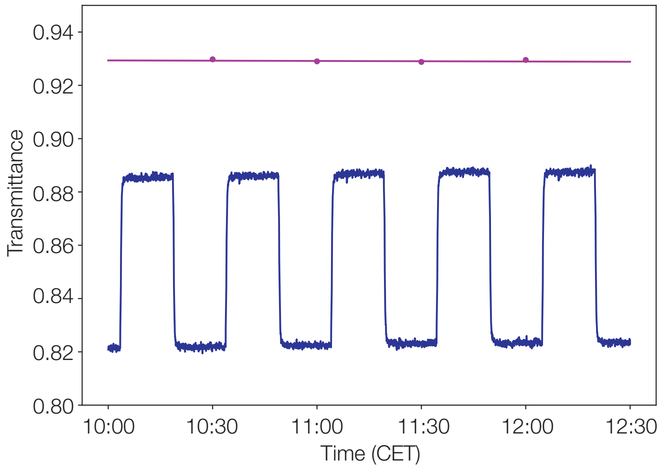


Figure 2. Transmittance of the quartz window as measured with MITRA on 21 September 2022. The blue line shows the ratio between the temperature increases of the sensing and reference detectors with respect to the dark detector: the higher ratio corresponds to an open state of both precision apertures whereas the lower ratio corresponds to a state where the precision aperture of the sensing detector is covered by a quartz window. The magenta line shows the measured spectrally integrated window transmittance.

The measurement principle of MITRA is based on the constant comparison of the temperature increases of two detectors (sensing and reference) illuminated by the sun, against the third non-illuminated ("dark") detector. The sensing and reference detectors are coated with carbon nanotubes, which absorb 99.85% of the incoming broadband DNI, and thus increase the temperature of the detectors. To determine the transmittance of the CSAR entrance window, an equivalent quartz window from the same production batch is installed in MITRA and periodically covers the aperture of the sensing detector during the measurement. This leads to a periodical attenuation of the solar irradiation through the reflection and absorption by the MITRA window and, therefore, a reduced temperature rise of the sensing detector relative to the dark detector. The relation between the temperature rises of sensing and reference detectors, in open and covered states of the sensing detector, defines the spectrally integrated window transmittance.

Figure 2 presents the results from the window transmittance measurement with MITRA on 21 September 2022. The blue line shows the ratio between the temperature rises of the sensing and reference detector when the former is in an open state (mean ratio is ~0.885) and covered by a window (mean ratio is ~0.822). The window transmittance (magenta line) is given by the division of these ratios, and equal to 0.92927 +/- 0.00039 for the indicated measurement period.

A new procedure to swap the CSAR and MITRA windows without breaking the vacuum during the CSAR operation in the cryogenic state is currently being implemented by the Solar Radiometry Section, PMOD/WRC. This technique will allow the equivalence in transmittance of both windows to be validated.

Spectral Aerosol Optical Depth Retrieved from Calibrated Solar Spectral Irradiance Measurements

Julian Gröbner, Natalia Kouremeti, Gregor Hülsen and Stelios Kazadzis in collaboration with GigaHertz-Optik GmbH (Germany)

Spectral aerosol optical depth (AOD) is retrieved from solar irradiance spectra traceable to SI via laboratory calibrations. The reference top-of-the-atmosphere solar spectra used for the AOD retrieval are the TSIS-1 HSRS or QASUMEFTS spectra, giving very good agreement with AOD retrieved by a collocated CIMEL sunphotometer from AERONET or a PFR from the GAW-PFR network. This study has shown that spectral AOD between 300 nm and 2100 nm can be retrieved with standard uncertainties of ~0.01 when using well characterised and calibrated spectroradiometers.

Atmospheric aerosols are minor constituents of the atmosphere, but a critical component in terms of impact on the climate. Their properties have been recognised as Essential Climate Variables (ECVs) by the Global Climate Observing System (GCOS) of the World Meteorological Organisation (WMO). As pointed out in all IPCC reports, aerosols continue to contribute the largest uncertainty to estimates and interpretations of the Earth's changing energy budget (IPCC, 2021).

In the joint research project, Metrology for Aerosol Optical Properties 19ENV04 MAPP, funded by the European Metrology Programme for Innovation and Research (EMPIR), emerging technologies based on array spectroradiometers are used to retrieve the spectral AOD over a wide spectral range. We show in this study that spectral AOD retrieved from calibrated spectroradiometers provides measurements with uncertainties comparable to those based on narrowband sunphotometers. The atmospheric transmission is obtained from direct solar irradiance measurements under cloudless conditions, using the Beer-Lambert law:

$$I(\lambda) = I_o(\lambda)\, e^{-\tau m} \qquad (1)$$

Where I is the solar irradiance at the Earth's surface, I_o the top-of-the-atmosphere (TOA) solar irradiance, τ the optical depth of the atmosphere, and m the airmass. AOD (τ_a) is then retrieved from these measurements by subtracting all known atmospheric absorbers for the corresponding wavelength regions:

$$\tau_a = (\log I_o/I - \Sigma\tau_i\, m_i)\,/\,m_a \qquad (2)$$

with τ_i and m_i representing the optical depth and airmass for the atmospheric absorber i. The TOA solar irradiance is either retrieved for each radiometer using the Langley technique (instrument units) or from published solar spectra (units of $Wm^{-2}nm^{-1}$). The latter method has the advantage that literature solar spectra traceable to SI can be used as a reference, thus providing a fully traceable AOD retrieval. In this study, we used the QASUMEFTS (Gröbner et al., 2017) solar spectrum covering the spectral range from 300 nm to 500 nm, and the TSIS-1 HSRS (Coddington et al., 2021) solar spectrum covering the spectral range from 202 nm to 2730 nm. As shown in the respective publications, the agreement of these two TOA solar spectra is well within their stated uncertainties.

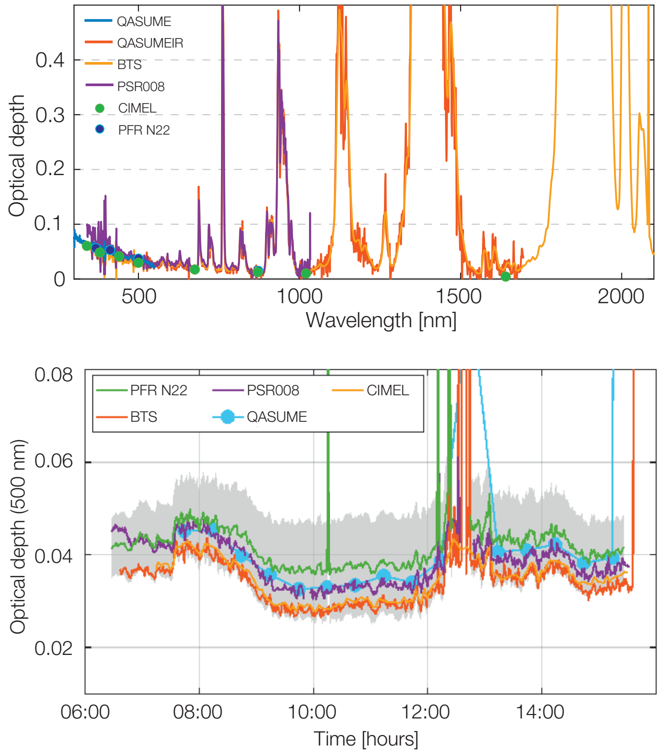


Figure 1. Optical depth (OD) measurements on 10 October 2021 at PMOD/WRC. Top: Spectral OD at 10:30 UTC (log-scale). Bottom: Diurnal variation of AOD at 500 nm. The AOD from CIMEL (AERONET) and PFR are obtained using the traditional Langley-plot calibration. The grey shaded area represents the WMO uncertainty U_{95} = 0.01/m+/-0.005.

As can be seen in Figure 1, the agreement between the AOD retrieved from the laboratory calibrated spectroradiometers and the AOD obtained from the AERONET and GAW-PFR sunphotometers using the in-situ Langley-calibration is in very good agreement. The slightly higher values of AOD at 1020 nm and 1640 nm from BTS and QASUMEIR compared to the CIMEL are due to water vapour (1020 nm) and CO_2, CH_4, and water vapour (1640 nm) absorption, respectively, which have not been taken into account here.

Acknowledgement: This work was supported by the European Metrology Program for Innovation and Research (EMPIR) within the joint research project, EMPIR 19ENV04 MAPP "Metrology for aerosol optical properties". EMPIR is jointly funded by the EMPIR participating countries within EURAMET and the European Union.

References:

Coddington, O.M., et al.: 2021, The TSIS-1 hybrid solar reference spectrum, Geophys. Res. Lett., 48, e2020GL091709

Gröbner, J., et al.: 2017, The high-resolution extraterrestrial solar spectrum (QasumeFTS) determined from ground-based solar irradiance measurements, Atmos. Meas. Tech., 10, 3375-3383, https://doi.org/10.5194/amt-10-3375-2017

IPCC: 2021, Climate Change 2021: The Physical Science Basis, Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, https://doi.org/10.1017/9781009157896

An Alternative Total Column Ozone Retrieval from Pandora Spectra

Luca Egli, Stelios Kazadzis and Julian Gröbner

In the project QA4EO (Quality Assurance for Earth Observation), funded by the European Space Agency (ESA), PMOD/WRC is responsible for three sub-projects: 1. Development of observation systems traceable to SI units, 2. Ground-based instrument calibrations, 3. Improving aerosol optical depth (AOD) and NO_2 corrections. The ground-based instrument calibration focuses on improved total column ozone measurements with state-of-the-art new technology instrumentation. As an alternative to the existing total column ozone product from Pandora, PMOD/WRC developed a custom double-ratio technique algorithm, which allows on-site calibration with our own existing instruments.

The standard instruments for measuring total column ozone (TCO) are Dobson and Brewer instruments (see page 18). These instruments require periodic field calibration campaigns to calibrate the instruments with a travel reference. In recent years, the Pandora system has been developed to derive TCO and NO_2 from spectral measurements of state-of-the-art array spectroradiometers, which only require laboratory calibration. The Pandora system forms a global network of more than 200 instruments worldwide (www.pandonia-global-network.org).

PMOD/WRC compared two operational Pandora TCO data products with the operational Brewer 156 instrument from the Arosa-Davos time-series. In a one-year intercomparison (Figure 1), the "out0" data product from the Pandora shows a relative difference to the Brewer 156 of -0.61% (averaged offset), with a seasonal amplitude of 2.5%. The new "out2" data product showed an averaged offset of -3.81% with a seasonal amplitude of 0.18%. The reduction of the seasonal amplitude is caused by the inclusion of a climatology of effective ozone temperature at Davos. However, the long-term averaged bias of "out2" data (-3.87%) is significantly larger than the bias of the "out0" data (-0.61%).

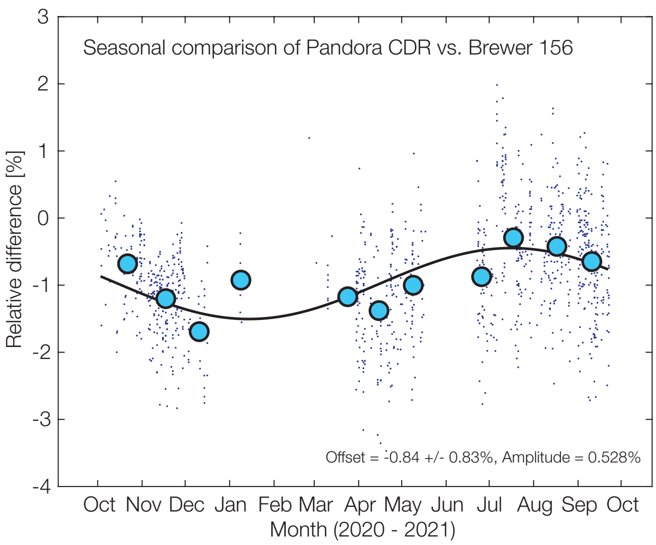


Figure 1. Comparison of total column ozone from Pandora spectra applying the custom double ratio technique.

Table 1. Relative difference of different total column ozone instruments at PMOD/WRC compared to Brewer 156 for one year of data.

