GCOS FINAL REPORT

1. Cover Page

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

Project duration: 1 Aug. 2020 – 31 Jul. 2022

Type of report: ExTrac Final Report

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2. Summary

Pyrgeometers are used to measure longwave radiation, an Essential Climate Variable. The ExTrac project focussed on developing a method to retrieve raw pyrgeometer data from the Baseline Surface Radiation Network (BSRN) archives (https://bsrn.awi.de), which may no longer be available from BSRN stations themselves due to legacy issues. It was possible to complete all four Work Packages despite the Covid pandemic.

As part of our in-kind contribution to GCOS and BSRN, the calibration of eight BSRN pyrgeometers was conducted. We focussed on either pyrgeometers that had not previously been calibrated at PMOD/WRC against the World Infrared Standard Group (WISG) or on pyrgeometers with a traceable calibration to the WISG older than +5 years. These efforts are important as the traceability of BSRN longwave radiation time-series is not fully known for historical reasons.

Raw pyrgeometer time-series (<2011 – 2020) from six BSRN stations, were obtained for analysis. Using these time-series to train a station-specific model, proxy raw pyrgeometer data were retrieved. Proxy longwave radiation was re-calculated, and gave a root-mean-square-deviation (RMSD) of 1.9 – 4.8 W m^{-2} (10-min mean) with respect to original data. Most results therefore lie within the absolute uncertainty of longwave radiation (±4.0 W m^{-2}; *Gröbner et al.*, 2014). The ability to retrieve unavailable/lost raw pyrgeometer data with a 10-min resolution is therefore tentatively possible at the BSRN stations in this study. Wider application of this method to other BSRN stations could then be conducted by training station-specific models.

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

3. Scientific Report

3.1 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; *GCOS*, 2016). The Baseline Surface Radiation Network (BSRN; bsrn.awi.de; *Driemel et al.*, 2018) is one of several international networks to coordinate the measurement and archiving of radiation data. Many national meteorological institutes contribute data to the BSRN archive, amongst which is MeteoSwiss who run the BSRN station in Payerne, Switzerland. On a national level, MeteoSwiss also conducts radiation measurements at three other stations (Locarno, Jungfraujoch and Davos), following similar BSRN guidelines. All four stations are part of the Swiss Alpine Climate and Radiation Monitoring (SACRaM) network.

Downward and upward longwave radiation (DLR, ULR) measurements are conducted with pyrgeometers, traceable to the World Infrared Standard Group (WISG) at the Physikalisch Meteorologisches Observatorium Davos / World Radiation Centre (PMOD/WRC; Davos, Switzerland). However, several important aspects concerning the traceability of the WISG as well as other instrumental issues remain to be resolved by the research community (*CIMO*, 2018; *Gröbner et al.*, 2014). The first aspect concerns the submission of longwave radiation data to the BSRN archive that may not be traceable to the WISG. Although BSRN has not routinely archived raw pyrgeometer data, this will soon be the case. At its last meeting in summer 2022, BSRN decided to make the recording and archiving of pyrgeometer raw data mandatory (*Lanconelli et al.*, 2022) with a grace period to be decided.

The second aspect concerns the WISG which is regarded as an interim transfer standard that is 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 the WMO in the future, then longwave radiation time-series would 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 (see further below).

In case a re-scaling of the WISG is conducted, archived longwave time-series could be affected by changes of up to 5 Wm^{-2} (*Gröbner et al.*, 2014; *Nyeki et al.*, 2017), 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 current data, this may be difficult for historical time-series in data archives such as BSRN for a number of reasons: i) possible loss of a knowledge-pool due to the retirement or transfer of station scientists, and ii) loss (or effective loss) of original time-series due to logistical or information technology issues.

The project, Extending the Calibration Traceability of Longwave Radiation Time-Series (ExTrac), is focused on developing a methodology that could be applied to archived BSRN longwave radiation data to retrieve the original raw measurement data from pyrgeometers. This would avoid the need to recover raw data from the BSRN stations themselves. The main aim is therefore 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).

