3.1 Executive Summary (max. 1 page)

1. Introduction

The Earth's surface radiation budget plays a crucial role in the climate system, and accurately characterising components of the radiation budget is therefore an important task (Hartmann et al., 2013). The Baseline Surface Radiation Network (BSRN; e.g. Driemel et al., 2018) is one of several international networks to coordinate the measurement and archiving of radiation data. On a national level, MeteoSwiss conducts radiation measurements at 4 stations following similar BSRN guidelines.

Longwave radiation measurements are conducted with pyrgeometers traceable to the World Infrared Standard Group (WISG) at PMOD/WRC, Davos. However, several important aspects concerning the traceability of the WISG and hence MeteoSwiss and BSRN archives remain to be resolved by the research community. In order to address these issues, a WMO CIMO Task Team on Radiation References recently published their recommendations (CIMO, 2018).

Our proposal intends to focus on these traceability and instrumental issues. Priorities 1.4, 1.6 and 2.3 of the GCOS Switzerland Strategy 2017 – 2026 are therefore addressed by this proposal.

2. Expertise and Current Research at PMOD/WRC

Several recent papers include: 1) The traceability of BSRN archives, and re-scaling of the WISG (*Nyeki et al*., 2017), 2) analysis of the longwave radiation time-series at four MeteoSwiss stations (*Nyeki et al*., 2019), and 3) collaboration with the CIMO Task Team (*CIMO*, 2018).

3. Research Plan

In order to maximise the available time for pyrgeometer calibrations and to use the financial resources optimally, it is proposed that this project runs for 24 months with a 40% position.

Work Package 1 (months 1 – 22): The pyrgeometers used at the Meteoswiss Payerne BSRN site to measure the atmospheric longwave irradiance over the last 20 years will be calibrated at PMOD/WRC in order to provide traceability to the WISG and to SI units, as strived by GCOS. Up to 2 BSRN sites chosen in WP3 will be contacted to send their pyrgeometers to PMOD/WRC for a calibration in order to reprocess their atmospheric longwave irradiance with traceability to the WISG.

WP1 constitutes the major in-kind contribution of PMOD/WRC to this project.

Work Package 2 (months 1 – 16): Methods and procedures will be developed to allow the re-calculation of atmospheric longwave irradiances from the BSRN archive using ancillary meteorological data archives or assimilated datasets such as ERA40 for atmospheric air temperature and humidity as proxys. The methods will be validated by using the pyrgeometer raw data from the Meteoswiss BSRN site recovered from the MeteoSwiss archives together with the calibrations performed in WP1.

Work Package 3 (months 12 – 24): The methodology developed in WP2 will be applied to key datasets from the BSRN archive for which traceable calibrations to the WISG either exist or for pyrgeometers recalibrated in WP1, to demonstrate the procedure to the BSRN community.

Work Package 4: Outreach and Impact

We will attend the forthcoming BSRN workshop (29 Jun. - 3 Jul. 2020, Bologna, Italy) and inform the radiation research community about our plans. Final project results will be presented at the following BSRN workshop in summer 2022. Central to the above activities will be the close collaboration with the CIMO Task Team on Radiation References. A guideline document describing how to re-analyse BSRN datasets to provide traceability to the WISG and SI units will be written and submitted as a WMO CIMO document.

3.2 **Research Plan (max. 6 pages)**

1) Detailed project plan

The Earth's surface radiation budget plays a crucial role in the climate system, and accurately characterising components of the radiation budget is therefore an important task (*Hartmann et al*., 2013). As part of the Global Climate Observing System (GCOS) Implementation Plan, the surface radiation budget is listed as an Essential Climate Variable (ECV). The Baseline Surface Radiation Network (BSRN; bsrn.awi.de; *Driemel et al*., 2018; and references therein) is one of several international networks to coordinate the measurement and archiving of radiation data. BSRN data are archived by the World Radiation Monitoring Center (WRMC), at the Alfred Wegener Institute (AWI) for Polar and Marine Research, Bremerhaven, Germany. On a national level, MeteoSwiss has four stations (Payerne, Locarno, Jungfraujoch and Davos) where radiation measurements are conducted following guidelines similar to those of BSRN. These are part of the Swiss Alpine Climate and Radiation Monitoring (SACRaM) network, while Payerne belongs to the BSRN.

