pmod wrc

Annual Report Jahresbericht 2018

Physikalisch-Meteorologisches Observatorium Davos und Weltstrahlungszentrum

Mission

Das PMOD/WRC

- dient als internationales Kalibrierzentrum für meteorologische Strahlungsmessinstrumente
- entwickelt Strahlungsmessinstrumente für den Einsatz am Boden und im Weltraum
- erforscht den Einfluss der Sonnenstrahlung auf das Erdklima.

Auftragerteilung

Das Physikalisch-Meteorologische Observatorium Davos (PMOD) beschäftigt sich seit seiner Gründung im Jahr 1907 mit Fragen des Einflusses der Sonnenstrahlung auf das Erdklima. Das Observatorium schloss sich 1926 dem Schweizerischen Forschungsinstitut für Hochgebirgsklima und Medizin Davos an und ist seither eine Abteilung dieser Stiftung. Auf Ersuchen der Weltmeteorologischen Organisation (WMO) beschloss der Bundesrat im Jahr 1970 die Finanzierung eines Kalibrierzentrums für Strahlungsmessung als Beitrag der Schweiz zum Weltwetterwacht-Programm der WMO. Nach diesem Beschluss wurde das PMOD beauftragt, das Weltstrahlungszentrum (World Radiation Center, WRC) zu errichten und zu betreiben.

Kerntätigkeiten

Das Weltstrahlungszentrum unterhält das Primärnormal für solare Bestrahlungsstärke bestehend aus einer Gruppe von hochpräzisen Absolut-Radiometern. Auf weitere Anfragen der WMO wurden 2004 das Kalibrierzentrum für Messinstrumente der atmosphärischen Langwellenstrahlung eingerichtet und 2008 das Kalibrierzentrum für spektrale Strahlungsmessungen zur Bestimmung der atmosphärischen Trübung. Seit 2013 wird auch das Europäische UV Kalibrierzentrum durch das Weltstrahlungszentrum betrieben. Das Weltstrahlungszentrum besteht heute aus vier Sektionen:

- Solare Radiometrie (WRC-SRS)
- Infrarot Radiometrie (WRC-IRS)
- Atmosphärische Trübungsmessungen (WRC-WORCC)
- UV Kalibrierzentrum (WRC-WCC-UV)

Die Kalibriertätigkeit ist in ein international anerkanntes Qualitätssystem eingebettet (ISO 17025) um eine zuverlässige und nachvollziehbare Einhaltung des Qualitätsstandards zu gewährleisten.

Das PMOD/WRC entwickelt und baut Radiometer, die zu den weltweit genauesten ihrer Art gehören und sowohl am Boden als auch im Weltraum eingesetzt werden. Diese Instrumente werden auch zum Kauf angeboten und kommen seit langem bei Meteorologischen Diensten weltweit zum Einsatz. Ein globales Netzwerk von Stationen zur Überwachung der atmosphärischen Trübung ist mit vom Institut entwickelten Präzisionsfilterradiometern ausgerüstet.

Im Weltraum und mittels Bodenmessungen gewonnene Daten werden in Forschungsprojekten zum Klimawandel und der Sonnenphysik analysiert. Diese Forschungstätigkeit ist in nationale, insbesondere mit der ETH Zürich, und internationale Zusammenarbeit eingebunden.

Physikalisch-Meteorologisches Observatorium Davos
und World Radiation Center (PMOD/WRC)
Dorfstrasse 33, 7260 Davos Dorf
Schweiz
Tel. +41 (0)81 417 51 11, www.pmodwrc.ch

pmod wrc

Annual Report
Jahresbericht 2018

Table of Contents

Jahresbericht 2018

Werner Schmutz

Bildlich gesprochen wurde die Zukunft des PMOD/WRC innerhalb eines Tages entschieden, am 27. September 2018, als vier der fünf besten Kandidaten für die zu besetzende Direktor Stelle ihre Vorträge präsentierten und bezüglich ihrer Zukunftspläne befragt wurden. Eine weitere Kandidatin, die an diesem Tag verhindert war, führte das Bewerbungsgespräch einen Monat danach. Die Stiftung Schweizerisches Forschungsinstitut für Hochgebirgsklima und Medizin Davos (SFI), zu dem das PMOD/WRC gehört, fand sich in der komfortablen Lage, aus fünf höchst-qualifizierten Kandidaten auswählen zu können. Hingegen war die Entscheidung für das Institut richtungsbestimmend und daher von grosser Bedeutung, da die Kandidaten sehr verschiedene Visionen für die Ausrichtung des zukünftigen Instituts vorstellten. Für die Auswahl war ein internationales Komitee zuständig, das extra für diese Aufgabe berufen wurde, und dieses empfahl Dr. Louise Harra, Irin, früher am Mullard Space Science Laboratory, UK, angestellt und Professorin am Department of Space and Climate Physics des University College London. Die Stiftung folgte dieser Empfehlung und wählte Dr. Harra als neue Direktorin mit Arbeitsbeginn am 1. Juni 2019. Diese Wahl sichert die Weiterführung von Sonnenforschung am Institut, und mit dieser neuen Leitung ist auch sichergestellt, dass der mehrjährige Aufwand des PMOD/WRC für Entwicklung und Bau von Experiment-Komponenten der nächsten ESA Sonnenmission Solar Orbiter für wissenschaftliche Auswertung genutzt werden wird.

In Wirklichkeit dauerte der Prozess, eine neue Leitung für das Institut zu finden, sehr viel länger als der oben erwähnte Tag. Tatsächlich begannen Gespräche mit dem Physikdepartment der ETH Zürich schon vor einigen Jahren. Diese Vorbereitung zahlte sich nun aus, da das Resultat für beide Seiten vorteilhaft ist. Die designierte Direktorin ist neu zugleich auch affiliierte Professorin an der ETH Zürich und die Vision ist, dass so Synergien zwischen dem PMOD/WRC und den ETH-Instituten genutzt werden können und durch eine Kombination der Stärken beider Seiten das Davoser Institut auch in neue ETH-Weltraumprojekte involviert sein wird.

Wissenschaft

Das PMOD/WRC wurde im Forschungsbereich Weltraumwetter ein anerkannter Kollaborations-Partner und es gehörte zu den Pionieren in der Disziplin Weltraumklima. Beiträge des Instituts zu theoretischen und technologischen Aspekten des Sonneneinflusses auf das Erdklima haben in den letzten zwanzig Jahren zum schnellen Fortschritt in den beiden jungen Forschungsbereichen beigetragen. Das Institut hat sich in den vergangenen Jahrzehnten auf die Erforschung des Sonneneinflusses konzentriert und wurde in diesem Bereich weltführend in der Experiment- und Instrumentenentwicklung. Eine Bewertung des Instituts im Jahr 2015 durch ein internationales Expertenteam kam zum Schluss, dass das PMOD/WRC in Metrologie der Sonneneinstrahlung eines der zwei weltweit führenden Instituten ist und seine hochqualitativen Dienstleistungen nationalen und internationalen Organisationen zur Verfügung stellt, wie der Meteorologischen Weltorganisation sowie Weltraumorganisationen im Allgemeinen und insbesondere der Europäischen Weltraumorganisation. Es erbringt für die Organisationen wichtige Ingenieur– und wissenschaftliche Beiträge.

Eine Abschätzung des natürlichen Sonneneinflusses auf den Klimawandel wurde letztes Jahr vom PMOD/WRC geführten FUPSOL Konsortium veröffentlicht, in dem die Schlussfolgerung war, dass in einem Szenario von 4°C Erwärmung innerhalb der nächsten 100 Jahre eine weniger aktive Sonne bis zu 0.5°C den Anstieg dämpfen könnte. Eine solche Abschätzung ist nicht nur für das volle Verständnis der Klimaerwärmung wichtig, sondern auch, um Skeptikern eine kompetente Antwort geben zu können.

Eine theoretische Rekonstruktion der Variationen der Sonneneinstrahlung während der letzten 10'000 Jahre wurde im Jahr 2011 veröffentlicht, und diese Publikation war eine der einflussreichsten Arbeiten des Instituts. Da in der Zwischenzeit die Abschätzung der möglichen Sonnenschwankungen neu beurteilt wurde und weil neue Publikationen, die als Basis benötigten Rekonstruktionen des sogenannten solaren Modulationspotenzials neu evaluiert haben, wurde letztes Jahr eine aktualisierte Rekonstruktion der Sonneneinstrahlung veröffentlicht. Dass das Institut auch sonst weiterhin zur Frage des Sonneneinflusses aktive Forschung betreibt, ist aus den zahlreichen Projekten in diesem Jahresbericht ersichtlich.

Entwicklung und Bau von Instrumenten

Die aktive Rolle des Institutes in der Entwicklung und Auswertung von Experimenten, die ausserhalb der Erdatmosphäre die Totale Sonneneinstrahlung messen, war entscheidend für die Erweiterung der Beobachtungsbasis, die nötig ist, um den Sonneneinfluss auf das Erdklima von kurz- bis langzeitiger Variabilität zu beurteilen. Das Institut hat das LYRA Radiometer gebaut, das auf dem ESA PROBA-2 Satelliten fliegt. Es leitete das Experiment Solar Variability and Irradiance Monitoring (SOVIM) auf der ISS und es baute das Precision Monitoring of Solar Variability (PREMOS) Experiment für den französischen Satelliten PICARD. PREMOS war das erste auf das SI-System rückführbar kalibrierte Weltraum-Radiometer und bestätigte so den neuen Wert von 1361 $W m^{-2}$ der Solarkonstante. Diese fundamentale Grösse wurde durch die internationale Gemeinschaft als nominaler Wert für die mittlere Sonneneinstrahlung anerkannt.

Die Entwicklung von Weltraumexperimenten wurde mit dem Start von CLARA auf dem norwegischen Satelliten NorSat-1 im Jahr 2017 fortgesetzt und geht auch in Zukunft weiter mit dem Radiometer-Experiment JTSIM-DARA, das als Nutzlast auf der chinesischen Mission FY-3E, mit geplantem Start im Jahr 2020, mitfliegen wird. Das PMOD/WRC liefert einen DARA-Typus

Radiometer für das Joint Total Solar Irradiance Monitor (JTSIM) Experiment. Ein weiteres DARA Radiometer befindet sich zurzeit in der letzten Bauphase und wird voraussichtlich ein Jahr später als FY-3E mit der ESA Mission PROBA-3 gestartet.

Dienstleistungsbetrieb Weltstrahlungszentrum

Das PMOD/WRC ist eines der Weltkalibrierzentren der Meteorologischen Weltorganisation (WMO). Als solches hat das Observatorium in den letzten zwei Jahrzehnten vier grosse internationale Pyrheliometer-Vergleiche (IPC) in den Jahren 2000, 2005, 2010 und 2015 organisiert: die IPC Nr. IX bis XII. Im Weiteren übernahm das Weltstrahlungszentrum zusätzliche Aufgabengebiete als Kalibrierzentrum für die Messung von ultravioletter und infraroter Strahlung und als Kalibrierzentrum für Messungen der atmosphärischen Trübung. Alle diese Kalibriertätigkeiten sind durch die WMO anerkannt. Schon zu Beginn meiner Tätigkeit am PMOD/WRC habe ich erkannt, dass die Kalibriertätigkeiten des Weltstrahlungszentrums auch durch das Internationale Komitee für Masse und Gewichte (CIPM) anerkannt sein sollten. Durch kontinuierliche Bemühungen erreichte das PMOD/WRC, dass es das einzige nicht-staatliche Mitglied des Konsultativkomitees für Photometrie und Radiometrie wurde. Die Metrologische Gemeinschaft arbeitet sehr sorgfältig, und keine Entscheidung wird hastig gefällt. Dennoch sind mittlerweile zwei der Kalibrieraufgaben als Kalibrier- und Messkompetenz in der Datenbank des Büros für Masse und Gewichte aufgeführt. Die anderen zwei Kalibrierzentren des PMOD/WRC sind zurzeit mitten im Prozess, ihre Tätigkeiten zu registrieren. Die formelle Integration der WMO-Aufgaben in die Metrologie-Welt ist essenziell wichtig, da in der Zukunft nur noch Kalibriertätigkeiten anerkannt werden, die auf das SI-System rückführbar sind.

Das zukünftige Weltstrahlungszentrum wird der weltweiten neuen Definition der SI-Einheiten folgen und die Standard-Gruppe von Radiometern als Strahlungs-Referenz aufgeben müssen. In Zukunft werden die Sonnenstrahlungsmessungen auf SI-kalibrierte Messinstrumente zurückgeführt werden. Mit diesem Ziel hat das Institut in Zusammenarbeit mit dem schweizerischen METAS und dem englischen NPL, beides nationale Metrologie-Institute, das erste SI-kalibrierte Tieftemperatur-Sonnenradiometer CSAR entwickelt. Die Absicht ist, dass dieses Instrument nicht nur als zukünftige Strahlungsreferenz dient, sondern, dass mit einem solchen Instrumententyp auch im Weltraum die Strahlungsmessungen um einen Faktor Zehn genauer realisiert werden können. Für die nächste Dekade ist eine ESA Mission TRUTHS geplant, auf der mit diesem Radiometer-Typ eine neue Strahlungsreferenz realisiert werden soll.

Personelles

Am 22. Februar 2019 ist der ehemalige PMOD/WRC Direktor Dr. Claus Fröhlich verstorben. Er war der Leiter des VIRGO Experiments auf dem ESA Satelliten SOHO, der 1995 gestartet wurde. Über all die Jahre hat er sein Experiment betreut. Wir sind von seinem Tod überrascht worden, da er bis zuletzt an einer neuen Auswertung der VIRGO Messreihe der Totalen Sonneneinstrahlung gearbeitet hat. Die Mitarbeiter des PMOD/WRC nehmen von einem wertvollen und sehr geachteten Kollegen Abschied.

Dank

Die Graphiken 1 bis 3 illustrieren, wie sich das Observatorium Davos in meiner Zeit als Direktor entwickelt hat. Ich bin dankbar dafür, dass das Institut kontinuierlich expandieren und seinen Aufgabenbereich erweitern konnte. Das PMOD/WRC ist finanziell, personell und organisatorisch gut aufgestellt und mit der gelungenen Kooperation mit der ETH Zürich sind die Voraussetzungen geschaffen, dass das Institut für die Zukunft gut gerüstet ist. Ich wünsche meiner Nachfolgerin, Prof. Dr. Louise Harra, viel Erfolg!

Ich danke dem Präsidenten der Stiftung SFI, Dr. Walter Ammann, und dem Präsidenten der Aufsichtskommission, Prof. Dr. Bertrand Calpini, sowie den Mitgliedern der Aufsichtskommission und des Stiftungsratsausschusses für die Förderung des PMOD/WRC über all die Jahre. Die Betreuung auf strategischer Ebene ist für ein Institut wie das PMOD/WRC, das sich weit weg von den Hochschulen behaupten muss, existenziell wichtig. Eine weitere Person mit einflussreichem positivem Wirken im Hintergrund ist der ständige Delegierte der Schweiz bei der Meteorologischen Weltorganisation, Peter Binder, Direktor der MeteoSchweiz. Ein weiteres Dankschön verdient der Quästor der Stiftung SFI, Heinz Wälti, der das Observatorium in all den Jahren begleitet hat und uns ab und zu in Notsituationen aus der Patsche geholfen hat. Diesen Personen danke ich im Namen des Observatoriums ganz herzlich.

Weiter danke ich den Partnern für die Finanzierung des Weltstrahlungszentrums, dem Bund, dem Kanton Graubünden und der Gemeinde Davos, die mit der Grundfinanzierung die Existenz des Observatoriums ermöglichen.

Meine hohe Wertschätzung gegenüber den Mitarbeitenden ist die letzte und wichtigste Aussage im Tätigkeitsbericht. Nur dank der ausgezeichneten Leistung der Mitarbeiterinnen und Mitarbeiter war der Erfolg des Observatoriums in den vergangenen Jahren möglich.

The PMOD/WRC staff in December 2018 on the roof platform with Lake Davos in the background.

Introduction

Werner Schmutz

Metaphorically speaking, the future of the Physikalisch-Meteorologisches Observatorium Davos and World Radiation Center (PMOD/WRC) was decided on one day, on the 27th of September 2018, when four of the five short-listed candidates for the director's vacancy presented their talks and were interviewed. One more candidate, who could not be present on that day, was interviewed a month later. The foundation, "Swiss Research Institute for High Altitude Climate and Medicine", of which PMOD/WRC is a department, was in the comfortable situation that all five candidates were excellent choices. However, they differed in their vision of how they would position PMOD/WRC institute in the future. The review of the candidates was performed by an international committee that was appointed for this task, and it recommended Dr. Louise Harra, from Ireland, formerly at the Mullard Space Science Laboratory, UK, and a professor at the Department of Space and Climate Physics, University College, London. In my view, her selection will ensure the continuation of research in solar physics at our institute and also ensure the exploitation of the investments of Swiss PRODEX funding for hardware on Solar Orbiter, which will be used for novel science in Switzerland.

In reality, the process of appointing a new director took much longer than just the one day mentioned above. In fact, exploratory talks began with the Department of Physics, ETH Zürich, several years ago. The outcome is very solid with the institute being more formally associated with ETH Zürich, as well as the new director being appointed as an affiliated professor in the Physics Department. The vision is that this will trigger synergies between Davos and Zürich. The strength of both partners should lead to synergies resulting in an even brighter future than the past 20 years.

The PMOD/WRC has become internationally recognised in the field of Space Weather, and it was among the pioneers of the emergent discipline, Space Climate. Its contribution to the theoretical and technological aspects of the influence of solar irradiance on Earth's atmosphere has played a decisive role in the rapid progress and development of Space Weather and Space Climate (SWSC) over the past two decades. The institute has oriented its efforts towards a deeper involvement in SWSC research and it has become a world leader in experimental and instrumental development. A review by an international team of experts in 2015 found that the PMOD/WRC is one of two world-wide leading institutions in the field of Total Solar Irradiance (TSI) metrology, and provides very high-quality services to international and national organisations such as the WMO and space agencies, in particular, ESA. In addition, important scientific and engineering contributions to similar organisations as well as to academia were highlighted.

The active role of the institute in the development and exploitation of space experiments measuring TSI and Solar Spectral Irradiance has been crucial to broaden observational data sets. Such resulting databases are necessary to address space climate issues regarding the solar irradiance from short to long-term variability. The institute built the LYRA radiometer, onboard the ESA PROBA-2 satellite, it was PI institute of the Solar Variability and Irradiance Monitoring (SOVIM) experiment, and PI institute of the Precision Monitoring of Solar Variability (PREMOS) instrument onboard the PICARD satellite. PREMOS was the first SI-traceable calibrated radiometer in space, and confirmed the new solar TSI value of 1361 $W m^{-2}$. This basic value has been adopted by the international community as the nominal irradiance value.

The development of space experiments continued with the launch of CLARA in 2017 and into the future with the upcoming radiometer experiment, JTSIM-DARA, a payload on the Chinese FY-3E mission, whose intended launch date is in 2020. PMOD/WRC

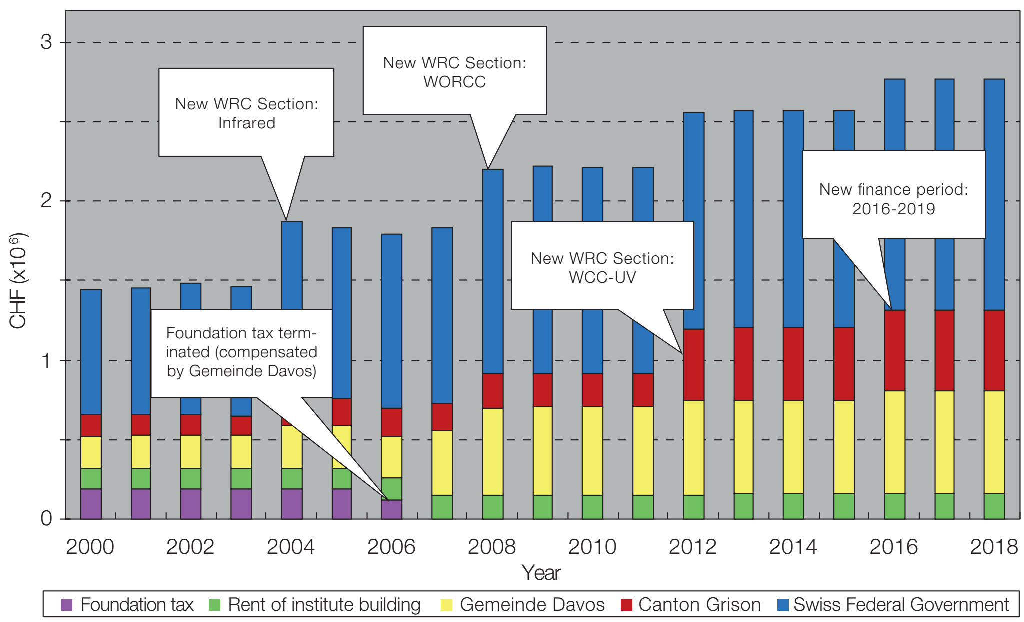


Figure 1. Funding development of the World Radiation Center from 2000 to 2018.

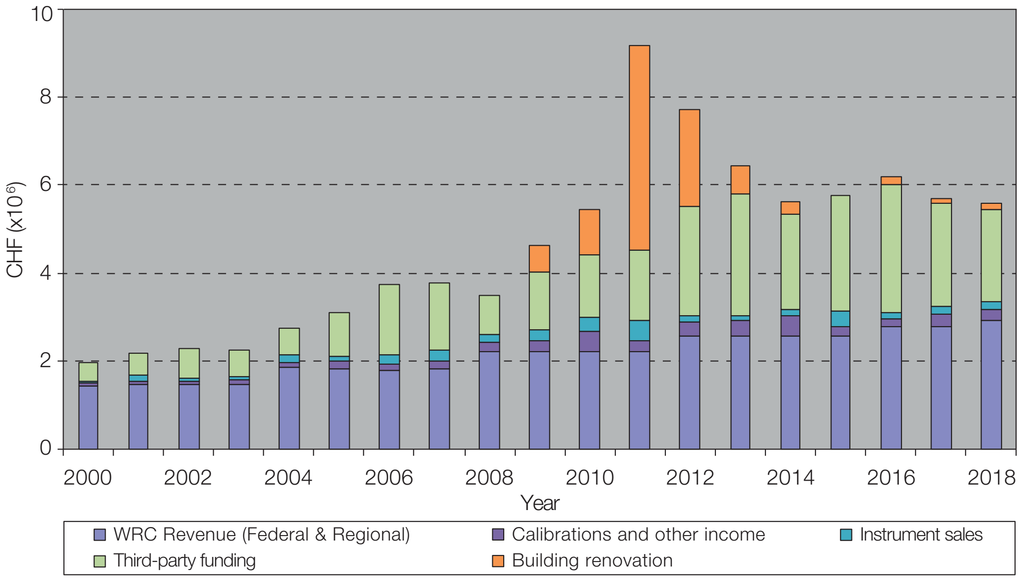


Figure 2. Revenue development of the PMOD/WRC from 2000 to 2018.

is contributing a DARA-type radiometer to the Joint Total Solar Irradiance Monitor (JTSIM) experiment. The other DARA radiometer, for ESA's technology satellite PROBA-3, is also in its final development phase with a launch probably one year later than FY-3E.

PMOD/WRC is one of the World Calibration Centers of the World Meteorological Organisation. As such, the institute organised four large international comparisons in the years 2000, 2005, 2010, and 2015; the so-called International Pyrheliometer Comparisons, IPC Nr. IX to XII. In addition, during the time of Werner Schmutz as director, the PMOD/WRC took on the additional responsibilities as a calibration center for ultraviolet and infrared radiation, and as a calibration center for aerosol optical depth determinations. All these calibration center activities are designated by WMO. It was realised early on that the calibration tasks of the WRCs should be recognised by the International Committee of Weights and Measures Mutual Recognition Arrangement (CIPM MRA). Through continued efforts, PMOD/WRC is now the only non-nation member of the Consultative Committee for Photometry and Radiometry (CCPR). The metrology community works very carefully, with no decisions made in haste, but it has already listed two of the PMOD/WRC WMO calibration tasks as Calibration Measurement Capabilities (CMC) in the data base of the International Bureau of Weights and Measures (BIPM). The other two calibration centers at the institute are also in the process of being integrated as CMCs. The formal integration of WMO activities in the framework of CIPM MRA is very important as only SI-traceable calibrations will be recognised in the future.

The future of the WRC will be to adopt the new definitions of the SI units, and it will have to take the step of abandoning the current World Radiation Reference, which is a conventional artifact as the prime reference, and to define the solar irradiance reference via realisation of SI calibrated instruments. Toward this goal, the institute has developed the first calibrated cryogenic detector for solar irradiance in collaboration with METAS (Switzerland) and NPL (England). The plan is that such an instrument will not only serve as a future detector-based, ground-reference but that this calibration will also be transferred to space with the TRUTHS mission, which is proposed to fly in the next decade.

The evolution of the PMOD/WRC in the past 19 years is illustrated in Figures 1 to 3. Basically, the funding of the World Radiation Center has doubled whereas the turnover of the whole institute has nearly tripled.

I acknowledge the continued and full support of the Supervising Commission and the Board of Trustees and as a final note, I would like to express a deeply felt appreciation for my staff. It is primarily their dedication to our activities, which has made the institute's success possible.

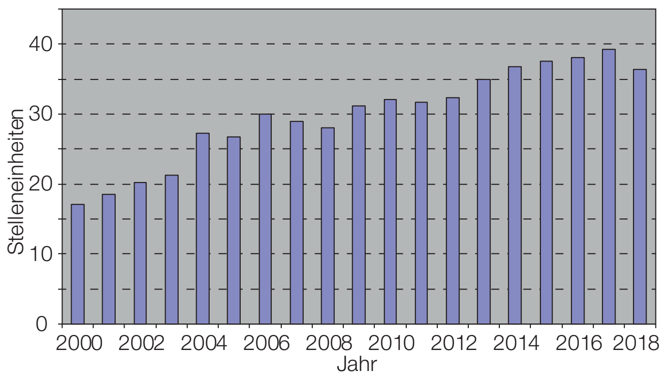


Figure 3. Development of staff numbers in full-time equivalent jobs from 2000 to 2018.

Obituary Claus Fröhlich

Werner Schmutz

Until almost his last day, Claus Fröhlich put his heart and soul into being a researcher. He was born on 10 October 1936, and came to Davos and the Physikalisch-Meteorologisches Observatorium Davos (PMOD) in 1969 as a physicist. His PhD thesis in the field of solid-state physics at the ETH Zurich was awarded a medal in the same year. With his willingness to take over the leadership of the newly created World Radiation Center, the specialist in heat conduction enabled the Center to be established at PMOD and, as such, revived the institute's traditional focus on instrument development.

In 1975, Fröhlich took over as institute director and in the same year oversaw the relocation of the now PMOD/WRC institute to the former schoolhouse of Davos Dorf, and subsequently its official opening two years later. Until his retirement in 1999, Fröhlich was also a lecturer at the ETH Zurich until 2001 when he was 65.

An important milestone for the development of the PMOD/WRC was the development of space experiments under the direction of Claus Fröhlich. His most important project, the VIRGO (Variability of Solar Irradiance and Gravity Oscillations) space experiment, was managed by him even after retirement. Through instruments onboard the SOHO (Solar and Heliospheric Observatory) satellite, operating since 1995, he was able to study solar irradiance variability in an eleven-year cycle. As the mission, originally planned for three years, still provides data to this day, Claus Fröhlich was examining the possible variability over an even longer period of time. Only a few days before his death on 22 February 2019, he was working on the latest calibration parameters, which ensure the continuity of the data.

The PMOD/WRC offers a valuable and very respected colleague our deepest regards.

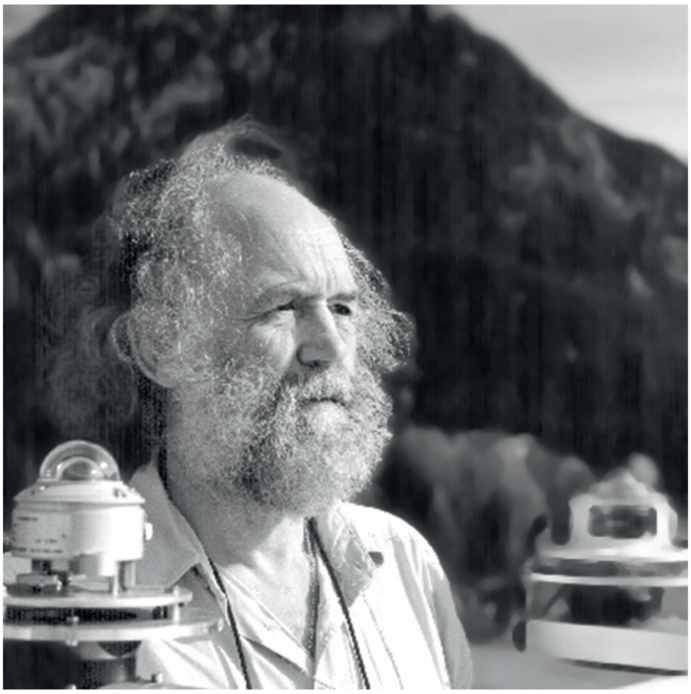
Nachruf Claus Fröhlich

Bis fast zu seinem letzten Tag war Claus Fröhlich Forscher mit Leib und Seele. Nach Davos und ans PMOD kam der am 10. Oktober 1936 in Zürich geborene Physiker im Jahre 1969. Seine Doktorarbeit im Bereich Feststoffphysik an der ETH Zürich war im gleichen Jahr mit einer Medaille ausgezeichnet worden. Mit seiner Bereitschaft , die Leitung des neu geschaffenen World Radiation Center zu übernehmen, machte der Spezialist für Wärmeleitung dessen Ansiedlung am PMOD erst möglich und liess als solcher die traditionelle Ausrichtung des Instituts auf Instrumentenentwicklung verstärkt aufleben.

