Strategy 2020-2024

Executive Summary

The Physikalisch-Meteorologisches Observatorium Davos/World Radiation Center (PMOD/WRC) has six key areas that will be further developed in the coming years. These are:

- World Radiation Center: serve as an international calibration center for meteorological radiation instruments and develop radiation instruments for use on the ground and in space.
- Space projects: develop instruments for imaging and radiation measurements of the Sun.
- Technology: underpin the design and development of the instruments for ground and space.
- Climate science: research the Earth's ozone layer and climate evolution
- Solar Science: research the causes of solar activity.
- Teaching: carry out teaching at different levels at ETH-Zürich.

Introduction

PMOD/WRC has a world-class reputation in developing and building radiometers that are among the most accurate of their kind in the world and are used both on the ground and in space. In recent years, the expertise has expanded to include space telescopes for solar research. The next 4 years sees new instrument development both on the ground and in space. In addition, the new director has an official role with the physics department at ETH-Zürich opening new opportunities for collaboration in teaching, research and technology. The following sections summarise our strategy for the next 4 years, which is then followed by an implementation plan for each area.

1.1 World Radiation Center strategy

The World Radiation Center is operated by PMOD/WRC on behalf of the World Meteorological Organisation (WMO) and consists of 4 sections:

- Solar Radiometry Section (WRC-SRS).
- Infrared Radiometry Section (WRC-IRS).
- World Calibration Center for UV (WRC-WCCUV).
- World Optical Depth Research and Calibration Center (WORCC).

The terms of reference of the WRC are to:

- Develop, operate and maintain reference radiation instrumentation for solar and infrared (terrestrial) radiation as well as atmospheric turbidity measurements.
- Initiate and support initiatives for the homogenisation of world-wide radiation & aerosol optical depth measurements.
- Implement and maintain a Quality Management System according to ISO 17025.
- Perform research on the impact of solar and infrared radiation on Earth's climate.

Over the next years, the objective will be to consolidate, strengthen and expand the role of the WRC as World reference center for solar and terrestrial radiation measurements as well as atmospheric composition (aerosol optical depth and total column ozone). To that effect we will extend the quality management system to all WRC sections, and where appropriate, submit corresponding Calibration and Measurement Capabilities (CMC) through the International Committee for Weights and Measures Mutual Recognition Agreement (CIPM MRA). In order to demonstrate traceability of the corresponding measurements to the SI, collaborations with national metrology institutes through joint initiatives such as EURAMET's European Metrology Research Programme for Innovation and Research (EMPIR) projects are implemented.

The dissemination of the radiation scales to the international community to provide traceable measurements to SI through WRC references is performed by the following activities:

- International campaigns at PMOD/WRC with the participation of meteorological agencies, universities, and research institutions.
- Participation in regional calibration campaigns (for example organised within the WMO framework).
- Deployment of reference instruments at regional, national and global monitoring networks.
- Participation in measurement campaigns.
- Providing fiducial reference measurements (e.g. traceable measurements) for the ground-truthing of satellite-based EO-products.

1.1.1 The Global Atmosphere Watch precision-filter radiometers (GAW-PFR) network of aerosol optical depth

PMOD/WRC has been responsible for the operation of the GAW-PFR network for aerosol optical depth measurements. For that purpose, it has developed the Precision Filter Radiometer (PFR) of which more than 80 units have been built. Currently, more than 40 PFR instruments are operating worldwide, of which 18 by MeteoSwiss. In order to ensure the long-term operation of the GAW-PFR network and sites maintained by associated institutes, new PFRs are being constructed to replace instruments which are approaching their end-of-life status. Additional improvements consist of enhancing the aerosol related products retrieved from GAW-PFR, to implement spectral AOD measurements using spectroradiometers (e.g. PSRs) at selected sites, and review the GAW-PFR network in view of relocating sites related with currently missing aerosol types (e.g. biomass burning and dust aerosols). The network visibility will be expanded through peer reviewed publications, conference presentations and online provision of the PFR data.

1.1.2 Solar Radiometry Section

The Solar Radiometry Section of the WRC (SRS/WRC) maintains and operates the primary reference for solar irradiance, the World Radiometric Reference (WRR). The WRR is based on the World Standard Group of pyrheliometers (WSG). It has been shown that the WRR was stable within <0.05% since its definition in 1977. Establishing traceability for the WSG to the SI optical power scale is technically challenging. Therefore, the accuracy (~0.3%) of the WRR is significantly lower than its precision and stability.