TCO instrument	Long-term offset [%]	Seasonal amplitude [%]
Brewer 040	-0.29	0.16
Brewer 072	-0.15	0.29
Brewer 163	0.21	0.02
Dobson 101	0.06	0.17
QASUME	1.13	0.22
Koherent CDR	0.02	0.17
Pandora "out0"	-0.61	2.50
Pandora "out2"	-3.87	0.18
Pandora CDR	-0.84	0.53

In 2020, PMOD/WRC developed an alternative TCO retrieval from the Pandora spectra, based on the custom double-ratio technique (CDR) as applied to the Koherent system (Egli et al., 2022). The comparison of the new retrieval with Brewer 156 showed an averaged offset with a relative difference of -0.84% and a seasonal amplitude of 0.53%.

The performance of this new retrieval is similar to the performance of "out0" data in terms of averaged offset and comparable to the "out2" product in terms of seasonal amplitude. Table 1 lists the performance of other TCO instruments compared to Brewer 156. The results show that the standard instruments, such as the Brewer and the Dobson, are within <1% for the long-term offset and <0.3% for the seasonal amplitude.

The new algorithm for Pandora is close to the performance of established instruments. However, further work, such as calibrating the extraterrestrial constant for the CDR technique and the development of a stray-light correction are needed to improve TCO estimates from Pandora spectra.

In the frame of QA4EO, an investigation of an aerosol optical depth retrieval correction for NO_2, based on real-time NO_2 data, has been developed. This is in collaboration with Serco (CNR, Italy) and the National Observatory of Athens (Greece).

Acknowledgment: This research was supported by the ESA project QA4EO, grant no. QA4EO/SER/SUB/09

References: Egli, L., Gröbner, J., Schill, H., Maillard Barras, E.: 2022, Total column ozone retrieval from novel array spectroradiometer, Atmos. Meas. Tech. Discuss, preprint, https://doi.org/10.5194/amt-2022-325, in review.

Spectral Irradiance Comparison Between High Temperature Blackbody, Tunable Laser Facility and the QASUME Scale from 280 nm to 1700 nm

Gregor Hülsen and Julian Gröbner in collaboration with PTB (Germany)

The spectral irradiance realised through the primary spectral irradiance standard, BB3200pg, of the German National Metrology Institute (PTB) was compared to that obtained with the tunable laser facility (TULIP) using trap detectors traceable to SI. The scanning spectroradiometers, QASUME (280 nm to 550 nm) and QASUMEIR (550 nm to 1700 nm), were used as comparison instruments using 250 W small power tungsten halogen lamps as transfer standards. The agreement of the spectral irradiances realised by TULIP and BB3200pg was better than 1%. In addition, the comparison shows the excellent agreement of better than 1% to the QASUME irradiance scale.

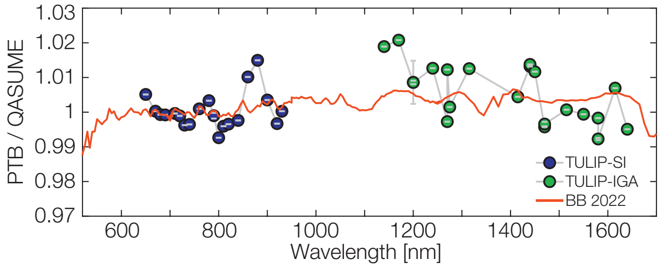


Figure 2. Ratio of spectral irradiance between TULIP and the BB3200pg blackbody (red line) relative to the QASUME scale. The blue dots are obtained using the silicon reference photodiode, while the green dots are from the InGaAs photodiode.

The primary spectral irradiance standard at the PTB is a high temperature blackbody, BB3200pg, operated at about 3200 K (Gröbner and Sperfeld, 2005). A second approach using a significantly reduced traceability chain to the cryogenic primary standard of power uses a reference detector in combination with a wavelength tunable laser facility. At the PTB, the facility is composed of a femto-second pulsed laser in combination with calibrated silicon or InGaAs photodiodes, providing traceability to the unit of optical power (Schuster et al., 2014).

The two realisations of spectral irradiance were compared using the transportable reference double monochromator spectroradiometer, QASUME, for the 280 nm to 550 nm spectral range, and the newly developed QASUMEIR single monochromator for the 550 nm to 1700 nm spectral range. Since the two systems are located in different physical locations at the PTB, and due to the long measurement times at the laser-based facility, small power tungsten-halogen lamps were used to monitor the stability and correct observed relative responsivity changes of the transfer spectroradiometers over the whole period.

The first comparison between the two facilities was performed in 2013 and 2014 for the 280 nm to 500 nm spectral range, using the QASUME spectroradiometer (Hülsen et al., 2016). The comparison was repeated with an improved laser-based tunable facility, TULIP, in spring 2022 over the extended spectral range from 280 nm to 1700 nm. The original QASUME double monochromator was used for the spectral range up to 550 nm, and QASUMEIR for the spectral range from 500 nm to 1700 nm. Figure 1 shows the comparison between TULIP and the high temperature blackbody for the shorter spectral range to 550 nm versus the transfer standard lamps, while Figure 2 shows the extended spectral range from 550 nm to 1700 nm.

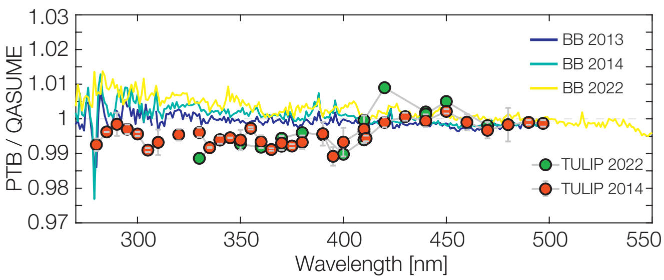


Figure 1. Ratio of spectral irradiance between TULIP (red and green dots) and the high temperature BB3200pg blackbody (blue, magenta and yellow lines) with respect to the spectral irradiances obtained from 1 kW FEL transfer standards traceable to SI (QASUME scale). Results are shown for comparisons performed in 2013, 2014 and 2022.

As can be seen in the figures, the comparisons between TULIP and BB3200pg performed in 2013, 2014, and 2022 are on average excellent, with no observable differences to within the uncertainty of the measurements. The slight under-estimation of the irradiances by TULIP of 0.5% with respect to the high temperature blackbody for wavelength below 400 nm was seen in all campaigns. This difference is as yet unexplained, but not significant. The reason for the relatively large spectral scatter of about ±1% for wavelengths greater than 600 nm from the TULIP based measurements is not yet understood.

This work was supported by the European Metrology Program for Innovation and Research (EMPIR) within the joint research project EMPIR 19ENV04 MAPP. EMPIR is jointly funded by the EMPIR participating countries within EURAMET and the European Union.

References: Gröbner, J., Sperfeld, P.: 2005, Direct traceability of the portable QASUME irradiance scale to the primary irradiance standard of the PTB, Metrologia, 42, 134-139.

Hülsen, G., et al.: 2016, Traceability of solar UV measurements using the QASUME reference spectroradiometer, Appl. Opt., 55, 26, 7265-7275.

Schuster, M., Nevas, S., Sperling, A.: 2014, Validation of short-pulse laser-based measurement setup for absolute spectral irradiance responsivity calibration, Appl. Opt., 53, 2815-2821.

Traceability of Lunar Direct Irradiances Measured with a Precision Filter Radiometer

Natalia Kouremeti, Julian Gröbner, Stelios Kazadzis in collaboration with PTB (Germany)

A Precision Filter Radiometer (PFR), measuring lunar direct irradiance for the retrieval of aerosol optical depth (AOD), has been characterised and calibrated at PTB and PMOD/WRC. The spectral irradiance responsivities of the instrument are used in the Langley extrapolation method to assess the precision of the top-of-atmosphere lunar spectral irradiance provided by the RIMO (ROLO Implementation for Moon's Observation) lunar irradiance model.

The growing interest in night-time observations of AOD, in an attempt to fill the gap in the annual cycle of the Arctic aerosol climatology, led to the development of the Lunar PFR. The current version of the Lunar PFR has been performing measurements at Ny-Ålesund since 2015. Within the MAPP project and in collaboration with PTB, the instrument was calibrated in the state-of-the-art TUnable Lasers In Photometry (TULIP) setup.

The PFR-98-L-002 is equipped with four independent narrow spectral channels centered at 412 nm, 500 nm, 675 nm and 862 nm. The spectral irradiance responsivity of the PFR in SI units was determined at the TULIP setup similar to the calibration described in Kouremeti et al. (2022), and was compared with a spectral irradiance transfer-standard lamp from the German National Metrology Institute (PTB) in November 2021. Measurements at the TULIP setup were performed in the spectral range from 310 nm to 1000 nm against a calibrated 3-element silicon trap detector equipped with an aperture. The reference plane of the PFR was validated against the reference detector with a well-characterised aperture position, introducing displacements along the PFR optical axis. The uncertainty of the spectral responsivity was determined using a Monte Carlo simulation algorithm accounting for uncertainty sources related to the trap detector, stability and homogeneity of the laser irradiance field, PFR signal and field-of-view (FOV). The combined expanded uncertainty of the calibration is less than 0.27% for all four channels. The difference to the lamp-based calibration was in the -0.2% - 0.3% range.

It is essential to determine the PFR internal gains as the laboratory measurements are performed with the lowest value while the highest value is used for lunar measurements. These were determined with an uncertainty of 0.3% in the TULIP setup by using the spectral responsivity of the instrument and by selecting appropriate wavelengths for the stepwise linking of the gain values.

Table 1. Percentage differences of RIMO to I_{TOA}, the relative uncertainties of I_{TOA} and variability of the seven I_L in the lunar cycle in September 2022.

	λ = 861.75 nm	λ = 675.39 nm	λ = 501.39 nm	λ = 411.95
RIMO - I_{TOA}(%)	6.75	10.10	9.52	7.84
U_{TOA} (%, k = 2)	0.64	0.62	0.64	0.68
Variability of I_{TOA} (%, k = 2)	1.04	0.30	0.72	0.24

Figure 1. The Lunar PFR at Izaña (Tenerife) during the MAPP campaign in September 2022.

The dataset used for the retrieval of the top-of-the-atmosphere (TOA) lunar irradiance is from measurements performed at the Izaña observatory (28.3°N, 16.5°E, 2390 m altitude, Tenerife, Spain) during the MAPP campaign from 3 - 23 September 2022 (Figure 1). Seven Langley-based TOA retrievals (I_L) were performed during one lunar cycle with lunar phases ranging from 6° to 58°. For this retrieval, the phase relative lunar irradiance of the RIMO models (Barreto et al., 2019; Kieffer and Stone, 2005) was used. The difference between mean I_L (I_{TOA}) and RIMO are presented in Table 1, as well as the uncertainty of I_L (U_{TOA}) accounting for the PFR calibration uncertainty, noise level, regression analysis and FOV inhomogeneity. The observed variability of I_{TOA} is within or close to U_{TOA}, indicating that RIMO model satisfactorily represents the phase dependence of lunar irradiance. The observed offsets are in the 6.75% - 10.10% range. We continue working on understanding the origin of this offset, and also to contribute to the improvement of TOA lunar irradiance models.

The stability of the instrument has been monitored since 2015 with lamp-based calibrations performed at PMOD/WRC in regular intervals. The calibrations were analysed using the information obtained in the TULIP setup. Differences with respect to the TULIP calibrations were scattered within ±1% (k = 2). This allows us to process the Ny-Ålesund and Davos datasets with respect to the TULIP calibration, hence giving more accurate results.

Acknowledgements: This work was supported by the European Metrology Program for Innovation and Research (EMPIR) within the joint research project EMPIR 19ENV04 MAPP and partially by the ESA-QA4EO project, contract QA4EO/SER/SUB/09.