1975 übernahm Fröhlich die Gesamtleitung und übersah im gleichen Jahr den Umzug des nunmehr PMOD/WRC genannten Instituts ins ehemalige Schulhaus der Fraktionsgemeinde Dorf und seine zwei Jahre später stattfindende offizielle Eröffnung. Bis über seine 1999 erfolgte Pensionierung hinaus, war Fröhlich ausserdem als Dozent an der ETH Zürich tätig.

Ein wichtiger Meilenstein für die Entwicklung des PMOD/WRC war, dass das Observatorium unter der Leitung von Claus Fröhlich begann, Weltraumexperimente zu entwickeln. Sein wichtigstes Projekt, das Weltraumexperiment VIRGO betreute er auch noch nach der Pensionierung. Mittels des 1995 an Bord des Satelliten SOHO platzierten Instruments konnte er die Variabilität der Intensität der Sonnenstrahlen in einem Elf-Jahres-Rhythmus aufzeigen. Da die ursprünglich auf drei Jahre geplante Mission bis heute noch immer Daten liefert, nahm sich Claus Fröhlich vor, eine mögliche Variabilität über einen noch grösseren Zeitraum zu überprüfen. Noch wenige Tage vor seinem Tod arbeitete er an den neuesten, die Kontinuität der Daten sicherstellenden Kalibrierungsparametern.

Das PMOD/WRC entbietet einem wertvollen und sehr geachteten Kollegen seinen letzten Gruss.



Operational Services

Quality Management System, Calibration Services, and Instrument Sales

Silvio Koller, Wolfgang Finsterle, Julian Gröbner, and Daniel Pfiffner

PMOD/WRC Quality Management System (QMS)

The World Radiation Center has six different Calibration and Measurement Capabilities (CMCs) listed in the KCDB of BIPM. These include:

- Responsivity, solar irradiance pyranometer (1)
- Responsivity, solar irradiance pyrheliometer (1)
- Responsivity, solar irradiance broadband detector (4)

Depending on the instrument's wavelength range, the CMCs belong to different WRC calibration sections. The modification of the four broadband detector CMCs with lower uncertainties, was approved on 28 November 2018 and published on the BIPM key comparison database in May 2019. Two new CMCs for QASUME spectral solar irradiance were approved on 3 May 2019 and published on the BIPM key comparison database in May 2019. No changes occurred in personnel regarding functions or responsibilities within the QMS.

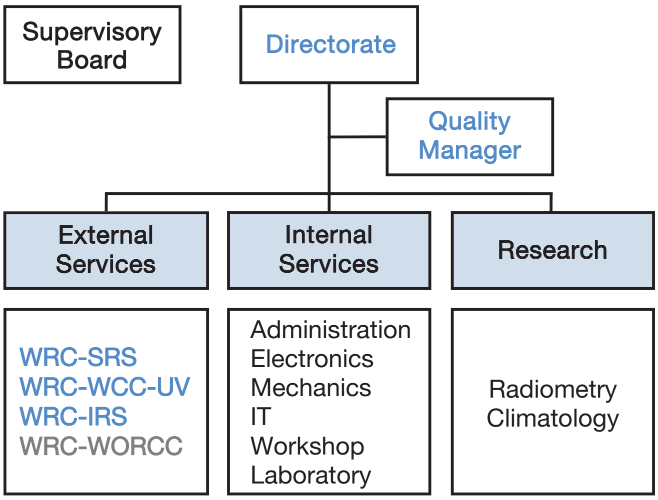


Figure 1. PMOD/WRC Quality Management System: Organisational chart. The WRC-SRS, WRC-WCC-UV and WRC-IRS sections (in blue) perform calibrations according to the EN ISO/IEC standard 17025.

Quality Management System Activities

In 2017, the modification and update of the entire QMS documentation began, and a more uniform structure and numbering system was achieved. This task was finalised and completed in 2018. In April 2018, PMOD/WRC presented its QMS and a summary of the last five years to the Technical Committee for Quality (TC-Q) of EURAMET. National Metrology Institutes (NMI) and Designated Institutes (DI) are re-evaluated every 5 years by the TC-Q to verify conformity of the applied QMS against the standard ISO 17025 and to prove the QMS functionality in daily life. The outcome of this assessment was very positive, and we passed the re-evaluation without any issues.

Calibration Services

The overall number of calibrations in 2018 was 202 within the different WRC calibration sections, and is similar to the long-term average shown in Figure 2.

Solar Radiometry Section (WRC-SRS)

In 2018, the WRC-SRS section calibrated 24 pyrheliometers and 81 pyranometers. All certificates were issued with the CIPM MRA logo for mutual recognition. The SRS participated in the Baltic Region Pyrheliometer Comparison (BRPC-2018), which was organised by the Swedish Meteorological and Hydrological Institute (SMHI) at their site in Norrköping, Sweden, as well as in the National Pyrheliometer Comparison, NPC-2018, at NREL in Golden, Colorado, USA (Figure 3).

Infrared Radiometry Section (WRC-IRS)

The WRC-IRS section performed calibrations on 45 pyrgeometer and one Infrared Integrating Sphere (IRIS) radiometer in 2018. The IRS section attended inter-laboratory comparisons at the German National Metrology (PTB), Germany, with the IRIS radiometer, shown in Figure 4.

Atmospheric Turbidity Section (WRC-WORCC)

The WRC-WORCC section calibrated 19 Precision Filter Radiometers (PFR) against the WORCC Triad standard. In addition, three Precision Solar Spectroradiometers (PSR) were calibrated against a PTB reference standard.

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

The WCC-UV section calibrated 20 UVB broadband radiometers and issued 68 certificates. The certificates typically cover different characteristics of the radiometers.

In addition, this section performed two lamp/diode calibrations. Five spectroradiometers were calibrated against the QASUME travelling reference. These calibrations resulted in 76 certificates, 23 of them with the CIPM MRA logo.

In conjunction with an inter-laboratory comparison, the PTB also performed lamp calibrations over the 250 - 2500 nm wavelength range for PMOD/WRC.

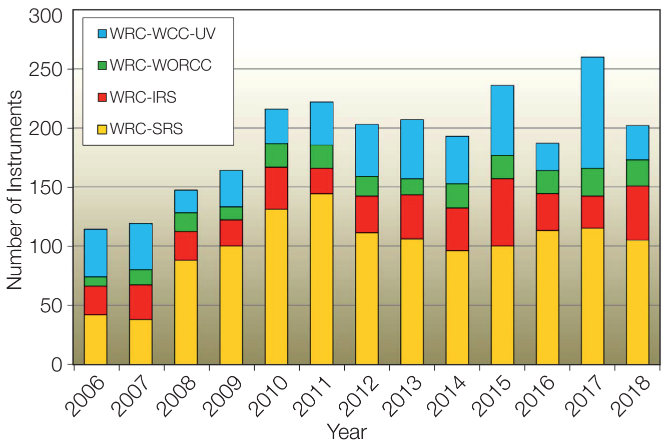


Figure 2. Statistics of instrument calibrations at PMOD/WRC for the 2006–2018 period. Remark: One instrument can result in more than one calibration certificate.

Figure 3. Christian Thomann (right; PMOD/WRC) and Markus Suter (Davos Instruments) during the NPC-2018 campaign in Golden, USA.

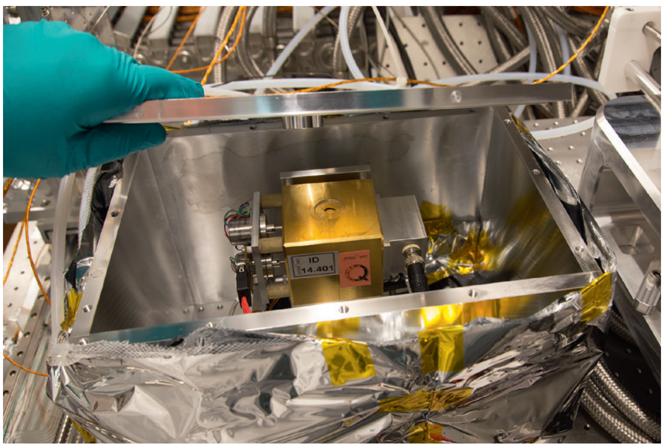


Figure 4. IRIS during the inter-laboratory comparison at PTB, Germany.

Instrument Sales

In 2018, PMOD/WRC sold the following instruments:

- Two PMO6-CC absolute radiometers to Indonesia and Spain.
- One Ventilated Heating System (VHS) to Germany.
- One Spectral Irradiance Calibration System for 1000 W standard lamps.

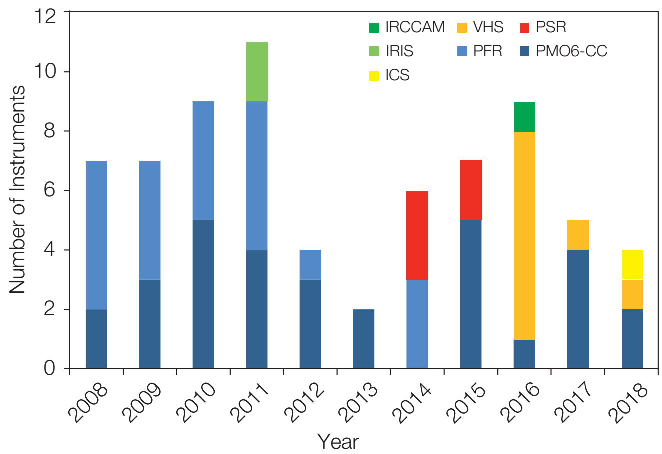


Figure 5. Number of PMOD/WRC instruments sold from 2008 up to and including 2018: i) IRCCAM = Infrared Cloud Camera, ii) VHS = Ventilated Heating Systems, iii) PSR = Precision Spectroradiometer, iv) IRIS = Infrared Integrating Sphere Radiometer, v) PFR = Precision Filter Radiometer, vi) PMO6-CC = absolute cavity pyrheliometer, and vii) ICS = Irradiance Calibration System.

Solar Radiometry Section (WRC-SRS)

Wolfgang Finsterle

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 a calibration laboratory according to the laboratory standard ISO/IEC 17025 for solar radiometers (pyrheliometers and pyranometers).

In 2018, the SRS/WRC calibrated 105 radiometers: These consisted of 81 pyranometers, 18 pyrheliometers with a thermopile sensor and six absolute cavity radiometers. The WSG was operated on 74 days and the Cryogenic Solar Absolute Radiometer and Monitor for Integrated Transmittance (CSAR/MITRA) on 6 days.

The 2018 calibration season at the SRS/WRC had to be accomplished without a regular laboratory technician. This situation arose because the position could not be filled due to a recruitment freeze as a result of budget restrictions. Thankfully, two staff members from the technical department were trained to temporarily fulfill the calibration tasks besides their regular duties. The situation intensified when the CSAR/MITRA scientist left PMOD/WRC. Luckily a new laboratory technician was hired for the upcoming 2019 calibration season who will also be able to operate CSAR/MITRA.

From March to May 2018, two undergraduate students from Silpakorn University (Nakhon Pathom, Thailand) visited PMOD/WRC. They were sponsored by the Thai Development and Promotion of Science and Technology Talent Project (DPST) to test and optimise a calibration method for pyranometers at PMOD/WRC using satellite data. This new method had been developed to facilitate the calibration of remote solar radiation stations. Another project was to analyse the performance of a solar cell.

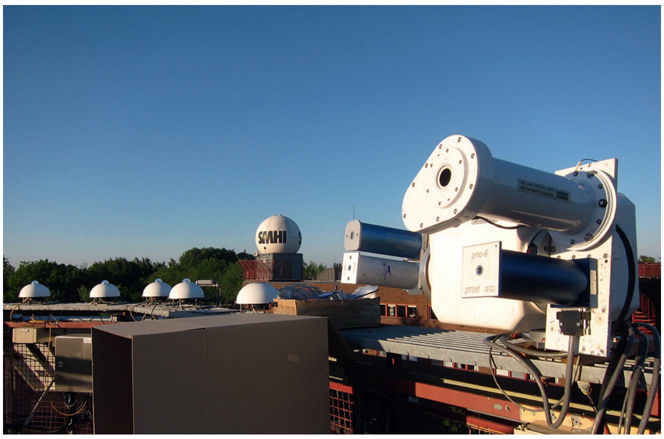


Figure 1. The WRC-SRS transfer standard group is set up and configured for the low-irradiance calibration experiment at SMHI in Norrköping, Sweden in the early morning on 5 May 2018.

Table 1. The WRR correction factors for the three transfer standard pyrheliometers determined during the BRPC-2018 and NPC-2018 agree extremely well with the results from IPC-XII in 2015. The US standard group, maintained by NREL, served as the independent reference during NPC-2018. The observed relative changes are well below the significance threshold of the comparison and confirm the stability of the WSG. Standard uncertainties (standard deviation/number$^{0.5}$) are <0.01%.

	IPC-XII (2015)	BRPC-2018	NPC-2018
PMO6-CC 0401	1.020799	1.02086	1.02097
PMO6-CC 0803	1.000335	1.00052	1.00005
AHF 32455	1.001380	1.00114	1.00140

The SRS participated in the Baltic Region Pyrheliometer Comparison (BRPC-2018), which was organised by the Swedish Meteorological and Hydrological Institute (SMHI) at their site in Norrköping, Sweden, as well as in the National Pyrheliometer Comparison, NPC-2018, at the National Renewable Energy Laboratory (NREL), Golden, Colorado, USA. Two PMO6-CC and one AHF absolute cavity radiometers served as the SRS transfer standard in both comparisons. The weather conditions were excellent during the entire BRPC-2018 and most of the NPC. A low-irradiance calibration experiment was performed on one day of the BRPC-2018. The instruments were set up as early as 2:30 UTC (4:30 local time) to capture the irradiance curve during the slow Swedish sunrise (Figure 1). With irradiance levels as low as 400 $W m^{-2}$, all particpating pyrheliometers still agreed well which each other as well as the reference. This important aspect gives confidence in the calibration results obtained at high-latitude sites where the Sun barely skims the horizon.

The results of NPC-2018 were published in the NREL technical report, NREL/TP-1900-72607. They confirm that the WSG has been stable since the last IPC (see Table 1). Results from the BRPC-2018 are also shown in Table 1, and have been distributed to the participants by the organiser.

Regular confirmation of the stability of the WSG through participation in pyrheliometer comparisons is required by ISO 17025 to maintain the Calibration and Measurement Capabilities (CMCs) of the SRS Section.

The SRS is leading the revision process for the ISO 9060 international standard (Solar energy – specification and classification of instruments for measuring hemispherical and direct solar radiation). One committee meeting and several telephone conferences were held in 2018 before a new International Standard was published. The International Standard introduces a new classification scheme for pyranometers and pyrheliometers based on application-specific requirements.

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) which 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 which are installed on the PMOD/WRC roof platform. The measurements of the individual WISG pyrgeometers with respect to their average are shown in Figure 1 for the period 2004 to the end of 2018. As can be seen, the long-term stability of the WISG is very satisfactory, with measurements from the four pyrgeometers agreeing to within ±1 $W m^{-2}$ over the whole time period.

A very generous loan from the National Renewable Energy Laboratory (NREL) saw the delivery of an Absolute Cavity Pyrgeometer (ACP) to the WRC-IRS. The objective is to establish a group of independent radiometers providing longwave irradiance measurements traceable to SI, to which the WISG will be regularly compared and calibrated. The ACP will be operated alongside the IRIS radiometers during clear sky nights on the PMOD/WRC measurement platform.

In 2018, two PMOD/WRC IRIS radiometers were characterised at the NPL (National Physical Lab., England) and PTB (Physikalisch-Technische Bundesanstalt, Germany) facilities within the EMPIR METEOC-3 project to determine their spectral responsivity and to determine their temperature dependence. The spectral responsivity of three IRIS detectors were determined at the NPL infrared spectral responsivity facility over the 1–20 µm wavelength range, while their temperature dependence was characterised in the Reduced Background Calibration Facility-2 at the PTB (Figure 2)

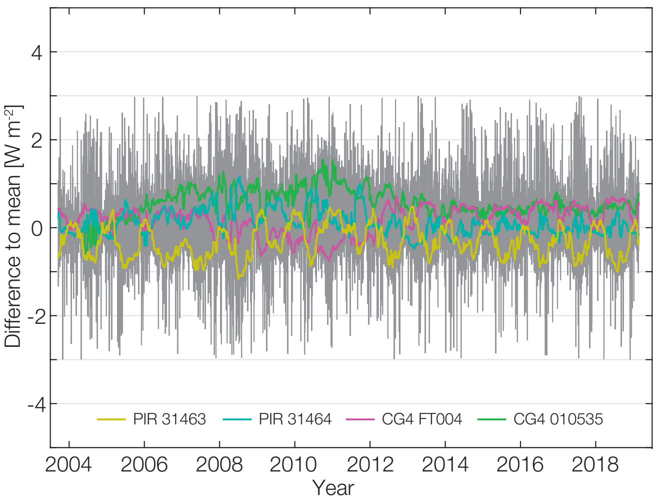


Figure 1. Night-time atmospheric longwave measurements of the WISG pyrgeometers relative to their average. The coloured lines represent a 30-day running mean of each WISG pyrgeometer, while grey-shaded areas represent daily measurements.

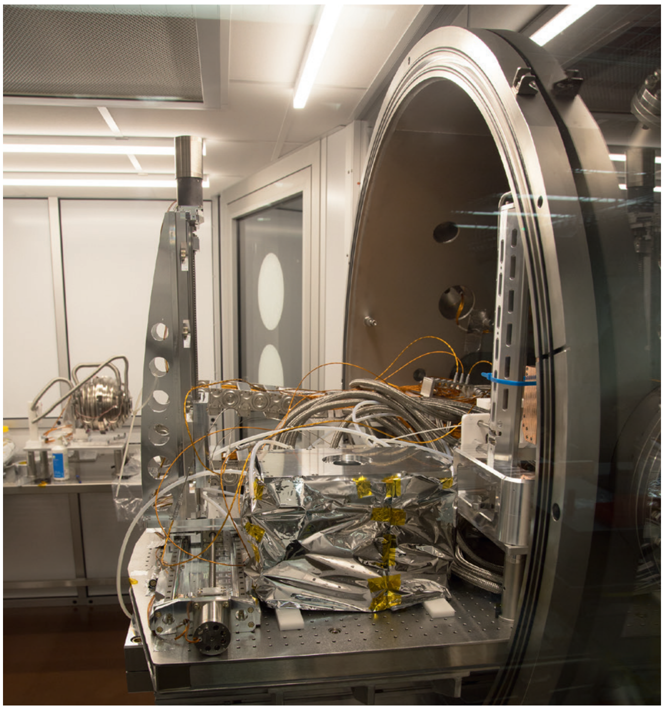


Figure 2. The Reduced Background Calibration Facility-2 at the PTB.

for values from -10°C to +25°C. The development of a dedicated blackbody for IRIS calibrations by PTB is progressing well and first tests are scheduled for the second half of 2019, with the aim of validating the calibrations obtained so far with the PMOD/WRC blackbody with those obtained from this new blackbody.

During its 17th session on 12–16 October 2018, the Commission for Instruments and Methods of Observation (CIMO) strengthened the role of the WISG as the reference standard for atmospheric longwave irradiance measurements, by adopting Resolution 1, and establishing a Governance framework for the WISG and its traceability to the International System (SI) of Units. The Governance framework is comprised of an advisory group of at least five experts, appointed by the CIMO president for each International Pyrgeometer Comparison (IPgC) to review and report on the status and stability of the WISG, and to provide advice on maintaining and improving traceability of atmospheric longwave irradiance measurements with respect to SI through the IPgC (CIMO-XVII, 2018).

Furthermore, CIMO adopted Decision 3 during CIMO-XVII, welcoming the reconfirmation by Switzerland of its commitment to ensure a sustainable governance and management by PMOD/WRC to support the organisation of the next IPC and IPgC in 2020. These comparisons represent CIMO high priority events that enable the traceability assurance for short and longwave radiation measurements, and ensure regular evaluation of the WSG and WISG. As stated in the justification to Decision 3, these events are essential to ensure high quality, traceable measurements of solar and longwave irradiance.

References: CIMO-XVII, WMO-No. 1227, 2018.

Atmospheric Turbidity Section (WRC-WORCC)

Stelios Kazadzis, Natalia Kouremeti, and Julian Gröbner

The Atmospheric Turbidity Section of 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 GAW-PFR AOD network.

The WORCC standard group of three PFRs (referred to as the "PFR triad") was established in 2005 by WORCC in order to fulfil the WMO mandate regarding: "homogenisation of global AOD through provision of traceability to the World Standard Group (WSG) of spectral radiometers for contributing networks at co-located sites and/or periodic international filter radiometer comparisons, and further standardisation of evaluation algorithms." Since 2005, five different well-maintained instruments have been used as part of the PFR triad. In the 13 years of 1-minute measurement data, >99% of retrieved AOD lies within the WMO U95 criterion, at all wavelengths. All differences of individual instruments with the triad are well within ±0.005 with only small shifts for different PFRs and particular wavelengths (Kazadzis et al., 2018).

Annual quality assured data from seven GAW-PFR stations were updated and submitted to WDCA. In 2018, one instrument from the GAW-PFR network and 19 instruments (17 PFRs from the extended GAW-PFR network, one POM and one SP0-L) were calibrated against the PFR reference triad at Davos.

Long-term measurements at four polar stations were analysed and presented at the Polar 2018 conference in June 2018 at Davos, Switzerland. Figure 1 presents results from Troll (TRO), Marambio (MBI), Summit (SUM), and Ny-Ålesund (NYA) polar stations.

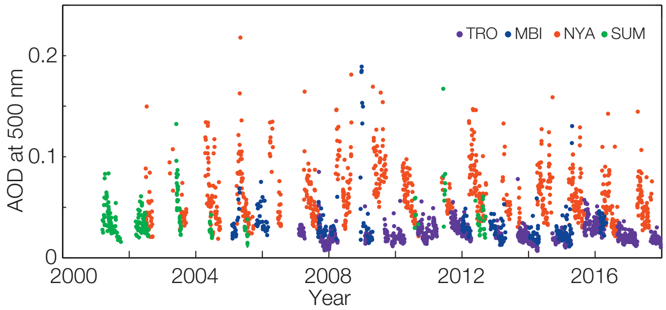


Figure 1. AOD at 500 nm at four polar stations using PFR instruments.

The lunar PFR participated in the first multi-instrument nocturnal AOD intercomparison campaign that was held at the high-mountain Izaña Observatory (Tenerife, Spain) in June 2017, involving 2-min synchronous measurements from two different types of lunar photometers (Cimel CE318-T and Moon Precision Filter Radiometer, Lunar-PFR) and one stellar photometer. The AOD was retrieved by performing a Langley-plot calibration each night which showed a remarkable agreement (better than 0.01) between the lunar photometers. However, when applying the Lunar-Langley calibration using the RIMO lunar model, AOD differences of up to 0.015 were found, partly linked to the uncertainties in the irradiance models, as well as instrumental deficiencies yet to be fully understood. The Lunar-PFR was also deployed at Ny Ålesund from November 2017 to March 2018 and November 2018 to March 2019 for AOD monitoring during the polar winter in the framework of the SIOS project, https://sios-svalbard.org/InfraNor.

WORCC have started a close collaboration with AERONET Europe and SKYNET Europe and Asia. A memorandum of understanding, including a four year collaboration plan, has been signed with CNR, Italy (representing Skynet Europe) for close scientific collaboration on the traceability of SKYNET instruments linked to the PFR triad. Under this agreement, a reference POM-2 instrument was calibrated at Davos from August–September 2017. In addition, a PFR instrument participated in the Quatram campaign (www.euroskyrad.net/quatram.html) from October 2017 to May 2018. The PFR was used as a reference sunphotometer for this campaign with the participation of a number of different instruments. A main objective is the initiation of an AOD traceability study of instruments among already existing federated networks, and to promote measurement synergies.

WORCC in collaboration with the AERONET main calibration facilities has worked towards an assessment of the suitability of the high-mountain stations Mauna Loa (USA) and Izaña (Spain) for Langley plot calibrations of sunphotometers. The data used for the investigations belong to the AERONET and GAW-PFR networks, which maintain reference sunphotometers at these stations with long measurement records: 22 years at Mauna Loa and 15 years at Izaña. Results showed that analysis of the long-term determination of extraterrestrial signals yields a calibration uncertainty of ~0.25–0.5%, where the uncertainty is smaller in the visible and near-infrared wavelengths and larger in the ultraviolet wavelengths (Toledano et al., 2018).

Three new Precision Spectroradiometers (PSR) were produced at PMOD/WRC and were operational during 2018. The instruments are operating in Davos in parallel to the PFR triad to investigate their stability and accuracy.

References:

Kazadzis S., Kouremeti N., Hansen G., Stebel K., Aaltonen V., Rodriguez E., Nyeki S.: 2018, Polar Conference, Davos, June 2018.

Kazadzis S., Kouremeti N., Nyeki S., Gröbner J., Wehrli C.: 2018, Geo. Instrum. Meth. Data Syst., 7, 39-53, doi.org/10.5194/gi-7-39-2018.

Toledano C., et al.: 2018, Atmos. Chem. Phys., 18, 14555-14567, doi.org/10.5194/acp-18-14555-2018.

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

Julian Gröbner, Gregor Hülsen, and Luca Egli

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

The WCC-UV portable reference spectroradiometer, QASUME, was used during three quality assurance site visits. In June, we visited the Arctic Space Centre of the Finnish Meteorological Institute (FMI) in Sodankylä, Finland. It was the 4th audit at this station, after 2003, 2007 and 2014. In addition to the two Brewer spectrophotometers operated by FMI, a Bentham DM150 from Tartu, Estonia, joined the campaign (Figure 1). Thereafter, we audited the FMI headquarters, Helsinki, for the first time after the relocation of instruments from the station in Jokioinen (Figure 2). In September, we organised the 3rd visit to the Univ. Reading, England, after 2003 and 2012. Reports describing the results of the campaign can be found on the QASUME website (see links at bottom of page).

Laboratory improvements: The 1000 W irradiance source of the spectral responsivity facility (SRF) was replaced by a 450 W Xe-lamp without UV-Stop quartz glass. The lamp coupling to the Acton SP2500 spectroradiometer was simplified by reducing the number of optical elements. These modifications are expected to improve the measurement temporal stability, and consequently, to reduce the calibration uncertainty. The modification resulted in a similar output power even though the lamp power was a factor 2 lower. Due to a power supply fault, the lamp system from the angular response facility was replaced by a Newport Xe-lamp system.

As described in Gröbner et al. (2017), a collimator tube (Figure 3) was designed for the QASUME entrance optic to perform direct solar spectral irradiance measurements with a full field-of-view of 2°. As demonstrated in the EMRP project, ATMOZ, these measurements can be used to retrieve total column ozone (Vaskuri et al., 2018) and aerosol optical depth over the 300–500 nm range.

Figure 1. Installation of the QASUME spectroradiometer (left) and the Bentham from Tartu (right) next to the two local Brewer spectrophotometers (background) during a site audit at FMI Sodankylä, Finland.

Figure 2. The new location of Brewer #107 (left) on the roof at the FMI headquarters in Helsinki, Finland.

Figure 3. The QASUME portable reference spectroradiometer measuring direct irradiance on the PMOD/WRC roof. The input optic is at the end of the 940 mm long collimator tube.

Four updated CMCs for broadband filter radiometer responsivity calibrations were approved by the CCPR in 2018 and have been published on the KCDB website. The new expanded uncertainties for UV Index, UVB, UVA and total UV irradiance are now between 3.0% to 3.5%. Furthermore, two CMCs for spectral solar responsivity and for solar spectroradiometer calibrations were recently approved and are published in the KCDB database. Through these CMCs, solar spectral irradiance measurements with QASUME are now traceable to SI, and will allow fully SI traceable calibrations to be conducted during QASUME site visits.

Results of all the QASUME site audits and reports of the campaigns can be found on the WCC-UV website: www.pmodwrc.ch/weltstrahlungszentrum/wcc-uv/ and www.pmodwrc.ch/en/world-radiation-center-2/wcc-uv/qasume-site-audits/

References:

Gröbner J., Kröger I., Egli L., Hülsen G., Riechelmann S., Sperfeld P.: 2017, Atmos. Meas. Tech., 10, 3375-3383, doi.org/10.5194/amt-10-3375-2017.

Vaskuri A., Kärhä P., Egli L., Gröbner J., Ikonen E.: 2018, Atmos. Meas. Tech., 11, 3595-3610, doi.org/10.5194/amt-11-3595-2018.

Section Ozone: Total Column Ozone and Umkehr Measurements

Julian Gröbner, Herbert Schill, and Luca Egli

Operational Total Column Ozone and Umkehr measurements are performed at PMOD/WRC with two Dobson and three Brewer spectrophotometers to monitor the stratospheric ozone layer, hence extending the world's longest continuous total ozone time-series at Arosa and Davos, Switzerland.