The Cryogenic Solar Absolute Radiometer and Monitor for Integrated Transmittance (CSAR/MITRA) are a set of instruments which have been designed and built by PMOD/WRC, NPL, and METAS in order to overcome these challenges and to establish traceability of the WSG to the SI optical power scale.

The CSAR/MITRA have been operated at PMOD/WRC since 2010. Our goal is to formally prove the absolute accuracy of CSAR/MITRA to within 0.02% (k=1) with respect to the SI optical power scale. The current accuracy of the WRR is within 0.09%.

The improved absolute accuracy is required not only by the solar energy sector but will also allow us to bridge potential gaps in the space-borne TSI time series by calibration of future space experiments against the CSAR/MITRA. TSI is recognized by WMO as an Essential Climate Variable (ECV) and accurate TSI (and SSI) measurements from space are critical to assess the Earth Energy Imbalance (EEI).

Three strategic goals are identified within SRS/WRC:

- Establish traceability of CSAR/MITRA to SI optical power scale with <0.02% (k=1) uncertainty.
- Improve calibration capabilities for TSI radiometers in order to transfer the CSAR/MITRA scale to space with <0.01% (k=1) uncertainty.
- Include space-borne irradiance measurements in the scope of the WRC.

1.1.3 Capacity development

Current training activities will be expanded in order to provide capacity development and educate local site operators and scientists to the best practice of solar and terrestrial radiation measurements and calibrations. Due to the increased recognition by the WMO and the international community of the importance of providing traceable measurements for climate assessments, there is a need for specific training and capacity development in this area which PMOD/WRC can offer due to its involvement in the metrological (PMOD/WRC is signatory of the CIPM MRA) and meteorological communities (e.g. via the Swiss branch of Global Atmosphere Watch, GAW-CH).

1.1.4 Instrument development & sales

The continuous development and improvement of reference instruments to fulfil the core objectives of the WRC is also an opportunity for providing these instruments to the international community and thereby consolidating the reputation of the PMOD/WRC as highest quality radiation instrument manufacturer.

1.1.5 Radiometric laboratory facilities

The radiometric facilities of the WRC will be maintained and expanded to satisfy the demands of the various WRC sections and the space activities of the PMOD/WRC. Furthermore, these unique facilities will be made available to external customers on a cost-based usage.

1.1.6 Solar energy applications

PMOD/WRC has been leading the development of the solar energy nowcasting and forecasting System (SENSE/nextSENSE). We plan to improve the accuracy and spatiotemporal resolution of the developed system and to contribute towards the GEOS/EuroGEO related goals including GEO vision for energy. In addition, to contribute to the International Energy Agency (IEA) goals related with solar resource for high penetration and applications. Finally, to use the SENSE system towards new application and products combined with Copernicus (CAMS and C3S) services and available data.

1.2 Space Projects strategy

Putting instruments into space provides a clean environment, with continuous observations, and no dependence on weather conditions. Continuous solar irradiance measurements are an important international goal as input into climate models, such as those from the SOHO-Virgo mission. Incoming solar radiation and outgoing reflected radiation will be measured with the TRUTHS mission to provide standards in space. Instruments in space can provide us with

different views unobtainable from Earth such as the Solar Orbiter Mission getting in close to the Sun, and taking observation of the Earth's radiation balance with the PMOD-built Compact Lightweight Absolute Radiometer (CLARA). These are all important research areas within the institute that are respected internationally. The space instrumentation provides key opportunities to work with industry within Switzerland.

1.2.1 Operational spacecraft

There are a number of operational spacecraft that we are involved in. SOHO-Virgo is the longest dataset – now at 25 years. CLARA is also now taking data again. Solar Orbiter was launched in February 2020, and PMOD/WRC has involvement in two instruments. The JT-SIM and Proba-3 DARA instruments will soon join the fleet. One of the key issues in Switzerland is lack of funding for the operational stages of missions. Through Karbacher funding we have support in the short-term for CLARA, Virgo, both DARAs and Solar Orbiter EUI and SPICE. In the future the aim is for this funding to be covered through ordinary budget allocation.

1.2.2 Future missions

JT-SIM DARA and Proba-3 DARA are approaching the end of the build and are planned to be launched in 2021/2022.

There are a number of future opportunities on the space projects side. These are:

Traceable Radiometry Underpinning Terrestrial- and Helio- Studies (TRUTHS) – this is an ESA mission which is led by Nigel Fox (NPL, UK). It is building on the CSAR instrument. A full proposal will be submitted to SSO in October 2020, with the major work starting in 2021. The ESA ministerial in 2019 approved this mission for the next stage.