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.

Priorities 1.4, 1.6 and 2.3 of the GCOS Switzerland Strategy 2017 – 2026 were addressed in this project.

3.2. Methods and Activities

Raw pyrgeometer data consists of the sensor voltage (*U*) and the temperature of the instrument body (T_b). This is the case for Kipp & Zonen (www.kippzonen.com), Hukseflux (www.hukseflux.com) and other pyrgeometers. Eppley pyrgeometers (www.eppleylab.com) have an additional temperature sensor to measure the dome temperature (T_d). Pyrgeometers used at the BSRN stations in this study were all mounted on a solar tracker with a shading device to shield the pyrgeometer dome from direct sunlight. In addition, pyrgeometers are run with a ventilation unit, composed of a fan to blow air over the body and dome, and a heater to slightly warm-up the incoming air (typically 1 – 2°C). Ventilation units help to reduce the riming of pyrgeometers at polar and high-altitude stations, and also help in drying off rain droplets (see *Vignola et al.*, 2019). T_b and T_d are therefore not only representative of the ambient temperature but also a small positive offset due to the ventilation unit heater.

In order to explain the rationale of our approach, the equation to calculate DLR is shown below. Several similar equations of varying complexity exist to calculate DLR (*Vignola et al.*, 2019). The method detailed in this study can be applied to all of these equations. However, for the sake of consistency, we use the extended Albrecht and Cox equation as used by PMOD/WRC since at least 2006:

$$DLR = \frac{U}{C}\left(1 + k_1\sigma T_\mathrm{b}^3\right) + k_2\sigma T_\mathrm{b}^4 - k_3\sigma\left(T_\mathrm{d}^4 - T_\mathrm{b}^4\right) \qquad 1)$$

DLR = downward longwave radiation [W m^{-2}]
U = measured voltage of the pyrgeometer sensor [V]
C = pyrgeometer sensitivity [V W^{-1} m^2]
σ = Stefan-Boltzmann constant (5.6704 x 10^{-8} W m^{-2} K^{-4})
T_b and T_d = measured body and dome temperatures of the pyrgeometer [K], respectively
k_i = instrument constants

The k_3 term in Eq. 1 with T_d can be disregarded for pyrgeometers which only measure T_b. In the standard calibration procedure at PMOD/WRC, k_i are determined with a laboratory reference black-body while *C* is determined relative to the WISG from outdoor night-time measurements during clear-sky conditions (*Gröbner and Wacker*, 2015).

Using DLR from the BSRN archive (DLR_{BSRN}), the retrieval of any one parameter out of *U*, T_b and T_d in Eq. 1 is trivial if the other two parameters are still available from station archives. However, if this is not the case (e.g. only one parameter is available) then the original values cannot be retrieved as there are multiple solutions. For pyrgeometers where only *U* and T_b are to be retrieved, the situation is similar, except that one parameter less needs to be determined. The retrieval is therefore ill-posed and hence a so-called inverse problem. Complex mathematical methods (e.g. *Nocedal*, 2006) exist to narrow-down the number of solutions but these are beyond the scope of the present study.

Despite this problem, a basic model whereby ambient temperature (T_{2m}, at a 2 m height) replaces T_b and T_d is a promising approach. This rationale is supported by the fact that: i) in-situ pyrgeometer and T_{2m} measurements are usually conducted within <10 - 20 m of each other, and ii T_b and T_d are representative of the ambient temperature, taking the positive offset from the ventilation unit heater into account. As an alternative to using T_{2m}, ambient temperature from ERA5 (5^{th} generation ECMWF atmospheric reanalysis of the global climate) was also investigated. However, a time resolution better than 24 hours was not available for BSRN stations used here. It would therefore not have been possible to model the time-series with resolutions of 1-min, 10-min or even 1-hr.