References:

Barreto, A., et al: 2019, https://doi.org/10.1016/j.atmosenv.2019.01.006

Kieffer, H. H., Stone, T. C.: 2005, The spectral irradiance of the Moon, https://doi.org/10.1086/430185

Kouremeti, N., et al.: 2022, https://doi.org/10.1088/1681-7575/ac6cbb

Solar Radiation Nowcasting Using a Markov Chain Multi-Model Approach

Xinyuan Hou, Kyriakoula Papachristopoulou and Stelios Kazadzis in collaboration with MINES (France)

Solar radiation nowcasting is important for various solar energy intraday applications. The objective of this study is to develop a hybrid approach in order to improve the accuracy of solar nowcasting with a lead time of up to one hour. The proposed method uses irradiance data from the Copernicus Atmosphere Monitoring Service (CAMS) for four European cities with different cloud conditions. The approach effectively improves the prediction accuracy in all four cities. In the prediction of global horizontal irradiance (GHI) for Berlin, the reduction in the mean daily error amounts to 2.5 Whm^{-2} over the period of a month, and the relative monthly improvement reaches nearly 5% compared with the traditional persistence method. Improvements in the accuracy can also be observed in the other three cities.

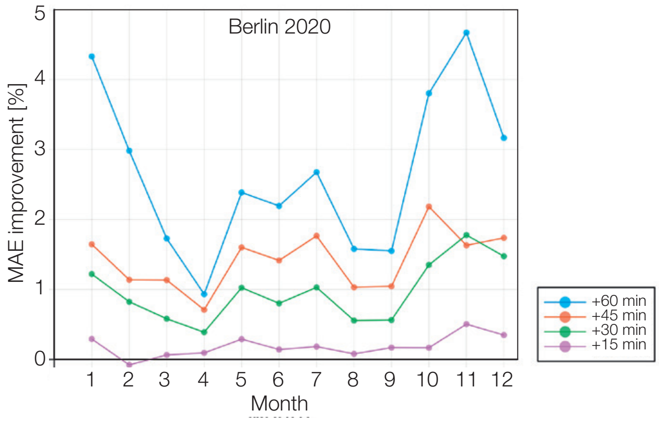


Figure 2. Relative improvement of the hybrid approach in 2020 for Berlin.

For the 2019 time-series, we evaluate the accuracy of the persistence method, neighbour inference, and Markov chain (MC) predictions in order to develop hybrid methods based on the mean absolute error (MAE) or root-mean-square-error (RMSE) for all 30 cloud modification factor (CMF) classes. If, for a given CMF class, the error rate of a certain approach is the lowest among the considered approaches, we adopt that approach for the CMF class in question. We then apply this to the 2020 time-series by choosing the optimal approach for the next time-step based on the CMF class at the current time-step.

Figure 1 (Hou et al., 2022) shows the GHI time-series provided by CAMS and predicted values with a lead time of 15 minutes using the hybrid approach based on RMSE for Berlin for the period 1 - 11 Jan. 2020. Night-time hours without sunshine are not included. We observe that both curves are in high agreement, especially when the absolute GHI values are high.

Figure 2 shows the monthly relative improvement of the hybrid approach based on MAE compared to the persistence method for four time-steps for Berlin. We observe an improvement from one to four time-steps ahead, across all months, except for 15 min ahead in February. For a lead time shorter than 45 min, the fluctuation of improvements throughout the year is relatively small. However, when predicting one hour ahead, the improvement is apparent during the winter months of October to January, even reaching nearly 5% in November.

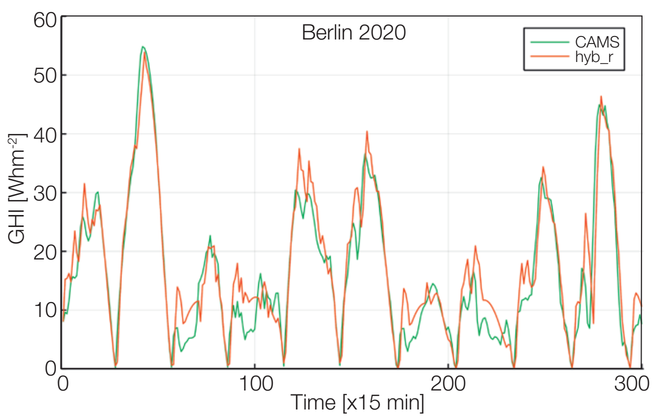


Figure 1. Comparison of actual daily GHI by CAMS (green) and predicted values with a lead time of 15 minutes by the hybrid approach, based on the root-mean-square-error (red) for Berlin for the period 1 - 11 January 2020.

The presented approach has the advantage that its straightforward model configuration does not require the input of other variables, such as wind speed or cloud motion vectors from all-sky imagers, both of which can introduce multiple uncertainties. Furthermore, the computational time required for prediction at one single site is trivial. Our approach also adjusts the transition matrix according to the input data for the MC prediction; thus, it is a generic model that can be readily applied to different geographical locations where CAMS data are available. Therefore, one prospect for the hybrid model is to upscale its application to, e.g., the pan-European domain to build an efficient network for solar radiation nowcasting. The presented method can be the basis for, or part of, hybrid approaches that include additional satellite-based cloud information and/or ground measurements (cloud cameras, solar irradiance instruments, and other atmospheric parameter measurements) with the goal of improving solar forecasting.

Acknowledgement: This study was funded by the European Commission project, EuroGEO e-shape (grant agreement No. 820852).

References: Hou, X., Papachristopoulou, K., Saint-Drenan, Y.-M., Kazadzis, S.: 2022, Solar radiation nowcasting using a Markov chain multi-model approach, Energies, 15, 2996, https://doi.org/10.3390/en15092996

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

Akriti Masoom, Natalia Kouremeti, Julian Gröbner and Stelios Kazadzis

The World Optical Depth Research and Calibration Center (WORCC) is participating in the Aerosol, Clouds and Trace Gases Research Infrastructure Switzerland (ACTRIS-CH, 2021-2025) programme, and collaborates with the Calibration of Aerosol Remote Sensing (CARS) of the ACTRIS European research infrastructure. In the ACTRIS-CH programme, WORCC maintains three precision filter radiometers (PFRs) at Izanã (IZO, Spain), Observatoire de Haute Provence (OHP, France) and University of Valladolid (VLD, Spain), which are part of the CARS activities. The aim of this collaboration is: i) the link of CARS with the WMO-defined AOD scale, maintained by WORCC, ii) the homogenisation of AOD retrievals and the provision of standard operating procedures, and iii) to process documents on the comparison of PFR (WORCC) and CIMEL (ACTRIS/CARS) sun-photometers.

Figure 1. PFR N014 installed at the University of Valladolid (Spain) on 7 June 2022.

WORCC aims to standardise and homogenise AOD reference scales, and to improve the calibration, processing algorithms and have consistent long-term AOD measurements. Under ACTRIS-CARS, PMOD/WRC aims to establish the traceability link between the ACTRIS-CARS PFR and CIMEL sun-photometers of the Aerosol Robotic Network (AERONET)-Europe. This includes the permanent establishment of WORCC PFR reference instruments at the three main ACTRIS sites: (OHP, France; IZO, Spain; VLD; Spain) with the objective of establishing the traceability of AOD within ACTRIS to the WMO primary AOD reference. This can be achieved by: i) calibration of ACTRIS reference sun-photometers with respect to the WMO primary AOD reference at WORCC, ii) quality control of AOD, calibrations and comparisons of PFR and ACTRIS/CARS reference instruments, and iii) creating a permanent cooperation between ACTRIS/CARS and WORCC for AOD measurements, calibration and standard operation procedures.

In 2022, a new PFR (N014) was installed in June 2022 at VLD (Figure 1) as a part of CARS under the ACTRIS-CH programme. In addition, two PFRs have been functional at OHP and IZO since 2020 and 2002, respectively. The AOD comparisons were performed between ACTRIS-CARS PFR and AERONET-Europe CIMEL sun photometers at IZO, OHP and VLD for 2022 (Figure 2). For comparison, the PFR AOD is extrapolated to the corresponding CIMEL wavelengths using the Ångström law. During the comparison period, only one CIMEL functioned at IZO (CIMEL#1089), three at OHP (CIMEL#1143, CIMEL#1265 and CIMEL#1141) and one at VLD (CIMEL#942). The WMO limits are defined as the differences between the measurements being within ±(0.005+(0.01/m)), where m is the airmass (the light path length through the atmosphere). The AOD comparisons were found to be above 99% at IZO, OHP and VLD at all wavelengths above 380 nm.

Acknowledgement: This research was funded by ACTRIS, CH.

References: Kazadzis, S., Kouremeti, N., Nyeki, S., Gröbner, J., Wehrli, C.: 2018, Geosci. Instrum. Method. Data Syst., 7, 39-53, https://doi.org/10.5194/gi-7-39-201

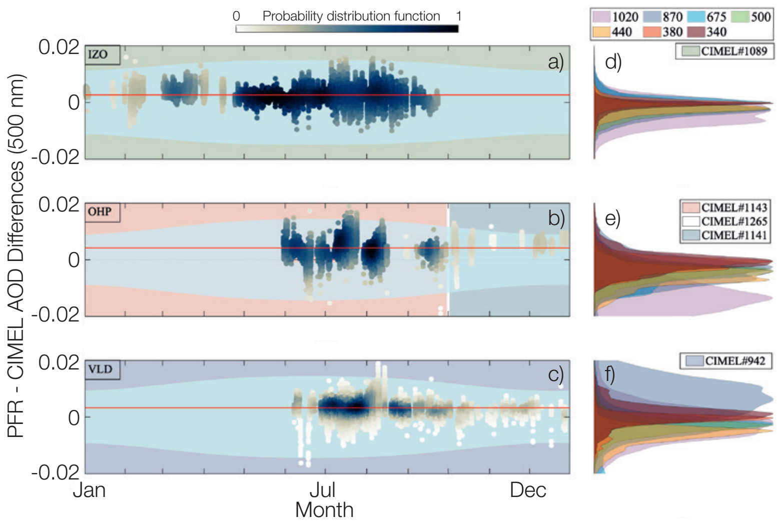


Figure 2. AOD comparison between PFR and CIMEL. Panels a and d: IZO (Spain). Panels b and e: OHP (France) in 2021. Panels c and f: VLD (Spain) in 2022. The light blue shaded areas represent the WMO limits.

Sensitivity of Aerosol Optical Depth Trends Using Long-Term Measurements from Different Sun-Photometers

Angelos Karanikolas, Natalia Kouremeti, Julian Gröbner, Luca Egli and Stelios Kazadzis

Aerosols are an important atmospheric component regarding the study of atmospheric processes as they have various effects on weather, climate and air quality. The most important parameter for Earth energy budget studies is the aerosol optical depth (AOD), which describes their overall direct effect on solar radiation attenuation. In this study, we assess differences in the AOD trend estimates due to different instrument characteristics, measurement frequencies, AOD averaging methods, and trend estimation methods. These estimates are then compared with the trend standard error and the effect of measurement uncertainty on trend uncertainty. Generally, the differences are within the uncertainties with the exception of linear trends for instruments of different types.

Table 1. Comparison of CIMEL–PFRN27 trends per decade using synchronous datasets. The Monte-Carlo trend standard deviation corresponds to the trend uncertainty attributed to the instrument measurement uncertainty.

Time-series	Trend per decade ($x10^{-3}$)	Standard error ($x10^{-3}$)	p value observed	Monte-Carlo trend SD ($x10^{-4}$)	Mean AOD
CIMEL 500 nm	-12.9	4.86	0.007	5.71	0.055
PFRN27 501 nm	-17.8	4.92	0.000	5.69	0.056
CIMEL 870 nm	-4.8	2.12	0.026	4.65	0.025
PFRN27 862 nm	-7.4	2.19	0.000	4.49	0.024

There are several sun-photometer networks around the world, using different instruments to measure the aerosol optical depth (AOD). In this study, we used two instruments from two networks. One instrument belongs to the largest global network, the Aerosol Robotic Network (AERONET), which uses CIMEL sun-photometers. The second is one of the three instruments constituting the world AOD reference and belongs to the Global Atmospheric Watch - Precision Filter Radiometer (GAW-PFR) network. These two instruments have been measuring AOD in parallel since 2005 at Davos, operated by PMOD/WRC. For data availability reasons, we used the period 2007 - 2019. These two instruments have several differences, of which some are technical. The CIMEL has a smaller field-of-view and is not temperature stabilised, while the PFR contains a quartz window before the aperture and its optical filter and detector are temperature stabilised. Also, PFRs measure every minute, while CIMELs have a frequency of ~15 minutes. Other differences include the AOD retrieval and cloud screening algorithms. In this work, we compared the synchronous AOD values and trends between the instruments and investigated the contribution of various factors to the trend uncertainty.