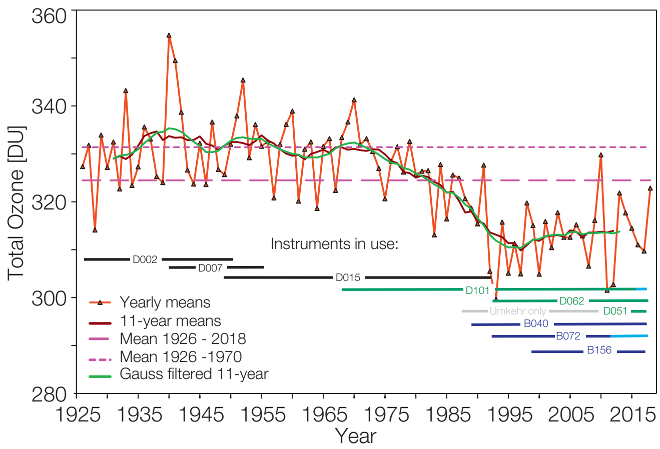


Figure 1. Homogenised total ozone D101 AD data from Arosa, for 1926–2018, and instruments used in the time-series.

With the agreement between MeteoSwiss and PMOD/WRC Davos in 2018 to continue the Arosa stratospheric ozone measurements from 2019 onwards in Davos, the world's longest total column ozone time-series somewhat returns to its origins. In 1914, F. W. Paul Götz went for health reasons to Davos and worked at the "Observatorium Dorno", the predecessor institution of the PMOD, for a few months in 1919–1920. He then moved to Arosa, where solar UV data were collected with an instrument based on a photo-electric cadmium cell, borrowed from Dorno (Staehelin et al., 2018).

In 1926, Götz founded the "Lichtklimatisches Observatorium" (LKO) in his newly-built house, "Firnelicht", which was equipped with a Fabry–Buisson type of solar spectrophotometer. In the same year, he began a collaboration with G. Dobson, an Oxford physicist and meteorologist. Arosa thus became one of six worldwide stations to house one of the first series of Dobson spectrophotometers. In the following decades, several Dobson instruments were used in Arosa (Figure 1). Several years after Götz' death in 1954, the ETH Zürich took responsibility of the LKO under the auspices of H.U. Dütsch. Two Dobson instruments have been used in parallel (D015, D101) since 1967, while Umkehr measurements to calculate coarse vertical ozone profiles have also been conducted since 1956.

After the retirement of Dütsch, MeteoSwiss became the responsible institution for the ozone measurements, which led to a significant extension of the instruments used in Arosa. Three Brewer spectrophotometers were subsequently installed in 1988, 1991 and 1998, and a hitherto semi-automated Dobson (D051) was fully-automated to measure Umkehr profiles.

In about 2011, MeteoSwiss became aware of the critical situation at the LKO regarding personnel changes, and the question of the transfer of measurements to the much larger PMOD/WRC arose, which would also allow synergy effects between both observatories. The key question was whether the world's longest, best-established and most-documented total ozone time-series could be transferred from Arosa to Davos, despite a horizontal distance between both locations of only 13 km, and an altitude difference of 260 m (Davos 1585 m, Arosa 1847 m).

As a first step, one of the Brewers (B072) from the Arosa triad was transferred to Davos in November 2011, where the double monochromator Brewer B163 had been measuring since 2007. At the same time, the LKO Dobsons were converted from their manual mode to fully automated instruments in 2012 (D051, D062) and 2014 (D101), a project that ran under the auspices of R. Stübi from MeteoSwiss. D051 was also occasionally used for total ozone measurements, thus becoming part of a Dobson spectrophotometer triad. In mid-January 2016, Dobson 101 was also transferred to Davos for parallel measurements. An important step was the slit-characterisation of this instrument at the Physikalisch-Technische Bundesanstalt, Braunschweig (Germany) within the EMRP project, ATMOZ in spring 2017 to obtain more precise ozone absorption coefficients. Both B072 and D101, as well as B163, were regularly taken back to Arosa for the biennial comparison with respect to the European reference Brewer from Izaña, and the European reference Dobsons from Hradec Kralove (2017) and Hohenpeissenberg (2018) in order to keep the instrument calibrations up-to-date.

In two peer-reviewed publications, Stübi et al. (2017) analysed the long-term stability of the Brewer triad in Arosa, and the effects after five years (2012–2016) of parallel measurements of B072 in Davos versus the two other Brewers (B040, B156) in Arosa. The conclusion was "that the ozone column series initiated at Arosa in 1926 would not be disrupted by a change of site. Local factors potentially influencing the measurements are below the measurement uncertainty and stay below the long-term stability of the Brewer instruments and within the uncertainties associated with the calibration procedures of the Brewer network" (Stübi et al., 2017). A similar study for the Dobson instruments is in preparation.

Following these encouraging results, PMOD/WRC signed a contract with MeteoSwiss to take responsibility of the operational aspects and quality assurance of the stratospheric ozone measurements in Davos. In autumn 2018, two more instruments (B156, D051) were transferred from Arosa to Davos. One Brewer (B040) and one Dobson (D062) will remain for a period of another 2½ years in Arosa so that a total overlapping period of 10 years between boths sites is attained.

References:

Staehelin J., Viatte P., Stübi R., Tummon F., Peter T.: 2018, Atmos. Chem. Phys., 18, 6567–6584, doi.org/10.5194/acp-18-6567-2018.

Stübi R., Schill H., Klausen J., Vuilleumier L., Gröbner J., Egli L., Ruffieux D.: 2017, Atmos. Meas. Tech., 10, 4479–4490, doi.org/10.5194/amt-10-4479-2017.

International Laboratory Intercomparison of UV Filter Radiometers

Gregor Hülsen and Julian Gröbner

A subset of radiometers which participated in the 2nd UV filter radiometer comparison, UVC-II held in 2017, were calibrated and characterised at their home institutes. A comparison of the calibration factors shows that the "USER" and the PMOD/WRC calibrations agree to within the uncertainties in 10 out of 11 cases.

Eight UV filter radiometers which participated in the 2nd international UV filter radiometer comparison (UVC-II, Figure 1), held at the WCC-UV in 2017 (GAW, 2018), were calibrated and characterised at their home institutes just before being sent to Davos.

These radiometers were from six countries, and consisted of four different radiometer types, including: Kipp & Zonen (3), Yankee UVB-1 (2), analog Solar Light V. 501 (1), and an EKO MS 212W. The filter-weighting function approximates the erythemal action spectrum (UVE). Three devices are dual channel radiometers (UVA and UVE/UVB). Table 1 shows the radiometers and their home institutes discussed here.

Figure 2 summarises the comparison results, showing the calibration factors with their estimated expanded uncertainties (k=2) as derived from the home institutes relative to the factors from the WCC-UV calibration. The USER error bar only corresponds to the measurement uncertainty (k=2) for YES990608. In general, the figure shows that the different calibrations are in good agreement. Only KZ110141 is outside of the uncertainty limit. In addition, YES921116 was only calibrated at LAP after the campaign.

Unfortunately not all institutes were able to check the radiometer response after the comparison at their home institute. In the case of ARPA Piemonte, INTA and BIRA, the radiometer arrived after the calibration period (late autumn). As mentioned above, LAP calibrated the radiometer only after the return (no initial calibration).

*Table 1. Radiometers and their home institutes. *Accredited Institutes.*

Institute	Radiometer	Country
ARPA Aosta	KZ000526 (UVA, UVE)	Italy
ARPA Piemonte*	KZ080003 (UVA, UVE)	Italy
ISOcal*	KZ110141 (UVA, UVB)	USA
UIIMP Innsbruck	SL19507	Austria
AEMET Madrid	YES030520	Spain
LAP	YES921116	Greece
INTA	YES990608	Spain
BIRA	EKO111320-4	Belgium

Figure 1. Outdoor calibration during the 2nd International UV Filter Radiometer Comparison on the PMOD/WRC roof platform with a total of 75 UV radiometers. View towards the south with the Jakobshorn mountain in the background.

KZ110141 suffered an electrical shock during the post calibration. Only ARPA Aosta, UIIMP Innsbruck and AEMET Madrid delivered the required post calibration (USER2). In addition, a QASUME site audit at ARPA Aosta was performed in September 2017 by PMOD/WRC. Through this activity, a PMOD2 calibration of KZ000526 was derived. The USER2 and PMOD2 results are illustrated in Figure 2.

Although weather conditions were not optimal during the 3-day audit at ARPA Aosta, USER2 and PMOD2 values show consistently that the sensitivity of the KZ00527 UVA channel decreased by 0.7% (PMOD2, 0.8%). The sensitivity of the UVE channel increased by 2.6% (PMOD2, 3.9%). YES030520 shows a very stable responsivity whereas the responsivity of SL19507 changed by over 6% when comparing the spring to the autumn calibration.

As an example, Figure 3 (a-d) shows detailed results of the laboratory characterisation of the KZ080003 UVE channel. Measurements of the angular and spectral responsivity (ARF/SRF) are in very good agreement. The corresponding cosine error deviates by less than 1% for solar zenith angles smaller than 60°. The correction matrix, f_n, calculated from the SRF differs by less than ±4% as a function of the SZA.

Panels in the lower row of Figure 3 show the UV index produced using the PMOD/WRC calibration (Figure 3e) and the USER calibration (Figure 3f) relative to the reference dataset using all the available data from the campaign (rain excluded). The difference of the absolute calibration factor leads to the systematic offset of the UVI using the USER calibration. As ARPA Piemonte did not use a cosine correction function, the difference of the correction matrix dominates the smaller UV Index values at higher solar zenith angles.

References: GAW, 2018: GAW Report No. 240, http://www.wmo.int/pages/prog/arep/gaw/gaw-reports.html.

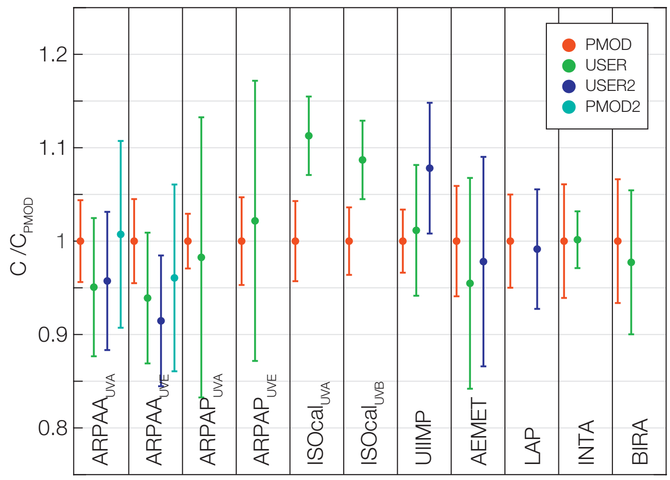


Figure 2. Comparison of the original (USER) and the new (PMOD) calibration. The calibration factor derived after the return of the device to its home institute is shown in blue (USER2 and PMOD2).

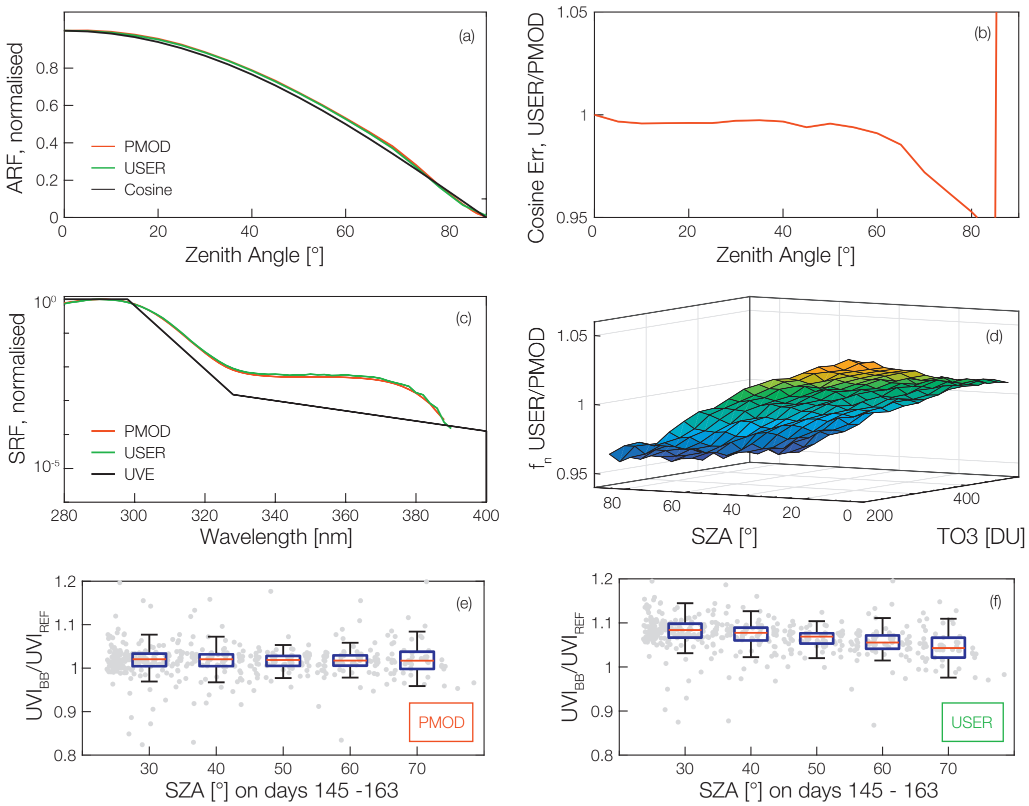


Figure 3. Comparison of the angular responsivity (ARF), the spectral responsivity (SRF), and UV index for KZ080003 (UVE) relative to the reference spectroradiometer.

Instrument Development

Space Experiments

Lloyd Beeler, Wolfgang Finsterle, Christian Fringer, Matthias Gander, Nuno Guerreiro, Manfred Gyo, Margit Haberreiter, Silvio Koller, Philipp Kuhn, Patrik Langer, Nathan Mingard, Dany Pfiffner, Pascal Schlatter, Werner Schmutz, Yanick Schoch, Marcel Spescha, Benjamin Walter

EUI

The Extreme UV Imager (EUI) instrument, a payload onboard the ESA/NASA Solar Orbiter mission. PMOD/WRC is responsible for the Optical Bench Structure (OBS) onto which the EUI channels are mounted.

In 2018, the integration and environmental test campaign of all instruments with the spacecraft continued at Airbus Defence and Space (Stevenage, UK). The tests were supported by the EUI consortium. Some issues during the integration campaign required on-site support to ensure that the EUI instrument was well-maintained.

Figure 1. EUI Consortium Meeting in 2018 at the Max Planck Institute for Solar Research (MPS), Germany, in front of a model of Solar Orbiter.

In autumn, the entire spacecraft was shipped to the Industrieanlagen-Betriebsgesellschaft (IABG, Ottobrunn, Germany) to continue the arduous environmental test campaign. The thermal vacuum test was successfully finished by the end of 2018. Further tests will continue in 2019 and include mechanical vibration testing. This will ensure that the spacecraft can cope with the stress of lift-off as well as the journey to operational orbit around the sun.

During the regular consortium meetings of the EUI team, in spring 2018 in Davos and autumn 2018 in Göttingen (Figure 1), preparation for commissioning and operation continued. Apart from these aspects, the meetings were also used to transfer detailed design information from the engineering to the science team members.

Solar Orbiter is scheduled for launch in February 2020, and will reach its initial operational orbit about two years later (http://sci.esa.int/solar-orbiter/).

SPICE

The Spectral Imaging of the Coronal Environment (SPICE) instrument, a payload onboard the ESA/NASA Solar Orbiter mission. PMOD/WRC is responsible for the low voltage power supply (LVPS), and the slit change (SCM) and SPICE door mechanisms (SDM).

Like EUI, the SPICE instrument was finally integrated into the spacecraft and participated during the spacecraft test campaign at Airbus Defence and Space (Stevenage, UK), as well as at the Industrieanlagen-Betriebsgesellschaft (IABG, Ottobrunn, Germany). These tests were supported by the consortium which had built the instrument.

In November 2018, a Consortium Meeting took place at PMOD/WRC (Figure 2). Amongst various topics discussed, an important aspect was the continued knowledge-transfer from the group which had built the instrument to the operational consortium members.

The regular continuation of these consortium meetings is being used to prepare the commissioning and operation of the SPICE instrument.

Solar Orbiter is scheduled for launch in February 2020, and will take about two years to reach its initial operational orbit using gravity-assisted flybys of Earth and Venus. It will then enter a highly elliptical orbit around the Sun (http://sci.esa.int/solar-orbiter/).

Figure 2. Meeting of the SPICE Consortium in November 2018 at PMOD/WRC, Davos.

DARA

The Digital Absolute Radiometer (DARA), a payload onboard the ESA PROBA-3 formation flying mission. DARA is a 3-channel radiometer designed for the long-term stable and highly accurate measurement of TSI which is fully traceable to SI.

The DARA instrument design had to be modified due to the outcome of the vibration test which was conducted with the Engineering Model in 2017. The various design modifications shifted the eigenmodes into the preferred frequency range and as required, an increased instrument structure stiffness was achieved (Figure 3). The DARA re-design also led to a slightly increased mass of approximately 3.1 kg.

This adapted design was the subject of the instrument critical design review, held at ESA/ESTEC early in 2018. It was not possible to fully complete the review as additional simulation tasks had to be performed. These further analysis iterations were no longer within the scope of the industry subcontractors. As a result, PMOD/WRC took over the mechanical and structural analyses and subsequent associated testing activities.

Regarding the instrument electronics, a hardware and software compatibility test was conducted at QinetiQ Space NV in Kruibeke, Belgium. The DARA engineering model was connected to the PROBA-3 power and data interface to verify correct communication and associated protocols in both directions. All DARA electronic boards were manufactured and assembled for both flight models – one engineering / qualification model, which can be used as a so-called "flight spare" and one as a flight model. By the end of the year, all electronics boards had been individually tested (e.g. Figure 4). The machining of the mechanical structural parts was partly subcontracted to a local provider and partly manufactured in-house at PMOD/WRC.

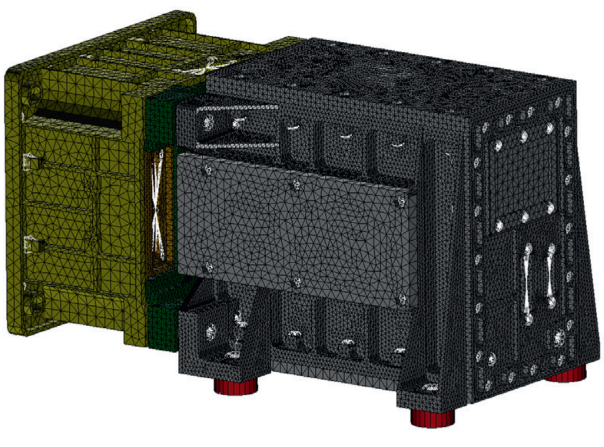


Figure 3. DARA Modified Finite Element Model (FEM) for structural analysis.

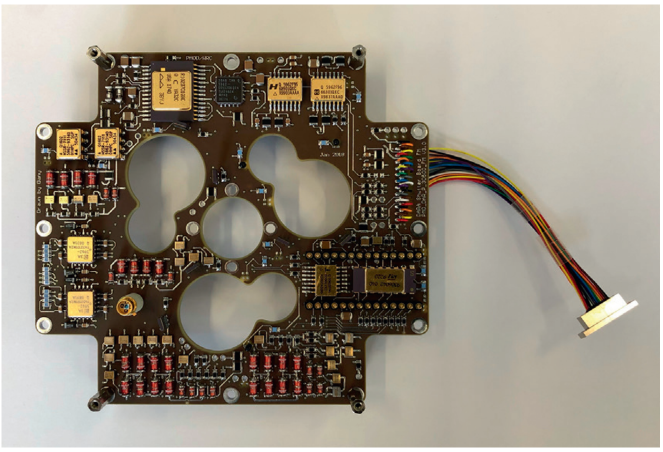


Figure 4. DARA shutter-board before integration.

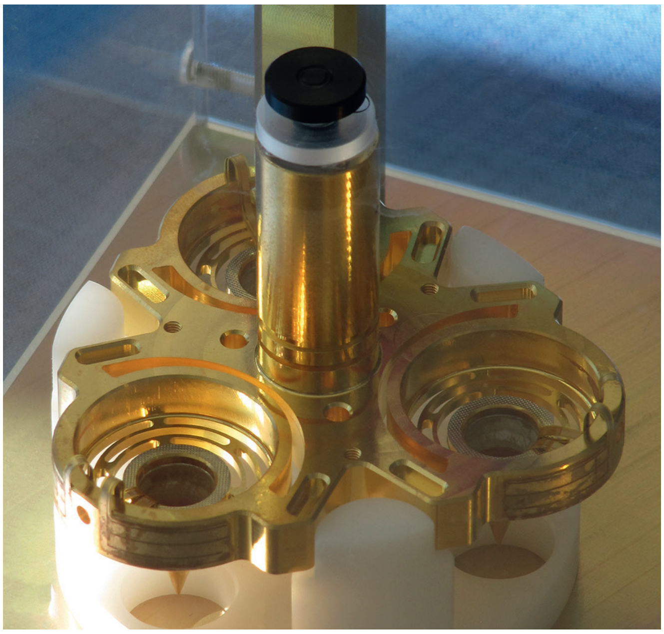


Figure 5. DARA heatsink in a transport container before coating.

A central element of DARA is the heatsink component, which incorporates the three blackbody receivers (see Figure 5). Several assemblies were manufactured for the JTSIM-DARA radiometer on the Chinese FY3-E mission and for DARA on PROBA-3. Reflectance measurements of the single cavities were conducted at PMOD/WRC to select the best parts for the flight units. The receiver cavities, coated with a thin layer of high solar absorbing black paint, have a low reflectance of about 400–700 ppm.

The AIT phase of the project will start next year. AIT consists of assembly, integration and test activities. Once the flight units are assembled, instrument characterisation and calibration will be performed, and the units will be qualified with various tests before delivery.

JTSIM-DARA

Joint Total Solar Irradiance Monitor-DARA (JTSIM-DARA), a radiometer onboard the Chinese FY-3E mission. JTSIM-DARA will measure TSI along with a Solar Irradiance Absolute Radiometer (SIAR), designed by CIOMP (China).

The JTSIM flight unit (Proto Flight Model; PFM) was tested, characterised and calibrated throughout 2018. The test campaign included sun measurements, pointing quantification and electrical calibration.

Two Chinese/Swiss Exchange Meetings also took place in 2018. In June, a Chinese delegation of engineers visited PMOD/WRC. During the 1-week visit, communication systems between DARA and the JTSIM onboard computer were tested. An acceptance review of the DARA hardware was conducted, and various additional topics such as the calibration and time schedule were discussed.

Figure 7. Chinese Delegation in Davos with representatives from PMOD/WRC, PRODEX, and the Royal Observatory of Belgium.

Figure 6. DARA radiometer for the JTSIM PFM instrument (inside the perspex box) installed on the World Standard Group (WSG) tracker during first solar measurements.

Later in September, PMOD/WRC organised a Chinese/Swiss Seminar in Switzerland with the participation of the Changchun Institute of Optics, Fine Mechanics and Physics Institute (CIOMP), Chinese Meteorological Administration (CMA) and Swiss Space players. A fruitful exchange was reached during the days in Lausanne, Berne and Davos. The Chinese groups were enthusiastic and impressed by the contributions from the involved institutions, including: the Swiss Space Center (SSC), the Swiss Space Office (SSO), the International Space Science Institute (ISSI), University of Berne, and the Royal Observatory of Belgium. During the whole seminar, a very open and inspiring working atmosphere was experienced by all participants.

Nevertheless, due to concerns about the export restrictions, the project schedule was further delayed. The export of parts (e.g. the instrument simulator) and exchange of technical details has not been possible to date. On the other hand further instrument tests with the Chinese instrument controller electronics would have been advantageous and will probably be performed in the next year.

The present year, 2019, is the last phase of the project. The flight model will be fully calibrated in Davos, and the instrument will then be shipped to China so that all environmental tests can be performed.

Finally, a comprehensive calibration and qualification period in China is planned, before the PFM instrument will be integrated at the end of 2019.

EUVI

Extreme Ultraviolet Imager (EUVI), an instrument onboard the Lagrange mission. ESA is planning the first dedicated space weather observatory to monitor events such as solar flares, coronal mass ejections, geomagnetic storms, and solar proton events.

Monitoring from the Lagrangian points L1 and L5 (Figure 8) will help to predict the arrival times of events at the Earth, enabling mitigation strategies to be implemented. L1 will provide information about the space weather coming directly towards Earth. In contrast, observations at L5 will allow the speed and direction of solar events to be determined (Figure 9).

PMOD/WRC is part of the Lagrange Mission Remote Sensing Instruments Phase A/B1 Study & Pre-Developments consortium led by the Rutherford Appleton Laboratory (RAL, UK).

The study, organised by the Earth Observation department of ESA, combines an analysis of in-situ and remote-sensing instruments as well as the required spacecraft. The three studies are being conducted in parallel to obtain operational specifications which can be implemented for a mission to L1 or L5.

PMOD/WRC, the Royal Observatory of Belgium (ROB), Belgium, and the Centre Spatial de Liège (CSL), France, are part of the remote sensing consortium, who are responsible for studying operational specifications of an extreme UV imager instrument. The EUVI group is led by CSL.

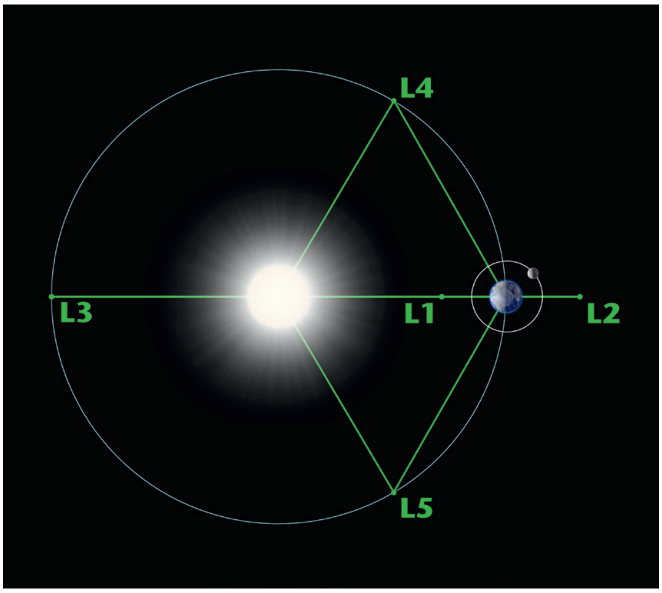


Figure 8. Lagrangian points L1 to L5. Image copyright NASA.

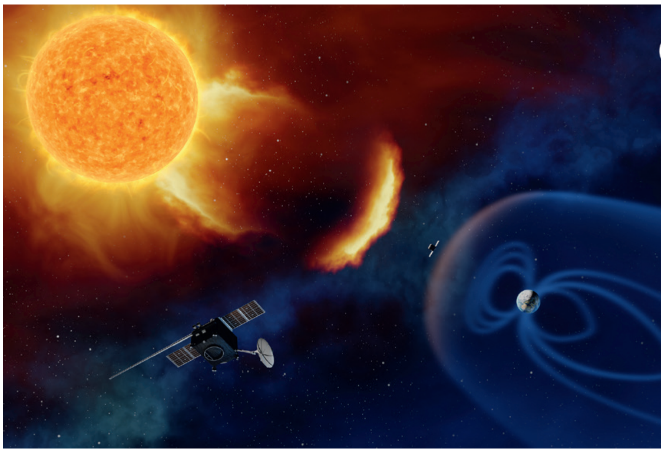


Figure 9. Artist's impression of the Lagrange mission showing spacecraft at the Lagrangian points L1 and L5 during a solar event. Image copyright ESA.

Based on the SWAP (Sun Watcher using Active Pixel System Detector and Image Processing) instrument on PROBA-2 and the EUI Instrument on Solar Orbiter, an implementation for an operational mission will be studied.

Phase A began in February 2018 and finished with the Preliminary Requirement Review (PRR) at the end of 2018. Based on the operational specifications, an updated design (Figure 10) to extend the field-of-view to 2.5 x that of the solar disc and use of a higher spatial resolution, 1.6 arcsec/pixel, are the major changes compared to the SWAP design. These changes will have an impact on the optical and mechanical design which is in the process of being determined.

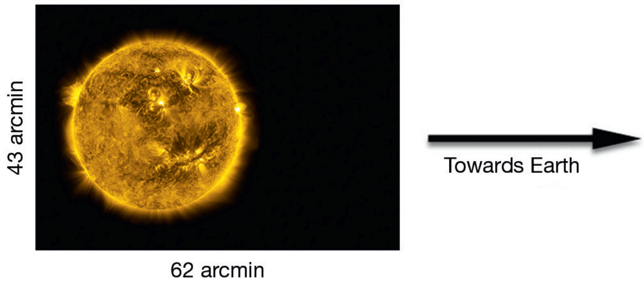


Figure 10. Field-of-view of the EUVI instrument.

Scientific Research Activities

Overview

Werner Schmutz

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.

The choice of projects to be conducted at the institute is governed by the synergy between the know-how obtained from the Operational Services of the World Radiation Center and other research activities. Basically, the same instruments are built for space-based experiments as are utilised for ground-based measurements. The research activities can be grouped into three themes:

- Climate modelling
- Terrestrial radiation balance
- Solar physics

The majority of research activities are financed through third party funding. Last year, the following funding sources were available: i) four projects were supported by the Swiss National Science Foundation, ii) two projects by MeteoSwiss in the framework of Swiss contributions to the WMO Global Atmosphere Watch programme, iii) a project through the Horizon 2020 programme of the European Commission, iv) one project through the European Metrology Research Programme, v) two projects by ESA's directorate for Earth Observation and Directorate of Operations, and vi) one project was funded by a sponsor. These funding sources supported two PhD thesis projects and five post-doctoral positions. Furthermore, one PhD student, and one bachelor student at the observatory were paid by external funding.