The basic model is an attempt to investigate whether proxy raw pyrgeometer data can be retrieved at any BSRN station without any further *a priori* information i.e., a universal method. However, it was soon discovered that the uncertainties were too large, so model development mainly focussed on creating a more refined, station-specific model. The latter model generates proxy values of the pyrgeometer body and dome temperatures ($T_{b\ proxy}$ and $T_{d\ proxy}$; 1-min, 10-min, or 1-hr resolution) using ground-based radiation and meteorological parameters in the BSRN archive, as well as the degree of cloudiness (cloud fraction). This estimated with the APCADA algorithm (Automatic Partial Cloud Amount Detection; *Dürr and Philipona*, 2004). APCADA uses T_{2m}, relative humidity and DLR from the BSRN archive, as well as observations from a cloud climatology. During development of the station-specific model, it was found that $T_{b\ proxy}$ and $T_{d\ proxy}$, depended to varying degrees on: i) global DSR, ii) wind speed (WS_{2m} at 2 m height), iii) T_{2m} itself, and iv) the cloud fraction. Other parameters were investigated (e.g. diffuse DSR, direct DSR, relative humidity, water vapour content, wind direction, etc) but only weak or no dependencies were found.

Examples of these main correlations are shown in Figure 1 which illustrate: i) T_b - T_{2m} versus global DSR binned with the cloud fraction, ii) T_b - T_{2m} versus global DSR binned with WS_{2m}, and iii) T_b - T_{2m} versus T_{2m}. Each of these three correlations represented three modules in the station-specific model whose output was $T_{b\ proxy}$. Likewise, T_d - T_{2m} (giving $T_{d\ proxy}$) and T_d - T_{2m} were also modelled. The procedure for running the station-specific model then consisted of several runs to identify which combination of the three modules gave the lowest root-mean-square-deviation (RMSD) when comparing DLR_{proxy} to DLR_{BSRN}. RMSD is a statistic to estimate the difference in two independent populations.

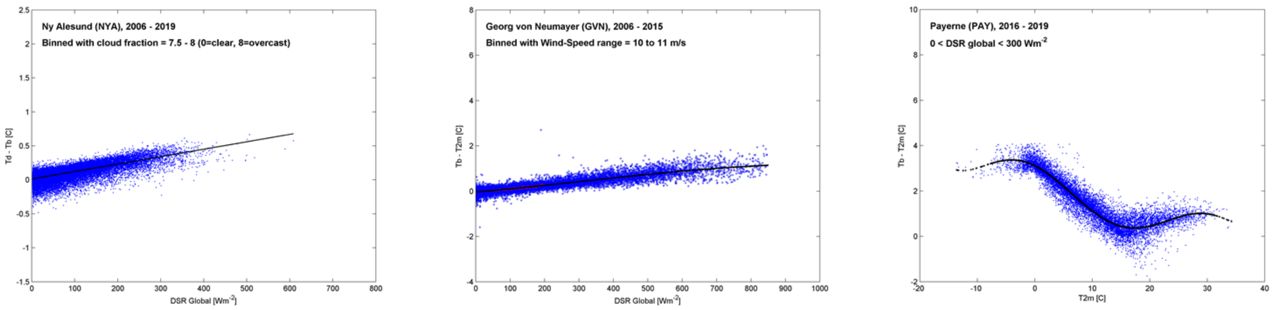

Figure 1. Graphs illustrating the three main correlations of the parameter T_b - T_{2m} are shown. Left: T_b - T_{2m} versus global DSR filtered with the cloud fraction. Middle: T_b - T_{2m} versus WS_{2m}. Right: T_b - T_{2m} versus T_{2m}. See the text for a further description.

The method outlined above was used on BSRN meteorological and radiation time-series from six stations shown in Table 1. The availability of data from the BSRN archive is also shown, and stretches back to at least 1992 for several stations. All stations provided raw pyrgeometer time-series from their own station archives which are in principle available for the same time period as the BSRN time-series. However, it would have required a large effort by some stations to make the oldest time-series available. The present study therefore only used raw time-series from about 2007 – 2021, as most station scientists were able to provide these from station archives with relatively little effort. Considerable time and effort were spent in getting the raw pyrgeometer data into a common format for this project. Each BSRN station has its own format with 1-sec or 1-min resolutions. Only CAB and GVN were able to provide raw data in the so-called BSRN LR4000 data format (1-min resolution) according to the BSRN guidelines (*König-Langlo et al*., 2013; *Lanconelli et al*., 2022).