Initially, we compared the AOD differences for synchronous CIMEL and PFR measurements in their two directly comparable spectral channels (500/501 nm and 862/870 nm). More than 95% of the differences were within the accepted limits defined by the WMO. The monthly median AOD differences showed a good correlation (coefficient of determination $R^2 > 0.95$) and most of them were within the monthly AOD measurement uncertainties.

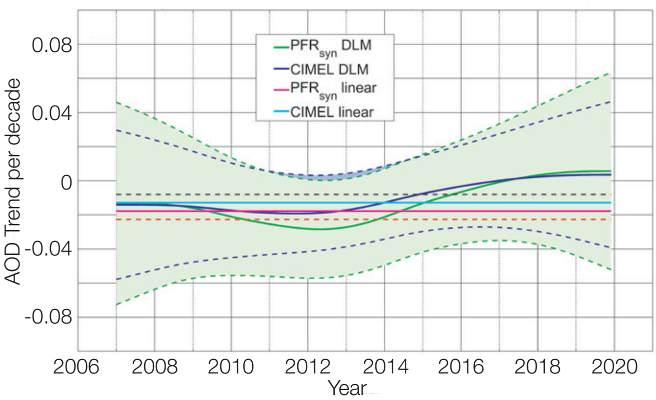


Figure 1. CIMEL–PFRN27 DLM and linear trends for 500/501 nm. The green line is the PFRN27 DLM trend and the blue line the CIMEL DLM trend. The shaded areas show their uncertainty. The magenta line shows the linear trend for PFRN27 and the cyan for CIMEL, while the dashed red and black lines are the linear trend standard errors.

The main part of the study was to estimate the AOD trends and their differences for various cases. The trend differences between CIMEL and PFR for synchronous data were similar or larger than the trend standard error (Table 1), despite the good agreement of the AOD observations mentioned in the previous paragraph. The trend uncertainties attributed to measurement uncertainties (1σ) are significantly smaller than the trend differences. This shows that the AOD trends can be very sensitive to AOD differences that are conventionally considered to be small. The choice of averaging method (median instead of mean), result in differences in AOD and its trend but they are smaller than the corresponding uncertainties. To assess the effect of measurement frequency on AOD values and trends, we compared two datasets from the same instrument (PFR). One dataset contains all data (one measurement per minute) and the other is synchronous with CIMEL measurements. In that case, the AOD differences and the trend differences were smaller compared to the CIMEL-PFR comparison and within the corresponding uncertainties showing that the measurement frequency difference between PFR and CIMEL has an insignificant effect on the long-term AOD intercomparison and variability. Finally, we calculated time-varying trends using dynamic linear modelling (DLM). All DLM trend differences were within the uncertainties. However, the trends were not consistent with least-squares linear trends as they were not monotonic (example in Figure 1). Since trends are not necessarily linear or monotonic, time-varying trends can provide a more objective criterion to identify deviations from linear or monotonic behaviour. The results of this work (Karanikolas et al., 2022) cannot be generalised to every location and instrument comparison, but they highlight various challenges in estimating AOD trends.

References: Karanikolas, A., et al.: 2022, Sensitivity of aerosol optical depth trends using long-term measurements of different sun photometers, Atmos. Meas. Tech., 15, 5667-5680, https://doi.org/10.5194/amt-15-5667-2022

Megacities Around the Globe: Aerosol Optical Depth Spatial Distribution and Trends Over the Last Two Decades Using Spaceborne Data

Kyriakoula Papachristopoulou, Akriti Masoom and Stelios Kazadzis

The air quality in megacities is determined by atmospheric aerosols. The state of urban aerosols in 81 cities with a population over 5 million was investigated. This was based on aerosol optical depth (AOD) from satellite measurements, with a fine spatial and temporal resolution (0.1°, daily), and over an 18-year period (2003 - 2020). According to the results, European and American cities have lower aerosol loads compared to African and Asian cities. For European, North American and East Asian cities, aerosols are decreasing over time, especially in China and the US. In the remaining cities, aerosol loads are increasing, particularly in India. These results are the output of the “Megacities around the globe: Aerosol optical depth Spatial distribution and Trends over the last two decades using spaceborne data (MAST)” project in the context of the Swiss Government Excellence Scholarship as a collaboration of ETHZ and PMOD/WRC. The project highlights the vital and essential contribution of space-borne products to monitor the aerosol burden over megacities.

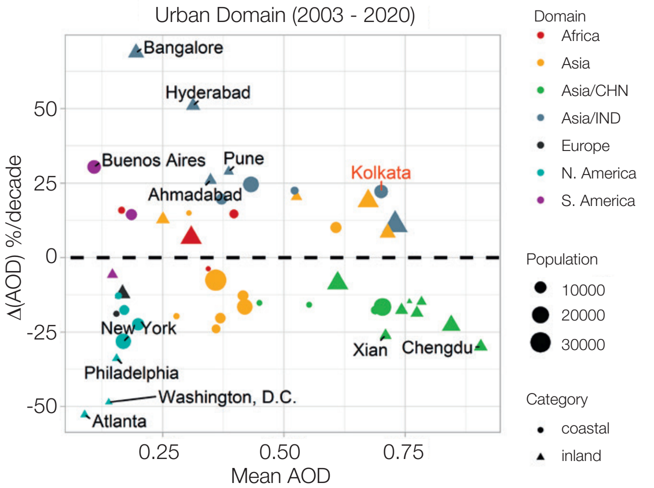


Figure 2. AOD decadal changes of various cities expressed in percentages (Δ(AOD)% per decade) versus their long-term mean AOD.

About 55% of the world’s population lives in urban areas, and current projections suggest that this percentage will significantly rise in the future. This population growth in cities, raises urgent and critical environmental issues, such as air quality (WHO, 2021) and its degradation, which is known to be related to increased morbidity and mortality rates. In particular, air pollution in cities constituted the 4th leading risk factor for early death on a global scale (HEI, 2020) in 2019. The worst pollutant affecting megacities is suspended particulate matter or aerosols, which can be quantified in optical terms using AOD. The latter is the most comprehensive variable for assessing the aerosol load of the atmospheric column.

While many countries worldwide have enforced policies in recent decades to reduce anthropogenic aerosol emissions in urban areas towards mitigating the aerosol adverse health effects, the exact policies and the level of implementation largely differ between countries. The main purpose of this study was to investigate the spatio-temporal variability of aerosols over megacities.

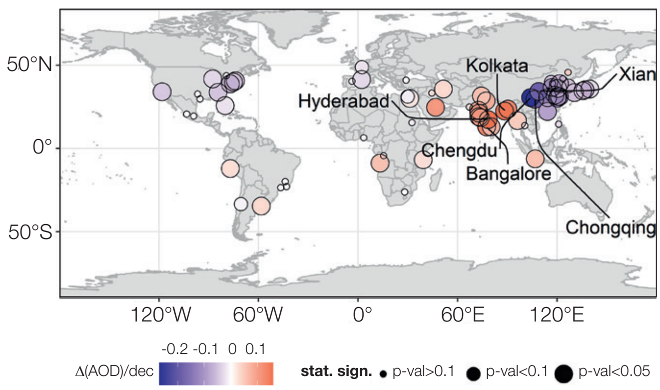


Figure 1. Changes of AOD per decade for the 81 greatest urban agglomerations of the world. The circle radius is in proportion to the statistical significance of the trends.

We used up-to-date and state-of-the art spaceborne AOD retrievals of fine spatio-temporal resolution (daily values, 0.1°) to study local and transported aerosols that can affect air quality in large cities around the globe. The detailed description of datasets and methodology are reported by Papachristopoulou et al. (2022). The geographical distribution of changes in AOD per decade (Figure 1) shows decreasing AOD values in US/Canadian, European and East Asian cities. Although Chinese cities have the highest aerosol load (Figure 2), they have the highest AOD decrease, in response to the rigorous emission control measures implemented in the country, especially after 2010. The highest AOD increase was found in Indian cities, reflecting the increasing urbanisation and industrialisation of the country.

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References:

Health Effects Institute (HEI): State of Global Air 2020: 2020, Special Report, Boston, MA, Health Effects Institute, Boston, ISSN 2578-6873.

Papachristopoulou, K., et al.: 2022, Aerosol optical depth regime over megacities of the world, Atmos. Chem. Phys., 22, 15703-15727, https://doi.org/10.5194/acp-22-15703-2022

World Health Organization (WHO): 2021, WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide, WHO, https://apps.who.int/iris/handle/10665/345329

Extending the Calibration Traceability of Longwave Radiation Time-Series (ExTrac)

Stephan Nyeki and Julian Gröbner in collaboration with MeteoSwiss (Switzerland) and other international institutes

The Baseline Surface Radiation Network (BSRN) is an archive of high quality traceable data going back to the early 1990s for several BSRN stations. However, raw pyrgeometer data from longwave surface radiation has not been stored in the BSRN archive, and may no longer be accessible from the stations themselves. The main aim of the ExTrac project was to develop a method to recover raw pyrgeometer data from calculated longwave data and to ensure their availability for future use when a number of traceability and instrumental issues have been resolved by the research community.

The Baseline Surface Radiation Network (BSRN; bsrn.awi.de) is one of several international networks to coordinate the measurement and archiving of surface radiation data. Amongst other parameters, downward longwave surface radiation (DLR) time-series using pyrgeometer instruments are also archived. Many of these time-series are traceable to the World Infrared Standard Group of pyrgeometers (WISG), established in 2004 and maintained by PMOD/WRC. Although this has led to better global homogenisation of DLR time-series and has considerably increased their reliability and accuracy, a number of traceability and instrumental issues still remain to be resolved by the research community (e.g. Gröbner et al., 2014; CIMO, 2018). The project, Extending the Calibration Traceability of Longwave Radiation Time-Series (ExTrac), focused on developing a methodology to recover raw pyrgeometer data from calculated DLR data in the BSRN archive. Only the stations themselves have archived raw pyrgeometer data. However, this may not be readily or fully available due to information technology issues or the loss of a knowledge-pool. The aim is to prevent the loss of raw legacy data and ensure their availability for future use when traceability and instrumental issues have been resolved.

Raw pyrgeometer data (voltage U, and body and dome temperatures, T_b and T_d) can be accurately recovered if no more than one parameter is missing. As the equation to calculate DLR is non-linear, recovering U, T_b and T_d from archived DLR is not possible. However, a promising method would be to determine proxy values of T_b and T_d based on in-situ temperature values (T_{2m}; at a height of 2 m). Raw pyrgeometer data from several BSRN stations was therefore acquired to investigate the feasibility of our approach. A refined or "station-specific" model was developed which also used meteorological and radiation parameters, and the cloud fraction to give the proxy pyrgeometer temperatures, $T_{b,proxy}$ and $T_{d,proxy}$. Full details of our method are discussed by Nyeki et al. (2023). Figure 1 illustrates a comparison of DLR_{proxy}, calculated using $T_{b,proxy}$ and $T_{d,proxy}$, with original DLR from the BSRN archives for the Payerne BSRN station. Root-mean-square-deviation (RMSD) values, which quantify the comparison, are shown in Table 1 for other BSRN stations. Results from the station-specific model give RMSD from 1.7 - 4.6 Wm^{-2} and 1.9 - 4.8 Wm^{-2} (1-hr and 10-min, respectively), and are similar or less than the current absolute uncertainty in DLR measurements of ±4.0 Wm^{-2}.