Surface radiation measurements are conducted with shortwave and longwave radiometers which are traceable to the World Standard Group (WSG) of pyrheliometers and the World Infrared Standard Group of pyrgeometers (WISG), respectively. Both standard groups are maintained by the Physikalisch Meteorologisches Observatorium / World Radiation Center (PMOD/WRC), Davos, Switzerland. Virtually all shortwave measurements are based on a calibration traceable to the WSG since 1977, but this is not the case for longwave measurements as the WISG was only established in 2004. Although many downward longwave radiation time-series at BSRN stations have become traceable to the WISG, which has led to better global homogenisation of such measurements and has considerably increased their reliability and accuracy, a large part of the BSRN archive contains data of unknown traceability. Therefore, several important aspects concerning instrumental issues still remain to be resolved by the research community. In order to address these issues, a WMO CIMO (Commission for Instruments and Methods of Observation) Task Team on Radiation References was established in 2014. The 2014 – 2018 working phase ended with recommendations (*CIMO*, 2018) which were adopted by the Task Team for the 2019 – 2022 phase.

The first aspect concerns the fact that many BSRN stations have submitted longwave radiation time-series in the past from pyrgeometers whose calibration was not traceable to the WISG. In a recent study of the BSRN and PMOD/WRC archives (*Nyeki et al*., 2017), calibration records for up to 100 out of 223 pyrgeometers were not traceable. To make matters even more difficult is the fact that only longwave irradiance data has been stored at the BSRN archive without the raw data signals, making an eventual reprocessing very challenging at the level of the BSRN.

The second aspect concerns the WISG and its reference scale which is the main responsibility of the PMOD/WRC Infrared section. Currently, the WISG is regarded as a transfer standard, traceable to SI through comparisons with absolute longwave radiometers such as IRIS (Infrared Integrating Sphere; *Gröbner*, 2012) or ACP (Absolute Cavity Pyrgeometer; *Reda et al*., 2012). A re-scaling of the WISG has long been debated in the research community (e.g. *Gröbner et al*., 2014; *Nyeki et al*., 2017; and references therein). If this were to be approved by CIMO in the future, then longwave radiation time-series need to be re-calculated. However, a simple linear re-scaling is not possible due to the non-linear nature of the pyrgeometer calibration equation (e.g. *Nyeki et al*., 2017).

In case a re-scaling of the WISG is adopted, archived longwave time-series will be affected by changes of up to 5 Wm^{-2}, which are significant in comparison to those expected from climate warming. While the responsibility of ensuring traceability to SI units resides with the institutions collecting present-day data, this is rendered difficult for historical datasets in data archives such as the BSRN, as responsible site scientists may have left and original datasets may no longer be available.

As it is anticipated that many institutions, who perform radiation monitoring for climate research, will not have the resources to make such an assessment, we propose to develop a methodology that can be applied to the data stored in the BSRN archive without the necessity of recovering the original raw measured signals.

Our proposal intends to address the above aspects by defining methods and procedures to re-calculate longwave radiation time-series (or parts thereof) belonging to the BSRN archive and thereby demonstrate how traceability to the WISG and SI can be achieved for these historical datasets.

This will benefit the BSRN and GCOS community by helping to:

i) Define methodologies to reduce uncertainties in the traceability of radiation budget studies which use the BSRN archive for climate models and to validate satellite data (e.g. *Wild et al*., 2016; and references therein). GCOS guidelines for data submission state that data should be traceable.
ii) Accurately monitor the trends in observed longwave radiation at the surface.
iii) Prevent the loss of legacy data and ensure their availability for future use when traceability and instrumental issues (e.g. *CIMO*, 2018) have been resolved.

Our proposal specifically aims to address Priorities 1.4, 1.6 and 2.3 of the GCOS Switzerland Strategy 2017 – 2026.

In order to maximise the available time for all work packages and to use the financial resources optimally, it is proposed that this project runs for 24 months with a 40% position, and is filled by an experienced radiation scientist. The work packages are based on items which were identified in previous studies and reports (*Gröbner et al*., 2014; *Nyeki et al*., 2017; *CIMO*, 2018) as being important aspects in achieving the global homogenisation of longwave radiation time-series.

Detailed research plan:

Work Package 1 (months 1 – 22)

BSRN recommends to calibrate all pyrgeometers against the WISG at PMOD/WRC. However, a large number were only calibrated in black-body cavities, commonly used prior to the realisation of the WISG in 2004. As a result, substantial discrepancies of up to 15 Wm^{-2} under clear sky conditions are possible. In order to encourage stations to calibrate such pyrgeometers against the WISG, their calibration history will be investigated with help from station managers and our project collaborators at BSRN. While this was partly achieved in a previous study (Nyeki et al., 2017), the calibration histories of up to 100 of 223 BSRN pyrgeometers still remain to be established and then documented in the BSRN archive.