Swiss participation in ESA's PRODEX programme (PROgramme de Développement d'Expériences scientifiques) funds the hardware development of space experiments. The institute's four PRODEX projects paid for the equivalent of five technical department positions. Another space-related contribution is the ESA IDEAS+ project, which is using the institute's laboratory calibration equipment.

In the past 19 years, the institute has been involved in the challenging task of characterising the natural influence on climate change. A full assessment of current climate change requires characterisation of the contribution by natural influences on the observed changes. Such an assessment is also required in order to provide competent answers to climate sceptics. A first estimate of the magnitude of such effects was recently published by the Future and Past Solar Influence on the Climate (FUPSOL) research consortium, led by PMOD/WRC, in which it was concluded that the solar influence might dampen climate warming by 0.5°C in the next 100 years when considering a warming scenario of 4°C.

A theoretical assessment of the variations of solar irradiance during the past 10,000 years was published in 2011 and was one of the institute's most influential papers. An updated reconstruction was published last year. Climate simulations that have solar forcing as a natural influence, either for understanding past climate changes or for predicting the influence on the evolution of future climate, are ongoing at PMOD/WRC, as can be seen in the research summarised in the section on Scientific Research Activities.

The institute's infrastructure and most of its overheads are paid for by the operational services 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. This is the best way to provide a service as it is common wisdom that tasks are only accomplished with excellence when based on genuine interest and curiosity. Several interesting examples of research, originating from the center's operational activities, are also summarised in the section on Operational Services.

Figure 1 statistically illustrates the good research reputation that PMOD/WRC staff have as well as the interest of the science community in results published by the institute.

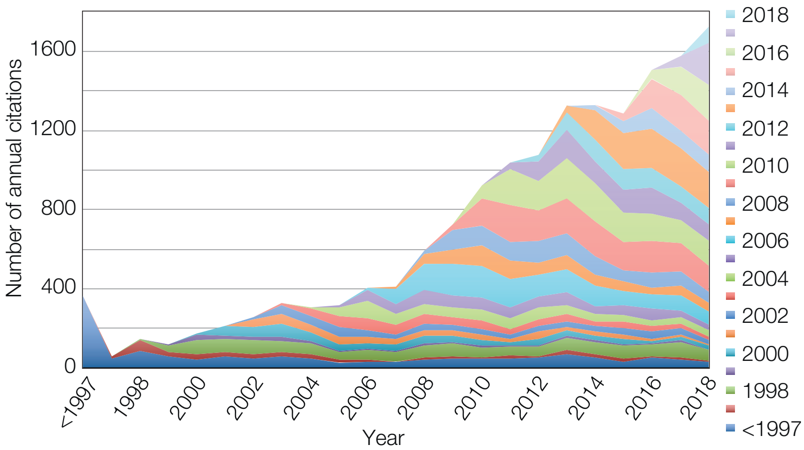


Figure 1. Number of annual citations of articles including an author with a PMOD/WRC affiliation. In April 2019, there were 16671 citations to 667 articles included in Thomson Reuter's Web of Science. The articles were selected using the search criteria address = (World Rad C*) OR (PMOD* NOT PMOD Technol* OR pmodak) OR (Phys* Met* Obs*).*

Quantification of Solar Irradiance Forcing by Combining Climate and Phenological Models

Tatiana Egorova, Werner Schmutz, Timofei Sukhodolov, and Eugene Rozanov

We continue analysis of the 100-year long MPI-Met Earth System Model (ESM) run covering 1650–1750, and CCMI SOCOL runs for 1950–2100, which are driven by solar forcing reconstructed by Egorova et al. (2018). Our present work concentrates on calculations and analysis of the full-flowering date during the above time periods.

In this internal project, we exploited the MPI-Met Earth System Model (ESM) and the Chemistry-Climate Model, CCM SOCOL. Two 100-year long simulations (1650–1750) were performed with the ESM driven by evolving solar irradiance (Egorova et al., 2018) and with two 150-year long simulations (1960–2100) with CCM SOCOL, in order to analyse the evolution of spring temperatures over Kyoto (see article in PMOD/WRC annual report, 2017). Using simulated daily mean temperatures with constant and variable solar irradiance, we calculated the full-flowering date of cherry trees in Kyoto for the two analysed time periods. To calculate full-flowering dates for Kyoto cherry trees from simulated temperatures we use the DTS (Days Transformed to Standard Temperature) model from Aono and Kazui (2008). DTS is a temperature accumulation model that is based on an exponential contribution of the temperature to the development of trees.

Figure 1 illustrates the simulated full-flowering date for the past historical period. The obtained date varies from 102 to 104 days, which is consistent with the observations published by Aono and Kazui (2008). Both model runs show some warming and earlier flowering during the 1650 – 1700 period. This is not related to solar activity because there was no solar irradiance trend during this period. After 1700, solar activity started to recover after the Maunder minimum and the temperature trends for the two model runs became different. Warming continued for the run with variable (increasing) Total Solar Irradiance (TSI) but disappeared for the case with constant TSI. The trend agrees with Aono and Kazui (2008), but the magnitude of the changes is only about 1–2 days, while the shift of the full-flowering day between 1650 and 1750 reached 4–5 days in the observations. One of the reasons for this difference could be related to a possible underestimation of the magnitude of solar irradiance forcing.

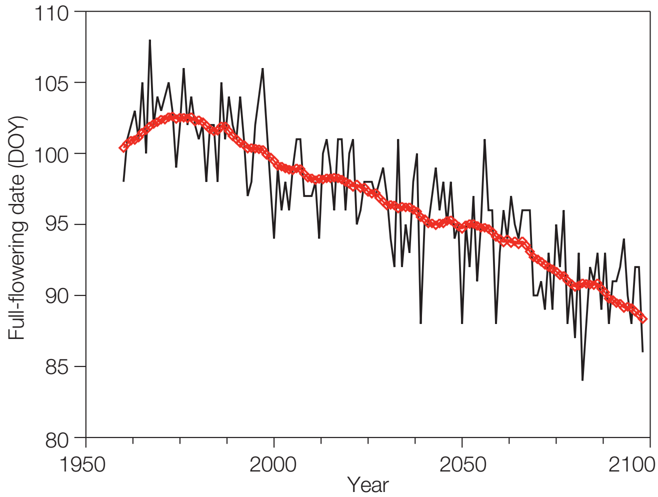


Figure 2. Inter-annual variations in cherry tree full-flowering dates at Kyoto based on calculated temperatures with CCM SOCOL for 1960–2100.

The CCM SOCOL run for the future period was mainly driven by anthropogenic forcing, which successfully simulates well-known greenhouse warming. Figure 2 illustrates that in conditions of permanent climate warming, the full-flowering date will shift by about half a month at the end of the 21st century while the cherry blossom event in Kyoto will shift from March–April to February–March.

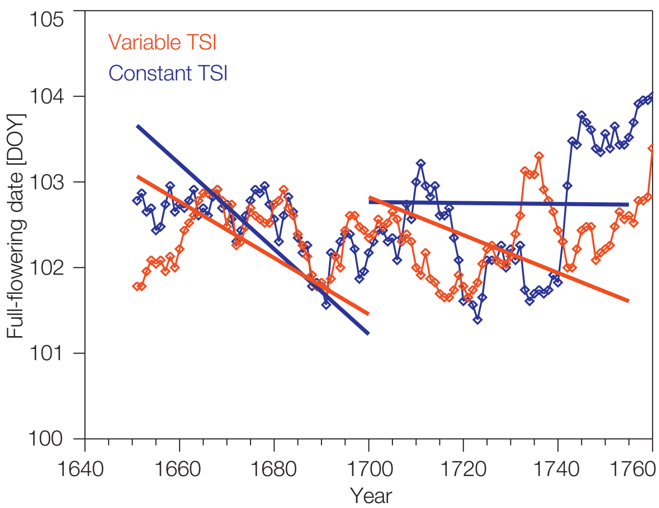


Figure 1. Evolution of the cherry tree full-flowering date at Kyoto calculated for 1650–1750 and linear trends extracted from the runs with variable (red) and constant (blue) TSI.

References:

Aono Y., Kazui K.: 2008, Phenological data series of cherry tree flowering in Kyoto, Japan, and its application to reconstruction of springtime temperatures since the 9th century, Int. J. Climatol., 28, 905, doi: 10.1002/joc.1594.

Aono Y.: 2015, Cherry blossom phenological data since the seventeenth century for Edo (Tokyo), Japan, and their application to estimation of March temperatures, Int. J. Biometeorol., 59, 427, doi: 10.1007/s00484-014-0854-0.

Egorova T. et al.: 2018, Revised historical solar forcing using updated model and proxy data, Astron. Astophys., doi: 10.1051/0004-6361/201731199.

Toward a Proper Representation of the Global Electric Circuit in Climate Models: Introduction of ^{222}Rn to the Chemistry-Climate Model SOCOL v2

Eugene Rozanov in collaboration with St. Petersburg University (Russia)

This scientific research is a part of the COST action CA-15211 (ELECTRONET) WG3 activity. The main aim was the installation of radon (^{222}Rn) treatment into the Climate-Chemistry Model (CCM) SOCOL v2 to study atmospheric conductivity and feedbacks between the Global Electric Circuit (GEC) and climate.

The radon contribution to the total atmospheric conductivity is important and its treatment in climate models is necessary to further understand feedbacks between atmospheric electricity and climate processes. Harrison et al. (2010) suggested that changes in surface ionisation caused by radon can modify the near surface atmospheric electric field and even the state of the lower ionosphere via the weak current in the fair-weather areas carrying negative charge upwards throughout the troposphere and stratosphere. In polluted air, the conduction current density can increase approximately linearly with increasing radon induced ionisation by about 10%. Baumgaertner et al. (2013) stated that the radon contribution leads to an enhanced variation in conductivity (up to 200%) near the surface. In the free troposphere between 300 and 700 hPa, conductivity varies by only about 40–50%, increasing again in the stratosphere up to 100%. The isotope ^{222}Rn has a half-life of 3.8 days and can stay suspended in the air and be transported over large distances. A global map of radon emissions was produced by Schery and Wasiolek (1998) and used as a source emission of radon in the CCM SOCOL v2 model.

Radon was also incorporated into the transport, chemical and atmospheric electricity modules of CCM SOCOL v2 as an additional source of atmospheric ionisation. Then, we performed several 2-year long model experiments for the 2004–2005 period to obtain and analyse the distribution of the radon concentration as well as to compare our results with available observations and model data. The comparison of the simulated ^{222}Rn mixing ratio with results from the ECHAM5 and WACCM data showed

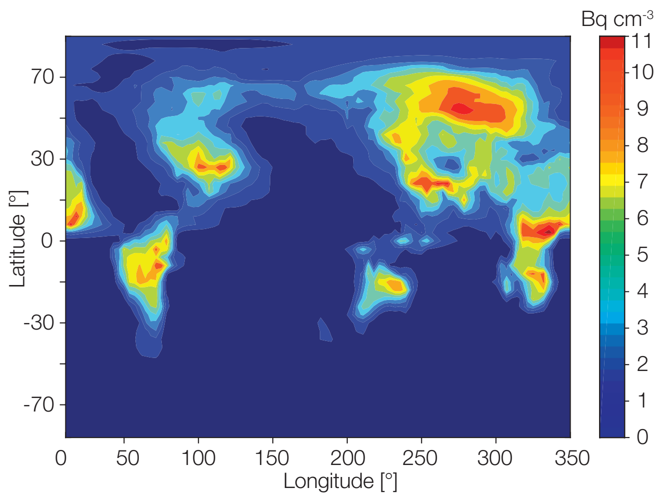


Figure 1. Simulated Janurary mean near-surface ^{222}Rn ion. rates (Bqcm^{-3}).

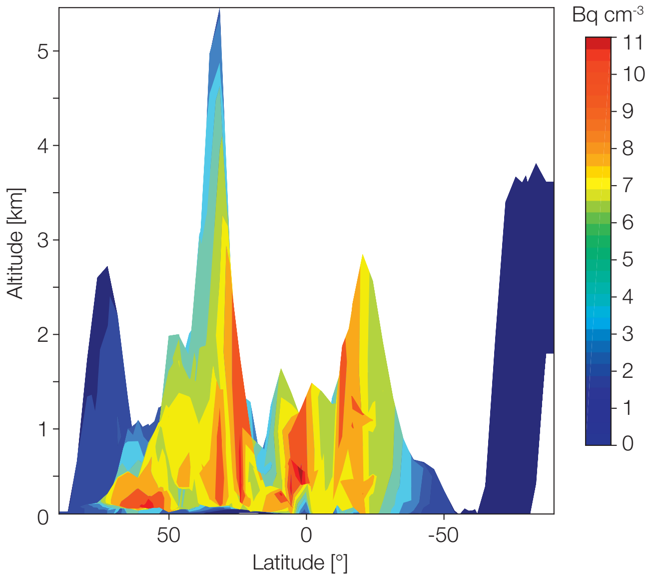


Figure 2. Simulated zonal and January mean ^{222}Rn ionisation rates (Bq. cm^{-3}).

that our model can reliably reproduce the variations of surface radon concentrations. The comparison for the free troposphere over the middle and low latitudes is less successful because convective radon transport was not implemented. This problem will be resolved during the follow-on short-term science mission planned for next year. We also plan to extend our model to include the conductivity modulation by clouds and aerosol as well as to simulate vertical electrical currents and the potential gradient in the atmosphere. It will allow more accurate model evaluation using the comparison with available atmospheric electricity measurements. The calculated radon activities were also compared to the Zhang et al. (2011) results. The simulated radon activities have a maximum during boreal winter due to increased atmospheric stability and the seasonal mean reaches about 6 Bq.cm^{-3}. In the middle and low-latitude continental areas, the zonal mean of the radon-induced ionisation rate is up to 10 Bq.cm^{-3} at 2000 m altitude. Further analysis of ionisation rates shows that in Russia and Canada, strong radon-related ionisation often occurs in winter at low temperatures, which provide favourable conditions for ion induced H_2O nucleation (Lucas, 2010).

References:

Baumgaertner A., et al.: 2013, J. Geophys. Res. Atmos., 118, 9221–9232, doi:10.1002/jgrd.50725.

Harrison R., et al.: 2010, J. Atmos. Sol. Terr. Phys., 72, 376–381, doi:10.1016/j.jastp.2009.12.004.

Kazil J., et al.: 2010, Atmos. Chem. Phys., 10, 10733–10752, doi:10.5194/acp-10-10733-2010.

Lucas G. M.: 2010, Thesis, B.S., University of Wisconsin.

Schery S. D., Wasiolek M. A.: 1998, In: Radon and Thoron in the Human Environment. World Sci. Publishing.

Zhang K., et al.: 2011, Atmos. Chem. Phys., 11, 7817-7838, 2011.

Contributions of Natural and Anthropogenic Forcing to the Early 20th Century Warming

Tatiana Egorova, Eugene Rozanov, and Werner Schmutz in collaboration with IAC ETHZ (Switzerland)

In the framework of the FUPSOL project, we studied the influence of natural and anthropogenic factors on the ozone layer and climate evolution during the first half of the 20th century. In our latest analysis of model simulations, we evaluated the contribution of different forcing types to global and seasonal mean ozone and temperature trends. The model results suggest a 0.3 K annual global warming during the analysed period which is 25% smaller than trends obtained from re-analysis of the observational data. It suggests the possibility of a larger than applied solar forcing. The ozone response is only driven by solar UV irradiance.

The observed early 20th century warming (ETCW, 1910 – 1940) is one of the most intriguing and least understood climate anomalies. To investigate the contributions of natural and anthropogenic factors to the surface temperature increase, we performed a reference run and seven model experiments using a Chemistry-Climate Model with an interactive ocean, SOCOL – MPIOM (Muthers et al., 2014). In the reference run (All), we applied all known climate drivers obtained from observations or reconstructed from proxies. The following were switched off one-by-one in the experimental runs: the variability of energetic particle precipitation (PAR), solar UV irradiance (UV), solar visible and infrared irradiance (VIS), well-mixed greenhouse gases (GHG), tropospheric ozone precursors (OPR) and stratospheric aerosols (VOL).

The global, hemispheric, annual and seasonal mean surface temperature trends are illustrated in Figure 1. Southern Hemisphere simulated temperature changes are about 0.3 K for all seasons, which is not significantly different from the CCC400 re-analysis. In the Northern Hemisphere, the temperature trends are substantially (up to 0.3 K) underestimated by the model for all seasons except boreal spring. Due to a deviation in the Northern Hemisphere, the model also underestimates global mean trends by up to 0.2 K. The results for all members of the ensemble simulation show that the internal variability does not play an important role because in nine out of 10 ensemble members the model underestimates the warming magnitude. Negative model bias in the simulation of the ETCW should not be related to anthropogenic activity, because the emissions of WMGHGs are well-constrained and highly uncertain tropospheric ozone precursors cannot contribute much to the global and annual mean trends. Our results suggest that the underestimation of the ETCW intensity can be improved by using even stronger solar irradiance changes during the early 20th century. It is partially confirmed by the better performance of our model in comparison with CMIP5 models, which underestimated the ETCW intensity even more when using weaker CMIP5 solar forcing recommendations. We also emphasise the dominating role of anthropogenic and solar forcing agents. A more detailed analysis of temperature trends is published in Egorova et al. (2018).

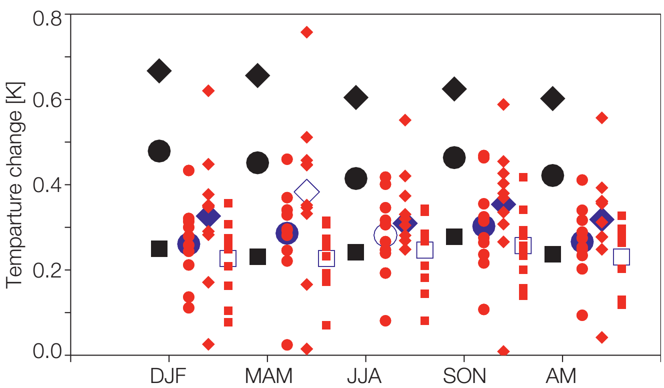


Figure 1. Comparison of the simulated and re-analysed global, annual mean and seasonal mean surface air temperature trends for the period 1910–1940. CCC400 data are shown in black. The results of model run, All, for the ensemble mean are shown in blue, while all 10 individual members are shown in red. Global, Northern Hemisphere and Southern Hemisphere mean trends are shown with circles, rhombii and squares. Filled large symbols mark the points where the simulated trends differ from observations by a statistical significance of >95%.

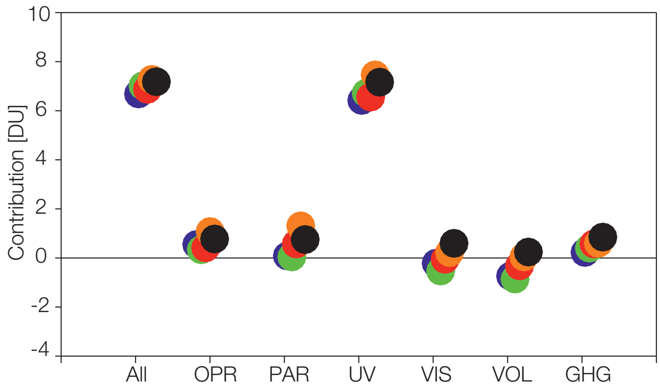


Figure 2. Contribution (DU) of different forcing types (see text) to the global and seasonal mean ozone trend for the period 1910–1940 from the reference simulation (All). Black, blue, green, red and orange colors represent annual, boreal winter, spring, summer and autumn mean values, respectively.

The contributions from all forcing types to the ozone trends are presented in Figure 2. Model results show a robust positive total ozone increase by 6–8 DU and suggest that the ozone response is driven exclusively by an increase in UV radiation during the analysed time period. The other forcing types do not significantly contribute to the annual and global mean ozone trend (1–2 DU). A more detailed analysis will be conducted in Egorova et al. (2019, in preparation).

References:

Egorova et al.: 2018, Contributions of natural and anthropogenic forcing agents to the early 20th century warming, Front. Earth Sci., doi.org/10.3389/feart.2018.00206

Egorova et al., 2019 in preparation.

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

Role of Volcanic SO_2 Emissions During Early 21st Century

Timofei Sukhodolov and Eugene Rozanov in collaboration with IAC ETHZ (Switzerland)

We used our aerosol-chemistry-climate model, SOCOL–AER, to study the role of small volcanic eruptions in the aerosol layer evolution over the early 21st century. We performed ensemble experiments by switching on and off different sulphur emission sources and by using different volcanic emission databases. We found that even though there are increasing trends in all the main sources of sulphur emissions, the observed trend in the sulphate aerosol layer is most likely defined by volcanic activity. However, we also demonstrated that the volcanic emission data are rather uncertain and need further clarification.

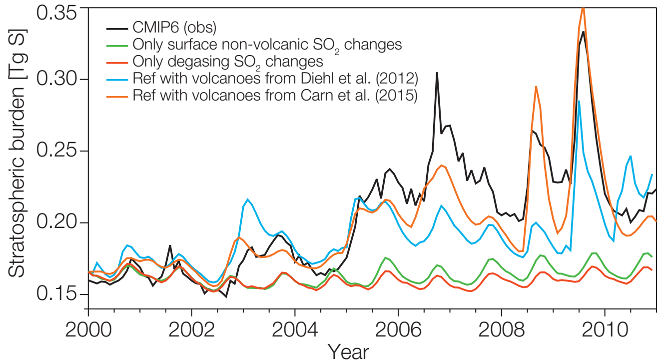


Figure 1. Time evolution of the globally averaged stratospheric aerosol burden from the CMIP6 observational composite (black) as well as from the four model experiments where only non-volcanic sulphur emissions are transient (NonVolc, green), only degassing volcanic emissions are transient (VolcDegas, red), and all emissions are transient (Ref, blue and orange). Blue and red lines represent different volcanic emission scenarios.

Volcanic activity is one of the major natural climate forcings and its influence on climate was recognised long ago. The beginning of the 21st century was not marked by any very powerful eruptions with a volcanic explosivity index of more than four. However, recently it was suggested that more numerous small volcanic eruptions can also significantly influence stratospheric aerosol loading and hence climate. Besides an increasing observed trend in explosive volcanic SO_2 emissions over this period, there is also an increasing trend in non-volcanic SO_2 emissions. Even though SO_2 emitted close to the surface can reach the stratosphere only through deep convection penetrating the tropopause, which mainly happens in the tropics, the SO_2 emission rate from surface sources (~65 Tg S yr^{-1}) is much larger than that from explosive eruptions (the strongest eruption in the 2000–2011 period being Kasatochi on 7 August 2008 with 0.85 Tg S). This study aimed to clarify the contribution of the volcanic activity to observed changes in the stratospheric aerosol layer, and to clarify its influence on the atmosphere.

We used the coupled aerosol-chemistry-climate model, SOCOL–AER. The model includes comprehensive sulphur chemistry and microphysics, in which the particle size distribution is represented by 40 size bins spanning radii from 0.39 nm to 3.2 µm. Radiative forcing is computed online using aerosol optical properties calculated according to Mie theory. We performed ensemble runs with all sulphur sources changing in time (Ref), with only non-volcanic sources changing in time (NonVolc), and with all sources constant at the year 2000 level but with degassing volcanic emissions changing in time (VolcDegas), which we compared with observational composite data (CMIP6). The modelled and observed evolution of the stratospheric aerosol burden is presented in Figure 1.

Our model experiments showed that non-volcanic sulphur emissions (NonVolc) and degassing volcanic emissions (VolcDegas), which are located at the surface, cannot explain the observed positive trend in the global aerosol evolution and introduce only a small increase to the global aerosol burden. For the explosive volcanic emissions, we first used the database by Diehl et al. (2012). This database helped to reproduce most of the observed aerosol variability, but also demonstrated some important inconsistency compared to observations. The database consists mostly of the date, location, magnitude and the plume top altitude. The emission magnitude can be very uncertain, depending on the eruption, due to instrumental limitations and interpretation of the early post-eruption processes. However, uncertainty of the plume altitude could be even more important because even 1 km uncertainty can define whether most of the plume will be located in the stratosphere, where aerosol lifetime is long, or in the troposphere, where aerosol is quickly washed out by precipitation. To account for this uncertainty, we used another database by Carn et al. (2015), which allowed us to obtain better agreement with observations and to illustrate how sensitive aerosol evolution can be to the emission uncertainties for each particular eruption.

Recently, two international programmes, aiming for a better evaluation of aerosol modules, have emerged in the framework of SPARC SSiRC (Stratospheric Sulfur and its Role in Climate) core project. VolRES (Science Response Plan for the Next Volcanic Eruption with Major Impact on Climate), will involve direct in-situ and satellite observations during and after a future major-eruption that can be used to improve modelling and forecasting of volcanic aerosol formation. ISA-MIP (Interactive Stratospheric Aerosol Model Intercomparison Project; Timmreck et al., 2018) aims to evaluate and improve interactive aerosol models and to characterise uncertainties in stratospheric aerosol properties. Our planned participation in these two programmes will provide benefits, both for our model and for the scientific community, and hence, society.

References:

Carn S. A., Clarisse L., Prata A. J.: 2015, Multi-decadal satellite measurements of global volcanic degassing, J. Volcanol. Geoth. Res., 311, 99-134.

Diehl T. et al.: 2012, Atmos. Chem. Phys. Discuss., 12, 24895–24954, doi.org/10.5194/acpd-12-24895-2012.

Timmreck C. et al.: 2018, The Interactive Stratospheric Aerosol Model Intercomparison Project (ISA-MIP): 2018, Motivation and experimental design, Geosci. Model Dev., doi: 10.5194/gmd-2017-308.

The Investigation of Low Energetic Particle Effects on the Middle Atmospheric Chemistry and Dynamics using the Chemical-Climate Model (CCM) SOCOL v2

Eugene Rozanov in collaboration with Earth Physics Dept. (St. Petersburg Univ., Russia)

Solar Proton Events (SPEs) can impact the atmosphere through additional middle atmospheric ozone depletion by nitrogen (NO_x) and hydrogen (HO_x) oxides. Previous modelling results with SOCOL v2 showed the overproduction of OH at ~0.01–0.1 hPa after SPEs in January 2005 compared to satellite data. This project aimed to improve the SOCOL v2 chemistry treatment at high altitudes in order to achieve better agreement with observations from the Microwave Limb Sounder (MLS) satellite.

The previously observed overproduction of OH could be related to overestimation of the ionisation rates or to some problems in chemical modules leading to an incorrect redistribution among hydrogen oxide family members. The problem could also be related to the fixed top altitude of the model layer at 80 km, which prevents mixing with the lower thermosphere. In this work, we concentrate on the second and third problems. The new ionisation rates for the solar proton event (SPE) on 17–20 January 2005 were calculated in the scope of this project, by also considering protons with energies <10 MeV which were omitted in previous experiments. These new ionisation rates were incorporated into CCM SOCOL v2 to simulate the chemical changes induced by the SPE.

Li et al. (2017) proposed that for better agreement between modelled and observed HO_x, the kinetic rate coefficient in the $O_2 + H + M \rightarrow HO_2 + M$ reaction should be increased by up to 134–310%. Based on this assumption, we increased the kinetic rate of this reaction by 300% in the model. In addition, we lowered HO_x production via solar protons by 40%. This correction represents compensation of the abscence of air mixing in the upper model layer with the lower thermosphere, where the HO_x mixing ratio is very low. We performed a 10-member 1-month long ensemble run with the new model version. The evolution of the OH mixing ratio at the 0.01 and 0.05 hPa levels are presented in Figures 1 and 2.

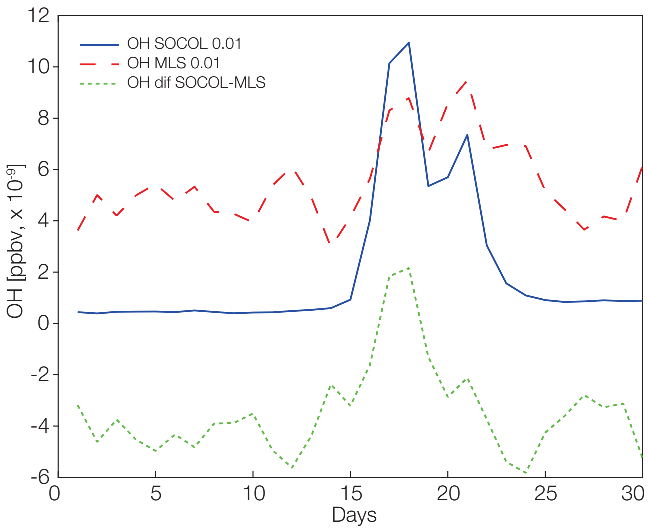


Figure 1. The mean OH evolution (ppbv) at 0.01 hPa during January 2005 from CCM SOCOL v2 (ensemble mean, blue) for latitude range 72°–80°N, MLS satellite data (red) and model deviation from observations (green).

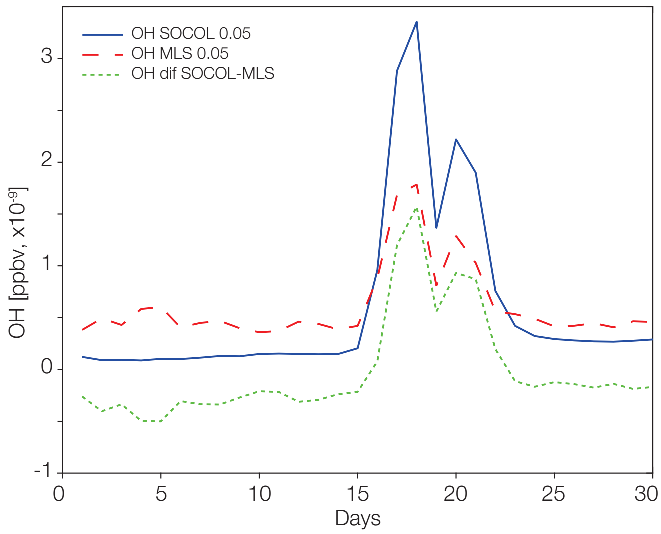


Figure 2. The mean OH (ppbv) evolution at 0.05 hPa during January 2005 from CCM SOCOL v2 (ensemble mean, blue) for the latitude range 72°–80°N, MLS satellite data (red) and model deviation from the observations (green).