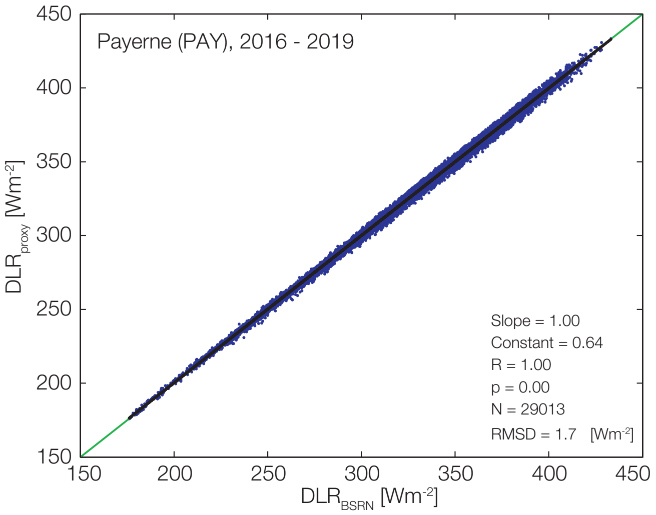

Figure 1. Comparison of DLR_{proxy} with DLR_{BRSN} (1-hr data) at Payerne (Switzerland) for the 2016 - 2019 period.

Table 1. BSRN station details and root-mean-square deviation (RMSD) values for a comparison of DLR_{proxy} vs DLR_{BSRN}. Pyrgeometer radiometer types: E = Eppley, K&Z = Kipp & Zonen.

Station and location	Time-series	Pyrgeometer type	RMSD (Wm^{-2})	
			1-hr	1-min
Cabauw, Netherlands	2011-2021	K&Z	2.3	2.4
Neumayer, Antarctica	2006-2015	E	2.4	2.8
Ny Ålesund, Svalbard	2006-2019	E	2.2	3.1
	2007-2010	E	3.5	4.5
Payerne, Switzerland	2011-2015	K&Z	2.1	2.3
	2016-2019	K&Z	1.7	1.9
South Pole, Antarctica	2008-2017	E	4.6	4.8
Syowa, Antarctica	2011-2019	K&Z	2.4	2.5

Considerable progress has been achieved by the BSRN community and the ExTrac project, in moving the agenda forward on the submission of raw pyrgeometer data to the BSRN archive. At a recent BSRN meeting in June 2022, it was decided to phase-in the mandatory submission of this data in the near future. Logistical aspects are currently being discussed, and new guidelines will appear in a forthcoming update of the BSRN Technical Manual. While the results from our project are encouraging, obtaining the original raw data from station archives is still the preferred approach to deal with past, present and future raw data. Such an approach will require substantial efforts by most BSRN stations available but could be supported by the resources of the BSRN and WMO communities.

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References:

CIMO: (2018), Commission for Instruments and Methods of Observation, CIMO-17, WMO, Amsterdam, 12-16 Oct. 2018.

Gröbner, J., et al: 2014, J. Geophys. Res. Atmos., 119, https://doi.org/10.1002/2014JD021630

Nyeki, S., et al.: 2023, Proc. Int. Radiation Symposium, Thessaloniki, 2022, in press.

Publications and Media

Refereed Publications

Alipour, N., Safari, H., Verbeeck, C., Berghmans, D., Auchère, F., Chitta, L. P., Antolin, P., Barczynski, K., Buchlin, É., Aznar Cuadrado, R., Dolla, L., Georgoulis, M. K., Gissot, S., Harra, L., Katsiyannis, A. C., Long, D. M., Mandal, S., Parenti, S., Podladchikova, O., Petrova, E., Soubrié, É., Schühle, U., Schwanitz, C., Teriaca, L., West, M. J., Zhukov, A. N.: 2022, Automatic detection of small-scale EUV brightenings observed by the Solar Orbiter/EUI, Astron. Astrophys., 663, 128, https://doi.org/10.1051/0004-6361/202243257

Badman, S. T., Brooks, D. H., Poirier, N., Warren, H. P., Petrie, G. R., Alexis, P., Nick, A. C., Bale, S. D., de Pablos Agüero, D., Harra, L., Jones, S. I., Kouloumvakos, A., Riley, P., Panasenco, O., Velli, M., Wallace, S.: 2022, Constraining global coronal models with multiple independent observables, Ap. J., 932, 135, https://doi.org/10.3847/1538-4357/ac6610

Barczynski, K., Meyer, K. A., Harra, L. K., Mackay, D. H., Auchère, F., Berghmans, D.: 2022, A statistical comparison of EUV brightenings observed by SO/EUI with simulated brightenings in nonpotential simulations, Sol. Phys., 297, 141, https://doi.org/10.1007/s11207-022-02074-6

Brooks, D.H., et al.: 2022, Plasma composition measurements in an active region from Solar Orbiter/SPICE and Hinode/EIS, Ap. J., 940, 66, https://doi.org/10.3847/1538-4357/ac9b0b

Chitta, L. P., Peter, H., Parenti, S., Berghmans, D., Auchère, F., Solanki, S.K., Aznar Cuadrado, R., Schühle, U., Teriaca, L., Mandal, S., Barczynski, K., Buchlin, É., Harra, L., Kraaikamp, E., Long, D. M., Rodriguez, L., Schwanitz, C., Smith, P.J., Verbeeck, C., Zhukov, A. N., Liu, W., Cheung, M. C. M.: 2022, Solar coronal heating from small-scale magnetic braids, Astron. Astrophys., 667, 166, https://doi.org/10.1051/0004-6361/202244170

de Pablos, D., Samanta, T., Badman, S. T., Schwanitz, C., Bahauddin, S. M., Harra, L. K., Petrie, G., Mac Cormack, C., Mandrini, C. H., Raouafi, N. E., Martinez Pillet, V., Velli, M.: 2022, Seaching for the source of magnetic field switchbacks in Parker Solar Probe's first enounter, Solar Phys., 297, 90, https://doi.org/10.1007/s11207-022-02022-4

Egli, L., Gröbner, J., Hülsen, G., Schill, H., Stübi, R.: 2022, Traceable total ozone column retrievals from direct solar spectral irradiance measurements in the ultraviolet, Atmos. Meas. Tech., 15, 1917-1930, https://doi.org/10.5194/amt-15-1917-2022

Erdélyi, R., et al.: 2022, HiRISE - High-Resolution Imaging and Spectroscopy Explorer - Ultrahigh resolution, interferometric and external occulting coronagraphic science, Exp. Astron., https://doi.org/10.1007/s10686-022-09831-2

Feierabend, M., Reiniger, M., Bories, J., Adibekyan, A., Häfner, R., Müller, C., Fehse, D., Gröbner, J., Müller, I., Monte, C.: 2022, Development and operation of the hemispherical blackbody (HSBB) for the calibration of infrared radiometers with a hemispherical acceptance angle, Opt. Express, 30, 46991-47003.

Fountoulakis, I., Papachristopoulou, K., Proestakis, E., Amiridis, V., Kontoes, C., Kazadzis, S.: 2022, Effect of aerosol vertical distribution on the modeling of solar radiation, Remote Sens., 14, 1143.

Gkikas, A., Proestakis, E., Amiridis, V., Kazadzis, S., Di Tomaso, E., Marinou, E., Hatzianastassiou, N., Kok, J. F., García-Pando, C. P.: 2022, Quantification of the dust optical depth across spatiotemporal scales with the MIDAS global dataset (2003-2017), Atmos. Chem. Phys., 22, 3553-3578, https://doi.org/10.5194/acp-22-3553-2022

Golubenko, K., Rozanov, E., Kovaltsov, G., Usoskin, I.: 2022, Zonal mean distribution of cosmogenic isotope (^{7}Be, ^{10}Be, ^{14}C, and ^{36}Cl) production in stratosphere and troposphere, J. Geophys. Res. Atmos., 127, e2022JD036726, https://doi.org/10.1029/2022JD036726

Harra, L., et al.: 2022, Experimental Astronomy, 54, 2-3, 157-183, https://doi.org/10.1007/s10686-021-09769-x

Hou, X., Papachristopoulou, K., Saint-Drenan, Y.-M., Kazadzis, S.: 2022, Solar radiation nowcasting using a Markov chain multi-model approach, Energies, 15, 2996, https://doi.org/10.3390/en15092996

Hülsen, G., Gröbner, J., Pfiffner, D., Gyo, M., Kouremeti, N., Föller, J.: 2022, Angular responsivity of ground-based and space-based direct solar irradiance radiometers, J. Phys. Conf. Ser., 2149, 012001, https://iopscience.iop.org/article/10.1088/1742-6596/2149/1/012001/meta

Karagkiozidis, D., Friedrich, M. M., Beirle, S., Bais, A., Hendrick, F., Voudouri, K. A., Fountoulakis, I., Karanikolas, A., Tzoumaka, P., Van Roozendael, M., Balis, D., Wagner, T.: 2022, Retrieval of tropospheric aerosol, NO_2, and HCHO vertical profiles from MAX-DOAS observations over Thessaloniki, Greece: intercomparison and validation of two inversion algorithms, Atmos. Meas. Tech., 15, 1269-1301, https://doi.org/10.5194/amt-15-1269-2022

Karagodin, A., Rozanov, E., Mironova, I.: 2022, On the possibility of modeling the IMF by weather coupling through GEC-related effects on cloud droplet coalescence rate, Atmosphere, 13, 881, https://doi.org/10.3390/atmos13060881

Karagodin-Doyennel, A., Rozanov, E., Sukhodolov, T., Egorova, T., Sedlacek, J., Ball, W., Peter, T.: 2022, The historical ozone trends simulated with the SOCOLv4 and their comparison with observations and reanalyses, Atmos. Chem. Phys., 22, 23, 15333-15350, https://doi.org/10.5194/acp-22-15333-2022

Karanikolas, A., Kouremeti, N., Gröbner, J., Egli, L., Kazadzis, S.: 2022, Sensitivity of aerosol optical depth trends using long-term measurements of different sun photometers, Atmos. Meas. Tech., 15, 5667-5680, https://doi.org/10.5194/amt-15-5667-2022

Kiselev, A., Rozanov, E., Frolkis, V., Smyshlyaev, S., Leonidovich Karol, I.: 2022, 70 Years in Science, ISSN 0001-4338, Izvestiya, Atmospheric and Oceanic Physics, 58, 2, 111-120, https://doi.org/10.1134/S0001433822020050

Koenigsberger, G., Morrell, N., Hillier, D. J., Schmutz, W., Gamen, R., Arias, J. I., Barba, R., Ferrero, G.: 2022, Observational constraints on the HD 5980 wind-wind collision, Rev. Mex. Astron. Astrof., 58, 403, https://doi.org 10.22201/ia.01851101p.2022.58.02.19

Kouremeti, N., Gröbner, J., Nevas, S.: 2022, Stray-light correction methodology for the precision solar spectroradiometer, J. Phys. Conf. Ser., 2149, 012002, https://iopscience.iop.org/article/10.1088/1742-6596/2149/1/012002/meta

Kouremeti, N., Nevas, S., Kazadzis, S., Gröbner, J., Schneider, P., Maria Schwind, K.: 2022, SI-traceable solar irradiance measurements for aerosol optical depth retrieval, Metrologia, 59, 4, https://doi.org/10.1088/1681-7575/ac6cbb

Maillard Barras, E., Haefele, A., Stübi, R., Jouberton, A., Schill, H., Petropavlovskikh, I., Miyagawa, K., Stanek, M., Froidevaux, L.: 2022, Dynamical linear modeling estimates of long-term ozone trends from homogenized Dobson Umkehr profiles at Arosa/Davos, Switzerland, Atmos. Chem. Phys., 22, 14283-14302, https://doi.org/10.5194/acp-22-14283-2022

Mandal, S., Chitta, Lakshmi P., Antolin, P., Peter, H., Solanki, S. K., Auchère, F., Berghmans, D., Zhukov, A. N., Teriaca, L., Cuadrado, R. A., Schühle, U., Parenti, S., Buchlin, É., Harra, L., Verbeeck, C., Kraaikamp, E., Long, D. M., Rodriguez, L., Pelouze, G., Schwanitz, C., Barczynski, K., Smith, P. J.: 2022, What drives decayless kink oscillations in active region coronal loops on the Sun?, Astron. Astrophys., 666, id.L2, 2022, https://doi.org/10.1051/0004-6361/202244403