As part of our in-kind contribution to GCOS and BSRN, we will calibrate the pyrgeometers used by the Swiss SACRaM network to which the BSRN station Payerne belongs, hence ensuring their continued traceability. Furthermore, through close collaboration with the BSRN project and database managers, pyrgeometers used for key BSRN datasets will be identified and the respective station managers contacted to offer a calibration of these pyrgeometers with respect to the WISG and therefor to SI units.

Work Package 2 (months 1 – 16)

Work Package 2 is concerned with two complementary tasks which constitute the core of this proposal.

Task 1: Development of a methodology to re-calculate longwave irradiance in the absence of the original raw data signals. In the case of pyrgeometers, the thermopile voltage and the various instrument temperatures (body and dome) from thermistors are the necessary raw signals, which are not saved in the BSRN archive and are therefore possibly not accessible anymore (this was the case for a significant number of BSRN stations, identified in a previous SNF project). Re-calculating the longwave irradiance only from the archived BSRN data requires additional information which can come from ancillary datasets. However the quality and uncertainty of such a re-calculation needs to be assessed and validated.

Task 2. Longwave radiation time-series as well as any available raw pyrgeometer data (signal voltage, dome and body temperatures) will be extracted from the MeteoSwiss and BSRN archives. Due to a number of legacy issues (e.g. data formats, computer hardware, personnel, etc), this will require on-site work at MeteoSwiss by the project investigator. At the same time, ancilliary data will also be

obtained from MeteoSwiss (temperature, pressure, relative humidity) and the STARTWAVE database (http://www.iapmw.unibe.ch/research/projects/ STARTWAVE/, integrated water vapour).

The method developed in Task 1 will be applied to the processed data stored in the BSRN archive and validated by comparing it to the processed longwave irradiance obtained from the corresponding raw data signals recovered from the Meteoswiss archive.

Two outcomes are possible, called **Method A** and **Method B**:

A. If the datasets are within the expected uncertainties and the methodology developed in Task 1 is shown to produce data of sufficiently high quality for the BSRN archive, then the method is validated and can be applied to additional BSRN stations (work performed in WP3) directly using data from the BSRN archive. This is "the preferred method".

B. If the method does not produce results within the expected uncertainties, then it is a clear indication that historical BSRN datasets require the corresponding raw data in order to be reprocessed and become traceable to SI units. This outcome would need substantially more effort from each BSRN station scientist and would require more resources from the community. This is the "less favoured method".

Work Package 3 (months 6-24)

Polar regions are experiencing faster changes in temperature trends than others, and we therefore intend to prioritise longwave radiation time-series from these BSRN stations. Time-series from two polar BSRN stations, Georg von Neumayer (Antarctica) and Ny Ålesund (Svalbard), have already been investigated by *Nyeki et al*. (2017). Other candidate BSRN stations include: Barrow (Alaska, USA), Eureka (Canada), Greenland, South Pole, and Syowa (Antarctica). The BSRN stations with traceable pyrgeometers to the WISG, or those for which the pyrgeometers can be obtained and calibrated in WP1 will be prioritised. The BSRN station scientists will be contacted with the support of the BSRN project manager to find out about the data and instrument availability. Depending on the individual situation, either **method A or B** as described in WP2 will be selected and updated longwave irradiances for these sites will be produced in collaboration with the BSRN site, project, and database managers.

Work Package 4: Outreach and Impact

We will attend the forthcoming BSRN workshop (29 June - 3 July 2020, Bologna, Italy) and inform the radiation research community about our plans. Final project results will be presented at the following BSRN workshop in summer 2022 (time and venue to be decided). A further important venue is the 3rd International Pyrgeometer Comparisons at PMOD/WRC which is held every 5 years. This will run in parallel with the 13th International Pyrheliometer Comparisons from 28 September to 16 October 2020. The WMO-sponsored event, composed of instrument field measurements and workshops, is a major opportunity for capacity building, the presentation of research, and decision-making within the community.

Central to the above activities will be the close collaboration with the CIMO Task Team on Radiation References in which PMOD/WRC is a member.

2) Timetable and milestones
Work Package 1 (months 1 – 22)

Deliverable M22: Up to 10 pyrgeometers used for producing key BSRN data sets including the BSRN site Payerne calibrated at PMOD/WRC.