Table 1. BSRN stations (see https:\\bsrn.awi.de for further details) and the availability of time-series used in this study.

BSRN station	Location	Availability of BSRN meteorological and radiation data	Availability of raw pyrgeometer data in station archives	Raw pyrgeometer data used in this study
Cabauw (CAB)	Netherlands	2005 – present	2005 – present	2019 – 2021
Georg v. Neumayer (GVN)	Antarctica	1982 – present	1982 – present	2006 – 2015
Ny Ålesund (NYA)	Svalbard	1992 – present	1992 – present	2006 – 2019
Payerne (PAY)*	Switzerland	1992 – present	1992 – present	2007 – 2019
South Pole (SPO)	Antarctica	1992 – present	1992 – present	2008 – 2017
Syowa (SYO)	Antarctica	1994 – present	1994 – present	2011 – 2019

* Time-series from the backup BSRN pyrgeometer were also available.

Brief Summary of Work Packages / Activities

Work Package 1 (months 1 – 22)

Task 1: “Update the calibration histories of BSRN pyrgeometers”.
Progress (Aug. 2020 – Jul. 2022): Completed.

Task 2: “As part of our in-kind contribution to GCOS and BSRN, we will calibrate up to five pyrgeometers used by the Swiss SACRaM network as well as up to five used by BSRN”.
Progress (Aug. 2020 – Jul. 2022): The pyrgeometers we calibrated were those that had not previously been calibrated by us against the WISG or those with a traceable calibration to the WISG older than +5 years. These efforts are important as the traceability of BSRN longwave radiation time-series is not fully known. MeteoSwiss had five pyrgeometers calibrated free-of-charge while a further three were calibrated at the normal rate. BSRN stations who submitted raw data to this study were invited to send a BSRN pyrgeometer for a free-of-charge calibration. The offer was taken up by the stations: South Pole, Syowa, and Cabauw. An offer to the community at the recent BSRN workshop (June 2022, JRC Ispra) to calibrate up to two pyrgeometers free-of-charge was not taken up.
Deliverable M22: Up to 10 pyrgeometers used for producing key BSRN data sets including the BSRN site Payerne are to be calibrated at PMOD/WRC.
Outcome: Eight pyrgeometers were calibrated at PMOD/WRC within the duration of ExTrac. Despite our efforts during two workshops and via personal contacts, we were not able to encourage more station managers to send their pyrgeometers for a free calibration (incl. 50% of shipping costs)..

Work Package 2 (months 1 – 16)

Task 1: "Development of a methodology to retrieve the original raw data from pyrgeometers (thermopile voltage, body and dome temperatures) using only DLR and ambient temperature from the BSRN archive".
Progress (Aug. 2020 – Jul. 2022): See above at beginning of Section 3.2.
Task 2 and Progress: Completed.
Deliverable M16: "Report on a methodology developed to retrieve raw pyrgeometer data from archived BSRN data".
Outcome: A short report was delivered in Nov. 2021.

Work Package 3 (months 12 – 24)

Task: "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".
Progress (Aug. 2020 – Jul. 2022): Results are shown in Section 3.3 further below.
Deliverable M24: "Datasets of up to two polar BSRN sites and the Payerne BSRN site reprocessed according to either Method A or Method B".
Outcome: Time-series from Payerne, four polar stations and one lowland station were investigated.

Work Package 4, Outreach, see section 3.5

Deliverable M24: A paper will be submitted by the end of 2022 either as a WMO CIMO technical report or to the journal, Atmospheric Measurement Techniques (EGU publications).