Mironova, I., Sinnhuber, M., Bazilevskaya, G., Clilverd, M., Funke, B., Makhmutov, V., Rozanov, E., Santee, M., Sukhodolov, T., Ulich, T.: 2022, Exceptional middle latitude electron precipitation detected by balloon observations: implications for atmospheric composition, Atmos. Chem. Phys., 22, 6703-6716, https://doi.org/10.5194/acp-22-6703-2022

Monteiro, A., et al.: 2022, Multi-sectoral impact assessment of an extreme African dust episode in the Eastern Mediterranean in March 2018, Sci. Tot. Environ., 843, 156861, https://doi.org/10.1016/j.scitotenv.2022.156861

Montillet, J.-P., Finsterle, W., Kermarrec, G., Sikonja, R., Haberreiter, M., Schmutz, W., Dudok de Wit, T.: 2022, Data fusion of total solar irradiance composite time series using 41 years of satellite measurements, J. Geophys. Res. Atmos. 127, e2021JD036146, https://doi.org/10.1029/2021JD036146

Morgenstern, O., Kinnison, D. E., Mills, M., Michou, M., Horowitz, L. W., Lin, P., Deushi, M., Yoshida, K., O'Connor, F. M., Tang, Y., Abraham, N. L., Keeble, J., Dennison, F., Rozanov, E., Egorova, T., Sukhodolov, T., Zeng, G.: 2022, Comparison of Arctic and Antarctic stratospheric climates in chemistry versus no-chemistry climate models, J. Geophys. Res. Atmos., 127, e2022JD037123, https://doi.org/10.1029/2022JD037123

Nerobelov, G., Timofeyev, Y., Virolainen, Y., Polyakov, A., Solomatnikova, A., Poberovskii, A., Kirner, O., Al-Subari, O., Smyshlyaev, S., Rozanov, E.: 2022, Measurements and modelling of total ozone columns near St. Petersburg, Russia, Remote Sens., 2022, 14, 3944, https://doi.org/10.3390/rs14163944

Odermatt, J., Barczynski, K., Harra, L. K., Schwanitz, C., Krucker, S.: 2022, Spatial distribution of jets in active regions, Astron. Astrophys., 665, A29, https://doi.org/10.1051/0004-6361/202243120

Papachristopoulou, K., Fountoulakis, I., Gkikas, A., Kosmopoulos, P. G., Nastos, P. T., Hatzaki, M., Kazadzis, S.: 2022, 15-Year analysis of direct effects of total and dust aerosols in solar radiation/energy over the Mediterranean basin, Remote Sens. 14, 1535, https://doi.org/10.3390/rs14071535

Pikulina, P., Mironova, I., Rozanov, E., Karagodin, A.: 2022, September 2017 solar flares effect on the middle atmosphere, Remote Sens., 14, 2560, https://doi.org/10.3390/rs14112560

Quintero Noda, C., Schlichenmaier, R., Bellot Rubio, L. R. and 278 more (contains Barczynski, K.): 2022, The European solar telescope, Astron. Astrophys., 666, 21, https://doi.org/10.1051/0004-6361/202243867

Raptis, I.-P., Moustaka, A., Kosmopoulos, P., Kazadzis, S.: 2022, Selecting surface inclination for maximum solar power, Energies, 15, 4784, https://doi.org/10.3390/en15134784

Remesal, O. A., Finsterle, W.: 2022, New detector for next generation solar radiometers, Optical Materials Express, 12, 10, 3882-3893, https://doi.org/10.1364/OME.469927

Rochus, P., et al.: 2022, The Solar Orbiter EUI instrument: The Extreme Ultraviolet Imager (corrigendum), Astron. Astrophys., 665, id.C1, https://doi.org/10.1051/0004-6361/201936663e

Schmutz, W.: 2022, Minima epoches of BF Draconis observed by the TESS satellite, Res. Notes AAS, 6, 173, https://doi.org/10.3847/2515-5172/ac8d0c

Shokri, Z., Alipour, N., Safari, H., Kayshap, P., Podladchikova, O., Nigro, G., Tripathi, D.: 2022, Synchronization of small-scale magnetic features, blinkers, and coronal bright points, Ap. J., 926 (1), 42, https://doi.org/10.3847/1538-4357/ac4265

Sterling, A., Schwanitz, C., Harra, L., Raouafi, N., Panesar, N., Moore, R.: 2022, Inconspicuous solar polar coronal X-ray jets as the source of conspicuous Hinode/EUV Imaging Spectrometer Doppler outflows, Ap. J., 940, 17, https://doi.org/10.3847/1538-4357/ac9960

Telloni, D., et al.: 2022, Observation of magnetic switchback in the solar corona, Ap.J., 936, 25, https://doi.org/10.3847/2041-8213/ac8104

Toledano, C., Cachorro, V. E., Mateos, D., Roman, R., Gonzalez, R., Smirnov, A., Grobner, J., Kazadzis, S., Kouremeti, N.: 2022, Sun Photometers, book chapter in "Field Measurements for Passive Environmental Remote Sensing", edited by Nicholas R. Nalli, Elsevier, ISBN: 978-0-12-823953-7

Media - Selected Highlights

7 Jan. 2022, “Davoser Persönlichkeiten: Dr. Mörikofer, der ehemalige PMOD/WRC-Direktor”, Davoser Zeitung newspaper.
https://www.pmodwrc.ch/wp-content/uploads/2022/01/PressArticle_20220107_DZ.pdf

13 Jan. 2022, “Unser Zentralgestirn im Blick”, Interview with Louise Harra on diversity, SCNAT website.
https://map.scnat.ch/de/activities/women_scientists/uuid/i/67bfeb3c-f02b-59a4-b037-d4ea7e010c40-Unser_Zentralgestirn_im_Blick

15 Feb. 2022, “PMOD/WRC-Werkstätte”, Davoser Zeitung newspaper
https://www.pmodwrc.ch/wp-content/uploads/2022/02/PressArticle_20220215_DZ.pdf

29 Mar. 2022, “Globales Trübungsmessnetz mit Sitz in Davos”, Davoser Zeitung newspaper.
https://www.pmodwrc.ch/wp-content/uploads/2022/04/PressArticle_20220329_DZ.pdf

7 Apr. 2022, “Support for national activities in the space sector”, article including our contribution on Solar-C/SoSpIM by SERI.
https://www.sbfi.admin.ch/sbfi/en/home/services/publications/data-base-publications/s-n-2022-2/s-n-2022-2b.html

8 Apr. 2022, “Architektur – Erfolgreiches Perlentauchen”, Davoser Zeitung newspaper.
https://www.pmodwrc.ch/wp-content/uploads/2022/04/PressArticle_20220408_DZ.pdf

11 Apr. 2022, “Davos und der Solarstrom”, EWD website.
https://www.pmodwrc.ch/wp-content/uploads/2022/04/PressArticle_20220411_EWD.pdf

26 Jul. 2022, “Solar Orbiter – der Sonne so nah wie noch nie”, Davoser Zeitung newspaper.
https://www.pmodwrc.ch/wp-content/uploads/2022/07/PressArticle_20220726_DZ.pdf

Sep. 2022, “Traceability of Solar UV Radiometers”, PMOD/WRC video for BIPM-WMO Metrology for Climate Action, Dr. G. Hülsen, PMOD/WRC.
https://www.pmodwrc.ch/wp-content/uploads/2022/11/Video_20221103_Traceability_Solar_UV_Filter_Radiometers.mp4

23 Sep. 2022, “Eine besondere Fahrt: Vom PMOD/WRC in Davos nach Teneriffa”, Davoser Zeitung newspaper.
https://www.pmodwrc.ch/wp-content/uploads/2022/09/PressArticle_20220923_DZ.pdf

Oct. 2022, “Getting close to the Sun: A space mission on a journey to discovery”, article in Swiss Physical Society magazine, Louise Harra.
https://www.sps.ch/fileadmin/articles-pdf/2022/Mitteilungen_Sun-Space-Mission.pdf

9 Dec. 2022, “Die Sonne birgt noch viele Geheimnisse”, Davoser Zeitung newspaper.
https://www.pmodwrc.ch/wp-content/uploads/2022/12/PressArticle_20221209_DZ.pdf

Administration

Personnel Department

Eliane Tobler and Kathrin Anhorn

The year 2022 was an eventful year from a personnel and administrative point of view.

In May, the focus was on the PMOD/WRC building. During the World Economic Forum (WEF 2022), the light artist Gerry Hofstetter used our exterior facade (Figure 1) to display various images based on the theme of Space. As the light display was a crowd puller, so was our employee's work. We were able to present our work and research results at various public events and research conferences after the forced break caused by Covid. We are very pleased that the demand for guided tours of the institute has increased again.

In addition to events for the public, two employee events were held. The Christmas dinner, which had already been postponed twice, took place in August 2022. At the end of the year in December, the entire workforce met for a Christmas aperitif at the local brewery "Davos Craft Beer". The highlights of the year, amongst other topics, were discussed and reviewed over some excellent beer.

Figure 1. View of the PMOD/WRC facade during the light show.

Awards and Degrees

Various successes of our apprentices were celebrated in July: Sotirios Filios successfully completed his apprenticeship (commercial studies, EFZ). He supported the administration department until the end of the year. Dario Tannò, in the 4th year of training (sport and commercial studies, EFZ) also completed the academic part of his training with flying colours. The professional exams will be held in the summer of 2023. In the technology department, Christian Fringer completed his training as an electronics technician (EFZ) with top marks. We congratulate our (former) apprentices and wish them all the best for the future. The PMOD/WRC also supervises numerous PhD, master and project students every year. We thank all students for their valuable contributions to the institute. A list of their names can be found on the following pages. In December, we celebrated another success. Arseni Doyennel received his doctoral degree with his work on the topic "Study of the Past and Future Evolution of the Ozone Layer". He left us at the end of the year to start a new job in the Netherlands.

Personnel Changes

All departments of the institute recorded changes in personnel. Christian Stiffler reached retirement age in April. We thank him for his many years of support and appreciate that we can still count on his expertise and support today. In June, Eliane Tobler, a former commercial apprentice EFZ (2011 - 2015), took over the management of the administration including HR and finance after successfully completing her master's degree in accounting and controlling.

At the end of June, our Structural Engineer Liviu Zambila left us after completing his work on one of our space projects. After the successful relocation of the ozone measurement series from Arosa to Davos and ensuring the sustainable transfer of knowledge, we were able to honour and say goodbye to Herbert Schill with a celebration of his retirement at the end of June. Another former apprentice, Kathrin Anhorn (2014 - 2017), returned to PMOD/WRC in July. Kathrin has been supporting the administration team ever since.

The second half of the year began by welcoming our new apprentice. On 1 August 2022, Karim El Sammra started his four-year apprenticeship as an EFZ electronics technician. As of November, the Solar Orbiter research team was strengthened by Dr. Nils Janitzek. In addition to many internal changes, the supervisory body also underwent changes. During the autumn meeting, the achievements of three people were recognised. We would like to thank Bertrand Calpini, Peter Blattner and Walter Ammann for their many years of support and wish them all the best for their well-deserved retirement. In December, Eugene Rozanov retired after being more than 20 years at PMOD/WRC. Timofei Sukhodolov, who returned to the institute in October after a break, will lead the climate group.

We would like to thank our former employees for their work and wish them all the best for their future. We extend a warm welcome to our new employees and look forward to future cooperation.

Civil Service Conscripts

As a long-standing provider of community service deployments, numerous civil service conscripts support us year after year. In the year under review, we would like to thank Ueli Honauer, Tishanth Sinnathamby, Marcel Stucki, Enea Tambini and Sandro Vattioni for their commitment.

PMOD/WRC Workshop Renovation

Christian Thomann and Pascal Schlatter

Since the PMOD/WRC moved into the old school building in Davos Dorf in 1977, the former gymnasium has been used as a mechanical workshop. All prototypes for ground and space-based instruments were, and still are, manufactured here.

Up to 2022, the gym consisted entirely of the old building structure that increasingly was no longer able to meet the requirements of modern lathe machines. The original floor consisted of a structure made up of different layers of wood, while the walls had no insulation. As a result, neither temperature stability nor the prevention of vibration dampening of our five-ton CNC lathe machine could be met. In addition, the room could only be reached via stairs, which made it increasingly difficult to deliver heavy parts. Last but not least, another goal was the ability to initiate immediate environmental protection measures in the event of any leakages. These aspects led the PMOD/WRC to carry out various renovations to the workshop, which began in March 2022. PMOD/WRC was able to count on the generous financial support of the "Bundesamt für Bauten und Logistik", to the amount of CHF 1.1 million.