Solar-C – this is a JAXA-led mission, and we have a solar spectral irradiance design submitted for the mission. We will submit a proposal in April 2020 to SSO. JAXA will make a decision on the mission in the next months. It is due to be launched in 2026.

Lagrange – this is a space weather mission, and is in the space situational awareness section of ESA. The ESA ministerial in 2019 approved continuing support for the payload, but a delayed review of the spacecraft bus itself. The work continues as normal at PMOD/WRC. We are involved in the design of an imager which builds on the work on Solar Orbiter EUI.

Solaris – this is a NASA mission – the proposal was submitted at the end of 2019 to NASA, and the results should be known in summer 2020. Our involvement would be through an imager similar to Lagrange.

There are other longer terms interests which include instrument making radiation measurements from the moon, and the Voyage 2050 process in which we led a white paper.

1.3 Technology strategy

The technology department has a broad remit. The current major tasks are:

- Support of terrestrial PMOD/WRC research projects and infrastructure with mainly technical (mechanics/electronics) developments and manufacturing activities, coordination of external process steps and sometimes S/W development.
- Research instrument development and manufacturing (e.g prototypes or single instrument developments)
- Small series instrument production
- Maintenance of specific WRC infrastructure (hardware and software)
- Operation & Maintenance of PMOD/WRC technical infrastructure (electronics & mechanics labs, workshop)
- Space projects: All tasks, except directly science related topics
- Operation & Maintenance of specific “Space” infrastructure (e.g. cleanroom, clean-bench, vacuum laboratory)
- Institute’s IT infrastructure set-up and maintenance & PC-support
- Apprentices education

The technology department has to manage many different tasks and has significant demands, with different deadlines and pressures. In the next few years the following will be actively explored to ensure that the technology department can continue to function effectively.

WRC support: this workload is approximately at a steady level, with a slow increase. However, forward planning is required, and we will continue to develop the optimum way to do this. For each year, the WRC will develop a plan for technical tasks required in the following year. This will include estimated staffing demands and priorities.

Instrument sales: there will be a review in summer 2020 on instrument sales. A strategy should be produced, which is clear on what is required for the WRC. A strategy looking at prototype and ‘ready for sale’ will be developed to ensure that costing for development, build and aftercare are clear, and that any legal issues selling are properly dealt with.

IT support: the IT support is at only at a 60% FTE level currently. This is currently not enough for the demands of the institute and suffers from lack of support when on vacation time. We will work on a solution to ensure backup.

Space projects: space projects go through peaks and troughs. Combined with the steady work required from WRC, this should provide continuous work for staff, but needs to be forward planned. In the next 4 years, it is possible that 3 space projects will be successful – TRUTHS, Solar-C and Lagrange. If these projects were funded and the peaks of workload overlapped, this would have a big impact and new staff required. We will look at task sharing with partners at ETH, FHNW and Bern to manage the workload, as well as hire new staff. A review of the structure of the technology group will be carried out once the demands of the new projects are known.

1.4 Climate Science strategy

The climate science group studies the natural and anthropogenic influences on the Earth's atmosphere, ozone layer and climate in the past and future using numerical models and observations. Understanding how climate varies due to natural forcings including solar irradiance variations, energetic particle participation and volcanic eruptions, can help to improve climate model predictions and identify the degree to which human activity can influence climate.

The current focus is the SNF funded POLE project (Past and future of the Ozone Layer Evolution) which aims to analyse the benefits of the Montreal Protocol and its Amendments (MPA) to increase public acceptance of the protocol's necessity. POLE intends to project and estimate the time when ozone layer recovery will occur, and to analyse observational and model data in order to detect changes in the ozone layer evolution.

The project will provide understanding and direction about how to protect the ozone layer and to make more accurate climate predictions. An impact on society and policymakers is foreseen, because we will suggest ways to enable ozone recovery even if extremely unfavourable future scenarios play out. The project will allow Switzerland to expand its participation in international assessments and activities aimed at conservation of the ozone layer as well as to underpin policy positions on sustainable development.

The modelling group have been working on the development and application of the Earth System Model (ESM) SOCOL (SOlar-Climate-Ozone Links); this is now our main modelling tool. The new version of ESM SOCOLv4 is currently being tested describing the majority of the processes responsible for changes in atmospheric composition and radiative properties. In addition to the interactive gas-phase/heterogeneous chemistry and bin-resolved stratospheric sulfate aerosol the model simulates the ocean circulation, dynamical vegetation, carbon cycle, emission of sulfur containing species from the ocean and other necessary quantities to simulate direct radiative forcing and feedbacks responsible for the ozone layer behavior. The model can also be used for understanding the impact of space weather on the Earth's atmosphere.