3.3 Results

Whether the basic and station specific models are valid for use, will depend on the uncertainty of retrieved proxy values of the pyrgeometer voltage (U_{proxy}), $T_{b\ proxy}$ and $T_{d\ proxy}$ which will in turn determine the uncertainty of the proxy DLR (DLR_{proxy}). Note that DLR_{proxy} is calculated in Eq.1 using U, $T_{b\ proxy}$ and $T_{d\ proxy}$. If U_{proxy}, $T_{b\ proxy}$ and $T_{d\ proxy}$ were used, then the result would be the original DLR time-series again, ie., DLR_{BSRN} itself. Determining the uncertainty in DLR_{proxy} is therefore difficult. Strictly speaking, the RMSD is not an uncertainty, but it gives a robust idea of how the station-specific model performs. In addition, while the RMSD of $T_{b\ proxy}$ versus $T_{b\ proxy}$ etc could be reported, comparing DLR_{proxy} with DLR_{BSRN} is perhaps more intuitive. Figure 2 illustrates this comparison for three representative BSRN datasets from the stations Payerne, Ny Ålesund and Syowa with a 1-hr resolution. A visual comparison shows that the basic model (top line in figure) provides a poorer fit of DLR_{proxy} with respect to DLR_{BSRN} than the station-specific model.

Results from all datasets at all six stations are shown in Table 2. RMSD values for the basic model are in the range 4.1 – 26.1 Wm^{-2} and 4.6 – 26.1 Wm^{-2} for a 1-hr and 10-min data resolution, respectively. This compares to a current absolute uncertainty in DLR measurements of ±4.0 Wm^{-2} (*Gröbner et al.*, 2014), and to a range of 1 – 2 Wm^{-2} for calibration with respect to the WISG. When the station-specific model is used, the RMSD ranges decrease significantly to 1.7 – 4.6 Wm^{-2} and 1.9 – 4.8 Wm^{-2}, again for 1-hr and 10-min data, respectively.

The ability to retrieve unavailable/lost raw pyrgeometer data with a 10-min or 1-hr resolution is therefore tentatively possible at the BSRN stations in this study. As datasets in the BSRN archive have a 1-min resolution, we also ran the station-specific model with this resolution. The calculations are computationally intensive, so only short runs for short time-series at Payerne were run. Table 1 shows these results which have RMSD values of 2.4 and 2.0 Wm^{-2} as opposed to 2.3 and 1.9 Wm^{-2} for a 10-min resolution. A more in-depth discussion with conclusions appears in the next section.