The old school building was classified as a property worthy of protection by the Graubünden Cultural Heritage authority. The project team was not only confronted with the requirements of a functioning workshop, but also with those of the authority. The cultural heritage renovation work is particularly evident on the exterior of the building: great effort was devoted to the reproduction of the former entrance door. The door (see Figure 1), made by hand with attention to detail, now adorns the workshop building on the car-park side.

Figure 1. The new door.

Figure 2. View of the newly renovated workshop at PMOD/WRC.

A ground-level gate was installed on the west side of the building, through which heavy loads can be delivered. It was important to ensure that the original appearance of the historical building was not affected by the additional gate. Preserving the original character was always a priority, not only for the building structure, but also the interior. Accordingly, the old panelling was dismantled, refurbished and, where necessary, renewed. The stairs to the gallery and the floor coverings were intentionally replaced with solid ash wood. To meet the requirements of a smoothly operating workshop, the following construction work was carried out: The original floor was removed and replaced by concrete floor slabs. In addition, floor heating was installed under the final anti-slip and anti-static floor covering. Two office workplaces and assembly rooms were created on the ground floor of the workshop. A gallery for storage space, a spray-room with ventilation and a changing room were created above these rooms. The building was insulated with natural products such as sheep's wool and Biotherme from the Haga company. Channels for electrical connections and compressed air lines were fixed on the ceiling. This will allow greater flexibility when purchasing new workshop machines in the future.

PMOD/WRC would like to thank Christian Thomann for his exceptional commitment. Christian managed the renovation project for PMOD/WRC and made a significant contribution to its success with his many years of experience. Special thanks also go to the team at Hartmann AG Architects, who ensured that all the needs and expectations of PMOD/WRC and the demands of Graubunden Cultural Heritage were met or exceeded. Another thank you goes to the "Bundesamt für Bauten und Logistik", in particular to the project manager Maike Lausen and the responsible persons at MeteoSwiss, who financially supported the renovation. These people and institutions have made a significant contribution to PMOD/WRC being able to carry out sustainable research and development at the highest level in a unique atmosphere.

Personnel

Scientific Personnel

Prof. Dr. Louise Harra	Director, affiliated Prof. at ETH-Zurich, Head of Solar Physics Group, Solar Physicist
Prof. Dr. Werner Schmutz	PI DARA/PROBA-3 Scientist, former Director, Physicist
Dr. Krzysztof Barczynski	Postdoc, Solar Physics Group, Physicist
Dr. Luca Egli	Scientist, WCC-UV and Ozone Sections, Physicist
Dr. Tatiana Egorova	Scientist, Climate Group, Climate Scientist
Dr. Natalia Engler	Instrument Scientist, WRC-SRS Section, Physicist
Dr. Wolfgang Finsterle	Co-Head WRC, Head WRC-Section Solar Radiometry, Physicist
Dr. Julian Gröbner	Co-Head WRC, Head WRC-Sections IR radiometry, WORCC, WCC-UV and Ozone Section, Physicist
Dr. Margit Haberreiter	Project Manager/Scientist Space, Instrument Scientist, WRC-SRS Section
Dr. Gregor Hülsen	Scientist, WCC-UV Section, Physicist
Dr. Nils Janitzek	Postdoc, Solar Physics Group, Physicist (since 11.2022)
Dr. Stylianos A. Kazantzis	Scientist, WORCC Section, Physicist
Dr. Natalia Kouremeti	Scientist, WORCC Section, Physicist
Dr. Akriti Masoom	Postdoc, WORCC Section, Physicist (since 03.2022)
Dr. Jean-Philippe Montillet	TSI Instrument Scientist, Geoscientist
Dr. Stephan Nyeki	Scientist, IR Radiometry Section, Physicist
Dr. Elena Podladchikova	Instrument Scientist, Solar Orbiter SPICE and EUI (until 02.2022)
Dr. Eugene Rozanov	Scientist, Climate Group, Physicist (former Head of Climate Group; until 12.2022)
Herbert Schill	Scientist, Ozone Section, Environmental Scientist (until 06.2022)
Dr. Jan Sedlacek	Scientist, Climate Group, Climate Scientist
Dr. Timofei Sukhodolov	Head of Climate Group, Climate Scientist (since 09.2022)
Andrea Battaglia	PhD student, ETH Zurich, FHNW
Hannah Collier	PhD student, ETH Zurich, FHNW
Arseni Doyennel	PhD student, 4th year, ETH Zurich (until 12.2022)
Xinyuan Hou	PhD student, 2nd year, ETH Zurich
Angelos Karanikolas	PhD student, 3rd year, WRC-WORCC Section
Jessica Kult-Herdin	PhD student, BOKU-met, Vienna, Austria
Kyriakoula Papachristopoulou	PhD student, NKU Athens, Greece
Conrad Schwanitz	PhD student, 4th year, ETH Zurich
Christina Brodowsky	MSc student, ETH Zurich (since 09.2022)
Adriana De Sassi	MSc student, ETH Zurich (since 09.2022)
Andrin Nico Jörimann	MSc student, ETH Zurich (since 09.2022)
Andreas Kuttel	MSc student, ETH Zurich (since 05.2022)
Justin Mazenauer	MSc student, ETH Zurich (until 12.2022)
Muriel Stiefel	MSc student, ETH Zurich (until 05.2022)
Sofia Tynelius	MSc student, ETH Zurich (until 03.2022)
Elia Wunderlin	MSc student, ETH Zurich (since 09.2022)
Nora Benz	BSc student, ETH Zurich (since 09.2022)
Jesse Connolly	BSc student, ETH Zurich (since 09.2022)
Alicia Köster	BSc student, ETH Zurich (since 09.2022)

Technical Personnel

Silvio Koller	Co-Head Technical Department, Project Manager Space
Daniel Pfiffner	Co-Head Technical Department, Project Manager Space
Andrea Alberti	Project Manager Space
Lloyd Beeler	Electronics Engineer, MSc
Valeria Büchel	Project Manager Space
Karim El Sammra	Electronics Apprentice, 1st year (since 08.2022)
Christian Fringer	Electronics Apprentice, 4th year (until 07.2022)
Matthias Gander	Electronics Engineer, BSc
Manfred Gyo	Electronics Engineer, MSc
Patrik Langer	Mechanics Engineer, MSc
Linus Luzi	Electronics Apprentice, 4th year
Nic Matthes	Poly-Mechanic Apprentice, 4th year
Leandro Meier	Electronics Engineer, BSc
Pascal Schlatter	Mechanic, Head Workshop, Safety Officer
Marco Senft	IT Systems Administrator
Marcel Spescha	Technician / Mechanics Dept.
Dan Tye	System Engineer, Space Projects (until 06.2022)
Fabrizio Vignali	IT Systems Administrator
Liviu Zambila	Structural Engineer, MSc (until 06.2022)

Technical Personnel within the Science Department

Jakob Föller	Technical Employee
Ricco Soder	Research Engineer, Quality Systems Manager
Christian Thomann	Technician
Franz Zeilinger	Technical Engineer, BSc, Ozone Section

Administration

Eliane Tobler	Head HR / Finances, Accountant, MSc (since 06.2022)
Barbara Bücheler	Head Human Resources / Finances / Administration (until 06.2022)
Kathrin Anhorn	Administration, Book-Keeping (since 06.2022)
Sotirios Filios	Administration Apprentice, 3rd year (until 12.2022)
Irene Keller	Administration, Import/Export
Angela Lehner	Administration, Book-Keeping
Christian Stiffler	Accountant (until 04.2022)
Dario Tannò	Administration Apprentice, 4th year

Caretaker(s)

Maria Sofia Ferreira Pinto	General caretaker, cleaning
Fatima Da Conceicao Alves D.C.	General caretaker, cleaning (back-up)

Civilian Service Conscripts

Ueli Honauer	06.12.2021 - 31.05.2022
Tishanth Sinnathamby	04.04.2022 - 22.05.2022
Marcel Stucki	03.01.2022 - 04.03.2022
Enea Tambini	06.06.2022 - 05.08.2022
Sandro Vattioni	25.07.2022 - 28.09.2022

Lecture Courses, Participation in Commissions

Louise Harra

Member of the follow-up committee of the CLOSE_UP project, Belgium.
Member of the advisory board for the "Solar Physics" journal.
Secretary of the Swiss Committee of Space Research.
Board member of Davos Science City.
Chair of ESA Heliophysics User archive committee.
Member of Board of Reviewing Editors for the "Science" journal.
Subject editor for Proceedings of the Royal Society A: Mathematical, Physical & Engineering Sciences.
Chair of ISSI science board.
Ministerial position on management committee of Armagh Observatory and Planetarium.
Risk and Audit committee of Armagh Observatory and Planetarium.
Co-chair of the Scientific Advisory Board of the MPS.
Member of the ESA space science advisory council.
Co-PI of EUV Imager, co-I on SPICE on Solar Orbiter.
Co-I on the NASA IRIS mission.
PI of SoSpIM instrument on the JAXA Solar-C mission.
Member of selection panel for editor of the "Solar Physics" journal.
Member of the ESA Athena Independent Science Review Team.
External member of the SNF evaluation commission Postdoc. Mobility in the area of Mathematics and Engineering sciences.
Member of RAS editorial board for the "Techniques and Instruments" journal.
Member of Congressi Stefano Franscini science committee.
Member of COSPAR Task Group on Establishing an International Geospace Systems Program (IGSP).
Lecture course: “The Sun, Stars and Planets - Properties, Processes and Interactions”, D-PHYS, ETHZ.
Lecture course: “Space research and exploration”, Autumn semester, D-PHYS, ETHZ.
Lecture course: Alpbach Summer School (Sun, stars and heliosphere), July 2022.

Werner Schmutz

Honorary Member of the International Radiation Commission (IRC, IAMAS).
PI of DARA on PROBA-3.
Co-I of EUV and SPICE instruments on Solar Orbiter.

Wolfgang Finsterle

Member of ISO-TC180/SC1.
Member of WMO ET-RR.

Julian Gröbner

Member Expert Review Board of the EUMETSAT FRM4SOC project.
Rapporteur for the Earth Energy Balance Topic, BIPM-WMO Metrology for Climate Action Workshop, 2022.
Member of the Dobson Ad-Hoc Committee, http://www.o3soft.eu/dobsonweb/committee.html, since 2021.
Member of the expert team on atmospheric composition measurement quality and QA-Central facilities of the WMO since 2020.
Member of the scientific advisory group for Ozone and UV in the Global Atmosphere Watch programme of the WMO (as of 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.
Member of the Expert Team on radiation references "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 International Ozone Commission, IAMAS since 2016.
Lecture course: “Atmospheric Remote Sensing”, D-USYS, ETHZ.