The MLS observational data show the presence of OH in the upper model layers (about 4 ppbv at 0.01 hPa and 0.5 ppbv at 0.05 hPa) before the event, while OH is virtually absent in the model. This indicates some problems with HO_x in-situ production or the absence of HO_x influx from the layers above the top of the model at 80 km. The two simulated spikes after the SPEs on 17 and 20 January are, in contrast, still higher than those observed. The simulated increase at 0.01 hPa is about 9 ppbv on 17 January, while MLS observations show only about 6 ppbv. At 0.05 hPa, the model shows a 3 ppbv increase compared to 1.5 ppbv in the MLS data. At 60 km (not shown), the OH response is about 10 times smaller than at the top, but the relative deviation is almost the same (~30%). Despite the encountered problems, the disagreement between the corrected model and observations is now substantially lower in comparison with the previous model version where the deviation exceeded 10 ppbv.

Further work is needed to obtain more satisfactory results. One of the directions is the additional refinement of ionisation rates. Vertical coupling will be the other focus. In our present model version, it was roughly parameterised only in terms of HO_x production by protons, while the obtained disagreement of the simulated and observed hydroxyl, also under background conditions, suggests that the under-represented mesospheric dynamics should receive more attention. We plan to continue our studies in this area.

References: Li K.-F et al.: 2017, Resolving the model observation discrepancy in the mesospheric and stratospheric HO_x chemistry, Earth Space Sci., 4, 607-624, doi:10.1002/2017EA000283.

Ionospheric Response to the January 2009 Sudden Stratospheric Warming

Timofei Sukhodolov and Eugene Rozanov in collaboration with IZMIRAN (Kaliningrad, Russia)

We apply our new Entire Atmosphere Global Model (EAGLE) to investigate the upper atmosphere response to the 2009 Sudden Stratospheric Warming (SSW) event. Our results agree well with the observed evolution of the neutral temperature in the upper atmosphere and with the low-latitude ionospheric disturbances over America, and therefore can help to explain the formation mechanism for the observed ionospheric anomalies.

Sudden stratospheric warming (SSW) events are driven by the upward propagating planetary waves from the troposphere. Wave-breaking in the stratosphere causes deceleration or even reversal of the polar vortex with a consequent significant rise of polar temperatures. These huge and abrupt stratospheric anomalies can propagate upwards modulating the thermosphere/ionosphere system. Several mechanisms responsible for the ionospheric response to SSWs have been proposed, however all modelling attempts to reproduce these effects have not been fully successful and therefore there are still open questions on the generation mechanism for the observed changes in ionospheric parameters (Pedatella et al., 2016).

To answer these questions, we used our recently developed EAGLE model, which covers the whole atmosphere from the surface to the top of the protonosphere. We compare our mode lled results with neutral temperature observations taken by the MIPAS/Envisat instrument and against total electron content (TEC) measurements from GPS over the American region (~75°W). To detect the response of the upper atmosphere to SSW, we used deviations of the selected parameters from the unperturbed pre-event conditions.

Figure 1 demonstrates day-to-day variability of the neutral temperature anomalies at northern high latitudes (70–90°N) modelled with EAGLE and observed by MIPAS. Continuous model dynamics from the surface allows the upward propagation of atmospheric waves to be reproduced well, and therefore the observed appearance of the stratospheric warming, mesospheric cooling, lower thermospheric warming, and thermospheric cooling caused by the event. Temperature changes are directly related to the wind disturbances, which is the main source for the formation of an electric field dynamo in the ionosphere. Figure 2 shows that proper forcing of the ionospheric dynamo then allows the disturbances in TEC to be sufficiently reproduced, such as the enhancement of the equatorial ionisation anomaly in the pre-noon hours as well as the equatorial and low-latitude TEC decrease in the afternoon. Even though there is still some inconsistency between the model results and observations, this is the closest agreement reported in the literature, which makes it valuable in detecting the logical sequence and interconnection of all involved neutral and electrified processes. A paper discussing this in detail is in preparation.

References: Pedatella N. M. et al.: 2016, Multimodel comparison of the ionosphere variability during the 2009 sudden stratosphere warming, J. Geophys. Res., 121, 7204-7225, doi:10.1002/2016JA022859.

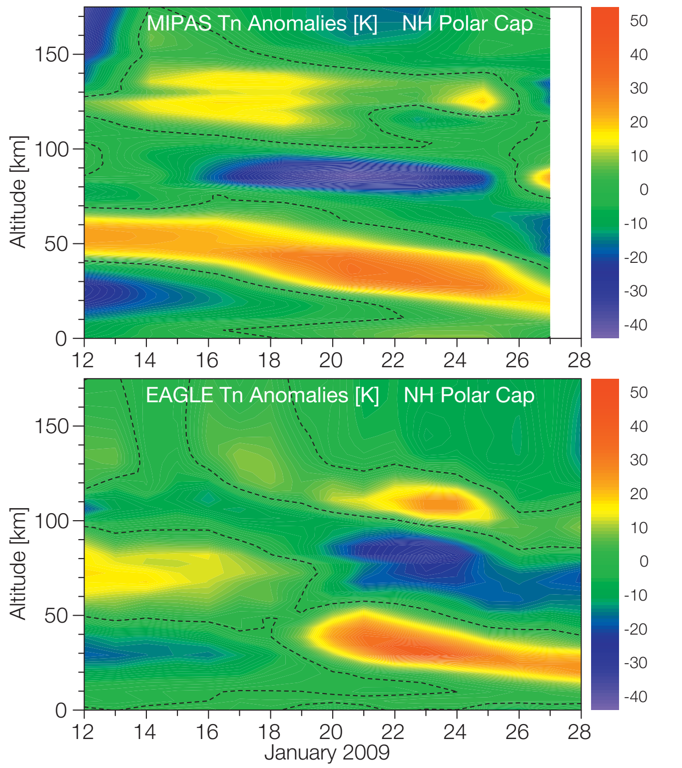


Figure 1. Day-to-day variability of zonal mean neutral temperature anomalies during January 2009 above the polar cap (70°–90°N) and in the Northern Hemisphere obtained using MIPAS observational data and EAGLE model results.

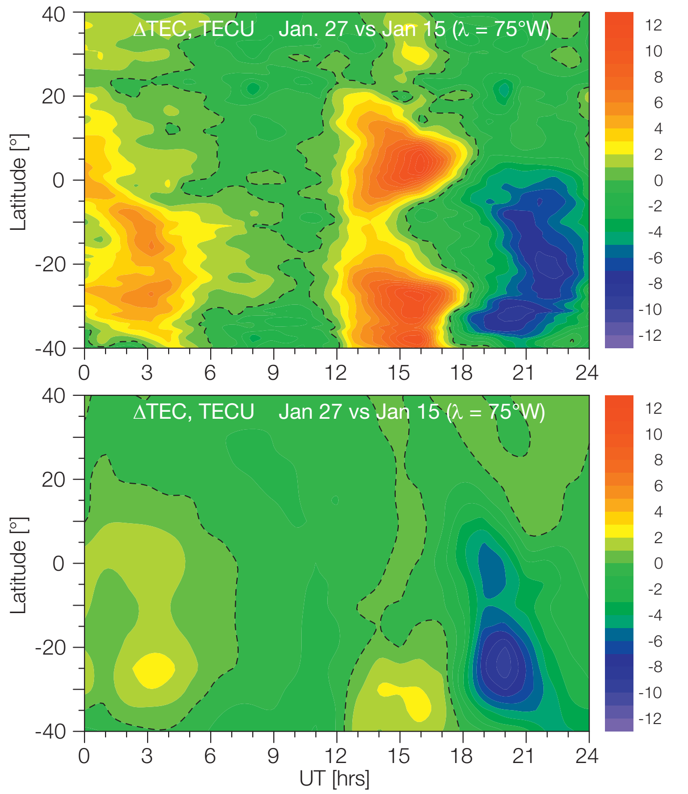


Figure 2. Diurnal variation of the TEC disturbances on 27 January 2009 with respect to the quiet conditions on 15 January 2009 obtained using GPS TEC measurements and EAGLE model results.

Study to Determine Spectral Solar Irradiance and its Impact on the Middle Atmosphere (SIMA)

William Ball, Eugene Rozanov, and Werner Schmutz in collaboration with multiple international partners

The SIMA project aimed to better understand the solar variability using observations such as ozone and temperature, together with our integrated physical knowledge encapsulated within chemistry climate models (CCMs); this was important to characterise and determine how spectral solar irradiance (SSI) variability forces the variability observed in the atmosphere. The project has now concluded, and the main results are now discussed below.

We developed new ozone datasets to estimate the ozone response to SSI variability. This ozone dataset (BASIC) is now being used in other research studies; it is considered the most robust to outliers affecting trend analysis (LOTUS, 2019). With BASIC we confirmed that ozone is recovering in the upper stratosphere, following the Montreal Protocol (Ball et al., 2017).

A consequence of developing BASIC was that we found lower stratospheric ozone had continued to decline since 1998 and was large enough to offset recovery in the upper stratosphere. The findings (Ball et al., 2018) were reported in major international media outlets, and have sparked a number of publications focusing on why the trends continue.

The result was a headline of the WMO 2018 ozone assessment report executive summary. We performed 2D and 3D model runs to estimate responses of multiple stratospheric chemical constituents and variables. We demonstrated using 3D models in specified dynamics and free running modes that these are robust and accurate estimates, and provided a new recommendation for an observational reference (BASICSG, Figure 1) for CCM intercomparisons (Ball et al., 2019). The 2D approach combined temperature and ozone observations to reconstruct solar cycle irradiance variability.

SSI variability from 1975 to 2015 was reconstructed. Our results suggest that solar cycle SSI inference from observations is good enough at least to exclude large changes estimated by earlier versions of the SORCE satellite. This result was one of the main goals of the SIMA project. An early SIMA-funded publication used a different approach, but also found that SORCE SSI is probably not correct (Ball et al., 2016).

Subsequent publications from other research groups support this result. For some spectral intervals (e.g., 242–260 nm) our SSI reconstruction is in good agreement with the state-of-the-art solar models, meaning that SSI variability simulated with the solar irradiance models SATIRE and NRLSSI is more likely.

SIMA successfully addressed its main goals, and contributed to 17 peer-reviewed publications. Some of the results were cited in the recent WMO ozone assessment report 2018, demonstrating the international-level contribution this project has provided.

References:

Ball W. T., et al.: 2016, Nature Geo., 9, 206-209.

Ball W. T., et al.: 2017, Atmos. Chem. Phys., 17, 12269-12302.

Ball W. T., et al.: 2018, Atmos. Chem. Phys., 18, 1379-1394.

Ball W. T., et al.: 2019, Geophys. Res. Lett., 46, 3, 1831, 1841.

LOTUS: 2019, SPARC/IO3C/GAW report on long-term ozone trends and uncertainties in the stratosphere, SPARC Report No. 9, WCRP-17/2018, GAW Report No. 241.

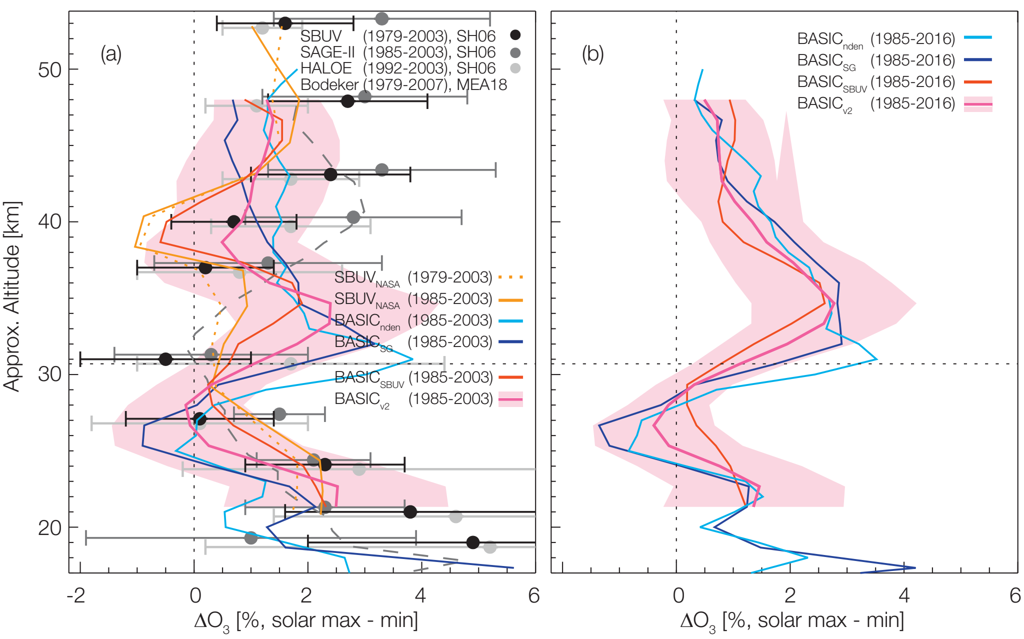


Figure 1. Equatorial (25°S–25°N) solar cycle ozone responses for: (a) earlier reference profiles; (b) new BASIC composite estimates for 1985–2016. The period for each dataset is given in the legends. Uncertainties are for BASICv2 (shading) and SH06 (bars) only; mean profiles for others. Multiple linear regression used the Mg-II solar proxy, equivalent to 100 solar flux units of the 10.7 cm radio flux.

Use of Global Chemistry-Climate Model, CCM-SOCOL, and Satellite Data for Ozone Trend Analysis over Switzerland

Luca Egli, Julian Gröbner, Timofei Sukodolov, William Ball, and Eugene Rozanov
in collaboration with IAC ETHZ and MeteoSwiss (Switzerland)

The project INFO3RS aims to investigate the future evolution of total column ozone (TCO) in Switzerland. To support the trend analysis of the development of the ozone layer, additional data sources to ground-based measurements are analysed. The global Chemistry-Climate Model, CCM-SOCOL, developed at PMOD/WRC, and the SBUV satellite data represent an independent data source to potentially enhance the statistical significance of future trends.

The question: "How and when can we detect the recovery of the ozone layer over Switzerland?", is the main aspect summarising the overall objective of the INFO3RS project, funded by the Swiss Global Atmosphere Watch Programme (GAW-CH). "How" indicates the method of observing the total column ozone (TCO) such as:

- Ground-based observations with Dobson or Brewer networks and novel array spectroradiometer systems (see page 33).
- TCO estimates with CCM-SOCOL (Stenke et al., 2013).
- Space-borne satellite TCO retrieval, such as solar backscatter UV (SBUV) (Bartia et al., 2013).

In order to increase the available TCO data points with additional data sources, the CCM-SOCOL output of the free running mode (1932–2015) and the "nudged" mode (1980–2015) are verified with ground-based measurements from the long-term Arosa ozone time-series (Staehelin et al., 2018) for 1932–2015. The "Nudged" mode means that the stratospheric temperature, wind fields and atmospheric pressure are driven using re-analysis data from the ERA-Interim database. Data from satellite observations are a merged composite of daily ozone values, publicly available from NASA, and are aggregated to annual means for 1980–2015.

Figure 1 shows the temporal course of the four different methods to estimate TCO over Arosa. The CCM-SOCOL model calculations and satellite data show systematic biases of up to 30 DU for

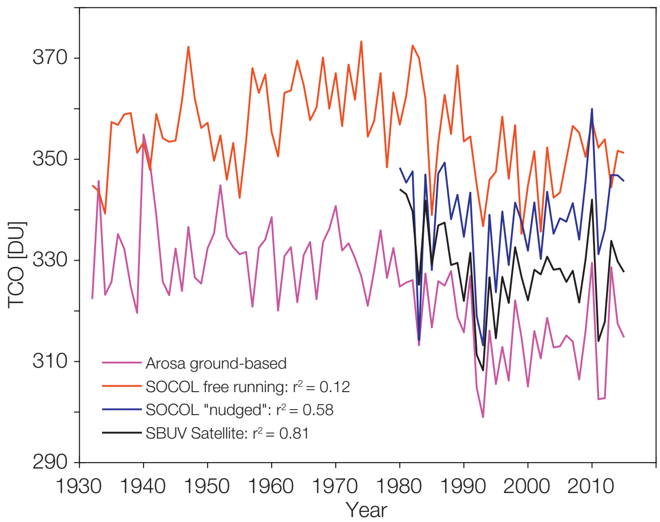


Figure 1. Annual mean total column ozone estimates from four different data sources over Arosa, Switzerland.

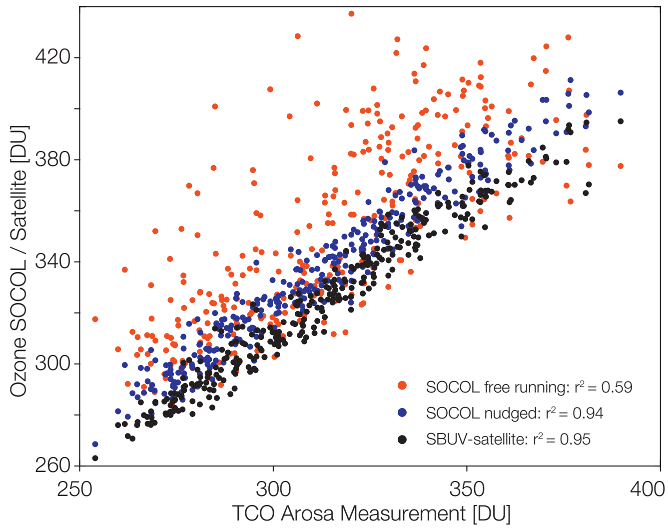


Figure 2. Correlation of CCM-SOCOL model output and SBUV satellite total column ozone data on a monthly time-scale compared to the Arosa time-series.

the CCM-SOCOL free-running and ~10 DU for the satellite and "nudged" CCM-SOCOL runs. Both the satellite and "nudged" CCM-SOCOL data correctly follow the annual variability as well as the climatological trend from 1980 to 1990. The free-running CCM-SOCOL mode, however, only correctly reproduced the long-term climatology, while the annual variations fluctuate randomly, resulting in a poor correlation. For this model calculation, only one realisation of the free-running mode is analysed; free-running models have their own, independent internal variability, and are not 'nudged'. All methods show a similar variability of the ozone layer of ~8 DU or 2.5%.

On a monthly time-scale, the correlations within the four methods are significantly better. Figure 2 shows the comparison of the three TCO estimates related to the ground-based measurements. The high correlation coefficients indicate that the seasonal variation of the Arosa time-series is reproduced well by the independent data and therefore, model calculations can be used to potentially remove the autocorrelation of the seasonal trend to enhance the statistical significance of ozone trends over Arosa. The improvement of the trend analysis, considering the effect of natural variability, measurement uncertainty, calibration uncertainty and impact of the instrument movement from Arosa to Davos will be further investigated in the project using the verified data source.

References:

Bartia P. K., et al.: 2013, Solar Backscatter UV (SBUV) total ozone and profile algorithm, Atmos. Meas. Tech., 6, 2533–2548, doi.org/10.5194/amt-6-2533-2013.

Staehelin et al.: 2018: Stratospheric ozone measurements at Arosa (Switzerland): history and scientific relevance, Atmos. Chem. Phys., 18, 6567–6584, doi.org/10.5194/acp-18-6567-2018.

Stenke A., et al.: 2013, The SOCOL version 3.0 chemistry-climate model: description, evaluation, and implications from an advanced transport algorithm, Geosci. Model Dev., 6, 1407–1427, doi:10.5194/gmd-6-1407-2013.

The Global Climate Observing System (GCOS) and the GAW-PFR Network for Aerosol Optical Depth Long-Term Measurements

Stelios Kazadzis, Natalia Kouremeti, and Julian Gröbner

The project "Global Atmosphere Watch Precision Filter Radiometer (GAW-PFR) Network for Aerosol Optical Depth long-term measurements" has received funds from the Swiss Global Climate Observing System (GCOS) Office at the Federal Office of Meteorology and Climatology MeteoSwiss for the period October 2018–March 2020.

GCOS is a co-sponsored programme which regularly assesses the status of global climate observations and produces guidance for its improvement. GCOS works towards a world where climate observations are accurate and sustained, and access to climate data is free and open. In Switzerland, GCOS is implemented by a variety of national partner institutions coordinated by the Swiss GCOS Office at MeteoSwiss. An important part of GCOS is the specification of a list of Essential Climate Variables (ECVs). These are variables of the atmospheric, oceanic and terrestrial domain that critically contribute to the characterisation of Earth's climate. One of the main ECVs is the aerosol optical depth (AOD).

In the early 1990's, PMOD/WRC developed the Precision Filter Radiometer (PFR) which has been used for long-term AOD measurements under a GAW-PFR Network of sun-photometers beginning in 1995 at Davos, Switzerland and from 1999 at other locations, worldwide. They provide long-term measurements of AOD. In this project, we harmonise, re-evaluate and improve the GAW-PFR AOD time-series which aims to:

• Construct an improved 1-minute AOD time-series at the four (WMO defined) wavelengths in terms of calibration, post-processing and cloud contamination, and based on GAW-PFR measurements and WORCC procedures.

• Include an uncertainty analysis of the retrieved AOD data and also an uncertainty of the long-term calculated trends for each GAW-PFR station, based on the GCOS and WMO-GAW related measurement and uncertainty requirements.

• Define spatial gaps of the GAW-PFR network and suggest inclusion of additional, associate PFR instruments/stations and/or relocation of existing instruments.

Figure 1. World map of core and associated monitoring stations in the GAW-PFR network of AOD measurements.

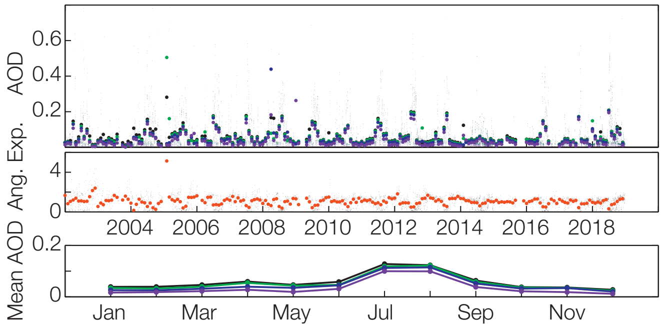


Figure 2. AOD (upper panel), Ångström Exponent (middle) time-series and AOD interannual variability (lower) at Izaña, Tenerife, Spain.

• Present the long-term trend analysis of the GAW-PFR AOD data with emphasis on the free tropospheric (high mountain), polar stations and also stations that coincide with sun-photometers from other existing AOD networks (e.g. AERONET, SKYNET).

• Submit the AOD data in an open access aerosol database such as the WMO World Data Center for Aerosols.

Out of the 15 GAW-PFR stations, seven have 15 or more years and another seven have 10 or more years of AOD measurements. More details about the calibration procedure and the instrument locations and measurement periods can be found in Kazadzis et al. (2018). In line with the Strategic Priorities of the GCOS Switzerland Strategy 2017–2026, the Swiss based GAW-PFR aerosol monitoring network has to introduce re-evaluation activities. This includes harmonisation of procedures and improvement of the existing global network.

AOD is an ECV with high importance for atmospheric and climate science since it consists of the most important parameter describing the Earth's aerosol radiative forcing. Especially in the case of the GAW-PFR network, the selection of the stations was based on the GAW programme criteria that are in line with the GAW goals of providing information on the aerosol composition of the atmosphere and its natural and anthropogenic change. They are supervised by the WMO-GAW Scientific Advisory Group for aerosols.

The review and re-evaluation of the GAW-PFR network in this project helps to achieve such goals since it consists of some of the longest un-interrupted AOD time-series. In this group of long-term AOD series, four Swiss based stations have contributed AOD data since the mid and late 1990's.

References: Kazadzis, S., Kouremeti, N., Nyeki, S., Gröbner, J., and Wehrli, C.: 2018, The World Optical Depth Research and Calibration Center (WORCC) quality assurance and quality control of GAW-PFR AOD measurements, Geosci. Instrum. Method. Data Syst., 7, 39-53, doi.org/10.5194/gi-7-39-2018.

Aerosol Optical Depth Measurements with the Lunar PFR

Natalia Kouremeti, Stelios Kazadzis, Julian Gröbner, Daniel Pfiffner, and Ricco Soder

The growing interest of night-time observations of aerosol optical depth (AOD) led to the development of the Lunar Precision Filter Radiometer at PMOD/WRC. The instrument is in operation since 2014, monitoring the AOD during the polar winter at Ny Ålesund, while its performance has been validated within the first multi-instrument nocturnal AOD intercomparison campaign, (Izaña Observatory, Tenerife, Spain).

Atmospheric aerosols are known to impact the climate, but they still represent one of the largest uncertainties in climate change studies. Night-time AOD measurements could provide valuable information aboout the climatology of aerosols at high-latitude stations, where direct sun measurements are not possible throughout the year. For example, in the northern hemisphere they can be used to monitor the arctic haze during polar winter.

The Lunar Precision Filter Radiometer (Lunar PFR) is a standard PFR instrument that has been developed at PMOD/WRC. The Lunar PFR is based on design and manufacturing experience from the solar PFR, and has an enhanced sensitivity due to the lower irradiance of the Moon. It measures at four wavelengths: 412, 500, 675 and 862 nm, while the sensor is temperature-stabilised at 20°C. The instrument was characterised using the radiometric calibration laboratory facilities at PMOD/WRC.

The Lunar PFR participated in the first multi-instrument nocturnal AOD intercomparison campaign, which was held at the high mountain Izaña Observatory (Tenerife, Spain) in June 2017. The aim was to assess the precision of lunar measurements and the expected accuracy of night-time AOD. The comparison of raw signal measurements at coincident wavelengths between the participating lunar photometers (Cimel and Lunar PFR) showed an agreement within the combined uncertainties at 870 nm and 675 nm, while slightly larger deviations were observed at 500 nm, pointing to some unaccounted instrumental variations during the measurement period. The AOD retrieved by applying a Langley-based calibration for each night, showed remarkable agreement between the lunar photometers of better than 0.01 at 500, 675 and 870 nm. In contrast, when applying the Lunar-Langley calibration

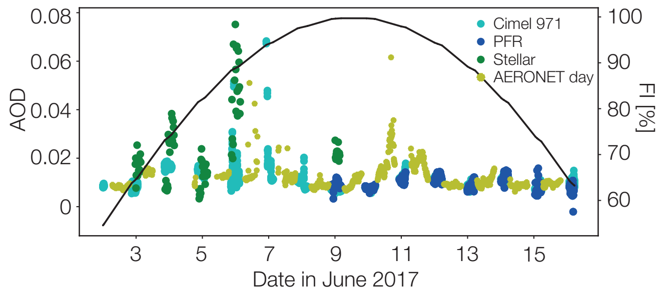


Figure 1. Night-time aerosol measurements at λ = 675 nm from the participating instruments (Cimel, Lunar PFR, Stellar photometer) based on Langley-plot calibration, and lunar irradiance modelled changes (black line, right axis) for the period of the intercomparison campaign at Izaña.

using the RIMO model, AOD variations of up to 0.01 (for 870 and 675 nm spectral bands) and 0.04 (500 nm) were found, where variations increased with phase angle (Barreto et al., 2019).

Since 2014, the Lunar PFR has been performing measurements during the Arctic winter at Ny-Ålesund, Svalbard, Norway (78.9°N, 11.9°E), within the framework of the projects: "The Lunar Arctic project" (March 2014 – June 2015) funded by the Svalbard Science Foundation, and "Svalbard Integrated Arctic Earth Observing System Infrastructure development of the Norwegian node" (2018 – 2022) as well as the extended activities of WORCC. During this period, 15 lunar cycles were measured, and despite the large number of cloudy occasions, a substantial number of AOD results were retrieved. In Figure 2, the 15-year time-series of daytime AOD at 862 nm and Ångstrom exponent are shown as daily (black dots) and monthly (coloured circles) mean values along with the night-time AOD daily mean values (stars). So far, the increased values observed in March and April in the daytime AOD has not been resolved by the night-time measurements. Further observations will allow us to increase the statistical significance of the results.

References:

Barreto A. et al.: 2019, Atmos. Environ., 202, 2019, 190-211, doi.org/10.1016/j.atmosenv. 2019.01.006

Kouremeti N,. Kazadzis S., Mazzola M., Hansen G., Stebel K., Gröbner, J.: 2018, Polar conference, Davos, June 2018.

Mazzola M. et al.: 2013, oral presentation, Aerosol & Cloud workshop, Bremen, Germany, December 16-19, 2013.