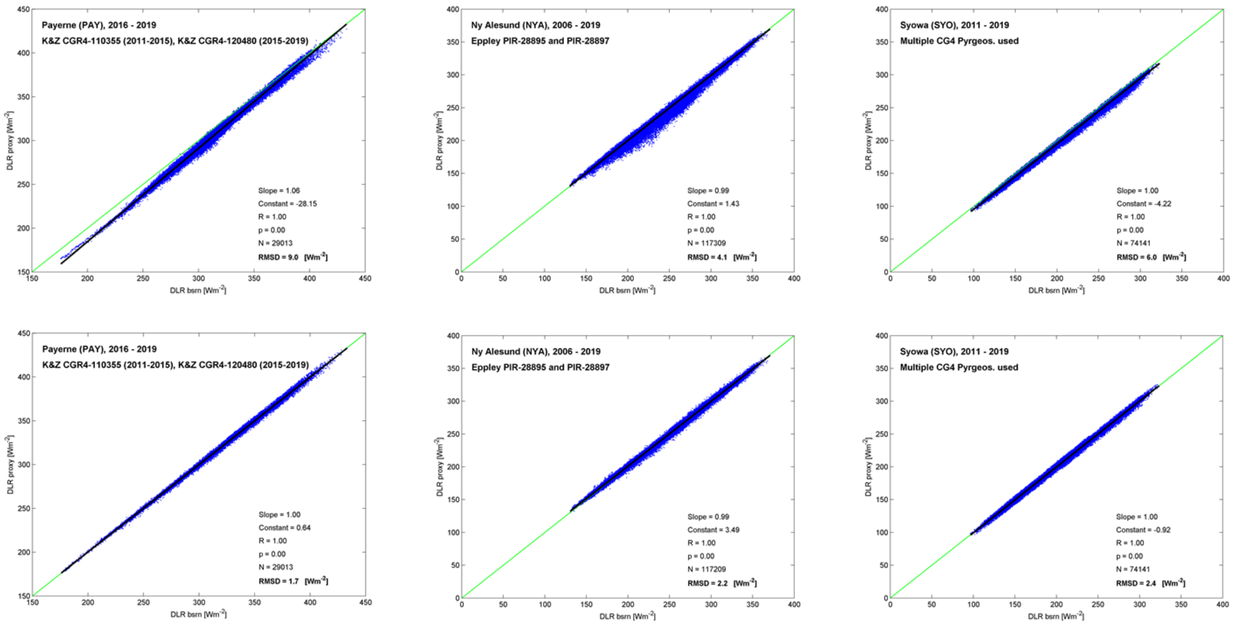

Figure 2. DLR_{proxy} vs DLR_{BSRN} (1-hr resolution) at BSRN stations. Top line, left to right: Basic model for Payerne (PAY), Ny Ålesund (NYA), and Syowa (SYO). Bottom line, left to right: Station-specific model for the same stations. Statistics and RMSD values are shown in each graph.

Table 2. Root-mean-square deviation (RMSD) values are shown for a comparison of DLR_{proxy} with DLR_{BSRN} for basic and station-specific models. Pyrgeometer types: E = Eppley, K&Z = Kipp & Zonen.

BSRN Station		**Pyrgeo. type**	**DLR_{proxy} vs DLR_{BSRN} RMSD (Wm^{-2})**			
			Basic Model 1-hr data	**Basic Model 10-min data**	**Station-Specific Model 1-hr data**	**Station-Specific Model 10-min data**
Cabauw (CAB)		K&Z	9.0	9.0	2.3	2.4
Georg v. Neumayer (GVN)		E	4.4	4.6	2.4	2.8
Ny Ålesund (NYA)		E	4.1	4.6	2.2	3.1
Payerne (PAY)*	(2007 – 2010)	E	9.8	9.9	3.5	4.5
	(2011 – 2015)	K&Z	10.1	10.1	2.1	2.3**
	(2016 – 2019)	K&Z	9.0	9.1	1.7	1.9**
	(2013 – 2016)	E	9.9	10.1	2.4	2.7
	(2016 – 2019)	E	7.9	8.0	2.1	2.5
South Pole (SPO)		E	26.1	26.1	4.6	4.8
Syowa (SYO)		K&Z	6.0	6.1	2.4	2.5

* Time-series from the main and backup BSRN pyrgeometers have been split-up to reflect periods when a pyrgeometer or a ventilation unit was changed.

** Provisional RMSD values for a 1-min resolution give 2.4 and 2.0, respectively.

3.4. Conclusions and Limitations

The ExTrac project started on 1 August 2020 and finished on 31 July 2022. Despite the Corona pandemic, which occurred during this time period, we believe that our goals were achieved in each Work Package. Our conclusions include the following:

i) Values of DLR_{proxy}, calculated from proxy raw pyrgeometer data (e.g., 1-hr or 10-min resolution) gave a root-mean-square-deviation (RMSD) of 1.9 – 4.8 W m^{-2} (10-min mean) with respect to DLR_{BSRN}. The majority of RMSD values were therefore within the absolute uncertainty of DLR measurements (±4.0 W m^{-2}; *Gröbner et al., 2014*). The ability to retrieve unavailable/lost raw pyrgeometer data with a 10-min or 1-hr resolution is therefore tentatively possible at the BSRN stations in this study. This also applies to the oldest parts of the raw pyrgeometer time-series in Table 1 not yet analysed in this study. The application of this method to other BSRN stations could then be conducted by training station-specific models with recent raw pyrgeometer data, allowing older parts of the time-series to be retrieved.