The head of the climate modelling group Dr. Eugene Rozanov will retire at the end of the SNF grant in December 2022. Climate modelling maintains a high priority at PMOD/WRC, and we will seek to hire a replacement in early 2022. The future goals are highlighted in the implementation section 1.11.

1.5 Solar Science strategy

The solar physics research areas are being driven by the missions that PMOD/WRC have played a part in defining and building such as Solar Orbiter (launched in 2020), and Lagrange (launch ~2026). Solar-C will also be launched in 2026. The science goals are focussed on understanding the physical phenomena on the Sun that impact the Earth, through magnetic fields, plasma and energetic particles. The climate group have been studying the link between solar extreme events and impact on the Earth's atmosphere. The solar aspect of research links to this through understanding the physics behind space weather.

Solar Orbiter is a key mission for Switzerland with three of the ten instruments having PMOD/WRC and FHNW (Fachhochschule Nordwestschweiz) involvement. Harra is co-Principle Investigator of both the EUV Images and the SPICE instrument. Säm Krucker (FHNW) is PI of the STIX instrument. Solar Orbiter observations will be coordinated with other space and ground facilities such as Hinode (Harra was PI of the EIS instrument for 13 years), NASA IRIS missions (Harra is co-I), NASA SDO and the new 4m ground-based solar telescope DKIST. The new datasets that will be available in the coming years guarantee discovery level science. The questions below will be the main focus:

Creation of fast solar wind: *Understanding jet behaviour in coronal holes*

The *fast solar wind* is known to come from coronal holes. Coronal holes, although described as 'holes' since they are dark in EUV and X-ray wavelengths, do show activity on small-scales, such as jets, plumes and bright points. An additional and intriguing phenomenon known as stealth jets has been found in the Hinode EIS spectroscopic data – these features are seen clearly in measurements on non-thermal velocity but not in intensity. Their cause is not yet understood. All these dynamical processes have the possibility of contributing to the fast solar wind. The new data from the Parker Solar Probe mission show that the closer to the Sun the measurements are made, the more structure is seen in the solar wind. Connecting the solar features with the solar wind will be key science for the Solar Orbiter mission.

Creation of slow solar wind: *Understanding the evolution and magnetic sources of active region upflows.*

The slow solar wind is highly variable and is known to come from a range of sources, from high out in the streamers to low down in the corona. In this work, we will focus on one potential source, which is based on one of the most significant results from the Hinode mission - that is the discovery of the consistent upflows at the edges of active regions. These are measurements as blue-shifts in the coronal emission lines. There is a wealth of data over 13 years of Hinode observations to allow statistical studies of these flows, that we will work on. This will provide the foundation to the data from Solar Orbiter. We have defined observing programmes with DKIST and Solar Orbiter which will be carried out once Solar Orbiter is in its science orbit. This will take advantage of not only new instrumentation, but also the different viewpoints that Solar Orbiter will provide during its orbit.

What triggers solar flares: *Understanding the differences between eruptive and non-eruptive flare triggers.*

Solar flares are sudden releases of energy caused by the reconnection of magnetic field lines at regions of strong magnetic activity in the solar atmosphere (known as active regions). These events can accelerate particles to very high energies and emit very strong bursts of radiation across the electromagnetic spectrum. Sometimes they produce eruptions and sometimes they do not. We will explore different aspects of flares. One question is understanding where and how the hot plasma is created. To do this we will take advantage of a new method of 'overlappogram' data highlighted by Harra et al. (2017). This method allows fast cadence measurements of hot plasma which will be combined with hard X-ray data in collaboration with FHNW. The Solar Orbiter EUI instrument has a flare trigger algorithm on board which will be

used with the STIX flare trigger, so there are plans for novel observations in the next few years. Before these exist we will be working on the existing databases.

1.6 Teaching strategy

PMOD/WRC has a good history of successful PhD student training, and we aim to continue this. The new link with ETH-Zürich with the affiliated professorship of Harra opens new opportunities for teaching. A new block course led by Harra and Quanz on 'The Sun, stars and exoplanets' will start in June 2020. This course will provide a good interaction with MSc students in physics.

One of the goals is to enhance our interaction with students in particular with MSc project students. This will take some time to develop because of the remote location of PMOD/WRC and students being unaware of what the expertise exists here. In 2019/2020, a MSc group project in the computer science department worked on analysing the long-term Virgo dataset to determine instrument degradation. This was based in Zürich. In addition, in physics, there is 1 MSc student working on solar chromospheric modelling – this is a collaboration with IRSOL. There are also possibilities in the department of environmental sciences through the climate modelling collaboration. To date no MSc students have been based at PMOD/WRC to carry out their project work.