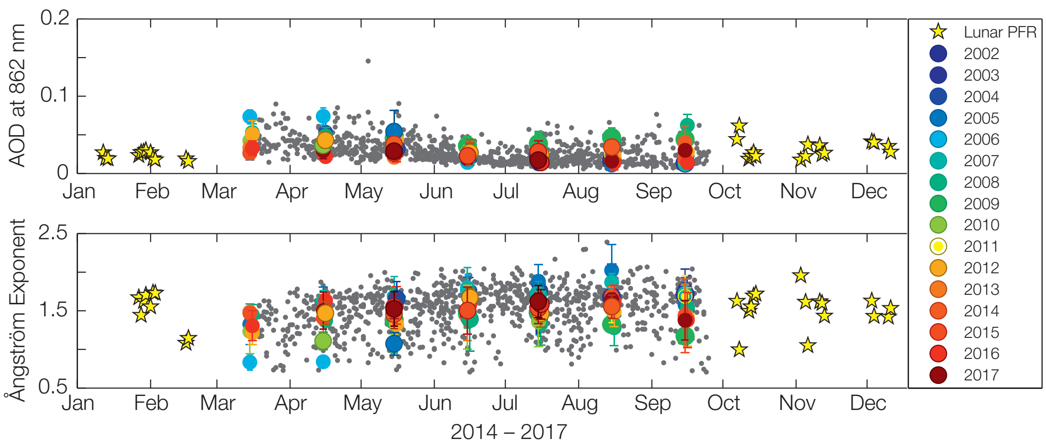


Figure 2. The daytime AOD time-series (daily and monthly means, PMOD/WRC) along with the night-time AOD from retrievals (daily mean values) over the period 2014 – 2017 (Kouremeti, 2018; Mazzola et al., 2013.

A Novel Array-Spectroradiometer System for Total Column Ozone Retrieval

Luca Egli and Julian Gröbner

The project INFO3RS aims to investigate the future evolution of total column ozone (TCO) in Switzerland. In order to supplement the existing TCO observations such as from Dobson and Brewer instruments, a novel system based on a commercially available array spectroradiometer was developed to ensure traceable TCO measurements in Davos.

The general objective of the INFO3RS project, funded by the Global Atmosphere Watch Programme Switzerland (GAW-CH), can be summarised with the following question: "How and when can we detect the recovery of the ozone layer over Switzerland?" "How" is related to the ozone observation techniques with ground- and space-borne instruments, such as Dobsons, Brewers and the SBUV satellite. In the framework of the INFO3RS project, PMOD/WRC developed a new cost effective and simple system, KOHERENT, based on an array spectroradiometer to retrieve TCO from a full spectrum in the UV band (300–350 nm). Contrary to Dobsons and Brewers, which use four wavelengths for the TCO measurement, the array spectroradiometer allows ozone to be retrieved from wavelengths of the full solar spectrum, in order to reduce the uncertainty of the ozone retrieval. Furthermore, the Dobson and Brewer networks are calibrated with their respective reference instruments, which require regular travel to Dobson or Brewer intercomparisons. In contrast, the KOHERENT system can be characterised and calibrated with laboratory facilities at PMOD/WRC on a regular schedule to ensure fully traceable TCO measurements.

During the first year of INFO3RS, the BTS-2048-UV-S-F array spectroradiometer from Gigahertz-Optik (Zuber et al., 2018), with optimised stray-light reduction using bandpass filters, was purchased and thoroughly tested at PMOD/WRC. An operational data acquisition software based on Python was developed in-house to ensure reliable TCO measurements. A new fore-optic telescope was assembled according to an optimised design with commercial optical parts and connected to an optical fibre light-guide on the BTS array spectroradiometer. The entire system is housed in a temperature stabilised box, which allows TCO observations to be performed on the PMOD/WRC measurement platform during all weather conditions in summer and winter (see Figure 1).

Figure 1. Left) temperature-stabilised housing of the KOHERENT system. Right) outdoor operation (KOHERENT telescope on the right of the solar tracker and QASUME telescope on the left).

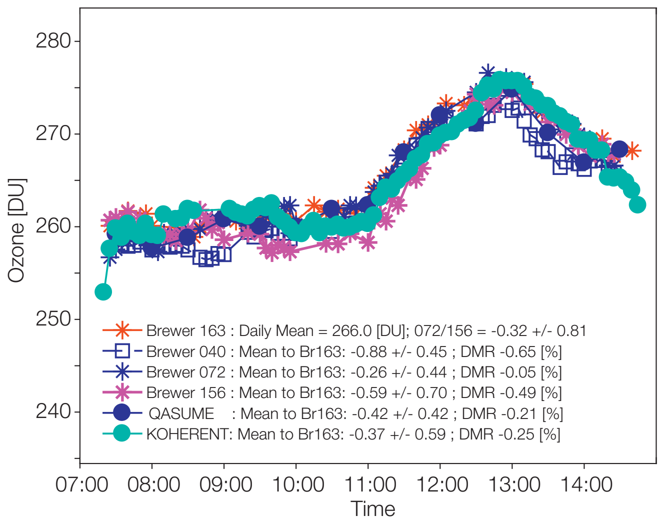


Figure 2. Intercomparison of TCO from the fully traceable KOHERENT system and all Brewers in Davos and Arosa. The deviation to Brewer #163 is less than 1% for all instruments (first number in the legend) including the PMOD/WRC reference instrument, QASUME.

Total column ozone is retrieved in near-realtime by a data post-processing chain including: a) spectral calibration, b) wavelength shift correction with the MatSHIC algorithm, and c) non-linear least-squares minimisation using the new QASUMEFTS reference extraterrestrial solar spectrum (Gröbner et al., 2017). The results show that TCO retrievals by KOHERENT agree to within ~1% of the Brewer TCO data in October 2018 (Figure 2), based on an in-situ spectral calibration with the QASUME reference spectroradiometer. In December 2018, after laboratory characterisation and calibration, the TCO observations showed a larger bias of up to 2%. This effect may be attributed to the very low temperatures in winter or some straylight effects during calibration. The long-term performance and potential limitations of the new KOHERENT system will be further investigated during the next three years of the INFO3RS project.

References: Gröbner J., Kröger I., Egli L., Hülsen G,. Riechelmann S., Sperfeld P.: 2017, The high-resolution extraterrestrial solar spectrum (QASUMEFTS) determined from ground-based solar irradiance measurements, Atmos. Meas. Tech., 10, 3375-3383.

Zuber R., Sperfeld P., Riechelmann S., Nevas S., Sildoja M., Seckmeyer G.: 2018, Adaption of an array spectroradiometer for total ozone column retrieval using direct solar irradiance measurements in the UV spectral range, Atmos. Meas. Tech., 11, 2477-2484.

The International Network to Encourage the Use of Monitoring and Forecasting Dust Products: InDust COST Action

Stelios Kazadzis in collaboration with inDust partners

The “International Network to Encourage the Use of Monitoring and Forecasting Dust Products” (inDust) is the COST Action CA16202 (2017–2021). The overall objective of inDust is to establish a network involving research institutions, service providers and potential end-users of information on airborne aerosol dust particles.

Dust affects and interacts with the climate system in many different ways. A wide range of disciplines—atmospheric modelers, paleoclimatologists, geologists, ice core scientists, biogeochemists, chemical oceanographers, and many others – are required to evaluate its role and impact. More specifically, mineral dust has an impact on: weather as well as global and regional climate, human and animal health, air quality, solar energy, aviation, agriculture and fishery, and other fields of interest (indirect or socio-economic).

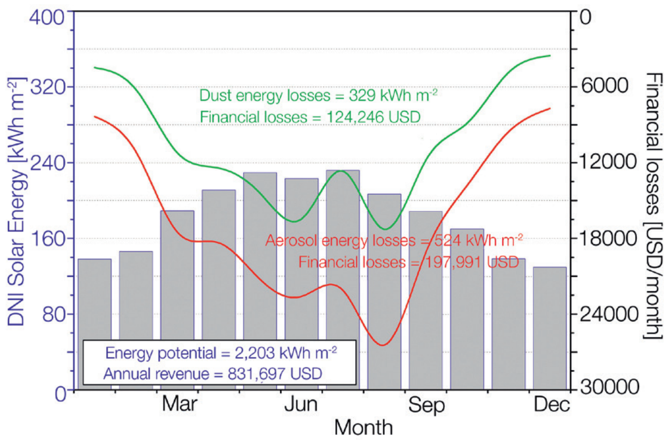


Figure 2. Aerosol and dust aerosol solar DNI/energy related attenuation and financial data for Aswan, Egypt.

Under the inDust COST action (Figure 1), a short-term scientific mission (STSM) was concluded at PMOD/WRC including the financing of a project (2–28 September, 2018) called Forecasting Dust Impact on Solar Energy in Egypt (FINDING). The main goal of FINDING was the investigation of dust effects on solar energy estimates and forecasting.

The principle study area was Egypt, so aerosols from anthropogenic (city pollution and industry) and natural (dust) sources play an important role in the attenuation of solar radiation. Source areas are aerosols from the Saharan desert and more specifically the Khamaseen dust storms that are annually frequent from mid/March through to April.

For this purpose, we used the synergy of satellite remote sensing observations from the Moderate Resolution Imaging Spectroradiometer (MODIS), radiative transfer model simulations, machine learning and aerosol forecasts from the Copernicus Atmosphere Monitoring Service. As cloudy conditions in this region are rare, aerosols in particular dust, are the most common sources of solar irradiance attenuation, causing performance issues in the photovoltaic (PV – total solar radiation) and concentrated solar power (CSP – direct solar radiation) plant installations. The proposed methodology is based on the Solar Energy Nowcasting System (SENSE), developed in the Geo-Cradle EU-funded project.

The forecasting accuracy was evaluated at various locations in Egypt which have a substantial PV and CSP installed capacity. Results were found to be within 5–12% of those obtained from the satellite observations. This highlights the ability to use such modelling approaches for solar energy management and planning, as shown in Figure 2 for Aswan, Egypt. Particulate matter resulted in an annual attenuation by up to 64–107 kWh m^{-2} for global horizontal irradiance (GHI) and 192–329 kWh m^{-2} for direct normal irradiance (DNI). It is estimated that under extreme dust conditions, such as during dust storms, AOD may exceed values of 3.5. As a result, daily energy losses of more than 4 kWh m^{-2} for a 10 MW system may are therefore possible (Kosmopoulos et al., 2018a; 2018b).

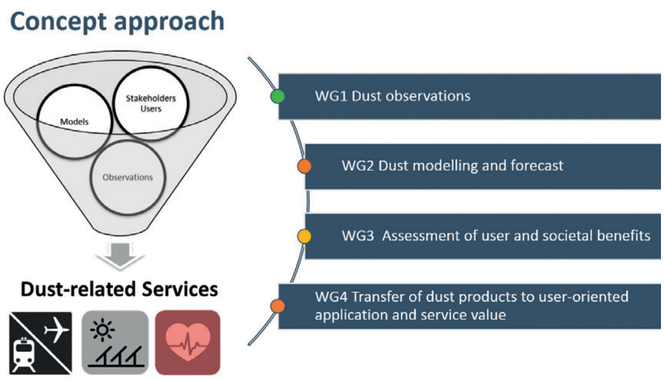


Figure 1. Concept of the InDust COST Action and Working Group structure.

References: Kosmopoulos P. G., Kazadzis S., Taylor M., Raptis P. I., Keramitsoglou I., Kiranoudis C., Bais A. F.: 2018a, Assessment of the surface solar irradiance derived from real-time modelling techniques and verification with ground-based measurements, Atmos. Meas. Tech., 11, 907–924, doi:10.5194/amt-11-907-2018.

Kosmopoulos P. G., Kazadzis S., El-Askary H., Taylor M., Gkikas A., Proestakis E., Kontoes C., El-Khayat M. M.: 2018b, Earth-observation-based estimation and forecasting of particulate matter impact on solar energy in Egypt, Remote Sens. 10, 1870.

ATLAS – A Pulsed Tunable Laser System for the Characterisation of Spectrometers

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

A Pulsed Tunable Laser System for the Characterisation of Spectrometers (ATLAS) is an ESA funded project which began in March 2015. ATLAS's main aim is the improved characterisation of array spectroradiometer systems that are widely used for satellite validation of various atmospheric products.

The ATLAS project aims to improve the accuracy of array spectroradiometers that are used for satellite validation of various atmospheric products. The objectives of the third phase of the project (Jan. 2018–July 2019) is the extensive radiometric characterisation of three PSR spectroradiometers, manufactured at PMOD/WRC in 2018. Moreover, the aerosol optical depth (AOD) product from the PSRs is validated by comparison to the reference PFR-Triad. The operational wavelength range of the PSRs (#008, #009, #010) is 314–1030 nm (±2 nm). The dispersion functions have been determined with an uncertainty of the order of 10 pm using ATLAS. The full-width-at-half-maximum (FWHM) of the spectroradiometers is 2 nm (±0.5 nm) over the 400–1025 nm range with a steep increase in the UV spectrum to reach 4 nm at 315 nm. This type of alignment compensates for the low sensitivity of the NMOS detector.

The experience gained through the characterisation of different diode array spectroradiometers, single monochromators (PSR, Pandora, Phaethon) in the ATLAS project has led to the conclusion that the major contributor in overestimating the irradiance is the stray-light contribution followed by the non-linearity. Through minimising the uncertainties of the line spread functions (LSF) by combining a highly over-exposed laser measurement with the rest of the non-saturated and saturated measurements, a stray-light correction with an expanded uncertainty of <5% (k=2) is possible.

This has given us the confidence to remove the order sorting filter for the 2nd and 3rd dispersion orders from the new PSR series. The LSF measurement and stray-light correction technique has been verified at the Physikalisch-Technische Bundesanstalt (PTB) in a comparison experiment organised in collaboration with Saulius Nevas in Oct. 2018. The stray-light correction along with the uncertainty of the three PSRs is shown in Figure 1. The absolute irradiance calibration and non-linearity correction were defined with the PMOD/WRC direct irradiance calibration setup using secondary irradiance standards. The uncertainty budget of the direct irradiance calibration is shown for PSR_009 in Figure 2. The combined expanded uncertainty (k=2) for the three PSRs is currently estimated to be 1.23%, 1.27% and 1.90%. The values are of the same order as the previous PSR 003–007 series (Gröbner and Kouremeti., 2019).

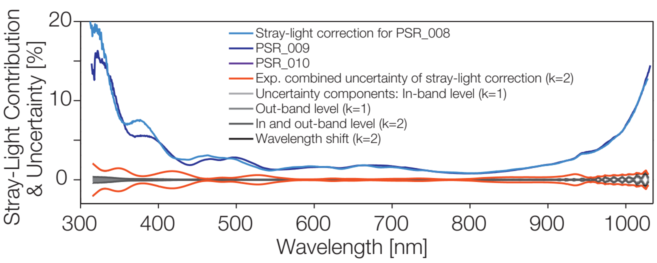


Figure 1. PSR stray-light contribution and estimated uncertainty.

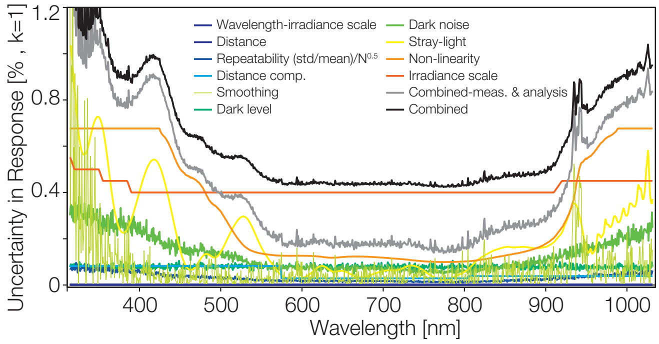


Figure 2. Uncertainty budget of the direct irradiance calibration of PSR_009.

The spectral AOD was retrieved using the direct irradiance in SI units and the extraterrestrial spectrum (ETS) of QASUMEFTS (Gröbner et al., 2017) and Thuillier et al. (2003) convolved with the LSF slit function information. The AOD comparison results in comparison to the PFR-TRIAD for the two instruments operated in 2018 are shown in Table 1. On average, the AOD differences are 67–99%, and are within the WMO agreement limits (WMO-AgLim) defined for Langley calibrated radiometers. Higher uncertainties are observed at the edges of the PSR spectrum due the lower sensitivity, and possibly due to the ETS uncertainty for λ >500 nm.

Table 1. Comparison of PFR_008 and PFR_010 against the PFR-Triad.

	PSR_008		PSR_010	
Wave-length	AOD difference Median [5th, 95th perc.]	WMO-AgLim	AOD difference Median [5th, 95th perc.]	WMO-AgLim
368 nm	0.009 [0.005, 0.014]	61%	-0.008 [-0.018, 0.000]	67%
412 nm	0.001 [-0.001, 0.004]	99%	-0.007 [-0.018, 0.000]	82%
500 nm	0.006 [0.004, 0.011]	96%	0.000 [-0.008, 0.005]	98%
862 nm	-0.008 [-0.014, -0.005]	82%	-0.002 [-0.012, 0.001]	93%

References:

Gröbner J., Kouremeti N.: 2019, Solar Energy, 185, 199-210,doi.org/10.1016/j.solener.2019.04.060.

Gröbner J., Kröger I., Egli L., Hülsen G., Riechelmann S., Sperfeld P.: 2017, Atmos. Meas. Tech., 10, 3375-3383, doi.org/10.5194/amt-10-3375-2017.

Thuillier G., Hersé M., Labs D., Foujols T., Peetermans W., Gillotay D., Simon P. C., Mandel H.: 2003, Solar Physics, 214, 1, doi.org/10.1023/A:1024048429145.

Cloud Optical Thickness Retrieval from Ground-Based Shortwave Radiation Measurements at the BSRN Station in Payerne

Christine Aebi, Stelios Kazadzis, and Julian Gröbner in collaboration with MeteoSwiss and Univ. Bern (Switzerland)

In the framework of the project, a Comprehensive Radiation Flux Assessment (CRUX), a shortwave radiative closure study was performed for the BSRN station in Payerne, Switzerland. This radiative closure study was used as a tool to determine cloud optical thickness (COT) values for the low-level water cloud class, stratus-altostratus, and the high-level ice cloud class, cirrus-cirrostratus.

A shortwave radiative closure study was performed for the BSRN station in Payerne, Switzerland. During the 2013–2017 period more than 9,000 cloud-free, almost 3,000 stratus-altostratus (St–As) and 202 cirrus-cirrostratus (Ci–Cs) downward shortwave radiation (DSR) measurements were simulated with the radiative transfer model libRadtran (Mayer and Kylling, 2005). The cases were selected using data from a visible all-sky cloud camera installed in Payerne (Aebi et al., 2017). Cloud-base height information was retrieved from a CHM15k ceilometer installed in Payerne. Additional input data to the model were aerosol optical depth (AOD; from MODIS satellites), total column ozone (from OMI satellite), integrated water vapour (IWV; from GPS measurements), surface pressure, the solar zenith angle (sza) as well as the surface albedo (calculated from ground-based upward and downward shortwave radiation measurements). The cloud cases have a cloud coverage of at least 95% and are assumed to be homogeneous.

The DSR under cloud-free conditions was simulated with a relative mean bias of 0.97 ± 2.15% and is thus within the instrument measurement uncertainty of 2% (Vuilleumier et al., 2014). A sensitivity analysis showed that the main contributor to the expanded combined uncertainty of the modelled DSR of 2.46% is AOD (Aebi et al., 2019).

The DSR of the cloud cases was simulated with different COT values as input. The effective COT (COT_{DSR}) is then determined

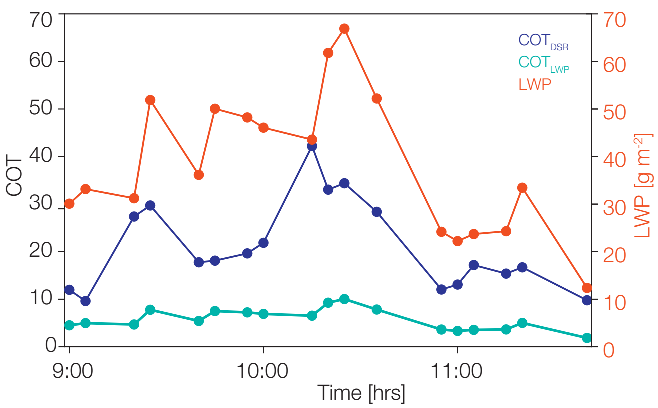


Figure 1. Time-series of COT_{DSR} (blue), COT_{LWP} (cyan) and LWP (red) during St–As conditions on 15 March 2015.

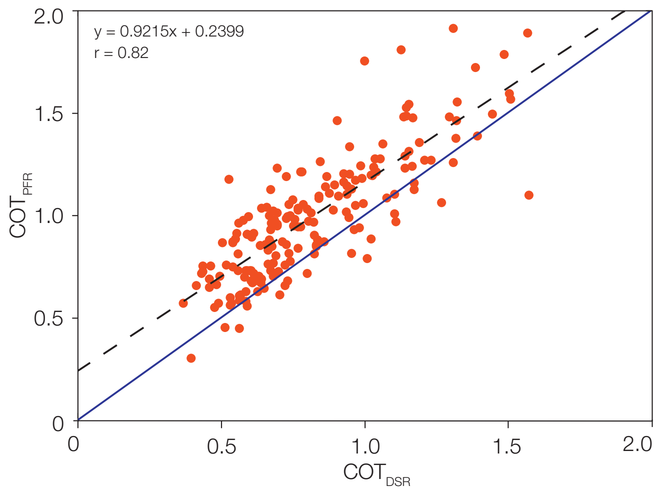


Figure 2. Correlation between COT values retrieved from DSR measurements (COT_{DSR}) and COT values retrieved from PFR measurements at $\lambda = 500$ nm (COT_{PFR}).

as the value when the simulated DSR equals the measured DSR. With this method, 95% of the analysed St-As cases have COT_{DSR} values between 9.9 and 87.7 (Aebi et al., 2019). The comparison with COT values retrieved with other methods and instruments showed relatively good agreement. Figure 1 shows the fluctuation of COT_{DSR} and COT_{LWP} (COT calculated with a formula using measured liquid water path (LWP) data) for several hours on 15 March 2015 during St–As conditions. This example shows that, without changing the cloud type, the COT values can change by about 20–30 COT within an hour.

COT was also determined for the ice-cloud class, cirrus-cirrostratus, where 95% of the COT_{DSR} values are between 0.44 and 1.47, and are thus in a similar range to those in other studies. The correlation between COT_{DSR} values and COT values retrieved from direct irradiance measurements of a precision filter radiometer (COT_{PFR}) at $\lambda = 500$ nm is shown in Figure 2. The next step wil be to compare COT_{DSR} with COT values retrieved from MODIS data.

References:

Aebi C. et al.: 2017, Cloud radiative effect, cloud fraction and cloud type at two stations in Switzerland using hemispherical sky cameras, AMT, doi:10.5194/amt-10-4587-2017.

Aebi C. et al.: 2019, Determination of cloud optical thickness using shortwave radiative closure studies in Payerne, to be submitted.

Mayer B. and Kylling A: 2005, Technical note: The libradtran software package for radiative transfer calculations – description and examples of use, ACP, doi:10.5194/acp-5-1855-2005.

Vuilleumier et al.: 2014, Accuracy of ground surface broadband shortwave radiation monitoring, JGR Atmos., doi:10.1002/2014JD022335.

Trends in Meteorological Parameters and Downward Radiation at Four Swiss Sites for 1996–2015

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

The trends of meteorological parameters and surface downward shortwave and longwave radiation (DSR, DLR) were investigated at four stations (between 370 and 3580 m asl) in Switzerland during the 1996–2015 period. Trends in ground temperature, specific humidity and atmospheric integrated water vapor (IWV) were all positive during all-sky and cloud-free conditions. Similar positive trends were found for DSR and DLR.

The trends of surface radiation for the 1996 – 2015 period at four Swiss SACRAM stations are investigated in this study (Nyeki et al., 2019). Surface radiation and meteorological data were obtained from four MeteoSwiss SACRAM stations: Davos (DAV, 1594 m asl), Jungfraujoch (JFJ, 3580 m), Locarno (LOC, 367 m) and Payerne, (PAY, 491 m). Our objectives are: i) to assess whether trends in the above-mentioned parameters during all-sky and cloud-free conditions can be determined and explained with any greater certainty, and ii) to assess the trends in the cloud radiative effect (CRE).

Trend analysis was conducted with linear least square and non-parametric methods. Table 1 illustrates that trends in temperature (2 m height, T_{2m}, Figure 1), specific humidity and IWV are all positive for all-sky and cloud-free conditions. More precisely, T_{2m}, specific humidity and IWV have increased at all four stations during all-sky and cloud-free conditions on average by ~0.3 – 0.6°C/decade, ~0.1 – 0.2 g kg^{-1} /decade and 0.2 – 0.8 mm/decade, respectively. About three quarters of these trends are significant at the >90% confidence level. Turning to surface radiation, DSR trends are all positive, but only few are significant at the 90% confidence level. DLR trends are similarly positive, with the largest trends for cloud free conditions (2.4 – 5.4 W m^{-2} /decade) which are all significant at the 95% confidence level. These trends in meteorological and surface radiation parameters were partly observed in previous studies (Philipona et al., 2004; Wacker et al., 2011) but not to the convincing and widespread extent as observed here.

Table 1. Trend analysis (only linear least squares, LLS, shown for clarity) of parameters for the 1996 – 2015 period during all-sky and cloud-free conditions at all four stations. Trend values in italic (bold) are significant at the 90% (95%) level.

	Station	All-sky slope/ decade	Cloud-free slope/decade
Temperature (°C)	LOC	**0.43**	**0.54**
	PAY	*0.35*	**0.59**
	DAV	0.30	*0.48*
	JFJ	0.34	0.20
Specific humidity (g kg^{-1})	LOC	**0.19**	0.14
	PAY	**0.18**	**0.23**
	DAV	*0.08*	*0.10*
	JFJ	**0.14**	**0.19**
IWV (mm)	LOC	0.37	0.36
	PAY	0.41	*0.58*
	DAV	**0.60**	**0.79**
	JFJ	**0.24**	**0.27**
DSR (W m^{-2})	LOC	*4.3*	3.3
	PAY	*3.4*	-
	DAV	0.6	3.1
	JFJ	*3.6*	-
DLR (W m^{-2})	LOC	*2.5*	**2.9**
	PAY	0.9	**2.4**
	DAV	**2.7**	**4.8**
	JFJ	**4.3**	**5.4**

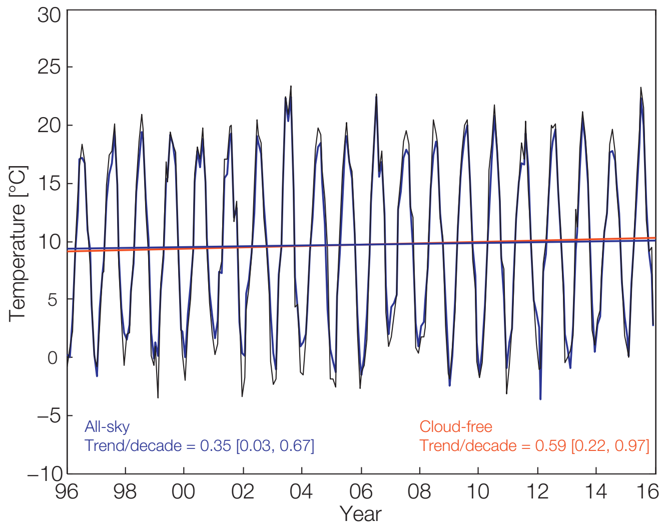


Figure 1. Monthly average temperature (T_{2m}) values during all-sky (blue) and cloud-free (red) conditions at Payerne from 1996 – 2015. Lines represent the all-sky and cloud-free linear least-square trends over the indicated period.

In summary, although accurate DSR and DLR time-series have been available for more than 20 years in Switzerland, the detection of trends with high confidence remains difficult due to the natural variability and measurement uncertainty in surface radiation and cloud properties. It is therefore important to continue providing facilities to maintain such radiation and ancillary atmospheric observations of the highest possible accuracy during day and night-time conditions.

References:

Nyeki, S. et al.: 2019, Trends in surface radiation and cloud radiative effect at four Swiss sites for the 1996–2015 period, Atmos. Chem. Phys. Discuss., doi.org/10.5194/acp-2018-1096, in review.

Philipona, R. et al.: 2004, Radiative forcing measured at Earth's surface corroborate the increasing greenhouse effect, Geophys. Res. Lett., 31, L03202, doi:10.1029/2003GL018765.

Wacker, S. et al.: 2011, Trend analysis of surface clear-sky downwelling long-wave radiation from four Swiss sites, J. Geophys. Res., 116, D10104, doi:10.1029/2010JD015343.

Absolute Radiometer as Onboard Calibration Facility for Spectrometers

Margit Haberreiter and Wolfgang Finsterle in collaboration with IPM (Freiburg, Germany)

PMOD/WRC is part of a consortium, which proposes to use a DARA-type absolute radiometer to monitor onboard degradation tracking. It is a key element of the proposed Solar Auto-Calibrating XUV-IR Spectrometer System spectrograph (SOLACER).

The space-borne measurement of solar spectral irradiance (SSI) on an absolute scale is a challenging task. The SSI composite by Haberreiter et al. (2017), which is based on the existing SSI datasets, shows a high uncertainty. Out of many difficulties for precise SSI measurements, onboard degradation tracking has been proven to be one of the most difficult problems. To monitor the instrument degradation in space, spectrometers are typically either equipped with on-board calibration lamps (e.g. ISS/SOLSPEC instrument) or use stars as a calibration source (Snow et al., 2015).

PMOD/WRC is part of a consortium, which proposes a new calibration concept that uses a DARA-type absolute radiometer to track the onboard degradation. It is a key element of the Solar Auto-Calibrating XUV-IR Spectrometer System spectrograph (SOLACER; Schmidtke et al., 2019). DARA is an update of the CLARA instrument onboard NORSAT-1 (Finsterle, et al., 2014; Walter et al., 2017) and is currently being built for ESA's PROBA-3 satellite.

The concept of SOLACER is to measure the uncalibrated solar spectrum with a set of spectrometers in subsequent spectral bands that cover the solar spectrum from the EUV to IR range. The absolute SSI in each specific spectral band is determined with the absolute DARA radiometer for the UV, visible and IR spectral range, and with an Ionisation Chamber (IC) for the EUV. In its current concept, the instrument consists of eight compact spectrometers (Figure 1, green element; Figure 2, SP1 to SP8), two ICs and two internal DARA-type radiometers (orange elements in Figure 2). All these elements are placed behind a filterwheel, which will be equipped with up to 34 filters to cover the full solar spectrum.