Work Package 2 (months 1 – 16)

Deliverable M16: Report on a methodology developed to retrieve atmospheric longwave irradiances from archived BSRN data.

Work Package 3 (months 12-24)

Deliverable M24: Datasets of up to 2 polar BSRN site and the Payerne BSRN site reprocessed according to either Method A or Method B.

Work Package 4 (months 1-24)

Deliverable (half-yearly): Contribution to the meetings and reporting of the WMO CIMO Task Team on Radiation References

Deliverable M20: Participation in the BSRN workshop (in 2022) and presentation of the results of this project.

Deliverable M24: A guideline document describing how to re-analyse BSRN datasets to provide traceability to the WISG and SI units will be written and submitted as a WMO CIMO document.

3) Embedding in current national and international activities

The mandates of the Infrared Radiometry Section of the World Radiation Center (WRC-IRS) are primarily concerned with developing reference radiometers, maintaining and running the WISG, and to provide calibration services to the research, meteorological and commercial communities (https://www.pmodwrc.ch/en/world-radiation-center-2/irs/) in view of homogenising meteorological radiation measurements on a worldwide scale. Although researching the radiation archives held by international institutes does not belong to our mandate, several recent longwave radiation studies at PMOD/WRC have been funded via external sources (SNF and GAW-CH). Recent research has focussed on:

i) Assessing the calibration traceability of BSRN archives, and the effect on BSRN longwave radiation time-series should a re-scaling of the WISG be implemented (Nyeki et al., 2017).

ii) Providing the calibration traceability of BSRN pyrgeometers through routine calibrations and inter-comparison campaigns, such as the International Pyrgeometer Calibrations (IPgC).

iii) Analysis of the longwave radiation time-series at four MeteoSwiss SaCRAM stations (Nyeki et al., 2019).

iv) Traceability issues of the WISG as part of the tasks of the CIMO Task Team on Radiation References (CIMO, 2018) in which PMOD/WRC is a member.

Regarding the first point, Nyeki et al. (2017) analysed downward longwave radiation over the 2006 – 2015 period at four stations (3 BSRN and Davos) in a project funded by the SNF (Grant 200021_157150).The results of the study demonstrated an increase by up to 3.5 Wm-2 and 5.4 Wm-2 for all-sky and clear-sky conditions, respectively, after application of a possible WISG reference scale correction. This represents an increase of up to 2% and 1% in downward longwave radiation, respectively. Estimates of the global energy balance which use BSRN data (e.g. Wild et al., 2015) suggest a higher global mean value of downward longwave radiation than typically advocated in various published estimates such as those in the IPCC assessments up to the Fourth Assessment Report.

In another recent study funded through the Swiss contribution to GAW (Comprehensive Radiation Flux Assessment, CRUX), the trends in surface radiation and meteorological parameters were analysed for the 1996 – 2015 period at the four MeteoSwiss SACRaM stations (Nyeki et al., 2019). Downward longwave radiation trends during clear-skies were all positive and significant at the 95% confidence level. Stronger cloud-free trends were found at mountain stations (Davos and Jungfraujoch) than at lowland stations (Locarno and Payerne). These results agree with a notable review by Pepin et al. (2015), who observed that climate warming appears to be stronger at higher elevations, an effect known as elevation-dependent warming.

Progress has also been achieved with respect to traceability and instrumental issues. The importance of providing traceability of atmospheric longwave measurements to SI units through pyrgeometer calibrations relative to the WISG was highlighted by creating a new governance framework described in resolution 1 of the recent CIMO XVII Session (Resolution 1; CIMO, 2018). Furthermore, the International Pyrgeometer Comparison (IPgC) held every 5 years at PMOD/WRC was recognised as an essential contribution to homogenise atmospheric longwave radiation measurements on a worldwide scale (Decision 3; CIMO, 2018).

4) Risk analysis

Provide an assessment of risk of failure and risk reduction measures.

WP1: There is no risk involved.
WP2 Task 2: Retrieving data from Meteoswiss archive might be time-consuming, but has no risks, as it has been done before.
WP2: If Method B needs to be applied to the BSRN archive, the risk might be that only a subset of BSRN stations can be reprocessed, depending on the availability of the original raw measured data. This might have implications on the traceability of specific BSRN stations to the WISG and the SI. This outcome, even if negative, is important to know for the BSRN network. The consequences would need to be discussed during the BSRN workshop (deliverable WP4-M20).

5) References

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