Our aim is to have 3 MSc students from ETH-physics be based in PMOD/WRC for 6 months of the year. The topics will be shared between the groups, which will provide a broad range of observations, modelling and hardware projects.

1.7 International coorperation, outreach strategy and publications

We consider it of importance to improve the profile of the institute at different levels:

Internationally – we intend to continue hold regular international meetings, and invite experts to visit. We will continue with our long-standing international collaborations, and develop new ones.

Regionally – we intend to build on the experience we had with Solar Orbiter to engage the national and local media in significant events and results from the institute. Our focus will be on the local population in Davos and the surrounding areas, school-children, and the national media.

Publications – refereed publications are important to maintain and expand our reputation scientifically. Publications are in our list of key performance indicators, and we consider this as a high priority.

Implementation plan

1.8 WRC Implementation plan

1.8.1 WRC-Solar Radiometry section

These are the key goals for the CSAR over the next 4 years.

- Build MITRA-3 to eliminate sensitivity to changing temperature (based on existing design)
- Establish/analyze CSAR/MITRA data record to demonstrate required accuracy and stability
- Work with WMO-CIMO TT RadRef on the formal replacement of the WSG by CSAR/MITRA

The TSI radiometer tasks are:

- Consolidate air-vacuum characterization capabilities with <0.01% uncertainty (may require new detector design for TSI radiometers, such as the flat receiver developed under Innosuisse)
- Spectral sensitivity of absorptance and diffraction correction needs to be quantified using model calculations and/or eliminated by design (field of view) to better than 0.01%

Space mission TSI tasks are:

- Ensure continuous funding for TSI/SSI missions through an extension to the WRC assignment, including operations of TSI/SSI missions
- Establish concepts for TSI/SSI reference measurements in space and participate in relevant projects and missions (e.g. TRUTHS, CLARREO, FY-3x).

1.8.2 WRC-IRS Infrared Radiometry Section

The activities of WRC-IRS are aligned with the activities defined in the work program of the Task Team on radiation references (TTref) of WMO CIMO for the period 2019 to 2022. In order to achieve formal traceability of the World Infrared Standard Group of Pyrgeometers (WISG) to the SI and submit corresponding CMCs to the Key Comparison Database (KCDB) of the International Committee for Weights and Measures (CIPM), PMOD/WRC is leading Work Package 4 of the EMPIR METEOC-4 (Metrology to establish an SI-traceable climate observing system) project coordinated by NPL (2020-2023). In this activity, the reference blackbody of WRC-IRS will be validated by an intercomparison to the reference standards of PTB. Furthermore, a new reference radiometer for infrared radiation measurements will be constructed and compared with the existing IRIS and ACP reference instruments. Finally, a spectrally uniform pyrgeometer will be designed and built with the collaboration of the company Hukseflux and PTB.

The IRIS radiometers in current operation were developed more than 10 years ago, and a new series of IRIS radiometers with improved characteristics (better detectors based on carbon

nanotube absorbing coatings, improved mechanics) is planned, to complement the current IRIS radiometers.

1.8.3 WRC-WORCC World Optical Depth Research and Calibration Center

The main objective of the EMPIR MAPP (Metrology for Aerosol Optical Properties) project is to develop methodologies and devices to achieve traceability of aerosol remote sensing properties to the SI. The activities in this project are aimed at characterising, calibrating and validating measurements of spectral solar radiation with filter radiometers (e.g. PFR) and spectroradiometers (e.g. PSR) and the models used to retrieve aerosol properties from these measurements. The project runs from 2020 to 2023 and is coordinated by PMOD/WRC with the participation of all major aerosol monitoring networks in Europe as well as national metrology institutes providing the metrological framework for these activities. This project will also support activities towards developing a reference for lunar based aerosol optical depth (AOD) measurements, with the aim of WORCC acting as European reference for Lunar AOD measurements.

The traceability of aerosol monitoring networks to WORCC will be achieved by the following activities:

- Organisation of the Filter Radiometer Comparison (FRC) at PMOD/WRC together with the IPC (2020 and 2025).
- Providing traceability to the Centre for Aerosol Remote Sensing (CARS) of ACTRIS through our participation to the Swiss component of ACTRIS. A funding request for ACTRIS-CH is coordinated by PSI, and PMOD/WRC has requested an annual support of 80 kCHF for this activity (0.5 FTE). If accepted, the activity will start sometimes between 2021 and 2025.
- Deployment of travelling reference filter radiometers (PFRs) and spectroradiometers (PSR) to European reference sites to provide continuous traceability measurements to WORCC via these instruments. This activity will be partly supported through the ESA QA4EO project (2019-2024).
- Renew and expand the current (2016-2020) MoU with the Skynet Network.