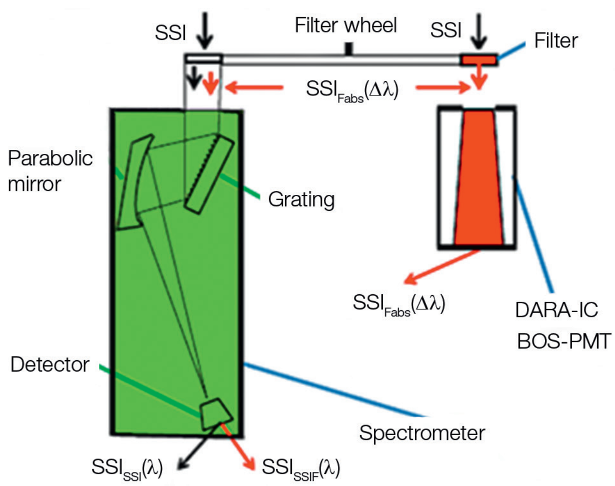


Figure 1. Scheme of the SOLACER instrument (adapted from Schmidtke et al., 2019).

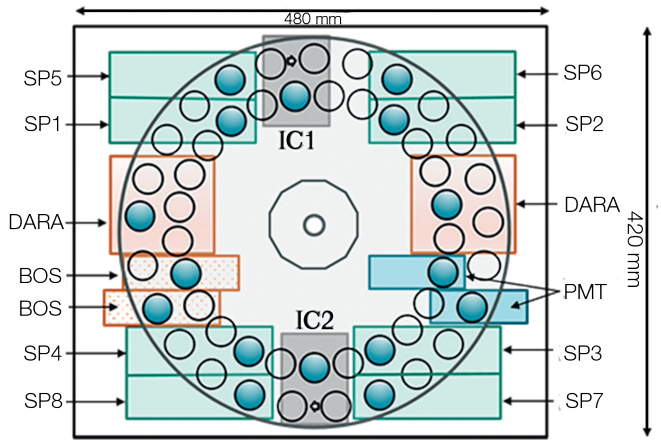


Figure 2. Top view of the SOLACER instrument with the internal absolute radiometer DARA (orange), the eight spectrometers (SP1–SP8) and the ionisation chambers (ICs, gray).

The advantage of this calibration concept is that it extends the calibration range of the spectrometer into the UV, visible and infrared part of the spectrum by use of the successful and reliable absolute radiometers (VIRGO/SOHO, PREMOS/PICARD, CLARA/NORSAT-1). Currently, a state-of-the-art absolute radiometer achieves an absolute uncertainty of 300 ppm and a stability of 40 ppm yr^{-1}. It is foreseen that with the new onboard calibration concept, a considerably improved absolute accuracy and stability can be achieved for SSI measurements.

Acknowledgment: The kind funding support by Daniel Karbacher is gratefully acknowledged.

References:

Finsterle W., et al.: 2014, The new TSI radiometer CLARA, Proc. SPIE, 9264, Earth Observing Missions and Sensors: Development, Implementation, and Characterization III, 926415.

Haberreiter M., et al: 2017, A new observational solar irradiance composite, J. Geophys. Res. Space Phys., 122, 6, doi:10.1002/2016JA023492.

Schmidtke G., et al.: 2019, Solar Auto-Calibrating XUV-IR Spectrometer System (SOLACER) for measurement of solar spectral irradiance, submitted to Applied Optics.

Snow M. et al.: 2015, Solar Stellar Irradiance Comparison Experiment II (Solstice II): Examination of the Solar Stellar Comparison Technique, Solar Physics, 230, 295-324, doi: 10.1007/s11207-005-8763-3.

Walter B. et al: 2017, The CLARA/NORSAT-1 solar absolute radiometer: instrument design, characterization and calibration, Metrologia, 54, 674, doi: 10.1088/1681-7575/aa7a63.

Degradation Process due to UV Radiation

Alberto Remesal Oliva and Wolfgang Finsterle

One of the biggest sources of uncertainty during the analysis of measurements from Total Solar Irradiance (TSI) radiometers is degradation during the lifetime of the mission.

TSI radiometers spend most of their life in space. There, they are exposed to different processes that may degrade the coating that absorbs solar radiation. The most likely processes that result in this degradation are: i) interaction with atomic oxygen, ii) UV radiation (photons are more energetic than at the surface), iii) cosmic rays (protection by the Earth's magnetic field at the surface), iv) chemical contamination due to residuals in and on the instrument, and v) photopolymerisation (triggered by chemical contamination and UV radiation).

Among all the degradation processes that may occur in space, UV radiation is most likely to be the main factor. UV radiation is therefore the main reason why there is a difference in the degradation that the active cavities suffer with respect to the compensating cavities. On the other hand, cosmic rays and atomic oxygen will affect both cavities in the same way.

This degradation effect has, for example, been observed in PREMOS which is an instrument that flew on the PICARD mission. Figure 1 illustrates the ratio between two cavities during a space mission where cavity B was 20 times less exposed than cavity A. A similar effect is also seen in SOVA cavities that were in space and came back safely to be studied. The difference in reflectance measurements of an active cavity and compensating cavity are shown in Figure 2, and means that the degradation process is most likely due to the exposure of light.

An experiment using a deuterium lamp (continuous source) that has a higher intensity than the sun in the UV range, about 6x greater in the 100–200 nm, was started. This UV radiation is most likely to produce this damage, as ground-based detectors (which are protected by the atmosphere) have the same coating as those in space, and they do not undergo a similar degradation effect. In this experiment, the lamp is directly connected to the vacuum tank and the samples are inside at the bottom, receiving direct radiation from the lamp.

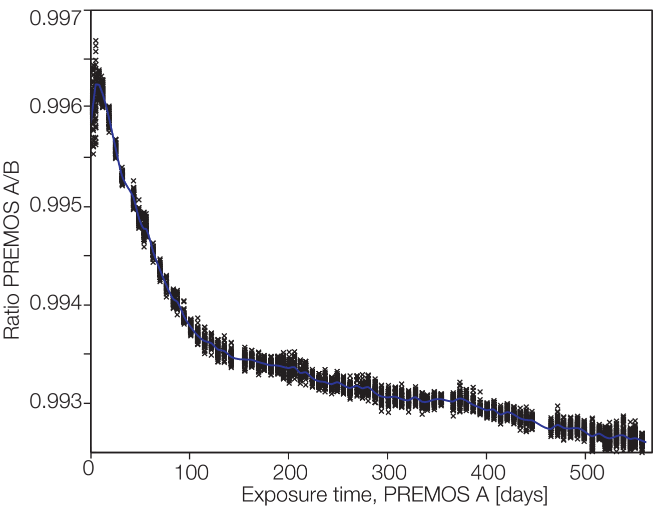


Figure 1. The ratio of A/B in PREMOS data.

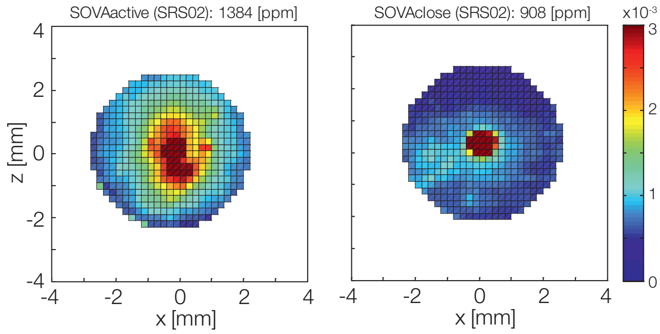


Figure 2. SOVA cavities (left: exposed; right: reference).

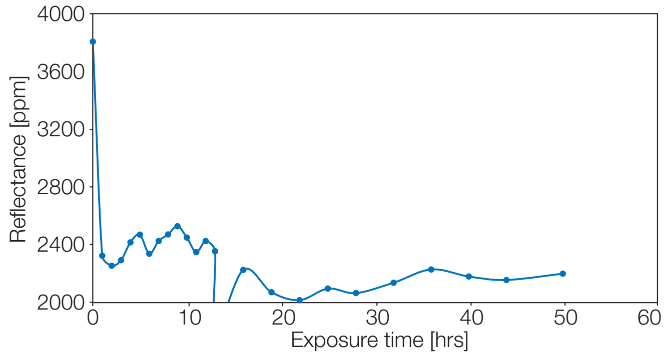


Figure 3. Reflectance of the PMO6 cavity during 50 hours of exposure to the UV lamp.

An old PMO6 cavity (similar to that in SOVA) is also being analysed. The same reflectance measurements will be performed during the experiment, every hour at the beginning and every four hours when stabilisation appears to occur. This will show us how UV radiation affects them. After 50 hours of experiments, the reflectance measurement appears to have stabilised, and no further degradation is observed in this old PMO6 cavity.

At the very beginning, a similar improvement in the absorptivity during the first hours of PREMOS (the so-called "early increase") was observed. The absence of degradation after the "early increase" might be produced by the long time period since manufacture of the PMO6 cavity. Further experiments will be performed with new samples (silicon and carbon nanotube paints).

Acknowledgement: This work is supported by SNF grant 200021 162926.

Modelling Solar Spectral Irradiance Based on 3D MHD Simulations

Margit Haberreiter and Nuno Guerreiro in collaboration with NSO and NCAR (Boulder, USA)

In collaboration with the National Solar Observatory (NSO) and the National Center for Atmospheric Research (NCAR), we aim to determine the uncertainty of Solar Spectral Irradiance (SSI) modelling as a consequence of the type of radiative transfer codes used. The differences in the spectral syntheses are investigated by using 1D atmosphere structures, as well as the temperature structures obtained from 3D magnetic hydrodynamic (MHD) simulations.

The reconstruction of the Solar Spectral Irradiance (SSI) on various time-scales is essential for the understanding of the Earth's climate response to SSI variability. However, different spectral synthesis codes lead to different projections of SSI variability. As part of an ISSI International Team, dedicated to analyse the uncertainty stemming from the radiative transfer codes used in irradiance reconstructions, we present here a progress report. The aim of this project is to use snapshots of 3D MHD simulation as input for the PMOD/WRC software programme, Code for Solar Irradiance (COSI). Figure 1 shows the input data, i.e. the temperature of a vertical section through the simulation box from three different MHD simulations: the hydrodynamic (HD) simulation with 0 G magnetic field (top), B = 100 G (middle), and B = 200 G (bottom). Figure 2 then shows the variation of the line-of-sight magnetic field over all grid points in the simulation box. Finally, Figure 3 then shows a spectrum for the 3800–3900 Å wavelength range that will be calculated column-by-column for the HD and MHD simulation. The technical setup to run the numerous calculations has been established and the calculations are in progress.

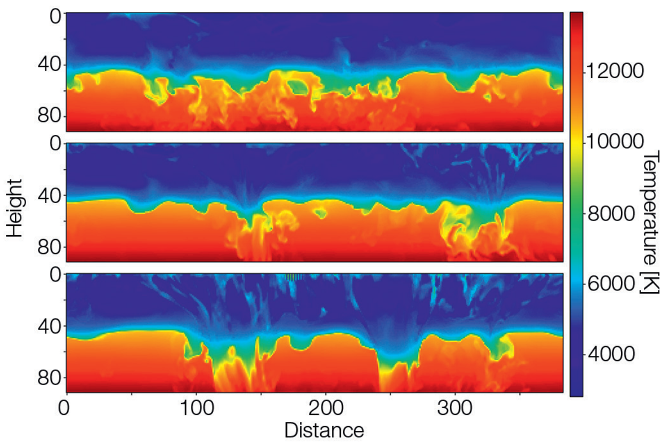


Figure 1. Vertical cut through a snapshot of 3D MHD simulations showing the temperature as a function of height. These vertical structures are input for the calculation of the emergent intensity with COSI.

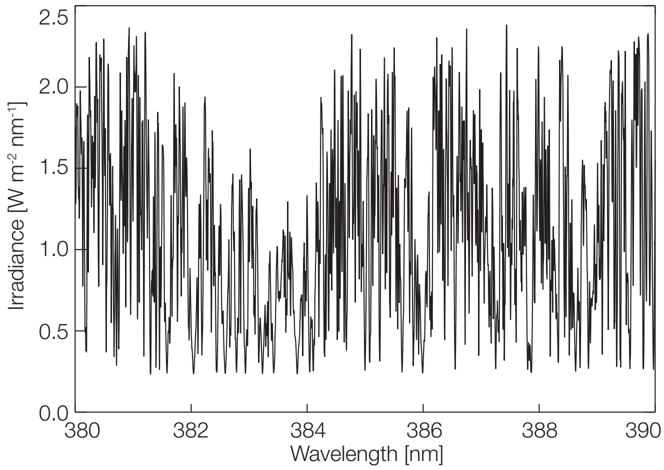


Figure 3. Example COSI spectrum showing the spectral range of interest for the calculation of the emergent spectra using the 3D MHD simulations.

After the calculation of the emergent spectrum for all grid points, the contrast in various spectral bands as a function of magnetic field strengths will be determined. Ultimately, in this project we aim to calculate the difference between the contrast of the magnetic versus non-magnetic structures for different spectral synthesis codes.

Acknowledgment: We kindly acknowledge the support by the International Space Science Institute, Berne, Switzerland during the International Team on Modeling Solar Irradiance with 3D MHD simulations, led by Serena Criscuoli. We thank Pascal Vescei for technical support. This work received kind support by Daniel Karbacher.

References: Criscuoli S., Haberreiter M., Rempel M., et al.: 2019, to be submitted.

Haberreiter M.: 2019, et al., in preparation.

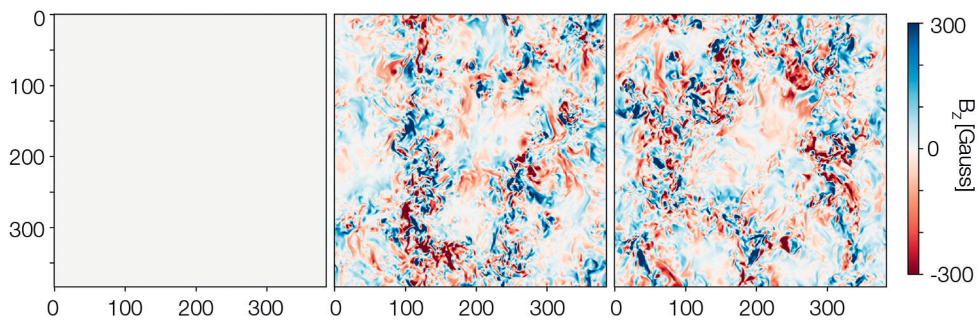


Figure 2. Comparison of the magnetic field topology of the 3D MHD simulations: HD (left panel), 100 G (middle panel) and 200 G (right panel).

Publications and Media

Refereed Publications

Aebi C., Gröbner J., Kämpfer N.: 2018, Cloud fraction determined by thermal infrared and visible all-sky cameras, Atmos. Meas. Tech., 11, 5549-5563, doi.org/10.5194/amt-11-5549-2018.

Arsenovic P., Rozanov E., Anet J., Stenke A., Schmutz W., Peter T.: 2018, Implications of potential future grand solar minimum for ozone layer and climate, Atmos. Chem. Phys. 18, 3469–3483, doi: 10.5194/acp-18-3469-2018.

Aschwanden M. J., Scholkmann F., Béthune W., Schmutz W., Abramenko V., Cheung M. C. M., Müller D., Benz A., Chernov G., Kritsuk A. G., Scargle J. D., Melatos A., Wagoner R., Trimble V., Green W. H.: 2018, Order out of randomness: Self-organization processes in Astrophysics, Space Sci. Rev. 214, eid: 55 (75 pp), doi: 10.1007/s11214-018-0489-2.

Ayarzagüena B., et al.: 2018, No robust evidence of future changes in major stratospheric sudden warmings: a multi-model assessment from CCMI, Atmos. Chem. Phys., 18, 11277–11287, doi: 10.5194/acp-18-11277-2018.

Ball W. T., et al.: 2018, Continuous decline in lower stratospheric ozone offsets ozone layer recovery, Atmos. Chem. Phys., 18, 1379–1394, doi: 10.5194/acp-18-1379-2018.

Benedetti A., et al.: 2018, Status and future of numerical atmospheric aerosol prediction with a focus on data requirements, Atmos. Chem. Phys., 18, 10615-10643, doi.org/10.5194/acp-18-10615-2018.

Chiodo G., Polvani L., Marsh D., Stenke A., Ball W., Rozanov E., Muthers S., Tsigaridis K.: 2018, The response of the ozone layer to quadrupled CO_2 concentrations, J. Climate, 31, 10, 3893-3907, doi:10.1175/JCLI-D-17-0492.1.

Dhomse S., et al.: 2018, Estimates of ozone return dates from Chemistry-Climate Model Initiative Simulations, Atmos. Chem. Phys., 18, 8409-8438, doi:10.5194/acp-18-8409-2018.

Dimitropoulou E., Assimakopoulos V. D., Fameli K. M., Flocas H. A., Kosmopoulos P., Kazadzis S., Lagouvardos K., Bossioli E.: 2018, Estimating the biogenic non-methane hydrocarbon emissions over Greece, Atmosphere, 9, 14, doi:10.3390/atmos9010014.

Dominique M., Zhukov A. N., Heinzel P., Dammasch I. E., Wauters L., Dolla L., Shestov S., Kretzschmar M., Machol J., Lapenta G., Schmutz W.: 2018, First detection of solar flare emission in mid-ultraviolet Balmer continuum, Astrophys. J. Letters 867, L24, doi: 10.3847/2041-8213/aaeace.

Dudok de Wit T., Funke B., Haberreiter M., Matthes K.: 2018, Better data for modeling the Sun's influence on climate, Eos, 99, doi.org/10.1029/2018EO104403.

Egorova T., Rozanov E., Arsenovic P., Peter T., Schmutz W.: 2018, Contributions of natural and anthropogenic forcing agents to the early 20th century warming, Front. Earth Sci. 6:206, (8 pp), doi: 10.3389/feart.2018.00206.

Egorova T., Schmutz W., Rozanov E., Shapiro A.I., Usoskin I., Beer J., Tagirov R.V., Peter T.: 2018, Revised historical solar irradiance forcing, Astron. Astrophys. 615, A85 (10 pp), doi: 10.1051/0004-6361/201731199.

García R. D., Barreto A., Cuevas E., Gröbner J., García O. E., Gómez-Peláez A., Romero-Campos P. M., Redondas A., Cachorro V. E., Ramos R.: 2018, Comparison of observed and modeled cloud-free longwave downward radiation (2010–2016) at the high mountain BSRN Izaña station, Geosci. Model Dev., 11, 2139-2152, doi.org/10.5194/gmd-11-2139-2018.

Janssen C., Elandaloussi H., Gröbner J.: 2018, A new photometric ozone reference in the Huggins bands: The absolute ozone absorption cross section at the 325 nm HeCd laser wavelength, Atmos. Meas. Tech., 11, 1707-1723, doi.org/10.5194/amt-11-1707-2018.

Kazadzis S., Founda D., Psiloglou B. E., Kambezidis H., Mihalopoulos N., Sanchez-Lorenzo A., Meleti C., Raptis P. I., Pierros F., Nabat P.: 2018, Long-term series and trends in surface solar radiation in Athens, Greece, Atmos. Chem. Phys., 18, 2395-2411, doi.org/10.5194/acp-18-2395-2018.

Kazadzis S., et al.: 2018, Results from the Fourth WMO Filter Radiometer Comparison for aerosol optical depth measurements, Atmos. Chem. Phys., 18, 3185-3201, doi.org/10.5194/acp-18-3185-2018.

Kazadzis S., Kouremeti N., Nyeki S., Gröbner J., Wehrli C.: 2018, The World Optical Depth Research and Calibration Center (WORCC) quality assurance and quality control of GAW-PFR AOD measurements, Geosci. Instrum. Method. Data Syst., 7, 39-53, doi.org/10.5194/gi-7-39-2018.

Klimenko M., Bessarab F., Sukhodolov T., Klimenko V., Koren'kov Yu., Zakharenkova I., Chirik N., Vasil'ev P., Kulyamin D., Schmidt H., Funke B., and Rozanov E.: 2018, Ionospheric effects of the sudden stratospheric warming in 2009: Results of simulation with the first version of the EAGLE model, Russian Journal of Physical Chemistry B, 12, 4, 760–770, doi: 10.1134/S1990793118040103.

Korenkov Y., Bessarab F., Timchenko A., and Rozanov E.: 2018, Global variations in critical frequency of the F2 layer in various models of solar EUV radiation, Russian Journal of Physical Chemistry B, 12, 4, 771–775, doi: 10.1134/S1990793118040115.

Kosmopoulos P. G., Kazadzis S., Taylor M., Raptis P. I., Keramitsoglou I., Kiranoudis C., Bais A. F.: 2018, Assessment of surface solar irradiance derived from real-time modelling techniques and verification with ground-based measurements, Atmos. Meas. Tech., 11, 907-924, doi.org/10.5194/amt-11-907-2018.

Lakkala K., Arola A., Gröbner J., León-Luis S. F., Redondas A., Kazadzis S., Karppinen T., Karhu J. M., Egli L., Heikkilä A., Koskela T., Serrano A., Vilaplana J. M.: 2018, Performance of the FMI cosine error correction method for the Brewer spectral UV measurements, Atmos. Meas. Tech., 11, 5167-5180, doi.org/10.5194/amt-11-5167-2018.

López-Solano J., Redondas A., Carlund T., Rodriguez-Franco J. J., Diémoz H., León-Luis S. F., Hernández-Cruz B., Guirado-Fuentes C., Kouremeti N., Gröbner J., Kazadzis S., Carreño V., Berjón A., Santana-Díaz D., Rodríguez-Valido M., De Bock V., Moreta J. R., Rimmer J., Smedley A. R. D., Boulkelia L., Jepsen N., Eriksen P., Bais A. F., Shirotov V., Vilaplana J. M., Wilson K. M., Karppinen T.: 2018, Aerosol optical depth in the European Brewer Network, Atmos. Chem. Phys., 18, 3885-3902, doi.org/10.5194/acp-18-3885-2018.

Marshall L., et al.: 2018, Multi-model comparison of the volcanic sulfate deposition from the 1815 eruption of Mt. Tambora, Atmos. Chem. Phys., 18, 2307–2328, 10.5194/acp-18-2307-2018.

Maycock A., Matthes K., Tegtmeier S., Schmidt H., Thiéblemont R., Hood L., Akiyoshi H., Bekki S., Deushi M., Jöckel P., Kirner O., Kunze M., Marchand M., Marsh D., Michou M., Plummer D., Revell L., Rozanov E., Stenke A., Yamashita Y., Yoshida K.: 2018, The representation of solar cycle signals in stratospheric ozone – Part 2: Analysis of global models, Atmos. Chem. Phys., 18, 11323–11343, doi: 10.5194/acp-18-11323-2018.

Maycock A., et al.: 2018, Revisiting the mystery of recent stratospheric temperature trends, Geoph. Res. Let., 45, doi: 10.1029/2018GL078035.

Meelis-Mait S., Nevas S., Kouremeti N., Gröbner J., Pape S., Pendsa S., Sperfeld P., Kemus F.: 2018, LED-based UV source for monitoring spectroradiometer properties, Metrologia, 55, S97-S103.

Meloni D., di Sarra A., Brogniez G., Denjean C., De Silvestri L., Di Iorio T., Formenti P., Gómez-Amo J. L., Gröbner J., Kouremeti N., Liuzzi G., Mallet M., Pace G., Sferlazzo D. M.: 2018, Determining the infrared radiative effects of Saharan dust: a radiative transfer modelling study based on vertically resolved measurements at Lampedusa, Atmos. Chem. Phys., 18, 4377-4401, doi.org/10.5194/acp-18-4377-2018.

Morgenstern O., et al.: 2018, Ozone sensitivity to varying greenhouse gases and ozone-depleting substances in CCMI-1 simulations, Atmos. Chem. Phys., 18, 1091–1114, doi: 10.5194/acp-18-1091-2018.

Orbe C., et al.: 2018, Large-scale tropospheric transport in the Chemistry–Climate Model Initiative (CCMI) simulations, Atmos. Chem. Phys., 18, 7217–7235, doi: 10.5194/acp-18-7217-2018.

Proestakis E., Amiridis V., Marinou E., Georgoulias A. K., Solomos S., Kazadzis S., Chimot J., Che H., Alexandri G., Binietoglou I., Daskalopoulou V., Kourtidis K. A., de Leeuw G., van der A. R. J.: 2018, Nine-year spatial and temporal evolution of desert dust aerosols over South and East Asia as revealed by CALIOP, Atmos. Chem. Phys., 18, 1337-1362, doi.org/10.5194/acp-18-1337-2018.

Raptis I.-P., Kazadzis S., Eleftheratos K., Amiridis V., Fountoulakis I.: 2018, Single scattering albedo's spectral dependence effect on UV irradiance, Atmosphere, 9, 364.

Raptis P.-I., Kazadzis S., Gröbner J., Kouremeti N., Doppler L., Becker, R., and Helmis C.: 2018, Water vapour retrieval using the Precision Solar Spectroradiometer, Atmos. Meas. Tech., 11, 1143-1157, doi.org/10.5194/amt-11-1143-2018.

Redondas A., et al.: 2018, EUBREWNET RBCC-E Huelva 2015 Ozone Brewer Intercomparison, Atmos. Chem. Phys., 18, 9441-9455, https://doi.org/10.5194/acp-18-9441-2018.

Remesal Oliva A., Finsterle W., Walter B., Schmutz W.: 2018, Characterisation of a new carbon nanotube detector coating for solar absolute radiometers, J. Phys. Conf. Ser., 972, 012007 (6 pp), doi: 10.1088/1742-6596/972/1/012007.

Revell L., et al.: 2018, Tropospheric ozone in CCMI models and Gaussian process emulation to understand biases in the SOCOLv3 chemistry–climate model, Atmos. Chem. Phys., 18, 16155–16172, doi: 10.5194/acp-18-16155-2018.

Rozanov E. V.: 2018, Effect of precipitating energetic particles on the ozone layer and climate, Russian Journal of Physical Chemistry B, 12, 4, 786-790, doi: 10.1134/S1990793118040152.

Solomos S., Kalivitis N., Mihalopoulos N., Amiridis V., Kouvarakis G., Gkikas A., Binietoglou I., Tsekeri A., Kazadzis S., Kottas M., Pradhan Y., Proestakis E., Nastos P. T., Marenco F.: 2018, From tropospheric folding to Khamsin and Foehn winds: How atmospheric dynamics advanced a record-breaking dust episode in Crete, Atmosphere, 9, 240.

Son S.-W., et al.: 2018, Tropospheric jet response to Antarctic ozone depletion: An update with Chemistry-Climate Model Initiative (CCMI) models, Environ. Res. Lett., 13, 5, doi: 10.1088/1748-9326/aabf21.

Sukhodolov T., Sheng J.-X., Feinberg A., Luo B.-P., Peter T., Revell L., Stenke A., Weisenstein D., Rozanov E.: 2018, Size-resolved stratospheric aerosol distributions after Pinatubo derived from a Coupled Aerosol-Chemistry-Climate Model, Geosci. Model Dev., 11, 2633-2647, doi: 10.5194/gmd-11-2633-2018.

Tatsiankou V., Hinzer K., Schriemer H., Kazadzis S., Kouremeti K., Gröbner J., Beal R.: 2018, Extensive validation of the spectral irradiance meters at the World Radiation Center, Solar Energy, 166, 80-89, doi.org/10.1016/j.solener.2018.03.044.

Toledano C., et al.: 2018, Assessment of Sun photometer Langley calibration at the high-elevation sites Mauna Loa and Izaña, Atmos. Chem. Phys., 18, 14555-14567, https://doi.org/10.5194/acp-18-14555-2018.

Vaskuri A., Kärhä P., Egli L., Gröbner J., Ikonen E.: 2018, Uncertainty analysis of total ozone derived from direct solar irradiance spectra in the presence of unknown spectral deviations, Atmos. Meas. Tech., 11, 3595-3610, https://doi.org/10.5194/amt-11-3595-2018.

Wales P. A., et al.: 2018, Stratospheric injection of brominated very short-lived substances: Aircraft observations in the Western Pacific and representation in global models, J. Geophys. Res. Atmos., 123, 5690-5719, doi:10.1029/2017JD027978.

Witzke V., Shapiro A. I., Solanki S. K., Krivova N. A., Schmutz W.: 2018, From solar to stellar brightness variations. The effect of metallicity, Astron. Astrophys. 619, A146 (11 pp), doi: 10.1051/0004-6361/201833936.

Zanatta M., Laj P., Gysel M., Baltensperger U., Vratolis S., Eleftheriadis K., Kondo Y., Dubuisson P., Winiarek V., Kazadzis S., Tunved P., Jacobi H.-W.: 2018, Effects of mixing state on optical and radiative properties of black carbon in the European Arctic, Atmos. Chem. Phys., 18, 14037-14057, doi.org/10.5194/acp-18-14037-2018.

Zempila M. M., Fountoulakis I., Taylor M., Kazadzis S., Arola A., Koukouli M. E., Bais A., Meleti C., Balis D.: 2018, Validation of OMI erythemal doses with multi-sensor ground-based measurements in Thessaloniki, Greece, Atmos. Environ., doi: 10.1016/j.atmosenv.2018.04.012.

Zhang J., et al.: 2018, Stratospheric ozone loss over the Eurasian continent induced by the polar vortex shift, Nature Communications, 9, 206, doi: 10.1038/s41467-017-02565-2.