ii) A universal method which can be applied to any BSRN station without the training of a station-specific model was an indirect aim, but our investigations suggest that this cannot be achieved with the desired accuracy. Although more complex, a station-specific model has led to a greater accuracy of retrieved pyrgeometer data. In addition, the retrieval of proxy raw data with a 1-min resolution was investigated as BSRN archived data has this resolution. A slightly higher uncertainty was found for selected time-series but the overall robustness of proxy data with this resolution would require further investigation in the future.

iii) Our method may not be suited to all BSRN stations for several reasons:

1. A poor correlation of T_b (and T_d) with T_{2m} was observed over time periods, ranging from weeks to years, at a few stations. Analysis of web cameras installed on the measurement platforms of several stations suggest that this is mainly due to the riming of pyrgeometer ventilation units with snow and ice. This can be a constant problem at arctic and high-altitude stations. The unstable long-term operation of ventilation units (i.e. air-flow and heating power issues) can also lead to a poor correlation.

2. The unsuitability (measurements may not be co-located) or unavailability (e.g., wind-speed) of measurements.

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

3.5 Outreach Work, Publication of Data and Results

Despite the Covid pandemic, the following outreach activities were carried out during ExTrac:

i) An ExTrac website was created at:
https://www.pmodwrc.ch/en/research-development/thematic-projects/extrac/

ii) A 1-page report on ExTrac was published in the 2020 and 2021 PMOD/WRC annual reports. Please see:
https://www.pmodwrc.ch/wp-content/uploads/2021/05/2020_PMODWRC_Annual_Report.pdf
https://www.pmodwrc.ch/wp-content/uploads/2022/05/2021_PMODWRC_Annual_Report.pdf

iii) The Swiss National GAW/GCOS Symposium, 13 – 14 September 2021. Virtual poster presented: "Extending the Calibration Traceability of Longwave Radiation Time-Series (ExTrac)".

iv) The IPC-XIII (International Pyrheliometer Comparisons) Symposium, 5 October 2021, PMOD/WRC, Davos, CH. A talk was given: "Extending the Calibration Traceability of Longwave Radiation Time-Series (ExTrac)".

v) The BSRN (Baseline Surface Radiation Network) Workshop, 27 – 30 June 2022, JRC Ispra, Italy. A talk was given: "Extending the Calibration Traceability of Longwave Radiation Time-Series (ExTrac)".

vi) A poster was presented at IRS-2022 (International Radiation Symposium), 4 – 8 July 2022, Thessaloniki, Greece.

vii) In order to keep up the momentum on this topic within WMO and BSRN circles, a paper will shortly be submitted as a CIMO technical paper or in a journal such as Atmospheric Measurement Techniques.

viii) Time-series used in this project belong to each individual BSRN station. Although we are not authorised by the stations to make this data available, the ExTrac project is working with BSRN, who will start to make this data available to the wider community in late 2022 or early 2023 via the BSRN website (https://bsrn.awi.de/).

3.6 Outlook

i) **Will the project continue in any form?**

As already mentioned in Section 3.4, significant progress has been achieved by the BSRN community and the ExTrac project, in moving the agenda forward on the submission of raw pyrgeometer data to the BSRN archive. ExTrac was able to nudge this topic forward on the BSRN agenda, and we now believe that there is enough momentum in the community to keep the progress going.

The PI and deputy PI of this project will continue to participate in working groups on this topic within the BSRN community.

ii) **Future objectives**

a) The mandatory submission of raw pyrgeometer data by BSRN stations into the BSRN LR4000 data is planned to begin in late 2022 or early 2023. The submission of current and raw pyrgeometer data will initially require time and effort. However, the submission of past data will most probably require resources that some stations may not have. Providing BSRN with manpower and financial support would be beneficial in this respect.

b) Once the submission of raw pyrgeometer data to the BSRN archive is running, then the next major topic concerns how this data will be managed and distributed with respect to a possible change of the WISG reference scale for longwave radiation. These aspects are currently being discussed within the BSRN and WMO communities.

3.7 Acknowledgements

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