1.8.4 The GAW-PFR aerosol monitoring network

GAW-PFR is supervised by the WMO Scientific Advisory Group for Aerosols and results and data are going to continue being submitted in WMO related databases such as the World Data Center for Aerosols.

We plan to renew and partly expand the GAW-PFR network using the new series of PFRs being manufactured, that will be ready by the end of 2020. The GAWPFR network is currently assessed and site relocations will be based on the results from the GCOS funded project (2019-2020). Enhanced products (e.g. effective radius and volume) will be derived by implementing the GRASP model in operational basis based on a foreseen scientific proposal/project. In addition, we plan to continue following the performance of PSR long term AOD measurements, in order to assess their performance and establish a testing period of PSR data to be included in the GAW-PFR system. In parallel, we plan to enhance the GAW-PFR networking activities including national (Germany, Sweden, Finland, MeteoSwiss) networks. Such activities are

included in the proposed COST action on aerosol spectroradiometry (Harmonia) lead by PMOD/WRC.

The inclusion of AOD as an essential climate variable from the Global Climate Observing System (GCOS) provides an opportunity on future funding by participating in projects related with satellite validation activities and also activities that combine global networks, satellite and modeling for climate studies. Currently aerosol dust related activities are initiated through the (2018-2022) EU funded COST action InDust. We finally plan to increase the Network visibility by publishing network overview results and case studies, also by developing a user-friendly web interface that will provide near real time data and information about the network activities.

1.8.5 WRC-WCCUV World Calibration Center for UV

We plan to expand the instrumentation of the optic radiometry laboratory of WCCUV as it is increasingly used by other sections of the WRC and for the characterization of space radiometers (e.g. pointing of JT-SIM and DARA). An upgraded pointing facility will be developed within EMPIR MAPP (2020-2023) for direct irradiance instruments. Furthermore, WCCUV will develop a spectroradiometer system for the measurement of spectral solar irradiance up to 1700 nm to complement the current QASUME and QASUME-2 spectroradiometers which measure in the range 250 nm to 500 nm. The aim is to measure the solar spectrum at the surface over the full range from 300 nm to 2500 nm to support solar energy applications, atmospheric applications requiring traceable reference solar spectra, and finally to complement the TSI measurements of the WRC-SRS. Similarly to the IPC, the WCCUV will organise the 3rd UV filter radiometer comparison (UVC-III) in 2022 (purposely shifted by 2 years relative to the IPC).

1.8.6 Section OZONE

It is planned to relocate the last two instruments from LKO Arosa to PMOD/WRC in summer of 2021. The operational activity is funded by a contract from Meteoswiss, while the scientific authority lies with Meteoswiss. The scientific ozone activities at PMOD/WRC are supported via the GAW-CH funded project INFO3RS (2018-2021). Additional project funding will be sought in order to support further scientific work to complement the operational activities (SNF project submission planned for April 2020). The ESA QA4EO project (2019-2024) will support the continued development of reference instrumentation and methodological developments for traceable total column ozone measurements (follow-up of EMRP ATMOZ, 2014-2017) in view of providing ground-truthing for the validation of EO products from Sentinel satellites. The aim is to incorporate the ozone funding in the WRC institutional funding at the next WRC funding negotiations in 2024 and to expand the operational ozone activities by the scientific exploitation of this unique dataset. Ozone will become a new section of the WRC.

1.8.7 Solar energy applications

The improvement of the solar nowcasting and forecasting system (SENSE/nextSENSE) is one of the main tasks of the EU funded project (2019-2023) E-Shape. E-Shape networking activities have been used for the participation of PMOD/WRC in two new proposals that are aiming towards the use of the system in various applications related with the EuroGEO initiative and

the Copernicus Services. E-Shape includes the supervision of 1 PhD student and one post doc in Greece.

The participation of PMOD/WRC in the EU funded project Excelsior (2019-2026) as external collaborator will help on transferring knowledge and use the developed system SENSE in the area of the Eastern Mediterranean (Cyprus). PMOD/WRC will continue participating in the activities of the IEA PV task 16 on solar resource on large scale applications. It is also foreseen that consulting services will be provided for future end-users of SENSE including CAMS solar radiation related data and applications through the recently applied TEDDIS and AFRON proposals.