Other Publications

Basart S., Nckovic S., Amiridis V., Dagsonn P., El Askary H., Durant A., Kazadzis S., Mona L., Monteiro L., Nemuc A., Tegen I., Vucovic A., Weinzeirl B., Varga G., Terradelas E.: 2018, InDust: International Network to encourage the use of monitoring and forecasting dust products, The 2nd IceDust Workshop, Reykjavik, Iceland, 14 February 2018.

Campanelli M., Iannarelli A. M., Kazadzis S., Vergari S., Estelles V. Diemoz H., di Sarra A., Cede A.: The QUATRAM Campaign: 2018, QUAlity and TRaceabiliy of Atmospheric aerosol Measurements, The 2018 WMO/CIMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation, Amsterdam, The Netherlands, October, 2018.

Fountoulakis I., Natsis A., Siomos A., Drosoglou T., Bais A., Balis D., Kazadzis S.: 2018, Measurements of the aerosol single scattering albedo in the UV over Thessaloniki, Greece, 14th International Conference of Meteorology, Climatology and Atmospheric Physics, COMECAP 2018, Alexandroupolis, Greece, 15–17 October, 2018.

Fountoulakis I., Natsis A., Siomos N., Drosoglou T., Bais A., Balis D., Kazadzis S.: 2018, Measurements of the aerosol single scattering albedo in the UV over Thessaloniki, Greece, 14th International Conference of Meteorology, Climatology and Atmospheric Physics, COMECAP 2018, Alexandroupolis, Greece, 15–17 October 2018.

Gkikas A., Proestakis E., Marinou E., Amiridis V., Kazadzis S., Hatzianastassiou N,: 2018, A synergistic use of passive and active satellite retrievals for dust identification at global scale, 14th International Conference of Meteorology, Climatology and Atmospheric Physics, COMECAP 2018, Alexandroupolis, Greece, 15–17 October, 2018.

Gratsea M., Bösch T., Kokkalis P., Richter A., Vrekoussis M., Kazadzis S., Papayannis A., Amiridis V., Mihalopoulos N., Gerasopoulos E.: 2018, Retrieval of aerosol vertical profiles over Athens using MAX-DOAS measurements, 11th International Conference on Air Quality – Science and Application Air Quality, Barcelona, Spain, 12–16 March 2018.

Guerreiro N., Haberreiter M., Hansteen V., Schmutz, W.: 2018, Small-scale heating events in the solar atmosphere: lifetime, total energy and magnetic properties, EGU General Assembly, Conference Abstracts 20, 14516.

Haberreiter M., Schöll M., Dudok de Wit T., Kretzschmar M., Misios S., Tourpali K., Schmutz W.: 2018, A new observational solar spectral irradiance composite, EGU General Assembly, Conference Abstracts 20, 10623.

Halain J.-P., et al.: 2018, The EUI flight instrument of Solar Orbiter: from optical alignment to end-to-end calibration. In: Society of Photo-Optical Instrumentation Engineers (SPIE) Conf. Series 10699, eid. 106990H (10 pp), doi: 10.1117/12.2309339.

Kazadzis S., Kouremeti N., Hansen G., Stebel K., Aaltonen V., Rodriguez E., Nyeki S.: 2018, Long term aerosol optical depth measurements in polar regions from the GAW-PFR network, Polar conference 2018, Davos, June 2018.

Kopp G., Dudok de Wit T., Ball W. T., Finsterle W., Fröhlich C., Kokkonen K., Meftah M., Schmutz W. K.: 2018, The New "Community-Consensus' TSI Composite" for Solar and Climate Researchers, AGU Fall Meeting 2018, abstract #SH32B-08.

Kosmopoulos P. G., Kazadzis, S., El-Askary H., Taylor M., Gkikas A., Proestakis E., Kontoes C., El-Khayat M. M.: 2018, Earth-observation-based estimation and forecasting of particulate matter impact on solar energy in Egypt, Remote Sens. 10, 1870.

Kosmopoulos P. G., Kazadzis S., Kontoes C., El-Askary H., Zografos D., Krestos G.: 2018, Access to solar energy applications using EO data through GEO activities: validation and demonstration of the SENSE system. 38th Annual EARSeL Symposium, ID 214, Chania, Greece, 9–12 July, 2018.

Kosmopoulos P. G., Kazadzis S., Kontoes C., Papoutsis I., Trypitsidis A.: 2018, Solar energy related EO data for Greece through the GEOSS portal. 14th International Conference of Meteorology, Climatology and Atmospheric Physics, COMECAP 2018, Alexandroupolis, Greece, 15–17 October, 2018.

Kouremeti N., Kazadzis S., Mazzola M., Hansen G., Stebel K., Gröbner J.: 2018, Development and aerosol optical depth measurements with a Lunar photometer at Ny-Ålesund, Polar conference 2018, Davos June 2018.

Pinardi G., et al.: 2018, Validation of TROPOMI NO2 and HCHO vertical columns with UV-Vis DOAS and FTIR instruments, ATMOS, ESA, Salzburg, Austria 2018.

Skinner S. L., Guedel M., Schmutz W., Zhekov S.: 2018, Chandra observations of the eclipsing Wolf-Rayet binary CQ Cep over a full orbital cycle, AAS Meeting Abstracts #232, #320.03.

The Solar Atlas of Egypt: 2018, Kosmopoulos P., Kazadzis S., El-Askary H., Ministry of Electricity and Renewable Energy of Egypt Publication, The Solar Atlas of Egypt.

Walter B., Schmutz W., Anderse B., Finsterle W., Kopp G., Koller S., Levesque P.-L., Pfiffner D., Beattie A.: 2018, The latest TSI measurement results from CLARA on NorSat-1, EGU General Assembly Conf. Abstracts 20, 17238.

Media

International media coverage on 6 February 2018

A scientific paper by William Ball, entitled "Evidence for Declining Lower Stratospheric Ozone", received international media coverage.

Ball W., Alsing J., Mortlock D., Rozanov E., Tummon F., Haigh J.: 2017, Reconciling differences in stratospheric ozone composites, Atmos. Chem. Phys., 17, 12269–12302, doi: 10.5194/acp-17-12269-2017.

Obituary: Claus Fröhlich, 22 Feb. 2019

Until almost his last day, Claus Fröhlich put his heart and soul into being a researcher. He was born on 10 October 1936, and came to Davos and the Physikalisch-Meteorologisches Observatorium Davos (PMOD) in 1969 as a physicist.

www.pmodwrc.ch/en/our-institute/press-media/

New PMOD/WRC Director and Affiliated Professor at the ETH Zürich

The ETH appointed Prof. Dr. Louise Harra during its meeting on 6 – 7 March 2019 as an Affiliate Professor of Solar Astrophysics at the Physics Department, ETH Zurich.

www.pmodwrc.ch/en/our-institute/press-media/

Administration

Personnel Department

Barbara Bücheler

Inspired, we welcomed the New Year, 2018, with ideas for innovation and progress.

Probably the biggest event in 2018 was the search for a new PMOD/WRC director. On 27 September 2018, the time had come. From the ranks of senior management, Silvio Koller represented the Institute and staff during the recruitment of the director. On that morning, together with many high-ranking representatives from business and politics, we waited in the PMOD/WRC seminar room for the presentations of the five candidates who had been chosen for the final round. In the afternoon, the candidates faced questioning by the recruiting committee for about 60 minutes. It consisted of 12 experts from the senior management of SFI, MeteoSwiss, ETH Zurich, the University of Bern, the EPFL Swiss Space Center, METAS, NASA, Max Planck Institute Göteborg, University of Colorado and the National Space Science Center/ Chinese Academy of Sciences. Prof. Louise Harra emerged as the favoured candidate. Thanks to the perfect organisation, the entire recruiting process went smoothly. On 1 June 2019 our director, Prof. Werner Schmutz, officially handed over the sceptre to Prof. Louise Harra. We are pleased to welcome her as our new Director at PMOD/WRC. We hope Prof. Werner Schmutz will continue to work at PMOD/WRC in a reduced capacity as a project Principal Investigator.

As host and member of the Innovation Committee “Innovation Grisons”, workshops were held at PMOD/WRC in January 2018 with the aim of redefining the research and development landscape of Grison. With this in mind, the Naturforschende Gesellschaft Davos organised a networking event on 15 June 2018 among research institutes through the "Science Rally Davos".

As part of the "Sounds Good" Music Festival, "The Hats" played at PMOD/WRC on 18 July 2018 and captivated our numerous blues, pop and rock lovers. The two young talents, Adriano Minelli on piano and Marcelo Uteo on drums, who are well-known in the Davos region, inspired the audience.

Motivated by the lively public interest in climate and space science, our staff once again showed their enthusiasm for the current state of research and development at PMOD/WRC during guided tours through the observatory. In addition, during the annual “Ferienpass”, organised by Pro Juventute, we introduced our young visitors to the world of technology in a playful way.

On the research and development side, we can once again record several successful projects and workshops this year. During the two PRODEX Meetings, EUI on 6 – 7 March 2018 and SPICE on 13 – 14 November 2018, the consortium of participating scientists and technicians established the current status of the project and discussed further steps. The future handling of calibrations was the subject of the Laboratoire Optique Atmosphérique (LOA) workshops on 4 – 5 April 2018. PMOD/WRC participated in Horizon 2020, a research and innovation programme of the EU, supported by the State Secretariat for Education, Research and Innovation (SBFI). Dr. Stylianos Kazantzis completed the GEO-CRADLE project at the end of 2018 with excellent results. As part of our Chinese space project, JTSIM-DARA, we organised a 4-day seminar across Switzerland from 30 October to 2 November 2018 entitled "Space-Based Solar Radiometry”. A Chinese delegation and members of the PMOD/WRC visited different Swiss space institutes. Current space activities and possible future cooperation and projects were also discussed with enthusiasm. Under the direction of Dr. Eugene Rozanov, the climate group were again successful. On 30 November 2018, they completed two projects financed by the Swiss National Science Foundation, "Volcanic Eruptions and Their Impact on Future Climate" (VEC) and "Study to Determine Spectral Solar Irradiance and its Impact on the Middle Atmosphere" (SIMA). The annual autumn meeting of the Supervisory Commission was held again at the PMOD/WRC on 2 November 2018.

Ongoing changes are also reflected by staff members at PMOD/ WRC. We congratulate Dr. Raptis Ioannis Panagiotis on gaining his PhD in Physical Science. We are pleased that Fabrice Eichenberger stayed on for another 6 months until 28 February 2018 after completing his civil service. After 5 years of scientific work as a physics lab technician, and after completing his school leaving exam, Nathan Mingard decided to continue his further education and left on 31 May 2018. We wish him good luck. Our former electronics apprentice, Andri Morandi, was able to compensate for a bottleneck in the technology department which lasted for two months until 30 September 2018. We had to say goodbye to Dr. Benjamin Walter on 30 September 2018, after five years of dedicated research. We are proud that our PhD student Christine Aebi moved on to her next career step in Brussels on 31 December 2018. She will complete her dissertation in 2019. We are particularly pleased about the increase in science staff with Herbert Schill, a scientist, and Verena Danuser, an observer in Arosa, who both joined us from MeteoSwiss on 1 January 2019. We are happy that Stefan Hartmann, after passing his final exam as a Kaufmann EFZ at the Diplommittelschule SAMD, stayed with us until 31 March 2019. As of 1 January 2019, Alexandra Sretovic is supporting our administration department while studying Business Information Systems at ZHAW Winterthur. Many thanks also to our guest, Patricia Martin Sanchez, who contributed to the PMOD / WRC as a science trainee from the University of Valladolid, Spain from 10 September to 31 December 2018.

With the energetic support of our dedicated civil service workers Bastian Oberholzer, Timon Stolz, Oliver Riser, Tobias Gammeter, Samuel Arnold, Luc Schnell, Niklaus Tschirky and Luca Zurmühlen, we managed to overcome the "Arctic" conditions this year despite the snow and bad weather while progressing on our mission with success.

The power of change and the dedication of our employees supports our progress, thereby allowing us to reach into the future.

Scientific Personnel

Prof. Werner Schmutz	Director, physicist
Dr. William Ball	Postdoc Climate Group, physicist
Dr. Luca Egli	Scientist WCC-UV and Ozone Sections, physicist
Dr. Tatiana Egorova	Scientist, Climate Group, climate scientist
Dr. Wolfgang Finsterle	Co-Head WRC, Head of WRC-Section Solar Radiometry, physicist
Dr. Julian Gröbner	Co-Head WRC, Head of WRC-Sections IR radiometry, WORCC, and WCC-UV, physicist
Dr. Nuno Guereirro	Postdoc Solar Physics Group, physicist
Dr. Margit Haberreiter	Head Solar Physics Group, physicist
Dr. Gregor Hülsen	Scientist WCC-UV Section, physicist
Dr. Stylianos Kazantzis	Scientist WORCC Section, physicist
Dr. Natalia Kouremeti	Scientist WORCC Section, physicist
Dr. Stephan Nyeki	Scientist IR Radiometry Section, physicist
Dr. Eugene Rozanov	Scientist Climate Group, physicist
Herbert Schill	Scientist Ozone Section, environmental scientist (since 01.01.2019)
Dr. Timofei Sukhodolov	Postdoc Climate Group, climate scientist
Dr. Benjamin Walter	Postdoc Solar Physics Group, physicist (until 30.09.2018)
Alberto Remesal Oliva	PhD student, 3rd year, University of Zurich
Christine Aebi	PhD student, GAW-CH project, 4th year, University of Bern (until 31.12.2018)
Patricia Martin Sanchez	Science Trainee, University of Valladolid, Spain (10.09.2018–31.12.2018)

Technical Personnel

Silvio Koller	Co-Head technical dept., project manager space, quality system manager, elec. engineer
Daniel Pfiffner	Co-Head technical dept., project manager space, electronics engineer
Lloyd Beeler	Electronics engineer MSc
Fabrice Eichenberger	Embedded systems engineer HES (until 28.02.2018)
Christian Fringer	Electronics apprentice, 1st year (since 01.08.2018)
Matthias Gander	Electronics engineer BSc
Manfred Gyo	Project manager space, electronics engineer
Philipp Kuhn	System engineer space experiments
Patrik Langer	Mechanics engineer BSc
Andri Morandi	Electronics technician (30.07.2018–30.09.2018)
Pascal Schlatter	Mechanic, head workshop, safety manager
Yanick Schoch	Electronics apprentice, 3rd year
Marco Senft	Systems administrator
Ricco Soder	Project manager technics, deputy quality system manager, electronics engineer
Marcel Spescha	Technician

Technical Personnel within the Science Department

Nathan Mingard	Physics laboratory technician (until 31.05.2018)
Christian Thomann	Technician

Administration

Barbara Bücheler	Head Administration/Human Resources
Stefan Hartmann	Administration, book-keeping
Irene Keller	Administration, import/export
Angela Lehner	Administration, book-keeping
Diana Fern. Dos Santos	Administration apprentice, 1st year (until 20.05.2018)
Alexandra Sretovic	Administration, book-keeping (since 01.01.2019)
Sarah Saiko	Administration, apprentice, 1st year (01.08.2018–30.09.2018)
Christian Stiffler	Accountant

Personnel in Arosa

Verena Danuser	Observer and maintenance ozone measurement station (since 01.01.2019)

Caretaker

Maria Sofia Ferreira Pinto	General caretaker, cleaning
Eufémia Soares Ferreira	General caretaker, cleaning (back-up)
Ana Rita Alves Ferreira	General caretaker, cleaning (back-up)

Civilian Service Conscripts

Bastian Oberholzer	26.02.2018 – 12.07.2018
Timon Stolz	02.04.2018 – 19.05.2018
Oliver Riser	02.07.2018 – 11.07.2018
Tobias Gammeter	02.07.2018 – 31.07.2018
Samuel Arnold	30.07.2018 – 27.10.2018
Luc Schnell	17.09.2018 – 21.12.2018
Niklaus Tschirky	24.09.2018 – 16.11.2018
Luca Zurmühle	03.12.2018 – 25.01.2019

Public Seminars

02.03.2018 Professor Mirela Voiculescu
Solar induced variability of cloud cover, reality or coincidence?

15.03.2018 Nattapon and James. PhD students, Thailand
Studying the fiber Bragg grating and applying to pressure sensor

A development of the calibration method for field pyranometers using satellite images

29.03.2018 Dr. Can Altunbulakli, SIAF Davos
Microbiome and transcriptome interactions in epithelial tissues in the context of allergic diseases

12.04.2018 U. Lanker and D. Thomann AO Foundation
Lecture AO Tierhaus: Past, present and future

12.09.2018 Markus Suter, Davos Instruments
The new radiometer control unit and beyond

24.09.2018 Dr. Panagiotis Kosmopoulos (NOA, Greece)
Earth Observation solar radiation studies and applications

27.09.2018 Prof. Dr. Louise K. Harra, Univ. College London & Mullard Space Science Lab., UK
Getting close to the Sun

Prof. Dr. Ilya G. Usoskin, University of Oulu, Finland
From past to future: Focus on natural forcing on Earth

Prof. Dr. Robert F. Wimmer-Schweingruber, Christian-Albrechts-University, Kiel,
Sun, wind, storms, and sunshine again

Prof. Dr. Svetlana Berdyugina, Albert-Ludwigs-University Freiburg
Living with the Sun

25.10.2018 Patricia Sanchez, Universidad de Valladolid
Inaccurate and insufficient research of physical laws in the film world

29.10.2018 Prof. Dr. Pieternel F. Levelt, Royal Netherlands Met. Inst. and Univ. of Delft, NL
High resolution air quality and emission monitoring from space: current and future potential of satellite instruments

08.11.2018 Dr. Mathias Bavay, WSL Institute for Snow and Avalanche Research, SLF Davos
MeteoIO: A pre-process. library for num. models

Meetings/Event Organisation

10.01.2018	Workshop Innovationsstrategie “Forschung” I
25.01.2018	Workshop Innovationsstrategie “Forschung” II
30.01.2018	Workshop Innovationsstrategie “Forschung” III
06.03.2018 – 07.03.2018	EUI (Extreme Ultraviolet Imager) consortium meeting
16.03.2018	Tagung der Bündner Zahnärztegesellschaft (BZG)
04.04.2018 – 05.04.2018	Workshop LOA (Laboratoire Optique Atmosphérique)
13.06.2018 – 14.06.2018	Qualitätsaudit GSGR (Graduate School Graubünden)
13.06.2018 – 14.06.2018	Sitzung MeteoSchweiz
15.06.2018	Science Rally Davos von NGD (Naturforschende Ges. Davos)
18.06.2018	SLF Meeting for Global Cryosphere Watch
18.07.2018	Davos Sounds Good “The Hats”
04.09.2018 – 06.09.2018	SOLSPEC (Solar Spectral Measurements) Workshop
27.09.2018	Wahlverfahren Professur für 2019
11.10.2018 – 12.10.2018	Workshop Ideas Plus, ATLAS Project
29.10.2018 – 03.11.2018	Chinese Delegation for Space-Based Solar Radiometry
02.11.2018	Aufsichtskommission Meeting
13.11.2018 – 14.11.2018	SPICE (Spectral Imaging of the Coronal Environment) consortium meeting
03.12.2018	Stiftungsratssitzung

Donations

A contribution from Mr. Daniel Karbacher (from Küsnacht, ZH) made it possible to again cover expenses of the solar physics research project, 3D-SOLSPEC, in addition to the project planning within the allocated budget. The aim of 3D-SOLSPEC is to determine the enhanced emission of the solar surface with magnetic structures versus non-magnetic regions. Furthermore, the project is, as part of an ISSI International Team effort, dedicated to determine the uncertainty of the spectral synthesis by comparing results obtained with different radiative transfer codes.

Lecture Courses, Participation in Commissions

Werner Schmutz	Honorary Member of the International Radiation Commission (IRC, IAMAS) Member of the Consultative Committee for Photometry and Radiometry (CCPR, OICM) Member of the Space Weather Working Team Steering Board of ESA Member of the National Committee on Space Research, SCNAT Member of the Commission for Astronomy, SCNAT Member of the GAW-CH Working Group (MeteoSwiss)
Wolfgang Finsterle	Member of CIMO ET-A3-II on Instrument Intercomparisons Member of CIMO TT Radiation References Member of EURAMET TC PR Chairman of ISO/TC180 SC1 (Solar Energy, Climate – Measurement and Data) Member of the PROBA-3 Science Working Team Lecture on “Solar Radiation as key source to be measured” at the “Forum on Regional Cooperation: Developing Quality Infrastructure for Photovoltaic Energy Generation”
Julian Gröbner	Lecture course in Solar Ultraviolet Radiation WS 2018, ETH-ZH GAW-CH Working group (MeteoSwiss) Member Scientific Advisory Group for UV, WMO GAW Chair of the NEWRAD Scientific committee Chairman of Infrared Working group of Baseline Surface Radiation Network (BSRN) Member IAMAS International Radiation Commission Member of the CIMO Task Group on Radiation – vice Chairman Member of the EURAMET Task Group on Environment Member International Ozone Commission (IO3C)
Margit Haberreiter	President of the EGU Division on Solar-Terrestrial Sciences Member of the EGU Program Group Vice-President of SGAA Member of the Swiss SCOSTEP Committee, Treasurer Swiss Rep. of Interprogramme Team on Space Weather, Information System & Services (IPT-SWISS) Member of the IAU Organizing Committee of Commission E3 “Solar Impact throughout the Heliosphere” Topical Editor Annales Geophysics Associate Member of the SPICE Operations Team
Eugene Rozanov	Co-Leader of SPARC SOLARIS-HEPPA WG3 Member of the Swiss SCOSTEP Committee Swiss representative in European COST CA15211, WG3 leader Editor of “Atmosphere and Ocean Physics”, Russian academy of Science Associated Editor of “Frontiers in Earth Science (Atmospheric Science)” Editor of “Proceedings of Main Geophysical observatory”
Stylianos Kazantzis	Scientific Advisory Group Aerosol (WMO/GAW) Associate Editor of Atmospheric Chemistry and Physics Swiss delegate to the Management Group of Cost 16202 International Network to Encourage the Use of Monitoring and Forecasting Dust Products Working Group, Leader of WG3 Co-Lecturer, “Fundamentals of Remote Sensing”, MSc in Space Science Technologies and Application, Univ. of Peloponnese, Greece GAW-CH Working Group (MeteoSwiss)
Luca Egli	Member IAMAS International Radiation Commission (since 2016) GAW-CH Working Group (MeteoSwiss)

Bilanz per 2018 (inklusive Drittmittel) mit Vorjahresvergleich

Aktiven	31.12.2018 CHF	31.12.2017 CHF
Flüssige Mittel	1'302'099.33	766'404.78
Forderungen	130'608.65	248'962.00
Warenvorräte	105'000.00	105'000.00
Aktive Rechnungsabgrenzungen	443'811.70	393'226.46
Total Aktiven	1'951'519.68	1'513'593.24

Passiven		
Verbindlichkeiten	163'311.65	322'323.75
Kontokorrent Stiftung	8'104.85	122'487.45
Passive Rechnungsabgrenzung	1'077'424.51	289'713.34
Rückstellungen	700'000.00	772'789.75
Eigenkapital	2'678.67	6'278.95
Total Passiven	1'951'519.68	1'513'593.24

Erfolgsrechnung 2018 (inklusive Drittmittel) mit Vorjahresvergleich

Ertrag	CHF	CHF
Beitrag Bund Betrieb WRC	1'460'000.00	1'460'000.00
Beitrag Bund (BBL)	141'141.30	102'139.75
Beitrag Kanton Graubünden	499'282.00	499'282.00
Beitrag Gemeinde Davos	651'168.00	651'168.00
Beitrag Gemeinde Davos, Mieterlass	160'000.00	160'000.00
Overhead SNF	47'117.00	59'977.00
Overhead EU	0.00	66'925.35
Auflösung Rückstellungen für Instrumentenbau	0.00	120'000.00
Instrumentenverkäufe	165'770.65	184'897.85
Reparaturen und Kalibrationen	214'447.11	227'583.77
Ertrag Dienstleistungen	20'207.84	14'772.95
Übriger Ertrag	31'562.00	11'589.85
Finanzertrag	1.35	5.55
Ausserordentlicher Ertrag	27'254.96	44'224.60
Drittmittel	2'048'427.19	2'216'383.05
Total Ertrag	5'466'379.40	5'818'949.72

Aufwand		
Personalaufwand	3'813'869.50	4'446'910.85
Investitionen Observatorium	243'993.03	97'910.93
Investitionen Drittmittel	81'576.35	105'702.50
Unterhalt Gebäude (Beitrag Bund)	141'141.30	102'139.75
Unterhalt	45'021.74	27'745.05
Verbrauchsmaterial Observatorium	32'523.86	30'174.00
Verbrauchsmaterial Drittmittel	403'682.71	262'833.54
Verbrauch Commercial	150'332.60	171'284.34
Reisen, Kurse	129'222.94	183'074.89
Raumaufwand/Energieaufwand	213'775.05	195'912.90
Versicherungen, Verwaltungsaufwand	106'835.69	116'483.64
Finanzaufwand	1'937.00	2'262.39
Übriger Betriebsaufwand	138'940.75	49'908.15
Ausserordentlicher Aufwand	39'916.91	27'490.01
Total Aufwand	5'542'769.43	5'819'832.94
Jahresergebnis vor Auflösung Rückstellungen	-76'390.03	-883.22
Auflösung Rückstellungen zur Defizitdeckung	72'789.75	0.00
Jahresergebnis	-3'600.28	-883.22
	5'466'379.40	5'818'949.72

Abbreviations

AERONET	Aerosol Robotic Network, GSFC, USA
AOCCM	Atmosphere-Ocean-Chemistry-Climate Model
AOD	Aerosol Optical Depth
BIPM	Bureau International des Poids et Mesures, Paris, France
BSRN	Baseline Surface Radiation Network of the WCRP
CCM	Chemistry-Climate Model
CCPR	Comité Consultatif de Photométrie et Radiométrie, BIPM
CIMO	Commission for Instruments and Methods of Observation of WMO, Geneva, Switzerland
CIPM	Comité International des Poids et Mesures
CLARA	Compact Light-weight Absolute Radiometer (PMOD/WRC experiment onboard the NorSat-1 micro-satellite mission)
CMC	Calibration and Measurement Capabilities
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)
DARA	Digital Absolute Radiometer (PMOD/WRC experiment onboard the ESA PROBA-3 formation flying mission)
EMRP	European Metrology Research Programme
ESA	European Space Agency
EUI	Extreme Ultraviolet Imager (international experiment onboard the Solar Orbiter mission)
EUV	Extreme Ultraviolet region of the light spectrum
FRC	Filter Radiometer Comparisons, held at PMOD/WRC every 5 years
FUPSOL	Future and Past Solar Influence on the Climate, SNF Sinergia Project
FY-3	Feng Yun 3 series of Chinese space missions (FY-3A to E)
GAW	Global Atmosphere Watch, a WMO Research Programme
GCM	General Circulation Model
IACETHZ	Institute for Climate Research of the ETHZ, Switzerland
IPC	International Pyrheliometer Comparisons, held at PMOD/WRC every 5 years
IPgC	International Pyrgeometer Comparisons, held at PMOD/WRC every 5 years
IRIS	Infrared Integrating Sphere Radiometer (PMOD/WRC research instrument)
IRCCAM	Infrared Cloud Camera (PMOD/WRC research instrument)
ISO/IEC	International Organisation for Standardisation/International Electrotechnical Commission
JTSIM-DARA	Joint Total Solar Irradiance Monitor - DARA (experiment onboard the Chinese FY-3E mission)
LVPS	Low Voltage Power Supply (PMOD/WRC contribution to the Solar Orbiter mission)
METAS	Federal Office of Metrology
MITRA	Monitor to Determine the Integrated Transmittance (PMOD/WRC research instrument)
MRA	Mutual Recognition Arrangement
MRR	Manufacturing Readiness Review
NASA	National Aeronautics and Space Administration, Washington DC, USA
NIST	National Institute of Standards and Technology, Gaithersburg, MD, USA
NorSat-1	Norwegian Satellite-1
NPL	National Physical Laboratory, Teddington, UK
NREL	National Renewable Energy Laboratory, Golden, CO, USA
PFR	Precision Filter Radiometer (previously manufactured by PMOD/WRC)
PMO6-CC	PMO6-CC type of radiometer (manufactured by PMOD/WRC)
PROBA	ESA Satellite Missions (PROBA-1 to 3)
PRODEX	PROgramme de Développement d'Expériences scientifiques, ESA
PSR	Precision Spectroradiometer (manufactured by PMOD/WRC)
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin, Germany
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)
SPICE	Spectral Imaging of the Coronal Environment (PMOD/WRC contribution to the Solar Orbiter mission)
SSI	Solar Spectral Irradiance
TSI	Total Solar Irradiance
VIRGO	Variability of Solar Irradiance and Gravity Oscillations (PMOD/WRC experiment onboard the SOHO mission)
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
WRR	World Radiometric Reference
WSG	World Standard Group of pyrheliometers (realises the WRR; maintained by WRC at PMOD/WRC)

Annual Report 2018

Editors: Werner Schmutz and Stephan Nyeki
Layout by Stephan Nyeki

Publication by PMOD/WRC, Davos, Switzerland
Edition: 600, printed 2019

Front/rear covers: Sunrise seen from the International Space Station. The PMOD/WRC logo was designed in 2007, based on a similar image, for the institute's 100th anniversary since foundation by Carl Dorno. The logo symbolises our scientific research efforts to investigate and model Sun-Earth interactions. Image courtesy of NASA/ESA.

Dorfstrasse 33, 7260 Davos Dorf, Switzerland
Phone +41 81 417 51 11, Fax +41 81 417 51 00
www.pmodwrc.ch