Eugene Rozanov	Co-chair of SCOSTEP PRESTO project. Member of the MDPI editorial board for the “Atmosphere” journal. Member of the RAS editorial board for the “Physics of the Atmosphere and Ocean” journal. Guest Editor for JGR Atmospheres, "Monitoring the Earth Radiation Budget and its Implications to Climate Simulations: Recent Advances and Discussions".
Margit Haberreiter	President of the Swiss Society for Astronomy and Astrophysics. Member Swiss National SCOSTEP Committee. Member of the Solar Irradiance Working Group in the International Radiation Commission. Swiss Delegate to WMO’s ET-SpWx (formerly IPT-SWeISS). Co-I on EUI and SPICE on Solar Orbiter. Lead ISSI International Team “Towards the determination of the Earth Energy Imbalance from Space”. Expert Member ISSI International Team “Modeling Space Weather And Total Solar Irradiance Over The Past Century”, Lead: Alexei Pevtsov. Topical Editor of the "Annales Geophysicae" journal. Reviewer for the Astrophysical Journal Supplement Series, "Solar Physics, Earth and Space Science". Editor of Proceedings of IPC-XIII/FRC-V/IPgC-III Symposium. Guest Editor for JGR Atmospheres, "Monitoring the Earth Radiation Budget and its Implications to Climate Simulations: Recent Advances and Discussions".
Stylianos Kazantzis	Member of the International Radiation Committee (IAMAS-IRC). Member of the Scientific Advisory Group for Aerosols of WMO (WMO-SAG). Member of the Expert Team on Atmospheric Composition Measurement Quality of WMO. Member of the Expert Team on Atmospheric Composition and Network Evolution of the World Meteorological Organization. Member of the Global Atmospheric Watch – Swiss panel. Member of the editorial board for the "Atmospheric Chemistry and Physics" journal. Chair of COST Action, Harmonia. Swiss representative of COST Action, Probe. Lecture course: “Atmospheric Remote Sensing”, D-USYS, ETHZ.
Timofei Sukhodolov	Guest editor of the research topic, “The evolution of the stratospheric ozone -Volume II” of the "Frontiers in Earth", Science journal . Member of the SPARC project, “High Energy Particle Precipitation in the Atmosphere”, HEPPA-3. Co-lead of the SPARC activity, “Interactive stratospheric aerosol model intercomparison”, ISA-MIP. Co-PI of the SOCOLv4 model, SPARC activity, “Chemistry-climate model initiative phase 2”, CCMI-2022. Lecture course: Atmospheric pollution and climate change, BOKU-Met, Vienna, Austria.
Jean-Philippe Montillet	Reviewer for the journals: Journal of Geophysical Research (JGR) Atmospheres (AGU), Earth Spaces Sciences (AGU), Remote Sensing (MDPI) Guest Editor for JGR Atmospheres, "Monitoring the Earth Radiation Budget and its Implications to Climate Simulations: Recent Advances and Discussions".
Luca Egli	Member IAMAS International Radiation Commission (since 2016).
Natalia Engler	Member of Expert committee of Swiss National Competition 2021 "Schweizer Jugend forscht!"
Andrea Alberti	Advisor for the Space4Impact non-profit initiative. Expert Evaluator for the Bench2Biz International workshop for young and aspiring entrepreneurs. Expert for the 4^{th} Cassini Hackaton / Swiss Chapter. Expert Evaluator for the Space2Earth Accelerator for startups and scale-up businesses. Lecture course: EPFL Space Economy MOOC, 7 on-line modules published in 03/2022.

Public Seminars given at PMOD/WRC

25 Jan. 2022 Don Hassler (SWRI, USA)
The Solaris mission
34 attendees

7 Mar. 2022 Maria Madjarska, (MPS, Germany)
What do the spectral and imaging views by IRIS and SDO/AIA/HMI together with data-driven modelling tell us about quiet-Sun's ubiquitous mini-eruptions and microflares?
30 attendees

4 Apr. 2022 Shin Toriumi (Univ. Tokyo, Japan)
Universal scaling laws for the solar and stellar atmospheric heating
20 attendees

11 Apr. 2022 Nicola Brehms (ETHZ Zurich, Switzerland)
Detection of solor proton events by using radio-carbon in tree-rings
20 attendees

23 Jun. 2022 René Stübi (MeteoSwiss, Switzerland) and Herbert Schill (PMOD/WRC)
Ozone seminar

17 Aug. 2022 Alexander Shapiro (MPS, Germany)
Understanding stellar atmospheres: advances brought by solar know-how

11 Oct. 2022 Dibyendu Nandi (Indian Institute of Science Education and Research, IISER, Kolkata, India)
Long term solar variability
33 attendees

5 Dec. 2022 Nil Janitzek (PMOD/WRC)
From the solar wind to suprathermal and energetic particles: Utilizing ion composition measurements to understand particle acceleration in the inner heliosphere
15 attendees

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

31 Jan. 2022	"SI-traceable Systems for Solar Radiation", presentation by Julian Gröbner, ESA QA4EO, virtual meeting.
5. Apr. 2022	The Advisory Commission (Aufsichts-Kommission) meeting.
18 Apr. 2022	"Recent modelling activities with the chemistry-climate model SOCOL and the whole atmosphere model EAGLE", seminar by Timofei Sukhodolov, Oulu University, Oulu, Finland.
4 May 2022	GAW-CH annual meeting, 26 - 27 April 2022, various presentations by PMOD/WRC staff, MeteoSwiss, Zurich, Switzerland.
25 May 2022	"Study of atmospheric processes from the surface to near space using the SOCOL and EAGLE models", presentation by Eugene Rozanov, MSU physics dept. public seminar, CH.
30 Jun. 2022	"Solar Irradiance Variability and Measurements", presentation by Margit Haberreiter, Sino-Swiss Space Sci and Tech. Cooperation Online Meeting, Transport Museum, Lucerne, CH.
9 Jun. 2022	Board of Trustees (Stiftungsrat) meeting.
5 Aug. 2022	"Solar Irradiance Meas. and Modelling", presentation by Margit Haberreiter, ISSI International Team Meeting on "Modeling space weather and Total Solar Irradiance over the past century", Bern, CH.
14 Sep. 2022	"How well do we need to measure solar UV irradiance to still be useful?", presentation by Julian Gröbner, European Conference on Solar UV Monitoring and Personal UV Exposure, Vienna, Austria.
27 Sep. 2022	"The World Calibration Center for UV (WCC-UV)", presentation by Julian Gröbner, Metrology for Climate Action, bipmwmo22.org, 26 - 30 September.
29 Sep. 2022	"TSI and OLR measurements with CLARA", presentation by Margit Haberreiter, 3rd meeting of the ISSI International Team Towards determining Earth Energy Imbalance from Space, Bern, CH.
11 Oct. 2022	"Metrology for aerosol optical properties", presentation by Julian Gröbner, TECO, Paris, France.
11 Oct. 2022	"The PMODWRC activities in ACTRIS", presentatiaon by Stelios Kazadzis, ACTRIS-CH meeting, Bern, Switzerland.
12 Oct. 2022	"The Precision Solar Spectroradiometer PSR", Professor Dr. Vilho Väisälä Award 2020 to Natalia Koureti and Julian Gröbner for an Outstanding Research Paper on Instruments and Methods of Observation.
13 - 23 Oct. 2022	OLMA Exhibition, participation with a PMOD/WRC exhibit, St. Gallen, Switzerland.
31 Oct. 2022	Talk and tour at PMOD/WRC for Heads of Department of Middle and Higher Education of Fürstentum Liechtenstein and Canton St. Gallen, Louise Harra and Julian Gröbner.
9 Nov. 2022	GAW-CH Landesausschussmeeting, presentations by several PMOD/WRC staff, MeteoSwiss, Zurich, Switzerland.
14. Nov. 2022	The Advisory Commission (Aufsichts-Kommission) meeting.
18 Nov. 2022	Board of Trustees (Stiftungsrat) meeting.
26 Nov. 2022	"Climate – does it have anything to do with me?", presentation by Jan Sedlacek, Engadine Childrens University of the Academia Engiadina.
15 Dec. 2022	TRUTHS/CSAR Swiss Industry Day attended by Silvio Köller and Andrea Alberti.

Bilanz per 2022 (inklusive Drittmittel) mit Vorjahresvergleich

Aktiven	31.12.2022 CHF	31.12.2021 CHF
Flüssige Mittel	2’223’046.07	2’091’765.44
Forderungen	48’416.50	88’338.15
Aktive Rechnungsabgrenzungen	147’685.38	830’857.44
Delkredere Drittmittel	0.00	-300’000.00
Warenvorräte	1’000.00	1’000.00
Total Aktiven	2’420’147.95	2’711’961.03

Passiven		
Verbindlichkeiten	80’356.45	411’312.45
Passive Rechnungsabgrenzung	909’568.74	1’236’259.55
Rückstellungen	1’150’000.00	840’000.00
Eigenkapital	280’222.76	224’389.03
Total Passiven	2’420’147.95	2’711’961.03

Erfolgsrechnung 2022 (inklusive Drittmittel) mit Vorjahresvergleich

Ertrag	CHF	CHF
Beitrag Bund Betrieb WRC	1’489’200.00	1’489’200.00
Beitrag Bund (BBL), Unterhalt Gebäude	1’250’185.65	77’922.60
Beitrag Kanton Graubünden WRC	509’268.00	509’268.00
Beitrag Kanton Graubünden für ETH Prof.	240’000.00	240’000.00
Beitrag Gemeinde Davos	664’191.00	664’191.00
Beitrag Gemeinde Davos, Mieterlass	160’000.00	160’000.00
Dienstleistungsauftrag MeteoSchweiz OZON	257’587.80	272’003.40
Dienstleistungsauftrag WMO Genève	21’881.00	21’881.00
Overhead SNF	27’422.50	44’461.40
Overhead Projekte	219’186.46	49’580.00
Instrumentenverkäufe	196’296.00	41’650.00
Reparaturen und Kalibrationen	235’531.55	233’009.33
Ertrag Dienstleistungen	61’602.70	63’498.51
Übriger Ertrag	6’426.20	827.85
Finanzertrag	200.70	0.00
Ausserordentlicher Ertrag	129’034.51	0.00
Drittmittel	2’132’769.14	2’488’050.19
Bildung Delkredere Drittmittel	0.00	-300’000.00
Total Ertrag	7’600’783.21	6’055’543.28

Aufwand		
Personalaufwand	4’557’109.00	4’711’968.30
Investitionen Observatorium	137’029.45	197’407.75
Investitionen Drittmittel	15’492.35	1’300.95
Unterhalt Gebäude (Beitrag Bund)	1’250’185.65	77’922.60
Unterhalt	86’075.17	63’751.55
Verbrauchsmaterial Observatorium	38’415.80	55’335.07
Verbrauchsmaterial Drittmittel	261’708.95	299’541.94
Verbrauch Commercial	111’013.57	104’688.70
Reisen, Kurse	81’698.37	45’763.80
Raumaufwand/Energieaufwand	260’054.40	259’488.70
Versicherungen, Verwaltungsaufwand	122’579.66	116’357.57
Finanzaufwand	4’483.75	7’459.24
Übriger Betriebsaufwand	264’486.44	62’806.71
Ausserordentlicher Aufwand	44’616.92	896.25
Total Aufwand	7’234’949.48	6’004’689.13
Jahresergebnis vor Bildung/Auflösung Rückstellungen	**365’833.73**	**50’854.15**
Auflösung Rückstellungen	0.00	15’000.00
Bildung Rückstellungen	310’000.00	0.00
Jahresergebnis	55’833.73	**65’854.15**
	7’600’783.21	6’055’543.28

Abbreviations

AERONET	Aerosol Robotic Network, GSFC, USA
AOD	Aerosol Optical Depth
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 experiment 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	Cyrogenic Solar Absolute Radiometer (PMOD/WRC research instrument, ground-based)
DARA	Digital Absolute Radiometer (PMOD/WRC experiment onboard the ESA PROBA-3 formation flying mission)
EAGLE	Entire Atmosphere Global Model
ECV	Essential Climate Variable
EMRP	European Metrology Research Programme
ESA	European Space Agency
EUI	Extreme Ultraviolet Imager (PMOD/WRC participation in EUI, 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, to be launched in the near future
GAW	Global Atmosphere Watch, a WMO Research Programme
GCM	General Circulation Model
GCR	Galactic Cosmic Rays
HEPPA	High Energy Particle Precipitation in the Atmosphere (SPARC activity)
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
MITRA	Monitor to Determine the Integrated Transmittance (PMOD/WRC research instrument)
MRA	Mutual Recognition Arrangement
NASA	National Aeronautics and Space Administration, Washington DC, USA

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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)
POLE	Past and Future of the Ozone Layer Evolution
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 Ultraviolet Measurements in Europe
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
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	SolO; 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)
SPARC	Stratosphere-troposphere Processes And their Role in Climate (a core project of the World Climate Research Programme)
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
TEC	Total Electron Content
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	Cyrogenic Solar Absolute Radiometer onboard the TRUTHS mission (PMOD/WRC space-based experiment)
TSI	Total Solar Irradiance
VHS	Ventilation Heating System (manufactured at PMOD/WRC)
VIRGO	Variability of Solar Irradiance and Gravity Oscillations (PMOD/WRC experiment 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)

Annual Report 2022

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