1.8.8 Staff and Personnel

We are planning to hire temporary staff to support these activities. The following applications have been submitted or planned.

EMPIR MAPP/EMPIR MET4CLIMOS: 1 PhD student or technician, 2021-2024

SNF - Quantifying **S**tratospheric **O**zone recovery using the world **L**ongest ground-based ozone time-series in S**W**itz**E**rland (SOLWE) (2020/24) : 2 PhD, 1 postdoc, 2021-2025

SNF on Aerosol measurement enhancements 1 Phd student, 1 post doc (2021-2025)

TEDDIS: 1 post doc (2021-2024)

AFRON: 1 post doc (2021-2024)

SNF radiometry - High-sensitivity absolute radiometry for measuring the Earth Radiation Budget – 1 PhD student (2020-2024)

1.9 Space Projects Implementation

A key issue is ensuring sustained funding for operations phases of instruments on spacecraft. Currently we have Karbacher funds, but in principle we should have a standard Swiss funding route. We will work with FHNW, ETH, AK and the board of trustees to try and find a long-term solution for this.

Another key issue is managing the workload on the space projects – these have significant peaks. Careful resource planning is required – with the WRC work being dominantly carried out during troughs. We are involved in three potential new space missions – TRUTHS, Solar-C and Lagrange. During the main build phase TRUTHS would require ~6 FTE, Solar-C ~3 FTW, and Lagrange 6 FTE. This would require a significant increase in the staffing in the technical department. In addition, more physical space would be required.

1.10 Technology strategy implementation

There is currently pressure on the multiple proposals being submitted for the space projects. In the near future a new systems engineer will be hired (from ETH start-up funds) to support new projects. A review of space requirements and new testing equipment will be made once the new space projects timeline is understood. In addition we will develop links with the shared pool of mechanical and electronics engineers of the Institute for Particle Physics and Astrophysics at ETH and can work with them on sharing particular tasks.

A key area of weakness is the IT support which is at too low a level for the size and demands of the institute. This will be assessed and determine if we can collaborate with ETH on addressing some issues, and looking in the longer term for a budget to have 100% temporal coverage.

1.11 Climate modelling strategy implementation

The set of numerical models developed during past almost 20 years can be applied for studies of important for the society and sustainable development processes:

(i) Space weather events can interrupt radio wave propagation, disturb global positioning satellite signals, damage electric power grids, satellite instrumentation and passenger jets on the polar routes. The damage is noticeable for moderately strong events but can be dramatic in case of rather rare but extremely strong solar explosive events. The Entire Atmosphere Global Model EAGLE developed at PMOD/WRC can help to understand the involved processes and to decrease the risk using future observation of the Sun from ongoing and planned missions.

(ii) The accelerated global warming threatens sustainable development of the human society and requires immediate actions. In the absence of consensus among world leaders the direct approach aiming at rapid limitation of the greenhouse gas emission does not look very promising. One way to proceed is to apply climate intervention to temporary decrease the damage and intensify work on the decarbonization approach. However, efficiency and safety of climate intervention measures has not been properly studied yet. The Earth system model SOCOLv4 developed at PMOD/WRC can help to understand pros and cons of the climate intervention based on injection of sulfur containing species into the upper air.

(iii) The same model can be used in the next IPCC Coupled Model Intercomparison Project. The model contains all necessary components and is installed and tested on

National Computer Center (CSCS) Facilities. With proper support the SOCOL4 can be the first Swiss model participating in IPCC CMIP activity.

The tasks stated above are interesting from the scientific point of view and valuable for the policy makers and society. The group is funded by PMOD/WRC and by the SNF POLE project until end of December 2022. It is important to have a new head of climate modelling in place early enough to submit an SNF proposal by the 1 April 2022 deadline. The vacant position of the group leader will be advertised in spring 2021 with interview due in summer/autumn 2021. The strategy beyond this time which be developed by the new head of climate modelling.

1.12 Solar Science strategy implementation

Harra joined in June 2019 and applied for a 2 year SNF grant to work on solar wind formation and solar flare science. This was successful and supports one PhD student and one postdoctoral research assistant from October 2019-October 2021. It is planned that a new grant will be applied for in April 2021. At this stage the Solar Orbiter science data will have begun. We will apply for funds to develop this in April 2021.

The scientific links across Switzerland will be developed – these include FHNW, IRSOL and KIS. The first Swiss solar physics meeting was held in November 2019, and are planned bi-annually. This will be very beneficial for Solar Orbiter and DKIST science as expertise in the mission and ground-based data are strong. We have started joint seminars and journal clubs and expect collaborations to develop. This will be important for future funding opportunities to coordinate together.

The space weather Lagrange mission is likely to launch in 2026. There will be opportunities for collaborative proposals such as SNF Synergia, NRP or EU proposals on space weather. We will develop a science case for opportunities based on space weather science that links most closely to the expertise in PMOD/WRC. For example, feature recognition in EUV images can translate to spectral irradiance in the higher energy bands. This can then be fed in to the ionospheric modelling. A possibility is to look at events over the last 20 years or so that have flares with/without CMEs and with/without SEPs and see the impact on the ionosphere, and see if the model predicts it – this could lead to nowcasting in the future when Lagrange is launched. Another approach is to look at extreme events – what happens in the worst case scenario.

Harra leads an ISSI team to connect Parker Solar Probe, Hinode, modelling and ground-based data to understand where the sources of solar wind emanate. This team started in January 2020, and will last for over a year. This work will be key for Solar Orbiter science.

1.13 Teaching Implementation

Since this is new area for PMOD/WRC it will take some time to develop. The first stage is starting the new course at ETH on solar and exoplanet science, and determining how popular this is with students. This course will allow the students to be introduced to research areas that take place at PMOD/WRC. This will be a good step in developing interest in students carry out project work at PMOD/WRC. Since we now have staff based part-time in ETH-Zürich, it is also possible for projects to be carried out in Zürich.

1.14 Outreach Implementation

We had funding to assist with outreach activities around the launch of Solar Orbiter. This helped significantly with advertising locally and resulted in the highest attendance at PMOD/WRC to any event. We would like to build on this success and aim to achieve additional funding in the future – although this is challenging.

1.15 Space aspects

With the addition of new projects, we will require additional desk space. New research projects are being applied for, which will provide additional PhD students and postdoctoral research assistants (>5 FTEs). The new space projects would require additional technical staff (~10). The additional numbers of new staff required are not yet certain and will depend on the timelines and selection of the different projects. There is still some capacity for new staff within the institute, and we will work on optimising that. Beyond that, there is some space in the old SIAF building, which can be explored. Another possibility is to explore a new building, which would house appropriate laboratory space and new offices.

Acronym list

ACP - Absolute Cavity Pyrgeometer

AOD – aerosol optical depth

CARS - Centre for Aerosol Remote Sensing

CIPM - International Committee for Weights and Measures

CIMO - Commission for Instruments and Methods of Observation

CLARA - compact lightweight absolute radiometer

CMC - Calibration and Measurement Capabilities

CSAR - Cryogenic Solar Absolute Radiometer

DARA - Davos Absolute Radiometer

ECV - Essential Climate Variable

EEI - Earth Energy Imbalance

EIS – EUV Imaging Spectrometer

EMPIR - European Metrology Research Programme for Innovation and Research

EO – Earth Observing

ESA – European Space Agency

ESM - Earth SystemModel

EUI – EUV Imagers

EURAMET – European Association of national metrology

EuroGEO – Earth Observation in Europe

FRC - Filter Radiometer Comparison

GAW - Global Atmosphere Watch

GEOSS - Global Earth Observation System of Systems

FHNW – Fachhochschule Nordwestchweiz

IEA - International Energy Agency

IRIS - InfraRed Integrating Sphere radiometer

IRS – infrared radiometry section

ISO - International Organization for Standardization

JAXA – Japan Aerospace Exploration Agency

KCDB - Key Comparison Database

MAPP - Metrology for Aerosol Optical Properties

METAS – Swiss Federal Institute of Metrology

MITRA - Monitor for Integrated Transmittance

MRA - Mutual Recognition Agreement

NASA - National Aeronautics and Space Administration

NPL – National Physical Laboratory

PFR - Precision Filter Radiometer

PTB - **Physikalisch-Technische Bundesanstalt**

SOCOL - SOlar-Climate-Ozone Links

SOHO – Solar and Heliospheric Observatory

SPICE - Spectral Imaging of the Coronal Environment Instrument

SRS- Solar Radiometry Section

STIX - The Spectrometer / Telescope for Imaging X-rays

TSI – total solar irradiance

TRUTHS - Traceable Radiometry Underpinning Terrestrial- and Helio- Studies

TTSM - Task Team on Radiation References

Virgo – Variability of solar irradiance and gravity oscillations

WCCUV - World Calibration Center for UV

WISG - World Infrared Standard Group of Pyrgeometers

WORCC- World Optical Depth Research and Calibration Center

WRC- World Radiation Center

WRR - World Radiometric Reference

WSG - World Standard Group of pyrheliometers

WMO - World Meteorological Organisation